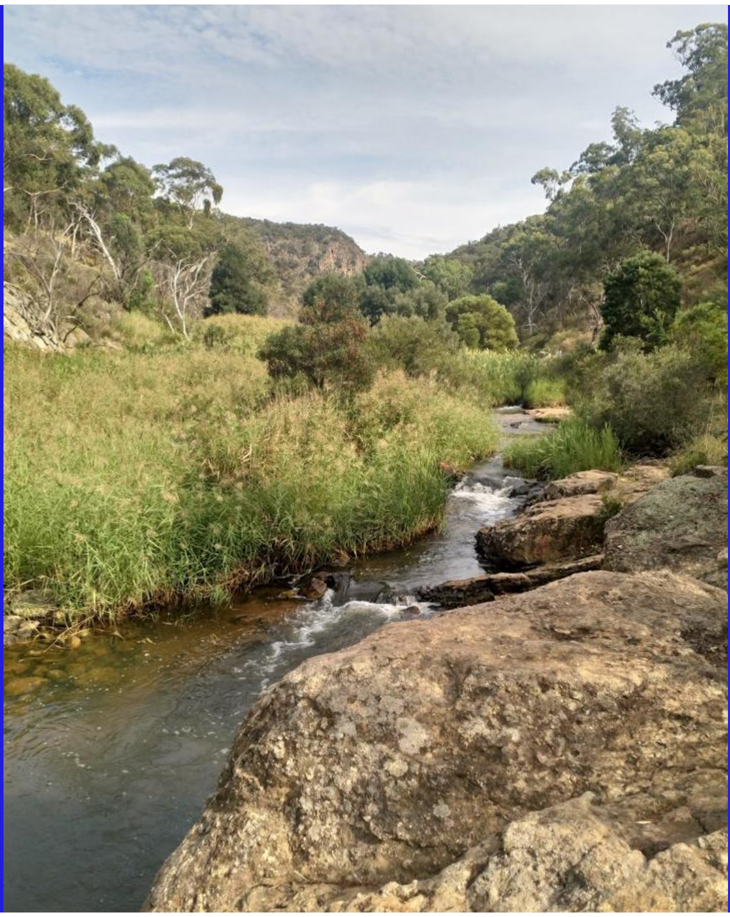
# Upper Werribee Environmental Flows Study - Recommendations Report

Document no: IA5000IN.R.03
Revision no: 02

Melbourne Water

Upper Werribee River (Wirribi Yaluk) Flows Study
23 February 2023



# Upper Werribee Environmental Flows Study - Recommendations Report

| | | | |
|---|---|---|---|
| Client name: | Melbourne Water | | |
| Project name: | Upper Werribee River (Wirribi Yaluk) Flows Study | | |
| | | Project no: | IA5000IN |
| Document no: | IA5000IN.R.03 | Project manager: | Fiona Gilbert |
| Revision no: | 02 | Prepared by: | Fiona Gilbert |
| Date: | 23 February 2023 | File name: | Upper Werribee Environmental Flows Study- Final recommendations paper_final_for MW issue_Rev02_for MW issue |
| Doc status: | Final | | |

## Document history and status

| Revision | Date | Description | Author | Checked | Reviewed | Approved |
|---|---|---|---|---|---|---|
| 00 | 14/10/2022 | Draft issued to Melbourne Water | Fiona Gilbert, Peter Sandercock, Simon Treadwell, Jo Szemis, Paul Boon, Josh Griffiths | Fiona Gilbert | Simon Treadwell | Simon Treadwell |
| 01 | 22/12/2022 | Final report issued to Melbourne Water | Fiona Gilbert, Peter Sandercock, Simon Treadwell, Jo Szemis, Paul Boon, Josh Griffiths | Fiona Gilbert | Simon Treadwell | Simon Treadwell |
| 02 | 23/02/2023 | Final report issued to Melbourne Water | Fiona Gilbert, Peter Sandercock, Simon Treadwell, Jo Szemis, Paul Boon, Josh Griffiths | Fiona Gilbert | Fiona Gilbert | Fiona Gilbert |

## Distribution of copies

| Revision | Issue approved | Date issued | Issued to | Comments |
|---|---|---|---|---|
| 00 | Fiona Gilbert | 14/10/2022 | Melbourne Water | Draft issued to Melbourne Water for comment |
| 01 | Fiona Gilbert | 22/12/2022 | Melbourne Water | Final report issued to Melbourne Water |
| 02 | Fiona Gilbert | 3/02/2023 | Melbourne Water | Final report issued to Melbourne Water with minor typographical amendments from Revision 01 |

Jacobs Group (Australia) Pty Limited

Floor 13, 452 Flinders Street
Melbourne, VIC 3000
PO Box 312, Flinders Lane
Melbourne, VIC 8009
Australia

T +61 3 8668 3000
F +61 3 8668 3001
www.jacobs.com

# Executive summary

The Werribee River (Wirribi Yaluk) system is highly regulated, and stream flows have been significantly altered from the natural flow regime, impacting ecological values and processes. Environmental flow recommendations for several reaches in the system have been developed and are used to help manage an environmental watering program which delivers environmental flows to the system. Melbourne Water has identified a need for the update of flow recommendations in some upper reaches, and the development of flow recommendations for some upper reaches which do not currently have specific flow recommendations. Assessment of flow requirements involves identification of flow dependant ecological values, identification of the flow regime required to protect and enhance those values, and evaluation of the degree to which the current flow regime either contributes to the maintenance of values, or represents a threat to those values.

This study uses the FLOWS method to determine the environmental flow requirements of Reaches 1-5 of the Werribee system. The FLOWS method is an expert panel format, which incorporates a desktop analysis of known environmental values, field assessments, and hydraulic modelling to determine the magnitude, frequency and duration of flows that are needed to maintain or improve geomorphological and ecological condition and water quality in rivers or streams.

The FLOWS method is implemented in two stages and has three main outputs:

- The *Site Paper*, which describes the reaches and sites selected for further assessment and the justification of that selection
- The *Issues Paper* which describes the ecological values and current condition of each reach and specifies environmental flow objectives that the environmental flows recommendations will aim to meet
- The *Environmental Flow Recommendations Report* which is an extension of the *Issues paper* and describes the specific flow components, including the magnitude, timing, duration and frequency of flow events that are required to meet the environmental flow objectives.

This report is the *Environmental Flow Recommendations Paper*, which incorporates findings from the *Site Paper* and *Issues Paper*, and presents the final flow recommendations for each reach. This report is the final of three papers delivered as part of this study. The *Site Paper* described the distinct reaches of the Werribee system designated for flow assessments, and identified specific sites used to inform the environmental flow assessment. The reaches are already well defined from previous studies and environmental flow management in the system. The site visit, existing studies review and Project Advisory Group meeting held as part of the *Site Paper* development confirmed that existing reach delineations are still relevant based on the locations of barriers, tributary inflows and key water diversion in delivery points. The *Issues Paper* summarised an assessment of the water dependent issues in the study reaches, and presented objectives for water dependent values for which environmental flow recommendations were to be developed. This *Environmental Flow Recommendations Paper* describes the specific flow components, including the magnitude, timing, duration and frequency of flow events that are required to meet the environmental flow objectives. The recommendations for Reaches 3, 4, and 5 were developed following a review and revision of existing flow recommendations in place for those reaches. Reaches 1 and 2 have no existing recommendations and flow recommendations presented in this report were developed for the first time as part of this project.

A summary of each reach, assessment sites, broad ecological objectives and final recommendations is provided below.

**Reach 1 – Werribee River (Wirribi Yaluk), from the headwaters of the river to the Upper Diversion Weir near Ballan.** This reach experiences naturally seasonally intermittent flows, with areas of shallow flowing riffles and pools, including permanent pools which provide refuge for aquatic fauna during cease-to-flow periods. There are no major storages, regulation or extractions in this reach and the flow regime cannot easily be manipulated by water managers. Flows in this reach are relatively unmodified, with no substantial regulation or major changes to the flow regime (such as seasonal flow reversal due to irrigation). However, urban development poses a risk to the existing regime from an increase in stormwater runoff, and there are likely to have been some impacts to natural flows from farm dams and other extractions and losses, as well as some small in-stream barriers in the form of minor weirs through Caledonian Park in Ballan.

The assessment site for Reach 1 is at Caledonian Park, in Ballan. The assessment at this site has considered the implications of increased stormwater runoff on the ability to meet flow objectives, and whether there are factors other than flow that are also limiting river health outcomes. A hydraulic model for this site is not currently available, and based on the types of factors influencing the flow regime the development of a hydraulic model is considered unnecessary. Ecological objectives and flow recommendations are based on hydrological analysis and management of the potential impacts of further urban development on the flow regime, rather than on specific characteristics of the channel form. The gauge and compliance point considered for Reach 1 was Werribee River @ Ballan (U/S Old Western H-Way) (231225A/B).

The ecological objective for this reach is to: *Support existing geomorphology, vegetation, and aquatic biota in the reach by managing threats from urban stormwater runoff and extractions to maintain a relatively natural flow regime.*

The flow recommendations for this reach have been set based on the overall objective of maintaining the current flow regime and minimising flow impacts from land use and climate change, to protect existing ecological values. Recommendations have been derived from key hydrological metrics that have been shown to represent particular risk to ecological values – cease-to-flows and disturbance flows. The final recommendations for Reach 1 are as follows:

| Flow | Objective/Function | Magnitude | Frequency | Duration |
|---|---|---|---|---|
| Cease-to-flow / low flow | Avoid an increase in the percentage of time that cease-to-flow conditions are experienced (maintain existing pattern of cease to flow and low flows) | < 0.1 ML/day | <25% of time | <40 days mean duration |
| Disturbance flows | Avoid increase in number of days per year with flow greater than the current mean daily flow (of 50 ML/day) (maintain existing pattern of low flows) | >50 ML/day | <22% of time | - |
| | Avoid an increase in the frequency and duration of flow that exceeds bed disturbance threshold (maintain existing pattern of freshes and high flows) | 1160 ML/day | <1.5 times per year | 1-2 days |
| | Avoid an increase in the frequency and duration of flow that exceeds bank disturbance threshold (maintain existing pattern of freshes and high flows) | 1440 ML/day | <1 every 2 years | 1 day |

**Reach 2 – Pykes Creek (Korjamnunnip Creek) between Pykes Creek Reservoir and the Werribee River (Wirribi Yaluk) confluence**. This short reach is used primarily as a conduit for irrigation flows released from Pykes Creek Reservoir, resulting in a flow regime that is highly modified from natural. Access to Reach 2 is difficult and there are no existing hydraulic models or flow recommendations for the reach. During this study, a site downstream of Pykes Creek Reservoir was able to be accessed during a site visit by some EFTP members. In addition, aerial drone footage was collected as part of the project and made available to the study team to inform the development of flow recommendations. The flow regime in this reach is heavily modified by the operation of Pykes Creek Reservoir and releases made for downstream irrigators; the storage and release patterns result in higher than natural summer flows and lower than natural winter flows in this reach. The flow recommendations developed in this study for this reach are based around the ability to implement a more seasonally variable regime in Reach 2, with benefits targeted at delivering environmental water to Reaches 4 and 5 in the Werribee River (Wirribi Yaluk). Ecological objectives and flow recommendations are based on hydrological analysis and management of the potential impacts from changes to the current flow regime. The gauge and compliance point considered for Reach 2 was Pykes Creek @ Pykes Creek Reservoir (231203C).

The ecological objective for this reach is to: *Support existing ecological values in the reach while targeting delivery of water to benefit values in Reaches 4 and 5 through the appropriate management of flow releases from Pykes Creek Reservoir.*

Reach 2 has no current flow recommendations, and the ability to deliver a more natural flow regime to the reach is limited by the operation of Pykes Creek Reservoir. The flow recommendations for this reach have been developed in this study to achieve the ecological objectives for the reach, to provide benefits to delivery of Reach 4 flows, and to avoid flows that could be damaging to Reach 2. The specific flow recommendations are based on hydrological metrics that are measures of ecologically/geomorphologically significant flows, as follows:

| Flow | Objective/Function | Magnitude | Frequency | Duration |
|---|---|---|---|---|
| Cease-to-flow | Avoid an increase in the percentage of time that cease-to-flow conditions are experienced | <0.5 ML/day | <25% of time | <30 days mean duration |
| Disturbance flow | Avoid increase in number of days with flow greater than mean daily flow (40 ML/day) | >40 ML/day | <30% of time | - |
| | Avoid an increase in frequency and duration of flow that exceeds bed disturbance threshold | 280 ML/day | <1.5 times per year | 1-2 days |
| | Avoid an increase in the frequency and duration of flow that exceeds bank disturbance threshold | 440 ML/day | <1 every 2 years | 1 day |
| Reservoir operations | Coordinate reservoir releases to contribute to downstream flow requirements<br>Piggyback on upstream flows to generate larger freshes in Reach 4<br>Avoid rapid onset of cease-to-flows conditions during reservoir operations | See Reach 4 recommendations | | |

**Reach 3 – Werribee River (Wirribi Yaluk), Downstream of the Upper Diversion Weir.** The EFTP was able to access an extensive length of Reach 3 downstream of the Upper Diversion Weir. The reach has existing flow recommendations, and there is an existing hydraulic model for the assessment site. The assessment site downstream of the weir remains a suitable site that represents the overall characteristics of the reach. As with Reach 2, flows in this reach are highly modified from natural. The Upper Diversion Weir results in a significant loss of overall flows into the reach, particularly mid-sized flows. Objectives for this site have considered the impacts of flow diversion at the Upper Diversion Weir. It should be noted, no gauge was present at Reach 3 and data was derived from subtracting the gauged flows through the Werribee Tunnel (gauge 231703A) from the gauged flows at Ballan (gauge 231225). The compliance point should therefore be located downstream of the Werribee Tunnel. If a gauge could be established in this part of the reach, flows could be more readily monitored and assessed for compliance.

The ecological objective for this reach is to: *Maintain and where possible enhance existing ecological values in the reach through management of the operation of the Upper Diversion Weir to deliver a more natural and seasonally variable flow regime.*

Flows in Reach 3 are highly modified due to the operation of the Upper Diversion Weir. While opportunities to deliver environmental flows to this reach have been limited, flow recommendations have previously been developed; these were published in the Ecological Associates (2005) flow study. The outcomes of the current assessment have identified a number of updates to the previous flow recommendations. The revised flow recommendations are as follows:

| Season | Flow | Objective/Function | Wet/ Avg/ Dry | Volume (ML/day) | Frequency and timing | Duration |
|---|---|---|---|---|---|---|
| Summer / Autumn (Dec-May) | Cease-to-flow | Not recommended but expected to occur naturally based on inflows from Reach 1 (upstream). | As per natural cease-to-flow from upstream | | | |
| | Low flow | Maintain refuge pools during low flow periods to maintain and if possible enhance habitat and vegetation for bugs, fish (River Blackfish, Mountain Galaxias, Common Galaxias, southern Pygmy Perch) and platypus. Maintain capacity of the stream to process organic matter. Maintain inundated stream channel to prevent colonisation by inundation-tolerant terrestrial vegetation. | Wet/Avg/Dry | 5 | As per natural inflows from upstream | |

| Season | Flow | Objective/Function | Wet/ Avg/ Dry | Volume (ML/day) | Frequency and timing | Duration |
|---|---|---|---|---|---|---|
| | Fresh | Maintain quality of riffle habitats by periodically scouring sediment & biofilms, maintain fringing and riparian non-woody vegetation, provide opportunities for fish movement. Mobilise and transport particulate organic matter to downstream reaches. | Wet/Avg | 14 | 8 (every 3 weeks) | 2 days |
| | | | Dry | 14 | 6 (every month) | 2 days |
| Winter / Spring (Jun-Nov) | Low flow | Higher flows increase access to habitat for bugs, fish and platypus. Maintain capacity of the stream to process organic matter. Maintain inundated stream channel to prevent colonisation by inundation-tolerant terrestrial vegetation. | Wet | 37 | 100% of days | |
| | | | Avg/Dry | 37 | 100% of days | |
| | Fresh | Maintain quality of riffle habitats by periodically scouring sediment & biofilms, maintain fringing and riparian non-woody vegetation, provide opportunities for fish movement. Mobilise and transport particulate organic matter to downstream reaches. | Wet | 165 | Every month | 8 days |
| | | | Avg | 165 | Every month | 3 days |
| | | | Dry | 165 | Every 2 months | 1 day |
| | Bankfull | Scour fine sediment from pools, engage higher channel surfaces and secondary flow channels/terraces, flush organic material that has accumulated in these areas. | Wet | 700 | 1 event | 2 days |
| | | | Avg | 700 | 1 every 2 years | 1-2 days |
| | | | Dry | Not expected to occur | | |

**Reach 4- Werribee River (Wirribi Yaluk) from Pykes Creek (Korjamnunnip Creek) to the Bacchus Marsh Weir**. Reach 4 begins at the confluence with Pykes Creek, flowing through Werribee Gorge to the Bacchus Marsh Weir. The EFTP visited the reach and inspected the current assessment site, which is still considered suitable for the current project. Reach 4 flows are affected by flow modification, regulation and extraction that occurs in the reaches upstream, particularly the reduced inflows from Reach 3 as a result of the Upper Diversion weir. Reach 4 is affected by flow modifications in upstream reaches. Despite this, Reach 4 has near permanent flows, extensive native vegetation and habitat, and maintains significant ecological values. Existing flow recommendations are in place. Ecological objectives have been set based on specific values present in the reach, and the opportunity to maintain or enhance these values through management of environmental flows. It should be noted, no gauge was present in Reach 4 and flows were derived from Reach 2 and 3 streamflow and the compliance point located downstream of the confluence.

The ecological objective for this reach is to: *Protect, maintain and enhance geomorphic values and the stream channel, and the aquatic biota it supports through delivery of an appropriate flow regime from upstream reaches.*

Ecological Associates (2005) recommended an environmental flow regime for Reach 4. A review by Jacobs (2014) recommended two amendments to the 2005 recommendations, which were further considered as part of this study. The outcomes of the current assessment have identified a number of updates to the previous flow recommendations, including some revised recommendations which were informed by updates to the hydraulic model. The final recommendations are as follows:

| Season | Flow | Objective/Function | Wet/ Avg/ Dry | Volume ML/day | Frequency and timing | Duration |
|---|---|---|---|---|---|---|
| Summer / Autumn (Dec-May) | Low flow | Maintain access to and protect diversity of habitat (pools, riffles, undercuts, large wood) and vegetation for bugs, fish (River Blackfish, Mountain Galaxias, Australian Smelt, Short-finned Eel) and platypus. Maintain capacity of the stream to process organic matter. Maintain inundated stream channel to prevent colonisation by inundation-tolerant terrestrial vegetation. | Wet/Avg | 10 | 100% of days | |
| | | | Dry | 10 | 100% of days | |
| | Fresh | Maintain quality of riffle and undercut habitats by periodically scouring sediment & biofilms, maintain fringing and riparian non-woody vegetation, provide opportunities for fish movement. Mobilise and transport particulate organic matter to downstream reaches. | Wet/Avg | 50 | 8 (every 3 weeks) | 2 days |
| | | | Dry | 50 | 6 (every month) | 2 days |
| Winter / Spring (Jun-Nov) | Low flow | Higher flows increase access to habitat for bugs, fish and platypus. Maintain capacity of the stream to process organic matter. Maintain inundated stream channel to prevent colonisation by inundation-tolerant terrestrial vegetation. | Wet | 50 | 100% of days | |
| | | | Avg / Dry | 30 | 100% of days | |
| | Fresh | Maintain quality of riffle and undercut habitats by periodically scouring sediment & biofilms, maintain fringing and riparian non-woody vegetation, provide opportunities for fish movement. Mobilise and transport particulate organic matter to downstream reaches. | Wet | 245<br>500 | 4<br>2 | 10 days<br>5 days |
| | | | Avg | 245 | Every month | 5 days |
| | | | Dry | 245 | Every month | 2 days |
| | Bankfull | Scour fine sediment from pools, engage higher channel surfaces and secondary flow channels/terraces, flush organic material that has accumulated in these areas | Wet | 1400-3000 | 1 event | 2 days |
| | | | Avg | 1400 | 1 every 2 years | 1-2 days |
| | | | Dry | Not expected to occur | | |

**Reach 5- Werribee River (Wirribi Yaluk) from Bacchus Marsh Weir to the Lerderderg River confluence.** Reach 5 extends from downstream of the Bacchus Marsh Weir to the confluence with the Lerderderg River. Flows in the reach are near permanent, except under extremely dry conditions. Existing flow recommendations are in place for the reach, which experiences lower than natural flows due to extractions at the Bacchus Marsh Weir. The EFTP was able to visit the reach and the existing survey and model site, which was considered to still represent a suitable assessment site (despite changes to the road and bridge crossing at the site). Substantial urban development in the immediate vicinity of the reach represents the most significant threat to the ecological values in this reach which include native fish and platypus. The gauge and compliance point considered for Reach 5 was Werribee River at Bacchus Marsh (231200B).

The ecological objective for this reach is to: *Support existing geomorphology, vegetation, and aquatic biota in the reach by managing threats from urban stormwater runoff and through delivery of an appropriate flow regime from upstream reaches.*

Ecological Associates (2005) recommended an environmental flow regime for Reach 5. The recommendations were reviewed in Jacobs (2014), and minor amendments were suggested. The outcomes of the current assessment have identified a number of updates to the previous flow recommendations. Flow recommendations for Reach 5 are generally of lower magnitude than the recommendations for Reach 4. This is largely due to the different channel dimensions in Reach 5, which mean that the ecological objectives of the flows (i.e. maintain depth over riffle habitat and connection between habitat) can be achieved with lower flow volumes than in Reach 4. Flow extractions at the Bacchus Marsh Weir also influence these recommendations, and it should be noted that the recommendations are for minimum flows – if higher flows occur in this reach due to higher flows in Reach 4, this will also achieve ecological objectives. The final recommendations are as follows:

| Season | Flow | Objective/Function | Wet/ Avg/ Dry | Volume ML/day | Frequency and timing | Duration |
|---|---|---|---|---|---|---|
| Summer / Autumn (Dec-May) | Low flow | Maintain access to and protect diversity of habitat (pools, riffles, undercuts, large wood) and vegetation for bugs, fish (River Blackfish, Mountain Galaxias, Australian Smelt, Short-finned Eel) and platypus. Maintain capacity of the stream to process organic matter. Maintain inundated stream channel to prevent colonisation by inundation-tolerant terrestrial vegetation. | Wet/ Avg | 4 | 100% of days | |
| | | | Dry | 4 | 100% of days | |
| | Fresh | Maintain quality of riffle and undercut habitats by periodically scouring sediment & biofilms, maintain fringing and riparian non-woody vegetation, provide opportunities for fish movement. Mobilise and transport particulate organic matter to downstream reaches. | Wet/ Avg | 18 | 8 (every 3 weeks) | 2 days |
| | | | Dry | 18 | 6 (every month) | 2 days |
| Winter / Spring (Jun-Nov) | Low flow | Higher flows increase access to habitat for bugs, fish and platypus. Maintain capacity of the stream to process organic matter. Maintain inundated stream channel to prevent colonisation by inundation-tolerant terrestrial vegetation. | Wet | 40 (range 30-50) | 100% of days | |
| | | | Avg/ Dry | 18 | 100% of days | |
| | Fresh | Maintain quality of riffle and undercut habitats by periodically scouring sediment & biofilms, maintain fringing and riparian non-woody vegetation, provide opportunities for fish movement. Mobilise and transport particulate organic matter to downstream reaches. | Wet | 141 | Every month | 10 days |
| | | | Avg | 141 | Every month | 5 days |
| | | | Dry | 141 | Every month | 2 days |
| | Bankfull | Scour fine sediment from pools, engage higher channel surfaces and secondary flow channels/terraces, flush organic material that has accumulated in these areas. | Wet | 1400 | 1 event | 2 days |
| | | | Avg | 1400 | 1 event | 1-2 days |
| | | | Dry | Not expected to occur | | |

# Important note about your report

The sole purpose of this report by Jacobs is to summarise an assessment of the water dependent issues in the study reaches, and present ecological objectives and specific recommendations for environmental flows. The report forms part of the Upper Werribee River FLOWS update study, in accordance with the scope of services set out in the contract between Jacobs and Melbourne Water.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by Melbourne Water and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from Melbourne Water, the Project Advisory Group and from field assessment. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report.

Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report should be read in full, and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context. This report has been prepared on behalf of, and for the exclusive use of, Melbourne Water, and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and Melbourne Water.

Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

# Acknowledgement of Country

Melbourne Water respectfully acknowledges the Bunurong, Wadawurrung and Wurundjeri Woi-wurrung peoples as the Traditional Owners and Custodians of the land and water of the Wirribi Yaluk (Werribee River) catchment on which we work. We pay our deepest respects to their Elders past, present and emerging.

We recognise and respect the continued cultural and spiritual connections that Aboriginal and Torres Strait Islander peoples have within the land and water they have cared for and protected for thousands of generations.

We demonstrate our ongoing commitment to reconciliation through our partnerships with Traditional Owners and the broader Aboriginal and Torres Strait Islander communities, as we work together to manage land and water now and into the future, while maintaining and respecting cultural and spiritual connections.

# Contents

## Appendices

## Tables

# Figures

# 1. Introduction

## 1.1 Upper Werribee River FLOWS study

Melbourne Water is seeking to improve its understanding of environmental water requirements for the mid and upper reaches of the Werribee River (Wirribi Yaluk) and Pykes Creek (Korjamnunnip Creek). Two investigations into the environmental flow requirements of this waterway have been undertaken in the past: a study of six reaches of the Werribee River system by Ecological Associates in 2005 using the original (2002) State-endorsed FLOWS framework (DNRE 2002); and an update in 2014 by Jacobs-SKM using the revised FLOWS2 framework (DEPI 2013a), but limited to Reaches 4 and 5 of the current investigation.

The current project seeks to update the flow recommendations made in the 2005 and 2014 reports, in light of recent studies of the waterway and more general advances in scientific understanding of environmental flows. It also seeks to achieve shared cultural and environmental outcomes for the waterway through collaboration with Traditional Owners of the catchment. The overarching objective of the project is to provide updated and improved environmental flow recommendations to inform environmental water planning and management in the mid and upper Werribee system. The river reaches to be assessed in this study are:

- Reach 1 – Werribee River (Wirribi Yaluk): Upstream of the Upper Diversion Weir
- Reach 2 - Pykes Creek (Korjamnunnip Creek) from Pykes Creek Reservoir to Werribee River
- Reach 3 - Werribee River (Wirribi Yaluk): Upper Werribee Diversion Weir to Pykes Creek (Korjamnunnip Creek)
- Reach 4 - Werribee River (Wirribi Yaluk): Confluence of Pykes Creek (Korjamnunnip Creek) to Bacchus Marsh Weir
- Reach 5 - Werribee River (Wirribi Yaluk): Bacchus Marsh Weir to Lerderderg River

Of these, specific flow recommendations already exist for Reaches 3, 4 and 5, as set out in the Ecological Associates (2005b) report. The flow recommendations for Reaches 4 and 5 were also reviewed in the Jacobs (2014) report, which provided recommendations for minor revisions of some flow components. The flow requirements for Reaches 1 and 2 were described in general terms in the 2005 report, but there are no specific, published flow recommendations for those reaches. Table 1-1 shows a summary of the status of existing recommendations for each reach, and the related requirements for this study.

**Table 1-1 Summary of reaches, existing flow assessments and required updates for this study**

| Reach | Existing flow recommendations | Updates required in this study |
|---|---|---|
| Reach 1 | Ecological Associates (2005) did not make specific flow recommendations for Reach 1. General flow-related objectives to support specific values were set out for the system more broadly. | Review existing information, develop a hydraulic model if required, develop specific flow or management recommendations for Reach 1 flows. |
| Reach 2 | Ecological Associates (2005) did not make specific flow recommendations for Reach 2. General flow-related objectives to support specific values were set out for the system more broadly. | Review existing information, develop a hydraulic model if required, develop specific flow or management recommendations for Reach 2 flows |
| Reach 3 | Ecological Associates (2005) recommended an environmental flow regime for Reach 3. Recommendations for this reach were not part of the Jacobs (2014) review study | Review existing hydraulic models and flow recommendations, and update where required |
| Reach 4 | Ecological Associates (2005) recommended an environmental flow regime for Reach 4. The | Review existing hydraulic models flow recommendations, and update where required |

| Reach | Existing flow recommendations | Updates required in this study |
|---|---|---|
| | recommendations were reviewed in the Jacobs (2014) and only minor amendments suggested | |
| Reach 5 | Ecological Associates (2005b) recommended an environmental flow regime for Reach 5. The recommendations were reviewed in the Jacobs (2014) and only minor amendments suggested | Review existing flow recommendations, and update where required |

## 1.2 Study Approach

Jacobs has been engaged to complete the Werribee FLOWS update study in accordance with the defined FLOWS methodology (DEPI 2013). The FLOWS method assumes that the flow regime required to achieve the desired ecological condition in a river can be represented by a set of flow components. Flow components are defined in terms of the timing, duration and magnitude of flow events. Flow components are attributed to a representative set of ecological and physical characteristics and functions.

A summary of the revised FLOWS method, showing the main project tasks is presented in Figure 1-1

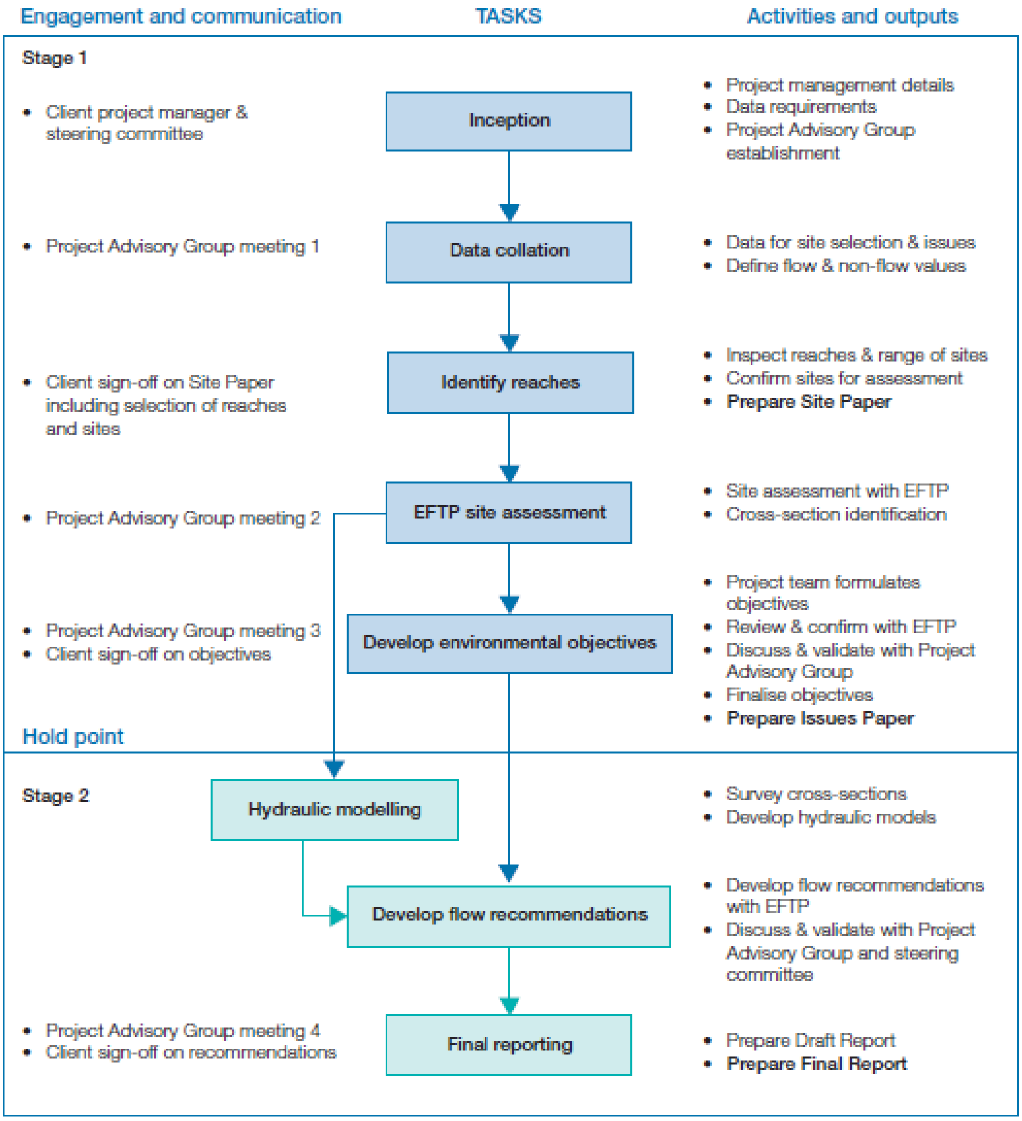



**Figure 1-1 Outline of the FLOWS method, taken from DEPI 2013.**

In this study, the FLOWS method is implemented in two stages. Stage 1 documents project inception, data collation and review, and an initial meeting with the Project Advisory Group (PAG) to discuss the outcome of the review and any identified knowledge gaps. In this stage, the study team documents the current condition of the system and the main flow dependent values and environmental issues within the catchment. Selected members of the Environmental Flows Technical Panel (EFTP) tour the catchment and conduct a preliminary review of background information, divide the catchment into reaches, and select sites within each reach where detailed assessments will be undertaken. The EFTP use observations made during the detailed site assessments and a detailed review of available literature to describe the main flow related issues for the catchment and to develop a set of environmental objectives to manage water dependent values in each reach.

Qualified surveyors then complete a feature survey of each FLOWS assessment site and the project hydrologist builds a hydraulic model if required to quantify the relationship between flow and inundation levels at each site.

Two important outputs from Stage 1 are: 1) A Site Paper, which describes the reaches and sites selected for further assessment and the justification of that selection and 2) An Issues Paper, which outlines the expected flow requirements and ecological responses to particular flow components.

Stage 2 uses the results of detailed channel surveys and hydraulic models (mostly using HEC-RAS) to derive flow recommendations that aim to meet the flow requirements of the water dependent assets and values identified in Stage 1. The main output from Stage 2 is a Flow Recommendations Report, which specifies the environmental flows that are required to meet the environmental flow objectives for each reach and describes any complementary management actions that may be required.

The FLOWS method contains no guidance on the inclusion of Aboriginal cultural values in the flow recommendations. Melbourne Water and the project team are exploring other ways to include consideration of cultural values in the development of objectives and flow recommendations, including the potential of undertaking a specific cultural flows study (after this project) to inform the recommendations. As part of this project, workshops and on Country visits with Traditional Owners have been held to discuss the most appropriate way to include cultural values in the objectives and flow recommendations, including input into this project or to a broader cultural values assessment for the entire catchment after this project.

## 1.3 Environmental Flow Technical Panel

The Environmental Flows Technical Panel (EFTP) for this project comprised the following members:

- Dr Simon Treadwell, Jacobs (EFTP Chair, Ecosystem processes and fish)
- Dr Peter Sandercock, Jacobs (Geomorphology)
- Dr Paul Boon, Dodo consulting (Vegetation)
- Fiona Gilbert, Jacobs (Water Quality & Macroinvertebrates)
- Josh Griffiths, EnviroDNA (Platypus)
- Dr Jo Szemis and Ben Mason, Jacobs (Hydrology and Hydraulic Modelling)

## 1.4 Project Advisory Group

A Project Advisory Group (PAG) was established to provide a forum in which key stakeholders and Traditional Owners can provide technical input into the study by:

- helping to locate reference materials
- providing local knowledge
- providing technical support
- providing local opinions about values and threats to the river and its users

- ensuring that all important details are considered by the scientific panel developing the objectives and recommendations
- providing an "on-ground" sanity check of the recommendations and data developed by the study
- assisting with selection of reference sites and reaches; and· assisting with development of flow objectives

During this stage of the project (Issues Paper) the involvement of the PAG included attending the on-site assessment with the EFTP, and attending the third PAG meeting to provide input on the proposed ecological objectives presented by the Jacobs team. Representatives from the Wurundjeri Woi-wurrung Cultural Heritage Aboriginal Corporation and Wadawurrung Traditional Owners Aboriginal Corporation were a part of the PAG and have been assisting with progressing additional Traditional Owner involvement in the flows study, outside of the scope of the regular PAG involvement.

## 1.5 Purpose and structure of this report

This report is the Final Recommendations Paper, the third major report deliverable associated with the project. The purpose of the report is to provide a summary of issues relevant to the development of ecological objectives and flow recommendations for the upper Werribee system, and to present the final flow recommendations developed as part of this study.

This Final Recommendations Paper incorporates the Issues Paper, which was the second major deliverable of the study. The Issues Paper included a detailed assessment of the water-dependent issues in the study area, and developed objectives for water-dependent values. The preparation of the Issues Paper involved a number of key tasks including:

- Background review, including preparation of Site Paper report
- A two-day field assessment by the EFTP, which provided the ecological specialists an opportunity to inspect the Werribee River (Wirribi Yaluk) at various locations and consider the ecological values currently present. Members of the PAG also attended the site assessment at Reach 5, in Bacchus Marsh
- Development of ecological objectives, which were formulated during the site assessment, discussed and refined during a dedicated EFTP workshop, and then presented to the PAG for feedback and comment (PAG meeting 3).
- A report describing the outcomes of the site assessments, the ecological objectives, and a review and discussion of current threats to the flow-dependent values in each reach.

The draft ecological objectives and the Issues Paper were presented to Melbourne Water and the PAG for comment and feedback; that feedback has been incorporated into this final report. This Final Recommendations Report incorporates the Issues Paper and also presents the final environmental flow recommendations and the method used to develop them.

The structure of the report is as follows:

- Section 2 provides a brief background on the study area and the ecological objective setting process
- Section 3 describes the method followed in this study for the review and development of specific flow recommendations for each reach
- Sections 4 to 8 present the reach description, hydrology, ecological objectives and final flow recommendations for each reach
- Section 9 lists the references used in the study.

# 2. Study area and ecological objective setting

The objective of this study is to review and revise existing flow recommendations for Reaches 3, 4 and 5, and to develop flow recommendations for Reaches 1 and 2 which currently do not have environmental flow recommendations. This process includes setting ecological objectives for each reach, then developing flow recommendations to achieve those objectives.

Section 1.1 contains an overview of the study reaches and the current status of recommendations for each reach. The reaches are already well defined from previous studies and environmental flow management in the system. The catchment visit on March 4th and the EFTP site visit on May 16th and 17th confirmed that existing reach delineations are still relevant based on the locations of barriers, tributary inflows and key water diversion and delivery points. Defined flow reaches in the Werribee system are shown in Figure 2-1; Figure 2-2 highlights the specific reaches included in this study.


Figure 2-1 Werribee system and defined flow reaches (from VEWH 2021)


**Figure 2-2 Defined flow reaches (1-5) assessed as part of this study**

Ecological objectives set the direction and target for the environmental water recommendations and are clear statements of what outcomes should be achieved in providing environmental flows. The process of setting environmental flow objectives involves first identifying the environmental assets, setting environmental objectives against these, and then identifying the flow required to meet the environmental objectives.

Objectives are developed for those ecological assets that have a clear dependence on some aspect of the flow regime, and include:

- individual species and communities
- habitats
- ecological (physical and biological) processes.

Objectives are typically developed such that, if met, the flow could sustain an ecologically healthy waterway. An ecologically healthy waterway will have flow regimes, water quality and channel characteristics such that:

- in the channel and riparian zone, the majority of plant and animal species are native and no exotic species dominate the system
- natural ecosystem processes are maintained
- major natural habitat features are represented and are maintained over time
- native riparian vegetation communities exist sustainably for the majority of the waterway's length
- native fish and other fauna can move and migrate up and down the waterway
- linkages between the channel and floodplain and associated wetlands are able to maintain ecological processes.

A waterway does not have to be pristine to be ecologically healthy. The definition of an ecologically healthy waterway that we use recognises that there can be some change from the natural state, and in highly developed catchments it will not be possible or desirable to return a waterway to its natural state because to do so would jeopardise some important social and economic values. However, where practical, changes from the natural state should not contribute to a major loss of natural features, biodiversity or function.

Ultimately, environmental flow objectives must be developed for assets that have a clear dependence on some aspect of the flow regime. The objectives need to clearly state what outcomes are expected (i.e. be meaningful and measurable) and that if met, mean that the flow could sustain an ecologically healthy waterway.

In this study specific ecological objectives have been set for geomorphology, vegetation, macroinvertebrates and water quality, fish, and platypus. Macroinvertebrates and water quality have been considered as part of a single set of objectives, given the significant overlap between these two components. Similarly, objectives for ecosystem processes are contained within other closely aligned ecological objectives, including those for geomorphology and for macroinvertebrates and water quality.

The Victorian Environmental Water Holder (VEWH) works with other water authorities to manage environmental flow releases in the Werribee system. The 2021 seasonal watering plan outlines the high-level environmental watering objectives for the Werribee River (Wirribi Yaluk) (Figure 2-3). These include maintaining fish, frog, macroinvertebrate and platypus populations, maintaining and promoting native aquatic plants and limiting spread of terrestrial plants, and maintaining channel substrate and habitat to support ecosystem processes. The environmental watering objectives include specific mention of fish, frogs and platypus. There are no specific watering objectives for other aquatic mammals (e.g. rakali), but flow recommendations that achieve other watering objectives are expected to be adequate for protecting other flow-dependent values and biota.


**Figure 2-3 Environmental watering objectives in the Werribee River, from VEWH 2021**

Specific objectives developed in this project for each reach are outlined in Sections 4 to 8.

# 3. Method for developing recommendations

**Review**

As outlined in Section 1.2, the FLOWS method includes a defined process for the development of flow recommendations. The Site Paper and Issues Paper summarise the first stages of the process, which involved review of existing data and reach assessment sites, selection of reach assessment sites for Reaches 1 and 2, site assessments with EFTP, cross section identification and review, formulation of objectives, and presentation and validation of objectives with the PAG.

**EFTP site visit**

Stage Two involved a site visit by the EFTP. The activities undertaken at each site depended on particular site characteristics and whether the site had existing flow recommendations.

At reaches with existing flows cross sections and hydraulic models (Reaches 3, 4, 5) the EFTP confirmed that those cross-sections were still relevant and exhibited the typical characteristics of the reach. Observations and photographs were taken at each cross section and a cross-section and long section sketch was made for future reference (see Figure 3-1 for an example). These sketches documented the typical characteristics of the channel and were later used in the EFTP workshop as a reminder of the reach characteristics. Observations were also made of channel features that may influence the suitability of existing hydraulic models, for example, channel roughness or major changes in channel morphology (see below for more details on the approach to hydraulic modelling).

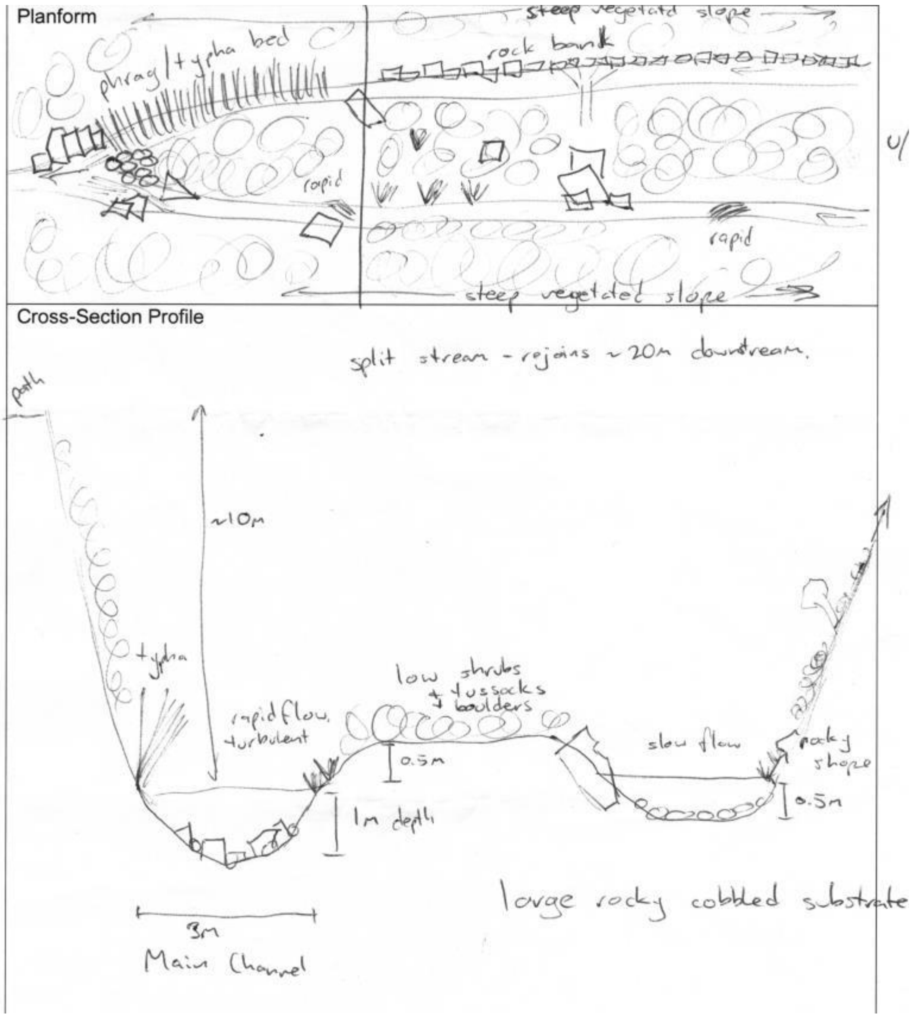



**Figure 3-1: Example cross section sketch – Reach 4, Cross Section 2**

At reaches with no existing cross sections or hydraulic model (Reaches 1 and 2) a decision was made as to whether a model was needed to inform flow recommendation and observations made to help inform the development of recommendations.

For Reach 1 it was confirmed that a hydraulic model was not needed. This was because the flow regime for the reach has not been substantially modified from natural, flow recommendations would ultimately be based on the maintain the natural regime and that this could be determined from an analysis of reach hydrology without the need for a specific hydraulic model. For this reach the EFTP took notes and photos to assist in discussions at the workshop.

For Reach 2 it was also confirmed that a hydraulic model was not needed. The flow regime for the reach is heavily constrained by the release regime from Pykes Creek Reservoir, so recommendations for environmental flows are based around management of the releases from the reservoir to provide a more natural, seasonally appropriate and variable flow regime. Recommended flows have been determined based on hydrological analysis, as for Reach 1. As such, development of a hydraulic model was not considered necessary given that the model would not substantially improve the ability to provide recommendations on flow release patterns to optimise environmental outcomes. Recommendations for this reach were informed by reach hydrology including an assessment of natural flow regimes, operational constraints and high-resolution drone footage of the reach characteristics.

**EFTP workshop and development of flow recommendations**

Following the site visits, a workshop was held to develop the flow recommendations. The EFTP convened a workshop to discuss the information collected during the previous stages of the project and to develop and refine draft environmental flow recommendations for each reach. Reach 1 and 2 have no existing flow recommendations; these were developed by the EFTP at the workshop. Reaches 3, 4 and 5 have existing flow recommendations and these were reviewed to identify whether any updates or amendments are necessary, based on changes in the reach or any other relevant new data since the initial recommendations were set.

Flow recommendations are determined for flow components that represent specific element of the flow regime that fulfils a particular ecological or biophysical function (Table 3-1).

**Table 3-1 Environmental functions of different flow components (Note, not all of these components are relevant to this study).**

| Flow component | Response function |
|---|---|
| Cease-to-flow | • Disturb lower channel features by exposing and drying sediment and bed material.<br>• Promote successional change in community composition through disturbance.<br>• Maintain a diversity of ecological processes through wetting and drying. |
| Low flow | • Allow accumulation and drying of organic matter in the higher areas of the channel such as benches.<br>• Maintain permanent pools with an adequate depth of water to provide habitat for aquatic biota.<br>• Maintain riffle habitats with a variety of fast and slow flowing areas, adequate width and depth for colonisation by macroinvertebrates and foraging by fish and exposes some large rocks that are likely to be important for insect oviposition.<br>• Slow the process of water quality degradation occurring in pools (avoid complete stagnation).<br>• Sustain longitudinal connectivity for movement of macroinvertebrates, fish and Platypus.<br>• Sustain inundation of lower benches to maintain habitat for emergent and marginal aquatic vegetation.<br>• Promote development of larval and juvenile fish that require shallow, slow flowing backwater habitats.<br>• Promote recruitment for fish that spawn during low flow periods. |
| Freshes/High flow | • Entrain terrestrial organic matter that has accumulated on benches and in the upper channel.<br>• Erode, transport and deposit sediment across a range of channel surfaces (i.e. deposition at channel margins and formation of benches).<br>• Provide spawning and migration cues for fish.<br>• Provide flow variability to maintain species diversity of emergent and littoral aquatic vegetation and to drive vegetation zonation patterns across the channel.<br>• Instigate die back of terrestrial vegetation that has encroached down the bank during the low flow period. |

| Flow component | Response function |
|---|---|
| | • Increase habitat area available for in-stream flora and fauna through inundation of benches and large woody debris located on banks. |
| Bankfull flows | • Disturb aquatic and riparian vegetation and rejuvenate successional patterns.<br>• Transport organic matter that has accumulated in the riparian zone and wetlands.<br>• Instigate die back of terrestrial vegetation that has encroached down the bank during the low flow period.<br>• Increase habitat area, including access to large woody debris and over hanging banks for in-stream biota.<br>• Maintain overall channel dimensions through scour of pools, formation and modification of existing bars and channel marginal elements (i.e. low lying benches). |
| Overbank flows | • Engage entire floodplain<br>• Form and maintain floodplain features (i.e. wetlands) |
| Definition of terms:<br>Cease-to-flow – no measurable flow in the waterway (although pools may retain water)<br>Low flow – flow that provides continuous flow through the channel within that reach<br>Freshes – small and short duration peak flow event<br>High Flow – large flow events with longer duration than freshes, these flows cover streambed and low in-channel benches<br>Bankfull Flow – fill the channel and adjacent wetlands with little spill onto the actual floodplain<br>Overbank Flow - greater than bankfull and result in inundation of floodplain habitats | |

At the workshop the EFTP worked through the process of determining flow recommendations on a reach by reach basis. For each reach the environmental flow objectives documented in the Issues Paper were discussed. Photos and field notes taken during the field assessment were examined along with transects from the hydraulic models in order to identify key habitat features (i.e. riffles, undercut banks, benches, pools, raised channel surfaces etc.).

Within each reach, each flow component was considered in turn. A range of criteria / rationale were used to determine suitable flows. These criteria / rationales are reach specific and vary according to the species present and channel features and are justified in the following sections where flow recommendations are provided. For each flow component the desired volume threshold, frequency of occurrence and duration was determined.

Consideration was given to the acceptable level of variability in flow components and differences between wet, average and dry years. Climate years were classified by an undertaking a tercile assessment whereby dry, average and wet years were defined at the 33% and 66% percentiles. This will ensure that a wide range of climatic conditions are considered in the flow recommendations set for the Werribee system, and provide for efficient environmental water management, particularly when there is low water availability in dry years. For instance, higher magnitude events or more frequent freshes are recommended to be provided in wet years compared to dry years, or shorter duration freshes are delivered during dry years.

Separate environmental flow recommendations are made for the dry seasons (i.e. summer/autumn) and wet seasons (i.e. winter/spring). For the purposes of this project, summer/autumn flow recommendations apply to the whole period from the start of December to the end of May. Winter/spring flow recommendations apply from the start of June to the end of November.

**Hydrology**

Observed daily streamflow data for the Upper and Mid Werribee River (Wirribi Yaluk) and Pykes Creek (Korjamnunnip Creek) reaches was obtained from BoM Water Data Online and DELWP Water Monitoring Information System. There were 7 relevant gauges available, generally of high quality and requiring minimal infilling and filtering. Reach 3 and 4 did not have gauges and as a result the flow series data was calculated using a water balance approach.

Source modelling data at each reach was also obtained from DELWP for natural, historical and climate change scenarios. Climate change scenarios were developed in accordance with DELWP (2020) for the RCP8.5 2045 and 2070 High Projection scenarios. The modelled and gauged data were used as part of the hydrological assessment, which is presented for each reach in subsequent sections.

For unregulated reaches or where no hydraulic model exists (i.e. Reaches 1and 2), ecologically relevant hydrological metrics adapted from Duncan et al (2014) were calculated to characterise the natural flow regime. These metrics were calculated in order to quantify the reach requirements and maintain natural flows, as well as understand the impact and risk associated with potential future modifications (e.g. land use) and climate change. According to Duncan et al (2014), the hydrological metrics provide explanatory variables for ecological and biological waterway condition, and are summarised in the table below. Results for all reaches are presented in Appendix A and metrics for individual reaches are discussed in relevant flow recommendation sections.

**Table 3-2 Hydrological Metrics and definition adapted from Duncan et al (2014).**

| Flow aspect | Metrics selected | Definition and comments on calculation | Ecological or geomorphic significance |
|---|---|---|---|
| Low flow duration | Days per year of zero flow<br><br>Mean duration of zero flow periods | Zero flow days in full record divided by number of years.<br><br>Zero flow days in full record divided by zero flow periods in full record.<br><br>Low flow has been defined as the 25$^{th}$ percentile | Low flow periods affect habitat availability, as well as facilitating presence of species adapted to ephemeral conditions. |
| Magnitude of low flow evens | Baseflow Index | 7-day minimum flow / water year mean daily flow, calculated each year then averaged | As many ecological processes are impacted (positively or negatively) by low flows, the magnitude of low flow spells is important. |
| Duration | Tq mean | Fraction of days with daily mean flow greater than annual mean flow. | Duration of peak flows is an indicator of the duration of 'disturbance events' (both water quality and hydraulic) |
| Rate of change | R-B Index | Sum of the absolute values of change in mean daily flows divided by the sum of the mean daily flows. | Variability of flows is an indicator of the duration of 'disturbance events' |
| Timing | Month of minimum monthly flow | Take mean of all flows in period of record in Jan, Feb, etc., and find minimum of these mean monthly flows. | Seasonality of minimum flows important for alignment with seasonal biological events. |
| Bed mobilisation | Fraction of time > $Q_{1.5yrARI}/2$ | Empirically derived based on analysis of sediments in study catchment and critical shear stress needed to mobilise them, combined with 1D hydraulic model (see Duncan et al 2014) | Bed erosion influences habitat availability |
| Bank mobilisation | Fraction of time > $Q_{2yr}$ARI/2 | Based on commonly used threshold for bank mobilisation | Bank mobilisation affects sediment transport, habitat availability, riparian vegetation, etc |

**Hydraulic modelling**

One-dimensional hydraulic models for Reaches 3-5 were previously developed in HEC-RAS as part of Jacobs 2014 and used to inform environmental flow recommendations. These models are used to develop a relationship between flow, water depth and velocity using the one-dimensional steady state backwater analysis. HEC- RAS calculates water surface profiles and other flow characteristics using a series of surveyed and interpolated cross-sections and estimated roughness factors.

The models were reviewed and found to be suitable for use, with some updates made to the roughness factors. Reaches 3 and 4 required minimal update, however, Reach 5 was found to be more overgrown resulting in a change of roughness factor.

A key output from the hydraulic model is a graphical representation of each cross-section (see Figure 5.3 for an example). The black line in the example ('ground' in the legend) represents the ground surface, reflecting the channel shape at that cross-section. Small black squares on the ground line show the exact points where field survey measurements were taken. Horizontal blue lines within the cross-section represent the estimated water surface at various modelled flows (which are detailed in the legend). The outputs from the model include the flows (expressed in ML/day) required to cover the stream bed to a certain depth, or inundate channel features such as the extent of riffles.

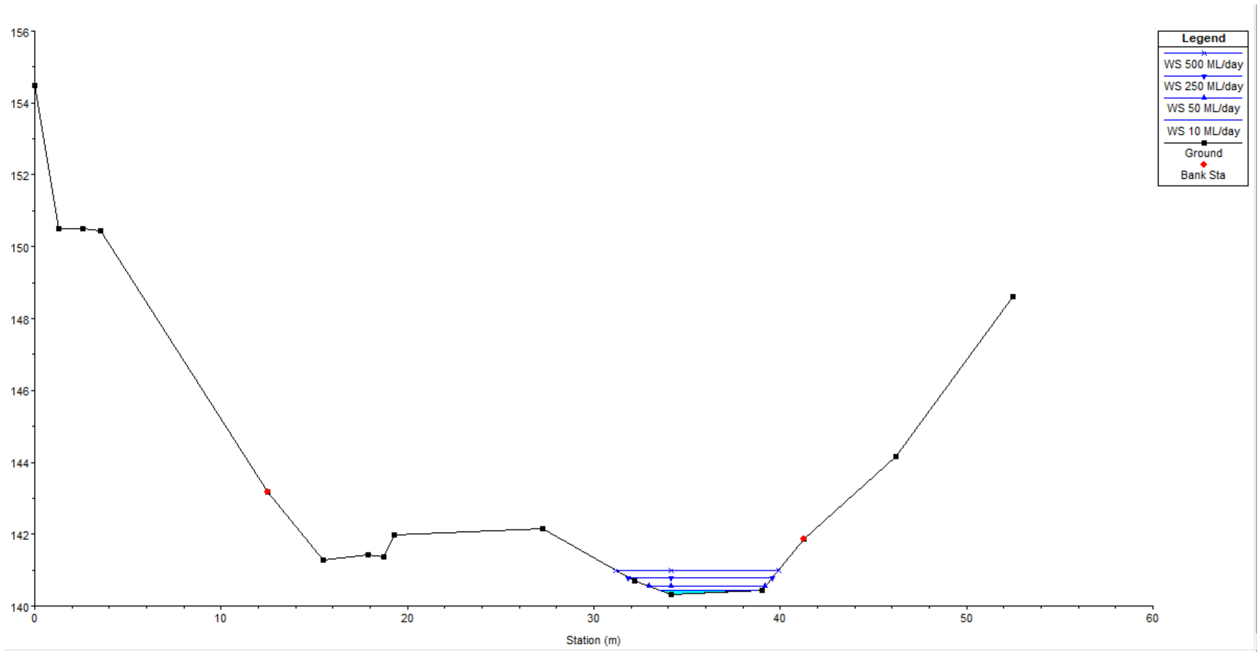



**Figure 3-2 Example cross-section output from the hydraulic model for Reach 4 cross-section 5, showing channel profile and modelled water surface levels for a Summer and Winter low flow and fresh recommendations of 10-500 ML/day.**

# 4. Reach One

## 4.1 Reach Description

**Reach One – Werribee River (Wirribi Yaluk) from headwaters to Upper Diversion Weir**

Reach 1 extends from the headwaters of the Werribee River (Wirribi Yaluk), through Ballan, and downstream to the Upper Diversion Weir. It is relatively unregulated, though small farm dams and extractions may influence flows on a minor scale in the upper reaches, which have predominantly rural land use. The headwaters of the Werribee system are naturally ephemeral, with a pronounced seasonal variation in flows (see Section 4.2). The major threat to flow-related values in Reach 1 are extractions and climate change leading to lower flows, and urban development.

The Werribee River (Wirribi Yaluk) in this reach has been affected by large scale vegetation and land use change, including clearance of swampy woodland vegetation for agriculture, and drainage and deepening of the channel. Drainage, loss of vegetation, and channel deepening would likely have had a significant impact on hydrology in the upper reaches. Currently, flows are impacted by smaller-scale extractions and farm dams, though their influence on overall flow volumes in the upper reaches is not well understood. It is likely to be minor on an overall catchment scale but may be sufficient to influence localised flows upstream of Ballan. The system is naturally ephemeral, often ceasing to flow on a seasonal basis, but extractions may reduce flow volumes year-round, resulting in longer or more frequent cease-to-flow events, or lower base flows which are insufficient to meet ecological objectives. Climate change also represents a threat to flow-dependent values based on forecast lower flows under future lower rainfall conditions. This is also likely to reduce low/base flows, and result in longer and or more frequent cease-to-flow periods which are outside the natural range of the ephemeral flow patterns.

An additional possible influence on flows in Reach 1 is the potential flow loss to underground sewer infrastructure through Ballan, which is thought to be causing losses of up to 6 ML/day from the river (Adam Barber, Melbourne Water, pers. comm.). Low flow or cease-to-flow conditions that are significantly different to the natural ephemeral flow regime (to which existing ecological communities are adapted) represent a potential risk to ecological values in the reach.

There is also potential for urban development in the upper catchment to influence flows and ecological values, primarily through water quality impacts (run off from urban and construction areas containing high levels of sediment and pollutants) and an increase in impervious surfaces leading to a ‘flashy’ stream hydrology with higher and more rapidly occurring peak flows.

The assessment site visited by the EFTP was Caledonian Park in Ballan. Some of the study team also visited other locations in the Reach on an earlier site visit, including an upstream site on Stone Hut Lane, additional areas in Caledonian Park, and downstream at the Old Melbourne Rd crossing (Figure 4-1).

**Figure 4-1 Reach 1 locations (L-R) – Stone Hut Lane, Caledonian Park, Old Melbourne Road crossing**

The EFTP site assessment location in Caledonian Park, Ballan (Figure 4-2), was considered by the EFTP to be suitably representative of the reach for the development of ecological objectives.

**Figure 4-2 EFTP Site assessment location – Caledonian Park, Ballan**

There are no current flow recommendations for this reach, and limited ability to influence flows. Recommendations for ecological objectives in the reach are largely based around maintaining current environmental values by preventing impacts which would significantly alter the current, relatively natural flow regime.

## 4.2 Hydrology

Reach 1 is in the upper reaches of the Werribee River (Wirribi Yaluk) and consists of mostly forested and agricultural land use with flows originating in the Wombat State Forest and flowing south through Ballan. Observed daily streamflow data for Reach 1 was obtained from the BoM Water Data Online and DELWP Water Monitoring Information System, while modelled data extracted from the Werribee Source model provided by DELWP. Details of the relevant streamflow data is presented in Table 4-1.

**Table 4-1 Reach 1 streamflow data**

| ID | Type | Description | Time Period |
|---|---|---|---|
| 1 | Observed | Observed Historical Scenario<br>The timeseries for Reach 1 was extended back to 1943 by combining the two Ballan gauges (231209 and 231225)<br>Details of the gauges are given below:<br>• Werribee River @ Ballan (231209)<br>• Werribee River @ Ballan (U/S Old Western H-Way) (231225A/B) | 22/04/1973 – 16/03/2022 (approximately 49 years of data) |
| 2 | Modelled | Historical Scenario | 01/01/1900 – 31/12/2020 (120 years of data) |
| 3 | Modelled | Natural Scenario (modelled with extractions turned off, water passing through storages, and stormwater, recycled water, Melbourne Supply and farm dam impacts turned off) | |
| 4 | Modelled | 2045 High Projection Climate Change Scenario. | |
| 5 | Modelled | 2070 High Projection Climate Change Scenario. | |

The Werribee River (Wirribi Yaluk) in Reach 1 is an unregulated ephemeral system, which has a significant variation in flows seasonally as well as between dry and wet years (see hydrograph plot and mean monthly daily flow in Figure 4-3 and Figure 4-4). A shorter period between from 2010 to 2011 to showcase the unregulated nature of the reach where there is little variation between the historical and natural scenarios is shown in Figure 4-5.

Assuming a cease-to-flow of <0.5 ML/day, historically Reach 1 has experienced cease-to-flow conditions for approximately 28% of the time for both observed modelled and observed historical data. This is shown in flow duration curve in Figure 4-6.

Considering 2045 and 2075 high projection climate change scenario, the mean monthly daily flows reduce significantly by 45-60% in winter-spring months, and 30-65% in summer-autumn months (see Figure 4-5 ). The overall reduction in flow is modelled to result in an increase in the percentage of time that cease-to-flow conditions are experienced from 28% to 38% of the time in 2045, and 45% of the time in 2070 (Figure 4-6). A similar trend is found when considering only the observed time period. A spells analysis of flows < 0.5 ML/day at Reach 1 was undertaken comparing the modelled historical and climate change scenarios, where the duration and number of cease-to-flow events increases.

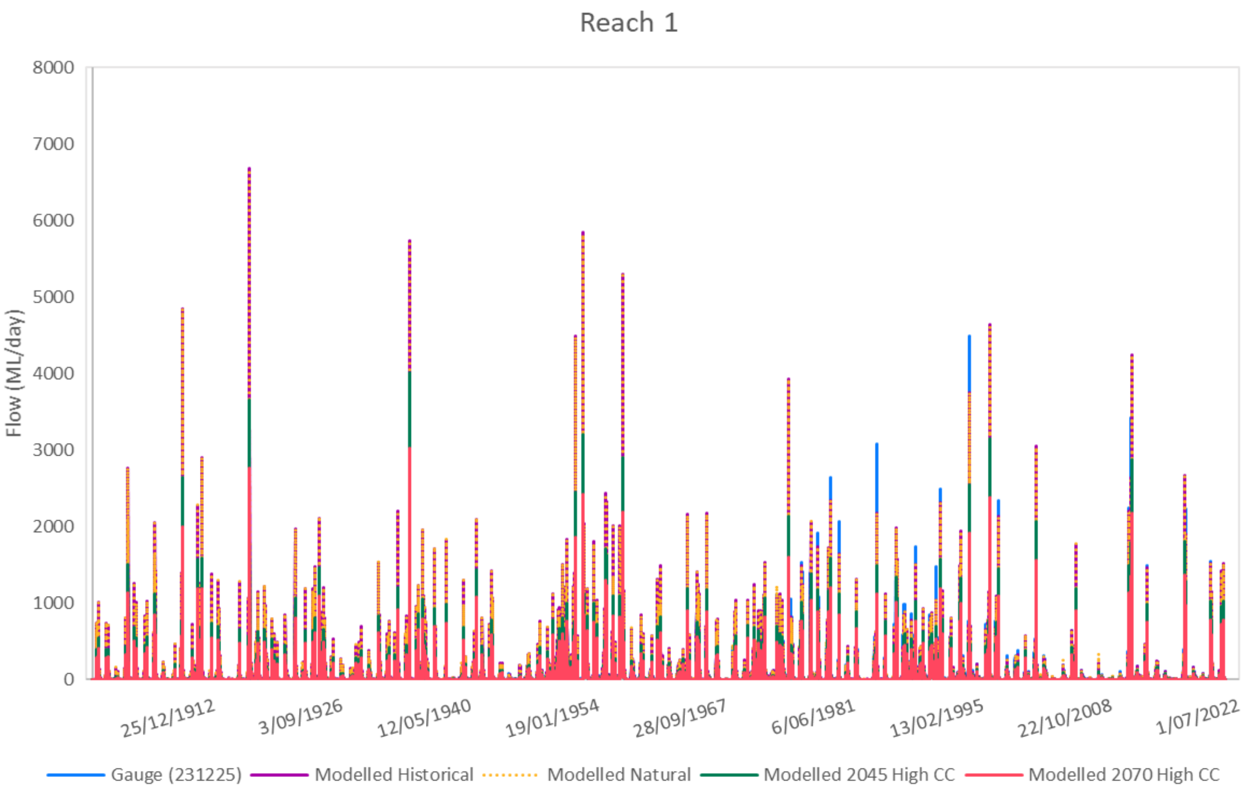



**Figure 4-3 Historical, natural and climate change daily flows for Reach 1**

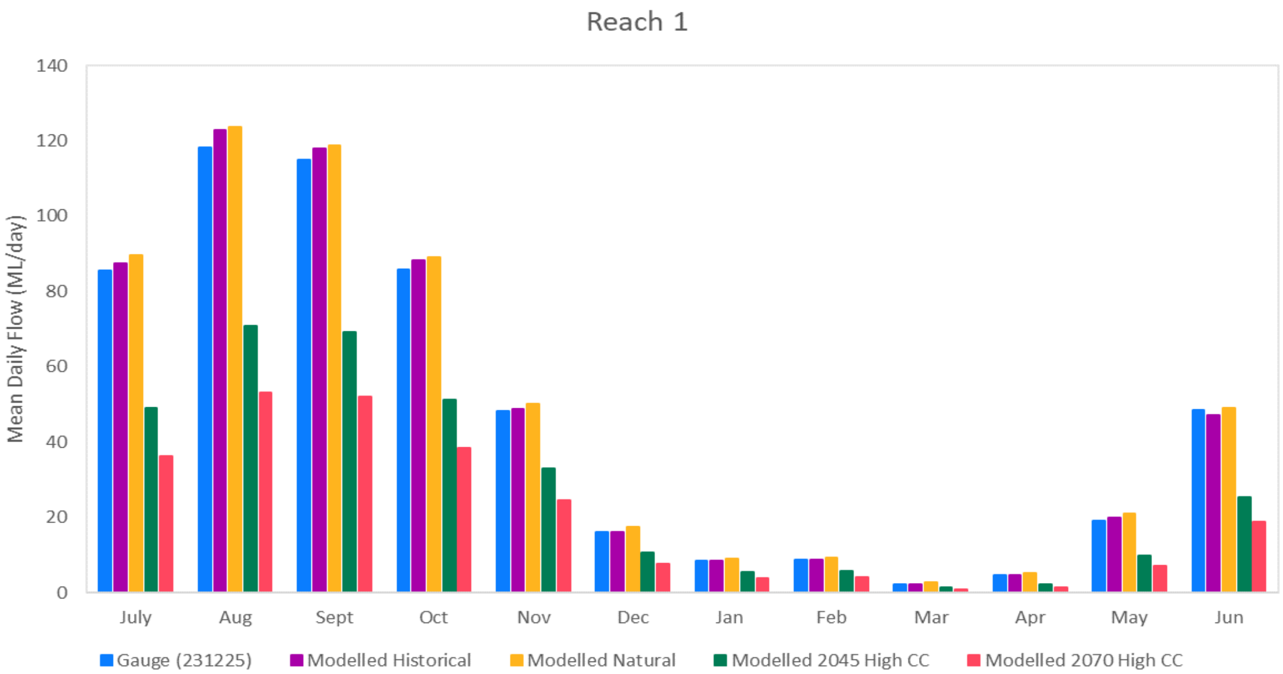



**Figure 4-4 Historical, natural and climate change mean monthly daily flows for Reach 1 considering the observed period only (22/04/1973 – 16/03/2022)**

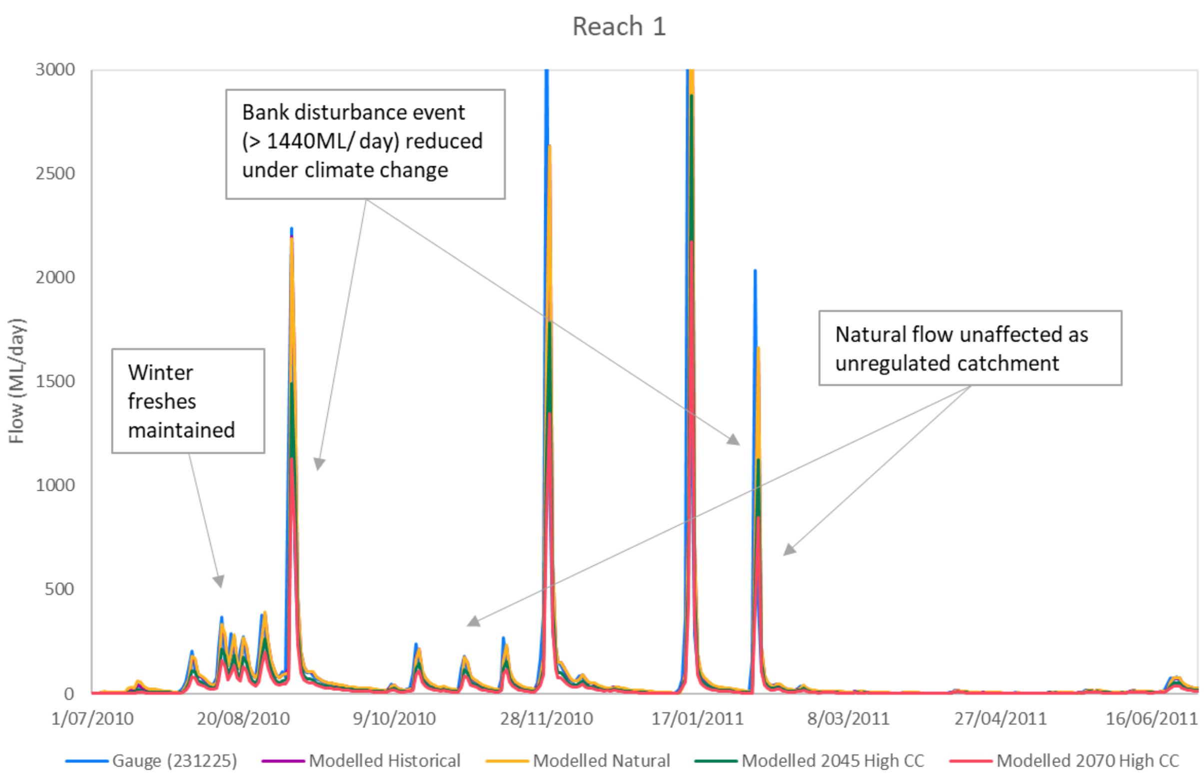



**Figure 4-5 Historical, natural and climate change daily flows between 2010 and 2011 for Reach 1**

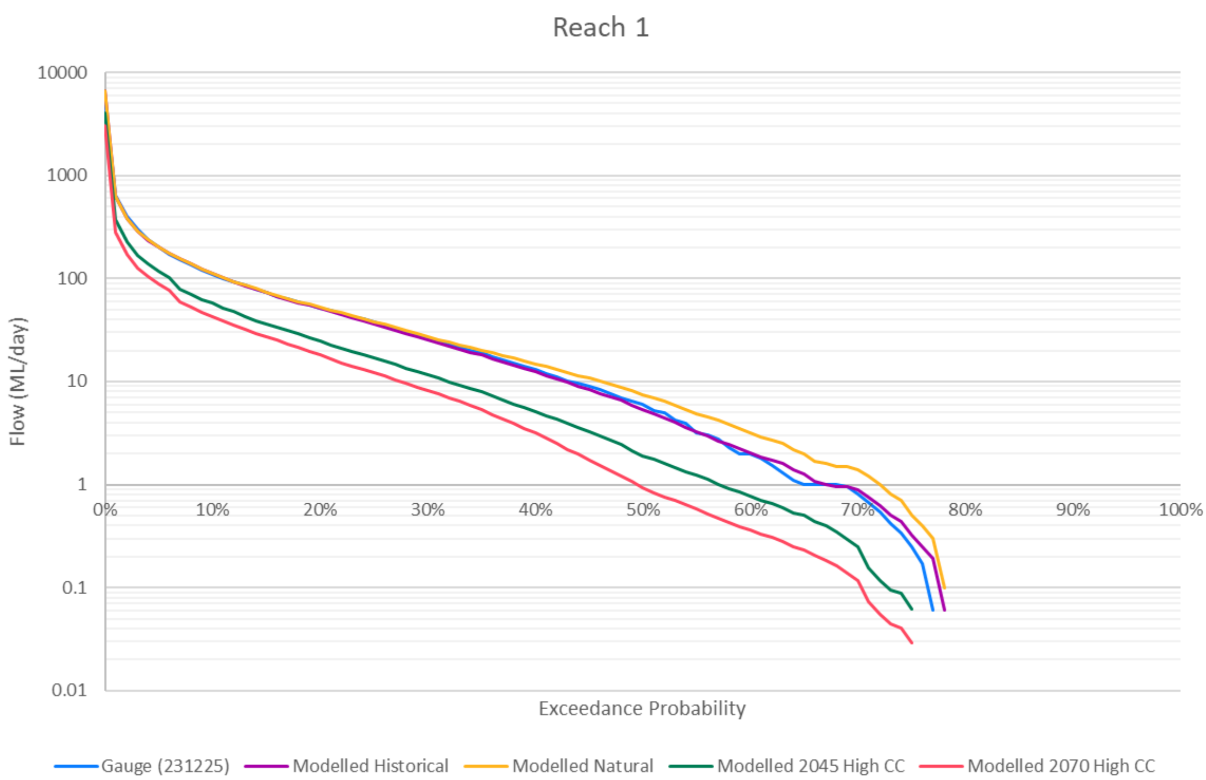



**Figure 4-6 Historical, natural and climate change daily flow duration curve for Reach 1 considering the modelled time period (01/01/1900 – 31/12/2020)**

## 4.3 Ecological objectives for Reach 1

### 4.3.1 Geomorphology

Reach 1 is characterised by a meandering channel and alluvial floodplain set within a confined valley ranging in width from 10 to >100 m in width. In some sections, particularly where the valley is wider, higher secondary channels or former abandoned channels are evident traversing the floodplain. The stream channel is 5-15 m wide, with banks about 1 m high. Basalt outcrops were observed in the bed of the channel, and in some locations these form steps in the bed profile. The channel form at the FLOWS assessment site includes rock cascades, boulder riffles and pools.

The objectives for geomorphology for Reach 1 are to: *Maintain channel dimensions, form and complexity; Maintain access to and quality of riffle and pool habitats; and engage higher channel surfaces and low-level floodplains*

The flow components and functions required to achieve these objectives are summarised in Table 4-2.

Whilst the catchment is mostly unregulated, land use change and in particular urbanisation poses the greatest risk. Risks to objectives and flow are:

- the potential for increased urban development to result in an increase in the frequency of flow events that exceed the critical erosion thresholds for scour of bed and bank sediments.
- degradation or modification of secondary flow channels arising from land use impacts (construction of farm dams, levelling of land and drainage works)
- any diversion of flows from the river which may have the effect of limiting the duration and frequency of flow components.

**Table 4-2 Reach 1 Geomorphology objectives**

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Maintain channel dimensions, form and complexity (G1.1) | Bankfull flow | Maintain gross channel dimensions and form channel features (i.e. pools, bars/riffles). (G1.1.1) | Winter-Spring |
| | Low flows | Scour and maintain undercuts, exposed roots and large wood habitat. (G1.1.2) | All year |
| | Freshes | Scour and maintain undercuts, exposed roots and large wood habitat.<br><br>Limit frequency and duration of flows above scouring thresholds (G1.1.3) | All year |
| Maintain access to and quality of riffle and pool habitats (G1.2) | Low flows | Maintain extent of riffle and pool habitats (G1.2.1) | All year |
| | Freshes | Scour fine sediment and biofilms from riffles[1]<br><br>Prevent any increase in the frequency of critical flows (G1.2.2) | All year |
| | High flow | Scour sediment from pools (G1.2.3) | Winter-Spring |
| Engage higher channel surfaces and low-level floodplains (G1.3) | High - Bankfull flow / Overbank flow | Maintain connectivity to and form of higher secondary flow channels (G1.3.1) | Winter-Spring |

[1] Bed shear stress during fresh capable of moving silt from cobbles ($\tau_c > 15$ N/m$^2$) and sand ($\tau_c > 8$ N/m$^2$). Source: Appendix B of Ecological Associates (2005b)

### 4.3.2 Vegetation

In-stream vegetation at the Reach 1 inspection site was limited to small clumps of Water Ribbons (*Cycnogeton procerum*, formerly *Triglochin procerum*). Other in-stream taxa, such as milfoils (*Myriophyllum* spp.), may be present in other parts of the reach, especially in the slow-moving pools.

Fringing non-woody emergent vegetation was sparse, but slightly downstream are beds of Common Reed (*Phragmites australis*). It is possible that elsewhere in the reach isolated clumps of reeds, sedges and rushes may occur (e.g. Tall Sedge, *Carex appressa* and Swamp Club-sedge, *Isolepis inundata*) ( Figure 4-7).

**Figure 4-7 Reach 1 vegetation**

The riparian zone in Reach 1 has been almost entirely removed (as discussed in the earlier Site Paper) and what remains is (i) discontinuous and (ii) largely exotic and weedy (Figure 4-8). Isolated specimens of indigenous taxa including acacia (e.g. Silver Wattle (*Acacia dealbata)*, Black Wattle (*Acacia mearnsii)* and Blackwood (*Acacia melanoxylon*), bottlebrushes and paperbarks (*Callistemon* and *Melaleuca* spp.)) were present at the inspection site but EVC mapping indicates very little remnant riparian vegetation along the length of the reach. Note that bottlebrushes and paperbarks are water-dependent taxa to various degrees. Ecological Associates (2005) reported the presence of many woody weeds in the riparian zone of this reach, including Desert Ash, Willow, Hawthorn, Blackberry and Gorse. Given the scale and intensity of urban development along this reach (with concomitant destruction of native vegetation in the streamside zone, alterations to run-off characteristics, and deterioration in water quality (e.g. turbidity, suspended solids, nutrients, toxicants) it is unlikely the condition of in-stream, fringing and riparian vegetation communities will improve unless strict and reach-long interventions are made.

These descriptions and conclusions validate the summary provided in the 2018 Healthy Waterways Strategy (Melbourne Water 2018, p. 89): "The value of vegetation across other parts of the catchment [i.e. other than in Werribee Gorge and Lerderderg State Park] is of low to moderate value as a result of the modified nature of the catchment". Moreover, the trajectory for improvement is rated as low without significant intervention.

**Figure 4-8 Discontinuous and weedy riparian vegetation, Reach 1.**

The co-designed catchment program for the Werribee catchment region (Melbourne Water 2018) includes specific actions to establish or maintain vegetation buffers along the stream channel for the length of the river in Reach 1 (see Melbourne Water 2018, Figure 8). The management objectives shown in Table 4-3 below for fringing and riparian vegetation recognise this potential for revegetation of the streamside zone with native taxa in this most-upstream reach of the Werribee River (Wirribi Yaluk).

The objective for water-dependent vegetation for Reach 1 therefore is to: *Maintain existing in-stream and fringing non-woody vegetation and provide a water regime that will facilitate the establishment (and subsequent maintenance) of riparian vegetation undertaken as part of Melbourne Water's revegetation plans for the middle Werribee River.*

The flow components and functions required to achieve this objective are summarised in Table 4-3

**Table 4-3 Reach 1 Vegetation objectives**

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Maintain in-stream vegetation (V1.1) | Low flow | Maintain existing plant communities by providing pool habitat over winter-spring period (note that taxa such as Water Ribbons are well adapted to periodic cease-to-flow periods) (V1.1.1) | Winter-spring |
| | Freshes | Downstream dispersal of plant propagules (V1.1.2) | Winter-spring |
| Maintain fringing non-woody vegetation (V1.2) | Low flow | Maintain existing plant communities of reeds, rushes and sedges by providing damp conditions along stream side over winter-spring period (note that many species of reed, rush and sedge are well adapted to periodic cease-to-flow periods) (V1.2.1) | Winter-spring |
| | Freshes | Promote vertical zonation of non-woody vegetation | Summer-autumn |

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| | | Downstream dispersal of plant propagules (V1.2.2) | |
| Facilitate the establishment and subsequent maintenance of riparian woody vegetation (V1.3) | Low flow | Maintain existing remnant plant communities of bottlebrushes and paperbarks by providing damp conditions over winter-spring period<br><br>Facilitate future revegetation efforts of similar vascular plant species (V1.3.1) | Winter-spring |
| | Freshes | Facilitate future revegetation efforts by watering juveniles during dry summer-autumn period (V1.3.2) | Summer-autumn |
| Prevent encroachment of the stream channel by undesirable terrestrial species (V1.4) | Low flow | Prolonged inundation of stream channel will prevent colonisation of inundation-intolerant plant taxa, including pasture species and garden escapees (V1.4.1) | Winter-spring |

### 4.3.3 Macroinvertebrates and Water Quality

Reach 1 is characterised by an ephemeral flow regime with cease-to-flow periods occurring naturally in summer and dry periods, and near permanent low flows (with occasional high flows) in winter. The assessment site for the reach is at Caledonian Park in Ballan, though the reach is quite long (extending from the headwaters to the Upper Diversion Weir) and includes a variety of stream conditions and habitat. The reach includes a variety of flow conditions, aquatic vegetation, and habitat types that can support macroinvertebrates, including pool, edge and riffle.

Macroinvertebrates contribute to ecosystem processes by assisting in the processing and decomposition of organic material and providing an important food source for fish and platypus. They are also an important component of overall stream biodiversity. Macroinvertebrates rely on streamflows and water quality to provide suitable habitat and support lifecycles processes, and can be vulnerable to degraded water quality or significant flow alteration.

Alteration to flows (in particular, water extraction that results in a reduction of flow volume in the channel) has the potential to 1) reduce the extent of physical habitat available for macroinvertebrates, 2) lead to altered water quality (e.g. temperature and dissolved oxygen), 3) affect sources and exchange of material and energy (for example by reducing the input of organic material which is a food source for macroinvertebrates), and 4) restrict connectivity and diversity of habitat (Rolls et al. 2012).

It is a principle of the FLOWS method that environmental flows are provided to support flow-dependant values and are not intended as a tool to protect or maintain water quality where impacts are caused by catchment sources unrelated to flows. However, where water quality is related to, and potentially affected by alterations to flow, these flow-related water quality objectives have been noted. Water quality objectives have been highlighted in this section as water quality has the potential to impact on macroinvertebrate populations (and therefore to the aquatic biodiversity and ecosystem processes that are supported by macroinvertebrates). Primarily, flow related water quality objectives relate to the risk of reduction in flows leading to higher water temperature, lower dissolved oxygen, and higher salinity. Increased flows, particularly ‘flashy’ flows from urban areas or from areas of disturbed soils, can also have a detrimental effect on water quality through the transport of high sediment loads into the waterways and resultant increased turbidity. High concentrations of suspended solids can clog the filter feeding mechanisms of some macroinvertebrates, and settle onto benthic surfaces, smothering benthic habitat. Macroinvertebrate communities can be sensitive to these changes in water quality that result in water quality conditions outside the natural range experienced, which can occur as a result of flow alteration.

As current flows in Reach 1 are relatively natural, the macroinvertebrate community is likely adapted to that flow regime including variable flow, low flows and cease-to-flow periods. Objectives for macroinvertebrates are therefore based largely on maintaining the current flow regime to support existing macroinvertebrate populations. There is limited ability to deliver environmental flows to this reach, so maintaining current flows is primarily about protecting the existing flow from impacts from urban development or climate change. Flows in the reach have potential to be impacted by climate change due to the forecast lower rainfall and lower flows. An increase in the frequency and duration of low flow and cease-to-flow periods from current has the potential to dry out important habitat area (e.g. shallow riffle habitats) and cause an overall reduction in habitat area. Reduced flows under climate change could be exacerbated by the presence of farm dams in the catchment.

The overall objective for macroinvertebrates in Reach 1 is to: *Maintain the abundance and diversity of macroinvertebrate communities throughout Reach 1 through the provision of flows that support habitat quality and availability, life cycle processes, and water quality.*

The flow components and functions required to achieve this objective are summarised Table 4-4.

**Table 4-4 Reach 1 Macroinvertebrate and water quality objectives**

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Maintain access to and quality of riffle and pool habitats (M1.1) | Low flows (noting existing/natural ephemeral conditions – this component relates to maintaining low flows at at least current levels, and avoiding loss of low flows outside of natural range) | Maintain extent and diversity of riffle and pool habitats, and avoid drying of critical habitats (i.e. shallow riffles and refuge pools)<br>Maintain connections between habitat areas<br>Maintain wetted width of channel and connection with littoral vegetation (M1.1.1) | All year |
| | Freshes | Flush fine sediment from riffles to expose new surfaces, prevent infilling of interstitial spaces or smothering, and provide quality habitat (M1.1.2) | All year |
| | High flow | Scour sediment from pools (M1.1.3) | Winter-Spring |
| Maintain water quality and important hydrological functions of current flow regime (M1.2) | Low flows | Maintain low flows to prevent an increase in cease-to-flow periods outside of natural range<br>Provide flows to prevent prolonged low flow periods that can result in decreased dissolved oxygen and increased salinity (M1.2.1) | All year |
| | Freshes | Maintain inputs of organic matter from upstream reaches and the catchment<br>Flush accumulated organic matter and fine sediments (M1.2.2) | Several events throughout the year |
| | High Flows | Mobilise and transport particulate matter to downstream reaches (M1.2.3) | Winter-Spring |

### 4.3.4 Fish

Reach 1 is characterised by a seasonal flow regime with cease-to-flows in summer and near permanent low flows in winter with occasional high flows. Habitat includes refuge pools, rocky bedrock outcrops, riffles and runs. The reach supports a small native fish community comprising the migratory Short-finned Eel and Common Galaxias, and the resident Mountain Galaxias and Southern Pygmy Perch (Jacobs 2022). These species are generally highly mobile or are adapted to low and no flow conditions by being able to persist in isolated refuge pools between flow events.

The objective for native fish for Reach 1 is to: *Maintain the existing native fish community by ensuring that refuge pools are sustained during low and cease-to-flow periods, and that higher base flows and freshes occur at suitable times to enable local fish movement and opportunities for re-colonisation of areas that may have experienced cease-to-flows.*

The flow components and functions required to achieve this objective are summarised in Table 4-5.

This reach is mostly unregulated and greatest risks are from poor water quality associated with land management practices and urban runoff. Risks to objectives and flow are:

- the potential for increased urban development to result in increased 'flashy' flows associated with rainfall runoff via the stormwater system that create more frequent channel disturbance, and
- climate change that results in an increase the frequency and duration of cease-to-flows and very low flows that contributes to the loss of refuge habitat. This could be exacerbated by the presence of farm dams in the catchment.

**Table 4-5 Reach 1 fish objectives**

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Maintain native indigenous fish community (e.g. Short-finned Eel, Southern Pygmy Perch, Mountain Galaxias) (F1.1) | Avoid prolonged cease-to-flow | Prevent loss of refuge pool habitat (F1.1.1) | Summer/autumn |
| | Summer Low flow | Maintain refuge pool habitat (F1.1.2) | Summer (cease-to-flows acceptable if natural – avoid prolonged/unnatural CtF) |
| | Winter Low flow | Maintain diversity of hydraulic habitats (i.e. pool, riffle, run)<br><br>Maintain connectivity (adequate depth) for local movement (F1.1.3) | Winter (ideally continuous and typically higher than summer) |
| | Freshes | Top-up/freshen water quality in refuge pools (F1.1.4) | Summer (especially if cease-to-flows have occurred) |
| | Freshes-high flows | Flush accumulated sediments to maintain or improve quality and availability of habitat<br><br>Maintain connectivity (adequate depth) for local movement and recolonisation following periods of cease-to-flow (F1.1.5) | Any time |
| | Freshes-high flows | Maintain cues for downstream migration by adult Short-finned Eels (F1.1.6) | Throughout year, particularly Summer |
| | Avoid increased frequency of disturbance flows from urban runoff | Prevent channel degradation and water quality decline (F1.1.7) | Any time |

### 4.3.5 Platypus

Platypuses are present in Reach 1 as far upstream as Ballan. Recent data from limited live-trapping and eDNA surveys as well as anecdotal records for online databases suggest a low-density population. As the most upstream extent of platypus distribution in the Werribee system, habitat is marginal largely due to regular and extensive cease-to-flow events in summer and autumn. The persistence of isolated pools during dry periods in the lower part of Reach 1 has likely allowed platypus to persist downstream of Ballan. Given the projected increase in cease-to-flows under climate change scenarios and unregulated nature of Reach 1, it is unlikely that platypuses will persist long term. However, limiting short-medium term declines may be achieved by preventing further degradation of the flow regimes that may arise through urbanisation of the surrounding catchment area and resultant stormwater run-off.

The objective for platypus in Reach 1 is to: *Limit declines in the platypus population and maintain at current levels if possible*.

The flow components and functions required to achieve this objective are summarised in Table 4-6.

**Table 4-6 Reach 1 Platypus objectives**

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Limit decline of platypus population (P1.1) | Low flow | Maintain refuge pools (P1.1.1) | Summer/autumn |
| | Low flow | Maintain habitat and longitudinal connectivity for platypuses, support food resources (macroinvertebrates) (P1.1.2) | Winter/spring |
| | Freshes | Limit flow variability and peaks above scouring threshold that will displace macroinvertebrates (P1.1.3) | All year. |

## 4.4 Flow recommendations

There are no current flow recommendations for Reach 1 of the Werribee River (Wirribi Yaluk). This is largely due to the relatively unregulated nature of the reach, which means that the natural flow regime is less impacted than in lower reaches, and that water managers do not have the ability to store and deliver environmental water to the reach.

The greatest risks to flow-dependent ecological values are from poor water quality associated with land management practices and urban runoff, and changes to key flow components as a result of future land use and climate change. Key risks to maintaining flows and associated ecological objectives in Reach 1 are a) the potential for increased urban development and associated increase in impervious surfaces to result in increased 'flashy' flows associated with rainfall runoff via the stormwater system that create more frequent channel disturbance, and b) climate change that results in lower rainfall and streamflows, and an increase in the frequency and duration of cease-to-flows and very low flow periods. While the reach is naturally seasonally intermittent, and frequently does not flow in summer, an increase in low or no flow conditions relative to current conditions as a result of climate change would contribute to the loss of refuge habitat and risk impacts to aquatic ecological values. This could be exacerbated by the presence of farm dams in the catchment which further reduce streamflows.

Due to the nature of the reach and the key threats to flows and ecological values, recommendations have been set based on the overall objective of maintaining the current flow regime to protect existing ecological values, and minimise flow impacts from land use and climate change. Recommendations have been derived from hydrological metrics that have been shown represent particular risk to ecological values (see Section 3). Recommendations are summarised in Table 4-7.

**Cease-to-flow**

Reach 1 currently experiences cease-to-flow around 25% of the time and for a mean duration of 40 days per cease-to-flow event. The recommendation is to avoid any increase in the percentage of time that cease-to-flows occur and to avoid an increase in the mean duration of cease-to-flow when they do occur.

The ability to manipulate flows in this reach is difficult because there are no storages that can be used to maintain low flows. The greatest risk to cease-to-flows is from climate change, which under 2070 dry conditions is modelled to result in an increase in the percentage to time that cease-to-flows occur to 28% of the time and increase in the mean duration to 47 days per event. While climate change may be difficult to mitigate, farms dams and other extractions during low flow periods can also contribute to cease-to-flow. Efforts should be made to avoid further proliferation of farm dams and where practicable, look to low flow bypasses and other mechanisms to mitigate the existing impact of farms dams.

Maintaining low flows is also important for a range of objectives particularly with respect maintain access to habitat. There is no specific low flow recommendation – suitable low flows will be maintained provided the frequency and duration of cease-to-flows does not increase.

**Disturbance flows**

Freshes and high flows have been identified as important for a range of objectives, including maintaining channel form, scouring sediments, providing fish movement opportunities and restricting encroachment of terrestrial vegetation. Given the unregulated nature of the reach there are no specific fresh and high flow recommendation. However, it is important to avoid any increase in the frequency and duration of flows that cause disturbance, for example as a result of urban development.

For Reach 1 we have identified metrics that represent potential disturbance flow with the recommendation being to maintain the current disturbance regime and avoid any increase in the frequency of disturbance flows. These include:

- No increase in the percentage of time (or number of days) that flow is greater than the mean daily flow of 50 ML/day (currently 22% of days experience flow that is greater than the mean daily flow)
- No increase in the frequency of the bed disturbance flow of 1160 ML/day, which currently occurs once every 1.5 year
- No increase in the frequency of the bank disturbance flow of 1440 ML/day, which currently occurs once every 2 years, mostly in a wet winter and spring (Figure 4-9). Figure 4-9 shows a spells analysis, with coloured bars representing periods where flows of a designated magnitude occur. The plot is separated into dry, average and wet periods, with years in order from driest to wettest. The plot clearly shows that bank disturbance flows of >1440 ML/day occur far more frequently in wet years than in dry or average years.

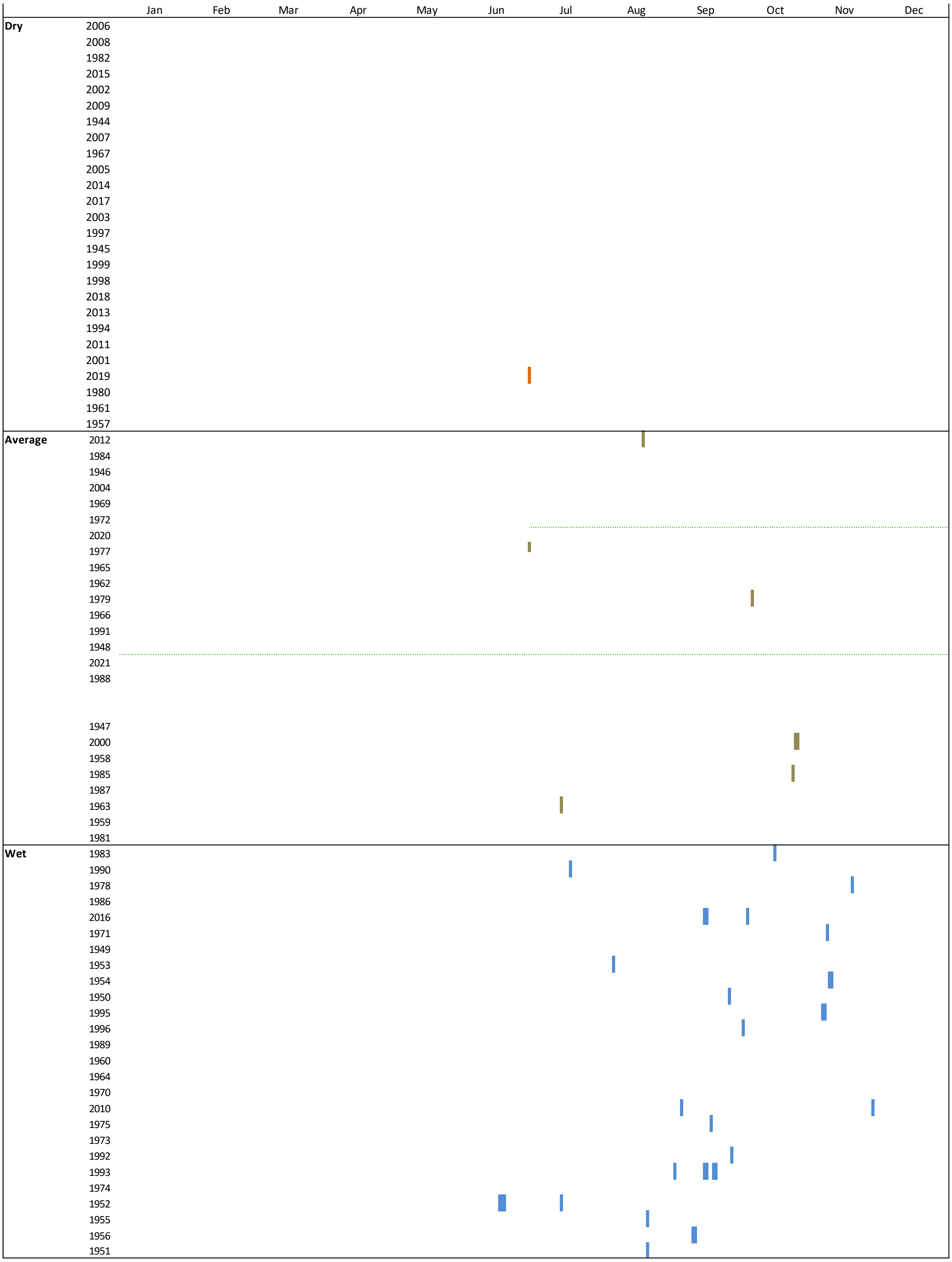



**Figure 4-9 Spells Analysis for bank disturbance event >1440 ML/day in winter using gauge data (231225)**

The final flow recommendations for the reach are summarised in Table 4-7. For each flow recommendation, the ecological objectives it is intended to achieve are listed, using codes for the specific ecological objectives listed in Section 4.3. A code has been allocated to each specific objective for geomorphology, vegetation, macroinvertebrates and water quality, fish, and platypus as listed in Tables 4-2 to 4-6; these objective codes are cross referenced with each flow recommendation component in the table below.

**Table 4-7 Flow recommendations for Reach 1**

| Flow | Objective/Function | Magnitude | Frequency | Duration | Ecological objectives |
|---|---|---|---|---|---|
| Cease-to-flow / low flow | Avoid an increase in the percentage of time that cease-to-flow conditions are experienced (maintain existing cease to flow and low flows patterns) | <0.1 ML/day | <25% of time | <40 days mean duration | **(G1.2.1, V1.1.1, V1.2.1, M1.1.1, M1.2.1, F1.1.1, F1.1.2, P1.1.1)** |
| Disturbance flows | Avoid increase in number of days with flow greater than mean daily flow (maintain existing low flow patterns) | >50 ML/day | <22% of time | - | **(G1.1.2, V1.3.1, V1.4.1, P1.1.2 , P1.1.3)** |
| | Avoid an increase in the frequency and duration of flow exceeds bed disturbance threshold (maintain existing fresh and high flow patterns) | 1160 ML/day | <1.5 times per year | 1-2 days | **(G1.1.3**, **G1.2.2**, **G1.2.3**, **V1.1.2, V1.2.2, V1.3.2 , M1.1.2, M1.1.3**, , **M1.2.2, M1.2.3, F1.1.3, F1.1.4, F1.1.5, F1.1.6, P1.1.3** |
| | Avoid an increase in the frequency and duration of flow exceeds bank disturbance threshold (maintain existing fresh/bankfull and high flow patterns) | 1440 ML/day | <1 every 2 years | 1 day | **(G1.1.1, G1.3.1, F1.1.7)** |

A summary of the objectives for each flow component is provided below, noting that many of the ecological objectives are set for the standard flow components (low flows, freshes etc) rather than the cease-to-flow and disturbance flow metrics developed for Reach 1 in this study. Although the objectives have identified flow components that are important, the key outcome for this reach is to maintain near current flows and avoid increasing disturbance flows. The objectives and flow components overlap to a large degree and are summarised below:

**Cease to flows / low flows:**

The inclusion of the cease-to-flow metric is about protecting ecological values from changes that would result in lower flows and an increase in cease-to-flow conditions. The ecological objectives that are relevant to this component are therefore generally the low flow objectives, as they relate to the ecological benefits of maintaining low flows and thereby avoiding an increase in cease-to-flow conditions. These relate to maintaining minimum flows which protect flow-dependent values. Each flow recommendation objective in Table 4-7 is cross referenced with the specific, numbered ecological objectives detailed in Section 4. They include specific objectives from each of geomorphology, vegetation, water quality and macroinvertebrates, fish and platypus categories – in summary;

- Scour and maintain undercuts, exposed roots and large wood habitat **(Geomorphology)**
- Maintain existing plant communities by providing pool habitat over winter-spring period; maintain existing plant communities of reeds, rushes and sedges by providing damp conditions along stream side over winter-spring period; prevent colonisation of inundation-intolerant plant taxa; maintain existing remnant plant communities of bottlebrushes and paperbarks by providing damp conditions over winter-spring period; facilitate future revegetation efforts of similar vascular plant species **(Vegetation)**
- Maintain access to and quality of riffle and pool habitats for macroinvertebrates; maintain extent and diversity of riffle and pool habitats, and avoid drying of critical habitats (i.e. shallow riffles and refuge

pools); maintain connections between habitat areas; maintain wetted width of channel and connection with littoral vegetation; maintain low flows to prevent an increase in cease-to-flow periods outside of natural range; provide flows to prevent prolonged low flow periods that can result in decreased dissolved oxygen and increased salinity **(Macroinvertebrates and water quality)**

- Limit decline of platypus population by achieving minimum low flows; maintain refuge pools; maintain habitat and longitudinal connectivity for platypuses, and support food resources **(Platypus)**
- Maintain native indigenous fish community; prevent loss of refuge pool habitat; maintain refuge pool habitat; maintain diversity of hydraulic habitats and maintain connectivity (adequate depth) for local fish movement

**Duration of disturbance events:**

The objectives for the duration of disturbance events relate most closely to the ecological objectives for the fresh and high flow components, as flows are of a similar magnitude and serve a similar ecological purpose.

In summary, these are:

- Maintain channel dimensions, form and complexity (**Geomorphology**)
- Downstream dispersal of plant propagules; promote vertical zonation of non-woody vegetation; facilitate future revegetation efforts by watering juveniles during dry summer-autumn period (**Vegetation**)
- Flush fine sediment from riffles to expose new surfaces, prevent infilling of interstitial spaces or smothering, and provide quality habitat; maintain inputs of organic matter from upstream reaches and the catchment; flush accumulated organic matter and fine sediments (**Macroinvertebrates and water quality**)
- Top-up/freshen water quality in refuge pools; flush accumulated sediments to maintain or improve quality and availability of habitat; maintain connectivity (adequate depth) for local movement and recolonisation following periods of cease-to-flow; maintain cues for downstream migration by adult Short-finned Eels (**Fish**)
- Limit flow variability and peaks above scouring threshold that will displace macroinvertebrates (**Platypus**)

**Channel disturbance:**

Channel disturbance flow objectives overlap with ecological objectives of freshes, high flows and bankfull/overbank flows, representing higher magnitude of flows.

- Maintain channel dimensions, form and complexity; engage higher channel surfaces and low-level floodplains (**Geomorphology**)
- Scour sediment from pools; mobilise and transport particulate matter to downstream reaches (**Macroinvertebrates and water quality**)
- Prevent channel degradation and water quality decline **(Fish)**

## 4.5 Flow delivery constraints

The overarching objective for flows in Reach 1 is to: s*upport existing geomorphology, vegetation, and aquatic biota in the reach by managing threats from urban stormwater runoff and extractions to maintain a relatively natural flow regime.*

The key constraint to achieving flow objectives in Reach 1 is the inability of Melbourne Water to directly address the key threats to the natural flow regime, namely climate change and urban development. The reach is expected to be impacted by lower flows forecast under climate change, resulting in increases in the frequency and duration of cease-to-flow periods. At the same time, urban development is likely to result in increased stormwater runoff to the system, and an increase in high velocity flows that can cause disturbance in the river. Melbourne Water has some opportunity to influence urban development planning and regulation, including responsibility for drainage and flood planning. The flow recommendations for this reach - which centre around essentially maintaining the current, relatively natural flow regime – should be considered as a key concern in the planning and drainage development process.

The upper reaches of the system are not regulated, so there is no mechanism by which water can be stored and released for environmental flows. This represents an additional constraint on Melbourne Water's ability to regulate, manipulate and deliver flows to offset threats or impacts to the natural flow regime. However, an opportunity exists for Melbourne Water to support delivery of the natural flow regime by investigating and remedying current losses and extractions from the system. The reach is thought to be losing significant flows through leaks into the sewerage infrastructure system. Additional research into farm dams, other extractions and other sources of potential loss could help Melbourne Water to manage and mitigate the risks associated with reduced natural flows and increased cease-to-flows.

# 5. Reach Two

## 5.1 Reach Description

**Reach Two – Pykes Creek (Korjamnunnip Creek) from Pykes Creek Reservoir to the confluence with the Werribee River (Wirribi Yaluk).**

Reach 2 is a short reach, which begins at the base of Pykes Creek Reservoir and extends for around three kilometres to the confluence with the Werribee River (Wirribi Yaluk) main channel. It is used as a conduit for irrigation releases from Pykes Creek Reservoir, resulting in a significantly altered flow regime. This includes a reduction in variability and a reversal of natural seasonal flow patterns, which would have been characterised by low flows in summer and autumn prior to the construction of the reservoir. The reach currently experiences much higher than natural flows in summer and autumn due to increased irrigation demand and supply.

There are no current recommendations for this reach, and there is limited ability to influence flows except through management of releases from the reservoir. Melbourne Water is currently exploring opportunities to provide additional environmental flow releases from the reservoir, based on the potential for additional environmental water to be made available as a result of other network savings.

Access to the reach is difficult, though two study team members were able to complete a site visit to the reach immediately below the reservoir (Figure 5-1). The reach was accessed with the assistance of SRW staff who provided access to their land. In addition, drone footage of the reach was collected as part of this project. A review of site photos, drone footage, aerial imagery and other data sources provided sufficient information for the EFTP to develop ecological objectives.

Ecological objectives are based around the ability to implement a more seasonally variable regime with benefits targeted at delivering environmental water to Reaches 4 and 5 in the Werribee River (Wirribi Yaluk).

**Figure 5-1 Reach 2, immediately downstream of Pykes Creek Reservoir**

## 5.2 Hydrology

Reach 2 comprises Pykes Creek (Korjamnunnip Creek) downstream of Pykes Creek Reservoir. Like Reach 1, the catchment consists of mostly forested and agricultural land use but with the addition of Pykes Creek Reservoir, which captures and stores runoff from the upstream catchment and also receives diversions from the Werribee River (Wirribi Yaluk) at the Upper Diversion Weir (at the downstream boundary of Reach 1). Observed daily streamflow data for Reach 2 was obtained from the BoM Water Data Online and DELWP Water Monitoring Information System, while modelled data extracted from the Werribee Source model provided by DELWP. Details of the relevant streamflow data is presented in Table 5-1.

**Table 5-1 Reach 2 streamflow data**

| ID | Type | Description | Time Period |
|---|---|---|---|
| 1 | Observed | Observed Historical Scenario<br><br>The timeseries for Reach 2 is the gauge data from gauge 231203C (Pykes Creek @ Pykes Creek Reservoir) with missing data days filtered out. | 16/06/1972 – 16/03/2022 (approximately 48 years of data) |
| 2 | Modelled | Historical Scenario | 01/01/1900 – 31/12/2020 (120 years of data) |
| 3 | Modelled | Natural Scenario (modelled with extractions turned off, water passing through storages, and stormwater, recycled water, Melbourne Supply and farm dam impacts turned off) | |
| 4 | Modelled | 2045 High Projection Climate Change Scenario. | |
| 5 | Modelled | 2070 High Projection Climate Change Scenario. | |

The Werribee River (Wirribi Yaluk) in Reach 2 is a regulated system due to being downstream of Pykes Creek Reservoir, with the hydrograph and mean monthly daily shown in Figure 5-2 and Figure 5-3. Due to the regulation the historical flows (both observed and modelled) show an inverted flow regime, where more water is released in summer autumn months (to supply downstream irrigation) compared to what would be expected under a natural scenario. A shorter period between from 2010 to 2011 was selected in Figure 5-4 to highlight the regulated nature of the Reach 2, where several fresh events are not delivered in the historical scenario versus natural scenario. However, once the reservoir is full and spilling, the natural and historical scenarios are similar as indicated by the last two freshes event.

Assuming a cease-to-flow of <0.5 ML/day, historically Reach 2 has experienced cease-to-flow conditions of approximately 5% and 25% for the historical modelled and observed, respectively. This is shown in the flow duration curve in Figure 5-5. This difference could be attributed to an uncertainty associated with the gauged data or the modelling (e.g. representation of the reservoir operations in the model could be estimated). In terms of the modelled natural versus the modelled historical, it can be seen that the cease-to-flow is much higher for modelled historical given that under the regulated regime water is released for irrigation in summer autumn, overriding the natural pattern of low flows.

Under climate change, the mean monthly daily flow is modelled to reduce by 50-75% in winter spring months, however in summer months, flow is modelled to remain similar to current or may even increase to maintain water for downstream users in drier condition (see Figure 5-5). Despite summer flows remaining similar to current, there is still the potential for an increase in the percentage of time that cease-to-flow occur – this would typically occur during periods outside of the irrigation season or during the irrigation season but when demands are low and hence flow release not required. A similar trend is found in Figure 5-6, when comparing the scenarios over only over the observed time period (16/06/1972 – 16/03/2022). It should be noted that there is a reduction of cease-to-flow for the modelled historical and climate change scenarios by approximately 4% when examining modelled time period versus the observed time period. This can be attributed to the fact that in recent years the Werribee River (Wirribi Yaluk) has experienced drier conditions (i.e. Millennium Drought). In addition to this, the potential changes in future flows and cease-to-flows were based on the modelled scenarios that assume current operating conditions. These may be less if there are changes in water availability within the system via alternative water supply, changes in the operating conditions or demands.

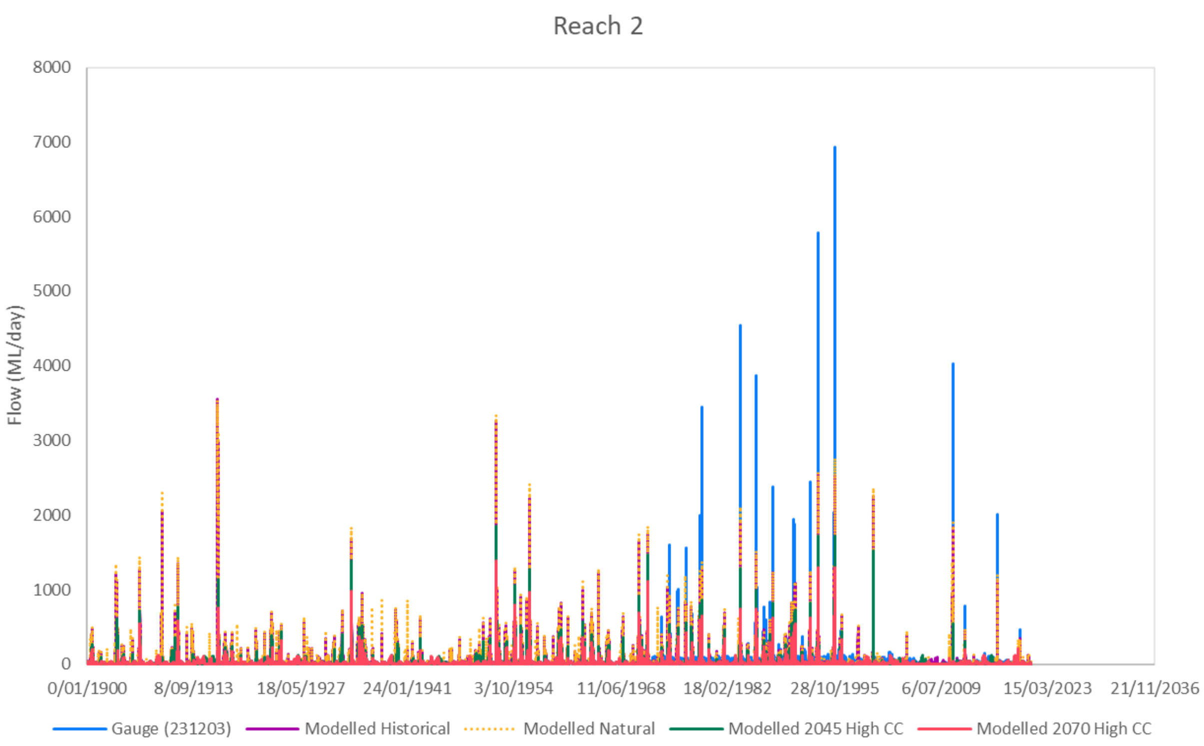



**Figure 5-2 Historical, natural and climate change daily flows for Reach 2**

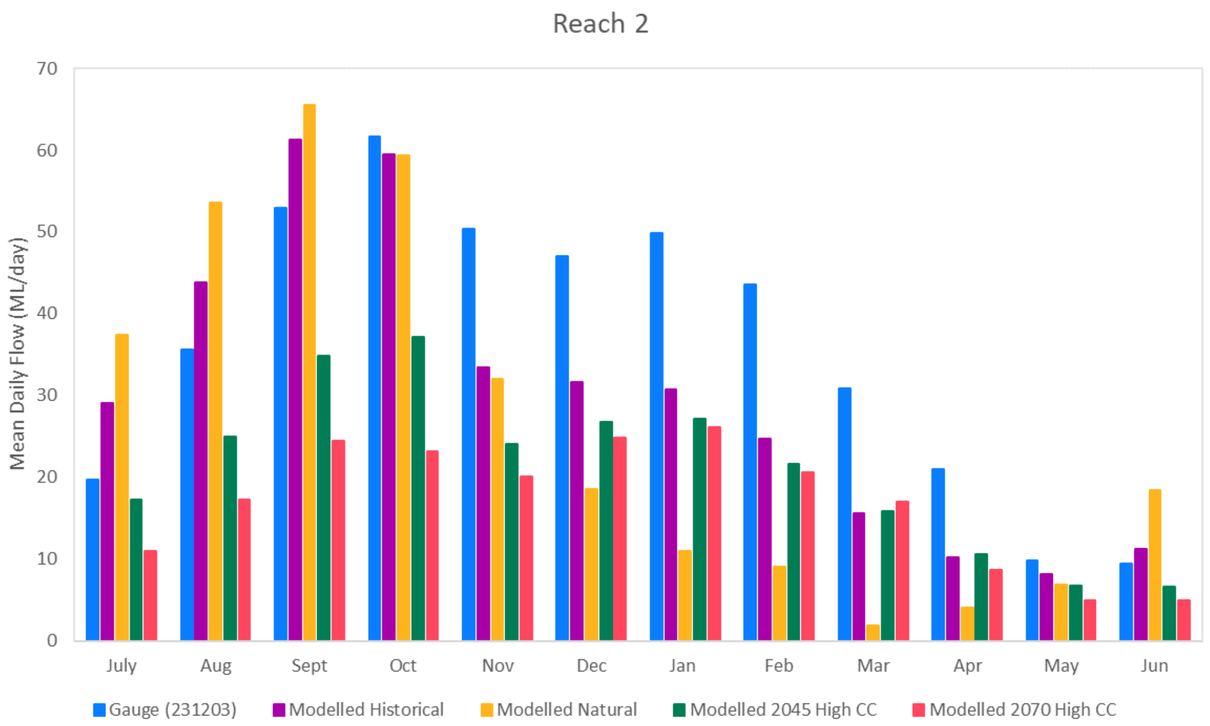



**Figure 5-3 Historical, natural and climate change mean monthly daily flows for Reach 2 considering the observed period only (16/06/1972 – 16/03/2022)**

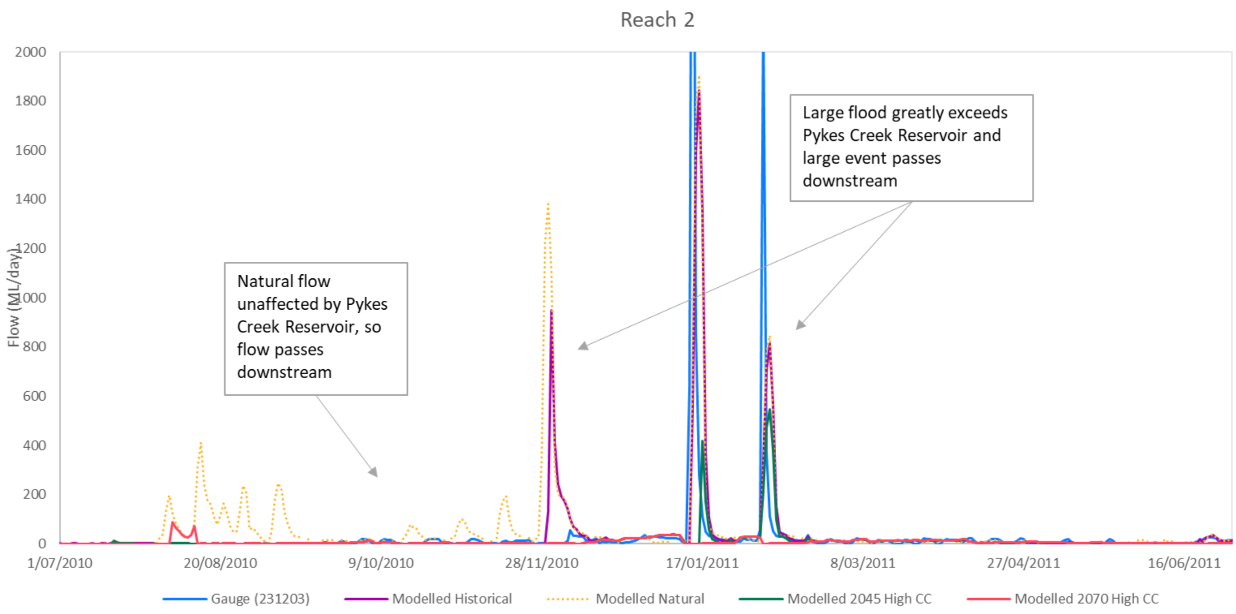



**Figure 5-4 Historical, natural and climate change daily flows between 2010 and 2011 for Reach 2**

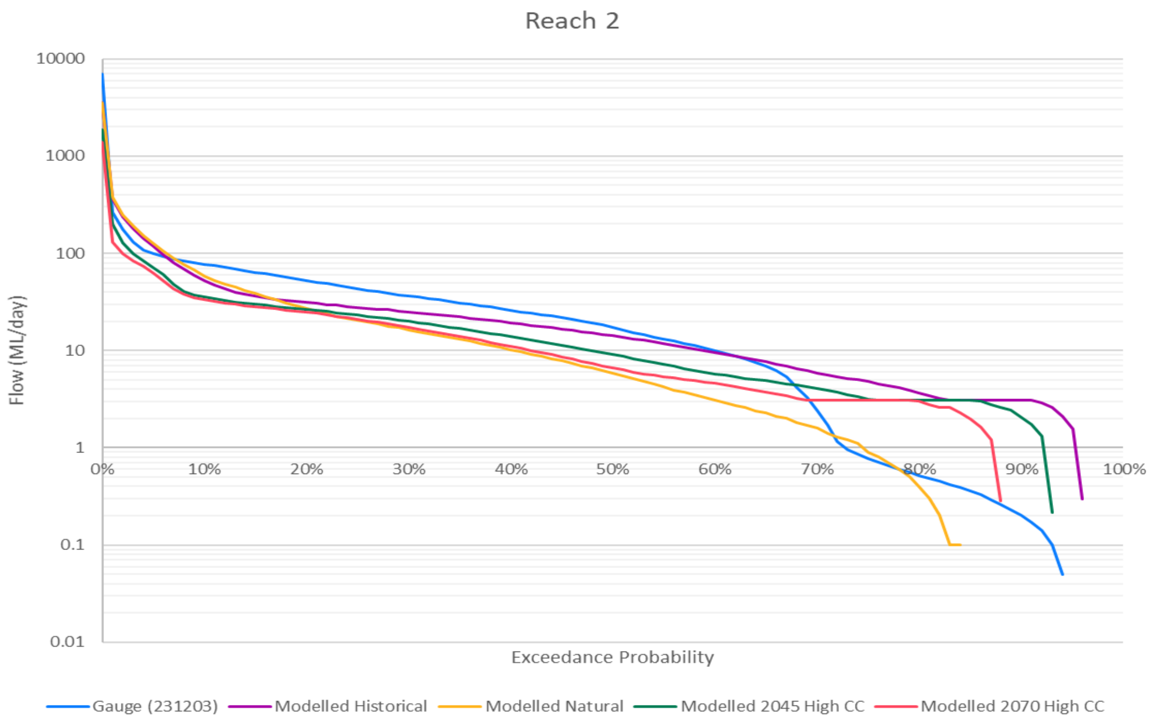



**Figure 5-5 Historical, natural and climate change daily flow duration curve for Reach 2 considering the modelled time period (01/01/1900 – 31/12/2020)**

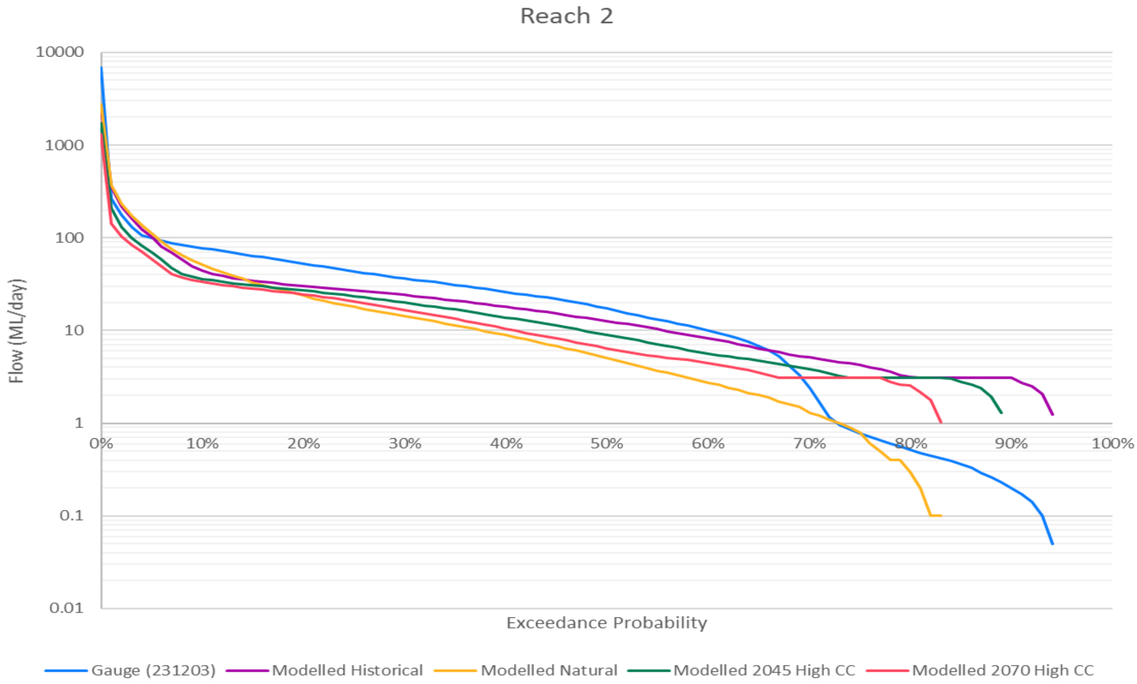



**Figure 5-6 Historical, natural and climate change daily flow duration curve for Reach 2 considering the observed period only (16/06/1972 – 16/03/2022)**

## 5.3 Ecological objectives for Reach 2

### 5.3.1 Geomorphology

This reach was not inspected in the field by the full EFTP, so this description has been developed with reference to Ecological Associates (2005a), notes and photos from the initial site visit by other team members, and a review of aerial and drone imagery. The creek downstream of Pykes Creek Reservoir is a meandering channel with some straight sections, the channel meandering its course within a confined valley. Floodplain development appears to be limited along the river, with pockets in sections where the valley widens. The physical form of the channel appears to comprise shallow pools and runs. Ecological Associates (2005a) describe the morphology of the channel in this section as having riffles, pools and fast flowing runs. Based on the review of aerial imagery during this study, riffles were not evident; the riffles observed by EA (2005) may have been due to lower flows in the channel at that time.

The objectives for geomorphology for Reach 2 are to: *Maintain channel dimensions, form and complexity; and maintain access to and quality of riffle and pool habitats*

The flow components and functions required to achieve these objectives are summarised in Table 5-2.

This reach is highly regulated, long duration flows and rapid water level changes associated with operational releases pose the greatest risk. The risks to objectives and flow are that regulated flow releases don't provide variability in flow components to maintain channel form and complexity.

**Table 5-2 Reach 2 Geomorphology objectives**

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Maintain channel dimensions, form and complexity (G2.1) | Bankfull flow | Maintain gross channel dimensions and form channel features (i.e. pools, bars/riffles). (G2.1.1) | Winter-Spring |
| | Low flows - Freshes | Scour and maintain undercuts, exposed roots and large wood habitat. (G2.1.2) | All year |

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Maintain access to and quality of riffle and pool habitats (G2.2) | Low flows | Maintain extent of riffle and pool habitats (G2.2.1) | All year |
| | Freshes | Scour fine sediment and biofilms from riffles[1] (G2.2.2) | All year |
| | High flow | Scour sediment from pools (G2.2.3) | Winter-Spring |

[1] Bed shear stress during fresh capable of moving silt from cobbles ($\tau_c$ > 15 N/m$^2$) and sand ($\tau_c$ > 8 N/m$^2$). Source: Appendix B of Ecological Associates (2005b)

### 5.3.2 Vegetation

This reach was not examined during the field inspections (because of poor accessibility), so the description of water-dependent vegetation is based on the EVC mapping available on the NatureKit webpage (see relevant sections in previous Site paper) and on the aerial drone imagery made available by MW in late June 2022.

The EVC mapping shows the dominant EVC in Reach 2 is EVC 851 Stream Bank Shrubland. This vegetation type has a sparse (10% projective cover) canopy layer of *Eucalyptus globulus* ssp. *pseudoglobulus* (Gippsland Blue-gum) over a shrub layer provided by a range of woody plants such as Cassinia (*Cassinia aculeata*) etc. Water-dependent taxa growing along the fringes may include Green Rush (*Juncus gregiflorus*), River Sedge (*Carex polyantha*), Tall Sedge and Swamp Club-sedge.

Imagery generated by drone flight over Reach 2 indicated the presence of beds of emergent non-woody macrophytes, tentatively identified as either Common Reed (*Phragmites australis*) or Cumbungi (*Typha* spp.) on the basis of their winter senescence. Large areas of in-stream submerged vegetation (e.g. Eelgrass, *Vallisneria australis*) were not evident in the imagery but patches of desiccation-tolerant taxa such as Water Ribbons may be present.

The co-designed catchment program for the Werribee catchment region (Melbourne Water 2018) does not include specific actions to establish or maintain vegetation buffers along the stream channel for Reach 2 (see Melbourne Water 2018, Figure 8). Moreover, as noted in Section 5.3.4 on fish objectives, Reach 2 is highly regulated, with the risk of extended cease-to-flow periods alternating with rapid increases in water levels prompted by operational factors, exacerbated by the lack of an environmental entitlement from Pykes Creek Reservoir.

Bearing in mind these limitations, the objective for water-dependent vegetation for Reach 2 is restricted to: *Maintain existing in-stream and fringing non-woody vegetation and prevent the encroachment of terrestrial, inundation-intolerant species into the stream channel.*

The flow components and functions required to achieve this objective are summarised in Table 5-3.

**Table 5-3 Reach 2 vegetation objectives**

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Maintain in-stream vegetation (V2.1) | Low flow | Maintain existing plant communities by providing pool habitat over winter-spring period (note that taxa such as Water Ribbons are well adapted to periodic cease-to-flow periods) (V2.1.1) | Winter-spring |
| Maintain fringing non-woody vegetation(V2.2) | Low flow | Maintain existing plant communities of reeds, rushes and sedges etc in EVC 851 by providing damp conditions along stream side over winter- | Winter-spring |

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| | | spring period (note that many species of reed, rush and sedge are well adapted to periodic cease-to-flow periods) (V2.2.1) | |
| Prevent encroachment of the stream channel by undesirable terrestrial species (V2.3) | Low flow | Prolonged inundation of stream channel will prevent colonisation of inundation-intolerant plant taxa, including pasture species and garden escapees (V2.3.1) | Winter-spring |

### 5.3.3 Macroinvertebrates and Water Quality

Reach 2 is a short reach which is characterised by highly regulated flow releases from Pykes Creek Reservoir, resulting in a reversal of natural seasonal flow patterns, lower base flows (particularly during winter and spring), and rapidly increasing flows during releases. Large flow releases at higher velocities which are outside of the natural range experienced have the potential to displace macroinvertebrates.

Water quality in the reach is predominantly controlled by water quality in the reservoir, with minimal catchment inflows or impacts relative to the flows from the reservoir releases. Flow related impacts on water quality in this reach could include temperature changes, based on high volume releases of typically colder water from the reservoir.

Access to Reach 2 is difficult and little is known about its macroinvertebrate communities but based on available data (including a site visit and aerial footage) there are some areas of suitable macroinvertebrate habitat throughout the reach. Macroinvertebrate communities in the reach are likely to have been impacted by the operation of the reservoir over a long period, possibly resulting in the loss of more sensitive taxa.

The overall objective for macroinvertebrates in Reach 2 is to: *maintain the abundance and diversity of macroinvertebrate communities throughout Reach 2 by minimising damaging flow patterns associated with reservoir releases and provision of additional environmental flows to Reaches 4 and 5.*

The flow components and functions required to achieve these objectives are summarised in Table 5-4.

**Table 5-4 Reach 2 Macroinvertebrate and water quality objectives**

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Maintain access to and quality of habitats (M2.1) | Low flows | Provide sufficient passing flows to maintain extent and diversity of habitats, connections between habitat areas, and connection with littoral vegetation (M2.1.1) | All year |
| | Freshes | Flush fine sediment from riffles to expose new surfaces, prevent infilling of interstitial spaces and provide quality habitat (M2.1.2) | All year |
| | High flows | Provide high flows to connect additional habitat areas and restore more natural wetting and drying patterns (M2.1.3) | All year |
| Maintain water quality and important hydrological functions of current flow regime (M2.2) | Low flows | Maintain more natural base flows in winter and spring through management of reservoir operations<br><br>Manage water quality in reservoir to prevent water quality impacts in passing flows (M2.2.1) | All year |

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| | High Flows | Manage flow releases from the reservoir to avoid rapid increase rate that could displace macroinvertebrates (M2.2.2) | Predominantly summer/autumn – when releases are made |

### 5.3.4 Fish

Reach 2 is characterised by highly regulated flow releases from Pykes Creek Reservoir. Habitat includes pools and runs, with abundant emergent vegetation (e.g. Common Reed and Cumbungi) covering large lengths of the channel (Figure 5-7a). Flows are low in late autumn and early winter while the reservoir is filling. Higher flows can occur in early spring if the reservoir fills and spills, and high but variable flows occur in summer when water is released for downstream irrigation use. Irrigation operations can result in rapid changes in the flow and water level associated with short duration flow releases in the range 50-70 ML/day followed by periods of no/low flow. The current flow pattern, especially the frequent low and cease-to-flows and rapid changes in water level, is likely to negatively affect the suitability of the reach for supporting a diverse and abundant native fish community. There are no fish survey records for the reach, however, it is likely to include the hardy species recorded in Reaches 1 and 2, such as Short-finned Eel and Common Galaxias (Jacobs 2022). Anecdotal observations indicate River Blackfish are present in the pools at the upper end of Reach 4, so it is possible that River Blackfish, and other species recorded in Reach 4, may also be present in pools in Reach 2 if suitable habitat is present (e.g. Figure 5-7b). Exotic species such as Red Fin Perch, Mosquito Fish and Common Carp are also likely to be present.

**Figure 5-7 Habitat in Reach 2 showing a) a section of channel containing emergent vegetation b) potential pool habitat for native fish (drone footage supplied by Melbourne Water – June 2022)**

The primary management objective for Reach 2 is to maximise opportunities for the delivery of environmental water to downstream reaches where higher water dependent values exist (e.g. Reach 4). The specific Reach 2 objective for native fish is to: *Maintain or enhance conditions for the opportunistic colonisation of the reach by native fish by avoiding long duration cease-to-flow periods and rapid rise and fall of water level during operational flow releases.*

The flow components and functions required to achieve this objective are summarised in Table 5-5.

This reach is highly regulated and greatest risks are from long duration cease-to-flows and rapid water level changes associated with operational releases. Risks to objectives and flow are:

- Lack of environmental entitlement in Pykes Creek Reservoir and an inability to alter existing release rules to achieve a more suitable flow regime for supporting environmental values

**Table 5-5 Reach 2 fish objectives**

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Maintain an opportunistic native indigenous fish community (e.g. Short-finned Eel, Common Galaxias) (F2.1) | Avoid prolonged cease-to-flow | Prevent loss of refuge pool habitat (F2.1.1) | Any time |
| | Avoid rapid water level rise and fall | Prevent stranding of aquatic biota and maintain quality of riffle habitat (F2.1.2) | Any time |
| | Winter Low flow | Maintain diversity of hydraulic habitats (i.e. pool, riffle, run)<br><br>Maintain connectivity (adequate depth) for local movement (F2.1.3) | Winter (ideally continuous and typically higher than summer) |
| | Freshes-high flows (where required to support downstream reach values) | Flush accumulated sediments to maintain or improve quality and availability of habitat<br><br>Maintain connectivity (adequate depth) for local movement and recolonisation following periods of cease-to-flow (F2.1.4) | Any time |

### 5.3.5 Platypus

Reach 2 is primarily a conduit for water releases from Pykes Creek Reservoir and as such, has highly modified flows. There is no data on platypus occurrence in this reach, but it might receive occasional transient visits of individuals who are likely to move into the reach from the adjacent Werribee River (Wirribi Yaluk) reach when flows are suitable. Overall, however, the habitat appears to be marginal for platypus, and combined with the short length of the reach and the flow impacts, the reach is of minimal value in supporting local populations. No flow recommendations for platypus are required for Reach 2.

## 5.4 Flow recommendations

Reach 2 has no current flow recommendations, and the ability to deliver a more natural flow regime to the reach is limited by the operation of Pyke Creek Reservoir. The flow recommendations for this reach have been developed in this study to achieve the ecological objectives for the reach (Section 5.3), to provide benefits to delivery of Reach 4 flows, and to avoid flows that could be damaging to Reach 2.

In the absence of a hydraulic model for Reach 2 (for the reasons described in Section 3) the specific flow recommendations are based on hydrological metrics that are measures of ecologically/geomorphologically significant flows (Table 5-6).

**Cease-to-flow / low flow**

Reach 2 currently experiences cease-to-flow around 25% of the time and for a mean duration of 30 days per cease-to-flow event. The recommendation is to avoid any increase in the percentage of time that cease-to-flows occur and to avoid an increase in the mean duration of cease-to-flow when they do occur.

Maintaining low flows is also important for a range of objectives particularly with respect maintain access to habitat. There is no specific low flow recommendation – suitable low flows will be maintained provided the frequency and duration of cease-to-flows does not increase.

Risks to cease-to-flows and low flows relate to the operation of Pyke Creek Reservoir. Any changes to operations, for example through reduced demand for irrigation supply, may result in increased cease-to-flow. The consequences of this for downstream reaches should be considered if the change in operation results in substantial increase in the duration of cease-to-flow, particularly for Reach 4.

**Disturbance flows**

Freshes and high flows have been identified as important for a range of objectives, including maintaining channel form, scouring sediments, providing fish movement opportunities and restricting encroachment of terrestrial vegetation. However, it is important to avoid any increase in the frequency and duration of flows that cause disturbance, for example as a result of changed reservoir operation.

For Reach 2 we have identified metrics that represent potential disturbance flow with the recommendation being to maintain the current disturbance regime and avoid any increase in the frequency of disturbance flows. These include:

- No increase in the percentage of time (or number of days) that flow is greater than the mean daily flow of 40 ML/day (currently 22% of days experience flow that is greater than the mean daily flow)
- No increase in the frequency of the bed disturbance flow of 280 ML/day, which currently occurs once every 1.5 year
- No increase in the frequency of the bank disturbance flow of 440 ML/day, which currently occurs once every 2 years, mostly in a wet winter and spring.

**Operation of Pykes Creek Reservoir**

Releases from Pykes Creek Reservoir can be used to assist with the delivery of environmental water to downstream reaches (namely Reach 4). Depending on water availability, summer freshes for Reach 4 could be released from the Reservoir. Larger freshes for Reach 4 could be supplied by a combination of flows from Reach 3 and piggybacking with releases from the reservoir.

Moreover, there may be opportunities to coordinate releases for irrigation purposes to match flow requirements for Reach 3 and also for Reach 4. This could include minimising the rapid ceasing of releases at the conclusion of an irrigation delivery, which currently may contribute to the rapid onset of a cease-to-flow event.

The final flow recommendations for the reach are summarised in Table 5-6. For each flow recommendation, the ecological objectives it is intended to achieve are listed, using codes for the specific ecological objectives listed in Section 5.3. A code has been allocated to each specific objective for geomorphology, vegetation, macroinvertebrates and water quality and fish as listed in Tables 5-2 to 5-5; these objective codes are cross referenced with each flow recommendation component in the table below.

**Table 5-6 Flow recommendations for Reach 2**

| Flow | Objective/Function | Magnitude | Frequency | Duration | Ecological objectives |
|---|---|---|---|---|---|
| Cease-to-flow / low flow | Avoid an increase in the percentage of time that cease-to-flow conditions are experienced (maintain existing cease to flow and low flow patterns) | <0.5 ML/day | <25% of time | <30 days mean duration | **(G2.1.2, V2.1.1, V2.2.1, V2.3.1, M2.1.1, M2.2.1, F2.1.1, F2.1.3)** |
| Disturbance events | Avoid increase in number of days with flow greater than mean daily flow (maintain existing low flow patterns) | >40 ML/day | <30% of time | - | **(G2.2.1, M2.2.1)** |
| | Avoid an increase in the percentage of time that flow exceeds bed disturbance threshold (maintain existing fresh and high flow patterns) | 280 ML/day | <1.5 times per year | 1-2 days | **(G2.2.2, G2.2.3, M2.1.2, M2.1.3, F2.1.3, F2.2.4)** |
| | Avoid an increase in the percentage of time that flow exceeds bank disturbance threshold (maintain existing fresh/bankfull and high flow patterns) | 440 ML/day | <1 every 2 years | 1 day | **(G2.1.1, M2.1.3)** |

| Flow | Objective/Function | Magnitude | Frequency | Duration | Ecological objectives |
|---|---|---|---|---|---|
| Reservoir operations | Coordinate reservoir releases to contribute to downstream flow requirements<br>Piggyback on upstream flows to generate larger freshes in Reach 4<br>Avoid rapid onset of cease-to-flows conditions during reservoir operations | See Reach 4 recommendations | | | **(F2.1.2, M2.2.2)** |

As for Reach 1, each flow recommendation in the summary table for Reach 2 (Table 5-6) is cross referenced to the specific ecological objectives it is intended to achieve, using codes for the specific ecological objectives listed in Section 5.3. A code has been allocated to each specific objective for geomorphology, vegetation, macroinvertebrates and water quality, fish, and platypus as listed in Tables 5-2 to 5-5.

As with Reach 1, the components of the flow recommendations for Reach 2 (cease-to-flows) overlap with the objectives set for components such as low flows, fresh flows and so on in Section 5.3.1-5.3.5.

These are summarised below for each component:

In summary:

**Cease to flows / low flows:**

- Scour and maintain undercuts, exposed roots and large wood habitat; maintain extent of riffle and pool habitats (**Geomorphology**)
- Maintain existing plant communities by providing pool habitat over winter-spring period (note that taxa such as Water Ribbons are well adapted to periodic cease-to-flow periods); maintain existing plant communities of reeds, rushes and sedges etc in EVC 851 by providing damp conditions along stream side over winter- spring period (note that many species of reed, rush and sedge are well adapted to periodic cease-to-flow periods); prolonged inundation of stream channel will prevent colonisation of inundation-intolerant plant taxa, including pasture species and garden escapees (**Vegetation**)
- Provide sufficient passing flows to maintain extent and diversity of habitats, connections between habitat areas, and connection with littoral vegetation; maintain more natural base flows in winter and spring through management of reservoir operations; manage water quality in reservoir to prevent water quality impacts in passing flows (**Macroinvertebrates and water quality**)
- Prevent loss of refuge pool habitat; Maintain diversity of hydraulic habitats (i.e. pool, riffle, run); maintain connectivity (adequate depth) for local movement (**Fish**)

**Duration of disturbance events**

- Scour fine sediment and biofilms from riffles (**Geomorphology**)
- Flush fine sediment from riffles to expose new surfaces, prevent infilling of interstitial spaces and provide quality habitat (**Macroinvertebrates and Water Quality**)

**Channel disturbance**

- Maintain extent of riffle and pool habitats; scour sediment from pools (**Geomorphology**)
- Provide high flows to connect additional habitat areas and restore more natural wetting and drying patterns; manage flow releases from the reservoir to avoid rapid increase rate that could displace macroinvertebrates (**Macroinvertebrates and water quality**)
- Flush accumulated sediments to maintain or improve quality and availability of habitat; maintain connectivity (adequate depth) for local movement and recolonisation following periods of cease-to-flow (**Fish**)

**Reservoir operations**

- Flush accumulated sediments to maintain or improve quality and availability of habitat; maintain connectivity (adequate depth) for local movement and recolonisation following periods of cease-to-flow; prevent stranding of aquatic biota and maintain quality of riffle habitat (**Fish**)

## 5.5 Flow delivery constraints

The ecological objective for this reach is to: *support existing ecological values in the reach while targeting delivery of water to benefit values in Reaches 4 and 5 through the appropriate management of flow releases from Pykes Creek Reservoir.*

The major constraint for flow delivery in Reach 2 is the operation of Pykes Creek Reservoir, including capture and storage of natural winter flows, and year-round releases of flows for irrigation. This results in a flow regime which is significantly disrupted from natural, with resultant impacts on ecological values. The recommendations developed for this reach are therefore primarily based on providing benefits to delivery of flows in Reach 4, and avoiding flows that could be damaging to Reach 2.

The obvious constraint around flow delivery in this reach is the operational requirements for Pykes Creek Reservoir. There is a potential opportunity for Melbourne Water to manage the recommendation for avoiding an increase in cease-to-flow conditions through an agreement with Southern Rural Water to provide passing flows in dry periods, to prevent cease-to-flows occurring. This assumes an agreement around environmental allocations could be made and that sufficient water is available in the reservoir. The recommendations for avoiding an increase in frequency and duration of disturbance flows can be managed by providing releases at a level that do not exceed disturbance thresholds, and at times when maximum benefits would occur in Reach 4 – i.e. by 'piggybacking' off natural flow peaks to contribute to achievement of freshes and other high flow recommendations in Reach 4.

# 6. Reach Three

## 6.1 Reach Description

**Reach Three – Werribee River (Wirribi Yaluk) from the Upper Diversion Weir to the confluence with Pykes Creek (Korjamnunnip Creek).**

Reach 3 extends from immediately below the diversion weir to the Pykes Creek (Korjamnunnip Creek) confluence. Flows in this reach are heavily regulated and controlled by the operation of the Upper Diversion Weir. Natural flows below ~5-7 ML/day pass through the diversion weir and into the reach downstream. However, all flows between ~5-7 ML and ~350 ML/day are diverted at the weir and flow into the tunnel which connects the diversion weir to Pykes Creek Reservoir. This results in a significant loss of natural flows into Reach 3, meaning the reach experiences much lower flow volumes and much less flow variability than what would naturally occur. When flows reach over 350 ML/day, the tunnel reaches capacity and flows above that volume pass downstream. The tunnel is also closed when Pykes Creek Reservoir is spilling, which means that natural flows to the reach also occur during those periods. There is limited opportunity to alter flows in this reach, except through management of the weir and tunnel operations. Melbourne Water is exploring the possibility of increased environmental flow volume in this reach due to additional water becoming available through other network savings. This could mean that the volumes diverted through the tunnel at the weir could be reduced, and additional flows allowed to pass through the weir and into Reach 3.

The reach has an existing channel survey site and flow recommendations, which were set in 2005 and have not been revised since then.

The EFTP visited the Upper Diversion Weir and Reach 3 downstream of the weir (Figure 6-1). The EFTP members were able to access a significant length of the reach downstream of the weir, including the original survey site. Based on inspection of the reach during the EFTP site visit, the original assessment site was considered sufficiently representative of the reach, and suitable as a basis for the development of ecological objectives and flow recommendations.

**Figure 6-1 Reach 3, downstream of the Upper Diversion Weir**

## 6.2 Hydrology

Reach 3 is in the upper reaches of the Werribee River (Wirribi Yaluk), downstream of the Upper Diversion Weir to the confluence with Pykes Creek (Korjamnunnip Creek). Observed daily streamflow data to estimate Reach 3 flows was obtained from the BoM Water Data Online and DELWP Water Monitoring Information System, while modelled data was extracted from the Werribee Source model provided by DELWP. Details of the relevant streamflow data and generation is presented in Table 6-1. For more information regarding the streamflow derivation, readers are referred to Jacobs (2022).

**Table 6-1 Reach 3 streamflow data**

| ID | Type | Description | Time Period |
|---|---|---|---|
| 1 | Observed | Observed Historical Scenario<br><br>Reach 3 receives the flow in the Werribee River downstream of Ballan that is not diverted into Pykes Creek Reservoir. This was calculated by subtracting the gauged flows through the Werribee Tunnel (gauge 231703A) from the gauged flows at Ballan (gauge 231225). Due to the lack of available data for the Werribee Tunnel gauge this calculated time series does not extend beyond 2016. | 16/05/1984 – 31/05/2016 (approximately 32 years of data) |
| 2 | Modelled | Historical Scenario | 01/01/1900 – 31/12/2020 (120 years of data) |
| 3 | Modelled | Natural Scenario (modelled with extractions turned off, water passing through storages, and stormwater, recycled water, Melbourne Supply and farm dam impacts turned off) | |
| 4 | Modelled | 2045 High Projection Climate Change Scenario. | |
| 5 | Modelled | 2070 High Projection Climate Change Scenario. | |

Currently, water from the Werribee River (Wirribi Yaluk) is diverted through a tunnel to Pykes Creek Reservoir at the Upper Diversion Weir. A low flow bypass allows for approximately 5 ML/day to flow down the Werribee River (Wirribi Yaluk) into Reach 3, with a maximum offtake capacity at the tunnel approximately 310 ML/day (as recorded in Collaborative NRM & MW, 2015; noting current information from SRW is tunnel capacity is maximum~350 ML/day (pers. comm. Mark Taylor, SRW, 14/7/22). In large flood events, when the offtake is at full capacity, water overtops the weir and flows down the main river channel. Water can also pass directly over the weir if the diversion tunnel is closed. This occurs when Pykes Creek Reservoir is full (i.e. diversions would not occur if the reservoir was otherwise full and spilling, and all flow in the Werribee River (Wirribi Yaluk) would pass down Reach 3). The hydrograph and mean monthly daily flow for the range of scenarios is shown in Figure 6-2 and Figure 6-3. It can be seen that the derived modelled historical is less than modelled natural due to the impact of the weir (see Figure 6-3).

A shorter period between from 2010 to 2011 was selected in Figure 6-4 to highlight the regulated nature of the Reach 3, where several fresh events are not delivered down the main river stem in the historical scenario versus natural scenario. However, once the outlet capacity is full or the reservoir is full and the diversion tunnel closed, the natural and historical scenarios are similar as indicated by the last three freshes. A log scaled graph over the 2010-2011 time period comparing the scenario daily flows with the 5 ML/day low flow bypass and the 310 ML/day max tunnel offtake is shown in Figure 6-5. As can be seen, for the modelled scenarios a minimum flow generally of 5 ML/day is conveyed through Reach 3, however, after March 2011 with natural flows low (less than 30 ML/day), the modelled historical, gauge and climate changed scenarios are also low.

Assuming a cease-to-flow of <0.5 ML/day, historically Reach 3 has experienced cease-to-flow conditions of approximately 30-50% for historical modelled and observed data, respectively. This is shown in the flow duration curve in Figure 6-6. The difference could be attributed to a variety of reasons such as uncertainty associated with the deriving the flows using gauged data as well as modelling (e.g. representation of the operations could have been estimated). In terms of the modelled natural versus the modelled historical, it can be seen that the cease-to-flow is much higher for modelled natural given that flows are extracted at the tunnel under the modelled historical.

Considering 2045 and 2075 high projection climate change scenario, the mean monthly daily flows reduce significantly ranging approximate 40-75% in winter spring months, however in summer month a decrease in flow by 40-80% (see Figure 6-3 ). An increased in mean daily flow reduction is felt in summer flows due to the impact of the weir and off taken. Cease-to-flows are increased further by 10% in 2045 and 20% in 2070, respectively.

A similar trend in the flow duration curve is shown when comparing the scenarios over the observed time period (see Figure 6-7). In general, there is a reduction in cease-to-flows over the observed time series compared to the modelled time series, except for the Modelled 2070 High CC scenario. This is likely due to the fact that there has been significant reduction of water in this climate change scenario that cannot meet consumptive users downstream compared with the other modelled scenarios, where more water is available.

The impact on high peak flows for each of the scenarios can be seen in Figure 6-8, where there is a reduction in peak flows under the climate change scenarios. For the modelled natural and modelled historical scenarios. similar peak flows are observed since at these times the Pykes reservoir would be full.

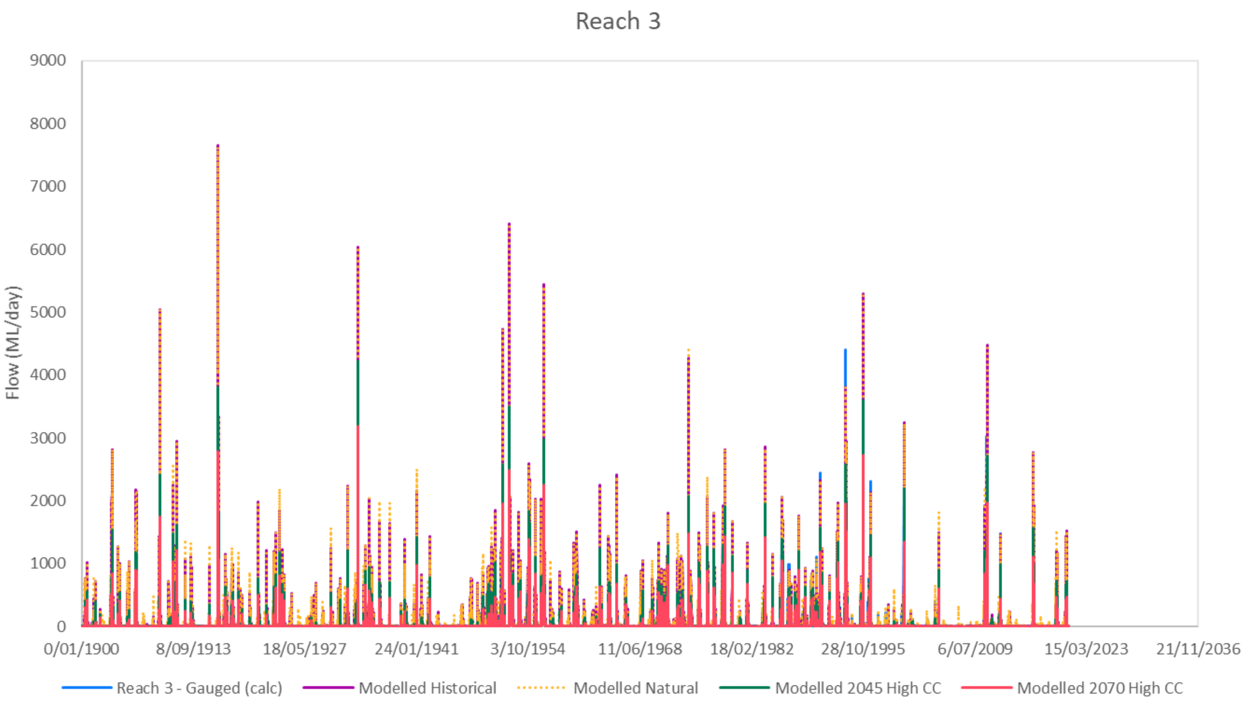



**Figure 6-2 Historical, natural and climate change daily flows for Reach 3**

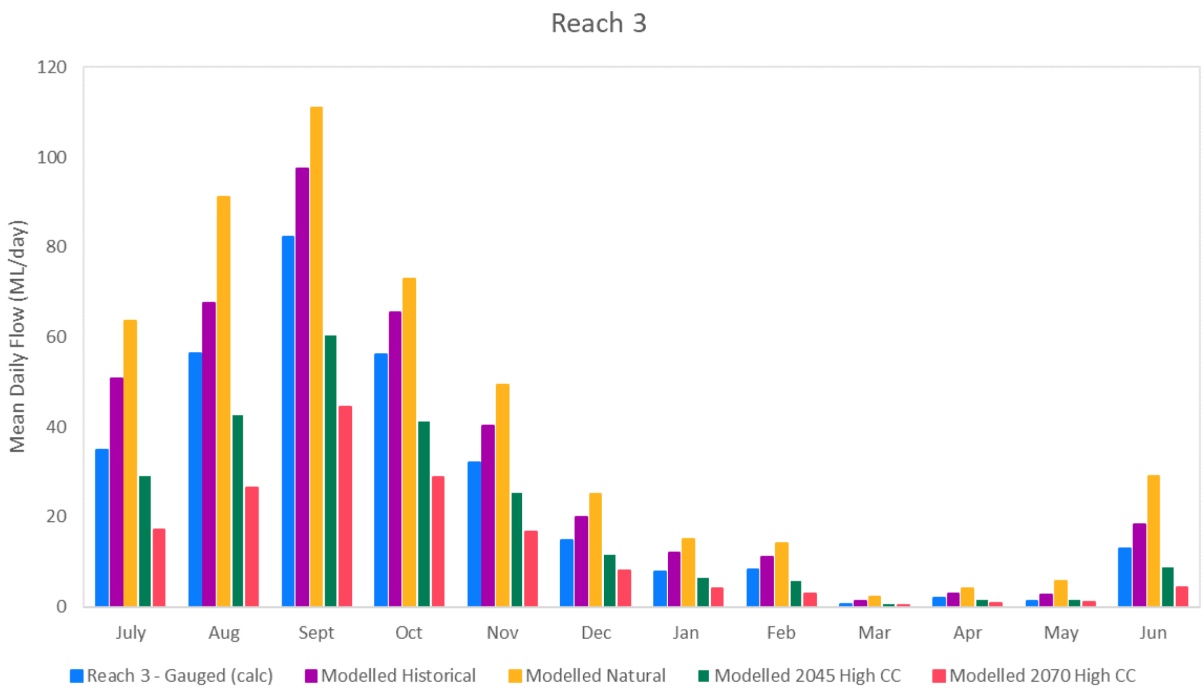



**Figure 6-3 Historical, natural and climate change mean monthly daily flows for Reach 3 considering the observed period only (16/05/1984 – 31/05/2016)**

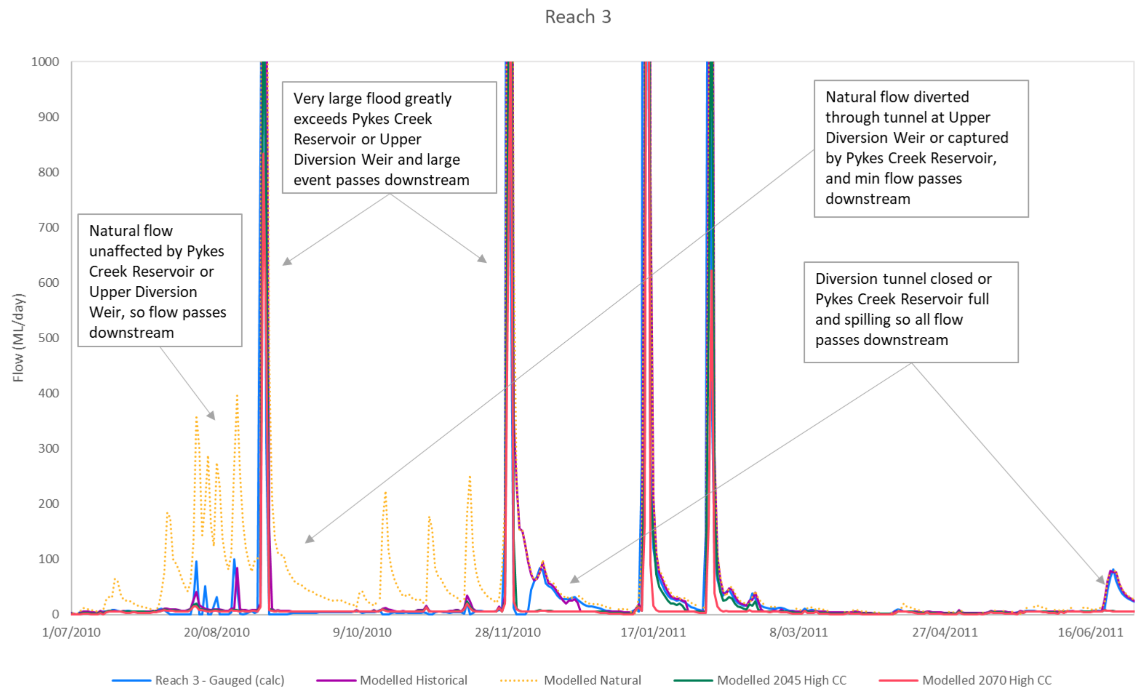



**Figure 6-4 Historical, natural and climate change daily flows between 2010 and 2011 for Reach 3**

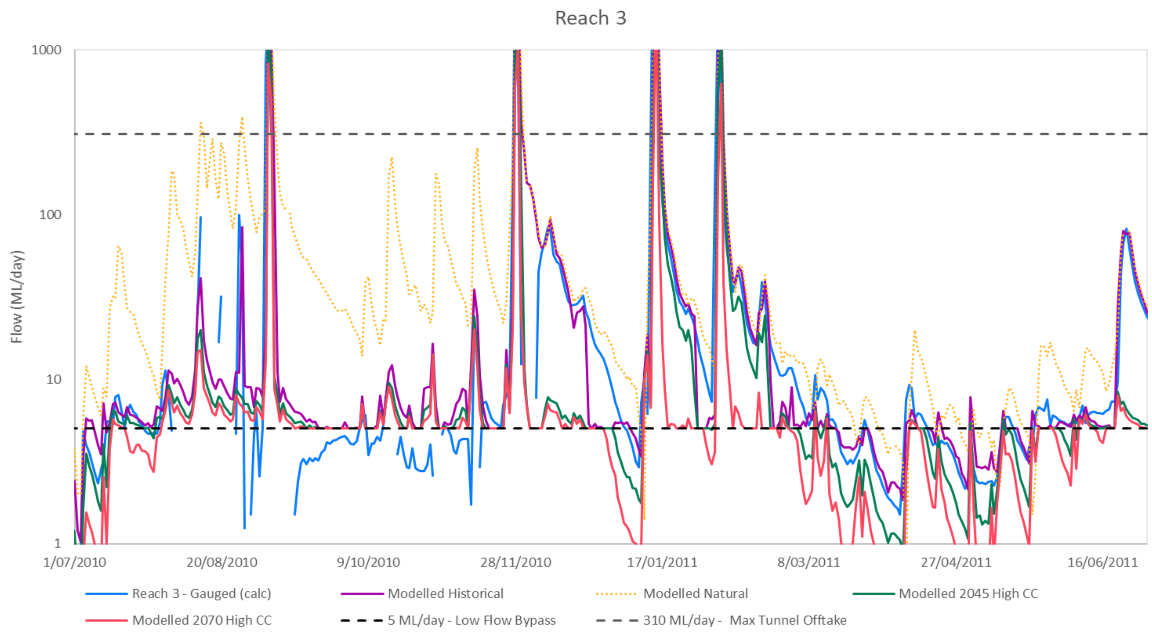



**Figure 6-5 Historical, natural and climate change daily flows between 2010 and 2011 for Reach 3 on a log scaled graph**

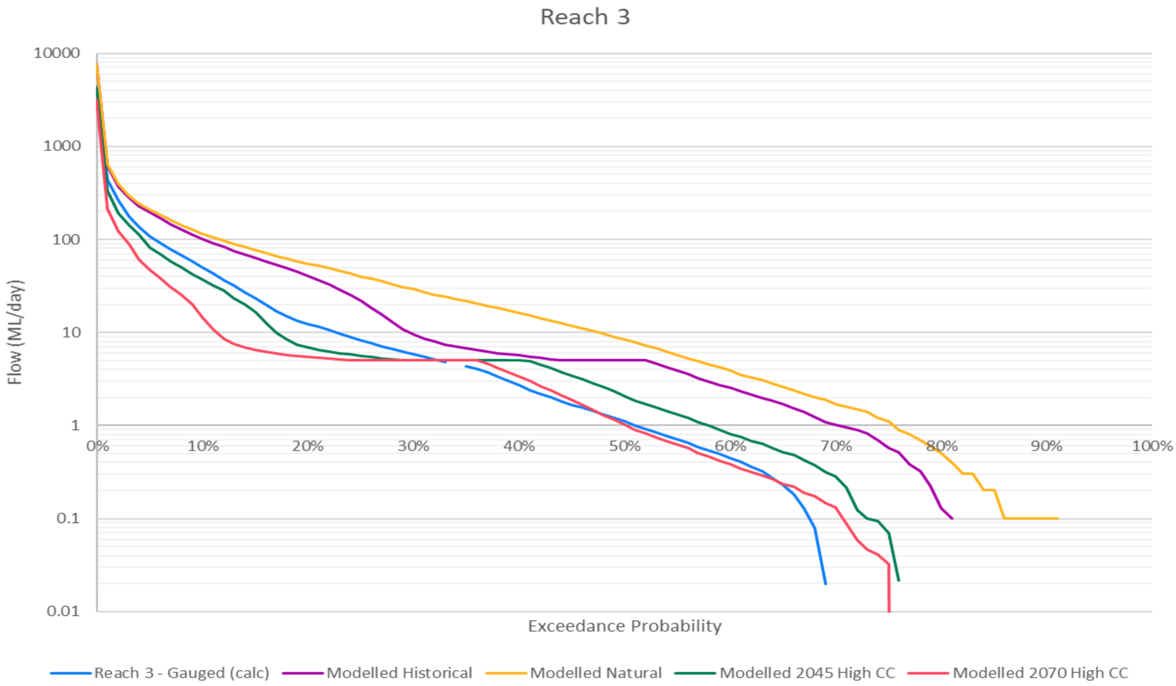



**Figure 6-6 Historical, natural and climate change daily flow duration curve for Reach 3 considering the modelled time period (01/01/1900 – 31/12/2020)**

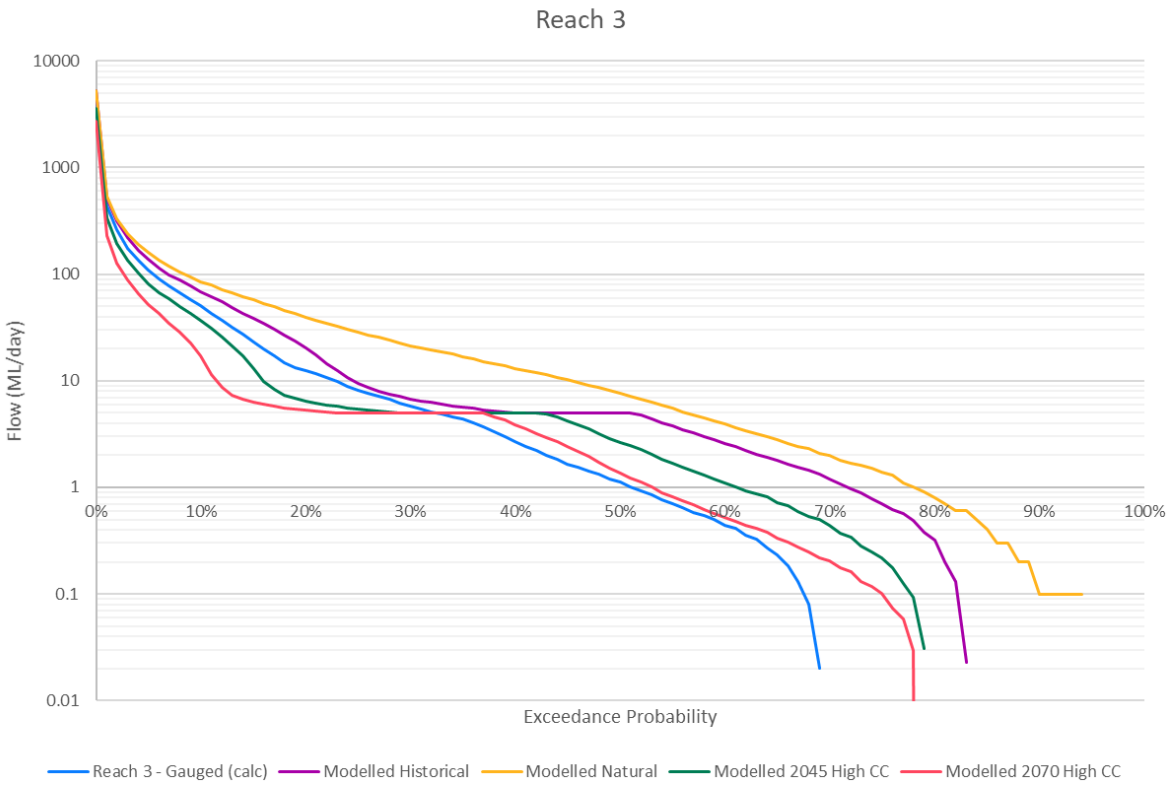



**Figure 6-7 Historical, natural and climate change daily flow duration curve for Reach 3 considering the modelled time period (16/05/1984 – 31/05/2016)**

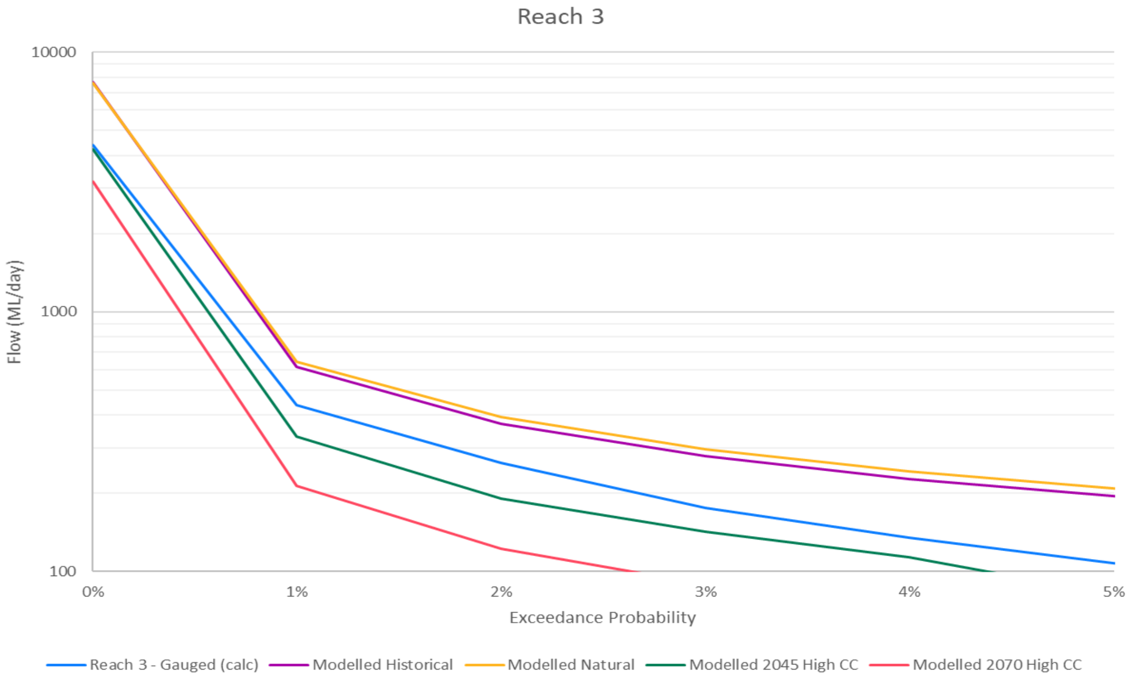



**Figure 6-8 Historical, natural and climate change daily flow duration curve over 0-5% Exceedance for Reach 3, considering the modelled time period (16/05/1984 – 31/05/2016)**

## 6.3 Ecological objectives for Reach 3

### 6.3.1 Geomorphology

The Werribee River (Wirribi Yaluk) in this reach is a 3-5 m wide channel which meanders through a narrow, steep sided basalt-bedrock controlled valley (Ecological Associates, 2005). The channel itself varies in width from 5-10 m, there is extensive outcrops of basalt in the bed of the channel, with bed substrates ranging in size from small cobbles through to large boulders. The diversion weir is considered to be too low to significantly interrupt transport of coarse sediment (Ecological Associates, 2005). The physical form of the channel comprises rocky bedrock outcrops, riffles and runs. Some pools are also evident when reviewing aerial and drone imagery. At the FLOWS assessment site, secondary channels were also noted around the back of point bars. It is unclear whether these secondary channels are still engaged by the current flow regime.

The objectives for geomorphology for Reach 3 are to: *Maintain channel dimensions, form and complexity; maintain access to and quality of riffle and pool habitats; and engage higher channel surfaces and low-level floodplains*

The flow components and functions required to achieve these objectives are summarised in Table 6-2.

The Upper Werribee Diversion Weir has the capacity to divert flows up to 350 ML/day, which has the potential to impact on low flows and variability of flows up to this threshold. Risks to objectives and flow are:

- Impact that the diversion has in reducing periods flow flows and maintain the extent of riffle and pool habitats
- Lack of fresh events to scour fine sediment and biofilms from riffles, this again being attributed to the diversion.

**Table 6-2 Reach 3 Geomorphology objectives**

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Maintain channel dimensions, form and complexity (G3.1) | Bankfull flow | Maintain gross channel dimensions and form channel features (i.e. pools, bars/riffles). (G3.1.1) | Winter-Spring |
| | Low flows - freshes | Scour and maintain undercuts, exposed roots and large wood habitat. (G3.1.2) | All year |
| Maintain access to and quality of riffle and pool habitats (G3.2) | Low flows | Maintain extent of riffle and pool habitats (G3.2.1) | All year |
| | Freshes | Scour fine sediment and biofilms from riffles[1](G3.2.2) | All year |
| | High flow | Scour sediment from pools (G3.2.3) | Winter-Spring |
| Engage higher channel surfaces and low-level floodplains (G3.3) | High flow – Bankfull flow | Maintain connectivity to and form of higher secondary flow channels (G3.3.1) | Winter-Spring |

[1] Bed shear stress during fresh capable of moving silt from cobbles ($\tau_c$ > 15 N/m$^2$) and sand ($\tau_c$ > 8 N/m$^2$). Source: Appendix B of Ecological Associates (2005b)

### 6.3.2 Vegetation

Water-dependent vegetation along Reach 3 is sparse and discontinuous, with the only EVC recorded on the NatureKit website being EVC 641 Riparian Woodland and even this is very narrow and highly fragmented (see Site paper). Imagery generated by the two drone flights over Reach 3 in June 2022 indicated the presence of large beds of emergent non-woody macrophytes, again tentatively identified as either Common Reed (*Phragmites australis*) or Cumbungi (*Typha* spp.) on the basis of their winter senescence. The exposed rocky substratum that underlies Reach 3 probably limits the extent of many areas suitable for colonisation by rhizomatous emergent plants such as rushes, reeds and sedges (see Figure 6-9), a situation possibly exacerbated by heavy grazing pressure (e.g. rabbits and domesticated stock). The current flow regime must also contribute to the discontinuous and sparse vegetation, as flows are either very low (<~5-7 ML/day) or on rare occasions, very high when the upstream diversion tunnel is overwhelmed.

As with Reach 2, in-stream submerged vegetation (e.g. Eelgrass, *Vallisneria australis*) were not evident in the imagery but patches of desiccation-tolerant taxa such as Water Ribbons may be present in the many large pools that occur in Reach 3. Some small beds of Water Ribbons were observed during the field inspection.

**Figure 6-9 Rocky substratum and emergent plants, Reach 3.**

Woody weeds in the riparian zone and more elevated land on either side of the stream are abundant and include Gorse, Hawthorn, and Dog Rose; these are supplemented by a host of non-woody weeds such as Common Sow-thistle (*Sonchus oleraceus*) and Ribwort *(Plantago lanceolata*) (see Figure 6-10).

**Figure 6-10 Sparse vegetation and woody weeds, Reach 3**

Evidence from the field site inspection and the drone imagery suggests that the description of in-stream habitats provided by Ecological Associates (2005, p. 6-28) still holds: "Shallow pools within the rocky stream bed support aquatic macrophytes including Water Ribbons and Waterwort [*Elatine* spp.]. Pools are separated by extensive riffles and are shallow and appear to be temporary. They are maintained by low flows in winter and spring and may be temporarily re-filled following rainfall events at other times of year".

The co-designed catchment program for the Werribee catchment region (Melbourne Water 2018) does not include specific actions to establish or maintain vegetation buffers along the stream channel for Reach 3 (see Melbourne Water 2018, Figure 8). Moreover, the flow regime in Reach 3 is highly artificial, being controlled by upstream diversion into the Pyke Creek Reservoir and the native riparian zone is almost non-existent, with no published plans for revegetation.

Bearing in mind these limitations, the objective for water-dependent vegetation for Reach 3 is restricted to: *Maintain existing in-stream and fringing non-woody vegetation and prevent the encroachment of terrestrial, inundation-intolerant species into the stream channel.*

The flow components and functions required to achieve this objective are summarised in Table 6-3.

**Table 6-3 Reach 3 vegetation objectives**

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Maintain in-stream vegetation (V3.1) | Low flow | Maintain existing plant communities by providing pool habitat over winter-spring period (note that taxa such as Water Ribbons are well adapted to periodic cease-to-flow periods) (V3.1.1) | Winter-spring |
| Maintain fringing non-woody vegetation (V3.2) | Low flow | Maintain existing plant communities of reeds, rushes and sedges etc by providing damp conditions along stream side over winter-spring period (note that many species of reed, rush and sedge are well adapted to | Winter-spring |

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| | | periodic cease-to-flow periods) (V3.2.1) | |
| | Freshes | Maintain existing plant communities of reeds, rushes and sedges etc over dry summer-autumn period<br><br>Introduce hydrological variability and promote zonation of fringing plant communities as well as inundating slightly elevated zones around stream perimeter<br><br>Downstream dispersal of plant propagules (V3.2.2) | All year (i.e., winter-spring and summer-autumn) |
| Prevent encroachment of the stream channel by undesirable terrestrial species (V3.3) | Low flow | Prolonged inundation of stream channel will prevent colonisation of inundation-intolerant plant taxa, including pasture species (V3.3.1) | Winter-spring |
| Provide ecological disturbance (V3.4) | Large fresh or Near-bankfull | Provide substantial ecological disturbance to scour sediments and in-stream boulders, disturb established vegetation and reset ecological communities (V3.4.1) | Winter-spring |

### 6.3.3 Macroinvertebrates and Water Quality

Flow in Reach 3 is highly modified as a result of the operation of the Upper Diversion Weir. The diversion of the majority of flows greater than 5~7 ML/day to Pykes Creek Reservoir via the diversion tunnel means that the current flow regime is mostly comprised of cease-to-flows or low flows (< ~5-7 ML/day) that pass through the diversion weir. Occasional higher flows do occur if the capacity of the diversion tunnel is exceeded but overall there is a significant reduction in mid-sized flows, and in frequency and magnitude of freshes compared to natural conditions.  The reach provides a variety of suitable habitat for macroinvertebrates including pools, riffles and runs, and abundant emergent and fringing aquatic vegetation.

The objective macroinvertebrates in Reach 3 is to: *Maintain the abundance and diversity of macroinvertebrate communities through the provision of a more natural flow regime that supports habitat quality and availability, life cycle processes, and water quality.*

The flow components and functions required to achieve this objective are summarised in Table 6-4.

**Table 6-4 Macroinvertebrate and water quality objectives for Reach 3.**

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Maintain access to and quality of riffle and pool habitats (M3.1) | Low flows | Maintain extent and diversity of riffle and pool habitats, and avoid drying of critical habitats<br><br>Maintain connections between habitat areas | All year |

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| | | Maintain wetted width of channel and connection with instream and littoral vegetation<br><br>Maintain refuge habitat in deeper pools during dry periods (M3.1.1) | |
| | Freshes | Flush fine sediment from riffles to expose new surfaces, prevent infilling of interstitial spaces and provide quality habitat (M3.1.2) | All year |
| | High flow | Scour sediment from pools (M3.1.3) | Winter-Spring |
| Maintain water quality and important hydrological functions of current flow regime (M3.2) | Low flows | Maintain low flows to prevent an increase in cease-to-flow periods outside of natural range<br><br>Provide flows to prevent prolonged low flow periods that can result in decreased dissolved oxygen and increased salinity (M3.21) | All year |
| | Freshes | Maintain inputs of organic matter from upstream reaches and the catchment<br><br>Maintain water quality in pools during low flow periods<br><br>Flush accumulated organic matter and fine sediments (M3.2.2) | Several events throughout the year |
| | High Flows | Mobilise and transport particulate matter to downstream reaches<br><br>Provide recolonisation opportunities following low flow periods (M3.2.3) | Winter-Spring |

### 6.3.4 Fish

Flow in Reach 3 is highly modified as a result of the operation of the Upper Diversion Weir, which diverts the majority of flows >~7 ML/day to Pykes Creek Reservoir. This means the current flow regime is mostly comprised of cease-to-flows or very low flows (<7 ML/day). Occasional higher flows do occur if the capacity of the diversion tunnel is exceeded (at ~350 ML/day). However, there is an overall reduction in frequency and magnitude of freshes compared to natural conditions. Despite the highly regulated flow regime, suitable habitat for native fish occurs within the reach, including refuge pools, rocky bedrock outcrops, riffles and runs, and emergent vegetation on channel margins and in some areas across the entire channel (Figure 6-11).

**Figure 6-11 Habitat types in Reach 3 a) large refuge pools in the lower parts of the reach, b) shallow pools and runs in the upper parts of the reach (when flowing), c) areas of emergent vegetation across entire channel**

There are no fish survey results for Reach 3, but it is likely to support a small native fish community comprising species recorded in Reaches 1 and 4, such as the migratory Short-finned Eel and Common Galaxias, and potentially Mountain Galaxias and Southern Pygmy Perch (Jacobs 2022). River Blackfish, which are present in Reach 4 (including anecdotal observations from the upper parts of Reach 4), may occur in the lower parts of Reach 3, where suitable large refuge pool habitat appears to exist, but are unlikely to be present in the upper parts of the reach where pools are smaller and more likely to dry out during cease-to-flow periods (compare Figure 6-11a and Figure 6-11b). The objective for Reach 3 is to maintain the existing native fish community and if possible, enhance opportunities for colonisation by species that prefer a more permanent flow regime (e.g. River Blackfish). However, this would likely require a change in the operational regime of the Upper Diversion Weir to enable a more variable flow regime and some higher winter and spring flows to pass through Reach 3 rather than be diverted via the diversion tunnel.

The specific Reach 3 objective for native fish is to: *Maintain, and if possible enhance, the existing native fish community by ensuring that refuge pools are sustained during low and cease-to-flow periods, and that higher base flows and freshes occur at suitable times to enable local fish movement and opportunities for re-colonisation of areas that may have experienced cease-to-flows.*

The flow components and functions required to achieve this objective are summarised in Table 6-5.

This reach is highly regulated and greatest risks are from lack of flow variability and connectivity between upstream and downstream reaches. Poor water quality as a result of the lack for flow variability may also represent a threat. Risks to objectives and flow are:

- Lack of (mostly winter) flow variability due to diversion to Pykes Creek Reservoir
- climate change that results in an increase the frequency and duration of cease-to-flows and very low flows that contributes to the loss of refuge habitat. This could be exacerbated by the presence of farm dams in the catchment and also sustained diversion to Pykes Creek (Korjamnunnip Creek) if the reservoir does not fill as often.

**Table 6-5 Reach 3 fish objectives**

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Maintain, and if possible enhance, the native indigenous fish community (e.g. Short-finned Eel, Common Galaxias, Southern Pygmy Perch, Mountain Galaxias) (F3.1) | Avoid prolonged cease-to-flow | Prevent loss of refuge pool habitat (F3.1.1) | Summer/autumn |
| | Summer Low flow | Maintain refuge pool habitat (F3.1.2) | Summer (cease-to-flows acceptable if natural – avoid prolonged/unnatural CtF) |
| | Winter Low flow | Maintain diversity of hydraulic habitats (i.e. pool, riffle, run)<br><br>Maintain connectivity (adequate depth) for local movement (F3.1.3) | Winter (ideally continuous and typically higher than summer) |
| | Freshes | Top-up/freshen water quality in refuge pools (F3.1.4) | Summer (especially if CtFs have occurred) |
| | Freshes-high flows | Flush accumulated sediments to maintain or improve quality and availability of habitat<br><br>Maintain connectivity (adequate depth) for local movement and recolonisation following periods of cease-to-flow (F3.1.5) | Any time |
| | Freshes-high flows | Maintain cues for downstream migration by adult Short-finned Eels (F3.1.6) | Throughout year, particularly Summer |

### 6.3.5 Platypus

There is very limited data on platypuses in this reach but they are likely to occur in low numbers throughout, based on occasional eDNA detections and anecdotal public sightings. The extent of platypus occurrence throughout the reach as well as overall abundance is likely limited by low base flows and regular cease-to-flow events driven by the diversion of most water to Pykes Reservoir at the top of the reach. The quality of riparian habitat is poor with sparse large trees, very limited woody understorey, and unrestricted stock access. Aerial photos and drone footage reveal some larger pools in the lower reaches which are likely critical refuges during cease-to-flow events.

Although the current status of platypuses is low and habitat quality relatively poor, there are opportunities to improve conditions in Reach 3 with increased flows, although this would require a significant change to operation of the Werribee Diversion Tunnel to allow more flows and increased variability down Reach 3 instead of being diverted to Pykes Reservoir.

The objective for Reach 3 is to: *Maintain current platypus populations and enhance if possible.*

The flow components and functions required to achieve this objective are summarised in Table 6-6.

**Table 6-6 Objectives for platypus in Reach 3**

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Maintain platypus population, enhance if possible (P3.1) | Low flows | Prevent increases to cease-to-flow events, maintain refuge pools (P3.1.1) | Summer/autumn |
| | Low flows | Maintain habitat and longitudinal connectivity for platypuses and food resources (macroinvertebrates) (P3.1.2) | Winter/spring |
| | Freshes | Increase frequency of freshes to improve water quality, scour fine sediment, enhance conditions for macroinvertebrates. (P3.1.3) | All year |

## 6.4 Flow recommendations

### 6.4.1 Existing recommendations

Flows in Reach 3 are highly modified due to the operation of the Upper Diversion Weir. While opportunities to deliver environmental flows to this reach have been limited, flow recommendations have previously been developed; these were published in the Ecological Associates (2005) flow study. Table 6-7 shows the original (Ecological Associates 2005) flow recommendations for Reach 3. The table has been modified for clarity; the complete original flow recommendations table is included in Appendix B.

**Table 6-7 Original flow recommendations for Reach 3 (adapted from EA 2005)**

| Flow recommendations | | | | | Rationale / objective |
|---|---|---|---|---|---|
| Season | Component | Magnitude | Frequency | Duration | |
| Jan-April | Cease-to-flow | 0 ML/day | 2 per year with a minimum separation of 7 days | 20 days each – 40 days total* | Curtail growing season of in-channel emergent macrophytes<br>Control trout |
| Dec-June | Low flow | 5 ML/day* | All years except extended drought | Residual time after other flows | Wet the perimeter of riffles to provide habitat for macroinvertebrates<br>Maintain pool water quality and extent for habitat<br>Mobilise sand and silt. |
| Dec-March | Freshes | 14 ML/day* | Minimum 2 per year with a minimum separation of 14 days | 5 days * | Maintain depth over thalweg for longitudinal connectivity |
| July-Nov | Low flow | 37 ML/day* | All years | Residual time after other flows | Maintain depth over thalweg for longitudinal connectivity of sufficient depth for dispersal of adult blackfish<br>Inundate bench vegetation<br>Provide spawning habitat in pools for River Blackfish and adequate depth through riffles to allow adult River Blackfish to disperse between pools<br>Inundate full wetted perimeter of channel to sustain macrophytes in the channel and at the channel margins and to provide foraging habitat for Platypus. |
| Anytime | High flow freshes | 165 ML/day* | Minimum 6 per year, minimum separation 14 days | At least 1 day | Prevent macrophyte advance<br>Mobilisation of gravel |
| Anytime | Bankfull flow | 700 ML/day | Natural (2 per year) | At least 1 day | Maintain channel dimensions and form through re-working of sediments |
| Anytime | Overbank flow | 3400 ML/day | Natural (1 in 10 years) | Minimum 1 day | Disturbance of woody vegetation and bench reworking approximately every ten years |

or natural if natural is less

### 6.4.2 Updated flow recommendations

The outcomes of the current assessment have identified a number of updates to the previous flow recommendations. Revised recommendations for are summarised in Table 6-8 and described in the following sections.

#### Cease-to-flow

A cease-to-flow was specifically recommended in the 2005 flow study to limit the growth (and thus extent) of emergent macrophytes such as cumbungi and common reed in Reach 3. We now recognise that short periods of drying (e.g. 3 weeks) even over summer are unlikely to limit the growth and extent of robust rhizomatous macrophytes such as cumbungi or common reed; they simply spring back when the water returns. A large fresh or near-bankfull flow is likely to be more effective at controlling excessive in-channel vegetation growth (Table 6-3). Hence we recommend the specific requirement for a cease-to-flow be removed – this removes the implied need to actively manage flows to 'generate' a cease-to-flow. Cease-to-flows will occur naturally in this reach in response to upstream cease-to-flow periods. Moreover, the natural pattern of cease-to-flow is not influenced by the operation of the upper diversion weir, which only impacts on flows >~7 ML/day.

**Summer low flow**

A summer low flow of 5 ML/day was recommended in the 2005 flow study. This flow aims to fill and connect refuge pools, provide flow over riffles for macroinvertebrate habitat and provide opportunities for local fish movement. Based on our review of the hydraulic model there is no justification for changing this recommendation. Low flows up to 5 ML/day will occur naturally in this reach in accordance with upstream flows. This pattern is not influenced by the operation of the upper diversion weir, which only impacts on flows >~7 ML/day.

**Summer fresh**

A summer fresh of 14 ML/day, 2 per year for 5 days duration each was recommend in the 2005 flows study. A magnitude of 14 ML/day is sufficient to provide increased depth over riffles and moisture to vegetation on the lower banks. It would also help mix refuge pools and improve water quality for fish and platypus. There is no justification to alter the magnitude of the recommendation however, we have altered the recommended number and duration of events.

This recommendation increases the number of events over the season, to 8 in average and wet climate years and 6 in dry climate years, but shortens the duration to 2 days per event. This pattern is more consistent with the natural regime from the upstream Reach 1 (as shown in Figure 6-12). However, under current conditions this flow component is often not delivered to Reach 3 because of the operation of the Upper Diversion Weir, which diverts low and medium sized flows and freshes >~7 ML/day. The impact of the Upper Diversion Weir is shown in Figure 6-13. The recommended increase in number of freshes aims to reinstate a more natural regime, and associated flow variability, to Reach 3.

Increasing the number of freshes through Reach 3 would also pass these events to Reach 4 and provide benefit along a longer length of waterway.

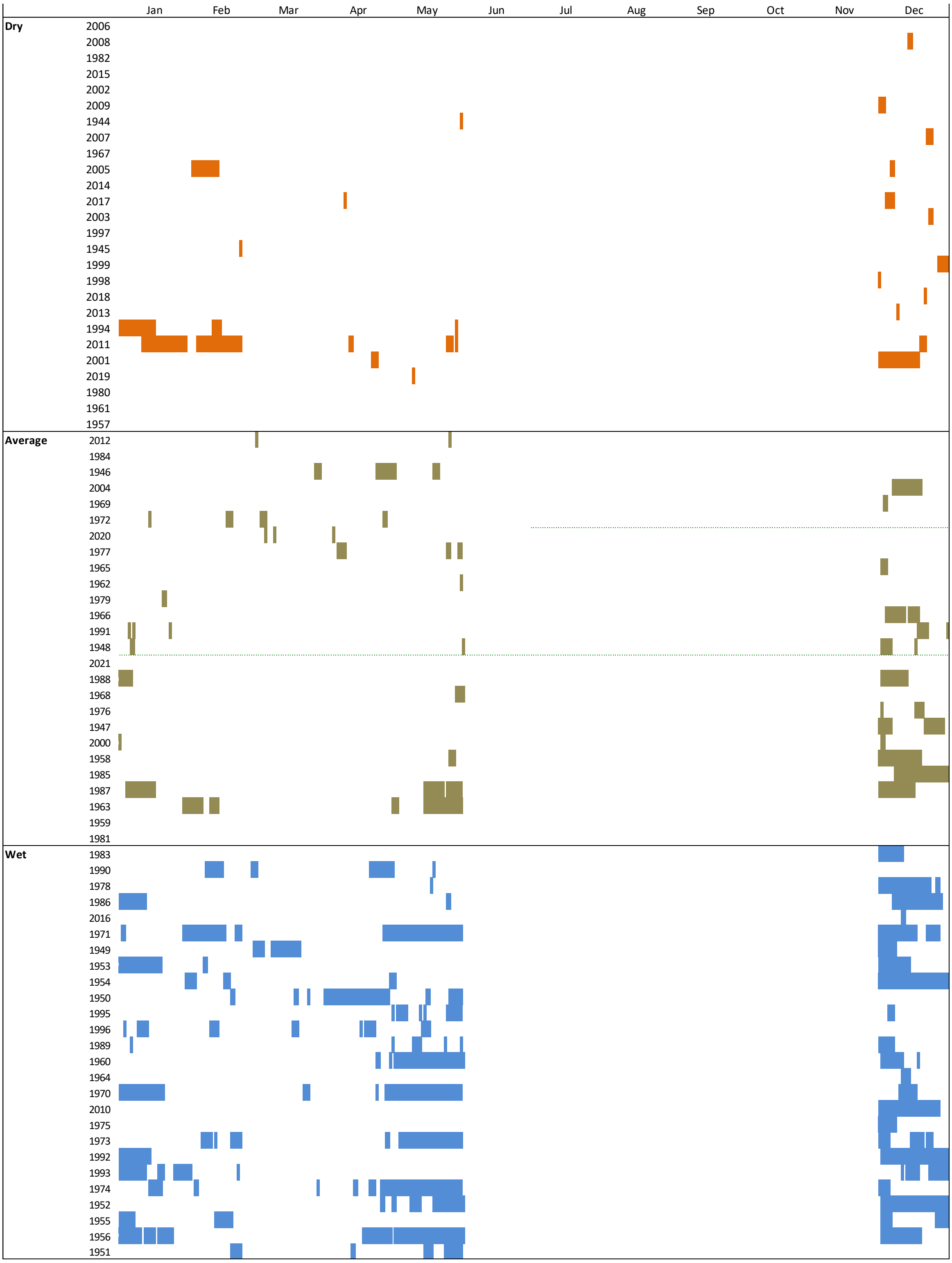



**Figure 6-12 Spells Analysis for a summer fresh >14 ML/day for Reach 1 and dry, average and wet years using gauge data**

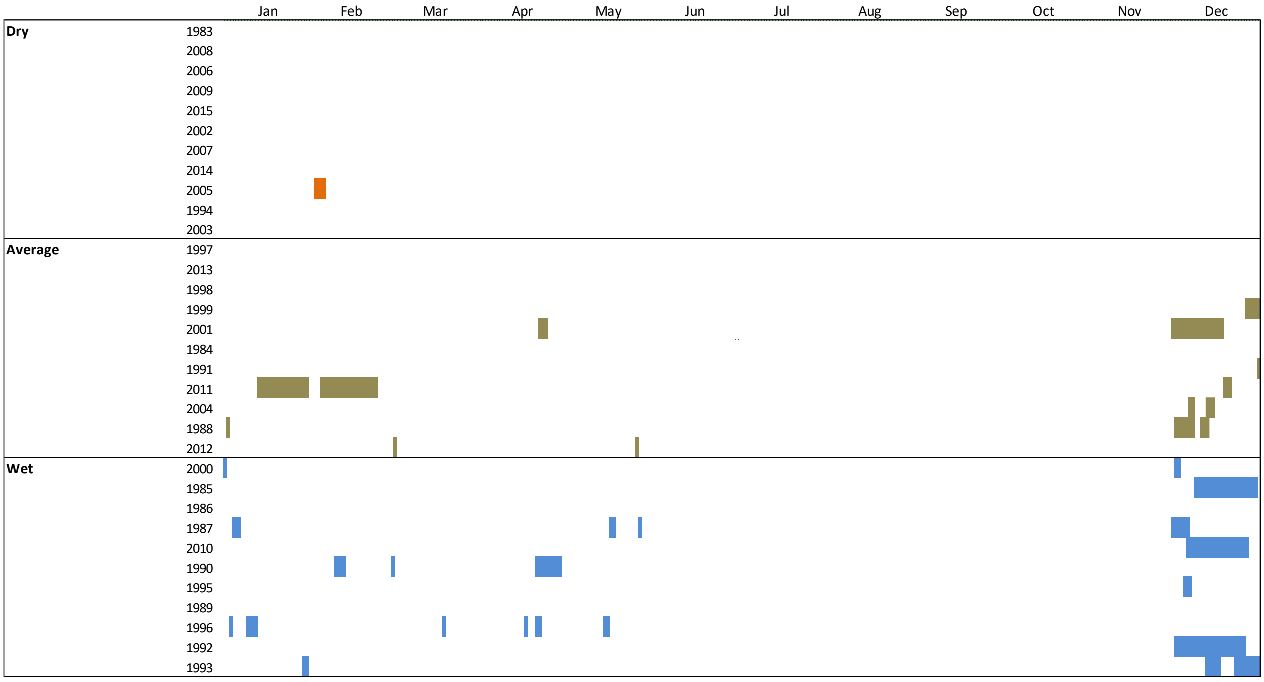



**Figure 6-13 Spells Analysis for a summer fresh >14 ML/day for Reach 3 and dry, average and wet years using gauge data showing that Reach 3 currently does not receive adequate summer freshes**

**Winter low flow**

A winter low flow of 37 ML/day or natural, based on upstream flow, was recommended in the 2005 flow study. This flow aims to provide continuous flow along the reach for the duration of the season and high flows up the bank for vegetation. Longer duration higher flows provide opportunities for longer scale movement by fish and platypus. Based on our review of the hydraulic model there is no justification for changing this recommendation. However, under current conditions this flow component is often not delivered to Reach 3, especially in dry years (see Figure 6-15), because of the operation of the Upper Diversion Weir, which diverts low and medium sized flows and freshes >~7 ML/day. The impact of the Upper Diversion Weir on winter low flows can be seen when comparing Reach 1 and Reach 3 spells analysis for >37 ML/day in Figure 6-14 and Figure 6-15, respectively

Increasing the magnitude of winter low flows past the upper diversion weir would improve the ecological condition of Reach 3, especially in dry years, and also assist with increasing the magnitude of winter low flows in Reaches 4 and 5.

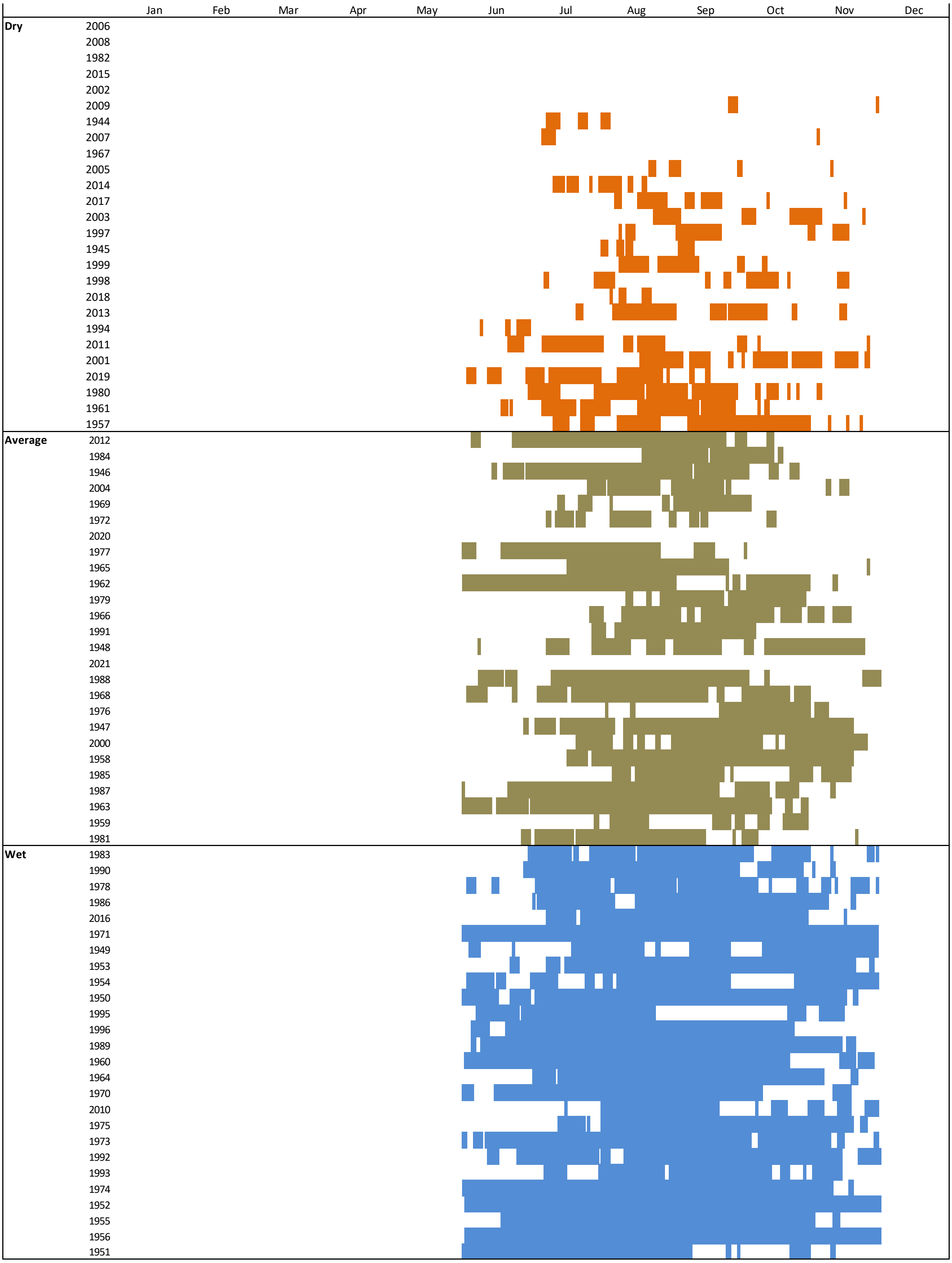



**Figure 6-14 Spells Analysis for a winter low flows >37 ML/day for Reach 1 and dry, average and wet years using gauge data**

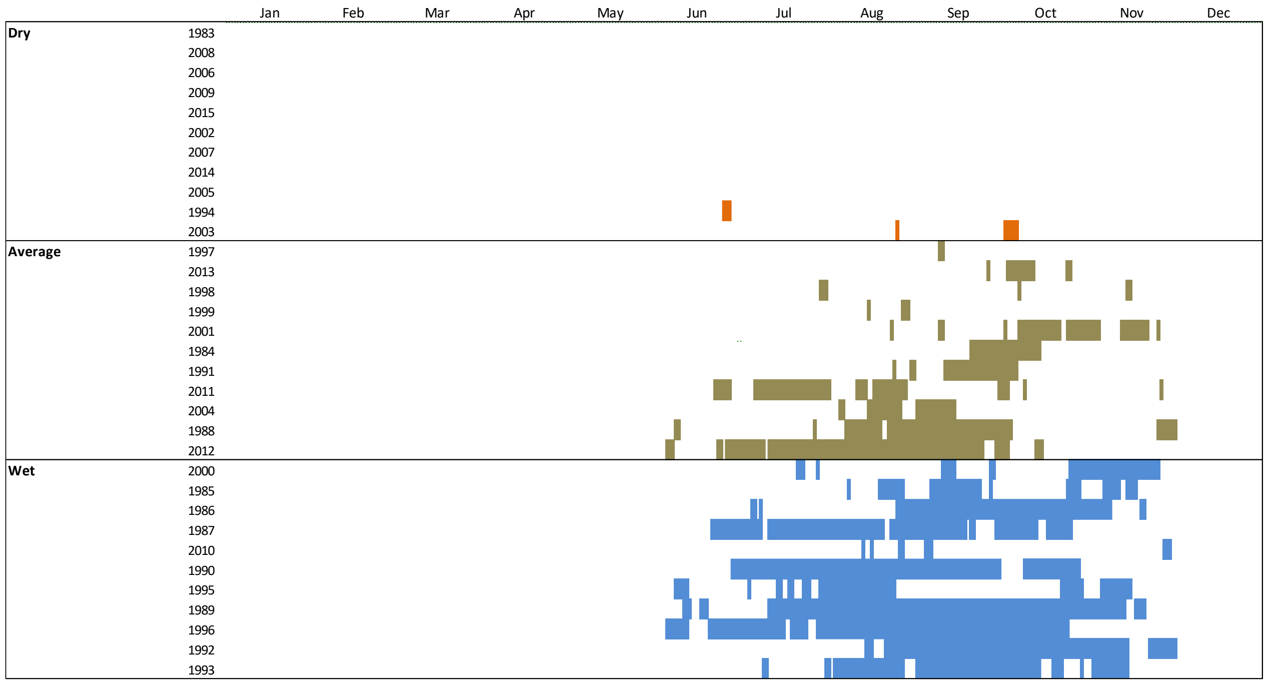



**Figure 6-15 Spells Analysis for a winter low flows >37 ML/day for Reach 3 and dry, average and wet years using gauge data which shows that they are not maintained in dry years**

### Winter fresh and high flow

A winter fresh of 165 ML/day, 6 per year for 1 day duration each was recommend in the 2005 flows study. A flow of this magnitude is sufficient to scour sediment and biofilm, improving the quality of pool and riffle habitat, provide moisture to vegetation higher up the bank and extend opportunities for fish and platypus movement. There is no justification to alter the magnitude of the recommendation however, we have altered the recommended number and duration of events.

For wet climate years we recommend 6 events for the winter/spring period (on average 1 fresh every month) for a duration of 8 days. For average climate years we also recommend 6 events but for a duration of 3 days. For dry climate years were recommend 3 events (one event every two months) for a duration of 1 day. Under current conditions the recommended frequency and duration of freshes is met for wet and most average climate years, even with the diversion of a portion of flows at the Upper Diversion Weir (Figure 6-16). This is because despite the diversions, high flows continue to occur in the reach and exceed the capacity of the diversion on enough occasion to deliver freshes to Reach 3. However, in dry years the recommended fresh is rarely achieved. Opportunities to delivery this fresh during dry years via manipulation of the diversion weir should be considered.

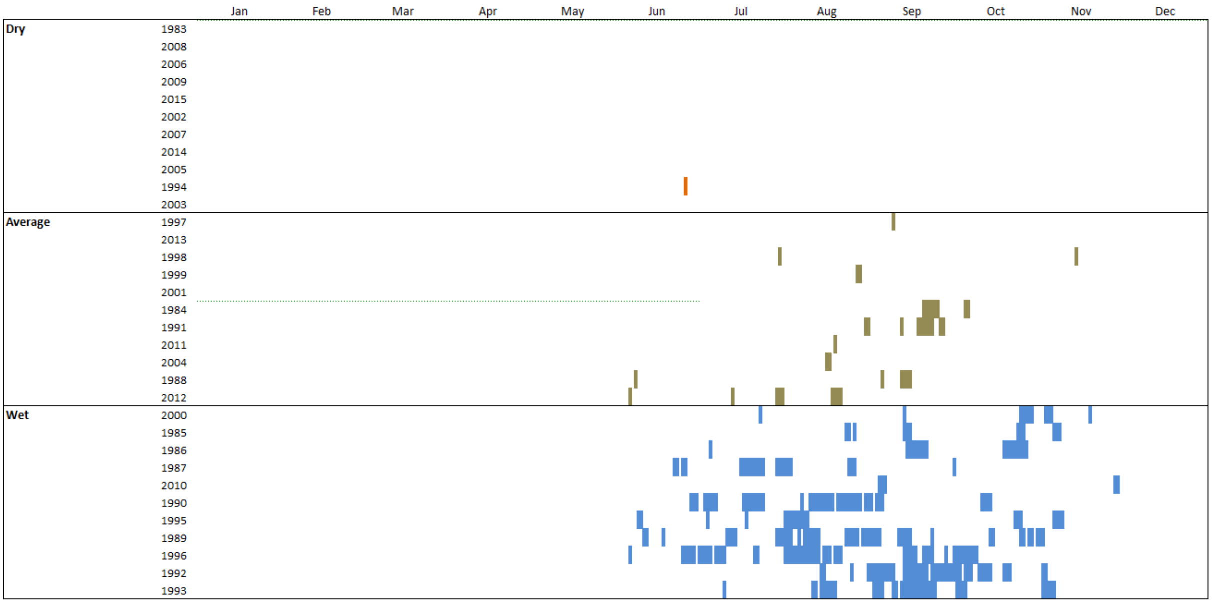



**Figure 6-16 Spells Analysis for a winter fresh >160 ML/day in winter for Reach 3 and dry, average and wet years using gauge data showing recommended number and duration of freshes is reached for wet years and most average years, but is not met for dry years.**

A bankfull flow of 700 ML/day, 2 times per year for 1 day duration each was recommended in the 2005 flow study. This event is sufficient to inundate the channel and wet the upper banks, low lying terraces and inset floodplain along the reach. There is no justification to alter the magnitude of this event, however we have adjusted the number and duration of events to more closely reflect the upstream natural regime and distinguish between wet and dry climate years (Figure 6-17).

For wet years the recommendation is 1 to 2 events per year for a duration 2 days. For average climate years the recommendation is 1 event every two years for 1 to 2 days and an event of this magnitude would not be expected to occur in a dry climate year. In reality, this event will occur naturally in response to upstream flows and is not substantially impacted by diversions at the Upper Diversion Weir.

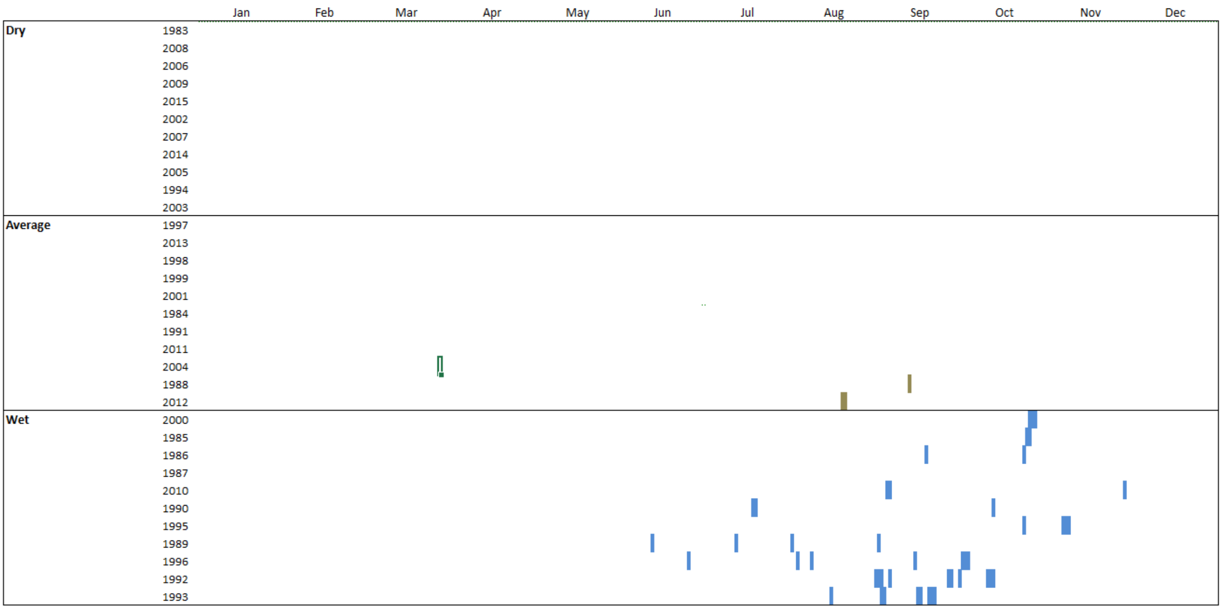



**Figure 6-17 Spells Analysis for bankfull flow >700 ML/day in winter for Reach 3 and dry, average and wet years using gauge data**

An Overbank flow was recommended in the 2005 flows study. There is no justification to specifically retain this recommended, but it may occur naturally around once every ten years.

The final flow recommendations for the reach are summarised in Table 6-8. For each flow recommendation, the ecological objectives it is intended to achieve are listed, using codes for the specific ecological objectives listed in Section 6.3. A code has been allocated to each specific objective for geomorphology, vegetation, macroinvertebrates and water quality, fish and platypus as listed in Tables 6-2 to 6-6; these objective codes are cross referenced with each flow recommendation component in the table below.

**Table 6-8 Updated flow recommendations for Reach 3**

<table>
<tr><th>Season</th><th>Flow</th><th>Objective/Function</th><th>Wet/Avg/ Dry</th><th>Volume (ML/day)</th><th>Frequency and timing</th><th>Duration</th><th>Ecological objectives</th></tr>
<tr><td rowspan="4">Summer / Autumn (Dec-May)</td><td>Cease-to-flow</td><td>Not recommended but expected to occur naturally based on inflows from Reach 1 (upstream)</td><td colspan="4">As per natural cease-to-flow from upstream</td><td></td></tr>
<tr><td>Low flow</td><td>Maintain refuge pools during low flow periods to maintain and if possible enhance habitat and vegetation for bugs, fish (River Blackfish, Mountain Galaxias, Common Galaxias, southern Pygmy Perch) and platypus. Maintain capacity of the stream to process organic matter. Maintain inundated stream channel to prevent colonisation by inundation-tolerant terrestrial vegetation.</td><td>Wet/Avg/Dry</td><td>5</td><td colspan="2">As per natural inflows from upstream</td><td>(G3.1.2, G3.2.1, M3.1.1, M3.2.1, F3.1.1, F3.1.2, P3.1.1)</td></tr>
<tr><td rowspan="2">Fresh</td><td rowspan="2">Maintain quality of riffle habitats by periodically scouring sediment & biofilms, maintain fringing and riparian non-woody vegetation, provide opportunities for fish movement. Mobilise and transport particulate organic matter to downstream reaches.</td><td>Wet/Avg</td><td>14</td><td>8 (every 3 weeks)</td><td>2 days</td><td rowspan="2">(G3.1.2, G3.2.2, G3.2.3, V3.2.2, M3.1.2, M3.2.2, F3.1.4, F3.1.5, F3.1.6, P3.1.3)</td></tr>
<tr><td>Dry</td><td>14</td><td>6 (every month)</td><td>2 days</td></tr>
<tr><td rowspan="5">Winter / Spring (Jun-Nov)</td><td rowspan="2">Low flow</td><td rowspan="2">Higher flows increase access to habitat for bugs, fish and platypus. Maintain capacity of the stream to process organic matter. Maintain inundated stream channel to prevent colonisation by inundation-tolerant terrestrial vegetation.</td><td>Wet</td><td>37</td><td colspan="2">100% of days</td><td rowspan="2">(G3.1.2, G3.2.1, V3.1.1, V3.2.1, V3.3.1, M3.1.1, M3.2.1, F3.1.3, P3.1.2)</td></tr>
<tr><td>Avg/Dry</td><td>37</td><td colspan="2">100% of days</td></tr>
<tr><td rowspan="3">Fresh</td><td rowspan="3">Maintain quality of riffle habitats by periodically scouring sediment & biofilms, maintain fringing and riparian non-woody vegetation, provide opportunities for fish movement. Mobilise and transport particulate organic matter to downstream reaches.</td><td>Wet</td><td>165</td><td>Every month</td><td>8 days</td><td rowspan="3">(G3.1.2, G3.2.2, G3.2.3, V3.2.2, M3.1.2, M3.1.3, M3.2.2, M3.2.3, F3.1.5, F3.1.6, P3.1.3)</td></tr>
<tr><td>Avg</td><td>165</td><td>Every month</td><td>3 days</td></tr>
<tr><td>Dry</td><td>165</td><td>Every 2 months</td><td>1 day</td></tr>
</table>

| Season | Flow | Objective/Function | Wet/Avg/ Dry | Volume (ML/day) | Frequency and timing | Duration | Ecological objectives |
|---|---|---|---|---|---|---|---|
| | Bankfull | Scour fine sediment from pools, engage higher channel surfaces and secondary flow channels/terraces, flush organic material that has accumulated in these areas. | Wet | 700 | 1 event | 2 days | **(G3.1.1, G3.3.1, V3.4.1)** |
| | | | Avg | 700 | 1 every 2 years | 1-2 days | |
| | | | Dry | Not expected to occur | | | |

As for Reach 1 and 2, each flow recommendation in the summary table for the Reach (Table 6-8) is cross referenced to the specific ecological objectives it is intended to achieve, using codes for the specific ecological objectives listed in Section 6.3. A code has been allocated to each specific objective for geomorphology, vegetation, macroinvertebrates and water quality, fish, and platypus as listed in Tables 6-2 to 6-6.

As with Reach 1 and 2, the components of the flow recommendations for the Reach (cease-to-flows) overlap with the objectives set for components such as low flows, fresh flows and so on in Section 6.3.1-6.3.5.

These are summarised below for each component:

**Summer / Autumn (Dec – May)**

**Low flow**

- Scour and maintain undercuts, exposed roots and large wood habitat; maintain extent of riffle and pool habitats (**Geomorphology**)
- Maintain extent and diversity of riffle and pool habitats, and avoid drying of critical habitats; maintain connections between habitat areas; maintain wetted width of channel and connection with instream and littoral vegetation; maintain refuge habitat in deeper pools during dry periods; maintain low flows to prevent an increase in cease-to-flow periods outside of natural range; provide flows to prevent prolonged low flow periods that can result in decreased dissolved oxygen and increased salinity (**Macroinvertebrates and water quality**)
- Prevent loss of refuge pool habitat; maintain refuge pool habitat (**Fish**)
- Prevent increases to cease-to-flow events, maintain refuge pools (**Platypus**)

**Fresh**

- Scour and maintain undercuts, exposed roots and large wood habitat; scour fine sediment and biofilms from riffles (**Geomorphology**)
- Maintain existing plant communities of reeds, rushes and sedges etc over dry summer-autumn period; introduce hydrological variability and promote zonation of fringing plant communities as well as inundating slightly elevated zones around stream perimeter; downstream dispersal of plant propagules (**Vegetation**)
- Flush fine sediment from riffles to expose new surfaces, prevent infilling of interstitial spaces and provide quality habitat; maintain inputs of organic matter from upstream reaches and the catchment; maintain water quality in pools during low flow periods; flush accumulated organic matter and fine sediments (**Macroinvertebrates and water quality**)
- Top-up/freshen water quality in refuge pools; flush accumulated sediments to maintain or improve quality and availability of habitat; maintain connectivity (adequate depth) for local movement and recolonisation following periods of cease-to-flow; maintain cues for downstream migration by adult Short-finned Eels (**Fish**)
- Increase frequency of freshes to improve water quality, scour fine sediment, enhance conditions for macroinvertebrates (**Platypus**)

**Winter / Spring (Jun-Nov)**

**Low flow**

- Scour and maintain undercuts, exposed roots and large wood habitat; maintain extent of riffle and pool habitats (**Geomorphology**)
- Maintain existing plant communities by providing pool habitat over winter-spring period (note that taxa such as Water Ribbons are well adapted to periodic cease-to-flow periods); maintain existing plant communities of reeds, rushes and sedges etc by providing damp conditions along stream side over winter-spring period (note that many species of reed, rush and sedge are well adapted to periodic cease-to-flow periods); prolonged inundation of stream channel will prevent colonisation of inundation-intolerant plant taxa, including pasture species (**Vegetation**)
- Maintain extent and diversity of riffle and pool habitats, and avoid drying of critical habitats; maintain connections between habitat areas; maintain wetted width of channel and connection with instream and littoral vegetation; maintain refuge habitat in deeper pools during dry periods; maintain low flows to prevent an increase in cease-to-flow periods outside of natural range; provide flows to prevent prolonged low flow periods that can result in decreased dissolved oxygen and increased salinity (**Macroinvertebrates and water quality**)
- Maintain diversity of hydraulic habitats (i.e. pool, riffle, run); maintain connectivity (adequate depth) for local movement (**Fish**)
- Maintain habitat and longitudinal connectivity for platypuses and food resources (macroinvertebrates) (**Platypus**)

**Fresh**

- Scour and maintain undercuts, exposed roots and large wood habitat; scour fine sediment and biofilms from riffles; scour sediment from pools (**Geomorphology**)
- Maintain existing plant communities of reeds, rushes and sedges etc over dry summer-autumn period. Introduce hydrological variability and promote zonation of fringing plant communities as well as inundating slightly elevated zones around stream perimeter; downstream dispersal of plant propagules (**Vegetation**)
- Flush fine sediment from riffles to expose new surfaces, prevent infilling of interstitial spaces and provide quality habitat; scour sediment from pools; maintain inputs of organic matter from upstream reaches and the catchment. Maintain water quality in pools during low flow periods; flush accumulated organic matter and fine sediments; mobilise and transport particulate matter to downstream reaches and provide recolonisation opportunities following low flow periods (**Macroinvertebrates and water quality**)
- Flush accumulated sediments to maintain or improve quality and availability of habitat; maintain connectivity (adequate depth) for local movement and recolonisation following periods of cease-to-flow; maintain cues for downstream migration by adult Short-finned Eels (**Fish**)
- Increase frequency of freshes to improve water quality, scour fine sediment, enhance conditions for macroinvertebrates (**Platypus**)

**Bankfull**

- Maintain gross channel dimensions and form channel features (i.e. pools, bars/riffles); maintain connectivity to and form of higher secondary flow channels (**Geomorphology**)
- Provide substantial ecological disturbance to scour sediments and in-stream boulders, disturb established vegetation and reset ecological communities (**Vegetation**)

## 6.5 Flow delivery constraints

The overarching ecological objective for Reach 3 is to: *maintain and where possible enhance existing ecological values in the reach through management of the operation of the Upper Diversion Weir to deliver a more natural and seasonally variable flow regime.*

Flows in the reach are currently highly modified as a result of the operation of the Upper Diversion Weir; this represents the major constraint to flow delivery in this reach. The opportunity to modify the current flow delivery regime past the weir through either structural changes or operational/water sharing arrangements is currently being further investigated by Melbourne Water and Jacobs. Removing the constraints around the weir operation is critical to being able to deliver flows in this reach, including winter low flows and fresh events.

The summer low flow recommendation is 5 ML/day; flow up to this level are not impacted by weir operations and pass through naturally. The ability to meet the 5 ML/day low flow is therefore constrained only by delivery of flow from Reach 1. As noted previously, there is no ability to deliver these flows except by managing threats (climate change, extractions and losses) that could contribute to a reduction in flows in Reach 1 and therefore in Reach 3.

# 7. Reach Four

## 7.1 Reach Description

**Reach Four – Werribee River (Wirribi Yaluk) from Pykes Creek (Korjamnunnip Creek) to Bacchus Marsh Weir**

Reach 4 comprises the main Werribee River (Wirribi Yaluk) channel between the Pykes Creek (Korjamnunnip Creek) confluence and Bacchus Marsh Weir, including the Werribee Gorge area.

Flows in this reach are modified from natural due to flow regulation in upstream Reaches 2 and 3, as outlined above. The reach experiences persistent summer base flows as a result of irrigation releases from Pykes Creek Reservoir and increasing groundwater discharge to the waterway as it passes through the Werribee Gorge also contribute to maintenance of base flows. Winter flows are lower and less variable than natural due to a loss of small and moderately sized freshes that would naturally have flowed through Reach 3 and into Reach 4, but are now diverted through the tunnel at the weir and into Pykes Creek Reservoir. Large flows that exceed the capacity of the diversion tunnel still occur and create some winter flow variability in Reach 4.

There are existing flow recommendations for Reach 4, which were set in 2005, and revised by Jacobs in 2014 with minor amendments. The EFTP visited the existing Reach 4 survey and model site, which is located in the Werribee Gorge State park, a short distance upstream from the Meikles Point picnic area. Based on inspection of the reach during the EFTP site visit, the original assessment site was considered to be sufficiently representative of the reach. There were no fundamental changes to the reach which would mean that the initial assessment site would not still be suitable as a basis for environmental flow recommendations.

## 7.2 Hydrology

Observed daily streamflow data to estimate Reach 4 flows was obtained from the BoM Water Data Online and DELWP Water Monitoring Information System, while modelled data was extracted from the Werribee Source model provided by DELWP. Details of the relevant streamflow data and generation is presented in Table 7-1. Further information regarding streamflow derivation is included in the Site Paper prepared in Stage 1 of this study (Jacobs 2022).

**Table 7-1 Reach 4 streamflow data**

| ID | Type | Description | Time Period |
|---|---|---|---|
| 1 | Observed | Observed Historical Scenario<br><br>Reach 4 was calculated by combining Reaches 2 and 3 streamflow; for the Reach 3 available data period without further adjustment.<br><br>It was directly metered (by gauge 231202 Werribee River @ Bacchus Marsh (The Falls)) for 15 years in the early 1900s but this data is too early compared to the other gauge data in the area for it to be of any use. | 16/05/1984 – 31/05/2016 (approximately 32 years of data) |
| 2 | Modelled | Historical Scenario | 01/01/1900 – 31/12/2020 (120 years of data) |
| 3 | Modelled | Natural Scenario (modelled with extractions turned off, water passing through storages, and stormwater, recycled water, Melbourne Supply and farm dam impacts turned off) | |
| 4 | Modelled | 2045 High Projection Climate Change Scenario. | |
| 5 | Modelled | 2070 High Projection Climate Change Scenario. | |

The hydrograph and mean monthly daily flow for the range of scenarios is shown in Figure 7-1 and Figure 7-2. The impact of the upstream regulation (i.e. Pykes Creek Reservoir and Upper Diversion Weir) is noticeable in summer month with higher mean daily flows observed in the modelled and observed historical data compared with the modelled natural scenario.

A shorter period between from 2010 to 2011 was selected in Figure 7-3 to highlight the regulated nature of the Reach 4, where several fresh events are not delivered down the main river stem in the historical scenario versus natural scenario. Like Reaches 2 and 3, once Pykes Creek Reservoir is full, the natural and historical scenarios are similar as indicated by the last three fresh events.

Assuming a cease-to-flow of <0.5 ML/day, historically Reach 4 experiences cease-to-flow conditions of approximately 0-5% for the historical modelled and observed data, respectively (Figure 7-4). Cease-to-flow conditions have increased since regulation with modelled natural flow suggesting that previously these events occurred 15% of the time. Cease-to-flows under climate change are increased further by 2% in 2045 and 5% in 2070, respectively.

Considering 2045 and 2075 high projection climate change scenario, the mean monthly daily flows reduce significantly by 29-75% in winter and spring months, however in summer autumn month the reduction is not as large approximately 5-60% (see Figure 7-2) due to regulation.

Comparing the flow duration curve over the observed time period (16/05/1984 – 31/05/2016) in Figure 7-5 it can be seen that there is an increase in the percentage of time that cease-to-flow conditions are experienced for the modelled historical, and climate change scenarios by approximately 1-8%, due to drier conditions.

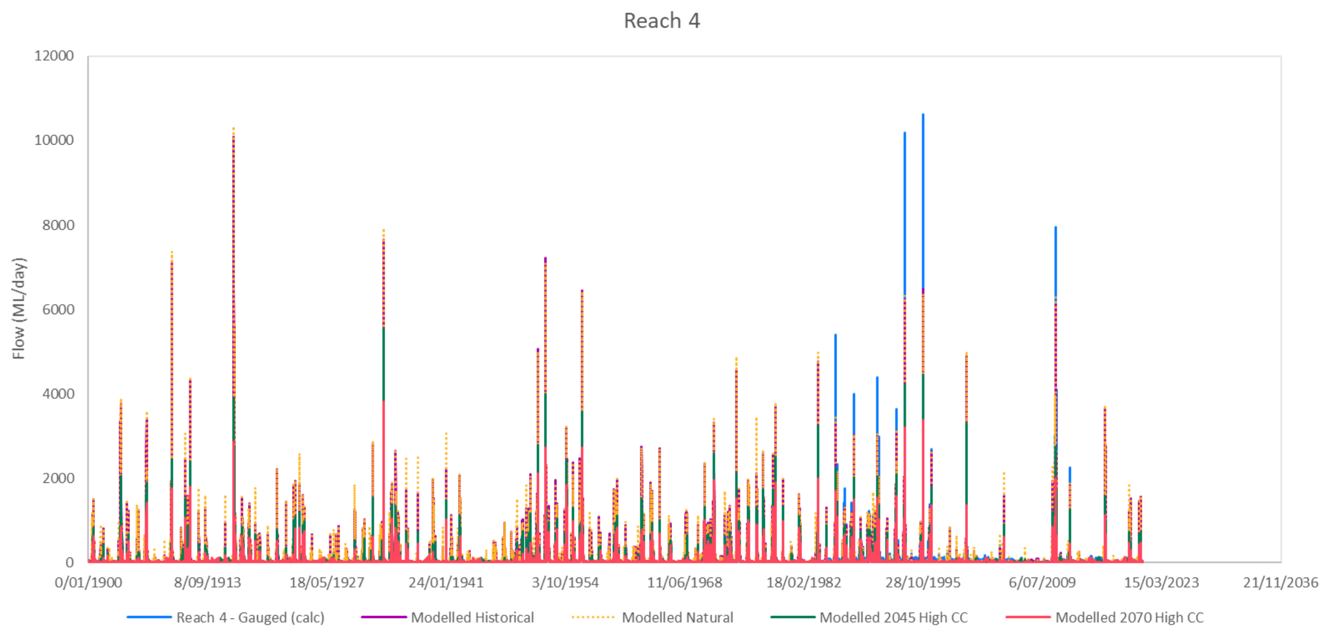



**Figure 7-1 Historical, natural and climate change daily flows for Reach 4**

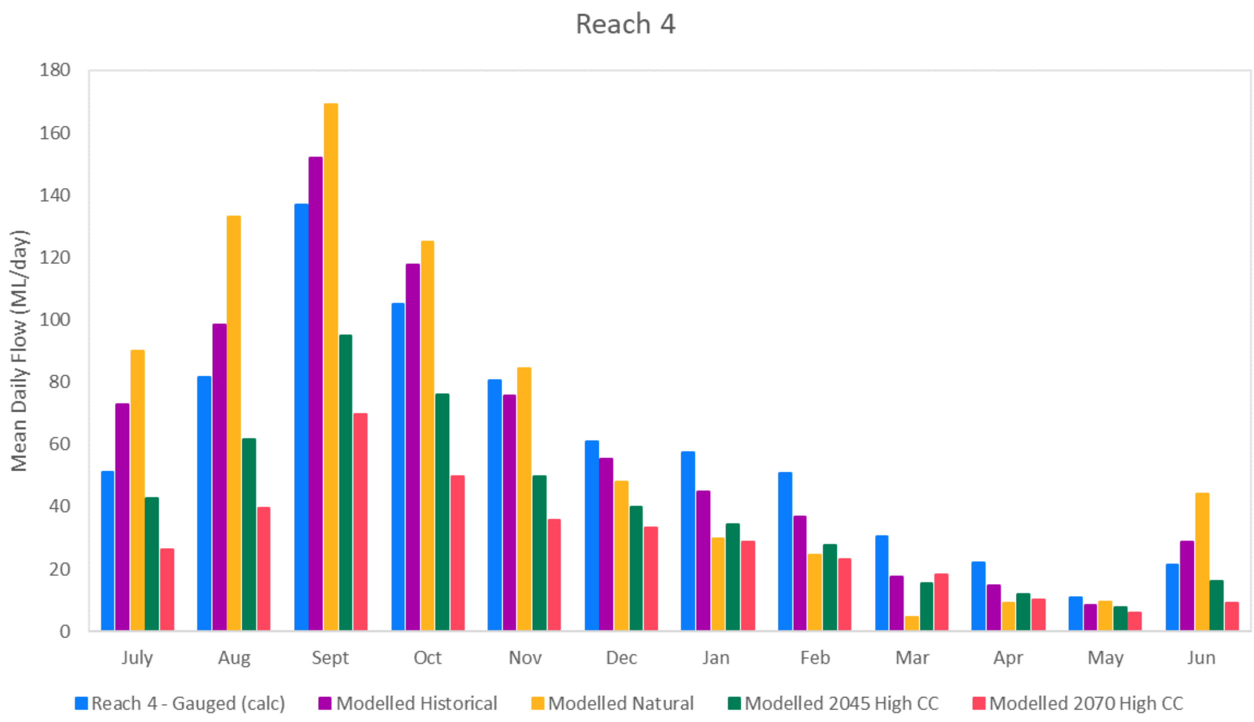



**Figure 7-2 Historical, natural and climate change mean monthly daily flows for Reach 4 considering the observed period only (16/05/1984 – 31/05/2016)**

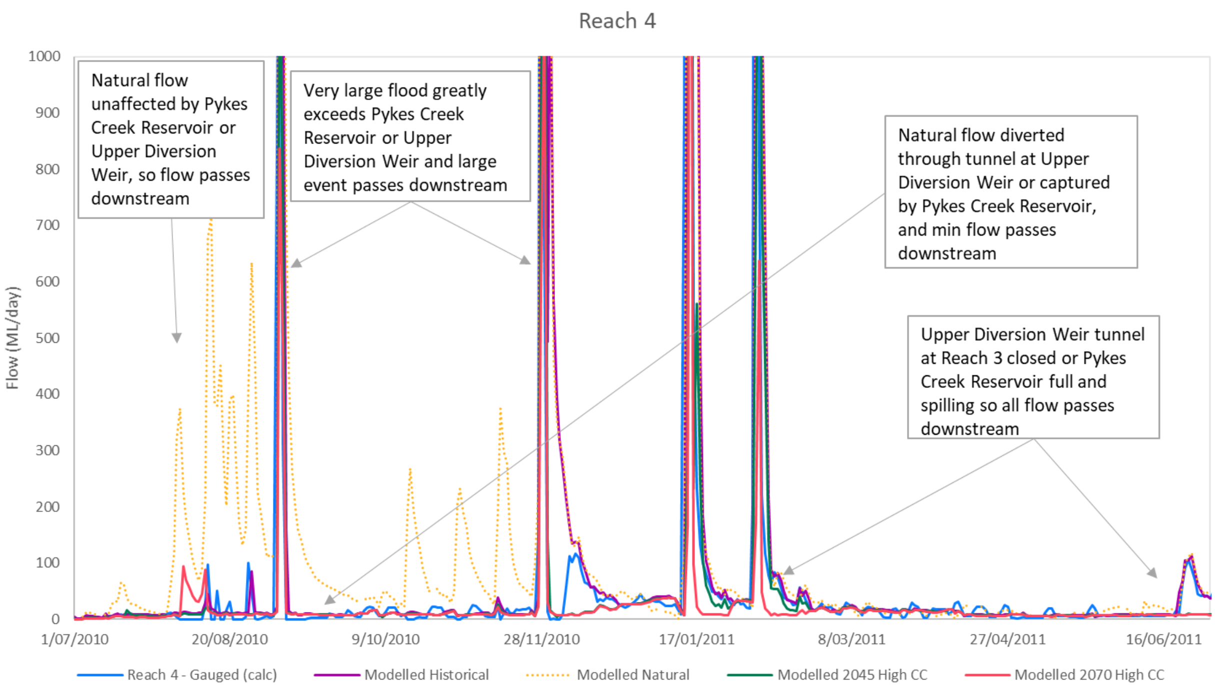



**Figure 7-3 Historical, natural and climate change daily flows between 2010 and 2011 for Reach 4**

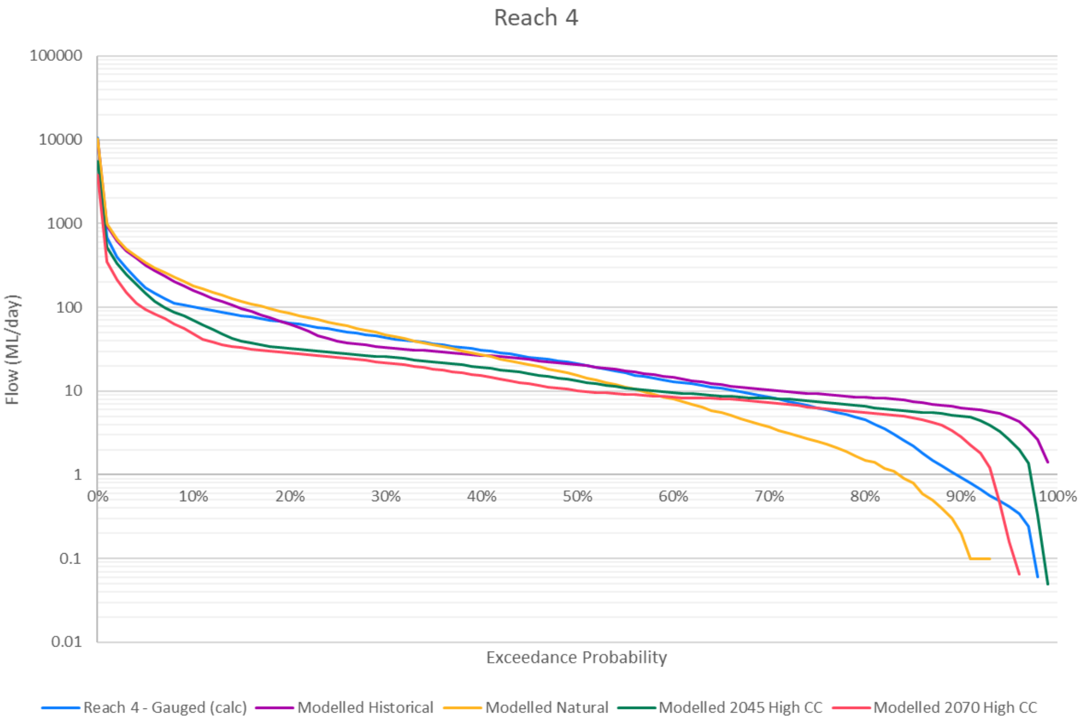



**Figure 7-4 Historical, natural and climate change daily flow duration curve for Reach considering the modelled time period (01/01/1900 – 31/12/2020)**

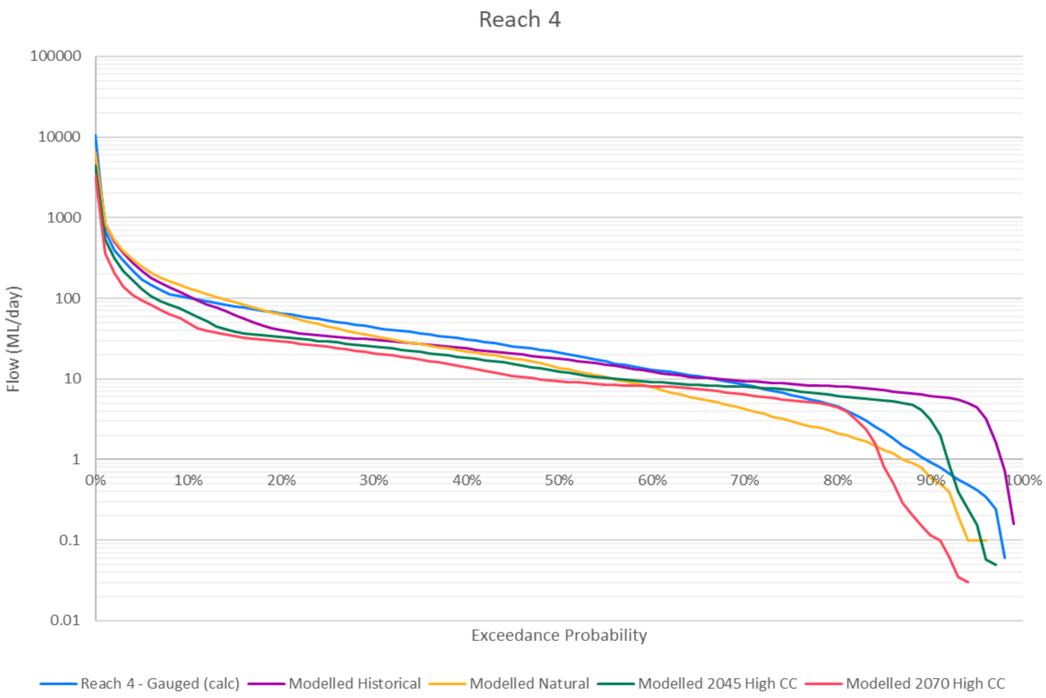



**Figure 7-5 Historical, natural and climate change daily flow duration curve for Reach 4 considering the modelled time period (16/05/1984 – 31/05/2016)**

## 7.3 Ecological objectives for Reach 4

### 7.3.1 Geomorphology

Werribee River (Wirribi Yaluk) in Reach 4 flows through a narrow, steep sided bedrock-controlled valley. Rock falls were evident at the margins of the valley indicating that there is a large supply of material direct from the valley walls. The morphology is highly variable, consisting of steep rapids, coarse riffles, deep and shallow pools and fast flowing runs in between. In some sections, flow is split around boulder/vegetated islands.

The objectives for geomorphology for Reach 4 are to: *Maintain channel dimensions, form and complexity; and maintain access to and quality of riffle and pool habitats*.

The flow components and functions required to achieve these objectives are summarised in Table 7-2.

Risks to objectives and flow are the impacts of regulation in reducing the magnitude, frequency and flows required to maintain extent and quality of riffle and pool habitats.

**Table 7-2 Reach 4 Geomorphology objectives**

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Maintain channel dimensions, form and complexity (G4.1) | Bankfull flow | Maintain gross channel dimensions and form channel features (i.e. pools, bars/riffles). (G4.1.1) | Winter-Spring |
| | Low flows to Freshes | Scour and maintain undercuts, exposed roots and large wood habitat. (G4.1.2) | All year |
| Maintain access to and quality of riffle and pool habitats (G4.2) | Low flows | Maintain extent of riffle and pool habitats (G4.2.1) | All year |
| | Freshes | Scour fine sediment and biofilms from riffles[1](G4.2.2) | All year |
| | High flow | Scour sediment from pools (G4.2.3) | Winter-Spring |

[1] Bed shear stress during fresh capable of moving silt from cobbles ($\tau_c$ > 15 N/m$^2$) and sand ($\tau_c$ > 8 N/m$^2$). Source: Appendix B of Ecological Associates (2005b)

### 7.3.2 Vegetation

The water-dependent, riparian and terrestrial vegetation of Reach 4 is the most diverse and intact of all those sites examined during the field inspection. In large part this is because in Reach 4 the stream flows through protected areas in the Werribee Gorge, where access is difficult and the streamside zone has not been markedly altered by agriculture, pastoral activities or urban development. Vegetation mapping available on the NatureKit website, summarised in the earlier Site paper, demonstrates the complexity and continuity of water-dependent vegetation in this reach of the Werribee River (Wirribi Yaluk). Water-dependent plant communities present is mostly EVC 851 Stream Bank Shrubland with some EVC 292 Red Gum Swamp, surrounded by a mosaic of terrestrial EVCs.

Because of the rocky substratum, confined nature of the bedrock-limited stream channel and episodically fast water flow, opportunities are limited for extensive beds of in-stream vegetation and fringing non-woody vegetation to develop in Reach 4. Nevertheless, small beds of emergent, rhizomatous fringing vegetation are common, as shown in the photograph below. Heavy densities of water-dependent woody vegetation, consisting of various species of bottlebrush, paperbark and tea-tree, line the stream (at least at the field inspection site) and produce a dense and continuous woody riparian zone throughout the Werribee Gorge stretch of the stream, consistent with the vegetation mapping available on the NatureKit webpage (See Figure 7-6 and Figure 7-7). Downstream, however, the stream-side zone becomes narrower and more fragmented.

**Figure 7-6 Instream and fringing vegetation including woody riparian zone, Reach 4**

**Figure 7-7 Instream and fringing vegetation, including emergent reeds, Reach 4**

The co-designed catchment program for the Werribee catchment region (Melbourne Water 2018, Figure 8) acknowledges these differences and includes two specific actions for streamside vegetation in Reach 4: (1) maintain the high-quality vegetation that exists in the upper and middle parts of the reach, and (2) establish or maintain vegetation buffers along the lower parts of the reach (see Melbourne Water 2018, Figure 8). The management objectives shown in Table 7-3 below acknowledges both intentions.

The objective for water-dependent vegetation for Reach 4 therefore is to: *Maintain existing high-value in-stream and fringing vegetation (woody and non-woody) and, for the downstream sections, provide a water regime that will facilitate the establishment (and subsequent maintenance) of stream-side and riparian vegetation undertaken as part of Melbourne Water's revegetation plans for the middle Werribee River*.

The flow components and functions required to achieve this objective are summarised in Table 7-3.

**Table 7-3 Reach 4 vegetation objectives**

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Maintain in-stream vegetation (V4.1) | Low flow | Maintain existing plant communities by providing deep pool habitat over winter-spring period (note that taxa such as Water Ribbons are well adapted to periodic cease-to-flow periods) and shallow pool habitat over summer-autumn (V4.1.1) | All year (higher in winter-spring than summer-autumn) |

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| | Freshes | Downstream dispersal of plant propagules (V4.1.2) | Winter-spring |
| Maintain fringing non-woody vegetation and, in lower parts of the reach, facilitate future revegetation efforts (V4.2) | Low flow | Maintain existing plant communities of reeds, rushes and sedges etc by providing inundated conditions along stream side over winter-spring period (note that many species of reed, rush and sedge are well adapted to periodic cease-to-flow periods) and damp conditions over summer-autumn<br><br>Facilitate future revegetation efforts of similar vascular plant species (V4.2.1) | All year (higher in winter-spring than summer-autumn) |
| | Freshes | Maintain existing plant communities of reeds, rushes and sedges etc over dry summer-autumn period<br><br>Facilitate future revegetation efforts of similar vascular plant species<br><br>Introduce hydrological variability and promote zonation of fringing plant communities as well as inundating the more elevated zones around stream perimeter<br><br>Downstream dispersal of plant propagules (V4.2.2) | All year (higher in winter-spring than summer-autumn) |
| Maintain fringing and riparian woody vegetation and, in lower parts of the reach, facilitate future revegetation efforts (V4.3) | Low flow | Maintain existing plant communities of bottlebrush, tea-tree and paperbark etc by providing damp conditions along streamside zone<br><br>Facilitate future revegetation efforts of similar vascular plant species (V4.3.1) | All year (higher in winter-spring than summer-autumn) |
| | Freshes | Maintain existing plant communities - bottlebrush, tea-tree and paperbark etc over dry summer-autumn period<br><br>Facilitate future revegetation efforts of similar vascular plant species<br><br>Introduce hydrological variability and promote zonation of fringing plant communities as well as inundating slightly elevated zones around stream perimeter<br><br>Downstream dispersal of plant propagules (V4.3.2) | All year (higher in winter-spring than summer-autumn) |
| Prevent encroachment of the stream channel by undesirable terrestrial species (V4.4) | Low flow | Prolonged inundation of stream channel will prevent colonisation of inundation-intolerant plant taxa, including bottlebrush, tea-tree and paperbark etc (V4.4.1) | Winter-spring |

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Provide ecological disturbance (V4.5) | Large fresh or Near-bankfull | Provide substantial ecological disturbance to scour sediments and in-stream boulders, disturb established vegetation and reset ecological communities (V4.5.1) | Winter-spring |

### 7.3.3 Macroinvertebrates and Water Quality

Reach 4 flows through Werribee Gorge, a narrow sided rocky valley with relatively intact riparian vegetation and a diversity of instream habitats. While flows are highly modified as a result of the upstream operation of Pykes Creek Reservoir, the reach maintains near permanent flows and supports a range of good quality habitat for macroinvertebrates. The reach also supports a native fish and platypus population for which the macroinvertebrates provide an important food source. The reach provides a diversity of pool, riffle and vegetation habitats. It is characterised by pools interspersed with fast flowing bedrock chutes, and riffles and runs with cobble, pebble and gravel substrate. Pools are fringed with emergent vegetation and in some areas contain undercut banks and submerged woody habitat. The reach represents relatively good habitat and water quality conditions for macroinvertebrate communities, and there is an opportunity to enhance populations in this reach.

The overall objective for macroinvertebrates in Reach 4 is to: *Maintain and where possible enhance the abundance and diversity of macroinvertebrate communities through the provision of flows that support habitat quality and availability, life cycle processes, and water quality.*

The flow components and functions required to achieve this objective are summarised in Table 7-4.

**Table 7-4 Water quality and macroinvertebrate objective**

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Maintain access to and quality of riffle and pool habitats (M4.1) | Low flows | Maintain extent and diversity of riffle and pool habitats, and avoid drying of critical habitats<br><br>Maintain connections between habitat areas<br><br>Maintain wetted width of channel and connection with instream and littoral vegetation<br><br>Maintain refuge habitat in deeper pools during dry periods (M4.1.1) | All year |
| | Freshes | Flush fine sediment from riffles to expose new surfaces, prevent infilling of interstitial spaces and provide quality habitat<br><br>Provide linkages between permanent and temporary pools to support distribution and abundance of macroinvertebrate communities (M4.1.2) | All year |
| | High flow | Scour sediment from pools<br><br>Fill temporary pools to support re-colonisation (M4.1.3) | Winter-Spring |

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Maintain water quality and important hydrological functions of current flow regime (M4.2) | Low flows | Maintain low flows to prevent an increase in cease-to-flow periods outside of natural range<br><br>Provide flows to prevent prolonged low flow periods that can result in decreased dissolved oxygen and increased salinity (M4.2.1) | All year |
| | Freshes | Maintain inputs of organic matter from upstream reaches and the catchment<br><br>Maintain water quality in pools during low flow periods<br><br>Flush accumulated organic matter and fine sediments (M4.2.2) | Several events throughout the year |
| | High Flows | Mobilise and transport particulate matter to downstream reaches<br><br>Provide recolonisation opportunities following low flow periods M4.2.3) | Winter-Spring |

### 7.3.4 Fish

Reach 4 flows through Werribee Gorge, where it is characterised by pools interspersed by fast flowing bedrock chutes and gravelly riffles and runs. Pools are fringed with emergent vegetation and in some areas contain undercut banks and submerged woody habitat. Flow is modified from natural as a result of the operational releases from Pykes Creek Reservoir, however, unlike upstream reaches, the regime is near permanent. The reach experiences persistent summer base flows as a result of releases from Pykes Creek Reservoir and increasing groundwater discharge to the waterway as it passes through the Werribee Gorge. Winter flows are lower and less variable than natural due to diversion of small and moderately sized freshes to Pykes Creek Reservoir, however larger flows that exceed the capacity of the diversion tunnel still occur and create some winter variability.

Reach 4 supports a diverse small-bodied native fish community, including River Blackfish, Mountain Galaxias, Common Galaxias, Flathead Gudgeon, Australian Smelt, Southern Pygmy Perch and Short-finned Eel (Jacobs 2022). Other than Short-finned Eel and Common Galaxias, migratory fish (e.g. Australian Grayling, Tupong, Lamprey, Spotted Galaxias and Climbing Galaxias) are absent from the reach due to downstream barriers to fish movement (the Lower Diversion Weir at Werribee, Melton Reservoir and the Bacchus Marsh Weir). Recent fish surveys in Reach 4 confirmed the presence of River Blackfish in the lower parts of the reach in a range of size classes indicating successful recruitment (James Shelley, Jacobs, pers. obs.). Anecdotal observations of River Blackfish have also been made in the upper parts of the reach, near the confluence with Pykes Creek (Korjamnunnip Creek) (Lisa Duncan, Melbourne Water, pers. com.). This suggest River Blackfish are likely to be distributed throughout the reach where suitable large pool habitat exists.

The sustained presence of River Blackfish in Reach 4 is notable. They prefer slow flowing pool habitat with cover provided by woody habitat and undercut banks, and a relatively stable flow regime. Higher flows are acceptable at times provided suitable cover is available for fish to seek shelter from fast currents. Within Reach 4 River Blackfish are likely to be restricted to the larger pools, such as those present within the lower parts of the reach (Figure 7-8a). The Millennium Drought is known to have resulted in a decline in the abundance of River Blackfish in the Werribee Gorge and recent surveys demonstrate recovery in the population, at least in the very lower parts of Reach 4 where large pool habitat (including that provided by the Bacchus Marsh Weir pool) persisted throughout the drought. Anecdotal observations suggest they also persisted higher in the reach. However, the presence of fast flowing water and natural barriers through the gorge (see Figure 7-8b) and the fact that River Blackfish typically have a high site fidelity, have poor swimming ability through fast flowing water and do not undertake large scale movement, means that populations throughout the reach are likely to be relatively isolated and individual populations would be at risk from prolonged cease-to-flow and climate change if their refuge pools were to dry out. Hence, objectives for Reach 4 are to protect the existing River Blackfish populations throughout the reach and maintain the broader native fish community likely to be present throughout the reach, including Short-finned Eel, Common Galaxias, Southern Pygmy Perch and Mountain Galaxias.

The specific Reach 4 objective for native fish is to: *Maintain the existing native fish community throughout Reach 4, including the specific protection of the River blackfish community throughout the Werribee Gorge by avoiding prolonged cease-to-flows (unless natural) and providing higher base flows and freshes at suitable times to enable local fish movement and opportunities for re-colonisation of areas that may have experienced cease-to-flows.*

The flow components and functions required to achieve this objective are summarised in Table 7-5.

Despite the more permanent flow regime, the reach is still exposed to rapid changes in flow as a result of operational releases from Pykes Creek Reservoir and an overall lower winter flow. Climate change that results in an increase the frequency and duration of cease-to-flows and very low flows is likely to represent the greatest risk the objectives through impacts on suitability of refuge habitat for sustaining River Blackfish. The lack of high flows is also likely to contribute to the accumulation of fine sediment on benthic surfaces (Figure 7-8c) that poses a risk to habitat quality for native fish and macroinvertebrates.

**Table 7-5 Reach 4 fish objectives**

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Protect the existing River Blackfish population in the lower Reach 4 and maintain the native indigenous fish community throughout the rest of the reach (e.g. Short-finned Eel, Common Galaxias, Southern Pygmy Perch, Mountain Galaxias) (F4.1) | Avoid prolonged cease-to-flow | Prevent loss of refuge pool habitat (F4.1.1) | Summer/autumn |
| | Summer Low flow | Maintain refuge pool habitat (F4.1.2) | Summer (cease-to-flows acceptable if natural – avoid prolonged/unnatural CtF) |
| | Winter Low flow | Maintain diversity of hydraulic habitats (i.e. pool, riffle, run)<br><br>Maintain connectivity (adequate depth) for local movement (F4.1.3) | Winter (ideally continuous and typically higher than summer) |
| | Freshes | Top-up/freshen water quality in refuge pools (F4.1.4) | Summer (especially if CtFs have occurred) |
| | Freshes-high flows | Flush accumulated sediments to maintain or improve quality and availability of habitat<br><br>Maintain connectivity (adequate depth) for local movement and recolonisation following periods of cease-to-flow (F4.1.5) | Any time |
| | Freshes-high flows | Maintain cues for downstream migration by adult Short-finned Eels (F4.1.6) | Throughout year, particularly Summer |

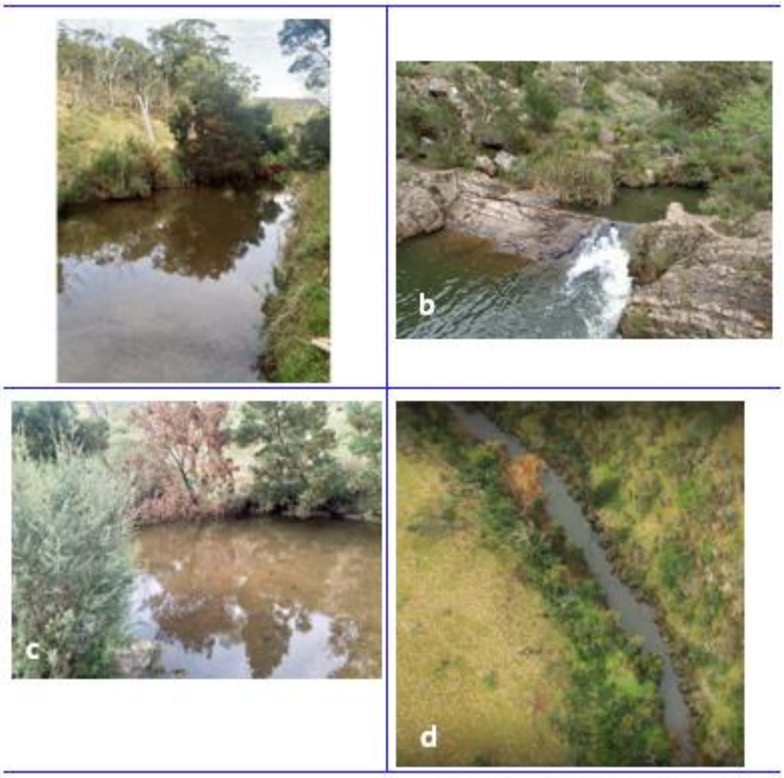



**Figure 7-8 Reach 4 characteristics – a) pool habitat in lower Reach 4 suitable for River Blackfish, b) rock bars that present a natural barrier to upstream movement, c) smothering of benthic habitat from accumulated fine sediment, d) pool habitat (from drone footage) in upper Reach 4 suitable for River Blackfish.**

### 7.3.5 Platypus

Although there is limited systematic data on platypuses, Reach 4 in Werribee Gorge appears to have been a refuge for platypuses throughout the Millennium Drought and is now a source population for recolonisation of reaches upstream and downstream. A small population seems to have persisted here throughout the Millennium Drought and is now expanding and re-colonising the Bacchus Marsh area (Reach 5). Reach 4 provides the best platypus habitat with permanent flows, deep pools, in-stream complexity (cobbled substrate, macrophytes, woody debris) and extensive riparian vegetation.

Reach 4 is characterised by permanent flows even during summer with baseflows maintained through water releases from Pykes Reservoir. Rocky substrate and banks and in-stream complexity provides diverse hydrology along the length of Reach 4 that would be important for supporting diverse and abundant food resources (macroinvertebrates). Habitat for platypuses is good with permanent baseflows, deeper pools throughout and healthy riparian and emergent vegetation.

The objective for Reach 4 is to: *Maintain platypus populations*. This should be considered a priority objective for the region as Reach 4 provides the best platypus habitat in the region and is a source population for the surrounding areas, particularly Reach 5.

The flow components and functions required to achieve this objective are summarised in Table 7-6.

**Table 7-6 Platypus objectives for Reach 4.**

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Maintain current platypus population (P4.1) | Low flows | Maintain refuge pools (P4.1.1) | Summer/autumn |
| | Low flows | Maintain habitat and longitudinal connectivity for platypuses and food resources (macroinvertebrates) (P4.1.2) | Winter/spring |
| | Freshes | Scour fine sediment, promote habitat diversity, support macroinvertebrate abundance and diversity (P4.1.3) | All year |
| | High flow | Scour sediment from pools, maintain refuge pools (P4.1.4) | Winter/early Spring |
| Prevent juvenile mortality (P4.2) | Bankfull/overbank flows | Prevent inundation of maternal burrows and drowning of nestling platypus (P4.2.1) | Nov-Mar |

## 7.4 Flow recommendations

### 7.4.1 Existing recommendations

Ecological Associates (2005) recommended an environmental flow regime for Reach 4 (Table 7-7). A review by Jacobs (2014) recommended two amendments to the 2005 recommendations.

First, the cease-to-flow recommendation was removed. The recommended cease-to-flow period is too short to meet its stated objective of drying out the beds of Typha and Phragmites that are already growing in the channel and preventing further expansion of those plants. The growth form and life history of these large emergent plants is such that they readily maintain moist soils and a quiescent, shaded and damp microclimate within their canopy that enable them to easily withstand short periods of desiccation. The recommended cease-to-flow is unlikely to harm any of the values identified in the middle reaches of the Werribee River (Wirribi Yaluk), but given it will not deliver any specific benefits, it was suggested for removal.

Second, the current environmental flow recommendations did not specifically consider the risk that high flows or floods may have on juvenile Platypus. Stabilising and increasing the Platypus population in the Werribee River (Wirribi Yaluk) is a very high management priority, but high flows during the breeding season can flood burrows and drown juveniles. The 2014 review suggested that the environmental flow recommendations for Reaches 4 and 5 should include several high freshes in July or August to encourage female Platypus to build their nests higher up the bank to reduce the risk of being flooded if higher flows are delivered in spring or summer. This 2022 review further considers this recommendation as presented below.

**Table 7-7 Original flow recommendations for Reach 4 (modified for clarity, see Appendix B for the complete original flow recommendations table).**

| Flow recommendations (REACH 4) | | | | | Rationale / objective |
|---|---|---|---|---|---|
| Season | Component | Magnitude | Frequency | Duration | |
| Feb-April | Cease-to-flow | 0 ML/day | 2 per year with a minimum separation of 7 days | 15 days each (30 days total per year)* | Curtail growing season of in-channel emergent macrophytes |
| Dec-May | Low flow | 10 ML/day* | All years except extended drought | Residual time after other flows | Wet the perimeter of riffles to provide habitat for macroinvertebrates<br>Maintain pool habitats for fish, macroinvertebrates and platypus<br>Maintain water quality in pools<br>Maintain natural hydrologic variability to maintain stable undercut banks and benches for fish and platypus. |
| Dec-Feb | Small freshes | 13 ML/day* | 2 per year with a minimum separation of 7 days | 5 days | Provide longitudinal connection between pools to allow River Blackfish fry to disperse throughout whole reach |
| Dec-May | Large freshes | 90 ML/day* | 2 per year with a minimum separation of 14 days | 1 day | Disturb in-stream emergent macrophytes to limit vegetation encroachment<br>Mobilise gravels on the streambed in riffles |
| Jun-Nov | Low flow | 29 ML/day* | All years | Residual time after other flows | Provide spawning habitat in pools for River Blackfish and adequate depth through riffles to allow adult River Blackfish to disperse between pools<br>Inundate full wetted perimeter of channel to sustain macrophytes in the channel and at the channel margins and to provide foraging habitat for Platypus. |
| Jul-Nov | Freshes | 245 ML/day* | 4 in Aug-Sep<br>2 in Oct-Dec with a minimum separation of 5 days | 2 days | Disturb in-stream emergent macrophytes to limit vegetation encroachment<br>Inundate benches frequently in winter and spring and less frequently towards summer to promote the growth of riparian shrubs and macrophytes<br>Mobilise gravels on the streambed in riffles and pools |
| Anytime | Bankfull flow | 3,160 ML/day | Natural (1 in 2 years) | 1 day | Rework sediment including gravels to maintain channel dimensions<br>Disturb shrub vegetation on channel benches and emergent macrophytes in the channel |

* Or natural if the natural magnitude or duration is less than what is specified.

### 7.4.2 Updated recommendations

The outcomes of the current assessment have identified a number of updates to the previous flow recommendations. he revised recommendations were also informed by updates to the hydraulic model to account for refined roughness conditions. Revised recommendations for are summarised in Table 7-9 and described in the following sections.

**Cease-to-flow**

As recommended in the Jacobs 2014 review the cease-to-flow recommendation was removed, and this is supported by the current review.

**Summer low flow**

A summer low flow of 10 ML/day was recommended in the 2005 flow study. This flow aims to fill and connect refuge pools, provide flow over riffles for macroinvertebrate habitat and provide opportunities for local fish movement. Based on our review of the hydraulic model there is no justification for changing this recommendation. Under current condition low flows up to 10 ML/day regularly occur across wet, average and dry years (Figure 7-9). However, these flows are mostly met by releases from Pykes Creek Reservoir to supply downstream irrigators. So changes to the future operation of Pykes Creek Reservoir, for example as a result in changes to irrigation demands and/or climate change impacts, especially in dry years, represents a potential risk to being able to maintain the current low flow regime and may result in more frequent occurrences of flows <10 ML/day and even cease-to-flows in very dry years.

**Summer fresh flow**

The 2005 flow study made recommendations for two types of summer fresh, a small fresh of 13 ML/day (2 events from Dec -Feb for 5 days) to provide connection between pools and a high fresh of 90 ML/day (2 events Dec-May for 1 day) to disturb instream vegetation and prevent encroachment of vegetation on the channel. The review of previous recommendations suggests the small fresh (13 ML/day) is not sufficiently different to the low flow recommendation of 10 ML/day and already regularly occurs in average/wet years. Furthermore, based on modelling and observations of current channel form, the high fresh (90 ML/day) is unlikely to seriously disturb instream macrophytes – these are more established now than previously (i.e. this is a change in the environment from when the previous recommendations were set). We have revised this recommendation to 50 ML/day for 8 events of 2 days duration in wet and average climate years and 6 events of 2 days duration in dry climate years. The increase in frequency and duration of summer freshes will improve conditions for macroinvertebrates, fish and platypus by increased habitat availability, improve longitudinal connectivity, increase hydrological variability.

Under current condition flows regularly exceed 50 ML/day (Figure 7-10). However, these flows are mostly met by releases from Pykes Creek Reservoir to supply downstream irrigators. So any changes to the future operation of Pykes Creek Reservoir, for example as a result in changes to irrigation demands and/or climate change impacts, especially in dry years, represents a potential risk to being able to maintain the current low flow regime and may result in a reduction in the frequency of events >50 ML/day.

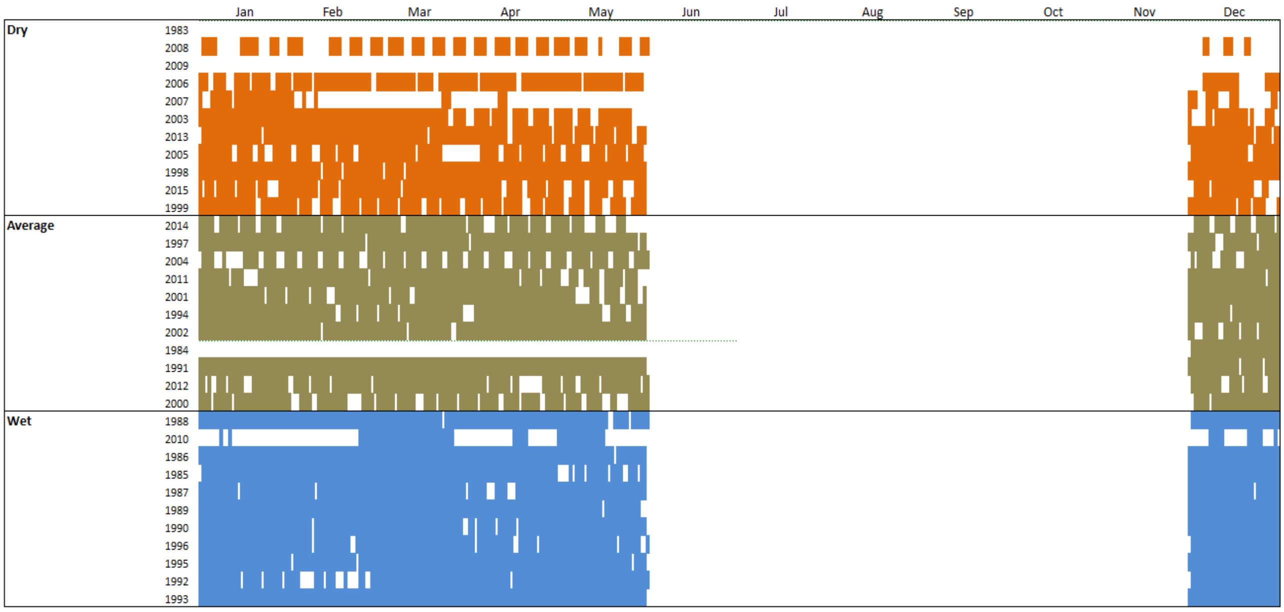



**Figure 7-9 Spells Analysis for summer low flows (>10 ML/day) for Reach 4 and dry, average and wet years using gauge data**

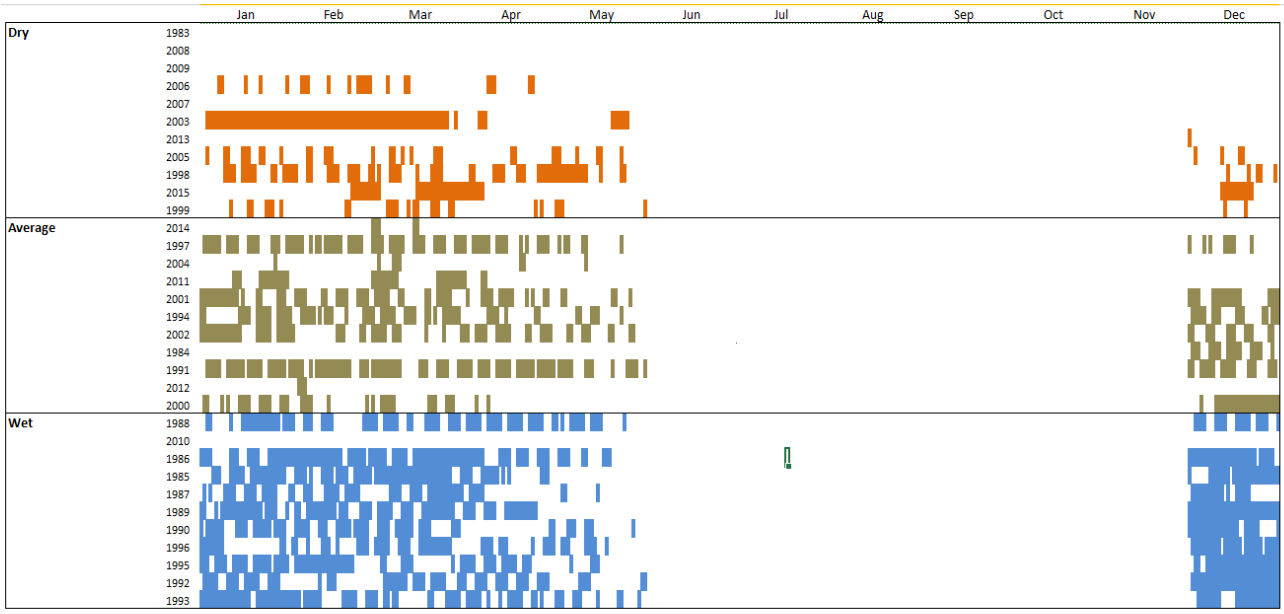



**Figure 7-10 Spells Analysis for summer freshes (>50 ML/day) for Reach 4 and dry, average and wet years using gauge data**

**Winter low flow**

A winter low flow of 29 ML/day or natural, based on upstream flow, was recommended in the 2005 flow study. This flow aims to provide continuous flow along the reach for the duration of the season and high flows up the bank for vegetation. Based on our review we have retained the current recommendation (rounded to 30 ML/day) for dry and average climate years, but increased the magnitude of the low flow recommendation to 50 ML/day in wet years in order to introduce more seasonal variation and provide greater opportunities for fish and platypus movement in wet years.

**Winter fresh and high flow**

A winter fresh of 245 ML/day, 6 per year for 2 days duration each was recommend in the 2005 flows study with 4 of these to occur in August-September and 2 in October-December. A flow of this magnitude is sufficient to scour sediment and biofilm, improving the quality of pool and riffle habitat, provide moisture to vegetation higher up the bank and extend opportunities for fish and platypus movement. The timings were recommended to ensure cues for migratory fish movement were provided at appropriate times of the year.

We have retained the 245 ML/day magnitude recommendation for dry and average climate years with a recommendation for 6 events over the winter / spring period (one per month). However we have adjusted the duration of events to 2 days in dry years and 5 days in average years. For wet years we recommend that two of the events reach a magnitude or 500 ML/day for 5 days and 4 events reach 245 ML/day for 10 days duration. The rational for event duration is based on the current duration of spells above the recommended magnitude (Table 7-8). The higher recommended fresh volume in wet years reflects naturally higher flows in wet climate conditions, and the opportunity to capture natural inter-annual variation in flow recommendations.

**Table 7-8 Exceedance Percentiles for Spells analysis of winter fresh events used to inform duration of fresh events in dry, average and wet years**

| Percentile | Duration (> 245 ML/day) | Duration (> 500 ML/day) |
|---|---|---|
| 25% | Approximately 2 days | Approximately 1 day |
| 50% | Approximately 4- 5 days | Approximately 3 days |
| 75% | Approximately 10 days | Approximately 5 days |

We have also removed the specific timing requirements for these event; the presence of a large number of downstream barriers to fish movement mean the ability for migratory fish to reach this far upstream are limited, and timing events specifically for native fish migration are not an imperative. However, if downstream barriers to movement are addressed or environmental flows are being delivered via Reach 4 to downstream reaches for the specific purpose of encouraging fish migration, then freshes in Reach 4 can be timed to facilitate flows for downstream objectives. These recommendations introduce a more variable pattern that also considers differences in flow patterns between dry, average and wet years. There is therefore no recommendation for the events to be delivered in a particular order.

A bankfull flow of 3,160 ML/day, once every 2 years for 1 day duration each was recommended in the 2005 flow study. Updated modelling indicates that flows >1400 ML/day are sufficient to meet bankfull requirements across the reach (Figure 7-11).

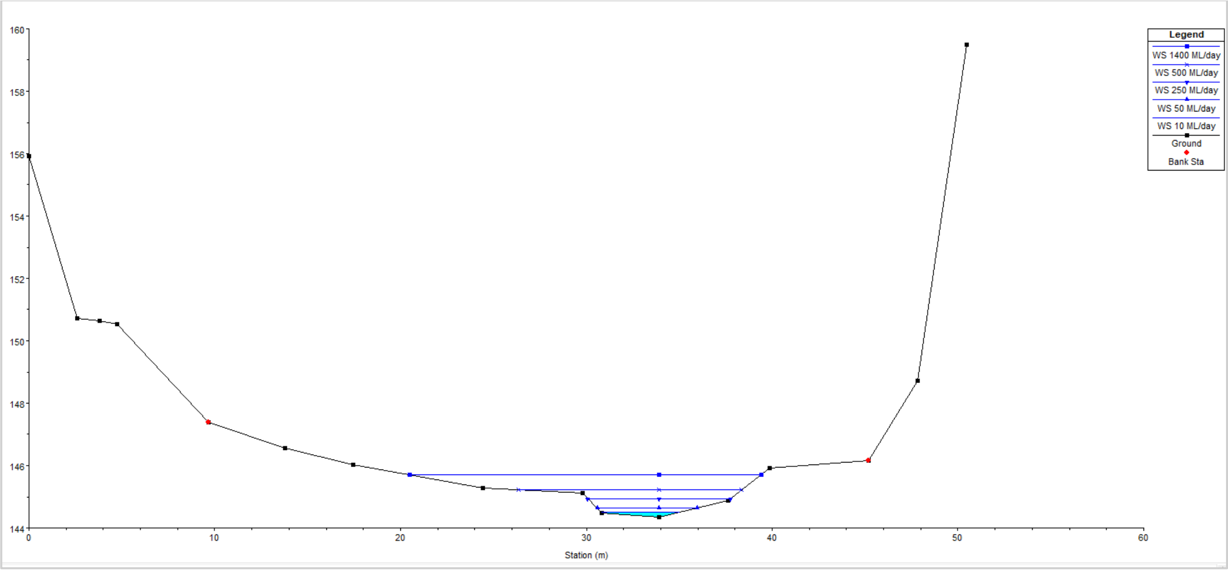



**Figure 7-11 Cross-section output from the hydraulic model for Reach 4 cross-section 5, showing channel profile and modelled water surface levels for bankfull event of 1400 ML/day**

This magnitude is also more consistent with bankfull flow estimates for Reach 5 further downstream (see Section 8.4). Hence, we have revised the bankfull flow recommendation to a minimum 1400 ML/day, although higher flows would be expected to occur, particularly in wet years.

We have also refined the frequency and duration to account for climate conditions, a bankfull flow would be expected to occur at least once in a wet year for 2 days, once every two to three years in an average year for 1 to 2 days and would not be expected to occur in a dry year (Figure 7-12). In terms of timing, it would be preferable for bankfull flows to occur in July to September in order to avoid periods of time when platypus juveniles are in burrows and could be drowned (October onwards). However, it is recognised that bankfull flows are not likely to be actively delivered and would only occur naturally based on upstream flows.


**Figure 7-12 Spells Analysis for a bankfull event (>1400 ML/day) for Reach 4 for dry, average and wet years using gauge data**

The final flow recommendations for the reach are summarised in Table 7-9**.** For each flow recommendation, the ecological objectives it is intended to achieve are listed, using codes for the specific ecological objectives listed in Section 7.3. A code has been allocated to each specific objective for geomorphology, vegetation, macroinvertebrates and water quality, fish and platypus as listed in Tables 7-2 to 7-6; these objective codes are cross referenced with each flow recommendation component in the table below.

**Table 7-9: Revised summary recommendations**

| Season | Flow | Objective/Function | Wet/Avg/Dry | Volume ML/day | Frequency and timing | Duration | Ecological objectives |
|---|---|---|---|---|---|---|---|
| Summer / Autumn (Dec-May) | Low flow | Maintain access to and protect diversity of habitat (pools, riffles, undercuts, large wood) and vegetation for bugs, fish (River Blackfish, Mountain Galaxias, Australian Smelt, Short-finned Eel) and platypus. Maintain capacity of the stream to process organic matter. Maintain inundated stream channel to prevent colonisation by inundation-tolerant terrestrial vegetation. | Wet/Avg | 10 | 100% of days | | **(G4.1.2, G4.2.1, V4.1.1, V4.2.1, V4.3.1, M4.1.1, M4.2.1, F4.1.1, F4.1.2, P4.1.1)** |
| | | | Dry | 10 | 100% of days | | |
| | Fresh | Maintain quality of riffle and undercut habitats by periodically scouring sediment & biofilms, maintain fringing and riparian non-woody vegetation, provide opportunities for fish movement. Mobilise and transport particulate organic matter to downstream reaches. | Wet/Avg | 50 | 8 (every 3 weeks) | 2 days | **(G4.1.2, G4.2.2, V4.2.2, V4.3.2, M4.1.2, M4.2.2, F4.1.4, F4.1.5, F4.1.6, P4.1.3)** |
| | | | Dry | 50 | 6 (every month) | 2 days | |
| Winter / Spring (Jun-Nov) | Low flow | Higher flows increase access to habitat for bugs, fish and platypus. Maintain capacity of the stream to process organic matter. Maintain inundated stream channel to prevent colonisation by inundation-tolerant terrestrial vegetation. | Wet | 50 | 100% of days | | **(G4.1.2, G4.2.1, V4.1.1, V4.2.1, V4.3.1, V4.4.1, M4.1.1, M4.2.1, F4.1.3, P4.1.2)** |
| | | | Avg / Dry | 30 | 100% of days | | |
| | Fresh | Maintain quality of riffle and undercut habitats by periodically scouring sediment & biofilms, maintain fringing and riparian non-woody vegetation, provide opportunities for fish movement. Mobilise and transport particulate organic matter to downstream reaches | Wet | 245<br>500 | 4<br>2 | 10 days<br>5 days | **(G4.1.2, G4.2.2, G4.2.3, V4.1.2, V4.2.2, V4.3.2, V4.5.1, M4.1.2, M4.1.3, M4.2.2, M4.2.3, F4.1.5, F4.1.6, P4.1.3, P4.1.4)** |
| | | | Avg | 245 | Every month | 5 days | |
| | | | Dry | 245 | Every month | 2 days | |

| Season | Flow | Objective/Function | Wet/Avg/Dry | Volume ML/day | Frequency and timing | Duration | Ecological objectives |
|---|---|---|---|---|---|---|---|
| | Bankfull | Scour fine sediment from pools, engage higher channel surfaces and secondary flow channels/terraces, flush organic material that has accumulated in these areas. | Wet | 1400-3000 | 1 event | 2 days | **(G4.1.1, V4.5.1)** |
| | | | Avg | 1400 | 1 every 2 years | 1-2 days | |
| | | | Dry | Not expected to occur | | | |

As for the previous Reaches, each flow recommendation in the summary table for the Reach (Table 7-9) is cross referenced to the specific ecological objectives it is intended to achieve, using codes for the specific ecological objectives listed in Section 7.3. A code has been allocated to each specific objective for geomorphology, vegetation, macroinvertebrates and water quality, fish, and platypus as listed in Tables 7-2 to 7-6.

These are summarised below for each component:

**Summer / Autumn (Dec-May**

**Low Flow**

- Scour and maintain undercuts, exposed roots and large wood habitat; maintain extent of riffle and pool habitats (**Geomorphology**)
- Maintain existing plant communities by providing deep pool habitat over winter-spring period (note that taxa such as Water Ribbons are well adapted to periodic cease-to-flow periods) and shallow pool habitat over summer-autumn; maintain existing plant communities of reeds, rushes and sedges etc by providing inundated conditions along stream side over winter-spring period (note that many species of reed, rush and sedge are well adapted to periodic cease-to-flow periods) and damp conditions over summer-autumn; facilitate future revegetation efforts of similar vascular plant species; maintain existing plant communities of bottlebrush, tea-tree and paperbark etc by providing damp conditions along streamside zone; facilitate future revegetation efforts of similar vascular plant species (**Vegetation**)
- Maintain extent and diversity of riffle and pool habitats, and avoid drying of critical habitats; maintain connections between habitat areas; maintain wetted width of channel and connection with instream and littoral vegetation; maintain refuge habitat in deeper pools during dry periods; maintain low flows to prevent an increase in cease-to-flow periods outside of natural range; provide flows to prevent prolonged low flow periods that can result in decreased dissolved oxygen and increased salinity (**Macroinvertebrates and water quality**)
- Prevent loss of refuge pool habitat; maintain refuge pool habitat (**Fish**)
- Maintain refuge pools (**Platypus**)

**Fresh**

- Scour and maintain undercuts, exposed roots and large wood habitat; scour fine sediment and biofilms from riffles (**Geomorphology**)
- Maintain existing plant communities of reeds, rushes and sedges etc over dry summer-autumn period; facilitate future revegetation efforts of similar vascular plant species; introduce hydrological variability and promote zonation of fringing plant communities as well as inundating the more elevated zones around stream perimeter; downstream dispersal of plant propagules; maintain existing plant communities - bottlebrush, tea-tree and paperbark etc over dry summer-autumn period; facilitate future revegetation efforts of similar vascular plant species. Introduce hydrological variability and promote zonation of fringing plant communities as well as inundating slightly elevated zones around stream perimeter (**Vegetation**)

- Flush fine sediment from riffles to expose new surfaces, prevent infilling of interstitial spaces and provide quality habitat; provide linkages between permanent and temporary pools to support distribution and abundance of macroinvertebrate communities; maintain inputs of organic matter from upstream reaches and the catchment; maintain water quality in pools during low flow periods; flush accumulated organic matter and fine sediments (**Macroinvertebrates and water quality**)

- Top-up/freshen water quality in refuge pools; flush accumulated sediments to maintain or improve quality and availability of habitat; maintain connectivity (adequate depth) for local movement and recolonisation following periods of cease-to-flow; maintain cues for downstream migration by adult Short-finned Eels (**Fish**)

- Scour fine sediment, promote habitat diversity, support macroinvertebrate abundance and diversity (**Platypus**)

**Winter / Spring (Jun-Nov)**

**Low flow**

- Scour and maintain undercuts, exposed roots and large wood habitat; maintain extent of riffle and pool habitats (**Geomorphology**)

- Maintain existing plant communities by providing deep pool habitat over winter-spring period (note that taxa such as Water Ribbons are well adapted to periodic cease-to-flow periods) and shallow pool habitat over summer-autumn; maintain existing plant communities of reeds, rushes and sedges etc by providing inundated conditions along stream side over winter-spring period (note that many species of reed, rush and sedge are well adapted to periodic cease-to-flow periods) and damp conditions over summer-autumn; facilitate future revegetation efforts of similar vascular plant species; maintain existing plant communities of bottlebrush, tea-tree and paperbark etc by providing damp conditions along streamside zone; facilitate future revegetation efforts of similar vascular plant species; Prolonged inundation of stream channel will prevent colonisation of inundation-intolerant plant taxa, including bottlebrush, tea-tree and paperbark etc (**Vegetation**)

- Maintain extent and diversity of riffle and pool habitats, and avoid drying of critical habitats; maintain connections between habitat areas.; maintain wetted width of channel and connection with instream and littoral vegetation; maintain refuge habitat in deeper pools during dry periods; maintain low flows to prevent an increase in cease-to-flow periods outside of natural range; provide flows to prevent prolonged low flow periods that can result in decreased dissolved oxygen and increased salinity (**Macroinvertebrates and water quality**)

- Maintain diversity of hydraulic habitats (i.e. pool, riffle, run); maintain connectivity (adequate depth) for local movement (**Fish**)

- Maintain habitat and longitudinal connectivity for platypuses and food resources (macroinvertebrates) (**Platypus**)

**Fresh**

- Scour and maintain undercuts, exposed roots and large wood habitat; scour fine sediment and biofilms from riffles; scour sediment from pools (**Geomorphology**)

- Downstream dispersal of plant propagules; maintain existing plant communities of reeds, rushes and sedges etc over dry summer-autumn period; facilitate future revegetation efforts of similar vascular plant species; introduce hydrological variability and promote zonation of fringing plant communities as well as inundating the more elevated zones around stream perimeter; maintain existing plant communities over dry summer-autumn period; facilitate future revegetation efforts of similar vascular plant species. Introduce hydrological variability and promote zonation of fringing plant communities as well as inundating slightly elevated zones around stream perimeter; provide substantial ecological disturbance to scour sediments and in-stream boulders, disturb established vegetation and reset ecological communities (**Vegetation**)

- Flush fine sediment from riffles to expose new surfaces, prevent infilling of interstitial spaces and provide quality habitat; provide linkages between permanent and temporary pools to support distribution and abundance of macroinvertebrate communities; scour sediment from pools; fill temporary pools to support re-colonisation; maintain inputs of organic matter from upstream reaches and the catchment; maintain water quality in pools during low flow periods; flush accumulated organic matter and fine sediments; mobilise and transport particulate matter to downstream reaches; provide recolonisation opportunities following low flow periods (**Macroinvertebrates and water quality**)

- Flush accumulated sediments to maintain or improve quality and availability of habitat; maintain connectivity (adequate depth) for local movement and recolonisation following periods of cease-to-flow; maintain cues for downstream migration by adult Short-finned Eels (**Fish**)
- Scour fine sediment, promote habitat diversity, support macroinvertebrate abundance and diversity; scour sediment from pools, maintain refuge pools (**Platypus**)

**Bankfull**

- Maintain gross channel dimensions and form channel features (i.e. pools, bars/riffles) (**Geomorphology**)
- Provide substantial ecological disturbance to scour sediments and in-stream boulders, disturb established vegetation and reset ecological communities (**Vegetation**)

## 7.5 Flow delivery constraints

The ecological objective for this reach is to: *Protect, maintain and enhance geomorphic values and the stream channel, and the aquatic biota it supports through delivery of an appropriate flow regime from upstream reaches.*

The primary constraint in flow delivery to Reach 4 is the impact of flow extraction, regulation and modification in upstream reaches. Reach 4 flows are impacted by the weir diversions and subsequent reductions in flow in Reach 3, and also receives seasonally reversed flows and flow reduction from Reach 2.

There are no environmental entitlements or storage and delivery mechanisms by which Melbourne Water can deliver flows to the Reach directly; management and achievement of flow recommendations in the reach is therefore constrained primarily by management options in the upper reaches. Flows can be delivered to the reach via releases from Pykes Creek Reservoir that pass down Reach 2 and into Reach 4, but the ability to do this is limited by the operational requirements of the irrigation delivery, and the lack of environmental entitlement in the reservoir. Similarly, additional flows provided to Reach 3 via changes in the operation of the Upper Diversion Weir would also provide benefits in terms of additional flows to Reach 4. Addressing the constraints on flow delivery to Reach 2 and Reach 3 therefore represent the primary mechanism by which Reach 4 flows can be managed.

# 8. Reach Five

## 8.1 Reach Description

**Reach Five – Werribee River (Wirribi Yaluk) from Bacchus Marsh Weir to the confluence with the Lerderderg River.**

Reach 5 starts immediately downstream of the Bacchus Marsh Weir and extends through Bacchus Marsh to the confluence with the Lerderderg River. Flow is modified from natural as a result of diversions from the Bacchus Marsh Diversion Weir to supply irrigation demands. A near-permanent flow regime is maintained except in the driest years, when cease-to-flow periods can occur but refuge pools persist.

There are existing flow recommendations for Reach 5, which were set in 2005, and revised by Jacobs in 2014 with minor amendments. The EFTP visited the existing Reach 5 survey and model site, which is located in Bacchus Marsh near the O'Leary's Way/ Hallett's Way road crossing. Since the original survey and model work was completed, there has been substantial urban development in the area. The original road crossing has been upgraded and a new bridge constructed over the river at the original site. There has been rapid and extensive urban development in the Bacchus Marsh area and construction of substantial areas of housing development in the immediate vicinity of the Reach 5 Assessment site. In addition to diversions from the weir resulting in lower and less variable flows through the reach, there are now risks to flow-related values based on the urban development. The extent of urban development means that runoff and flow patterns could be significantly modified as a result of an increase in impervious area in the catchment. This is likely to result in lower baseflows, but higher and more rapid peak flows. There are additional risks to water quality during construction (largely through runoff from disturbed ground transporting large sediment loads into the river) and also after completion (from urban runoff and transport of pollutants from urban areas).

Based on inspection of the reach during the EFTP site visit, the original assessment site was considered to be sufficiently representative of the reach. Changes to the bridge crossing at the original assessment site will be considered in the review and update of the modelling which underpins the original flow recommendations. Ecological objectives have been developed based on the original reach and assessment site, with additional focus on risks that have arisen in recent years due to the changes in land use and more extensive urban development.

## 8.2 Hydrology

Reach 5 is between the Bacchus Marsh Weir and the confluence with the Lerderderg River. Observed daily streamflow data for Reach 5 was obtained from the BoM Water Data Online and DELWP Water Monitoring Information System, while modelled data was extracted from the Werribee Source model provided by DELWP. Details of the relevant streamflow data and generation is presented in Table 8-1. For more information regarding the streamflow derivation, readers are referred to the Jacobs (2022).

**Table 8-1 Reach 5 streamflow data**

| ID | Type | Description | Time Period |
|---|---|---|---|
| 1 | Observed | Observed Historical Scenario<br>The timeseries flow for Reach 5 is the gauge data from gauge 231200B (Werribee River at Bacchus Marsh) | 24/06/1978 – 16/03/2022 (approximately 44 years of data) |
| 2 | Modelled | Historical Scenario | 01/01/1900 – 31/12/2020 (120 years of data) |
| 3 | Modelled | Natural Scenario (modelled with extractions turned off, water passing through storages, and stormwater, recycled water, Melbourne Supply and farm dam impacts turned off) | |
| 4 | Modelled | 2045 High Projection Climate Change Scenario. | |
| 5 | Modelled | 2070 High Projection Climate Change Scenario. | |

The hydrograph and mean monthly daily flow for the range of scenarios is shown in Figure 8-1 and Figure 8-2. The impact of the upstream regulation (i.e. Pykes Creek Reservoir, Upper Diversion Weir and Bacchus Marsh Weir) is noticeable in all months with the mean daily flows modelled historical lower than modelled natural.

A shorter period between from 2010 to 2011 was selected in Figure 8-3 to highlight the regulated nature of the Reach 5, where several fresh events do not occur naturally down the main river stem due to regulation in the modelled historical scenario versus natural scenario. Like the upstream reaches, once Pykes Creek Reservoir is full, the natural and historical scenarios are similar as indicated by the last three fresh events.

Assuming a cease-to-flow of <0.5 ML/day, Reach 5 varies little in cease-to-flows when comparing modelled historical and natural at approximately 5% (see Figure 8-4). The impact of regulation can be seen in the flow duration curve, with higher lows flows historically compared to the modelled natural scenario due to constant releases made to meet consumptive user demands in summer months, and lower high flows historically as fresh events are captured by the upstream reservoir.

Considering 2045 and 2075 high projection climate change scenario, the mean monthly daily flows reduced significantly ranging approximate 15-75% in winter spring months, however in summer autumn month the reduction is approximately 13-70% (see Figure 8-2). Cease-to-flows under climate change are increased further by 5% in 2045 and 10% in 2070, respectively (see Figure 8-4). A similar trend is found in Figure 8-5, when comparing the scenarios over only over the observed time period (24/06/1978 – 16/03/2022). It can be seen that the modelled historical and gauged data are relatively similar and that the climate change scenarios have lower flows compared to the historical as to be expected.

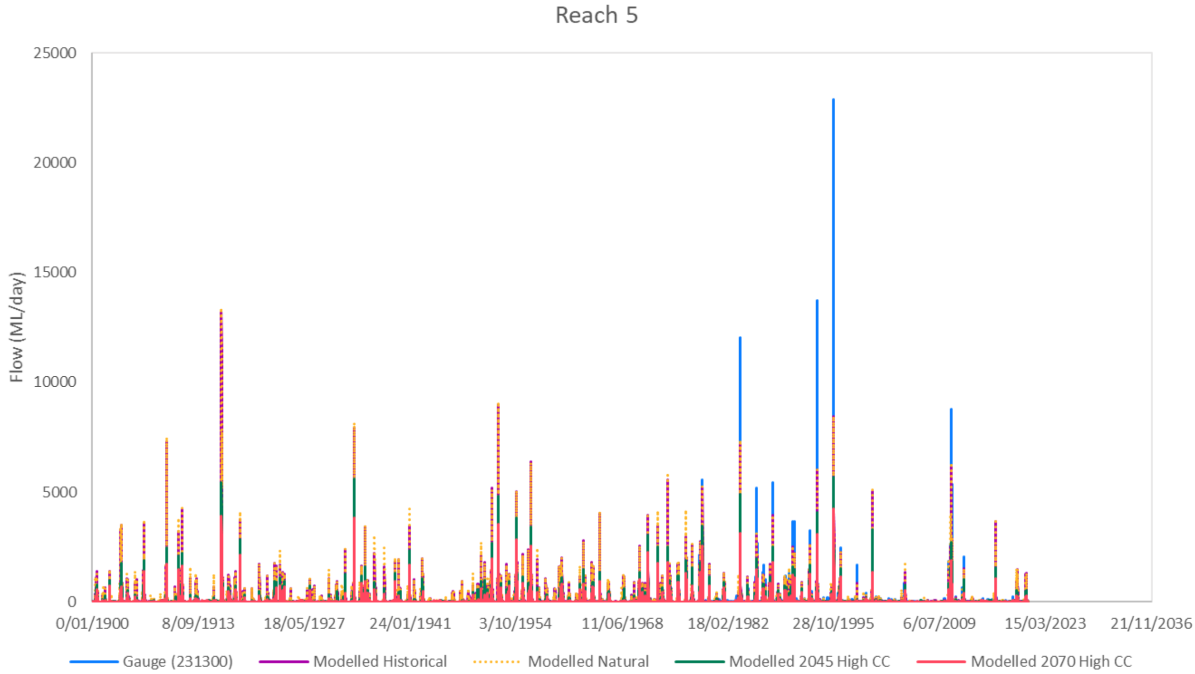



**Figure 8-1 Historical, natural and climate change daily flows for Reach 5**

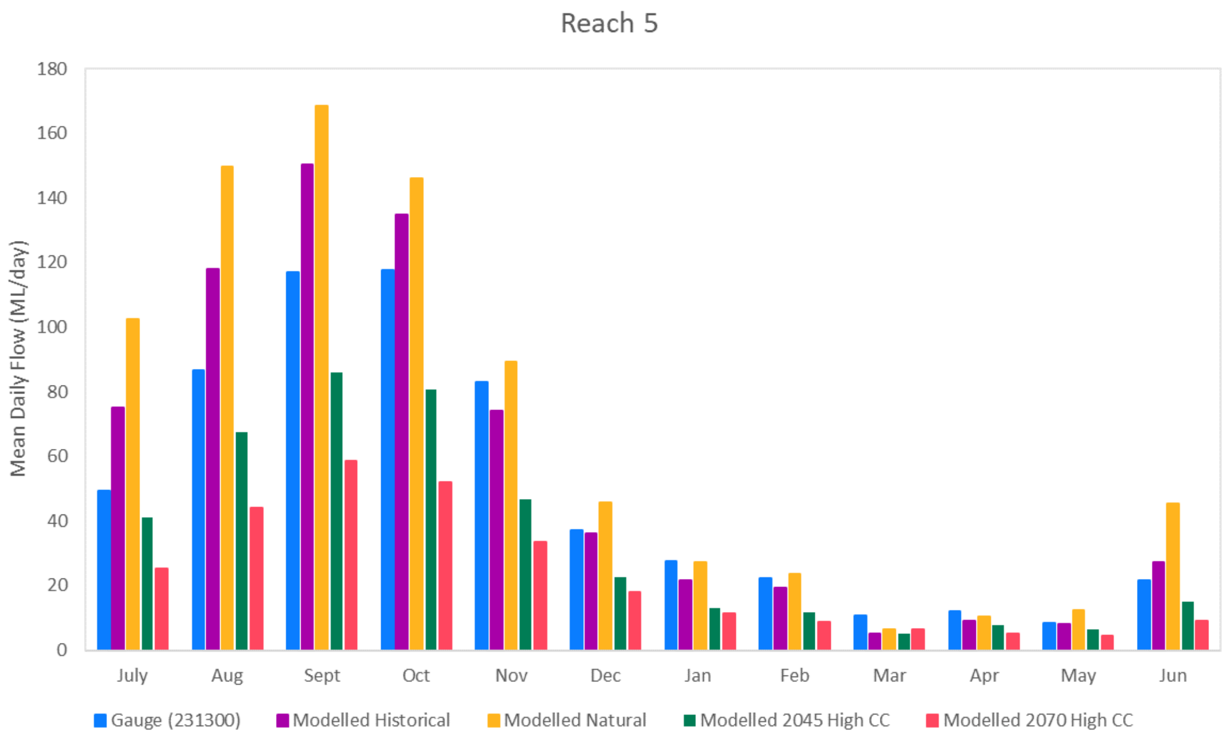



**Figure 8-2 Historical, natural and climate change mean monthly daily flows for Reach 5 considering the modelled time period (24/06/1978 – 16/03/2022)**

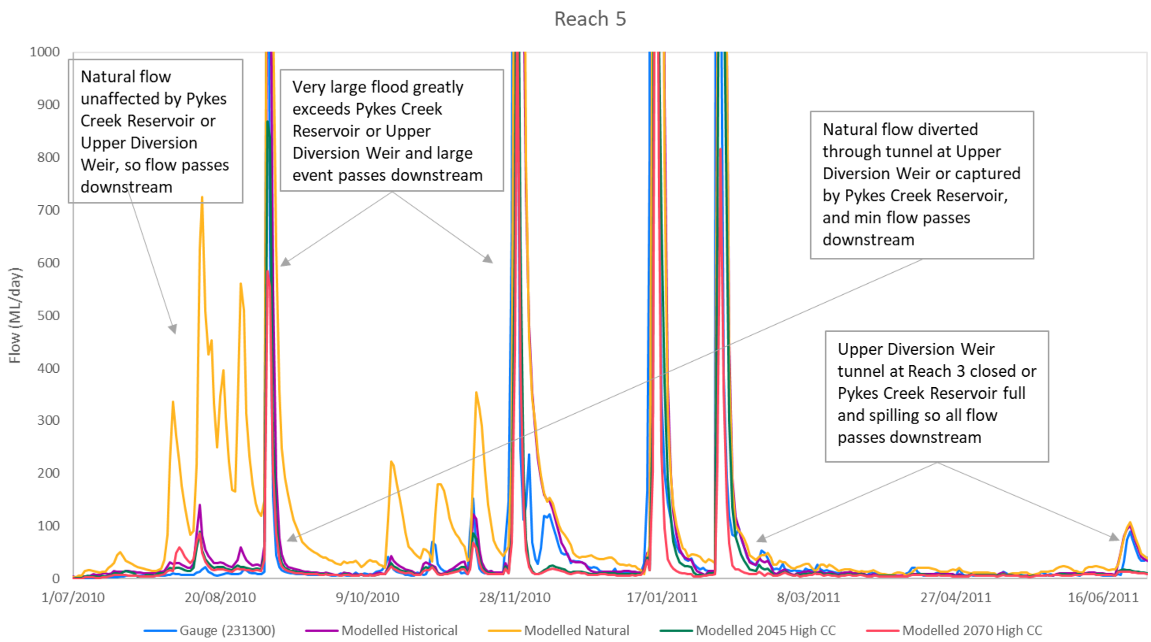



**Figure 8-3 Historical, natural and climate change daily flows between 2010 and 2011 for Reach 5**

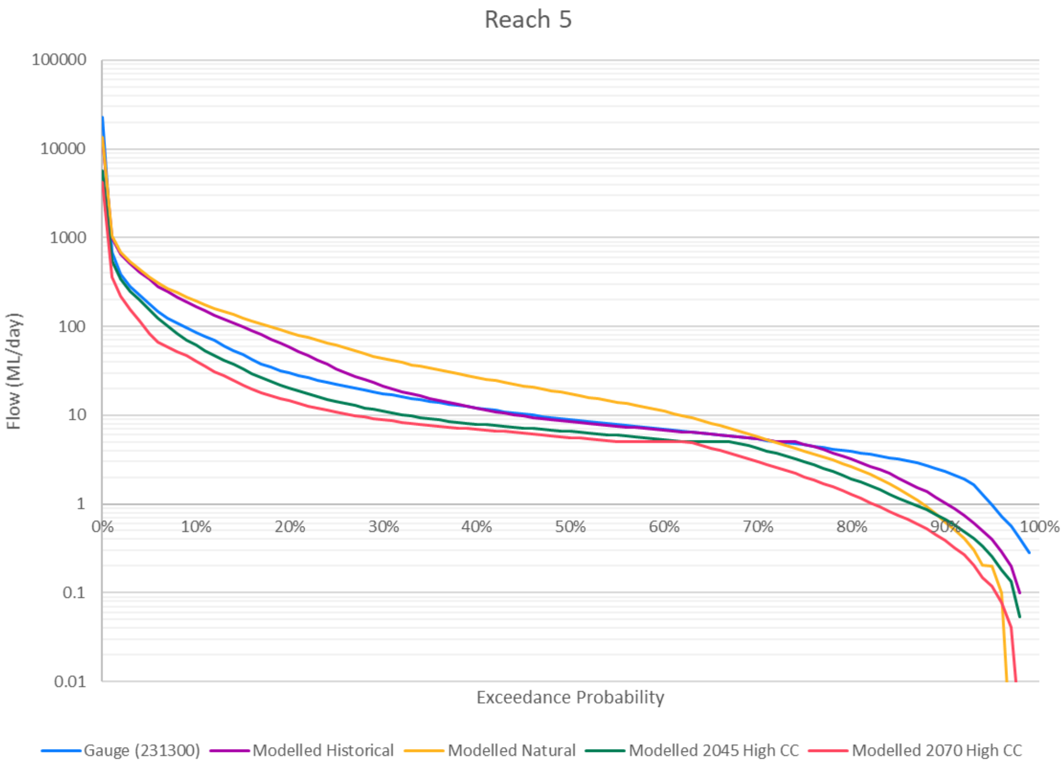



**Figure 8-4 Historical, natural and climate change daily flow duration curve for Reach 5 considering the modelled time period (01/01/1900 – 31/12/2020)**

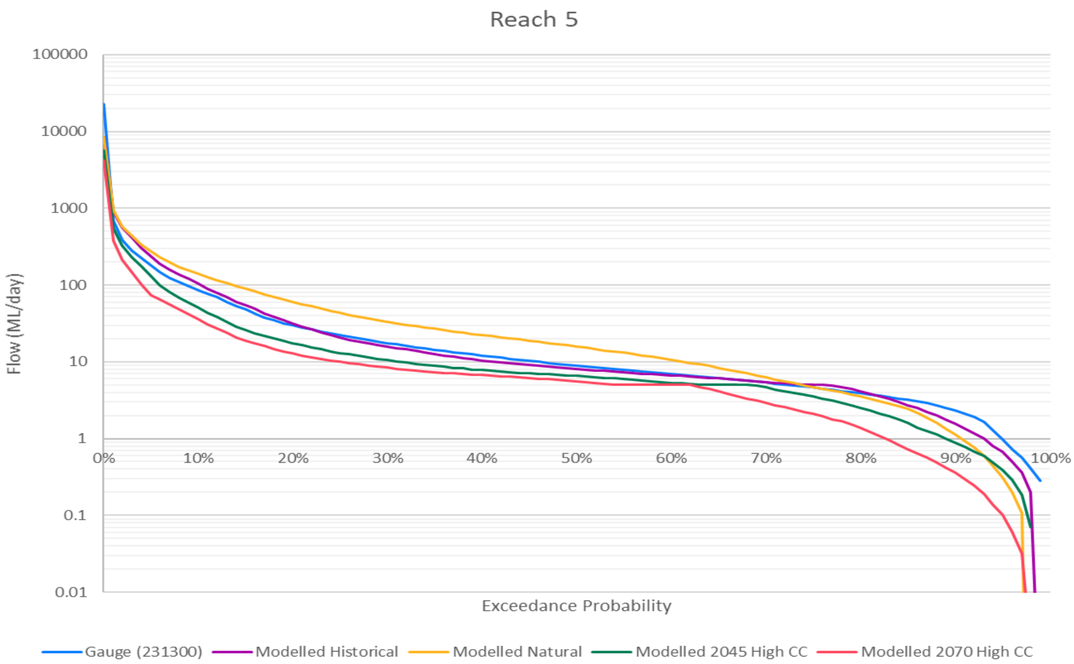



**Figure 8-5 Historical, natural and climate change daily flow duration curve for Reach 5 considering the modelled time period (24/06/1978 – 16/03/2022)**

## 8.3 Proposed objectives for Reach 5

### 8.3.1 Geomorphology

Werribee River (Wirribi Yaluk) in this reach meanders through an alluvial plain, the plain is inset with an incised valley. The FLOWS Assessment site was previously described by Ecological Associates (2005a) as having a stream morphology, consisting of coarse riffles, pools and runs. Bed substrates surveyed at riffles ranged from gravels to cobbles. At the time of our inspection, water levels were high and the water turbid, and as such it was not possible to observe the characteristics of riffles. Reeds also appear to have encroached into the channel.

The objectives for geomorphology for Reach 5 are to: *Maintain channel dimensions, form and complexity; and maintain access to and quality of riffle and pool habitats.*

The flow components and functions required to achieve these objectives are summarised in Table 8-2.

Risks to objectives and flow are the urban development occurring on alluvial plains and higher in the valley. Coupled with this is an increase in the frequency of flow events that exceed the critical erosion thresholds for scour of bed and bank sediments. Also, with development and associated clearing of areas, there appears to have been an increase in the amount of sediment entering the river, leading to accumulation of sediments in the channel. This may also be causing changes to vegetation along the stream, in particular an increase in reeds.

**Table 8-2 Reach 5 Geomorphology objectives**

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Maintain channel dimensions, form and complexity (G5.1) | Bankfull flow | Maintain gross channel dimensions and form channel features (i.e. pools, bars/riffles) (G5.1.1) | Winter-Spring |
| | Low flows | Scour and maintain undercuts, exposed roots and large wood habitat (G5.1.2) | All year |
| | Freshes | Scour and maintain undercuts, exposed roots and large wood habitat.<br><br>Limit frequency and duration of flows above scouring thresholds (G5.1.3) | All year |
| Maintain access to and quality of riffle and pool habitats (G5.2) | Low flows | Maintain extent of riffle and pool habitats (G5.2.1) | All year |
| | Freshes | Scour fine sediment and biofilms from riffles[1]<br><br>Prevent any increase in the frequency of critical flows (G5.2.2) | All year |
| | High flow | Scour sediment from pools (G5.2.3) | Winter-Spring |

[1] Bed shear stress during fresh capable of moving silt from cobbles ($\tau_c$ > 15 N/m$^2$) and sand ($\tau_c$ > 8 N/m$^2$). Source: Appendix B of Ecological Associates (2005b)

### 8.3.2 Vegetation

The extent and diversity of water-dependent vegetation in Reach 5 is heavily constrained by a number of land-use and hydrological factors: (1) the ecological consequences of intensive adjacent and upstream urban development and infrastructure, including the physical destruction of native vegetation in the stream-side zone, introduction of a myriad of exotic weed species, and poor water quality (e.g. exceptionally turbid water on the day of the EFTP site visit, see Figure 8-6 below) and (2) alterations to the flow regime arising from diversion at the two upstream weirs (Upper Werribee Diversion Weir and Bacchus Marsh Weir) and releases from Pykes Creek Reservoir.

**Figure 8-6 Reach 5 at Bacchus Marsh, showing highly turbid water quality**

Native stream-side vegetation is accordingly sparse, as related in the earlier Site Paper. The NatureKit website indicates the only water-dependent vegetation community to be EVC 292 Red Gum Swamp just upstream of Bacchus Marsh. Otherwise, however, the riparian zone appears to be either non-existent or, if present, very narrow and discontinuous. Observations during the field inspection revealed extensive beds of Common Reed in some areas, as well as a narrow and fragmented riparian fringe dominated by a mixture of native (e.g. bottlebrush, tea-tree and paperbark) and introduced (e.g. willow, blackberry, peppercorn etc) plants. Note that the reed beds may be, in part, an artefact arising from sedimentation of inorganic material generated by upstream urban development, and the absence of submerged plants a consequence of the turbid water and related poor underwater light regimes.

**Figure 8-7 Reach 5, riparian fringe**

The co-designed catchment program for the Werribee catchment region (Melbourne Water 2018, Figure 8) includes provision for the establishment and maintenance of vegetation buffers along Reach 5 (see Melbourne Water 2018, Figure 8). Unlike the case with Reach 4, there is no explicit provision for the maintenance of existing high-value stream-side vegetation, probably an acknowledgement of the highly modified nature of the riparian zone in this reach of the river.

Accordingly, the objective for water-dependent vegetation for Reach 5 is to: *Maintain existing in-stream (if any), native fringing non-woody and native fringing woody vegetation and provide a water regime that will facilitate the establishment (and subsequent maintenance) of riparian vegetation undertaken as part of Melbourne Water's revegetation plans for the middle Werribee River.*

The flow components and functions required to achieve this objective are summarised in Table 8-3

**Table 8-3 Reach 5 vegetation objectives**

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Maintain in-stream vegetation (if any) (V5.1) | Low flow | Maintain existing plant communities by providing deep pool habitat over winter-spring period (note that taxa such as Water Ribbons are well adapted to periodic cease-to-flow periods) and shallow pool habitat over summer-autumn (V5.1.1) | All year (higher in winter-spring than summer-autumn) |
| | Freshes | Downstream dispersal of plant propagules (V5.1.2) | Winter-spring |
| Maintain fringing native non-woody vegetation and facilitate future revegetation efforts (V5.2) | Low flow | Maintain existing plant communities of reeds, rushes and sedges etc by providing inundated conditions along stream side over winter-spring period and damp conditions over summer-autumn<br><br>Facilitate future revegetation efforts of similar vascular plant species (V5.2.1) | All year (higher in winter-spring than summer-autumn) |
| | Freshes | Maintain existing plant communities of reeds, rushes and sedges etc over dry summer-autumn period<br><br>Facilitate future revegetation efforts of similar vascular plant species<br><br>Introduce hydrological variability and promote zonation of fringing plant communities as well as inundating the more elevated zones around stream perimeter<br><br>Downstream dispersal of plant propagules (V5.2.2) | All year (higher in winter-spring than summer-autumn) |
| Maintain fringing native woody vegetation and facilitate future revegetation efforts (V5.3) | Low flow | Maintain existing plant communities of bottlebrush, tea-tree and paperbark etc by providing damp conditions along stream side over winter-spring period<br><br>Facilitate future revegetation efforts of similar vascular plant species (V5.3.1) | All year (higher in winter-spring than summer-autumn) |
| | Freshes | Maintain existing plant communities - bottlebrush, tea-tree and paperbark etc over dry summer-autumn period<br><br>Facilitate future revegetation efforts of similar vascular plant species<br><br>Introduce hydrological variability and promote zonation of fringing plant | All year (higher in winter-spring than summer-autumn) |

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| | | communities as well as inundating slightly elevated zones around stream perimeter<br><br>Downstream dispersal of plant propagules (V5.3.2) | |
| Prevent encroachment of the stream channel by undesirable terrestrial species (V5.4) | Low flow | Prolonged inundation of stream channel will prevent colonisation of inundation-intolerant plant taxa, including bottlebrush, tea-tree and paperbark etc (V5.4.1) | Winter-spring |
| Provide ecological disturbance (V5.5) | Large fresh or Near-bankfull | Provide substantial ecological disturbance to scour sediments and reset ecological communities. The critical function of this flow component in Reach 5 is the removal of sediment that has accumulated in-stream (a result of upstream residential development) (V5.5.1) | Winter-spring |

### 8.3.3 Macroinvertebrates and Water Quality

Reach 5 is the Werribee River (Wirribi Yaluk) between the Bacchus Marsh Weir and the confluence with the Lerderderg River. Natural flows have been heavily modified in this reach from natural as a result of diversions from the Bacchus Marsh Weir, however a near permanent flow regime is still maintained. The reach is still exposed to lower summer flows due to diversion from the Bacchus Marsh Weir and an overall lower winter flow due to diversion from the upper Reaches to Pykes Creek Reservoir.

The reach is characterised by pools (which increase in size further downstream) interspersed by gravelly riffles and run area. There is a variety of habitat to support macroinvertebrates, which provide an important food source for platypus and fish populations known to be present in the reach.

Water quality in the reach is impacted by low flows, as well as by catchment factors including sediment runoff from surrounding areas which are being developed for housing. The EFTP observed highly turbid water in this reach during the site visit. High suspended solids in the water column represent a threat to macroinvertebrates through the potential to block filter feeding mechanisms, and when suspended solids settle to the stream bed they can smother habitat. The objectives for macroinvertebrates in this reach are similar to the other reaches (Table 8-4) noting that catchment sediment runoff poses a particular threat to macroinvertebrates in this reach, but is best managed through complementary measures rather than specific flow objectives.

The overall objective for macroinvertebrates in Reach 5 is to: *Maintain the abundance and diversity of macroinvertebrate communities through the management of flow and water quality threats, and provision of flows that support habitat quality and availability, life cycle processes, and water quality.*

**Table 8-4 Macroinvertebrates and water quality**

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Maintain access to and quality of riffle and pool habitats (M5.1) | Low flows | Maintain extent and diversity of riffle and pool habitats, and avoid drying of critical habitats<br><br>Maintain connections between habitat areas | All year |

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| | | Maintain wetted width of channel and connection with instream and littoral vegetation<br><br>Maintain refuge habitat in deeper pools during dry periods (M5.1.1) | |
| | Freshes | Flush fine sediment from substrate to prevent smothering of habitat or blocking of gills. Scour sediment from riffles and benthic surfaces to expose new surfaces, and to prevent infilling of interstitial spaces and degradation of habitat (M5.1.2) | All year |
| | High flow | Scour sediment from pools (M5.1.3) | Winter-Spring |
| Maintain water quality and important hydrological functions of current flow regime (M5.2) | Low flows | Maintain low flows to prevent an increase in cease-to-flow periods outside of natural range, particularly in light of diversion at the weir and forecast climate change impacts.<br><br>Provide flows to prevent prolonged low flow periods that can result in decreased dissolved oxygen and increased salinity (M5.2.1) | All year |
| | Freshes | Maintain water quality in pools during low flow periods<br><br>Flush accumulated organic matter and fine sediments (M5.2.2) | Several events throughout the year |
| | High Flows | Mobilise and transport particulate matter to downstream reaches<br><br>Provide recolonisation opportunities following low flow periods (M5.2.3) | Winter-Spring |

### 8.3.4 Fish

Reach 5 is located downstream of the Bacchus Marsh Weir and is characterised by pools interspersed by gravelly riffles and runs. Pools are fringed with emergent vegetation and in some areas contain undercut banks and submerged woody habitat. The size of pools increases further downstream. Flow is modified from natural as a result of diversions from the Bacchus Marsh Weir, however a near permanent flow regime is still maintained, except in the driest years when cease-to-flow can occur but refuge pools persist.

A diverse small-bodied native fish community has been recorded in the past, including River Blackfish, Mountain Galaxias, Common Galaxias, Flathead Gudgeon, Australian Smelt and Short-finned Eel (Jacobs 2022). However, recent surveys (2022) downstream of the Bacchus Marsh Diversion Weir only recorded Australian Smelt and Short-finned Eel and a number of exotic species (Redfin Perch, Roach and Tench) (James Shelley, Jacobs, pers. obs.).

Assuming the likely presence of a larger number of native species, objectives for Reach 5 are to maintain the existing native fish community likely to be present throughout the reach including River Blackfish, Mountain Galaxias, Common Galaxias, Flathead Gudgeon, Australian Smelt and Short-finned Eel.

The specific Reach 5 objective for native fish is to: *Maintain the existing native fish community throughout Reach 5 by avoiding prolonged cease-to-flows (unless natural) and providing higher base flows and freshes at suitable times to enable local fish movement.*

The flow components and functions required to achieve this objective are summarised in Table 8-5.

Despite the more permanent flow regime, the reach is still exposed to lower summer flows due to diversion from the Bacchus Marsh Weir and an overall lower winter flow due to diversion from upper Reaches to Pykes Creek Reservoir. Risks to achieving objectives in this reach are from poor water quality associated with increasing urban runoff and climate change:

- Urban development is rapidly occurring in the catchment and can result in increased 'flashy' flows associated with rainfall runoff via the stormwater system that create more frequent channel disturbance. Moreover, there is a large sediment load entering the waterway from the stormwater system due to land disturbance associated with construction activities. This is leading to the accumulation of sediment on benthic surfaces and is leading to the degradation of habitat for native fish and macroinvertebrates.
- Climate change has the potential to result in an increase the frequency and duration of cease-to-flows and very low flows that contributes to the loss of refuge habitat.

**Table 8-5 Reach 5 fish objectives**

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Maintain the native indigenous fish community throughout the rest of the reach (e.g. River Blackfish, Mountain Galaxias, Common Galaxias, Flathead Gudgeon, Australian Smelt and Short-finned Eel) (F5.1) | Avoid prolonged cease-to-flow | Prevent loss of refuge pool habitat (F5.1.1) | Summer/autumn |
| | Summer Low flow | Maintain refuge pool habitat (F5.1.2) | Summer (cease-to-flows acceptable if natural – avoid prolonged/unnatural CtF) |
| | Winter Low flow | Maintain diversity of hydraulic habitats (i.e. pool, riffle, run)<br><br>Maintain connectivity (adequate depth) for local movement (F5.1.3) | Winter (ideally continuous and typically higher than summer) |
| | Freshes | Top-up/freshen water quality in refuge pools (F5.1.4) | Summer (especially if CtFs have occurred) |
| | Freshes-high flows | Flush accumulated sediments to maintain or improve quality and availability of habitat<br><br>Maintain connectivity (adequate depth) for local movement and recolonisation following periods of cease-to-flow (F5.1.5) | Any time |
| | Freshes-high flows | Maintain cues for downstream migration by adult Short-finned Eels (F5.1.6) | Throughout year, particularly Summer |

### 8.3.5 Platypus

Since the end of the Millennium Drought, an increase in anecdotal sightings and positive detections from eDNA surveys indicate platypuses have started recolonising Reach 5. This is supported by results of live-trapping surveys undertaken in early 2022 where 4 individuals were recorded (Serena *et al.* 2022).

Prior to this, during the Millennium Drought, a long-term live-trapping monitoring program (2008-2015; Griffiths & Weeks 2017) revealed platypuses were rarely present in Reach 5 although anecdotal evidence suggested a permanent population existed upstream (Reach 4) (Griffiths et al 2016, Griffiths et al 2018). Sporadic captures during this period suggested Reach 5 received occasional vagrant individuals but did not support a resident population. Not surprisingly, the re-colonisation of Reach 5 by platypus has coincided with an overall improvement in the flow regime with more reliable baseflows and a reduction in cease-to-flow events since the end of the Millennium Drought.

However, significant urban development in the catchment of Reach 5 poses a significant risk to this fragile population re-establishing itself through increased flow variability (urban stream syndrome; Walsh et al. 2005) and sedimentation leading to depauperate macroinvertebrate communities.

The objective for Reach 5 is to *enhance conditions for platypuses and increase their distribution and abundance*. The flow components and functions required to achieve this objective are summarised in (Table 8-6).

Limiting the impacts of urbanisation will be critical to achieve the flow objectives relating to stormwater management and urbanisation. Direct connected imperviousness (DCI) should be kept to <1% and the coefficient of variation in daily flows should be kept to <0.5 to limit impacts on platypuses (Griffiths et al. 2019). Currently, the DCI for the Middle Werribee subcatchment is 1.4% (MW data from ~2019, as per Griffiths et al 2019), and Melbourne Water's objective is to reduce this to 0.4%.

**Table 8-6 Platypus objectives for Reach 5**

| Objective | Flow Component | Function | Timing |
|---|---|---|---|
| Improve current platypus population (distribution and abundance) (P5.1) | Low flows | Maintain refuge pools (P5.1.1) | Summer/autumn |
| | Low flows | Maintain habitat and longitudinal connectivity for platypuses and food resources (macroinvertebrates) (P5.1.2) | Winter/spring |
| | Freshes | Scour fine sediment, promote habitat diversity, support macroinvertebrate abundance and diversity (P5.1.3) | All year |
| | High flow | Scour sediment from pools, maintain refuge pools (P5.1.4) | Winter/early Spring |
| Prevent degradation of flow regime from urbanisation. (P5.2) | Stormwater management | Limit frequency of scouring flows above threshold to displace macroinvertebrates, reduce sedimentation degrading habitat for macroinvertebrates (P5.2.1) | All year |

## 8.4 Flow Recommendations

### 8.4.1 Existing recommendations

Ecological Associates (2005) recommended an environmental flow regime for Reach 5 (Table 8-7). A review by Jacobs (2014) recommended two amendments to the 2005 recommendations similar to those made for Reach 4.

First, the cease-to-flow recommendation was removed. The recommended cease-to-flow period is too short to meet its stated objective of drying out the beds of Typha and Phragmites that are already growing in the channel and preventing further expansion of those plants. The growth form and life history of these large emergent plants is such that they readily maintain moist soils and a quiescent, shaded and damp microclimate within their canopy that enable them to easily withstand short periods of desiccation. Cease-to-flows may also impact on the sustainability of platypus populations.

Second, the current environmental flow recommendations did not specifically consider the risk that high flows or floods may have on juvenile Platypus. Stabilising and increasing the Platypus population in the Werribee River (Wirribi Yaluk) is a very high management priority, but high flows during the breeding season can flood burrows and drown juveniles. The 2014 review suggested that the environmental flow recommendations for Reaches 4 and 5 should include several high freshes in July or August to encourage female Platypus to build their nests higher up the bank to reduce the risk of being flooded if higher flows are delivered in spring or summer. This 2022 review further considers this recommendation as presented below.

**Table 8-7 Original flow recommendations for Reach 5**

| Flow recommendations (Reach 5) | | | | | Rationale / objective |
|---|---|---|---|---|---|
| Season | Component | Magnitude | Frequency | Duration | |
| Feb-April | Cease-to-flow | 0 ML/day | 2 per year with a minimum separation of 7 days | 15 days each (30 days total per year)* | Curtail growing season of in-channel emergent macrophytes |
| Dec-May | Low flow | 4 ML/day* | All years except extended drought | Residual time after other flows | Wet the perimeter of riffles to provide habitat for macroinvertebrates<br>Maintain pool habitats for fish, macroinvertebrates and platypus<br>Provide longitudinal connection between pools to allow River Blackfish fry to disperse throughout whole reach<br>Maintain natural hydrologic variability to maintain stable undercut banks and benches for fish and platypus. |
| Dec-May | Freshes | 12 ML/day* | 4 per year with a minimum separation of 14 days | ≥1 day | Maintain water quality in pools during low flow period<br>Duration of event should be less than 5 days to avoid flushing fish from the reach |
| Jun-Nov | Low flow | 18 ML/day* | All years | Residual time after other flows | Provide spawning habitat in pools for River Blackfish and adequate depth through riffles to allow adult River Blackfish to disperse between pools<br>Inundate full wetted perimeter of channel to sustain macrophytes in the channel and at the channel margins and to provide foraging habitat for Platypus.<br>Flush fine sediment and sand from streambed to maintain habitat quality for macroinvertebrates and Platypus |
| Jun-Nov | Freshes | 141 ML/day* | 1 per month | 2 days | Disturb in-stream emergent macrophytes to limit vegetation encroachment<br>Inundate shrub assemblages on benches to support growth in winter and spring.<br>Mobilise sand throughout entire reach and gravels in riffles |
| Anytime | Bankfull flow | 1,400 ML/day | Natural (1 in per year) | 1 day | Rework sediment including gravels to maintain channel dimensions |
| Anytime | Overbank flow | 3580 ML/day | 1 in 10 years | 1 day | Disturb shrub vegetation on channel benches and emergent macrophytes in the channel<br>Rework sediment including gravels to maintain channel dimensions |

* Or natural if the natural magnitude or duration is less than what is specified.

### 8.4.2 Updated recommendations

The outcomes of the current assessment have identified a number of updates to the previous flow recommendations. The revised recommendations were also informed by updates to the hydraulic model to account for refined roughness conditions. Revised recommendations for are summarised in Table 8-9 and described in the following sections.

**Cease-to-flow**

As recommend in the Jacobs 2014 review the cease-to-flow recommendation was removed and this is supported by the current review.

**Summer low flow**

A summer low flow of 4 ML/day was recommended in the 2005 flow study. This flow aims to fill and connect refuge pools, provide flow over riffles for macroinvertebrate habitat and provide opportunities for local fish movement. Based on our review of the hydraulic model there is no justification for changing this recommendation. Under current condition low flows up to 4 ML/day regularly occur across wet, average and dry years (Figure 8-8). However, these flows are mostly met by releases from Pykes Creek Reservoir to supply downstream irrigators and subsequent flows over the Bacchus Marsh Diversion Weir. So changes to the future operation of Pykes Creek Reservoir, for example as a result in changes to irrigation demands and/or climate change impacts, especially in dry years, represents a potential risk to being able to maintain the current low flow regime and may result in more frequent occurrences of flows <4 ML/day and even cease-to-flows in very dry years. The summer low flow recommendation of 4 ML/day in Reach 5 is lower than the summer low flow recommendation for Reach 4 upstream (10 ML/day). Both of these recommendations were included in the original flow recommendations study, and based on the hydraulic model review there is no justification for these recommendations to be changed. The low flow recommendations for both reaches have the same ecological objectives - providing flow over riffles for macroinvertebrate habitat, and opportunities for fish movement. The slightly lower recommendation for Reach 5 is based on the physical characteristics of the reach, and the modelled minimum low flow required to meet the riffle habitat coverage and depth for fish movement. This results is a slightly lower recommended flow than what is required to meet those requirements in Reach 4, noting that the flows are a *minimum* recommendation - if summer low flows of 10 ML/day are met in Reach 4 and pass to Reach 5, then the Reach 5 recommendations are also achieved – there is no maximum limit on the low flow recommendation. Some extraction also occurs at the Bacchus March Weir, so higher flows in Reach 4 will not always result in the same flow levels in Reach 5.

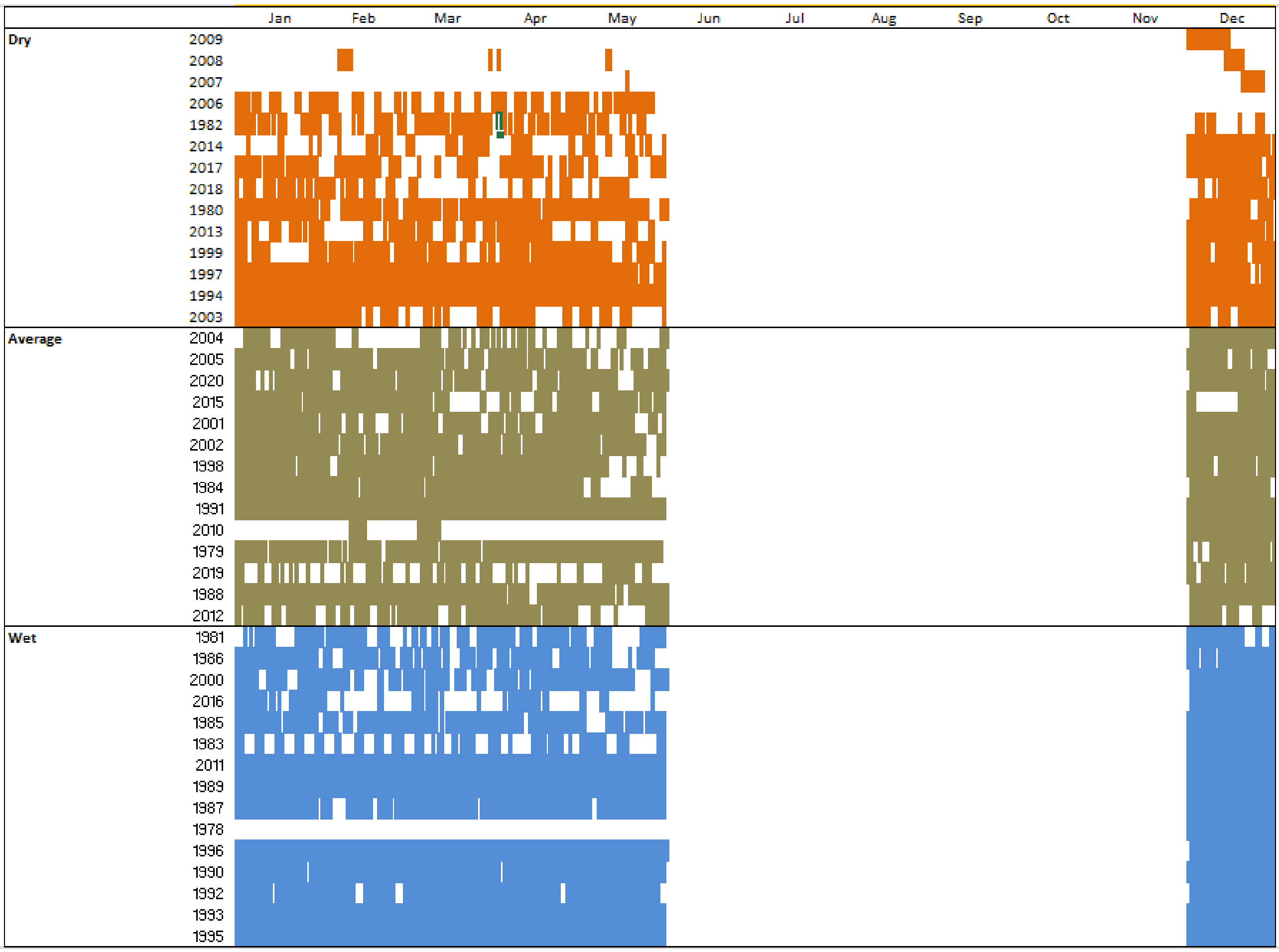



**Figure 8-8 Spells Analysis for summer low flows (> 4 ML/day) for Reach 5 and dry, average and wet years using gauge data**

### Summer fresh flow

The 2005 flow study made recommendations for two types of summer fresh, a small fresh of 12 ML/day (4 events for >1 day) to freshen water quality. The review of previous recommendations suggests the small fresh (12 ML/day) is not sufficient to meet the water quality objective given changes in the catchment (namely urban development) since the last study. The fresh magnitude has hence been increased to 18 ML/day and the frequency increased to 6 in total (1 per month) in dry climate conditions and 8 in total (1 every 3 weeks) in average and wet climate conditions. The duration has also been increased to 2 days. The current regime generally meets the fresh recommendations (Figure 8-9).

Increasing the magnitude, number and duration of the summer fresh will provide additional water quality benefits and also help scour fine sediments from riffles, which will improve the quality of habitat for macroinvertebrates and food for platypus and fish. More frequent freshes will also provide more opportunities for local fish movement.

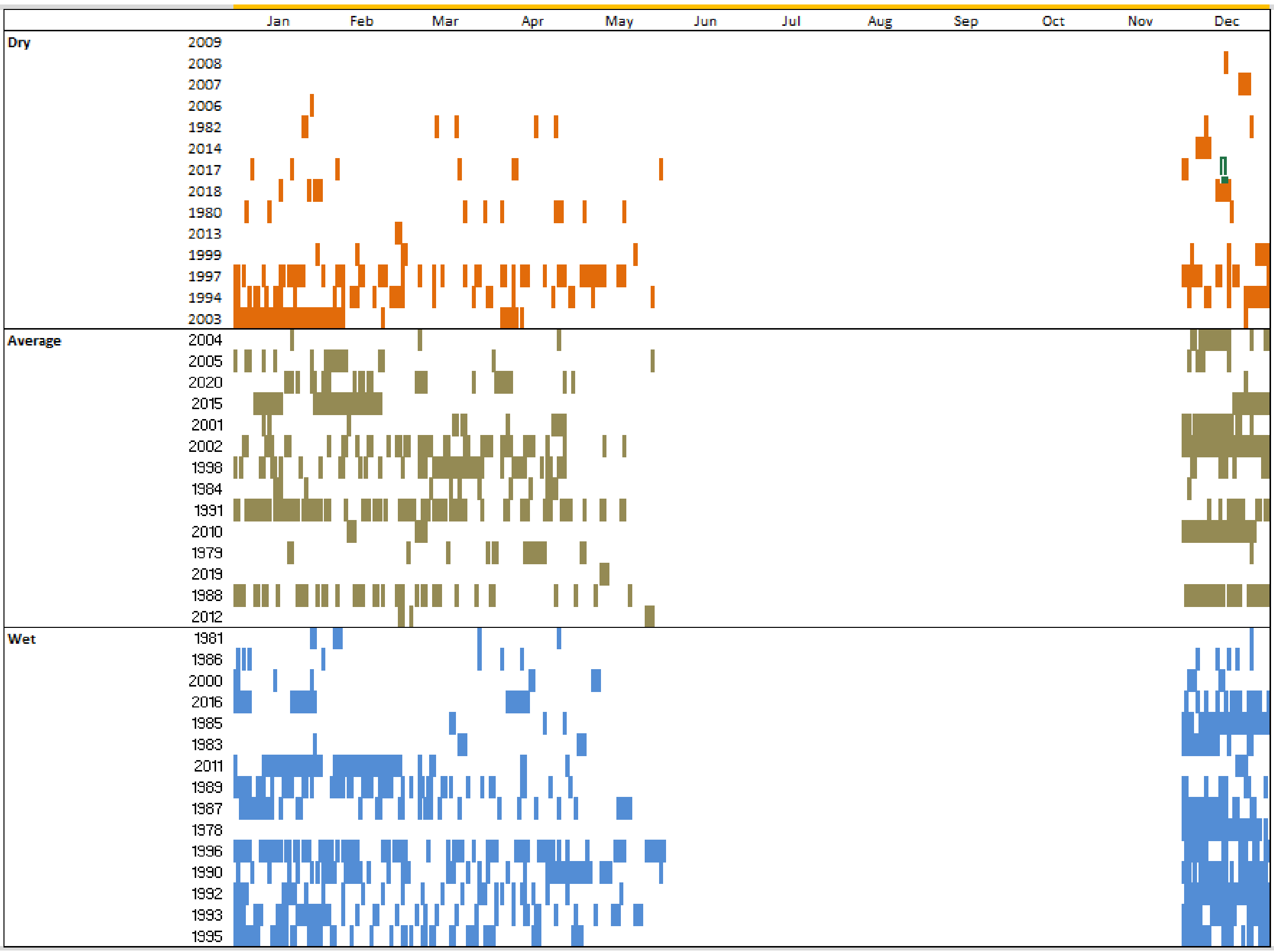



**Figure 8-9 Spells Analysis for summer fresh (>18 ML/day) for Reach 5 in dry, average and wet years using gauge data**

**Winter low flows**

A winter low flow of 18 ML/day or natural, based on upstream flow, was recommended in the 2005 flow study. This flow aims to provide continuous flow along the reach for the duration of the season, for fish and platypus movement and to increase access to habitat, and high flows up the bank for vegetation. Based on our review we have retained the current recommendation (18 ML/day) for dry and average climate years (Figure 8-10), but increased the magnitude of the low flow recommendation to 40 ML/d (within an acceptable range of 30-50 ML/day) in wet years (Figure 8-11) in order to introduce more seasonal variation and provide greater opportunities for fish and platypus movement in wet years.

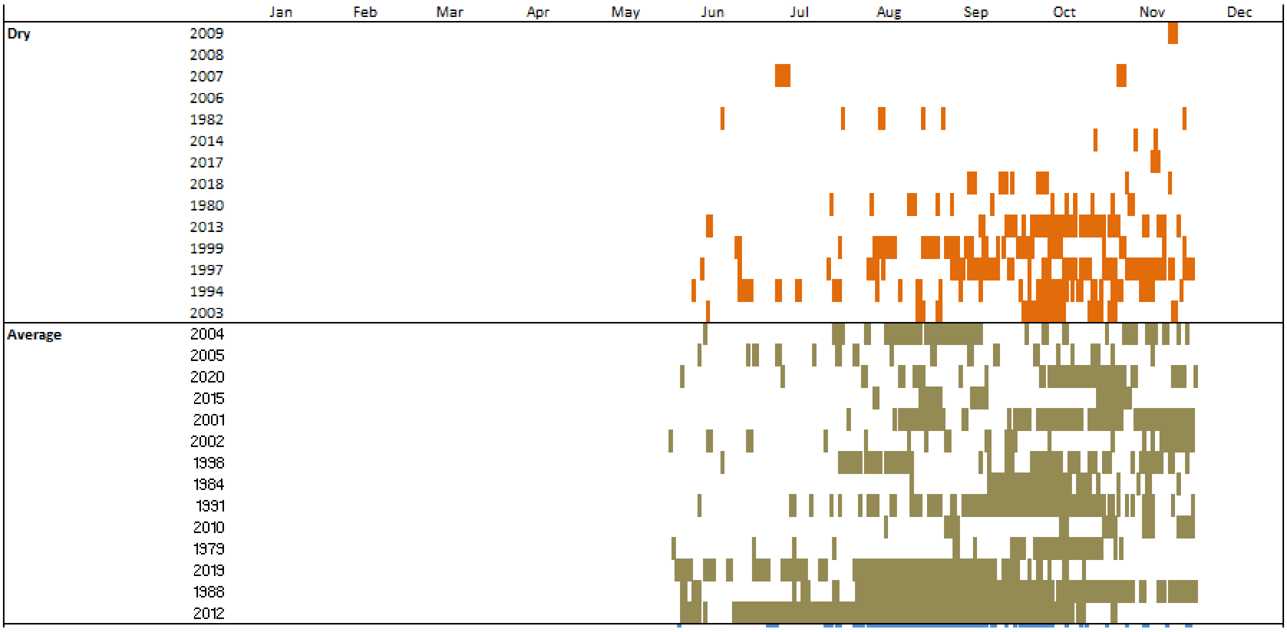



**Figure 8-10 Spells Analysis for winter low flows > 18 ML/day for Reach 5 in dry and average years using gauge data**

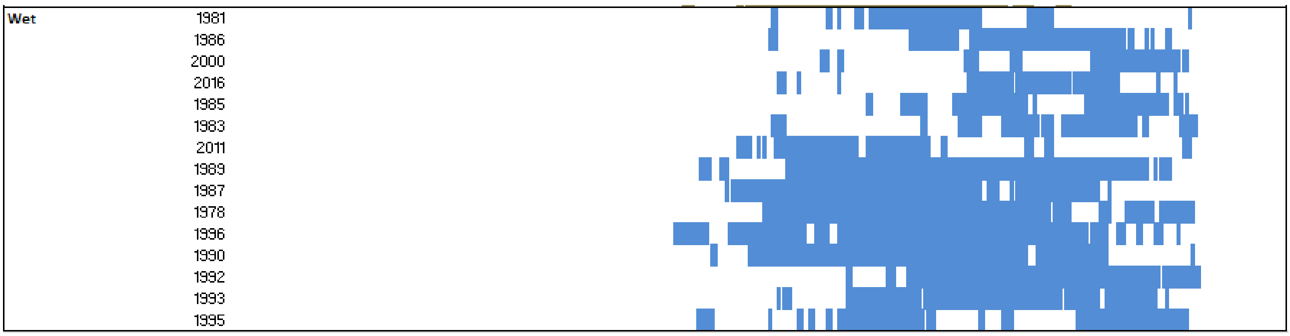



**Figure 8-11 Spells Analysis for winter low flows > 40 ML/day for Reach 5 in wet years using gauge data**

**Winter fresh and high flow**

A winter fresh of 141 ML/day, 6 per year for 2 days duration each was recommend in the 2005 flows study. A flow of this magnitude is sufficient to scour sediment and biofilm, improving the quality of pool and riffle habitat, provide moisture to vegetation higher up the bank and extend opportunities for fish and platypus movement.

We have retained the 141 ML/day magnitude and frequency (6 events over the winter / spring period - one per month). However we have adjusted the duration of events to 2 days in dry years and 5 days in average years and 10 days in a wet year. The rational for event duration is based on the current duration of spells above the recommended magnitude (Table 8-8).

**Table 8-8 Exceedance Percentiles for Spells analysis of winter fresh events (>141 ML/day) used to inform duration of fresh events in dry, average and wet years**

| Percentile | Duration (> 141 ML/day) |
|---|---|
| 25% | Approximately 2 days |
| 50% | Approximately 5 days |
| 75% | Approximately 9-11 days |

A bankfull flow of 1,400 every year and an overbank flows of 3,160 ML/day every ten years was recommended in the 2005 flow study. The current review confirms the bankfull flow magnitude of 1,400 ML/day is still relevant once per year in average and wet climate years, but would not be expected to occur in dry years (Figure 8-12). In terms of timing, it would be preferable for bankfull flows to occur in July to September in order to avoid periods of time when platypus juveniles are in burrows and could be drowned (October onwards). However, it is recognised that bankfull flows are not likely to be actively delivered and would only occur naturally based on upstream flows.

We have removed the specific recommendation for an overbank flow. The review indicates that overbank flows wouldn't provide any benefits in the location that aren't achieved by the bankfull flow and are in fact more likely to have unwanted/damaging effects.

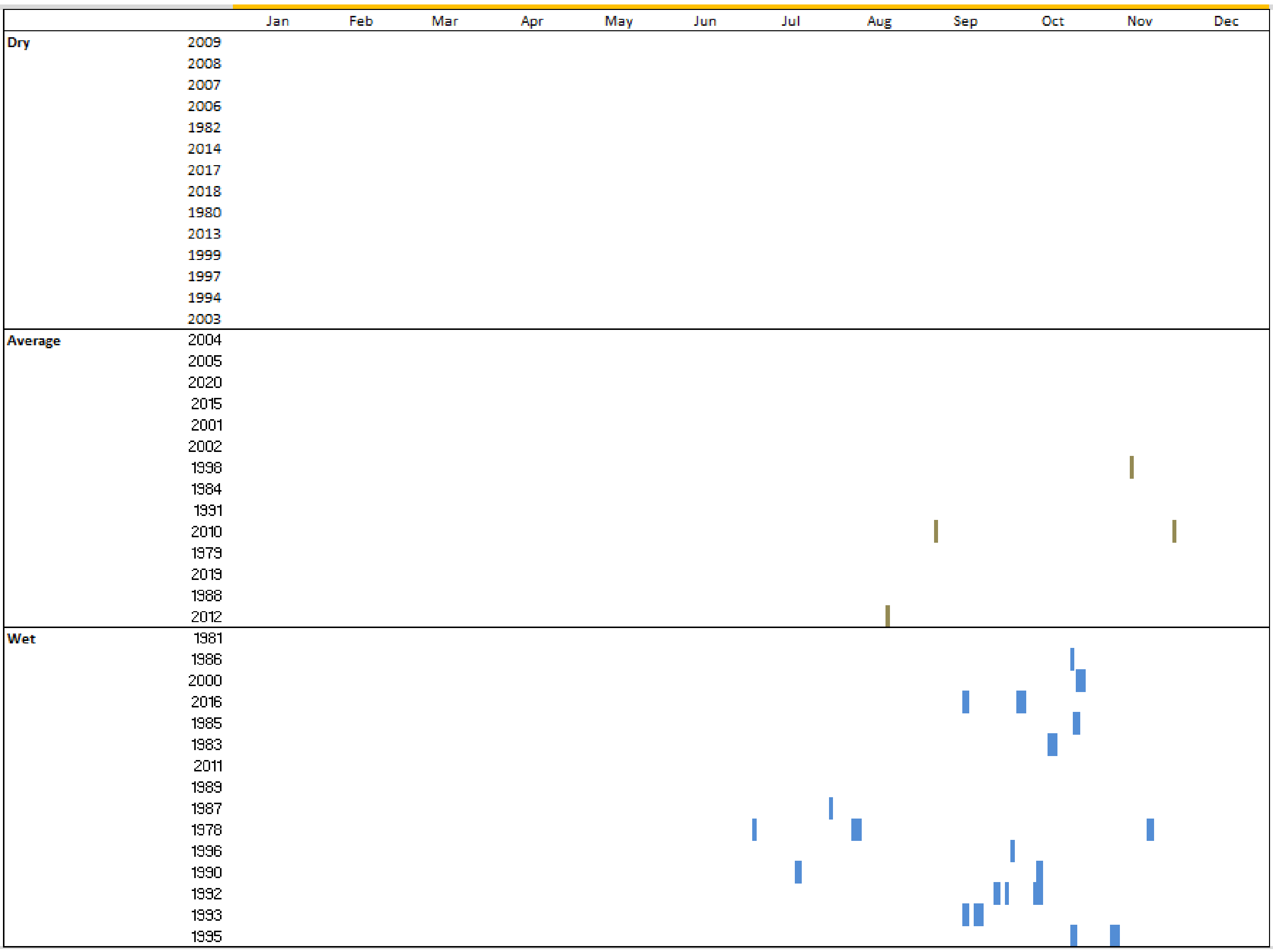



**Figure 8-12 Spells Analysis for bankfull event >1400 ML/day for Reach 5 in dry, average and wet years using gauge data**

### Disturbance flows

Flow recommendations for this reach are based on key components of a natural flow regime (low flows, freshes, etc) and to meet the specific ecological objectives for geomorphology, vegetation, macroinvertebrates and water quality, fish and platypus outlined in Section 8.3. In this reach, stormwater runoff from urban development poses a risk to the achievement of flow recommendations. We have therefore included additional specific reference to disturbance events to assist with managing the potential effects of increased stormwater runoff.

The final flow recommendations for the reach are summarised in Table 8-9. For each flow recommendation, the ecological objectives it is intended to achieve are listed, using codes for the specific ecological objectives listed in Section 8.3. A code has been allocated to each specific objective for geomorphology, vegetation, macroinvertebrates and water quality, fish and platypus as listed in Tables 8-2 to 8-6; these objective codes are cross referenced with each flow recommendation component in the table below.

**Table 8-9 Revised flow recommendations for Reach 5**

| Season | Flow | Objective/Function | Wet/Avg/Dry | Volume ML/day | Frequency and when | Duration | Ecological Objectives |
|---|---|---|---|---|---|---|---|
| Summer / Autumn (Dec-May) | Low flow | Maintain access to and protect diversity of habitat (pools, riffles, undercuts, large wood) and vegetation for bugs, fish (River Blackfish, Mountain Galaxias, Australian Smelt, Short-finned Eel) and platypus. Maintain capacity of the stream to process organic matter. Maintain inundated stream channel to prevent colonisation by inundation-tolerant terrestrial vegetation. | Wet/Avg | 4 | 100% of days | | **(G5.1.2, G5.2.1, V5.1.1, V5.2.1, V5.3.1, M5.1.1, M5.2.1, F5.1.1, F5.1.2, P5.1.1,** |
| | | | Dry | 4 | 100% of days | | |
| | Fresh | Maintain quality of riffle and undercut habitats by periodically scouring sediment & biofilms, maintain fringing and riparian non-woody vegetation, provide opportunities for fish movement. Mobilise and transport particulate organic matter to downstream reaches. | Wet/Avg | 18 | 8 (every 3 weeks) | 2 days | **G5.1.3, G5.2.2, V5.2.2, V5.3.2, M5.1.2, M5.2.2, F5.1.4, F5.1.5, F5.1.6, P5.1.3)** |
| | | | Dry | 18 | 6 (every month) | 2 days | |
| Winter / Spring (Jun-Nov) | Low flow | Higher flows increase access to habitat for bugs, fish and platypus. Maintain capacity of the stream to process organic matter. Maintain inundated stream channel to prevent colonisation by inundation-tolerant terrestrial vegetation. | Wet | 40 (range 30-50) | 100% of days | | **(G5.1.2, G5.2.1, V5.1.1, V5.2.1, V5.3.1, V5.4.1, M5.1.1, M5.2.1, F5.1.3, P5.1.2)** |
| | | | Avg / Dry | 18 | 100% of days | | |
| | Fresh | Maintain quality of riffle and undercut habitats by periodically scouring sediment & biofilms, maintain fringing and riparian non-woody vegetation, provide opportunities for fish movement. Mobilise and transport particulate organic matter to downstream reaches. | Wet | 141 | Every month | 10 days | **(G5.1.3) G5.2.2, G5.2.3, V5.1.2, V5.2.2, V5.3.2, V5.5.1, M5.1.2, M5.1.3, M5.2.2, M5.2.3, F5.1.5, F5.1.6, P5.1.3, P5.1.4)** |
| | | | Avg | 141 | Every month | 5 days | |
| | | | Dry | 141 | Every month | 2 days | |
| | Bankfull | Scour fine sediment from pools, engage higher channel surfaces and secondary flow channels/terraces, flush organic material that has accumulated in these areas. | Wet | 1400 | 1 event | 2 days | **(G5.1.1, V5.5.1)** |
| | | | Avg | 1400 | 1 event | 1-2 days | |
| | | | Dry | Not expected to occur | | | |

| Season | Flow | Objective/Function | Wet/Avg/Dry | Volume ML/day | Frequency and when | Duration | Ecological Objectives |
|---|---|---|---|---|---|---|---|
| | Disturbance flows | Avoid increase in number of days with flow greater than mean daily flow | | 49.8 | <15% of time | | **P5.2.1, G5.1.3** |
| | | Avoid an increase in the percentage of time that flow exceeds bed disturbance threshold | | 830 | <1.5 times per year | 1-2 days | **V.5.5.1, P5.2.1** |
| | | Avoid an increase in the percentage of time that flow exceeds bank disturbance threshold | | 1380 | <1 every 2 years | 1 day | **P5.2.1** |

As for the previous Reaches, each flow recommendation in the summary table for the Reach (Table 8-9) is cross referenced to the specific ecological objectives it is intended to achieve, using codes for the specific ecological objectives listed in Section 8.3. A code has been allocated to each specific objective for geomorphology, vegetation, macroinvertebrates and water quality, fish, and platypus as listed in Tables 8-2 to 8-6.

These are summarised below for each component:

**Summer / Autumn (Dec-May)**

**Low Flow**

- Scour and maintain undercuts, exposed roots and large wood habitat; maintain extent of riffle and pool habitats (**Geomorphology**)
- Maintain existing plant communities by providing deep pool habitat over winter-spring period (note that taxa such as Water Ribbons are well adapted to periodic cease-to-flow periods) and shallow pool habitat over summer-autumn; maintain existing plant communities of reeds, rushes and sedges etc by providing inundated conditions along stream side over winter-spring period and damp conditions over summer-autumn; facilitate future revegetation efforts of similar vascular plant species; maintain existing plant communities of bottlebrush, tea-tree and paperbark etc by providing damp conditions along stream side over winter-spring period; facilitate future revegetation efforts of similar vascular plant species (**Vegetation**)
- Maintain extent and diversity of riffle and pool habitats, and avoid drying of critical habitats; maintain connections between habitat areas; maintain wetted width of channel and connection with instream and littoral vegetation; maintain refuge habitat in deeper pools during dry periods; maintain low flows to prevent an increase in cease-to-flow periods outside of natural range, particularly in light of diversion at the weir and forecast climate change impacts. Provide flows to prevent prolonged low flow periods that can result in decreased dissolved oxygen and increased salinity (**Macroinvertebrates and water quality**)
- Prevent loss of refuge pool habitat; maintain refuge pool habitat (**Fish**)
- Maintain refuge pools (**Platypus**)

**Fresh**

- Scour and maintain undercuts, exposed roots and large wood habitat; limit frequency and duration of flows above scouring thresholds; Scour fine sediment and biofilms from riffles; prevent any increase in the frequency of critical flows (**Geomorphology**)
- Maintain existing plant communities of reeds, rushes and sedges etc over dry summer-autumn period; facilitate future revegetation efforts of similar vascular plant species; introduce hydrological variability and promote zonation of fringing plant communities as well as inundating the more elevated zones around stream perimeter; downstream dispersal of plant propagules; maintain existing plant communities - bottlebrush, tea-tree and paperbark etc over dry summer-autumn period; facilitate future revegetation efforts of similar vascular plant species. Introduce hydrological variability and promote zonation of fringing plant communities as well as inundating slightly elevated zones around stream perimeter (**Vegetation**)

- Flush fine sediment from substrate to prevent smothering of habitat or blocking of gills; scour sediment from riffles and benthic surfaces to expose new surfaces, and to prevent infilling of interstitial spaces and degradation of habitat; maintain water quality in pools during low flow periods; flush accumulated organic matter and fine sediments (**Macroinvertebrates and water quality**)
- Top-up/freshen water quality in refuge pools; flush accumulated sediments to maintain or improve quality and availability of habitat; maintain connectivity (adequate depth) for local movement and recolonisation following periods of cease-to-flow; maintain cues for downstream migration by adult Short-finned Eels (**Fish**)
- Scour fine sediment, promote habitat diversity, support macroinvertebrate abundance and diversity (**Platypus**)

**Winter / Spring (Jun-Nov)**

**Low flow**

- Scour and maintain undercuts, exposed roots and large wood habitat; maintain extent of riffle and pool habitats (**Geomorphology**)
- Maintain existing plant communities by providing deep pool habitat over winter-spring period (note that taxa such as Water Ribbons are well adapted to periodic cease-to-flow periods) and shallow pool habitat over summer-autumn; maintain existing plant communities of reeds, rushes and sedges etc by providing inundated conditions along stream side over winter-spring period and damp conditions over summer-autumn; facilitate future revegetation efforts of similar vascular plant species; maintain existing plant communities of bottlebrush, tea-tree and paperbark etc by providing damp conditions along stream side over winter-spring period; facilitate future revegetation efforts of similar vascular plant species; prolonged inundation of stream channel will prevent colonisation of inundation-intolerant plant taxa, including bottlebrush, tea-tree and paperbark etc (**Vegetation**)
- Maintain extent and diversity of riffle and pool habitats, and avoid drying of critical habitats; maintain connections between habitat areas; maintain wetted width of channel and connection with instream and littoral vegetation; maintain refuge habitat in deeper pools during dry periods; maintain low flows to prevent an increase in cease-to-flow periods outside of natural range, particularly in light of diversion at the weir and forecast climate change impacts; provide flows to prevent prolonged low flow periods that can result in decreased dissolved oxygen and increased salinity (**Macroinvertebrates and water quality**)
- Maintain diversity of hydraulic habitats (i.e. pool, riffle, run); maintain connectivity (adequate depth) for local movement (**Fish**)
- Maintain habitat and longitudinal connectivity for platypuses and food resources (macroinvertebrates) (**Platypus**)

**Fresh**

- Scour and maintain undercuts, exposed roots and large wood habitat; limit frequency and duration of flows above scouring thresholds; scour fine sediment and biofilms from riffles; prevent any increase in the frequency of critical flows; scour sediment from pools (**Geomorphology**)
- Downstream dispersal of plant propagules; maintain existing plant communities of reeds, rushes and sedges etc over dry summer-autumn period; facilitate future revegetation efforts of similar vascular plant species. Introduce hydrological variability and promote zonation of fringing plant communities as well as inundating the more elevated zones around stream perimeter; maintain existing plant communities - bottlebrush, tea-tree and paperbark etc over dry summer-autumn period; facilitate future revegetation efforts of similar vascular plant species. Introduce hydrological variability and promote zonation of fringing plant communities as well as inundating slightly elevated zones around stream perimeter; provide substantial ecological disturbance to scour sediments and reset ecological communities. The critical function of this flow component in Reach 5 is the removal of sediment that has accumulated in-stream (a result of upstream residential development) (**Vegetation**)

- Flush fine sediment from substrate to prevent smothering of habitat or blocking of gills; scour sediment from riffles and benthic surfaces to expose new surfaces, and to prevent infilling of interstitial spaces and degradation of habitat; scour sediment from pools; maintain water quality in pools during low flow periods; flush accumulated organic matter and fine sediments; mobilise and transport particulate matter to downstream reaches; provide recolonisation opportunities following low flow periods (**Macroinvertebrates and water quality**)
- Flush accumulated sediments to maintain or improve quality and availability of habitat; maintain connectivity (adequate depth) for local movement and recolonisation following periods of cease-to-flow; maintain cues for downstream migration by adult Short-finned Eels (**Fish**)
- Scour fine sediment, promote habitat diversity, support macroinvertebrate abundance and diversity; scour sediment from pools, maintain refuge pools (**Platypus**)

**Bankfull**

- Maintain gross channel dimensions and form channel features (i.e. pools, bars/riffles) (**Geomorphology**)
- Provide substantial ecological disturbance to scour sediments and reset ecological communities. The critical function of this flow component in Reach 5 is the removal of sediment that has accumulated in-stream (a result of upstream residential development) (**Vegetation**)

## 8.5 Flow delivery constraints

The ecological objective for this reach is to: *Support existing geomorphology, vegetation, and aquatic biota in the reach by managing threats from urban stormwater runoff and through delivery of an appropriate flow regime from upstream reaches*.

The ecological objective for Reach 5 summarises the two main components of flow recommendations for the reach. Firstly, management of threats to the current flow regime based on the potential for altered stormwater inflow patterns as a result of urban development. As with Reach 1, Melbourne Water is constrained by lack of direct control over this process, but has the opportunity to influence certain aspects of the process with these flow recommendations in mind.

The other key component of the overarching objective is to support existing ecological values *through delivery of an appropriate flow regime from upstream reaches*. This recognises that as with Reach 4, flows in the reach are heavily influenced by flow management in upstream reaches which results in an impacted flow regime in Reach 5. The key constraints to achieving flow recommendations for Reach 5 therefore include flow delivery from upstream reaches, as well as the operation of the Bacchus Marsh diversion weir, which further impacts on flows in Reach 5.

# 9. Flow prioritisation

Table 9-1 summarises the flow component priorities for the Werribee River (Wirribi Yaluk) under various climate conditions. The highest priority flow component in all climate years is to maintain summer low flow to maintain access to habitat for fish and other biota, and prevent drying out of critical habitat and refuge pools. Low flows and summer freshes are also critical in dry climate years to minimise the risk of degraded water quality. In average and wet years the summer flows under current conditions are generally sufficient to maintain water quality in all reaches, although it is important that further water extraction does not increase the chance of these events not occurring.

In conjunction with maintaining summer low flows it is necessary to avoid any increase in the frequency and/or duration of cease-to-flow periods. Cease-to-flows may sometimes occur naturally in dry years, particularly in the upper reaches. This is not problematic in itself, but minimising further increase in the frequency and/or duration of cease-to-flow is a high priority and requires that any future water resource development (e.g. farm dams or other extractions), particularly in Reach 1, does not impact further on summer flows, especially in dry years.

Summer/autumn freshes are important flow components to minimise the risk of water quality degradation, and are a high priority to deliver in dry and average years. In wet years, these events are more likely to be occur through unregulated flows and are a therefore medium priority for managed delivery.

Winter low flows are important in all reaches but there can be some acceptable variability around the magnitude of the flow, provided it is generally higher than the summer low flow.

Winter freshes are a desirable component of the natural flow regime and assist with maintain access to habitat, scouring sediment and flushing organic material. Unregulated flows are likely to achieve the fresh requirements in average and wet climate years, but active delivery may be required in dry years.

Bankfull flows are a high priority in wet years, but are likely to be met by unregulated flows and not require active delivery.

In Reach 1 and Reach 5, preventing impacts from urban development and stormwater runoff is a high priority. In addition to degradation of water quality, flow-related impacts of urban runoff include an increase in high volume and velocity inflows from rapid urban runoff, which cause disturbance in the waterway. Flow recommendations therefore include measures which relate to preventing a significant increase in the frequency or magnitude of disturbance flows. Disturbance flows can be those that are above mean flow volume, or bed or bank disturbance velocity. These flows cause scour and erosion, with resultant physical impacts to the river as well as an increase in sediment and turbidity in the water column, which has undesirable biological effects.

**Table 9-1 Flow component prioritisation for dry, average and wet climate years**

| Flow component and reach | Priority | | | Rationale |
|---|---|---|---|---|
| | Dry | Average | Wet | |
| Cease to flow (Reaches 1, 2, 3, 4) | High | High | High | Prevent further increase in the frequency and/or duration of cease-to-flow, especially in dry years. |
| Summer low flows (all reaches) | High | High | High | Maintain access to habitat for fish and other biota |
| Summer / autumn freshes (all reaches) | High | High | Medium | Minimise risk of water quality degradation (esp. Reaches 3 & 4)<br>Water vegetation on lower banks<br>High priority to deliver in dry and average years but medium priority for managed delivery in wet years if provided by unregulated flows |
| Winter low flows (all reaches) | High | Medium | Medium | Provide additional access to habitat, maintain capacity of stream to process organic material. Actual magnitude is not critical (if recommended magnitude can't be met for |

| Flow component and reach | Priority | | | Rationale |
|---|---|---|---|---|
| | Dry | Average | Wet | |
| | | | | operational reasons), but should be higher than summer low flows if possible.<br>High priority to deliver in dry years but medium priority for delivery in average and wet years if provided by unregulated flows |
| Winter freshes (all reaches) | High | Medium | Medium | Maintain habitat quality, scour sediments and biofilms, flush accumulated organic material, general watering of banks and riparian vegetation<br>High priority to deliver in dry years but medium priority for delivery in average and wet years if provided by unregulated flows |
| Bankfull flow | Low | Medium | High | Not expected to occur in dry years.  Higher priority in wet years but most likely achieved through unregulated flows |

# 10. References


Collaborative NRM & MW (2015). Werribee River Environmental Water Management Plan. Report prepared by Collaborative NRM and Melbourne Water

DELWP (2020) Guidelines for Assessing the Impact of Climate Change on Water Availability in Victoria. Department of Environment, Land, Water and Planning (DELWP)

DEPI (2013). FLOWS – a method for determining environmental water requirements in Victoria. Edition 2

Duncan, H. P., Fletcher, T. D., Vietz, G., & Urratiguer, M. (2014) The feasibility of maintaining ecologically and geomorphically important elements of the natural flow regime in the context of a superabundance of flow: Stage 1 – Kororoit Creek study . Report prepared for Melbourne Water

Ecological Associates (2005). The Environmental Water Needs of the Werribee River: Final Report – Flow Recommendations. Report prepared by Ecological Associates for Melbourne Water, September 2005.

Ecological Associates (2005b). The Environmental Water Needs of the Werribee River - Issues Paper (Incorporating Site Paper). Report prepared by Ecological Associates for Melbourne Water

Griffiths J., Maino J. & Weeks A. (2019) Identifying key flow variables and quantifying their impact on platypus populations (Report to Melbourne Water). cesar, Parkville, VIC.

Griffiths J., van Rooyen A. & Weeks A. (2017) Using eDNA to assess the current distribution of platypuses in the greater Melbourne area (Report to Melbourne Water). cesar, Parkville, VIC.

Griffiths J., van Rooyen A., Song S. & Weeks A. (2018) Distribution and relative abundance of platypuses in the greater Melbourne area : MWUPP 2013-18. cesar, Parkville, VIC.

Griffiths J. & Weeks A. (2017) Distribution and relative abundance of platypuses in the greater Melbourne area: survey results 2016/17. (Report to Melbourne Water). cesar, Parkville.

Jacobs (2014). Werribee River Environmental Flows Review. Report prepared by Jacobs for Melbourne Water

Jacobs (2022). Werribee Flows update – Site Paper. Report prepared by Jacobs for Melbourne Water

Melbourne Water (2018). Co-designed catchment program for the Werribee catchment region. October 2018.

Melbourne Water (2018). Healthy Waterways Strategy 2018. December 2018

Rolls, R. J., Leigh, C., & Sheldon, F. (2012). Mechanistic effects of low-flow hydrology on riverine ecosystems: ecological principles and consequences of alteration. Freshwater Science, 31, 1163–1186.

Serena, M., Bloink, C., and Williams, G. (2022). Results of platypus survey work in the Werribee River at Bacchus Marsh and Werribee Township: Summer 2022. Report prepared for Bacchus Marsh Platypus Alliance and Werribee River Association.

VEWH (2021) Seasonal Watering Plan 2021-22 – Central Region, Victorian Environmental Water Holder, East Melbourne, Victoria

Walsh C. J., Roy A. H., Feminella J. W., Cottingham P. D., Groffman P. M. & Morgan R. P. (2005) The urban stream syndrome: current knowledge and search for a cure. J. North Am. Benthol. Soc. 24, 706-723

# Appendix A. Ecological Relevant Hydrological Metrics for each Reach

Reach 1:

| Ecological or Geomorphic Significance | Metric | #231225 | Modelled Historical | Modelled Natural | Modelled 2045 Low CC | Modelled 2045 High CC | Modelled 2070 Low CC | Modelled 2070 High CC |
|---|---|---|---|---|---|---|---|---|
| | | Scenarios | | | | | | |
| | | All | | | | | | |
| | | Observed | Modelled | | | | | |
| Low flow periods affect habitat availability | *1. Days per year of zero flow:* | 23% | 24% | 23% | 24% | 27% | 24% | 28% |
| | *2. Mean duration of zero flow periods:* | 42.2 | 40.4 | 40.5 | 40.5 | 46.8 | 40.5 | 46.5 |
| | *1(b). Days per year of low flow:* | 25% | 25% | 25% | 25% | 25% | 25% | 25% |
| | *2(b). Mean duration of low flow periods:* | 40.7 | 40.0 | 40.0 | 45.6 | 45.6 | 45.6 | 45.6 |
| | *3. Low flow frequency* | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 |
| Duration of 'disturbance events' both WQ and hydraulic | *4(a). Duration (own right) - % of days > overall mean daily flow* | 22% | 21% | 22% | 20% | 20% | 20% | 20% |
| | *4(b). Duration (relative to 'Natural') - % of days > overall mean daily flow* | 21% | 21% | 22% | 20% | 13% | 19% | 9% |
| Variability of flows is an indicator of duration of 'disturbance events' | *5. Rate of change (Variability over time)* | 41% | 42% | 42% | 44% | 45% | 44% | 45% |
| Min flows important for alignment with seasonal biological events | *6. Timing (min flow month)* | Mar | Mar | Mar | Mar | Mar | Mar | Mar |
| Bed erosion | *7. Bed mobilisation (1160 ML/day 1.5yr ARI)* | 1% | 1% | 1% | 1% | 0% | 1% | 0% |
| Impacts sediment transport, riparian veg, habitat availability | *8. Bank mobilisation (1440 ML/day 2yr ARI)* | 1% | 1% | 1% | 1% | 0% | 1% | 0% |

*Zero flow assumed as 0.1 ML/day*
*Low flow assumed as the 25th percentile (0.3 ML/day)*

Reach 2:

| Ecological or Geomorphic Significance | Metric | #231203 | Modelled Historical | Modelled Natural | Modelled 2045 Low CC | Modelled 2045 High CC | Modelled 2070 Low CC | Modelled 2070 High CC |
|---|---|---|---|---|---|---|---|---|
| | | Scenarios | | | | | | |
| | | All | | | | | | |
| | | Observed | Modelled | | | | | |
| Low flow periods affect habitat availability | *1. Days per year of zero flow:* | 7% | 5% | 18% | 5% | 10% | 5% | 16% |
| | *2. Mean duration of zero flow periods:* | 28.7 | 103.4 | 41.2 | 107.6 | 199.3 | 111.9 | 168.1 |
| | *1(b). Days per year of low flow:* | 25% | 25% | 25% | 25% | 25% | 25% | 25% |
| | *2(b). Mean duration of low flow periods:* | 27.1 | 32.6 | 44.8 | 31.9 | 36.6 | 32.4 | 43.9 |
| | *3. Low flow frequency* | 0.15 | 0.45 | 0.14 | 0.43 | 0.50 | 0.45 | 0.53 |
| Duration of 'disturbance events' both WQ and hydraulic | *4(a). Duration (own right) - % of days > overall mean daily flow* | 30% | 20% | 18% | 19% | 28% | 19% | 30% |
| | *4(b). Duration (relative to 'Natural') - % of days > overall mean daily flow* | 39% | 26% | 18% | 27% | 20% | 26% | 17% |
| Variability of flows is an indicator of duration of 'disturbance events' | *5. Rate of change (Variability over time)* | 48% | 25% | 36% | 25% | 24% | 25% | 22% |
| Min flows important for alignment with seasonal biological events | *6. Timing (min flow month)* | Jun | May | Mar | May | Jun | May | May |
| Bed erosion | *7. Bed mobilisation (280 ML/day 1.5yr ARI)* | 2.8% | 3.5% | 3.9% | 3.9% | 1.8% | 3.7% | 1.0% |
| Impacts sediment transport, riparian veg, habitat availability | *8. Bank mobilisation (440 ML/day 2yr ARI)* | 1.4% | 2.0% | 2.1% | 2.2% | 1.0% | 2.1% | 0.5% |

*Zero flow assumed as 0.1 ML/day*
*Low flow assumed as the 25th percentile (0.8 ML/day)*

## Reach 3:

| | | Scenarios | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Ecological or Geomorphic Significance** | **Metric** | **Reach3 (Calc)** | **Modelled Historical** | **Modelled Natural** | **Modelled 2045 Low CC** | **Modelled 2045 High CC** | **Modelled 2070 Low CC** | **Modelled 2070 High CC** |
| | | All | | | | | | |
| | | Observed | Modelled | | | | | |
| Low flow periods affect habitat availability | *1. Days per year of zero flow:* | 32% | 18% | 5% | 20% | 22% | 20% | 25% |
| | *2. Mean duration of zero flow periods:* | 36.8 | 20.6 | 34.4 | 41.7 | 39.6 | 41.4 | 42.3 |
| | *1(b). Days per year of low flow:* | 30% | 25% | 25% | 25% | 25% | 25% | 25% |
| | *2(b). Mean duration of low flow periods:* | 35.2 | 25.8 | 38.2 | 40.2 | 41.4 | 40.5 | 42.3 |
| | *3. Low flow frequency* | 0.00 | 0.17 | 0.19 | 0.16 | 0.15 | 0.16 | 0.15 |
| Duration of 'disturbance events' both WQ and hydraulic | *4(a). Duration (own right) - % of days > overall mean daily flow* | 14% | 16% | 20% | 17% | 13% | 17% | 11% |
| | *4(b). Duration (relative to 'Natural') - % of days > overall mean daily flow* | 11% | 15% | 20% | 16% | 9% | 15% | 6% |
| Variability of flows is an indicator of duration of 'disturbance events' | *5. Rate of change (Variability over time)* | 44% | 42% | 40% | 39% | 38% | 39% | 40% |
| Min flows important for alignment with seasonal biological events | *6. Timing (min flow month)* | Mar | Mar | Mar | Mar | Mar | Mar | Mar |
| Bed erosion | *7. Bed mobilisation (800 ML/day 1.5yr ARI)* | 1% | 1% | 2% | 2% | 1% | 2% | 0% |
| Impacts sediment transport, riparian veg, habitat availability | *8. Bank mobilisation (1230 ML/day 2yr ARI)* | 1% | 1% | 1% | 1% | 0% | 1% | 0% |

*Zero flow assumed as 0.1 ML/day*
*Low flow assumed as the 25th percentile (0.1ML/day)*

## Reach 4:

| | | Scenarios | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Ecological or Geomorphic Significance** | **Metric** | **Reach4 (Calc)** | **Modelled Historical** | **Modelled Natural** | **Modelled 2045 Low CC** | **Modelled 2045 High CC** | **Modelled 2070 Low CC** | **Modelled 2070 High CC** |
| | | **All** | | | | | | |
| | | **Observed** | **Modelled** | | | | | |
| Low flow periods affect habitat availability | *1. Days per year of zero flow:* | 2% | 1% | 3% | 0% | 4% | 1% | 8% |
| | *2. Mean duration of zero flow periods:* | 63.3 | 35.0 | 43.2 | 38.0 | 38.6 | 31.0 | 48.2 |
| | *1(b). Days per year of low flow:* | 24% | 24% | 25% | 25% | 24% | 25% | 23% |
| | *2(b). Mean duration of low flow periods:* | 32.9 | 23.8 | 28.4 | 29.6 | 36.1 | 29.6 | 59.7 |
| | *3. Low flow frequency* | 0.20 | 0.97 | 0.21 | 0.90 | 0.95 | 0.91 | 0.88 |
| Duration of 'disturbance events' both WQ and hydraulic | *4(a). Duration (own right) - % of days > overall mean daily flow* | 22% | 15% | 20% | 16% | 15% | 16% | 20% |
| | *4(b). Duration (relative to 'Natural') - % of days > overall mean daily flow* | 20% | 15% | 20% | 16% | 10% | 16% | 8% |
| Variability of flows is an indicator of duration of 'disturbance events' | *5. Rate of change (Variability over time)* | 46% | 27% | 33% | 27% | 27% | 27% | 27% |
| Min flows important for alignment with seasonal biological events | *6. Timing (min flow month)* | May | May | Mar | May | May | May | May |
| Bed erosion | *7. Bed mobilisation (580 ML/day 1.5yr ARI)* | 3% | 4% | 4% | 4% | 2% | 4% | 1% |
| Impacts sediment transport, riparian veg, habitat availability | *8. Bank mobilisation (1340 ML/day 2yr ARI)* | 1% | 1% | 1% | 2% | 1% | 1% | 0% |

*Zero flow assumed as 0.1 ML/day*
*Low flow assumed as the 25th percentile (6 ML/day)*

## Reach 5:

| | | Scenario | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Ecological or Geomorphic Significance** | **Metric** | **#231300** | **Modelled Historical** | **Modelled Natural** | **Modelled 2045 Low CC** | **Modelled 2045 High CC** | **Modelled 2070 Low CC** | **Modelled 2070 High CC** |
| | | All | | | | | | |
| | | **Observed** | **Modelled** | | | | | |
| Low flow periods affect habitat availability | *1. Days per year of zero flow:* | 0% | 0% | 3% | 1% | 2% | 1% | 5% |
| | *2. Mean duration of zero flow periods:* | 18.0 | 18.0 | 32.4 | 32.8 | 26.0 | 29.9 | 30.2 |
| | *1(b). Days per year of low flow:* | 25% | 25% | 25% | 25% | 25% | 26% | 25% |
| | *2(b). Mean duration of low flow periods:* | 33.6 | 33.0 | 32.9 | 33.2 | 32.9 | 33.8 | 37.1 |
| | *3. Low flow frequency* | 0.75 | 0.76 | 0.28 | 0.39 | 0.42 | 0.38 | 0.38 |
| Duration of 'disturbance events' both WQ and hydraulic | *4(a). Duration (own right) - % of days > overall mean daily flow* | 15% | 14% | 18% | 15% | 13% | 15% | 13% |
| | *4(b). Duration (relative to 'Natural') - % of days > overall mean daily flow* | 12% | 11% | 18% | 15% | 8% | 14% | 5% |
| Variability of flows is an indicator of duration of 'disturbance events' | *5. Rate of change (Variability over time)* | 48% | 48% | 27% | 29% | 28% | 29% | 27% |
| Min flows important for alignment with seasonal biological events | *6. Timing (min flow month)* | May | May | Mar | Mar | Mar | Mar | May |
| Bed erosion | *7. Bed mobilisation (830 ML/day 1.5yr ARI)* | 2% | 2% | 3% | 3% | 1% | 3% | 1% |
| Impacts sediment transport, riparian veg, habitat availability | *8. Bank mobilisation (1380 ML/day 2yr ARI)* | 1% | 1% | 2% | 2% | 1% | 2% | 0% |

*Zero flow assumed as 0.1 ML/day*
*Low flow assumed as the 25th percentile (5 ML/day)*

# Appendix B. Original Flow recommendations

Reach 3:

Table 13. Flow objectives for Reach 3 – Upper Werribee Diversion Weir to Pykes Creek.

| Flow | | | | Rationale |
|---|---|---|---|---|
| **Season** | **Magnitude** | **Frequency** | **Duration** | |
| January to April | Cease to flow | 2 x 20 days per year<br>minimum event separation 7 days | 40 days total or natural if natural is less | 2 d) curtail growing season of in-channel emergent macrophytes<br>1 g) control trout |
| December – June | Low flows<br>5 ML/d<br>or natural if natural is less | all years except extended drought | residual time after other flows | 3 a) fully wetted perimeter achieved at 3 of 5 riffle sites at 5 ML/d and 4 of 5 riffle sites at 15 ML/d; 140mm hydraulic depth over riffles ($d_{50}$ hydraulic depth + 10mm) achieved at 4 of 5 riffle sites at 24 ML/d)<br>1 f) suitable pool water quality (<3 ML/d for entire reach)<br>1 b, 3 c) maintain pool extent<br>3 b) Sand and silt mobilised (<3 ML/d for entire reach) |
| December – March | Low flow freshes<br>14 ML/d or natural if natural is less | minimum 2 per year<br>minimum event separation 14 days | 5 days | 1 a) 180mm depth over thalweg–($d_{50}$ at thalweg + 50mm) longitudinal flow connectivity for fry dispersal achieved at 3 of 5 riffles at 16 ML/d and 4 of 5 riffles at 19 ML/d (median 14 ML/d)<br>1 d) duration lesser of 5 days or natural |
| July – November | Baseflows<br>37 ML/d or natural if natural is less | all years | residual time after other flows | 1 c) 230mm depth at thalweg ($d_{50}$ at thalweg +100mm) of shallowest riffle – to ensure longitudinal flow connectivity of sufficient depth for adult blackfish to disperse dispersal achieved at 37 ML/d<br>2 a, 5e) Platypus habitat and stream edge macrophyte growth supported by fully wetted perimeter at 4 of 5 sites at 15 ML/d<br>1 e) Blackfish spawning habitat<br>2 b) bench vegetation part inundated (low benches not distinctive on cross-sections) |
| Anytime | High flow freshes<br>165 ML/day or natural if natural is less | min 6 per year<br>minimum event separation 14 days | at least 1 day | 2 e) macrophyte advance does not occur at Q95 for entire reach (achieved at 165 ML/d)<br>4 b i) mobilisation of gravels (7 of 8 cross-sections achieved by 87 ML/d) |
| Anytime | Bankfull Flows<br>700 ML/d | Natural<br>(2 in 1 year) | at least 1 day (in excess of 700 ML/d) | 4 bii, 3 e) Maintain channel dimensions and form through sediment reworking (bankfull for lower part of reach is 1500 ML/d and upper reach is 700 ML/d; Q99.9 occurs at half of sites at 2800 ML/d so is largely an overbank phenomenon; at 700 ML/d $d_{16}$ mobilised at 6 of 8 sites (4 of 5 riffle sites) and $d_{50}$ mobilised at 2 of 8 sites (1 riffle site); at 1500 ML/d $d_{16}$ mobilised at 7 of 8 sites (4 of 5 riffle sites) and $d_{50}$ mobilised at 6 of 8 sites (3 of 4 riffle sites)) |
| Anytime | Overbank flows<br>3,400 ML/d | Natural<br>(1 in 10 years) | minimum 1 day | 4 biii, 2 f) woody vegetation disturbance and bench reworking approximately every 10 years. Natural flood occurring 1 in 10 years is 3400 ML/d. Macrophyte removal Q99.9 occurs at 6 of 8 of sites at 3400 ML/d; grass removed from benches at 7 of 8 sites at 3400 ML/d. |

Reach 4:

**Table 15. Flow objectives for Reach 4 - Werribee Gorge**

| Flow | | | | Rationale |
|---|---|---|---|---|
| **Season** | **Magnitude** | **Frequency** | **Duration** | |
| February to April | Cease to flow | 2 x 15 days per year minimum event separation of 7 days | 30 days total or natural if natural is less | 2 d) curtail growing season of in-channel emergent macrophytes |
| December – May | Low flows 10 ML/d or natural if natural is less | all years except extended drought | residual time after other flows or natural if natural is less | 3 a) 90mm hydraulic depth over riffle ($d_{50}$ hydraulic depth +10mm) at 3 of 5 riffle cross sections at 10 ML/d; a flow of 5 ML/d will satisfy this criterion at 2 of 5 riffle sites; at 13 ML/d wetted perimeter inundated at 2 of 5 riffle sites<br>1 b, 3 c, 5 c) maintain pool habitat<br>1 f, 5 b) suitable pool water quality achieved by 0.1 m/s flow at 2 ML/d<br>3 b, 3e, 5 a) Sand and silt mobilised from all pools and riffles by 2 ML/d<br>4 c, 5 d) Avoid long periods of high regulated flows in summer |
| December – February | Small Low flow freshes 13 ML/d or natural if natural is less | 2 per year minimum event separation 7 days | 5 days | 1 a) 130mm depth ($d_{50}$ at thalweg + 50mm) across riffle - longitudinal flow connectivity for fry dispersal achieved over entire reach at 13 ML/d |
| December – May | Large Low flow freshes 90 ML/d or natural if natural is less | minimum 2 per year minimum event separation 14 days | 1 day | 2 e) macrophyte advance does not occur at Q95 for entire reach at 150 ML/d, and for 4 of 6 cross sections (90 ML/d)<br>4 b i) Mobilisation of gravels (and sand) occurs for entire reach at 186 ML/d, and at 5 of 6 cross-section at 72 ML/d<br>1 d) duration lesser of 5 days or natural |
| June – November | Baseflows 29 ML/d or less if natural is less | all years | residual time after other flows | 1 c) 180mm depth at thalweg ($d_{50}$ at thalweg +100mm) of shallowest riffle to provide longitudinal flow connectivity, for adult dispersal occurs at 29 ML/d<br>2 a, 5e) Platypus feeding habitat and stream edge macrophytes part inundated - wetted perimeter fully inundated at 2 of 6 sites at 13 ML/d, and $d_{50}$ + 10mm over all riffles for entire reach achieved at 20 ML/d<br>1 e) spawning habitat provided in pools |
| June – November | High flow freshes 245 ML/d or natural if natural is less | 4 in Aug to Sep 2 in Oct to Dec minimum event separation 5 days | 2 days | 2 b) Low benches are not well defined in this reach. Bed fully wetted over entire reach at 245 ML/d, which will partly inundate the lower extent of stream edge macrophytes over much of the reach<br>2 c) Inundate aquatic macrophytes in riparian zone with decreasing frequency towards summer followed by transition to low flows<br>2 e) Q95 to disturb macrophytes achieved over entire reach at 151 ML/d<br>4 bi) Gravels mobilised in all riffles and pools at 186 ML/d, and mobilised at all riffles at 72 ML/d |

| Flow | | | | Rationale |
|---|---|---|---|---|
| **Season** | **Magnitude** | **Frequency** | **Duration** | |
| Anytime | Bankfull flows<br>3160 ML/d | Natural<br>(1 in 2 years) | 1 day | 4 bii) Maintain channel dimensions and form through sediment reworking (median value of morphological bankfull is 3160 ML/d; Q99.9 occurs at 4 of 6 cross sections at 2230 ML/d; at 3340 ML/d $d_{50}$ mobilised over entire reach); maintain natural frequency and rate of rise and fall<br>2 f) disturbance to shrubby vegetation required at least approx 1 in 5 years. Q99.9 achieved at 4 of 6 cross sections at 2230 ML/d; grass removed from channel at 4 of 6 sites at 2160 ML/d.<br>3 e) $d_{16}$ and $d_{50}$ mobilised at all riffle cross sections by 1413 ML/d |

Reach 5:

**Table 17. Flow objectives for Reach 5 - Bacchus Marsh**

| Flow | | | | Rationale |
|---|---|---|---|---|
| **Season** | **Magnitude** | **Frequency** | **Duration** | |
| February – April | Cease to flow | 2 x 15 days per year<br>minimum event separation of 7 days | 30 days total<br>or natural if natural is less | 2 d) curtail growing season of in-channel emergent macrophytes |
| December – May | Low flows<br>4 ML/d or natural if natural is less | all years except extended drought | residual time after other flows | 3 a) 72.5 mm hydraulic depth over riffle ($d_{50}$+10mm across riffle) achieved at 3 of 4 riffle sites at 4 ML/d and all riffle sites at 7 ML/d; full wetted perimeter at 1 riffle and all pools at 5 ML/d, 2 of 4 riffles sites at 15 ML/d and all riffle sites at 18 ML/d<br>1 b, 3 c, 5 c) maintain pool habitat<br>1 a) 112mm depth ($d_{50}$ at thalweg+50) –for longitudinal flow connectivity for fry dispersal achieved over entire reach at 4 ML/d)<br>3 c) survival of drought intolerant fauna<br>4 c, 5 d) Avoid long periods of high regulated flows in summer |
| December – May | Low flow freshes<br>12 ML/day or natural if natural is less | minimum 4 per year<br>minimum event separation of 14 days | minimum 1 day | 1 f, 5 b) suitable pool water quality achieved at 1 of 3 pools at 6 ML/d and 2 of 3 pools at 12 ML/d<br>1 d) duration lesser of 5 days or natural |
| June – November | Baseflow<br>18 ML/d or natural if natural is less | all years | residual time after other flows | 2 a, 5e) perimeter fully inundated at all sites at 18 ML/d and 3 of 6 sites at 10 ML/d; $d_{50}$ + 10mm over all riffles for entire reach achieved at 7 ML/d<br>1 c) 162.5mm depth ($d_{50}$ at thalweg + 100mm) of shallowest riffle to ensure longitudinal flow connectivity, for adult dispersal occurs at 9 ML/d<br>1 e) provide deep spawning habitat in pools or submerged rocks and snags<br>3b, 3e, 5a) Silt mobilised over entire reach at 8 ML/d; |
| June – November | High flow freshes<br>141 ML/d or natural if natural is less | 1 per month | 2 days | 2 e) Q95 to disturb macrophytes achieved over entire reach at 141 ML/d and 4 of 7 sites at 120 ML/d<br>2 b) Low benches are generally not well defined in this reach. One well-defined bench is inundated at 133 ML/d.<br>3 b, 3e,5a i) Mobilisation of sand occurs for entire reach, and mobilisation of gravels at 2 of 4 riffles, occurs at 116 ML/d<br>4 bi) Gravels mobilised in 2 of 4 riffles at 9 ML/d |
| Anytime | Bankfull Flows<br>1400 ML/d | Natural<br>(1 per year) | 1 day | 4 bii) Maintain channel dimensions and form through sediment reworking (median value of morphological bankfull in upper part of reach where it is well-defined is 1350 ML/d; at 1400 ML/d gravel mobilised over 4 of 7 sites; maintain natural frequency and rate of rise and fall |
| Anytime | Overbank<br>3580 ML/d | 1 in 10 years | 1 day | 2 f) Q99.9 for shrubby vegetation disturbance occurs at 4 of 7 sites at 3580 ML/d; Natural flood occurring 1 in 10 years was 6,680 ML/d<br>3 e) d16 achieved at 2 of 4 riffle sites at 1810 ML/d. |