Latrobe Valley Regional Water Study – Ecological Effects Assessment

DELWP Cover Note

November 2020

The 'Ecological Effects Assessment' (EEA)[1], was commissioned by the Department of Environment, Land, Water and Planning (DELWP) as part of the *Latrobe Valley Regional Water Study* and was used to inform the development of the *Latrobe Valley Regional Rehabilitation Strategy* (LVRRS). The EEA's authors, Jennifer Hale and colleagues, are independent scientists with expertise in aquatic ecology.

The EEA provides Government with scenario-based evidence to inform policy development. Specifically, the EEA answers the following question:

If surface water from the Latrobe River system currently permitted to be used for power generation was permitted to be used for mine rehabilitation once power generation ceases, what would be the likely effects of these ongoing extractions on the aquatic ecosystems of the Latrobe River system?

The approach taken to answering this question was to assess and compare the likely impacts of flows on the ecology of the Latrobe River system under five different climate and water-use scenarios. One scenario assumes less water use than current, two scenarios are based on current water use, and two further scenarios assume higher than current use.[2]

The key conclusions of the EEA are that:

- If water from the Latrobe River system continues to be taken and used at current rates, under a drier future climate this would lead to a decline in the environmental values of the Latrobe system and a loss of biodiversity.
- These declines would be exacerbated if there was an increase in the amount of water extracted from the system.
- Decreases in water availability in the Latrobe River system from increased extraction and/or reduction in return flows from power stations would lead to the emergence of multiple and interconnected threats, resulting in loss of the environmental, Aboriginal cultural and social values of the Latrobe River, its estuary and the Ramsar-listed Gippsland Lakes.

Like the Latrobe River, the Thomson-Macalister (and Avon) Rivers flow into Lake Wellington. The impacts of diversions from individual waterways on receiving waters—the Lower Latrobe wetlands and Gippsland Lakes—are cumulative. Nevertheless, consumptive use from these rivers is independent of potential extractions from the Latrobe system for the purposes of mine rehabilitation, and therefore, the EEA is focused on the latter. (Refer to the text box 'Water resource use in the Thomson River Basin' on page 28 of the report for further information.)

The *Latrobe Valley Regional Rehabilitation Strategy* includes a principle — any water used for mine rehabilitation should not negatively impact on Traditional Owners' values, environmental values of the Latrobe River system or the rights of other existing water users. The LVRRS also notes that to protect the security of existing entitlements for other water users and prevent further environmental impacts, "…the maximum annual supply of water for mine rehabilitation would need to be no more than the power stations' current annual net usage, and may need to be limited to a volume smaller than this", should the Minister for Water decide to permit the take and use of water for the purpose of mine rehabilitation. The findings of the EEA, along with other studies, informed this position.

[1] Formal citation for report: Hale, J., Boon, P., Lloyd, L., Vietz, G. and Jempson, M. (2020) *Latrobe Valley Regional Water Study – Ecological Effects Assessment.* A report to the Department of Environment, Land, Water and Planning.

[2] The EEA was informed by Alluvium (2020) *Latrobe environmental water requirements investigation*, dated June 2020. A copy of this report is available at: https://www.water.vic.gov.au/planning/LVRRS/support

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The authors would like to thank the steering committee members, representing DELWP, and West and East Gippsland Catchment Management Authorities for their advice and insights. Thanks also to Alluvium for sharing their modelling and outputs of the Latrobe Flows Assessment.

Photo credit: Australasian darter at Sale Common, Sean Phillipson.

Executive summary

The Latrobe Valley holds significant brown coal reserves and there are three open-cut mines in the region at Hazelwood, Loy Yang and Yallourn. These mines are all large, each extending over 12 km^2 and with a combined void space of around 2800 GL (million cubic metres). The Hazelwood mine closed in March 2017, and the Yallourn and Loy Yang mines are scheduled for closure in 2032 and 2048 respectively.

The Victorian Government initiated the Latrobe Valley Regional Rehabilitation Strategy (LVRRS), which aims to address some of the identified knowledge gaps and specifically investigate the feasibility of water based rehabilitation for the Latrobe Valley coal mines. This project - the Latrobe Valley Regional Water Study - Ecological Effects Assessment - seeks to assess the potential environmental effects on the region's aquatic ecosystems that would arise from altered hydrology that would be caused if different volumes of water were permitted to be used from the Latrobe River system for mine rehabilitation.

The aquatic ecosystems of the Latrobe Valley that could potentially be affected by mine rehabilitation extend from the Tanjil and Tyers Rivers downstream of Blue Rock and Moondarra Reservoirs respectively to Lake Wellington in the Gippsland Lakes and include the Morwell River and Traralgon Creek which currently receive water discharges from power station operations. These ecosystems support significant ecological values, and the end of the system contains the internationally listed Gippsland Lakes Ramsar Site.

The condition of aquatic ecosystems in the region has been affected by a number of factors including water resource use and climate change, which have resulted in a reduction in ecologically important flow regimes. Despite this, much of the system retains high ecological and geomorphological values including:

- the Latrobe River Silt jetties, which are of State geomorphic significance;
- a mosaic of freshwater dependent vegetation communities such as the bioregionally endangered Floodplain Riparian Woodland that lines the Latrobe River, as well as swamp paperbark, tall marsh and submerged macrophytes in the Lower Latrobe Wetlands;
- a diverse estuarine and freshwater fish community that includes a number of diadromous species that move between fresh, estuarine and / or marine habitats to complete their lifecycle such as the nationally vulnerable Australian grayling; and
- a large number of waterbird species that forage and breed in the wetlands of the system including threatened and internationally protected species.

These ecological values provide important ecological functions and ecosystem services including significant Traditional Owner cultural values as well as tourism, recreation and amenity.

This report compares risk to ecological values under five scenarios:

1. Natural (current climate) – what the system would look like under current climatic conditions but with no extraction from the Latrobe River. This is the base case against which the effects of water resource extraction and climate change are evaluated.
2. Current conditions (current climate) – what the system is experiencing now, with current water use and current climatic conditions.
3. Current conditions (future climate) – what if the amount of water extracted remained the same as today but the climate continues to dry.
4. Full uptake (current climate) – what would happen if additional water were used for mine rehabilitation under current climatic conditions.
5. Full uptake (future climate) – what would happen if additional water were used for mine rehabilitation and the climate continues to dry.

Hydrological modelling indicates that climate change and continued water use at current levels will have further highly adverse impacts on hydrological regimes, and that a full uptake of water entitlements for mine rehabilitation would exacerbate the effects of insufficient flows in this heavily flow-stressed river system. It is expected that a continued decline in water availability for the ecologically important components of the flow regime (e.g. baseflows, freshes and bankfull/overbank flows) will have escalating impacts on the ecological condition of the system.

Rivers, estuaries and wetlands, like all ecosystems, adapt to changes in the environment. In terms of reduced freshwater inflows and increased salinity, it is likely that there will be a transition to more terrestrial environments and salt-tolerant biota. This change will be at the expense of freshwater dependent values and most likely represent a reduction in biodiversity. As it is, there remains only one natural freshwater wetland (Sale Common) in the Gippsland Lakes Ramsar Site. To maintain freshwater dependent values and meet the management objectives for the Latrobe River (developed in conjunction with the local community), more fresh water for the environment is required − not less − and will need to be carefully managed to optimise ecological outcomes.

Further impacts to the system, through continued and increasing water extraction will undermine the resilience of ecosystems and the biota they support to future changes in climate and other stresses. While the system has proven resilient so far to reduced flow by maintaining much of its ecological values, there will be thresholds beyond which the system cannot recover. It is vital that we manage water extraction from the system within these thresholds of resilience.

The key messages of this EEA are:

- Continued water resource use under a future drier climate will lead to the decline in environmental values of the Latrobe system and a loss of biodiversity. This would be exacerbated if there were to be an increased or full uptake of mine operators' entitlements for mine rehabilitation.
- Decreases in water availability in the Latrobe system (from continued or increasing abstraction to fill mine pits) will result in multiple and interconnected threats resulting in loss of ecosystem and social values of the Latrobe River, its estuary and the Lakes. These losses will stem from:
    - Altered river channel geomorphology which will impact on habitat for fish and other biota as well as productivity
    - Decreased native fish breeding and recruitment
    - Decreased abundance and diversity of native fish
    - Decreased success of waterbird breeding
    - Decreased abundance and diversity of water birds
    - Decreased abundance and reproduction of frogs and turtles
    - Decreased condition and diversity of wetland vegetation
- Hydrology, salinity, vegetation, fish and waterbirds are all identified as critical to the ecological character of the Gippsland Lakes Ramsar Site. The predicted impacts from reduced flows in the Latrobe River to the aquatic ecosystems of the Lower Latrobe Wetlands, Lake Wellington and the Latrobe Estuary have implications with respect to Australia's obligations under the Ramsar Convention.
- Harvesting floods to fill pit lakes would have negative impacts to the system, particularly for Lake Wellington and the Lower Latrobe Wetlands. It will potentially lead to a change in the ecological character of the Gippsland Lakes Ramsar Site, which would have national and international implications.

Any decline in condition and loss of values in the Latrobe region would have implications for Traditional Owners with a loss of values associated with healthy waters and indigenous fisheries*.* There would also be impacts to the social and economic activities that rely on healthy wetlands and rivers, impacting on tourism, recreation and community well-being.

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1 Introduction

1.1 Context

The Latrobe Valley is an inland portion of the Latrobe River Basin, between the Strzelecki and Baw Baw Ranges in West Gippsland, Victoria. The Valley holds large reserves of brown coal, with an estimated resource of 65 billion tonnes, half of which is considered economically viable to extract. The brown coal reserves of the Latrobe Valley are found near the surface and there are three open-cut mines in the region at Hazelwood, Loy Yang and Yallourn (Figure 1). These mines are all large, each extending over 12 square kilometres and with a combined void space of 2800 gigalitres (GL; million cubic metres). The Hazelwood mine closed in March 2017, and the Yallourn and Loy Yang mines are scheduled for closure in 2032 and 2048 respectively (Latrobe Valley Mine Rehabilitation Commissioner 2018).

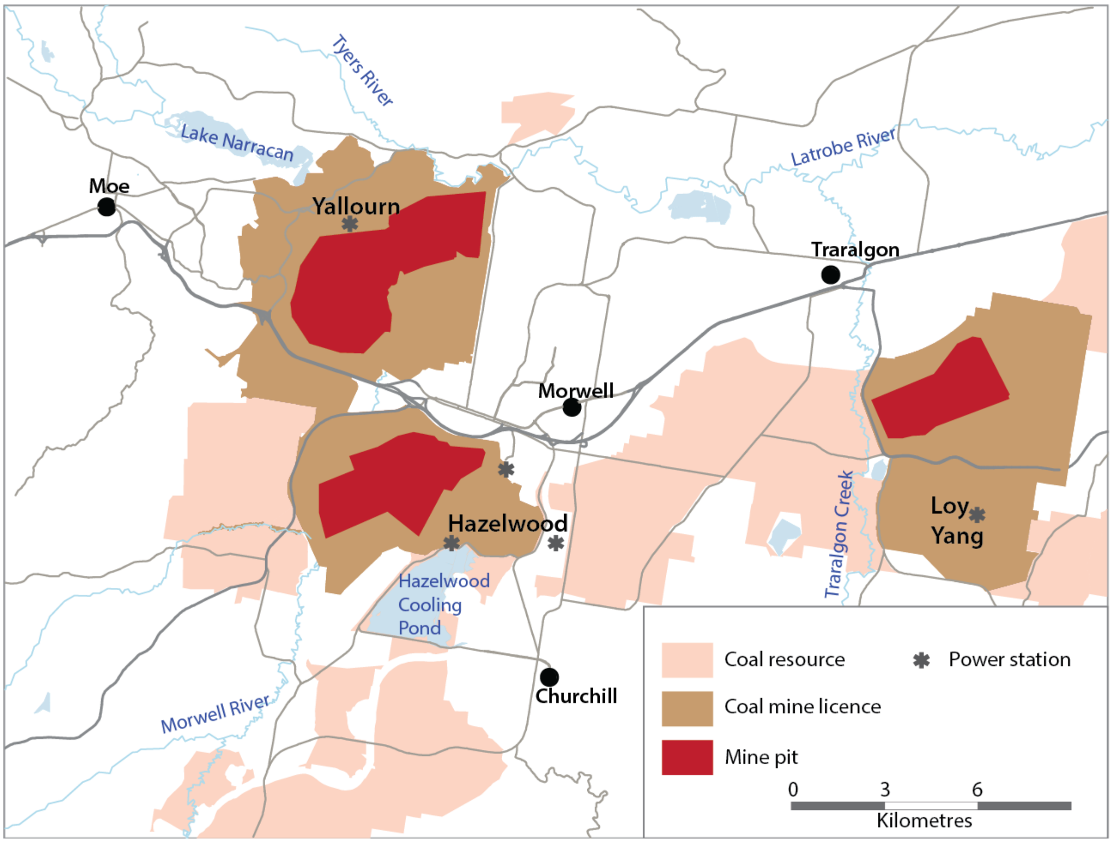


Figure 1: Latrobe Valley mine locations (adapted from Department of Economic Development, Jobs, Transport and Resources and Victoria 2018).

A fire at the Hazelwood mine in 2014, which had many adverse impacts on local communities, was the subject of the Hazelwood Mine Fire Inquiry[3]. The inquiry found significant knowledge gaps and uncertainties surrounding the closure and rehabilitation of the Latrobe Valley's three brown coal mines. Of most relevance to this report, the inquiry found that, with the current knowledge available, some form of pit lake was the most viable rehabilitation option for the coal mine voids, but that there remain many unanswered questions concerning the feasibility of pit lakes as a rehabilitation option.

In response to the findings of the Hazelwood Mine Fire Inquiry, The Victorian Government initiated the Latrobe Valley Regional Rehabilitation Strategy (LVRRS), which aims to address some of the identified knowledge gaps and specifically investigate the feasibility of pit lake rehabilitation for the Latrobe Valley coal mines.

The LVRRS is to be delivered by June 2020, and its preparation will involve a suite of technical studies covering hydrology, hydrogeology, geotechnical aspects, water quality, geochemistry, statutory/regulatory and environmental, socioeconomic and cultural impacts. In essence, the

[3] http://report.hazelwoodinquiry.vic.gov.au/

objective of the LVRRS technical investigation program is to (Department of Economic Development, Jobs, Transport and Resources and Victoria 2018):

"*determine if the pit lakes option can deliver a safe, stable and sustainable rehabilitation solution for the Latrobe Valley in the context of limited water availability, a sensitive downstream environment, climate change, aboriginal and non-aboriginal heritage values, and strong community interest in achieving a final landform that can support beneficial land uses*."

As part of this technical investigation, this project - the Latrobe Valley Regional Water Study - Ecological Effects Assessment - seeks to assess the potential environmental effects arising for altered hydrology of the pit lake option for mine rehabilitation on the aquatic ecosystems of the region.

1.2 Objectives

The objectives of the Latrobe Valley Regional Water Study - Ecological Effects Assessment (EEA) are to:

- identify the values of the aquatic ecosystems that could be affected by the use of water from the Latrobe River system for mine rehabilitation,
- describe current condition and existing trajectories of change, with respect to those values,
- determine the potential effects of mine rehabilitation on aquatic ecosystems, and
- recommend mechanisms for potentially improving the condition of the region's aquatic ecosystems.

1.3 Approach

The Ecological Effects Assessment was based on information from multiple lines of evidence. The identification of values and their current ecological condition was compiled from a thorough review of the grey and scientific literature. The environmental water requirements to maintain those values in the Latrobe River, Latrobe Estuary and the Lower Latrobe Wetlands was provided by the recent update to the Latrobe Environmental Flows Assessment (Alluvium 2020). The Flows Assessment identifies the important components of the river flow and wetland water regimes, and provides quantitative recommendations with respect to volumes, duration, frequency and timing of flows to maintain the ecological and cultural values of the Latrobe River system, including the Latrobe Estuary and Lower Latrobe Wetlands.

The EEA has used the outputs of the Latrobe Environmental Flows Assessment[4] (Alluvium 2020) as the basis for evaluating the potential impacts of pit lakes as an option for mine rehabilitation in the context of water resource use and climate change. It was informed with the input of a steering committee comprising representatives of the Department of Environment, Land Water and Planning (DELWP) and West Gippsland Catchment Management Authority (CMA).

It should be noted that this is not a formal Environmental Effects Statement, developed in accordance with the *Environment Effects Act 1978*. That process requires a detailed design of the action, in this case mine rehabilitation, to be defined in terms of construction and operational procedures. This level of detail has not yet been defined, and in some respects will be informed by the LVRRS.

[4] The Latrobe Environmental Flows Assessment was informed with the input of a steering committee comprising representatives of the Department of Environment, Land Water and Planning (DELWP), West Gippsland Catchment Management Authority (CMA), Gunaikurnai Land and Waters Aboriginal Corporation (GLaWAC), Victorian Environmental Water Holder (VEWH) and East Gippsland CMA, and an advisory group which included representatives from Gippsland Water, Southern Rural Water, Field and Game Australia, VRFish, Native Fish Australia, and Latrobe Valley Field Naturalists, as well as landholders whose properties adjoin the river.

2 Values, current condition and trends

2.1 Which aquatic ecosystems could be affected?

The aquatic ecosystems that could be affected extend from the Tanjil and Tyers Rivers downstream of Blue Rock and Moondarra Reservoirs, respectively, to Lake Wellington in the Gippsland Lakes and also include the tributary streams the Morwell River and Traralgon Creek, which currently receive water discharges from power station operations. The study area is large and includes a variety of aquatic ecosystems types (Figure 2).

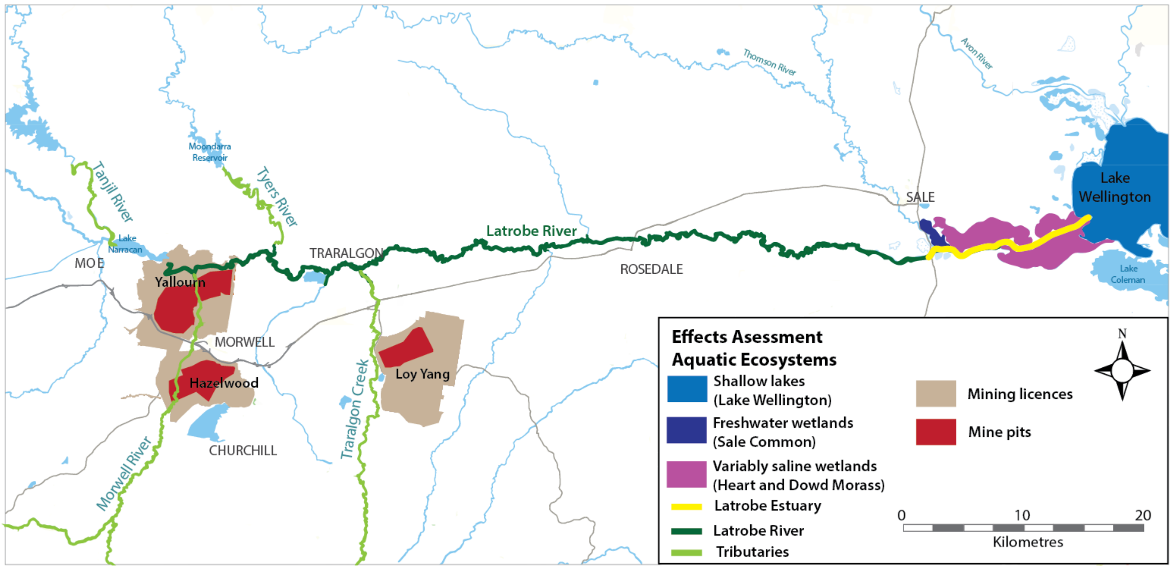


Figure 2: Aquatic ecosystem mega-habitats considered in this ecological effects assessment (adapted from Tilleard et al. 2009).

The aquatic ecosystems considered in this EEA consist of:

Mainstem of the **Latrobe River** downstream of Lake Narracan – a large alluvial river that has been highly modified in the past by straightening, clearing of large woody debris and water resource use. It supports a variety of native fish, macroinvertebrates and riparian vegetation communities.

Latrobe Estuary – defined here as the reach that extends from the Swing Bridge to the delta at Lake Wellington. This is a permanently open, salt-wedge estuary that supports a range of freshwater and estuarine fish, salt-tolerant vegetation communities, and is important for the passage of native diadromous fish (species that migrate between habitats for part of their lifecycle).

Tributaries of the Latrobe River:

> **Tanjil and Tyers Rivers** downstream of Blue Rock and Moondarra Reservoirs, respectively – the confined reaches of the Tyers are in relatively good condition and support significant in-stream and streamside biodiversity.
>
> **Morwell River and Traralgon Creek** downstream of Yallourn and Loy Yang Power Stations respectively – modified rivers in generally poor condition.

Lake Wellington[5] – a large (13,800 hectare) shallow, brackish-water lagoon that accounts for a significant component of the 61,150 hectare Gippsland Lakes Ramsar Site. The lake itself supports a variety of waterfowl and other waterbirds and several fish species including black bream. Lake Wellington, however, is perhaps more significant for the role it plays in influencing the condition and values of the large expanses of diverse wetlands that fringe it and the Latrobe Estuary.

Sale Common – the only remaining freshwater wetland in the Lower Latrobe Wetland complex and one of a few freshwater wetlands in the region. It is approximately 300 hectares and part of the Gippsland Lakes Ramsar Site. It supports significant biodiversity values.

Heart Morass and Dowd Morass – representing two of the many brackish-water wetlands that fluctuate between fresh and saline conditions that fringe Lake Wellington. Both wetlands are

[5] Noting that while Lakes Victoria and King are connected to Lake Wellington through McLennan Strait these are more heavily influenced by the eastern rivers and their proximity to the permanent ocean entrance, rather than the Latrobe River and are not considered in this EEA.

located on the Lower Latrobe River, the Heart Morass on the northern bank and Dowd Morass on the southern side. Parts of both wetlands are within the Gippsland Lakes Ramsar site.

Why do the Gippsland Lakes need to be considered in the LVRWS?

There are international, national and State based obligations maintain the ecological character of the Gippsland Lakes. The Gippsland Lakes, including Lake Wellington, Sale Common, parts of Dowd and Heart Morass and a short section of the lower Latrobe Estuary are a designated wetland of international importance under the Ramsar Convention and support many nationally listed threatened species and ecological communities including: Australasian bittern (*Botaurus poiciloptilus*), green and golden bell frog (*Litoria aurea*), growling grass frog (*Litoria raniformis*) and Australian grayling (*Prototroctes maraena*).

As a signatory to the Convention, Australia has an obligation to maintain the ecological character of the site. This is recognised under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), which regulates actions that will have or are likely to have a significant impact on any matter of national environmental significance (MNES) The ecological character of a Ramsar wetland and nationally listed threatened species and ecological communities are all identified MNES.

In addition, the *Flora and Fauna Guarantee Act 1988* (FFG Act) lists several potentially threatening processes that are relevant to mine rehabilitation such as alteration to the natural flow regimes of rivers and streams and the input of toxic substances to Victorian rivers and streams. The EPBC Act, FFG Act, the *Environment Effects Act 1978* and the recently passed Flora and Fauna Guarantee Amendment Bill 2019 provide protection for the conservation of biodiversity. These pieces of legislation establish assessment processes for activities that are capable of having a significant effect on the environment, which would include mine rehabilitation. There are also requirements for the consideration of biodiversity across government to ensure decisions and policies are made with proper consideration of the potential impacts on biodiversity.

The ecological character of the Gippsland Lakes and the species and communities that are supported by the system, particularly Lake Wellington and the Lower Latrobe Wetlands are reliant on receiving adequate freshwater from river inflows. The Latrobe River plays a significant role in providing freshwater to the Gippsland Lakes. Over the past two decades, the Latrobe River has contributed between 13 and 46 % of the total riverine inflow to the Gippsland Lakes as a whole, and on average provides nearly 60 % of the freshwater inflows to Lake Wellington (Figure 3).

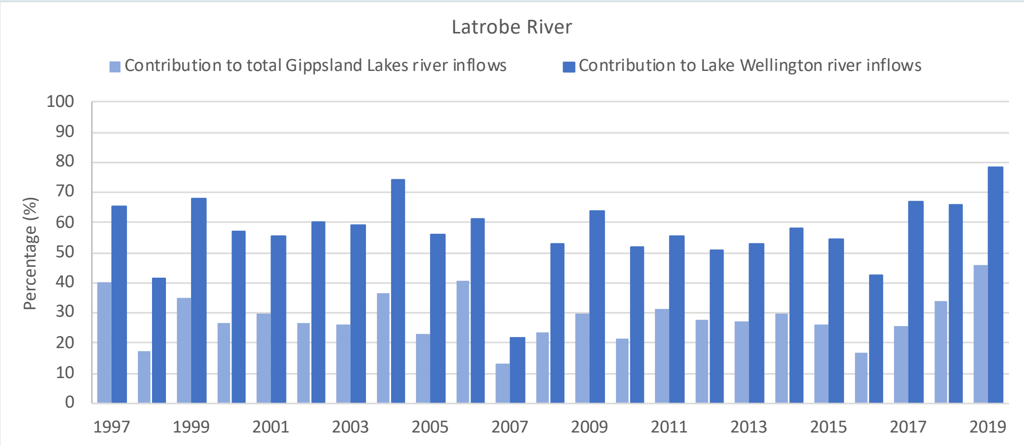


Figure 3: Percentage of measured Latrobe riverine flow contributed to the Gippsland Lakes and Lake Wellington by the Latrobe River (Water Measurement Information System).

Dowd Morass December 2017, Australian UAV.

2.2 Hydrology

The Latrobe River Basin, in West Gippsland, covers an area of approximately 4,700 square kilometres stretching from the southern slopes of the Yarra Ranges to Lake Wellington, representing around 23 % of the total catchment of the Gippsland Lakes. The upper part of the catchment is largely forested through the Strzelecki Ranges and the Great Dividing Range where major tributaries such as the Tanjil and Tyers Rivers rise and flow into the Latrobe River. Approximately 70 kilometres from its source, the Latrobe River emerges from the foothills onto the broad floodplain before discharging through the Latrobe Estuary to Lake Wellington.

2.2.1 Riverine systems

The average annual flow of the Latrobe River system is highly variable and ranges from more than 1000 GL/year in wet years to less than 350 GL/year in dry years. Seasonality is typical of rivers in south-eastern Australia, with peak volumes in winter and spring (due to seasonal rainfall and snow melt) and low flows in late summer and early autumn. Although there has been a decline in total annual flow in the Latrobe River (Figure 4), particularly since 1997, seasonality of flow remains unaltered in both the main stem of the river and the estuary (Figure 5). The difference between natural and current flows is evident in both reaches, but the difference is considerably larger in the Latrobe Estuary. This is because the Latrobe River at Kilmany shows the effects, of extraction from the Latrobe system, while the estuarine reach is downstream of the Thomson confluence and so includes the effects of extraction from both the Latrobe and Thomson Basins.

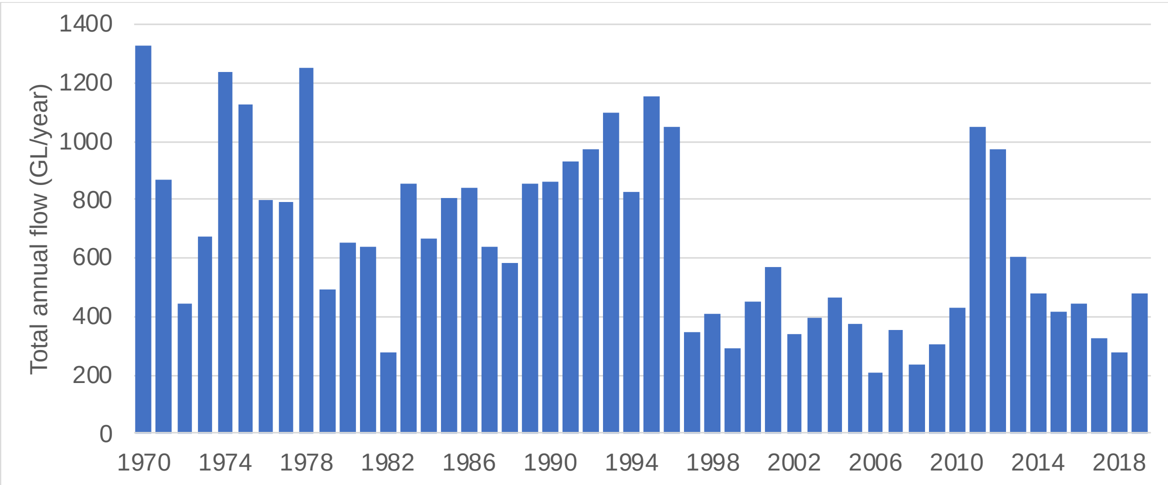


Figure 4: Annual flow in the lower Latrobe River at Rosedale (data from http://data.water.vic.gov.au).

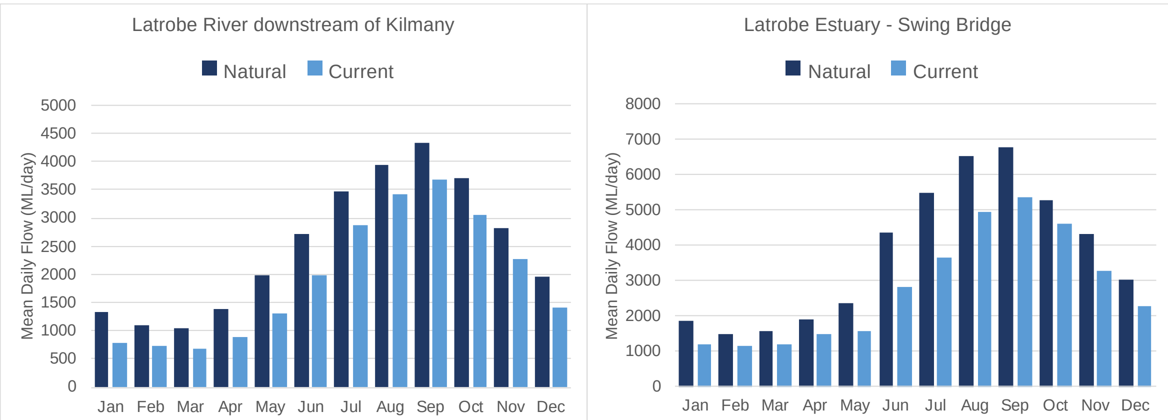


Figure 5: Mean daily flow (ML/day) in the Latrobe River between Kilmany and the confluence with the Thomson (left) and the Latrobe Estuary (right) under natural and current extraction conditions (Alluvium 2020).

Approximately a quarter of the total annual volume of flow in the Latrobe River is extracted for consumptive use, for which power generation is the single biggest use (Department of Sustainability and Environment 2011). This varies annually and can be high in drought years, for example almost half the total flow was extracted in 2006/07, but is a smaller proportion in wet years (e.g. 10% of the total flow in 2011/12) (Figure 6).

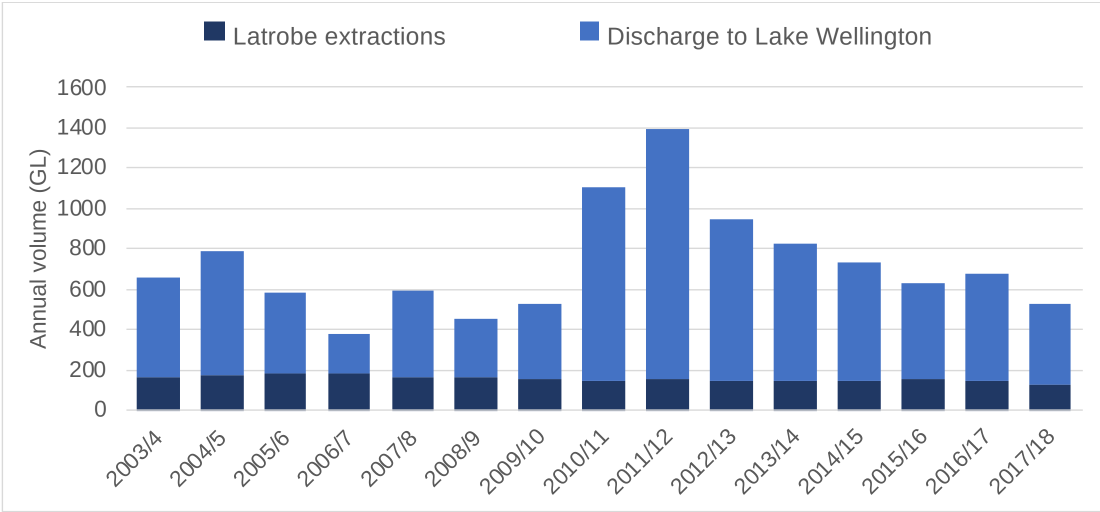


Figure 6: Water extraction and end of system flows to Lake Wellington in the Latrobe Basin, upstream of confluence with the Thomson River (DELWP 2005, 2007, 2009, 2014, 2015, 2016).

The Tyers and Tanjil Rivers have altered flow regimes due to water storages in their upper reaches (Moondarra Reservoir and Blue Rock Reservoir, respectively). The capture of streamflow in the two water storages has resulted in a reduction of over 50 % in the average flow in the Tyers River and 20 % in the Tanjil (Figure 7). Of note is the alteration to the seasonal pattern in the Tanjil River, with increased flows in summer as a result of dam releases to meet consumptive demands.

The Morwell River and Traralgon Creek both receive discharge water from power stations and as a consequence, average flow in these rivers is higher than would be under natural conditions (18 % more in Traralgon Creek and 11 % more in the Morwell River). The return flows from power generation and mine operations follow seasonal patterns of increased availability in winter/spring and lower availability in summer/autumn, as such seasonality of flow in these two rivers remains unchanged (Figure 7).

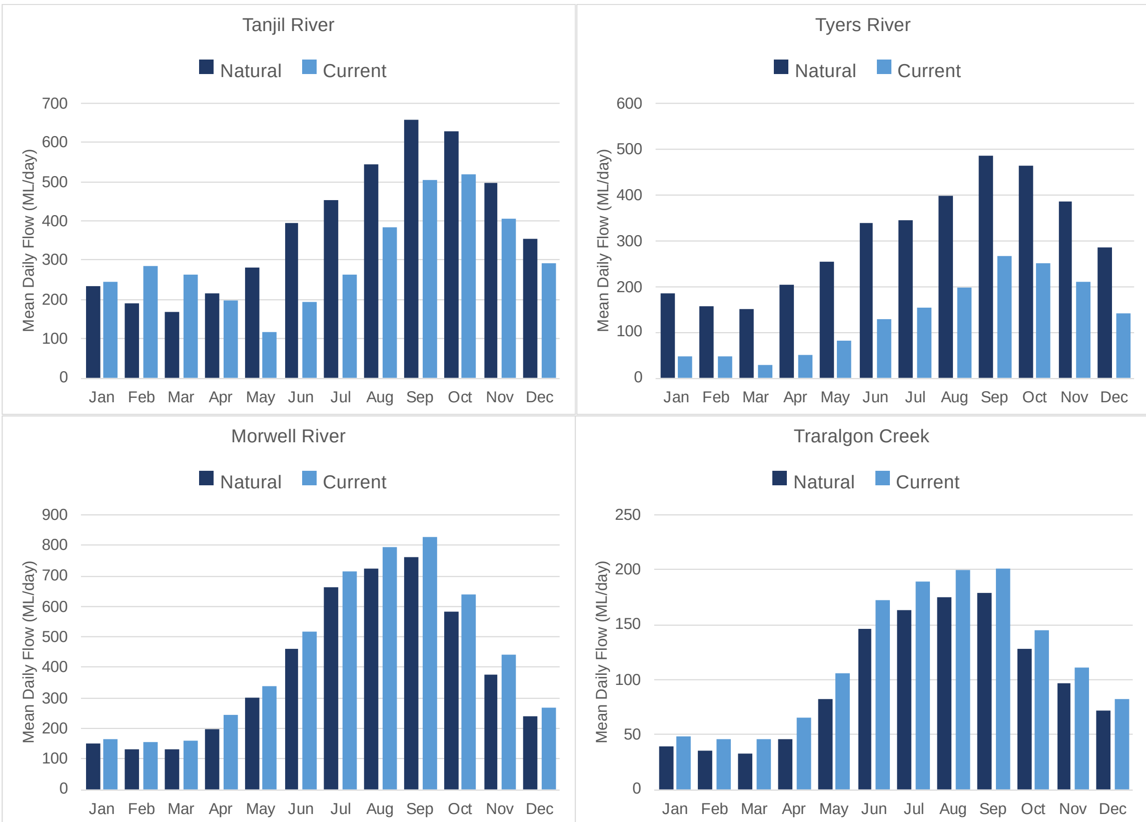


Figure 7: Mean daily flow (ML/day) in the Tanjil, Tyers and Morwell Rivers and Traralgon Creek under natural and current extraction conditions (modelled over 60 year period; data provided by Alluvium).

2.2.2 Wetlands

The water regimes of Sale Common, Heart and Dowd Morass have similarities and differences. Sources of freshwater are largely from direct rainfall and the Latrobe River, and all of these wetlands have regulating structures in place to enable water regime management and the delivery of environmental water. Delivering water to these wetlands can be complicated by the salt wedge in the Latrobe Estuary, which if it extends too far up the Latrobe River, past the structures connecting the river to the wetlands, can prevent managed inundation with freshwater.

Inundation of Sale Common is affected by flows in the Thomson and Latrobe Rivers as well as water levels in Lake Wellington. With respect to the Latrobe River, water moves into Sale Common overbank when flows in the lower Latrobe River exceed 15,000 ML/day. There is a gated structure between the lower Latrobe River and Sale Common which allows for the active management of water regimes in the wetland (Arrowsmith et al. 2011).

The water regime of Sale Common could be described as "commonly wet" although the system does have intermittent periods of drawdown (Figure 8). There is not a strong seasonal pattern to inundation, but water levels are generally lower in autumn and highest in spring. The wetland is reliant on large natural floods for flushing (Alluvium 2020), which has not occurred since 2011/12.

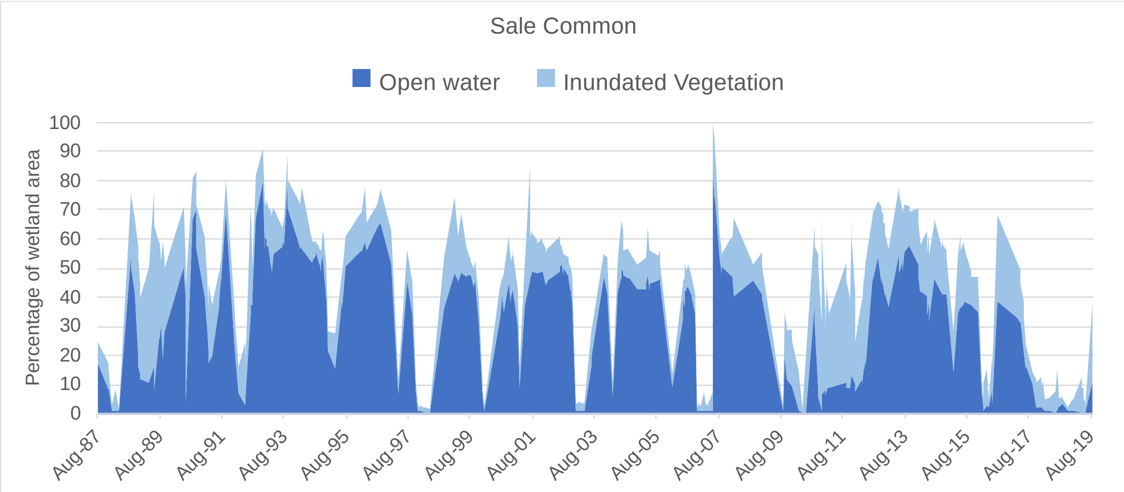


Figure 8: Inundation of Sale Common 1987 to 2019 (derived from Water Observations from Space; GeoScience Australia).

The water regimes of Heart and Dowd Morass are influenced by two water sources: freshwater moving from the Latrobe River and inflows of variably saline water from Lake Wellington. Both wetlands have historically altered water regimes due to a variety of factors related to both altered river flows and internal levee structures, plus changes in the overall level of water in the Gippsland Lakes (Boon et al. 2018).

Heart Morass can receive surface water overbank from the Latrobe River under flood conditions. The more common surface water inflows are, however, through several culvert structures from the Latrobe River which were originally installed to drain the wetland when it was managed for farming and are therefore not optimal for filling it. There are 10 structures on the Latrobe River connecting it to Heart Morass, plus several culverts through internal levees.

The water regime of Dowd Morass is complex and water (of various salinities) can enter the wetland via several sources (SKM 2001, Boon et al. 2008, Arrowsmith and Dermek 2014):

- Inflows from the Latrobe River through Long Waterhole, an anabranch of the Latrobe River located about 5 kilometres upstream of the western end of morass.
- Overbank flows from the Latrobe River along a section of low-lying bank near the mouth of the river.
- Overflows from Lake Wellington through the Dardenelles, a fringing but hydrologically permeable border vegetated with reeds and paperbarks.
- Through two culverts that have been cut between the Latrobe River and the wetland with flow-control devices for filling and draining.

The lowest parts of both Heart and Dowd Morass are lower than sea level and so complete flushing does not occur readily. Instead, the two wetlands fill during high flow periods (or when managed through infrastructure) and drain largely via evaporation (Arrowsmith and Dermek 2014). Water level data has been regularly collected for the past three years and clearly shows filling and then a drying cycle in March 2019 (Figure 9)

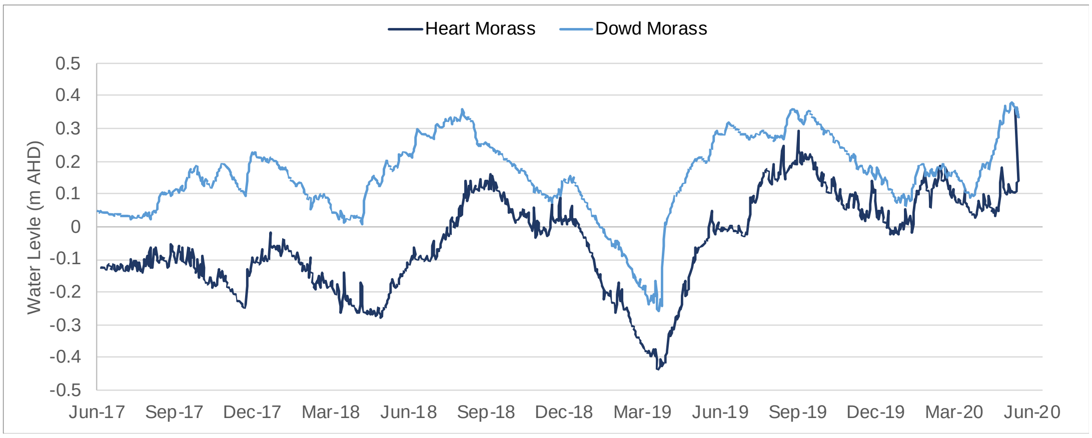


Figure 9: Surface water level at Dowd and Heart Morass (data from http://data.water.vic.gov.au/).

There is some evidence of increased water movement from Lake Wellington into Dowd Morass due to decreased freshwater inflows and increases in sea level (Hale et al. 2018). There is predicted further increases in movement of saline water into both these wetlands under future climate conditions (Arrowsmith and Dermek 2014, Hale et al. 2018).

2.2.3 Lake Wellington

The hydrodynamics of Lake Wellington are a complex interaction between inflowing freshwater from the Thomson and Latrobe Rivers (through the Latrobe Estuary) and marine origin water through McLennan Strait (Brizga et al. 2013). The lake level is affected on a day to day basis primarily by marine conditions and inflows of saline water from the eastern lagoons of the Gippsland Lakes, and over episodic time periods by floodwaters coming down the Latrobe River. In relation to marine conditions tides have a minor influence but with the dominant forces atmospheric pressure variations (e.g. storm surge in Bass Strait associated with low pressure systems) and wind (which includes wave effects in Lake Wellington). The effect of storm surge and atmospheric pressure on water levels in Lake Wellington is illustrated in Figure 10, with the water level in the lake closely mimicking that in Bass Strait. Under moderate to high river flow conditions, freshwater enters the Lake and exerts hydrodynamic pressure on the connection through McLennan Strait, limiting intrusion of marine origin waters and raising water levels with freshwater. Under low flow conditions, increased water flows through McLennan Strait into Lake Wellington (Tilleard et al. 2009).

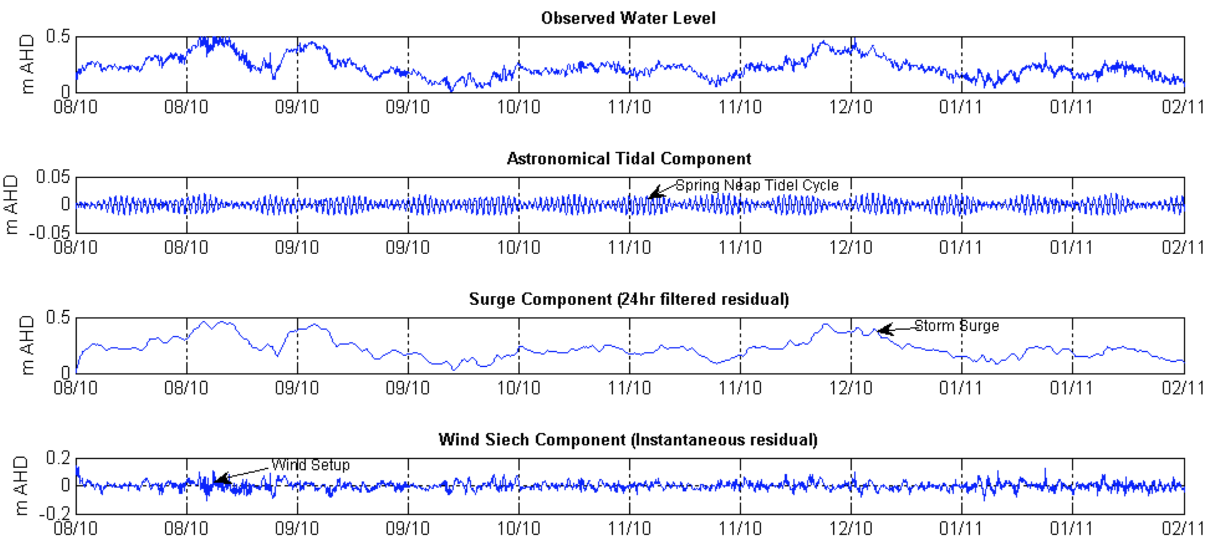


Figure 10: Lake Wellington water levels, August 2010 to February 2011 (Brizga et al. 2013).

There has been a marked decline in freshwater inflows to Lake Wellington since the commissioning of the Thomson Dam (on the Thomson River, which joins the Latrobe River near Sale) and Blue Rock Reservoir (on the Tanjil River) in the mid 1980s. This, coupled with rising sea levels, has led to an increased movement of marine water into Lake Wellington (Boon et al. 2016; DELWP unpublished). This has major consequences for lake water salinity and thus for the environmental values of Lake Wellington and its fringing wetlands (see section 2.4).

2.3 Geomorphology

Geomorphology is the study of landforms and processes that influence landforms. With respect to aquatic ecosystems, fluvial geomorphology describes the size, shape and physical characteristics of rivers, lakes and wetlands. Geomorphology is a driver of wetland and river ecology and is important in determining habitat availability and diversity (Mitsch and Gosselink 2007).

The Latrobe River is a large alluvial river with channel substrate grading from silt-clay (downstream of Lake Narracan) to sands and gravels (Alluvium 2020). Sandy deposits are evident in the upper sections near Lake Narracan. The river has been highly modified, with an estimated 77 meander cut-offs in the mid to lower reaches between Yallourn and Lake Wellington, over 80% of which were since 1924 (Alluvium 2020). This has reduced channel length by up to 25% (Reinfelds et al. 1995), and subsequently will have increased slope and stream energy. It has also undergone major ‘desnagging’ or wood removal since the 1930s, resulting in up to 2 m of bed lowering (Reinfelds et al. 1995). The channel is said to have undergone channel incision (deepening and widening) with subsequent reductions in overbank flows, and loss of channel complexity, e.g. in-channel benches (Alluvium 2009). This has also increased sediment loads.

The physical condition of the tributaries is highly dependent on catchment context, both in terms of land use and flow regime. The geomorphology of each of the tributaries was summarised by Earth Tech (2007) as follows:

- The Tanjil River, downstream of Blue Rock, flows through a short, confined reach before emerging onto a broader floodplain. There has been widespread clearing of vegetation leading to erosion.
- The Tyers River downstream of Moondarra Reservoir flows through steep, inaccessible terrain and is in excellent condition with intact pool-riffle morphology.
- The geomorphology of the Morwell River is highly modified as it has been diverted on numerous occasions to allow for coal mining expansions.
- Traralgon Creek has both meander and straight sections with several artificial rock riffles.

The Latrobe Estuary is characterised by a levee-back swamp configuration, with the Latrobe River perched between natural levees above Heart and Dowd Morasses. The river channel is wide and deep with a silty substratum, though sands are also likely. There is more extensive bank erosion along northern bank of the river, which is associated with differences in historical land use, particularly the impact of grazing and fire on reed beds. Phragmites plays a significant role in bank stability in this part of the estuary. Bank erosion occurs as a result of wind induced wave action and boat wake under low flow conditions, as well as by scour by flow currents during river floods (Boon et al. 2015, 2018). The channel in this reach has been modified by dredging, straightening and de-snagging (Water Tech 2013).

The Latrobe River silt jetties (prograding cuspate delta) that protrude 2 km into Lake Wellington are of State geomorphic significance (Figure 11). These silt jetties are undergoing erosion and recession. Visual comparisons of aerial photographs indicate receding shorelines and narrowing of common reed (*Phragmites australis*) reed beds since the 1950s (Sjerp et al. 2002, Boon et al. 2015). The maintenance of silt jetties is highly dependent on the fringing reeds (primarily common reed) that trap river silt and decaying vegetation to a level that can be colonised by swampy tree species. Vegetation establishment is sensitive to salinity levels, that have been within tolerances in this section of Lake Wellington. Changes to salinity (such as from reduced inflows) have and will continue to negatively impact on the silt jetties, in addition to increasing erosion potential for shorelines (Vietz et al. 2003).

Lake Wellington is a large, shallow wetland with unconsolidated sediments that are continually resuspended due to wind and wave action. Assessments of shoreline erosion susceptibility indicate that much of the 60 kilometre shoreline of Lake Wellington has a high risk of erosion (Arrowsmith et al. 2014). Erosion susceptibility at Lake Wellington is related to sediment type (and associated vegetation communities) with higher erosion potential in silty shorelines and more stable sandy sediments backed by swamp scrub vegetation (Figure 12).

Figure 11: Latrobe River Silt Jetties (Photo: Paul, Boon).

Figure 12: Eroding shoreline between Plover Point and Bull Bay, Lake Wellington 2014. (Photo: Paul Boon).

The morphologies of the wetlands of the Lower Latrobe system have all been modified by levees, either within the bed of the wetland, or along the banks of the rivers. Heart and Dowd Morass in particular, have had a long history of clearing, drainage and grazing, with significant alterations to wetland beds. From the 1970s to the 1990s extensive levees were established which restrict the movement of water within the wetlands. Some of these, such as Boultons levee in Heart Morass have culverts to facilitate water movement. Sediment regimes and changes in sediments over time, however, remain unknown for all three wetlands (Arrowsmith and Duggan 2009).

2.4 Water quality

Water quality in the aquatic ecosystems of the Latrobe River is important for maintaining biodiversity and ecological function. In many respects, water quality has been altered significantly by the combined effects of land use and water resource use. Water quality objectives established in the State Environment Protection Policy (Waters) (SEPP(Waters)) provide the required water quality to protect beneficial uses including ecological values of these systems.

2.4.1 Riverine systems

Water quality data is limited for the system, with regular monthly sampling in the Latrobe, Tanjil and Morwell Rivers for nutrients, electrical conductivity, pH and turbidity; and for a range of metals in the Latrobe River only.

Water quality in the Lower Latrobe and Morwell Rivers rarely meets any SEPP (Waters) objectives (Table 1 and Table 2). Water in both rivers is generally turbid and nutrient enriched, and although electrical conductivity (an indicator of salinity) is still within the limits described as "fresh" salinity exceeds the SEPP (Waters) objectives. There is some evidence that both rivers are increasing in salinity. In contrast, water quality in the Tanjil River is clear, fresh and has moderate nutrient concentrations, all within the SEPP (Waters) objectives (Table 3).

Table 1: Water quality indicators Latrobe River at Rosedale. Shading indicates exceedance of SEPP(Waters) objective. Data from WMIS. TN = total nitrogen (μg/L), TP = total phosphorus (μg/L), EC = electrical conductivity (μS/cm).

Indicator	SEPP Objective	2013	2014	2015	2016	2017	2018	2019
Turbidity (75th)	25	75	54	55	54	42	38	37
pH (25th – 75th)	6.7-7.7	7.0-7.2	7.0-7.3	7.0-7.2	7.0-7.1	6.9-7.1	7.2-7.5	7.1-7.5
TN (75th)	1100	1302	1030	995	1155	1160	1265	1152
TP (75th)	55	102	85	110	96	76	126	115
EC (75th)	250	335	320	358	359	426	428	483

Table 2: Water quality indicators Morwell River at Yallourn. Shading indicates exceedance of SEPP(Waters) objective. Data from WMIS. TN = total nitrogen (μg/L), TP = total phosphorus (μg/L), EC = electrical conductivity (μS/cm).

Indicator	SEPP Objective	2013	2014	2015	2016	2017	2018	2019
Turbidity (75th)	25	71	53	51	48	46	37	48
pH (25th – 75th)	6.7-7.7	7.0-7.3	7.0-7.2	7.1-7.3	7.1-7.3	7.2-7.3	7.4-7.7	7.5-7.7
TN (75th)	1100	1303	1045	883	885	960	872	950
TP (75th)	55	120	85	77	67	68	63	71
EC (75th)	250	456	455	574	605	676	722	712

Table 3: Water quality indicators Tanjil River at Tanjil Junction. Shading indicates exceedance of SEPP(Waters) objective. Data from WMIS. TN = total nitrogen (μg/L), TP = total phosphorus (μg/L), EC = electrical conductivity (μS/cm).

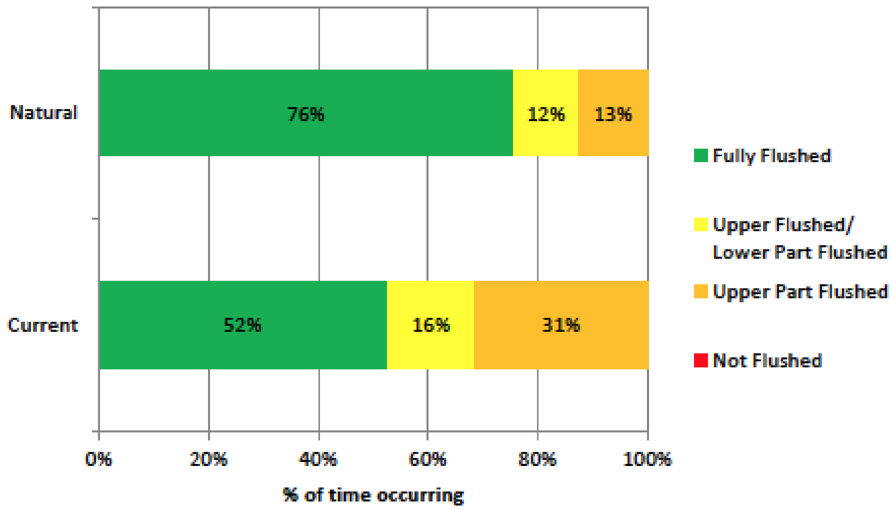
Indicator	SEPP Objective	2013	2014	2015	2016	2017	2018	2019
Turbidity (75th)	15	7	6	7	8	9	6	4
pH (25th – 75th)	6.4-7.6	7.0-7.4	6.9-7.1	6.7-7.4	6.8-7.4	6.8-7.2	6.6-7.2	6.8-7.1
TN (75th)	900	373	420	433	468	460	450	410
TP (75th)	35	17	17	19	21	21	19	14
EC (75th)	100	54	51	57	52	46	46	48

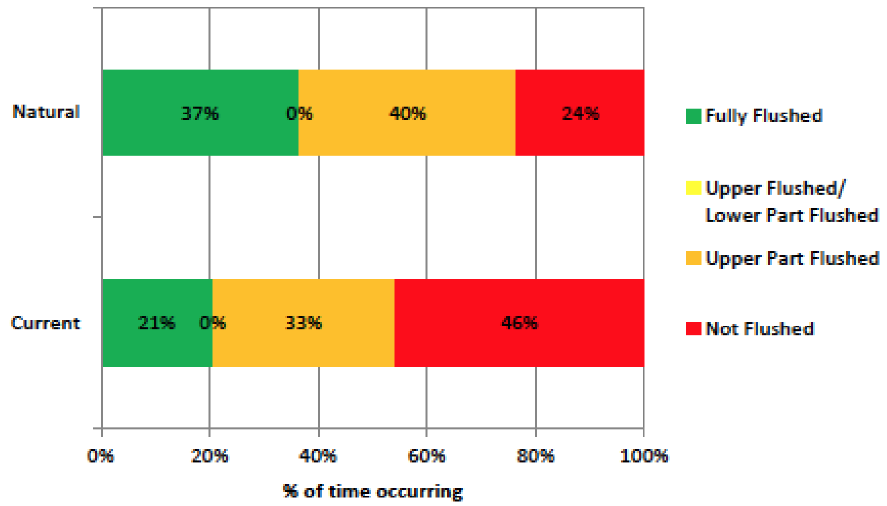
In addition, there are times when the metal concentrations the Latrobe River at Rosedale exceed the SEPP (Waters) guideline values, most often coinciding with large flows, indicating movement of metals from the catchment. The metals of most concern are[6]:

- Cadmium (guideline value of 0.2 µg/l) – maximum of 1.3 µg/l in April 2011
- Chromium (guideline value of 4.4 µg/l) – maximum of 6 µg/l in February 2013
- Lead (guideline value of 3.4 µg/l) – maximum of 9 µg/l in July 2016
- Zinc (guideline value of 8 µg/l) – maximum of 42 µg/l in July 2016
- Copper (guideline value 1.4 µg/l) – almost constantly exceeded with an average of 3 µg/l.

Water quality data for the Latrobe Estuary is limited largely to recent conditions, with only modelled salinity providing any indication of condition and trend. Salinity in the estuary is a function of river flow and water level in Lake Wellington. Under prolonged low flow conditions (flows < 650 ML/day at the Swing Bridge) saline water (water > 1 ppt) extends over 17 kilometres from Lake Wellington (Brizga et al. 2013). In channel freshes can flush salt from the upper layer of water and an increase in volume or duration can result in a fully flushed water column in the estuary.

An assessment of salinity conditions in the estuary indicates that under “natural” (pre-water development) conditions, the estuary at the Swing Bridge is generally fresh (< 1 ppt) throughout the water column 76% of the time. Currently, due to reduced water volumes (and potentially sea level rise) this is reduced to around half the time. In the lower Estuary, the water column was fully fresh around 37% of the time, which has been reduced under current conditions to around 20% of the time (Figure 13).





[6] Data based on monthly samples between 2002 to 2020 (200+ sample points) Victorian Water Measurement Information System

Figure 13: Salinity conditions at the Swing Bridge (top) and river mouth (bottom) (Brizga et al. 2013).

2.4.2 Wetlands

Water quality data for the Lower Latrobe Wetlands is patchy and until recently, was very limited. This remains the case at Sale Common, where information from community monitoring (Waterwatch) is all that could be sourced. These data indicate that Sale Common is fresh (electrical conductivity between 200 and 755 µS/cm), neutral (pH averaging around 7), periodically turbid (maximum turbidity 300 NTU). There is, however, no indication of trend.

Heart and Dowd Morass were once more commonly fresh than they under current conditions, although empirical data is limited. Since 2017, water quality in terms of electrical conductivity and pH has been logged at both Heart and Dowd Morass. Electrical conductivity has been largely similar at both monitoring stations (noting that there is a degree of spatial variability in water quality in both wetlands). In March 2019, when water levels fell, salinity increased in both wetlands, but was significantly higher in Dowd Morass (Figure 14). Dowd Morass is connected to Lake Wellington at a lower threshold than Heart Morass, and it seems likely that the spike in salinity may have been influenced by the movement of saline water from Lake Wellington into the Morass when freshwater levels fell.

Dowd Morass remained relatively neutral to slightly alkaline with pH mainly between 6 and 8. Heart Morass is generally more acidic, due to the exposure of acid sulfate soils (Boon et al. 2007, Taylor 2011), although in more recent times it has fluctuated considerably over short timescales (Figure 14).

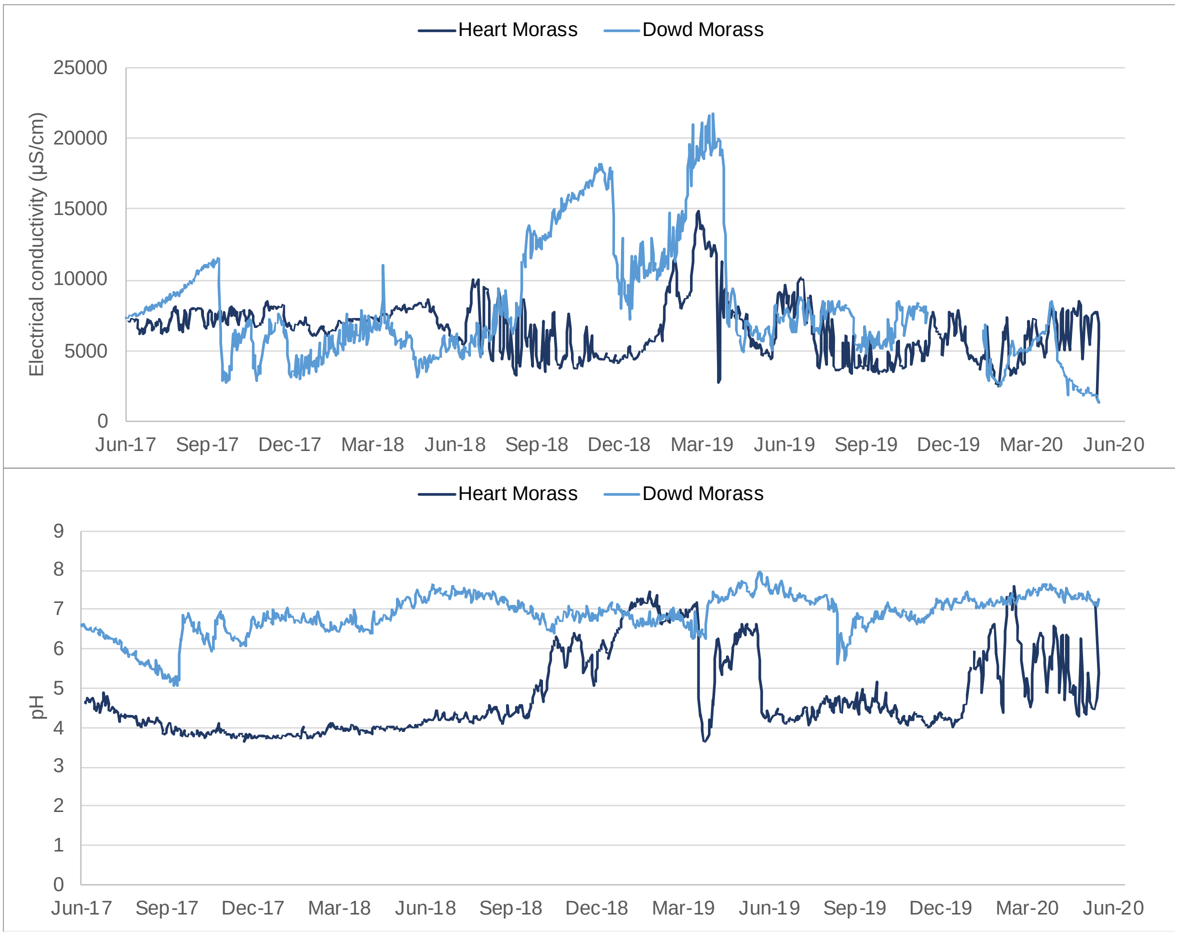


Figure 14: Heart Morass and Dowd Morass electrical conductivity (top) and pH (bottom) (data from http://data.water.vic.gov.au/).

2.4.3 Lake Wellington

Historically (i.e. pre-European), Lake Wellington was fresh and supported extensive beds of submerged and fringing vascular plants. Salinity impacts started to be seen soon after the creation of the artificial entrance in 1889 (Boon et al. 2018). Salinity in Lake Wellington in recent years has been increasing (Figure 15). Lake Wellington can only be flushed of saline water when flows exceed 130 GL/ month in the Latrobe River (Brizga et al. 2013).

An assessment of water quality against SEPP (Waters) objectives from 2013 – 2017 is provided in Table 4. Lake Wellington is mostly turbid as a result of catchment derived sediments, wind generated resuspension of bottom sediments and the actions of European carp (Harris et al. 1998). This change to a highly turbid system is believed to have taken place over 50 years ago, around 1967, and there is no evidence of an ongoing trend. Nutrient concentrations in Lake Wellington are also high and the water body has been classified as eutrophic by OECD trophic condition standards (Harris et al. 1998). There is some evidence of an ongoing increasing trend in both total nitrogen and total phosphorus (data from the water measurement information system). The high turbidity often restricts algal growth, due to low light availability, but there are occasional algal blooms. High chlorophyll-a concentrations (> 50 µg/L) were recorded in spring 2013, although the species remain unknown.

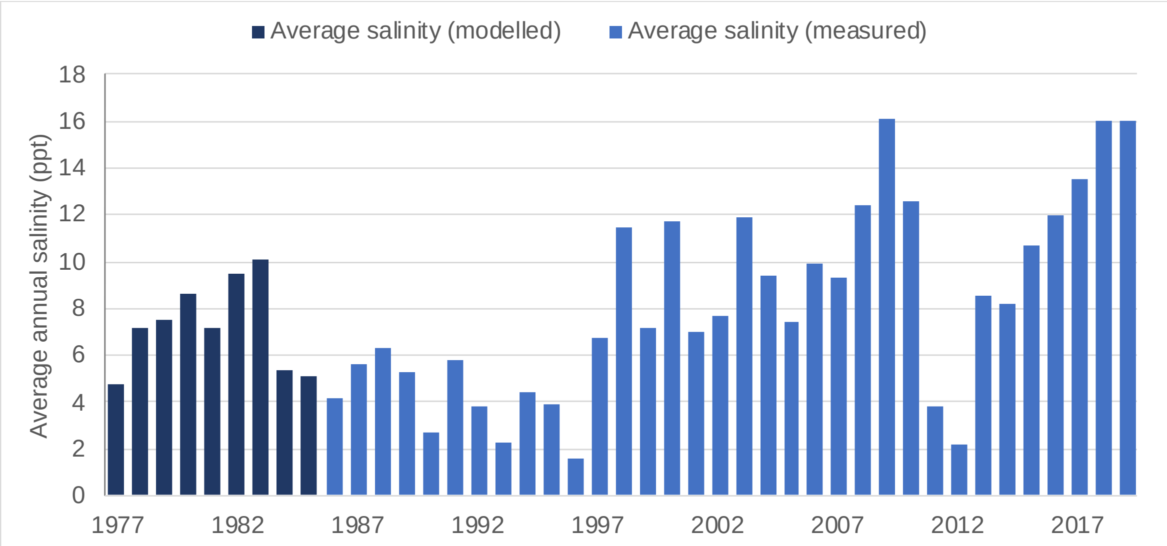


Figure 15: Average annual salinity in Lake Wellington (ppt). Data from EPA Victoria, Brizga et al. 2013; Victorian Water Measurement Information System.

Table 4: Water quality indicators (75th percentiles, with the exception of dissolved oxygen). Shading indicates exceedence of SEPP(Waters) objective. Data from EPA Victoria. DO = dissolved oxygen, DIN = dissolved inorganic nitrogen, TN = total nitrogen, DIP = dissolved inorganic phosphorus, TP = total phosphorus, TSS = total suspended solids.

Indicator	SEPP Objective	2013	2014	2015	2016	2017
Chlorophyll-a	25	40	21	19	20	16
DO (25th – max)	95-130	98-112	93-107	95-103	94-105	96-109
DIN	15	10	20	11	19	16
TN	1000	887	820	828	880	830
DIP	15	3	3	3	7	5
TP	120	125	100	100	100	90
TSS	30	35	35	35	38	31

2.5 Vegetation

The aquatic ecosystems of the Latrobe catchment support a diversity of inundation dependent vegetation communities that include riparian vegetation along the rivers and streams, the littoral vegetation around Lake Wellington and the mosaic of wetland vegetation communities present in the Lower Latrobe Wetlands. These vegetation communities have inherent biodiversity values as well as providing habitat and resources to fauna. In addition, littoral and riparian vegetation play a role in the overall condition of aquatic ecosystems by stabilising shorelines and riverbanks, inputting carbon sources to drive productivity and regulating water temperature (Boon et al. 2005, Capon and Dowe 2007, Alluvium 2011).

2.5.1 Riverine vegetation

There are small areas of submerged macrophytes in the deep clear pools of the Tanjil River, and some localised beds of common reed (*Phragmites australis*) along the Latrobe River. By and large, however, there is little submerged vegetation and few areas of emergent reeds and sedges in the streams of the study area.

The main Ecological Vegetation Classes (EVCs) on the tributaries of the Latrobe River are:

- EVC 1 Riparian Scrub/Swampy Riparian Woodland Complex (endangered)
- EVC 29 Damp Forest
- EVC 53 Swamp Scrub (endangered)
- EVC 82 Riverine Escarpment Scrub (endangered)
- EVC 83 Swampy Riparian Woodland (endangered)
- EVC 126 Swampy Riparian Complex (endangered)

On the main stem of the Latrobe, however, the dominant riparian vegetation is EVC 56 Floodplain Riparian Woodland, which is present almost continuously downstream of Lake Narracan to the beginning of the Latrobe Estuary. The width of this zone tends to increase downstream, especially downstream of Rosedale and in the region near Kilmany South, where there can be areas of intact woody riverine vegetation and emergent reeds. Upstream (e.g. between Morwell and Rosedale) it can be non-existent or very narrow, perhaps only one tree wide. This EVC is listed as endangered in the Gippsland Plains bioregion. The dominant canopy species are variously river red gum (*Eucalyptus camaldulsensis*), Gippsland red gum (*E. tereticornis* ssp. *mediana*) and swamp gum (*E. ovata*). There are also small patches of EVC 82 Riverine Escarpment Scrub just downstream of Lake Narracan.

Although there is little information on the condition of vegetation in the riparian zone, the Index of Stream Condition (ISC) assessment, covering the period 2004−2010, indicated generally poor condition along the Latrobe River and much of the Morwell River streamside zone. In contrast, the condition of riparian vegetation in the Tanjil and Tyers River reaches was considered moderate (DELWP 2014).

These findings are consistent with the observations from site visits by Alluvium (2020) which indicated poor condition and high percentages of exotic species in the riparian zone, particularly in the understorey in the Latrobe River (e.g. Figure 16). While there was good vegetation condition in the Tyers River downstream of Moondarra Reservoir, there were high percentages of exotic species in the riparian zones of the other tributaries, which were generally poor condition (e.g. Figure 17).

Figure 16: Latrobe River at Glengarry (West Gippsland CMA).

Figure 17: Morwell River adjacent to Morwell Wetlands, November 2018 (Alluvium 2020)

The riparian vegetation of the estuarine reach of the Latrobe River is dominated by EVC 953 Estuarine Scrub, EVC 53 Swamp Scrub and EVC 952 Estuarine Reedbed. There is a transition from fresher communities in the upper estuary, with emergent macrophytes such as giant rush (*Juncus ingens*), common reed and cumbungi (*Typha* spp.) in the lower banks, backed by river red gum forest. Downstream more salt tolerant species persist (e.g. common reed) and swamp paperbark. There are no submerged macrophytes (e.g. seagrasses) in the estuary.

There is little information available on vegetation condition in this section of the Latrobe although Brizga et al. (2011) suggested that there has been a broad decline in condition as a result of increased salinity, nutrients and sediment supply.

2.5.2 Wetland vegetation

The Lower Latrobe Wetlands support a diversity of wetland vegetation and a number of threatened plant taxa. Eight water-dependent rare and threatened plant taxa have been recorded from within the Lower Latrobe Wetlands (Atlas of Living Australia):

- Wavy swamp wallaby-grass (*Amphibromus sinuatus*)
- Tall club-sedge (*Bolboschoenus fluviatilis*)
- Water parsnip (*Berula erecta*)
- Starwort (*Callitriche palustris* var. *palustris*)
- Eastern water ribbons (*Cycnogeton microtuberosum)*
- Veiled fringe-sedge (*Fimbristylis velata*)
- Hypsela (*Hypsela tridens*)
- Feather-leaf buttercup (*Ranunculus amplus*).

The three wetlands all support a mosaic of open water, submerged and emergent vegetation, which varies in composition and extent in response to inundation and salinity. The composition of vegetation communities at each wetland, however, varies.

Sale Common supports a diversity of wetland vegetation including submerged macrophyte beds, emergent sedges and rushes and woody littoral vegetation (Figure 18). Floodway Pond Herbland (EVC 810) and Tall Marsh (EVC 821) are the two most extensive aquatic vegetation types in the wetland (Frood et al. 2015). There are also areas of swamp scrub dominated by paperbark and the mosaic of habitats is identified as critical to ecological character of the Ramsar site.

Figure 18: Sale Common (photo Sean Phillipson).

Heart Morass is spatially and topographically very complex, and Frood et al. (2015) reported over 60 spatially discrete vegetation patches. The most common EVCs recorded in 2015 were tall marsh, aquatic herbland, swamp scrub, floodplain riparian woodland and several saltmarsh communities. Twenty years ago, the vegetation at Heart Morass was described as degraded and in need of restoration (Borg and Savage 2005), and an extensive collaborative project involving the WET Trust and WGCMA has restored much of the condition at the site. Evaluations in 2015 indicated that wetland vegetation communities were in good condition (Frood et al. 2015).

Figure 19: Heart Morass (photo West Gippsland CMA).

Dowd Morass supports a habitat mosaic of three main vegetation types (Frood et al. 2015):

1. Brackish-water, open forest or woodland communities dominated by swamp paperbark
2. Tall marsh, most often dominated by common reed
3. Open-water areas, sometimes vegetated with submerged vascular plants.

In addition, the vegetation in west Dowd Morass, which is subject to greater freshwater influences is complex and diverse with a large number of species and communities. As recently as 2000, open water areas across Dowd Morass contained a variety of submerged aquatic plants such as ribbonweed (*Vallisneria australis*), water milfoil (*Myriophyllum* spp.), pondweed (*Potamogeton* spp.) and water ferns (*Azolla* spp.) (SKM 2001). The 2014 surveys suggest that these submerged wetland vegetation communities are no longer present in any significant way (Frood et al. 2015). Evaluations in 2015 indicated good vegetation condition, however, this is in stark contrast to other investigations, which indicate that the swamp paperbark component of this wetland is in poor condition, stressed by high salinity and prolonged flooding (Robinson et al. 2006, Salter et al. 2007, 2010, Hamilton-Brown et al. 2009, Raulings et al. 2010, 2011).

Figure 20: Dowd Morass (photo West Gippsland CMA).

2.5.3 Littoral vegetation at Lake Wellington

Local knowledge (e.g. Ellis and Lee 2002) and scientific studies (Boon et al. 2015, 2018) show that Lake Wellington was once characterised by extensive beds of submerged macrophytes (*Vallisneria* sp.), fringing vegetation dominated by common reed (*Phragmites australis*) and swamp paperbark (*Melaleuca ericifolia*). Now Lake Wellington is turbid, phytoplankton dominated system with no submerged vascular plants and reduced areas of fringing vegetation. This shift is thought to have occurred in the late 1960s, in response to a sequence of fire, drought and flood in the catchment.

Shorelines of Lake Wellington support common reed beds, swamp scrub communities and saltmarsh. Statewide mapping of saltmarsh estimated a total of 2399 ha of saltmarsh around Lake Wellington, 90% of which was wet saltmarsh herbland (Boon et al. 2011). There was also 413 hectares of estuarine wetland (EVC 10), a type of coastal brackish-water wetland dominated by sea rush (*Juncus kraussii*).

As mentioned above, there is strong evidence of reduced fringing vegetation (related largely to increased salinity over the past 100+ years) and a transition from fresher vegetation communities to saltmarsh. With respect to saltmarsh there is no evidence of a significant decline in extent in the last three decades, it was assumed (with a low degree of confidence) that the extent of saltmarsh has been maintained and represents "good" condition in recent environmental assessments of the Gippsland Lakes (EGCMA 2019).

2.6 Fauna

The aquatic ecosystems of the study area support a diversity of riverine, estuarine and wetland fauna species, reflecting the diversity of ecosystem and habitat types.

2.6.1 Fish

The fish of the Latrobe system have been classified according to their habitat requirements and movements into several groups (Figure 21):

- **Resident freshwater** – complete their entire lifecycle in freshwater rivers and wetlands. These species do not migrate but can undertake local movements (e.g. in and out of wetlands or along rivers) to find food, mates or new habitats.
- **Estuarine dependent (freshwater)** – generally live in freshwater but migrate to the estuary or the sea to complete part of their lifecycle. Maintaining connectivity between these habitats is important for these species.
- **Estuarine resident** – live mostly in the estuary and complete their whole lifecycle in estuarine conditions. They may move between freshwater, estuarine and marine habitats, but do not need to do so to complete their lifecycle.
- **Marine stragglers** – live mostly in marine systems, but opportunistically move into estuarine areas to feed under certain conditions.

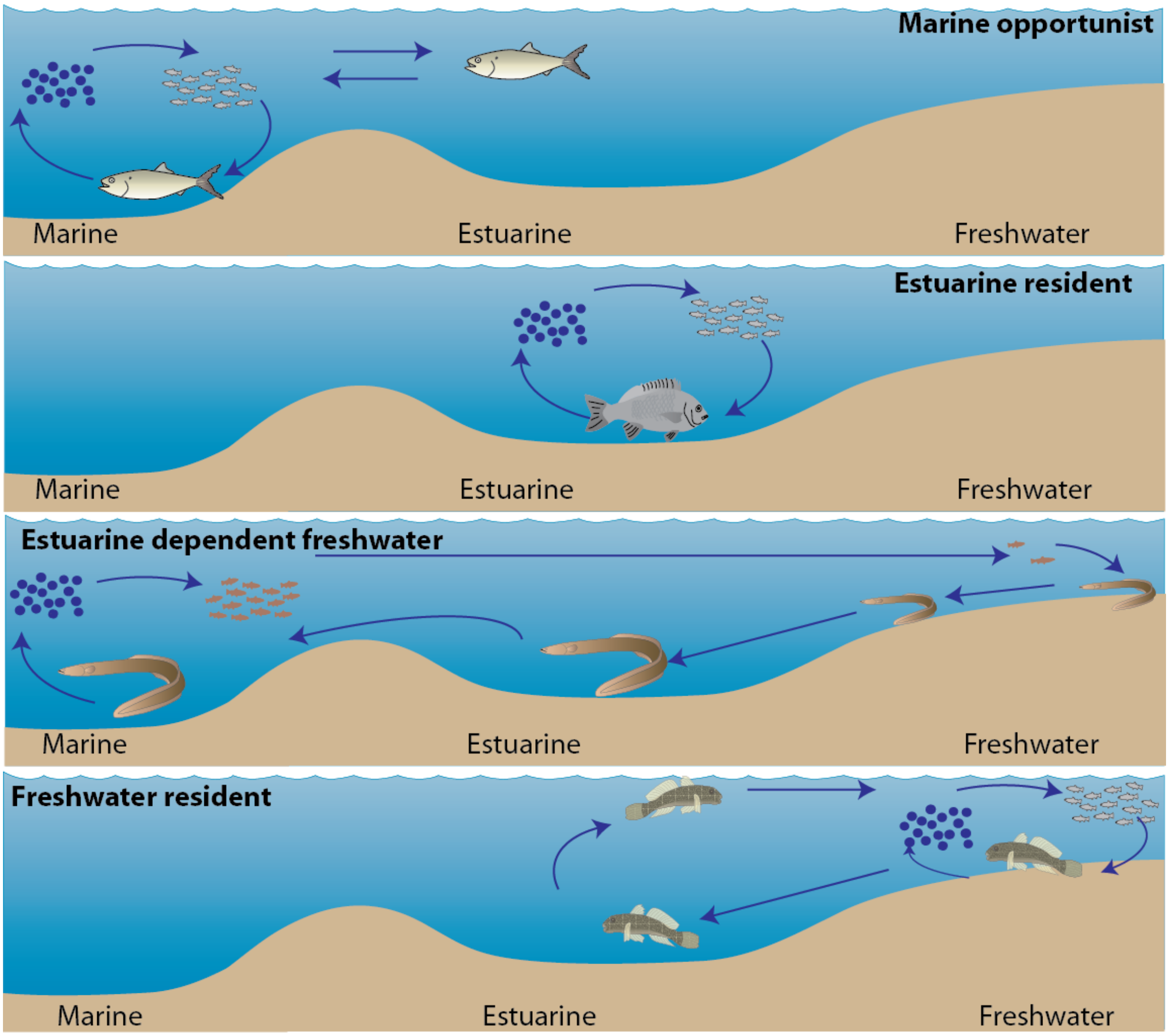


Figure 21: Fish function groups (adapted from Potter et al. 2015).

The highest diversity of native fish occurs within the Latrobe Estuary, which supports all of the four functional groups of fish found in the study area (Figure 22). In comparison, there are relatively small numbers of native fish species within the wetland systems, although this has to be considered in the context of low sample effort. Most likely these represent opportunistic movements of fish into wetted wetland habitats for feeding during times of high productivity.

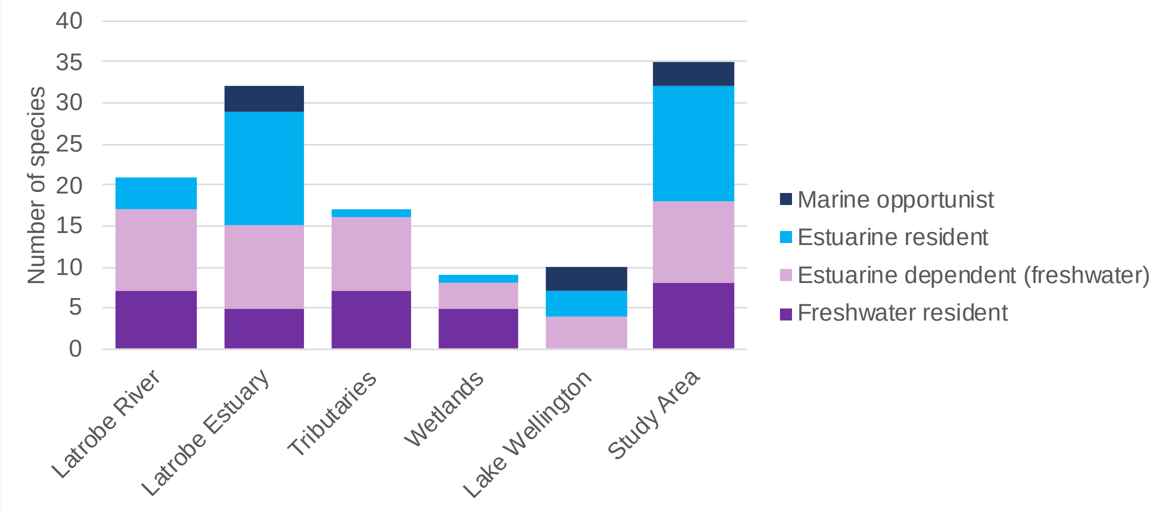


Figure 22: Species richness of native fish by functional group and location (data from Alluvium 2020).

The aquatic ecosystems of the region have supported three nationally listed threatened species:

- **Australian grayling** (*Prototroctes maraena*) – listed as vulnerable, this diadromous species migrates to and from marine environments as part of its lifecycle (Crook et al. 2006, Schmidt et al. 2011). It is likely that larvae of the Australian grayling drift downstream through the Latrobe Estuary into the Southern Ocean, with return upstream migration in spring of juveniles (Jenkins 2011). They spend most of their life in freshwater, with adults typically found in clear, flowing water, with a high dependence of oxygenated streams.
- **Dwarf galaxias** (*Galaxiella pusilla*) – listed as vulnerable, this short-lived species prefers areas of dense submerged macrophytes and completes its life cycle within a single year. Maintaining adequate conditions (water quality, aquatic vegetation), is therefore important for maintaining populations of this species (Saddlier et al. 2010).
- **Macquarie perch** (*Macquaria australasica*) – listed as endangered, is a medium sized, long-lived fish that is heavily reliant on large flow events in late spring or early summer for recruitment (Tonkin et al. 2017). The Latrobe population was translocated from its natural range within the Murray-Darling Basin. It has not been recorded in the system since the 1990s (Victorian Biodiversity Atlas) and flow modification may mean that this species is no longer sustained in the river system.

There are several exotic fish species present in the aquatic ecosystems of the study area. This includes goldfish (*Carassius auratus*), common carp (*Cyprinus carpio*), eastern gambusia (*Gambusia holbrooki*), oriental weather loach (*Misgurnus anguillicaudatus*), redfin (*Perca fluviatilis*), rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*). These species are found mostly in the freshwater reaches of the rivers and impact on native fish through predation, competition and habitat alteration.

Common carp in particular, are known throughout the system and can occur in large numbers in Lake Wellington. Lake Wellington has supported commercial carp fishing with reports from spring 2017 of very large carp spawning event (http://www.carp.gov.au/-/media/Fish-NCCP/News/2017--October--Media-Release--Gippsland-Lakes-Overrun-with-CarpFINAL31102017.ashx). The species spawned in the river, but large numbers of eggs and juvenile occurred in Lake Wellington.

2.6.2 Waterbirds

Over 85 species of waterbird have been observed in the study area (Atlas of Living Australia; Appendix A) although this list includes several vagrants and old records, such as the single Australian painted snipe (*Rostratula australis*) at Sale Common in 1970. Waterbirds, or more correctly birds that rely on inundated habitat, can be divided into ecohydrological groups in accordance with habitat preferences:

- **Emergent vegetation dependent** – species that prefer to forage in dense emergent vegetation such as bitterns, or reed inhabiting birds such as the Australian reed warbler (*Acrocephalus australis*).
- **Herbivore** – species that rely on wetland vegetation as a food source such as grazing waterfowl who eat algae, wetland vegetation, or terrestrial vegetation adjacent to waterbodies.
- **Large wader** – walking foragers that prefer less dense macrophytes or open shallow water as feeding habitat. This group includes fish eating species as herons and egrets as well as species with a diet of mainly insects such as glossy ibis (*Plegadis falcinellus*).
- **Open water forager** – species that forage in areas of low or very low vegetation density either by aerially diving for fish such as terns, gulls and cormorants, or by swimming, such as the diving ducks. Many of these species prefer deeper water.
- **Small wader** – Australian residents and international migratory shorebirds that feed in very shallow water or mudflats, typically with very low vegetation cover.
- **Wetland generalist** – opportunistic foragers that can feed over a large range of aquatic habitats with no preference necessarily for water depth or cover of macrophytes. This group includes species that often occur in large numbers such as grey teal (*Anas gracilis*) as well as adaptable species like white-bellied sea eagles (*Haliaeetus leucogaster*).

While all of the ecosystems in the study area play a role in supporting waterbirds, it is the wetland and lake ecosystems that are most important in terms of both diversity of species (Figure 23) and abundance. The Lower Latrobe Wetlands also support a number of listed threatened waterbird species including:

- Australasian bittern (*Botaurus poiciloptilus*) – endangered nationally and in Victoria
- Australasian shoveler (*Anas rhynchotis*) – listed as vulnerable in Victoria
- Common greenshank (*Tringa nebularia*) – listed as vulnerable in Victoria
- Eastern great egret (*Ardea modesta*) – listed as vulnerable in Victoria
- Hardhead (*Aythya australis*) – listed as vulnerable in Victoria
- Intermediate egret (*Ardea intermedia*) – listed as endangered in Victoria
- Little egret (*Egretta garzetta*) – listed as endangered in Victoria
- Musk duck (*Biziura lobata*) – listed as vulnerable in Victoria

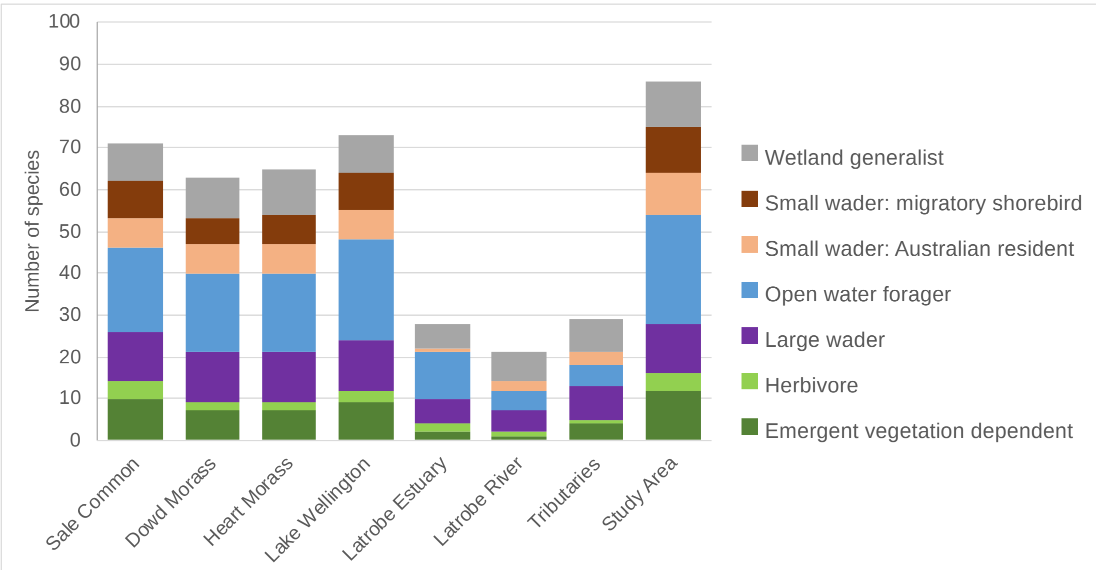


Figure 23: Species richness of waterbird by functional group and location (data from Atlas of Living Australia, DELWP unpublished and Field and Game Australia).

There are several international migratory species, protected by international treaties that are regularly recorded in the Lower Latrobe Wetlands including common greenshank (*Tringa nebularia*), Latham's snipe (*Gallinago hardwickii*), red-necked stint (*Calidris ruficollis*) and sharp-tailed sandpiper (*Calidris acuminata*). There are international obligations to protect these species, which are also protected under the EPBC Act.

Ramsar: A network of sites

There is a network of over 2000 Ramsar wetlands across the globe that is dedicated to sustaining biodiversity and wise use. One of the important functions, and a primary purpose for the establishment of the Convention, is to protect sites in different countries that are important for migratory birds.

The migratory birds that visit Australia are part of the East Asian-Australasian Flyway and most of them migrate from breeding grounds in North-east Asia and Alaska to non-breeding grounds in Australia and New Zealand, covering the journey of 10 000 kilometres twice in a single year.

The lifecycle of most international migratory shorebirds involves (Bamford et al. 2008):

- breeding in May to August (northern hemisphere);
- southward migration to the southern hemisphere (August to November);
- feeding and foraging in the southern hemisphere (August to April); and
- northward migration to breeding grounds (March to May).

The Lower Latrobe Wetlands regular support moderate numbers of at least four species of international migratory wader. Migratory waders in Australia need to build up their energy reserves for the homeward journey. This means that they not only require abundant food sources, but they need to minimise their activity. Populations of many migratory wader species are in decline, primarily through loss of habitat in breeding and staging areas outside Australia. This makes them more vulnerable while in Australia and increases the importance of doing everything in our power to maintain habitat and conditions.

Waders in Heart Morass (photo Sean Phillipson).

The Lower Latrobe wetlands are also important with respect to breeding waterbirds. Heart Morass supports waterbird breeding which previously included colonial nesting species such as royal spoonbill and eastern great egret (Borg and Savage 2005). Sale Common also supports breeding of several waterfowl species, including large numbers of black swans and a small colony of Australasian darters. Dowd Morass supports a breeding colony of colonial nesting waterbirds, mainly Australian white ibis and straw-necked ibis (*Threskiornis spinicollis*) with smaller numbers of royal spoonbills (*Platalea regia*). Historically it has also supported cormorant and egret breeding but not in recent decades. These colonial nesting species use the swamp paperbarks in the west end of Dowd Morass as nesting habitat. Thousands of birds have been recorded breeding at the wetland in the 1970s, 80s and 90s and there are records of thousands of nests as recently as 2017 (Atlas of Living Australia). These waterbirds have continental scale distributions and are likely to use Dowd Morass as a nesting site, particularly when surrounding landscapes are dry.

Waterbird breeding requirements with respect to water regimes vary according to species. Typically, however, colonial nesting species such as the ibis, cormorants, spoonbill and egrets that breed in the Lower Latrobe Wetlands require inundation under nest habitat (trees, shrubs, dense reeds, standing dead trees) for the duration of nesting, until chicks are fledged (three to four months). Drops in water levels can lead to nest abandonment and breeding failure (Brandis 2010, Arthur et al. 2012). In addition to water under nests, breeding waterbirds require adequate foraging habitat and moderate to high productivity to ensure recruitment of nestlings into the adult population (McGinness et al. 2019).

Figure 24: Black swan nest in Heart Morass in 2018 (Photo West Gippsland CMA).

2.6.3 Other aquatic fauna

The aquatic ecosystems of the study area support a range of other aquatic fauna including frogs, turtles, platypus, rakali (water rat) and a diversity of macroinvertebrates. Of note is the two nationally listed frog species that are present in the Lower Latrobe Wetlands, the green and golden bell frog (*Litoria aurea*) and the growling grass frog (*L. raniformis*).

In addition, all aquatic ecosystems in the study area support a diversity and abundance of macroinvertebrates. These are important components of the food chain, but also have inherent biodiversity values. The Latrobe River and tributaries support two Victorian endangered crustaceans: South Gippsland spiny crayfish (*Euastacus neodiversus*) and Strzelecki burrowing crayfish (*Engaeus rostrogaleatus*).

2.7 Water related requirements of ecological values

The water requirements for the ecosystems of the Latrobe River system, including the tributaries, Lower Latrobe Wetlands and Estuary have been described in detail in the Latrobe Flows Study (Alluvium 2020), together with quantitative flow recommendations to meet those requirements. These are not duplicated here but can be summarised in terms of the linkages with the important flow components as illustrated in Figure 25.

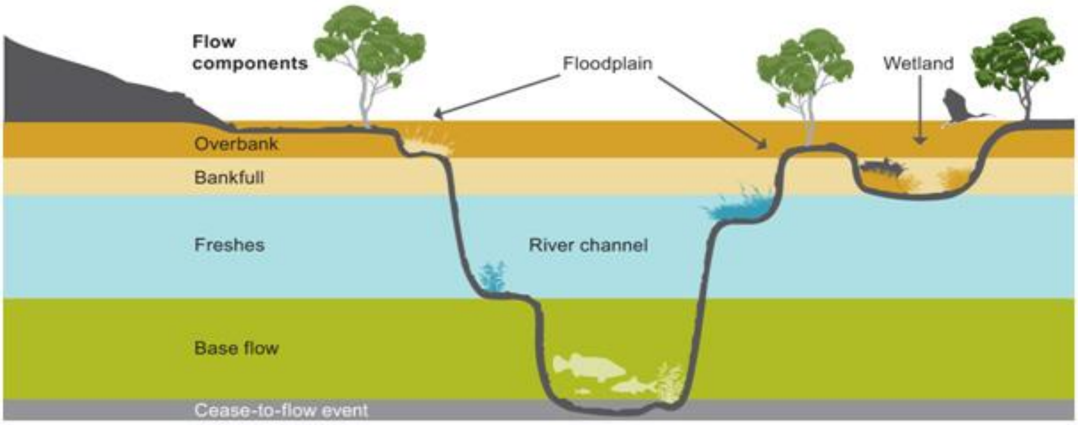


Figure 25: Flow component types and their influence on different parts of the river channel, wetlands and floodplains (Young et al. 2011).

Base flows – are low flows that maintain water movement through the channel, maintaining longitudinal connectivity along the waterway and keeping in-stream habitats wet and in channel pools full. These flows occur even after prolonged periods without rain and are often due to groundwater inputs into the stream channel. These are essential for obligate aquatic species such as fish, some species of aquatic plants, and macroinvertebrates for maintaining wetted habitat and ensuring adequate water quality, particularly dissolved oxygen.

Freshes – are in channel pulses that may be short duration (days) in summer or longer (several weeks), typically in winter. These are important for inundating in-channel benches and stimulating productivity, they act as triggers for reproductive behaviours (migration, spawning) in many native fish species and maintain water quality by flushing salts and nutrients and oxygenating the water. If adequately large they can also maintain channel form such as through scouring pools of fine-grained sediments and depositing sediments on banks and benches.

Bankfull flows – large in-channel flows typically in late winter and spring that scour the channel, restoring geomorphic diversity and habitat. They provide water for riparian vegetation and provide nesting habitat for turtles. These flows move sediments, nutrients and salts out of the system, into downstream reaches and ultimately into the ocean. In the Latrobe Estuary they are vital for flushing the river system and for pushing freshwater through Lake Wellington, maintaining low salinity conditions in the fringing wetlands.

Overbank flows – large flows, typically in late winter or early spring that spill out of the channel and inundate the floodplain. These flows are important for the movement of carbon from the floodplain to the river for maintaining productivity, for riparian and floodplain vegetation, flushing wetlands, and provision of large areas of habitat for fish, waterbirds, frogs and invertebrates. They connect the wetlands, floodplains and river systems to allow for the movement and dispersal of biota. These very large flows allow for the complete flushing of Lake Wellington, restoring freshwater conditions and resetting the system to maintain values in the long term.

Wetland water regimes – almost all wetlands in Australia are adapted to periods of wet and dry and prolonged inundation can be as much of a problem as prolonged periods of desiccation. There are several aspects to wetland water regime that are important ecologically:

Depth – different waterbird foraging groups have specific water depth requirements, for example small waders require very shallow water or wet mud to forage, while aerial diving, fish eating species like cormorants require deeper water. Water depth is also a determinant of vegetation growth-form and size. Wetland plants species often occur along a gradient of water depth and duration of inundation and have been classified into functions groups according to their preferences and tolerances (Figure 26).

Duration of inundation – is important for plants and animals that require the presence of surface water to complete reproductive cycles (i.e. to grow, flower, and set seed, or to nest and fledge). For example, growling grass frogs require extended durations of inundation, particularly in cooler climates as they have a long larval stage (Clemann and Gillespie 2012).

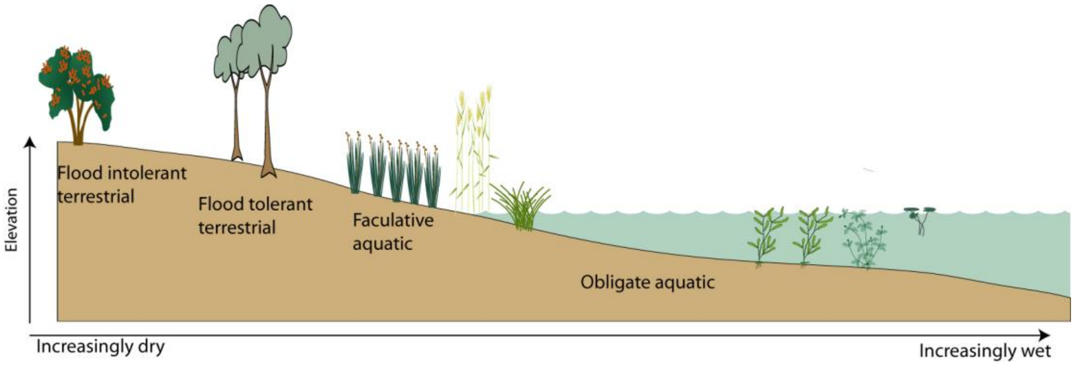


Figure 26: Effect of elevation and duration of inundation on the zonation of wetland plants (adapted from Brock and Casanova 1997).

Season of flooding – season of inundation is important mostly due to seasonal effects on temperature. Inundation in spring, as temperatures are warming, speeds physiological processes. Productivity is higher in warmer temperatures and some species of plant have germination temperature thresholds (Roberts and Marston 2011) Aseasonal inundation has proven to be determinantal to some wetland species for example, spring inundation has been shown to improve frog recruitment success, compared to inundation in winter (Wassens et al. 2017).

Rate of rise or fall - rapidly rising water levels can drown out aquatic plants before they can grow to keep leaves or stems above the water line. Rapid rates of fall can prevent the completion of lifecycle stages such as storing of energy in underground vegetated states, fledging of waterbirds, metamorphosis of tadpoles to adult frogs, or movement of fish back into the river system.

Magnitude of inundation – the extent and force of an inundation event is particularly important for the Lower Latrobe Wetlands, where wetland beds are low, requiring large flows to flush the system. This means, that in the absence of large flood events, salts, and nutrients accumulate.

Period of dry – many wetland biota and ecological processes are reliant on a dry phase. Several species of wetland plant require dry periods to survive (e.g. aeriation of soils for floodplain and riparian trees Roberts and Marston 2011) or to reproduce sexually (e.g. swamp paperbark; Salter et al. 2007). Extended periods of dry conditions can also cause impacts. For example, the native species giant rush (*Juncus ingens*) can become invasive under prolonged dry conditions (Mayence et al. 2010). Prolonged periods of dry and disturbance of wetland sediments can lead to the acidic condition upon re-wetting when acid sulfate soils are present. There is evidence of acid sulfate soils in both Heart and Dowd Morass, with periods of acidity common after long dry conditions (Taylor 2011, Unland 2015).

Zonation of wetland plants at Sale Common, with submerged macrophytes in the foreground, emergent species further back and grading to flood tolerant species in the background (photo: West Gippsland CMA).

3 Environmental effects assessment

3.1 Current operations

The mines and power stations of the Latrobe Valley have significant interactions with the rivers of the region. The generation of electricity requires large volumes of good quality water. Water is used in (Smart and Aspinall 2009):

- the boiler for steam raising
- the cooling system
- managing and disposing of ash
- services and potable water supplies.

The water arrangements for the brown coal-fired plants included in the mine rehabilitation assessment are summarised in Table 5 and illustrated in Figure 27: Schematic of water use and average discharges to the rivers of the Latrobe Valley.. It should be noted that while the Hazelwood mine and power station ceased operation on 31 March 2017 (Department of Economic Development, Jobs, Transport and Resources and Victoria 2018), mine de-watering continues as do discharges to the Latrobe River. Average groundwater extraction for the three mines is 28 GL/year.

Table 5: Water access arrangements for Latrobe Valley power generators (Smart and Aspinall 2009)

Generator	Water use*	Source	Contractual arrangements
Yallourn Power Station	Low quality water - 27.4 GL/year with around 13.1 GL/year returned to the river system – a net consumption of 14.3 GL/year.	Blue Rock Dam, Lake Narracan plus Latrobe River unregulated – 36.5 GL/year bulk water entitlement.	Bulk water entitlement
Loy Yang A Power Station	High quality water around 1 GL/year. Low quality water – around 21.8 GL/year with 4.6 GL/year returned to the river system by Loy Yang A and Loy Yang B. .	High quality water from Moondarra reservoir Low quality water from Blue Rock Dam, Lake Narracan and Latrobe River – 40 GL/year bulk water entitlement. Groundwater from mine dewatering.	High quality water supplied under contract from Gippsland Water on a volumetric basis. Low quality water supplied under a bulk water entitlement.
Loy Yang B Power Station	High quality water - 1 GL/year. Low quality water 14.8 GL/year.	High quality water for domestic Services Water ex Moondarra Reservoir. Low quality water from Blue Rock Dam, Lake Narracan & Latrobe River under a 20 GL/year entitlement.	High quality water supplied under contract from Gippsland Water. Low quality water supplied under licence from Southern Rural Water.
Hazelwood Power Station	High quality water 14 GL/year with around 3.7 GL/year returned to the river system – a net consumption of 10.3 GL/year.	High quality water supplied from Moondarra Reservoir. Groundwater from mine dewatering.	Supplied by agreement with Gippsland Water.

* Water use and return flow data from Smart and Aspinall (2009) has been updated with the average volume between 2006/07 to 2018/19 as recorded in the Victorian Water Register.

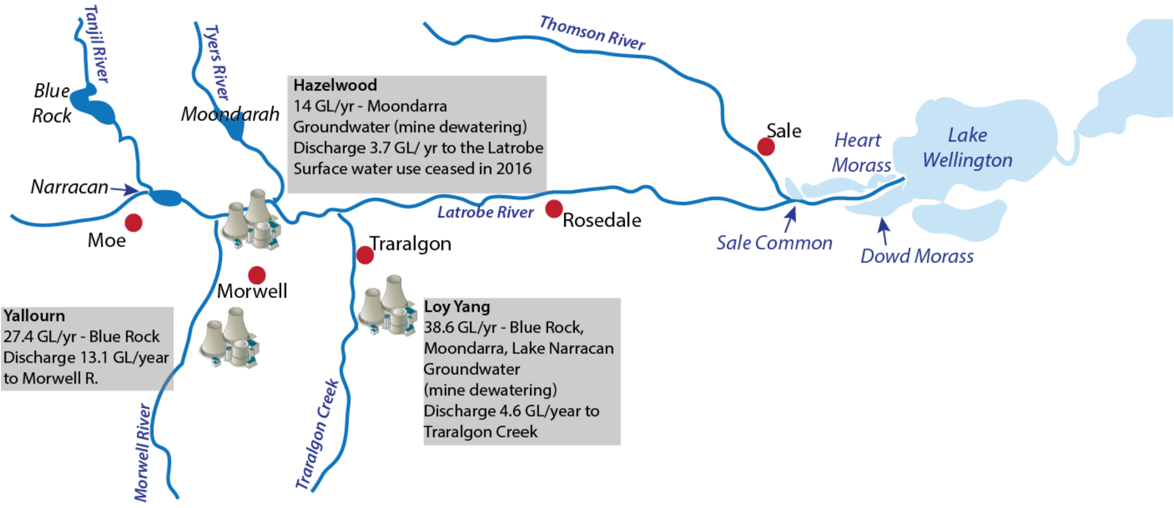


Figure 27: Schematic of water use and average discharges to the rivers of the Latrobe Valley.

All power stations discharge water to the rivers and streams of the study region. Although these discharges are subject to EPA licence conditions, there is undoubtedly an effect on both the quantity and quality of water within the rivers as a result. In comparison with river water, discharges (particularly from Hazelwood) are warm (6ºC on average above ambient), alkaline, turbid and salty (Table 6). In 2017-2018, there was a combined load of approximately 17 tonnes of salt discharged to the rivers of the region from the power stations, 65% of which came from Hazelwood (data from EPA Annual Performance Statements).

Table 6: Annual average water quality of discharges to rivers from Hazelwood, Yallourn and Loy Yang from July 2017 – June 2018 (data from EPA Annual Performance Statements).

Parameter	Hazelwood	Yallourn	Loy Yang
Annual discharge (ML)	14,099	12,640	3931
Temperature (°C above ambient)	6		6
pH	8.5	7.1	7.4
Colour (pt-Co)	36	30	45
Turbidity (NTU)	14	29	4
Total Suspended Solids (mg/l)	8	13	2.5
Salinity (ppt)	0.78	0.41	0.37

3.2 Large scale drivers of change

The potential ecological effects of mine rehabilitation must be considered in the context of current and future factors that are impacting on the condition of the aquatic ecosystems of the study area. The Millennium Ecosystem Assessment identified human population growth and associated increases in resource use as the major driver of change for aquatic ecosystems systems on a global scale (Millennium Ecosystem Assessment Program 2005). More recently, climate change has been predicted to be the second most important driver of global biodiversity change in the 21st century (second only to land use change associated with population growth) (Elmhagen et al. 2015). While these two drivers of change result in a wide range of threats and stressors to the aquatic ecosystems of the region (e.g. land use change, increased nutrients and sediments), the focus of this assessment is the potential effects of continued or increasing water resource use in the context of a changing climate.

3.2.1 Population growth and water resource use

Population in the Latrobe Valley has grown and is continuing to grow. The regional population in the Latrobe Valley has increased from around 100,000 in 1988 to almost 150,000 in 2019 (data from the Australian Bureau of Statistics). One of the consequences of increases in population has been an increase in the demand for and abstraction of water from the rivers of the Latrobe Basin. There are several major dams in the Latrobe system (Table 7). The consumptive uses are for industry and power generation, as mentioned above, for agriculture as well as domestic water supply (Department of Sustainability and Environment 2011). From 2002 to 2017, an average of 157,000 ML was extracted from the Latrobe for consumptive use ranging from 141,000 ML in 2013/14 to 185,000 ML in 2006/7 (Victorian Water Register).

Table 7: Major storages in the Latrobe Basin.

Basin	River	Dam	Capacity (ML)	Date
Latrobe	Latrobe	Lake Narracan	8,600	1961
	Tyers	Moondarra Reservoir	30,000	1962
	Tanjil	Blue Rock Reservoir	208,000	1984

Licenced groundwater extraction from the surficial aquifers the Latrobe Basin is very small compared to surface water extraction (Department of Environment, Land, Water and Planning 2019). Groundwater in the Latrobe region is being lowered, predominantly by Latrobe Valley coal mine dewatering, but these deep aquifers are also not well connected to rivers and wetlands (Department of Environment, Land, Water and Planning 2019) so the impact on major aquatic ecosystems is negligible.

Water resource use in the Thomson River Basin

Although the focus of this ecological effects assessment is the Latrobe River Basin, the lower parts of the system including the Latrobe Estuary, Lake Wellington and the Lower Latrobe Wetlands, are also influenced by water from the Thomson River Basin and so the effects of mine rehabilitation, water resource use and climate change must be considered in the context of reduced flows down the Thomson River.

A large proportion of the water in the Thomson River Basin is diverted to supply Greater Metropolitan Melbourne. Therefore, it is not only population growth in the Latrobe River and Thomson River Basins, but also increased population in Greater Melbourne that has driven and continues to drive increased water resource use in the catchment of Lake Wellington. The population of Greater Melbourne has increased substantially over the past three decades, from around 3 million in 1988 to over 5 million in 2019. It is projected to increase to over 8 million by 2050. Over the same period, the regional population in the Latrobe Valley and Wellington area has increased from around 100,000 to almost 150,000 (data from the Australian Bureau of Statistics).

Data from the Victorian Water Register indicate that on average 316,000 ML are extracted from the Thomson Basin for consumptive use (2003 to 2017) ranging from a low of 148,000 ML in the wet year of 2011/12 to a high of 435,000 ML in 2015/16. Typically, about half the consumptive use is for Melbourne water supplies and half for irrigation in the Gippsland region (e.g. the Macalister Irrigation District), with other minor urban and industrial uses accounting for a small percentage (DELWP 2005, 2007, 2009, 2014, 2015, 2016a).

It should be noted that although there are return flows (where a portion of the water extracted is returned to the river system), for irrigation and some commercial uses (such as power supply), the water diverted to the Yarra River for Melbourne water supplies is completely removed from the Lake Wellington system. The relatively high levels of water resource use in this system, particularly in dry years, results in more water being extracted from the Thomson River Basin for consumptive use than is discharged to Lake Wellington in some years.

3.2.2 Climate change

High resolution climate change projections for the Latrobe Valley (Jacobs et al. 2017) projected the following aggregated changes in hydroclimate variables under emission scenario RCP8.5 relative to the baseline period of 1975 – 2014:

- Increase in average annual temperature of 1.53^0 C for dry (90th percentile) scenario and 1.21^0 C for median (50th percentile) scenario by 2040, with increases of 2.82^0 C and 2.21^0 C for respective scenarios by 2065.
- Increase in annual potential evapotranspiration (PET) of 5.84% for dry scenario and 4.51% for median scenario by 2040, with increases of 11.47% and 7.6% for respective scenarios by 2065.
- Decrease in annual rainfall of 14.23% for dry scenario and 4.17% for median scenario by 2040, with decreases of 20.9% and 4.45% for respective scenarios by 2065. Reduction in cool-season rainfall has been predicted for Victoria.
- Decrease in annual runoff of 35.46% for dry scenario and 10.0% for median scenario by 2040, with decreases of 49.21% and 17.86% for respective scenarios by 2065.

Although there is growing evidence for projected changes in surface water runoff in the future, there is also very strong evidence that many of these changes are already being realised currently. Recent assessments of water availability (i.e. the entire volume of water in the river system including rivers flows and consumptive use) in the Latrobe Basin indicate that there has already been a demonstrable decline in surface water due to warmer and drier conditions. The period 1975 to 2018, for example, saw a 5% decline in surface water in the Latrobe Basin, compared with the long-term historical record. There have been further declines in surface water after 1997 (around 27% compared to the historical record), but this period includes the decade long Millennium Drought, which may not be indicative of a continuing trend (DELWP 2020). These quantifiable changes in regional hydrology are consistent with other reports from elsewhere in Australia that similarly indicate climate change is already having demonstrable impacts on rivers and wetlands (e.g. Lough and Hobday 2011, Finlayson et al. 2013, 2017).

Latrobe River, West Gippsland CMA.

3.3 Potential effects on values and condition

3.3.1 Hydrological analysis

Hydrological modelling has been conducted to investigate the impact of climate change and potential future demands on the environmental values of the Latrobe River system. Achievement of the flow recommendations (as detailed in Alluvium 2020) for maintaining ecological values under several different scenarios has been explored. In recognition that the climate has already experienced change, scenarios have been assessed relevant to the current climatic conditions (represented by post 1975 climate) and the potential future climate (represented by the post 1997 climate). This was completed in accordance with DELWP's Guidelines for Assessing the Impact of Climate Change on Water Supplies in Victoria (DELWP 2016). The five scenarios used here for comparison are[7]:

6. Natural (current climate) – what the system would look like under current climatic conditions but with no extraction from the Latrobe River. This is the base case against which we can evaluate the effects of water resource extraction and climate change.
7. Current conditions (current climate) – what the system is experiencing now, with current water use and current climatic conditions.
8. Current conditions (future climate) – what if the amount of water extracted remained the same as today but the climate continues to dry.
9. Full uptake (current climate) – what would happen if we had full uptake of industrial demands for water and current climatic conditions.
10. Full uptake (future climate) – what would happen if we had full uptake of industrial demands for water and the climate continues to dry.

To enable a meaningful comparison of the provision of ecologically important flows under the different scenarios, achievement of recommended flows has been assessed relevant to the natural (unimpacted) historical climate model outputs (1957 to 2016). That is, the conditions that the ecosystems of the Latrobe Valley would have experienced in the absence of extraction and climate change. This is to account for flows that are not expected to occur in every year. For example, we would only expect overbank flows in wet years, and so the number of times the overbank flow recommendations have been achieved under each scenario have been compared over the 60-year model period, with the number of times this flow would have naturally occurred. The results are expressed as the proportion of natural. Therefore, if a flow component would naturally have occurred, on average, in half of the modelled years, and under scenario 3 (current extraction, future climate) it occurs in a quarter of years, this would be assessed as 50% achievement of the flow component.

Model outputs were available for three reaches on the Latrobe River (all downstream of Lake Narracan), the Latrobe Estuary and the Tanjil River. Changes in hydrology for wetlands have been inferred from river flows.

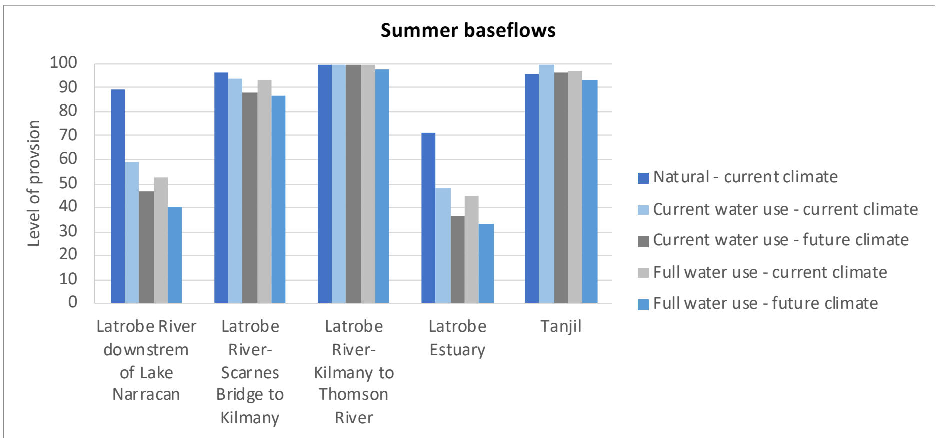
Shorebirds at Heart Morass (photo: Sean Phillipson).

[7] The hydrological modelling was undertaken using the REALM model as that described in Alluvium (2020).

Effects on baseflows

Although the effects of water extraction and climate change on the provision of baseflows in the Latrobe River system varies with location, all are lower under future climates and with full uptake of water entitlements than experienced presently (Figure 28). Summer baseflows in the Latrobe River immediately downstream of Lake Narracan are provided currently only 60% of the time. A similar situation holds for the lowest reach, the estuary. In the sections of the Latrobe River between Scarnes Bridge and the confluence with the Thomson River, baseflow recommendations are almost always met. This may be partially explained by the constant discharge of water from the mine dewatering and power plant operations and passing flows from Lake Narracan. It should be noted that the reduction in flows due to the cessation of discharge from power stations has not been incorporated into the modelling. This would further reduce the provision of baseflows in the Latrobe River.

In the Tanjil River, summer baseflows are nearly always provided as recommended, largely due to the release of water from Blue Rock over summer for consumptive use. In winter, however, baseflow recommendations are met less often, most likely due to the holding of winter flows in storage. Under the scenario of full uptake of entitlements and future climate, winter baseflows in the Tanjil River become highly impacted, and would likely result in substantial cease to flow periods. It is highly unlikely that the Tanjil River would ever have experienced cease-to-flow conditions in the natural past, most especially during winter (when flows would normally be high, due to seasonal rain and snow melt from the highlands parts of the catchment).



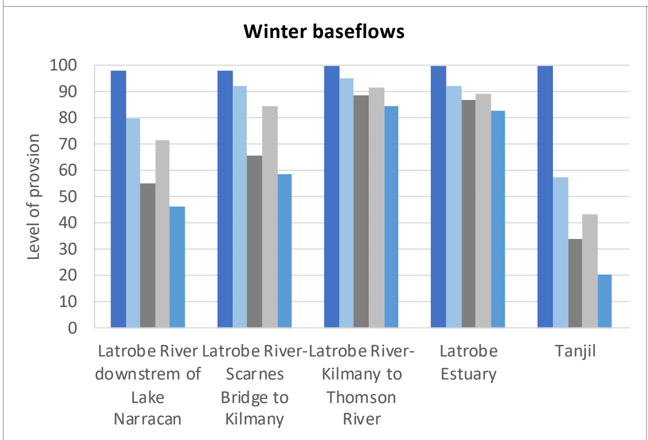


Figure 28: Provision of baseflows under the five modelled scenarios relevant to natural. Latrobe River Reaches comprise: upstream (Lake Narracan to Scarnes Bridge); middle (Scarnes Bridge to Kilmany South) and lower (Kilmany South to the confluence with the Thomson River). Refer to Figure 29 for geographical location.

Figure 29 Reaches of the Latrobe system

Effects on freshes

The impact of current and future water resource use and climate change on the provision of freshes is substantial (Figure 30). The provision of summer freshes in the Latrobe Estuary is very low under all scenarios, noting that this will be influenced also by the extraction of water from the Thomson River (for which large volumes of water are diverted to Melbourne for domestic supply). So, while the recommendations are met only a third of the time in summer, even without extraction from the Latrobe system (natural- current climate), the situation under future climate and full uptake of entitlements, is even worse, with provision of less than 10 % of the required flows.

The provision of winter freshes in the two reaches downstream of storages (Latrobe below Lake Narracan and Tanjil below Blue Rock) are also heavily impacted by water resource use and climate change (Figure 30). Winter freshes in these two reaches are so reduced over the natural flow regime under full water use and future climate that they can be expected to occur <15 % of the required incidence. Even in the Latrobe River estuary, the incidence of winter freshes is decreased under full water use and future climate by about 30 % from natural.

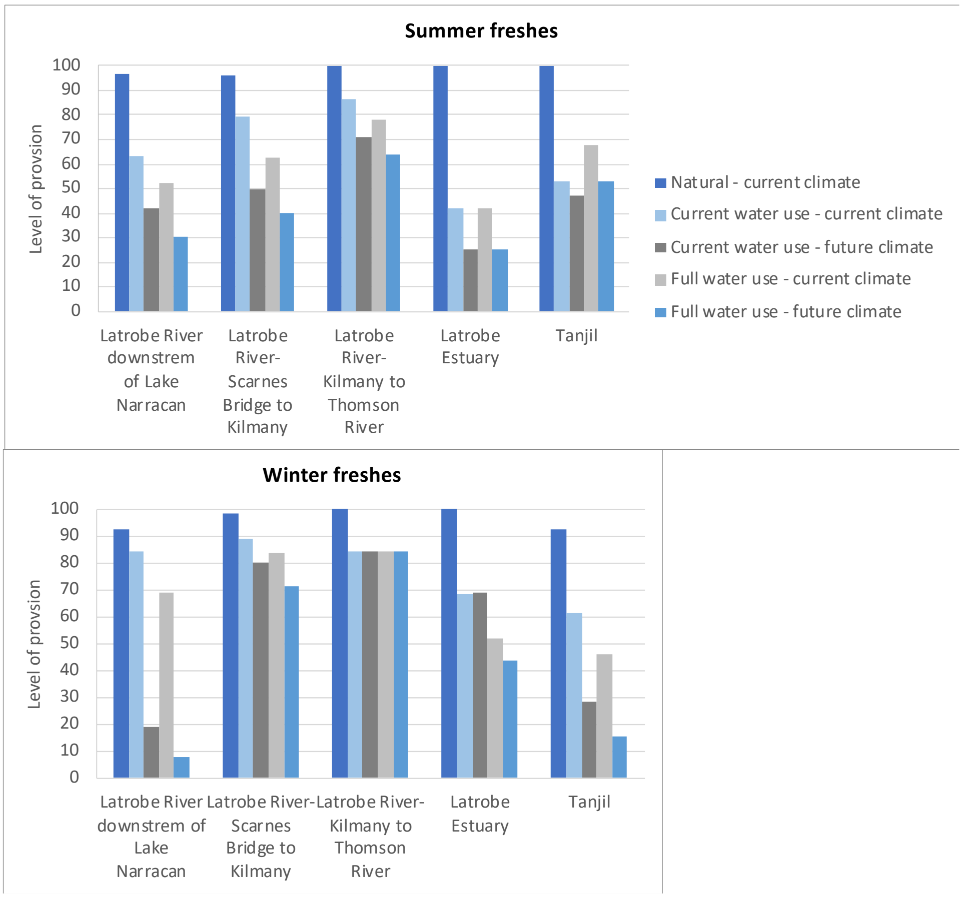


Figure 30: Provision of freshes under the five modelled scenarios relevant to natural. Latrobe River Reaches comprise: upstream (Lake Narracan to Scarnes Bridge); middle (Scarnes Bridge to Kilmany South) and lower (Kilmany South to the confluence with the Thomson River).

Effects on bankfull

Bankfull conditions occur regularly under conditions without extraction in most reaches, except the Latrobe Estuary. Impacts to the provision of bankfull flows from extraction and climate change are most keenly seen in the Estuary as well as the Latrobe below Lake Narracan and the Tanjil River (Figure 31). In several reaches, the recommended maximum duration between has also been exceeded.

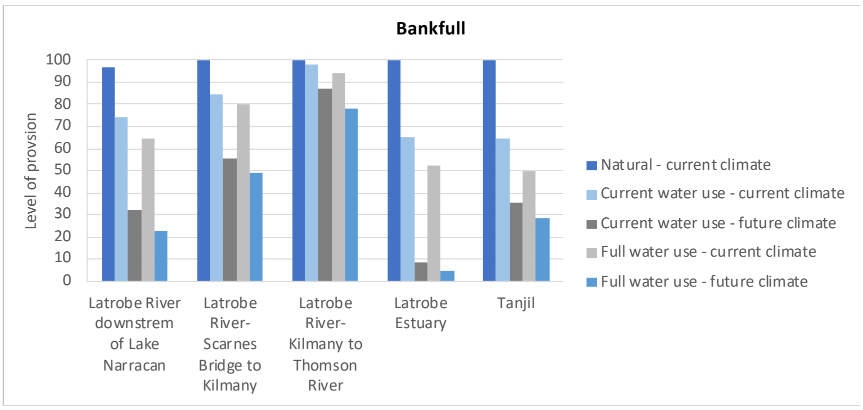


Figure 31: Provision of bankfull flows under the five modelled scenarios relevant to natural. Latrobe River Reaches comprise: upstream (Lake Narracan to Scarnes Bridge); middle (Scarnes Bridge to Kilmany South) and lower (Kilmany South to the confluence with the Thomson River).

Effects on overbank flows

Overbank flows are highly affected by both extraction and by climate change in all rivers except the Latrobe River between Kilmany South and the confluence with the Thomson, where flow recommendations are met more often (Figure 32). The effect of climate change on overbank flows in the Tanjil is extreme, with no incidence of these flows in the 60 year model record. The combined effects of full uptake of entitlements and future climates results in a 60 % reduction in overbank flows in most reaches.

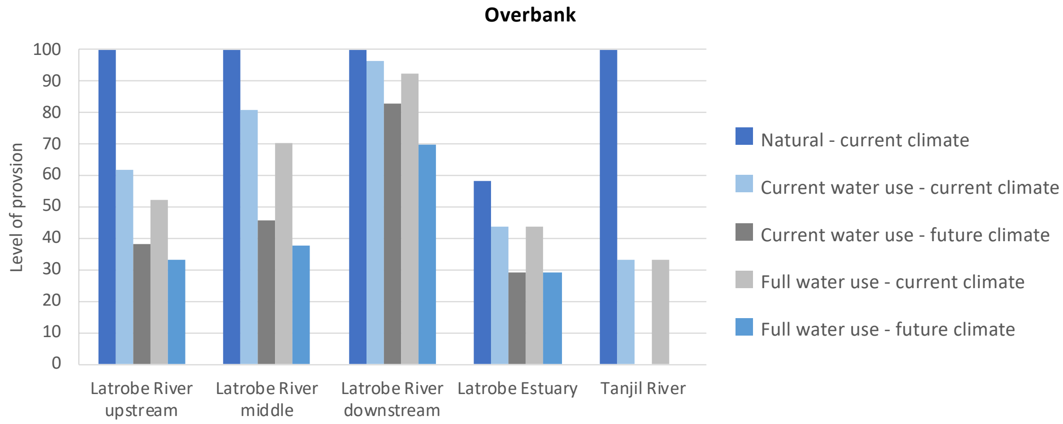


Figure 32: Provision of overbank flows under the five modelled scenarios relevant to natural. Latrobe River Reaches comprise: upstream (Lake Narracan to Scarnes Bridge); middle (Scarnes Bridge to Kilmany South) and lower (Kilmany South to the confluence with the Thomson River).

Effects on wetlands and lakes

Filling and drawdown of the Lower Latrobe Wetlands is largely achieved by managed watering with environmental entitlements and infrastructure. There are, however, several important flows required to maintain the ecological character of these wetlands, and the condition of Lake Wellington.

It is estimated that total flows of 130 GL/ month are required in the Latrobe Estuary to flush salts from Lake Wellington (Brizga et al. 2013). This is not only relevant to the lake itself, but also for maintaining the low salinity conditions of the lake's fringing wetlands. Under natural (current climate, no extraction) conditions, this flow is achieved in about 45 % of months. Under current conditions, this has been reduced by about one third to 30 % of months and under full uptake of entitlements and future climates this is reduced to just 18 % of months (Table 8).

Table 8: Flow statistics for wetland flows under the different water use and climate scenarios.

Flow component	Natural current climate	Current water use current climate	Current water use future climate	Full water use current climate	Full water use future climate
130GL/month in the Latrobe Estuary, to flush Lake Wellington					
Percentage of months flow occurs	46	31	20	28	18
Percentage of years flow not met	5	20	32	20	35
3200 ML/day in the Latrobe Estuary to allow freshwater inflows to wetlands through infrastructure					
Percentage of days flow threshold is exceeded	44	27	19	25	17
Maximum interval flow threshold is not achieved (days)	249	613	626	614	630
15,000 ML/day in the Latrobe Estuary to flush wetlands					
Percentage of years flow is met	25	15	2.5	15	2.5

In order to manage water regimes in the Lower Latrobe Wetlands, water must be fresh at the inlet structures. To achieve this for all three wetlands, requires a flow of around 3,200 ML/day at the Swing Bridge during winter and spring (Alluvium 2020). While this is achieved around 44 % of the time currently, this drops to just over 17 % under full uptake of entitlements and future climate.

Flushing of Sale Common can currently only occur from overbank flows, with water moving overbank from the Latrobe into the wetland at around 15,000 ML/day. This can currently be achieved in around 25 % of years. Under future climates this reduces to just 2.5 times every 100 years.

Other hydrological changes

As power stations are decommissioned, the discharge of cooling water and groundwater from mine dewatering will cease. This is predicted to result in a 15% further decline in baseflows in the Latrobe River downstream of the Morwell River confluence. Although the quantitative effects of this on the flow regime in the tributaries have not been assessed in this study, it can be assumed that there will be a greater reduction in flows in the Morwell River and Traralgon Creek. Summer baseflow recommendations for Traralgon Creek are 40 ML/day (Alluvium 2020). Current discharge from Loy Yang is around 6000 ML/year. If this is a relatively constant flow, then it comprises 40% of summer baseflows in the system. Similarly, the discharge from Yallourn to the Morwell River is around 16,000 ML / year. This represents about half the summer baseflow recommendation of 90 ML/day.

3.3.2 Ecological effects

Ecological effects have been assessed against the objectives for the aquatic ecosystems of the system, which were developed with the input of local communities, relevant agencies and tradition Owner's (Alluvium 2020):

- Avoid adverse water quality conditions, including limiting surface water salinity in the estuary, and maintaining freshwater supply to the wetlands
- Improve the condition and increase the extent and diversity of submerged, emergent, riparian and floodplain vegetation
- Maintain abundance, improve breeding and recruitment of native fish (migratory, resident freshwater, and estuary) populations
- Maintain or enhance waterbird breeding, recruitment, foraging and sheltering opportunities
- Maintain refuge habitats for, and improve extent of, frog populations
- Improve abundance of all macroinvertebrates and zooplankton populations
- Maintain abundance and improve extent of platypus and rakali populations
- Maintain abundance of freshwater turtle populations
- Maintain habitat to support ecological values and processes.

There is much that is unknown about mine rehabilitation such as the timing, volume and sequencing of fill events; if the pit lakes will be completely full or partially, and if there is the potential for pit water to spill back into the river system. As a consequence, this EEA is evaluating the potential effects of continued extraction and uptake of full entitlements under current and future climates on the ecology of the aquatic ecosystems of the Latrobe River Basin. The hydrological analysis provides a perspective on the impact of these scenarios on the ecologically important aspects of the flow regime. This, together with an understanding of flow-ecology relationships and the values and condition of the aquatic ecosystems in the study area, provide the basis for this evaluation.

The outputs of the hydrological analysis indicate that the aquatic system currently does not receive the important flows that it needs to maintain ecological condition and to achieve the objectives identified in Alluvium (2020). Moreover, under future climatic conditions the situation will be worse. The hydrological analysis also indicates that a full uptake of water entitlements would further exacerbate the existing poor compliance with the required flow regime. The decline in freshwater inflows affects not only hydrological regimes, but also ecological processes such as sedimentation and deposition, carbon cycling and productivity and water quality, most notably dissolved oxygen and salinity.

The relationship between altered flows and ecological values is illustrated in a stressor model in Figure 33.

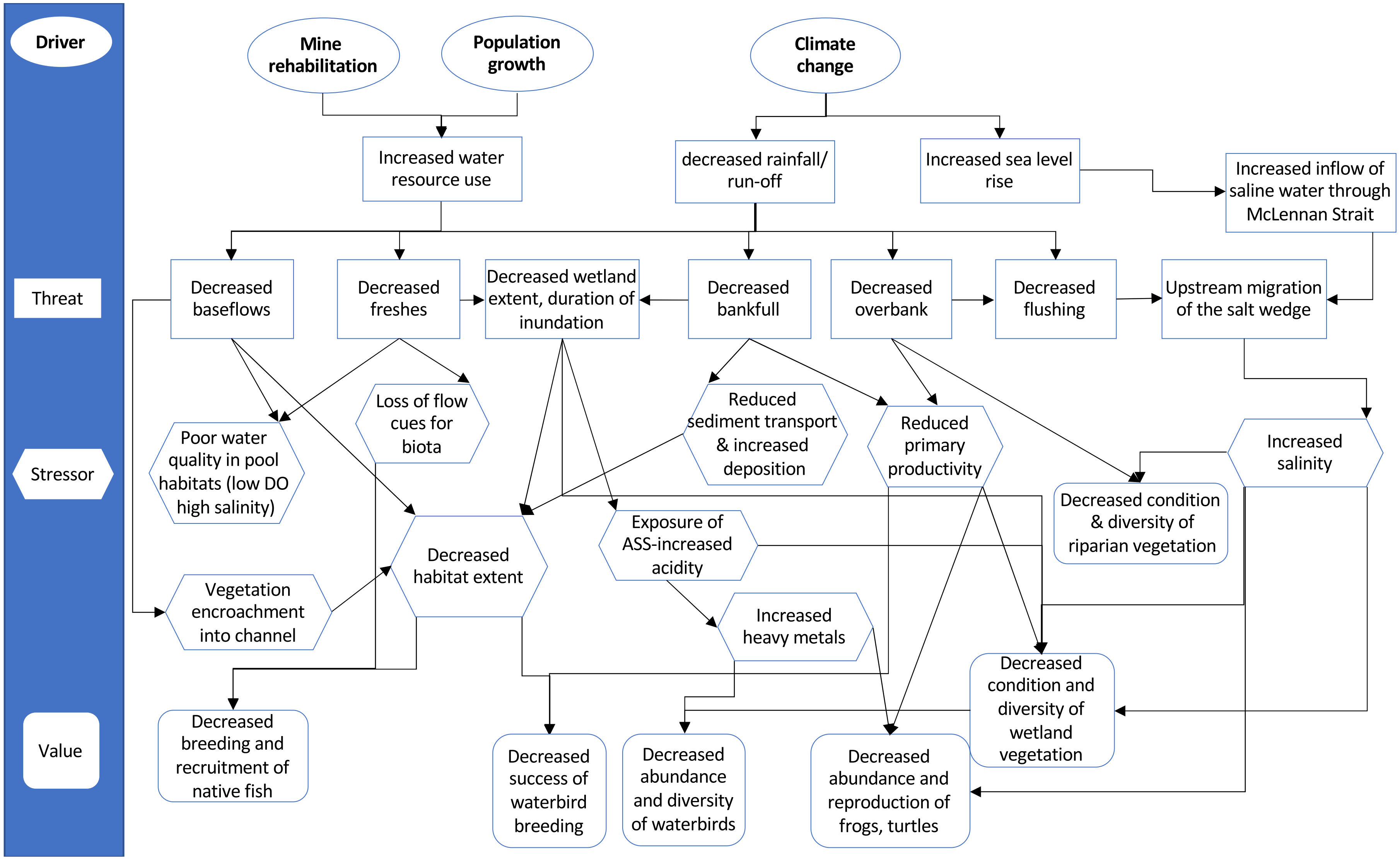


Figure 33: Stressor model of the impacts of altered flow regimes on the ecological values of the aquatic ecosystems in the study area.

The stressor model is consistent with the Driver-Pressure-State-Response Model (OECD 1993) and looks at:

- Drivers – large scale changes in the environment
- Threats – the events or activities arising from these drivers
- Stressors – the physical or chemical changes in the aquatic ecosystem(s).

This is a simplified model that does not show every link and relationship, just the major pathways. It illustrates the complex and interactive nature of the impacts of altered flow regimes on the system. A brief description of the ecological consequences of the predicted future states is provided for each of the major biological values.

Effects on water quality

Several impacts of altered water regimes on water quality are predicted, of which the most important include: (1) increased salinity in the estuary, Lake Wellington and the fringing wetlands; (2) exposure of acid sulfate soils in Heart and Dowd Morass; and (3) decreased DO concentrations in the in-channel riverine habitats.

Increasing salinity

As mentioned in section 2.4, the salinity in Lake Wellington and the Latrobe Estuary is a product of freshwater inflows pushing salt out of these systems and the incursion of marine water from the Southern Ocean, through McLennan Strait into Lake Wellington (and potentially up the Latrobe Estuary). There is no doubt that a further decline in periods where flows exceed 130 GL/month, especially if coupled with continued rising sea levels and storm surges, will result in continued salinisation of Lake Wellington, the Latrobe Estuary and several of the fringing wetlands.

Of the Lower Latrobe Wetlands, Dowd Morass is likely to be the most affected in the short-to-medium term by increased salinity, as it is hydrologically connected to Lake Wellington through the Dardenelles at 0.35 mAHD, considerably lower than Heart Morass or Sale Common (Brizga et al. 2013). The available data indicate that since 1975, water levels in Lake Wellington exceed 0.35 mAHD about 7% of the time. Most often when this occurs, however, the salinity in Lake Wellington is low. This is because higher water levels in Lake Wellington most often occurred due to freshwater inflows from rivers during high flow and flood events. There is evidence in the historical record for a clear increase in the incidence of saline water intrusion into Dowd Morass from Lake Wellington, over the past decade. While there are only two confirmed records of this occurring prior to 2000 (1978 and 1998); it has happened nearly every year since 2007 (Figure 34). In addition, as sea levels rise and freshwater inflows continue to decline, it is likely that this will occur with increasing frequency.

A complication that is particularly relevant for Dowd Morass is that the morass lies in a depression adjacent to the lower Latrobe River such that once water enters the wetland it is retained within it except during large floods. In other words, it is a 'retentative' wetland rather than a 'flow-through' wetland. This characteristic makes it almost impossible to flush the morass of saline water, and significant flushing can occur only during large floods. The morass is not a simple 'flow-through' wetland in which environmental water can easily be used to flush saline or nutrient-enriched water out of the wetland and into Lake Wellington or the lowest parts of the Latrobe River. Therefore, when saline water enters the system, it remains in the wetland for relatively long periods of time, with the concomitant accumulation of salt in the water column and sediments.

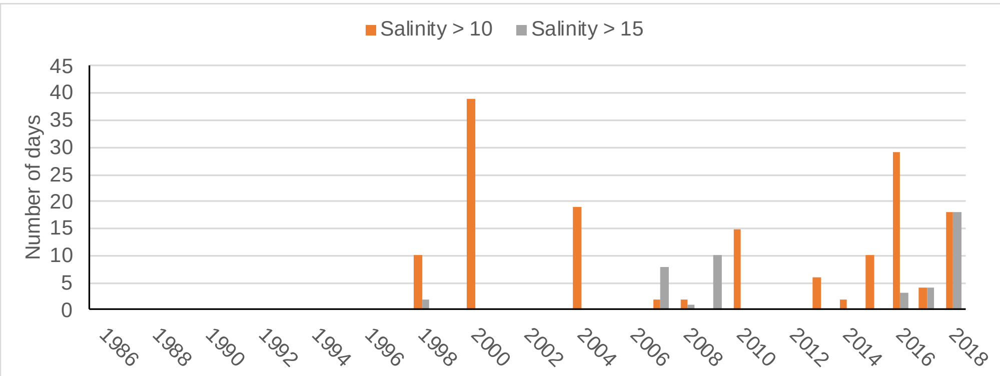


Figure 34: Days when water level in Lake Wellington exceeded 0.35 m AHD and salinity was > 10 ppt and > 15 ppt (Hale et al. 2018).

Similar events could occur in the medium to long term at Heart Morass and eventually Sale Common, if freshwater inflows continue to decline and sea level rises. Although they have much reduced unregulated connectivity with the Estuary and Lake Wellington, increased salinity in the Estuary will affect salinity in these systems by limiting opportunities for delivery of environmental water. If water in the estuary adjacent to wetland infrastructure is saline, then freshwater cannot be diverted into these wetlands.

Activation of acid sulfate soils

Previous investigations have indicated that acid sulfate soils are present in both Heart and Dowd Morass, but not in Sale Common (Unland 2009). The results at Sale Common, however, should be considered in the context of limited sampling and the area around this wetland was mapped as being within the high-risk zone for acid sulfate soils (Department of Sustainability and Environment 2009). The iron sulphides in acid sulfate soils remain stable when underwater and thus in reduced (non-oxidising) conditions, but once the soils are dried and come into contact with the oxygen in air they are oxidised, leading to the release of sulfuric acid. This is accompanied by a release of aluminium and potentially other heavy metals from the sediments and usually has very serious adverse ecological and social impacts (Sammut et al. 1996).

Studies have also indicated that the acid sulfate soils in Dowd and Heart Morass have led to the mobilisation of metals at concentrations that are likely to cause biological effects (Unland 2009, Taylor 2011). The effects of acidification have been more prevalent at Heart Morass, with very low pH levels (< 3) associated with periodic drying (data from http://data.water.vic.gov.au).

Prolonged periods of low flows and periods when there is no opportunity to fill these wetlands with freshwater will inevitably lead to increased dry periods and exposure of acid sulphate soils at these sites.

Decreases in dissolved oxygen

The hydrological analysis predicts there will be a decline in the volume of baseflows during both summer and winter. Baseflows maintain lateral connectivity along river channels. In the absence of baseflows, rivers dry to a series of small in-channel pools. These pools become refuges for native fish, who would otherwise die in dry stream beds. The duration of these cease-to-flow periods is critical, especially given the fact that cease-to-flows are most unlikely to have taken place in any parts of the river system under normal conditions. Over time the water in pools becomes less (through evaporation) but even if water persists until the flow recommences, water quality declines. Dissolved oxygen levels decrease and if they reach critical levels, many native species cannot survive. Common carp are generally more tolerant of low dissolved oxygen conditions and can out compete native fish species under periods of hypoxia (low dissolved oxygen)(Stuart and Jones 2006, King et al. 2012).

Effects on physical form and habitat (geomorphology)

Flow regulation, and river channelization, are known to modify waterway geomorphology, reducing the ability of the waterway to support habitat (Vietz and Finlayson, 2017). The Latrobe River, and many of the tributaries, are more sensitive to flow regulation and the impacts on habitat and physical form. For example, the channels (particularly the Latrobe River) are:

- Straighter and steeper with gradient channels which increasea the efficacy with which sediments are mobilised, and decreases habitat diversity
- Desnagged extensively which reduces roughness, increasing velocities, and decreases habitat diversity (including refuge pools)
- Incised, with increased flowing energy exerted on the bed of the channel, increasing mobilisation of bed sediments; and
- More prone to erosion, which can increase sediment smothering (silts/clays) of bed sediments

The impacts of flow regime changes due to mine filling are such that:

- Not achieving the full suite of flow recommendations will lead to a loss of in-channel complexity (e.g. bars, benches and refuge pools). This will reduce habitat complexity, such as habitat niches including slackwaters (low velocity environments for retention of macroinvertebrates, juvenile fish, and organic matter)
- Bankfull flows and freshes (particularly winter freshes) are primarily impacted by mine filling, and these are the flows that provide most geomorphic value. This will reduce the maintenance of channel morphology, such as depositional zones (benches that provide

higher level sediments for terrestrial plant growth) and bed diversity (depth and sediment diversity).

Effects on vegetation

Riparian and floodplain vegetation in most parts of the Latrobe River system is already in poor condition, especially along the mainstem of the Latrobe River. A further decline in bankfull and overbank flows will result in continued decline in condition, extent and floristic diversity, increasing terrestrialisation and a loss of diversity in understorey communities. Large riparian and floodplain trees are adapted to periods of dry and can survive for periods of time between inundation events. They cannot survive prolonged desiccation, and that is why they are found in the usually well-watered riparian zone. The condition of riparian eucalypts has been linked to lateral movement of water through the bank (Doody et al. 2014), with declines in large freshes and bankfull events linked to declines in canopy condition and resilience of trees to non-flow stressors such as invasive species and grazing. In addition, there are several species that require inundation for reproduction, with flowering stimulated by flooding and germination on receding waters.

In many respects the history of the eastern portion of the Gippsland Lakes following the opening of a permanent connection to the sea in 1889 at Lakes Entrance provides an indication of likely future changes in Lake Wellington and the fringing wetlands. The wetlands in the area closest to Lakes Entrance were modified by increasing salinity and lower water levels, which resulted in a die back of paperbark and common reed and their replacement with saltmarsh communities dominated by sea rush and beaded glasswort (Bird 1966, 1978); Figure 35. A similar transition can be predicted in the littoral zone of Lake Wellington and eventually in the Lower Latrobe Wetlands, with widespread death of native trees such as eucalypts and swamp paperbarks, and their replacement by halophytic plant taxa including saltmarshes.

Figure 35 Vegetation at Blonde Bay, Gippsland Lakes showing saltmarsh replacing paperbark communities in response to increased salinity. Photo P. Boon.

The diversity of vegetated habitats in the Lower Latrobe Wetlands is reliant on inundation with freshwater and periodic drying. The predicted decreases in wetland filling and flushing flows are likely to result in shifts in community composition and increasing salt tolerant species. As described above, Dowd Morass is likely to be affected by increased salinity sooner than Heart Morass or Sale Common, and there are already areas of saltmarsh in the wetland (Frood et al. 2015). The impacts at Dowd Morass are likely to be exacerbated by the high degree of connectivity to Lake Wellington, which may lead to permanent inundation with salt water, a decline in most vegetation communities (or a restriction to the littoral zone) and the formation of lake conditions (Hale et al. 2018).

Prolonged dry conditions in Sale Common in the past have led to an expansion of giant rush at the expense of other, more diverse, vegetation communities. It is possible that this could occur more frequently if dry periods increase in duration and frequency.

Effects on native fish

The major impact pathways of the predicted hydrological regimes on native fish include:

- Decreased baseflows leading to poor water quality (increased salinity, low dissolved oxygen) in residual pools, affect the condition of native fish and survival of native fish species. This may also favour invasive species like carp, which may be more tolerant of poor water quality and low dissolved oxygen (Stuart and Jones 2006, King et al. 2012). The loss of summer baseflows is particularly critical as water quality can deteriorate quickly in refuge pools when temperatures are high and biological process occur more rapidly than in cooler winter months. The loss of suitable conditions in pools reduces the habitat availability for fish, smaller and patchier populations and increases the likelihood of local extinctions and eventually loss of biodiversity at a reach scale.
- Decreased baseflows can lead to a reduction in the area of channel with flowing water facilitating the encroachment of riparian and terrestrial vegetation to the banks, benches and beds of the river, reducing habitat for native fish. Decreased baseflow may also restrict the migration or local movement of fish to find suitable habitat, mates or food.
- A decrease in summer and winter freshes can remove important migration and breeding cues for native fish, impacting on breeding, recruitment and ultimately populations. For example, increased discharges in April-May cue downstream spawning migration of adults to lower freshwater reaches. Eggs rely on river flow to drift downstream into saline estuary waters. Increased flows in September-December may attract juveniles to migrate upstream into rivers as they return from the sea (Amtstaetter et al. 2016). Modelling has indicated that the probability of recruitment of Australian grayling in the Latrobe system under current flow conditions is impaired and would be further impacted under continued decline of the flow regime (Shenton et al. 2011). The loss of freshes also means less productivity of invertebrate prey species and this in turns reduces the population size of native fish present, and smaller populations are more likely to be subject to other adverse conditions, resulting in patchy distribution of fish and increase the risk of loss from a reach entirely, if recruitment and migration is also impeded.
- Any reduction in longitudinal connectivity will be detrimental to all diadromous fish that move between fresh, estuarine and / or marine ecosystems to complete their lifecycles. Noting that connectivity is also impacted by physical barriers.
- Bankfull flows in the Latrobe system have been identified as being important in providing slack water habitat for native fish species, including the larvae of river black fish (Shenton et al. 2011). These flows are already much declined from natural and the predicted further decrease is likely to be critical for some fish species.
- Changes to flushing flows will alter the salinity regime of the estuary, lakes and wetlands and this will alter the distribution of fish species, eventually leading to the loss of these species if the estuary becomes too saline or the conditions for spawning (for black bream for example) are not met.
- Changes to the salinity regime (in particular a progression upstream) may also affect the aquatic vegetation and this will affect recruitment of fish larvae and the populations of fish that require aquatic plants (e.g. the listed Dwarf galaxias).
- A loss of productivity through reductions freshes, bankfull and overbank flows will affect all fish populations through the food chain.

Effects on waterbirds

The major waterbird habitats in the study area are in the wetlands and Lake Wellington and it is changes to these systems that are likely to have the most effect of waterbird usage of the site. Waterbirds are predicted to be affected directly from altered water regimes and also from a loss of habitat.

The vast majority of the waterbirds that are regularly supported by the Lower Latrobe Wetlands occur in both fresh and saline environments. Most waterbirds, however, do have specific water depth requirements for foraging. While there may be periods of adequate shallow water habitat for shallow water foragers such as shorebirds and large bodied waders in drying wetlands under decreased frequency of inundation, this habitat is likely to be transitory. Once wetlands are completely dry, there will be little suitable habitat for foraging or breeding.

There is likely to be an increased risk of nest abandonment (or birds not beginning a breeding cycle) if duration of inundation cannot persist for sufficient periods to allow chicks to fledge. In addition, any loss of vegetation that is used as nesting habitat (emergent macrophytes, shrubs; inundated trees) will reduce waterbird use of the site.

Reductions in productivity from reduced wetland and floodplain inundation will also affect waterbirds. Large congregation of waterbirds occur in areas of high productivity (Kingsford and Norman 2002, Kingsford et al. 2010) and highly productive foraging grounds are particularly important for internationally migratory shorebirds. These species need to consume large amounts of food in order to make the return journey to the northern hemisphere (Parry et al. 2013).

Some of the species in the Lower Latrobe Wetlands, such as the nationally endangered Australasian bittern have specific vegetated habitat requirements. Any loss of the dense emergent macrophyte beds as a result of decreased inundation and / or increased salinity, will reduce the utility of the site for these species.

Effects on other wetland biota

The combined effects of reduced frequency and duration of inundation and likely deterioration of water quality in the Lower Latrobe wetlands will have major adverse impacts on frog populations, including the two threatened species, green and golden bell frog and growling grass frog. Although the green and golden bell frog have some capacity of survival in brackish water, amphibians as a whole are very poorly adapted to saline conditions and they are not tolerant of high salinities. Frogs are also particularly susceptible to changes in pH, and the acidic conditions and heavy metals that may occur following the activation of acid sulfate soils are likely to present additional stresses (Ferraro and Burgin 1993).

Impacts of reduced baseflows and freshes will affect habitat for macroinvertebrates and the loss of productivity from reduced bankfull and overbank flows are likely to affect all biota through the food chain.

Why can't we fill the mines with flood water?

River ecosystems and the wetlands and estuaries that are connected to them rely on periodic large scale floods to maintain condition. Floods not only flush contaminants such as salt, nutrients and toxicants downstream and ultimately into the ocean, but are ecologically vital for the functioning of riverine, floodplain and estuarine ecosystems. For instance, they reset ecological systems, promote the creation of new habitats via disturbance, and provide the essential movement cues for native fish. The loss of floods leads inevitably to reduced biodiversity, the worsening of the condition of native ecosystems and populations, and a disruption of the important ecological functions that maintain these ecosystems.

Floods provide lateral and longitudinal connectivity, they facilitate the movement of carbon, nutrients and biota between ecosystems and between the floodplain and the river. The accumulated leaf litter and woody debris on the floodplain flows to the river providing a boost in productivity and a carbon source that lasts for the years between floods

Floods provide a mosaic of habitats across the landscape for large numbers of aquatic species. They provide riparian and floodplain vegetation with a much needed drink, sustaining them for the years between flood events. They often stimulate fish and waterbird breeding and they allow for the dispersal and exchange of seeds, propagules and biota with connected systems improving genetic diversity. In systems with dams, weirs and other impediments to fish movement, floods restore connectivity.

In this Latrobe system they are very important for flushing the Lower Latrobe wetlands of nutrients and salts, and for reducing salinity in Lake Wellington. The movement of freshwater through McLennan Strait also benefits the broader Gippsland Lakes system. It is the reduction in flood events, in part, which has resulted in the increasing salinity in Lake Wellington and the risk of saline water intrusion into the Lower Latrobe Wetlands. Any further loss of flood events is likely to result in accelerated decline in condition of these ecosystems and the biota they support.

Latrobe River in Flood, October 2019, photo West Gippsland CMA.

4 Conclusions and recommendations

The aquatic ecosystems of the Latrobe River system support highly significant biodiversity values. They have, however, been subject to significant ecological stress from altered flows and water regimes over the past 100+ years. All the important aspects of the flow regime have been altered and the recommended water regimes defined by Alluvium (2020) in the most recent FLOWS analysis are largely not met. This inability to meet even the flow requirements requiring the least amount of additional flows has contributed significantly to the decline in condition of the Latrobe River system and its associated floodplains, wetlands and estuary.

Hydrological modelling indicates that climate change and continued water use at current levels will have further highly adverse impacts on hydrological regimes, with a full uptake of water entitlements for mine rehabilitation exacerbating the already ominous situation of insufficient flows in this heavily flow-stressed river system. It is expected that a continued decline in water availability for the ecologically important components of the flow regime (e.g. baseflows, freshes and bankfull/overbank flows) will have escalating impacts on the ecological condition of the system.

Rivers, estuaries and wetlands, like all ecosystems, adapt to changes in the environment. In terms of reduced freshwater inflows and increased salinity, it is likely that there will be a transition to more terrestrial environments and salt-tolerant biota. This change will be at the expense of freshwater dependent values and most likely represent a reduction in biodiversity. As it is, there remains only one natural freshwater wetland (Sale Common) in the Gippsland Lakes Ramsar Site. To maintain freshwater dependent values and meet the management objectives for the Latrobe River (developed in conjunction with the local community), more fresh water for the environment is required − not less − and will need to be carefully managed to optimise ecological outcomes.

Further impacts to the system, through continued and increasing water extraction will undermine the resilience of ecosystems and the biota they support to future changes in climate and other stresses. While the system has proven resilient so far to reduced flow by maintaining much of its ecological values, there will be thresholds beyond which the system cannot recover. It is vital that we manage water extraction from the system within these thresholds of resilience.

The key messages of this EEA are:

- Continued water resource use under future climates will lead to the decline in environmental values of the Latrobe system and a loss of biodiversity. This would be exacerbated if there were to be an increased or full uptake of mine operator’s entitlements from the Latrobe river system for mine rehabilitation.
- Decreases in water availability (from continued or increasing abstraction to fill mine pits) will result in multiple and interconnected threats resulting in loss of ecosystem and social values of the Latrobe River, its estuary and the Lakes. These losses will stem from:
    - Altered river channel geomorphology which will impact on habitat for fish and other biota as well as productivity
    - Decreased native fish breeding and recruitment
    - Decreased abundance and diversity of native fish
    - Decreased success of waterbird breeding
    - Decreased abundance and diversity of water birds
    - Decreased abundance and reproduction of frogs and turtles
    - Decreased condition and diversity of wetland vegetation
- Hydrology, salinity, vegetation, fish and waterbirds are all identified as critical to the ecological character of the Gippsland Lakes Ramsar Site. The predicted impacts to the aquatic ecosystems of the Lower Latrobe Wetlands, Lake Wellington and the Latrobe Estuary have implications with respect to Australia’s obligations under the Ramsar Convention.
- Harvesting floods to fill pit lakes will be detrimental to the system, particularly for Lake Wellington and the Lower Latrobe Wetlands. It will potentially lead to a change in the ecological character of the Gippsland Lakes Ramsar Site, which would have national and international implications.

Any decline in condition and loss of values in the Latrobe region would have implications for Traditional Owners with a loss of values associated with healthy waters and indigenous fisheries. There would also be impacts to the social and economic activities that rely on healthy wetlands and rivers, impacting on tourism, recreation and community well-being.

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Appendix A: Species lists

Table 9: Native fish of the study area (Alluvium 2020).

Group	Common Name	Scientific Name	Latrobe R.	Estuary	Tributaries	Wetlands	**L. Wellington**
Resident freshwater	River Blackfish	*Gadopsis marmoratus*	X		X		
	Dwarf Galaxias	*Galaxiella pusilla*	X		X		
	Striped Gudgeon	*Gobiomorphus australis*		X			
	Southern Pygmy Perch	*Nannoperca australis*	X		X		
	Flinders Pygmy Perch	*Nannoperca sp 1*	X	X	X	X	
	Flathead Gudgeon	*Philypnodon grandiceps*	X	X	X	X	
	Dwarf Flat-headed Gudgeon	*Philypnodon macrostomus*	X	X	X		
	Australian Smelt	*Retropinna semoni*	X	X	X	X	
Estuarine Dependent (Freshwater)	Southern Shortfin Eel	*Anguilla australis*	X	X	X	X	X
	Longfin Eel	*Anguilla reinhardtii*	X	X	X	X	X
	Climbing Galaxias	*Galaxias brevipinnis*	X	X	X		
	Common Galaxias	*Galaxias maculatus*	X	X	X		
	Spotted Galaxias	*Galaxias truttaceus*	X	X	X		
	Macquarie Perch	*Macquaria australasica*	X	X			
	Australian Bass	*Macquaria novemaculeata*	X	X	X	X	
	Shorthead Lamprey	*Mordacia mordax*	X	X	X		X
	Non-parasitic Lamprey	*Mordacia praecox*	X	X			X
	Australian Grayling	*Prototroctes maraena*	X	X	X		
Estuarine Resident	Black Bream	*Acanthopagrus butcheri*		X			X
	Tamar River Goby	*Afurcagobius tamarensis*		X			
	Yellow-eye Mullet	*Aldrichetta forsteri*	X	X			X
	Port Jackson Glassfish	*Ambassis jacksoniensis*		X			
	Bridled Goby	*Arenigobius bifrenatus*		X			
	Smallmouth Hardyhead	*Atherinosoma microstoma*		X			
	Australian Anchovy	*Engraulis australis*		X			
	Glass goby	*Gobiopterus semivestitus*		X			
	River Garfish	*Hyporhamphus regularis*	X	X			
	Estuary Perch	*Macquaria colorum*	X	X		X	X
	Sea Mullet	*Mugil cephalus*		X			
	Tupong (Congolli)	*Pseudaphritis urvillii*	X	X	X		
	Eastern Blue-spot Goby	*Pseudogobius* sp. 9		X			
	Lagoon Goby	*Tasmanogobius lasti*		X			
Marine Opportunist	Luderick	*Girella tricuspidata*		X			X
	Tailor	*Pomatomus saltatrix*		X			X
	Trevally	*Pseudocaranx* spp.		X			X

Table 10: Waterbirds of the study area with maximum count, “x” signifies presence recorded but not abundance (Atlas of Living Australia).

Group	Common Name	Scientific Name	Dowd Morass	Hear Morass	L. Wellington	Estuary	Sale Common
Emergent vegetation dependent	Australasian bittern	*Botaurus poiciloptilus*	2		x		1
	Australian little bittern	*Ixobrychus dubius*	1				0
	Australian reed-warbler	*Acrocephalus australis*	0	12			7
	Australian spotted crake	*Porzana fluminea*		1	x		0
	Baillon's crake	*Porzana pusilla*			x		3
	Buff-banded Rail	*Gallirallus philippensis*		2			
	Golden-headed csticola	*Cisticola exilis*	3	5	x		6
	Lewin's rail	*Lewinia pectoralis*			x		
	Little grassbird	*Megalurus gramineus*	0	3	2		10
	Purple swamphen	*Porphyrio porphyrio*	65	28	9	x	243
	Spotless crake	*Porzana tabuensis*			1		1
	Swamp harrier	*Circus approximans*	7	6	12	x	6
Herbivore	Australian shelduck	*Tadorna tadornoides*	420	800	263	x	21
	Australian wood duck	*Chenonetta jubata*	85	90	12	x	36
	Cape Barren goose	*Cereopsis novaehollandiae*					3
Large wader	Australian white ibis	*Threskiornis molucca*	3600	2000	20	x	60
	Cattle egret	*Ardea ibis*	2	x	1		40
	Eastern great egret	*Ardea modesta*	200	24	12		55
	Glossy ibis	*Plegadis falcinellus*	2	100	x		1
	Intermediate egret	*Ardea intermedia*	1	1	x		7
	Little egret	*Egretta garzetta*	1	1	4		25
	Nankeen night heron	*Nycticorax caledonicus*	100		x	x	12
	Royal spoonbill	*Platalea regia*	500	160	12	10	80
	Straw-necked Ibis	*Threskiornis spinicollis*	3600	1500	200	20	100
	White-faced heron	*Egretta novaehollandiae*	30	25	50	x	100
	White-necked Heron	*Ardea pacifica*	3	1	x		7
	Yellow-billed spoonbill	*Platalea flavipes*	91	30	4	x	100
Open water forager	Australasian darter	*Anhinga novaehollandiae*	1	2	15	1	100
	Australasian grebe	*Tachybaptus novaehollandiae*	40	4	8		35
	Australian fairy tern	*Sternula nereis nereis*	1		36		
	Australian pelican	*Pelecanus conspicillatus*	136	129	250	10	166
	Azure kingfisher	*Alcedo azurea*	x		x	x	3
	Black-faced cormorant	*Phalacrocorax fuscescens*		1			
	Blue-billed duck	*Oxyura australis*	3		x		2
	Caspian tern	*Hydroprogne caspia*	3	3	8		3
	Common tern	*Sterna hirundo*		1	101	2	
	Crested tern	*Thalasseus bergii*	9		1000		
	Eurasian coot	*Fulica atra*	2968	450	850		315

Group	Common Name	Scientific Name	Dowd Morass	Hear Morass	L. Wellington	Estuary	Sale Common
	Great cormorant	*Phalacrocorax carbo*	28	30	444	x	30
	Great crested grebe	*Podiceps cristatus*		x	7		1
	Gull-billed Tern	*Gelochelidon nilotica*			1		
	Hardhead	*Aythya australis*	50	80	1000		70
	Hoary-headed Grebe	*Poliocephalus poliocephalus*	38	16	97		3
	Little black cormorant	*Phalacrocorax sulcirostris*	1500	350	148	x	100
	Little pied cormorant	*Microcarbo melanoleucos*	1000	200	200	1	100
	Little tern	*Sternula albifrons sinensis*			62	37	2
	Musk duck	*Biziura lobata*	3	6	21		3
	Pacific gull	*Larus pacificus*	3	2	4		
	Pied cormorant	*Phalacrocorax varius*	11	2	200	10	10
	Silver gull	*Chroicocephalus novaehollandiae*	157	154	200	x	1804
	Whiskered tern	*Chlidonias hybrida*	30	500	300	1	6
	White-winged Black Tern	*Chlidonias leucopterus*	12	33	30		
Small wader: Australian resident shorebird	Australasian pied stilt	*Himantopus himantopus*	70	230	x		170
	Australian painted snipe	*Rostratula australis*					x
	Australian pied oystercatcher	*Haematopus longirostris*			x		
	Banded lapwing	*Vanellus tricolor*			x		
	Banded stilt	*Cladorhynchus leucocephalus*	8	7			
	Black-fronted dotterel	*Elseyornis melanops*	17	21	1		20
	Masked lapwing	*Vanellus miles*	18	28	18	x	38
	Red-capped plover	*Charadrius ruficapillus*	1	125	x		1
	Red-kneed dotterel	*Erythrogonys cinctus*	2	8	x		25
	Red-necked avocet	*Recurvirostra novaehollandiae*	0	30			15
Small wader: Migratory shorebird	Bar-tailed godwit	*Limosa lapponica*			x		x
	Common greenshank	*Tringa nebularia*	52	135	x		15
	Curlew sandpiper	*Calidris ferruginea*	1		x		40
	Double-banded plover	*Charadrius bicinctus*		3	x		15
	Eastern curlew	*Numenius madagascariensis*		x	x		
	Latham's snipe	*Gallinago hardwickii*	7	55	2		15
	Marsh sandpiper	*Tringa stagnatilis*	1	1			2
	Red-necked stint	*Calidris ruficollis*	38	150	x		1
	Sharp-tailed sandpiper	*Calidris acuminata*	250	200	30		40
	Whimbrel	*Numenius phaeopus*			x		
	Wood sandpiper	*Tringa glareola*					5
	Australasian shoveler	*Anas rhynchotis*	150	220	35		50

Group	Common Name	Scientific Name	Dowd Morass	Hear Morass	L. Wellington	Estuary	Sale Common
Wetland generalist	Black swan	*Cygnus atratus*	1162	1500	3000	x	1150
	Black-tailed native-hen	*Tribonyx ventralis*	x	x			
	Chestnut teal	*Anas castanea*	1500	1500	2800	150	412
	Dusky moorhen	*Gallinula tenebrosa*	3	4	4	x0	42
	Freckled duck	*Stictonetta naevosa*	4	1	30		13
	Grey teal	*Anas gracilis*	600	3400	1500	190	350
	Pacific black duck	*Anas superciliosa*	2000	1200	607	35	460
	Pink-eared duck	*Malacorhynchus membranaceus*	20	1000	x		100
	Sacred kingfisher	*Todiramphus sanctus*		1	x		3
	White-bellied sea eagle	*Haliaeetus leucogaster*	1	1		2	