UPDATED FINAL RECOMMENDATIONS REPORT:

Upper Barwon, Yarrowee and Leigh Rivers FLOWS study update

June 2021

Document history

Revision:

Revision no.	05
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Distribution:

Revision no.	05
Issue date	30 June 2021
Issued to	Jayden Woolley (CCMA)
Description:	Updated final report Updates to flow frequencies and use of 'reference' reaches for nearby waterway reaches not included in the FLOWs study.
Revision no.	04
Issue date	31 May 2019
Issued to	Jayden Woolley (CCMA)
Description:	Final report
Revision no.	03
Issue date	1 May 2019
Issued to	Jayden Woolley (CCMA)
Description:	Final report
Revision no.	02
Issue date	06 December 2018
Issued to	Jayden Woolley (CCMA)
Description:	Draft for PAG comment
Revision no.	01
Issue date	30 November 2018
Issued to	Jayden Woolley (CCMA)
Description:	Draft for CMA comment

Citation:

Alluvium (2021) *Upper Barwon, Yarrowee and Leigh rivers FLOWS study update*. Report prepared by Alluvium Consulting Australia for Corangamite Catchment Management Authority, Colac.

Ref: C:\Users\emma.hodson\Desktop\Barwon Flows Updates\P118025_Recommendations_Paper_Upper_Barwon_Yarrowee_Leigh_FLOWS_study_update_V05.docx

Acknowledgement:

‘The Wadawurrung team would like to acknowledge and pay its utmost respects to our Ancestors, and Elders past and present and future, and pledge to live by Bunjil’s Lore to care for ALL of Country, just as our Wadawurrung Ancestors have.’

The authors would like to acknowledge the Traditional Owners of the lands of this study and pay respects to their Elders past, present and future. We will work with the Traditional Owners to ensure their knowledge and culture is incorporated into our project methodology and assessment of the flow requirements of the Barwon River system.

Summary

During 2018 and 2019, the Corangamite CMA commissioned an update of the environmental flow study for the Upper Barwon, Yarrowee and Leigh River systems. The update was led by Alluvium Consulting Australia – in partnership with Lloyd Environmental and Wadawurrung Traditional Owners – and in consultation with community, stakeholder and agency representatives of two Project Advisory Groups. This 2021 version provides an update to the recommendations provided in the May 2019 version of the report. These updates include:

- Updates to flow frequency recommendations for all reaches. The update has been undertaken to address inconsistencies and improve clarity on the number of freshes recommended per period (for each reach). The flow compliance and water recovery targets have been reviewed and confirmed for this update.
- Use of 'reference' reaches for nearby waterways not included in this FLOWs study.

All other aspects of the report, including flow compliance and water recovery targets have been checked and remain the same.

The Barwon River basin is a major water supply for Geelong, smaller urban centres, and farm water supply for the region. The system is significantly altered via extensive farm dam storages, on-stream reservoirs and many diversion licences. While the Barwon system still retains significant values for recreation, tourism, biodiversity and Aboriginal Culture, the abundance of native plants and animals has substantially declined and the aesthetic values and environmental services the waterways provide have diminished.

This environmental flow study represents a transparent science-based approach to assessing the flow requirements of freshwater reaches of river systems. It has examined the flow-dependent environmental values and objectives of the system and determined the flow regime required to meet these objectives.

Ecological values

The Upper Barwon, Yarrowee and Leigh River system supports significant ecological values including the endangered growling grass frog and iconic platypus. Macroinvertebrates provide a food source for these species, along with resident freshwater and migratory fish, including Dwarf galaxias, Yarra & Southern pygmy perch, tupong, short-finned eel, Australian smelt, and common jollytail. The Barwon River has also been listed as important habitat in the National Recovery Plan for the Australian grayling *Prototroctes maraena* (DSE, 2008). The endangered ecological vegetation class (EVC) 'floodplain riparian woodland' can be found throughout the study area, with vegetation providing habitat and shading for significant fish species.

The Lower Barwon wetlands, which include Reedy Lake, Hospital Swamp and Lake Connewarre, form part of the internationally significant Port Phillip Bay (Western Shoreline) and Bellarine Peninsula Ramsar site. The system supports high-value mangroves, saltmarshes, intertidal mudflats, seagrass bed habitat and seasonal freshwater swamps and lakes. These wetlands are important for Australia's migratory waders and represent one of Victoria's most important wetland systems. The Lower Barwon wetlands are downstream of the waterways included in this assessment but are dependent on freshwater flows from the Barwon River system.

Aboriginal Cultural values

Aboriginal Cultural values incorporate traditional ecological knowledge and are applicable to all sites within Wadawurrung Country. Values include maintaining watering requirements for healthy, thriving culturally significant species such as Buniya (eel), Turrpurt (native trout) and Ware-rap (blackfish) which are all important food sources. The area holds significant places related to Buniya (eels) such as Benia Wulla (Buckley Falls) which is the place where you eat eels and indicates the area as a place of gathering or Baieer.

Significant flow-dependent vegetation includes Polango/ Warngare (water ribbons) which are crisp and sweet food; Tark (common reed) which can be used as food, for spear shafts, necklaces and basket weaving; Toolim (pale rush) used for weaving baskets; and Bal-yan (cumbungi) of which the fluff can be used to pack wounds under a paperbark bandage. Across the river banks and floodplain, significant species include Biyal (river red gums), used for making canoes, shelters and tools; and Larrap (manna gum) used for making club-shields called Malka. The priority for maintaining Aboriginal Cultural values is to protect these totem species.

All river confluences hold great significance as meeting, ceremony and trade places for the Wadawurrung and often identify the Clan Boundaries. The maintenance of deep and permanent water holes and refuge pools is also important.

NB: Eastern Maar Aboriginal Corporation also have Country within the FLOWS study area. It is important to note that Traditional Owners, the Wadawurrung, are restricted from commenting on or conducting site assessments on Eastern Maar Country for Cultural reasons. Eastern Maar Aboriginal Corporation were invited to participate in the environmental flow study and declined but expressed interest in the outcomes of the study and seasonal watering proposals on their Country.

Environmental flow recommendations

Environmental flow recommendations have been determined for ten reaches of the Barwon River system. Each recommendation is comprised of a flow component, discharge (magnitude), timing (dry or wet period), frequency (number of times per season) and duration (generally in days), as well as the inclusion of seasonality. An overview of the flow recommendation magnitudes for each reach is presented in the following figure.

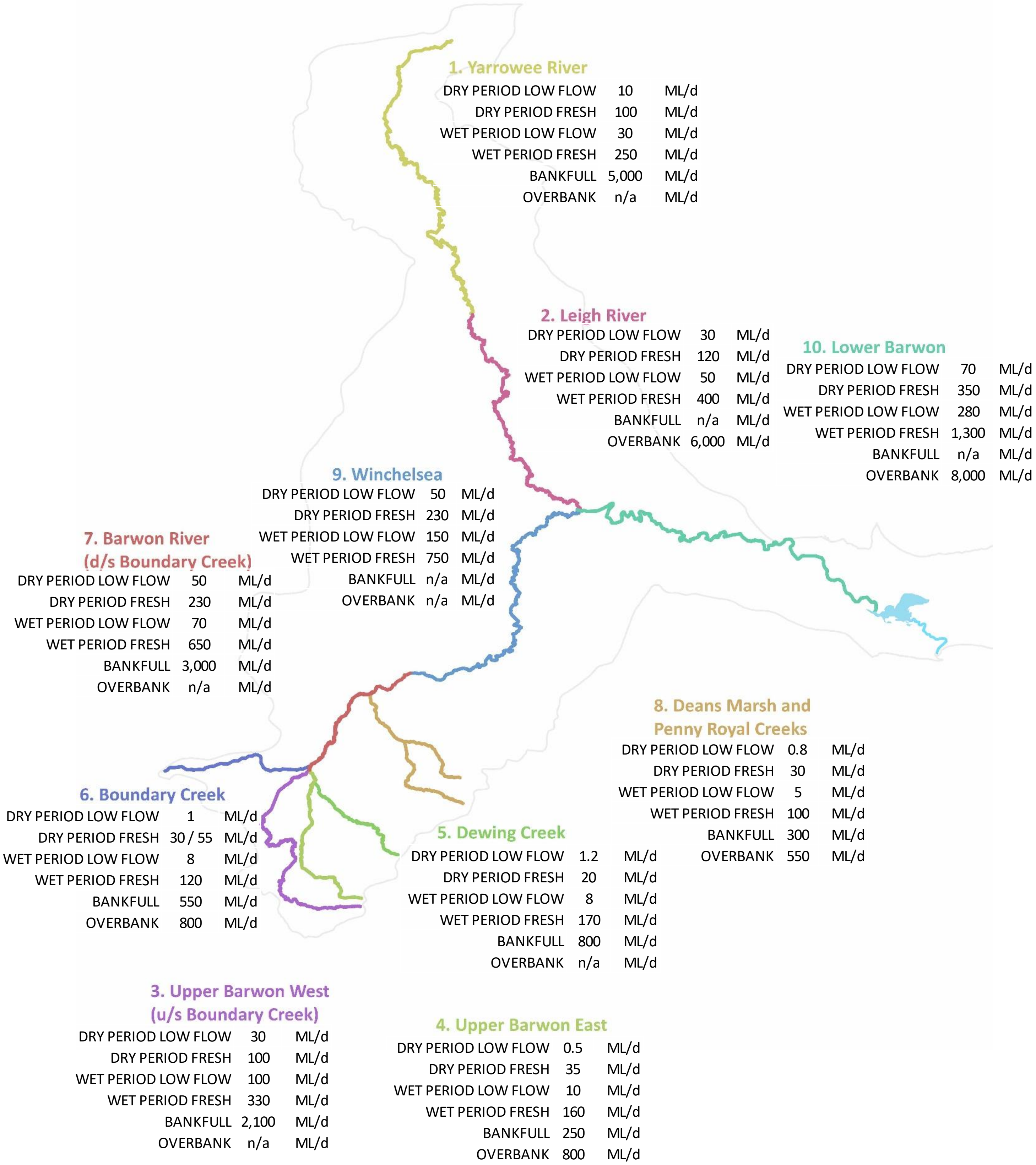

Figure: *Reach overview of flow recommendation magnitudes*

Climatic regime recommendations

A set of environmental flow recommendations have also been developed for dry, average and wet years. The recommended dry year flow recommendations can assist to provide refuge during dry years. However, these recommendations should not be applied to every year.

Dry conditions regime

The dry conditions regime will provide refuge habitat for most species but will not provide essential breeding and migration opportunities. Culturally important species such as blackfish, native trout, and platypus would have limited opportunities for movement between pools, reducing availability of food, reproduction of the species and migration to new habitats. While eels are resilient and can survive in reduced water levels, they do require higher flows to allow migration to and from the estuary for breeding. An extended dry condition flow regime is likely to result in localised extinctions of a number of these species, with severely reduced opportunities for spawning and reproduction for resident and migratory fish, growling grass frogs and macroinvertebrates.

Average conditions regime

The environmental flow recommendations for average conditions provide balance between the seasonal drawdown needs of instream vegetation and the fresh and bankfull requirements for spawning, migration and vegetation watering. Low flows provide habitat for fish and other fauna while allowing flow to reduce periodically as it would have done naturally providing a mosaic of drying areas and seasonal drawdown to promote recruitment of instream vegetation. Variability in wetting and drying will provide inundation of sediments, important for hatching of invertebrate eggs. While water may be more readily available in average years, than in dry years, it is important to maintain flow variability. Exotic species such as gambusia and carp thrive in regulated systems with minimal flow variability.

Low flows will maintain turnover of water, with freshes providing flushes to maintain adequate water quality. Increased wet period low flows will maintain the sediment transport capacity of the river, channel cross-section size and form, and important habitats such as pools and riffles.

Wet conditions regime

The recommended wet condition flow regime will provide plentiful migration and movement opportunities for resident and migratory fish species.

However, persistent high flows will result in the loss of important wetting and drying sequences. Drying results in invertebrates laying desiccant-resistant eggs which hatch on subsequent inundations, providing vital food sources for fish, platypus, and frogs. This wetting and drying cycle results in carbon and nutrient exchange and drives ecosystem processes in aquatic environments.

Environmental water shortfalls

An assessment of the performance of the environmental flow recommendations has been undertaken to identify the additional water required (or shortfall) to move from the current flow regime, to that required to meet all of the recommended environmental flows for the Barwon River system. The figures below identify the volume of additional water required in order to fully implement the suite of environmental flow recommendations in each reach. This assessment has examined the environmental flow demands in all reaches independently of each other. To estimate the total environmental water requirements (and shortfalls) of the Barwon system, the study team adopted the environmental water requirements in the most downstream reach, Reach 10 (Lower Barwon) to represent the total environmental water requirements of the Barwon system. The annual average flow rates in Reach 10 under the unimpacted, current, and recommended flow regimes are set out below:

Reach 10 average annual flow rates and shortfall

Model operating condition	Average annual flow ML/year	Average annual volume compared to natural
Natural (unimpacted) flow regime	287,405	
Current flow regime	173,033	60%
Recommended flow regime	217,451	76%
Shortfall between current and recommended flow regime	44,419	

An additional 44GL/yr of water would be required to return the Barwon River flow regime to within 75% of the natural flow regime and allow for provision of all environmental flow recommendations.

Prioritisation of flow delivery

With limited environmental water available in the Barwon catchment, and recognising the practicalities of environmental water delivery, the CCMA and environmental water managers may need to prioritise delivery of the most essential flow components to priority reaches that can benefit the most. Prioritised reaches and flow components are set out below.

Reach priorities:
The prioritisation of reaches for the retention and provision of environmental water has been based on waterway condition, fish presence, fish passage and significant barriers within the catchment, the practicalities of water delivery, and our capacity to influence the system with environmental water.

Highest priority reaches

Reaches 1 and 2 - Yarrowee and Leigh Rivers
Fish such as common galaxias, short-finned eel, and Australian smelt have been recently recorded in the Leigh and lower Yarrowee Rivers. These rivers have relatively few major fish barriers, with Shelford Church Farm road crossing and Leighburn Station Ford posing the greatest threats to fish passage. As such, flow variability will allow native fish populations to build and potentially reduce exotic fish populations such as gambusia and carp, which thrive in regulated flow regimes. Other fauna such as growling grass frog and platypus have also been recorded in this reach.

Reaches 9 and 10 - Winchelsea and Lower Barwon
Fish species – including those listed under legislation for protection – such as dwarf galaxias, Yarra pygmy perch, common galaxias, short-finned eel, spotted galaxias, Australian smelt, and tupong have been recently recorded in the Lower Barwon and Winchelsea reaches. The culturally significant river blackfish has also been recently recorded in these reaches, among other resident freshwater and migratory fish. The Barwon River has been listed as an important river in the National Recovery Plan for the Australian grayling *Prototroctes maraena* (DSE, 2008). Australian grayling distribution is currently limited to downstream of Geelong and the Lower Barwon wetlands.

Other priority reaches
Delivery of water to the Winchelsea and Lower Barwon River will require the development of priorities for flow delivery from the West Barwon Reservoir.

Reach 4 - Upper Barwon East
Short-finned eels, blackfish, and Southern pygmy perch have recently been recorded in the Upper Barwon East. There are relatively few major barriers to fish migration in the East Barwon River, and those that are present can be addressed through fish barrier programs. Water can also be delivered, with limited losses, to the Upper Barwon East with water from the West Barwon Reservoir.

However, riparian condition and vegetation continuity is poor, with infestations of exotic species throughout the reach.

We recommend that water be provided to the Upper Barwon East to meet the environmental water requirements in this reach and (in part) to meet environmental water requirements for the Winchelsea and Lower Barwon Reaches. However:

- The environmental water requirements for the Upper Barwon East should not be exceeded and additional water required to meet downstream requirements should be delivered via the Upper Barwon West (downstream from the West Barwon Reservoir)
- Fish barrier issues should be addressed as a priority
- Work will be required to improve vegetation condition throughout the Upper Barwon East.

Reach 3 - Upper Barwon West
Dwarf galaxias, Yarra pygmy perch, short-finned eels, blackfish, and several other fish species have recently been recorded in the Upper Barwon West. This reach has been adversely impacted by the loss of flows arising from the construction and operation of the West Barwon Reservoir and can be readily supplied with environmental water. However, the provision of fish passage over the reservoir will be difficult and as a consequence provision of water in this reach will provide limited fish passage outcomes and may compromise fish outcomes by encouraging fish to move up through the reach to a point near the dam wall that fails to meet life cycle requirements. As a consequence, environmental water should only be delivered to the lower Barwon River via the Upper Barwon West, once environmental requirements for the Upper Barwon East have been achieved.

Prioritised flow components:
Flow component prioritisation relies on the capacity for components to provide essential functions.

Highest priority flow components

Dry period low flows
The most critical aspects of the flow regime for the survival of valued species are the dry period low flows. These flows provide essential habitat for aquatic fauna and provide moisture to instream and emergent macrophyte vegetation. These continuous flows through the dryer months of summer and autumn provide refuges for species such as platypus, growling grass frog, fish, and macroinvertebrates. These low flows also provide minimum water velocity for mixing of pools, reducing the risk of stratification and poor water quality. Adequate depth of water and water quality are essential to the survival of aquatic species. The dry period low flow recommendations should be provided as a priority. These flow rates are essential in the dry period and are to be provided as a minimum during the wet period.

Dry period freshes
These freshes during the December to May period provide flushes that assist in maintaining adequate water quality and provide opportunities for migration of fish and other fauna between reaches. Without the provision of these dry period freshes, there may be regional extinctions, with many species unable to move to new habitats and reproduce. Crowding in pools may become prevalent, with increased competition for food and resources.

Second priority flow components

Wet period freshes
Fresh events during the wet period provide migration cues and opportunities for fish and other fauna, including platypus, tupong, short-finned eel, Australian smelt, common jollytail, spotted

galaxias, and Australian grayling. These events also provide moisture for vegetation on banks and benches. There will be limited spawning opportunities for fish and other fauna in the event that these freshes are not provided for extended periods, and populations of these species will decline.

Average annual discharges and shortfalls

The following table details the average annual discharges and shortfalls for the prioritised flow components and all flow components under proposed and current conditions in Reach 10.

Average annual discharges and shortfalls for prioritised flow components in Reach 10.

	Dry period low flow and dry period freshes	Dry period low flow, dry period freshes and wet period fresh	All flow components
Proposed (ML/yr)	176,803	203,498	217,451
Current (ML/yr)	173,030	173,030	173,033
Shortfalls (ML/yr)	3,773	30,468	44,419

It will be difficult to supply all the additional water requirements for the Lower Barwon River from the Leigh River and as a consequence, additional water will be required from the West Barwon Reservoir and delivered via the Barwon River system. The delivery of water to the Lower Barwon River, via the Barwon River, will also be necessary to meet the environmental water requirements of the Winchelsea Reach (Reach 9), one of the highest priorities for environmental water. Average annual discharges and shortfalls for the prioritised flow components under proposed and current conditions for Reach 9 are set out below. Attainment of all of the environmental flow component recommendations would return the flow regime in the Winchelsea Reach to within 70% of natural.

Average annual discharges and shortfalls for prioritised flow components in Reach 9.

	Dry period low flow and dry period freshes	Dry period low flow, dry period freshes and wet period fresh	All flow components
Proposed (ML/yr)	100,003	115,967	126,353 (70% of natural)
Current (ML/yr)	96,666	96,666	96,668 (54% of natural)
Shortfalls (ML/yr)	3,336	19,301	29,685

Water recovery targets from the West Barwon Reservoir

The estimated additional water required to meet the priority environmental flow requirements of the Barwon River delivered via the West Barwon Reservoir are set out in the following table. These targets have been developed using historical flow data and do not account for the impacts of future climate change.

Additional water recovery required from West Barwon Reservoir.

	Highest priority target No. 1 Dry period low flow & dry period freshes	**High priority target No. 2** Dry period low flow, dry period freshes & wet period fresh	**Priority target No. 3** All flow components
Estimated shortfalls (ML/yr)	3,336	19,301	29,685
Existing entitlement (ML/yr)	1,000	1,000	1,000
Additional water requirements (ML/yr)	2,336	18,301	28,685

Highest priority water recovery: Target No. 1
This water recovery target would enable the delivery of 100,003 ML/yr to the Barwon River (Reach 9) and would provide dry period low flows year round and dry period freshes. This would require an additional allocation of 2,336 ML/yr from the West Barwon Reservoir.

This recovery target includes low flows, providing essential habitat for aquatic fauna, moisture to instream and emergent macrophyte vegetation, and refuges for platypus, growling grass frog, fish, and macroinvertebrates. Dry period freshes will provide flushes that assist in maintaining adequate water quality and opportunity for migration of fish and other fauna between reaches. Without the provision of these flows, there may be regional extinctions, with many species unable to move to new habitats and reproduce. Resultant crowding in pools, will increase competition for food and resources.

While the provision of these flows will allow the short-term survival of these species, the continued provision of this regime will not provide opportunity for migration, breeding and long-term proliferation of species. There will be limited spawning opportunities for fish and other fauna such as the culturally significant platypus, leading to population decline over the long term. Emergent and riparian vegetation, such as the culturally significant common reed, pale rush, river red gum, and swamp wallaby grass, among others will also die-back without wet period freshes and bankfull/overbank flows.

High priority water recovery: Target No. 2
This water recovery target would enable the delivery of 115,967 ML/yr in the Barwon to provide dry period low flows year round, dry period freshes, and wet period freshes. This would require an additional allocation of 18,301 ML/yr from the West Barwon Reservoir. This recovery target would require significant adjustment to the current entitlements within the system and will not provide for all of the environmental water needs of the Barwon system.

The addition of fresh events during the wet period will provide migration opportunities and cues for fish and other fauna, including culturally significant fish such as native trout and eels, and other migratory fish such as Australian smelt, common jollytail, spotted galaxias, and Australian grayling. These events also provide moisture for emergent vegetation such as the culturally significant cumbungi and common reed on banks and benches.

The lack of wet period low flows, bankfull and overbank flows will lead to the decline of riparian and floodplain vegetation such as the culturally significant river red gum, manna gum and swamp wallaby grass. Floodplain connectivity will be limited, reducing nutrient cycling, carbon exchange and organic matter supply to the stream. The reduced low flow component will also reduce transport capacity of the stream, leading to sediment accumulation and shallowing of pools. Deep pools are culturally significant and an important habitat for a number of fish and fauna.

Priority water recovery: Target No. 3
This water recovery target would enable the delivery of 126,353 ML/yr in the Barwon to provide all recommended flow components. This would require an additional allocation of 28,685 ML/yr from the West Barwon Reservoir. This recovery target would require significant adjustment to the current entitlements within the system.

This recovery target would provide the best ecological and cultural outcomes for the system but does not attempt to return the system to a pre-European flow regime. The recovery target would return the volume of water in the Barwon River to within 70% of the pre regulation flow regime. The provision of this flow regime will maintain and improve the ecological and cultural values of the system over the long term.

Complementary actions

This study has identified the water requirements to achieve a set of adopted environmental and Aboriginal Cultural objectives for the Barwon River system. However, the provision of environmental water alone will not result in the attainment of the adopted objectives. This study has identified threats that require management intervention beyond the provision of water, in order to attain the adopted objectives. Complementary management actions that will be necessary in order to realise the benefits of additional environmental water include:

Groundwater management

Groundwater extraction can reduce flows into rivers and impact on water quality. Groundwater extractions have been and are continuing to have an impact on stream flow and water quality (including acidity - pH) in Boundary Creek. The attainment of the outcomes sought by the environmental water recommendations set out in this report will not be achieved in Boundary Creek and affected reaches of the Barwon River while these conditions persist.

At the time of writing, management of groundwater extraction impacting on Boundary Creek is the subject of investigations through the Boundary Creek remediation working group. Resolution of the groundwater and related water quality and river health impacts will need to be achieved in order to reach the outcomes sought by the provision of environmental water.

It should be noted that the environmental water requirements set out in this report have not been developed to address the water quality issues in and downstream of Boundary Creek. Additional water would be required above and beyond that set out in this report for these purposes. These water quality issues are best addressed through the management of groundwater extractions, beyond the scope of this environmental flow determination.

Water quality management

Beyond the groundwater related water quality issues outlined above, water quality issues including nutrient loads from urban stormwater and wastewater discharges will limit the ecological condition of the Upper Barwon, Yarrowee and Leigh River system.

- *Stormwater management*: Improved stormwater management in Ballarat and Geelong have the most potential for addressing stormwater pollutant loads.

- *Ballarat South Wastewater Treatment Plant releases*: There is significant potential for the installation of additional storage and treatment of wastewater from the Ballarat South Wastewater Treatment Plant to improve the quality and timing of wastewater releases. The creation of additional storage to at the Ballarat South Wastewater Treatment Plant would enable a more variable flow release pattern consistent with the recommended flow regime set out in this report, would contribute to the water recovery targets set out in this report and has the potential to improve water quality in the Barwon River system.

Riparian vegetation management

Many of the reaches assessed for this investigation had degraded riparian zones. Instream and riparian vegetation limit channel erosion processes and provide essential instream and riparian habitat for species targeted for environmental water. In the longer-term, riparian vegetation provides the source of essential large wood to the stream system. The degraded riparian corridor can be attributed to past clearing and ongoing grazing pressure. The provision of environmental water to the system should be accompanied by a program of catchment-scale riparian vegetation management. Failure to provide such riparian vegetation will limit the attainment of the objectives sought through the provision of environmental water.

Exotic species management
Increasing flow variability and instream habitat complexity will allow native fish populations to build and potentially reduce exotic fish presence in the basin. However, targeted management of exotic fish species will assist in system recovery and allow native fish species to thrive. Exotic weeds such as willows, blackberry, and reed sweet grass can influence flow and channel form, reducing suitable habitat for fish, platypus, and other fauna. Managed removal of exotic species and the revegetation of the riparian zone with native species will support the values of the system and the attainment of the objectives sought through the provision of environmental water.

Management of flow limiting infrastructure
The provision of environmental flows can be constrained by the capacity of available infrastructure to deliver water from storages (i.e. channels and gates) and flow capacity constraints in the system (e.g. weirs, levees, and bridges).

An assessment of potential flow limiting infrastructure should be undertaken to identify the extent to which existing infrastructure impacts on environmental water delivery and is capable of delivering the flow rates set out in this assessment. Works may be required to modify structures that are found to limit the delivery of environmental water.

A significant constraint includes the East Barwon River downstream of the diversion tunnel. This reach has sections with limited flow capacity as a result of willow colonisation. Delivery of the flow recommendations set out in this report will result in some unintended overbank inundation. Removal of willow alone is unlikely to address the issues in this reach. This reach will require a program of management to rehabilitate the waterway (including willow removal, channel modifications and revegetation) to enable discharge of the recommended flows in a manner that meets ecological and adjoining land use objectives.

Fish habitat and barrier management
The attainment of the fish-related objectives set out in this assessment is reliant on adequate fish passage throughout and between reaches. In recent years, fish passage has been restored through a number of techniques, including the removal of obsolete structures that limit fish migration, modification of structures (e.g. culverts) and construction of fishways on structures (e.g. weirs and dams) that have an ongoing function. Marsden *et al.* (2016) reviewed barriers to upstream fish passage within the Barwon River system including prioritisation of major barriers and providing recommendations to address fish passage in the catchment, including environmental flow considerations. Removal or modification of fish barriers to enable fish movement through the Barwon River system will be required.

Monitoring and evaluation
This study has been undertaken based on the best available science for the Upper Barwon, Yarrowee and Leigh system. The science underpinning environmental water management will continue to evolve with more monitoring, research, and management experience. The provision of environmental water to the system should be accompanied by a monitoring and evaluation program that contributes to the understanding of the system and the delivery and outcomes from the provision of environmental water. This program may need to extend beyond the state-wide environmental flow assessment and monitoring program.

Critical considerations

Flow through Geelong
This environmental flow study has sought to identify the water requirements to meet environmental and Aboriginal Cultural objectives in the Barwon River system. The recommendations have not been

based on water requirements to meet urban social and liveability objectives in major regional centres such as Geelong. Additional water may be required to meet water quality expectations in the Barwon River through Geelong, to support recreational activities and amenity. A separate social and urban liveability investigation would be required to identify the water requirements to meet these objectives.

Existing alternate water sources

The environmental water recovery targets set out in this report are reliant on the ongoing supply of water from the Leigh River (including the Ballarat South Wastewater Treatment Plant) and from both the Moorabool River and discharges from Batesford Quarry. Loss of input from these sources would increase the volume of additional water required to meet environmental water requirements.

There are pressures on water utilities across Victoria over the management of wastewater discharges to waterways. These pressures include concerns over water quality and pressure for the consumptive reuse of water. The Ballarat South Wastewater Treatment Plant currently provides water to the Barwon River system via the Leigh River. However, the timing of the current discharges does not reflect that required to meet environmental flow requirements. Further, it was not within the scope of this study to investigate the extent of any water quality issues associated with the current releases. With appropriate flow modification and water quality management, the Ballarat South Wastewater Treatment Plant discharges can play an important role in the long-term supply of environmental water to the Barwon River system. Additional investigations would be required to develop options for water quality treatment and modifications to the discharge regime to enable the Ballarat South Wastewater Treatment Plant discharges to meet environmental water requirements.

As set out above, discharges from the Batesford Quarry provide water to the Barwon River system. The long-term supply of water to the Lower Barwon River, via discharges from the Batesford Quarry, is not guaranteed. Further work will be required to identify the implications of any cessation to the Batesford Quarry discharges on the flow regime in the Barwon River. Cessation of discharges from Batesford Quarry may increase the water required to meet environmental and other instream uses.

Impacts on water availability

Activities on the land upstream, surrounding or adjacent to waterways such as the installation of farm dams and plantation forestry, can have a significant impact on waterway condition through changed water regimes, erosion or water quality impacts from salinity, sediment and nutrient run-off.

The hydrology of the Barwon River systems has been modified by the presence of small catchment dams that capture surface runoff and change evaporation and groundwater seepage. These small catchment dams (also referred to as farm dams, hillside dams or runoff dams) reduce the volume of surface runoff that might otherwise become streamflow in a basin. Small catchment dams are estimated to capture approximately 16% of total inflows to the Barwon basin, with an estimated total capacity of 34,600 ML (DELWP, 2017). Assessment of the impact of these catchment dams is being undertaken as part of the Long Term Water Resource Assessment (LTWRA). Ongoing farm dam construction has the potential to have ongoing and increasing impacts on catchment hydrology and the availability of water for the environment.

Plantation forestry activities also have the potential to impact on the quality and availability of water for the environment and downstream users. This investigation has not sought to identify the extent of any proposed additional or extended plantation forestry operations within the catchment. Further work will be required to identify the implications of any future plantation forestry operations on the availability of water for the environment in the Barwon River system.

Use of environmental water to manage acid events
As set out above, groundwater extractions are having an adverse impact on water quality (including pH) and waterway health in Boundary Creek and some reaches of the Barwon River. The environmental water recommendations contained in this report have not been developed to address the pH issues in Boundary Creek or impacted reaches of the Barwon River. Attempts to address the water quality issues via dilution would require significantly greater water volumes than those set out in this report. As previously discussed, the remediation of Boundary Creek and Big Swamp has been highlighted as a community priority and will be best addressed by managing groundwater levels within the areas of acid sulphate soils. We don't support the use of limited environmental water entitlements to address water quality problems arising from consumptive groundwater extractions in the Barwon River system.

The value of water to the environment and society
Provision of water for the environment and for cultural and social needs requires a trade-off with consumptive water uses and or available budgets. An economic evaluation can assist to identify the scale of environmental water recovery and/or investment appropriate to the Barwon River system. Such an evaluation could assist to identify the value of existing additional water supplies to the Barwon River (e.g. Ballarat South Wastewater Treatment Plant, Batesford Quarry), would provide insights into an appropriate trade-off or investment in environmental water, and may assist to resolve such trade-offs. Such an evaluation could also assist to quantify the impacts of cease-to-flow events on amenity and recreation through Geelong.

Integrated instream (environmental, social and cultural) water management

This environmental flow investigation has identified the environmental and Aboriginal Cultural water requirements for the Barwon River system. The investigation has also identified

- priorities for the provision of environmental water
- complementary actions necessary to achieve the desired environmental outcomes
- critical considerations in the provision of environmental water

An opportunity exists to integrate the outcomes of this study and these other outcomes (complementary actions and critical considerations) to develop a long-term instream /non-consumptive (environmental, social and cultural) watering strategy for the Barwon River system. The development of such a strategy would explore the alternate options for the provision of non-consumptive water in and to the Barwon system and identify a preferred arrangement of water entitlements, policy and works that meets societal expectations.

Contents

Figures

Tables

Abbreviations

Alluvium	Alluvium Consulting Australia Pty Ltd
BSWWTP	Ballarat South Wastewater Treatment Plant
CCMA	Corangamite Catchment Management Authority
DELWP	Department of Environment, Land, Water and Planning
EFTP	Environmental Flows Technical Panel
EPA	Environmental Protection Authority
EVC	Ecological Vegetation Classes
FLOWS	The environmental flows determination method (DEPI, 2013a)
ISC	Index of Stream Condition
LAWROC	Land and Water Resources Otway Catchments
LTWRA	Long-term water resource assessment
PAG	Project Advisory Group
SEPP	State Environment Protection Policy
SWS	Sustainable Water Strategy
TO	Traditional Owner
UBSWAG	Upper Barwon Surface Water Advisory Group
VEWH	Victorian Environmental Water Holder
WMIS	Water Measurement Information System
WoV	Water of Victoria
WWTP	Wastewater Treatment Plant
YLFC	Yarrowee Leigh Flow Committee

1 Introduction

This report presents environmental flow recommendations for the Upper Barwon, Yarrowee and Leigh River system. It is the culmination of a nine-month FLOWS assessment commissioned by Corangamite Catchment Management Authority (CCMA) in 2018 and delivered in line with the Victorian Government's FLOWS Edition 2 methodology (DEPI, 2013a). The assessment was led by Alluvium Consulting Australia Pty Ltd (Alluvium) – in partnership with Lloyd Environmental and Wadawurrung Traditional Owners – and in consultation with community, stakeholder and agency representatives of the two Project Advisory Groups (PAGs). This 2021 version provides an update to the recommendations provided in the May 2019 version of the report. These updates include:

- Updates to flow frequency recommendations for all reaches. The update has been undertaken to address inconsistencies and improve clarity on the number of freshes recommended per period (for each reach). The flow compliance and water recovery targets have been reviewed and confirmed for this update.
- Use of 'reference' reaches for nearby waterways not included in this FLOWs study.

All other aspects of the report, including flow compliance and water recovery targets have been checked and remain the same.

1.1 Background

The Barwon River system includes the Upper Barwon, rising in the northern slopes of the Otway Ranges, and the Yarrowee-Leigh, with headwaters in the central Victorian uplands around Ballarat, joining the Barwon River at Inverleigh. Flows in the upper and mid reaches of the system are important contributors to the internationally significant wetlands including Lake Connewarre, Reedy Lake and the lower Barwon further downstream.

The Barwon River basin is a major water supply for Geelong, smaller urban centres, and farm water supply for the region. The system is significantly altered via extensive farm dam storages, on-stream reservoirs and many diversion licences.

In this river system – like many others across the state – reduced and altered river flows have disrupted breeding cycles for native fish, frogs, platypus, and other animals; restricted the growth and recruitment of native plants; and reduced the overall productivity of waterways. While the Barwon system still retains significant values for recreation, tourism, biodiversity and Aboriginal Culture, the abundance of native plants and animals has substantially declined and the aesthetic values and environmental services the waterways provide have diminished.

Recent assessments of the ecological condition of the river system, as part of the Corangamite Waterway Strategy (2014-2022), have indicated that most reaches are in moderate condition (previously, most were in marginal to very poor condition), however, there are still very few streams in good or excellent condition. Dedicated water for the environment (known as 'environmental flows') and careful management of how this water is used, is an important element of maintaining and improving the health of waterways and the life that depends on them.

In April 2018 an environmental entitlement was established in the Upper Barwon system, in line with Action 3.5 of Water for Victoria (DELWP, 2016) and Action 4.17 of the Central Region Sustainable Water Strategy (DSE, 2006). This entitlement commits to providing a long-term average of 1,000 ML of water per year for the environment, by allocating a 3.8 per cent share of inflows into the West Barwon Reservoir.

With this entitlement established, and the Central Region Sustainable Water Strategy due for revision, Corangamite CMA sought to update its understanding of the environmental flow needs of the Upper Barwon, Yarrowee and Leigh River system by commissioning an updated FLOWS study. A FLOWS study is a transparent science-based approach to assessing the environmental flow requirements of freshwater reaches of river systems. It provides a process for developing flow-dependent environmental objectives and the flow regime required to meet these objectives.

The Corangamite CMA previously undertook a FLOWS study of the Barwon River system in 2005/6 (Lloyd Environmental *et al.* 2006) for much of the catchment. The CCMA sought to update the assessment in 2018 and 2019 to encompass further reaches and to provide greater detail on the environmental water requirements of the system. This 2019 assessment has been undertaken in response to:

- improvements in the ecological and hydrological knowledge of the Barwon River system,
- an update in the FLOWS methodology (DEPI, 2013a), and
- a desire by stakeholders to understand water recovery options to meet environmental water requirements.

The recent updates in Victorian policy and scientific research will help validate the project deliverables, including environmental flow recommendations and prioritisation of water recovery. The prioritisation will be based on values protected, water recovered, and community expectations. It has been important for the project team to liaise with the community, including agency stakeholders, community groups and the recently established stakeholder advisory committees – the Upper Barwon Surface Water Advisory Group (UBSWAG), the Yarrowee Leigh Flow Committee (YLFC) – as well as work in partnership with Traditional Owners.

1.2 Project scope and objectives

A major aim of the project is to improve the CCMA's ability to manage and deliver the environmental water reserve (in particular, held water), river flows and groundwater discharge into the system. Specifically, this project will assist the CCMA to improve their planning and management in the Upper Barwon and Yarrowee-Leigh River systems, noting the changes due to climate change and increasing urbanisation of the catchment since the previous study in 2006. For the most part urbanisation of a catchment will result in a net decline in the water quality and hydrologic regime required to support aquatic ecosystems.

The study has examined the environmental water needs within each of ten freshwater river reaches and determined water recover targets required to meet these needs, through the application of the FLOWS2 method (DEPI, 2013a). The project team has worked in partnership with Traditional Owners (TOs) within the study area to incorporate Aboriginal Cultural values and Traditional Ecological Knowledge into the assessment and subsequent environmental flow recommendations. This included Aboriginal Corporation representation on the environmental flows technical panel (ETFP). The study also included a specific groundwater conceptualisation task, in order to gain a better appreciation of the surface water and groundwater interactions in this system, and the impact of groundwater resource extraction on the surface water riverine flow.

It should be noted that this study will not result in an allocation of water for the environment. However, the investigation and results will contribute to the information base upon which water entitlements can be considered.

This report also provides some commentary on additional management actions – such as removal of physical barriers to fish movement and management of exotic species – that would complement the delivery of environmental flows and will be necessary to achieve the intended outcomes of the recommended environmental water and/or enhance the effectiveness of environmental water delivery.

1.3 Project stages and outputs

The project has been delivered over four stages, each with a corresponding key output (Figure 1). This Recommendations Report is an output of the final stage of the project. This report builds on the previous Site Paper and Issues Paper, developed in Stages 2 and 3 of the project. Project Advisory Group (PAG) meetings have been held during each stage for community and stakeholder representatives to provide input and feedback.

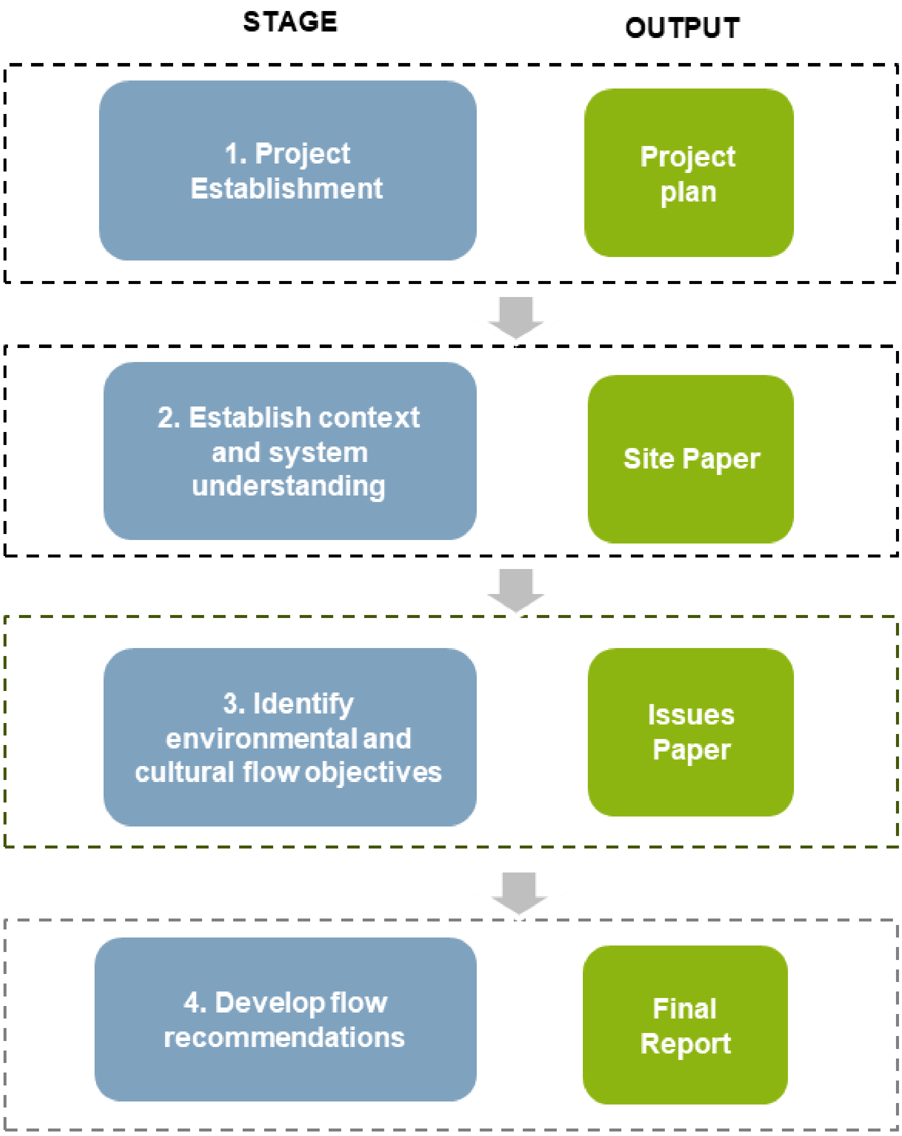

Figure 1. *Project staging and outputs.*

1.4 Project team

The project team has comprised:

Technical Lead	Lance Lloyd, Lloyd Environmental
Project Director	Ross Hardie, Alluvium Consulting Australia
Geomorphology	Emma Hodson, Ross Hardie and Kira Woods, Alluvium Consulting Australia
Fish and Aquatic Fauna	Lance Lloyd, Lloyd Environmental
Vegetation	David Carew, Alluvium Consulting Australia
Water Quality	Peter Newall, Independent ecological consulting
Hydrology	Ross Hardie, Andrew John, Lisa Walpole, Alluvium Consulting Australia
Groundwater	Eliza Wiltshire and Jon Fawcett, CDM Smith
Project management	Leonie Duncan, Alluvium Consulting Australia
Aboriginal Cultural values	Tammy Gilson Wathaurung Aboriginal Corporation Project Officer Corrina Eccles Wathaurung Aboriginal Corporation Cultural Education Coordinator Melinda Kennedy Wadawurrung employee currently undertaking Graduate Diploma Land Sea and Country Management. Kristen Lees, Corangamite CMA

Acknowledgement: Brad Clingin (previously CCMA) contributed in a variety of ways to initiate the project in terms of the project management, site selection, field work, inputs to discussions and reviews of initial documentation.

1.5 Project Steering Committee

The project has been overseen by a Project Steering Committee, comprised of:

Jayden Woolley	CCMA
Jared Scott	Barwon Water
Alison Miller	Victorian Environmental Water Holder (VEWH)
Tara Ash	Central Highlands Water

1.6 Project Advisory Group (PAG) – members and observers

Two Project Advisory Groups (PAGs) have been formed to contribute to the project: the Yarrowee Leigh FLOWS Committee (YLFC) and the Upper Barwon Surface Water Advisory Group (UBSWAG). The PAG members and meeting observers are listed below.

PAG	Name	Affiliation
YLFC	Nick McKinley	Leigh Catchment Group
YLFC	Hedley Fraser Thomson	Community/Environment Vic
YLFC	Tristan McGrath	Melbourne Uni student/community member
YLFC	Kurtis Noyce	Ballarat Goldmine
YLFC	Tim Fletcher	Field Naturalists Ballarat
YLFC	Daryl Wallis	City of Ballarat
YLFC	Garry Wishart	Leigh Landcare Group
YLFC	Mark Prunty	Community member
YLFC	David Ebbs	Federation University
YLFC	Susan Wilshart	Leigh Landcare group
UBSWAG	Peter Greig	Upper Barwon Landcare Network
UBSWAG	Daryl Hoffmann	Otway Agroforestry
UBSWAG	Cameron Steele	People for a Living Moorabool
UBSWAG	Angus Ramsay	Southern Rural Water
UBSWAG	Malcolm Gardiner	Land and Water Resources Otway Catchments (LAWROC) Landcare Group
UBSWAG	Geoff Gayner	Geelong Environmental Council
UBSWAG	Andrew McClennan	Land and Water Resources Otway Catchments (LAWROC) Landcare Group
UBSWAG	Stuart Mathison	Winchelsea Land and River Care Group
UBSWAG	Jamie Willey	Community Member
UBSWAG	Brett Smith	Geelong Field Naturalist Club
UBSWAG	Jacob Wade	Geelong Field and Game
UBSWAG	Jim Lidgerwood	Winchelsea Land and River Care Group
N/A	Kristen Lees	CCMA
N/A	Sharon Blum-Caon	CCMA
N/A	Phil Mitchell & Yi-Ming Ma	DELWP
N/A	Jayden Woolley	CCMA
N/A	Jared Scott	Barwon Water
N/A	Alison Miller & Caitlin Davis	Victorian Environmental Water Holder (VEWH)
N/A	Tara Ash	Central Highlands Water
N/A	Carolyn Francis	EPA Victoria
N/A	Stuart Willsher	Parks Victoria
N/A	Travis Riches	Colac Otway Shire

2 The Barwon River system

The Barwon basin (Figure 2) is located within the Corangamite catchment region. The main river, the Barwon River, is fed by the confluence of the East and West branches, which rise south of Forrest, in the Otway Ranges. The Barwon River flows for around 160km, first in a north-easterly direction before turning east. A major tributary of the Barwon River, the Leigh River rises near Ballarat as the Yarrowee River and flows in a southerly direction, with its confluence with the Barwon River near Inverleigh. The Barwon River downstream from Inverleigh flows in an eastern direction though (adjacent) to Geelong and through Lake Connewarre, draining into the Bass Strait at Barwon Heads. Most of the river flows through the western basalt plains, with outcrops of basalt rock particularly around Inverleigh, Pollocksford and at Buckley Falls.

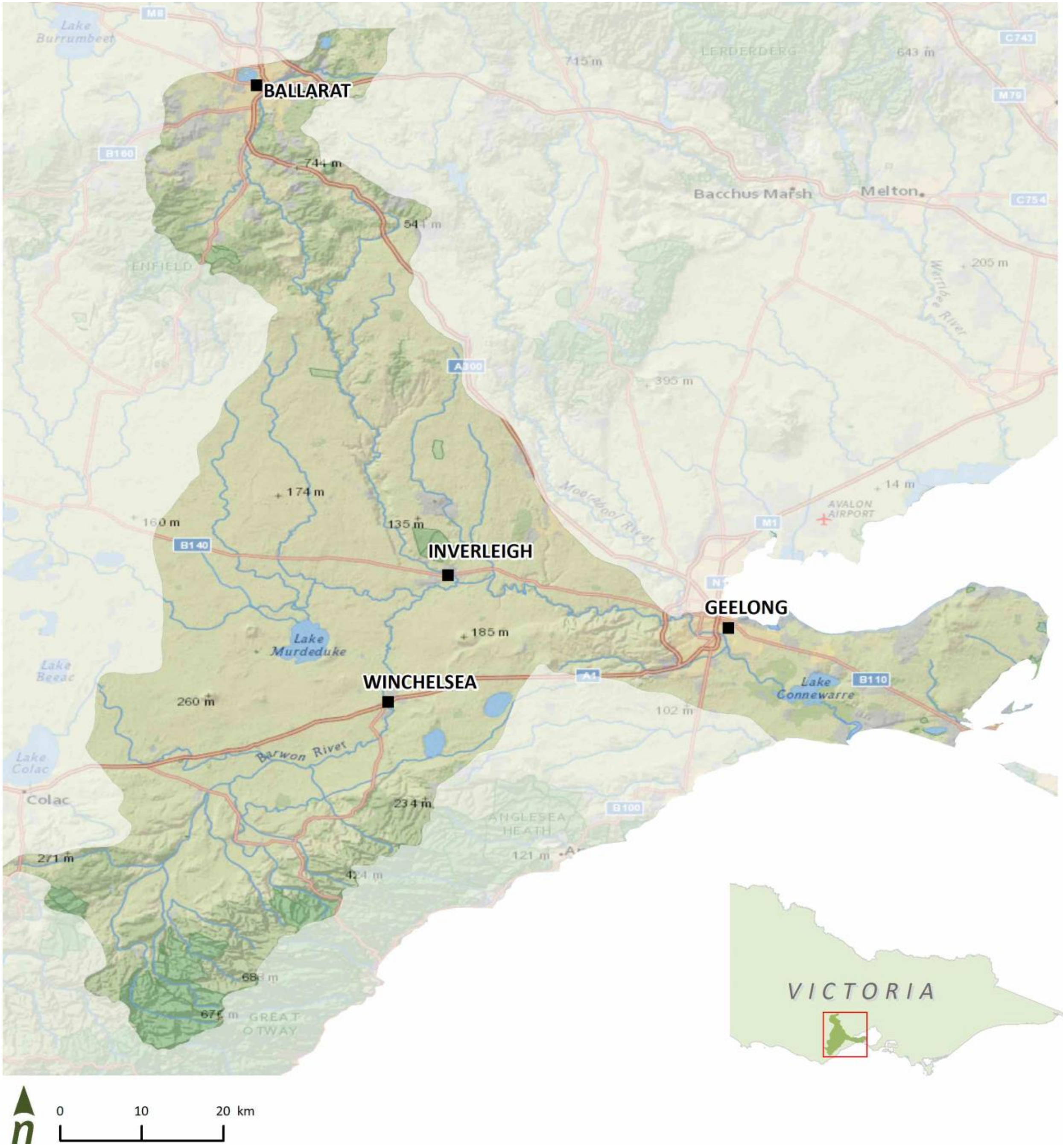

Figure 2. *Overview of the Barwon River basin.*

The Barwon River catchment has three sections, the Otways to the west, the Brisbane Ranges (southern slopes of Great Dividing Range) to the north and the Bellarine Peninsula in the lower reaches. This project just considers the first two sections with the Bellarine Peninsula section being assessed and flows recommended by Lloyd *et al.* (2012a). The Barwon catchment thus includes two major river systems, the Barwon River which drains from the south and west, and the Yarrowee/Leigh River which drains from the north. Birregurra Creek and Warrambine Creek are the other major tributaries with a series of smaller streams entering the Barwon River upstream of Birregurra Creek. The west of the catchment features several inland, saline/brackish lakes including Lakes Murdeduke, Modewarre and Gherang (Lloyd *et al.* 2012a) but these are not considered in this project. The northern and southern areas of the catchment are mountainous to undulating sedimentary country, while the central area forms part of the western basalt plain.

The Barwon River provides essential freshwater inputs to the Ramsar-listed Bellarine Peninsula wetlands. These wetlands, particularly Reedy Lake and Hospital Swamps, provide a home for many thousands of migratory birds, including some of Victoria's rarest species.

2.1 Land use change

Prior to European settlement, the area of forest and woodland would have been more extensive, but the central part of the catchment would have been grassland (DWR, 1989). Prior to European settlement, the Barwon catchment was the Country of Aboriginal groups now represented by Wathaurung Aboriginal Corporation and Eastern Maar Aboriginal Corporation. John Batman and his party arrived in the Port Phillip region in 1835 and within two years runs were taken as far as Winchelsea. The port of Geelong developed from the earliest days of Victorian settlement. The gold rush of the 1850s attracted a large number of people to the Ballarat region, with alluvial mining in the Upper Yarrowee River.

In 2006, an assessment of the land use showed that natural forests and woodlands remain in parts of the Otways and Brisbane ranges headwater areas, forming 13% of the catchment area (excluding the Moorabool catchment). Grassland used for grazing and cleared land used for grain cropping occupies 81% of the area (excluding the Moorabool catchment). The other major categories of land use are intensive agriculture (2%), plantation (1%) and urban areas (2%) (DWR, 1989). Potatoes are grown in the upper basin, near Colac, and there is some market gardening in the vicinity of Geelong (Drew and Atkin-Smith, 1987). In recent years, there has been a significant increase in urbanisation, which is likely having impacts on flow regimes. In addition, the production of recycled water from sewage plants and stormwater has the potential to be used for environmental purposes if the water quality and flow regimes can be improved before discharge.

2.2 Major threats within the basin

Aside from environmental flow-related issues, a number of threats have been identified through a review of relevant literature, site visits, expert knowledge, stakeholder engagement and review of spatial datasets. While environmental flow determination and provision can contribute to alleviating some of these threats, a number of these issues are considered outside of the scope of this project and are addressed through other projects. Section 8 highlights complementary actions that would contribute to addressing some of these threats and enhance the outcomes of environmental flow delivery.

Groundwater extraction

Groundwater can supply water to wetlands, springs and the low flows in stream systems. Extraction of groundwater, connected to surface water systems, can reduce the availability of surface water. Groundwater extractions can also impact on instream water quality during low flow periods**.**

Deterioration of water quality
Declining water quality is evident through the catchment. Threats include acidification, eutrophication, pollution, litter and stormwater inputs. Water quality is an important factor for the survival of most flora and fauna.

Stream bed and bank condition
Geomorphic processes are strongly influenced by riparian vegetation. The root systems of trees increase the shear strength of the bank sediments, reducing the likelihood of mass failure. Ground cover vegetation 'shield' bank material from high shear stress and reduce hydraulic entrainment (removal) of sediment particles. Clearing of vegetation, including through stock grazing, can result in bank erosion and bed incision of streams, increasing sediment delivery to the river and changes in channel morphology. Much of the Barwon River basin has been subjected to past clearing and stock and grazing pressures, with livestock access to waterways causing bank erosion, degraded riparian vegetation and water quality issues.

Exotic species
Invasive species are one of the biggest threats to the environment. Exotic species that require complementary management include, but are not limited to:

- exotic vegetation species such as willows, blackberry, spiny rush and reed sweet grass
- introduced fish species such as exotic carp species, including goldfish, carp, roach, tench, eastern gambusia, redfin perch, rainbow trout and brown trout
- invasive fauna such as rabbits and foxes.

Flow limiting infrastructure
The provision of environmental flows can be constrained by the capacity of the available infrastructure to deliver water from storages (i.e. channels and gates) and flow capacity constraints in the system (e.g. weirs, levees and bridges).

Barriers to fish movement
Fish need to be able to move freely between habitats and reaches for spawning, feeding and dispersal. Waterways have been modified and barriers to fish passage, such as dams, weirs and road culverts have been constructed. Unrestricted fish movement is a key characteristic of a healthy waterway and while environmental flows can assist in fish movement, physical barriers can limit their effectiveness.

3 Project reaches and study sites

3.1 Reach and site selection

The application of the FLOWs method requires that the study area be divided into representative reaches (Figure 3), where possible, ensuring that each reach comprises relatively uniform characteristics of the river system (i.e. geomorphology, hydrology, hydrogeology, system operation and biology). A representative site must then be identified within each reach for the project team to undertake an on-ground field assessment and to feed into the hydraulic modelling and determination of environmental water requirements.

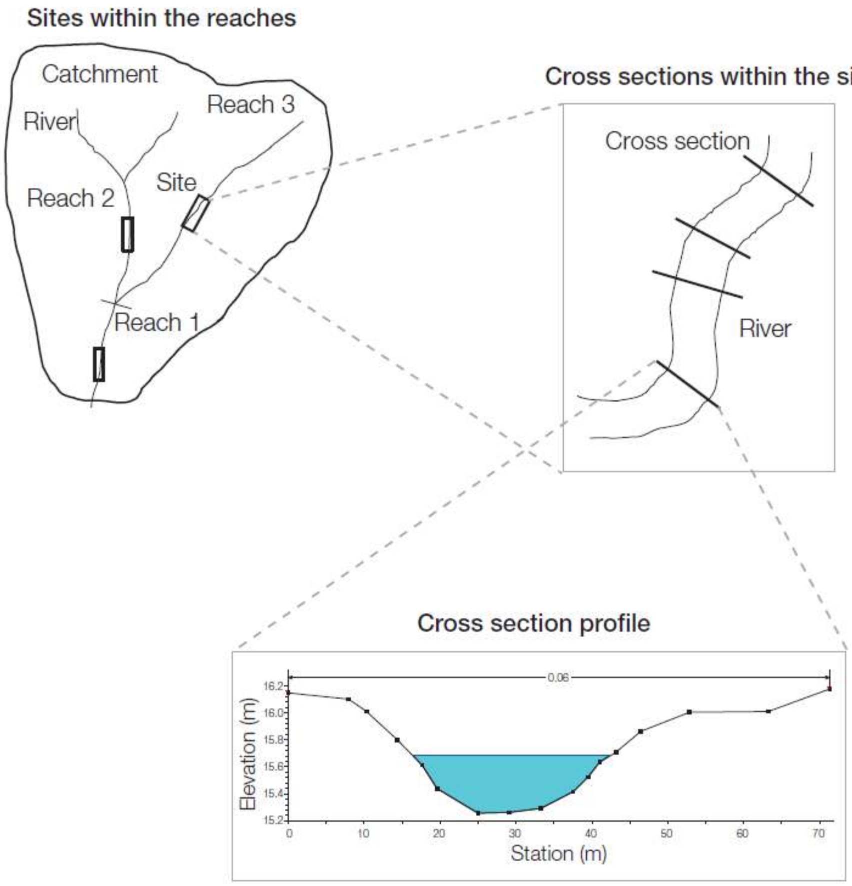

Figure 3. *Schematic demonstrating reach, site and cross-section location selections (DEPI, 2013)*

A number of factors were considered in the selection of a final set of 10 representative reaches. including:

- Geomorphology
- Hydrology
- System operation
- Gauge locations
- Major tributaries
- Data availability

Information derived from the PAG meetings was also considered and used in reach delineation and site selection (for instance, a reach in the Yarrowee was deemed useful). Field site selection and hydraulic modelling sites were also influenced by accessibility requirements and availability of topographic data.

3.2 Reach delineation

The reach delineations adopted for this FLOWS assessment are shown in Figure 4 and outlined in Table 1. The arrangement of reaches allows previous sites (within reaches) to be utilised and flow recommendations updated. The proposed arrangements also result in the establishment of new reaches where flow requirements can be determined and updated to take into account the changed system hydrology and new water management opportunities available now and into the future.

Reaches which were the same as the 2006 study utilised the same representative sites as the 2006 study and new sites were chosen for additional reaches on the basis of proximity to gauge stations, representation of the reach and accessibility.

Table 1. 2019 adopted FLOWS reaches

2019 reach number	2019 reach name	2006 site and reach
1	Yarrowee	New site not included in 2006 study
2	Leigh River	Existing Lower Leigh site
3	Upper Barwon West- u/s Boundary Creek	Existing site
4	Upper Barwon East	New site not included in 2006 study
5	Dewing Creek	New site not included in 2006 study
6	Boundary Creek	Existing Boundary Creek site
7	Barwon River - d/s Boundary Creek	New site not included in 2006 study
8	Pennyroyal / Deans Marsh Creeks	New site not included in 2006 study
9	Winchelsea	Existing Winchelsea site
10	Lower Barwon	Existing Murgheboluc site

Reference reaches
Given the specific data required to develop flow recommendations for a reach (e.g. potential need for new topographic survey, hydrological modelling and ecological survey), the reaches described above have been prioritised and consolidated where possible.

However, while specific recommendations have not been developed for other reaches in the system, flow recommendations for reaches included in the study can be used as a reference to approximate flow recommendations for these other reaches. Based on the catchment area, likely hydrology, geographic setting and land use:

- Flow recommendations for the Pennyroyal / Deans Marks Creeks reach (Reach 8) can be used as a reference for Matthews Creek, a similar right-bank tributary of the Upper Barwon River.
- Flow recommendations for Dewing Creek (Reach 5) can be used as a reference for Callahan Creek, a similar right-bank tributary of the Upper Barwon East Branch.

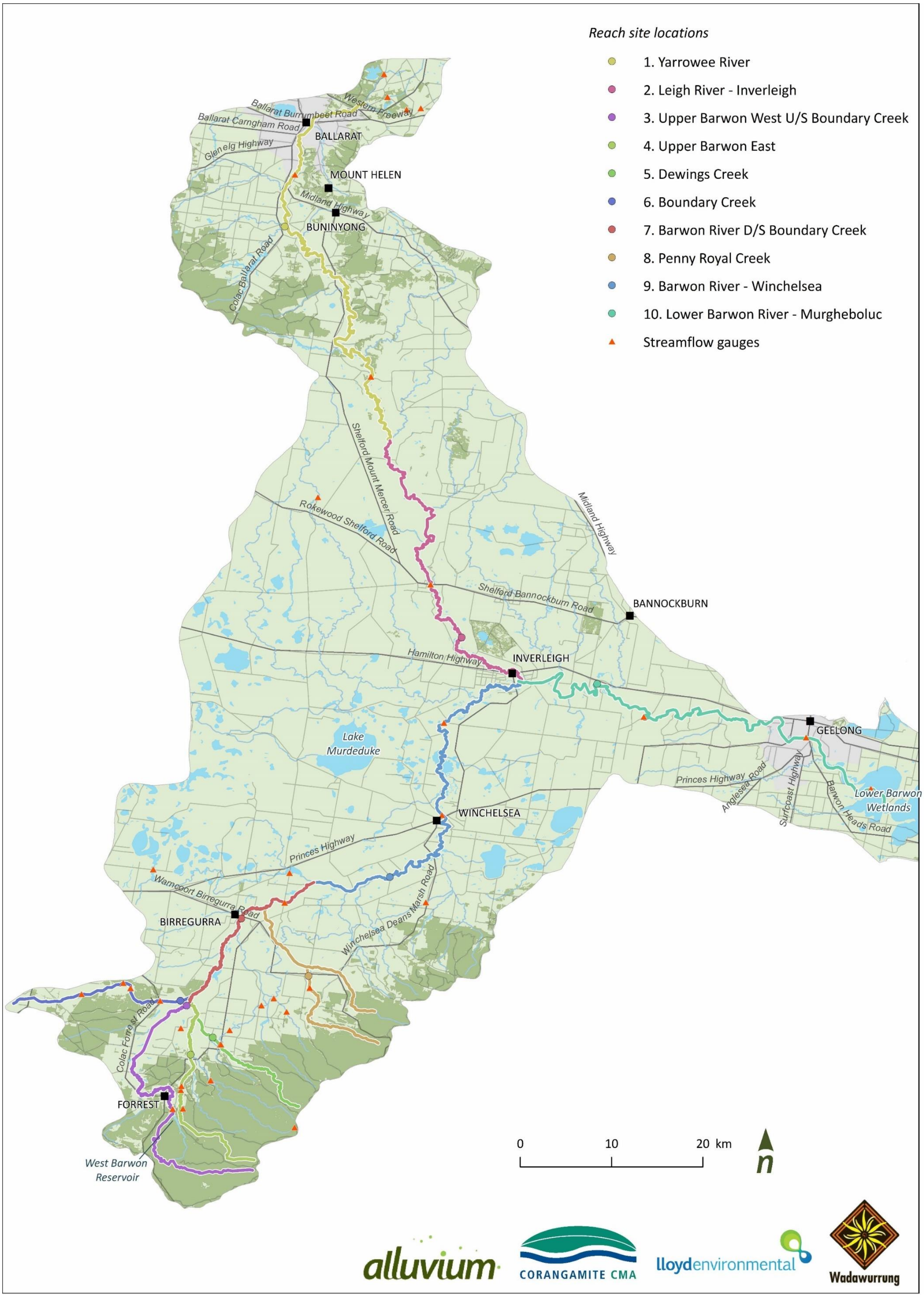

Figure 4. *Adopted 2019 FLOWs study reaches and site locations (points)*

3.3 Site selection for Aboriginal Cultural values

Traditional Owners, the Wadawurrung, from the Wathaurung Aboriginal Corporation, informed site selection and conducted site inspections and background Aboriginal Cultural values research on those reaches on Wadawurrung Country. Eastern Maar Aboriginal Corporation also have Country within the FLOWS Study and it is important to note that Traditional Owners the Wadawurrung are restricted from commenting or conducting site assessments on Eastern Maar Country for Cultural reasons. Eastern Maar Aboriginal Corporation were invited to participate in the FLOWS study and declined but expressed interest in the outcomes of the study and any Seasonal Watering Proposals on their Country.

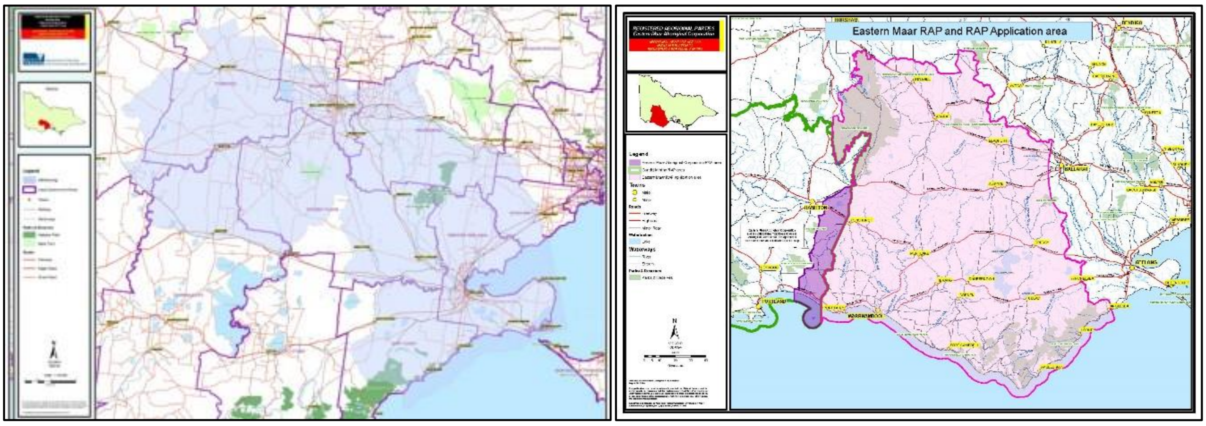

Figure 5. *Wadawurrung Country (left) and Eastern Maar Country (right)*

Site Inspections and Aboriginal Cultural value investigations have been undertaken on sites within the following reaches. It is important to note that site selection for Aboriginal Cultural values has resulted in additional site assessments to those undertaken by the technical panel in many reaches:

- Reach 1: Yarrowee
- Reach 2: Leigh River
- Reach 9: Winchelsea
- Reach 10: Lower Barwon – Murgheboluc

Site selection for Aboriginal Cultural values has been informed by the Wadawurrung historical Clan maps (Appendix A) that identify the confluences of waterways as being of significant Aboriginal Cultural value as places where Clans met to conduct the ceremonial trading or *Bai eer*.

3.4 Site visits

12 sites (including the previous Geelong and Matthews Creek sites) were inspected by Brad Clingin (previously CCMA), Kristen Lees (CCMA), Lance Lloyd (Lloyd Environmental), David Carew (Alluvium), Kira Woods (Alluvium) and Tammy Gilson (WAC) over 3 days in May 2018. The purpose of this field assessment was for the Environmental Flows Technical Panel (EFTP) to assess the values present in each reach and gain an understanding of the implications of flow management. Information and data gathered during the field inspections included:

- Geo-referenced photos
- Planform and cross-section field sketches

- Vegetation inventory, including type, dominant species and condition
- Substrate types
- Channel form and dimensions
- Instream habitat features and disturbances
- Land use impacts and potential complementary actions
- Flow characteristics

Appendix B provides site summaries including locations, photos, field sketches and large-scale map.

3.5 Desktop review

Aboriginal Cultural values
In the absence of a fully developed Aboriginal Waterways Assessment Tool or Cultural Values Mapping methodology for Wadawurrung Country, a combination of desktop research on historical documents, an interrogation of Aboriginal Victoria's Aboriginal Cultural Heritage Register and Information System (ACHRIS) and site inspections on areas identified as having Cultural significance was conducted.

Figure 6. *Melinda Kennedy and Tammy Gilson undertaking desktop analysis of the flows study area.*

Ecological and river health values
Previous stream condition assessments and various databases were used to identify the presence of ecological values and assess the state of river health within the FLOWS study area. Data sources included:

- Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP)
- Water Measurement Information System (WMIS)
- 2010 Index of Stream Condition (ISC)
- The NatureKit biodiversity decision support tool (DELWP)
- Waterwatch monitoring data

4 Hydrology and water resource management

This section of the report characterises the hydrology of the Barwon River system, describes the surface and groundwater system operation, hydrological modelling methodology, and provides an analysis of estimated change in the flow regime between current and pre-development conditions using a range of hydrological indicators.

The FLOWS study process requires hydrological information that enables the EFTP to specify flow components in terms of magnitude, duration, frequency, timing, and rate of change and to assess the degree to which the flow components are provided by the current flow regime. Availability of tailored hydrological statistics reduces subjectivity in the environmental flow assessment process. To support this environmental FLOWS assessment project, modelling of daily streamflow series at various locations throughout the catchment has been undertaken using a combination of existing and new hydrological models, for the period 1st July 1927 to 20th June 2018. These results are also compared with the analysis undertaken in 2006.

4.1 System operation

The Barwon River originates in the Otway Ranges, receives inflows from the Leigh River and the Moorabool River, before flowing into the ocean at Barwon Heads. The system is regulated from its upper reaches in the south through the West Barwon Dam and diversions from some tributaries as well as through a series of smaller dams in the upper Yarrowee catchment and stock & domestic use along the river length.

The catchment of the West Barwon Dam (constructed in 1964; SKM, 2005) sits in part of the catchment with the highest rainfall (up to 1400 mm per annum), almost double that of Geelong. The West Barwon Reservoir has a capacity of 21,500 ML which is shared between Barwon Water and the VEWH under the Upper Barwon Bulk Entitlement and Upper Barwon Environmental Entitlement. The Bulk Entitlement allows Barwon Water to store 96.2% of flow into the West Barwon Reservoir, subject to passing flow conditions, while the Environmental Entitlement provides for VEWH to capture 3.8% of inflows into the reservoir and store up to 2000 ML.

Water from Barwon Water's share of inflows and storage capacity is transferred to Wurdee Boluc Reservoir via the 57 km Wurdee Boluc Inlet Channel (Barwon Water, 2018) where it can be treated for drinking water supply. During transfer periods, up to 180 ML/day is released from West Barwon Reservoir and diverted to the East Barwon River via a tunnel. The water travels down a section of the East Barwon River before being diverted into the Wurdee Boluc Inlet Channel and transferred down to the Wurdee Boluc Reservoir. Water can also be diverted from the East Barwon River, Callahan's Creek, Dewing's Creek, Pennyroyal Creek and Matthews Creek. These diversions are managed in accordance with the maximum diversion rates and minimum passing flow requirements outlined in the Upper Barwon Bulk Entitlement[1], with the maximum total diversion down the channel of 240 ML/day.

The Central Region SWS (DSE 2006) gave a commitment to 'Increase environmental flows in the Barwon River by 4,700 ML by 2015', including a transfer of entitlements in the West Barwon Reservoir to the environment.

[1] Refer to https://waterregister.vic.gov.au/water-entitlements/bulk-entitlements for full listing of the passing flow requirements and maximum diversion limits relevant to this entitlement

Lloyd Environmental (2006) reported that the mean annual discharge in the Barwon River is reduced by over 60% immediately downstream of the West Barwon Dam due to the capture of flow. However, this impact is tempered downstream by inflows from unregulated and partly regulated tributaries, with flows reduced by less than 10% (Lloyd Environmental 2006). There are several small tributaries flowing from the south into the Barwon River upstream of Birregurra. Boundary Creek joins the river from the north and groundwater extraction within the catchment is known to have reduced flows in this tributary, with the creek no longer receiving groundwater contributions of 1 to 2 ML/day to sustain flows during the dry period. At the time of writing, further studies are underway to confirm if long-term groundwater extraction could impact the Barwon River or other tributaries.

In addition to reduced flows and altered seasonality due to large-scale storages and diversions, small catchment dams (i.e. farm dams) are estimated to capture approximately 16% of total inflows to the basin (DELWP, 2017), with an estimated total capacity of 34,600 ML (DELWP, 2017). Assessment of the impact of these catchment dams is being undertaken as part of the Long Term Water Resource Assessment (LTWRA). Ongoing farm dam construction has the potential to have ongoing and increasing impacts on catchment hydrology and the availability of water for the environment.

The upper Yarrowee (and Leigh) River catchment is situated in a drier part of the catchment only receiving about 700 mm per year (DWR, 1989). Central Highlands Water operates four reservoirs in the northernmost part of the catchment to supply Ballarat and other small urban demands (SKM, 2005). These reservoirs are primarily filled by water from the Moorabool catchment, however, spills from these reservoirs enter the Leigh River (SKM, 2005). The Ballarat South Wastewater Treatment Plant (BSWWTP) discharges treated effluent into the Yarrowee River (SKM, 2005). These discharges are managed in accordance with the maximum discharge limits outlined in the EPA Section 20 Licence. The average discharge is 20 ML/day with 7260 ML discharged in the 2017/18 year. The Ballarat gold mine also discharges into the Yarrowee.

As at the time of the previous FLOWS study, the flow issues for downstream reaches of the Yarrowee and Leigh Rivers are the impact of increased low flows and loss of cease-to-flow events (Lloyd Environmental *et al.* 2006). Urban runoff processes will have no doubt altered the hydrology of the river in the reaches downstream of Ballarat but also provide flows to the Yarrowee River. Further storage and management of this water is likely to provide an alternative source of environmental water into the Yarrowee River in the future.

A review by EPA of water authorities discharge is expected to be a key driver for improving the quality of discharges. This provides the potential for future opportunities for complementary actions to support flow manipulation and alternative water resources to meet ecological objectives. There are a number of urban wetlands and upstream reservoirs that could also be augmented to provide flows into the Yarrowee River (Tara Ash pers. comm.).

4.2 Hydrologic non-stationarity and climate change

Significant hydrologic change has been observed within the greater Barwon River catchment since the completion of the previous environmental flow study in 2006. The Millennium Drought (~1997-2010) presented a severe, long-term impact on rainfall inputs to the system. It was the most extreme drought on historical record for large parts of south-east Australia (Van Dijk *et al*. 2013). Riparian wetlands and aquatic ecosystems were severely affected as a result of substantial reductions in runoff and diminishing water in storages (Bond & Lake 2005; VEAC 2007). Although drought conditions were alleviated in 2010 and 2011 when parts of Australia experienced the highest two-year rainfall on record, conditions in much of Victoria have yet to return to pre-drought averages (refer Figure 7). The relatively flat trajectory within the period since 1997 could imply that a return to pre-drought rainfall conditions may take some time, if at all.

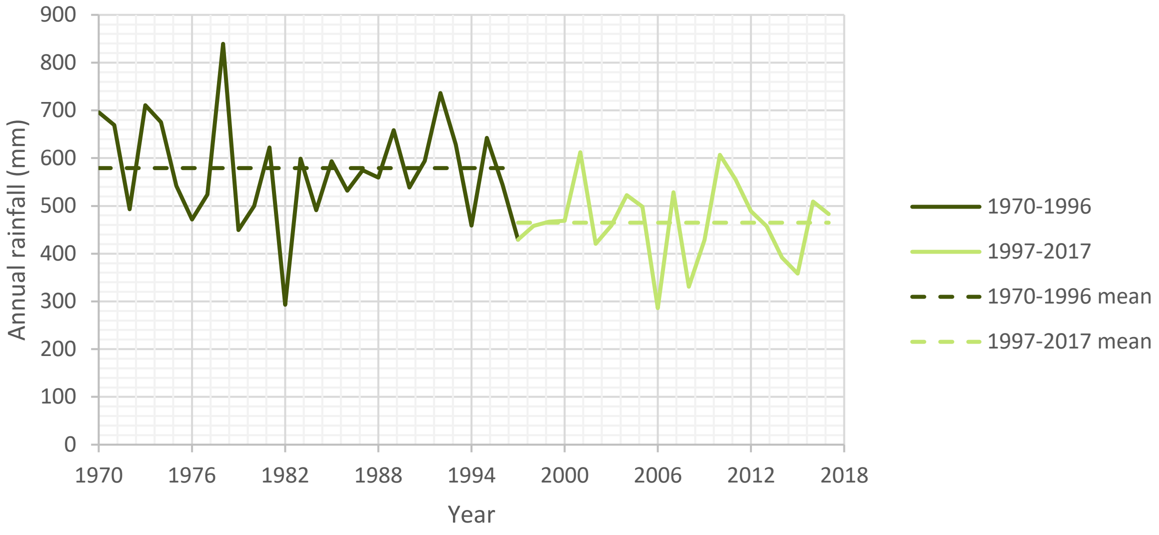

Figure 7. *Annual rainfall totals near the town of Inverleigh within the Barwon River catchment. This location is approximately the centroid of the wider Barwon River catchment*

Reduced rainfall has potentially severe implications for surface water availability, given the non-linear response of runoff to rainfall inputs. Figure 8 shows the relationship between annual rainfall and annual runoff for Birregurra Creek (233211 Birregurra Creek at Ricketts Marsh), just upstream of the confluence with the Barwon River. Although the relationship shows significant scatter, possibly due to groundwater extractions in the area, there is a threshold below about 450 mm of rainfall where no runoff occurs. Average rainfall before the drought was 650 mm, with recent conditions since 1997 (shown in red) approximately 515 mm, clustered very close to the cease-to-flow threshold. In this case, long-term annual rainfall reductions of approximately 21% have led to a corresponding reduction in average annual runoff of 83%.

A similar narrative is presented in the larger Barwon River downstream of its confluence with the Leigh River (233200 Barwon River at Pollocksford - Figure 9). An apparent step-change in average rainfall inputs of approximately 20% has led to a decrease in average runoff by 69%.

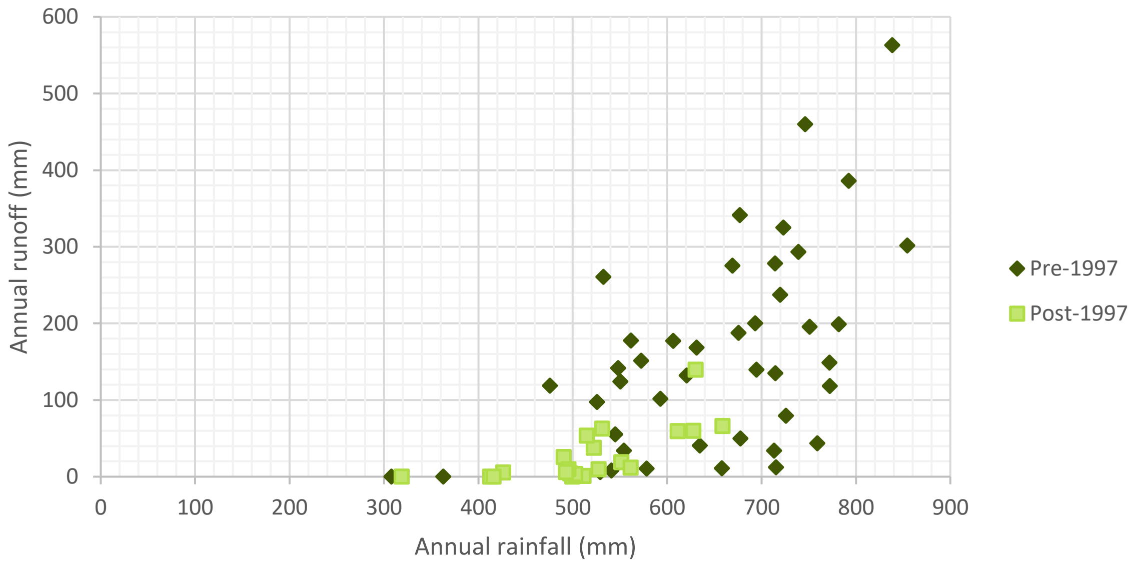

Figure 8. *Relationship between annual rainfall and runoff for Birregurra Creek (233211 Birregurra Creek at Ricketts Marsh) for the years 1954-2017*

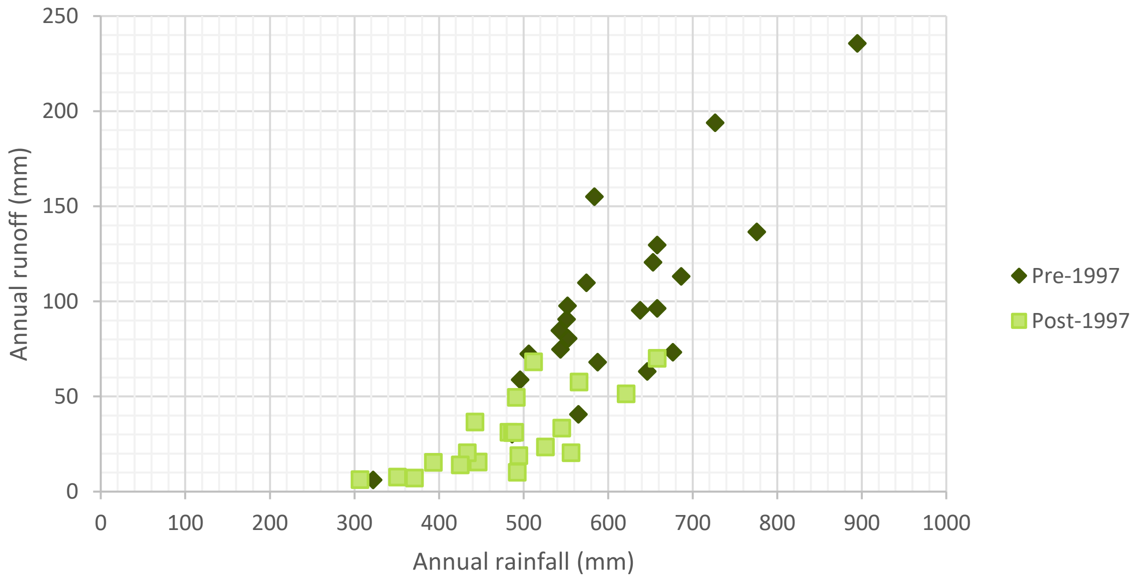

Figure 9. *Relationship between annual rainfall and runoff for the Barwon River (233200 Birregurra Creek at Pollocksford) for the years 1974-2017*

Work progressing at the University of Melbourne has highlighted some implications for the hydrologic response of catchments during and after long-term droughts. Saft *et al*. (2015) found significantly less streamflow for a given rainfall during the Millennium Drought for 44% of studied catchments around Australia, including changes in the annual rainfall-runoff relationship. The permanence of these changes and whether they are coupled to the meteorological (rainfall) drought is currently unknown, although early work is suggesting persistence of 'drought-state' behaviour in gauged runoff well after rainfall returns to pre-drought conditions in many parts of Victoria. This may mean that for parts of the Barwon River system where rainfall has recovered post-drought, runoff may be slow to respond.

In the case of the wider Barwon River system, the primary driver of reduced surface water availability appears to be climate-related, although there are other factors that seem to influence runoff. Figure 10 shows the linearised rainfall-runoff relationship for the Barwon River at Pollocksford and the Leigh River at Mt Mercer. A change in the rainfall-runoff relationship (hence flow reductions not driven by rainfall) should appear as a deviation in slope between the two periods in the time series. This change is relatively minor for both cases and may be due to the limited sample size of the pre and post-drought periods but is nonetheless suggestive of other changes in catchments somehow influenced by drought conditions.

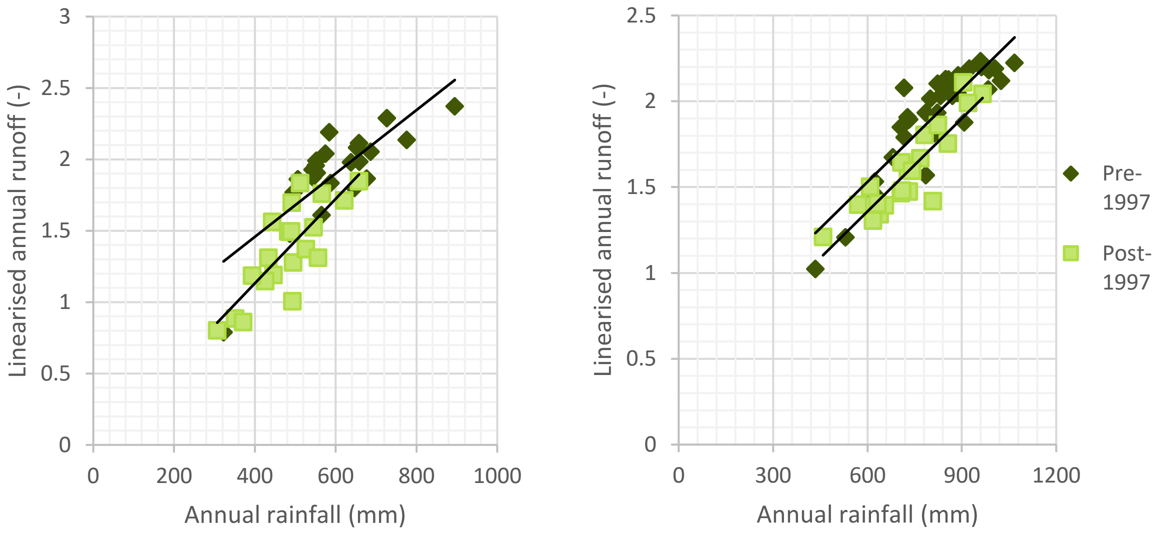

Figure 10. *Linearised rainfall-runoff relationship for the Barwon River (233200 Barwon River at Pollocksford) – left panel; Leigh River (233215A Leigh River at Mt Mercer) – right panel*

Mounting evidence suggests that stationarity in hydrologic systems (where the mean and variability of a system do not change over time) is rapidly destabilising due to climate change, with forecast conditions only exacerbating the impact (Milly *et al*. 2008; Poff, 2017). Most parts of the Victoria, including the Barwon River catchment, are projected to experience ongoing reductions in annual rainfall, with corresponding reductions in available runoff. Median projections from a range of climate scenarios and global circulation models predict a further reduction of 5% in annual rainfall from current conditions, with more conservative estimates (90th percentile) as high as 20%. The corresponding predicted runoff reductions are 22% (median) and 48% (90th percentile) (DELWP 2016). It should be noted that these estimates do not consider changing physical conditions within the catchment that would likely occur as a result of climate change, hence the actual reduction in runoff may be even higher. The implications of hydrological non-stationarity are that 'natural' flow regimes become increasingly less reliable predictors of future conditions, environmental targets shift, and our ability to manage environmental water and understand the magnitude of risks posed by climate change diminishes.

These factors suggest there may be significantly lower water availability in the Barwon River system than might be otherwise predicted when looking at the historical record. The current FLOWS method relies heavily on assessing the unimpacted modelled record for identification of flow components (e.g. freshes). However, some care needs to be taken in considering the long-term trajectory of climate-related change and the implications for surface water availability for the delivery of environmental flows.

4.3 Hydrological analysis

The purpose of the hydrological analysis included as part of this study is to compare various components of the flow regime that may influence ecological response under current levels of development conditions compared with under natural conditions. This project builds on the existing representation of river operations and system demands using outputs from the existing weekly REALM model and uses the eWater Source software to develop a catchment model which represents hydrological response based on climate and land use. Hydrological modelling provided daily current and unimpacted stream flows for a representative site within each of the environmental flow reaches from 1st July 1927 to 30th June 2018. Although the impacts of the Millennium drought and climate change are noted (Section 4.2, above), it was not within the scope of this project to attempt to model future rainfall or climate change scenarios. Further details of the hydrological modelling methodology and results can be found in Appendix C.

Numerous flow gauging stations are located on streams within the Barwon River basin which support resource managers to make short and long term decisions and allow analysis of changes in measured flow over time. Some gauging stations have been discontinued, have patchy records or have a short period of record. Using gauged flow data to compare the current (regulated) flow regime with the unimpacted (natural) flow regime can be complicated by the lack of consistent data sets for the periods of interest and confounded by changing hydrological conditions through time that are independent of regulation (i.e. naturally occurring extended dry and wet periods). For these reasons, it is preferable to use modelled flow data, derived for a consistent and representative period of time. Modelling also allows current and natural flow time series to be derived for locations throughout the system where there is limited or no historic streamflow records.

To support this environmental FLOWS assessment project, modelling of daily streamflow series at various locations throughout the catchment was undertaken using a combination of existing and new hydrological models, for the period 1st July 1927 to 20th June 2018. Detailed methodology and results are available in Appendix C. Where possible, results were compared with gauged streamflow as well as with previous modelling results (SKM 2005) over the period 1st January 1955 to 30th June 2004. On the whole, the method used to model daily streamflow was considered fit for purpose, with the exception of Reach 6: Boundary Creek. It is widely acknowledged that Boundary Creek is a complex system, with strong influences from changing water table levels and groundwater extractions. Detailed modelling is currently being undertaken for this catchment, and as such gauged data (1985 to 2018) was used to represent current flow for Reach 6 to inform environmental flow recommendations for this reach.

Unimpacted streamflows are the streamflows that would have occurred over the historical climate sequence without private diversions, irrigation district diversions, urban diversions, the effects of farm dams and the effects of major reservoirs. Unimpacted flows are also referred to here by the term ‘natural’, which is a more conventional term. They are modelled natural flows, not actual natural flows. As part of the 2006 study, no attempt was made to correct streamflows for change in vegetation cover and urbanisation (SKM, 2005), however, this 2019 study uses the eWater Source catchments software package to account for changed land use. Current conditions include 2016 land use with 2010 level of development demands and bulk entitlement and private diversion rules as per the REALM model provided (GHD, 2011). Modelling results were extracted and analysed for ten locations, with each location representing an environmental flow reach (see Figure 11). Hydrological analysis was undertaken at various model locations to align with streamflow gauge locations rather than field sites, and with 2006 analysis locations where possible to allow a comparison of flow estimates (see Table 2).

Table 2. Summary of hydrological site locations and corresponding streamflow gauge and 2006 site

Reach number/name		Reference gauge	Corresponding 2006 site	Source model location
1	Yarrowee River	233215	8 Mid Leigh	Node representing Gauge 233215
2	Leigh River Inverleigh	n/a	9 Lower Leigh	Flow to SC#44
3	Upper Barwon West	n/a	Reach 1 (Site not comparable)	Flow to SC#07
4	Upper Barwon East	233214 (U/S)	New site	Flow to SC#04
5	Dewing Creek	no gauge	New site	Flow from SC#05
6	Boundary Creek	233228	7 Boundary Ck	Flow from link #68
7	Barwon River D/S Boundary Creek	233224	New site	Node representing Gauge 233224
8	Pennyroyal and Deans Marsh Creeks	233258	New site	Node representing Gauge 233258
9	Barwon River - Winchelsea	233201	Site moved (Reach 2 Winchelsea)	Node representing Gauge 233201
10	Lower Barwon River - Murgheboluc	233200	3 Murgheboluc	Node representing Gauge 233200

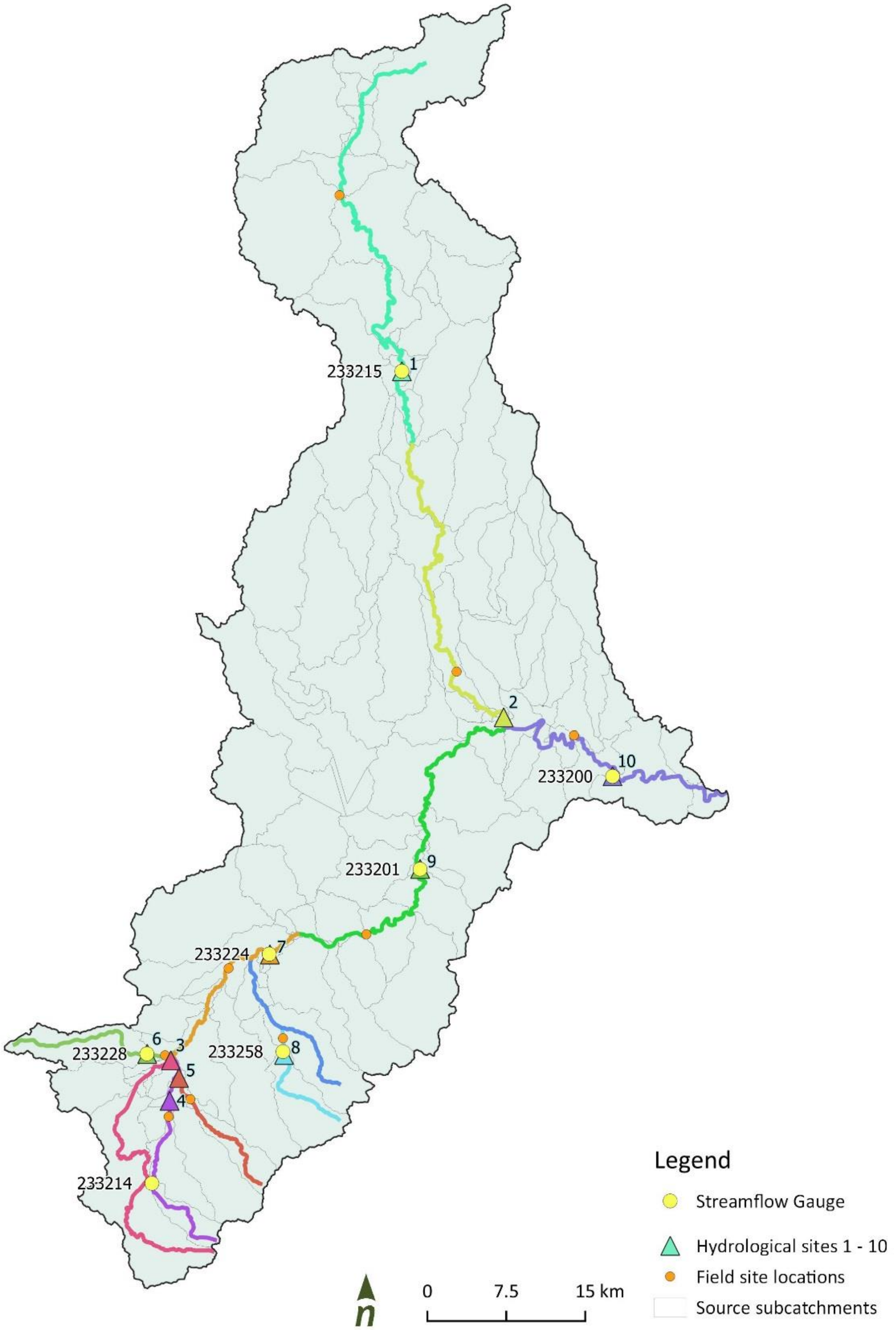

Figure 11. *Map of hydrological sites for each of the ten reaches compared with streamflow gauges and field site locations*

Hydrological analysis overview
Most of the standard statistical analysis tools used by hydrologists were developed in response to the traditional engineering problems of drought management, flood mitigation, or development of water supply systems. In contrast, environmental flow assessment uses established or hypothesised relationships between hydrological characteristics of a stream and ecological response, so that the regulated flow regime can be tailored to provide a basic level of ecosystem protection. Gippel (2001) suggested an approach to hydrological analysis appropriate to the problem of assessing environmental flows, especially when using one of the expert panel or holistic-type approaches, such as FLOWS. The approach is grounded in the assumption that the hydrological time series (or regime) contains identifiable, recurring ecologically and/or geomorphologically relevant facets or events. These facets are then dissected from the record and their hydrological characteristics determined separately. Given the hypothesised importance of hydrological variability, there is an emphasis on characterising the extremes of the distributions.

The FLOWS method requires recommendations to be made for a number of different flow components (Figure 12 and Table 3). Each component has a known or assumed important environmental function, although the method is generic for Victoria, we have selected flow components that are important or critical for the reaches of the Barwon River included in this study. The Environmental Flows Technical Panel assesses which flow components based on the suite of species present (or previously present) and their requirements in each reach.

Figure 12. *Visual representation of the FLOWS method flow components (DSE, 2007)Note that terminology differs from that adopted throughout this study (see Table 3).*

Table 3. Hydrological description of the FLOWS method flow components

FLOWS flow component	Hydrological description	Relevant timing[2]
Cease-to-flow (also called 'zero flows')	Cease-to-flow is defined as periods where no flows are recorded in the channel. Any pools are isolated with no flow between them.	Not present in some streams, nearly always occurs in the dry period but can occur in the wet period
Dry period low flows	Dry period low flows are the natural dry period flows or 'baseflows' that maintain water flowing through the channel, keeping in-stream habitats wet and pools full.	Dry period (summer/autumn)
Dry period freshes	Dry period freshes are frequent, small, and short duration flow events that last for one to several days as a result of localised rainfall during the dry period.	Dry period (summer/autumn)
Wet period low flows	Wet period low flows refer to the persistent increase in low or base flow that occurs with the onset of the wet period.	Wet period (winter/spring)
Wet period freshes	Wet period freshes refer to sustained increases in flow during the wet period as a result of sustained or heavy rainfall events.	Wet period (winter/spring)
Bankfull flows	Bankfull flows fill the channel, but do not spill onto the floodplain.	More common in the wet period but occur in the dry period
Overbank flows	Overbank flows are higher and less frequent than bankfull flows and spill out of the channel onto the floodplain.	More common in the wet period but occur in the dry period

Results summary

The analysis characterised the hydrology of the Barwon River catchment at ten sites for various elements of the flow regime. These characteristics were compared for modelled natural and current flow conditions (Table 4 and Table 5). This information is provided to minimise subjectivity in the expert panel process when specifying the characteristics of environmental flows required to achieve the geomorphological and ecological objectives. Detailed results are available in Appendix C.

Overall, the analysis showed greater impact due to development on the main stem of the Barwon River downstream of West Barwon Reservoir when compared with the Yarrowee and Leigh Rivers in the northern part of the catchment. Generally, the current seasonality of flows is shown to be reasonably consistent with natural conditions, though the overall magnitude of flows for each month is varied.

The Source catchments and REALM combined modelling approach was shown to give a good representation of historic flows to produce a current and natural flow time series over the period 1927 to 2018. The Source catchment records tend to be 'flashier' than the 2006 REALM flow time series, and show a higher proportion of very low flows, rarely showing cease-to-flow events. This is likely due to the sensitivity of the model parameterisation to small rainfall events that do not result in actual flows. Nevertheless, the model has been shown to represent observed monthly to annual flows well across the majority of the Barwon catchment and is an improvement when compared to the 2006 modelling results. There are advantages and disadvantages to using water resource models (e.g. REALM), catchment models (e.g. Source catchments) or a combination (as used for this study) of modelling platforms and this study has provided an opportunity to compare the simulated results from the 2006 study with the most recent flow time series.

[2] For this project, the dry period is defined as summer and autumn (December to May) and the wet period is defined as winter and spring (June to November).

Table 4. Summary of the impacts of regulation on hydrology, Barwon River main stem (current level of development compared with natural conditions)

Flow component/index	Reach 3: Upper Barwon West U/S Boundary Creek	Reach 7: Barwon River D/S Boundary Creek	Reach 9: Barwon River - Winchelsea	Reach 10: Lower Barwon River - Murgheboluc
Annual discharge	-20%	-9%	-46%	-40%
Flow variability	Reduced flow magnitude across the entire range of flows.	Reduced flow magnitude across the entire range of flows.	Reduced flow magnitude across the entire range of flows.	Reduced flow magnitude across the entire range of flows.
Seasonality	Consistently lower flows under current conditions for all months of the year	Consistently lower flows under current conditions for all months of the year	Consistently lower flows under current conditions for all months of the year	Consistently lower flows under current conditions for all months of the year
Cease-to-flow	Increased frequency and duration (negligible to mean duration of 7 days once every 3 years)	Cease-to-flow did not naturally occur and not observed in current time series	Cease-to-flow did not naturally occur and not observed in current time series	Cease-to-flow did not naturally occur and rarely observed in current time series
Dry period low flows	Reduced under current conditions	Reduced under current conditions	Reduced under current conditions	Reduced under current conditions

Table 5. Summary of the impacts of regulation on hydrology, Barwon River tributaries (current level of development compared with natural conditions)

Flow component/index	Reach 1: Yarrowee River	Reach 2: Leigh River	Reach 4: Upper Barwon East	Reach 5: Dewing Creek	Reach 6: Boundary Creek	Reach 8: Pennyroyal Creek
Annual discharge	-19%	-22%	8%	-6%	-30%	14%
Flow variability	Increased proportion of low and moderate flows, reduced higher flows	Increased proportion of low and moderate flows, reduced higher flows	Similar distribution with increased magnitude of very low flows	Similar distribution with increased magnitude of very low flows	Similar distribution with decreased magnitude of very low flows	Similar distribution with increased magnitude of very low flows
Seasonality	Mean daily flows higher than natural over the dry months, and lower over the wet months	Mean daily flows higher than natural over the dry months, and lower over the wet months	Consistently higher flows under current conditions for all months of the year	Similar flows for all months, but lower in April and May for current compared with natural	Consistently lower flows under current conditions, with the exception of August	Consistently higher flows under current conditions for all months, especially August to October
Cease-to-flow	Similar frequency (once in 3 years), increased duration (<1 day to 8 days)	Similar frequency (once in 9 years), increased duration (<1 day to 7 days)	Decreased frequency (>1 per year to 1 in 90 years) and duration (10 days to 3 days)	Decreased frequency (once per year to 2 in 90 years) and duration (9 days to 2 days)	Decreased frequency (61 to 46 in 33 years) and increased duration (10 days to 42 days)	Decreased frequency (1-2 per year to 1 in 90 years) and duration (3 days to 1 day)
Dry period low flows	Increased under current conditions	Increased under current conditions	Similar except for increased magnitude of very low flows	Reduced under current conditions	Reduced under current conditions	Reduced under current conditions

4.4 Groundwater

Groundwater and surface water systems interact in most catchments, in one of two primary ways:

- Gaining streams – streams gain groundwater through the streambed when the water table elevation is higher than the stream elevation; or
- Losing streams – streams leak to groundwater through the streambed when the water table elevation is lower than the stream elevation.

For most streams, the interaction between groundwater and surface water will change from gaining to losing along the stream length (i.e. spatially) and at different times of the year (i.e. temporally). Ideally, the comparison between river and groundwater elevations can inform the nature of groundwater connection if the river gauge and the observation bore are located within close proximity to one another. Figure 13 provides an example and shows groundwater (111232) and river (Barwon River at Inverleigh stream gauge) levels.

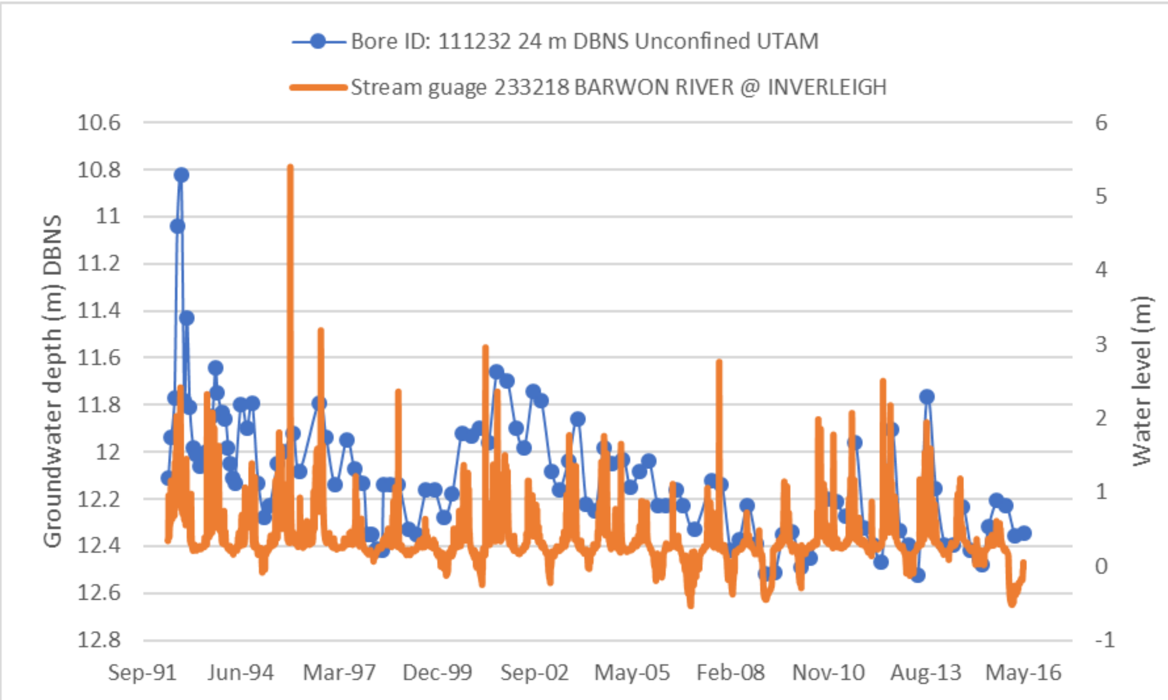

Figure 13. *Groundwater and river levels at bore 111232 and gauge 233218.*

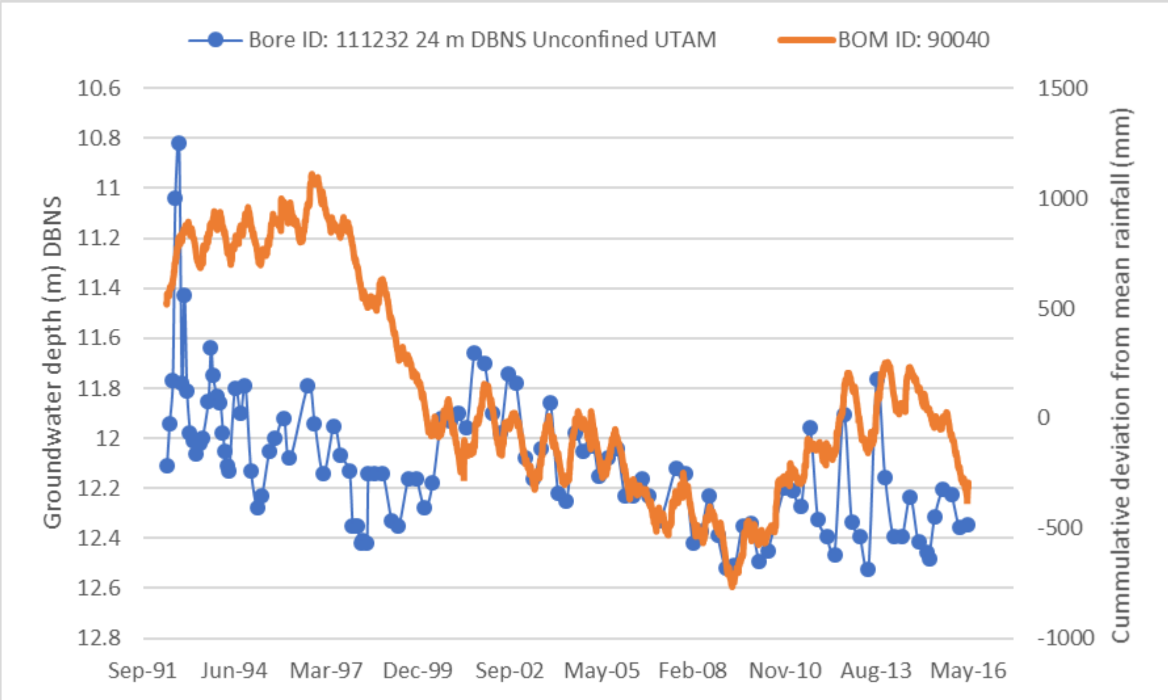

Figure 14. *Groundwater (111232) and rainfall cumulative deviation from the mean (CDFM) (90040).*

Figure 13 and Figure 14 show that the groundwater level fluctuation at bore 111232 is influenced by both rainfall patterns and the stream water level. The stream and groundwater levels are connected with both showing similar fluctuations – peaking and falling at the same interval. Groundwater levels began declining in 1996 in response to the influence of the Millennium Drought and continued until early 2000 before showing a continuous pattern of rising and falling similar to the rainfall pattern. In this instance groundwater in the river is likely to be gaining and losing depending on seasonal rainfall patterns.

With exception to specific river reaches, this detail of information does not exist, therefore the nature of groundwater-surface water connection is qualitatively discussed with recommendations regarding potential future works provided below.

Groundwater conditions for the region are summarised below and in Table 6. Further information on groundwater conditions for each reach can be found in Appendix D. Reach numbers relate to Figure 4, with an overview of groundwater bores and their uses available in Figure 15. Figure 16 shows simplified surface geology and surface aquifers for the Barwon catchment and indicates that the Palaeozoic bedrock outcrops mainly in the Otway Ranges in the southeast of the catchment and Mid Tertiary Aquitard outcrops in the central valley (the geological graben). The Lower Tertiary Aquifer (LTA) outcrops to a limited extent along the flanks of the Otway Ranges and also in the vicinity of Boundary Creek. Given that groundwater fluxes to and from a river reach are associated with the shallow (i.e. water table) aquifer, this means that the interaction in this area varies between groundwater contained in the bedrock aquifer, the Mid Tertiary Aquitard and the Lower Tertiary Aquifer.

Of particular focus within this area is the Barwon Downs borefield, which comprises six deep groundwater bores constructed in the Lower Tertiary Aquifer, in an area overlain by a thick sequence of Mid Tertiary Aquitard. Extensive hydrogeological investigations have occurred in this area because of the presence of the borefield, which has an entitlement of up to 20 GL/year at a long-term average of 4000 ML/year. Jacobs (2017a) developed a numerical groundwater model for the area and concluded that water table aquifer drawdowns were not significant where the overlying aquitard is thick; however, they do occur where the aquitard is thin (i.e. around the margins of the graben and where the LTA outcrops). Groundwater extraction from the borefield was predicted to result in changes to the low flow in Boundary Creek but was considered insignificant for all other rivers in this area.

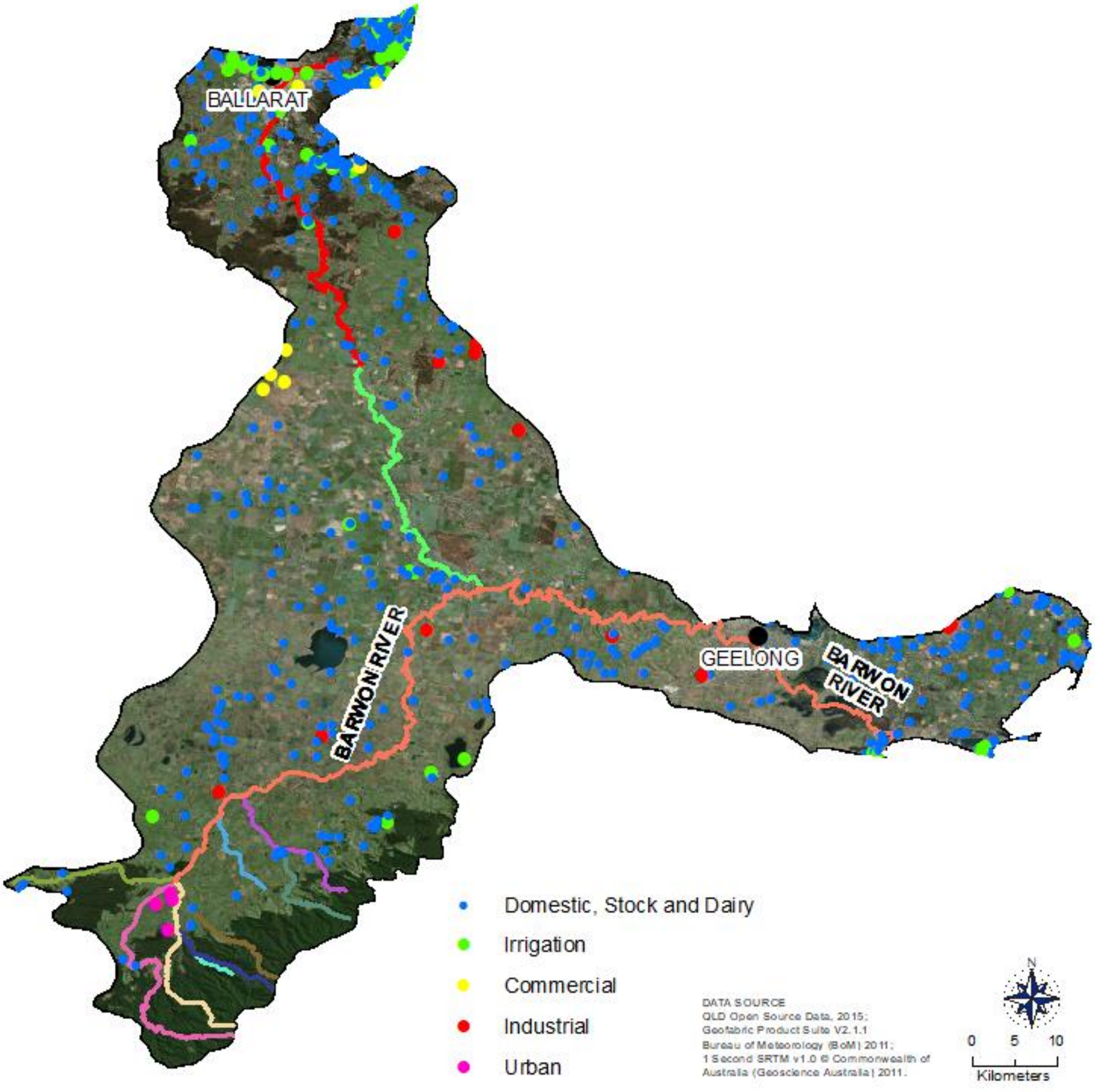

Figure 15. *Groundwater bores in the Barwon basin and their uses.*

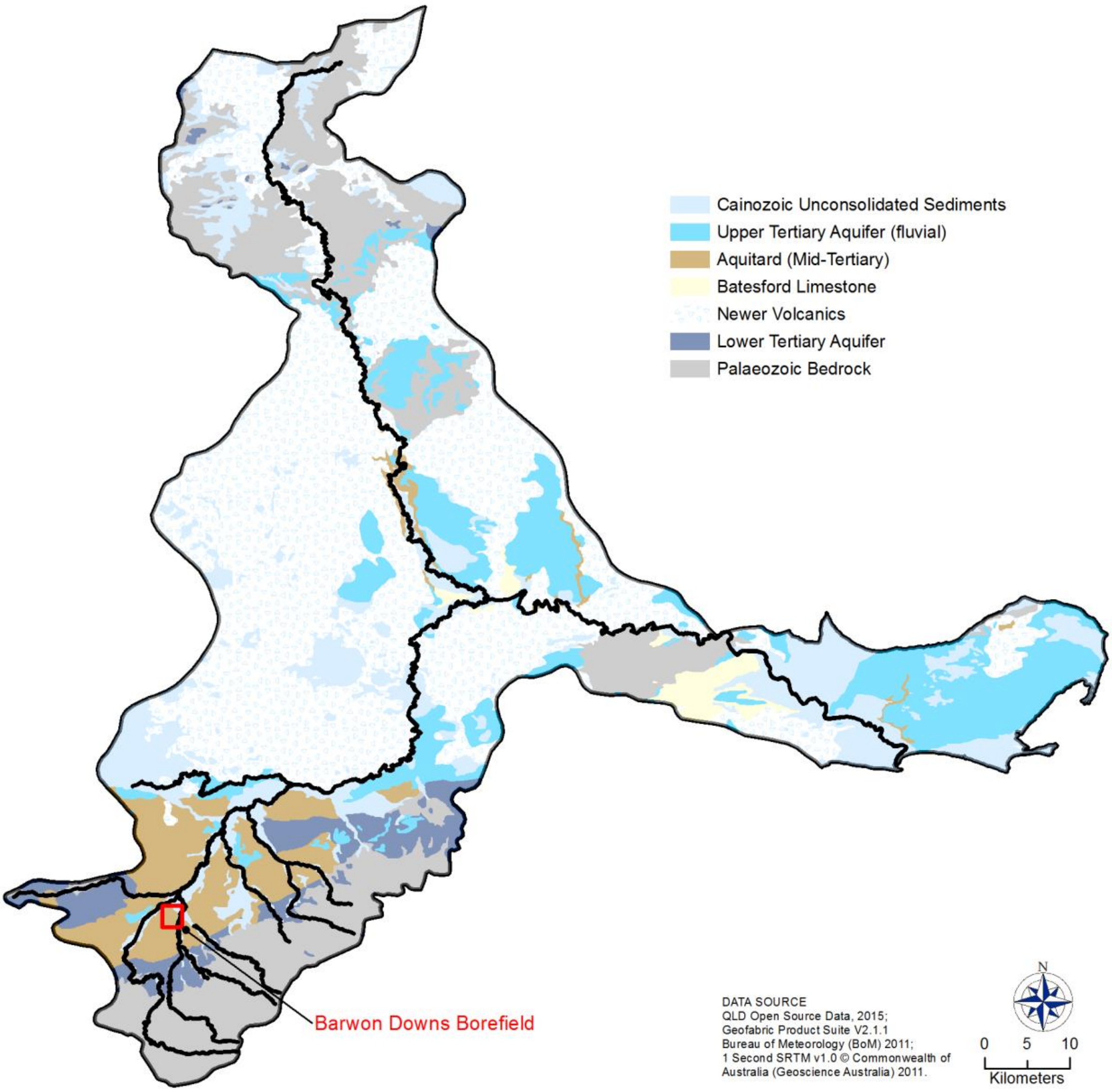

Figure 16. *Simplified surface geology for the Barwon study area*

Reach 1 – Yarrowee River

The key issue in this area is the potential for groundwater extraction to reduce groundwater discharge, which is likely to occur in the form of spring discharges and low flow to streams. This may have implications for instream water quality during low flow periods.

If future recommendations require a quantitative assessment of the impact of groundwater extraction on stream flow this may be achieved by:

- Determining the relative volume of groundwater extraction to low flow within the river reach. This would require significant assumptions regarding the volume of groundwater extractions, as there is likely to be minimal metered groundwater extraction data. An initial assessment of the magnitude of extraction could provide information on what the potential impact could be.
- Installing groundwater observation bores adjacent to stream gauge locations to measure the difference in elevation of groundwater compared to the stream bed and flow. This new data

can be incorporated into the regional groundwater monitoring network of DELWP and Federation University. From the combined dataset it would be possible to develop potentiometric surfaces (imaginary surfaces that define the level to which water in a confined aquifer would rise were it completely pierced with wells) illustrating the hydraulic gradient relationships between the groundwater and stream elevations, providing a measure of groundwater inflows. The temporal nature of changes in the gradients can be compared to climate and/or likely periods of groundwater extraction from which the driving influence of groundwater inflows into the river reach can be determined.

Reach 2 – Leigh River

The key issue in this area is the potential for saline groundwater to pool within the streams during low flow. While the stream is likely to be dominantly losing, periods of high water tables such as the mid-1990s could cause episodic periods of groundwater inflows.

If future recommendations require a quantitative assessment of the impact of groundwater saline inflows into the reach is required, this may be achieved by:

- Installing groundwater observation bores adjacent to river reach pools. This will provide a measure of the likely groundwater gradients towards the stream.
- Monitoring of the stream water quality during low flow periods. This can identify if groundwater inflows are adversely impacting stream water quality as groundwater inflows are likely to be saline. From this data, mitigating measures may be developed.

Reaches 3-8 – Upper Barwon River

A key issue in this reach is maintaining shallow groundwater levels that allow groundwater discharge to surface water. Groundwater is an important source of water required to meet the needs of (surface) freshwater ecosystems. The maintenance of groundwater levels is also important in preventing the oxidation of naturally occurring acid sulphate soils. For most of this reach, shallow groundwater levels are primarily controlled by climate, creating complexities for the management of groundwater and surface water interactions.

This complexity is exacerbated in Boundary Creek, where low flow is also impacted by groundwater extraction. In this area, Barwon Water’s licence conditions include mitigation measures to account for reduced low flows during extraction periods. We recognise that the groundwater relationships in the area surrounding Boundary Creek and the Barwon Downs Borefield are complex. We understand that the impacts associated with groundwater extraction include reduced water quality in Boundary Creek and the Barwon River downstream of Boundary Creek through activation of acid sulphate soils as well as reduction of groundwater inflows in these reaches. The environmental water recommendations contained in this report have not been developed to address the pH issues in Boundary Creek or impacted reaches of the Barwon River. The issue is complex and is being dealt with through other mechanisms by Barwon Water, CCMA and others.

Reach 9 – Winchelsea

The key issue in this area will be to understand the spatial and temporal nature of groundwater discharge to surface water. Conditions that allow groundwater to discharge to the river are favourable in some areas as groundwater provides an import component of the environmental water requirement of surface ecosystems (i.e. Birregurra Creek where salt-tolerant species are observed).

Table 6. Summary of groundwater conditions

	Reach	GW zone	Topography / land use setting characteristic	Hydrostratigraphy	Groundwater users	Preliminary indication of groundwater & surface water Interaction in the groundwater zone	Data sources (confidence in results)
1	Yarrowee River	Yarrowee River	Steep topography, urban intensive uses	Palaeozoic Bedrock & Newer Volcanics Basalt.	High density of bores in this area: Irrigation commercial stock and domestic	*Gaining*: Upland streams that are likely to gain low flow from fractured rock aquifers.	There are no suitable observation bores positioned near stream gauges in this zone to inform the direction or rate of groundwater and surface water interaction in this area. Given the lack of monitoring data, gw-sw interaction will rely heavily on the conceptual model developed for this area.
2	Leigh River	Leigh River	Flat topography, modified pasture	River incised into Newer Volcanic Basalt, which has infilled a valley in the Palaeozoic Bedrock.	Low density of bores in this area, mainly stock and domestic bores.	*Variable*: narrow alluvial valley, shallow groundwater levels, fluxes likely to occur in both directions, but generally net losing.	There are no suitable observation bores positioned near stream gauges in this zone to inform the direction or rate of groundwater and surface water interaction in this area. Given the lack of monitoring data, gw-sw interaction will rely heavily on the conceptual model developed for this area.
3	Barwon River West Branch (U/S Boundary)	Upper Barwon	Steep topography, river reaches initiate in the Otway National Park. Land use dominantly national park/plantation forest in the upper reaches of these creeks and modified pastures in the lower reaches	Palaeozoic bedrock in the upper reaches, Lower Tertiary Aquifer and Aquitard in lower reaches.	Significant groundwater extraction in this area. Extraction from the borefield was predicted to result in changes to the low flow in Boundary Creek but was considered insignificant for all other rivers in this area (Jacobs 2017a).	*Gaining*: Upland streams that gain low flow from fractured rock aquifer. Area characterised by predominantly gaining streams.	Previous studies have been undertaken in this area, that quantify groundwater and surface water interactions. These studies indicate the rivers are primarily gaining in this area. For stream gauge 233224 (Barwon River @ Ricketts Marsh), an average annual BFI of 23% was determined (i.e. 23% of streamflow is comprised of groundwater). This study also included analysis of Boundary Creek and found an average annual BFI of 25% Another study found an average annual low flow gain of ~10GL/year in this area.
4	Barwon River East Branch						
5	Dewing Creek						
6	Boundary Creek						
7	Barwon River (D/S Boundary)						
8	Deans Marsh/Pennyroyal Creek						

	Reach	GW zone	Topography / land use setting characteristic	Hydrostratigraphy	Groundwater users	Preliminary indication of groundwater & surface water Interaction in the groundwater zone	Data sources (confidence in results)
9	Barwon River – Winchelsea Reach	Middle Barwon	Flat topography, modified pasture	Newer Volcanics Unconsolidated sediments (Cainozoic and Upper Tertiary)	Low density of bores in this area, mainly stock and domestic bores.	*Variable*: Evidence of groundwater discharge. Flux likely to be in both directions.	A number of studies have been undertaken in this area that suggest groundwater and surface water interaction is variable. Groundwater discharge to the river occurs in some areas under certain hydrological conditions.
10	Lower Barwon River	Lower Barwon River (and Estuary)	Reasonably flat topography. Modified pasture, urban intensive uses & nature conservation.	Newer Volcanics, Palaeozoic bedrock and unconsolidated sediments.	Low density of bores in this area, mainly stock and domestic bores.	*Variable:* Finer alluvial aquifer material & structural controls lead to shallower groundwater levels and connected reaches. Evidence of groundwater discharge. Flux likely to be in both directions.	There are no suitable observation bores positioned near stream gauges in this zone to inform the direction or rate of groundwater and surface water interaction in this area. Recent hydrogeochemical studies in this area provide a good source of information, that indicates groundwater and surface water connection is important in this area.

5 Values

This section describes our understanding of the values present in the system, the current condition of these values and their connection to flow. Reach-by-reach descriptions of values and issues are available in Appendix E. Values have been classified into five themes: Aboriginal Cultural values, fish, other fauna, vegetation and supporting functions. Specific values or species have been further classified into groups, as detailed in Figure 17 and Figure 18.

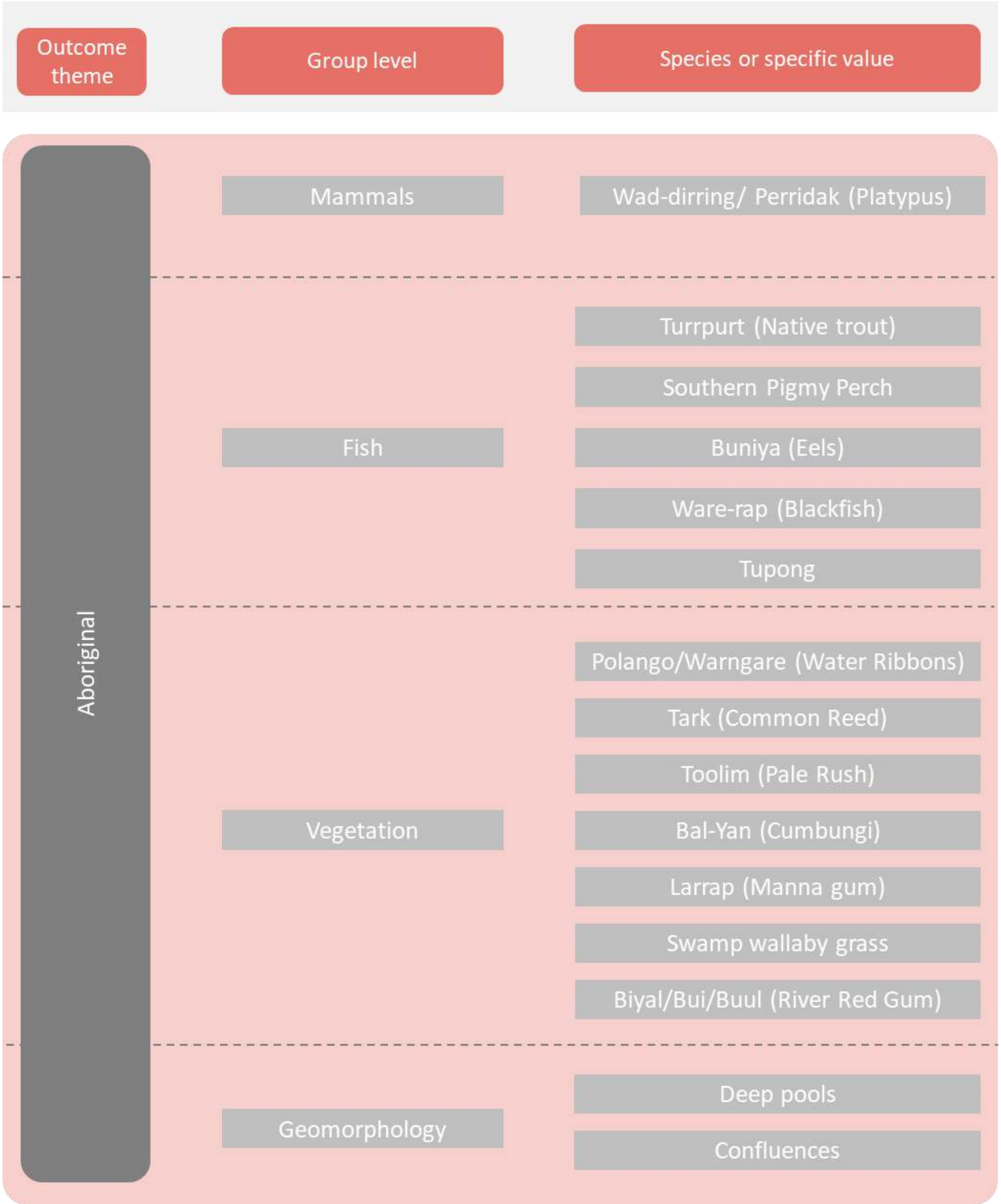

Figure 17. *Summary of Aboriginal Cultural values of the Yarrowee, Leigh and Lower Barwon.*

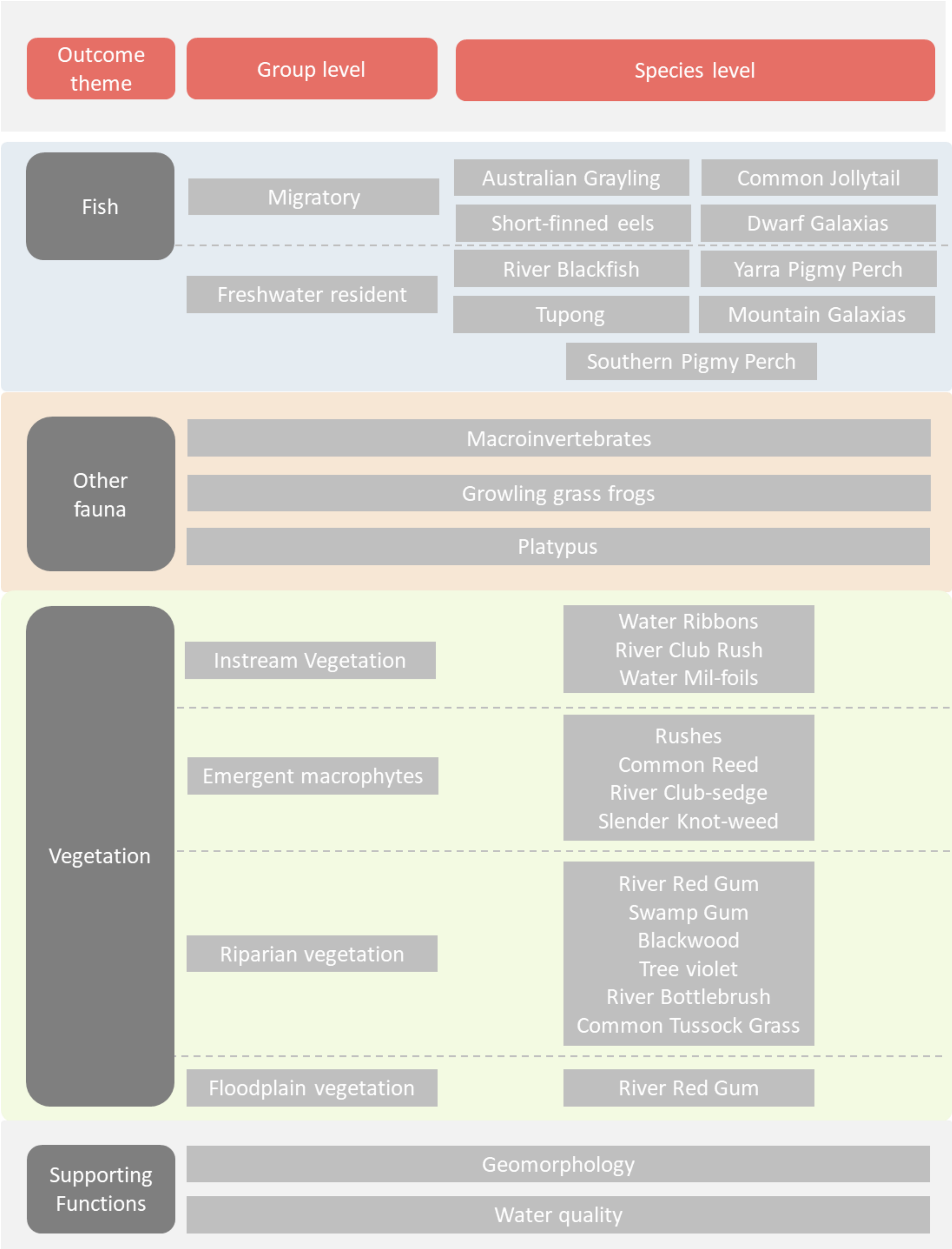

Figure 18. *Summary of ecological values identified in the Upper Barwon, Yarrowee and Leigh Rivers.*

5.1 Aboriginal Cultural values

'Ngubitj Murrup is Water Spirit. Water is the foundation of our life journey, our connection to water starts at conception. Our mother's waters protect us and nourish us to grow, our journey then continues with our connection to water'

Corrina Eccles Wadawurrung Woman, Wathaurung Aboriginal Corporation

In the absence of a fully developed Aboriginal Waterways Assessment Tool or Aboriginal Cultural values Mapping methodology for Wadawurrung Country, a combination of desktop research on historical documents, an interrogation of Aboriginal Victoria's *Aboriginal Cultural Heritage Register and Information System (ACHRIS)* and site inspections on areas identified as having Cultural significance was conducted to identify Aboriginal Cultural values, within the reaches of the Barwon within Wadawurrung Country.

The following Aboriginal Cultural values and Traditional Ecological Knowledge are applicable across all sites within Wadawurrung Country:

- Maintaining watering requirements for healthy thriving Culturally significant species is crucial. A table of Culturally significant species for the Wadawurrung is provided in Appendix F.
- Protection of totem species is a priority.
- Recognition of confluences as meeting / ceremony / trade places.
- Identifying Clan Boundaries with confluences.
- Maintain Deep / Permanent Waterholes and Refuge Pools.
- Maintain access to culturally important sites – story places, ceremonial places.
- Protection of artefact sites.
- Use of appropriate Wadawurrung Language for places of Cultural importance.
- Incorporate Kulin Nation Seasonal Calendar with Flow regime for Cultural species noting that further development of Wadawurrung specific language and seasonal indicators is required (see Appendix G)
- Adhere by Wadawurrung decisions on sharing information and support the development of Intellectual Property Agreements for Wathaurung Aboriginal Corporations.
- Acknowledge the need for development of Wadawurrung Aboriginal Waterway Assessment Tools and further Aboriginal Cultural values Mapping.
- Wadawurrung Technical panel member states the importance of water to the Wadawurrung: *'We were using canoes and waterways as roads. Think about where our waterways go and how far it takes you on our Country'.*

5.2 Fish

Fish communities

Fish are a critical ecological component within the Barwon River catchment as they connect the river along its length and they have great appeal to the community. The Barwon River system has about 44 species within both the freshwater and estuarine sections (Lloyd Environmental *et al*. 2006), there are only 29 fish species in the reaches considered by this study (Table 7). While this study does not include the lower and estuarine reaches of the Barwon, estuarine-dependent fish still inhabit the system. The flow requirements of the estuary were determined by Sherwood *et al*. (1988), Lloyd Environmental *et al.* (2006) and Lloyd *et al.* (2012a) which used fish as one of the major assets considered. Fish communities in the freshwater reaches of the Barwon were also considered in the 2006 FLOWS study and this project updates those requirements.

The fish of the freshwater reaches of the Barwon system comprise 3 broad types based on their salinity tolerances, habitat preference and migration habits, which are:

- Freshwater Species
- Migratory Species (which are also estuarine dependent)
- Euryhaline species

Freshwater species

Mountain galaxias, ornate galaxias, dwarf galaxias, Yarra & Southern pygmy perch, and big-headed gudgeons are all freshwater species but sometimes opportunistically visit the estuary, this is especially so of the big-headed gudgeons. These species are not migratory but do undertake local movements to find mates, new habitat and better food resources.

Three translocated species are present within the system in the records (VBA, 2017). These are native Australian fish from the Murray-Darling Basin including the Murray cod, golden perch and Macquarie perch which have been translocated into the Barwon. These species are not known to have formed significant populations and are not considered further in this study.

Many exotic fish are present within the Barwon although they are mostly found in the freshwater reaches, however, eastern gambusia are able to inhabit highly saline environments. The system has a large range of exotic carp species, including goldfish, carp, roach, tench, eastern gambusia, redfin perch, rainbow trout, and brown trout are quite common in the freshwater reaches (Table 7, Table 8). Exotic fish have impacts from competition, predation and other impacts on native fish. Gambusia, redfin, and trout exert significant predation pressure on native fish (Lintermans 2007).

Migratory species

These fish live most of their lives in freshwater but migrate between the estuary or sea and freshwater environments to complete their life-cycle. 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 Barwon, this group includes the tupong, short-finned eel, Australian smelt, common jollytail, and spotted galaxias. The Australian grayling migrates up from the estuary to mature and breeds in freshwater with larvae returning to the estuary by drifting with the flow downstream.

Euryhaline species

These are species that can live in both freshwater and estuarine habitats and include blue spot goby, tupong, and small-mouthed hardyhead. These fish can penetrate some distances upstream into freshwater and can remain there for their whole life cycle although most generally breed in the estuary (Lloyd *et al*. 2012b).

Table 7. Fish of the Barwon River system (derived from Lloyd Environmental *et al.* 2006, VBA 2018, and Raadik, 2014)

Common name	Scientific name	1. Yarrowee River	2. Leigh River	3. Upper Barwon West u/s Boundary Creek	4. Upper Barwon East	5. Dewing Creek	6. Boundary Creek	7. Barwon River d/s Boundary Creek	8. Deans Marsh – Pennyroyal Creeks	9. Winchelsea	10. Lower Barwon
Native fish											
Mountain galaxias	*Galaxias olidus*	o	o	✓	o	o	✓	✓		✓	✓
Ornate galaxias	*Galaxias ornatus*	✓	✓	✓	✓	✓	✓	✓	✓	✓	
River blackfish	*Gadopsis marmoratus*	o	✓	✓	✓		✓	✓	o	✓	✓
Common jollytail	*Galaxias maculatus*		✓	✓	✓		✓	✓		✓	✓
Spotted galaxias	*Galaxias truttaceus*	o	✓	o	o		o	o		✓	✓
Broad-finned galaxias	*Galaxias brevipinnis*	o	✓	✓	o		✓	✓		✓	✓
Dwarf galaxias^	*Galaxiella pusilla*			✓	o		✓	✓	o	✓	o
Big-headed gudgeon	*Philypnodon grandiceps*	✓	✓	✓	o	o	✓			✓	✓
Blue spot goby	*Pseudogobius olorum*										✓
Tupong	*Pseudaphrits urvilli*			✓						✓	✓
Short-finned eel	*Anguilla australis*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Pouched lamprey	*Geotria australiis*			✓				✓		✓	✓
Short-headed lamprey	*Mordacia mordax*			✓				✓		✓	✓
Southern pygmy perch	*Nannoperca australis*	o	✓	✓	✓	✓	✓	✓	✓	✓	✓
Yarra pygmy perch^	*Edelia obscura*			✓			✓	✓	✓	✓	✓
Australian smelt	*Retropinna semoni*	o	✓	✓	o	o	✓	✓	o	✓	✓
Australian grayling^	*Prototroctes maraena*		o							✓	✓

Common name	Scientific name	1. Yarrowee River	2. Leigh River	3. Upper Barwon West u/s Boundary Creek	4. Upper Barwon East	5. Dewing Creek	6. Boundary Creek	7. Barwon River d/s Boundary Creek	8. Deans Marsh – Pennyroyal Creeks	9. Winchelsea	10. Lower Barwon
Small-mouthed hardyhead	*Atherinosoma microstoma*										✓
Murray cod*^	*Maccullochella peelii*						✓			○	○
Golden perch*	*Macquaria ambigua*						✓			○	○
Macquarie perch*^	*Macquaria australasica*									✓	○
Exotic fish											
Eastern gambusia	*Gambusia holbrooki*	✓	✓	✓	○	○	✓	✓	✓	✓	✓
Goldfish	*Carassius auratus*	✓	✓		○	○	○	○	○	✓	✓
Redfin perch	*Perca fluviatilis*	✓	✓	✓	✓	○	✓	✓	○	✓	✓
Brown trout	*Salmo trutta*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Rainbow trout	*Oncorhynchus mykiss*	✓	○	○			○	○		○	○
Carp	*Cyprinus carpio*		✓	✓	○	○	✓	✓		✓	✓
Roach	*Rutilus*		○	○	○		✓	○	✓	○	○
Tench	*Tinca*	✓	✓							✓	✓

○ Expected in this reach

✓ Recorded in this reach

^ Listed Species (under EPBC Act or FFG Act)

* Translocated species, i.e., not native to the catchment (these are recorded here but not used in the analysis or determination of flow requirements)

Table 8. Native and exotic fish diversity in the Barwon River system (excluding translocated Murray-Darling species).

Reach number	Reach name	No. of native fish	No. of exotic fish	% native fish
1	Yarrowee	9	6	69
2	Leigh River	11	8	58
3	Upper Barwon West- u/s Boundary Creek	15	6	71
4	Upper Barwon East	11	6	65
5	Dewing Creek	6	5	55
6	Boundary Creek	12	7	63
7	Barwon River - d/s Boundary Creek	13	7	65
8	Deans Marsh and Penny-Royal creeks	7	5	58
9	Winchelsea	16	8	67
10	Lower Barwon	17	8	68

Flow requirements of fish communities

The flow requirements of each group of fish can be quite different with each species having specific habitat requirements, but generally, they are robust and tolerate a broad salinity range (DELWP 2013; Lloyd *et al.* 2006 & 2012a, Koehn & O'Connor 1990, McDowall 1980). There are diverse habitat types within the Barwon River Catchment for native fish system and include riverine pools, riffles, runs, woody debris, undercut banks, rocks & boulders, swamps, and floodplains wetlands. These habitats are created and maintained by adequate flow regimes.

The species listed in Table 7 are those recorded in each reach in the past, and while not all species may be currently present, we consider all these species when developing flow requirements, in order to restore requirements for this species to allow them to recolonise and restore these values.

The dwarf galaxias and the pygmy perches all require heavily vegetated waters, whereas the Australian grayling needs open water and quite specific flow and salinity conditions for breeding. blue spot goby is susceptible to predation and requires good vegetation to provide cover. The Mountain galaxias is able to survive in pools over the dry period, provided some water remains in the pools but the relatives, the common jollytail requires access to move up and down the river to find food resources or to get to the estuary to breed. They will need flows to get past natural and man-made barriers in the river. Many other fish species will require the opportunity to migrate upstream and downstream to either complete their life-cycle or to find suitable habitats. Instream barriers such as drop-structures, road crossings, piped sections, weirs, erosion control structures, and zones of very poor habitat can all prevent fish from being able to move within the system. This increases the likelihood of local extinctions of species.

The understanding of these requirements can be best summarised in conceptual models, these are diagrams and text which describe our understanding of the biological and flow requirements of the element we are interested in. The conceptual model which explains the common jollytail lifecycle and flow needs is shown in Figure 19 below and in the text which follows:

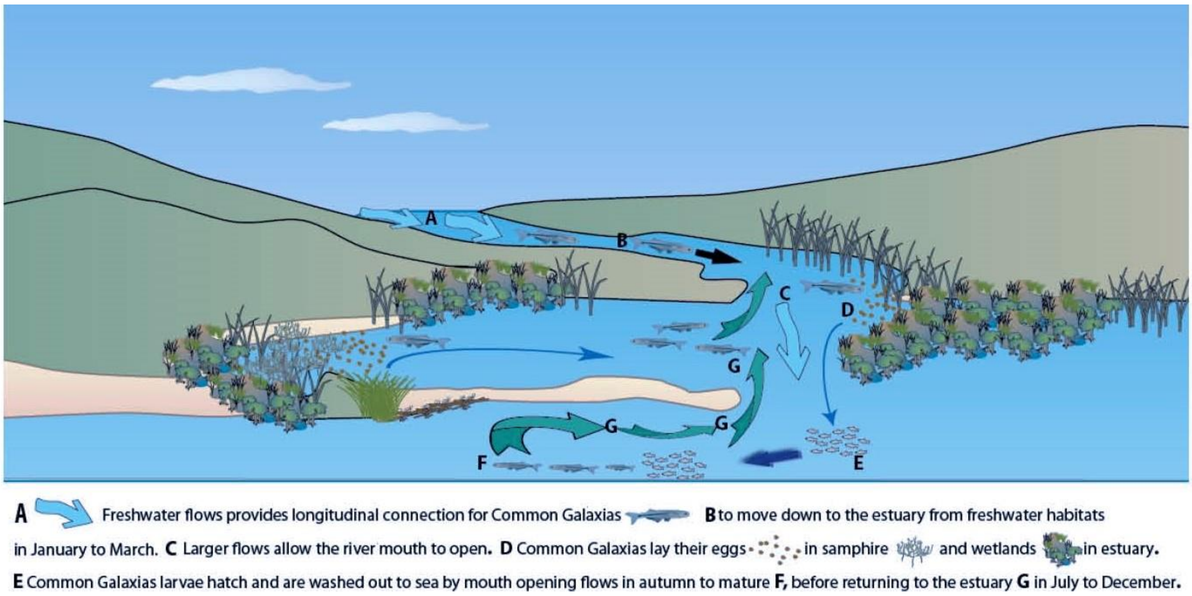

Figure 19. *Conceptual model of common Jollytail life cycle and flow requirements.*

Representative objective – Common jollytail (*Galaxias maculatus*) – estuarine dependent (freshwater derived)
Common jollytails are a widespread and often abundant species in Australia found in coastal lakes and stream 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 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'Conner, 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 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 jollytail

- Provide flows (dry period 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 period 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.

A common issue across all the reaches is the relatively large number of introduced fish, with each reach having at least six exotic species present. These exotic species impact upon native species by competing for space and food and can predate upon native fish. These fish include:

- Eastern gambusia
- Goldfish
- Redfin perch
- Brown trout
- Rainbow trout
- Carp
- Roach
- Tench

Increasing flows and flow variability and instream habitat complexity will allow native fish populations to build and potentially reduce the exotic fish (gambusia and carp thrive in altered and low flows). Complementary actions such as revegetation of instream and streamside species will increase habitat complexity and support more food resources which will also support native fish.

5.3 Other fauna

Aquatic macroinvertebrates
Habitat diversity is an important determinant of invertebrate and aquatic fauna abundance in aquatic ecosystems. Instream benches, deep holes, undercut banks, woody debris, aquatic vegetation, and overhanging vegetation all contribute to habitat diversity, breeding and feeding locations and protection from predators. Hydraulic diversity is also an important part of habitat with fast and slow-flowing sections of stream providing different niches for a diversity of invertebrates (Brookes *et al.* 2009).

The bacteria-rich biofilms, which support invertebrates, depend upon water level fluctuations. The dominance of bacteria in biofilms reduces after long periods of inundation of the sediment, woody debris and rocks logs on the base of the stream and becomes dominated by algae which have a lower nutritional value than the bacteria (Burns and Walker 2000).

Flow events in streams and wetlands provide a period of 'predictable' changes to the environment which can be exploited by many aquatic and floodplain organisms (Lloyd *et al.* 1994). Flooding and inundation of sediments is a major factor in the hatching of invertebrate eggs, and the growth of invertebrate populations (Boulton and Lloyd 1992, Quinn *et al.* 2000; Balcombe *et al*. 2007; Brookes *et al.* 2009). Flow freshes and higher flows inundate benches and engage low lying areas within the river channel which creates hydraulically diverse habitats. Drying results in invertebrates laying desiccant resistant eggs which hatch on subsequent inundations, proving vital resources to fish, platypus, and frogs. This wetting and drying cycle streams and their margins result in significant carbon and nutrient fluxes which drive ecosystem processes in these systems (Burns *et al.* 2001). Organic carbon and nutrients drive microbial production, including the growth of algae, bacteria, and fungi, which form the food for zooplankton and many grazing and filter feeding invertebrates. Consequently, microbial productivity has implications for the food available for vertebrate fauna including fish, frogs, waterbirds, and platypus.

A value of invertebrates lies in their roles in nutrient and organic matter processing and in the role of larger invertebrates, such as yabbies, shrimps and insect larvae, in the food chains of fish, frogs, platypus, turtles, and waterbirds (Brookes *et al.* 2009).

Growling grass frogs (*Litoria raniformis*)
Most frogs are stimulated to breed by inundation at temporary (ephemeral) wetlands and stream-side channel sites and with these conditions preferred over solely permanent waters (Wassens &

Maher 2011). The exception to this is the growling grass frog which needs permanent water adjacent to grasslands for feeding and breeding (Heard *et al.* 2010). Hydraulic and water regime diversity is required, with permanent pools and regularly inundated benches and stream margins to support growling grass and other frog species. Expected growling grass frog presence is detailed in Table 9.

Platypus (*Ornithorhynchus anatinus*)

Platypus are well studied elsewhere but are known to exist throughout the Barwon River system and are observed by people on occasion (Serena and Williams, 2010; VBA 2018). Table 9 details reaches where platypus have been observed or are expected. While the species is not conservation listed, it is regarded as significant by local communities and will only persist if the correct habitat and food resource conditions exist. As a predatory species, healthy populations of platypus in the stream indicate high levels of macroinvertebrate productivity.

Platypus require low flows as their preferred habitat which enable foraging for aquatic macroinvertebrates. However, significant periods of cease-to-flows resulting in drying will be detrimental to platypus' condition, leading to overcrowding in permanent habitats and potentially reduced population sizes (Serena and Williams, 2010). Fast flows can be tolerated for short periods.

Platypus generally prefer slow-flowing waters and conditions which support large macroinvertebrate populations to allow feeding and gaining condition for breeding. Long periods of cease-to-flows are likely to lead to a reduction in condition and reproductive success (Serena and Williams, 2010).

The following conditions provide optimal platypus habitat and conditions (Serena and Williams, 2010):

- water present through the dry period (summer/autumn) for the survival of young;
- pools at least 0.5 m deep in channels wider than 5 m, with a minimum of 0.3 m in small habitats;
- slow flows are required from 0.3m/s to 0.5m/s (up to a maximum of 1m/s for short periods);
- water depths below 3 m are preferred for feeding, but they can dive up to 9m deep;
- large woody debris of >20 snags per 100m is preferred by platypus; and
- Inundation of the littoral habitat to enhance aquatic macroinvertebrate populations in spring and summer.

Table 9. Presence of growling grass frog and platypus within the study reaches. (Lloyd 2018, pers. comm., 10 August).

Reach		Growling grass frog	Platypus
1	Yarrowee River	✓	✓
2	Leigh River	✓	✓
3	Upper Barwon West	-	✓
4	Upper Barwon East	-	✓
5	Dewing Creek	-	-
6	Boundary Creek	✓	-
7	Barwon River (d/s Boundary Creek)	-	✓
8	Pennyroyal and Deans Marsh Creeks	-	✓
9	Winchelsea	✓	✓
10	Lower Barwon	✓	✓

5.4 Vegetation

Vegetation communities and broad objectives
The vegetation communities of the waterways in the study area occupy the following broad niches: instream, shallow water and exposed but frequently inundated benches/lower bank, channel bank with adjacent floodplain, and broader floodplain. The plant population of those niches can be grouped as follows.

Instream vegetation
This is aquatic vegetation which can survive permanent inundation of 50cm or more. Species observed in this group include blunt pondweed *Potamogeton ochreatus* and water ribbons *Triglochin procerum*. These species generally require a period of low flow or cease-to-flow events to occur in spring/summer to expose damp substrate and allow seed germination to occur.

Objective: to maintain or improve condition and extent of instream vegetation to provide structural habitat for macroinvertebrates and various fish species

Emergent vegetation
These are the herbs, grasses, and sedges which can survive short periods of inundation and occupy the shallow waterway benches to lower banks. They also grow in floodplain features such as billabongs which remain moist during flood events. Species observed in this group include; marsh club-rush *Bolboschoenus medianus,* tall sedge *Carex appressa,* rushes *Juncus sp.,* slender knotweed *Persicaria decipiens,* Australian gipsywort *Lycopus australis,* common reed *Phragmites australis,* common tussock-grass *Poa labillardierei,* and river club-sedge *Schoenoplectus tabernaemontani*.

Objective: to maintain or improve condition, extent, and diversity of emergent macrophyte vegetation to provide structural habitat and channel/lower bank stability to low and moderate flows.

Riparian Vegetation
This is the terrestrial vegetation occupying the channel bank and adjacent floodplain. This changes from the forests and woodlands in the upper areas of the catchment, to shrublands in the middle, and floodplain woodland in the lower reaches below. However, the remnant riparian vegetation in the study is highly modified, quite narrow and in a few instances not expressed by representative species. Species observed in this group include blackwood *Acacia melanoxylon,* river bottlebrush *Callistemon sieberi,* prickly tea-tree *Leptospermum continentale,* tree violet *Melicytus dentata,* lignum *Muehlenbeckia florulenta,* swamp gum *Eucalyptus ovata,* manna gum *Eucalyptus viminalis.* The Ecological Vegetation Classes (EVCs) modelled in the study area are mostly representations of the riparian vegetation – these are discussed for the individual reaches in Appendix E.

Objective: to maintain or improve condition, extent, and diversity of riparian vegetation as part of endangered EVCs and provide shade and stability to the waterway channel.

Floodplain vegetation
This is the vegetation which relies on interseason overbank flows for adequate water. This is largely cleared from the study area and replaced with pasture or other agricultural plants. Species observed include river red gum *Eucalyptus camaldulensis*, with floodplain depressions likely to support the instream and emergent species above, when conditions suit.

Objective: to maintain or improve condition and extent of floodplain vegetation as part of endangered EVCs

Flow requirements of vegetation communities

Hansen *et.al*. (2010) describe the benefits of riparian vegetation and objectives to retain or improve vegetation on waterways with the following points:

- Improve water quality (reduce excess nutrient and contaminant inputs to waterways)
- Reduce streambank erosion and sediment inputs
- Increase shading and moderate water temperature
- Provide wood, leaf litter and other resource inputs to streams (i.e. facilitate resource transfers between the terrestrial and aquatic environment)
- Increase in-stream biodiversity
- Improve the structure and composition of riparian vegetation communities, and increase terrestrial biodiversity
- Increase lateral and longitudinal connectivity of biota and other material

To achieve these benefits and objectives for vegetation health, we can target the flows that support the waterway vegetation. These flows and the current threats to vegetation are identified for each group below.

Instream vegetation

Requires water throughout the year to survive and so low flows are required. In some instances, cease-to-flow events will assist in regenerating the plants and ensuring their ongoing occupation and expansion through the site. Threats to this vegetation include changes to hydrology, with frequently reduced flow lowering water levels and stressing the aquatic plants.

Emergent vegetation

These plants can grow in permanent, shallow water but will be stressed by extended periods of emersion in depths >50cm. They require moist soils to grow and recruit new individuals so freshes throughout the year will support diversity of niches in the waterway and a variety of species. Threats to this vegetation include stock access, changes to seasonal flow with increased low flow from storage release, urban or industrial sources and stormwater pulses from catchment drainage changes. Weeds such as willows, and spiny rush are a constant threat.

Riparian vegetation

These plants require a variety of wet and dry niches in the waterway to support a diversity of shrubs and trees. High flow freshes and bank full events cause some disturbance to provide spaces for recruitment and rejuvenation. Threats to this vegetation include stock access, reduced frequency of high freshes which leave the upper bank vegetation stressed, and woody weeds.

Floodplain vegetation

This vegetation requires full floodplain inundation via overbank flows to receive adequate soil moisture and fill floodplain depressions. Threats to this vegetation include water diversions reducing the frequency of overbank events, agricultural practices, and stock. The occurrences of overbank flows may also be limited by contemporary incision of the channel as a result of hydrology or land use changes.

5.5 Supporting functions

Water quality and stream health

The third (most recent) Index of Stream Condition (ISC) assessment (DEPI, 2013b; Figure 20; Table 10), found the majority of stream length in the Barwon basin to be in moderate or poor condition. Despite the heavily modified environment, water quality in the Barwon basin was generally found to be in moderate condition. Many sites had elevated phosphorus levels and acidification is a major issue in Boundary Creek, with this heavily forested area of the upper Barwon basin having significantly low pH. The upper reaches of the Yarrowee River have been impacted by mine dewatering, treated effluent disposal and urban stormwater runoff from Ballarat.

It should be noted that while the ISC assessment provides an overview of river and stream condition across the state, a number of metrics are combined with reaches of around 10-30 km long. Subsequent and more localised assessments and monitoring (where available) will provide a better representation of stream health.

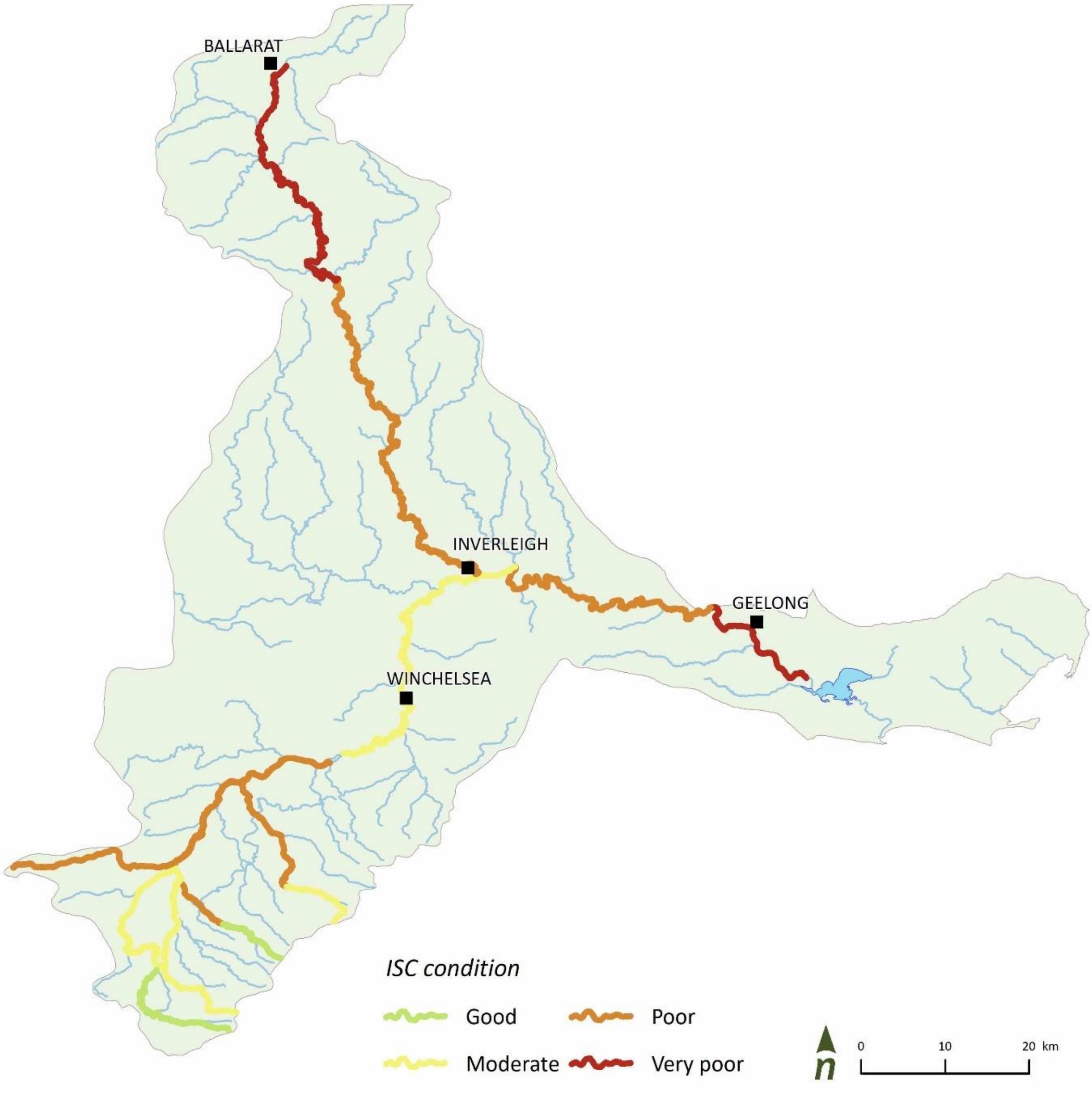

Figure 20. *ISC condition for the FLOWS study reaches of the Barwon basin (DEPI, 2013b).*

Table 10. ISC assessment for the Barwon catchment FLOWS Reaches (DEPI, 2013b).

FLOWS reach		ISC reach[3]	Sub-indices					ISC score	Condition
			Hydrology	Physical form	Streamside zone	Water quality	Aquatic life		
1	Yarrowee	33-14/15	1/1	5/5	5/5	-/-	6/3	17/15	Very Poor/ Very Poor
2	Leigh River	33-11/12	2/2	5/7	6/6	6[4]/3	9/7	23/20	Poor/Poor
3	Upper Barwon West- u/s Boundary Creek	33-6/7	3/10[5]	7/5	5/8	6[4]/-	9/8	25/36	Moderate/ Good
4	Upper Barwon East	33-27/28	4/4	7/9	6/9	8/-	6/8	28/34	Moderate/ Moderate
5	Dewing Creek	33-25/26	6/6	8/9	5/10	3[4]/-	5/8	23/38	Poor/ Good
6	Boundary Creek	33-33	3	7	6	6	4	23	Poor
7	Barwon River - d/s Boundary Creek	33-5	3	5	4	8	6	22	Poor
8	Pennyroyal / Deans Marsh Creeks	33-23/24	3/3	7/8	4/9	-/6[4]	7/6	22/27	Poor/ Moderate
9	Winchelsea	33-4	4	5	6	6	8	26	Moderate
10	Lower Barwon	33-2/3	1/3	8/6	5/5	4/5	3/8	16/23	Very Poor/ Poor

Comparison of overall ISC rating for each reach from the 2005 ISC assessment (DSE, 2005) to the most recent (DEPI, 2013b) assessment is provided in Table 11. The comparison reveals a slight decline in system wide stream condition with improvements in systems subject to programs of active waterway management such as Penny Royal and Deans Mash Creek and declines in systems such as Boundary Creek with declining water quality and ecological condition.

Table 11. Comparison of ISC rating for the study reaches from 2005 to 2013.

FLOWS reach		ISC reach[3]	2005 condition	2013 condition	Change
1	Yarrowee	33-14/15	Very Poor/Very Poor	Very Poor/ Very Poor	→ / →
2	Leigh River	33-11/12	Moderate/Moderate	Poor/Poor	↓ / ↓
3	Upper Barwon West- u/s Boundary Creek	33-6/7	Poor/Excellent	Moderate/ Good	↑ / ↓
4	Upper Barwon East	33-27/28	Very Poor/Moderate	Moderate/ Moderate	↑ / →
5	Dewing Creek	33-25/26	Moderate/Good	Poor/ Good	↓ / →
6	Boundary Creek	33-33	Moderate	Poor	↓
7	Barwon River – d/s Boundary Creek	33-5	Poor	Poor	→
8	Pennyroyal / Deans Marsh Creeks	33-23/24	Very Poor/Poor	Poor/ Moderate	↑ / ↑
9	Winchelsea	33-4	Moderate	Moderate	→
10	Lower Barwon	33-2/3	Poor/Poor	Very Poor/ Poor	↓ / →

[3] Some FLOWS reaches are made up of more than one ISC reach. These reaches and their corresponded scores are denoted as XX/XX.
[4] Only 1 year water quality data available
[5] Hydrology result from 2004 ISC

Water quality and flow
High temperatures in summer can result in stratification of the water column in pools. Stratification can lead to oxygen depletion, an undesirable outcome for instream ecosystems. Provision of dry period low flows and freshes that limit the potential for stratification and that can break up stratified layers are proposed for the Barwon system.

Richardson number is a hydraulic parameter used in fluid dynamics to identify the likelihood of establishing mixing between two fluid layers. Estimation of Richardson numbers for the waters and pools within each reach of the Barwon River is beyond the scope of this project. The velocity of water passing through a pool has been adopted as a surrogate for the use of Richardson numbers. Based on the experience of the project team, a velocity of 0.1m/s is proposed as a minimum velocity through pools to prevent the establishment of stratified layers. A velocity of 0.3m/s is proposed as that suitable to break up established stratified layers via a fresh. These velocities are proposed through the dry period (summer and autumn).

Geomorphology
Fluvial geomorphology describes the size, shape, and diversity of the river channel. The geomorphology (or physical form) of a river can be described at a range of spatial scales, from the catchment to the microhabitat scale (Sear 1996), which can each correlate with habitat types (Frissell *et al.* 1986). A diversity of habitat types provides the physical basis for a diversity of biota (Treadwell *et al*. 2006, Newson 2002), and consequently is an important factor in providing a healthy river.

Physical features that provide habitat niches include meanders, pools, benches, bars, bank undercuts, and variations in substrate. Each of these physical features interacts with flow to create hydraulic habitats (e.g. secondary flow structures at meanders, or areas of slack water on benches) that are preferentially used by different biota (Sagnes, Merigoux and Peru 2008). A diversity of channel form thus provides a diversity of both physical and hydraulic habitats.

While stream geomorphology often has limited inherent value (other than sites of geomorphic significance), it imparts value by providing essential structural habitat and facilitating ecological processes to occur. A key focus of fluvial geomorphology in environmental flow assessments is linking physical characteristics to the important ecological processes identified. For example, fish eggs will not incubate if they are covered by sand and finer material after being deposited on gravel.

The primary issues impacting geomorphic objectives are related to sediment supply and physical form stability. Stock access to the riparian zone can impact the physical form of the river in a number of ways, including by:

- Reducing the integrity, coverage, and structure of riparian vegetation, leading to reduced bank stability and increased sediment loads
- Reducing large woody debris which interacts with the hydraulics and sediment dynamics in the channel and creates habitat
- Impacting on bank stability and water quality directly through trampling and physical disturbance.

Within the Barwon catchment, historical mining activities and physical modification of channels also have an impact on sediment dynamics and geomorphology.

Geomorphology and flow
The diversity and complexity of habitats that support ecological values, such as pools, riffles, and benches, are maintained by the geomorphic processes that shape the channel and floodplain. The

physical form of a stream depends on its flow regime, the characteristics of its bed and bank sediment, the riparian and instream vegetation, valley controls (such as confinement and valley slope) and the sediment inflow regime. The geomorphic processes and form change over time if any of the factors are altered, for example, changes in the flow regime through regulation (Gregory *et al.* 2008), removal of riparian vegetation (Simon & Collison 2002) and interruptions or increases in the sediment supply from upstream (Petts & Gurnell 2005).

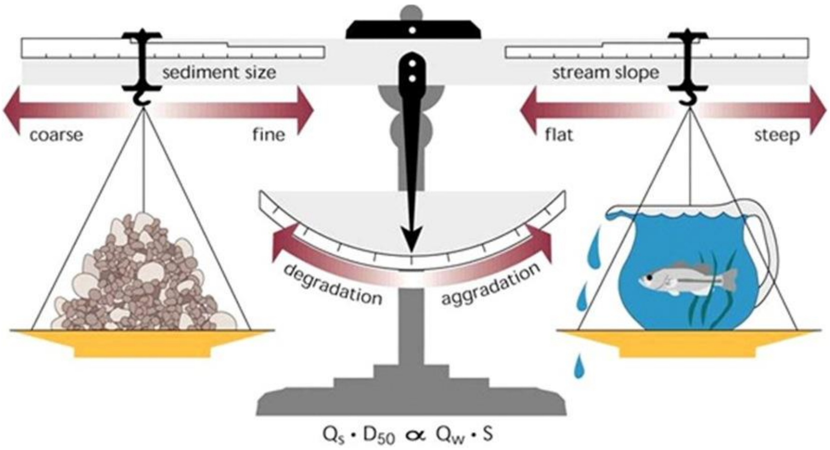

Figure 21. *Lane's balance diagram*

Sediment aggradation, transport, and deposition are determined by a number of factors, as outlined in Lane's balance diagram (Figure 21) including sediment size (and volume), stream slope and discharge (or flow). Given the context of a FLOWS study, and limited ability to influence sediment size, volume and stream slope. The focus is to make recommendations for flow components required to maintain and/or improve the extent, abundance, and diversity of geomorphic features. Freshes, bankfull and overbank flows are the most relevant flow components in terms of sediment mobilisation, transport and deposition as these are the components that account for most 'geomorphic work'.

Dry period freshes: Recent research has found that biofilms that establish on stream beds, riffles, and large wood are not readily removed by flowing water. Research has shown that biofilms can be removed by scour processes. Freshes will be important to mobilise sediments settling in the stream bed and to scour algal films that have established on riffles and large wood.

Shear stress is a hydraulic parameter used to identify the stream flow necessary to initiate mobilisation of bed sediments. The shear stress necessary to mobilise sediments of various size is illustrated in Shields diagram (refer Figure 22).

For the purpose of this study, a shear stress of 0.1 N/m^2 has been adopted as that necessary to mobilise silts (0.1mm diameter) and 1.0 N/m^2 for the mobilisation of fine sand (1mm diameter).

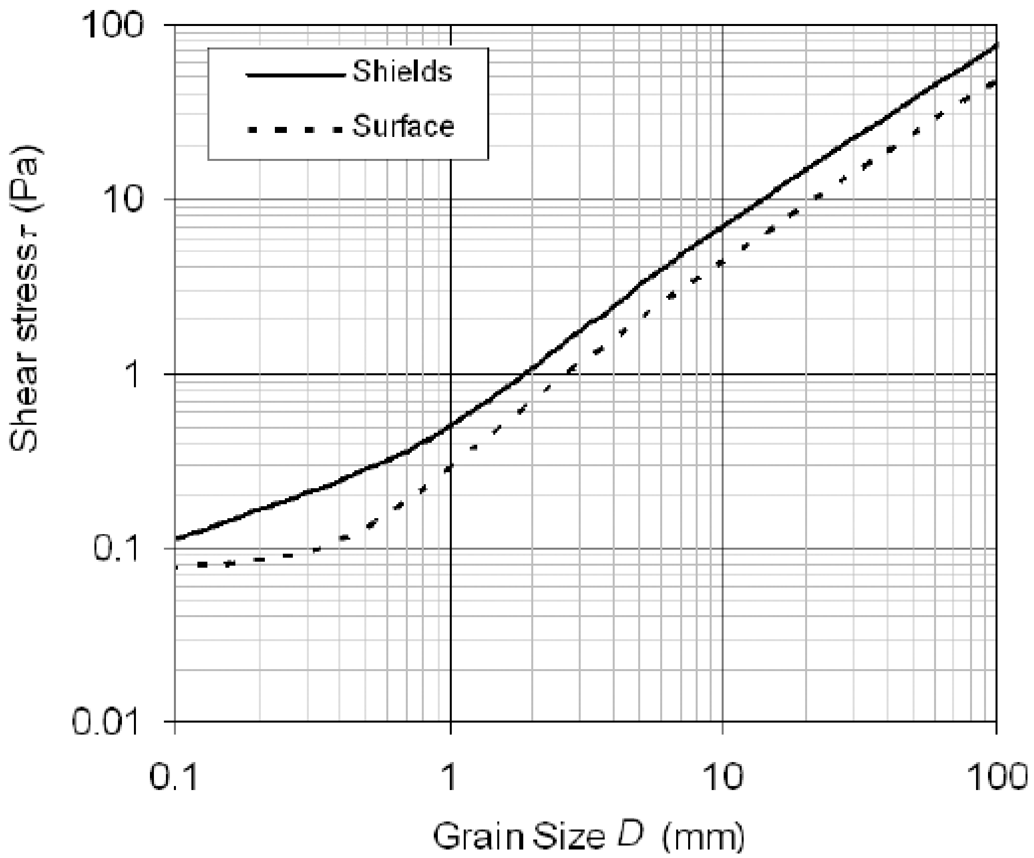

Figure 22. *Shields Curve in dimensional* space (from Wilcock *et al*., 2009)

Wet period low flow: The effective discharge of a stream system has been found to have a defining influence on the shape and size of a stream system (refer to Figure 23). The establishment and maintenance of deep pools and a cross-sectional size and shape capable of supporting aquatic ecosystems will rely on the retention of the effective discharge. Wet period low flows above the threshold for mobilising sediments will be important to maintain the effective discharge and hence the shape and size of the channel cross-section.

Wet period freshes: Wet period freshes will be important to maintain the effective discharge, but also the deposition and scour of sediments on high channel benches. Water flow over benches, where present, will assist to maintain the bench establishment processes

Bankfull flow: Bankfull flow is particularly important for the formation and maintenance of channel form and diversity (US Department of Agriculture 2007; Knighton 1998). It is commonly used as an analog for the dominant or 'effective' discharge, i.e. the single flow that determines channel features such as cross-sectional capacity (Wolman & Leopold 1957) or the flow considered to do most geomorphic work in terms of sediment transport (Wolman & Miller 1960; Figure 23). Changes in the frequency of bankfull flow are likely to lead to changes in channel form, potentially leading to the removal of physical features important as habitats. Providing bankfull flows is therefore important to maintain the cross channel form (i.e. the general size and shape of the channel) and in particular deep pools. Bankfull flows are also important for mobilising sediment trapped in marginal vegetation communities that drive channel contraction.

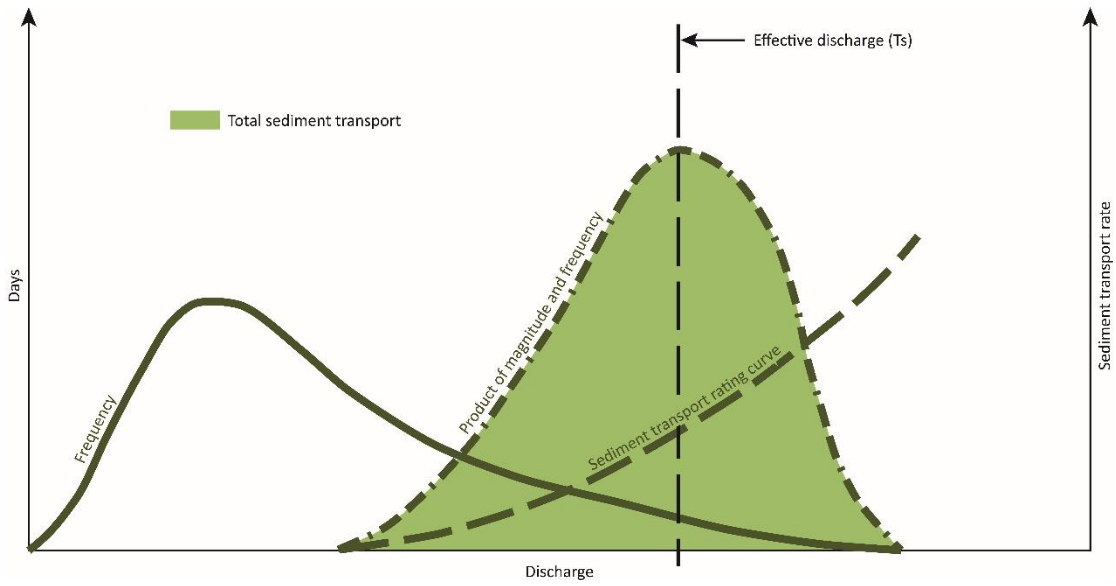

Figure 23. *Effective discharge determination from sediment and flow duration curves.*

Overbank events: Overbank events will be important in maintaining the effective discharge, but also in distributing sediment., carbon and other nutrients.

Catchment- and reach-scale geomorphology for the FLOWS study reaches are described in Appendix E, along with potential pressures and issues observed in each reach.

6 Flow objectives

6.1 Flow requirements

Aboriginal Cultural objectives

Aboriginal Cultural values are important to develop flow objectives for, so these values are supported into the future and remain able to provide Wadawurrung with resources to use and teach their youth the values that are central to culture and country. Wadawurrung have chosen key culturally important species and values, and in discussions with FLOWS scientists, have developed the flow recommendations that support that species or process.

Cultural flow objectives designed to support Aboriginal Cultural values on Wadawurrung Country are presented in Table 12.

Table 12. Aboriginal Cultural flow objectives for the reaches of Wadawurrung Country.

Value	Objective		Cultural value	FLOWS reaches[6]	Function	Period	Component
Mammals	A1	Maintain or improve abundance, breeding and recruitment of Wad-dirring/ Perridak (platypus)	Meat and pelt	1, 2, 9, 10	Provide pool habitat	Dry	Low flow
					Provide longitudinal connectivity between reaches	Wet	Fresh
Fish	A2	Maintain or improve abundance of Buniya (eels)	Meat, important food source sometimes smoked. Large gatherings during eel run at Benia Wulla (Buckley Falls)	1, 2, 9, 10	Provide water in pools for habitat and food sources	Dry	Low flow
					Provide water over riffles to allow fish to migrate upstream from estuary	Dry	Fresh
	A3	Maintain or improve abundance of Turrpurt (Native trout *galaxias spp*.)	Meat	1, 2, 9, 10	Provide water in pools for habitat and food sources	Dry	Low flow
					Provide water over riffles to allow fish to move between pools to breed, feed and find new habitats	Dry	Fresh
					Provide prolonged seasonal inundation of vegetation beds and instream benches as habitat to stimulate invertebrate hatching and fish breeding	Wet	Fresh
	A4	Maintain or improve abundance of Ware-rap (blackfish)	Meat	1, 2, 9, 10	Submerge and clean woody debris and hard surfaces to provide breeding substrate	Dry	Fresh
Vegetation	A5	Maintain or improve abundance of Polango/ Warngare (water ribbons *Triglochin procera*)	Plant food, finger-shaped tubers are crisp and sweet. Cooked in a ground oven	1, 2, 9, 10	Maintain adequate depth of permanent water in the channel, with natural seasonal drawdown to promote recruitment	Dry	Low flow
	A6	Maintain or improve condition, extent, and abundance of Tark (common reed *Phragmites australis*), Toolim (pale rush *Juncus pallidus*), and Bal-yan (cumbungi *Typha latifolia*)	Tark: Weapon-stems used for spear shafts for fishing. Reed cut while still green to make necklaces and weave-bags and baskets. Also a food plant. Toolim: Weaving baskets Bal-yan: Fluff used to pack wounds under paperbark bandage	1, 2, 9, 10	Maintain adequate depth of permanent water in stream channel to limit terrestrial encroachment into aquatic habitats	Dry	Low flow
					Provide a mosaic of spatially and temporally differentially wetted areas within stream channel, on benches, and on lower banks	Dry	Fresh
					Support growth on terraces, channel edge, and lower bank	Dry	Fresh

[6] Reaches only include those on Wadawurrung Country. Eastern Maar Aboriginal Corporation also have Country within the FLOWS study area and it is important to note that Traditional Owners the Wadawurrung are restricted from commenting or conducting site assessments on Eastern Maar Country for Cultural reasons.

Value	Objective		Cultural value	FLOWS reaches[6]	Function	Period	Component
					Provide a mosaic of spatially and temporally differentially wetted areas within stream channel, on benches, and on lower banks	Wet	Fresh
	A7	Maintain or improve abundance of Biyal (river red gum *Eucalyptus camaldulensis*)	Bark removed for canoe, shelter and tools, Tarnuk (bowl), nectar drink, medicinal – gum or sap was used for burns to shrink or seal them, the sap is high in tannin. Leaves for steam baths.	2, 10	Support growth on terraces, channel edge, and lower bank	Dry	Fresh
					Support growth on terraces, channel edge, and lower bank	Wet	Fresh
					Support growth in channel and upper bank, disturb riparian zone and channel to open recruitment niches for riparian plants	Anytime	Bankfull
	A8	Maintain or improve abundance of Larrap (manna gum *Eucalyptus viminalis*) and Kokibainang (swamp wallaby grass *Amphibromus reservatus*).	Larrap: Timber used for making club-shields called Malka. Sap-sucking lerp bug gathered each season Young leaves were fed onto fire near a patient. A poultice of well-chewed leaves can be applied for backache. Quail flocks attracted to Manna. Kokibainang: Leaves split, dried out & re-constituted in running water. Fibres twisted into rope to make long nets for game hunting.	2, 9, 10	Inundate floodplain, provide moisture and fill floodplain depressions and billabongs to support the growth of seasonal and emergent wetland vegetation	Anytime	Overbank
Geomorphology	A10	Deep pools	The presence of deep pools has cultural significance.	1, 2, 8, 10	Scour sediment from base of pools to maintain pool and to use bed sediments to scour algae from riffles	Dry	Fresh
					Scour sediment from base of pools to maintain pool and to use bed sediments to scour algae from riffles	Wet	Fresh
					Mobilise sediment from base of pools	Dry	Fresh
					Mobilise sediment from base of pools for a sustained duration	Wet	Low flow
	A11	Confluences of Barwon and Leigh rivers, and Yarrowee River and Cargerie Creek	High cultural value due to the historical use of site as a meeting place for three different Clans including the Wongerra. ACRIS registered site.	1, 2, 10	Maintain adequate depth of permanent water in the channel	Dry	Low flow

Ecological objectives

Fish

The flow requirements of each group of fish can be quite different with each species having specific habitat requirements, but generally, they are robust, tolerating a broad range of water quality and flow conditions (Lloyd *et al.* 2006 & 2012a, Koehn & O'Connor 1990, McDowall 1980). There are diverse habitat types within the Barwon River Catchment are created and maintained by adequate flow regimes.

While there have been recordings of many species throughout the Barwon system, objectives and recommendations have not been set for the larger migratory fish such as short-finned eels, Australian grayling, and tupong in the smaller tributaries of the system (Upper Barwon East, Dewing Creek, Boundary Creek, and Pennyroyal and Deans Marsh Creeks).

Providing flows, flow variability and instream habitat complexity will allow native fish populations to breed, grow and build strong populations which are resilient to the pressures from exotic fish or temporarily unfavourable conditions. Improved instream and streamside vegetation will increase habitat complexity and support more food resources, thereby supporting more native fish.

In determining the environmental flow for a river system, it is important to consider its fish community and the life history of key species, together with other organisms. There are key characteristics which determine the useful ecology-flow relationships such as life span, spawning season, incubation, duration, migration, and habitat requirements. Key species with a suite of requirements should be chosen to represent the fish community. The criteria used should include the conservation status or ecological role of key species.

Table 13 identifies all the species in each reach and the habitats present to support them. These are based on current knowledge but can only be considered as approximate until further research is conducted on these species. The key species used in the flows assessment will be the:

- resident freshwater fish such as river blackfish, pygmy perch, and dwarf galaxiids
- small-bodied migratory species (such as the *galaxias* spp. Species)
- larger migratory species (such as Australian grayling and short-finned eels).

Together, this suite of fish cover most of the requirements of the whole fish community and putting in place flows for these species, will ensure the whole community is supported.

Ecological flow objectives designed to support fish values are presented in Table 14.

Table 13. Ecological requirements of key fish species actually or likely to inhabit the Barwon River system[7].

Common name	Scientific name	Life span	Spawning season	Incubation duration*	Migration	Other
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 and along anabranches	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	Larvae washed to sea – May – July Juveniles migrate from sea upstream Oct – Dec	Demersal non-adhesive eggs Fry slender and buoyant 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 Need high O_2 Can swim up riffles at flow of 2-4m/s sustained swimming 0.6m/sec Prefer 0.2 to 0.35 m/sec
Tupong (Congolli)	*Pseudaphritis urvillii*	>5years	Sept – Dec	Unknown (likely to be short – 3 or so days)	Adults migrate downstream to estuary for breeding April to July. Juveniles migrate upstream Oct – Feb.	Congolli are susceptible to impacts from the presence of water flow barriers
Common jollytail	*Galaxias maculatus*	2-3 years	April - June	Normally take 10-16 days between flow events or tides (in estuary	Downstream to estuary in autumn.	Aquatic/riparian/intertidal macrophytes required as a substrate for laying eggs
Broad-finned (or climbing) galaxias	*Galaxias brevipinnis*	2-4 years (Uncertain)	May-June	Unknown – perhaps 5-7 days (same as *G. olidus*)	Larvae are washed downstream to the sea in winter. Juveniles return upstream in spring and early summer.	Prefer rocky streams with flowing water and good riparian vegetation. Are also found in habitats with silt substrates.
Spotted galaxias	*Galaxias truttaceus*	2-4 years (Uncertain)	May-June	28 days at 12 degrees	Downstream to estuary in the wet period (winter/spring). Larvae swept to sea	LWD, undercut banks, boulders and good riparian vegetation. Are also found in habitats with silt substrates. Pools are also used extensively.

[7] 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).
* 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

Common name	Scientific name	Life span	Spawning season	Incubation duration*	Migration	Other
					Juveniles return from sea upstream in spring and early summer (Oct – Jan)	Highly salt tolerant and occurs in turbid water – prob very tolerant of poor WQ. Can swim at 3.3m/sec for 1 hour – prefer 0.2m/sec
Smallmouth hardyhead	*Atherinosoma microstoma*	1 year	Sept – Feb	4-7 days	Local only	Breeding probably occurs in estuary or lower reaches of rivers
Mountain galaxias	*Galaxias olidus*	2-4 years	July – Oct	5-7 days	Upstream, if at all	Leaf litter required
Dwarf galaxias	*Galaxiella pusilla*^V, @V	1 year	Aug – Oct	10-17 days	Local	Frequently associated with aquatic vegetation and eggs are laid in separate batches on flooded vegetation, leaf litter or rocks – preferred egg site is the underside of leaves or stems. Adults probably die after spawning. May use yabby holes to over summer.
River blackfish	*Gadopsis marmoratus*	4–7 years	Nov – Jan	7 – 10 days (plus 21 days 'tethered' larvae)	Local	Hard substrate required – hollow logs as a substrate for laying eggs
Southern pygmy perch	*Nannoperca australis*	2-5yrs	Sept – Nov	2-4 days	Local	Aquatic plants for spawning and habitat Vegetation or rocks instream habitat required
Yarra pygmy perch	*Edelia obscura*^NT, @V	2-5yrs (assuming similar to Southern pygmy perch)	Sept – Oct	2-4 days (assuming similar to Southern pygmy perch)	Local	Aquatic plants for spawning and habitat Vegetation or rocks instream habitat required
Big-headed gudgeon	*Philypnodon grandiceps*	4-7 years	Oct – Feb	4-6 days	Local only	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.

^V Listed as vulnerable species under FFG Act
@V Listed as vulnerable under EPBC Act
^NT Listed as a near threatened species under FFG Act
@V Listed as vulnerable under EPBC Act

Other fauna
Ecological flow objectives to support other fauna such as platypus and growling grass frog were developed to improve breeding and recruitment, as well as provide habitat for these species. Macroinvertebrate objectives focus on maintaining abundance as a food source for these species, other fauna, and fish.

Ecological flow objectives designed to support flow-dependent fauna values are presented in Table 15.

Vegetation
The ecological flow objectives to support vegetation were chosen as they target the requirements of the species which occupy the broad niches identified in the waterway environments.

Rutherford *et al.* (2000) describe the role of aquatic, emergent and riparian plants in supporting waterway ecosystems. They describe how the plants, being the primary producers in the system, form the framework of the waterway ecosystems. The food, structure, shade, and stability they provide in the channel provide the resources and conditions for the other organisms in the system.

The ecological flow objectives presented in Table 16 provide the seasonal water requirements which enable the plant's lifecycle of seed/propagule generation, dispersal, regeneration, maturation, and persistence. If the plants are enabled to complete their lifecycle they will persist and expand in the waterways improving the ecological health of the system overall.

Table 14. Ecological objectives for migratory and freshwater resident fish.

Value group	Objective		FLOWS reaches	Function	Period	Component
Migratory fish	F1	Maintain abundance of migratory fish including short-finned eels, Australian grayling, and tupong	1, 2, 3, 7, 9, 10	Provide water in pools for habitat and food sources	Dry	Low flow
				Provide water over riffles to allow fish to migrate upstream from estuary	Dry	Fresh
				Provide water over riffles to allow longitudinal connectivity and for fish to move between pools	Wet	Fresh
	F2	Improve breeding and recruitment of migratory fish including Broad-finned galaxias and common Jollytail	All reaches	Provide connectivity to allow fish to migrate downstream to breed	Wet	Fresh
Resident freshwater fish	F3	Maintain abundance of resident freshwater fish, including galaxias, smelt, big-headed gudgeon, and Yarra pygmy perch	All reaches	Provide water in pools for habitat and food sources	Dry	Low flow
				Provide water over riffles to allow fish to move between pools to breed, feed and find new habitats	Dry	Fresh
	F4	Improve breeding and recruitment of resident freshwater fish including blackfish	1, 2, 3, 4, 6, 7, 9, 10	Submerge and clean woody debris and hard surfaces to provide breeding substrate	Dry	Fresh
	F5	Improve breeding and recruitment of resident freshwater fish, including galaxias, smelt, big-headed gudgeon, and Yarra pygmy perch	All reaches	Provide prolonged seasonal inundation of vegetation beds and instream benches as habitat to stimulate invertebrate hatching and fish breeding	Wet	Fresh

Table 15. Ecological flow objectives for other fauna (i.e. excluding fish)

Value group	Objective		FLOWS reaches	Function	Period	Component
Macroinvertebrates	O1	Maintain abundance of macroinvertebrates as a food source for fish, frog and platypus populations	All reaches	Sustain macroinvertebrate communities during the dry period	Dry	Fresh
			All reaches	Create and extend aquatic habitats for macroinvertebrates	Wet	Fresh
	O2	Improve breeding and recruitment of macroinvertebrates as a food source for fish, frog and platypus populations	All reaches	Allow growth and reproduction of macroinvertebrate communities	Wet	Fresh
Growling grass frog	O3	Maintain abundance of growling grass frog	1, 2, 6, 9, 10	Provide pool habitat	Dry	Low flow
	O4	Improve breeding and recruitment of growling grass frog	1, 2, 6, 9, 10	Allow growth and reproduction of macroinvertebrate communities	Wet	Fresh
	O5	Improve condition and extent of growling grass frog	1, 2, 6, 9, 10	Provide longitudinal connectivity between reaches	Wet	Fresh
Platypus	O6	Maintain abundance of platypus	1, 2, 3, 4, 7, 8, 9, 10	Provide pool habitat	Dry	Low flow
	O7	Improve condition and extent of platypus	1, 2, 3, 4, 7, 8, 9, 10	Provide longitudinal connectivity between reaches	Dry	Fresh

Table 16. Ecological flow objectives for vegetation

Value group	Objective		FLOWS reaches	Function	Period	Component
Instream	V1	Maintain or improve condition and extent of instream vegetation to provide structural habitat for macroinvertebrates and various fish species	All reaches	Maintain adequate depth of permanent water in the channel, with natural seasonal drawdown to promote recruitment	Dry	Low flow
Emergent macrophyte	V2	Maintain or improve condition, extent, and diversity of emergent macrophyte vegetation to provide structural habitat and channel/lower bank stability to low and moderate flows.	All reaches	Maintain adequate depth of permanent water in stream channel to limit terrestrial encroachment into aquatic habitats	Dry	Low flow
			All reaches	Provide a mosaic of spatially and temporally differentially wetted areas within stream channel, on benches, and on lower banks	Dry	Fresh
			All reaches	Support growth on terraces, channel edge, and lower bank	Dry	Fresh
			All reaches	Provide a mosaic of spatially and temporally differentially wetted areas within stream channel, on benches, and on lower banks	Wet	Fresh
Riparian	V3	Maintain or improve condition, extent, and diversity of riparian vegetation as part of endangered EVCs	All reaches	Support growth on terraces, channel edge, and lower bank	Dry	Fresh
			All reaches	Support growth on terraces, channel edge, and lower bank	Wet	Fresh
			1, 3, 4, 5, 6, 7, 8	Support growth in the channel and upper bank, disturb riparian zone and channel to open recruitment niches for riparian plants	Anytime	Bankfull
Floodplain	V4	Maintain or improve condition and extent of floodplain vegetation as part of endangered EVCs	5	Groundwater interactions with floodplain features supports flow-dependent species	Dry	Low flow
			3, 4, 6, 8	Maintain a shallow water table with low salinity groundwater throughout the year	Dry	Low flow
			2, 4, 6, 8, 10	Inundate floodplain, provide moisture and fill floodplain depressions and billabongs to support the growth of seasonal and emergent wetland vegetation	Anytime	Overbank

Supporting functions
Water quality and geomorphology are important factors in maintaining or improving the health of a stream and their value is mostly focussed on providing physical habitat for a range of biota. Regulated environmental flows will almost always be less variable than natural flows and as such, the resulting geomorphology will most likely be less diverse (Gippel, 2002). The focus of geomorphic flow objectives is to retain, and where possible, improve key existing geomorphic features that support ecological values, rather than seeking to return physical form to previous unaltered states. Flow objectives designed to support water quality and geomorphology values are presented in Table 17.

Specific flow recommendations for acid conditions in the Barwon River or Boundary Creek are not made as these events are the result of specific environmental conditions upstream of our study site. Separate investigations are underway to develop management options to prevent acid conditions from occurring within the Boundary Creek and related Barwon River system.

Table 17. Flow objectives for supporting functions

Value group	Objective		FLOWS reaches	Function	Period	Component
Water quality	S1	Reduce prolonged stratified conditions in pools and promote adequate levels of water quality to allow fish and macroinvertebrate populations to persist	All reaches	Provide minimum velocity to maintain mixing in pool	Dry	Low flow
			All reaches	Provide minimum velocity to establish mixing and flushing of pools	Dry	Fresh
Geomorphology	S2	Improve and maintain abundance and condition of pools, large wood and riffles to provide structural habitat for macroinvertebrates and various fish species	All reaches	Scour sediment from base of pools to maintain pool and to use bed sediments to scour algae from riffles	Dry	Fresh
			All reaches	Scour sediment from base of pools to maintain pool and to use bed sediments to scour algae from riffles	Wet	Fresh
	S3	Maintain channel capacity, shape and form to support flora and fauna values and objectives	All reaches	Mobilise sediment from base of pools	Dry	Fresh
			All reaches	Mobilise sediment from base of pools for a sustained duration	Wet	Low flow
			All reaches	Maintain volume and size of transported sediments by maintaining flows above the threshold for mobilisation of sediments	Wet	Fresh
			All reaches	Maintain volume and size of transported sediments by maintaining the occurrence of bankfull events	Anytime	Bankfull
	S4	Improve and maintain the level of floodplain connectivity to support instream and riparian flora and fauna	All reaches	Connect the channel and floodplain to promote sediment deposition, carbon exchange, and organic matter supply	Anytime	Overbank

7 Flow recommendations

7.1 How the environmental flow recommendations were derived

The process for deriving environmental flow recommendations (Figure 24) includes identifying water dependent values in the system and ecological objectives to support those values (see Section 5). The flow components and hydraulic criteria (detailed below) are derived from these objectives using conceptual models as described in Section 5. Based on the hydraulic criteria, relevant hydraulic models (see below) are used to determine the magnitude of the flow recommendation. An understanding of the system hydrology (see Section 4) is used in conjunction with the conceptual models and hydraulic criteria to determine the frequency, duration, and timing of the flow recommendation. The determination of the number and duration of recommended flow events has then been considered in this study for three prevailing climatic conditions; dry, average and wet years (see below).

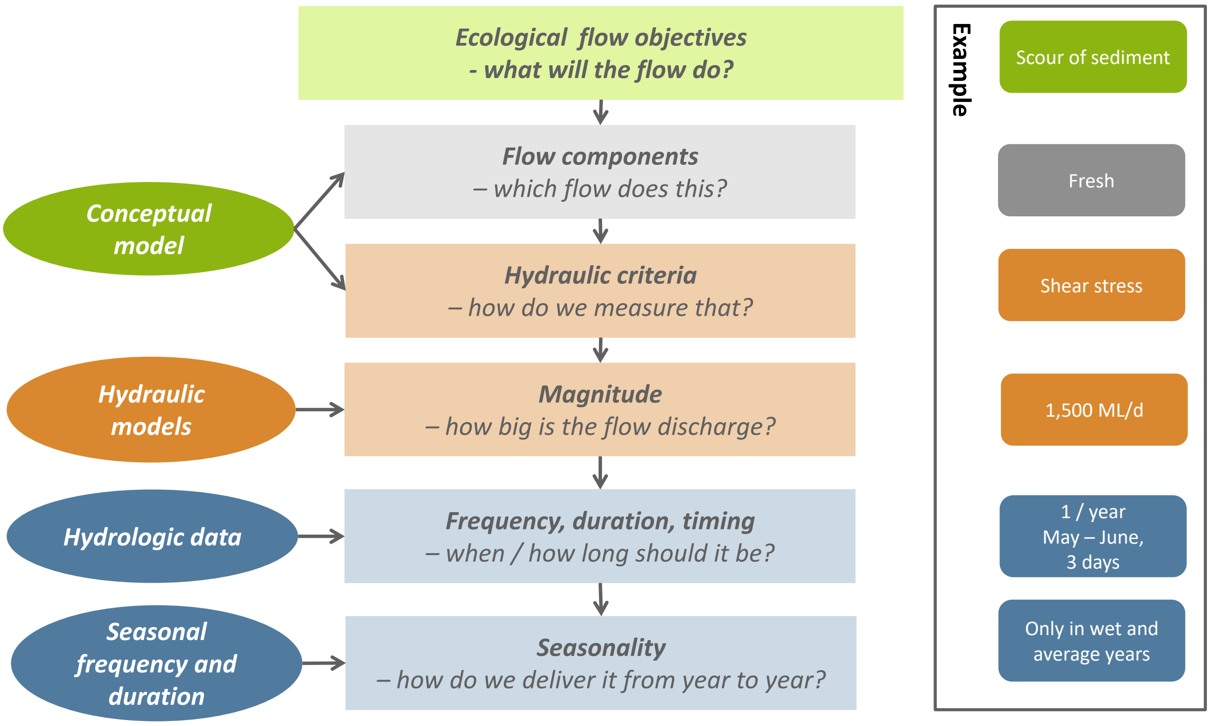

Figure 24. *Process for determining environmental flow requirements.*

Application of hydraulic criteria

The hydraulic criteria required to support the values identified and achieve the flow objectives in Section 6 are detailed in Table 18. Hydraulic criteria have been determined by Environmental Flow Technical Panel members based on relevant literature, expert knowledge and using the conceptual models detailed in Section 5.

Table 18. Hydraulic criteria for flow objectives in the Upper Barwon, Yarrowee and Leigh Rivers, arranged by value.

Value	Objective	Reaches	Function	Period	Component	Criteria	
			ABORIGINAL CULTURAL				
Mammals	Maintain or improve abundance, breeding and recruitment of Wad-dirring/ Perridak (platypus)	1, 2, 9, 10	Provide pool habitat	Dry	Low flow	AM1	See other fauna (PL1)
		1, 2, 9, 10	Provide longitudinal connectivity between reaches	Wet	Fresh	AM2	See other fauna (PL2)
Fish	Maintain or improve abundance of Buniya (eels)	1, 2, 9, 10	Provide water in pools for habitat and food sources	Dry	Low flow	AF1	See fish (MF1)
		1, 2, 9, 10	Provide water over riffles to allow fish to migrate upstream from estuary	Dry	Fresh	AF2	See fish (MF2)
	Maintain or improve abundance of Turrpurt (native trout *galaxias spp.*)	1, 2, 9, 10	Provide water in pools for habitat and food sources	Dry	Low flow	AF3	See fish (RF1)
		1, 2, 9, 10	Provide water over riffles to allow fish to move between pools to breed, feed and find new habitats	Dry	Fresh	AF4	See fish (RF2)
		1, 2, 9, 10	Provide prolonged seasonal inundation of vegetation beds and instream benches as habitat to stimulate invertebrate hatching and fish breeding	Wet	Fresh	AF5	See fish (RF4)
	Maintain or improve abundance of Ware-rap (blackfish)	1, 2, 9, 10	Submerge and clean woody debris and hard surfaces to provide breeding substrate	Dry	Fresh	AF6	See fish (RF3)
Vegetation	Maintain or improve abundance of Polango/Warngare (water ribbons *Triglochin procera*)	1, 2, 9, 10	Maintain adequate depth of permanent water in the channel, with natural seasonal drawdown to promote recruitment	Dry	Low flow	AV1	See vegetation (IV1)
	Maintain or improve condition, extent, and abundance of Tark (common reed *Phragmites australis*), Toolim (pale rush Juncus pallidus), and Bal-yan (cumbungi *Typha latifolia*)	1, 2, 9, 10	Maintain adequate depth of permanent water in stream channel to limit terrestrial encroachment into aquatic habitats	Dry	Low flow	AV2	See vegetation (EV1)
			Provide a mosaic of spatially and temporally differentially wetted areas within stream channel, on benches, and on lower banks	Dry	Fresh	AV3	See vegetation (EV2)
			Support growth on terraces, channel edge, and lower bank	Dry	Fresh	AV4	See vegetation (EV3)
			Provide a mosaic of spatially and temporally differentially wetted areas within stream channel, on benches, and on lower banks	Wet	Fresh	AV5	See vegetation (EV4)
	Maintain or improve abundance of Biyal (river red gum *Eucalyptus camaldulensis*)	2, 10	Support growth on terraces, channel edge, and lower bank	Dry	Fresh	AV6	See vegetation (RV1)
			Support growth on terraces, channel edge, and lower bank	Wet	Fresh	AV7	See vegetation (RV2)
			Support growth in the channel and upper bank, disturb riparian zone and channel to open recruitment niches for riparian plants	Anytime	Bankfull	AV8	See vegetation (RV3)
	Maintain or improve abundance of Larrap	2, 9, 10	Inundate floodplain, provide moisture and fill floodplain	Anytime	Overbank	AV9	See vegetation (FV3)

Value	Objective	Reaches	Function	Period	Component	Criteria	
	(manna gum *Eucalyptus viminalis*) and Kokibainang (swamp wallaby grass *Amphibromus recurvatus*).		depressions and billabongs to support the growth of seasonal and emergent wetland vegetation				
Geomorphology	Deep pools	1, 2, 8, 10	Scour sediment from base of pools to maintain pool and to use bed sediments to scour algae from riffles	Dry	Fresh	AG1	See supporting functions (GE1)
			Scour sediment from base of pools to maintain pool and to use bed sediments to scour algae from riffles	Wet	Fresh	AG2	See supporting functions (GE2)
			Mobilise sediment from base of pools	Dry	Fresh	AG3	See supporting functions (GE3)
			Mobilise sediment from base of pools for a sustained duration	Wet	Low flow	AG4	See supporting functions (GE4)
	Confluences of Barwon and Leigh rivers, and Yarrowee River and Cargerie Creek	1, 2, 10	Maintain adequate depth of permanent water in the channel	Dry	Low flow	AG5	Flow between pools
			FISH				
Migratory fish	Maintain abundance of migratory fish including short-finned eels, Australian grayling, and tupong	1, 2, 3, 7, 9, 10	Provide water in pools for habitat and food sources	Dry	Low flow	MF1	600 mm water depth in pools
			Provide water over riffles to allow fish to migrate upstream from estuary	Dry	Fresh	MF2	500 mm water depth over riffles
			Provide water over riffles to allow longitudinal connectivity and for fish to move between pools	Wet	Fresh	MF3	500 mm water depth over riffles
	Improve breeding and recruitment of migratory fish including broad-finned galaxias and common Jollytail	All reaches	Provide connectivity to allow fish to migrate downstream to breed	Wet	Fresh	MF4	300 mm water depth over riffles
Resident freshwater fish	Maintain abundance of resident freshwater fish, including galaxias, smelt, big-headed gudgeon, and Yarra pygmy perch	All reaches	Provide water in pools for habitat and food sources	Dry	Low flow	RF1	250 mm water depth in pools
			Provide water over riffles to allow fish to move between pools to breed, feed and find new habitats	Dry	Fresh	RF2	300 mm water depth over riffles
	Improve breeding and recruitment of resident freshwater fish including blackfish	1, 2, 3, 4, 6, 7, 9, 10	Submerge and clean woody debris and hard surfaces to provide breeding substrate	Dry	Fresh	RF3	500 mm water depth over some instream benches and vegetation beds or meet criteria GE2
	Improve breeding and recruitment of resident freshwater fish, including galaxias, smelt, big-headed gudgeon, and Yarra pygmy perch	All reaches	Provide prolonged seasonal inundation of vegetation beds and instream benches as habitat to stimulate invertebrate hatching and fish breeding	Wet	Fresh	RF4	500 mm water depth over some instream benches and vegetation beds

Value	Objective	Reaches	Function	Period	Component	Criteria	
			OTHER FAUNA				
Macro-invertebrates	Maintain abundance of macroinvertebrates as a food source for fish, frog and platypus populations	All reaches	Sustain macroinvertebrate communities during the dry period	Dry	Fresh	MA1	Inundation of benches
		All reaches	Create and extend aquatic habitats for macroinvertebrates	Wet	Fresh	MA2	Extend wetted area
	Improve breeding and recruitment of macroinvertebrates as a food source for fish, frog and platypus populations	All reaches	Allow growth and reproduction of macroinvertebrate communities	Wet	Fresh	MA3	Scour sediment and disturb biofilm, see objective S2 (GE1 and GE2)
Growling grass frog	Maintain abundance of growling grass frog	1, 2, 6, 9, 10	Provide pool habitat	Dry	Low flow	GF1	Flow between pools
	Improve breeding and recruitment of growling grass frog	1, 2, 6, 9, 10	Allow growth and reproduction of macroinvertebrate communities	Wet	Fresh	GF2	Scour sediment and disturb biofilm, see objective S2 (GE1 and GE2)
	Improve condition and extent of growling grass frog	1, 2, 6, 9, 10	Provide longitudinal connectivity between reaches	Wet	Fresh	GF3	300 mm water depth over riffles
Platypus	Maintain abundance of platypus	1, 2, 3, 4, 7, 8, 9, 10	Provide pool habitat	Dry	Low flow	PL1	Flow between pools
	Improve condition and extent of platypus	1, 2, 3, 4, 7, 8, 9, 10	Provide longitudinal connectivity between reaches	Dry	Fresh	PL2	200 mm water depth over riffles
			VEGETATION				
Instream	Maintain or improve condition and extent of instream vegetation to provide structural habitat for macroinvertebrates and various fish species	All reaches	Maintain adequate depth of permanent water in the channel, with natural seasonal drawdown to promote recruitment	Dry	Low flow	IV1	400 mm water depth in pools
Emergent macrophyte	Maintain or improve condition, extent, and diversity of emergent macrophyte vegetation to provide structural habitat and channel/lower bank stability to low and moderate flows.	All reaches	Maintain adequate depth of permanent water in stream channel to limit terrestrial encroachment into aquatic habitats	Dry	Low flow	EV1	400 mm water depth in pools
		All reaches	Provide a mosaic of spatially and temporally differentially wetted areas within stream channel, on benches, and on lower banks	Dry	Fresh	EV2	Water level rise from low flow level of 100-200 mm
		All reaches	Support growth on terraces, channel edge, and lower bank	Dry	Fresh	EV3	Inundate channel terraces and lower bank
		All reaches	Provide a mosaic of spatially and temporally differentially wetted areas within stream channel, on benches, and on lower banks	Wet	Fresh	EV4	Water level rise from low flow level of 100-200 mm
Riparian	Maintain or improve condition, extent, and diversity of riparian	All reaches	Support growth on terraces, channel edge, and lower bank	Dry	Fresh	RV1	Inundate lower bank and channel terraces
		All reaches	Support growth on terraces, channel edge, and lower bank	Wet	Fresh	RV2	Inundate lower bank and channel terraces

Value	Objective	Reaches	Function	Period	Component	Criteria	
	vegetation as part of endangered EVCs	1, 3, 4, 5, 6, 7, 8	Support growth in the channel and upper bank, disturb riparian zone and channel to open recruitment niches for riparian plants	Anytime	Bankfull	RV3	Inundate all channel
Floodplain	Maintain or improve condition and extent of floodplain vegetation as part of endangered EVCs	5	Groundwater interactions with floodplain features supports flow-dependent species	Dry	Low flow	FV1	400 mm water depth in pools
		3, 4, 6, 8	Maintain a shallow water table with low salinity groundwater throughout the year	Dry	Low flow	FV2	400 mm water depth in pools
		2, 4, 6, 8, 10	Inundate floodplain, provide moisture and fill floodplain depressions and billabongs to support the growth of seasonal and emergent wetland vegetation	Anytime	Overbank	FV3	Water flows to floodplain
SUPPORTING FUNCTIONS							
Water quality	Reduce prolonged stratified conditions in pools and promote adequate levels of water quality to allow fish and macroinvertebrate populations to persist	All reaches	Provide minimum velocity to maintain mixing in pool	Dry	Low flow	WQ1	Minimum velocity in pools of 0.1m/s
		All reaches	Provide minimum velocity to establish mixing and flushing of pools	Dry	Fresh	WQ2	Minimum velocity in pools of 0.3m/s
Geomorphology	Improve and maintain abundance and condition of pools, large wood and riffles to provide structural habitat for macroinvertebrates and various fish species	All reaches	Scour sediment from base of pools to maintain pool and to use bed sediments to scour algae from riffles	Dry	Fresh	GE1	Shear stress in pool exceeds 1N/m² for sand bed streams and 0.1N/m² for silt bed streams
		All reaches	Scour sediment from base of pools to maintain pool and to use bed sediments to scour algae from riffles	Wet	Fresh	GE2	Shear stress in pool exceeds 1N/m² for sand bed streams and 0.1N/m² for silt bed streams
	Maintain channel capacity, shape and form to support flora and fauna values and objectives	All reaches	Mobilise sediment from base of pools	Dry	Fresh	GE3	Shear stress in pool exceeds 1N/m² for sand bed streams and 0.1N/m² for silt bed streams
		All reaches	Mobilise sediment from base of pools for a sustained duration	Wet	Low flow	GE4	Shear stress in pool exceeds 1N/m² for sand bed streams and 0.1N/m² for silt bed streams
		All reaches	Maintain volume and size of transported sediments	Wet	Fresh	GE5	Inundate high channel benches
		All reaches	Maintain volume and size of transported sediments	Anytime	Bankfull	GE6	'Effective discharge' (around 1.5 yr ARI event)
	Improve and maintain level of floodplain connectivity to support instream and riparian flora and fauna	All reaches	Connect the channel and floodplain to promote sediment deposition, carbon exchange, and organic matter supply	Anytime	Overbank	GE7	Water flows to floodplain

Hydraulic modelling
The magnitudes of the flow required to achieve the flow functions were estimated using one-dimensional hydraulic models. The HECRAS modelling software, developed by the US Army Corp of Engineers, has been used as the hydraulic modelling platform for this investigation.

Hydraulic models have been developed based on existing and newly acquired stream cross-section surveys at the representative sites for each reach.

Three model and topographic survey sources available for this study:

1. Five existing hydraulic models used in the 2006 Barwon FLOWS study
2. Two hydraulic models developed during this study utilising 2010 Index of Stream Condition LiDAR topographic data
3. Three hydraulic models utilising feature survey collected during this study.

The model details are outlined in Table 19.

The hydraulic models assist to estimate the flow rate necessary at a site (over benches of floodplains or within pools or riffles) to achieve nominated target criteria such as stream velocity, shear stress, inundation depths, and inundation extents.

Table 19. Topographic data and details of models utilised for this study.

Reach		Topographic data or model source	Length of model (m)
1	Yarrowee River	Feature survey (2018)	960
2	Leigh River	Existing FLOWS study model (2006)	645
3	Upper Barwon West	Existing FLOWS study model (2006)	1430
4	Upper Barwon East	Feature survey (2018)	760
5	Dewing Creek	ISC LiDAR (2010)	800
6	Boundary Creek	Existing FLOWS study model (2006)	370
7	Barwon River (d/s Boundary Creek)	Feature survey (2018)	900
8	Pennyroyal and Deans Marsh Creeks	ISC LiDAR (2010)	1000
9	Winchelsea	Existing FLOWS study model (2006)	575
10	Lower Barwon	Existing FLOWS study model (2006)	800

Seasonal frequency and duration
Where known, the frequency and duration of the flow recommendations were informed by the life-cycle traits of the value. The unimpacted flow scenario is then used where life-cycle traits are not known and ensure the flow recommendations align with the unimpacted frequency and duration of the flow events.

The determination of the number and duration of recommended flow events has been considered in this study for three prevailing climatic conditions; dry, average and wet years. These climatic conditions can be used in combination with other factors to prioritise environmental watering actions. The recommendations for wet years, when water resources are abundant, maximise recruitment and connectivity, and conversely the recommendations for drought years, when water is scarce, aim to avoid critical loss and maintain key refuges.

The three climatic conditions used in this study are defined as:

- Wet years – when the total annual flow is exceeded in greater than 75% of years,
- Average years – when the total annual flow is exceeded in 25 – 75% of years
- Dry years – when the total annual flow is exceeded in less than 25% of years.

The climatic conditions were determined based on the 91 year (1927-2018) modelled unimpacted flow sequence.

7.2 Environmental flow recommendations

Environmental flow recommendations have been determined for ten reaches of the Barwon River system. Each recommendation is comprised of a flow component, discharge (magnitude), timing (dry or wet period), frequency (number of times per season) and duration (generally in days), as well as the inclusion of seasonality (Figure 25). In this section, the recommendations are described for each reach and for each flow component.

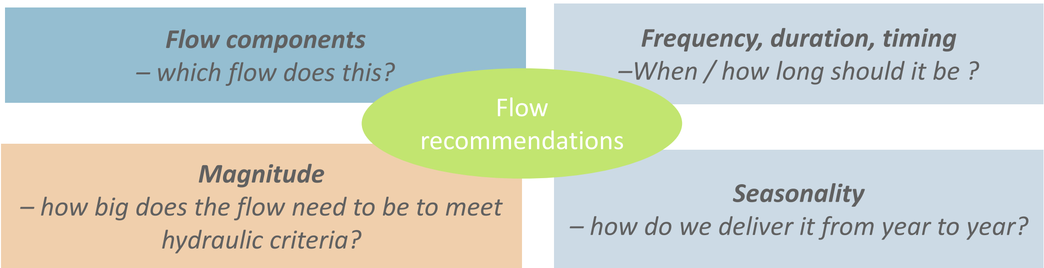

Figure 25. *Components of a flow recommendation*

Interpretation of flow recommendations

'or natural'

Natural flow variability is an important aspect of an environmental flow regime. While all low flows are expressed as 'continuous', an 'or natural' clause has been added to these flows. This clause is designed to allow reduced flows and seasonal drawdown to occur if it would have done so naturally. Determining the natural flow variability in these circumstances will need to be addressed as part of the implementation of the environmental flow recommendations.

Period definition

The below flow recommendations have been developed and expressed as occurring either in the 'dry period' or 'wet period'. The 'dry period' recommendations cover summer and autumn months from December to May and the 'wet period' covers winter and spring months from June to November. Flow frequencies expressed as '/period' denote the number of flows over the entire period. For example, a dry period fresh with a frequency of 3/period would occur three times in total over the summer and autumn period.

The variation in seasonal definitions is recognised and the exact timing of flows should be coordinated to take into consideration:

- The unimpacted or natural regime
- Cultural seasons
- Weather events
- Ecological life cycles

The delivery of the recommended flow regime can be developed further in an environmental water management plan.

Achievement of criteria

Where possible, flow magnitudes were calculated in order to achieve the greatest number of objectives and criteria possible, keeping in mind the current flow regime and operational constraints of the system. Criteria marked with an asterisk (*) are deemed 'partially achieved' by the listed flow magnitude. These include situations where criteria could not fully be met by other constraints such as channel capacity, channel morphology, flow availability, criteria of other values or additional constraints.

Recommendations by reach

Flow recommendations are presented below for each of the 10 reaches. Hydraulic criteria codes are available in Table 18. An overview of recommendations by reach is available in Figure 26, showing how recommended flow magnitudes are linked reach-to-reach.

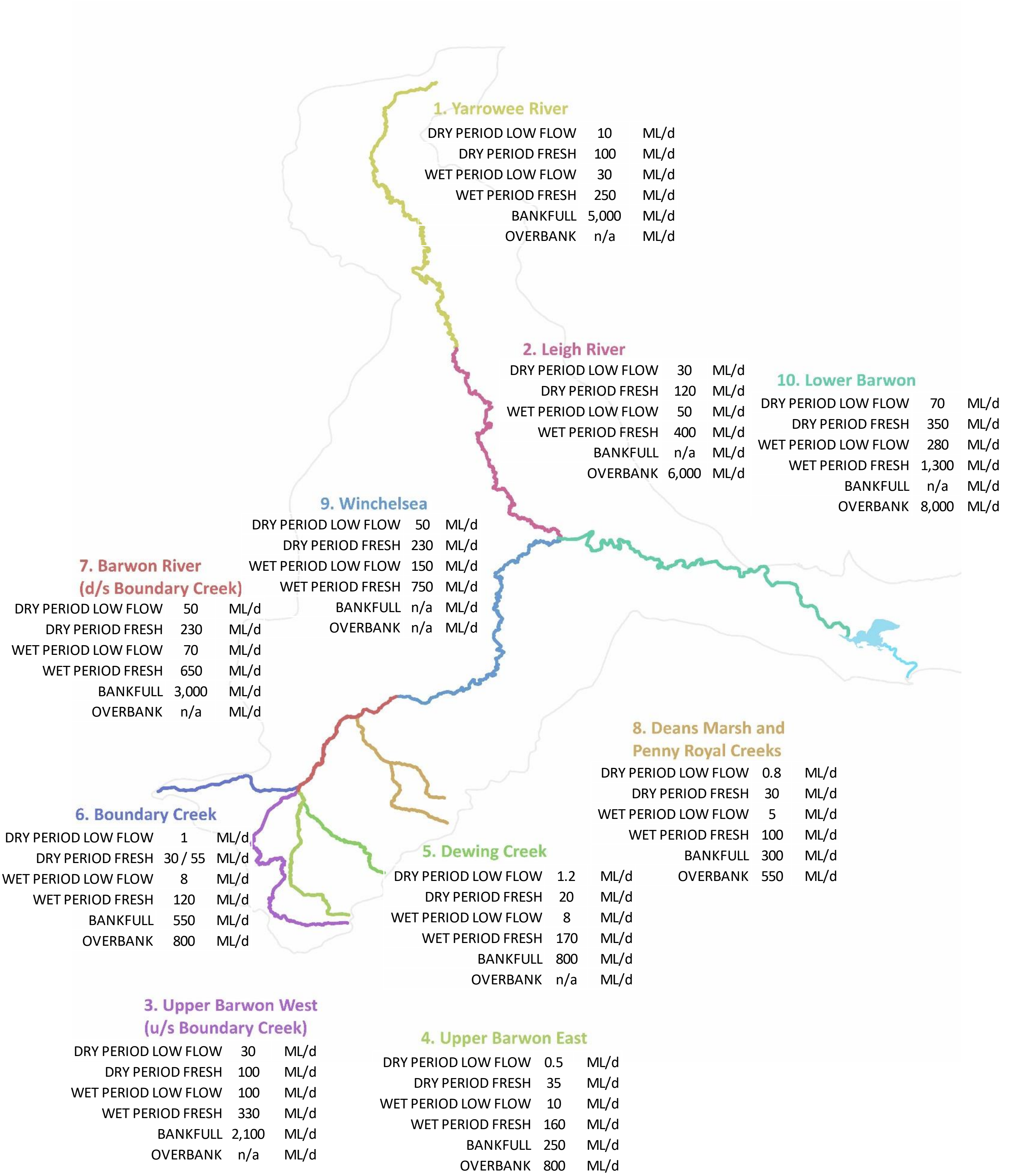

Figure 26. *Reach overview of flow recommendation magnitudes.*

Reach 1 – Yarrowee River

As noted in Section 4.3, the current modelled low flows within this reach are much higher than in the unimpacted scenario. The elevated low flows are a result of discharges from the BSWWTP. Recommendations in this reach focus on returning flow variability to the reach and allowing seasonal drawdown and larger flows through freshes and bankfull events. As a result of contemporary incision in this reach, achieving an overbank flow was deemed unfeasible. Flow recommendations, therefore, focus on maintaining the values within the channel.

Flow component	Magnitude (ML/day)	Frequency (No/period)		Duration (days)		Hydraulic criteria met
Dry period low flow	10 or natural	DRY	Cont	DRY	Cont	AM1, AF1*, AF3, AV1, AV2*, AG5, MF1*, RF1, GF1, PL1, IV1*, EV1*, WQ1
		AVG		AVG		
		WET		WET		
Dry period fresh	100	DRY	0	DRY	0	AF2, AF4, AF6, AV3, AV4, AV6, AG1, AG3, MF2, RF2, RF3, MA1, PL2, EV2, EV3, RV1, WQ2, GE1, GE3
		AVG	3	AVG	4	
		WET	3	WET	4	
Wet period low flow	30 or natural	DRY	Cont	DRY	Cont	As dry period low flow, AG4, GE4
		AVG		AVG		
		WET		WET		
Wet period fresh	250	DRY	1	DRY	3	AM2, AF5, AV5, AV7, AG2, MF3, MF4, RF4*, MA2, MA3, GF2, GF3, EV4, RV2, GE2, GE5
		AVG	3	AVG	4	
		WET	8	WET	4	
Bankfull	5,000	DRY	0	DRY	0	AV8, RV3, GE6
		AVG	1/year	AVG	As natural	
		WET		WET		
Overbank	No recommendation					

Note: The above flow recommendations have been developed and expressed as occurring either in the 'dry period' or 'wet period'. The 'dry period' recommendations cover summer and autumn months from December to May and the 'wet period' covers winter and spring months from June to November. Flow frequencies expressed as '/period' denote the number of flows over the entire period. For example, a dry period fresh with a frequency of 3/period would occur three times in total over the summer and autumn period.

Reach 2 – Leigh River

Similar to the Yarrowee reach upstream, this reach again exhibits higher low flows and less variability in the flow regime. Flow recommendations achieve similar objectives of returning variability to the system. In this reach, there are little values present in the upper bank section, with freshes supporting most in-channel values. A recommendation has, therefore ,not been made for a bankfull flow in this reach.

Flow component	Magnitude (ML/day)	Frequency (No/period)		Duration (days)		Hydraulic criteria met
Dry period low flow	30 or natural	DRY	Cont	DRY	Cont	AM1, AF1, AF3, AV1, AV2, AG5, MF1, RF1, GF1, PL1, IV1, EV1, WQ1
		AVG		AVG		
		WET		WET		
Dry period fresh	120	DRY	0	DRY	0	AF2, AF4, AF6, AV3, AV4, AV6, AG1, AG3, MF2, RF2, RF3, MA1, PL2, EV2, EV3, RV1, WQ2, GE1, GE3
		AVG	2	AVG	3	
		WET	2	WET	6	
Wet period low flow	50 or natural	DRY	Cont	DRY	Cont	As dry period low flow, AG4, GE4
		AVG		AVG		
		WET		WET		
Wet period fresh	400	DRY	1	DRY	3	AM2, AF5, AV5, AV7, AG2, MF3, MF4, RF4*, MA2, MA3, GF2, GF3, EV4, RV2, GE2, GE5
		AVG	3	AVG	4	
		WET	7	WET	6	
Bankfull	No recommendation					
Overbank	6,000	DRY	0	DRY	0	AV9, FV3, GE7
		AVG	1 in 3 years	AVG	As natural	
		WET		WET		

Note: The above flow recommendations have been developed and expressed as occurring either in the 'dry period' or 'wet period'. The 'dry period' recommendations cover summer and autumn months from December to May and the 'wet period' covers winter and spring months from June to November. Flow frequencies expressed as '/period' denote the number of flows over the entire period. For example, a dry period fresh with a frequency of 3/period would occur three times in total over the summer and autumn period.

Reach 3 – Upper Barwon West

In this reach, due to the high connectivity with the floodplain and swampy landscape, a bankfull flow will engage the floodplain and achieve overbank flow objectives. A separate overbank flow has, therefore, not been recommended.

Flow component	Magnitude (ML/day)	Frequency (No/period)		Duration (days)		Hydraulic criteria met
Dry period low flow	30 or natural	DRY	Cont	DRY	Cont	MF1, RF1, PL1, IV1, EV1, FV2, WQ1
		AVG		AVG		
		WET		WET		
Dry period fresh	100	DRY	5	DRY	6	MF2, RF2, RF3, MA1, PL2, EV2, EV3, RV1, WQ2, GE1, GE3
		AVG	5	AVG	6	
		WET	6	WET	8	
Wet period low flow	100 or natural	DRY	Cont	DRY	Cont	As dry period low flow, AG4, GE4
		AVG		AVG		
		WET		WET		
Wet period fresh	330	DRY	6	DRY	5	MF3, MF4, RF4*, MA2, MA3, EV4, RV2, GE2, GE5
		AVG	6	AVG	6	
		WET	8	WET	8	
Bankfull	2,100	DRY	0	DRY	0	RV3, FV3, GE6, GE7
		AVG	2 in 3 years	AVG	As natural	
		WET		WET		
Overbank	No recommendation					

Note: The above flow recommendations have been developed and expressed as occurring either in the 'dry period' or 'wet period'. The 'dry period' recommendations cover summer and autumn months from December to May and the 'wet period' covers winter and spring months from June to November. Flow frequencies expressed as '/period' denote the number of flows over the entire period. For example, a dry period fresh with a frequency of 3/period would occur three times in total over the summer and autumn period.

Reach 4 – Upper Barwon East

Water quality criteria are only partially met within this reach with the recommended flow magnitudes; however, water quality can be improved with complementary revegetation of native species to increase shading along the reach.

Flow component	Magnitude (ML/day)	Frequency (No/period)		Duration (days)		Hydraulic criteria met
Dry period low flow	0.5 or natural	DRY	Cont	DRY	Cont	RF1, PL1, IV1*, EV1*, FV2*
		AVG		AVG		
		WET		WET		
Dry period fresh	35	DRY	2	DRY	2	RF2, RF3, MA1, PL2, EV2, EV3, RV1, WQ2*, GE1, GE3
		AVG	2	AVG	2	
		WET	3	WET	2	
Wet period low flow	10 or natural	DRY	Cont	DRY	Cont	As dry period low flow, AG4, GE4
		AVG		AVG		
		WET		WET		
Wet period fresh	160	DRY	0	DRY	0	RF4*, MA2, MA3, EV4, RV2, GE2, GE5
		AVG	2	AVG	1	
		WET	2	WET	2	
Bankfull	250	DRY	0	DRY	0	RV3, GE6
		AVG	2 in 3 years	AVG	As natural	
		WET		WET		
Overbank	800	DRY	0	DRY	0	FV3, GE7
		AVG	1 in 5 years	AVG	As natural	
		WET		WET		

Note: The above flow recommendations have been developed and expressed as occurring either in the 'dry period' or 'wet period'. The 'dry period' recommendations cover summer and autumn months from December to May and the 'wet period' covers winter and spring months from June to November. Flow frequencies expressed as '/period' denote the number of flows over the entire period. For example, a dry period fresh with a frequency of 3/period would occur three times in total over the summer and autumn period.

Reach 5 – Dewing Creek

The floodplain in this reach appears to be inundated by groundwater with a spring located on the break of slope near the study site. As such, an overbank flow was not deemed necessary in this reach.

Flow recommendations for Dewing Creek (Reach 5) can be used as a reference for Callahan Creek, a similar right-bank tributary of the Upper Barwon East Branch.

Flow component	Magnitude (ML/day)	Frequency (No/period)		Duration (days)		Hydraulic criteria met
Dry period low flow	1.2 or natural	DRY	Cont	DRY	Cont	RF1, IV1*, EV1*, FV1*, WQ1
		AVG		AVG		
		WET		WET		
Dry period fresh	20	DRY	4	DRY	3	RF2, MA1, PL2, EV2, EV3, RV1, WQ2*, GE1, GE3
		AVG	4	AVG	3	
		WET	5	WET	4	
Wet period low flow	8 or natural	DRY	Cont	DRY	Cont	As dry period low flow, AG4, GE4
		AVG		AVG		
		WET		WET		
Wet period fresh	170	DRY	1	DRY	1	RF4*, MA2, MA3, EV4, RV2, GE2, GE5
		AVG	3	AVG	2	
		WET	6	WET	3	
Bankfull	800	DRY	0	DRY	0	RV3, GE6
		AVG	2 in 3 years	AVG	As natural	
		WET		WET		
Overbank	No recommendation					

Note: The above flow recommendations have been developed and expressed as occurring either in the 'dry period' or 'wet period'. The 'dry period' recommendations cover summer and autumn months from December to May and the 'wet period' covers winter and spring months from June to November. Flow frequencies expressed as '/period' denote the number of flows over the entire period. For example, a dry period fresh with a frequency of 3/period would occur three times in total over the summer and autumn period.

Reach 6 – Boundary Creek

The below recommendations have not sought to use dilution to address the pH levels in Boundary Creek. These pH issues will be best addressed by managing groundwater levels within the areas of acid sulphate soils. Management of groundwater extraction impacting on Boundary Creek is the subject of current investigations by others.

Flow component	Magnitude (ML/day)	Frequency (No/period)		Duration (days)		Hydraulic criteria met
Dry period low flow	1 or natural	DRY	Cont	DRY	Cont	RF1, GF1, IV1, EV1, FV2
		AVG		AVG		
		WET		WET		
Dry period fresh	30	DRY	1	DRY	1	RF2, MA1, PL2, EV2, EV3, RV1, GE1, GE3
		AVG	2	AVG	2	
		WET	3	WET	2	
	55	DRY	0	DRY	0	RF2, RF3, MA1, PL2, EV2, EV3, RV1, WQ2, GE1, GE3
		AVG	1	AVG	2	
		WET	1	WET	2	
Wet period low flow	8 or natural	DRY	Cont	DRY	Cont	As dry period low flow, AG4*, GE4*
		AVG		AVG		
		WET		WET		
Wet period fresh	120	DRY	0	DRY	0	RF4*, MA2, MA3, GF2, GF3, EV4, RV2, GE2, GE5
		AVG	3	AVG	2	
		WET	3	WET	1	
Bankfull	550	DRY	0	DRY	0	RV3, GE6
		AVG	2 in 3 years	AVG	As natural	
		WET		WET		
Overbank	800	DRY	0	DRY	0	FV3, GE7
		AVG	1 in 4 years	AVG	As natural	
		WET		WET		

Note: The above flow recommendations have been developed and expressed as occurring either in the 'dry period' or 'wet period'. The 'dry period' recommendations cover summer and autumn months from December to May and the 'wet period' covers winter and spring months from June to November. Flow frequencies expressed as '/period' denote the number of flows over the entire period. For example, a dry period fresh with a frequency of 3/period would occur three times in total over the summer and autumn period.

__Reach 7 – Barwon (Downstream of Boundary Creek)__

The following recommendations have not sought to use dilution to address the pH levels in this reach of the Barwon downstream of Boundary Creek. These pH issues will be best addressed by managing groundwater levels within the areas of acid sulphate soils. Management of groundwater extraction impacting on Boundary Creek and the downstream reaches of the Barwon is the subject of current investigations by others.

Flow component	Magnitude (ML/day)	Frequency (No/period)		Duration (days)		Hydraulic criteria met
Dry period low flow	50 or natural	DRY	Cont	DRY	Cont	MF1, RF1, IV1, EV1, WQ1*
		AVG		AVG		
		WET		WET		
Dry period fresh	230	DRY	3	DRY	4	MF2, RF2, RF3, MA1, PL2, EV2, EV3, RV1, WQ2, GE1, GE3
		AVG	3	AVG	5	
		WET	4	WET	8	
Wet period low flow	70 or natural	DRY	Cont	DRY	Cont	As dry period low flow, AG4, GE4
		AVG		AVG		
		WET		WET		
Wet period fresh	650	DRY	3	DRY	4	MF3, MF4, RF4, MA2, MA3, EV4, RV2, GE2, GE5
		AVG	3	AVG	4	
		WET	6	WET	8	
Bankfull	3,000	DRY	0	DRY	0	RV3, GE6
		AVG	2 in 3 years	AVG	As natural	
		WET		WET		
Overbank	No recommendation					

Note: The above flow recommendations have been developed and expressed as occurring either in the 'dry period' or 'wet period'. The 'dry period' recommendations cover summer and autumn months from December to May and the 'wet period' covers winter and spring months from June to November. Flow frequencies expressed as '/period' denote the number of flows over the entire period. For example, a dry period fresh with a frequency of 3/period would occur three times in total over the summer and autumn period.

Reach 8 – Pennyroyal and Deans Marsh Creeks
Achieving sufficient water depth over benches for breeding of resident freshwater fish with a wet period fresh was challenging in this reach. Benches do not appear to be well defined, although this could be a limitation of the use of LiDAR data. 100ML/day provided around 200 mm depth over benches, while 500 mm is ideal. It appeared that the total bench depth from top of bank was only around 400 mm.

Flow recommendations for the Pennyroyal / Deans Marks Creeks reach can also be used as a reference for Matthews Creek, a similar right-bank tributary of the Upper Barwon River.

Flow component	Magnitude (ML/day)	Frequency (No/period)		Duration (days)		Hydraulic criteria met
Dry period low flow	0.8 or natural	DRY	Cont	DRY	Cont	RF1, PL1, IV1*, EV1*, FV2*, WQ1
		AVG		AVG		
		WET		WET		
Dry period fresh	30	DRY	2	DRY	2	RF2, MA1, PL2, EV2, EV3, RV1, WQ2, GE1, GE3
		AVG	3	AVG	3	
		WET	3	WET	3	
Wet period low flow	5 or natural	DRY	Cont	DRY	Cont	As dry period low flow, AG4, GE4
		AVG		AVG		
		WET		WET		
Wet period fresh	100	DRY	1	DRY	1	RF4*, MA2, MA3, EV4, RV2, GE2, GE5
		AVG	3	AVG	2	
		WET	5	WET	2	
Bankfull	300	DRY	0	DRY	0	RV3, GE6
		AVG	2 in 3 years	AVG	As natural	
		WET		WET		
Overbank	550	DRY	0	DRY	0	FV3, GE7
		AVG	1 in 4 years	AVG	As natural	
		WET		WET		

Note: The above flow recommendations have been developed and expressed as occurring either in the 'dry period' or 'wet period'. The 'dry period' recommendations cover summer and autumn months from December to May and the 'wet period' covers winter and spring months from June to November. Flow frequencies expressed as '/period' denote the number of flows over the entire period. For example, a dry period fresh with a frequency of 3/period would occur three times in total over the summer and autumn period.

Reach 9 – Winchelsea

As a result of contemporary incision, the wider floodplain has become disconnected with the channel, with no compelling flow-dependent values present outside the inset floodplain. Recommendations in this reach aim to preserve the in-channel values. High stream power values at the downstream extent also suggest instability within the reach and potential for ongoing channel adjustment through widening.

Flow component	Magnitude (ML/day)	Frequency (No/period)		Duration (days)		Hydraulic criteria met
Dry period low flow	50 or natural	DRY	Cont	DRY	Cont	AM1, AF1, AF3, AV1, AV2, MF1, RF1, GF1, PL1, IV1, EV1, WQ1
		AVG		AVG		
		WET		WET		
Dry period fresh	230	DRY	3	DRY	3	MF2, RF2, RF3, MA1, PL2, EV2, EV3, RV1, WQ2, GE1*, GE3*
		AVG	3	AVG	4	
		WET	3	WET	11	
Wet period low flow	150 or natural	DRY	Cont	DRY	Cont	As dry period low flow, AG4, GE4
		AVG		AVG		
		WET		WET		
Wet period fresh	750	DRY	3	DRY	5	AM2, AF5, AV5, AV7, AG2, MF3, MF4, RF4, MA2, MA3, GF2, GF3, EV4, RV2, GE2, GE5
		AVG	3	AVG	5	
		WET	5	WET	11	
Bankfull	No recommendation					
Overbank	No recommendation					

Note: The above flow recommendations have been developed and expressed as occurring either in the 'dry period' or 'wet period'. The 'dry period' recommendations cover summer and autumn months from December to May and the 'wet period' covers winter and spring months from June to November. Flow frequencies expressed as '/period' denote the number of flows over the entire period. For example, a dry period fresh with a frequency of 3/period would occur three times in total over the summer and autumn period.

Reach 10 – Lower Barwon (Murgheboluc)

In this reach, a 'true' overbank flow that inundates the historic floodplain would need to be around 17,000ML/day. This was deemed unfeasible and an overbank flow of 8,000 ML/day inundates the inset floodplain and fulfils the requirements of a bankfull flow, providing moisture to riparian and upper bank vegetation.

Flow component	Magnitude (ML/day)	Frequency (No/period)		Duration (days)		Hydraulic criteria met
Dry period low flow	70 or natural	DRY	Cont	DRY	Cont	AM1, AF1, AF3, AV1, AV2, AG5, MF1, RF1, GF1, PL1, IV1, EV1, WQ1
		AVG		AVG		
		WET		WET		
Dry period fresh	350	DRY	2	DRY	8	MF2, RF2, RF3, MA1, PL2, EV2, EV3, RV1, WQ2, GE1, GE3
		AVG	3	AVG	8	
		WET	3	WET	11	
Wet period low flow	280 or natural	DRY	Cont	DRY	Cont	As dry period low flow, AG4, GE4
		AVG		AVG		
		WET		WET		
Wet period fresh	1,300	DRY	1	DRY	5	AM2, AF5, AV5, AV7, AG2, MF3, MF4, RF4, MA2, MA3, GF2, GF3, EV4, RV2, GE2, GE5
		AVG	3	AVG	5	
		WET	5	WET	10	
Bankfull	No recommendation					
Overbank	8,000	DRY	0	DRY	0	AV9, FV3, GE7
		AVG	2 in 3 years	AVG	As natural	
		WET		WET		

Note: The above flow recommendations have been developed and expressed as occurring either in the 'dry period' or 'wet period'. The 'dry period' recommendations cover summer and autumn months from December to May and the 'wet period' covers winter and spring months from June to November. Flow frequencies expressed as '/period' denote the number of flows over the entire period. For example, a dry period fresh with a frequency of 3/period would occur three times in total over the summer and autumn period.

Rates of rise and fall

The rate of rise and fall relates to the rate of change in flow from day to day, with a focus on the rate of increase up to a target flow and a rate of decrease from this target flow. These fluctuations in the flow rate serve important ecological and geomorphic functions in a river system. Excessive rates of water-level fall can result in fish being stranded by falling waters or bank slumping. It is therefore important that the rate of rise and fall is not significantly altered from the natural (unimpacted) rates of rise and fall in stream flow.

As noted in Section 4.3, streams in the Barwon River catchment appear to typically have a rapid natural rate of rise, with the major peak in the stream level normally reached within 1 – 2 days of the onset of the rainfall event. Recession rates are typically lower, with the initially high rate of decline decaying slowly for an extended period after rainfall ceases.

Within the context of flow management, recommended rates of rise and fall are useful to ensure that the delivery of *managed* flows is such that ecological harm is minimised. The recommended rates of rise and fall were determined from the modelled unimpacted daily flow data. Rates of rise and fall are reported as the maximum rate of permissible rise/fall from one day to the next. For example, if the flow is at 100 ML/d and the recommended rate of fall is 0.7, the flow on the following day should not be below 70 ML/d. Similarly, if the flow rate was 100 ML/d and the recommended rate of rise is 1.8, the flow on the following day should not exceed 180 ML/d.

The recommended maximum rate of rise and fall have been defined as the long term median rates of rise and fall for modelled unimpacted case (Table 20).

Table 20. Rates of rise and fall for the Barwon, Yarrowee and Leigh Rivers.

Reach		Period	Rise	Fall
1	Yarrowee River	Dry	1.2	0.9
		Wet	1.4	0.8
		Bankfull	18.2	0.7
2	Leigh River	Dry	1.1	0.9
		Wet	1.3	0.7
		Bankfull	3.8	0.7
3	Upper Barwon West	Dry	1.5	0.8
		Wet	1.4	0.8
		Bankfull	6.1	0.4
4	Upper Barwon East	Dry	2.6	0.7
		Wet	2.2	0.7
		Bankfull	5.2	0.6
5	Dewing Creek	Dry	2.4	0.7
		Wet	1.9	0.7
		Bankfull	9.9	0.5
6	Boundary Creek	Dry	2.4	0.7
		Wet	2.3	0.7
		Bankfull	11.3	0.3
7	Barwon River (d/s Boundary Creek)	Dry	1.2	0.8
		Wet	1.3	0.8
		Bankfull	2.8	0.8

Reach		Period	Rise	Fall
8	Pennyroyal and Deans Marsh Creeks	Dry	2.7	0.7
		Wet	2.3	0.7
		Bankfull	10.4	0.6
9	Winchelsea	Dry	1.2	0.8
		Wet	1.2	0.9
		Bankfull	-	-
10	Lower Barwon	Dry	1.2	0.8
		Wet	1.2	0.9
		Bankfull	2.0	0.8

7.3 Achievement of environmental flow recommendations

An assessment of the performance of the environmental flow recommendations has been undertaken to identify the water recovery required to move from the current flow regime to that required to meet all of the identified environmental flows requirements for the Barwon system. Delivery of the recommended environmental flows has been simulated in eFlow Predictor for the following periods:

- All reaches except Reach 6: 1928-2017
- Reach 6: 1979 – 2017

For each of the flow recommendations considered in this project, the eFlow Predictor augmentation options have been set to 'extend' (i.e. if an event has commenced then augmented the flow until the duration requirement is achieved) and 'force' whereby a water release is forced to provide compliance of the flow recommendation. This 'force' produces a flow series where an augmented flow is provided if this flow component has not been achieved within the desired period.

For example, Figure 27 shows the current and augmented flow series for bankfull events in Reach 5 (Dewing Creek). The inset shows a scenario where an 800 ML/day flow has been augmented at the end of the period because it had not yet been met, in line with the recommendations. However, the flow was almost met by a 798 ML/day flow a few months before. Because the 798 ML/day flow did not meet the 800ML/day threshold, it was not recorded as a bankfull flow and an 800Ml/day flow was 'ordered' for the stream. In addition, a 1070 ML/day flow occurred around 2 months after the augmented flow. However, as eFlow predictor does not look forward through the flow record, even if a flow is likely to be provided naturally in a couple of months, it will still augment a flow at the end of each period if it has not previously been met in that period. This augmentation process can result in an over-prediction of the estimated water requirements to meet the recommended flow rates.

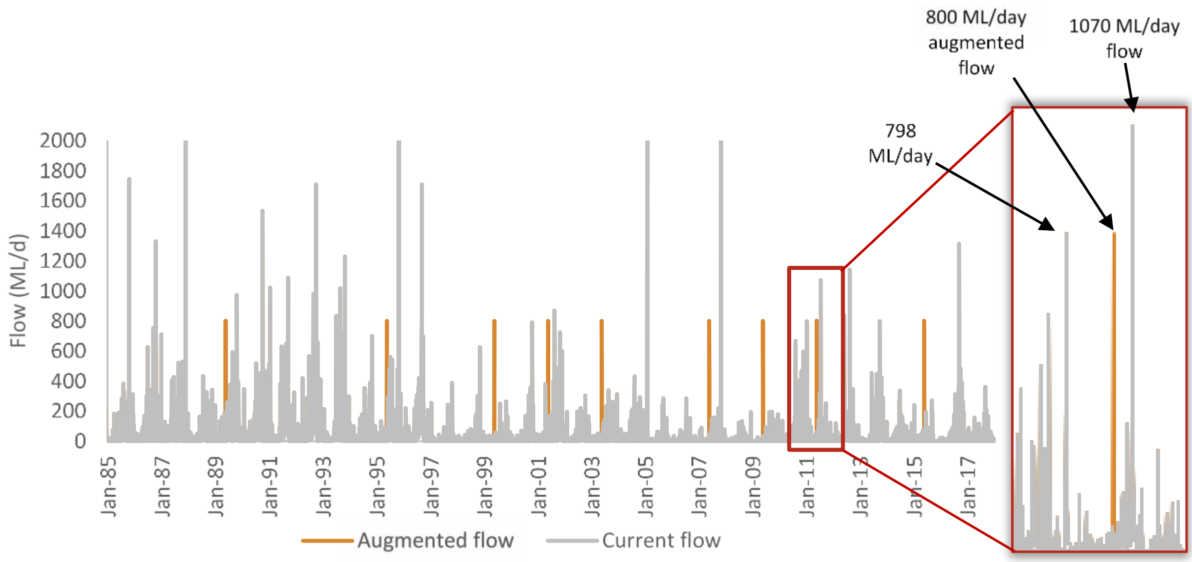

Figure 27. *Example augmented flow series for bankfull flows for Reach 5 (Dewing Creek) from 1985 to 2017.*

A comparison of the recommendations from the 2006 FLOWS study (Lloyd Environmental, 2006)) and the recommendations set out in this study is provided in Appendix K.

Environmental water shortfalls

An assessment of the performance of the environmental flow recommendations has been undertaken to identify the additional water required (or shortfall) to move from the current flow regime, to that required to meet all of the recommended environmental flows for the Barwon River system. The figures below identify the volume of additional water required in order to fully implement the suite of environmental flow recommendations in each reach. This assessment has examined the environmental flow demands in all reaches independently of each other (Appendix J). Accurately accounting for the total water recovery across the reaches would require a daily water resource model with a sophisticated environmental water demand module that can account for routing effects between the reaches. This level of modelling sophistication was not available for this project. We, therefore, adopted the average annual flow figure in most downstream reach at Reach 10 (Lower Barwon) to represent the total water recovery requirements of the Barwon system. The annual average flow in Reach 10 under the unimpacted, current, and recommended flow regime are set out in Table 21. The modelled shortfall of the Barwon system (Reach 10) is estimated to be 37,118 ML/yr. Water recovery of this magnitude would return average annual flows from the current 60% to 73% of the unimpacted flow regime and would allow provision of all flow component recommendations.

Table 21. Reach 10 average annual flow rates and shortfalls

Model operating condition	Average annual flow ML/year	Average annual volume compared to natural
Natural (unimpacted) flow regime	287,405	
Current flow regime	173,033	60%
Recommended flow regime	217,451	76%
Shortfall between current and recommended flow regime	44,419	

The estimated shortfall figures for provision of all the recommended flow components in the three nominated climate conditions for the Barwon system (Reach 10) are:

- Dry: 80,835 ML/yr
- Average: 39,068 ML/yr
- Wet: 18,237 ML/yr

The greatest shortfall between the current and recommended flow regime for Reach 10 occurs in dry and drought conditions. It is in dry and drought conditions that the greatest pressure is placed on the Barwon system in terms of water extractions, with associated adverse impacts on aquatic ecosystems.

7.4 Effects of flow recommendations for wet, average and dry years

The following section provides an overview of the effects of implementing the full suite of flow components for dry, average and wet regimes. The recommended dry year flow recommendations can assist to provide refuge during dry years. However, these recommendations should not be applied to every year.

Dry conditions regime

The dry conditions regime will provide refuge habitat for most species but will not provide essential breeding and migration opportunities. Culturally important species such as blackfish, native trout, and platypus would have limited opportunities for movement between pools, reducing availability of food, reproduction of the species and migration to new habitats. While eels are resilient and can survive in reduced water levels, they do require higher flows to allow migration to and from the estuary for breeding. An extended dry condition flow regime is likely to result in localised extinctions of a number of these species, with severely reduced opportunities for spawning and reproduction for resident and migratory fish, growling grass frogs and macroinvertebrates.

While seasonal drawdown is important for the recruitment of instream vegetation, the emergent macrophyte and riparian vegetation would suffer from lack of water in an extended dry regime. Woody weeds and terrestrial vegetation may encroach into the channel and significant changes to the structure of the vegetation could occur. This can impact on populations of phragmites, pale rush and, cumbungi. Floodplain and riparian vegetation including the culturally significant river red and manna gums will die back in prolonged dry conditions, with no overbank flows to provide moisture.

Without seasonal freshes, water may pool and stagnate. Organic matter and vegetation debris accumulate on the stream bed, leading to reduced oxygen and potential algal growth. Lower water velocities also mean water can heat up in the dry period (mainly summer), again encouraging algal growth. Reduced water quality can have severe impacts on a number of other values and can result in fish kills and vegetation dieback.

Sustained low flows and more infrequent freshes and bankfull flows will reduce the sediment transport capacity of the river. This can lead to the accumulation of sediment in pools and aggradation of the channel bed. This aggradation of fine sediment reduces breeding substrate available to macroinvertebrates and some fish species. Eventually, pools begin to fill with sediment, minimising the available pool habitat for fish, platypus, and other species. Deep pools and confluences hold great cultural significance and without larger magnitude flows, pools will not be maintained and water may not reach confluences, with periods of ceased flow.

Average conditions regime
The environmental flow recommendations for average conditions provide balance between the seasonal drawdown needs of instream vegetation and the fresh and bankfull requirements for spawning, migration and vegetation watering. Low flows provide habitat for fish and other fauna while allowing flow to reduce periodically as it would have done naturally providing a mosaic of drying areas and seasonal drawdown to promote recruitment of instream vegetation. Variability in wetting and drying will provide inundation of sediments, important for hatching of invertebrate eggs. While water may be more readily available in average years, than in dry years, it is important to maintain flow variability. Exotic species such as gambusia and carp thrive in regulated systems with minimal flow variability.

Low flows will maintain turnover of water, with freshes providing flushes to maintain adequate water quality. Increased wet period low flows will maintain the sediment transport capacity of the river, channel cross-section size and form, and important habitats such as pools and riffles.

Wet conditions regime
The recommended wet condition flow regime will provide plentiful migration and movement opportunities for resident and migratory fish species. However, persistent high flows will result in the loss of important wetting and drying sequences. Drying results in invertebrates laying desiccant-resistant eggs which hatch on subsequent inundations, providing vital food sources for fish, platypus, and frogs. This wetting and drying cycle results in carbon and nutrient exchange and drives ecosystem processes in aquatic environments.

Instream vegetation such as water ribbons and emergent macrophytes such as phragmites, pale rush, and cumbungi may not survive continuous deep inundation and require seasonal drawdown to promote recruitment. It is important for these species to have a habitat made up of different wetted areas over space and time, including the bed of the channel, benches, bars and lower banks. Inundation of the floodplain is important to provide water for floodplain vegetation and for carbon exchange, however, prolonged inundation may cause localised floodplain scour, with riparian species such as river red gum unable to survive prolonged inundation.

More frequent high magnitude events could result in increased erosion of the bed and banks, with localised areas of incision initiating as the system adjusts to continued higher flows. Increased erosion and sediment liberation downstream could adversely impact on downstream reaches, with sediment filling pools or wetlands.

7.5 Prioritisation of flow delivery

With limited environmental water available in the Barwon catchment, and recognising the practicalities of environmental water delivery, the CCMA and environmental water managers may need to prioritise delivery of the most essential flow components to priority reaches that can benefit the most. Prioritised reaches and flow components are set out below.

Reach priorities:
The prioritisation of reaches for the retention and provision of environmental water has been based on waterway condition, fish presence, fish passage and significant barriers within the catchment, the practicalities of water delivery, and our capacity to influence the system with environmental water. Recent records of fish distributions and an assessment of fish barriers in the Barwon and Yarrowee-Leigh catchment is available in Marsden *et al.* (2016).

Highest priority reaches

Reaches 1 and 2 - Yarrowee and Leigh Rivers
Migratory fish such as common galaxias, short-finned eel, and Australian smelt have been recently recorded in the Leigh and lower Yarrowee Rivers. These rivers have relatively few major fish barriers, with Shelford Church Farm road crossing and Leighburn Station Ford posing the greatest threats to fish passage. As such, flow variability will allow native fish populations to build and potentially reduce exotic fish populations such as gambusia and carp, which thrive in regulated flow regimes. Other fauna such as growling grass frog and platypus have also been recorded in this reach.

Reaches 9 and 10 - Winchelsea and Lower Barwon
Migratory fish such as common galaxias, short-finned eel, spotted galaxias, Australian smelt, and tupong have been recently recorded in the Lower Barwon and Winchelsea reaches. The culturally significant river blackfish has also been recently recorded in these reaches, among other resident freshwater and migratory fish. The Barwon River has been listed as an important river in the National Recovery Plan for the Australian grayling *Prototroctes maraena* (DSE, 2008). Australian grayling distribution is currently limited to downstream of Geelong and the Lower Barwon wetlands.

Other priority reaches
Delivery of water to the Winchelsea and Lower Barwon River will require the development of priorities for flow delivery from the West Barwon Reservoir.

Reach 4 - Upper Barwon East
Short-finned eels, blackfish, and Southern pygmy perch have recently been recorded in the Upper Barwon East. There are relatively few major barriers to fish migration in the East Barwon River, and those that are present can be addressed through fish barrier programs. Water can also be delivered, with limited losses, to the Upper Barwon East with water from the West Barwon Reservoir. However, riparian condition and vegetation continuity is poor, with infestations of exotic species throughout the reach.

We recommend that water be provided to the Upper Barwon East to meet the environmental water requirements in this reach and (in part) to meet environmental water requirements for the Winchelsea and Lower Barwon Reaches. However;

- The environmental water requirements for the Upper Barwon East should not be exceeded and additional water required to meet downstream requirements should be delivered via the Upper Barwon West (downstream from the West Barwon Reservoir)
- Fish barrier issues should be addressed as a priority
- Work will be required to improve vegetation condition throughout the Upper Barwon East.

Reach 3 - Upper Barwon West
This reach has been adversely impacted by the loss of flows arising from the construction and operation of the West Barwon Reservoir and can be readily supplied with environmental water. However, the provision of fish passage over the reservoir will be difficult and as a consequence provision of water in this reach will provide limited fish passage outcomes and may compromise fish outcomes by encouraging fish to move up through the reach to a point near the dam wall that fails to meet life cycle requirements. As a consequence, environmental water should only be delivered to the lower Barwon River via the Upper Barwon West, once environmental requirements for the Upper Barwon East have been achieved.

Other reaches

Dewing, Pennyroyal and Deans Marsh Creeks
Short-finned eels are present in the Upper Barwon tributaries, including the Upper Barwon East and Dewing Creek. River blackfish and Southern pygmy perch have also been recently recorded in the Upper Barwon East, Dewing and Pennyroyal Creeks, with Pennyroyal Creek also supporting Yarra pygmy perch. Boundary Creek was not sampled for that investigation. There are relatively few major barriers to fish migration in these reaches, however, riparian condition is poor, with poor vegetation continuity and infestations of exotic species.

While it is feasible to deliver water from the West Barwon Reservoir to these reaches, it is understood that there would be considerable losses in such delivery. These reaches are not prioritised for the delivery of additional water. However;

- existing environmental water in these systems should be retained to protect existing values
- it may be possible to reduce harvesting from and pass additional wet period freshes through these systems.

Prioritisation of and between these reaches will be reliant on the improvement of riparian vegetation, resolution of fish barriers and addressing pH issues in the Barwon River downstream of Boundary Creek.

Upper Barwon (d/s Boundary Creek) and Boundary Creek
There are limited populations of migratory fish above the Winchelsea reach in the Upper Barwon and Boundary Creek. We have not recommended the use of environmental water to address existing pH issues in Boundary Creek. Further, we have not recommended the use of additional formal environmental entitlements in Boundary Creek prior to the resolution of the current water quality (pH) issues.

As the Upper Barwon River (downstream of Boundary Creek) would be used to deliver environmental water, some effort will be required to improve the stream condition and optimise the outcomes of environmental water deliveries.

Prioritised flow components:
Flow component prioritisation relies on the capacity for components to provide essential functions.

Highest priority flow components

Dry period low flows
The most critical aspects of the flow regime for the survival of valued species are the dry period low flows. These flows provide essential habitat for aquatic fauna and provide moisture to instream and emergent macrophyte vegetation. These continuous flows through the dryer months of summer and autumn provide refuges for species such as platypus, growling grass frog, fish, and macroinvertebrates. These low flows also provide minimum water velocity for mixing of pools, reducing the risk of stratification and poor water quality. Adequate depth of water and water quality are essential to the survival of aquatic species. The dry period low flow recommendations should be provided as a priority. These flow rates are essential in the dry period and are to be provided as a minimum during the wet period.

Dry period freshes
These freshes during the December to May period provide flushes that assist in maintaining adequate water quality and provide opportunities for migration of fish and other fauna between

reaches. Without the provision of these dry period freshes, there may be regional extinctions, with many species unable to move to new habitats and reproduce. Crowding in pools may become prevalent, with increased competition for food and resources.

Second priority flow components

Wet period freshes
Fresh events during the wet period provide migration cues and opportunities for fish and other fauna, including platypus, tupong, short-finned eel, Australian smelt, common jollytail, spotted galaxias, and Australian grayling. These events also provide moisture for vegetation on banks and benches. There will be limited spawning opportunities for fish and other fauna in the event that these freshes are not provided for extended periods, and populations of these species will decline.

Other flow components:

Wet period low flows and bankfull events
Wet period low flows and bankfull events play an important role in the maintenance of channel shape and form over longer time scales. These flows are not as essential to the survival of valued species in the short term, however, failure to provide these flows over long periods of time may result in the reduction of available habitat due to aggradation in pools and other changes in channel form.

Overbank events
These higher flow events are difficult to augment with regulated water supplies and are largely driven by natural events. To augment these events would take a very large volume of water and would not be the most efficient use of the limited water resources available. That being said, it is important that these overbank events are permitted to occur. These events provide moisture for floodplain vegetation such as the culturally significant river red gum and manna gums. They also play an important role in promoting sediment deposition, carbon exchange, and organic matter supply. As a consequence, these events should not be harvested as a long-term water source.

Table 22 below details the average annual discharges and shortfalls for the prioritised flow components and all flow components under proposed and current conditions in Reach 10.

Table 22. Average annual discharges and shortfalls for prioritised flow components in Reach 10.

	Dry period low flow and dry period freshes	Dry period low flow, dry period freshes and wet period fresh	All flow components
Proposed (ML/yr)	176,803	203,498	217,451
Current (ML/yr)	173,030	173,030	173,033
Shortfalls (ML/yr)	3,773	30,468	44,419

It will be difficult to supply all the additional water requirements for the Lower Barwon River from the Leigh River and as a consequence, additional water will be required from the West Barwon Reservoir and delivered via the Barwon River system. The delivery of water to the Lower Barwon River, via the Barwon River, will also be necessary to meet the environmental water requirements of the Winchelsea Reach (Reach 9), one of the highest priorities for environmental water. Average annual discharges and shortfalls for the prioritised flow components under proposed and current conditions for Reach 9 are set out below. Attainment of all of the environmental flow component recommendations would return the flow regime in the Winchelsea Reach to within 70% of natural.

Table 23. Average annual discharges and shortfalls for prioritised flow components in Reach 9

	Dry period low flow and dry period freshes	Dry period low flow, dry period freshes and wet period fresh	All flow components
Proposed (ML/yr)	100,003	115,967	126,353 (70% of natural)
Current (ML/yr)	96,666	96,666	96,668 (54% of natural)
Shortfalls (ML/yr)	3,336	19,301	29,685

7.6 Water recovery targets

The current water regime included in the hydrologic modelling undertaken for this project has not included the 1GL of water entitlement within the West Barwon Reservoir that has been made available to the environment. The estimated additional water required to meet the priority environmental flow requirements of the Barwon River delivered via the West Barwon Reservoir are set out in Table 24. These targets have been developed using historical flow data and do not account for the impacts of future climate change.

Table 24. Additional water recovery required from West Barwon Reservoir

	Highest priority target No. 1 Dry period low flow & dry period freshes	**High priority target No. 2** Dry period low flow, dry period freshes & wet period fresh	**Priority target No. 3** All flow components
Estimated shortfalls (ML/yr)	3,336	19,301	29,685
Existing entitlement (ML/yr)	1,000	1,000	1,000
Additional water requirements (ML/yr)	2,336	18,301	28,685

Highest priority water recovery: Target No. 1

This water recovery target would enable the delivery of 100,003 ML/yr to the Barwon River (Reach 9) and would provide dry period low flows year round and dry period freshes. This would require an additional allocation of 2,336 ML/yr from the West Barwon Reservoir.

This recovery target includes low flows, providing essential habitat for aquatic fauna, moisture to instream and emergent macrophyte vegetation, and refuges for platypus, growling grass frog, fish, and macroinvertebrates. Dry period freshes will provide flushes that assist in maintaining adequate water quality and opportunity for migration of fish and other fauna between reaches. Without the provision of these flows, there may be regional extinctions, with many species unable to move to new habitats and reproduce. Resultant crowding in pools, will increase competition for food and resources.

While the provision of these flows will allow the short-term survival of these species, the continued provision of this regime will not provide opportunity for migration, breeding and long-term proliferation of species. There will be limited spawning opportunities for fish and other fauna such as the culturally significant platypus, leading to population decline over the long term. Emergent and riparian vegetation, such as the culturally significant common reed, pale rush, river red gum, and swamp wallaby grass, among others will also die-back without wet period freshes and bankfull/overbank flows.

High priority water recovery: Target No. 2

This water recovery target would enable the delivery of 115,967 ML/yr in the Barwon to provide dry period low flows year round, dry period freshes, and wet period freshes. This would require an additional allocation of 18,301 ML/yr from the West Barwon Reservoir. This recovery target would require significant adjustment to the current entitlements within the system and will not provide for all of the environmental water needs of the Barwon system.

The addition of fresh events during the wet period provide migration opportunities and cues for fish and other fauna, including culturally significant fish such as native trout and eels, and other migratory fish such as Australian smelt, common jollytail, spotted galaxias, and Australian grayling. These events also provide moisture for emergent vegetation such as the culturally significant cumbungi and common reed on banks and benches.

The lack of wet period low flows, bankfull and overbank flows will lead to the decline of riparian and floodplain vegetation such as the culturally significant river red gum, manna gum and swamp wallaby grass. Floodplain connectivity will be limited, reducing nutrient cycling, carbon exchange and organic matter supply to the stream. The reduced low flow component will also reduce transport capacity of the stream, leading to sediment accumulation and shallowing of pools. Deep pools are culturally significant and an important habitat for a number of fish and fauna.

Priority water recovery: Target No. 3
This water recovery target would enable the delivery of 126,353 ML/yr in the Barwon to provide all recommended flow components. This would require an additional allocation of 28,685 ML/yr from the West Barwon Reservoir. This recovery target would require significant adjustment to the current entitlements within the system.

This recovery target would provide the best ecological and cultural outcomes for the system but does not attempt to return the system to a pre-European flow regime. The recovery target would return the volume of water in the Barwon River to within 70% of the pre regulation flow regime. The provision of this flow regime will maintain and improve the ecological and cultural values of the system over the long term.

8 Complementary actions and critical considerations

8.1 Complementary actions

This study has identified the water requirements to achieve a set of adopted environmental and Aboriginal Cultural objectives for the Barwon River system. However, the provision of environmental water alone will not result in the attainment of the adopted objectives. This study has identified threats that require management intervention beyond the provision of water, in order to attain the adopted objectives.

These threats are discussed in Section 6. Complementary management actions that will be necessary in order to realise the benefits of additional environmental water include:

Groundwater management

Groundwater extraction can reduce flows into rivers and impact on water quality. Groundwater extractions have been and are continuing to have an impact on stream flow and water quality (including acidity - pH) in Boundary Creek. The attainment of the outcomes sought by the environmental water recommendations set out in this report will not be achieved in Boundary Creek and affected reaches of the Barwon River while these conditions persist.

At the time of writing, management of groundwater extraction impacting on Boundary Creek is the subject of investigations through the Boundary Creek remediation working group. Resolution of the groundwater and related water quality and river health impacts will need to be achieved in order to reach the outcomes sought by the provision of environmental water.

It should be noted that the environmental water requirements set out in this report have not been developed to address the water quality issues in and downstream of Boundary Creek. Additional water would be required above and beyond that set out in this report for these purposes. These water quality issues are best addressed through the management of groundwater extractions, beyond the scope of this environmental flow determination.

Water quality management

Beyond the groundwater related water quality issues outlined above, water quality issues including nutrient loads from urban stormwater and wastewater discharges will limit the ecological condition of the Upper Barwon, Yarrowee and Leigh River system.

- *Stormwater management*: Improved stormwater management in Ballarat and Geelong have the most potential for addressing stormwater pollutant loads.
- *Ballarat South Wastewater Treatment Plant releases*: There is significant potential for the installation of additional storage and treatment of wastewater from the Ballarat South Wastewater Treatment Plant to improve the quality and timing of wastewater releases. The creation of additional storage to at the Ballarat South Wastewater Treatment Plant would enable a more variable flow release pattern consistent with the recommended flow regime set out in this report, would contribute to the water recovery targets set out in this report and has the potential to improve water quality in the Barwon River system.

Riparian vegetation management

Many of the reaches assessed for this investigation had degraded riparian zones. Instream and riparian vegetation limit channel erosion processes and provide essential instream and riparian habitat for species targeted for environmental water. In the longer-term, riparian vegetation provides the source of essential large wood to the stream system. The degraded riparian corridor can be attributed to past clearing and ongoing grazing pressure. The provision of environmental water to the system should be accompanied by a program of catchment-scale riparian vegetation management. Failure to provide such riparian vegetation will limit the attainment of the objectives sought through the provision of environmental water.

Exotic species management
Increasing flow variability and instream habitat complexity will allow native fish populations to build and potentially reduce exotic fish presence in the basin. However, targeted management of exotic fish species will assist in system recovery and allow native fish species to thrive. Exotic weeds such as willows, blackberry, and reed sweet grass can influence flow and channel form, reducing suitable habitat for fish, platypus, and other fauna. Managed removal of exotic species and the revegetation of the riparian zone with native species will support the values of the system and the attainment of the objectives sought through the provision of environmental water.

Management of flow limiting infrastructure
The provision of environmental flows can be constrained by the capacity of available infrastructure to deliver water from storages (i.e. channels and gates) and flow capacity constraints in the system (e.g. weirs, levees, and bridges).

An assessment of potential flow limiting infrastructure should be undertaken to identify the extent to which existing infrastructure impacts on environmental water delivery and is capable of delivering the flow rates set out in this assessment. Works may be required to modify structures that are found to limit the delivery of environmental water.

A significant constraint includes the East Barwon River downstream of the diversion tunnel. This reach has sections with limited flow capacity as a result of willow colonisation. Delivery of the flow recommendations set out in this report will result in some unintended overbank inundation. Removal of willow alone is unlikely to address the issues in this reach. This reach will require a program of management to rehabilitate the waterway (including willow removal, channel modifications and revegetation) to enable discharge of the recommended flows in a manner that meets ecological and adjoining land use objectives.

Fish habitat and barrier management
The attainment of the fish-related objectives set out in this assessment is reliant on adequate fish passage throughout and between reaches. In recent years, fish passage has been restored through a number of techniques, including the removal of obsolete structures that limit fish migration, modification of structures (e.g. culverts) and construction of fishways on structures (e.g. weirs and dams) that have an ongoing function. Marsden *et al.* (2016) reviewed barriers to upstream fish passage within the Barwon River system including prioritisation of major barriers and providing recommendations to address fish passage in the catchment, including environmental flow considerations. Removal or modification of fish barriers to enable fish movement through the Barwon River system will be required.

Monitoring and evaluation:
This study has been undertaken based on the best available science for the Upper Barwon, Yarrowee and Leigh system. The science underpinning environmental water management will continue to evolve with more monitoring, research, and management experience. The provision of environmental water to the system should be accompanied by a monitoring and evaluation program that contributes to the understanding of the system and the delivery and outcomes from the provision of environmental water. This program may need to extend beyond the state-wide environmental flow assessment and monitoring program.

8.2 Critical considerations in the provision of environmental water

Flow through Geelong

This environmental flow study has sought to identify the water requirements to meet environmental and Aboriginal Cultural objectives in the Barwon River system. The recommendations have not been based on water requirements to meet urban social and liveability objectives in major regional centres such as Geelong. Additional water may be required to meet water quality expectations in the Barwon River through Geelong, to support recreational activities and amenity. A separate social and urban liveability investigation would be required to identify the water requirements to meet these objectives.

Existing alternate water sources

The environmental water recovery targets set out in this report are reliant on the ongoing supply of water from the Leigh River (including the Ballarat South Wastewater Treatment Plant) and from both the Moorabool River and discharges from Batesford Quarry. Loss of input from these sources would increase the volume of additional water required to meet environmental water requirements.

There are pressures on water utilities across Victoria over the management of wastewater discharges to waterways. These pressures include concerns over water quality and pressure for the consumptive reuse of water. The Ballarat South Wastewater Treatment Plant currently provides water to the Barwon River system via the Leigh River. However, the timing of the current discharges does not reflect that required to meet environmental flow requirements. Further, it was not within the scope of this study to investigate the extent of any water quality issues associated with the current releases. With appropriate flow modification and water quality management, the Ballarat South Wastewater Treatment Plant discharges can play an important role in the long-term supply of environmental water to the Barwon River system. Additional investigations would be required to develop options for water quality treatment and modifications to the discharge regime to enable the Ballarat South Wastewater Treatment Plant discharges to meet environmental water requirements.

As set out above, discharges from the Batesford Quarry provide water to the Barwon River system. The long-term supply of water to the Lower Barwon River, via discharges from the Batesford Quarry, is not guaranteed. Further work will be required to identify the implications of any cessation to the Batesford Quarry discharges on the flow regime in the Barwon River. Cessation of discharges from Batesford Quarry may increase the water required to meet environmental and other instream uses.

Impacts on water availability

Activities on the land upstream, surrounding or adjacent to waterways such as the installation of farm dams and plantation forestry, can have a significant impact on waterway condition through changed water regimes, erosion or water quality impacts from salinity, sediment and nutrient run-off.

The hydrology of the Barwon River systems has been modified by the presence of small catchment dams that capture surface runoff and change evaporation and groundwater seepage. These small catchment dams (also referred to as farm dams, hillside dams or runoff dams) reduce the volume of surface runoff that might otherwise become streamflow in a basin. Small catchment dams are estimated to capture approximately 16% of total inflows to the Barwon basin, with an estimated total capacity of 34,600 ML (DELWP, 2017). Assessment of the impact of these catchment dams is being undertaken as part of the Long Term Water Resource Assessment (LTWRA). Ongoing farm dam construction has the potential to have ongoing and increasing impacts on catchment hydrology and the availability of water for the environment.

Plantation forestry activities also have the potential to impact on the quality and availability of water for the environment and downstream users. This investigation has not sought to identify the extent of any proposed additional or extended plantation forestry operations within the catchment. Further work will be required to identify the implications of any future plantation forestry operations on the availability of water for the environment in the Barwon River system.

Use of environmental water to manage acid events
As set out above, groundwater extractions are having an adverse impact on water quality (including pH) and waterway health in Boundary Creek and some reaches of the Barwon River. The environmental water recommendations contained in this report have not been developed to address the pH issues in Boundary Creek or impacted reaches of the Barwon River. Attempts to address the water quality issues via dilution would require significantly greater water volumes than those set out in this report. As previously discussed, the remediation of Boundary Creek and Big Swamp has been highlighted as a community priority and will be best addressed by managing groundwater levels within the areas of acid sulphate soils. We don't support the use of limited environmental water entitlements to address water quality problems arising from consumptive groundwater extractions in the Barwon River system.

The value of water to the environment and society
Provision of water for the environment and for cultural and social needs requires a trade-off with consumptive water uses and or available budgets. An economic evaluation can assist to identify the scale of environmental water recovery and/or investment appropriate to the Barwon River system. Such an evaluation could assist to identify the value of existing additional water supplies to the Barwon River (e.g. Ballarat South Wastewater Treatment Plant, Batesford Quarry), would provide insights into an appropriate trade-off or investment in environmental water, and may assist to resolve such trade-offs. Such an evaluation could also assist to quantify the impacts of cease-to-flow events on amenity and recreation through Geelong.

Integrated instream (environmental, social and cultural) water management

This environmental flow investigation has identified the environmental and Aboriginal Cultural water requirements for the Barwon River system. The investigation has also identified

- priorities for the provision of environmental water
- complementary actions necessary to achieve the desired environmental outcomes
- critical considerations in the provision of environmental water

An opportunity exists to integrate the outcomes of this study and these other outcomes (complementary actions and critical considerations) to develop a long-term instream /non-consumptive (environmental, social and cultural) watering strategy for the Barwon River system. The development of such a strategy would explore the alternate options for the provision of non-consumptive water in and to the Barwon system and identify a preferred arrangement of water entitlements, policy and works that meets societal expectations.

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Appendix A:

Clan-territories of the Wathaurung-tribe

Appendix A: Clan territories of the Wathaurung tribe

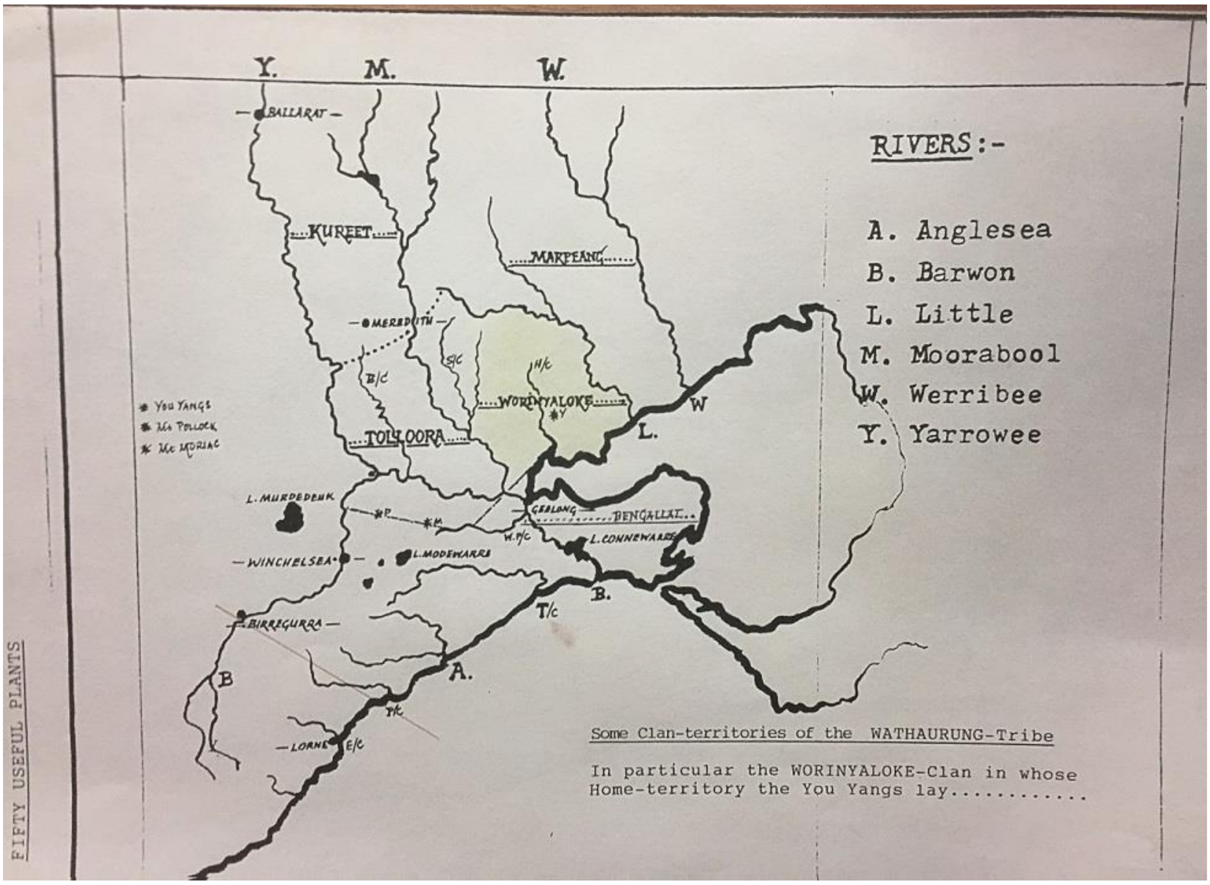


Figure 28. *Clan-territories of the Wathaurung-tribe*

Appendix B:

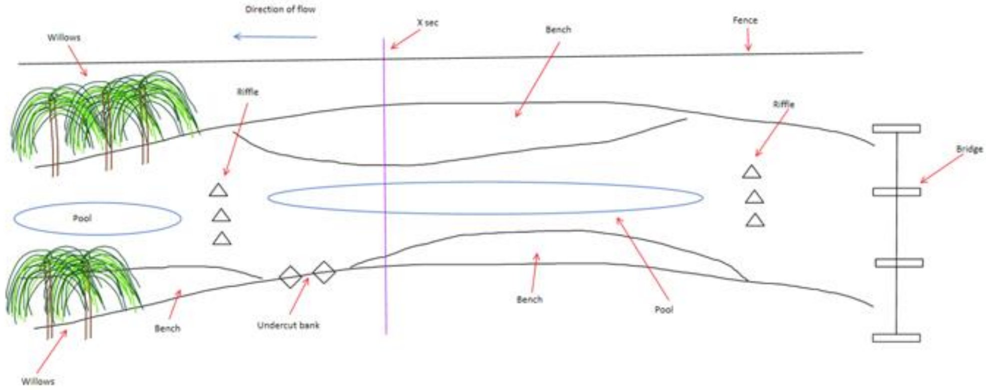
Site location summaries and detailed map

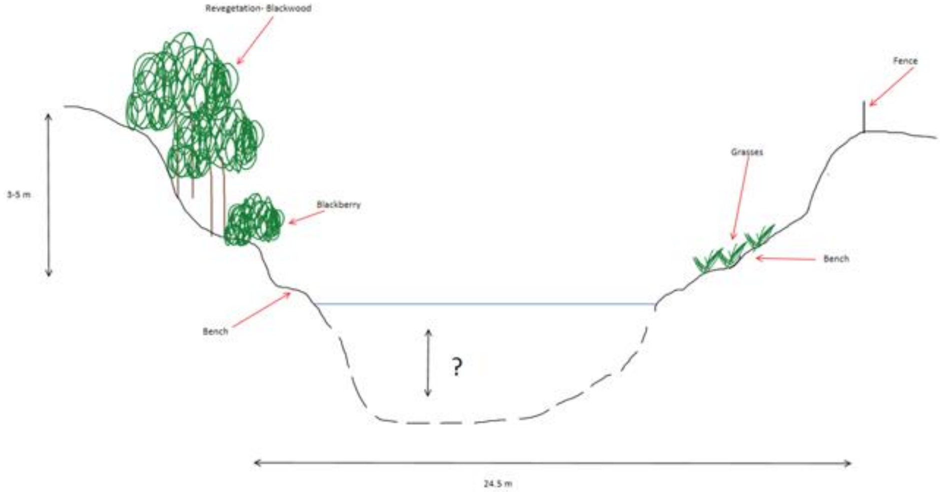
Appendix B: Site location summaries and detailed map

A selection of photos and field sketches from site visits are provided below, with a detailed map of study reaches, field site locations and flow gauges also provided.

Reach No.	1
Reach name	Yarrowee River
Site inspection location # 1	*Longitude*: 143.834397 *Latitude*: -37.664818 Leigh River at Nolans Road Crossing
Photo	

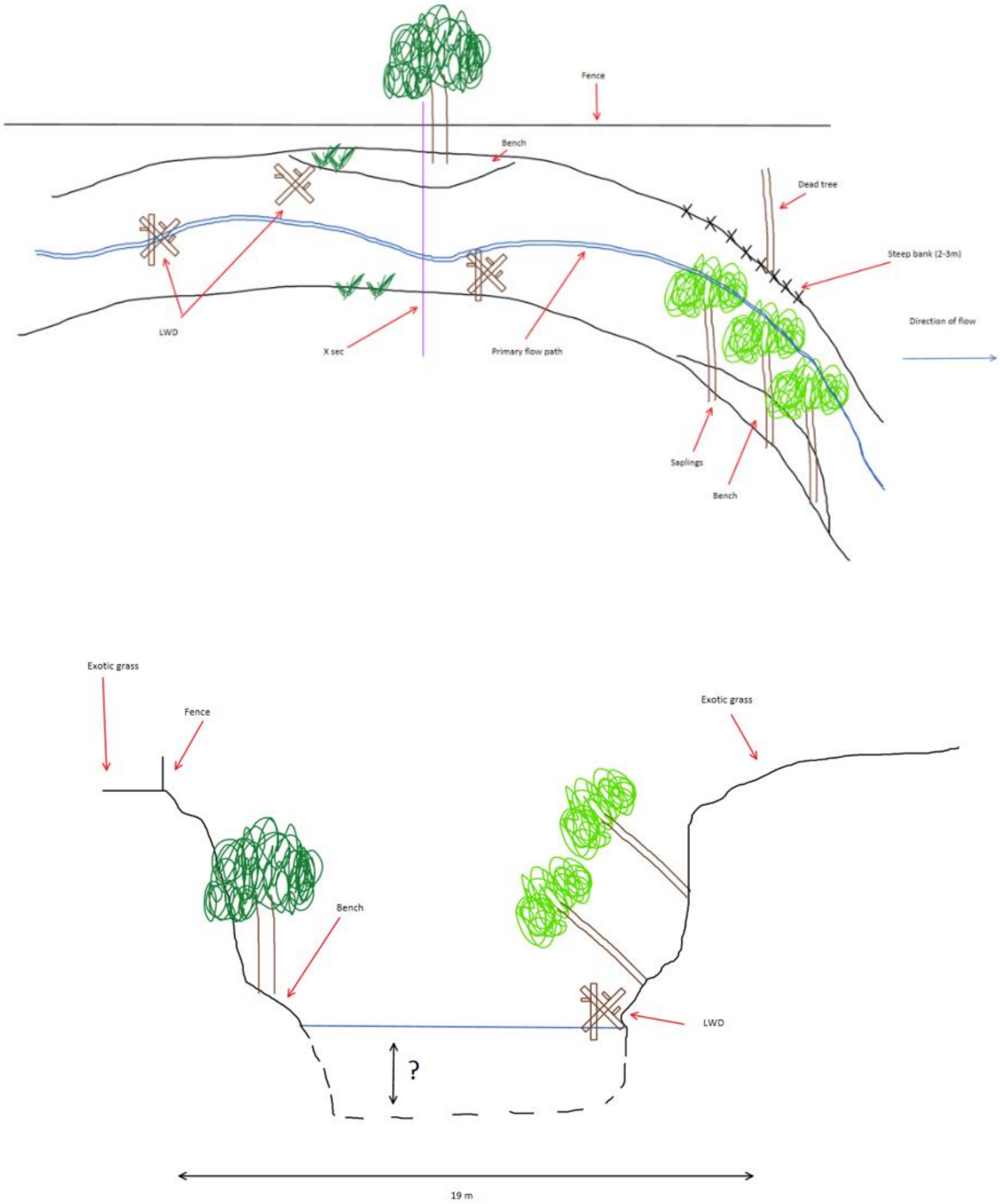
Planform and cross-section field sketch





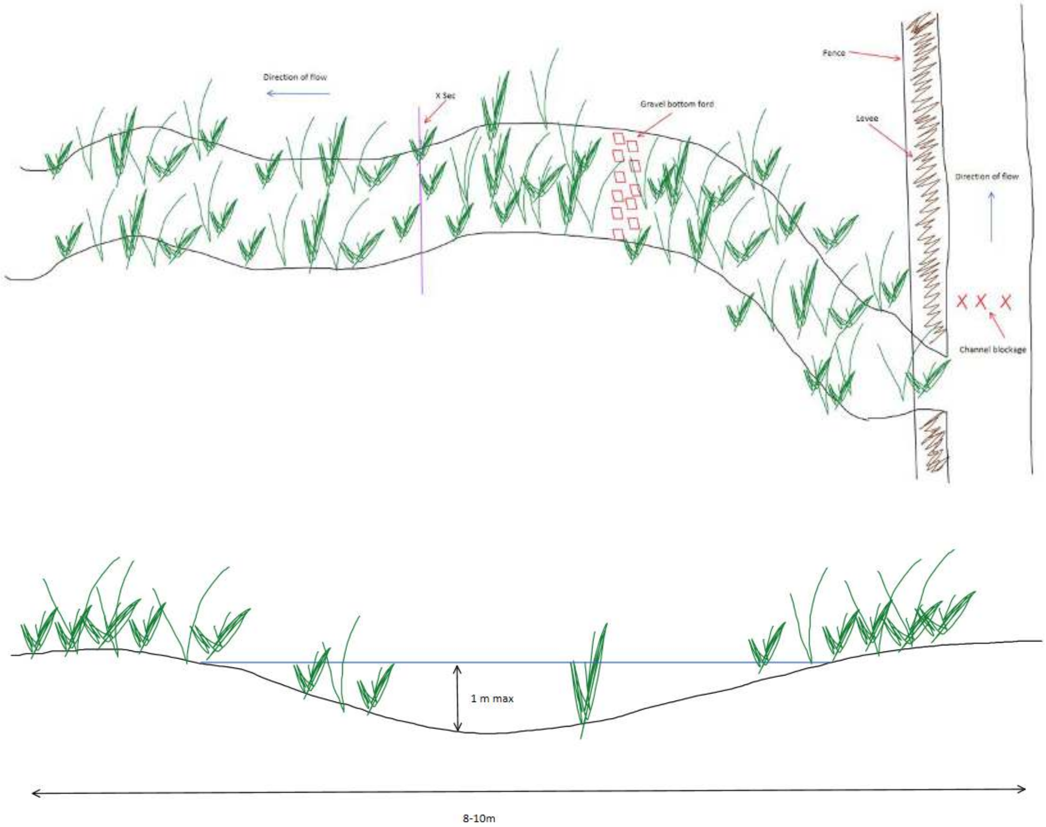
Reach no.	2
Reach name	Leigh River
Site inspection location #1	*Longitude*: 144.008575 *Latitude*: -38.067320 Lower Leigh off Inverleigh-Shelford Road, Inverleigh.
Photo	 

Planform and cross-section field sketch



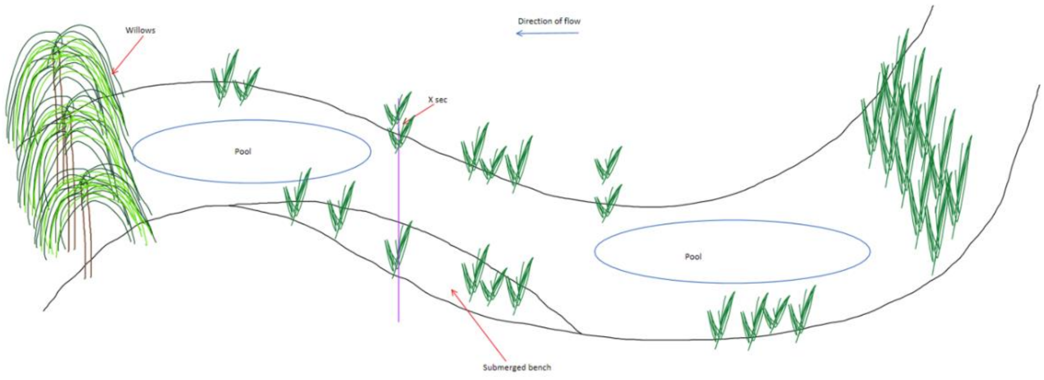
Reach no.	3
Reach name	Upper Barwon West (upstream of Boundary Creek)
Site inspection location	*Longitude*: 143.737296 *Latitude*: - 38.426026 Gerangamete Flats Upstream of Boundary Creek confluence
Photo	 

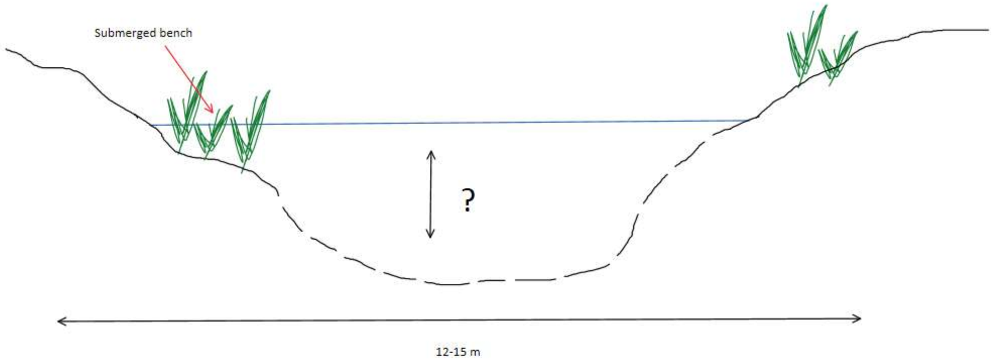
Planform and cross-section field sketch



Reach no.	4
Reach name	Upper Barwon East
Site inspection location	*Longitude*: 143.740525 *Latitude*: - 38.474248 Barwon River East Branch on Railway Reserve Downstream of Birregurra-Forrest Road after Seven Bridges Road heading Towards Barwon Downs
Photo	 

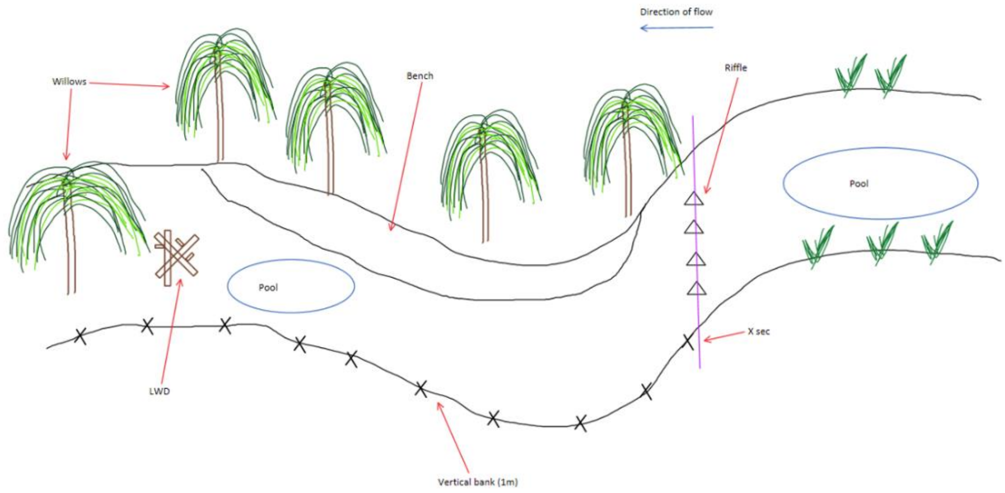
Planform and cross-section field sketch

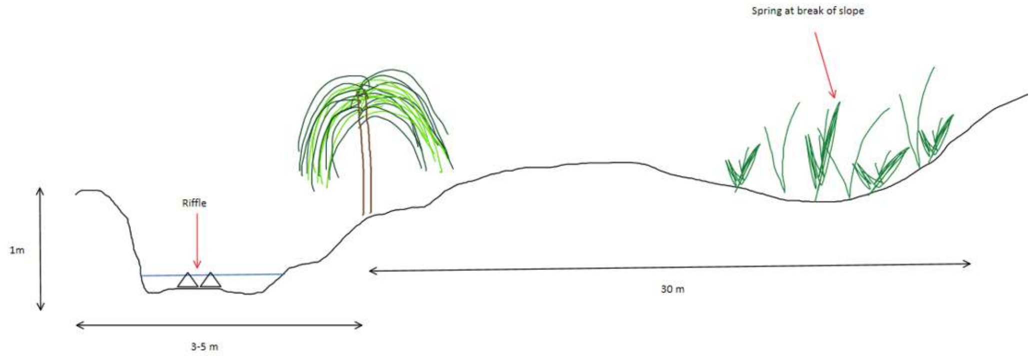




Reach no.	5
Reach name	Dewing Creek
Site inspection location	*Longitude*: 143.762685 *Latitude*: - 38.457104 Upstream of Road Crossing on Callahans Lane heading Towards Callahans Road from Birregurra-Forrest Road.
Photo	 

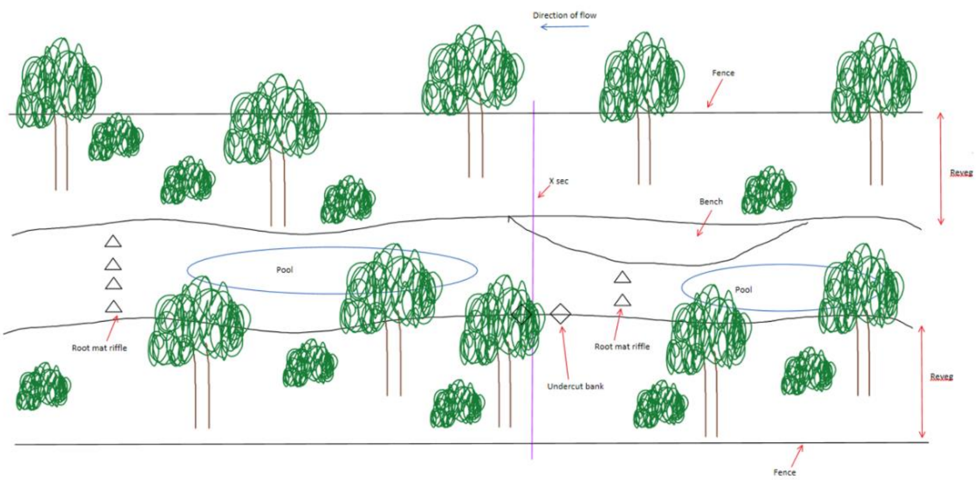
Planform and cross-section field sketch

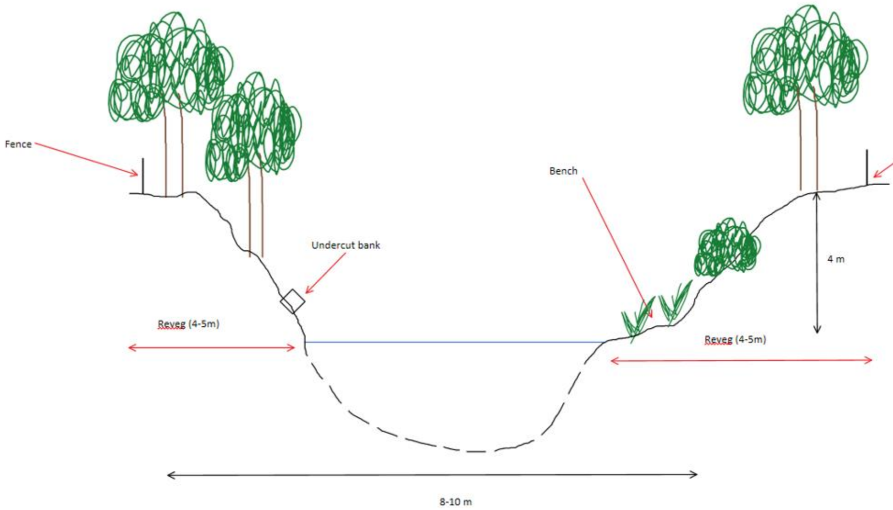




Reach no.	6
Reach name	Boundary Creek
Site inspection location	*Longitude*: 143.730806 *Latitude*: - 38.421111 Gerangamete Flats – either side of main track. Upstream of Barwon River confluence.
Photo	 

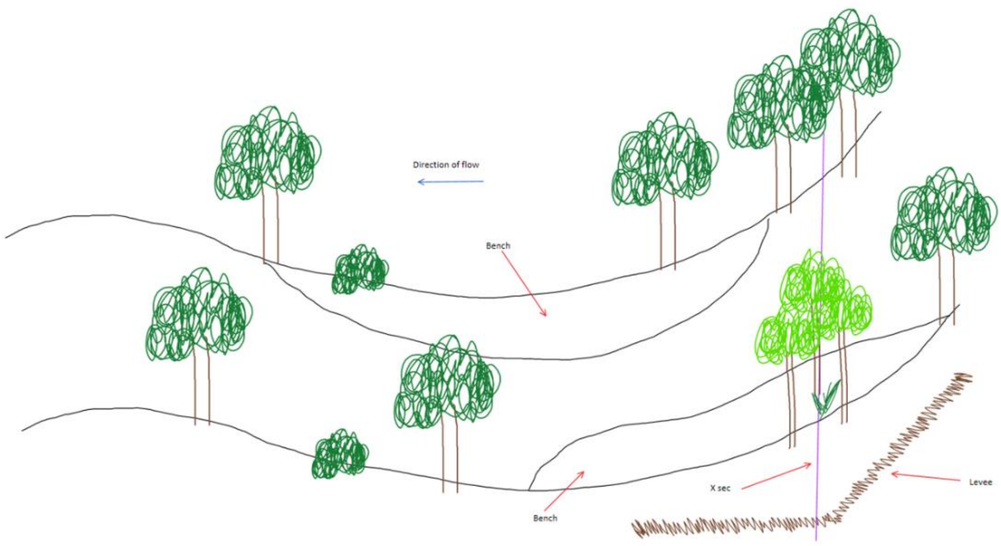
Planform and cross-section field sketch

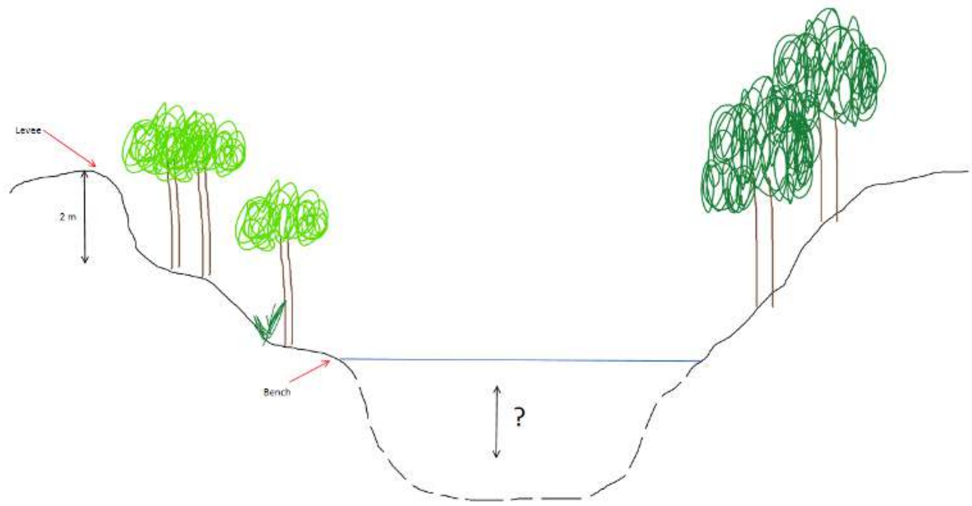




Reach no.	7
Reach name	Barwon (downstream of Boundary Creek)
Site inspection location	*Longitude*: 143.790207 *Latitude*: - 38.341086 Off Barwon St, Birregurra, adjacent Public park from 100 upstream of Road crossing with Birregurra-Deans Marsh Rd, to Golf Course
Photo	 

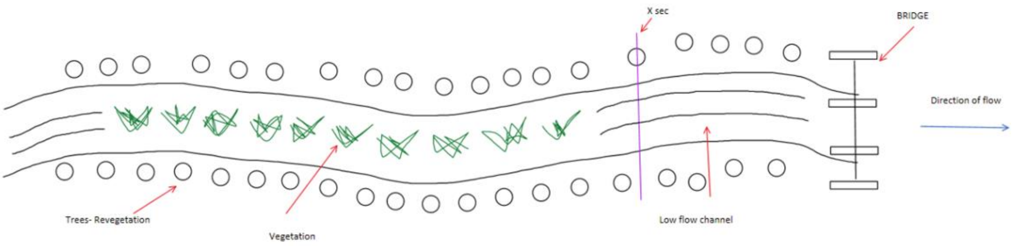
Planform and cross-section field sketch

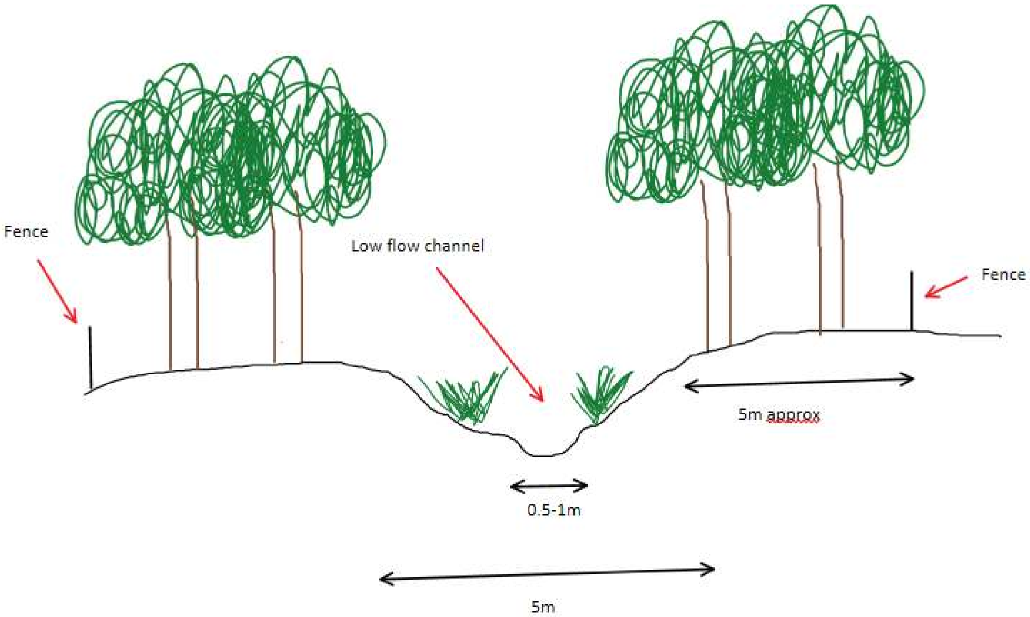




Reach no.	8
Reach name	Pennyroyal and Deans Marsh Creeks
Site inspectio n location	*Longitude*: 143.857011 *Latitude*: - 38.396867 Pennyroyal Creek, Birregurra-Deans Marsh Road, Deans Marsh Upstream of Road Crossing Just past Bushs Road heading towards Deans Marsh.
Photo	 

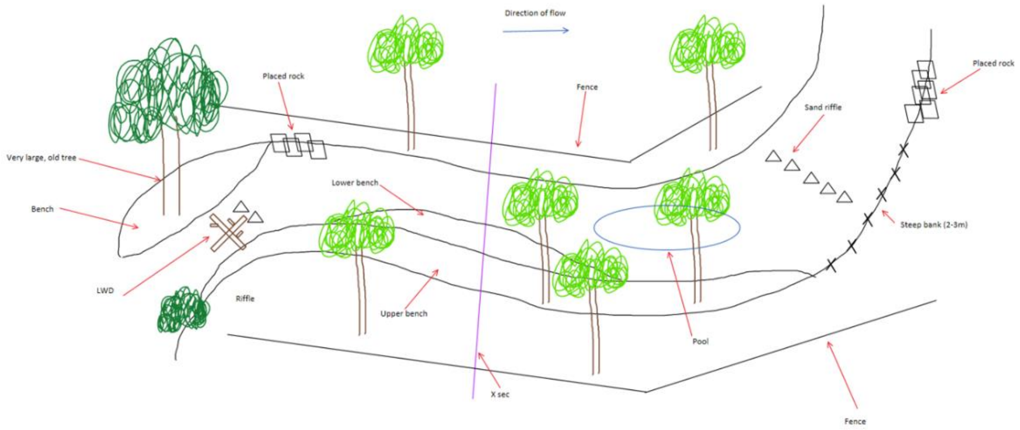
Planform and cross-section field sketch

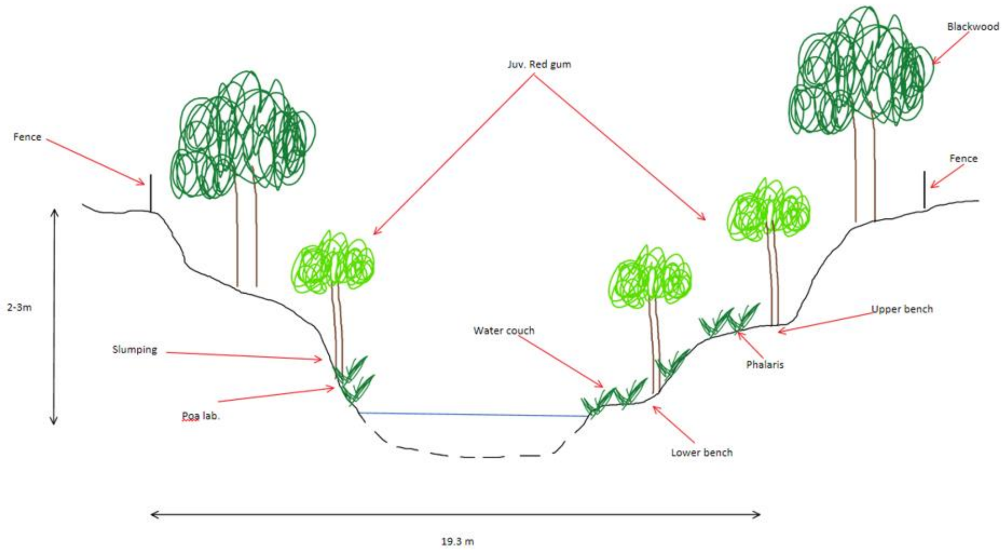




Reach no.	9
Reach name	Winchelsea
Site inspection location	*Longitude*: 143.937455 *Latitude*: - 38.300157 Kildean Road Public Reserve (same as 2005/06 Site).
Photo	 

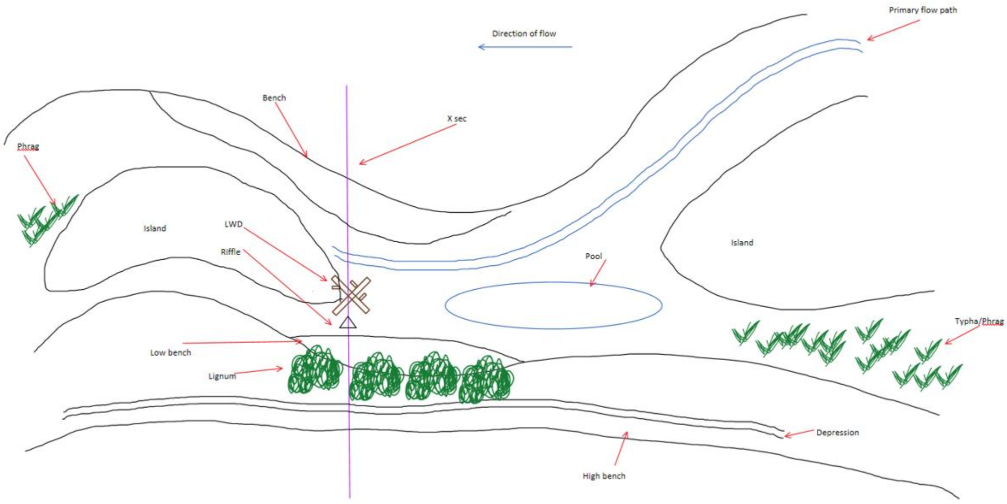
Planform and cross-section field sketch

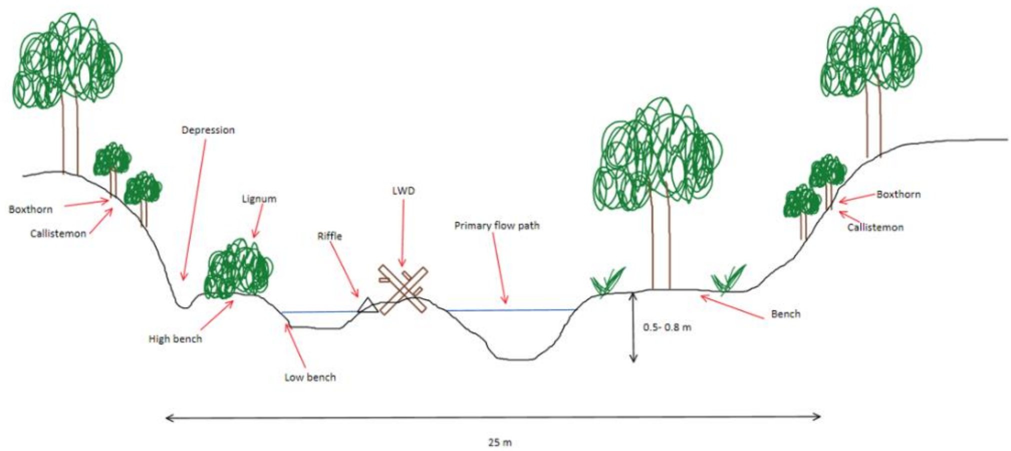


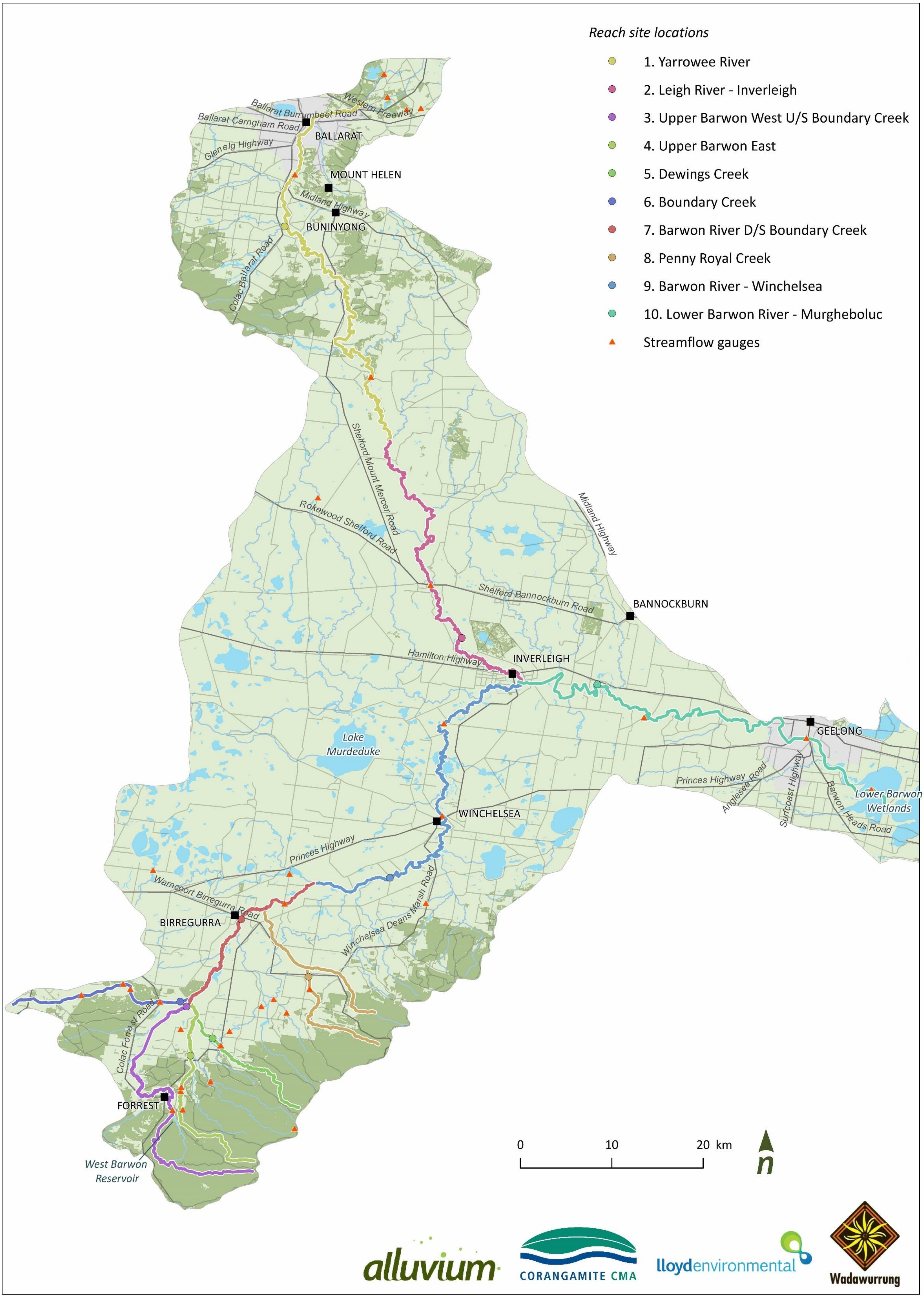


Reach no.	10
Reach name	Lower Barwon
Site inspection location # 1	*Longitude*: 144.141017 *Latitude*: - 38.111035 Murgheboluc - Track adjacent a bluestone house (same site as 2005/06 assessment). Access via public track shared by the adjoining landowners.
Photo	 

Planform and cross-section field sketch






Reach site locations
1. Yarrowee River
2. Leigh River - Inverleigh
3. Upper Barwon West U/S Boundary Creek
4. Upper Barwon East
5. Dewings Creek
6. Boundary Creek
7. Barwon River D/S Boundary Creek
8. Penny Royal Creek
9. Barwon River - Winchelsea
10. Lower Barwon River - Murgheboluc
Streamflow gauges
BALLARAT
MOUNT HELEN
BUNINYONG
BANNOCKBURN
INVERLEIGH
GEELONG
WINCHELSEA
BIRREGURRA
FORREST
Lake Murdeduke
Lower Barwon Wetlands
West Barwon Reservoir
Western Freeway
Ballarat Burrumbeet Road
Ballarat Carngham Road
Glenelg Highway
Midland Highway
Colac Ballarat Road
Shelford Mount Mercer Road
Rokewood Shelford Road
Shelford Bannockburn Road
Hamilton Highway
Princes Highway
Anglesea Road
Surfcoast Highway
Barwon Heads Road
Warncoort Birregurra Road
Winchelsea Deans Marsh Road
Colac Forrest Road
0
10
20 km
n

Appendix C:

Hydrology – detailed information

Appendix C: Hydrology – detailed information

Methodology

The most recent and relevant water resource model available for the Barwon system (noting that there are models currently in development) is the Barwon-Moorabool REALM Model which runs at a weekly time step from January 1927 to June 2004 (GHD, 2011). The model includes representation of separate private diverter demands, farm dam and stock and domestic dam impacts, as well as the impact of groundwater pumping from Boundary Creek. It also represents the operation of West Barwon Reservoir and diversions to the Wurdee Boluc inlet channel via the tunnel system and smaller transfers throughout the system.

As part of this FLOWS study, the project team, in discussion with Corangamite CMA, Barwon Water, and DELWP, considered a variety of options for representing daily flows at current and natural level of development. There is considerable debate about the advantages and disadvantages of different hydrological modelling platforms and approaches and the 'cost-benefit' of increased model complexity. As such, this project builds on the existing representation of river operations and system demands using outputs from the existing weekly REALM model and uses the eWater Source software to develop a catchment model which represents hydrological response based on climate and land use. Daily gridded (5km) rainfall and evapotranspiration data between January 1927 and June 2018 was accessed from Queensland Government's SILO (Scientific Information for Land Owners) database. Land Use data, updated in 2016 in the Barwon catchment, was accessed from the Victorian Land Use Information System (VLUIS) database. The Land Use dataset was divided into 16 functional units which groups similar land use types based on the hydrological response.

A geographical representation of the system was developed using digital elevation model (DEM) data at a 20m resolution, resulting in a node-link network across 123 sub-catchments (see Figure 29). Releases from West Barwon Reservoir and private diverter extractions and transfers to the Wurdee Boluc inlet channel were derived from the 2011 weekly REALM model, disaggregated to a daily time step uniformly and extended to June 2018 using a combination of repeating annual patterns, or regressions with climate data. The model parameters were calibrated to historic streamflow records in two sections, gauge 233224 for the southern part of the model, and gauge 233215 for the north. The model was further validated using six streamflow gauges within the catchment, as well as being compared with the previous natural and current time series from the 2006 FLOWS study.

On the whole, the method used to model daily streamflow was considered fit for purpose, with the exception of Reach 6: Boundary Creek. It is widely acknowledged that Boundary Creek is a complex system, with strong influences from changing water table levels and groundwater extractions. Detailed modelling is currently being undertaken for this catchment, and as such gauged data was used to represent current flow for Reach 6 to inform environmental flow recommendations for this reach. The analysis was therefore undertaken over the period of record for gauge 223228, March 1985 to June 2018.

Figure 29. *Overview of the Source catchments model developed for the Barwon system*

Calibration and validation results

The rainfall-runoff model, SIMHYD, was used to simulate the runoff response across the Barwon catchment. The flow calibration tool within Source was used to obtain acceptable model parameterisation at two gauges; 233224 and 233215 (Figure 29). The model hydrological performance was assessed using the Moriasi *et al.* (2007) categorisation (Table 25) for the following statistical measures:

- Nash-Sutcliffe efficiency (NSE) coefficient
- Percent Bias (PBIAS)
- Root Mean Square Error (RMSE) to observed data standard deviation ratio (RSR).

Table 25. Performance ratings for model statistics for a monthly streamflow (adapted from Moriasi *et al.*, 2007)

Performance indicator	PBIAS (Stream flow)	NSE	RSR
Very good	PBIAS < ±10	0.75 < NSE ≤ 1	0 ≤ RSR ≤ 0.5
Good	±10 ≤ PBIAS < ±15	0.65 < NSE ≤ 0.75	0.5 < RSR ≤ 0.6
Satisfactory	±15 ≤ PBIAS < ±25	0.5 < NSE ≤ 0.65	0.6 < RSR ≤ 0.7
Unsatisfactory	PBIAS ≥ ±25	NSE ≤ 0.5	RSR > 0.7

An assessment of the monthly PBIAS, NSE, and RSR values against the performance ratings show that the hydrological parameterisation performance for the 2018 Source model is rated good to very good across most of the calibration and validation regions for the three optimisation criteria (Table 26). This indicates that the Barwon model is capturing the monthly variation in observed streamflow data well.

However, two upper tributary gauges (233228; 233258) did not perform well, either in the 2018 Source model or the 2006 REALM model. This is likely due to upper tributaries often not being well represented by regional model parameters due to steeper terrain, altering the rainfall-runoff processes. The validation of these gauges would likely be improved with targeted calibration for these reaches. Nevertheless, the remaining gauges on the main reaches of the Barwon and Leigh River all performed well and therefore the calibration is still fit for purpose. Additionally, based on the hydrological statistics, monthly and annual plots (Figure 30 to Figure 33), the 2018 Source model is able to capture observed streamflow processes better than the 2006 REALM model. As discussed above, gauged data was used to represent current conditions for Reach 6.

Table 26. Statistical hydrology calibration and validation results (colours relate to Moriasi acceptance criteria outlined in Table 25)

Gauge	Reach number and name (calibration or validation)	2018 Source model			2006 REALM model		
		PBIAS	NSE	RSR	PBIAS	NSE	RSR
233215	1. Yarrowee (calibration)	-0.02	0.77	0.48	-34.13	0.71	0.54
233228	6. Boundary Creek (validation)	-51.3	0.12	0.93	-24.88	0.45	0.74
233224	7. Barwon River d/s Boundary Creek (calibration)	9.2	0.85	0.39	Not included		
233258	8. Pennyroyal Creek (validation)	-84.77	0.24	0.87	Not included		
233201	9. Barwon River – Winchelsea (validation)	-18.02	0.82	0.42	-104.8	-9.86	3.29
233200	10. Lower Barwon River – Murgheboluc (validation)	18.73	0.78	0.46	-36.7	-0.88	1.37

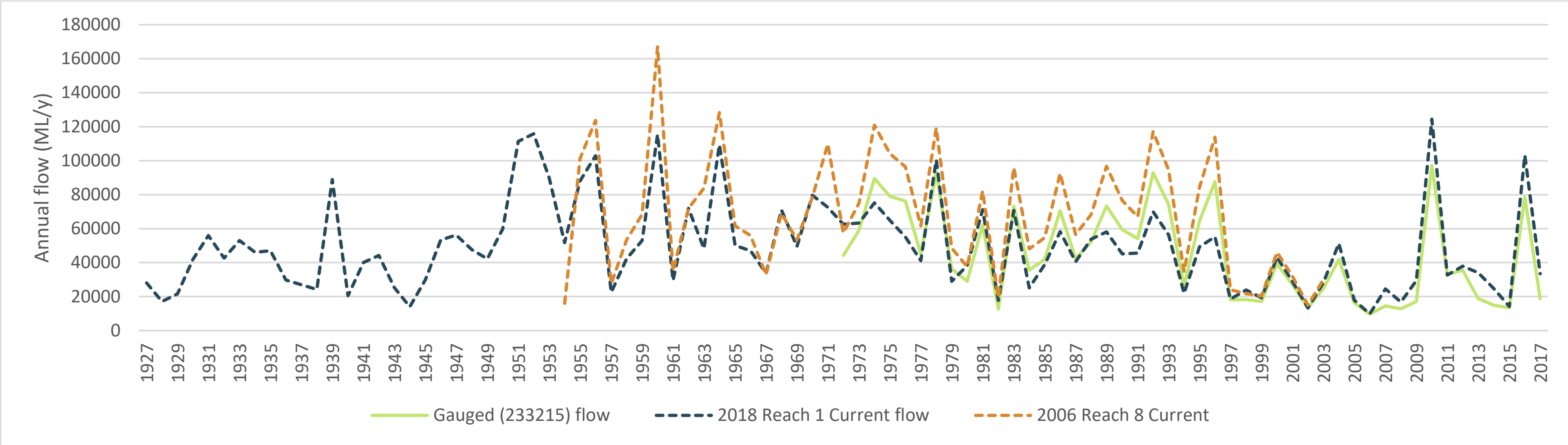


Figure 30. *Annual streamflow comparison for Reach 1 Yarrowee River*

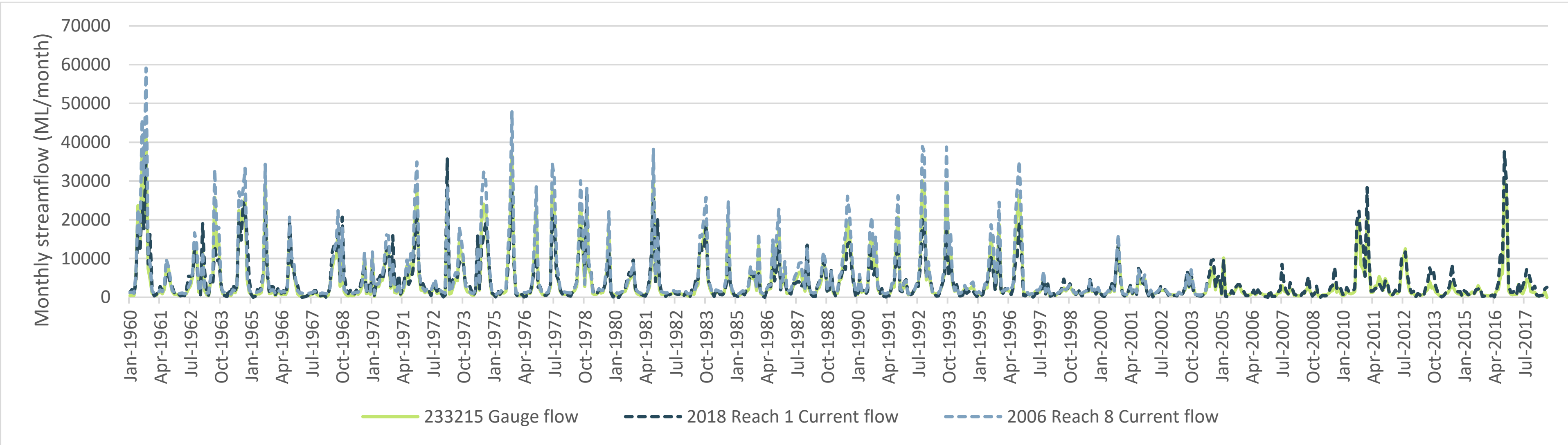


Figure 31. *Monthly streamflow comparison for Reach 1 Yarrowee River*

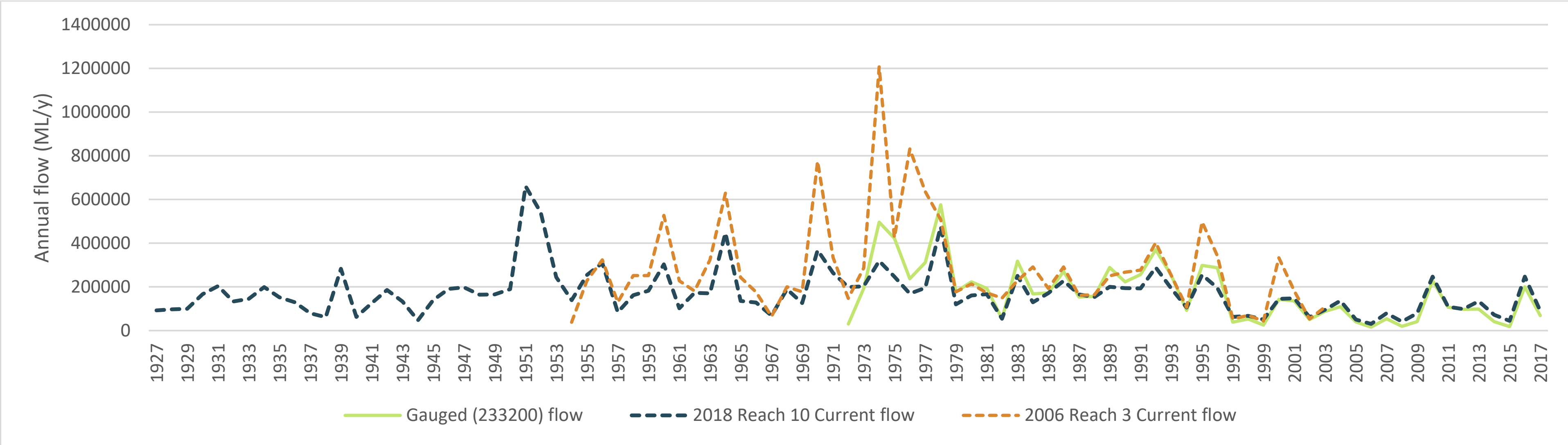


Figure 32. *Annual streamflow comparison for 2018 Reach 10 – Lower Barwon River (Murgheboluc)*

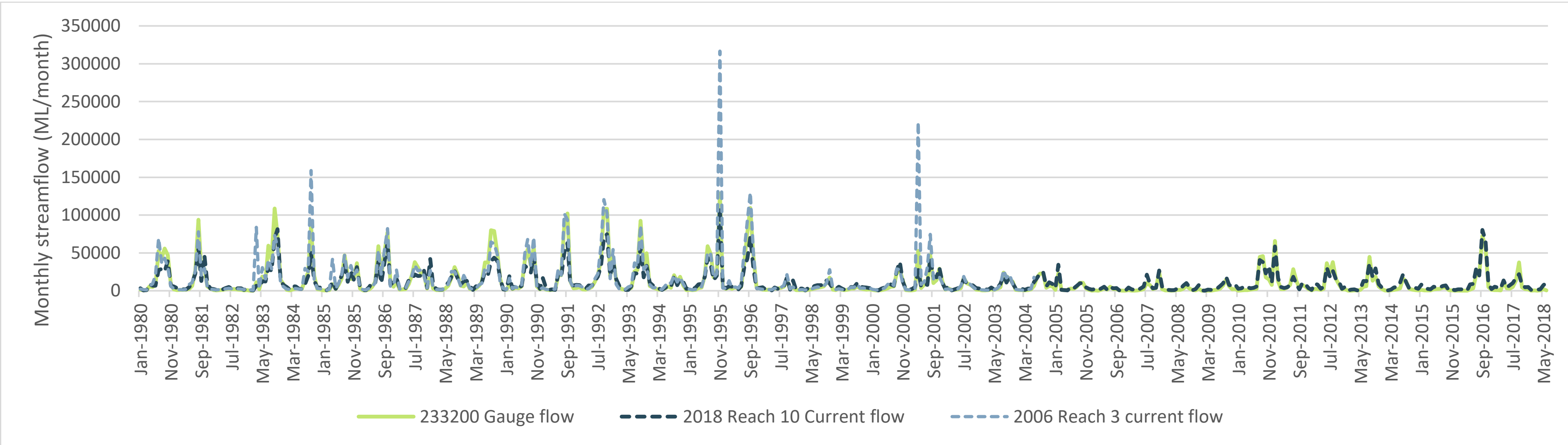


Figure 33. *Monthly streamflow comparison for 2018 Reach 10 - Lower Barwon River (Murgheboluc)*

Modelling results

Low flow and storm event separation

Many standard hydrological analysis tools perform calculations on data sets that contain both low flow and higher flow data. Environmental flow assessment involves assembling a regime from various hydrological events (low flows and various higher flow events) that are meant to mimic the characteristics of those events as they exist in the natural system. Thus, it is important to separate low flows from higher flows.

Low flow (also known as base flow) is defined as water which enters a stream or river from persistent, slowly varying sources, maintaining streamflow between rainfall events, which contrasts with water that enters a stream or river rapidly, called storm flow, quickflow or event flow. Pyrce (2004) and Hughes *et al.* (2002) recommended the use of continuous low flow separation procedures in environmental flow assessments. Nathan and McMahon (1990) suggested that a Lyne and Hollick (1979) recursive digital filter was a fast and objective method of continuous low flow separation. Various tools have been created to support the low flow separation process, including the eWater toolkit River Analysis Package (RAP), which has been used for this study.

Flow event statistics

The primary hydrological characteristics of interest when considering flow-dependent ecological and geomorphological processes are:

- Magnitude
- Frequency
- Duration
- Timing
- Rate of change

These are the primary flow characteristics because they translate directly to specifications for an environmental flow regime, and they allow estimation of the volume of water required for allocation to the environment.

Cease-to-flow duration was analysed using the River Analysis Package (RAP) – or 'spells analysis' – for spell duration below a threshold of 0.01 ML/d. Spells were assumed independent if separated by more than 7 days. Low flows were analysed for low flow separated from the flow records on the basis of the digital baseflow filter using an alpha value of 0.925.

Rates of rise and fall need to be specified for any storm events (freshes and floods) recommended in an environmental flow regime. The rates of rise of individual stormflow events are largely determined by the initial event rainfall intensity. The rates of fall (recession) depend on the pattern of ongoing rainfall and the physical characteristics of the catchment and stream. For streams in the Barwon River catchment, the natural rate of rise is typically rapid, with the major peak in the stream level normally reached within 1 – 2 days of the onset of the rainfall event. Recession rates are typically lower, with the initially high rate of decline decaying slowly for an extended period after rainfall ceases.

Ecologically, the limiting aspect of the rate of discharge change is the peak rate of change. On the rising limb of an event, some biota need to seek out sites of refuge, and on the falling limb, some biota need to avoid being stranded. The analysis of the rate of rise and fall was not undertaken as part of this study given previous analysis available to inform the flow recommendations.

Annual Discharge

Annual discharge in the Barwon River increases in a predictable way with catchment area (Figure 34). As expected, there is a consistent reduction in mean annual flows for current conditions compared with natural conditions (Table 27).

Although urbanisation has increased, particularly around Ballarat (Reach 1), the modelling results showed an overall decrease in flow in this region for current level of development compared with unimpacted conditions. Examination of the model results showed that urbanised areas generated higher flows under current conditions, as is to be expected with increased imperviousness. The decrease in overall flow in this reach was found to be a result of reduced runoff in agricultural areas which appeared to be far more significant in influencing flow in Reach 1. This could be the result of farm dams and/or changed low flow behaviour.

NB: Detailed modelling is currently being undertaken for the Boundary Creek (Reach 6) catchment, and as such gauged data (1985 to 2018) was used to represent current flow and to inform environmental flow recommendations for this reach.

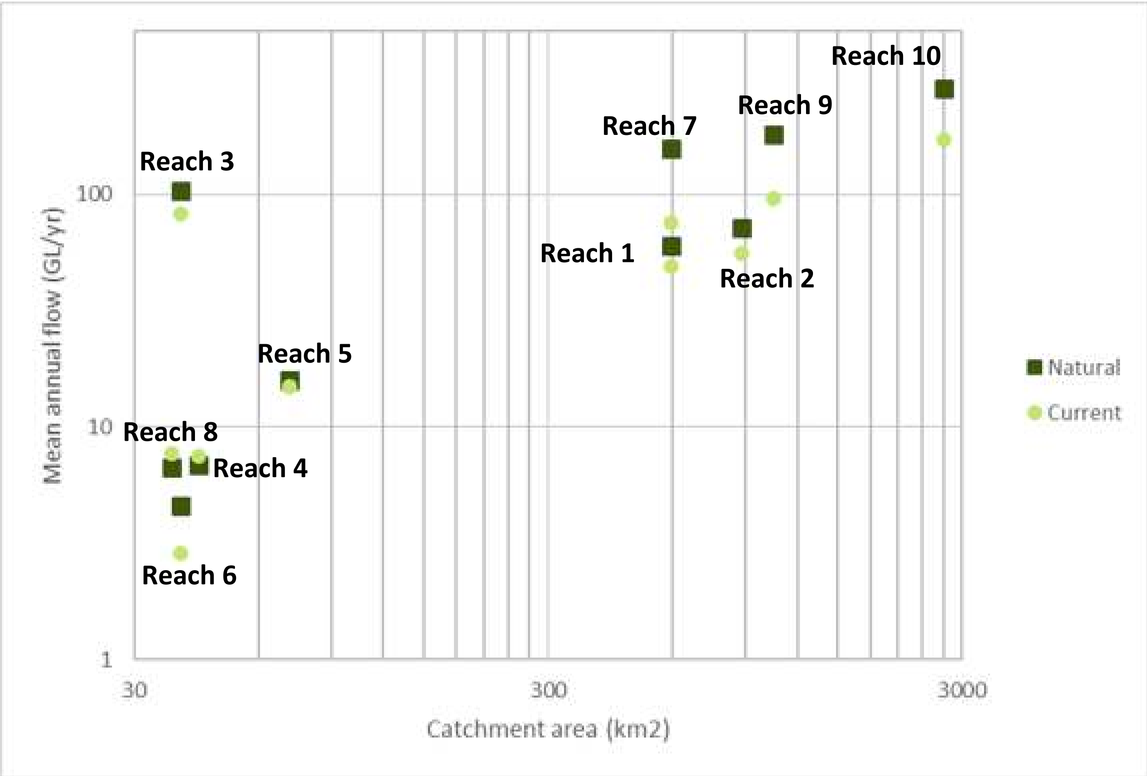


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Figure 34. *Mean annual flow as a function of catchment for natural and current levels of development*

Table 27. Comparison of estimated mean annual flows under natural and current conditions

Reach		Catchment area (km²)	Natural (GL/y)	Current (GL/y)	Percentage change	2006 change
1	Yarrowee River	593	60	49	-19%	-6%
2	Leigh River Inverleigh	881	71	55	-22%	-9%
3	Upper Barwon West U/S Boundary Creek	39	103	83	-20%	
4	Upper Barwon East	43	7	7	8%	
5	Dewing Creek	71	16	15	-6%	
6	Boundary Creek	39	4	3[8]	-30%	-21%
7	Barwon River D/S Boundary Creek	593	157	75	-52%	-9%
8	Pennyroyal Creek	37	7	8	14%	
9	Barwon River - Winchelsea	1052	179	96	-46%	-0.4%
10	Lower Barwon River - Murgheboluc	2713	285	172	-40%	-3%

Flow variability

Flow duration curves are used to summarise the entire flow distribution and can indicate the range of flows that are impacted by land and water resource development. They do not, however, allow examination of the extremes of low flows and higher flows or indicate seasonal impacts.

Figure 35 below shows that regulation and land use change has reduced the entire range of flows immediately downstream of West Barwon Dam and Boundary Creek (Reaches 7, 9 and 10) while development has increased low and moderate flows while reducing the proportion of time of higher flows for in the northern part of the catchment (Reaches 1 and 2). The impacts are more subdued at the other sites except for very low flows which will be discussed in more detail below. These results are reasonably consistent with the findings of the 2006 study.

[8] Detailed modelling is currently being undertaken for the Boundary Creek (Reach 6) catchment, and as such gauged data (1985 to 2018) was used to represent current flow to inform environmental flow recommendations for this reach.

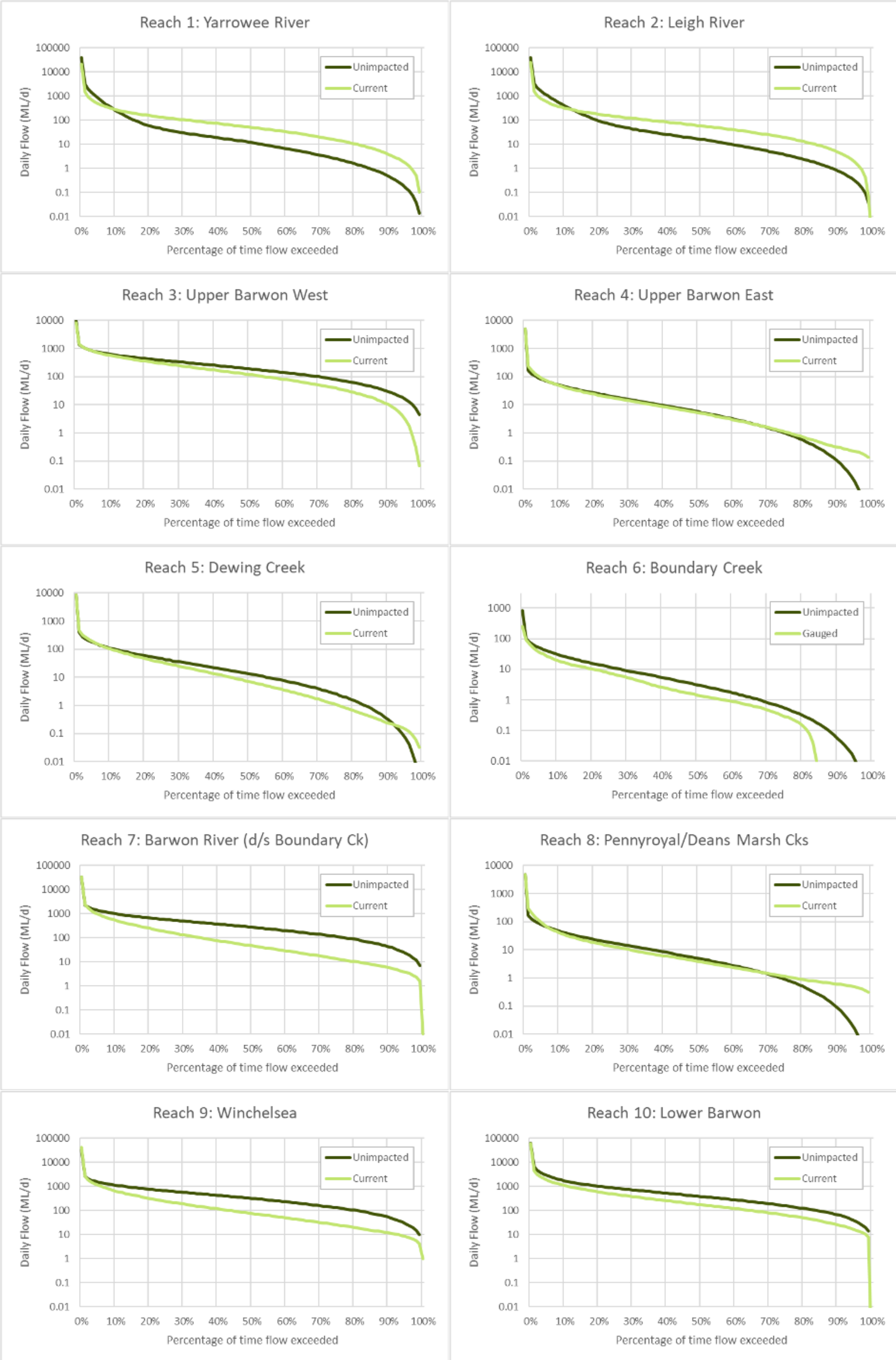
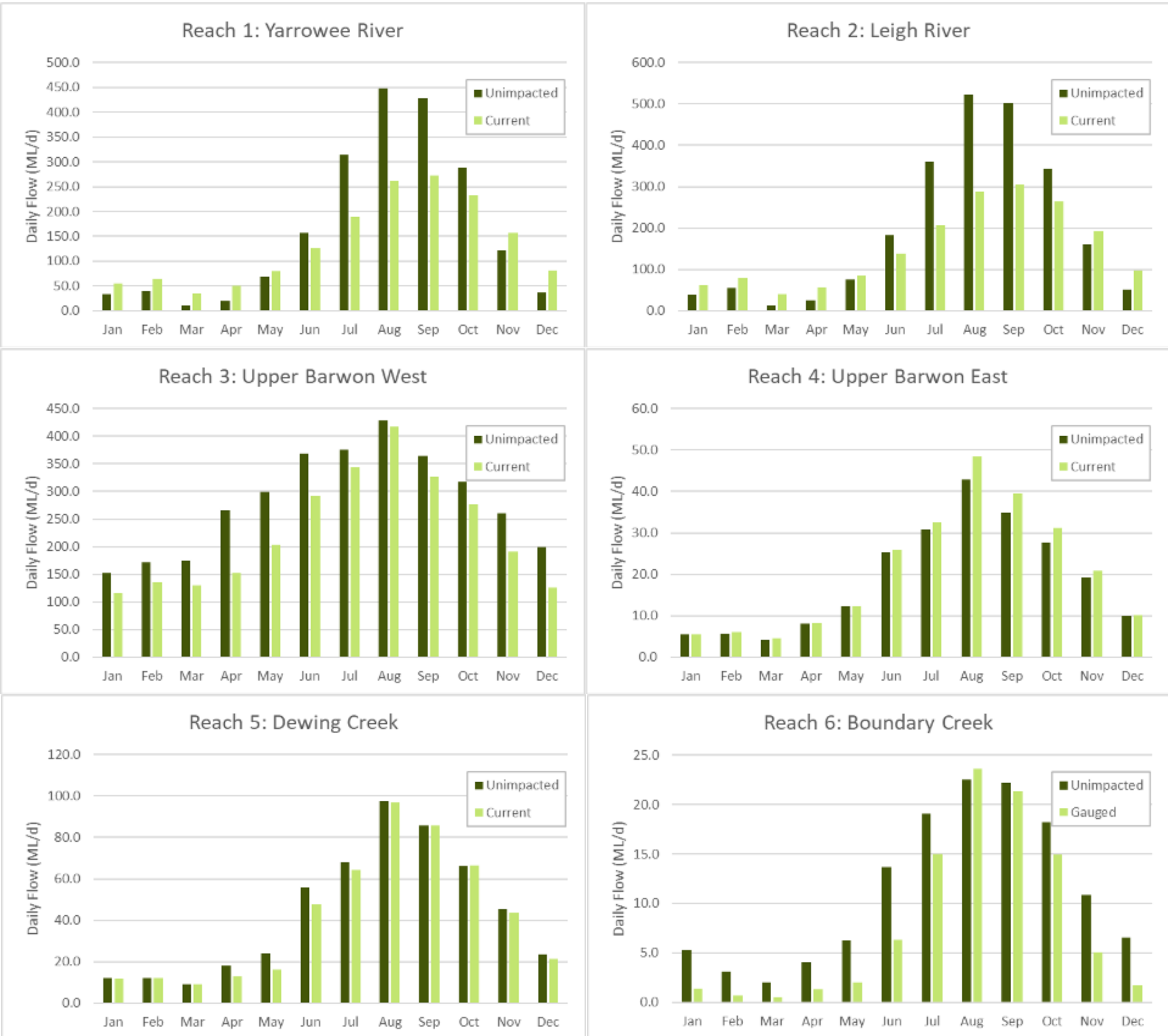


Figure 35. *Flow duration curves for modelled current and natural flow time series*

Seasonality

Flow regulation and extraction to meet domestic and agricultural demands can have a varied level of impact on the flow regime temporally throughout the year and spatially across a catchment. Figure 36 shows a comparison of mean daily flows in each reach under the natural and current level of development conditions for each month of the year. Across the catchment, mean flows are higher in the months of June to November than in the months of December to May, for the main stem and tributaries, and for natural and current flow conditions.

The plots also show that the increase or decrease in mean daily flows for current conditions compared with natural is not consistent throughout the year, with different reaches showing some months with an increase and others with a decrease. For example, for Reach 1 and Reach 2 in the northern part of the catchment, under current conditions, mean daily flows were found to be higher than natural over the dry period, and lower over the wet period. Reaches 7, 9 and 10, however, showed consistently lower flows under current conditions for all months of the year, which is likely a reflection of significant diversions to the Wurdee Boluc inlet channel as well as private diversions throughout this part of the catchment. As discussed further below, low flow under the current scenario was found to be higher than natural. This is somewhat counterintuitive and may suggest limitations in the model calibration and a bias toward representing higher flow components of the flow regime.



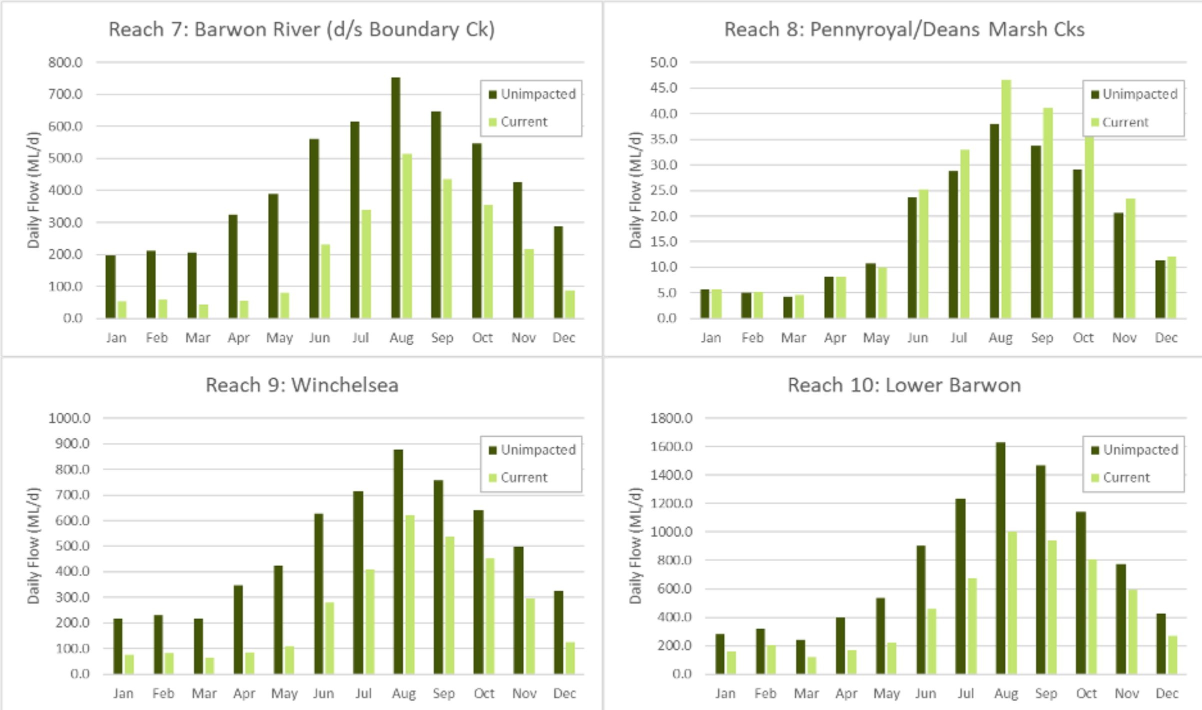


Figure 36. *Comparison of mean daily flow for each month under natural and current conditions*

Cease-to-flow frequency-duration

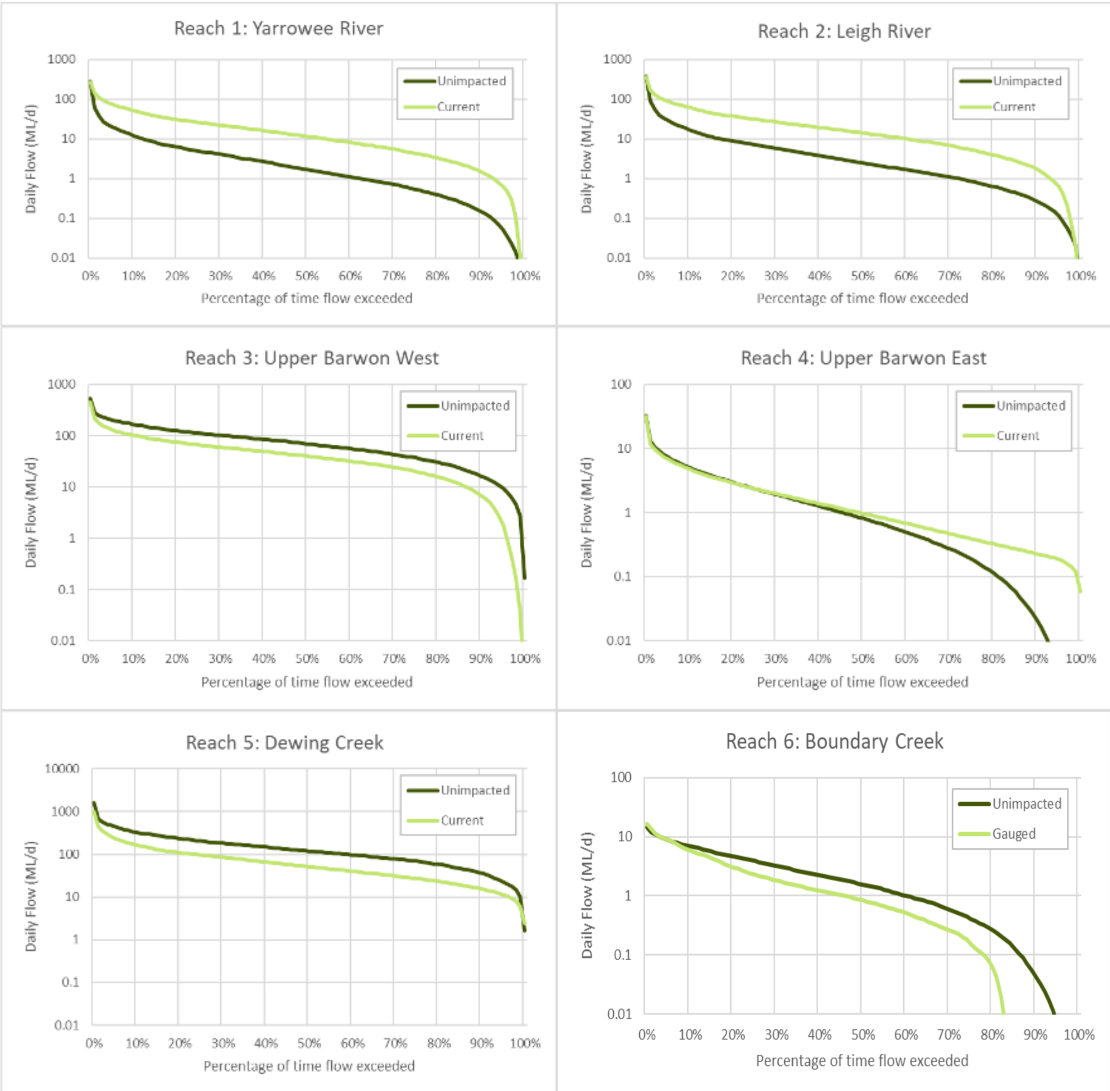
An analysis of flows less than 0.01 ML/d was undertaken to assess cease-to-flow events, where events were considered independent if 7 or more days apart (Table 28). Consistent with the 2006 study, negligible frequency or duration of cease-to-flow events was observed in the modelled current or natural flow time series for the main stem of the Barwon River. For the northern part of the catchment (Reaches 1 and 2), the frequency was found to be similar under the current and natural level of development, while the mean duration was longer under current conditions, about 1 week compared with less than 1 day. For the tributaries, the frequency of cease-to-flow events became negligible under current conditions compared with approximately annually under natural conditions. This is likely a symptom of the current level of development model showing more consistent low flows across the system than the natural scenario as discussed below. When comparing model unimpacted flow with the gauged flow, under current conditions, cease-to-flows were shown to be less frequent but for a longer period (noting this analysis is over the period from 1985).

Table 28. Comparison of estimated cease-to-flow event frequency and duration under natural and current conditions.

Reach		Natural		Current	
		Frequency (over 90 years)	**Mean duration**	**Frequency (over 90 years)**	**Mean duration**
1	Yarrowee River	27	<1	21	7.8
2	Leigh River Inverleigh	8	<1	13	7.3
3	Upper Barwon West U/S Boundary Creek	1	0	27	4.3
4	Upper Barwon East	133	9.7	1	3
5	Dewing Creek	84	8.5	2	1.5
6	Boundary Creek	61	9.5	46	42
7	Barwon River D/S Boundary Creek	1	3	0	NA
8	Pennyroyal and Deans Marsh Creeks	140	9.9	1	1
9	Barwon River - Winchelsea	1	3	0	NA
10	Lower Barwon River - Murgheboluc	1	3	1	2

Low flow

Dry period low flows were filtered from the hydrographic records using the RAP baseflow filter over the December to May period. Low flows were found to be consistently higher under natural conditions for five out of ten reaches including the Barwon River (reaches 7, 9, and 10), the Upper Barwon West (Reach 3), Dewing Creek (Reach 5) and Boundary Creek (Reach 6). The Yarrowee and Leigh reaches (1 and 2) show higher low flows under current conditions, likely due to releases from the BSWWTP. The tributaries (Upper Barwon East, Boundary Creek, and Pennyroyal Creek) showed minimal difference between scenarios with the exceptions of flows around 1 ML/d and below, which is likely a result of the model calibration as shown in the cease-to-flow analysis.



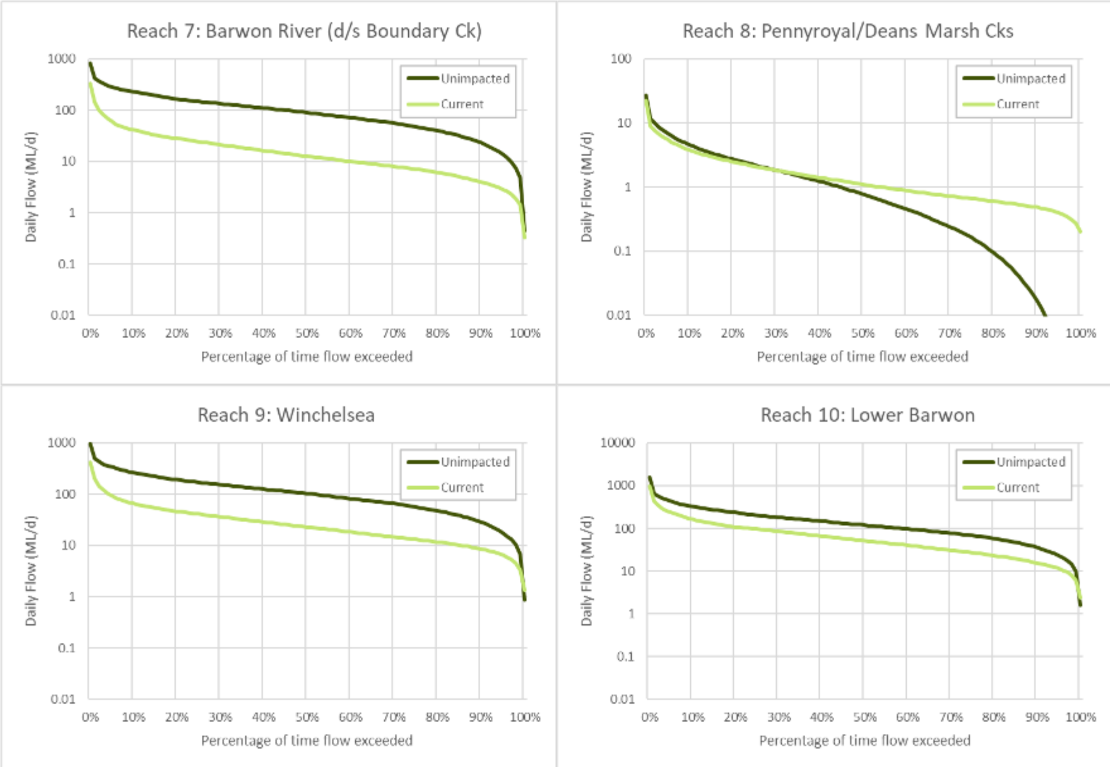


Figure 37. *Flow duration curve for dry period low flows (December to May) under natural and current level of development*

Appendix D:

Groundwater – detailed information

Appendix D: Groundwater – detailed information

Reach 1 – Yarrowee River
This area is characterised by steep topography, with the surface drainages carved into the basalts of the Newer Volcanics aquifer. Palaeozoic bedrock outcrops away from the rivers and thin and discontinuous alluvial sediments are also present in some areas. There are no suitable observation bores positioned near stream gauges to inform groundwater and surface water interaction in this area.

Groundwater discharge to surface water is likely in this area, given the position of the reach in the upper parts of the catchment where topographically driven local groundwater flow systems are likely to develop, indicated by the occurrence of numerous springs which have been mapped in close proximity.

Shallow groundwater salinity is variable but dominantly fresh, with eight of the fifteen bores recording groundwater salinity <1,000 µS/cm. The salinity measurements available for these bores are from the 1970s and 1980s, with no current measurements available.

There is a high density of groundwater users in this area relative to all reaches (besides the extraction occurring at the Barwon Downs Borefield). Groundwater bores are registered for irrigation, commercial, and stock and domestic use. There is likely to be some potential of groundwater pumping impacting streamflow, however, without metred groundwater extraction data and appropriately placed groundwater monitoring, it is difficult to determine this magnitude.

Reach 2 – Leigh River
This area resides on relatively flat, volcanic plains geology. There is a notable absence of the stony rise volcanic geology that is observed in the reach directly above (i.e. Reach 1 and upper Reach 2).

There are no suitable observation bores positioned near stream gauges to inform groundwater and surface water interactions in this area.

Shallow groundwater is saline, with 12 of the 14 observation bores indicating groundwater salinity is greater than 5,000 µS/cm. These electrical conductivity (EC) measurements were all collected in the 1970s and 1980s.

There is a lower density of groundwater users in this area relative to Reach 1 and upper Reach 2, and this is likely correlated to the poorer groundwater quality observed.

Groundwater and surface water interaction is likely to occur in both directions in this area, but streams are conceptualised to generally lose water to groundwater in this area.

Reaches 3, 4, 5, 8
The north-westerly flowing streams in the Upper Barwon all initiate from the Palaeozoic bedrock geology of the elevated Otway Ranges. They eventually flow over the mudstones and sandstones of the Lower Tertiary Aquifer and the clays and marls of the Gellibrand and Narrawaturk Marl. The headwaters for most of the tributaries that rise in the Otways are likely to gain groundwater from the bedrock aquifer through which they are incised. In the absence of data, this conceptualisation is based on a common spatial pattern in groundwater and surface water connection that relates to basin geomorphology. Figure 38 provides a schematic transect that demonstrates the generalised connection across a groundwater basin. Installation of monitoring infrastructure (e.g. a stream staff gauge and a shallow monitoring bore) could confirm this assumption.

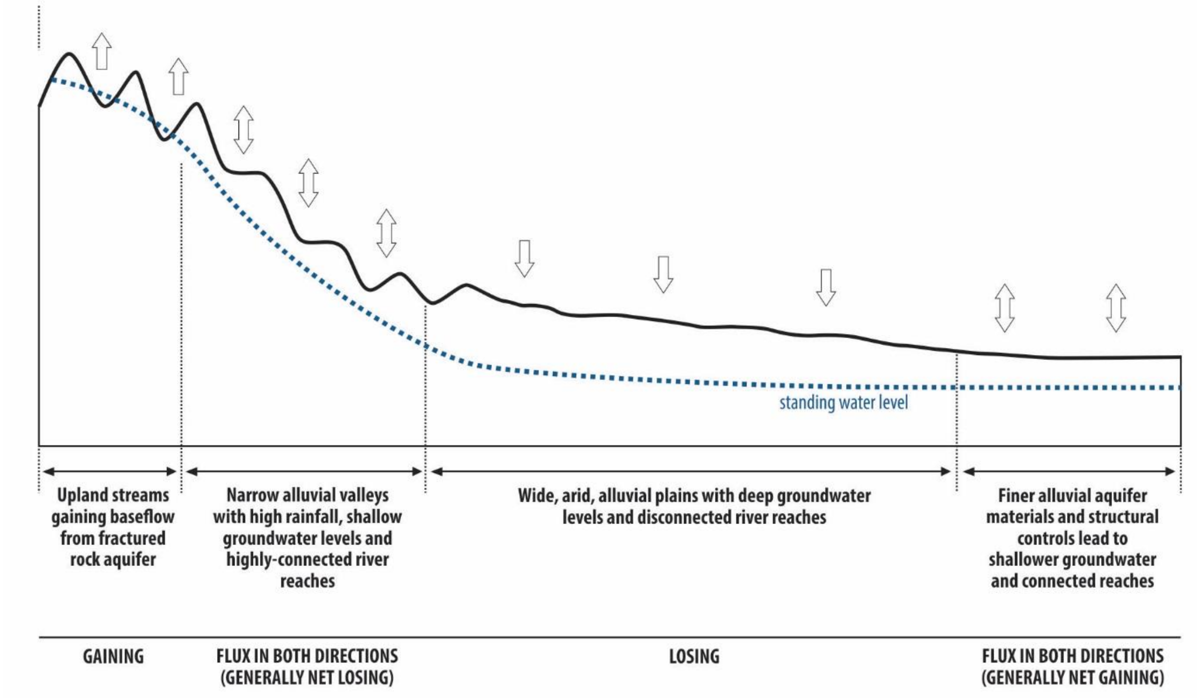


Figure 38. *Schematic transect showing groundwater and surface water connection across a basin (after Braaten and Gates, 2003). The Barwon East and West branches flow over the Middle Tertiary Aquitard through the centre of the valley and are thought to be marginally gaining streams (Jacobs, 2017a)*

Reach 6 – Boundary Creek

Figure 39 shows a long-section of Boundary Creek, from its upstream extent to its confluence with the Barwon River. Boundary Creek is predominantly a gaining stream, albeit the rate of groundwater discharge to the creek varies along the length of the creek, largely depending on the underlying aquifer material. Where Boundary Creek is incised into the Lower Tertiary Aquifer, it is considered to gain groundwater at higher rates relative to other areas, such as where it incises the bedrock aquifer upstream of McDonalds Dam and where it incises the Middle Tertiary Aquitard (Jacobs, 2017a).

The lower section of Boundary Creek (i.e. downstream of McDonalds Dam) was historically a gaining reach, however, is now losing. The groundwater and surface water interaction has been altered by groundwater level declines experienced during the Millennium drought, which were driven by reduced rainfall and pumping from the Barwon Downs borefield (Jacobs, 2017a). Barwon Water's groundwater licence includes minimum flow requirements for Boundary Creek during groundwater pumping periods as a means of offsetting the reduction in groundwater contributions to low flows in Boundary Creek.

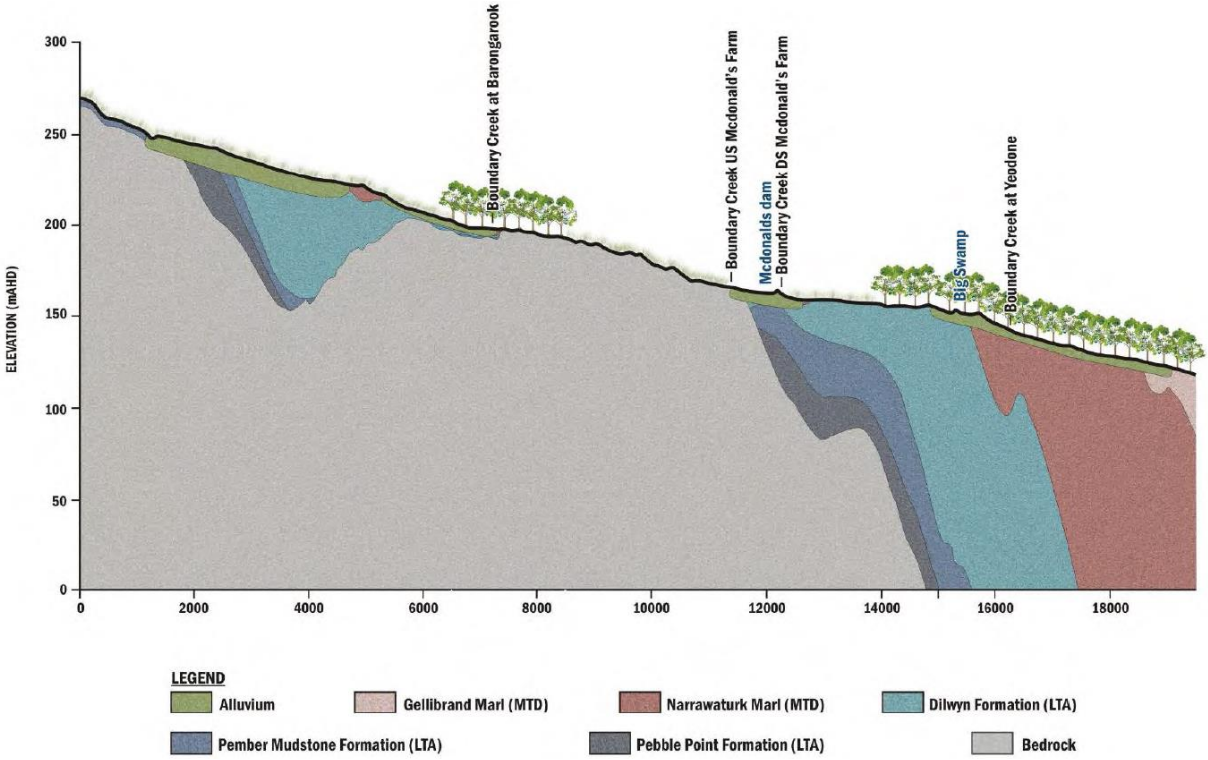


Figure 39. *West to east long-section for Boundary Creek (from Jacobs, 2017a)*

The current conceptualisation of the groundwater-surface water interaction relationship focusing on groundwater extraction is shown in Figure 40 below. The combination of dry periods and increased groundwater extraction caused changes to the nature of groundwater connection within Boundary Creek, as follows:

1. Reduced rainfall recharge
2. Increased extraction activity within the bore field has reduced heads in the LTA and led to a corresponding increase in the hydraulic gradient that in turn led to an increased throughflow in the LTA, transmitting more water away from the Barongarook High
3. The combined effect of reduced recharge and higher rates of groundwater extraction resulted in declines in groundwater levels in the Barongarook High
4. Lower groundwater heads in the Barongarook High led to reduced discharge to Boundary Creek and, in places, induced leakage from Boundary Creek
5. Lower groundwater heads in the LTA will have also led to reduced discharge rates to the Gellibrand River
6. Overall discharge via evapotranspiration from the Graben will not yet have been noticeably affected by groundwater extraction as the confining layers (aquitards) prevent a change in shallow groundwater levels, unlike areas where the aquitards are absent. There will be some leakage from the aquitard downward into the LTA aquifer in response to the groundwater head declines and will be contributing to the pumping volumes yielded from the aquifer

Wetter years (e.g. 2010-11) have resulted in a return to higher rates of recharge, reduced demand on groundwater extraction and a temporary recovery in groundwater levels.

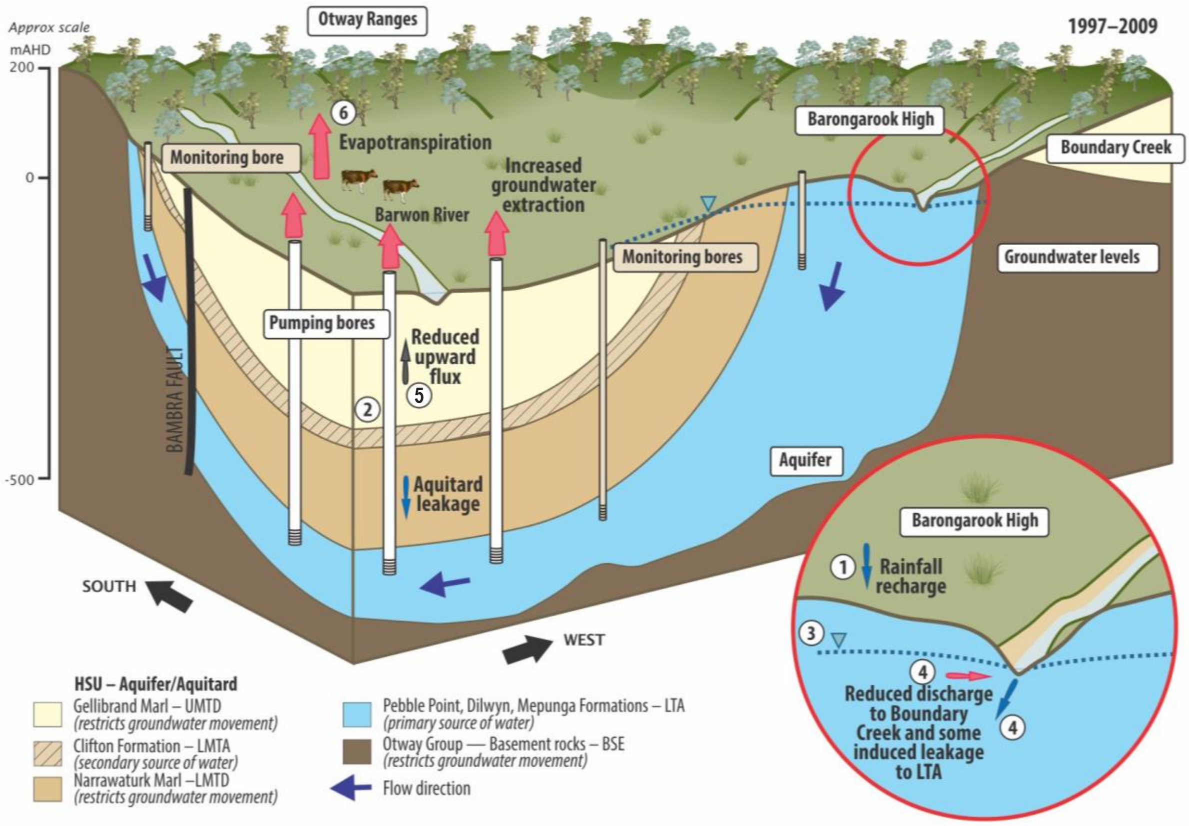


Figure 40. *Conceptual water balance - Gerangamete (after Jacobs, 2016).*

It is reasonable to expect that there could be potential losses owing to both groundwater pumping and changes in climate. A definitive answer on this would require more specific investigations, however no such studies were publicly available at the time of writing.

Reach 7 – Barwon River (d/s Boundary Creek)

GHD (2013) determined that on a long-term average annual basis, the Barwon River gains low flow (~10 GL/year) from groundwater between the East Barwon and Ricketts Marsh.

Reach 9 – Winchelsea

This area resides on relatively flat, volcanic plains geology, devoid of the stony rise volcanic geology that is observed in Reach 1 and upper Reach 2.

A groundwater and surface water level hydrograph was plotted for this area and shows hydraulic connection between the two, with groundwater levels rising and falling in unison with surface water levels. The lack of surveyed elevation data for the stream gauge means that the direction of the flux cannot be determined.

Shallow groundwater is saline, with a median salinity of 8,500 µS/cm (from 24 shallow observation bores. These EC measurements were all collected from 1970-1990. Three shallow bores located in close proximity to the river have fresher groundwater salinity (460-900 µS/cm) which could indicate a location of surface water leakage to groundwater.

There is a lower density of groundwater users in this area and this is likely correlated to the poorer groundwater quality observed.

A previous study quantified groundwater and surface water interaction in this reach (GHD, 2013) and indicated that the interaction was variable, however, the river reach was primarily losing, at a rate

~14GL/year to groundwater in this area. SKM (1997) identified increased salinity levels in the Barwon River between Inverleigh and Winchelsea in comparison to upstream and downstream reaches, which was interpreted as the result of saline groundwater discharge to the river. GHD (2010) developed trigger levels for Lake Murdeduke (located about 6km west of the river) to manage the interaction between groundwater and surface water. The Lake was determined to be a groundwater dependent ecosystem that receives saline groundwater discharge and also leaks fresh water to the underlying aquifer (GHD, 2010).

Appendix E:

Values – detailed information

Appendix E: Values – detailed information

Aboriginal Cultural values

Reach 1 – Yarrowee River

Two site visits and a desktop analysis was conducted for Reach 1. Both sites are within the Clan boundaries of the Kureet. The Kureet Clan traditionally occupied the upper to mid-Yarrowee above Meredith through to Ballarat. The area between the Yarrowee and Williamsons Creeks below Meredith near Garibaldi is Toolloora Bulluc Clan area. See Appendix A. Wadawurrung lived by two Moiety groups, one being Waa and the other Bunjil. Marriage consisted of two Wadawurrung peoples from opposite moieties. The Sutherlands Creek opal silcrete quarry was owned by the Kureet Clan and is an important Cultural resource in the study area. It is important to note that the site at Gong on land currently managed by Central Highlands Water has great Cultural significance to the Wadawurrung but was not visited in the study.

Redan Wetlands

This site though highly modified has Cultural Significance and a strong connection to the story of *Djirnap* the Sulphur Crested Cockatoo and carrying fire. The name Yarrowee has also been recorded as Yarrowyn and has a connection to *Wyn* meaning Fire. 'The cockatoo was our fire carrier, carrying the fire on the top of his head. He would not share his fire, he kept it to himself. Crow and pigeon were the first to try and steal the fire, but they could not. Along came the sparrow hawk. He befriended the cockatoo, they shared some tucker at camp. After a big feed, later that night Cockatoo fell asleep beside the fire. Sparrow hawk took the fire and shared it amongst the people. Cockatoo still wears his yellow Firecrest and underneath his crest lies a bald patch where the fire was' Tammy Gilson and Melinda Kennedy. This site historically would have been a Backwater Billabong and valued as both a source of culturally important plants such as *Tal* or weaving plants and seasonal campsite. See Appendix F Wadawurrung Cultural Species list.

Scotchmans Lead

No site-specific Aboriginal Cultural values beyond maintaining watering requirements for healthy thriving Culturally significant species is crucial. A table of Culturally significant species for the Wadawurrung is provided in Appendix F. Protection of totem species is a priority. Maintain Deep / Permanent Waterholes and Refuge Pools. Maintain access to culturally important sites – story places, ceremonial places. Protection of artefact sites. Use of appropriate Wadawurrung Language for places of Cultural importance. Incorporate Kulin Nation Seasonal Calendar with Flow regime for Cultural species noting that further development of Wadawurrung specific language and seasonal indicators is required.

Reach 2 – Leigh River

Two site visits and a desktop analysis were conducted for Reach 2. The area was identified as being within Tooloora Bulluc Clan boundaries.

Cargerie Creek

This site is on the edge of the lava flow and is the boundary of two different Bioregions. This change in Country aligns with Clan boundaries and is an excellent example of how Clan groups were affiliated with different Country. Large Scar Trees, Culturally valued plants and ease of access contributed to identifying the site as a gathering place for the *Bai eer* where Clans would come together for Ceremonial purpose. Wadawurrung site assessors saw the site as in excellent condition and that it demonstrated a key meeting place for Clans as the only place to access River on flat country. Site of Cultural significance for *Bai eer* due to access and changes in landscape correlate with Clan boundaries. Reports of a number of culturally important species including nesting grounds for Bunjil the Kulin Creator add to the importance of this site.

Lower Leigh Inverleigh-Shelford Road
No site-specific Aboriginal Cultural values beyond maintaining watering requirements for healthy thriving Culturally significant species is crucial. A table of Culturally significant species for the Wadawurrung is provided in Appendix F Aboriginal Cultural values. Protection of totem species is a priority. Maintain Deep / Permanent Waterholes and Refuge Pools. Maintain access to culturally important sites – story places, ceremonial places. Protection of artefact sites. Use of appropriate Wadawurrung Language for places of Cultural importance. Incorporate Kulin Nation Seasonal Calendar with Flow regime for Cultural species noting that further development of Wadawurrung specific language and seasonal indicators is required. See Appendix G.

Reaches 3 to 8
These reaches include Upper Barwon West (upstream of Boundary Creek), Upper Barwon East, Dewing Creek, Boundary Creek, Barwon (downstream of Boundary Creek), Pennyroyal and Deans Marsh Creeks. These reaches are within Eastern Maar Country and no Aboriginal Cultural values assessment was undertaken.

Reach 9 – Winchelsea
A site visit was not conducted, but maintaining watering requirements for healthy thriving Culturally significant species is crucial. A table of Culturally significant species for the Wadawurrung is provided in Appendix F. Protection of totem species is a priority. Maintain Deep / Permanent Waterholes and Refuge Pools. Maintain access to culturally important sites – story places, ceremonial places. Protection of artefact sites. Use of appropriate Wadawurrung Language for places of Cultural importance. Incorporate Kulin Nation Seasonal Calendar with Flow regime for Cultural species noting that further development of Wadawurrung specific language and seasonal indicators is required (see Appendix G). NB: Part of the Reach is Eastern Maar Country and no Aboriginal Cultural values Assessment were undertaken.

Reach 10 – Lower Barwon (Murgheboluc)
Two sites were visited in this reach to assess the Cultural values of the Lower Barwon.

One of many traditional Wadawurrung names for the Barwon is ‘Barwong’. The Barwon has a connection story to ‘Parrwang’ the Magpie. The area holds significant places related to eel ‘Buniya’. Buckley Falls ‘Benia Wulla’ the place where you eat eels indicating the area as a place of gathering.

Confluence Barwon and Leigh Rivers
High cultural value due to the historical use of site as a meeting place for three different Clans including the Wongerra. ACRIS registered site. No further identified Aboriginal Cultural values beyond maintaining watering requirements for healthy thriving Culturally significant species is crucial. A table of Culturally significant species for the Wadawurrung is provided in Appendix F. Protection of totem species is a priority. Maintain Deep / Permanent Waterholes and Refuge Pools. Maintain access to culturally important sites – story places, ceremonial places. Protection of artefact sites. Use of appropriate Wadawurrung Language for places of Cultural importance. Incorporate Kulin Nation Seasonal Calendar with Flow regime for Cultural species noting that further development of Wadawurrung specific language and seasonal indicators is required (see Appendix G).

Murgheboluc
The presence of deep pools has cultural significance as does the presence of freshwater mussels an important food source for the Wadawurrung. No other site-specific Aboriginal Cultural values beyond maintaining watering requirements for healthy thriving Culturally significant species is crucial. A table of Culturally significant species for the Wadawurrung is provided in Appendix F. Protection of totem species is a priority. Maintain Deep / Permanent Waterholes and Refuge Pools. Maintain access to culturally important sites – story places, ceremonial places. Protection of artefact sites. Use of appropriate Wadawurrung Language for places of Cultural importance. Incorporate Kulin Nation Seasonal Calendar with Flow regime for Cultural species noting that further development of Wadawurrung specific language and seasonal indicators is required (see Appendix G).

Barwon at Balyang

While a site assessment was not conducted historical records reveal the strong Cultural significance of the Balyang area. *Balyang* means Bull Rush and there is also a connection story to the Bat *Palyang*. No site-specific Aboriginal Cultural values beyond maintaining watering requirements for healthy thriving Culturally significant species is crucial. A table of Culturally significant species for the Wadawurrung is provided in Appendix F. Protection of totem species is a priority. Maintain Deep / Permanent Waterholes and Refuge Pools. Maintain access to culturally important sites – story places, ceremonial places. Protection of artefact sites. Use of appropriate Wadawurrung Language for places of Cultural importance. Incorporate Kulin Nation Seasonal Calendar with Flow regime for Cultural species noting that further development of Wadawurrung specific language and seasonal indicators is required (see Appendix G).

Fish

Reach 1 – Yarrowee River
The site on the Yarrowee River is a sandy stream with pools, riffles and flowing water next to a road crossing. There was bedrock in the downstream section of the site. Much of the floodplain and streamside vegetation has been cleared but some eucalypts and wattles remain providing shelter over some sections of the stream. The instream vegetation is in poor condition and large amounts of open water exists. Sandy riffles, multiple shallow and deep benches exist, shallow and deep pools, and sedges and reeds along the edge all provide habitat for fish.

The landholder reported that eels were once very abundant (less so these days) but Brown and Rainbow trout, Tench, Redfin were present. We observed a small fish which was likely to be a galaxias spp.

There are multiple issues present in this reach which require flow and complementary actions to address the likely impacts upon biodiversity and ecological functions. These include:

- high levels of nutrients
- sedimentation
- erosion
- poor bank and instream vegetation
- exotic vegetation (such as grasses, willows, and blackberries).

Reach 2 – Leigh River
This reach is a relatively shallow river with a sandy/silt bed and clay banks. While the floodplain is cleared, there is streamside overstorey (river red gums). There are good aquatic vegetation beds in the form of emergent reeds such as common reeds and Club Rush and submergents such as water ribbons but these beds are patchy. Habitats for fish include pools, woody debris, sandy benches, aquatic vegetation beds and hydraulic diversity within the stream.

There are multiple issues present in this reach which require flow and complementary actions to address the likely impacts upon biodiversity and ecological functions. These include:

- high levels of nutrients
- sedimentation
- erosion
- poor bank and instream vegetation.

Reach 3 – Upper Barwon West (upstream of Boundary Creek)
This is a shallow silty stream which has a cleared reedland/sedgeland floodplain and instream is dominated by extensive aquatic plants, such as Rushes, Tall sedge, Milfoil, Knotweeds, and the floating fern. The site is grazed but it still provides good fish habitat in terms of pools, aquatic and floodplain vegetation and shallow runs between pools (no riffles evident).

There are multiple issues present in this reach which require flow and complementary actions to address the likely impacts upon biodiversity and ecological functions. These include:

- grazing
- high levels of nutrients
- sedimentation

- erosion
- poor bank vegetation.

Reach 4 – Upper Barwon East
This reach has silt and sand bed stream with cleared floodplain and streamside vegetation. There are beds of reeds along the stream which are quite diverse (4-5 species of sedges and reeds) and some submerged plants such as water ribbons, pond weeds, water plantain, and knotweeds. The habitats for fish include pools (some long and deep), aquatic vegetation beds and shallow benches.

There are multiple issues present in this reach which require flow and complementary actions to address the likely impacts upon biodiversity and ecological functions. These include:

- grazing
- high levels of nutrients
- sedimentation
- erosion
- poor bank vegetation
- exotic vegetation (such as grasses, willows, and blackberries).

Reach 5 – Dewing Creek
This is a shallow stream with silt/clay bed and no floodplain vegetation (except pasture grasses), there is a wide swampy riparian zone (especially on one side of the stream which is watered by a break of slope groundwater discharge, where some marsh vegetation exists between grasses. The instream vegetation is a marshland with a diverse range of aquatic plant habitats suitable for fish and invertebrates. Several key habitats exist which would support fish species present such as riffles (which are clay held with willow roots in some sections and sand/gravel in other sections), pools (some short and deep and others long and shallow), aquatic vegetation beds and shallow benches.

There are multiple issues present in this reach which require flow and complementary actions to address the likely impacts upon biodiversity and ecological functions. These include:

- grazing
- high levels of nutrients
- sedimentation
- erosion
- poor bank vegetation
- exotic vegetation (such as grasses, willows, and blackberries).

Reach 6 – Boundary Creek
Boundary Creek at the site we inspected was largely dry at the time of inspection with some pools in the upper sections of the site. There is no floodplain vegetation being cleared for pasture many years ago while the streamside vegetation had extensive plantings in the past have now matured with a narrow line of wattles, eucalypts, tea tree, and Banksia present shading much of the stream. The sediment along the site is an organic black peaty/clay soil. Some common reed is present as is some ribbon wed and other aquatic plants but these are very patchy and lacking in shaded areas. It appears some vegetation has died recently due to some event. The habitat supporting fish includes pools, aquatic vegetation, and shallow benches.

There are two main issues present in this reach which require flow and complementary actions to address the likely impacts upon biodiversity and ecological functions. These include:

- poor water quality (low pH)
- poor bank and instream vegetation (potentially as a result of the water quality issue).

It is likely that works upstream to remediate the pH issue will have a significant improvement to instream and streamside vegetation. In-stream revegetation may be required to allow rapid recolonization and habitat creation following water quality improvement.

Reach 7 – Barwon (downstream of Boundary Creek)
The Barwon downstream of Boundary Creek is a moderate sized stream with strong flow and quite deep areas. The floodplain is cleared but there is patchy streamside vegetation of Eucalypts and wattles as well as willows, blackberries, and other weeds. Instream there are sparse beds of water ribbon and reeds on shallow benches but large amounts of open water exists. The habitats important for fish include pools, aquatic vegetation, benches along the bank and riffles created by willow roots. Apart from the shallow benches, the site is lacking bed diversity or woody debris.

There are multiple issues present in this reach which require flow and complementary actions to address the likely impacts upon biodiversity and ecological functions. These include:

- sedimentation
- poor instream vegetation
- exotic vegetation (such as grasses, willows, and blackberries).

Reach 8 – Pennyroyal and Deans Marsh
The site within Deans Marsh Creek was a dry clay-lined channel at the time of inspection with no floodplain vegetation and a replanted streamside zone (Eucalypts and wattles). The is some aquatic vegetation within the channel of common reed, knotweed, and sedges covering much of the stream channel, creating habitat when water is present. The channel is simplified (through clearance and channelization but some structure is re-establishing itself with some shallow pools and riffles present adding to the bed diversity and habitat. However, the most important habitat for fish, when water is present would the vegetation beds. Deep holes may be present within other sections of the reach which would provide refuge habitat for fish to recolonise other sections when flow begins, or fish recolonise from the Barwon itself when the stream starts flowing each year.

There two main issues present in this reach which require flow and complementary actions to address the likely impacts upon biodiversity and ecological functions. These include:

- high levels of nutrients
- channelisation.

Reach 9 – Winchelsea
The study site within this reach is a moderate sized stream with clay banks and sand bed with a strong pool, riffle, run sequence. While the floodplain vegetation is largely cleared there is still good streamside vegetation present in river red gum stands and black wattle with native and exotic grassland understorey and while it was relatively continuous it was disturbed and altered from the natural condition. The instream vegetation has reedbeds and submerged aquatic beds of common reed, club sedge, water couch and water ribbons which are large and extensive. Habitats supporting fish are many and varied including riffle-pools sequence, sandy, woody and rocky substrates, shallow and deep pools, vegetation beds, and overhanging vegetation.

Grazing of the floodplain margins is the major non-flow related issue in this reach and complementary actions (such as fencing and revegetation) are the best ways to address the likely impacts upon biodiversity and ecological functions.

Reach 10 – Lower Barwon (Murgheboluc)

The Lower Barwon reach is a wide natural channel with ample bed diversity in cross-section, depth and hydraulic diversity with a clay bed and rocks in sections. While the floodplain is largely cleared scattered river red gums still persist. The streamside vegetation is in good condition and diverse with river red gum and bottle brushes, lignum and poa grasslands. The instream vegetation is dominated by sedges and reeds, but some submerged aquatic vegetation beds do occur. The habitats for fish include gravel bar riffles, pools, multiple channels, bars, benches and islands, fast and flowing sections and dry anabranches.

There few issues in this reach, apart from elevated nutrients, which require flow and complementary actions to address the likely impacts upon biodiversity and ecological functions.

Vegetation

Reach 1 – Yarrowee River

The riparian vegetation on the Yarrowee River is highly modified. The waterway originates in the Central Victorian Uplands (CVU) bioregion and then passes through the Ballarat urban areas and gold workings. At a distance downstream of Ballarat, it passes along the boundary between the Victorian Volcanic Plain (VVP) and CVU bioregions. The lower Yarrowee passes through a gorge with more intact vegetation with an *EVC851 Streambank shrubland* in moderate condition. From there it passes to a confined floodplain before becoming the open floodplain Leigh River. Willow (*Salix spp*.) commonly dominate the waterway with a ground cover of exotic grasses and *blackberry (*Rubus fruitcosus spp. agg.*) thickets.

The vegetation of the Yarrowee River site at Nolans Road is severely impacted by historic gold mining and then urban or agricultural activity with no expression of the original Ecological Vegetation Class (EVCs) *EVC83 Swampy Riparian Woodland* evident on site. There are some juvenile river red gum (*Eucalyptus camaldulensis*) and river bottlebrush (*Callistemon sieberi*) emerging along the lower bank. Selective willow (*Salix spp.*) control has been undertaken (within 10 years - on the left-hand bank downstream of the road bridge) with revegetation utilising swamp gum (*Eucalyptus ovata*) and blackwood (*Acacia melanoxylon*) at the top of the bank. Thickets of *blackberry (*Rubus fruitcosus spp. agg.*) cover 50% with exotic grasses (eg *cocksfoot (*Dactylis glomerata*) and herbs (eg *hemlock (*Conium maculatum)* and *spear thistle *(Cirsium vulgare)*) dominating the ground layer from 0.5 m above the channel benches. The right-hand bank has a peri-urban residential property with willow (*Salix spp.*) or highly managed grass to waterway edge.

Low cover <10% of native macrophytes are present along the channel toe including common reed *(cultural enagmites australis),* club rush *(Bolboschoenus sp.),* rush (*Juncus sp.),* swamp crassula (*Crassula helmsii)* and variable willow-herb (*Epilobium billardierianum)*. The toe and up to 0.5m above the channel benches is dominated by exotic species such as *drain flat-sedge (*Cyperus eragrostis),* *water couch (*Paspalum distichum),* *running marsh-flower (*Ranunculus repens),* *greater plantain (*Plantago major)* and *burr medic *(Medicago polymorpha)*. The waterway is incised with more of the flow confined to the channel increasing the power of the flows which would disturb the instream and emergent vegetation and restrict its expansion.

The floodplain is highly modified with the ground layer dominated by exotic grasses.

Dry period freshes covering the channel benches and sediment bars (especially in summer) are required to expand the native macrophytes by providing moisture for seed germination and expansion of these plants.

Reach 2 – Leigh River

The vegetation in this reach retains the river red gum (*Eucalyptus camaldulensis)* canopy of the inferred EVC (the endangered *EVC56 Floodplain Riparian Woodland*) but is otherwise highly modified. The mature trees are restricted to the channel and some of the floodplain depressions or flood runners. There is a >50% projected canopy cover of mature *Eucalyptus camaldulensis* over the channel with 5% blackwood (*Acacia melanoxylon*) mid-storey and low level of (<5%) tree violet (*Melicytus dentata*) as a shrub layer. Sporadic common tussock-grass (*Poa labillardierei*) occurs as isolated plants. The ground layer is dominated >75% with exotic grasses and herbs. The ground layer is predominately exotic grasses such as *Toowoomba canary-grass (*Phalaris aquatica*) with herbs such as *spear thistle (*Cirsium vulgare*), *hemlock (*Conium maculatum)*, *wild teasel (*Dipsacus fullonum*) expanding seasonally and providing >25% cover at times. *boxthorn (*Lycium ferocissimum*) and *blackberry (*Rubus fruitcosus* spp. agg.) occur in a few locations but are at low levels of cover <5%.

Instream there are beds of club rush (*Bolboschoenus* sp) and common reed *(Phragmites australis)* on the bank toe and on some of the sediment bars. The *Phragmites* grows up to 1m above the low water level in a few locations. C*ycnogeton procerum* (syn *Triglochin procerum*) occurs at approx. 5%.

*Water couch (*Paspalum distichum*) has colonised some of the sand bars especially those that rise above the low water level. *Spiny rush *(Juncus acutus)* is present along the bank toe as sporadic plants.

Reach 3 – Upper Barwon West (upstream of Boundary Creek)
The floodplain has been cleared of the original woodland canopy and woody vegetation of the inferred EVC (the endangered *EVC56: Floodplain Riparian Woodland*) for the agricultural enterprise. In lower/wetter areas the vegetation represents *EVC 932: Wet Verge Sedgeland* with the ground cover dominated by a tall sedge (*Carex appressa*), rush (*Juncus sp*.) sedgeland (>50% cover) with exotic grasses between the tussocks. The sedgeland can extend up to 200m from the channel. On higher ground exotic pasture dominates.

The excavated channel cut to drain the floodplain has been colonised by native herbs and macrophytes at >80% cover including common reed *(Phragmites australis),* tall sedge *(Carex appressa),* rush *(Juncus sp),* native gipsywort (*Lycopus australis),* mud dock (*Rumex bidens),* slender knotweed (*Persicaria decipiens),* and large bindweed *(Calystegia sepium)*. The spoil bank from the channel excavation has a narrow revegetation planting of swamp gum *(Eucalyptus ovata),* silver wattle *(Acacia dealbata),* blackwood *(Acacia melanoxylon),* sweet bursaria (*Bursaria spinosa)* and prickly tea-tree (*Leptospermum continentale)*. The channel capacity has been reduced by vegetation growth or sedimentation with a significant proportion of the flow moving through older floodplain channels.

The old floodplain channel has a healthy 100% cover of aquatic herbs, grasses, and sedges. The native plants make up approximately 80% of the channel vegetation and 20 to 50% of the channel buffer. Aquatic species include red water fern (*Azolla filiculoides), **common starwort (*Callitriche stagnalis*), *water buttons (*Cotula coronopfolia),* upright water-milfoil (*Myriophyllum crispatum),* mud dock *(Rumex bidens),* slender knotweed *(Persicaria decipiens),* rush *(Juncus sp),* tall sedge (*Carex appressa*). If Wet Verge Sedgeland is adjacent to the channel the native cover is >50% - if pasture abuts the channel the ground layer is dominated by exotic species >80%. Instream aquatic habitat is good.

The herbaceous wetland vegetation in the floodplain channels and depressions is potentially regionally significant and further vegetation survey in spring early summer is warranted to determine status.

If the excavated drainage channel was cleaned out to reinstate previously modified drainage levels most of the water currently flowing down the floodplain channels would not pass that way. The current vegetation in the channels and floodplain would decline with reduced water levels and frequency of inundation.

Low flow to provide water to the channels with wet period freshes to fill the shallow waterway channels will be required to maintain the vegetation at this reach.

Reach 4 – Upper Barwon East
The vegetation at this study site is highly modified following agricultural usage. The inferred EVC (*EVC83: Swampy Riparian Woodland*) is represented by swamp gum *(Eucalyptus ovata)* present at low levels (canopy cover <10%). The bank vegetation has low native diversity and structure and is dominated by willow (*Salix sp*.) and exotic ground covers.

Instream vegetation has a cover of approximately 50% with some large stands of tall spike-sedge (*Eleocharis sphacelata*) on channel benches with submerged aquatics *water-ribbons (Cycnogeton procerum (syn Triglochin procerum s.l.)* and blunt pondweed (*Potamogeton ochreatus)*. Tassel sedge *(Carex fascicularis),* swamp crassula *(Crassula helmsii),* rush *(Juncus sp),* common spike-sedge (*Eleocharis acuta)* occur on the lower banks.

The riparian zone is accessed by stock and damage to the vegetation is apparent.

Downstream of the study site willows dominate the waterway and have altered the channel invert and capacity causing upstream pooling of water. This is selecting the tall spike-sedge (*Eleocharis sphacelata*), Water-ribbons *(Cycnogeton procerum, syn Triglochin procerum s.l.)* and blunt pondweed *(Potamogeton ochreatus)* in the permanent pool. This vegetation would suffer if the willows were removed or the channel invert was lowered downstream.

Reach 5 – Dewing Creek

The vegetation in this study area is highly modified with little remnants of the inferred EVC (*EVC83: Swampy Riparian Woodland*). There are no native canopy or shrub layer species present.

The ground layer is predominately exotic with low cover <10% provided by tall sedge (*Carex appressa*) and Rush (*Juncus sp*.). Instream natives covering up to 50% instream include water-ribbons *(Cycnogeton procerum (syn Triglochin procerum s.l.),* swamp crassula *(Crassula helmsii),* mud dock *(Rumex bidens),* common spike-sedge (*Eleocharis acuta),* swamp club-sedge (*Isolepsis inundata*). Exotic aquatic species include *common starwort (*Callitriche stagnalis*), *drain flat-sedge (*Cyperus eragrostis*), *watercress (*Nasturtium aquatica*) and *running marsh-flower (*Ranunculus repens*).

There is a spring to the high ground on the north side of the waterway. This would contribute low flow to the stream water most of the year indicated by tall spike-sedge (*Eleocharis sphacelata*) which is an aquatic sedgeland species requiring water or saturated substrate to establish and persist.

*Willow (*Salix fragilis)* both mature and juvenile have colonised the small channel and will cause disruption the channel form. Exotic pasture and herbs dominate outside the channel covering >90% of the area.

Reach 6 – Boundary Creek

The vegetation in this reach of Boundary Creek was highly modified and has two distinct sections upstream and downstream of the farm crossing. The original vegetation has been cleared for agricultural purposes. The existing vegetation is the result of two episodes of revegetation - the upper section being approx. 20 years old and the lower being around 10 years old. The revegetation is fenced off approximately 5m each side of the channel with the floodplain vegetation replaced by exotic pasture.

The older revegetation is a mix of blackwood *(Acacia melanoxylon)* and *Banksia marginata*. The newer planting is swamp gum *(Eucalyptus ovata),* blackwood *(Acacia melanoxylon),* silver wattle *(Acacia dealbata),* prickly tea-tree *(Leptospermum continentale)* and woolly tea-tree (*Leptospermum lanigerum).* A small number of bracken (*Pteridium esculentum)* have regenerated in the upper section with the recruitment of blackwood *(Acacia melanoxylon)* occurring in the lower section.

There is minimal instream vegetation in the revegetation areas. Common reed *(Phragmites australis)* and exotic grasses such as *Toowoomba canary-grass *(Phalaris aquatica)* and *brome (*Bromus* sp) are present in the upper section under the canopy. In the lower section, previously healthy vegetation including tall sedge *(Carex appressa)* and common reed *(Phragmites australis)*) are now present as dead stumps. The cause of this is not clear.

Downstream of the revegetation area swamp club-sedge (*Isolepsis inundata*)*,* slender knotweed *(Persicaria decipiens),* and water-ribbons *(Cycnogeton procerum* (syn Triglochin procerum s.l.) are growing in the damp substrate at the base of the channel.

Reach 7 – Barwon (downstream of Boundary Creek)

The vegetation in the study area is highly modified and almost entirely exotic (>80% cover). A few mature remnant river red gum (*Eucalyptus camaldulensis)* provide a reference to the inferred EVC (the endangered *EVC56: Floodplain Riparian Woodland*). Native species retained on the waterway banks occur as isolated plants providing <10% cover. They include *Eucalyptus camaldulensis,* blackwood *(Acacia melanoxylon),* prickly current-bush (*Coprosma quadrifida),* tree violet *(Melicytus dentata),* common tussock-grass *(Poa labillardierei)*. Instream water-ribbons *(Cycnogeton procerum*, *syn Triglochin procerum s.l*.) and club rush (*Bolboschoenus sp*.) persist on channel benches. They will increase in density with increased light following woody weed (willow) control.

The left-hand bank and surrounds abuts the Birregurra township with residential property, churchyard, and a golf course. The right-hand bank is grazing farmland. The left-hand bank has been dominated by *Salix fragilis* (up to 100% cover) with *white poplar (*Populus alba),* *wild plum (*Prunus sp.),* *hawthorn (*Crataegus monogyna*)*,* *English elm (*Ulmus procerus*) forming a dense woodland with *English ivy (*Hedera helix*) as ground cover where they have been allowed to grow. *sweet pittosporum (*Pittosporum undulatum*) and *blackberry *(Rubus fruitcosus spp. agg.)* are also present forming dense stands. Some very recent weed control has been undertaken of these in selected areas

Ground cover outside the dense exotic woodlands is predominately exotic species including *flatweed (*Hypochaeris radicata*)*,* *ribwort *(Plantago lanceolate*)*,* *onion grass (*Romulea rosea*)*,* *Toowoomba canary-grass *(Phalaris aquatica), **kikuyu (*Pennisetum clandestinum).*

The right-hand bank has sections of waterway without fencing with pasture and stock to the water's edge. These areas without fencing and vegetation are experiencing active erosion beyond natural disturbance in areas of higher velocity (outside of bends) or flow deflection.

Reach 8 – Pennyroyal and Deans Marsh

The vegetation in this study site is highly modified having been originally cleared for agriculture. The current tree and shrub vegetation is a result of revegetation. The site is fenced off and has nearly 100% ground cover where the channel has been widened with shallow laid-back banks. Where the channel is incised the channel is poorly vegetated due possible to erosion or rapid filling of the channel to a depth that kills establishing juvenile plants.

The revegetation is comprised of swamp gum (*Eucalyptus ovata*) as the dominant canopy species with manna gum *(Eucalyptus viminalis),* silver wattle *(Acacia dealbata),* blackwood *(Acacia melanoxylon)* and black she-oak (*Allocasuarina littoralis)*.

The ground layer is a mixture of slender knotweed *(Persicaria decipiens)* in the shallow pilot channel with **Toowoomba canary-grass *(Phalaris aquatica),* *common reed *(Phragmites australis),* tall sedge *(Carex appressa),* river mint (*Mentha australis),* *hemlock *(Conium maculatum),* *drain flat-sedge *(Cyperus eragrostis),* *prickly lettuce (*Lactuca serriola)* on the banks. Some deeper sections (damp mud) had emerging water-ribbons *(Cycnogeton procerum* (syn *Triglochin procerum* s.l.)).

The dense ground cover is providing habitat for ground-dwelling native marsupials and land crays.

The dense vegetation has low biodiversity value but does provide channel stability and some habitat.

Reach 9 – Winchelsea

This study site reflects the inferred EVC (the endangered *EVC56: Floodplain Riparian Woodland*) with a healthy canopy cover of river red gum (*Eucalyptus camaldulensis)*. The canopy is of mixed ages with signs or recruitment. Swamp gum (*Eucalyptus ovata*) is present as a secondary canopy species. The vegetation community has low diversity with only blackwood *(Acacia melanoxylon)* in the mid-canopy and no shrub layer present. Steeper south facing sections of the left-hand bank have dense swards of common tussock-grass *(Poa labillardierei)* on them.

Instream there are water-ribbons *(Cycnogeton procerum* (syn *Triglochin procerum* s.l.)) *and* river club-sedge (*Schoenoplectus tabernaemontani*) on deep benches with club-sedge (*Bolboschoenus* sp) and common reed (*Phalaris australis)* on shallower areas. Higher sandy benches are dominated by *water couch (*Paspalum distichum*). Other sections of the bank ground layer, especially the right-hand bank, are dominated by exotic grasses *Toowoomba canary-grass (*Phalaris aquatica*) and *kikuyu (*Pennisetum* *clandestinum*). Low level of *blackberry *(Rubus fruitcosus spp. agg.)* and *gorse (*Ulex europaeus)* are present to <5% cover.

The vegetation present in this study site is characteristically robust species tolerant of strong flow and periodic inundation.

Dry and wet period freshes are required to maintain the open shrubby vegetation. Low flow is required to retain water in the deeper pools for the instream vegetation.

Reach 10 – Lower Barwon - Murgheboluc

The vegetation at this study site is more complex and diverse reflecting the complex channel morphology. The volume of water coming from the catchment is now confined to the main channel resulting in higher velocities and water levels more frequently than other waterway reaches. This is reflected in the inferred EVC being (*EVC851_61: Treed Streambank Shrubland*). This site has the shrub components of that EVC with a 50% river red gum *(Eucalyptus camaldulensis)* canopy cover. Silver Wattle *(Acacia dealbata)* represents the mid-storey. Shrub species representative of the EVC present in lower sections of the channel include river bottle-bush *(Callistemon sieberi),* prickly tea-tree *(Leptospermum continentale),* woolly tea-tree *(Leptospermum lanigerum)* and tree violet (*Melicytus dentata s.l.).* Lignum (*Muehlenbeckia florulenta)* and kangaroo apple (*Solanum aviculare)* occur in a dense (>70%) band higher on the channel bank. The lower areas of the channel have a native ground layer at >60% cover comprised of knobby club-sedge (F*icinia nodosaI,* rush *(Juncus sp),* common tussock-grass *(Poa labillardierei),* fire-weed *(Senecio sp),* stinging nettle (*Urtica incisa)*. Bare ground showing exposed gravels are throughout the site occupying approximately 20% of the ground.

The aquatic areas and small channels are vegetated with a mixture of red water fern *(Azolla filiculoides),* club rush *(Bolboschoenus sp)*, rush *(Juncus sp),* creeping cotula (*Leptinella reptans s.l.),* shining swamp-mat (*Selliara radicans),* water-ribbons *(Cycnogeton procerum (syn Triglochin procerum s.l.),* common reed *(Phragmites australis),* river club-sedge *(Schoenoplectus tabernaemontani).* *Water couch *(Paspalum distichum)* and *spiny rush *(Juncus acutus)* have colonised some of the sands and gravels covering up to 20% in some areas.

Other weeds of significance include *Brassica sp*, *hemlock *(Conium maculatum),* scutch grass (*Cynodon dactylon var. dactylon*), *boxthorn *(Lycium ferocissimum),* *sour-sob *(Oxalis pes-caprae),* *Toowoomba canary-grass *(Phalaris aquatica),* sweet briar *(Rosa rubiginosa),* crack willow *(Salix fragilis)*. The *boxthorn *(Lycium ferocissimum)* competes with the lignum *(Muehlenbeckia florulenta)* on the upper bank.

High flow freshes are required to maintain the shrubby vegetation and reduce the growth of the emergent vegetation via disturbance.

Supporting functions – Water quality and stream health

Reach 1 – Yarrowee River
The Yarrowee River originates upstream of Ballarat in a catchment containing a mixture of rural residential, agricultural and bushland reserve land uses. From there it flows through the City of Ballarat as primarily a bluestone channel, receiving effluent from the BSWWTP and continuing southwards through a predominantly agricultural landscape with generally poor riparian vegetation, direct stock access, and deeply incised channels.

Index of Stream Condition
This reach of the study contains ISC reaches 14 and 15, and the upstream half of ISC reach 12, in the Barwon basin. Reaches 14 and 15 were rated as 'Very poor' and were among the lowest scoring ISC reaches in the Barwon basin during the most recent ISC assessment (DEPI 2013). Neither reach had water quality data but both had a very low rating for hydrology. Both of these reaches are impacted by mine dewatering, treated effluent disposal and urban stormwater runoff from Ballarat (DEPI 2013). ISC reach 12 was rated as 'Poor', with hydrology and water quality receiving the lowest scores (2 and 3 out of 10, respectively).

Water quality
Waterwatch sampling sites in and close to the urban area of Ballarat, typically contain fewer sampling events than required for confident comparison against State Environment Protection Policy, Waters of Victoria (SEPP WoV) objectives and those that do, have the sampling events spread over several years. However, the data from across the sites typically supports the very poor ISC rating for the site, with results indicative of highly elevated nutrients and turbidity, moderate oxygen stress, and mildly elevated salinity. The only site on the Yarrowee River close to Ballarat that has sufficient sampling events for calculating the 75th percentile recorded a reactive phosphorus concentration more than double the SEPP (WoV) objective for total phosphorus. Refer to Appendix H for further detail.

Water quality and macroinvertebrate data were gathered in Yarrowee River in 2009 from approximately 1 km upstream of the BSWWTP to approximately 1 km downstream as part of a monitoring program (ALS Laboratory Group 2009). The report of the monitoring program summarised the water quality in this reach as being degraded throughout, with non-compliance with water quality objectives being identified at the majority of sites for electrical conductivity, pH, total nitrogen, oxidised nitrogen and total phosphorous. Similarly, the macroinvertebrate community were indicative of degraded stream condition along the reach. Although the discharge from the BSWWTP was shown to be having an impact on water quality, there was some indication that the increased flow volume was creating extra habitat, benefiting edge-habitat macroinvertebrate assemblages.

Approximately 17 km south of Ballarat, and 10 km south of the discharge from BSWWTP, a Waterwatch sampling site at South Durham Bridge provides data indicative of very poor water quality. Electrical conductivity and turbidity results at the site exceed SEPP objectives without reaching harmful levels, whereas reactive phosphorus (75th percentile = 0.26 mg/L) was more than 10 times the SEPP objective for total phosphorus (0.025 mg/L), indicating that total phosphorus is present at a substantially higher concentration. Reactive phosphorus is typically readily bio-available for uptake by algae and plants, exacerbating the potential for serious algal blooms.

Further downstream, approximately 30 km south of Ballarat, an active Water Measurement Information System (WMIS) site at Mt Mercer provides water quality data suggesting that the 'Poor' rating for ISC reach 12 could have been 'Very poor' if water quality had been included in the assessment. Over the full period of measurement at the site, the 75th percentile of total phosphorus concentrations was approximately 25 times greater than the SEPP objective and total nitrogen concentrations approximately 7 times greater than the SEPP objective.

The water quality of this reach reflects significant impacts from catchment clearance, urban stormwater inputs, sewage treatment plant discharge, poor riparian cover and stock access to the waterway. The very high nutrient concentrations are almost certain to lead to eutrophic conditions impacting the physical habitat and contributing to an already oxygen-stressed river. Flow measures to ameliorate these impacts would include the provision of small and large freshes, particularly during warmer periods when flows are likely to be very low, plant and algal growths high, and oxygen concentrations dangerously low for the stream biota. Coordination of any water extractions would also assist management of the flow regime in the river. Complementary actions to improve stream condition and water quality include:

- Provision of stormwater retarding wetlands to filter contaminants in the water and reduce geomorphic impacts of unnatural and damaging peak flows from the stormwater system to the river;
- Further improvements to the quality of the discharge from the BSWWTP and its storage capacity to enable flow manipulation;
- Investigate opportunities to enable flow manipulation in this reach including harvesting of stormwater, control of release from BSWWTP and upstream storages;
- Improved riparian vegetation along the river banks, providing shade, and woody debris for instream biota, while also providing bank stability and trapping sediment being delivered from the catchment during storm events;
- Instream rehabilitation works, including the planting of native aquatic macrophytes and the development of wetlands and backwaters to assist in the processing of nutrients and capture of sediments;
- Removal of stock access to the river, thereby reducing bank erosion and slumping, as well as reducing inputs of nutrients and sediments to the channel.

Reach 2 – Leigh River
Reach 2 of this study, the Leigh River, flows through an almost entirely agricultural landscape before entering the Barwon River.

Index of Stream Condition
This reach consists of the lower half of ISC reach 12, from the confluence of Yarrowee Creek and Cargerie Creek to the Leigh's confluence with Woodbourne/Wilson Creek approximately 10 km north of Shelford; and ISC reach 11 from the downstream end of ISC reach 12 to the Leigh River's confluence with the Barwon River near Inverleigh.

ISC reaches 12 and 11 were both rated as poor, although the lowermost reach (ISC reach 11) was only one point below a score of moderate. These scores reflect a gradual improvement in stream condition downstream. ISC reach 11 received a rating of 'excellent' for its aquatic life, despite its very poor rating for hydrology and relatively poor rating for physical form, streamside zone, and water quality. The poorer ratings for these components likely reflect the river draining a largely agricultural landscape, often with poor riparian vegetation and substantial stock access to the channel. Refer to Appendix H for further detail.

Water quality
The WMIS database has one active site in the Leigh River reach, at Shelford, which only has electrical conductivity data from 2011 to 2018. Over the full period of measurement, the 75th percentile of electrical conductivity was approximately 1440 µS/cm, just below the objective of 1500 µS/cm for the coastal plains.

A Waterwatch site at Inverleigh, near the end of the Leigh River reach shows water quality in the Leigh River near Inverleigh to have been similar to that at the most downstream site in Reach 1 (Mt Mercer).

There was a slight increase in phosphorus concentrations between the two sites, indicating that any instream processing of nutrients that is occurring is negated by inputs from the local catchment (e.g. through erosion and stock access). Refer to Appendix H for further detail.

The water quality of this reach reflects the poor quality of the water delivered from upstream with ongoing significant impacts from catchment clearance, poor riparian cover and stock access to the waterway. Similar to Reach 1 of this study, the very high nutrient concentrations are almost certain to lead to eutrophic conditions in the river, impacting the physical habitat and contributing to oxygen-stress. Flow measures to ameliorate these impacts would include coordination of any water extractions from the river or nearby groundwater, and provision of small and large freshes, particularly during warmer periods when flows are likely to be very low, plant and algal growths high, and oxygen concentrations dangerously low for the stream biota. Complementary actions to improve stream condition and water quality include:

- Improved riparian vegetation along the river banks, providing shade, and woody debris for instream biota, while also providing bank stability and trapping sediment being delivered from the catchment during storm events;
- instream rehabilitation works, including the planting of native aquatic macrophytes and the development of wetlands and backwaters to assist in the processing of nutrients and capture of sediments;
- Removal of stock access to the river, thereby reducing bank erosion and slumping, as well as reducing inputs of nutrients and sediments to the channel.

Reach 3 – Upper Barwon West (upstream of Boundary Creek)

Index of Stream Condition
The Upper Barwon West (upstream of Boundary Creek) covers two ISC reaches 6 and 7.ISC reach 7 is the reach upstream of the West Barwon Reservoir and, despite having a near natural catchment, it received a poor rating for physical form due to the reservoir itself creating significant barriers to fish passage. Other indicators for the reach were rated between 'Good' and 'Excellent' and the reach received an overall rating of 'Good'. There was no water quality data available for ISC reach 7.

ISC reach 6 (between the West Barwon Reservoir and the confluence with Boundary Creek) received and ISC rating of 'Moderate' due to the hydrological impacts of the West Barwon Reservoir. Reach 6 was also noted to have extended periods of low flow during the wet period attributed to diversions, catchment modifications, and rainfall patterns. Nonetheless, the site received a rating of 'Excellent' for aquatic life.

Water quality
This reach had no active WMIS recording water quality, however, there are two Waterwatch sites within the reach, one being the West Barwon River below West Barwon Reservoir at Forrest (156 visits between 1995 and 2018) and the other being the Barwon River at Seven Bridges Road (110 site visits between 2006 and 2016). The water in the reach near Forrest typically meets, or is close to, the objectives, with indications of inputs and reduced shading from the poor quality riparian zones leading to reduced dissolved oxygen concentrations and elevated phosphorus concentrations. Refer to Appendix H for further detail.

The near-natural catchment and no water diversions upstream of the West Barwon Reservoir suggest that there are no obvious management actions for that part of the reach. Downstream of the West Barwon Reservoir the impacts of reduced dissolved oxygen concentrations and elevated phosphorus concentrations may be mitigated through the use of increased freshes delivered from the reservoir. Complementary actions to improve stream condition and water quality include:

- Improved riparian vegetation along the river banks, providing shade and woody debris for instream biota, while also providing bank stability and trapping sediment being delivered from the catchment during storm events;
- Removal of stock access to the river, thereby reducing bank erosion and slumping, as well as reducing inputs of nutrients and sediments to the channel.

Reach 4 – Upper Barwon East

Index of Stream Condition
Reach 4, the Upper Barwon East Branch covers two ISC reaches 27 (lower Upper Barwon East Branch) and 28 (Upper Barwon East Branch.). Both reaches have predominantly forested catchments and are in upland areas and therefore are primarily in the Forests B (Otways) water quality segment of SEPP. Both reaches also received an ISC rating of 'Moderate', primarily due to low scores for hydrology.

Water quality
The Upper Barwon East Branch has no Waterwatch sites but does have an active site on the WMIS database, at Forrest upstream of impacts from the Forrest township. The site has approximately monthly data from 1990 to 2018 for pH, electrical conductivity, turbidity, total phosphorus, oxides of nitrogen (nitrate and nitrite) and total Kjeldahl nitrogen. The water quality data are indicative of a catchment with only minor disturbance. Electrical conductivity and pH were both well within their corresponding objectives, and turbidity and total nitrogen were only marginally above their objectives. Total phosphorus was slightly higher than a marginal exceedance and this may be indicative of runoff from tracks or some other causes of erosion. Refer to Appendix H for further detail.

Flow measures to ameliorate hydrological impacts may include coordination of any water extractions from the river or nearby groundwater, and provision of small and large freshes to meet natural flow regimes. Ameliorative actions to reduce inputs of sediments and nutrients would include track maintenance and increased management of runoff from tracks.

Reach 5 – Dewing Creek

Index of Stream Condition
Dewing Creek covers two ISC reaches 25 (lower Dewing Ck.) and 26 (upper Dewing Ck.). ISC reach 25 received a 'Poor' rating due to low scores for water quality, aquatic life, and streamside zone. The upper reach of Dewing Ck (ISC reach 26) was rated as 'Good' by the ISC, with no indicator receiving a low rating but with no water quality data. The upper reach has forests in the majority of its catchment, with cleared agricultural land becoming prevalent in only the lower reach. Therefore, ISC reach 26 is primarily in the Forests B (Otways) water quality segment of SEPP whereas ISC reach 25 is in the Coastal Plains segment of SEPP.

Water quality
There are no WMIS sites within the Dewing Creek reach however, there is one active Waterwatch site on the lower Dewing Creek, which has 93 site visits between 2007 and 2018. The Dewing Creek results are indicative of agricultural influence with the catchment disturbance reflected in high turbidities as well as phosphorus concentrations reaching harmful levels for the instream biota. The particularly high reactive phosphorus may also indicate horticultural activities in the catchment or other inputs of fertilisers. The dissolved oxygen concentrations vary widely, indicating eutrophic conditions with high levels of photosynthesis during the day producing large amounts of oxygen and high levels of respiration during the night consuming large amounts of oxygen. Refer to Appendix H for further detail.

Similar to other reaches located in predominantly agricultural catchments, the very high nutrient concentrations are almost certain to lead to eutrophic conditions in the river, impacting the physical habitat and contributing to oxygen-stress. Flow measures to ameliorate these impacts would include coordination of any water extractions that may impact the creek's flow regime, and provision of small and large freshes, particularly during warmer periods when flows are likely to be very low, plant and algal growths high, and oxygen concentrations dangerously low for the stream biota. Complementary actions to improve stream condition and water quality include:

- Improved riparian vegetation along the river banks, providing shade, and woody debris for instream biota, while also providing bank stability and trapping sediment being delivered from the catchment during storm events;
- instream rehabilitation works, including the planting of native aquatic macrophytes and the development of wetlands and backwaters to assist in the processing of nutrients and capture of sediments;
- Removal of stock access to the river, thereby reducing bank erosion and slumping, as well as reducing inputs of nutrients and sediments to the channel.

Reach 6 – Boundary Creek

Index of Stream Condition
Boundary Creek forms a single ISC reach: ISC reach 13 from its headwaters to its confluence with the Barwon River. Boundary Creek received a 'Poor' rating, with its hydrology and aquatic life returning the lowest ratings of the reach. The creek was noted for returning significantly low pH results.

Water quality
Data from a WMIS sampling site and a Waterwatch sampling site, both at Yeodene, indicate that although high nitrogen concentrations and low dissolved oxygen concentrations are a genuine concern in Boundary Creek, the greatest concern in this reach is pH, which is substantially below the 25th percentile objective and is at harmfully low levels. Low pH (acidic) conditions can impact physiological function and dermal erosion of instream biota as well as leading to release of toxic concentrations of metals from the waterway sediments. A significant change in water quality over the last 10 years is the 75th percentile for pH which has dropped to 4.1, indicating that harmful acidic conditions are now the normal situation for the reach (i.e. occurring more than 75% of the time. Refer to Appendix H for further detail.

The cause of the acidic conditions has been identified as the aeration (oxidation) of acid sulphate soils at Big Swamp (Yeodene Swamp) through drying out with subsequent soaking by heavy rainfall, flushing low pH water into Boundary Creek. The low pH water has then flowed into the upper Barwon River.

Flow management measures to ameliorate the impacts of the acid sulphate releases need to recognise that there are upper layers of sediment in the Big Swamp that are now acidic and simply returning the groundwater to 'pre-Millennium Drought' levels will not immediate reverse the acidification. The issue is complex and is being dealt with through other mechanisms by Barwon Water, CCMA and others.

Reach 7 – Barwon (downstream of Boundary Creek)

Index of Stream Condition
The Barwon River downstream of Boundary Creek mostly overlaps with ISC reach 5 (the Barwon River from Boundary Creek to the Retreat Creek confluence). This ISC reach is rated as 'Poor' with hydrology and physical form indicators obtaining the lowest scores. Reach 5 was also noted to have extended periods of low flow during the wet period attributed to diversions, catchment modifications, and rainfall patterns. Within this reach, the vast majority of the Barwon River is surrounded by agricultural land use with thin strips of riparian vegetation often consisting of introduced species.

Water quality
The Barwon River downstream of Boundary Creek has an active site on the WMIS database, at Ricketts Marsh, approximately 2 km downstream of its confluence with Pennyroyal Creek. There are also two

Waterwatch sites within the reach. The Ricketts Marsh site has approximately monthly data from 1991 to 2018 for pH, electrical conductivity, turbidity, total phosphorus, oxides of nitrogen (nitrate and nitrite) and total Kjeldahl nitrogen. The site is near the end of the reach and therefore provides a good condition summary of its catchment. pH and electrical conductivity both met their SEPP objectives, whereas turbidity and the nutrients each breached their SEPP objectives, although not substantially. Failing to meet objectives for these water quality measures is indicative of inputs typical of grazed land – sediment and nutrient inputs from catchment, bed and bank erosion and animal droppings.

There were low pH events in both 2016 and June-July 2018 in the Barwon River and Boundary Creek resulting from acid water releases arising in the Big Swamp. The acidic conditions have been identified as arising from the aeration of acid sulphate soils at Big Swamp (Yeodene Swamp) from drying out and then been soaked by heavy rainfall and flushing low pH water into Boundary Creek. The low pH water has then flowed into the Barwon River. Low pH (acidic) conditions can impact physiological function and dermal erosion of instream biota as well as leading to release of toxic concentrations of metals from the waterway sediments. Barwon Water is working with stakeholders and agencies to develop a plan to remediate Big Swamp and Boundary Creek to improve stream flow and water quality in the water bodies and downstream. Refer to Appendix H for further detail.

Similar to other reaches located in predominantly agricultural catchments, the elevated nutrient concentrations may lead to eutrophic conditions in the river, contributing to oxygen-stress. Flow measures to ameliorate these impacts would include coordination of any water extractions that may impact the river's flow regime, and provision of small and large freshes, particularly during periods when flows are low, and oxygen concentrations low for the stream biota. Complementary actions to improve stream condition and water quality include:

- Improved riparian vegetation along the river banks, providing shade, and woody debris for instream biota, while also providing bank stability and trapping sediment being delivered from the catchment during storm events;
- instream rehabilitation works, including the planting of native aquatic macrophytes and the development of wetlands and backwaters to assist in the processing of nutrients and capture of sediments;
- Removal of stock access to the river, thereby reducing bank erosion and slumping, as well as reducing inputs of nutrients and sediments to the channel.

Reach 8 – Pennyroyal and Deans Marsh

Index of Stream Condition

There was no ISC reach for Deans Marsh Creek. Pennyroyal Creek covers two ISC reaches 23 (lower Pennyroyal Ck.) and 24 (upper Pennyroyal Ck.). ISC reach 23 received a 'Poor' rating due to low scores for hydrology and streamside zone. The upper reach of Pennyroyal Ck (ISC reach 24) was rated as 'Moderate' by the ISC, with hydrology being the indicator with the lowest rating. The upper reach has forests in the majority of its catchment, with cleared agricultural land becoming prevalent in only the last 2 to 3 km of the reach's catchment. Therefore, ISC reach 24 is primarily in the Forests B (Otways) water quality segment of SEPP whereas ISC reach 23 is in the Coastal Plains segment of SEPP.

Water quality

This reach had no active WMIS recording water quality, however, there are several Waterwatch sites on Pennyroyal Creek. The lowest site is Pennyroyal Creek at Cape Otway Road which has 101 site visits between 2005 and 2018 and has been used in this study. Pennyroyal Creek at Cape Otway Road has passed through mostly open pastures in the Coastal Plain and is therefore assessed against the Coastal Plain SEPP objectives. The results are indicative of agricultural influence and high flows, the catchment disturbance reflected in high turbidities as well as phosphorus and electrical conductivity measurements reaching harmful levels for the instream biota. The particularly high reactive phosphorus may also indicate horticultural activities in the catchment or other inputs of fertilisers. Refer to Appendix H for further detail.

Flow measures to ameliorate hydrological impacts in upper Pennyroyal Creek may include coordination of any water extractions that may impact the creek's flow regime, and provision of small and large freshes, particularly during warmer periods. In lower Pennyroyal Creek, similar to other reaches located in predominantly agricultural catchments, the very high nutrient concentrations are very likely to lead to eutrophic conditions in the river, impacting the physical habitat and contributing to oxygen-stress. Flow measures to ameliorate these impacts would include coordination of any water extractions that may impact the creek's flow regime, and provision of small and large freshes, particularly during warmer periods when flows are likely to be very low, plant and algal growths high, and oxygen concentrations dangerously low for the stream biota.

Complementary actions to improve stream condition and water quality include:

- Improved riparian vegetation along the river banks, providing shade, and woody debris for instream biota, while also providing bank stability and trapping sediment being delivered from the catchment during storm events;
- instream rehabilitation works, including the planting of native aquatic macrophytes and the development of wetlands and backwaters to assist in the processing of nutrients and capture of sediments;
- Removal of stock access to the river, thereby reducing bank erosion and slumping, as well as reducing inputs of nutrients and sediments to the channel.

Reach 9 – Winchelsea

Index of Stream Condition
The Winchelsea Reach of this study mostly overlaps with ISC reach 4 (the Barwon River from the Retreat Creek confluence to the Leigh River confluence). This ISC reach is rated as being in 'Moderate' condition, with hydrology and physical form indicators obtaining the lowest scores. ISC reach 4 was also noted to have extended periods of low flow during the wet period attributed to diversions, catchment modifications, and rainfall patterns. Within this reach, the vast majority of the Barwon River is surrounded by agricultural land use with thin strips of riparian vegetation consisting of a mix of native and introduced species. The reach also flows through the urban area of Winchelsea and is likely to receive urban stormwater runoff and, possibly, discharges from the Winchelsea Wastewater Treatment Plant.

Water quality
The Winchelsea Reach has an active site on the WMIS database, at Winchelsea, within the Coastal Plains water quality region. The Winchelsea site has approximately monthly data from 2015 to 2018 for pH, electrical conductivity, turbidity, total phosphorus, oxides of nitrogen (nitrate and nitrite) and total Kjeldahl nitrogen. There are also two active Waterwatch sites within the reach. pH was the only indicator to meet its SEPP objectives, with all other indicators triggering without reaching known harmful levels. Turbidity and total phosphorus, however, are approaching levels that are considered to cause harm. These results are indicative of inputs typical of grazed land – sediments and nutrients from bed and bank erosion and animal droppings. Refer to Appendix H for further detail.

The water quality of this reach reflects impacts from catchment clearance, poor riparian cover and stock access to the waterway. There are also likely to be urban stormwater inputs and, possibly, occasional sewage treatment plant discharge. The elevated nutrient concentrations may lead to eutrophic conditions contributing oxygen-stress to the river. Flow measures to ameliorate these impacts would include the provision of small and large freshes, particularly during periods when flows are unnaturally low and oxygen concentrations dangerously low for the stream biota. Coordination of any water extractions would also assist management of the flow regime in the river. Complementary actions to improve stream condition and water quality include:

- Provision of stormwater retarding wetlands to filter contaminants in the water and reduce geomorphic impacts of unnatural and damaging peak flows from the stormwater system to the river;

- Improved riparian vegetation along the river banks, providing shade, and woody debris for instream biota, while also providing bank stability and trapping sediment being delivered from the catchment during storm events;

- Instream rehabilitation works, including the planting of native aquatic macrophytes and the development of wetlands to assist in the processing of nutrients and capture of sediments;

- Removal of stock access to the river, thereby reducing bank erosion and slumping, as well as reducing inputs of nutrients and sediments to the channel.

Reach 10 – Lower Barwon (Murgheboluc)

Index of Stream Condition
The Lower Barwon - Murgheboluc reach of this study, incorporating the Lower Barwon River from Leigh River confluence to the Lower Breakwater encompasses ISC reaches 3, 2 202 and 201. The first three of these ISC reaches are rated as being in 'Poor', 'Very Poor', and 'Very Poor' condition, with reach 201 being rated as having insufficient data.

ISC reach 3 is the Barwon River from its confluence with the Leigh River to its confluence with the Moorabool River. It's 'Poor' rating is influenced by low scores for the hydrology, streamside zone, and water quality indicators. ISC reach 2 runs from the end of ISC reach 3 to the start of Lake Connewarre. The 'Very Poor' for this reach included very low scores for hydrology and aquatic life, as well as low scores for water quality and streamside zone. ISC reach 202 had no data for water quality, very low scores for hydrology, streamside zone, and aquatic life, but excellent physical form.

Water quality
The Lower Barwon - Murgheboluc reach has an active site on the WMIS database, at Pollocksford Road, within the Coastal Plains water quality region and upstream of the urban influences of Geelong. The Pollocksford site has approximately monthly data from 1990 to 2018 for pH, electrical conductivity, turbidity, total phosphorus, oxides of nitrogen (nitrate and nitrite) and total Kjeldahl nitrogen. There are also several active Waterwatch sites within the reach. pH was the only indicator to meet its SEPP objectives, with all other indicators triggering. Electrical conductivity and turbidity triggered their objectives without reaching known harmful levels whereas total nitrogen and total phosphorus both reached concentrations that are likely to lead to eutrophic conditions. Refer to Appendix H for further detail.

The water quality of this reach reflects impacts from catchment clearance, poor riparian cover and stock access to the waterway. There may also be urban stormwater inputs from Inverleigh. The elevated nutrient concentrations are very likely to lead to eutrophic conditions contributing oxygen-stress to the river. Flow measures to ameliorate these impacts may include the provision of small and large freshes, particularly during periods when flows are unnaturally low and oxygen concentrations dangerously low for the stream biota. Coordination of any water extractions would also assist management of the flow regime in the river. Complementary actions to improve stream condition and water quality include:

- Provision of stormwater retarding wetlands to filter contaminants in the water and reduce geomorphic impacts of unnatural and damaging peak flows from the stormwater system to the river

- Improved riparian vegetation along the river banks, providing shade, and woody debris for instream biota, while also providing bank stability and trapping sediment being delivered from the catchment during storm events
- Instream rehabilitation works, including the planting of native aquatic macrophytes and the development of wetlands to assist in the processing of nutrients and capture of sediments
- Removal of stock access to the river, thereby reducing bank erosion and slumping, as well as reducing inputs of nutrients and sediments to the channel.

Supporting functions - Geomorphology

Reach 1 – Yarrowee River

Catchment geomorphology

The catchment of the Yarrowee River lies within the dissected uplands of the Western Uplands geomorphological unit and drains gently to moderately sloping hills. The underlying geology is largely sedimentary although the catchment also drains areas of basalt volcanic plains (VGF, 2018). The catchment has been significantly impacted by human activities since the settlement of Ballarat in 1837 which lies at the top of the catchment. Gold was discovered in the Ballarat region in 1851 and activities associated with its mining have caused the most significant impacts on the catchment. Floodplain deposits within the catchment were disturbed to access gold-bearing gravels through alluvial mining activities between Ballarat and Garibaldi and mining of the valley hillsides left large volumes of rock and tailings exposed to weathering and transport processes (EarthTech, 2004).

Reach geomorphology

Between Ballarat and Napoleons, the Yarrowee River is partly confined with extensive erosion of gravel, silt and sandy banks (EarthTech, 2004). The channel is incised approximately 3-5 m with sandy-silt banks, likely the result of a reduction in sediment supply to the river following the cessation of mining activities. Incision in this reach appears to have ceased owing largely to the fact that the channel bed and instream bars are composed of gravel to small cobbles. Benches are well developed along the reach and consist of well-vegetated sandy silts and exposed sands and gravel to small cobbles, indicating an increasing level of stability. This reach of the Yarrowee also features a step-pool channel form sequence with exposed bedrock and large boulders. Willow (*Salix spp*.) are present throughout the reach and channel banks in willow infested areas show signs of erosion. This, along with further reductions in sediment and increases in runoff as a result of urbanisation in the upper catchment, have the potential to disrupt the stability of the reach.

Reach 2 – Leigh River

Catchment geomorphology

The mid-Leigh River lies within the dissected uplands of the Western Uplands geomorphological unit and drains basalt volcanic plains and gently undulating rises and plains comprising Cainozoic sands and gravels (VGF 2018). The lower-Leigh River lies largely within the volcanic plains of the Western Plains geomorphological unit, although parts of the catchment also lie within the sedimentary plains of the Western Plains geomorphological unit.

Reach geomorphology

The floodplain along the reach is wide (approximately 1.5 km) with multiple abandoned channels and billabongs. The channel is moderately sinuous and has historically incised approximately 4 m, likely as a result of a decrease in post-mining sediment inputs. Channel energy through this reach is likely to be considerably lower than in upstream reaches, indicated by the relatively homogenous sand bed and the deposition of sand silt benches (EarthTech, 2004). The banks are well-vegetated sand, except at the outside of some meander bends were grassy vegetation is absent and erosion is evident. Large wood accumulations are common throughout the reach and are important in creating hydraulic diversity.

Reach 3 – Upper Barwon West (upstream of Boundary Creek)

Catchment geomorphology

The most upstream extent of the Barwon catchment drains the steep, forested slopes of Otway Ranges which consist of sedimentary geology. However, the majority of the catchment of the Upper Barwon west branch lies within the low and very low relief hills of the Southern Uplands geomorphological unit, which drains the more gently undulating hills on sedimentary deposits (VGF 2018). The headwaters of the Barwon and its tributaries are still largely forested although floodplain reaches have generally been cleared for agriculture.

Reach geomorphology
The geomorphic form of the channel through this reach is highly variable. The upper section of the reach in the vicinity of the West Barwon Dam flows through the foothills and has a narrow floodplain confined by steep valley walls. As the river emerges from the foothills onto the plain, the channel becomes shallow and wide, flowing through a wide partly-confined and sometimes unconfined floodplain. Since European settlement, the floodplain area has been drained and the main channel has been straightened and deepened. Prior to these works, the floodplain areas were likely swamps that were wet in the wet period with multiple, meandering channels (Lloyd Environmental *et al*. 2006).

At the study site, the channelised main channel was heavily vegetated with rushes and reeds. A small levee was present along the channel likely a remnant from when the reach was channelised. This reach appeared to be blocked and the majority of the flow was flowing across the floodplain in a wide, shallow, poorly defined, meandering channel. The channel in this reach has a maximum depth of approximately 1.5 m although many areas much are shallower. Banks are poorly defined, and substrate consists of clay – silty loam.

Reach 4 – Upper Barwon East

Catchment geomorphology
The most upstream extent of the catchment drains the steep, forested slopes of Otway Ranges which consist of sedimentary geology. However, the majority of the catchment of the Barwon Rise east branch lies within the low and very low relief hills of the Southern Uplands geomorphological unit, which drains the more gently undulating hills on sedimentary deposits (VGF 2018). A large proportion of the upper catchment is still forested although the lower floodplain reach has generally been cleared for agriculture.

Reach geomorphology
The channel in this reach is slightly sinuous and flows through cleared agricultural land. The riparian zone is sparsely vegetated with willows, some native eucalypts and rushes, however, in unprotected zones there is evidence of minor stock damage. Bed and bank material is silty clay and there is some bench development, mostly submerged during the time of inspection but indicated by the growth of partly submerged reeds and rushes. Channel form through the study site is largely a single continuous pool, which may be the result of instream willows at the downstream end of the site.

Reach 5 – Dewing Creek

Catchment geomorphology
The most upstream extent of the catchment drains the steep, forested slopes of Otway Ranges which consist of sedimentary geology. However, the majority of the catchment of Dewing Creek lies within the low and very low relief hills of the Southern Uplands geomorphological unit, which drains the more gently undulating hills on sedimentary deposits (VGF 2018). The headwaters of the catchment are still largely forested although the floodplain reaches have generally been cleared for agriculture.

Reach geomorphology
This reach is a small channel flowing largely through a cleared agricultural setting. Many sections of the creek have been straightened. The creek has incised (approximately 1 -1.5 m) and there is evidence of channel widening, most likely as a result of stock trampling causing damage to the banks. In the sections that flow through agricultural areas, riparian vegetation is largely absent and tree cover consists primarily of willows. Willow encroachment into the channel as well as the willow root masses are currently influencing that riffle/pool form of the creek. Bed material within the reach is silty clay and channel banks are predominately clay. A groundwater-fed spring is present at the study site which drains into Dewing Creek.

Reach 6 – Boundary Creek

Catchment geomorphology

The Boundary Creek catchment lies within the very low relief hills of the Southern Uplands geomorphological unit and drains gently undulating hills formed on sedimentary Palaeogene sediments (VGF 2018). The Boundary Creek catchment has been significantly impacted by a variety of factors that continue to have a potential impact on streamflow within the creek. These factors include:

- Agriculture - the development of agriculture resulted in the construction of a number of drains across the low-lying floodplain areas, impacting on vegetation, likely resulting in lowered groundwater levels near drains and increase groundwater recharge in areas of reduced forest cover
- McDonalds Dam - the 160 ML dam was constructed in the mid-catchment in 1979. The dam has altered streamflow in the channel downstream
- Groundwater extraction - the Boundary Creek catchment overlays the aquifer supplying the Barwon Downs borefield. The borefield operates during drought periods to supplement water supply and was operational between; August 1982 and June 1983, 1985 and 1990, 1997-2001, 2005-2010 and in 2016 resulting in a total extraction of approximately 115,000 ML
- Climatic conditions - between 1995 and 2010 and again between 2014 and the current day, the catchment has experienced below average rainfall and reduced streamflow.
- Yeodene Swamp fire - in the summer 1997 a bushfire in state forest ignited a peat fire within Yeodene Swamp. The fire was thought to be extinguished in 1998, however, it was re-ignited in 2010, suggesting it may have been smouldering below the surface since 1997. In response to the re-ignition, a fire trench was excavated, this along with other trenches are likely to have intercepted a proportion of the local runoff and potentially drained the local groundwater water, lowering the water table (Jacobs 2017b).

These pressures within the catchment have raised concerns about the impact of reduced streamflows and contamination from exposed acid-sulphate soil within the swamp.

Reach geomorphology

The lower reach of Boundary Creek is channelised through pasture and incised (approximately 1-1.5 m). The upper part of the study reach is partly confined with a floodplain of approximately 300-500 m wide. The lower, straighter section of the reach is unconfined to its confluence with the Barwon River west branch. Groundwater appears to have a strong influence on streamflow within the reach. At the time of the inspection, some sections of the reach had streamflow, while others were completely dry. As noted in the previous FLOWS study (Lloyd Environmental *et al.* 2006) the channel has a pool/run/riffle form controlled largely by organic root mats that form hydraulic controls. Bed and bank sediment throughout the reach is generally high in organic matter. In the section where streamflow was present, bed and banks are black clay/peat material. In the dry section of the reach bed and bank material consisted of black clay peat material and orange-red clay silt. In this section, bed and bank sediments often appeared hydrophobic. This fine clay silt material was overlain by brown mulch like soil, high in organic matter, the result of extensive die-off of understory vegetation including, shrubs, macrophytes, and grasses.

Reach 7 – Barwon (downstream of Boundary Creek)

Catchment geomorphology

The Upper Barwon (downstream of Boundary Creek) reach lies on the terraces and floodplains of the Southern Uplands geomorphological unit (VGF 2018). The upper catchment drains the steep, forested slopes of Otway Ranges and the low and very low relief hills of the Southern Uplands geomorphological unit, which consist of sedimentary deposits (VGF 2018).

Reach geomorphology
The channel within this reach is moderately sinuous and incised. Bank material consists of silty clay and major bank erosion is evident at the outside of the meander bend. Benches have developed in some areas along the reach and are also silty clay. Hydraulic diversity within the reach is largely the result of willow encroachment or submerged vegetation. Riparian vegetation along the reach is largely exotic.

Reach 8 – Pennyroyal and Deans Marsh

Catchment geomorphology
The most upstream extent of the catchment drains the steep, forested slopes of Otway Ranges which consist of sedimentary geology. However, the majority of the catchment of Pennyroyal and Deans Marsh creek lies within the low and very low relief hills of the Southern Uplands geomorphological unit, which drains the more gently undulating hills on sedimentary deposits (VGF 2018). The headwaters of the catchment are still mostly forested, although the floodplain reaches have been cleared for agriculture.

Reach geomorphology
This reach is a small, highly modified channel flowing largely through cleared agricultural land. The creek through the floodplain areas has largely been straightened and in some areas has been highly modified, displaying a trapezoidal cross-section with a defined low channel. In areas that haven't been fully modified, the channel has incised (approximately 1-2 m). The bed and bank material consist of silty clay.

Reach 9 – Winchelsea

Catchment geomorphology
The Winchelsea reach of the Barwon River lies within the alluvial terraces and floodplains of the Western Plains geomorphological unit. The upper catchment drains the sedimentary deposits of the steep, forested slopes of Otway Ranges and the low and very low relief hills of the Southern Uplands geomorphological unit to the south. To the north, the upper catchment drains the volcanic plains of the Western Plains geomorphological unit (VGF 2018).

Reach geomorphology
In this reach, the river has incised a narrow valley into both the sedimentary and volcanic plain, with a narrow, confined floodplain present within the valley. The bed of the river is partly bedrock controlled as evidenced by large boulders throughout the reach and occasional steeper riffles and cascades through exposed bedrock (Lloyd Environmental *et al.* 2006). Bed and bank material is largely silty clay, however, there are some sand deposits within the channel creating hydraulic diversity, along with scattered large woody debris. Vegetated, silty clay benches are well developed throughout the reach.

Reach 10 – Lower Barwon (Murgheboluc)

Catchment geomorphology
The Murgheboluc reach largely drains areas of the volcanic plains of the Western Plains geomorphological unit. In this reach, the Barwon River receives major inputs from the Leigh River which also largely drains volcanic geology. To the south of the channel, the catchment also drains sedimentary plains (VGF 2018).

Reach geomorphology
The river in this reach sits within a narrow, confined floodplain that has been incised into the volcanic plain. The channel is partly bedrock controlled and bed material ranges between sand and gravel to cobbles and boulders (Lloyd Environmental *et al*. 2006). Channel morphology at the study site is complex with well-vegetated islands, vegetated sandy/silt benches and gravel/cobble instream bars. Cobbles, boulders, large wood, and instream vegetation create hydraulic diversity and pools, runs, and riffles are present within the reach. Aside from Buckley Falls, the bottom of the reach contains extensive pools with a meandering channel , resulting from the influence of Balms Weir (Lloyd Environmental *et al.* 2006).

Appendix F:

Table of culturally significant species for the Wadawurrung

Appendix F: Table of culturally significant species for the Wadawurrung

Wadawurrung language name	Common name	Aboriginal Cultural value
Birds		
Kark-wi-in	Brolga	Meat, eggs, feathers for decoration, first animal to form as a human
Bunjil	Wedge-tailed eagle	Spiritual, creator being of Kulin, people, lore, animals, plants, rivers & mountains. Wadawurrung totem
Waa	Crow / Raven	Wadawurrung totem forbidden to eat
Barrimul	Emu	Meat, eggs, feathers for adornments
Toolim	Black Ducks	Meat, eggs, feathers for adornment forbidden food only initiated man or elder
Moodiwarr	Musk Duck	Feathers for adornments, forbidden to eat.
Kunuwarra	Black Swan	Meat, eggs, feathers for adornment Bundjils Wife
Gherin Gherang or Willam	Yellow tailed Black Cockatoo	Meat, eggs, feathers for adornments.
Parwan	Magpie	Forbidden to eat, feathers for adornments.
Koor-nait	Kookaburra	Meat, eggs, feathers for adornments.
Djirnap	Sulphur crested Cockatoo	Kulin Fire creation story. The cockatoo carries fire on his yellow crest.
Mammals		
Goim	Kangaroo	Meat, pelt, sinew, teeth for decoration, rib cage bones for tools. Leg bones for making sewing needle 'Awl'. Pelt for ceremonial cloak.
Go-yin	Wallaby	Meat, pelt, sinew, teeth for, adornments, bones for tools.
Barnong (ringtail) Walert (brushtail)	Possum	Meat, pelt for making ceremonial cloaks and footballs and blankets.
Quenda (kwenda) Bo yang	Bandicoot	Meat, pelt
Mon ngarrk	Echidna	Meat, quills for adornments such as necklace.
Yurn	Quoll	Meat, pelt
Warran	Wombat	Meat, pelt
Karbor	Koala	Meat, pelt
Karn Kadak	Snake	Meat
Wad-dirring Perridak	Platypus	Meat, pelt
Fish Touit		
Buniya Koonan	Eel	Meat. Important food source sometimes smoked. Large gatherings during eel run at Benia Wulla (Buckley Falls)
Ware-rap	Blackfish	Meat
Turrpurt	Trout small	Meat
Food Plants		
Roots, Tubers		
Murnang	Murnong, Plains Yam-daisy. *Microseris lanceolata*	Food plant, very important food diet plant, radish shape like- non starchy tuber roots sometimes eaten raw although mostly cooked in baskets placed in an earth oven. Often carried. Mozaic firesticks burns were done to encourage re-growth. Digging sticks were used to unearth yams and tubers for food, but also 'turned' the soil.

Wadawurrung language name	Common name	Aboriginal Cultural value
Polango Warngare	Water Ribbons *Triglochin procera*	*Plant food, finger-shaped tubers are crisp and sweet. Cooked in a ground oven.*
Name nor known most lilly-roots called 'Bom'.	Pale Vanilla-lily *Arthropodium milleflorum*	Non-starchy crisp tuber eaten raw. Found in damp areas.
Pike meaning sharp or nasty	Yellow Bulbine-lilly *Bulbine Bulbosa*	Food plant, under the stalk and leaves is a plump round corm. Can be cooked and eaten. Has a sweet root. Has a spherical corm surrounded with a ring of swollen roots. The corm needs baking on ashes to disperse the roots.
Yep-eurt	Milkmaids *Burchadia umbellata*	Harvested by the woman any time of the year. Tubers/bulb is edible and dug up and eaten before cooked. Each plant can produce up to 10 tubers.
Bom	Grass lilies *Caesia species-*	Food plant, sweet tasting finger-shaped tubers. Crisp texture and can be eaten fresh.
Bom	Chocolate lily *Dichopogon strictus-*	Purple flower smells like chocolate. Food plant, tubers dug up and roasted before eating
Banganga	Fringe lilies *thysanotus-*	Called this because they have a fringed flower petal. Food plant, tubers cooked before eaten. Harvested in Spring eaten as a vegetable.
Name not known	Orchids *Orchidaceaae*	All orchids have edible tubers/bulbs can vary in taste depending on the amount of starch that they contain
Tarook or Dintini (peppery yam)	Small-leaved Clematis *microphylla*	This plant is used for treating aching bones. Tough starchy root cooked in baskets then kneaded on *Wangat*, hearth made of bark. Rolled and re-cooked on coals. Young roots tasted peppery. Leaves crushed and inhaled for headaches. Stem used for fibre for string Traditional knowledge required in the processing.
Tharook Min nam-berung	Pink Bindweed *Convolvulus arvensis*	Edible tap root. The roots eaten during colder season as yam daisies were bitter until Spring. Poisonous if eaten raw.
Terraat	Native Geranium *solanderi*	Radish like tuberous roots. Very tough so pounded before eaten. Root contains nutritious starch and can be eaten after cooking in ground oven. Roots used to treat diarrhoea.
Balout	Cherry Ballart *Exocarpos cupressiformis*	Ceremonial men's plant to Wadawurrung. Food, the red berry produces its seed on top of the fruit not on the inside, timber used to make tools such as boomerang and clap sticks, medicinal sap used to treat snake bites.
Toolain	Late black Wattle *Acacia mearnsil*	Important source of gum, was eaten or dissolved into drink with flower nectar. When mixed with burnt mussel shell or wood ash it formed a cement. Fibre was used for making course string. Medicinal - bark was infused in hot water and taken for indigestion.
Tark	Common reed *Phragmites australis*	Water plant. Weapon-stems used for spear shafts for fishing. Reed cut while still green to make necklaces and weave- bags and baskets. Also a food plant.
Warour re rup or Toolain	Late Black Wattle *Acacia mearnsil*	Gum was eaten. Dried balls of gum were stored in baskets & re-constituted by being soaked in water when needed. The bark is high in tannins and was broken into small pieces, mashed on an anvil and soaked in water. Used to aid indigestion. Strong timber for wooden implements. Ceremonial use flower used for Womans Lingan line fishing dance.
Wurrak or Wooriki	Silver Banksia *marginata*	Dried cones used as drinking water strainer. Another important plant. The flowers are harvested for their nectar, making a bush cordial. The dry cone was stuffed with coals and used to slight spot fires for fire stick burning. Food plant- an edible grub can be found in rotten trees. Also timber used to make tools and fire.
Burn-naa-look Mooee-yung	Blackwood *Acacia melanoxylon*	Tools- spear-thrower, boomerang, club and parrying shield. Medicinal bark infused in water for joint pain and fibres from inner bark used for string for fishing nets

Wadawurrung language name	Common name	Aboriginal Cultural value
Nurm-bal	Flax-lily *Dianella species*	Leaves used for making string from the fibre *Dee-reep* used in headbands made from kangaroo teeth and feathers.
Toolim	Pale Rush *Juncus pallidus*	Weaving baskets
Bal-yan	Bull Rush/ Cumbungi *Typha latifolia*	Fluff used to pack wounds under paperbark bandage
Name not known	Spiny-headed mat-rush *Lomandra longifolia*	The long leaves were used in fine basketry. The pith at the base of the leaf is edible and the seed is ground, mixed with water and made into a paste for making flour/johnny cakes.
Nareta	Rudy Saltbush *Enchylaena tomentosa*	Food plant-red berry can be eaten
Name not known	Austral Bugle *Ajuga australis*	Medicinal
Koon-yang Gunyang	Kangaroo Apple *Solanum laciniatum*	Women's plant (knowledge to process is required).
Nareem	Small leave bramble-Native Raspberry *Rubus parvifolius*	Food plant- edible berries
Trees		
Ngarri	Drooping She-oaks *Allocasuarina verticillata*	Tools- boomerang, club, shield, digging stick. Important coastal trees such as the Dropping She-oak and the Coastal Banksia are an important part of traditional Kulin life on the coast, providing food, shelter and wood.
Biyal	River red-gum – *Eucalyptus camaldulensis*	Bark removed for Canoe, shelter and tools –Tarnuk (bowl), nectar drink, medicinal – gum or sap was used for burns to shrink or seal them, the sap is high in tannin. Leaves for steam baths.
Bi-et-mai	Yellow Gum *Eucalyptus leucoxlon*	Timber tough, strong and durable. Sought after for digging sticks kanan-kulk. Also for parrying shields, *geeam* said to have magical properties.
Larrap	Manna Gum *Eucalyptus viminalis*	Timber used for making club-shields called *Malka*. Sap-sucking lerp bug gathered each season Young leaves were fed onto fire near a patient. A poultice of well-chewed leaves can be applied for backache. Quail flocks attracted to Manna.
Kokibainang	Swamp Wallaby Grass *Amphibromus recurvatus*	Leaves split, dried out & re-constituted in running water. Fibres twisted into rope to make long nets for game hunting.
Bar-rang Woo-loitj	Kangaroo Grass *Themeda triandra*	The grain was collected, ground, mixed with animal fat and baked in coals like bread. Culms and leaves were broken on a mortar with hammerstone *kulki* then spun into twine and coloured with ochers.
Wangarra	Messmate *Eucalyptus obliqua*	Inner bark for rope and timber for wooden implement. Medicinal purposes.

Appendix G:

Kulin Nation Seasonal Calendar

Appendix G: Kulin Nation seasonal calendar

Adapted from Kulin Nation Seasonal Calendar Melbourne Museum

https://museumsvictoria.com.au/forest/climate/apple.html

The Kulin have a detailed local understanding of the seasons and the environment. Each season is marked by the movement of the stars in the night sky and changes in the weather, coinciding with the life cycles of plants and animals. Overlaid on the seven seasons are two other non-annual seasons - Flood season which is likely to occur on average about every 28 years, and Fire season which occurs on average about every seven years.

Eel Season [March]

Hot winds cease and temperatures cool. Eels are fat and ready to harvest. Manna Gum is flowering. Days and nights are of equal length. Lo-An Tuka, the Hunter, is the star Canopus, seen almost due south at sunset.

Wombat Season [April-July]

Cool, rainy days follow misty mornings. The time of highest rainfall and lowest temperatures. Days are short and nights are long. The constellation of Sagittarius rises in the southeast after sunset, indicating the midpoint of cold weather.

Orchid Season [August]

Cold weather is coming to an end. Orchids are flowering. The star Arcturus is seen on the north western horizon soon after sunset. Koalas begin mating. Males bellow at night

Tadpole Season [September-October]

Temperatures are rising but the rain continues. Flax-lilies are flowering. The flowering of plants such as Myrnong, (Yam Daisy), indicates the tubers are ready for eating. Days and nights are of equal length.

Grass Flowering Season [November]

The weather is warm, and it is often raining. Kangaroo Grass is flowering. Bats are catching insects in flight. Balayang, the Creation Being, is also referred to as the bat. Male Common Brown butterflies are flying. Victorian Christmas Bush is coming into flower. The Orion constellation is setting in the western sky around sunrise.

Kangaroo-apple Season [December]

Changeable, thundery weather. Bats are catching insects in flight. Days are long and nights are short. Fruits appear on Kangaroo-apple bushes. Cherry Ballart is fruiting. Bunjil (Wedge-tailed Eagles) are breeding.

Dry Season [January-February]

Hot, dry weather. High temperatures and low rainfall. Tussock-grass is long and dry. The Southern Cross is high in the south at sunrise.

Appendix H:

Water Quality – detailed information

Appendix H: Water quality – detailed information

Detailed water quality information is provided below. Green shading indicates result meets SEPP objectives; orange shading indicates result does not meet SEPP objective without reaching harm thresholds and red shading indicates result does not meet SEPP objectives and may reach harm thresholds.

Reach 1 - Yarrowee River
There are no WMIS sites within the Yarrowee Creek above Cambrian Hill, although there are several active Waterwatch sites within the reach. Most of the Waterwatch sites have fewer sampling events than required for confident comparison against SEPP WoV objectives and those that do, have the sampling events spread over several years. However, the data from across the sites typically provide results indicative of highly elevated nutrients and turbidity, moderate oxygen stress, and mildly elevated salinity.

The only site on the main stem of the Creek that has sufficient sampling events for calculating the 75th percentile is at Queen Street in Ballarat, with 16 site visits between 2010 and 2016 (Table 29). The SEPP (WoV) objectives were derived for annual assessments using monthly sampling data rather than occasional sampling over several years. Nonetheless, these data provide useful background information on the condition of the waterway and their comparison against the SEPP objectives can be used as an indicative assessment.

Table 29. Water quality data gathered by Waterwatch at the Queen Street site on Yarrowee Creek in north Ballarat.

Indicator		pH	Electrical conductivity (µS/cm)	Turbidity (NTU)	Reactive phosphorus (mg/L)
25th percentile*		7	NA	NA	NA
75th Percentile*		7	850	17.5	0.06
SEPP (WoV) objective (Cleared Hills)	25th percentile*	≥6.5	NA	NA	NA
	75th Percentile*	≤8.3	500	10	0.025ɣ

*These percentiles are calculated from 15 – 16 samples collected between 2010 and 2016.

ɣ The SEPP objective is for total phosphorus. Reactive phosphorus is a component of total phosphorus and therefore if the reactive phosphorus concentration exceeds the objective, the total phosphorus must also exceed the objective.

pH at the Queen Street site was always around neutral (7 to 7.5), electrical conductivity at the site was slightly above the SEPP 75th percentile objective of ≤ 500 µS/cm, with a 75th percentile of 850 µS/cm and turbidity had a 75th percentile of 17.5 NTU (SEPP objective = 10 NTU). Although each of these results is indicative of a breach of their SEPP objective and should trigger further investigation, they are not approaching harm thresholds. In contrast, reactive phosphorus (75th percentile = 0.06 mg/L) was 2 to 3 times the SEPP objective for total phosphorus (0.025 mg/L). Reactive phosphorus is one of the constituents of total phosphorus and the fact that it is more than twice the objective for total phosphorus strongly suggests a much higher concentration of total phosphorus. Exacerbating this is the fact that reactive phosphorus is typically readily bio-available for uptake by algae and plants.

The site is situated in the urban area of Ballarat and much of its non-urban catchment is agricultural, so the poor water quality is not surprising. However, the site is located on Yarrowee Creek as it enters Ballarat and the creek will receive a greater volume of urban stormwater as it passes through the city of Ballarat and then receives discharge from the BSWWTP approximately 5 km downstream from the Ballarat CBD. This suggests that the remainder of the Yarrowee Reach is likely to have very high nutrients, elevated turbidity, and problematic algal blooms.

Reach 2 - Leigh River

Water Measurement Information System

The WMIS database has an active site at Mt Mercer, in the Leigh River reach, with data from 1990 to 2018 for pH, dissolved oxygen, electrical conductivity, turbidity, total phosphorus, oxides of nitrogen (nitrate and nitrite) and total Kjeldahl nitrogen (Table 30). The Mt Mercer WMIS site is located just downstream of ISC reach 14 and the water quality data for this site reflects the very poor rating for that ISC reach. Over the full period of measurement, the 75th percentile of total phosphorus concentrations was approximately 25 times greater than the SEPP objective and total nitrogen concentrations approximately 7 times greater than the SEPP objective (Table 30). During that period, however, there has been a marked improvement in phosphorus concentrations and over the most recent 10 years of measurement with the 75th percentile dropping to approximately 10 times the objective (Figure 41). Total nitrogen also dropped to a lesser degree, to approximately 5 times the objective. Although these concentrations are a marked reduction, possibly reflecting improvements made to the discharge from the BSWWTP, they are still very high and likely to contribute algal blooms and excessive plant growths. During both periods turbidity has remained close to the SEPP objective, while pH has remained close to the upper levels of its objective and electrical conductivity has remained at approximately two to three times its objective for the segment. Electrical conductivity has more latitude for exceedance of objectives that most indicators, with harmful levels in the region estimated to be at 1500 µS/cm.

Table 30. Summarised water quality data from the WMIS database, for the Leigh River at Mt Mercer.

Indicator		pH	Electrical conductivity (µS/cm)	Turbidity (NTU)	Total nitrogen (mg/L) ˠ	Total phosphorus (mg/L)
1990 - 2018	25th percentile	7.8	NA	NA	NA	NA
	75th percentile	8.4	1300	10	4.2	0.62
2008 - 2018	25th percentile	7.9	NA	NA	NA	NA
	75th Percentile	8.3	1236	11	2.8	0.22
SEPP (WoV) objective (Cleared Hills)	25th percentile	≥6.5	NA	NA	NA	NA
	75th Percentile	≤8.3	≤ 500	≤ 10	≤ 0.6	≤ 0.025

ˠ calculated sum of oxides of nitrogen and total Kjeldahl nitrogen

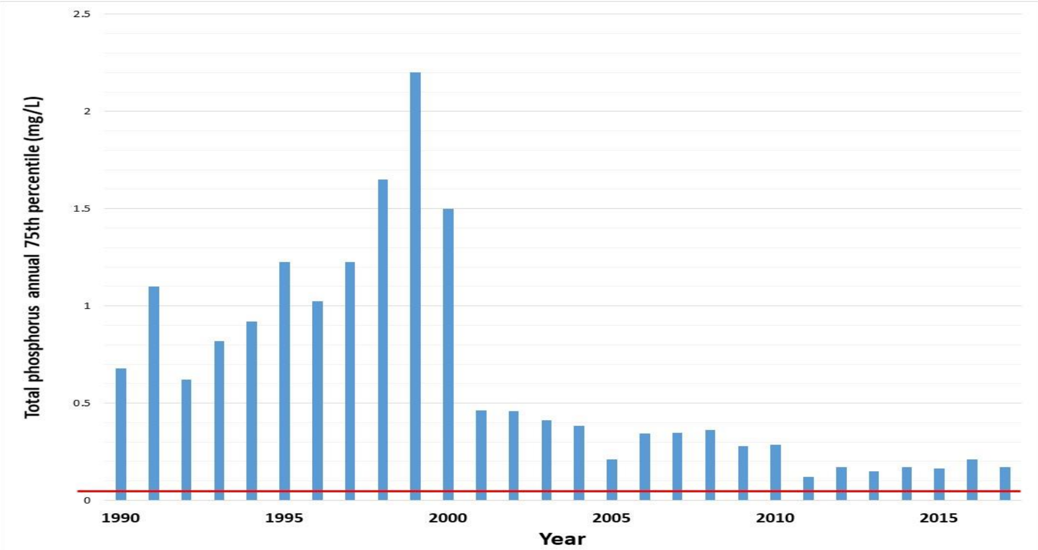


Figure 41. *Annual 75th percentiles of total phosphorus recorded in the Leigh River at Mt Mercer (source: http://data.water.vic.gov.au/monitoring.htm).*

Waterwatch

There were three sites on the main stem of the Creek within the Leigh River reach that had sufficient sampling events for calculating the 75th percentile (at South Durham, Grenville, and Mt Mercer), with the site at South Durham Bridge having the most site visits (52) between 2008 and 2014 and therefore this site was used for assessment. The SEPP (WoV) objectives were derived for annual assessments using monthly sampling data rather than occasional sampling over several years. Nonetheless, these data provide useful background information on the condition of the waterway and their comparison against the SEPP objectives can be used as an indicative assessment (Table 31).

pH at the South Durham Bridge site was always around neutral (7 to 7.5), electrical conductivity at the site was substantially above the SEPP 75th percentile objective of ≤ 500 µS/cm, with the 75th percentile of 850 µS/cm and turbidity had the 75th percentile of 15.5 NTU (SEPP objective = 10 NTU). Although electrical conductivity and turbidity results are indicative of a breach of their SEPP objective and should trigger further investigation, they are not approaching harm thresholds. In contrast, reactive phosphorus (75th percentile = 0.26 mg/L) was more than 10 times the SEPP objective for total phosphorus (0.025 mg/L), indicating that total phosphorus is present at a much higher concentration. As described for Reach 1 of this study (Yarrowee), the fact that reactive phosphorus is typically readily bio-available for uptake by algae and plants exacerbates the potential for serious algal blooms.

Table 31. Water quality data gathered by Waterwatch at the South Durham Bridge on Yarrowee Creek/Leigh River in Durham Lead.

Indicator		Dissolved oxygen (%sat)	pH	Electrical conductivity (µS/cm)	Turbidity (NTU)	Reactive phosphorus (mg/L)
25th percentile*		65	7.2	NA	NA	NA
75th Percentile (max for DO)*		105	7.5	1190	15.5	0.266
SEPP (WoV) objective (Cleared Hills)	25th percentile*	85	≥6.5	NA	NA	NA
	75th Percentile (max for DO)*	110 (max)	≤8.3	500	10	0.025ˠ

*These percentiles are calculated from 15 – 16 samples collected between 2010 and 2016.

ˠ The SEPP objective is for total phosphorus. Reactive phosphorus is a component of total phosphorus and therefore if the reactive phosphorus concentration exceeds the objective, the total phosphorus must also exceed the objective.

The South Durham Bridge site is situated between Reach 1 of this study (Yarrowee) and Mt Mercer. The data from the Mt Mercer Waterwatch site returned similar results to South Durham (and therefore is not shown here). However, the reactive phosphorus concentrations at the Mt Mercer Waterwatch site were slightly lower (0.19 mg/L) then the South Durham site upstream, suggesting that the inputs from Ballarat stormwater and the BSWWTP could be being partly processed by the stream. This is supported by the Mt Mercer WMIS site (Table 30) having a total phosphorus concentration that is also slightly lower than the reactive phosphorus concentration upstream at South Durham (Table 31).

Although instream processing may be contributing to a net uptake of phosphorus between South Durham and Mt Mercer, ongoing reductions do not appear to be occurring between Mt Mercer and Inverleigh, near the end of the Leigh River reach (Table 32). Table 32 shows water quality in the Leigh River near Inverleigh to be similar to that at Mt Mercer. The slight increase in phosphorus concentrations between the two sites indicates that any instream processing of nutrients that is occurring is negated by inputs from the local catchment (e.g. through erosion and stock access).

Table 32. Water quality data gathered by Waterwatch from the Leigh River at the Teesdale Road Bridge, Inverleigh.

Indicator		Dissolved oxygen (%sat)	pH	Electrical conductivity (µS/cm)	Turbidity (NTU)	Reactive phosphorus (mg/L)
25th percentile*		65	8.0	NA	NA	NA
75th Percentile (max for DO)*		80	8.4	1512	15.5	0.223
SEPP (WoV) objective (Coastal Plains)	25th percentile*	≥85	≥6.5	NA	NA	NA
	75th Percentile (max for DO)*	110 (max)	≤8.3	1500	10	0.045ɣ

*These percentiles are calculated from 60 – 70 samples collected between 2007 and 2015.

ɣ The SEPP objective is for total phosphorus. Reactive phosphorus is a component of total phosphorus and therefore if the reactive phosphorus concentration exceeds the objective, the total phosphorus must also exceed the objective.

Reach 3 - Upper Barwon West (upstream of Boundary Creek)

Water Measurement Information System

This reach had no active WMIS recording water quality. A site at the Compensation Weir Spillway recorded electrical conductivity and turbidity almost daily for a four-year period between 2002 and 2006. The 75th percentile recorded for electrical conductivity was 166 µS/cm (Otways SEPP objective = 500 µS/cm) and the 75th percentile for turbidity was 8 (SEPP objective = 5).

Waterwatch

There are two active Waterwatch sites on Upper Barwon West (upstream of Boundary Creek), one being the West Barwon River below West Barwon Reservoir at Forrest (156 visits between 1995 and 2018) and the other being the Barwon River at Seven Bridges Road (110 site visits between 2006 and 2016). The results for the West Barwon River at Forrest (in the Otways SEPP Segment) are shown in Table 33 and the results for the Barwon River at Seven Bridges Road (in the Coastal Plain SEPP Segment) are shown in Table 34.

Table 33. Water quality data gathered by Waterwatch from West Barwon River at Forrest.

Indicator		pH	Dissolved oxygen (%sat)	Electrical conductivity (µS/cm)	Turbidity (NTU)	Reactive phosphorus (mg/L)
25th percentile*		6.8	66	NA	NA	NA
75th Percentile*		7.5	86	180	10	0.03
SEPP (WoV) objective (Forests B: Otways)	25th percentile*	≥6.4	≥90	NA	NA	NA
	75th Percentile*	≤7.7	≤110	500	5	≤ 0.025ɣ

*These percentiles are calculated from 90 – 100 samples collected between 2004 and 2018.

ɣ The SEPP objective is for total phosphorus. Reactive phosphorus is a component of total phosphorus and therefore if the reactive phosphorus concentration exceeds the objective, the total phosphorus must also exceed the objective.

For the Barwon River, the township of Forrest is the interface between the start of the Coastal Plain and the end of the Otway forest. The water flows out of the West Barwon Reservoir and through a flat, broadening valley with riparian vegetation consisting mostly of grasses for pasture or recreation areas. As the vast majority of the catchment is the forested Otway Ranges (SEPP Forests B segment), the water quality at Forrest was assessed against the objectives for that segment (Table 33). The water in the reach near Forrest typically meets or is close to the objectives, with indications of inputs and reduced shading from the poor quality riparian zones leading to reduced dissolved oxygen concentrations and elevated phosphorus concentrations. As noted above, the reactive phosphorus concentrations breaching the objective is indicative of even greater breaches by total phosphorus concentrations.

Table 34. Water quality data gathered by Waterwatch from West Barwon River at Seven Bridges Road.

Indicator		pH	Dissolved oxygen (%sat)	Electrical conductivity (µS/cm)	Turbidity (NTU)	Reactive phosphorus (mg/L)
25th percentile*		5.8	50	NA	NA	NA
75th Percentile*		6.8	94	321	7	0.089
SEPP (WoV) objective (Coastal plains)	25th percentile*	≥6.5	≥85	NA	NA	NA
	75th Percentile*	≤8.3	≤110	1500	10	≤ 0.045[ɣ]

*These percentiles are calculated from 90 – 100 samples collected between 2004 and 2018.

ɣ The SEPP objective is for total phosphorus. Reactive phosphorus is a component of total phosphorus and therefore if the reactive phosphorus concentration exceeds the objective, the total phosphorus must also exceed the objective.

The Barwon River at Seven Bridges Road has traversed approximately 20 river kilometres from Forrest, through mostly open pastures in the Coastal Plain and is therefore assessed against the Coastal Plain SEPP objectives. As would be expected, phosphorus concentrations have increased and the lower dissolved oxygen concentrations have decreased to the extent that they each trigger the less stringent Coastal Plain objectives. Similarly, it is not unusual for electrical conductivities to increase with distance downstream, particularly through increasingly disturbed catchments. There are also some unexpected results for this site, with decreasing pH and turbidity measures. The lower turbidities, with the reduced dissolved oxygen 25th percentiles, may reflect less turbulent flows in this part of the reach. The reduced pH measures are difficult to interpret, although there is a possibility of some minor inputs of acid sulphate discharge to the river within this reach.

Reach 4 - Upper Barwon East

Water Measurement Information System

The Upper Barwon East Branch has an active site on the WMIS database, at Forrest, within the Forest B (Otways) water quality region and upstream of impacts from the Forrest township. The site has approximately monthly data from 1990 to 2018 for pH, electrical conductivity, turbidity, total phosphorus, oxides of nitrogen (nitrate and nitrite) and total Kjeldahl nitrogen (Table 35). The site is located next to the West Barwon Reservoir.

Table 35. Summarised water quality data from the WMIS database, for the Upper Barwon East Branch.

Indicator		pH	Electrical conductivity (µS/cm)	Turbidity (NTU)	Total nitrogen (mg/L) [ɣ]	Total phosphorus (mg/L)
1990 - 2018	25th percentile*	6.8	NA	NA	NA	NA
	75th Percentile*	7.3	176	6	0.383	0.4
SEPP (WoV) objective (Forests B: Otways)	25th percentile*	≥ 6.4	NA	NA	NA	NA
	75th Percentile*	≤7.7	≤ 500	≤ 5	≤ 0.350	≤ 0.025

ɣ calculated sum of oxides of nitrogen and total Kjeldahl nitrogen

The Upper Barwon East Branch results are indicative of a catchment with only minor disturbance pH and electrical conductivity were both well within their corresponding objectives, and turbidity and total nitrogen were only marginally above their objectives. Total phosphorus was slightly higher than a marginal exceedance and this may be indicative of runoff from tracks or some other causes of erosion.

Waterwatch

There are no Waterwatch sites on the Upper Barwon East Branch.

Reach 5 - Dewing Creek

Water Measurement Information System

This reach had no active WMIS recording water quality.

Waterwatch

There is one active Waterwatch site on Dewing Creek, which has 93 site visits between 2007 and 2018. The results for the site are shown in Table 36.

Table 36. Water quality data gathered by Waterwatch from Dewing Creek.

Indicator		pH	Dissolved oxygen (%sat)	Electrical conductivity (µS/cm)	Turbidity (NTU)	Reactive phosphorus (mg/L)
25th percentile*		6.3	77	NA	NA	NA
75th Percentile*		7.0	111	410	26	0.13
SEPP (WoV) objective (Coastal plains)	25th percentile*	≥6.5	≥85	NA	NA	NA
	75th Percentile*	≤8.3	≤110	1500	10	≤ 0.045[ϒ]

[ϒ] The SEPP objective is for total phosphorus. Reactive phosphorus is a component of total phosphorus and therefore if the reactive phosphorus concentration exceeds the objective, the total phosphorus must also exceed the objective.

The Dewing Creek results are indicative of agricultural influence with the catchment disturbance reflected in high turbidities as well as phosphorus concentrations reaching harmful levels for the instream biota. The particularly high reactive phosphorus may also indicate horticultural activities in the catchment or other inputs of fertilisers. The dissolved oxygen concentrations vary widely, indicating eutrophic conditions with high levels of photosynthesis during the day producing large amounts of oxygen and high levels of respiration during the night consuming large amounts of oxygen.

Reach 6 - Boundary Creek

Water Measurement Information System

Boundary Creek has an active site on the WMIS database, at Yeodene, approximately 4 km upstream of its confluence with the Barwon River. The creek could be placed in either the Forests B (Otways) water quality region or the Coastal Plains water quality region. Since the majority of the creek flows through a cleared, reasonably flat catchment, the site at Yeodene was classed as Coastal Plain.

The Yeodene site has data from 1990 to 2018 for pH, electrical conductivity, turbidity, total phosphorus, oxides of nitrogen (nitrate and nitrite) and total Kjeldahl nitrogen (Table 37). The site is near the lower end of the Boundary Creek catchment and therefore provides a good condition summary of its catchment. Over the full period of measurement, the 75th percentiles of total phosphorus concentrations and electrical conductivity were lower than their SEPP objectives whereas total nitrogen concentrations were approximately 3 times greater than the SEPP objective, and turbidity was one and a half times the objectives (Table 37). The greatest concern, however, is pH, which is substantially below the 25th percentile objective and is considered to be at harmfully low levels. The cause of the acidic conditions has been identified as the aeration of acid sulphate soils at Big Swamp (Yeodene Swamp). Low pH (acidic) conditions impact physiological function and dermal erosion of instream biota as well as leading to release of toxic concentrations of metals from the waterway sediments.

The summary statistics for the last 10 years are not substantially different to the longer term data for turbidity, total phosphorus or total nitrogen (although the total nitrogen concentration has dropped below the harmful level, it is still more than double the SEPP objective). Similarly, although the electrical conductivity 75th percentile has nearly doubled, it remains below the SEPP objective. The most significant change in water quality over the last 10 years is the 75th percentile for pH which has dropped to 4.1, indicating that harmful acidic conditions are now the normal situation for the reach.

Table 37. Summarised water quality data from the WMIS database, for Boundary Creek at Yeodene.

Indicator		pH	Electrical conductivity (µS/cm)	Turbidity (NTU)	Total nitrogen (mg/L) ɣ	Total phosphorus (mg/L)
1990 - 2018	25th percentile*	3.7	NA	NA	NA	NA
	75th Percentile*	5.6	628	15	1.81	0.03
2008 - 2018	25th percentile*	3.6	NA	NA	NA	NA
	75th Percentile*	4.1	1136	15	1.27	0.03
SEPP (WoV) objective	25th percentile*	≥ 6.5	NA	NA	NA	NA
	75th Percentile*	≤8.3 (Coastal Plains)	≤ 1500 (Coastal Plains)	≤ 10 (Coastal Plains)	≤ 0.6 (Coastal Plains)	≤ 0.045 (Coastal Plains)

ɣ calculated sum of oxides of nitrogen and total Kjeldahl nitrogen

Waterwatch

The only active Waterwatch site on Boundary Creek was at Yeodene, at the same location at the WMIS site. The site has been active for approximately 14 years with 142 site visits and data from 2004 to 2018 (Table 38). The SEPP (WoV) objectives were derived for annual assessments using monthly sampling data rather than sampling over several years. Nonetheless, these data provide useful background information on the condition of the waterway and their comparison against the SEPP objectives can be used as an indicative assessment.

Similar to the WMIS site data for the last 10 years, the Waterwatch data for the site indicates that the reach suffers from harmful acidic conditions for at least 75 percent of the time, that the electrical conductivity is approaching, but remains below, the SEPP objective and that the turbidity 75th percentile is above the objective without entering into harmful conditions. In contrast to the WMIS data, the Waterwatch data suggests that phosphorus concentrations in the reach exceed the SEPP Objective. Whereas the WMIS data set measures dissolved oxygen concentrations in mg/L and therefore cannot be compared with the SEPP Objectives, the Waterwatch data is measured in percent saturation and therefore can be assessed against the SEPP objectives. The data for Boundary Creek at Yeodene indicate considerable oxygen stress for the reach, with a 25 percentile of 30% saturation, likely to cause asphyxiation for some biota.

Table 38. Water quality data gathered by Waterwatch from Boundary Creek at Yeodene.

Indicator		pH	Dissolved oxygen (%sat)	Electrical conductivity (µS/cm)	Turbidity (NTU)	Reactive phosphorus (mg/L)
25th percentile*		3.5	30	NA	NA	NA
75th Percentile*		4.8	90	1124	17.5	0.07
SEPP (WoV) objective (Coastal plains)	25th percentile*	≥6.5	≥85	NA	NA	NA
	75th Percentile*	≤8.3	≤110	1500	10	≤ 0.045ɣ

*These percentiles are calculated from 90 – 100 samples collected between 2004 and 2018.

ɣ The SEPP objective is for total phosphorus. Reactive phosphorus is a component of total phosphorus and therefore if the reactive phosphorus concentration exceeds the objective, the total phosphorus must also exceed the objective.

Reach 7 - Barwon River (downstream of Boundary Creek)

Water Measurement Information System

The Barwon River (downstream of Boundary Creek to Birregurra Creek confluence) has an active site on the WMIS database, at Ricketts Marsh, approximately 2 km downstream of its confluence with Pennyroyal Creek. The reach is within the Coastal Plains water quality region.

The Ricketts Marsh site has approximately monthly data from 1991 to 2018 for pH, electrical conductivity, turbidity, total phosphorus, oxides of nitrogen (nitrate and nitrite) and total Kjeldahl nitrogen (Table 39). The site is near the reach and therefore provides a good condition summary of its catchment. pH and electrical conductivity both met their SEPP objectives, whereas turbidity and the nutrients each breached their objectives. This is indicative of inputs typical of grazed land – sediments from bed and bank erosion and animal droppings.

Table 39. Summarised water quality data from the WMIS database, for the Barwon River at Ricketts Marsh.

Indicator		pH	Electrical conductivity (µS/cm)	Turbidity (NTU)	Total nitrogen (mg/L) ˠ	Total phosphorus (mg/L)
1991 – 2018	25th percentile*	7.0	NA	NA	NA	NA
	75th Percentile*	7.4	1100	23	0.83	0.05
SEPP (WoV) objective	25th percentile*	≥ 6.5	NA	NA	NA	NA
	75th Percentile*	≤8.3 (Coastal Plains)	≤ 1500 (Coastal Plains)	≤ 10 (Coastal Plains)	≤ 0.6 (Coastal Plains)	≤ 0.045 (Coastal Plains)

ˠ calculated sum of oxides of nitrogen and total Kjeldahl nitrogen

Waterwatch

There are two active Waterwatch sites on Upper Barwon West (downstream of Boundary Creek), one being located within Birregurra and the other being further upstream, closer to Boundary Creek. The Birregurra site data is presented here as it provides a better summary of the condition of the catchment. The site has had 181 site visits between 1995 and 2018. The results are shown in Table 40.

Table 40. Water quality data gathered by Waterwatch from West Barwon River at Seven Bridges Road.

Indicator		pH	Dissolved oxygen (%sat)	Electrical conductivity (µS/cm)	Turbidity (NTU)	Reactive phosphorus (mg/L)
25th percentile*		7.0	58	NA	NA	NA
75th Percentile*		7.5	84	940	29	0.033
SEPP (WoV) objective (Coastal plains)	25th percentile*	≥6.5	≥85	NA	NA	NA
	75th Percentile*	≤8.3	≤110	1500	10	≤ 0.045ˠ

*These percentiles are calculated from 90 – 100 samples collected between 2004 and 2018.

ˠ The SEPP objective is for total phosphorus. Reactive phosphorus is a component of total phosphorus and therefore if the reactive phosphorus concentration exceeds the objective, the total phosphorus must also exceed the objective.

The Barwon River at Birregurra has passed through mostly open pastures in the Coastal Plain and is therefore assessed against the Coastal Plain SEPP objectives. The results are broadly similar to the nearby Ricketts Marsh site (Table 39), with pH and electrical conductivity both being below the SEPP objective while turbidity triggers its objective. Reactive phosphorus was below the SEPP objective for total phosphorus but this is expected as it is only a component of the total phosphorus. The low dissolved oxygen concentration for the 25th percentile may result from the inputs of nutrients and organic matter to the river. Field notes written by the samplers often noted that the river was low and/or not flowing which may also contribute to the low dissolved oxygen concentrations.

Reach 8 - Pennyroyal and Deans Marsh Creeks

Water Measurement Information System

This reach had no active WMIS recording water quality. A site at the railway culvert recorded electrical conductivity and turbidity almost daily for a four-year period between 2002 and 2006. The WMIS site is located in the lower reach of the creek (Coastal Plains SEPP segment). The 75th percentile recorded for electrical conductivity was 500 µS/cm (Coastal Plains SEPP objective = 1500 µS/cm) and the 75th percentile for turbidity was 15 (SEPP objective = 10).

Waterwatch

There are several active Waterwatch sites on Pennyroyal Creek. The lowest site is Pennyroyal Creek at Cape Otway Road (in the Coastal Plain SEPP Segment), which has 101 site visits between 2005 and 2018. The results for the site are shown in Table 41.

Table 41. Water quality data gathered by Waterwatch from Pennyroyal Creek at Cape Otway Road.

Indicator		pH	Dissolved oxygen (%sat)	Electrical conductivity (µS/cm)	Turbidity (NTU)	Reactive phosphorus (mg/L)
25th percentile*		6.8	88	NA	NA	NA
75th Percentile*		7.6	109	3187	26	0.085
SEPP (WoV) objective (Coastal plains)	25th percentile*	≥6.5	≥85	NA	NA	NA
	75th Percentile*	≤8.3	≤110	1500	10	≤ 0.045[¥]

¥ The SEPP objective is for total phosphorus. Reactive phosphorus is a component of total phosphorus and therefore if the reactive phosphorus concentration exceeds the objective, the total phosphorus must also exceed the objective.

Pennyroyal Creek at Cape Otway Road has passed through mostly open pastures in the Coastal Plain and is therefore assessed against the Coastal Plain SEPP objectives. The results are indicative of agricultural influence with reasonably good flows (?), the catchment disturbance reflected in high turbidities as well as phosphorus and electrical conductivity measurements reaching harmful levels for the instream biota. The particularly high reactive phosphorus may also indicate horticultural activities in the catchment or other inputs of fertilisers.

Reach 9 - Winchelsea

Water Measurement Information System

The Winchelsea Reach has an active site on the WMIS database, at Winchelsea, within the Coastal Plains water quality region. The Winchelsea site has approximately monthly data from 2015 to 2018 for pH, electrical conductivity, turbidity, total phosphorus, oxides of nitrogen (nitrate and nitrite) and total Kjeldahl nitrogen (Table 42). The site is approximately in the middle of the reach.

Table 42. Summarised water quality data from the WMIS database, for the Barwon River at Winchelsea.

Indicator		pH	Electrical conductivity (µS/cm)	Turbidity (NTU)	Total nitrogen (mg/L) [¥]	Total phosphorus (mg/L)
2005 - 2018	25th percentile*	7.2	NA	NA	NA	NA
	75th Percentile*	7.6	1558	22	0.98	0.073
SEPP (WoV) objective	25th percentile*	≥ 6.5	NA	NA	NA	NA
	75th Percentile*	≤8.3 (Coastal Plains)	≤ 1500 (Coastal Plains)	≤ 10 (Coastal Plains)	≤ 0.6 (Coastal Plains)	≤ 0.045 (Coastal Plains)

¥ calculated sum of oxides of nitrogen and total Kjeldahl nitrogen pH was the only indicator to meet its SEPP objectives, with all other indicators triggering without reaching known harmful levels. Turbidity and total phosphorus, however, are approaching levels that are considered to cause harm. These results are indicative of inputs typical of grazed land – sediments and nutrients from bed and bank erosion and animal droppings.

Waterwatch

There are two active Waterwatch sites in the Winchelsea Reach, one being located within Winchelsea and the other being further downstream, close to the Leigh River confluence. The Winchelsea site data is presented here as it complements the WMIS data. Also, it was uncertain as to whether the site near the Leigh River confluence could be affected by any backflow from the Leigh River. The site has had 194 site visits between 1995 and 2018. The results are shown in Table 43.

Table 43. Water quality data gathered by Waterwatch from West Barwon River at Seven Bridges Road.

Indicator		pH	Dissolved oxygen (%sat)	Electrical conductivity (µS/cm)	Turbidity (NTU)	Reactive phosphorus (mg/L)
25th percentile*		7.0	62	NA	NA	NA
75th Percentile*		7.6	88	1510	24	0.05
SEPP (WoV) objective (Coastal plains)	25th percentile*	≥6.5	≥85	NA	NA	NA
	75th Percentile*	≤8.3	≤110	1500	10	≤ 0.045Ɏ

*These percentiles are calculated from 90 – 100 samples collected between 2004 and 2018.

Ɏ The SEPP objective is for total phosphorus. Reactive phosphorus is a component of total phosphorus and therefore if the reactive phosphorus concentration exceeds the objective, the total phosphorus must also exceed the objective.

The Barwon River at Winchelsea has passed through mostly open pastures in the Coastal Plain and is therefore assessed against the Coastal Plain SEPP objectives. The results are broadly similar to the WMIS site near this location (Table 42), with pH meeting the SEPP objective while electrical conductivity narrowly triggers its objective and turbidity is more than double its SEPP objective. Reactive phosphorus was above the SEPP objective for total phosphorus and this is a concern as it is only a component of the total phosphorus. The low dissolved oxygen concentration for the 25th percentile may result from the inputs of nutrients and organic matter to the river.

Reach 10 - Lower Barwon

Water Measurement Information System

The Lower Barwon - Murgheboluc Reach has an active site on the WMIS database, at Pollocksford Road, within the Coastal Plains water quality region and upstream of the urban influences of Geelong. The Pollocksford site has approximately monthly data from 1990 to 2018 for pH, electrical conductivity, turbidity, total phosphorus, oxides of nitrogen (nitrate and nitrite) and total Kjeldahl nitrogen (Table 44). The site is in the middle to lower end of the reach.

Table 44. Summarised water quality data from the WMIS database, for the Barwon River at Pollocksford Road.

Indicator		pH	Electrical conductivity (µS/cm)	Turbidity (NTU)	Total nitrogen (mg/L) Ɏ	Total phosphorus (mg/L)
2005 - 2018	25th percentile*	7.6	NA	NA	NA	NA
	75th Percentile*	8.1	2200	18	167	0.110
SEPP (WoV) objective	25th percentile*	≥ 6.5	NA	NA	NA	NA
	75th Percentile*	≤8.3 (Coastal Plains)	≤ 1500 (Coastal Plains)	≤ 10 (Coastal Plains)	≤ 0.6 (Coastal Plains)	≤ 0.045 (Coastal Plains)

Ɏ calculated sum of oxides of nitrogen and total Kjeldahl nitrogen pH was the only indicator to meet its SEPP objectives, with all other indicators triggering. Electrical conductivity and turbidity triggered their objectives without reaching known harmful levels whereas total nitrogen and total phosphorus both reached concentrations that are likely to lead to eutrophic conditions. These results are again indicative of inputs typical of grazed land – sediments and nutrients from bed and bank erosion and animal droppings.

Waterwatch

There are several active Waterwatch sites in this Reach, one being located close to the WMIS Pollocksford Road site, and its data is presented here as it complements the WMIS data. The site has had 202 site visits between 1995 and 2018. The results are shown in Table 45.

Table 45. Water quality data gathered by Waterwatch from the Barwon River at Pollocksford Road.

Indicator		pH	Dissolved oxygen (%sat)	Electrical conductivity (µS/cm)	Turbidity (NTU)	Reactive phosphorus (mg/L)
25th percentile*		7.0	62	NA	NA	NA
75th Percentile*		7.6	88	1510	24	0.05
SEPP (WoV) objective (Coastal plains)	25th percentile*	≥6.5	≥85	NA	NA	NA
	75th Percentile*	≤8.3	≤110	1500	10	≤ 0.045[Ɣ]

[Ɣ] The SEPP objective is for total phosphorus. Reactive phosphorus is a component of total phosphorus and therefore if the reactive phosphorus concentration exceeds the objective, the total phosphorus must also exceed the objective.

Similar to the upstream reaches, the Barwon River at Pollocksford Road has passed through mostly open pastures in the Coastal Plain and is therefore assessed against the Coastal Plain SEPP objectives. The results are broadly similar to the WMIS site near this location (Table 44), with pH meeting the SEPP objective while electrical conductivity narrowly triggers its objective and turbidity is more than double its SEPP objective. Reactive phosphorus was above the SEPP objective for total phosphorus and this is a concern as it is only a component of the total phosphorus. The low dissolved oxygen concentration for the 25th percentile may result from the inputs of nutrients and organic matter to the river.

Appendix I:

Hydraulic modelling

Appendix I: Hydraulic modelling

Hydraulic parameters

Table 46 lists the boundary conditions and hydraulic roughness adopted for each model. These parameters were adopted on the basis of the calibration, field observations and aerial photography.

Table 46. Hydraulic parameters adopted in HEC-RAS.

Reach		Manning's roughness – channel	Manning's roughness – floodplain	Downstream boundary (Normal depth)
1	Yarrowee	0.045	0.05	0.0041
2	Leigh	0.052	0.03	0.003
3	Upper Barwon West	0.042	0.05	0.0018
4	Upper Barwon East	0.06	0.05	0.0006
5	Dewing Creek	0.035	0.05	0.00355
6	Boundary Creek	0.046	0.03	0.0088
7	Barwon (d/s Boundary Creek)	0.07	0.05	0.002
8	Pennyroyal and Deans Marsh Creeks	0.075	0.05	0.0069
9	Winchelsea	0.044	0.03	0.00089
10	Lower Barwon	0.056	0.06	0.0034

Appendix J:

Average annual flows and shortfalls

Appendix J: Shortfalls and compliance

Average annual flows and shortfalls

The tables below detail the estimated average annual flows and shortfalls for the various climate conditions. The shortfall is the difference between current average annual flows and proposed average annual flows.

All climate conditions:

Reach		Natural	Current	Proposed	Shortfall
Reach 1	Average annual flow (ML/yr)	60697	49294	53742	4448
	% of natural flow		81%	89%	
Reach 2	Average annual flow (ML/yr)	71999	55760	66240	10480
	% of natural flow		77%	92%	
Reach 3	Average annual flow (ML/yr)	103529	83236	93013	9776
	% of natural flow		80%	90%	
Reach 4	Average annual flow (ML/yr)	6957	7531	8269	738
	% of natural flow		108%	119%	
Reach 5	Average annual flow (ML/yr)	15920	15023	16777	1754
	% of natural flow		94%	105%	
Reach 6	Average annual flow (ML/yr)	5303	3255	5092	1837
	% of natural flow		61%	96%	
Reach 7	Average annual flow (ML/yr)	158510	75998	102890	26892
	% of natural flow		48%	65%	
Reach 8	Average annual flow (ML/yr)	6745	7719	8359	640
	% of natural flow		114%	124%	
Reach 9	Average annual flow (ML/yr)	180359	96668	126353	29685
	% of natural flow		54%	70%	
Reach 10	Average annual flow (ML/yr)	287405	173033	217451	44419
	% of natural flow		60%	76%	

Dry years:

Reach		Natural	Current	Proposed	Shortfall
Reach 1	Average annual flow (ML/yr)	12508	19033	27595	8562
	% of natural flow		152%	221%	
Reach 2	Average annual flow (ML/yr)	14149	20699	37698	16999
	% of natural flow		146%	266%	
Reach 3	Average annual flow (ML/yr)	83057	53299	67286	13987
	% of natural flow		64%	81%	
Reach 4	Average annual flow (ML/yr)	3589	3663	5007	1345
	% of natural flow		102%	140%	
Reach 5	Average annual flow (ML/yr)	7755	6114	9371	3256
	% of natural flow		79%	121%	
Reach 6	Average annual flow (ML/yr)	7175	4185	5826	1642
	% of natural flow		58%	81%	
Reach 7	Average annual flow (ML/yr)	110001	25726	69093	43367
	% of natural flow		23%	63%	
Reach 8	Average annual flow (ML/yr)	3279	3396	4470	1074
	% of natural flow		104%	136%	
Reach 9	Average annual flow (ML/yr)	119998	35205	85808	50602
	% of natural flow		29%	72%	
Reach 10	Average annual flow (ML/yr)	141595	63407	144242	80835
	% of natural flow		45%	102%	

Average years:

Reach		Natural	Current	Proposed	Shortfall
Reach 1	Average annual flow (ML/yr)	55263	45327	49040	3713
	% of natural flow		82%	89%	
Reach 2	Average annual flow (ML/yr)	62908	49670	59722	10052
	% of natural flow		79%	95%	
Reach 3	Average annual flow (ML/yr)	101805	81094	89952	8857
	% of natural flow		80%	88%	
Reach 4	Average annual flow (ML/yr)	6199	6707	7203	496
	% of natural flow		108%	116%	
Reach 5	Average annual flow (ML/yr)	14171	13292	14622	1330
	% of natural flow		94%	103%	
Reach 6	Average annual flow (ML/yr)	5212	3345	5020	1675
	% of natural flow		64%	96%	
Reach 7	Average annual flow (ML/yr)	151459	67597	92118	24521
	% of natural flow		45%	61%	
Reach 8	Average annual flow (ML/yr)	6113	7178	7700	523
	% of natural flow		117%	126%	
Reach 9	Average annual flow (ML/yr)	171955	85532	112184	26652
	% of natural flow		50%	65%	
Reach 10	Average annual flow (ML/yr)	260463	150798	189866	39068
	% of natural flow		58%	73%	

Wet years:

Reach		Natural	Current	Proposed	Shortfall
Reach 1	Average annual flow (ML/yr)	119280	87144	88884	1740
	% of natural flow		73%	75%	
Reach 2	Average annual flow (ML/yr)	147241	102471	107251	4780
	% of natural flow		70%	73%	
Reach 3	Average annual flow (ML/yr)	127299	117272	124596	7324
	% of natural flow		92%	98%	
Reach 4	Average annual flow (ML/yr)	11776	12975	13570	595
	% of natural flow		110%	115%	
Reach 5	Average annual flow (ML/yr)	27431	27242	28306	1064
	% of natural flow		99%	103%	
Reach 6	Average annual flow (ML/yr)	4195	2405	4737	2332
	% of natural flow		57%	113%	
Reach 7	Average annual flow (ML/yr)	220505	142341	157296	14955
	% of natural flow		65%	71%	
Reach 8	Average annual flow (ML/yr)	11419	13078	13507	430
	% of natural flow		115%	118%	
Reach 9	Average annual flow (ML/yr)	256798	179433	194003	14570
	% of natural flow		70%	76%	
Reach 10	Average annual flow (ML/yr)	484754	325195	343432	18237
	% of natural flow		67%	71%	

Compliance

An assessment of the performance of the updated environmental flow recommendations against the observed gauge records has been undertaken to demonstrate the achievement and shortfalls associated with current water management in the system.

Reach	Dry period low flow	Wet period low flow	Dry period fresh (dry)	Dry period fresh (ave)	Dry period fresh (wet)	Wet period fresh (dry)	Wet period fresh (ave)	Wet period fresh (wet)	Bankfull	Overbank
Reach 1	98%	100%		69%	69%	94%	68%	39%	24%	
Reach 2	97%	100%		83%	62%	82%	61%	20%		44%
Reach 3	74%	70%	84%	84%	49%	56%	50%	30%	79%	
Reach 4	99%	67%	57%	57%	44%		83%	41%	90%	57%
Reach 5	91%	70%	79%	71%	46%	96%	73%	26%	69%	
Reach 6	46%	32%	15%	8%	5%		17%	17%	21%	26%
Reach 7	28%	63%	30%	20%	6%	59%	59%	15%	78%	
Reach 8	99%	76%	59%	18%	18%	97%	62%	46%	96%	88%
Reach 9	42%	55%	58%	44%	7%	57%	57%	12%		
Reach 10	58%	60%	46%	35%	18%	73%	56%	15%		37%

Appendix K:

2006 and 2019 flow recommendation comparison

Appendix K: 2006 and 2019 flow recommendation comparison

There have been a number of changes since the 2006 FLOWS study was completed, including updates to the FLOWS methodology, increased scientific knowledge and modelling capabilities and changes to community priorities, as reflected in an updated Project Advisory Group. Throughout this project we have also updated the delineation of a number of reaches. Given these changes, we have not sought to maintain the recommendations developed in the previous study and have applied the FLOWS 2 methodology to develop new recommendations. This has meant that the new recommendations vary, sometimes considerably, from the 2006 recommendations.

A comparison of the recommendations from the 2006 FLOWS study (Lloyd Environmental, 2006) and the recommendations set out in this study is provided below. Recommendations have only been compared for reaches and sites that are comparable as detailed in Table 1.

Reach 2 – Leigh (Lower Leigh)

The 2019 flow recommendations are for the Leigh River include higher dry period low flows, with the addition of dry period freshes. The 2006 wet period fresh, bank full and overbank recommendations appear ambitious, with the 2019 recommendations including a lower wet period fresh and an overbank flow that achieves the objectives of a bankfull flow.

Period	Flow component	Magnitude (ML/day)		Frequency		Duration	
		2006	2019	2006	2019	2006	2019
Dry	Low flow	8	30	Continuous	Continuous	Continuous	Continuous
Dry	Fresh	-	120	-	2 per period	-	3 days
Wet	Low flow	52	50	Continuous	Continuous	Continuous	Continuous
Wet	Fresh	2217	400	2	3 per period	8 days	4 days
Anytime	Bankfull	8476	-	1 in 5 yr	-	17 days	-
Anytime	Overbank	11000	6000	1 in 5 yr	1 in 3 yr	22 days	1 to 2 days

Reach 3 – Upper Barwon West (Barwon River at Upper Barwon)

The 2019 flow recommendations include higher dry and wet period low flows, with dry period freshes at a lower magnitude, more frequent and for a longer duration. 2019 wet period fresh recommendations are for a higher magnitude, more often and slightly longer duration than the 2006 recommendations. Bankfull flows are similar with a higher magnitude, but lower frequency in the 2019 recommendations.

Note that the 2006 study Barwon River at Upper Barwon reach covers the 2019 Upper Barwon West and Barwon Downstream of Boundary Creek reaches. The hydraulic modelling site utilised in the 2006 study is the same as that used in the Upper Barwon West in this study.

Period	Flow component	Magnitude (ML/day)		Frequency		Duration	
		2006	2019	2006	2019	2006	2019
Dry	Low flow	5	30	Continuous	Continuous	Continuous	Continuous
Dry	Fresh	215	100	2 to 3 per yr	5 per period	2 days	6 days
Wet	Low flow	50	100	Continuous	Continuous	Continuous	Continuous
Wet	Fresh	153	330	2 to 3 per period	6 per period	5 days	6 days
Anytime	Bankfull	1600	2100	1 in 1 yr	2 in 3 yrs	7-10 days	1 to 2 days
Anytime	Overbank	-	-	-	-	-	-

Reach 6 – Boundary Creek

The 2006 recommendations provided a cease-to-flow. This is accounted for in an 'or natural' clause for the 2019 dry period low flow recommendation. A dry period fresh has been added in the 2019 recommendations, as well as a higher magnitude wet period low flow. 2019 wet period fresh recommendations were at a higher magnitude, but fewer per period and shorter duration (i.e. a 'flashier' flow). A bankfull flow has been added in 2019, along with a much higher, less frequent and shorter duration overbank flow.

Period	Flow component	Magnitude (ML/day)		Frequency		Duration	
		2006	2019	2006	2019	2006	2019
Dry	Cease-to-flow	-	-	2 per yr	-	2 weeks	-
Dry	Low flow	1	1	Continuous	Continuous	Continuous	Continuous
Dry	Fresh	-	30 / 55	-	2 per period (1 of 55 ML)	-	2 days
Wet	Low flow	1	8	Continuous	Continuous	Continuous	Continuous
Wet	Fresh	64	120	4 per period	3 per period	6 days	2 days
Anytime	Bankfull		550		2 in 3 yrs		1 to 2 days
Anytime	Overbank	137	800	1 in 2 yrs	1 in 4 yrs	9 days	1 to 2 days

Reach 9 – Winchelsea

The 2019 recommendations include increased low flows in both the dry and wet periods, with a higher magnitude dry period fresh that occurs more often. The 2019 wet period fresh recommendation is much lower magnitude, with no bankfull or overbank flow.

Period	Flow component	Magnitude (ML/day)		Frequency		Duration	
		2006	2019	2006	2019	2006	2019
Dry	Low flow	12	50	Continuous	Continuous	Continuous	Continuous
Dry	Fresh	175	230	2 per yr	3 per period	4 days	4 days
Wet	Low flow	120	150	Continuous	Continuous	Continuous	Continuous
Wet	High flow	240	-	1-2 per yr	-	14 days	-
Wet	Fresh	2400	750	3-5 per yr	3 per period	7 days	5 days
Anytime	Bankfull	12000	-	1 per yr	-	12 days	-
Anytime	Overbank	30000	-	1 in 5 yrs	-	16 days	-

Reach 10 - Lower Barwon (Murgheboluc Valley)

The 2019 recommendation is for higher dry and wet period low flows, with lower magnitude, more frequent freshes. The 2019 recommendation for a much lower overbank flow will inundate the inset floodplain in this reach and fulfils the requirements of a bankfull flow.

Period	Flow component	Magnitude (ML/day)		Frequency		Duration	
		2006	2019	2006	2019	2006	2019
Dry	Low flow	22	70	Continuous	Continuous	Continuous	Continuous
Dry	Fresh	498	350	2 per yr	3 per period	5 days	8 days
Wet	Low flow	56	280	Continuous	Continuous	Continuous	Continuous
Wet	High flow	196	-	1-2 per yr	-	14 days	-
Wet	Fresh	11000	1300	2 per yr	3 per period	10 days	5 days
Anytime	Bankfull	28000	-	Every 1.5 yrs	-	15 days	-
Anytime	Overbank	40000	8000	1 in 10 yrs	2 in 3 yrs	17 days	1 to 2 days