Yarra River Environmental Flow Study Review

FLOW RECOMMENDATIONS REPORT

- Final
- 13 September 2012

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Executive summary

This project reviews and updates the environmental flow recommendations that were initially determined for the Yarra River in 2005. The review specifically focuses on the six freshwater reaches of the Yarra River between the Upper Yarra Reservoir and Dights Falls and one reach of the Watts River between Maroondah Reservoir and the Yarra River. Revised flow requirements for the Yarra River estuary and Plenty River will be determined through separate projects.

The 2005 environmental flow recommendations were determined using the FLOWS method (DNRE, 2002), and were based on the best available information at that time. Specific monitoring associated with environmental flow releases, responses to natural floods and the drought, and other targeted ecological research have increased our understanding of the flow requirements of many environmental values in the Yarra River. Moreover, the FLOWS method has been updated to provide more reliable and more flexible environmental flow recommendations (DSE, unpublished). Melbourne Water commissioned this review of the 2005 flow recommendations to incorporate the new information and to reflect recent advances in the FLOWS method.

The FLOWS method provides a scientific framework for the assessment of flow requirements for waterways where there is some information available on the ecology, geomorphology and hydrology of the study area. The method has been specifically developed for determining environmental water requirements in Victoria and is based on the concept that key flow components of a natural flow regime influence various biological, geomorphological and physicochemical processes in waterways. Key flow components are likely to vary between river systems, but every stream system has some key flow components that are essential to maintain a healthy functioning aquatic ecosystem.

This report presents the revised environmental flow recommendations for Yarra River, and is the third and final output for the current project. It is preceded by a *Site Paper* (SKM, 2012a) and an *Issues Paper* (SKM, 2012b). The *Site Paper* described the process used to review existing reaches and sites. The *Issues Paper* detailed the available information on the environmental values of the study area – water system management, hydrology, geomorphology, ecology and water quality. Specifically, it reviewed new information that has become available since the 2005 study and proposed alternative objectives where considered necessary based on new information. The *Site Paper* and *Issues Paper* inform the revised flow recommendations and should be read in conjunction with this report.

Reach and site selection

Existing reach boundaries from the 2005 study were retained, however some of the original flow assessment sites were moved and several additional sites were added to augment existing sites. All of the original flow assessment sites in the main stem of the Yarra River (i.e. Reaches 1-5) were retained, but new sites were assessed in Reaches 2, 3 and 6 (Table 1-1). An existing hydraulic model developed for the Millgrove Gauge site was used to check environmental flow recommendations for Reach 2. A new hydraulic model and flow assessment was conducted at a site immediately upstream of the Healesville - Woori Yallock Road to more reliably estimate low flow requirements for Reach 3. A new survey and assessment were also conducted at Finns Reserve in Reach 6 to develop a two-dimensional hydraulic model to better assess the flow requirements for Macquarie Perch and other native fish. The flow assessment site in the Watts River (Reach 8) was moved to a point immediately downstream of the confluence with Donnelly Creek that had a distinct riffle/pool sequence, and therefore provided a better assessment of low flow requirements for that reach.

■ **Table 1-1: Yarra River reaches and field assessment sites used in 2012 review.**

Reach no.	Location	Site no.	Site location	2005 Assessment site
1	Upper Yarra Reservoir to Armstrong Creek junction	1	Downstream of Upper Yarra Reservoir, Reefton	Yes
2	Armstrong Creek to Millgrove	2a	Warburton East (downstream of major tributary harvesting operations)	Yes
		2b	Millgrove gauge	No
3	Millgrove to Watts River junction	3a	Immediately upstream of Healesville-Woori Yallock Rd	No
		3b	Everard Park, upstream of Maroondah Highway.	Yes
4	Watts River to top of Yering Gorge	4	Tarrawarra Abbey, Yarra Glen.	Yes
5	Top of Yering Gorge to Mullum Mullum Creek	5a	Immediately downstream of Yering Gorge pumping station.	Yes
		5b	Everard Drive, Warrandyte	Yes
6	Mullum Mullum Creek to Dights Falls	6a	Finns Reserve	No
		6b	Banyule Flats, downstream of Plenty River	Yes
8	Watts River from Maroondah Reservoir to Yarra River confluence	8	Immediately downstream confluence with Donnelly Creek	No

Revised environmental flow recommendations

The 2005 environmental flow recommendations were only modified in cases where new information improved our understanding of the flow requirements for particular species or ecological processes, or where improved hydraulic models indicated that a different flow magnitude was required to meet an existing flow objective. The main changes relate to the requirements for two species of native fish (Australian Grayling and Macquarie Perch) and the minimum flows required to prevent adverse water quality outcomes in the Dights Falls weir pool.

Flow recommendations to support Australian Grayling

Australian Grayling require high flows in autumn (specifically April or May) to trigger migration and spawning. The 2005 environmental flow assessment recommended a summer high flow of 900 ML/day in Reach 3, 1100 ML/day in Reach 4 and 1500 ML/day in Reaches 5 and 6 to facilitate Australian Grayling migration and spawning. Recent work by Koster and Dawson (2011) demonstrated that slightly smaller flows may trigger Australian Grayling spawning in the Yarra River, but that work demonstrated that the duration of the event is also important, particularly for individuals in the most upstream reaches that need to migrate to spawning sites just upstream of the estuary. The updated flow recommendations include a recommended summer high flow of 900-1100 ML/day in Reaches 3 and 4, and at least 1,300 ML/day in reaches 5 and 6, with a condition that larger flows should be passed if they occur (Table 1-2). These events should last for at least seven days in all reaches and elevated flows should last for up to 14 days in Reaches 3 to 5 (Table 1-2). The updated flow recommendations also acknowledge that high autumn flows will not occur every year, but because Australian Grayling only live for 3-4 years, it is important that the flows are delivered at least once every three years.

Flow recommendations to support Macquarie Perch

Since 2006, Melbourne Water has commissioned several studies to investigate the condition and flow requirements of the Macquarie Perch population in the Yarra River. King *et al.* (2011) surveyed Macquarie Perch abundance and recruitment in the Yarra River in 2006/07, 2008/09, 2009/10 and 2010/11. They observed the greatest recruitment in 2009/10 and concluded that the combination of high spring flows, which are likely to flush spawning and egg development sites, and relatively stable summer flows, which will prevent developing eggs and larvae from being washed away may be important factors in determining recruitment success (King *et al.*, 2011). The timing and magnitude of the spring high flows is important because high flows in late spring are important for promoting the growth of native riparian plant species, and care needs to be taken to ensure the environmental flow recommendations that aim to enhance native fish recruitment do not inadvertently disadvantage other environmental values. Three large spring flows occurred in the Yarra River in 2009. The highest of those flows, occurred at the start of October and reached a peak of approximately 5000 ML/day at Warrandyte (King *et al.*, 2011). That flow was followed by a smaller flow of approximately 2500 ML/day in late October. Flow at Warrandyte did not exceed 1000 ML/day between the start of November 2009 and the start of February 2010 (King *et al.*, 2011). Based on that flow sequence, we concluded that freshes and high flows up to 2500 ML/day at Warrandyte in spring would meet the requirements of riparian vegetation and Macquarie Perch. However, bankfull and overbank flows in October or November would potentially disrupt Macquarie Perch recruitment. The updated environmental flow recommendations specify that the winter bankfull and overbank flows should not be delivered in October or November (Table 1-2), unless they occur naturally.

Revisions based on improvements to hydraulic models

The magnitude of the winter fresh, winter high flow and bankfull flows for reaches 3 to 6 of the Yarra River have also been revised in the updated environmental flow recommendations. In most cases these adjustments have been due to improvements in the hydraulic models. The magnitude of the winter freshes and high flows have increased slightly to ensure that the flows inundate low benches within the channel and are competent to move fine sediment from riffle habitats. The use of LiDAR information and field observations during minor floods allowed much more accurate estimates of the specific flows that engage flood runners and wetlands close to the main river channel. The recommended bankfull flow for Reach 3 has reduced from 7,500 ML/day to 4,000 ML/day, the bankfull flow for Reach 4 has reduced from 9,000 ML/day to 5,000 ML/day and the bankfull flow for Reach 5 has reduced from 10,000 ML/day to 5,000 ML/day (Table 1-2). The new bankfull flow recommendations will not necessarily fill the channel, but do engage the lowest flood runners and therefore are the minimum flows required to get water into some billabongs and backwaters near the main channel. There is a recognition that these flows will not occur every year and are unlikely to occur in dry years (Table 1-2).

The new flow assessment site in the Watts River had distinct riffle and pool habitats and therefore the hydraulic model developed for that site provided a more reliable assessment of the minimum flow requirements for Reach 8. Based on the site observations and the new hydraulic model, the recommended summer low flow for Reach 8 was reduced from 20 ML/day to 10 ML/day and the recommended winter low flow was reduced from 180 ML/day to 80 ML/day (Table 1-2).

Flow recommendations to manage water quality

The 2005 environmental flow recommendations for the Yarra River specified a summer low flow of 200 ML/day for Reaches 5 and 6. However, subsequent investigations by McGuckin (2010) and SKM (2011b) demonstrated that a minimum flow of 300 ML/day was required to maintain dissolved oxygen at an adequate level at the upstream end of the Dights Falls weir pool. Moreover, Robinson (2011) demonstrated that parts of the Dights Falls weir pool became stratified and bottom layers became anoxic when the water temperature exceeded 16 °C and flow dropped below 450 ML/day. The Dights Falls weir is an artificial structure that increases pool depth and reduces flow velocity throughout the 17 km long weirpool (Melbourne Water, 2009). If Dights Falls was not present then it is likely that substantially lower flows would be able to keep the water column mixed.

Stratification and low levels of dissolved oxygen represent a threat to aquatic biota including native fish. Increasing flow is one way of increasing dissolved oxygen levels and mixing the water column. Other methods may include fixed or mobile aerators. The current report does not specify how the water quality problems in the Dights Falls weir pool should be managed. Rather it presents two flow management options. The first option includes a recommended summer low flow of 300 ML/day for Reach 6 (see Table 1-2). This flow will be sufficient to maintain dissolved oxygen levels at an acceptable level at the Chandler Highway flow gauge and should also maintain adequate dissolved oxygen levels at the surface of the weir pool most of the time. However, it is likely that parts of the Dights Falls weir pool will stratify during the warmest months. The second option, recommends a minimum flow of 450 ML/day during December, January and February and a minimum flow of 300 ML/day in November and from March to May. This second option is intended to prevent stratification within the Dights Falls weir pool.

Separate flow recommendations for wet, average and dry years

To further assist with implementation, separate flow recommendations are provided for dry, average and wet years where the panel considered there was a reasonable justification for doing so. Wet, average and dry years were determined by rainfall records because the Bureau of Meteorology (BoM) provides long term predictions about rainfall that can be used by Melbourne Water when planning environmental water allocations and operations for a particular year. The specific recommendations provided in this report were based on separate hydrological analyses of wet, dry and average years in the available record.

Reliable hydrological and rainfall records for the Yarra River extend back to 1964. These data were divided into three equal groups based on rainfall. Dry years correspond to those with the driest third of rainfall years during the flow record, average years correspond to the middle third of years, and wet years correspond to the wettest third of years.

The main differences between wet, average and dry year recommendations relate to the frequency, duration or timing of particular flow events as well as distinctions between minimum and median flow requirements. For example, the recommended median winter low flow magnitude for Reaches 5 and 6 is 750 ML/day in wet and average rainfall years, but is only 600 ML/day in dry years. Similarly, summer high flows to trigger Australian Grayling migration and spawning are not expected to occur in all dry years (see Table 1-2).

- **Table 1-2: Summary of updated environmental flow recommendations for each reach. The volume (ML/day), duration (days) and number (per year / season) are specified for each flow component in wet, average and dry climate years. × indicates flow components not expected to occur under the specified climate conditions.**

Season	Flow	Climate		Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 8
Summer										
Dec - May	Low flow	All	Volume	10 *	80 *	150 *	200 *	200 *	>300 ^	>10 *
Dec - May	Fresh	Wet / Average	Volume	60 *	350 *	450 *	450 *	750	750 *	80 *
			Duration	≥1	≥3	≥3	≥3	2	≥2	≥2
			Number	≥4	≥2	≥2	≥2	Wet 5 Ave 4	≥3	≥4
		Dry	Volume	60	350	450	450	750	750	80 *
			Duration	4	3	3	3	2	2	≥2
			Number	1	2	2	2	3	3	≥4
Apr - May	High	Wet / Average	Volume	×	560 *	900-1100 #	900-1100 #	1300 #	1300 #	×
			Duration		≥7	7-14	7-14	7-14	≥7	
			Number		1	1	1	1	1	
		Dry	Volume	×	560	900-1100 #	900-1100 #	1300 #	1300 #	×
			Duration		≥7	7-14	7-14	7-14	7	
			Number		1	≥1 in 3 yrs	≥1 in 3 yrs	≥1 in 3 yrs	≥1 in 3 yrs	
Winter										
Jun - Nov	Low flow	Wet / Average	Volume	10 *	>350	>350	>350	>350 (median 750)	>350 (median 750)	80 *
		Dry	Volume	10 *	>200 (Median 350)	>350 (Aug – Nov)	>350 (Aug – Nov)	>350 (median 600)	>350 (median 600)	80 *
Jun - Sep (Jun – Nov Reach 8)	Fresh	Wet / Average / Dry	Volume	100 *	700 *	1800 *	2000 *	2500 *	2500 *	180 *
			Duration	≥2	≥7	≥7	≥7	≥7	≥7	≥2
			Number	≥3	≥2	≥2	≥2	≥2	≥2	Wet 4-5 Ave 3-4 Dry 2-3

Season	Flow	Climate		Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Reach 8
Jun - Nov	High	Wet / Average	Volume	300	700	1800	2000	2500	2500	×
			Duration	3	14	14	14	14	14	
			Number	1 in 2 years (Jun – Sep)	1 (Sep)	1 (Oct – Nov)	1 (Oct – Nov)	1 (Oct – Nov)	1 (Oct – Nov)	
		Dry	Volume	300	×	×	×	×	×	×
			Duration	3						
			Number	1 in 2 years (Jun – Sep)						
Not Oct - Nov	Bankfull	Wet	Volume	1100	2700	4000	5000	5000	13000	1000
			Duration	3	2	2	2	2	1-2	2
			Number	1 in 10 years	1 in 2 years	1	2-3	2-3	1 in 2 years	1 in 2 years
		Average	Volume			4000	5000	5000	13000	1000
			Duration			2	2	2	1-2	2
			Number			1	1-2	1-2	1 in 2 years	1 in 2 years
		Dry	Volume			×	×	×	×	×
Not Oct - Nov	Overbank	Wet and/or Average years only	Volume	×	×	9000	10000	14000	21500	×
			Duration			2	1-2	1-2	1-2	
			Number			1 in 2 years	1 in 2 years	1 in 2 years	1 in 4 years	

* Minimum delivered flow, allow tributary inflows to provide variation on top of stated flow.

^ Low flow needs to be >450 ML/day between Dec – Feb if flow will be used to keep Dights Falls Weir Pool mixed.

Larger flows should be passed if they occur.

Achievement of flow recommendations

Most of the recommendations for summer and winter low flows and freshes are currently met in wet and average climate years, but the shortfall in dry years can be significant, particularly in the reaches downstream of the Yering Pump station. The recommended summer high flow is also not met as often as required in many reaches, which may have important implications for Australian Grayling spawning.

Water release patterns from Upper Yarra Reservoir, O'Shannassy Reservoir and Maroondah Reservoir and water harvesting operations at the Yering Pumps and in various tributaries in Reach 2 and Reach 8 may need to be modified to help meet the environmental flow recommendations. However, the results of this study show that operational rules mainly need adjusting in dry years.

The Upper Yarra Reservoir has significantly reduced the frequency of bankfull and overbank flows in many reaches. However, the social and economic consequences of flooding in the Yarra River catchment mean that it is neither practical nor desirable to generate these types of events through deliberate flow releases.

Complementary works and further investigations

Environmental flows are critical to ensuring the health of the Yarra River, however their effect will be limited if other complementary management works are not implemented. Moreover, as the differences between the current environmental flow recommendations and the 2005 recommendations demonstrate, our understanding of flow-ecology relationships continues to evolve and the environmental flow recommendations should continue to be updated as new information becomes available. Specific management actions that will improve the effectiveness of these environmental flow recommendations include rehabilitation of floodplain wetlands and billabongs, riparian weed management and re-vegetation, reinstatement of large wood to the river and water quality management programs that aim to control the factors that contribute to poor water quality at their source.

Melbourne Water is also planning two separate investigations to determine the environmental flow requirements of the Yarra estuary and water management strategies for selected floodplain wetlands and billabongs. Both of those studies are likely to have a direct bearing on the environmental flow recommendations presented in this report and any potential conflicts between the three studies should be identified and addressed.

Contents

Document history and status

Revision	Date issued	Reviewed by	Approved by	Date approved	Revision type
Draft A	19/6/2012	Andrew Sharpe	Simon Treadwell	20/6/2012	Practice review
Final	17/8/2012	Andrew Sharpe	Simon Treadwell	16/8/2012	Practice review

Distribution of copies

Revision	Copy no	Quantity	Issued to
Draft A	1	1	Anna Lucas (MW)
Final	2	1	Anna Lucas (MW)

Printed:	26 November 2012
Last saved:	24 September 2012 05:13 PM
File name:	I:\VWES\Projects\VW06625\Deliverables\Reports\recs report\R01_SAT Yarra Flow Recomendations Report_Final version.docx
Author:	Andrew Sharpe, Simon Treadwell, Amanda Woodman
Project manager:	Andrew Sharpe
Name of organisation:	Melbourne Water
Name of project:	Yarra River Environmental Flow Study Review
Name of document:	Flow Recommendations Report
Document version:	Final
Project number:	VW06625

Acknowledgements

The project team would like to acknowledge the Steering Committee and Advisory Committee for their assistance in this project.

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Glossary of terms and abbreviations

AUSRIVAS	Australian River Grade and Assessment System used for assessing macroinvertebrate community composition and as an indicator of river health
Anastomosing	A channel that splits into several channels that rejoin regularly.
Biofilm	An organic matrix comprised of microscopic algae, bacteria and micro-organisms that grow on stable surfaces in water bodies (e.g. logs, rocks or large vascular plants).
Catchment	The area of land drained by a river and its tributaries.
Current flow series	Series of streamflows which represent the current level of development.
Compliance point	Gauging station at which flows are measured to ensure compliance with recommendations.
Debouching	Emerge into larger body or area.
Diadromous	Fish that migrate between fresh and marine waters as part of various life cycle requirements. For example, eels migrate from river reaches to sea to spawn, the juvenile eels then migrate back to the river. Migration is often cued by changes in flow, season or water temperature
Dissolved oxygen (DO)	Concentration of oxygen in the water column. A measure of the amount of oxygen available to aquatic flora and fauna.
DSE	Department of Sustainability and Environment.
EFTP	Environmental Flows Technical Panel.
Environmental flow	Releases of water, periods of drying, or river flows allocated for the maintenance of aquatic and riparian ecosystem, measured in megalitres per day (ML/d).
EPBC Act	Environment Conservation and Biodiversity Protection Act. Commonwealth threatened species act aimed at identifying and protecting nationally threatened species and ecological communities.
Ephemeral stream	A waterway containing water only after unpredictable rain.
FFG Act	Flora and Fauna Guarantee Act. Victorian threatened species act aimed at identifying and protecting Victorian threatened species and ecological communities.
Floodplain	Temporarily inundated lateral river flats, usually of lowland rivers.
FSR	Flow Stressed Ranking.
Geomorphology	The study of the physical form of, and processes operating in, rivers. It aims to provide an understanding of the physical processes governing the current state of a river.
Groundwater	Water occurring below the ground surface.
Habitat	The place or environment in which a plant or animal usually lives; the subset of physical and chemical environmental variables that allow an organism to survive and persist.
Hydraulic modelling	The modelling of fluid flow in pipes and channels. Used in environmental flow studies to model flow in river channels.
Hydrology	The study of the surface and subsurface water. Sometimes used loosely to describe the water regime.
In-stream	Of, or occurring within the wetted area of a running water body.
ISC	Index of Stream Condition. Presents an indication of the extent of

	change in respect of five key 'stream health' indices: hydrology, physical form, streamside zone, water quality and aquatic life.
Littoral	Edge or shore region where the water is shallow enough for continuous mixing.
Lowland waterway	A stream section at low altitude, that is sinuous and often with width to depth ratios greater than 20.
LWD	Large Woody Debris. Branches and trees that have fallen in the river channel. Often referred to as snags.
Macroinvertebrates	Aquatic invertebrates whose body length usually exceeds 1 mm. Includes insects, crustacean, aquatic worms, and aquatic snails.
Macrophytes	The term is used to describe water plants other than microscopic algae; they may be floating or rooted.
Mean	Average. Equally far from two extremes.
Median	The middle value in an ordered sequence of values.
Megalitre (ML)	One million litres (an Olympic size swimming pool is about two megalitres).
Migration	Active movement, undertaken by some species of fish, as part of a life history requirement, usually initiated by a change in flow, season or temperature.
Unimpacted flow series	Series of streamflows which represent what streamflows would have historically been like without man-made diversions, demands and impoundments, not withstanding changes to land use over time.
Nutrients	Natural elements (usually phosphorus and nitrogen) that are essential for plant and animal growth.
Percentile exceedence flows	The flow which is exceeded for the defined percentage of time. E.g. the 80^{th} percentile flow is exceeded 80% of the time and is therefore a low flow. Also commonly used: 20^{th} and 50^{th} percentile where 20^{th} percentile exceedence flow is a relatively high flow and the 50^{th} percentile exceedence flow may also be called the median flow.
pH	Level of acidity in a range from 0-14: low pH (values <7) refers to high acidity and high pH (values >7) refers to low acidity.
Pool	A stream section where there is no discernable flow and usually deep.
Ramsar wetland	A wetland that has been identified to be of International Importance under the Ramsar Convention. The Ramsar Convention is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. The treaty was adopted in the Iranian city of Ramsar in 1971.
Reach	A length of stream that is reasonably uniform with respect to geomorphology, flow and ecology.
REALM	REsource ALlocation Model (REALM) is a Windows based computer program that can simulate the operation of both urban and rural water supply systems during droughts as well as during periods of normal and high streamflows. In environmental flow studies it is used to develop time series of river flows under current and unimpacted conditions. Current conditions reflect the current levels of demands and extractions from the system.
Recruitment	The addition of new members into a population through reproduction or immigration.
Regulated catchment/river	A river or creek where the flow of the river is controlled through the operation of large dams or weirs to meet water use demands

	downstream.
Riffle	A stream section with fast and turbulent flow over a pebble bed with protruding rocks. Characterised by a broken water surface.
Riparian	Vegetation found along the banks of streams and rivers.
Riparian zone	Any land which adjoins, directly influences, or is influenced by a body of water.
Run	A stream section with low to moderate laminar flow with unbroken water surface.
SEPP	State Environment Protection Policy.
SIGNAL	Stream Invertebrate Grade Number Average Level used for assessing macroinvertebrate community composition and as an indicator of river health.
SFMP	Stream Flow Management Plan.
Spawning	Production and deposition of eggs; related to fish reproduction.
SKM	Sinclair Knight Merz.
Snag	Branches and trees that have fallen in the river channel; also called Large Woody Debris (LWD).
Substrate	The base, or material, on the bed of the river.
Taxa	Any defined unit in the classification of living organisms (i.e. species, genus, family).
Threatened	A generic term used to describe taxa that are rare, vulnerable, endangered or insufficiently known and are subject to a threatening process.
Transect	Line drawn across a stream channel and perpendicular to the direction of flow for standardising measurements of width, depth velocity discharge etc.
Tributary	A river or creek that flows into a larger river.
Turbidity	The cloudy appearance of water due to suspended material (sediment).
Unregulated catchment/river	A river system where no major dams or weir structures have been built to assist in the supply, or extraction of water.
Upland	A stream section at high altitudes with a river channel often less than 10 times the channel depth.
Water-dependent	Aquatic species or those dependent on river water for survival
Weed	Any useless, troublesome or noxious plant, especially one that grows profusely.
VRHS	Victorian River Health Strategy.
VWQMN	Victorian Water Quality Monitoring Network.

1. Introduction

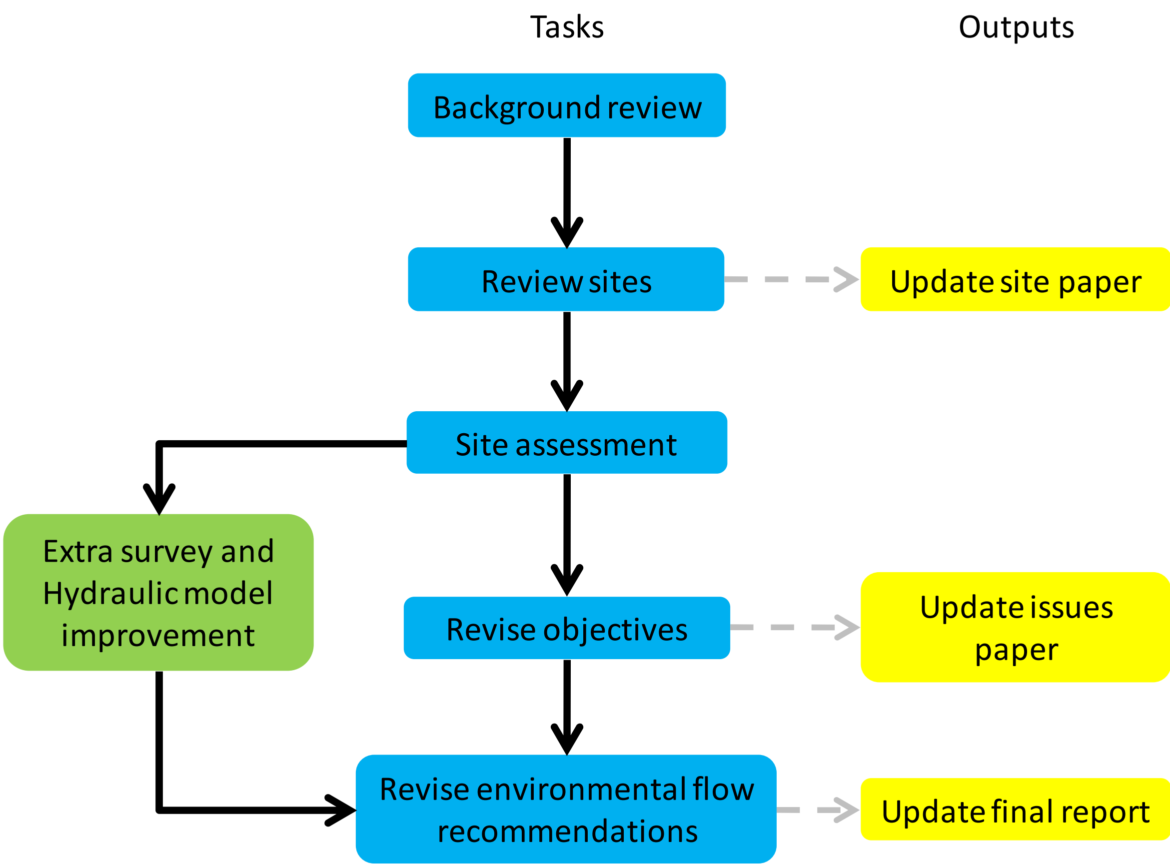
1.1. Overview

In 2005 SKM determined the minimum environmental water requirements for the Yarra River downstream of the Upper Yarra Dam, the Watts River downstream of Maroondah Reservoir and the Plenty River between Toorourrong Reservoir and Mernda (SKM, 2005b). The recommendations from the 2005 study were used to determine an environmental water reserve that would ensure the environmental flow needs of the Yarra River system were protected into the future.

The 2005 environmental flow recommendations were determined using the FLOWS method (DNRE, 2002), and were based on the best available information at that time. Specific monitoring associated with environmental flow releases, responses to natural floods and the drought, and other targeted ecological research have increased our understanding of the flow requirements of many environmental values in the Yarra River. Moreover, the FLOWS method has been updated to provide more reliable and more flexible environmental flow recommendations (DSE, unpublished). Melbourne Water requires a review of the 2005 flow recommendations to incorporate the new information and to reflect recent advances in the FLOWS method.

This project builds extensively on the 2005 FLOWS study, namely the Site Paper (SKM, 2005c), Issues Paper (SKM, 2005a) and Flow Recommendations Paper (SKM, 2005b), a review of new knowledge to inform the revision of flow recommendations (SKM, 2011a) and related documents. More specifically, the background review focused on the new information that has become available since the 2005 assessment. Most of that new information has been summarised by SKM (2011a), but has been expanded on through input from all members of the Environmental Flows Technical Panel (EFTP and see Section 1.2), the project steering committee and the project advisory committee.

The major components of the FLOWS method applied to this review are shown in Figure 1-1. The tasks for the current project include a review of existing flow assessment sites to determine their ongoing suitability, EFTP assessments at those sites to confirm environmental values, additional channel survey where required to improve hydraulic models, a detailed review and where necessary revision of the environmental objectives for each reach and a project workshop to set environmental flow recommendations for the updated objectives. Project outputs include an updated Site Paper, Issues Paper and Final Report that outlines all project recommendations.



▪ **Figure 1-1 Outline of the steps involved in the FLOWS method as applied to this project.**

1.2. Environmental flows technical panel

The EFTP for the review of environmental flow requirements for the Yarra River consists of the following members:

- Dr Andrew Sharpe – macroinvertebrates and general ecological processes
- Dr Simon Treadwell – water quality and general ecological processes
- Professor Paul Boon – aquatic and riparian vegetation and floodplain wetland ecology
- Wayne Koster – fish ecology
- Dr Peter Sandercock – fluvial geomorphology
- Robert Morden – hydrology and hydraulics
- Amanda Woodman – hydrology and hydraulics

1.3. This report

This report presents the third and final output of the study; the environmental flow recommendations for the Yarra River. The current report was preceded by a *Site Paper* (SKM, 2012a) and an *Issues Paper* (SKM, 2012b). The *Site Paper* described the process used to review existing reaches and sites. Existing reach boundaries and sites from the 2005 study were retained, however several additional sites were added to augment existing sites. The *Issues Paper* detailed the available information on the environmental values of the study area – water system management, hydrology, geomorphology, ecology and water quality. Specifically, it reviewed new information that has become available since the 2005 study and proposed alternative objectives where considered necessary based on new information. The *Issues Paper* summarised all the supporting information required to determine the updated environmental flow requirements for the Yarra River.

This report documents the updated environmental flow recommendations for the Yarra River. Using hydrological and hydraulic data and information contained in the *Issues Paper*, the EFTP reviewed and where necessary adjusted the 2005 flow recommendations to account for new information or revised objectives. The updated flow recommendations specify the minimum flow required to meet the environmental objectives identified in the *Issues Paper*.

1.3.1. Report structure

Following this introduction, Section 2 provides a summary of the method used to review existing flow recommendations and where necessary derive new recommendations. Sections 3 to 9document the flow recommendations for each reach. Section 10 provides advice on priorities for flow components and recommendations for complementary waterway works and further investigations required to support the environmental objectives and complement the environmental flow recommendations.

1.4. Assumptions, exclusions and inclusions

This report has been developed using readily available information and field observations. Data provided from Melbourne Water and the Department of Sustainability and Environment has been reviewed for accuracy but we have not undertaken further field verification. Data on current and unimpacted daily flows is assumed to be correct and fit for purpose. The outcomes of this study are for the benefit of Melbourne Water in their efforts to improve river health in the Yarra River catchment. SKM is not responsible for any use of these outcomes by third parties or for purposes other than for informing river health issues.

2. Approach to setting flow recommendations

Environmental flow recommendations in the Yarra River were determined in 2005 using the framework of the standardised statewide method for determining environmental water requirements in Victoria, referred to as the FLOWS method (NRE, 2002). The FLOWS method was recently updated (DSE, unpublished) and those updates have been incorporated into the review of flow recommendations for the Yarra River.

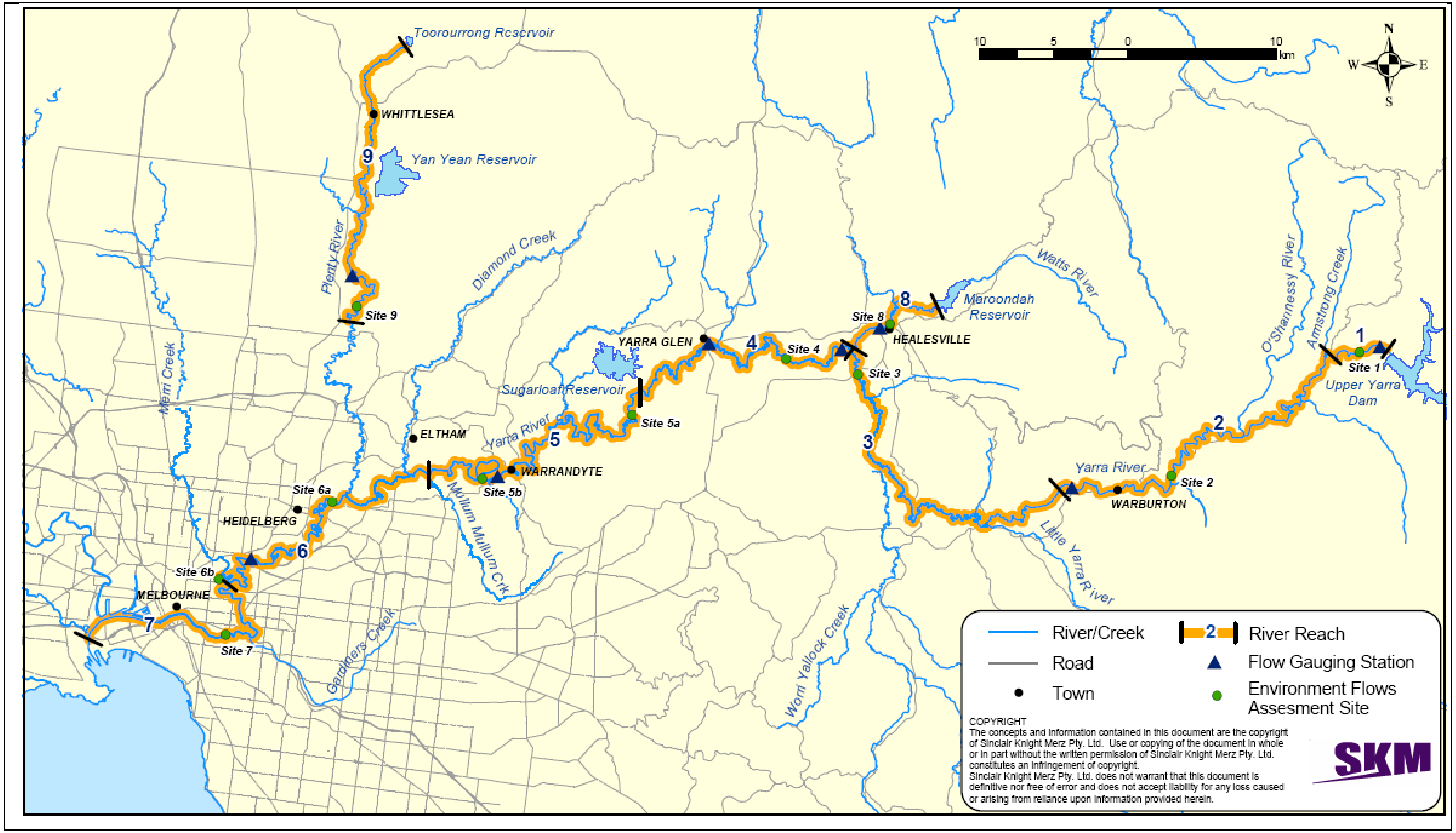
The FLOWS method provides a scientific framework for the assessment of flow requirements for waterways where there is some information available on the ecology, geomorphology and hydrology of the study area. The method has been specifically developed for determining environmental water requirements in Victoria and is based on the concept that key flow components of an unimpacted flow regime influence various biological, geomorphological and physicochemical processes in waterways. Key flow components are likely to vary between river systems, but every stream system has some key flow components that are essential to maintain a healthy functioning aquatic ecosystem.

2.1. Reach and site selection

A critical part of the current review of the 2005 FLOWS study involved an evaluation of the suitability of the existing flow assessment sites. As a result of that evaluation we elected to retain the main flow assessment sites in Reaches 1-5, but moved or added sites in some reaches to better assess low flow requirements through shallow riffle and run habitats (Table 2-1). We moved the Watts River (Reach 8) assessment site to a point immediately downstream of the confluence with Donnelly Creek that had a distinct riffle/pool sequence. We replaced the supplementary site at Dights Falls from Reach 6 with a new site at Finns Reserve (which is the most downstream of the significant rock bar/riffle habitats in the Yarra River) to better assess likely Macquarie Perch habitat, fish movement and flow requirements for vegetation. We also added a new site in Reach 3 (immediately upstream of the Healesville-Woori Yallock Road) because the site at Everard Park had no significant shallow riffle or run habitat. The EFTP also visited the Millgrove Gauge at the downstream end of Reach 2 and used an existing hydraulic model of that site to provide a check of the flow recommendations determined at the main site in East Warburton. The identification and justification for selecting environmental flow reaches and flow assessment sites is presented in the updated *Site Paper* (SKM, 2012c). The location of each environmental flow reach and the assessment sites is shown in Figure 2-1. Various survey and assessments completed at each site are described in more detail in Section 2.4. Note, Reach 7 (Yarra Estuary) and Reach 9 (Plenty River) from the 2005 study were not included in the current study. They are the subject of separate review projects.

Table 2-1 Yarra River reaches and field assessment sites used in 2012 review.

Reach no.	Location	Site no.	Site location	Gauge	2005 Assessment site
1	Upper Yarra Reservoir to Armstrong Creek junction	1	Downstream of Upper Yarra Reservoir, Reefton	Doctors Creek	Yes
2	Armstrong Creek to Millgrove	2a	Warburton East (downstream of major tributary harvesting operations)	Millgrove	Yes
		2b	Millgrove gauge	Millgrove	No
3	Millgrove to Watts River junction	3a	Immediately upstream of Healesville-Woori Yallock Rd	Yarra Grange	No
		3b	Everard Park, upstream of Maroondah Highway.	Yarra Grange	Yes
4	Watts River to top of Yering Gorge	4	Tarrawarra Abbey, Yarra Glen.	Yarra Glen	Yes
5	Top of Yering Gorge to Mullum Mullum Creek	5a	Immediately downstream of Yering Gorge pumping station.	Warrandyte	Yes
		5b	Everard Drive, Warrandyte		Yes
6	Mullum Mullum Creek to Dights Falls	6a	Finns Reserve	Chandler Hwy	No
		6b	Banyule Flats, downstream of Plenty River		Yes
8	Watts River from Maroondah Reservoir to Yarra River confluence	8	Immediately downstream confluence with Donnelly Creek	Healesville	No



- **Figure 2-1 The Yarra catchment showing reach boundaries and EFTP site assessment locations.**

2.2. Hydrology

Two flow series were developed to assist in the setting of flow recommendations. The current flow series is the flow regime that refers to current use, including the effect of impoundments (e.g. farm dams) and diversions. The unimpacted flow series is the flow regime that would exist if no diversion or impoundment of water occurred (ignoring the changes in flows that have occurred because of vegetation removal or landuse). Flow series were updated from the 2005 project by extending the time series of daily flows to the end of 2010. A detailed analysis of current and unimpacted hydrology in the Yarra River is provided in the *Issues Paper*. To assist in the understanding of environmental flow objectives, throughout this report there is reference to wet, dry and average years. These divisions were based on rainfall records from a representative gauge in each environmental flow reach. There is typically a strong correlation between annual rainfall and annual streamflow in the Yarra River (see Appendix B), but rainfall was used as the grouping variable because the Bureau of Meteorology makes long range rainfall predictions that may be used to determine in advance what flow objectives need to be considered in the coming year.

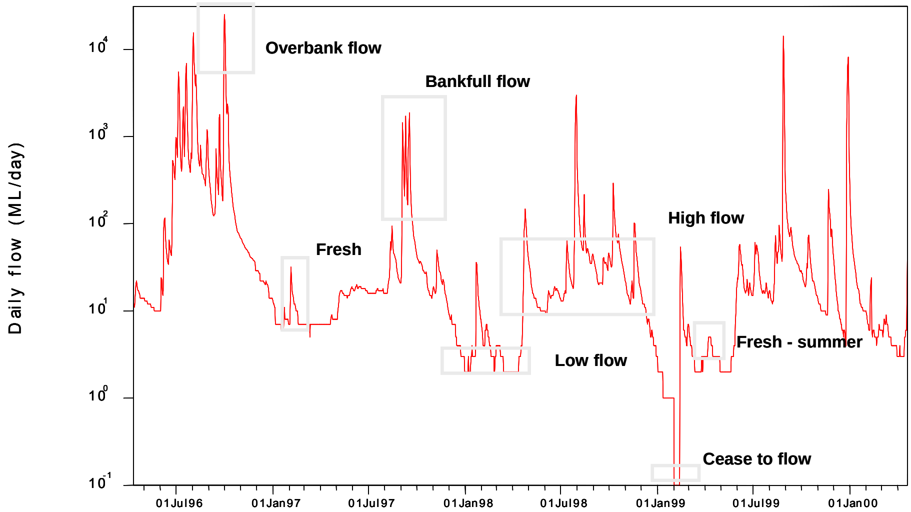
For this project, the historical rainfall record for each reach was interrogated to allocate individual years to one of three equal sized groups. The third of years that had the highest annual rainfall were allocated to the wet year group, the third of years that had the lowest annual rainfall were allocated to the dry year group and the remaining third of years were allocated to the average year group. Data from each group were analysed separately as needed throughout the project.

2.3. Environmental flow objectives and flow components

Environmental flow objectives set the direction and target for the environmental flow recommendations and are clear statements of what outcomes should be achieved in providing environmental flows. Environmental flow objectives were developed for those ecological assets that have a clear dependence on some aspect of the flow regime, such as:

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

Flow components relevant to each objective were also identified. A flow component is a specific element of the flow regime (see Figure 2-2) that fulfils a particular ecological or biophysical function (Table 2-2)



- **Figure 2-2 Typical daily flow series for a perennial stream. Note, in intermittent or ephemeral streams the cease-to-flow period is longer and there is often more variability in the frequency of higher flow events.**

- **Table 2-2: Environmental functions of different flow components.**

Flow component	**Function**
Summer/autumn (December-May)	
Cease-to-flow	■ Disturb lower channel features by exposing and drying sediment and bed material. ■ Promote successional change in community composition through disturbance. ■ Maintain a diversity of ecological processes through wetting and drying.
Low flow	■ Disturb lower channel features by exposing and drying. ■ Allow accumulation and drying of organic matter in the dry areas of the channel such as benches. ■ Maintain permanent pools with an adequate depth of water to provide refuge habitat for aquatic biota.
Freshes	■ Provide flow variability to maintain species diversity of emergent and marginal aquatic vegetation and to drive vegetation zonation patterns across the channel. ■ Maintain emergent and marginal aquatic vegetation by wetting lower channel banks and benches. ■ Improve water quality by flushing and turning over any stratified pools. ■ Temporary increase in longitudinal connectivity between pools to allow fish movement.
Winter/spring (June – November)	
Low flow	■ Sustained longitudinal connectivity for fish movement. ■ Sustained inundation of riffles and lower benches to maintain habitat for emergent and marginal aquatic vegetation. ■ Instigate die-back of terrestrial vegetation that has encroached down the bank during the summer low flow period. ■ Increase habitat area for instream flora and fauna including access to large woody debris and overhanging banks.
Freshes / High flow	■ Entrain terrestrial organic matter that has accumulated on benches. ■ Provide sediment transport (sediment entrainment and deposition with no, or limited, net change in channel form). ■ Provide flow variability to maintain species diversity of emergent and marginal aquatic vegetation and to drive zonation patterns on the banks. ■ Provide cues for fish movement and spawning.

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Flow component	Function
Summer/autumn (December-May)	
Bankfull	■ Disturbance and resetting of aquatic and riparian vegetation communities. ■ Transport sediment that has accumulated in pools. ■ Transport organic matter that has accumulated in the upper channel. ■ Removal of aquatic and riparian vegetation through scouring. ■ Engage floodrunners and wetlands connected around bankfull.
Definition of terms: Cease-to-flow – no measurable flow in the river (although pools may retain water) Low Flow – flow that provides continuous flow through the channel within that reach Freshes – small and short duration peak flow event High Flow – large flow events with longer duration than freshes, these flows cover streambed and low in-channel benches Bankfull Flow – fill the channel and adjacent wetlands with little spill onto the actual floodplain	

Updated environmental flow objectives for Yarra River are detailed in the *Issues Paper* and have been endorsed by the project steering committee and PAG. A summary of issues and objectives is provided in Section 2.7.

2.4. Survey of selected reaches

For most reaches, existing 1-dimensional hydraulic (HecRas) models were used. Existing models were developed during the 2005 study and have since been augmented with survey collected as part of the Victorian Environmental Flow Monitoring and Assessment Program (VEFMAP). For some reaches, additional cross-sections were considered necessary to improve the quality of existing hydraulic models or to capture obvious changes in channel structure that have occurred since the last surveys. For three reaches, new sites were selected to augment existing sites or because a new site was considered to better represent the reach. Details are provided in the *Site Paper* and summarised below:

Reach 1. Additional survey to increase the number of downstream cross-sections to improve model calibration and to capture an additional channel feature (i.e. a deep pool) between the existing cross-sections 5 and 6 that was not included in the original model.

Reach 2. No new surveys, however, VEFMAP surveys were used to create a new model for a secondary site (Millgrove) to test recommendations made at the primary flow assessment site (East Warburton).

Reach 3. The primary flow assessment site (Everard Park) was resurveyed to determine whether recent floods have significantly altered the channel morphology and to better capture details regarding the commence-to-flow levels for a large wetland on the eastern bank. A secondary site was also added (upstream of the Healsville - Woori Yallock Road) to incorporate some reach features (gravel riffles and runs) not present at the primary assessment site and to test that recommendations at the primary site are applicable to the secondary site and it’s channel features.

Reach 4. The primary flow assessment site (Tarrawarra Abbey) was resurveyed to determine whether recent floods have significantly altered the channel morphology. Light Detection and Ranging (LiDAR) data were also used at this site to extend the channel survey onto the floodplain to determine the flows that are required to inundate wetlands close to the main river channel.

Reach 5. No new survey undertaken, although additional cross-sections collected as part of VEFMAP surveys have been incorporated into existing models at Yering Gorge and Warrandyte.

Reach 6. No new surveys were undertaken at the primary flow assessment site. However, a new site was added at the end of Duncan Street, Templestowe Lower (Finns Reserve). This site is a large riffle area and the new survey is to inform the development of a 2-D model (River2D) that relates flow and channel characteristics to habitat and lifestage preferences for important fish species. The benefit of the 2-D model is that it assesses proportional habitat availability as a distribution across the site, rather than in 1-dimensional space (as per HecRas models), and can better characterise the multiple flow paths that exist at the site under low flow conditions.

Reach 8. The 2005 study site was not used for the 2012 study. An assessment of the 2005 site showed significant changes to the site as a result of revegetation and other stream works which were likely to render previous surveys and recommendations obsolete. A new site was assessed downstream of Donnellys Creek. The new site was assessed to capture channel features (gravel and cobble riffles and shallow pools) not present at the 2005 assessment site.

Where new survey was completed, cross-section survey points focussed on the channel detail, with fewer points located within the riparian zone and floodplain. A total station was used to measure any significant changes in elevation associated with channel features across each cross section. Water level was recorded at all cross-sections to assist in calibration of the hydraulic model. Invert levels (i.e. the lowest point) of inlets to nearby wetlands were also surveyed to determine levels at which water commences to enter the floodplain and wetland habitats. Cross-sections were surveyed to AHD (Australian Height Datum).

2.5. Hydraulic modelling

A one-dimensional hydraulic model of each site was prepared to develop a relationship between flow, water depth and velocity using the one dimensional steady state backwater analysis model HEC-RAS (v4.1.0). HEC-RAS calculates water surface profiles and other flow characteristics using a series of surveyed and interpolated cross sections and estimated roughness factors. Details of the Hydraulic model development, including assumptions, uncertainties and calibration are provided in Appendix C..

2.5.1. Model limitations

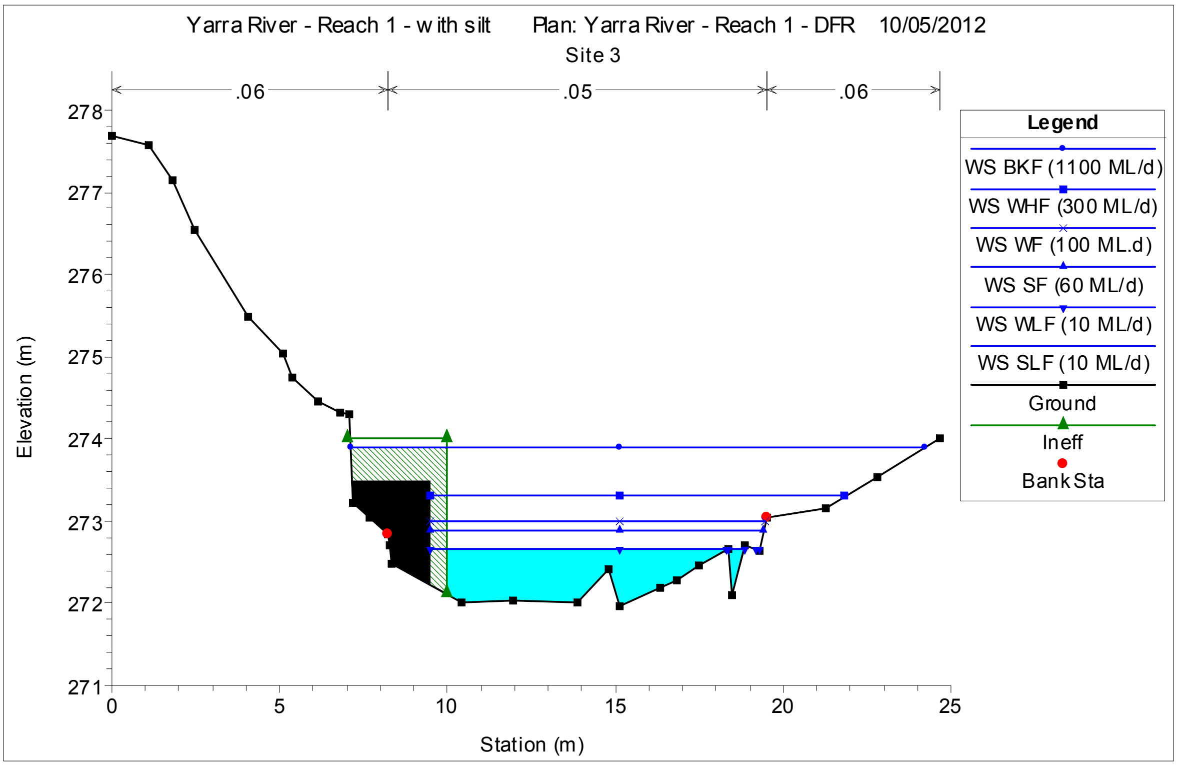
Significant effort has been made to ensure the hydraulic models are accurate, however it should be noted that the models have been calibrated to only one flow as observed on the day of the SKM survey. The flows at each site on the day of survey were relatively small, and therefore there are potentially significant errors inherent in using the HEC-RAS models to estimate water levels at high flows. In other words, while the hydraulic models are relatively accurate at the flows observed on the days of survey, they may not be accurate for higher or lower flows. Each model has been created so as to minimise this error, but it is not possible to avoid it entirely without surveying the water levels at each site over a wide range of different flows. This level of effort would be time consuming (and potentially dangerous at high flows) and is outside the scope of this project.

Gauged data within the catchment is available for each reach. These gauges are considered to represent flows throughout the reach, but are typically not at the actual location of the flows assessment site. Flow data applied to the hydraulic models were obtained from gauged data. Flow data applied for the hydrological components and compliance were based on the hydrological (REALM) modelling that was completed as part of the development of current and unimpacted flows, which have been adopted from data derived from the Yarra Headworks REALM model. The model, held by Melbourne Water, was run at both current and unimpacted levels of development at a monthly timestep. Flows at various locations within the network were then extracted and disaggregated to a daily timestep. These daily data have been adopted for this study, and cover the period from May 1963 to December 2010. This model calibrates reasonably, although it should be noted that modelled data are not gauged data and uncertainty can arise through the assumptions applied to the model.

2.5.2. Model outputs

A key output from the hydraulic model is a graphical representation of each cross-section. An example of a hydraulic output is provided in Figure 2-3. The black line (‘ground’ in the legend) represents the ground surface, reflecting the channel shape at each cross section. Small black squares on the ground line show the exact points where survey measurements were taken. Horizontal blue lines within the cross section represent the estimated water surface at various flows (which are detailed in the legend). The green hatching represents vegetation in the channel that prevents or restricts flow in that area, black areas represent blockages, such as large wood, that also impede flow.

The outputs from the model include the flows (expressed in ML/d) required to cover the steam bed to a certain depth, or inundate channel features such as benches.



- **Figure 2-3 Example cross section output from the hydraulic model for Site 1, Yarra River at Reefton, showing channel profile, water surface levels at various flow magnitudes, and areas of ineffective channel (green hash) and flow obstructions (black areas).**

2.6. Development of environmental flow recommendations

Environmental flow recommendations for the Yarra River were determined by the EFTP in a workshop conducted on 28 May 2012. The workshop was also attended by Anna Lucas from Melbourne Water.

The EFTP worked through the process of determining flow recommendations on a reach by reach basis. For each reach the objectives and flows recommendations from the 2005 study were reviewed. Revised environmental objectives documented in the revised issues paper were also 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. benches, pools, backwaters etc.).

Within each reach, each flow component was considered in turn. Flow recommendations from the 2005 study were used as a starting point and were retained unless there was significant new information or analysis that deemed it appropriate to alter the recommendations. A range of criteria were used to determine suitable flows (Table 2-3). These criteria are reach specific depending on the species present and channel features. For each flow component the desired volume threshold, frequency of occurrence and duration was determined (although see Section 2.6.3 for a discussion of uncertainty in recommendations and the use of elements of the current regime to inform some recommendations). Consideration was given to the acceptable level of variability in flow components and on differences between dry, average and wet years.

An ‘or natural’ proviso applies to all of the flow recommendations, except where higher than unimpacted flows are specified for a specific purpose (e.g. to mix the Dights Falls Weir pool). The proviso allows for natural variability in the flow regime and is applicable to the low flow magnitude, and the frequency and duration of freshes, high flows and bankfull flows. The proviso requires the recommendations to be measured against the unimpacted flow frequency and duration that would have occurred without any diversions, defined as ‘unimpacted’ in this study.

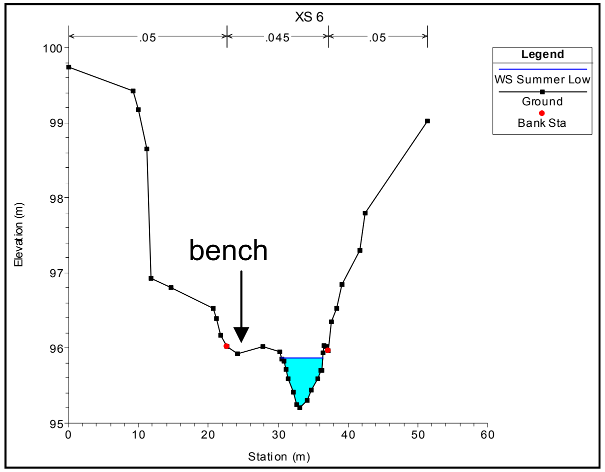
The addition of the ‘or natural’ proviso to freshes, high and bankfull flows means that these flows will occur at their natural frequency and duration. If the unimpacted flow at a compliance point in a reach is lower than the recommended flow, then the unimpacted flow should be met rather than the minimum flow value. In this way, the natural flow variability is maintained. In other words, for events below the recommended duration or frequency the natural event needs to be preserved.

2.6.1. Flow seasons

Separate environmental flow recommendations are made for the dry seasons (i.e. summer / autumn) and the wettest 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.

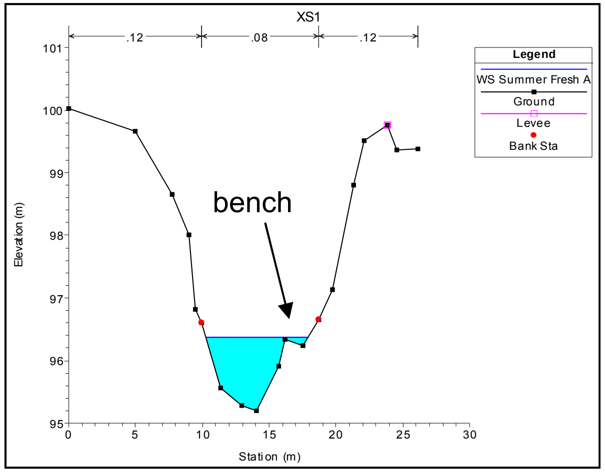
Table 2-3 Criteria used in determining environmental flow recommendations for each flow component.

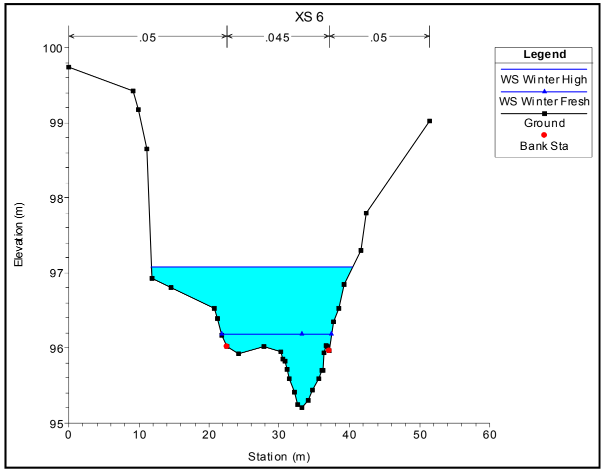
Function	Criteria for determining recommendation
Low flow	
Minimum flow that provides a continuous flow throughout the channel (maintains permanent pools with an adequate depth of water to provide habitat for aquatic biota).	The EFTP used minimum depths for the following biota: **Macroinvertebrates** Majority of riffle width inundated with a range of water depths and velocities and some rocks exposed as sites for oviposition. Assume depth of 100 mm at the deepest point of the shallowest cross section. **Platypus** Minimum depth in riffles to cover the backs of platypus when foraging (Scott and Grant, 1997). Assumed to be 100 mm at the deepest point of the shallowest cross section on the basis of the size of platypus. **Fish** Dependent on size and therefore height of individual fish species. Depth needs to be sufficient such that each fish species remains wholly submerged. Larger blackfish (>55 mm) avoid depths <200 mm and prefer pools >1000 mm deep. Small black fish have a preference for pool depths ranging from 100-200 mm (Koehn, 1986, Koehn et al., 1994). Lamprey and tupong prefer slow flowing pools with depth >300mm (Davies, 2005). Australian Grayling prefer fast flowing water over gravels but also slower flowing pools >500mm deep. For the purposes of the Yarra River flow study, we have assumed a minimum pool depth of 500 to 1000 mm to be sufficient to provide a range of pools habitat depths for the species present in the system. Minimum depth for general fish movement through riffles is around 120 mm for small bodied fish (Starrs *et al.*, 2011) and greater for large bodied fish. Optimal resting habitat for large bodied fish is probably around 240 cm based on radio tracking fish locations in the Yarra. Tolerable velocity for small fish movement is 0.15 – 0.30 m/s (Doehring *et al.*, 2011, Mitchell, 1989), and up to 0.52 m/s for Macquarie Perch (Starrs *et al.*, 2011). Macquarie Perch spawning sites should be less than 1 m deep (Tonkin *et al.*, 2011) and have velocities in the range 0.2-0.8 m/s based on European species that spawn in gravel (Crisp, 1996). The optimal rearing habitat for Macquarie Perch larvae will be between 250 and 1000 mm deep and will have a velocity <0.1 m/s. Flow velocity > 0.25m/s is too fast.
Minimum flow that provides a continuous flow throughout the channel for the inundation of habitat elements (e.g. aquatic vegetation).	Minimum inundation of channel (similar to that required for fish and macroinvertebrates)
Minimum flow that minimises the risk of degraded water quality, particularly dissolved oxygen.	Based on analysis of minimum flows required to minimise risk of deoxygenation of pools (~150 ML/day for pools in the Yering Gorge (Ewert and Pettigrove, 2003), ~300 ML/day for pools upstream of Chandler Highway (SKM, 2011b), ~450 ML/day for Dights Falls Weir pool (Robinson, 2011)) .

<table>
<tr><th>Function</th><th>Criteria for determining recommendation</th></tr>
<tr><td>Minimum flow that provides a continuous flow throughout the channel, but allows the lower banks, benches and bars to dry.</td><td>


Morphological feature defined by individual cross sections.

Example provided is for a summer low flow recommendation. Note, banks and benches are not inundated.</td></tr>
<tr><td colspan="2">Freshes</td></tr>
<tr><td>Disturbance to scour biofilms and flush fine sediments from riffles.</td><td>A velocity greater than 0.4 m/s was considered suitable to generate scouring flows (Biggs et al., 1999).
Shear stress: >8 N/m^2 to scour silt from sand, >15 N/m^2 to scour silt from cobble and to scour sand and > 45 N/m^2 to scour coble (based on criteria adopted by Ecological Associates, 2005).</td></tr>
<tr><td>Access to habitat – between pools.</td><td>Fish and platypus
Availability of fish passage in the shallowest cross section (see low flow – access to habitat above).
Minimum depth for general fish movement is around 120 mm for small bodied fish (Starrs et al., 2011), at least 200 mm for adult River Blackfish, and greater for large bodied fish.
Tolerable velocity for small fish movement is between 0.15 – 0.30 m/s (Doehring et al., 2011, Mitchell, 1989), and up to 0.52 m/s for larger fish like Macquarie Perch (Starrs et al., 2011).</td></tr>
<tr><td>Maintenance of littoral vegetation on bars and lower banks.</td><td>The EFTP used the inundation of in-channel low-flow benches as morphological features (see HEC-RAS example output above) to set flow levels to water littoral vegetation such as Phragmites.</td></tr>
</table>

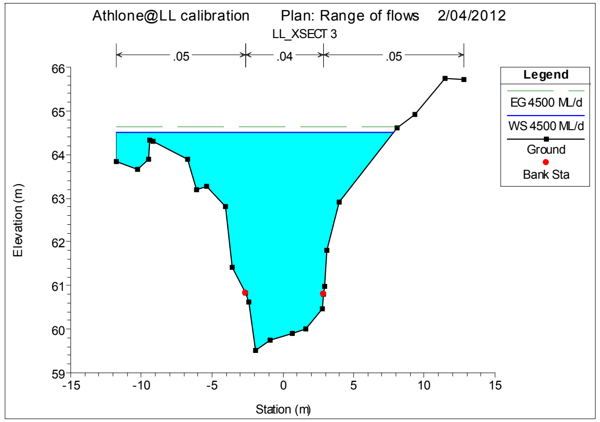
<table>
<tr><th>Function</th><th colspan="2">Criteria for determining recommendation</th></tr>
<tr><td>Access to habitat – increase riffle width and depth, inundation of in-channel benches.</td><td>
</td><td>The EFTP used an increase in habitat area (compared to low flows) and the inundation of in-channel benches and high flow channels as morphological features.
Example provided is for a summer fresh recommendation. Note, that the bench is inundated.</td></tr>
<tr><td colspan="3">High flows</td></tr>
<tr><td>Provide spawning and movement opportunities for fish.</td><td colspan="2">Australian Grayling movement and spawning has been shown to occur when autumn flows exceed 1300 ML/day at Heidelberg (Koster, W., unpublished data).
High flows in late winter and spring aid upstream movement of fish migrating from estuary to freshwater environments. The magnitude of high flows is not well understood, but timing is critical, which is linked to the biological requirements of individual fish species.</td></tr>
</table>

<table>
<tr><th>Function</th><th colspan="2">Criteria for determining recommendation</th></tr>
<tr><td>Bank wetting to promote littoral vegetation and limit terrestrial vegetation.</td><td>
</td><td>The EFTP used the inundation of in-channel low flow and high flow benches as morphological features to set levels for high flow events. In some reaches, a freshening flow fulfilled the objectives of a high flow.

Example provided is for a winter fresh and high flow recommendation. The fresh inundates the low bench and the high flow inundates the higher bench located further up the bank.

In some reaches high flows may water billabongs via flood runners or through the banks.</td></tr>
<tr><td colspan="3">Bankfull and overbank flow</td></tr>
<tr><td>Disturbance and entrainment of organic material from the riparian zone.

Maintain or rehabilitate current channel geometry.

Inundate floodplain features and wetlands by engagement with the river channel via flood-runners.</td><td>
</td><td>Morphologically defined, with some interpretation required as cross-sections may differ in capacity.

The volume required for the engagement of flood-runners and old channel courses is determined by the invert or commence to flow level flow in these flood-runners/wetlands. The invert level is specific to each flood-runner and reach.

Example provided is for a winter bankfull / overbank flow recommendation. Note water level is sufficient to inundate wetland area to the left of the channel.</td></tr>
</table>

2.6.2. Tailoring flow recommendations for wet, average and dry years

To further assist with implementation, flow recommendations are provided for dry, average and wet years where the panel considered there was a reasonable justification for doing so. This allows, for example, higher magnitude events in wet years compared to dry years, fewer freshes during dry years, or longer duration high flows during wet years.

The rainfall record for each site was selected based on location and quality of data of rainfall gauges. The selected rainfall gauges applied is shown in Table 2-4. SKM has a database of rainfall gauges that have been infilled based on relationships with neighbouring gauges – this data was applied. The correlation of rainfall to streamflow was reasonably correlated at each site. However, rainfall is preferred for predicting whether a season or year is likely to be dry, average or wet because the Bureau of Meteorology (BoM) is better able to make longer term predictions around rainfall than stream flow.

Dry years correspond to those with the driest third of rainfall years during the flow record, average years correspond to the middle third of years, and wet years correspond to the wettest third of years. These values are presented in Table 2-4.

- **Table 2-4 Rainfall gauges applied to determine wet, average[1] and dry years.**

Reach	Rainfall Gauge	Dry years rainfall (mm/year)	Average years rainfall (mm/year)	Wet years rainfall (mm/year)
Reach 1: Upper Yarra Dam to Armstrong Creek	086090 Warburton (O'Shannassy Reservori)	<1253	1253-1485	>1485
Reach 2: Armstrong Creek to Millgrove	086090 Warburton (O'Shannassy Reservori)	<1253	1253-1485	>1485
Reach 3: Millgrove to Watts River	086070 Maroondah Weir	<1003	1003-1135	>1135
Reach 4: Watts River to Yering Gorge	086066 Lilydale	<813	813-922	>922
Reach 5: Yering Gorge to Mullum Mullum Creek	086035 Eltham	<666	666-839	>839
Reach 6: Mullum Mullum Creek to Dights Falls	086035 Eltham	<666	666-839	>839
Reach 8: Watts River downstream of Maroondah Reservoir	086070 Maroondah Weir	<1003	1003-1135	>1135

Notes:

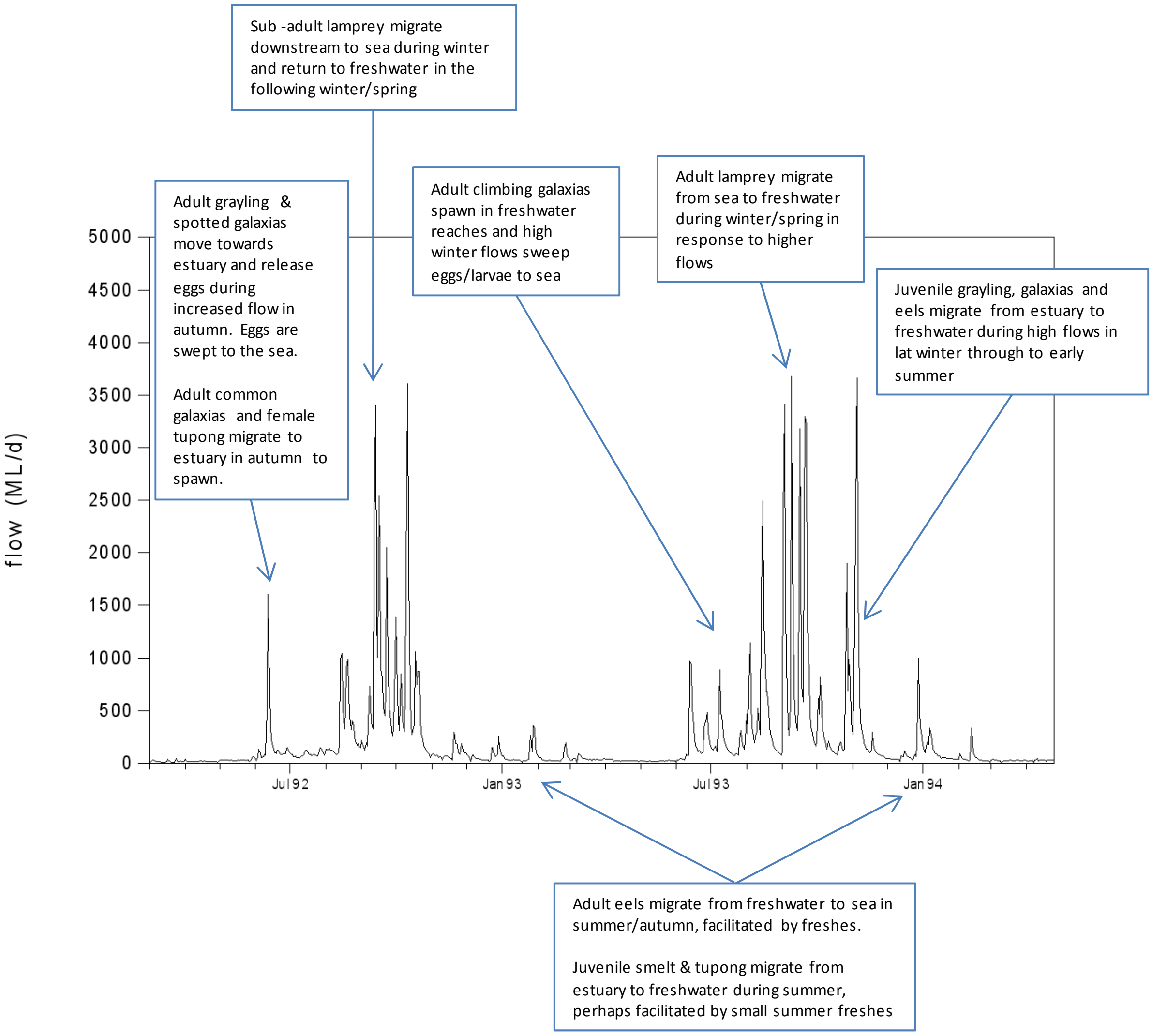
1. Average years are those with a rainfall between dry and wet year thresholds.

In wet years it is likely that significantly more flow will occur than is recommended. Under these circumstances it is not necessary to reduce or manage flows just in order to 'meet' or 'comply with' the flow recommendations. The flow recommendations are the minimum required to achieve environmental objectives and more flow than recommended (or longer duration freshes, even if it means fewer events above a particular threshold or flow events outside the suggested time intervals) is acceptable if it occurs naturally in response to wet climatic conditions.

Critical maximum thresholds between events are also provided where necessary. For example, the maximum interval between summer/autumn high flow events for Grayling spawning in a sequence of dry years is important because Grayling are short lived and need to spawn frequently to maintain population viability. In some circumstances, recommendations are expressed as the minimum number of events over a ten year period, this aims to preserve inter annual variability over a longer time frame.

To assist with developing the flow recommendations a range of flow statistics were examined for the current and unimpacted flow regimes, these include spells plots to identify the pattern over time of flows above or below certain flow volume thresholds and spell duration statistics to summarise the frequency or number of events above or below a specified flow volume threshold per year, the duration in days of flow above or below the specified threshold volumes and the distribution of start month of flow events above or below specified threshold volumes.

The timing of various flow components is also important, especially for fish. The timing of the various life history stages varies from species to species, as do the specific triggers for spawning and movement. However, increased flows in autumn, and high flows in winter and spring are typical triggers for various movement and life history stages (e.g. Figure 2-4).



- **Figure 2-4 Summary of timing of various fish life history stages related to seasonal flow components.**

2.6.3. Current achievement of the environmental flow recommendations

The current level of achievement of the environmental flow recommendations for each reach was assessed separately for wet, average and dry climate years. The assessment is based on an analysis of the historical flow record in wet, average and dry years in each reach under unimpacted conditions (i.e. assuming no dams or direct extractions from the catchment) and under current conditions. The level of achievement is presented as the percent of events that would occur without any development in the catchment that have occurred in the historical record. For example, if the recommended summer high flow occurred in 20 out of 30 average climate years, but would have occurred in 25 out of 30 years under unimpacted conditions, then the level of achievement would be reported as 80 % (i.e. 20/25 × 100).

It is important to note that a higher level of achievement for a particular flow component in dry climate years compared to a wet climate years does not mean that those events occur more often in dry years. Rather it indicates that under current conditions a higher proportion of the events that would have occurred in dry years under unimpacted conditions; still occur under current levels of development.

2.6.4. Uncertainty in flow recommendations

As discussed in Section 2.5.1 a range of uncertainties exist in the modelling of current and unimpacted flows and in HecRas models. There are also uncertainties in the response of various physical and biological processes and functions to flow. For example, we know that some fish require an increase in flow at the right time of the year to trigger migration or spawning, however we don't know whether the biological response is related to the rate of flow change, whether a specific flow threshold must be achieved, whether the flow increase must be of a certain duration, or whether there are other confounding factors. These unknowns in the biological response introduce further uncertainties to the flow recommendations.

Many of the flow recommendations are based on maintaining elements of the current flow regime (i.e. the current magnitude, frequency and duration of various events), especially if there is no clear justification for a particular flow recommendation. For example, there is a good relationship between water quality and flow in some reaches, so this provides confidence in the relationship between water quality response and flow and provides good justification for setting a flow recommendation to maintain water quality. However, for other recommendations where there is an understanding of the general flow requirements (e.g. for fish spawning) but no site specific data to support a specific recommendation, we have resorted to using elements of the current regime to inform the recommendation.

The updated environmental flow recommendations presented in this report take account of new information that has become available since 2005, but many information gaps remain. It is important that as our understanding of biological responses to flow improves (e.g. through monitoring and scientific research) the flow recommendations are amended to improve overall confidence.

2.7. Summary of issues and objectives

Flow recommendations are underpinned by the current conditions and issues faced by the river and the objectives established to address issues. Below is a summary of the critical issues and objectives across the river. More details are provided in the *Issues paper*.

Water harvesting in the upper catchments for Melbourne's water supply, agricultural development and extractions in mid reaches and urban impacts in lower reaches has resulted in significant modification to the flow regime and environmental condition in the Yarra River. The ecological issues facing the Yarra River and tributaries can be broadly grouped into two main categories, those related to an altered flow regime and those related to a general degradation in environmental condition.

Water harvesting and diversions in the Yarra catchment have reduced the mean annual flow in the Yarra River by around 95% in the reach immediately downstream of the Upper Yarra Dam and around 40-50% in other reaches. Brizga and Craigie (1998) noted that major reduction in flow has invoked sediment adjustment processes in the Yarra channel. At a broad scale, a reduction in flows since the 1950s has resulted in encroachment of terrestrial vegetation into the river and localised contraction by bar development in the upper reaches. However, downstream of Millgrove, channel adjustments are less discernible. The most obvious effect of reduced flows is on the channel geometry in Reach 1 where lateral bars have developed and become stabilised with vegetation and pools have been infilled with fine inorganic and organic material. The major phase of sediment input to Reach 1 has likely past, but large volumes of sediment are now stored in the Reach. Downstream of Reach 1 the channel capacity increases significantly with increase tributary inflows and the mean annual flow recovers to around 50% of unimpacted flows.

Reduced flows and channel contraction have likely impacted on the health of aquatic biota in Reach 1. Prior to the implementation of a 10 ML/day minimum flow in 1993 the macroinvertebrate and fish communities suffered from low diversity and abundance and poor recruitment success (Doeg and Saddlier, 1992). Since environmental flow releases commenced there has been a relatively steady improvement in the condition of the macroinvertebrate community (Marchant and Hehir, 2002, SKM, 2012d), although some sensitive taxa are still absent. There has also been marginal improvement in the abundance of River Blackfish associated with the minimum flow releases (SKM, 2012d, Saddlier and Doeg, 1997). However, the minimum flow release has not been sufficient to flush fine sediment from pools so lack of suitable pool habitat is likely to continue to limit further increases in recruitment success and abundance. Recommendations for flushing flows to scour fine sediment from pools have been made and a flushing flow volume of 300 ML/day has been determined (Wilkinson and Rutherford, 2001). In 2011, Melbourne Water released a flow of 200 ML/day, which removed some of the finest silt from shallow habitats, however larger flows are required to flush the desired amount of sediment from target pools (SKM, 2012d).

Further downstream the health of macroinvertebrate and fish communities improve rapidly. The macroinvertebrate community in Reach 2 is considered equivalent to reference condition and typically meets State Environment Protection Policy (SEPP) Schedule F7 Waters of the Yarra River objectives and the more recent SEPP Waters of Victoria (WoV) Cleared Hills and Coastal Plains objectives. There is also an increase in the diversity and abundance of native fish and an increase in the number of diadromous species (Saddlier and Doeg, 1997).

Water quality and the condition of the riparian zone in Reach 2 are also relatively good. Although there is a decline in the condition of the riparian vegetation and an increase in the abundance of terrestrial weeds further downstream where clearing for agriculture and rural township development has occurred.

Downstream of Reach 2 the Yarra opens onto the upper floodplain. Land clearing and urban development has contributed to a further decline in the condition of the riparian zone and water quality also declines with increased concentrations of nutrients, particularly nitrogen, and increased turbidity. In the mid and lower reaches, land use changes, particularly the clearing of native vegetation and urbanisation, are likely to have a bigger impact than flow induced changes on channel morphology (Brizga and Craigie, 1998).

The macroinvertebrate health is maintained through Reach 3 but declines in Reach 4, most likely due to degradation of the riparian zone, loss of instream habitat and declining water quality. Sedimentation of benthic habitat is also likely to be factor in contributing to the decline in macroinvertebrate health. Two mechanisms are likely to contribute to sedimentation of benthic habitats 1) increased sediment input from cleared agricultural land and tributary inflows and 2) reduced scouring associated with a reduction in the duration of scouring flows. Increasing nutrient concentrations and reduced scouring flows probably also contributed to a decline in habitat quality by contributing to the growth of filamentous algae, rather than diatoms, on submerged wood and other hard surfaces. Biofilm communities dominated by diatoms offer a more palatable food resource to macroinvertebrates compared to filamentous algae (Lamberti, 1996), which also smother benthic surfaces in a thick mat that limits access to surfaces by macroinvertebrates.

Fish diversity remains high with a combination of resident and diadromous species present (Pitman *et al.*, 2007). However, a long history of desnagging has resulted in a significant loss of habitat that has likely impacted on the overall diversity and abundance of native fish. Some species, such as the threatened Australian Grayling, require specific flow components to trigger life history events. Australian Grayling are likely to require an autumn high flow event to trigger spawning and assist in transporting larvae to the estuary (Koster and Dawson, 2011, O'Connor and Mahoney, 2004). A reduction in the frequency and duration of autumn high flow events has the potential to impact on recruitment success of Australian Grayling and limit the establishment of a viable population in the river.

Through Reaches 3 and 4 there is evidence of encroachment of terrestrial vegetation on banks, particularly weed species such as blackberries, wild Watsonia and *Tradescantia*. There is also evidence of the colonisation within the channel by the semi-aquatic wetland plant yellow flag iris. The encroachment of terrestrial vegetation down banks and semi-aquatic plants along the littoral zone indicate a contraction in the zone of flood-tolerant species on the bank. This may be attributed to a reduction in the duration of high flow events that under natural conditions inundate the mid and upper banks for prolonged periods during the active growing season. Such flows drown out terrestrial and semi-aquatic species that prefer stable flow and provide conditions more favourable to flood-tolerant plants. Weed infestation is also enhanced by clearing of native vegetation and disturbance by uncontrolled stock access.

Reduced flood flow has reduced the frequency of inundation of wetlands along Reaches 3 and 4. However, clearing of the floodplain has also resulted in a significant impact on wetland habitats. There has been a significant loss of wetland area in theses reaches and a shift in wetland type from near permanent deep freshwater marshes to infrequently inundated freshwater meadows that only hold water for around four months at a time. Preservation of flows that inundate wetlands and rehabilitation through fencing, stock removal and revegetation are necessary to improve wetland condition.

In Reach 5 there is some improvement in water quality as the river flows through a series of gorges. Stable bedrock bed and banks, deep pools and riffles may promote improved ecosystem processing and assimilation that leads to an improvement in water quality. However, urban impacts increase through this reach and may counteract improvements further downstream.

Water is extracted from this reach at the Yering Pumps. However, the native fish community is perhaps at its most diverse with good numbers of at least three threatened species (Australian Grayling, Murray Cod and Macquarie Perch) and evidence of successful recruitment (Ryan *et al.*, 2003, Pitman *et al.*, 2007). Even so, a lack of autumn flows may limit recruitment potential for Australian Grayling and low flows may limit opportunities for fish passage across bedrock bars. The lack of high flows in late winter / early spring to prepare spawning sites for Macquarie Perch and too frequent freshes during summer when Macquarie Perch eggs and larvae are developing could reduce the recruitment of this species (King *et al.*, 2011).

Rapid increases in urban development are likely to present the greatest threat to ecosystem condition in Reach 6 with declining water quality and macroinvertebrate community health. However, flow reduction has contributed to a reduced frequency of wetland inundation and this may be contributing to a shift in community composition in wetlands. Evidence of reduced zonation in flood-tolerant vegetation on the banks and terrestrialisation of the upper banks is also present, indicating a reduction in the duration of high flow events.

Under very low flows, sections of the Dights Falls weirpool become stratified and potentially uninhabitable for native fish. Flows around 450 ML/day are required throughout summer when water temperatures exceed 16 °C to keep the water column mixed and prevent hypoxia (Robinson, 2011). Such flows are higher than would naturally occur and it is not clear whether there is a need to keep these pools permanently mixed. For the purposes of this project, the EFTP has determined two sets of environmental flow recommendations. One that ensures the Dights Falls weir pool is permanently mixed and another that ensures the weir pool is mixed in autumn and spring and occasionally throughout the summer when diadromous fish need to move through it.

Across the system, objectives have been developed to:

- Maintain channel geometry throughout all reaches;
- Improve access to suitable habitats for fish and macroinvertebrates by providing flows that scour sediment from pool and benthic surfaces in riffles;
- Maintain longitudinal connectivity for fish passage;
- Increase the zone of flood-tolerant vegetation on banks by drowning terrestrial vegetation encroaching on banks;
- Ensure minimum flows do not cause flow related declines in water quality; and
- Preserve inundation of wetlands and floodplains.

Objectives for each reach are summarised in Appendix A and described in detail in the *Issues Paper*.

The specific flow recommendations that, if delivered, will maximise the likelihood of these objectives being achieved are described for each reach in subsequent Sections.

3. Reach 1: Upper Yarra Dam to Armstrong Creek

3.1. Description

Reach 1 is relatively short (~5 km long) extending from the Upper Yarra Dam to Armstrong Creek, which is the first major tributary input to the Yarra River downstream of the Upper Yarra Dam. The current minimum flow in this reach is 10 ML/day with some minor variability provided by inflow from Doctors Creek, a small tributary that enters just downstream of the dam wall. The environmental flows assessment site was located approximately 3 km downstream of the dam wall and the gauge for compliance purposes is located downstream of Doctors Creek (upstream of the assessment site).

3.2. Revised flow recommendations

Based on objectives for Reach 1 flows have been developed to maintain the current channel geometry, reinstate some variability in the current flow regime and increase quality of habitat for fish and macroinvertebrates by scouring sediment from riffles and pools. Returning the channel to its natural dimensions was considered inappropriate due to the potential risks associated with transporting large amounts of sediment to downstream reaches and the need for significantly higher flow volumes to establish and maintain a natural channel. No cease-to-flow recommendation has been made because the river is a permanent stream. No overbank flows have been recommended because the channel is confined and no floodplain is present.

In general, the flow recommendations derived in 2005 are considered suitable and no major changes are recommended. However, additional advice is provided on the timing of some flow components and the maximum volume able to be released when using this reach for delivering environmental flows to downstream reaches.

The environmental flow recommendations for Reach 1 are summarised in Table 3-1 and each flow component recommendation is discussed in the following sections.

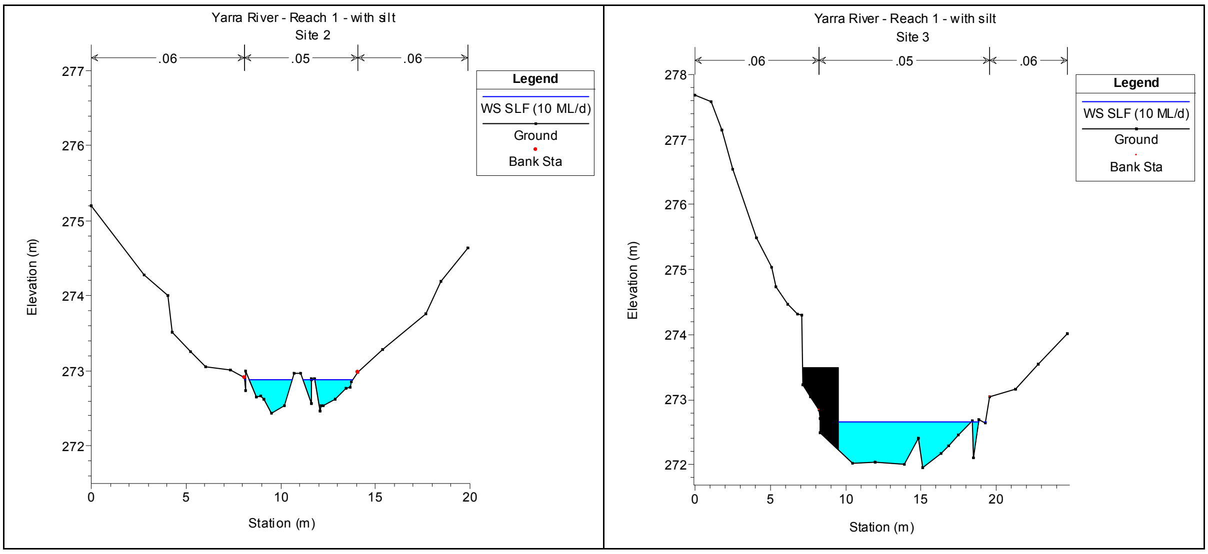
Table 3-1 Flow recommendations for Reach 1.

Stream	Yarra River			Reach	Upper Yarra Dam to Armstrong Creek confluence		
Compliance point	Doctors Creek Gauge			Gauge No.	229103		
Season	**Flow**	**Objective (refer to objectives tables for id reference)**	**Wet/Average/Dry**	**Volume**	**Frequency and when**	**Duration**	**Rise/Fall**
Summer / Autumn (Dec-May)	Low flow	Maintain access to habitat for bugs & fish, drying period for bank vegetation (M1-1, F1-1, V1-1)	Wet	10 ML/day released from storage. Inflow from Doctors Creek and local catchment run-off provide additional flow and the required flow variation.			
			Average				
			Dry				
	Fresh	Maintain suitable riffle habitat by periodically scouring sediment & biofilms, maintain flood-tolerant vegetation on banks (G1-2, M1-2, F1-1, V1-2)	Wet	60 ML/day released from storage plus Doctors Creek flow on top of this to provide increased magnitude and variability during average and wet years.	Minimum 4 events delivered + additional events provided by Doctors Creek.	Min 1 day at peak, additional duration provided by Doctors Creek.	1.6/0.7
			Average				
			Dry	60 ML/day	4	1	
	High	Not recommended					
Winter / spring (Jun-Nov)	Low flow	Maintain access to habitat for bugs & fish (M1-1, V1-1)	Wet	10 ML/day released from storage. Inflow from Doctors Creek and local catchment run-off provide additional flow and the required flow variation.			
			Average				
			Dry				
	Fresh	Maintain suitable riffle habitat by periodically scouring sediment & biofilms, maintain flood-tolerant vegetation on banks, provide local fish passage (G1-2, M1-2, F1-1, V1-2, F1-2)	Wet	100 ML/day releases from storage with Doctors Creek flow on top of this provide increased magnitude and variability during average and wet years.	Minimum 3 events delivered + additional events provided by Doctors Creek.	Min 2 day at peak, additional duration provided by Doctors Creek.	1.6/0.7
			Average				
			Dry	100 ML/day	3	2	
	High	Scour sediment from pools to increase habitat availability, provide a disturbance regime to promote flood-tolerant species and limit encroachment of terrestrial vegetation, fish passage, entrain organic material (G1-3, M1-3, F1-2, V1-3)	Wet	300 ML/day	Once every two years Restrict to June-September period.	3 days	1.6/0.7
			Average				
			Dry				
	Bankfull	Maintain existing channel geometry & prevent further vegetation encroachment in channel (G1-1, V1-4)	Wet	1100 ML/day	1 in 10 year	3 days	1.6/0.7
			Average				
			Dry				
	Overbank	Not recommended					

3.2.1. Summer/autumn low flow

A continuous low flow of 10 ML/day released from Upper Yarra Reservoir is recommended for Reach 1. Regular tributary inputs from Doctors Creek, particularly in average and wet years provide additional variation that should be allowed to progress downstream. It is important to note that the flow recommendations assume that these tributary inputs are in addition to the constant 10 ML/day release from the Upper Yarra Reservoir.

A flow of 10 ML/day is sufficient to inundate the full width of riffles (e.g. Transect 2), yet allow drying of benches and banks (see Figure 3-1). This flow is sufficient to prevent sediment accumulation on riffles by providing an average velocity >40 cm/s in the active part of the channel so low-flow habitat in riffles for macroinvertebrates will be maintained. The recommended flow will also maintain pool depths greater than 50 cm throughout the reach to provide suitable habitat for River Blackfish. Fish movement is provided most of the time, except perhaps over some rock bars during dry periods. However, tributary inflows provide occasional higher flows that facilitate local movement. Lateral bars are mostly dry, but variation in level with tributary inflows provides frequent wetting to maintain semi-aquatic plants on the margins of the bars.



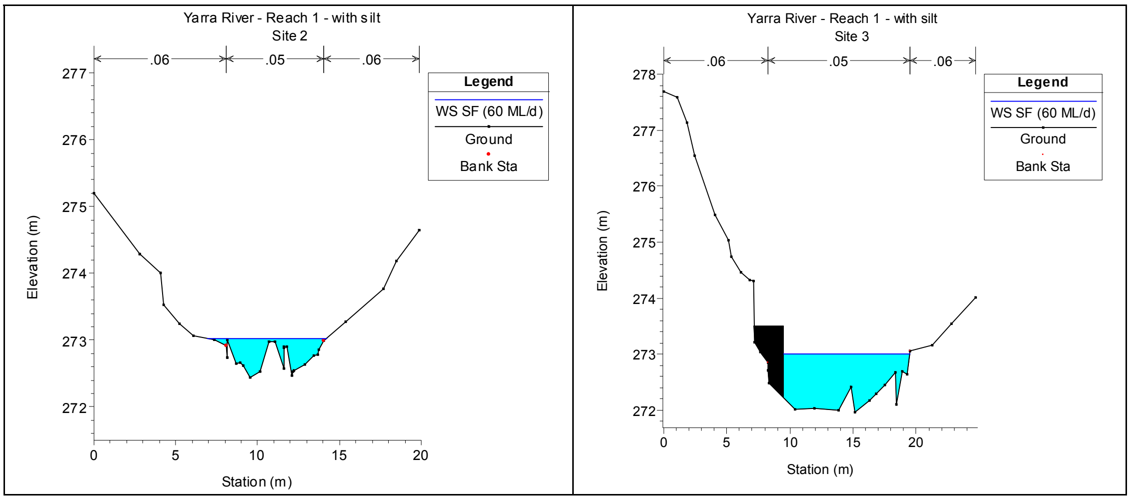
- **Figure 3-1 Stage height in riffle (Transect 2, left) and pool (Transect 3, right) at the recommended threshold for summer/autumn low flows in Reach 1.**

3.2.2. Summer/autumn freshes

The recommend magnitude for summer/autumn freshes in dry years is 60 ML/day. Outputs from HEC RAS modelling show that 60 ML/day is sufficient to increase depth over riffles by 10-20 cm compared to the low flow (see Figure 3-2) and achieve a minimum flow velocity through riffles of ~40 cm/s and shear stress of >10 N/m^2 that is sufficient to scour fine material that has deposited in riffles during low flow periods. This flow also wets emergent and littoral vegetation that has dried out over the low flow period and will help to improve water quality by flushing and re-oxygenating pools. Flows less than 60 ML/day may fail to create velocity conditions suitable for scouring fine material in riffles and may not extend far enough up the channel side to wet littoral vegetation.

In average and wet climate years the recommended release volume is still 60 ML/day, however releases should be timed to coincide with natural tributary fresh flows in Doctors Creek. These inflows would increase the magnitude of the event above 60 ML/day as measured at the Doctors Creek gauge. They may also increase the duration of the event. Both of which provide acceptable variability in average and wet years.

The maximum volume of water that could be released (combined flow with Doctors Creek) during summer for contributing to flow components downstream is 200 ML/day. This is equivalent to the median annual peak flow in summer months under current conditions. An event of 200 ML/day would not cause excessive scour in Reach 1, although it would generate elevated turbidity in downstream reaches (based on monitoring of 2011 release (SKM, 2012d)) that may be undesirable from an aesthetics perspective. Releases in the order of 200 ML/day should be avoided in the early summer because they may flush developing River Blackfish larvae out of suitable nursery habitats.



- **Figure 3-2 Stage height in riffle (Transect 2, left) and pool (Transect 3, right) at the recommended threshold for summer/autumn freshes in Reach 1.**

3.2.3. Winter/spring low flow

The winter/spring low flow recommendation is the same as the summer/autumn recommendation of 10 ML/day released from the Upper Yarra Reservoir with additional top up provided by inflows from Doctors Creek and local catchment run-off. These tributary inflows are expected to be greater in winter/spring compared to summer/autumn, which will provide some seasonal variation. Tributary inflows are also expected to be greater in average and wet climate years than in dry years, which should provide the required variation between different years.   Given the changes in channel geometry and impacts associated with the Upper Yarra Dam and overall reduced flow it is considered that little ecological benefit can be achieved with a higher release from storage in winter/spring compared to summer/autumn.

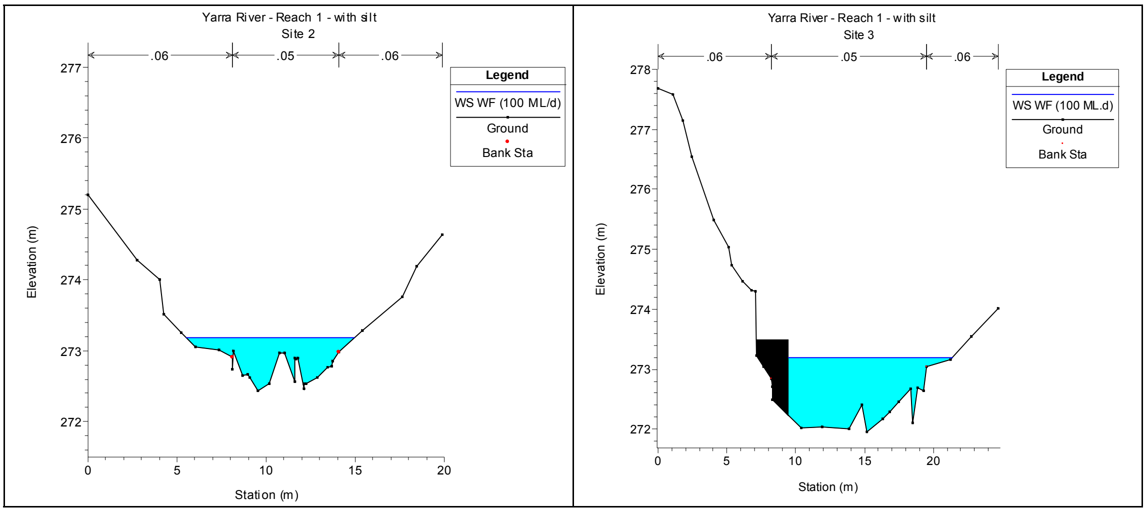
3.2.4. Winter/spring freshes

The recommended threshold for winter/spring freshes is 100 ML/day. This flow fills the bottom width of the channel and inundates the top of rocks in riffles and the lower parts of the bank. The flow will also inundate benches within the channel (Figure 3-3), which will wet vegetation and entrain accumulated organic material. This flow provides a minimum depth of 30 cm over riffles to provide suitable depths for fish passage and a minimum shear stress >10 N/m^2 to scour silt and sediment from riffles.

It is recommended that three freshes occur in the winter/spring period for two days duration. This will provide some flow variability during the winter/spring period and the duration is sufficient to entrain organic material and redistribute it through the reach. Fish passage in this reach is required for local movements, so relatively short durations of high flows are required to allow fish to move between pools.

In average and wet climate years the recommended release volume is still 100 ML/day. However, releases should be timed to coincide with natural tributary fresh flows in Doctors Creek to increase the magnitude of the event above 100 ML/day as measured at the Doctors Creek gauge. Inflows from Doctors Creek may also increase the duration of the event. Both of those outcomes would provide acceptable variability in average and wet years.

A flow of 100 ML/day is well below the unimpacted winter low flow (the 80th percentile winter unimpacted flow was 200 ML/day). Under current conditions flows greater than 100 ML/day frequently occur across the winter/spring period in average and wet climate years due to unregulated tributary inflows from Doctors Creek.



- **Figure 3-3 Stage height in riffle (Transect 2, left) and pool (Transect 3, right) at the recommended threshold for winter/spring fresh in Reach 1.**

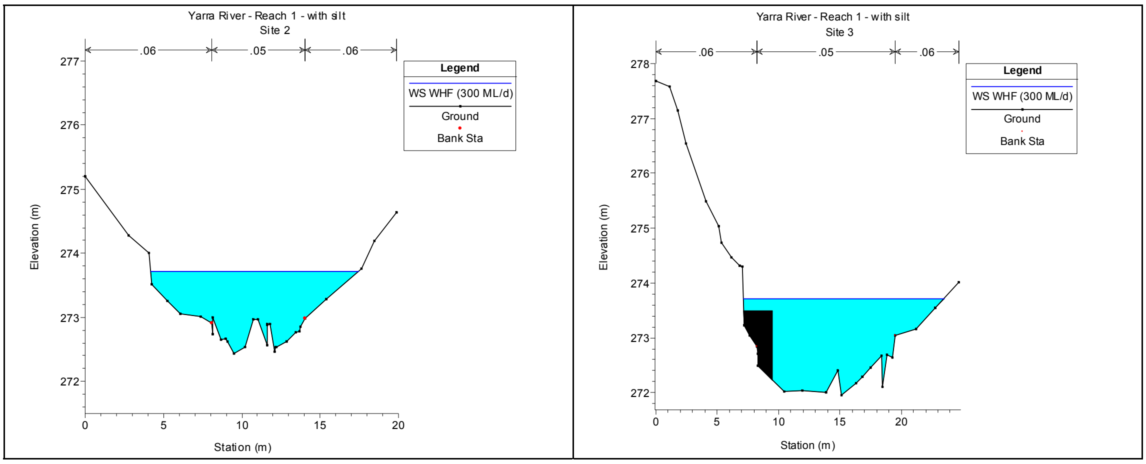
3.2.5. Winter/spring high flows

A winter/spring high flow threshold of 300 ML/day is recommended. This flow is predicted to be sufficient to maintain pool habitat relatively free of fine sediment material once pools have initially been flushed of sediment material. A flow of 300 ML/day is sufficient to create the velocity and shear stress in pools required to mobilise and transport sediment and is consistent with the flushing flow recommendation of Wilkinson and Rutherford (2001). This flow will also significantly increase water depth in pools and riffles and inundate vegetation on the banks (Figure 3-4).

A trial flow release of 200 ML/day in September 2011 was effective at flushing some material, but not competent to achieve the stated objective (SKM, 2012d). Trial releases will continue in order to determine the most appropriate flow magnitude and duration required to flush fine sediment from pools without mobilising consolidated sediment in lateral bars.

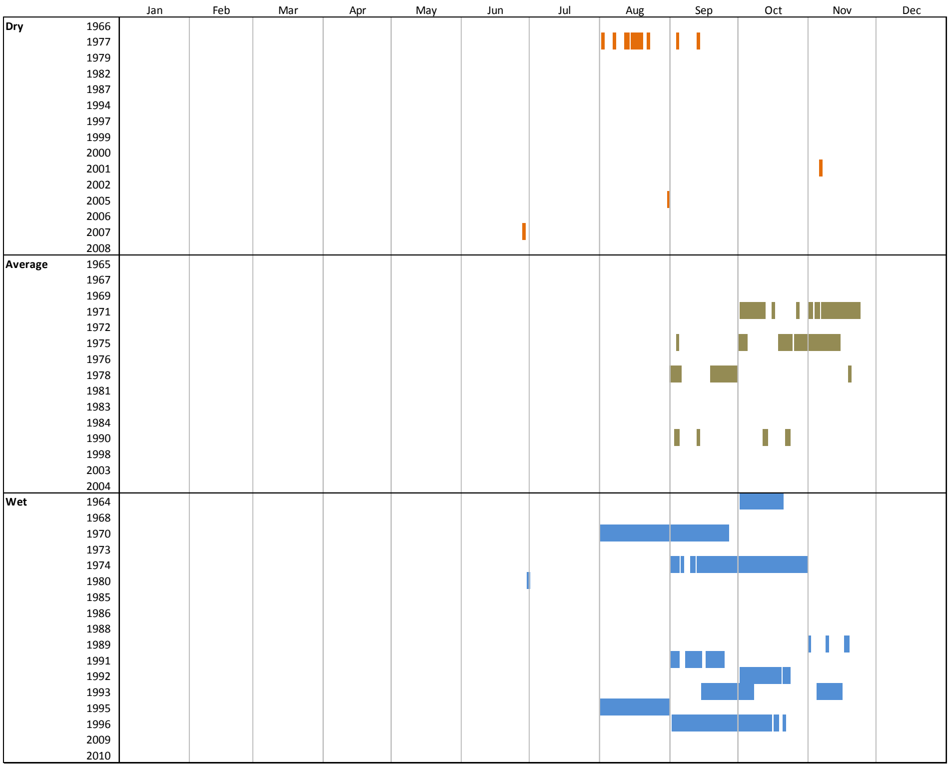
The recommended frequency of the high flow is once every two years. These flows should persist for three days to allow sufficient time to transport fine material to downstream reaches where higher flows will further redistribute that material along the river. High flow releases should be avoided from October onwards to minimise risks to spawning River Blackfish by flushing larvae downstream.

In addition to maintaining pool habitat, the high flow will provide a disturbance regime for terrestrial vegetation encroaching on banks and will provide further opportunity for local fish movement throughout the reach.

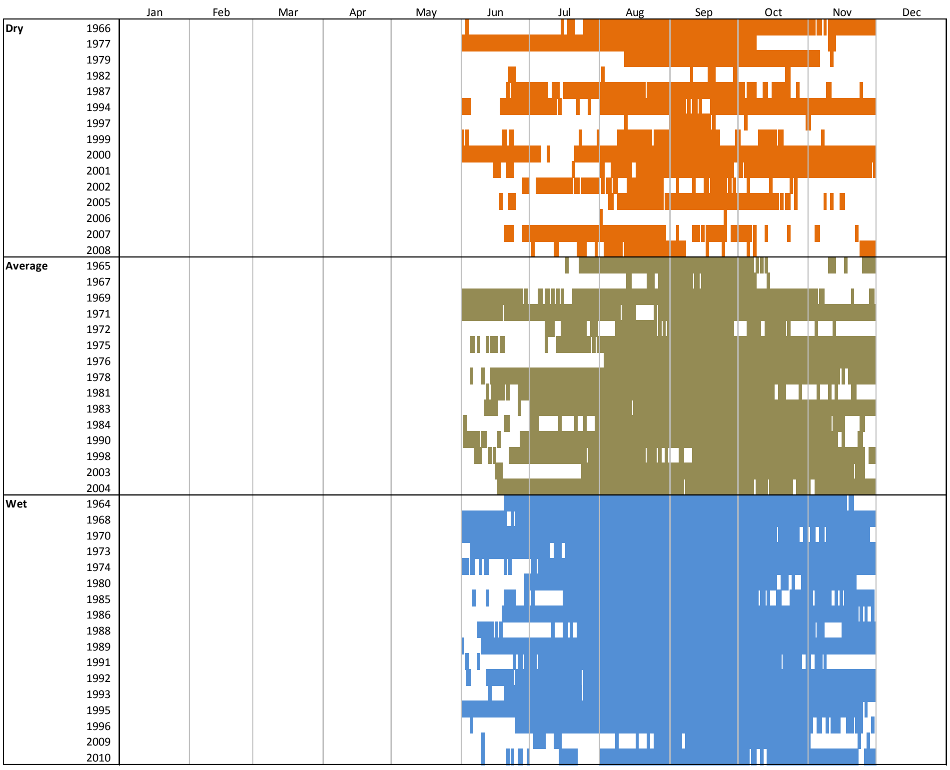


- **Figure 3-4 Stage height in riffle (Transect 2, left) and pool (Transect 3, right) at the recommended threshold for winter/spring high flows in Reach 1.**

Under current conditions a flow of 300 ML/day occurs once every four years, naturally such a flow would have occurred several times throughout the year (Figure 3-5 and Figure 3-6). Under unimpacted conditions, the median duration of a flow >300 ML/day was 10 days with 20% of events lasting longer than approximately 120 days. Currently, the median duration of flows >300 ML/day is one day. The current recommendation would extend the duration of these events to three days.



- **Figure 3-5 Characteristics of winter/spring high flow threshold for current conditions for Reach 1.**



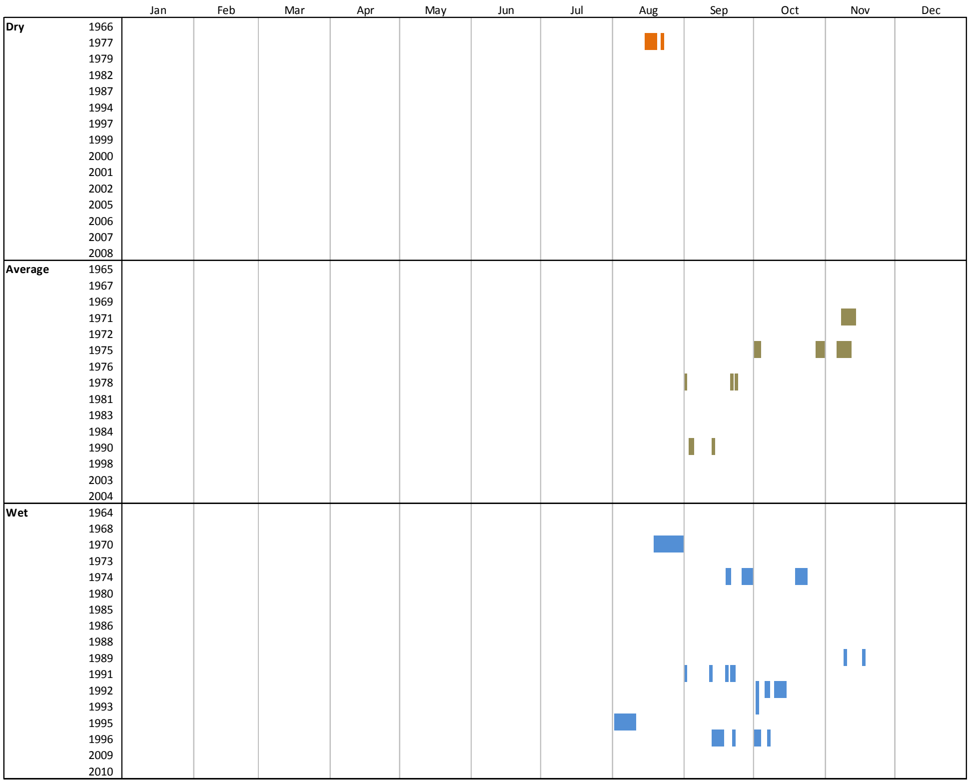
- **Figure 3-6 Characteristics of winter/spring high flow threshold for unimpacted conditions for Reach 1**

3.2.6. Bankfull

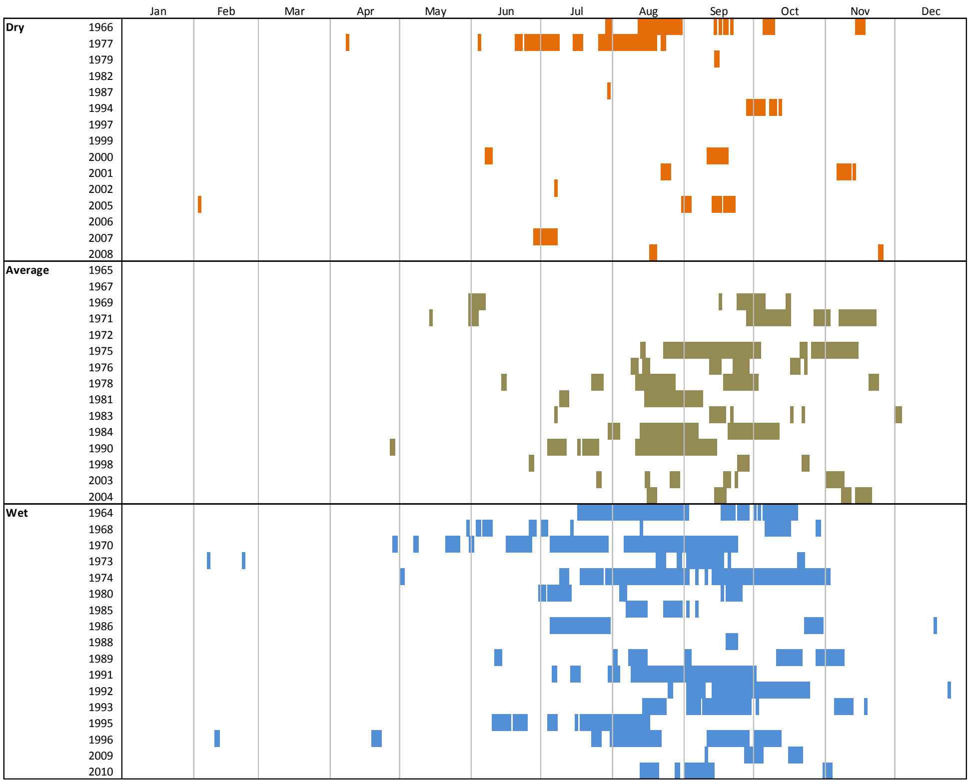
A bankfull flow threshold of 1100 ML/day was recommended in 2005. The purpose of this flow is to provide a significant ecosystem and geomorphic disturbance. In particular it is aimed at scouring sediment and fine material from the deepest pools, to partly scour consolidated lateral material along the channel margins without mobilising the entire sediment load stored in lateral bars, and to scour vegetation encroaching on the active channel and lower banks.

The 1100 ML/day flow is consistent with the flushing flow recommendation of Wilkinson and Rutherford (2001). However, there is considerable uncertainty regarding the magnitude and duration of flow required to achieve the stated objective. A trial flow release of 200 ML/day in 2011 was insufficient to mobilise significant amounts of accumulated fine organic material in pools. It is recommended that trial releases continue with the flow magnitude progressively increasing in each trial to determine the threshold at which accumulated material moves. Once sufficient material is removed (based on monitoring), the specific flow recommendation can be reset. This approach will better manage risks (i.e. mobilisation of the entire sediment store) associated with such a large volume release.

The recommended frequency of the bankfull flow is one every 10 years for a duration of three days. Under unimpacted conditions flows greater than 1100 ML/day would have occurred one to two times per year with a median duration of five days (Figure 3-7 and Figure 3-8). However, flows of this magnitude have rarely occurred in 40 years since the Upper Yarra Dam was completed. The recommended flow frequency is designed, in conjunction with the high flow recommendation, to scour fine sediment from pools and then to maintain pool habitat in the context of the current channel geometry. More frequent bankfull flows would increase the risk of mobilising the entire sediment load. A one in 10 year frequency will allow lateral bars to remain relatively stable, but over time will ensure pools do not fill with fine material. To ensure the scoured material is transported and redistributed long distances downstream releases from Upper Yarra Dam need to be made in conjunction with high flows further downstream.



■ **Figure 3-7 Characteristics of bankfull flow threshold for current conditions for Reach 1.**

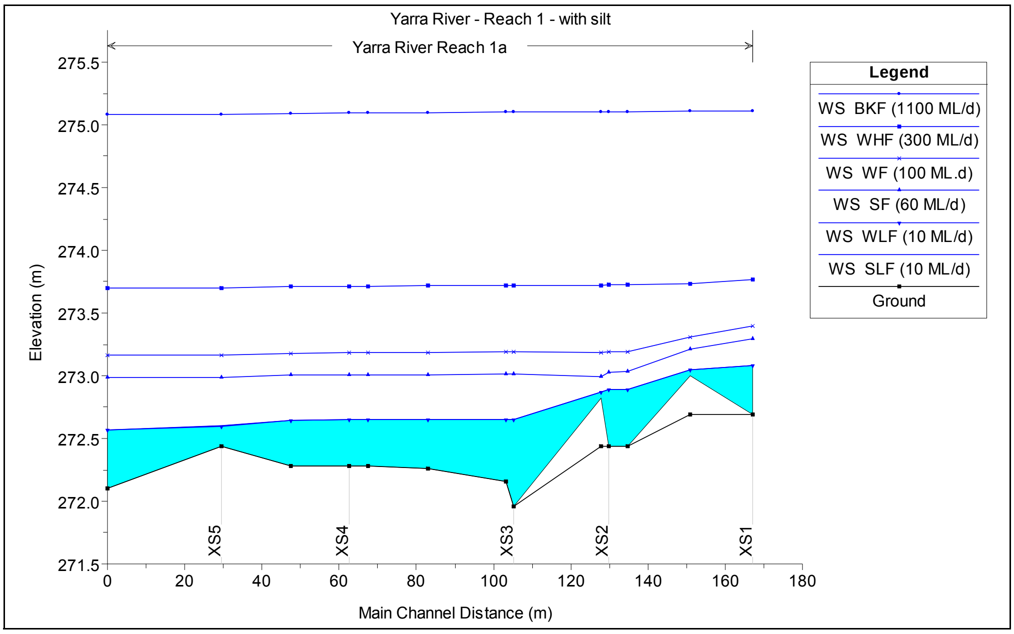


■ **Figure 3-8 Characteristics of bankfull flow threshold for unimpacted conditions for Reach 1.**

The ability to achieve ecological objectives for Reach 1 is contingent on the bankfull flow recommendation being delivered to initially scour pools of fine sediment. Subsequent high flows will maintain pool habitat relatively free of fine sediment. To take full advantage of higher flows to scour sediment it is important that further sediment input to the reach is minimised through adherence to best practice guidelines and codes of practice for road construction and maintenance and for forest activities in the Doctors Creek catchment.

3.2.7. Long section

Figure 3-9 shows the depth of water over riffles and in pools in Reach 1 under each flow threshold. It is evident that the summer/autumn low flow maintains a shallow flow over riffles and sufficient depth in pools. Fresh flows increase depth over riffles to provide fish passage and high and bankfull flows completely drown out riffles structures.



- **Figure 3-9 Long section of Reach 1 showing depth in pools and riffles under each flow threshold.**

3.2.8. Current achievement of flow recommendations

An assessment of how well the flow recommendations for Reach 4 are currently met in dry, average and wet years is presented in Table 3-2, Table 3-3 and Table 3-4, respectively. It should be noted that these assessments include an 'or natural' clause, which considers the flows that would have occurred in Reach 1 in wet, dry and average years under unimpacted conditions. For example, if the hydrological analysis shows that the recommended winter high flow would only occur in 25 out of 30 years in average years then the level of achievement is based on how many of those 25 events are delivered under the current level of development and system operation.

The summer and winter low flow recommendations and the summer fresh recommendations for Reach 1 are currently met nearly 100% of the time in wet, average and dry years. Additional releases from Upper Yarra Reservoir will seldom be required to meet these flow recommendations in the future.

The recommended winter fresh is met 94% of the time in wet years, 69% of the time in average years and 44% of the time in dry years. Additional releases from Upper Yarra Reservoir are likely to be required to meet these flow requirements in future.

The recommended winter high flow is achieved 100% of the time in wet years, 40% of the time in average years and 13% of the time in dry years. Winter high flows would naturally occur more often in wet years than average and dry years. As this recommendation needs to be met 1 in 2 years, there may not be many occurrences that would require a change in the historic release pattern from Upper Yarra Reservoir, but some additional releases may be needed in dry years.

Recommended bankfull flows are met 100% of the time in wet and average years and 63% of the time in dry years. Given that these flows are required once every ten years, these flows are met over the historic record. Many more events occur under unimpacted conditions than under current conditions, therefore some releases may be required to meet these flows.

In summary, the recommended flows are nearly always met in wet years. Summer and winter low flows and summer freshes are currently met in all climate years. However, additional releases may need to be made from Upper Yarra Reservoir to increase the number of winter freshes and winter high flows in average climate years and to increase the number of winter freshes, winter high flows and bankfull flows in dry climate years.

While the summer and winter fresh recommendations are frequently met, they will not deliver all of their intended environmental benefits until an initial bankfull flow has been delivered and the recommended winter high flows are met. The bankfull flow should be timed to coincide with high flows in downstream reaches to help distribute scoured sediment along a long section of river and minimise the risk of accumulation in the reach immediately downstream.

The compliance point for this Reach is the Doctors Creek gauge.

- **Table 3-2 Extent to which the environmental flow recommendations for Reach 1 are currently being met during dry years.**

Component	Months	Flow Recommendation					Or Natural	Achievement
Summer low	Dec - May	Magnitude	10	ML/d			Yes	96%
Summer fresh	Dec - May	Magnitude	60	ML/d			Yes	100%
		Frequency	4	per year				
		Duration	1	days				
Summer high	Apr - May	Not recommended						
Winter low	Jun - Nov	Magnitude	10	ML/d			Yes	100%
Winter fresh	Jun - Nov	Magnitude	100	ML/d			Yes	44%
		Frequency	3	per year				
		Duration	2	days				
Winter high	Jun - Nov	Magnitude	300	ML/d			Yes	13%
		Frequency	1	in	2	years		
		Duration	3	days				
Bankfull	Jan - Dec	Magnitude	1100	ML/d			Yes	63%
		Frequency	1	in	10	years		
		Duration	3	days				
Overbank	Jan - Dec	Not recommended						

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- **Table 3-3 Extent to which the environmental flow recommendations for Reach 1 are currently being met during average years.**

Component	Months	Flow Recommendation					Or Natural	Achievement
Summer low	Dec - May	Magnitude	10	ML/d			Yes	97%
Summer fresh	Dec - May	Magnitude	60	ML/d			Yes	100%
		Frequency	4	per year				
		Duration	1	days				
Summer high	Apr - May	Not recommended						
Winter low	Jun - Nov	Magnitude	10	ML/d			Yes	100%
Winter fresh	Jun - Nov	Magnitude	100	ML/d			Yes	69%
		Frequency	3	per year				
		Duration	2	days				
Winter high	Jun - Nov	Magnitude	300	ML/d			Yes	40%
		Frequency	1	in	2	years		
		Duration	3	days				
Bankfull	Jan - Dec	Magnitude	1100	ML/d			Yes	100%
		Frequency	1	in	10	years		
		Duration	3	days				
Overbank	Jan - Dec	Not recommended						

- **Table 3-4 Extent to which the environmental flow recommendations for Reach 1 are currently being met during wet years.**

Component	Months	Flow Recommendation					Or Natural	Achievement
Summer low	Dec - May	Magnitude	10	ML/d			Yes	98%
Summer fresh	Dec - May	Magnitude	60	ML/d			Yes	100%
		Frequency	4	per year				
		Duration	1	days				
Summer high	Apr - May	Not recommended						
Winter low	Jun - Nov	Magnitude	10	ML/d			Yes	100%
Winter fresh	Jun - Nov	Magnitude	100	ML/d			Yes	94%
		Frequency	3	per year				
		Duration	2	days				
Winter high	Jun - Nov	Magnitude	300	ML/d			Yes	100%
		Frequency	1	in	2	years		
		Duration	3	days				
Bankfull	Jan - Dec	Magnitude	1100	ML/d			Yes	100%
		Frequency	1	in	10	years		
		Duration	3	days				
Overbank	Jan - Dec	Not recommended						

4. Reach 2: Armstrong Creek to Millgrove

4.1. Description

Reach 2 runs from Armstrong Creek to Millgrove. Armstrong Creek is the first major tributary input to the Yarra River downstream of Upper Yarra Dam and from this point on the channel width increases significantly as tributary inflows increase. The channel is confined in a narrow bedrock-controlled valley with a few small alluvial fans and is characterised by fast flowing water over predominantly pool-riffle structure with cobbled bed and dense riparian forest. Downstream of Millgrove the valley opens in to a wide alluvial floodplain. The environmental flows assessment site is located at East Warburton, downstream of all major tributary harvesting activities. During the 2012 flows review the EFTP visited a secondary site at Millgrove to test that flow recommendations made at East Warburton were suitable for the Millgrove site. The gauge for compliance purposes is located at Millgrove.

4.2. Flow recommendations

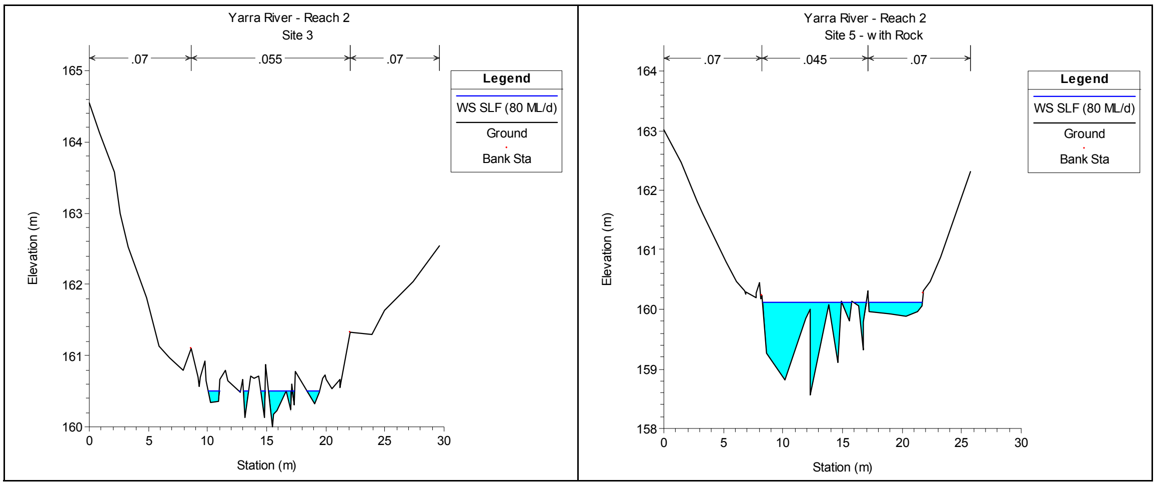
Objectives for this reach are to provide increased variability in low flow periods and return some of the high flows, particularly the longer lasting high flows in spring, to inundate the banks with the intent of drowning terrestrial vegetation that is encroaching down the banks. Key flow components are summer freshes to ensure a variable low flow and increased duration of spring high flows to inundate the bank for a longer duration during the main vegetation growing season. Flow recommendations are largely unchanged compared with the 2005 study, however, the adoption of flow recommendations for dry, average and wet years has allowed a revision of some components. The environmental flow recommendations for Reach 2 are summarised in Table 4-1.

Table 4-1 Flow recommendations for Reach 2.

Stream	**Yarra River**			**Reach**	**Armstrong Creek confluence to Millgrove**		
Compliance point	**Millgrove Gauge**			**Gauge No.**	**229212**		
Season	**Flow**	**Objective (refer to objectives tables for id reference)**	**Wet/Avg/ Dry**	**Volume**	**Frequency and when**	**Duration**	**Rise/Fall**
Summer / Autumn (Dec-May)	Low flow	Maintain access to habitat for bugs & fish, drying period for bank vegetation (M2-1, F2-1, V2-1)	Wet	Minimum recommendation of 80 ML/day, allow tributaries to provide variation greater than 80 ML/day in average and wet years.			
			Average				
			Dry				
	Fresh	Maintain suitable riffle habitat by periodically scouring sediment & biofilms, maintain flood-tolerant vegetation on banks (G2-2, M2-2, F2-1, V2-2)	Wet	350 ML/day, tributary inflows provide variation during average and wet years. Higher magnitude and longer duration flows are acceptable and beneficial in average and wet years.	Minimum 3 events delivered + additional events provided by Tributaries.	Min 2 day at peak. Longer duration flows acceptable in average and wet years.	1.4/0.85
			Average				
			Dry	350 ML/d	3	2	
	High	Trigger spawning by Australian Grayling and transport larvae downstream. (F2-3)	Wet	560 ML/day tributary inflows provide variation during average and wet years. Higher magnitude and longer duration flows are acceptable and beneficial in average and wet years.	1 (April/May)	Min 7 day at peak. Longer duration flows acceptable in average and wet years.	1.4/0.85
			Average				
			Dry				
Winter / spring (Jun-Nov)	Low flow	Maintain access to habitat for bugs & fish (M2-1, V2-1)	Wet	Minimum recommendation of 350 ML/day, allow tributaries to provide additional flow and variation in average and wet years.			
			Average				
			Dry	Median flow 350 ML/day, minimum 200 ML/day.			
	Fresh	Maintain suitable riffle habitat by periodically scouring sediment & biofilms, maintain flood-tolerant vegetation on banks, provide local fish passage, entrain organic material (G2-2, M2-2, F2-1, V2-2, F2-2)	Wet	700 ML/day tributary inflows provide variation during average and wet years. Higher magnitude and longer duration flows are acceptable and beneficial in average and wet years.	Minimum 2 events between June and September.	Min 7 day at peak. Longer duration flows acceptable in average and wet years.	1.4/0.85
			Average				
			Dry				
	High	As per fresh but provides prolonged disturbance to favour flood-tolerant vegetation (G2-3, M2-3, F2-2, V2-3)	Wet	700 ML/d	Deliver 1 event in September, allow to occur naturally at other times.	14 days	1.4/0.85
			Average				
			Dry	Not necessary to deliver but allow to occur naturally			
	Bankfull / overbank	Maintain existing channel geometry & prevent further vegetation encroachment in channel, entrain organic material, engage high flow channels (G2-1, M2-3, V2-3, G2-2)	Wet	2700 ML/day. Higher magnitude and longer duration flows are acceptable and beneficial in average and wet years.	1 in 2 years, although may not occur in dry years and not necessary to actively deliver.	2 days at peak. Longer duration flows acceptable in average and wet years.	1.4/0.85
			Average				
			Dry				

4.2.1. Summer/autumn low flow

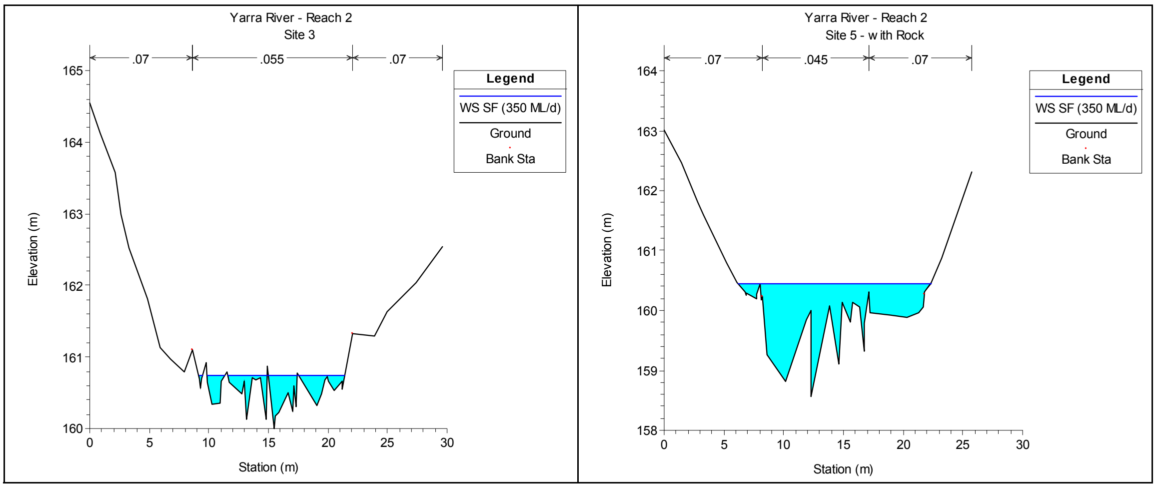
The recommended summer low flow threshold in Reach 2 is 80 ML/day, this is unchanged from 2005. This flow is sufficient to inundate the full width of riffles (e.g. Transect 3) and to maintain sufficient depth in pools of around 1 m (e.g. Transect 5) (see Figure 4-1). The flow threshold also allows a drying regime for benches and the lower bank. Flows lower than this would reduce the area of riffles available for macroinvertebrates and may introduce water quality problems, particularly deoxygenation in the deeper pools. In average and wet years tributary inflows provide variation above the minimum recommended magnitude. Higher magnitude and longer duration flows are acceptable, and beneficial, in average and wet years.



- **Figure 4-1 Stage height in riffle (Transect 3, left) and pool (Transect 5, right) at the recommended threshold for summer/autumn low flows in Reach 2.**

4.2.2. Summer/autumn fresh

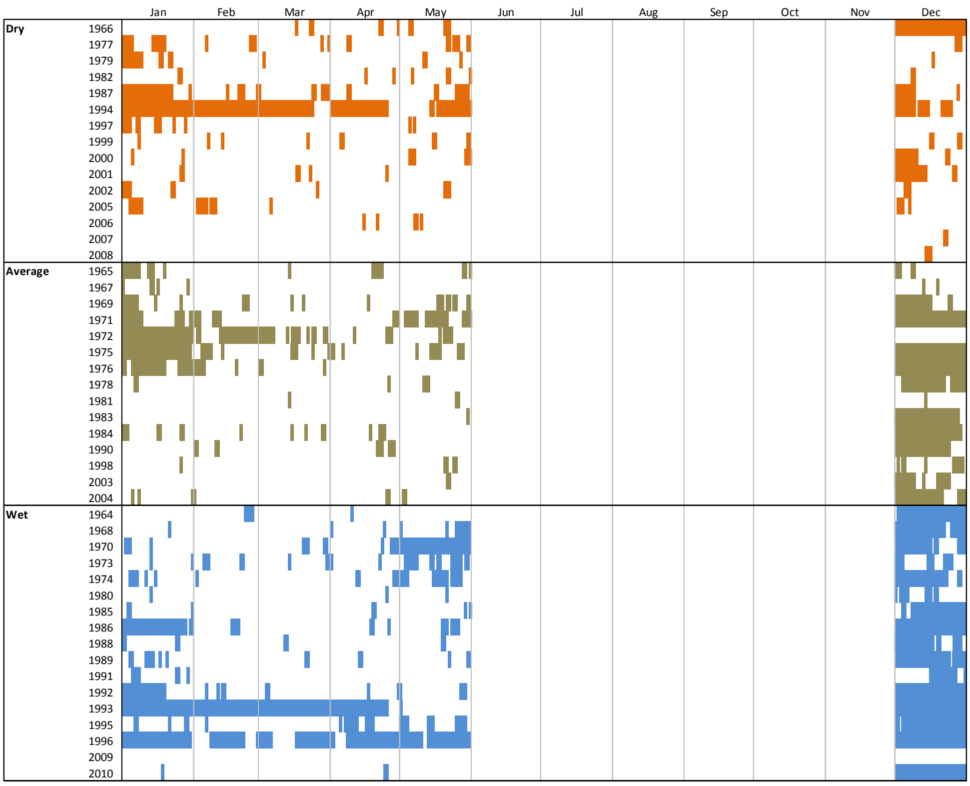
A summer /autumn fresh threshold of 350 ML/day is recommended, this is unchanged from 2005. This flow inundates rocks and boulders located in riffles and pool margins (Figure 4-2) and achieves an average flow velocity through riffles of ~40 cm/s to scour sediment and biofilms. The fresh flow also wets banks to maintain flood-tolerant vegetation through the low-flow period. Higher flows were considered to provide marginal incremental advantage in scouring riffles and runs and significantly higher flows are required to wet further up the banks.



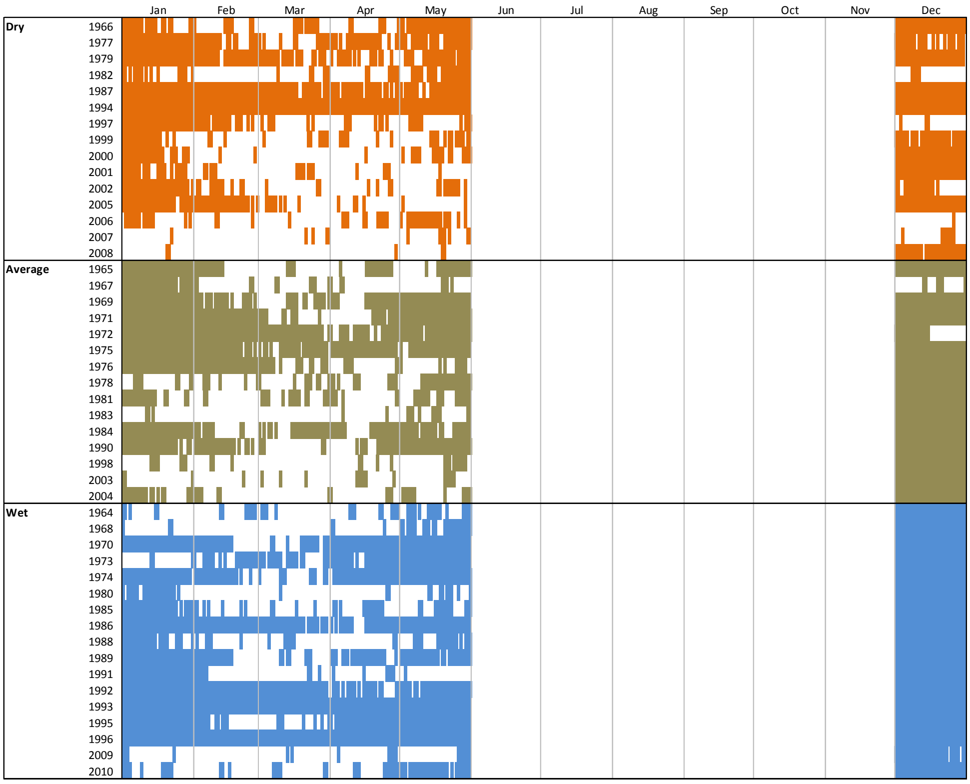
- **Figure 4-2 Stage height in riffle (Transect 3, left) and pool (Transect 5, right) at the recommended threshold for summer/autumn freshes in Reach 2.**

Three fresh flows of a minimum duration of two days are recommended in each summer/autumn period. The current frequency of flows above the fresh threshold is similar to the unimpacted flow regime (with several events per year) (Figure 4-3 and Figure 4-4). However, the median duration of each event has more than halved (2 days compared to 5 days), although two days is probably sufficient to meet the main environmental objectives of the event. There has been a slight shift in the timing of freshes. Under the current flow regime, freshes occur most commonly at the start or end of the summer/autumn period. Ideally, these events should occur throughout summer and autumn, rather than be restricted to the start or end of the season.

Tributary inflows provide variation in average and wet years and it is acceptable (and desirable) for the magnitude, frequency and duration to be longer than recommended in these years. It also acceptable for individual events to have a longer than recommended duration, even if this means fewer events occur in that year.



- **Figure 4-3 Characteristics of summer/autumn fresh flow threshold for current conditions for Reach 2. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**



- **Figure 4-4 Characteristics of summer/autumn fresh flow threshold for unimpacted conditions for Reach 2. This plot shows the number and duration of flows above the recommended threshold that have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.**

4.2.3. Summer/autumn high flows

A summer/autumn high flow threshold of 560 ML/day is recommended to provide suitable spawning conditions for Australian Grayling, which require a high flow in autumn to trigger spawning and transport of larvae to the estuary (O'Connor and Mahoney, 2004). This recommendation is unchanged from 2005. The flow needs to occur in autumn and the recommended timing is April or May. There is uncertainty about the flow magnitude required to trigger spawning in the Yarra River, although recent studies suggest that at least 1300 ML/day is required in downstream reaches (Koster, unpublished). To achieve a flow of this magnitude in downstream reaches, a portion of the flow needs to be delivered via upstream reaches. The recommended flow threshold of 560 ML/day is based on the median unimpacted flow for May and June. The duration of the flow event is also uncertain; as it is unknown whether a short duration event is sufficient to trigger spawning or whether a longer duration event is required to promote movement of adult fish towards the estuary prior to the release of eggs. Recent monitoring in the Bunyip River suggests that adult Australian Grayling move towards the estuary before spawning (Koster and Dawson, 2011). The recommended duration for the autumn high flow event is seven days to allow sufficient time to transport larvae to the estuary. The flow recommendation would be met if the first high flow in autumn is allowed to progress down the entire system and the flow magnitude remains above the summer low flow level for at least seven days.

In average and wet climate years, it is expected that tributary inflows will increase the magnitude and/or duration of the autumn high flow. These increases are desirable and therefore the contributions from tributaries should be protected.

HEC RAS modelling also shows that the recommended autumn high flow is also sufficient to engage high flow channels (e.g. Transect 2) and disturb vegetation on the lower banks (Figure 4-5). Both of these outcomes are likely to have environmental benefits.

Under current conditions a high flow of the recommended threshold occurs on average once every year for a median duration of two days and a maximum duration of around five days (Figure 4-6). Under unimpacted conditions (Figure 4-7) the flow threshold would have been exceeded several times per year for a median duration of three days. However, 30% of events would have lasted between three and 10 days, and 20% of events would have lasted between 10 and 20 days. This means in average and wet climate years at least one event in each year would have had sufficient duration to transport larvae long distances downstream.

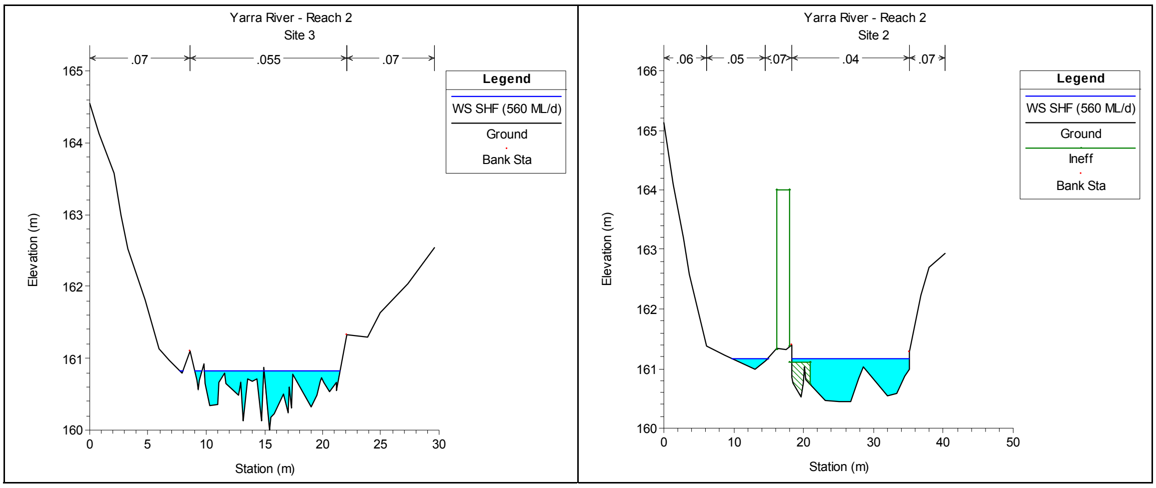
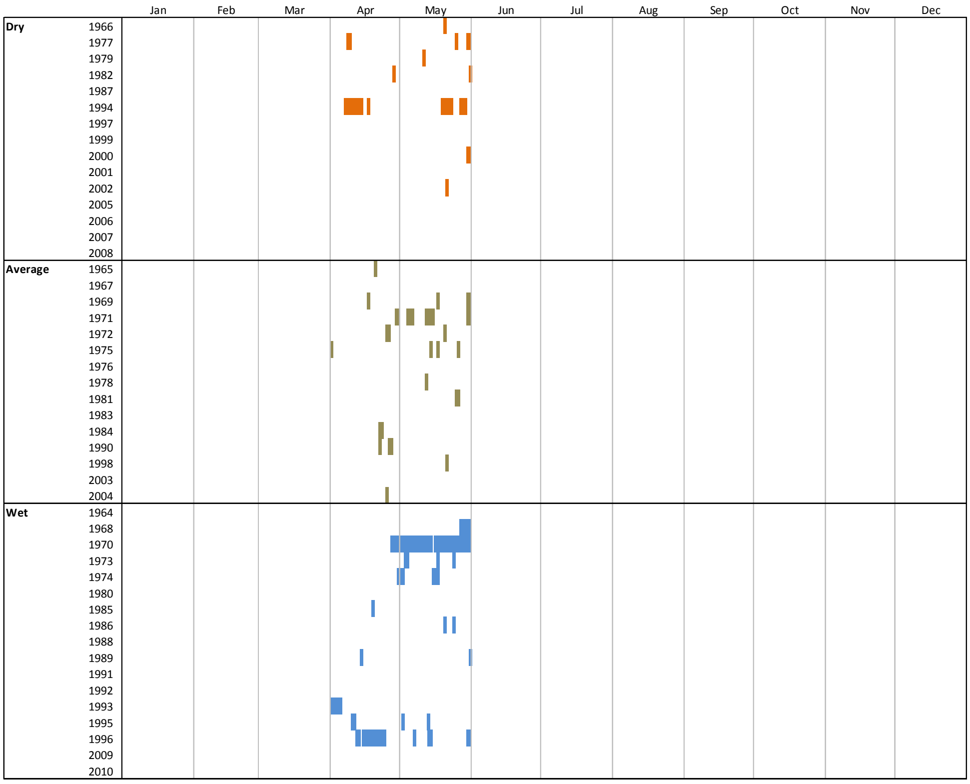
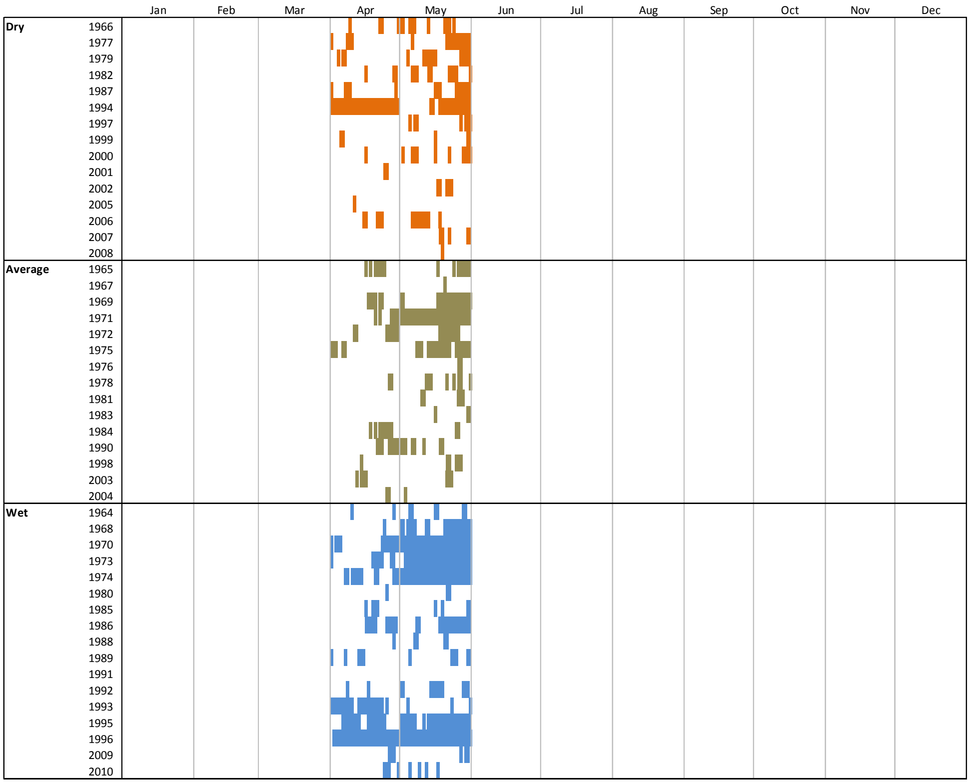


Figure 4-5 Stage height in riffle (Transect 3, left) and pool (Transect 2, right) at the recommended threshold for summer/autumn high flows in Reach 2.



- **Figure 4-6 Characteristics of summer/autumn high flow threshold for current conditions for Reach 2. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**



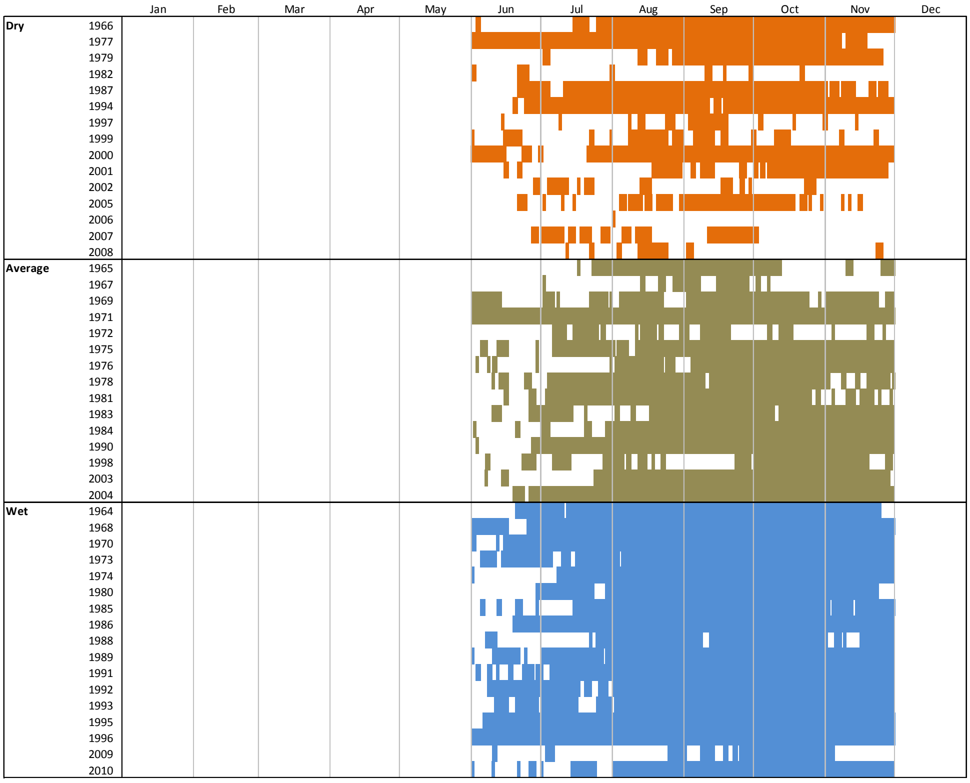
- **Figure 4-7 Characteristics of summer/autumn high flow threshold for unimpacted conditions for Reach 2. This plot shows the number and duration of flows above the recommended threshold that would have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.**

4.2.4. Winter/spring low flow

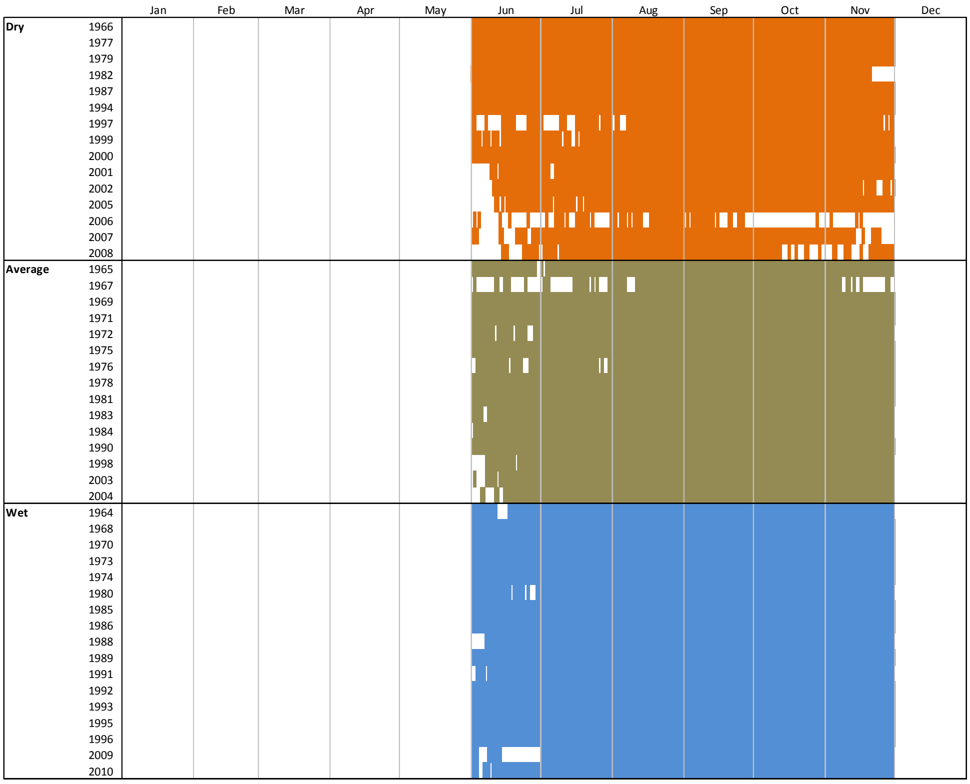
The winter/spring low flow threshold of 350 ML/day recommended in the 2005 study has been modified in this review. During dry climate years the recommendation is revised to a median low flow of 350 ML/day with a daily minimum of 200 ML/day. It is also acceptable for the increase in winter base flow to be delayed by 4-6 weeks in dry years (i.e. to late June or early July). In average and wet climate years, the recommendation is for a daily minimum low flow of 350 ML/day. This subtle difference allows for slightly lower flow on some days in dry years, and also preserves natural seasonality.

The recommended flow is sufficient to inundate the full width of riffles to a depth of around 10 cm. The prolonged duration of the higher flow through winter provides a prolonged disturbance on the lower banks to favour flood-tolerant vegetation and provide conditions unfavourable for aquatic plants that prefer stable water levels (e.g. Yellow Flag Iris).

Under current conditions flows fall below the recommended winter/spring low flow threshold on average 2.5 times per year for a median duration of 15 days each time with 20% of events lasting between 35 and 55 days (Figure 4-8). Under unimpacted conditions, spells below the threshold would have occurred approximately once every 18 months but only for a median duration of five days (Figure 4-9). The maximum duration of flows less than 350 ML/day under unimpacted conditions would have been 12 days (Figure 4-9). Under current conditions, winter flows less than 350 ML/day most often occur in June and November (Figure 4-8). That pattern emphasises the effect that flow regulation has had on extending the summer low flow period and reducing the period of naturally higher flows through winter and spring.



- **Figure 4-8 Characteristics of winter/spring low flow threshold for current conditions for Reach 2. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**

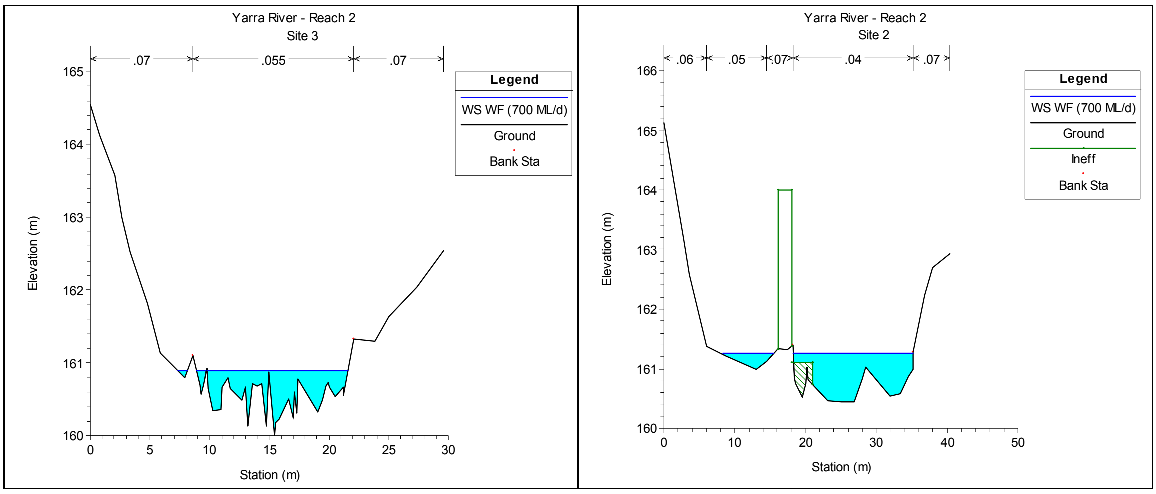


- **Figure 4-9 Characteristics of winter/spring low flow threshold for unimpacted conditions for Reach 2. This plot shows the number and duration of flows above the recommended threshold that have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.**

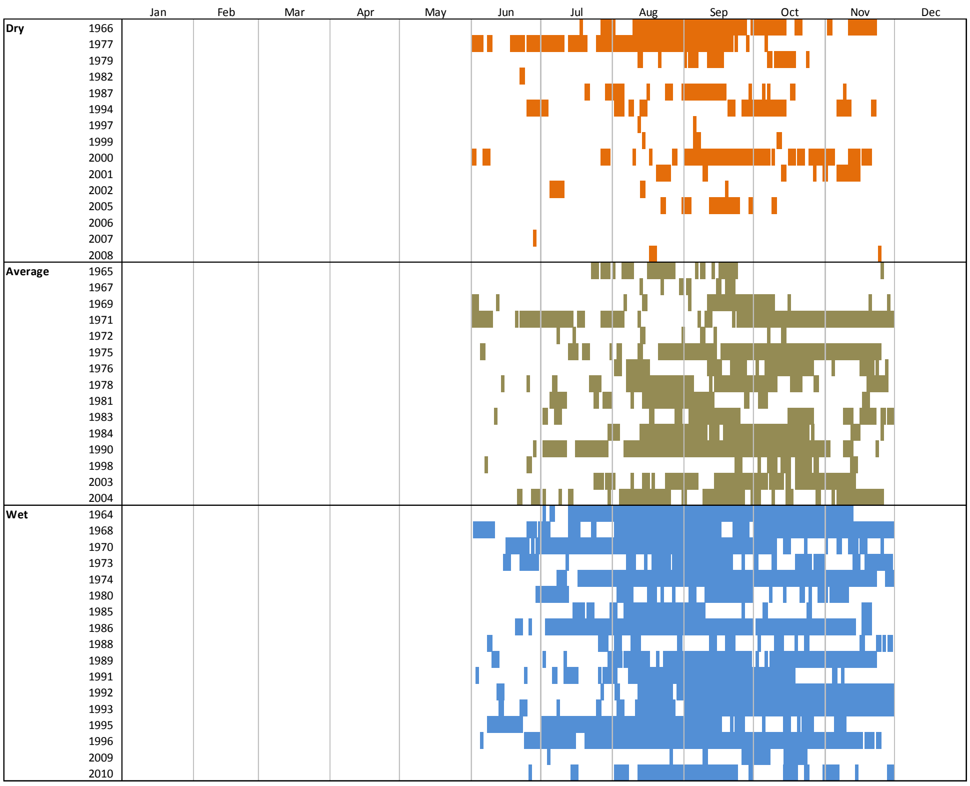
4.2.5. Winter/spring fresh and high flows

The recommended winter/spring fresh threshold is 700 ML/day. This is unchanged from 2005. Two events, that each last for seven days, are recommended for the months between June and September. The recommended flow achieves a minimum flow velocity of approximately 40 cm/s through riffles to scour cobbles and riffles of sediment and algal growth and will assist in resetting successional patterns in algal biofilms. The winter fresh is higher than the summer fresh and wets further up the banks and is sufficient to engage the high flow channel at Transect 2 (Figure 4-10).

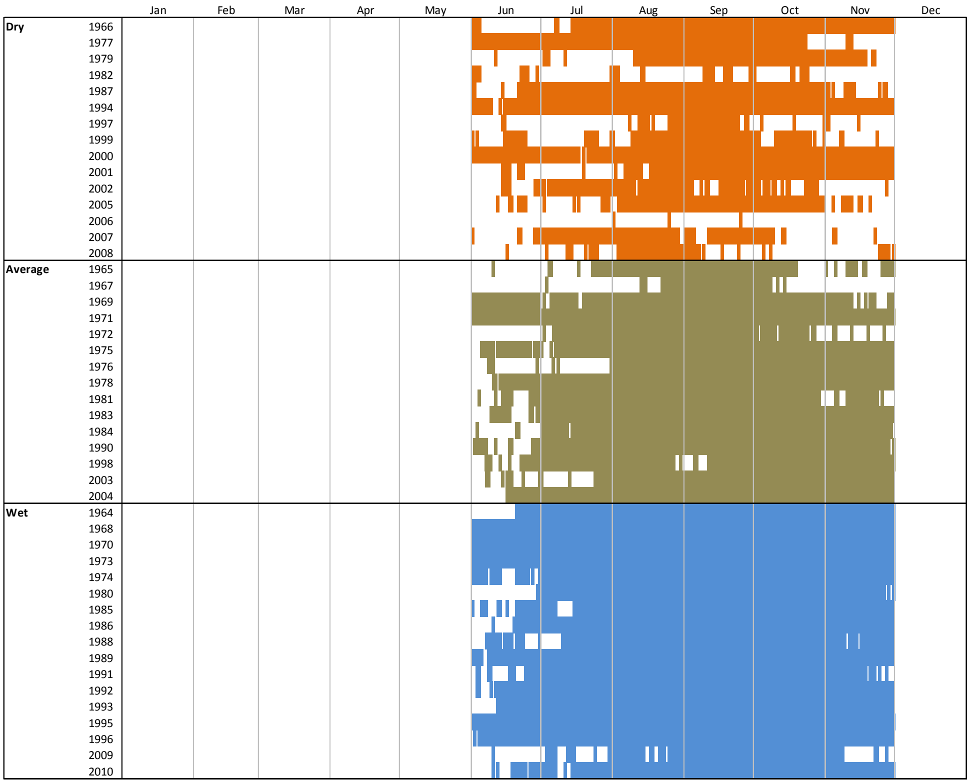
A winter high flow event of 700 ML/day is also recommended in average and wet years, however the recommended duration is double the fresh duration (14 days). This flow is aimed at inundating terrestrial vegetation on the banks to minimise the encroachment of terrestrial vegetation, particularly weeds such as blackberry and Wild Watsonia. A prolonged high flow in the spring growing season will also help to provide conditions unfavourable to semi-aquatic weeds such as the Yellow Flag Iris, which prefer stable flows during the growing season. To avoid impacting on the October-December spawning period for Macquarie Perch and River Blackfish, the winter high flow should be delivered in September. However, similar magnitude and duration events should still be allowed to occur naturally at other times (Figure 4-11 and Figure 4-12). It is un-necessary for the winter high flow event to occur in dry years, although it should be allowed to progress if one occurs naturally.



- **Figure 4-10 Stage height in riffle (Transect 3, left) and pool (Transect 2, right) at the recommended threshold for winter/spring freshes in Reach 2.**



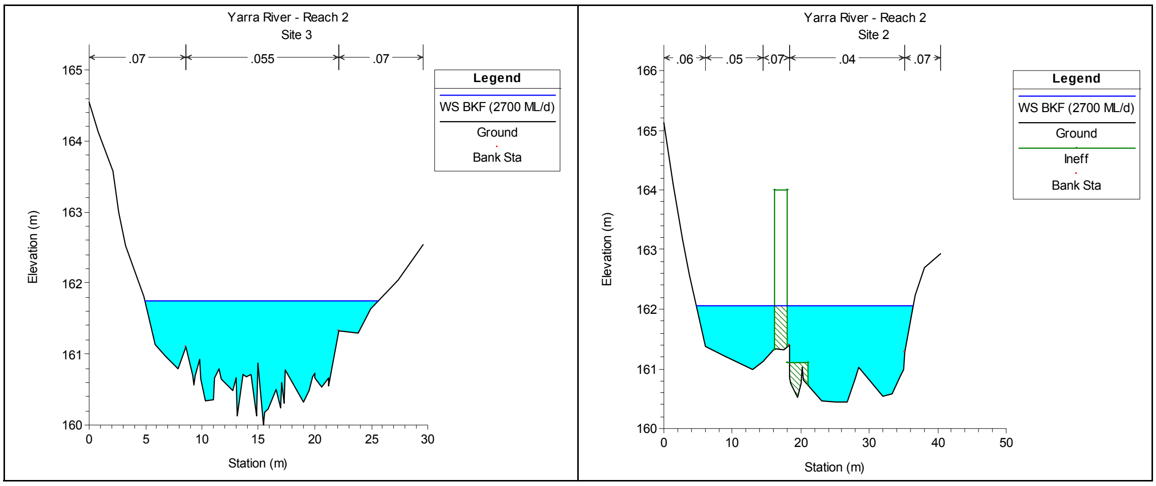
- **Figure 4-11 Characteristics of winter/spring fresh and high flow threshold for current conditions for Reach 2. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**



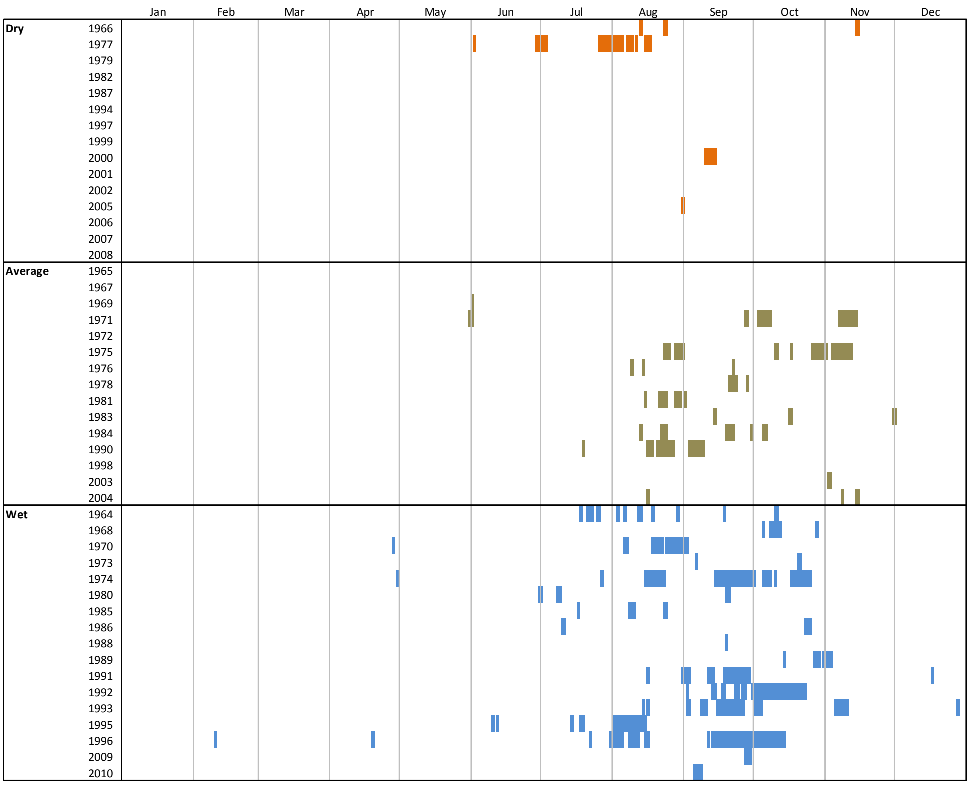
- **Figure 4-12 Characteristics of winter/spring fresh and high flow threshold for unimpacted conditions for Reach 2. This plot shows the number and duration of flows above the recommended threshold that have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.**

4.2.6. Bankfull flow

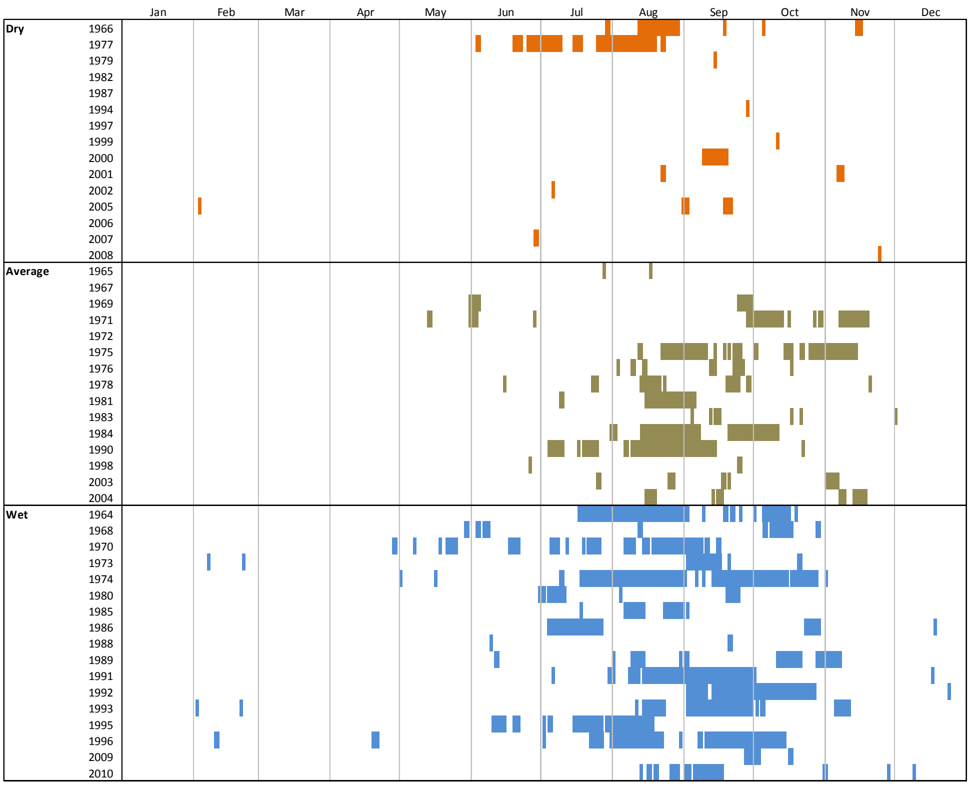
A bankfull flow of 2700 ML/day that lasts for two days is recommended every second year. This recommendation is unchanged from 2005. This flow is sufficient to reach the top of the banks (typically ill defined due to confined nature of channel and steep valley side slopes) along most transects and inundates a small floodplain and high flow channel at Transects 1 and 2 at the FLOWS assessment site (Figure 4-13). The recommended bankfull flow is considered sufficient to maintain current channel geometry by scouring in-channel vegetation and sediment in deepest pools. A flow of 2700 ML/day is unlikely to occur in dry climate years (Figure 4-14 and Figure 4-15), although it should be allowed to progress if an event occurs naturally.



- **Figure 4-13 Stage height in riffle (Transect 3, left) and pool (Transect 2, right) at the recommended threshold for bankfull flows in Reach 2.**



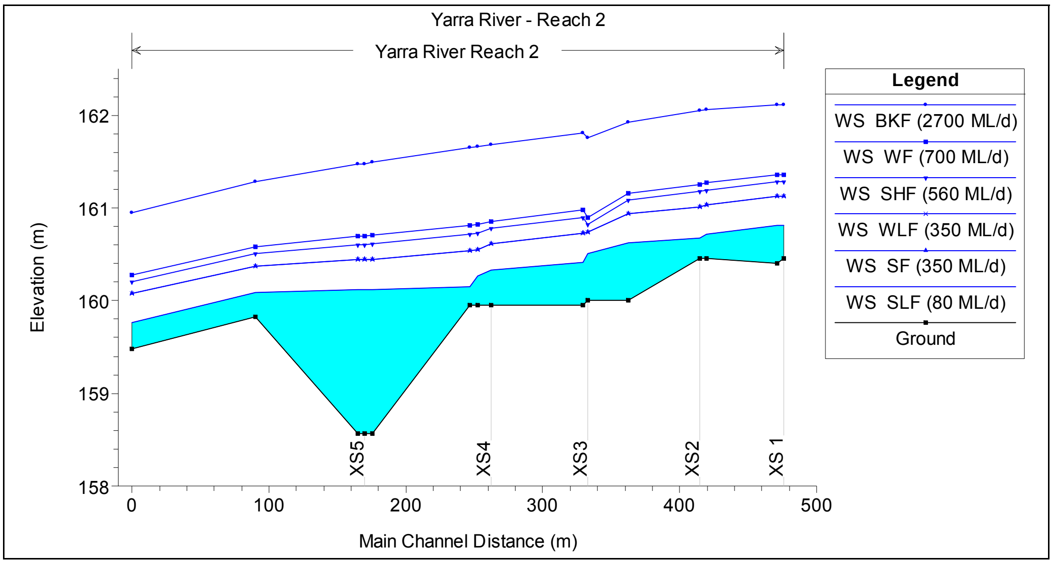
- **Figure 4-14 Characteristics of bankfull flow threshold for current conditions for Reach 2. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**



- **Figure 4-15 Characteristics of bankfull flow threshold for unimpacted conditions for Reach 2. This plot shows the number and duration of flows above the recommended threshold that have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.**

4.2.7. Long section

Figure 4-16 shows the depth of water over riffles and in pools in Reach 2 under each flow threshold. It is evident that the summer/autumn low flow maintains a shallow flow over riffles and sufficient depth in pools. Fresh flows increase depth over riffles to provide fish passage and high and bankfull flows completely drown out riffle structures.



- **Figure 4-16 Long section for Reach 2 showing water surface levels for each recommended flow threshold.**

4.2.8. Current achievement of flow recommendations

An assessment of how well the flow recommendations for Reach 2 are currently met in dry, average and wet years is presented in Table 4-2, Table 4-3 and Table 4-4, respectively. It should be noted that these assessments include an 'or natural' clause, which considers the flows that would have occurred in Reach 2 in wet, dry and average years under unimpacted conditions. For example, if the hydrological analysis shows that the recommended winter high flow would only occur in 25 out of 30 years in average years then the level of achievement is based on how many of those 25 events are delivered under the current level of development and system operation.

The summer low flow recommendations for Reach 2 are currently met nearly 100% of the time in wet, average and dry years. The winter low flow is met 88% of the time in wet years, 69% of the time in average years but only 48% of the time in dry years. The summer fresh flow is met approximately 90% of the time in wet and average years, although only 44% in dry years. Additional managed releases from the Upper Yarra Reservoir, O'Shannassy Reservoir or from storages on some smaller tributaries will be needed to make up the shortfall between the current and the recommended flow regime for the winter low and summer fresh flows.

The recommended summer high flow is met 50% of the time in wet and average years and 75% of the time in dry years. The higher achievement in dry years, does not indicate that more of these events occur in dry years (under unimpacted conditions, these events would have occurred in four out of the 30 dry years in the available record and in 14 out of the 30 wet years in the available record). Rather it indicates that a higher proportion of the flows that would naturally occur are still observed. It is important that summer high flows are delivered in most wet and average climate years and extra releases may need to be made from upstream storages to achieve those recommendations.

The recommended winter fresh is achieved 100% of the time during wet years, 81% of the time during average years and 50% of the time during dry years. Winter freshes provide important flow variability and therefore it may be necessary to make additional releases from upstream storages to deliver more of these events in dry years.

The recommended winter high flow is achieved around 90% of the time wet years and average years, and is not necessarily expected in dry years. The recommended number of bankfull flows is currently delivered in wet and average years, but only 43% of the recommended bankfull flows occur in dry years. As the bankfull flow is only required once every two years, the current release regime should meet the flow recommendations. However, it may be necessary to make additional releases from upstream storages to deliver an occasional bankfull flow in prolonged dry periods.

In summary, most flow components are achieved in the wet and average climate years, but the flow recommendations are not well met in dry years. Years that are dry will require releases from reservoirs to achieve the recommended flows. The summer high flow is the most difficult to achieve and will require active management to ensure achievement.

Environmental objectives related to Australian Grayling spawning may be affected if summer high flows are not achieved and vegetation zonation on banks may be affected if winter high flows are not achieved.

Existing harvesting operations from tributary streams that flow into Reach 2 may need to be modified to deliver all of the recommended environmental flows for this reach. No additional releases will be needed to deliver the recommended bankfull flow, but natural bankfull events will need to be protected. Moreover, it is important that high flows and bankfull flows that occur in this reach are allowed to progress through the entire system so that they can contribute to equivalent flow components in downstream reaches. The Millgrove flow gauge is the compliance point for Reach 2.

- **Table 4-2 Extent to which the environmental flow recommendations for Reach 2 are currently being met during dry years.**

Component	Months	Flow Recommendation			Or Natural	Achievement
Summer low	Dec - May	Magnitude	**80**	ML/d	**Yes**	*99%*
Summer fresh	Dec - May	Magnitude	**350**	ML/d	**Yes**	*44%*
		Frequency	**3**	per year		
		Duration	**2**	days		
Summer high	Apr - May	Magnitude	**560**	ML/d	**Yes**	*75%*
		Frequency	**1**	per year		
		Duration	**7**	days		
Winter low	Jun - Nov	Magnitude	**350**	ML/d	**Yes**	*48%*
Winter fresh	Jun - Sep	Magnitude	**700**	ML/d	**Yes**	*50%*
		Frequency	**2**	per year		
		Duration	**7**	days		
Winter high	Oct - Nov	Not necessary to deliver, but allow to occur naturally				
Bankfull	Jan - Dec	Magnitude	**2700**	ML/d	**Yes**	*43%*
		Frequency	**1**	in **2** years		
		Duration	**2**	days		
Overbank	Jan - Dec	Not recommended				

Table 4-3 Extent to which the environmental flow recommendations for Reach 2 are currently being met during average years.

Component	Months	Flow Recommendation					Or Natural	Achievement
Summer low	Dec - May	Magnitude	80	ML/d			Yes	99%
Summer fresh	Dec - May	Magnitude	350	ML/d			Yes	88%
		Frequency	3	per year				
		Duration	2	days				
Summer high	Apr - May	Magnitude	560	ML/d			Yes	50%
		Frequency	1	per year				
		Duration	7	days				
Winter low	Jun - Nov	Magnitude	350	ML/d			Yes	69%
Winter fresh	Jun - Sep	Magnitude	700	ML/d			Yes	81%
		Frequency	2	per year				
		Duration	7	days				
Winter high	Sep - Sep	Magnitude	700	ML/d			Yes	88%
		Frequency	1	per year				
		Duration	14	days				
Bankfull	Jan - Dec	Magnitude	2700	ML/d			Yes	100%
		Frequency	1	in	2	years		
		Duration	2	days				
Overbank	Jan - Dec	Not recommended						

Table 4-4 Extent to which the environmental flow recommendations for Reach 2 are currently being met during wet years.

Component	Months	Flow Recommendation					Or Natural	Achievement
Summer low	Dec - May	Magnitude	80	ML/d			Yes	100%
Summer fresh	Dec - May	Magnitude	350	ML/d			Yes	94%
		Frequency	3	per year				
		Duration	2	days				
Summer high	Apr - May	Magnitude	560	ML/d			Yes	50%
		Frequency	1	per year				
		Duration	7	days				
Winter low	Jun - Nov	Magnitude	350	ML/d			Yes	88%
Winter fresh	Jun - Sep	Magnitude	700	ML/d			Yes	100%
		Frequency	2	per year				
		Duration	7	days				
Winter high	Sep - Sep	Magnitude	700	ML/d			Yes	94%
		Frequency	1	per year				
		Duration	14	days				
Bankfull	Jan - Dec	Magnitude	2700	ML/d			Yes	100%
		Frequency	1	in	2	years		
		Duration	2	days				
Overbank	Jan - Dec	Not recommended						

5. Reach 3: Millgrove to Watts River

5.1. Description

Reach 3 encompasses the upper floodplain reach of the Yarra River between Millgrove and a narrow constriction called the Healesville Gorge near the confluence with the Watts River. Several large tributaries enter this reach including the Little Yarra River and Woori Yallock Creek. The channel meanders across the floodplain, which has been predominantly cleared of vegetation for agricultural production. The 2005 environmental flows assessment site is located at the lower end of the reach at Everard Park. The channel here is a long pool with steep outer banks and a sandy point bar. A billabong is located within the meander that is inundated at flows around bankfull. A second environmental flows assessment site was added to this reach for the current project. The new assessment site is just upstream of the Healesville – Woori Yallock Road, and is upstream of the confluence with Woori Yallock Creek. The channel at the new assessment site has lower banks than Everard Park and more distinct riffle and run habitats. There is also a distinct rock bar feature at the downstream end and a large billabong on the right hand bank that is connected to the river by inlet and outflow channels. Flow in this reach is measured at the Yarra Grange gauge. The Yarra Grange gauge is located downstream of the confluence with the Watts River so adjustments have been made to the daily flow time series by subtracting flows contributed from the Watts River. For compliance purposes a gauge may need to be established upstream of the Watts River confluence.

5.2. Flow recommendations

The general flow objective for Reach 3 is to maintain some variability in the summer low flow period, provide flows to assist Australian Grayling spawning in autumn, increase the duration of bank inundation to limit encroachment of terrestrial vegetation and provide for appropriate bankfull and overbank flows for inundation of billabongs and the floodplain. The environmental flow recommendations for Reach 3 are summarised in Table 5-1.

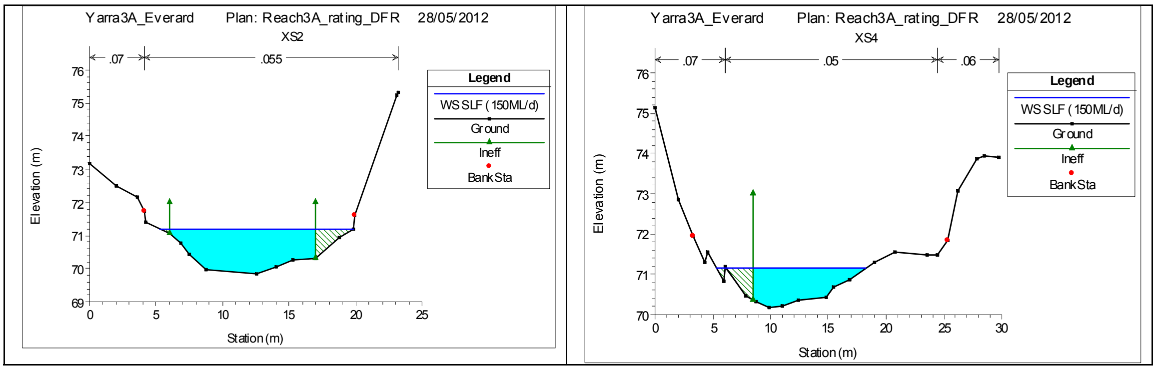
Table 5-1 Flow recommendations for Reach 3.

Stream		Yarra River		Reach	Millgrove to Watts River confluence		
Compliance point		Yarra Grange		Gauge No.	229653		
Season	**Flow**	**Objective (refer to objectives tables for id reference)**	**Wet/Avg/ Dry**	**Volume**	**Frequency and when**	**Duration**	**Rise/Fall**
Summer / Autumn (Dec-May)	Low flow	Maintain access to habitat for bugs & fish, drying period for bank vegetation (M3-1, F3-1, V3-1)	Wet	Minimum recommendation of 120 ML/day at Woori Yallock and 150 ML/day at Everard Park, allow tributaries to provide additional flow above the minimum recommendation in average and wet years. Tributary inflows will contribute to important flow variation.			
			Average				
			Dry				
	Fresh	Maintain suitable riffle and LWD habitat by periodically scouring sediment & biofilms, maintain flood-tolerant vegetation on banks (M3-2, F3-1, V3-2)	Wet	350 ML/day at Woori Yallock and 450 ML/day at Everard Park, tributary inflows provide variation during average and wet years. Higher magnitude and longer duration flows are acceptable and beneficial in average and wet years.	Minimum 3 events delivered + additional events provided by Tributaries.	Min 2 day at peak, additional duration provided by tributaries. Longer duration flows acceptable in average and wet years.	1.4/0.85
			Average				
			Dry	350 ML/day at Woori Yallock and 450 ML/day at Everard Park	3	2	
	High	Trigger downstream migration and spawning by Australian Grayling and transport larvae to sea. (F3-3)	Wet	900-1100 ML/day to ensure minimum flow of 1300 ML/day at Chandler Hwy. Events that exceed the recommendation should be protected through downstream reaches. Higher magnitude and longer duration flows are beneficial in average and wet years.	1 (April/May) every year	Min 7 day at peak and event should last for 14 days from start to finish. Higher and longer duration flows are desirable in average and wet years.	1.4/0.85
			Average				
			Dry	900-1100 ML/day to ensure minimum flow of 1300 ML/day at Chandler Hwy. Larger magnitude flows should be passed and protected through downstream reaches.	1 (April/May). Must occur at least once every three years.		
Winter / spring (Jun-Nov)	Low flow	Maintain access to habitat for bugs & fish & inundate bank vegetatation (M3-1, F3-1, V3-1)	Wet	Minimum recommendation of 350 ML/day, allow tributaries to provide variation above 350 ML/day in average and wet years.			
			Average				
			Dry	Minimum flow 350 ML/day, but may not reach this magnitude until late June or mid July.			
	Fresh	Maintain suitable riffle habitat by periodically scouring sediment & biofilms, maintain flood-tolerant vegetation on banks, provide fish passage, entrain organic material (M3-2, F3-1, V3-2, F3-2)	Wet	1800 ML/day- tributary inflows provide variation during average and wet years. Higher magnitude and longer duration flows are beneficial in average and wet years.	Minimum 2 events between June and September with 1 event occurring in June or July to facilitate migration of Tupong and galaxids.	Min 7 day at peak, additional duration provided by tributaries. Longer duration flows acceptable in average and wet years.	1.4/0.85
			Average				
			Dry				
	High	As per fresh but provides prolonged disturbance to favour flood-tolerant vegetation (G3-3, M3-3, F3-2, V3-3)	Wet	1800 ML/d	Deliver 1 event in October- November but allow to occur naturally at other times.	14 days	1.4/0.85
			Average				

			Dry	Not expected to occur in dry years, but allow to occur naturally.				
	Bankfull	Maintain existing channel geometry & prevent further vegetation encroachment in channel, entrain organic material, deliver water to billabongs via flood-runners (G3-1, M3-3, V3-3)	Wet	4000 ML/day	1 per year but avoid during October and November if possible.	2 days	1.4/0.85
			Average	4000 ML/day	1 per year but avoid during October and November if possible.	2 days	
			Dry	Not expected, but let it occur naturally.			
	Overbank	Engage and provide flow through billabongs and inundate low level floodplains (G3-4, V3-6)	Wet	9000 ML/d	1 event every 1-2 years but avoid during October and November if possible.	1-2 days	1.4/0.85
			Average	Not expected, but let it occur naturally.			
			Dry				

5.2.1. Summer/autumn low flow

The recommended summer low flow at Everard Park is 150 ML/day, which corresponds to a flow of 120 ML/day at the site upstream of Woori Yallock Creek. This flow is unchanged from the 2005 recommendation and is sufficient to inundate the full width of the channel at Everard Park, while allowing low benches to dry (see Figure 5-1). A flow of 120 ML/day at the Woori Yallock site also wets the full width of riffle habitats and provides a minimum depth of 40 cm through the shallowest riffles.



- **Figure 5-1 Stage height in pools (Transect 2, left and Transect 4, right) at the recommended threshold for summer/autumn low flows in Reach 3.**

The recommended low flows are the minimum that is required for this reach. In dry years, flows may remain close to the minimum recommendation throughout most of summer and autumn. However, greater tributary inflows in average and wet years will ensure that summer/autumn flows vary above the recommended minimum most of the time. The flow variation provided by tributary inflows will promote the production of biofilms on submerged logs and rocks and help to maintain productive edge habitats that may be used by macroinvertebrates and small fish. Such variation should be preserved and therefore flows should not be managed down to the minimum levels recommended.

Under current conditions the summer low flow falls below 150 ML/day once every two years for a median duration of three days. Under unimpacted conditions flow fell below the threshold only eight times in 100 years, but the median duration was longer than current.

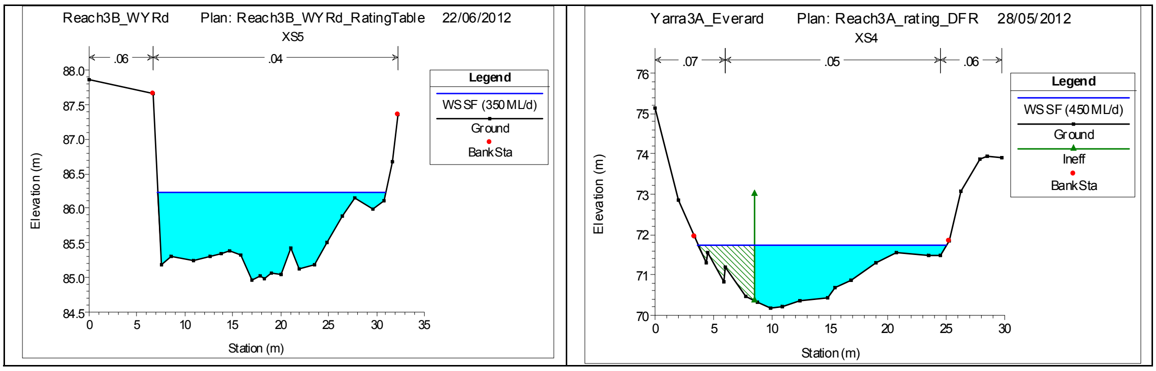
The provision of suitable in-stream habitat is critical to achieving ecological objectives in this reach. A program for reach scale reinstatement of LWD and revegetation of the riparian zone is required. Such a program will complement the gains achieved through the flow recommendations.

5.2.2. Summer/autumn freshes

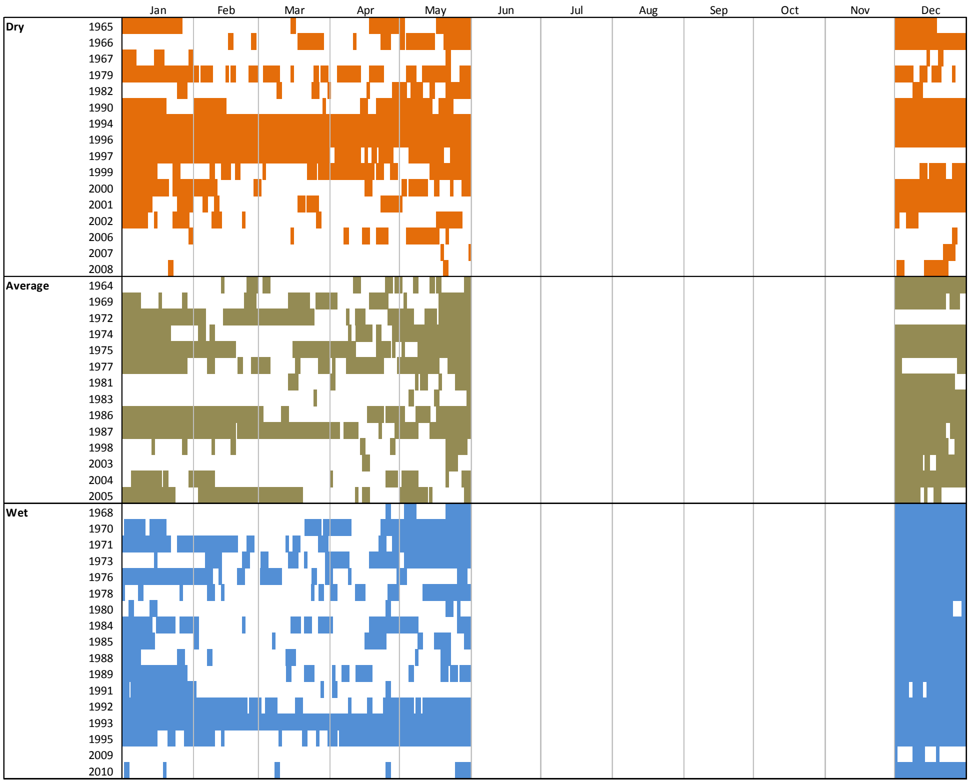
The summer/autumn fresh flow recommendation is 450 ML/day three times per season for two days at Everard Park. The equivalent flow upstream of Woori Yallock Creek will be 350 ML/day. These events may occur more than three times per season and have a larger magnitude and longer duration in average and wet climate years because the catchment will be wetter and run-off will be higher.

The recommended flow is sufficient to inundate low benches in the channel (Figure 5-2), which will help to maintain flood-tolerant vegetation. In particular the recommended flow of 350 ML/day should inundate the low bench at cross section 5 at the Woori Yallock site by approximately 20 cm, which will help promote the growth of *Phragmites*. It will also provide a minimum flow velocity of approximately 40 cm/s, which will help to flush fine sediment that has accumulated on LWD and rock surfaces over the low flow periods and improve quality of habitat for macroinvertebrates.

Under current conditions the summer fresh threshold occurs on average five times per year for a median duration of five days (Figure 5-3), which easily meets the recommendation. Summer freshes in excess of 450 ML/day would occur more frequently under unimpacted conditions (Figure 5-4).



- **Figure 5-2 Stage height in pools (Transect 5 at Woori Yallock Road, left and Transect 4 at Everard Park, right) at the recommended threshold for summer/autumn freshes in Reach 3.**



- **Figure 5-3 Characteristics of summer/autumn fresh flow threshold for current conditions for Reach 3. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**

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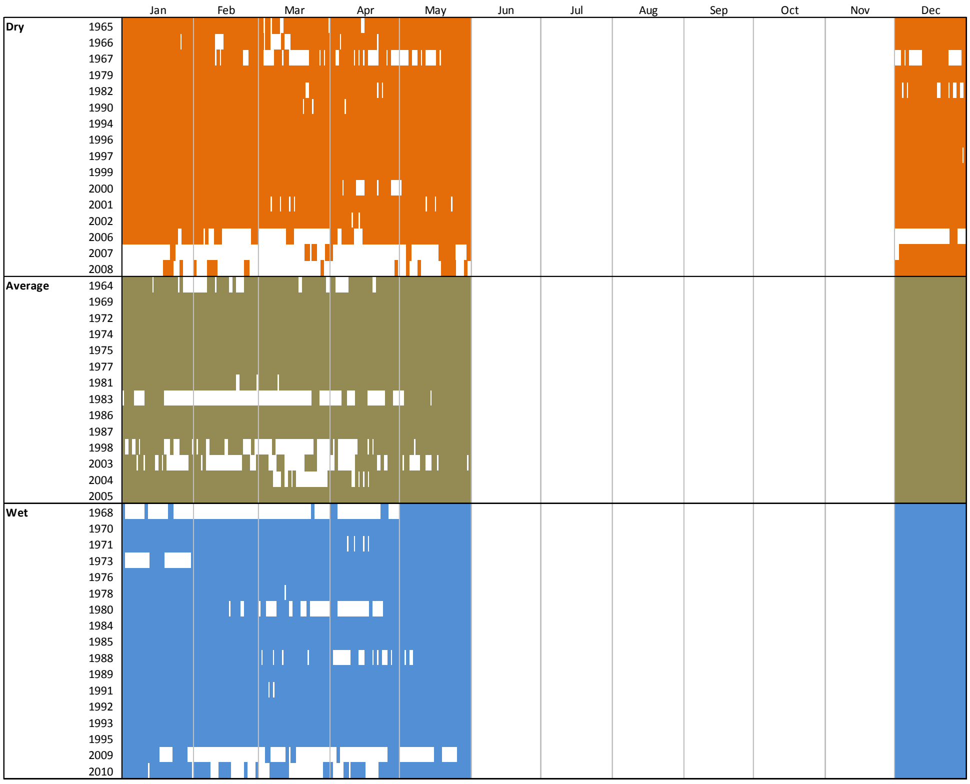


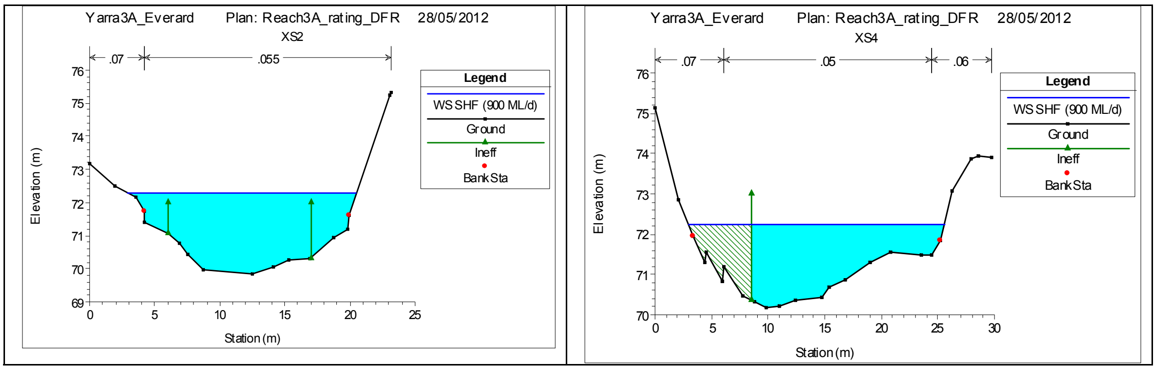
- **Figure 5-4 Characteristics of summer/autumn fresh flow threshold for unimpacted conditions for Reach 3. This plot shows the number and duration of flows above the recommended threshold that have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.**

5.2.3. Summer/autumn high flows

The summer/autumn high flow recommendation for Reach 3 is between 900 and 1100 ML/day. The exact magnitude of the high flow is difficult to determine for this reach, but the objective is to deliver a flow of at least 1300 ML/day downstream in Reach 6 to provide suitable migration and spawning cues for Australian Grayling. These high flows need to occur in April or May to coincide with the Australian Grayling spawning season and the total duration of the event from the start of the rise to the end of the fall should be 14 days to allow enough time for adult Australian Grayling to migrate to the bottom of Reach 6 and spawn. If the event is too short, Australian Grayling are likely to cease their downstream migration and may not spawn (Koster and Dawson, 2011).

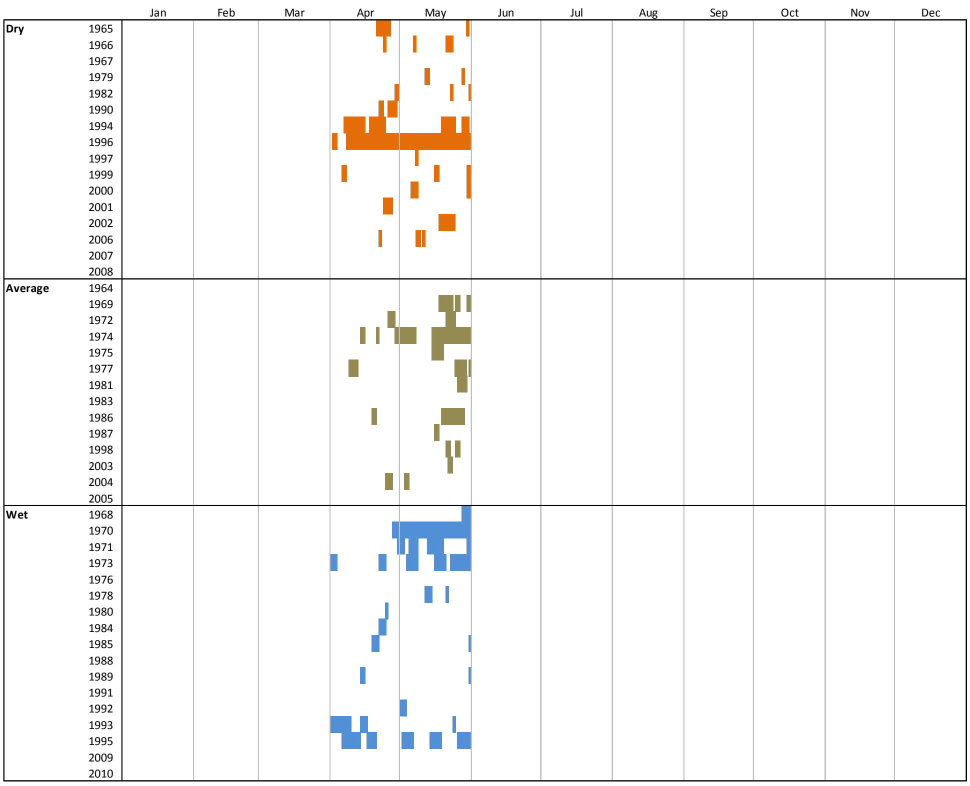
In average and wet climate years, the autumn high flow event is likely to exceed the recommended magnitude. Larger flows are likely to be beneficial to Australian Grayling and therefore should be allowed to pass. These events should occur every year in average and wet climate years. They may not occur in some dry years, but it is important that at least one autumn high flow event is delivered every three years in dry years, because Australian Grayling only live for about three years and will not spawn without the autumn high flow.

While the main objective for the autumn high flow is to promote Australian Grayling recruitment, these flows will also help to maintain flood-tolerant vegetation higher up the banks (Figure 5-5) and control unwanted encroachment by terrestrial vegetation by inundating them during their growing season.

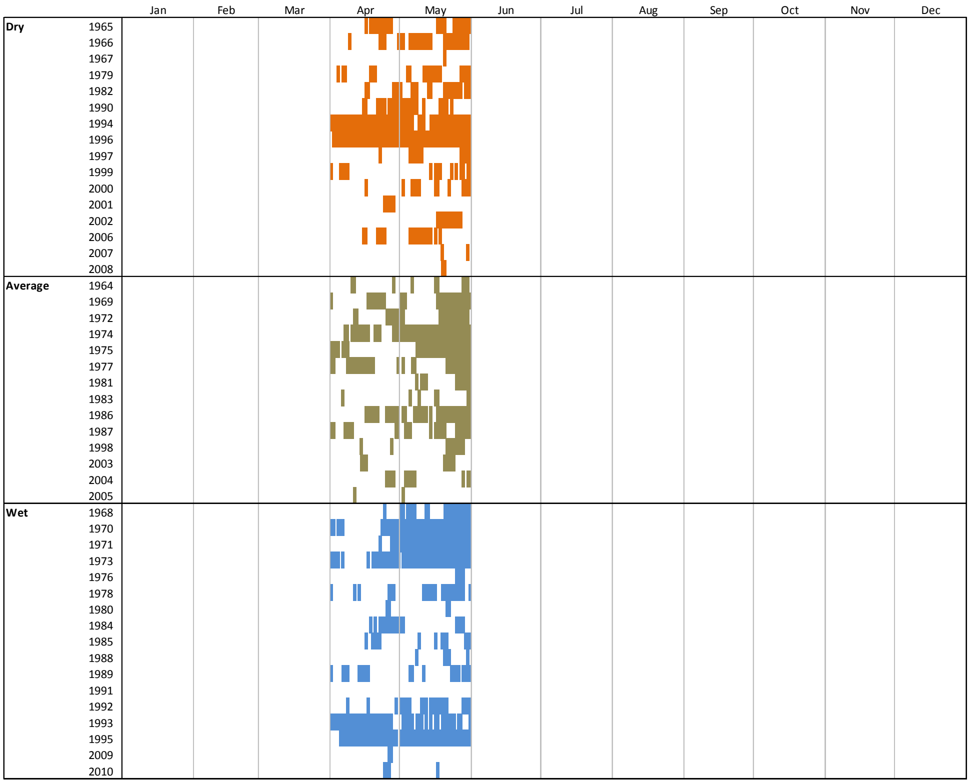


- **Figure 5-5 Stage height in pools (Transect 2, left and Transect 4, right) at the recommended threshold for summer/autumn high flows in Reach 3.**

Under current conditions the autumn high flow event occurs on average once every year and has a median duration of three days (Figure 5-6). Under unimpacted flow conditions, the event would have occurred twice per year on average and had a median duration of four days, although many events lasted much longer (Figure 5-7), which would have increased Australian Grayling spawning rates.



- **Figure 5-6 Characteristics of summer/autumn high flow threshold for current conditions for Reach 3. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**

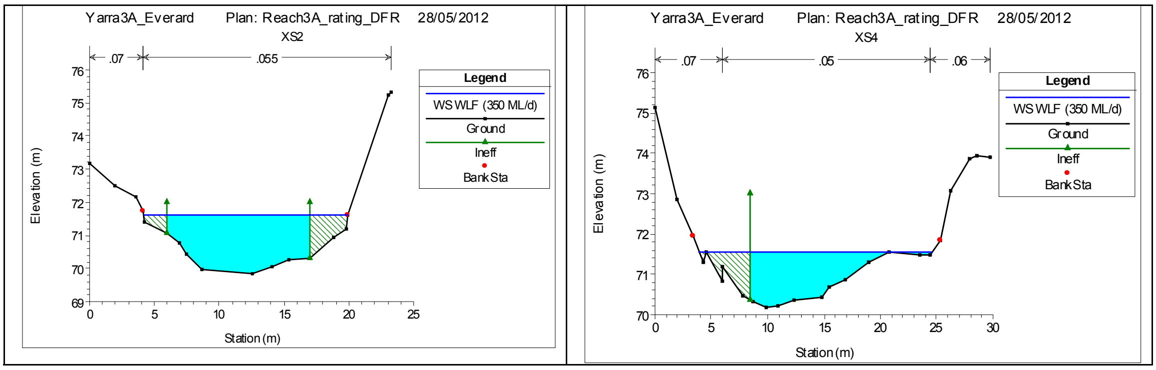


- **Figure 5-7 Characteristics of summer/autumn high flow threshold for unimpacted conditions for Reach 3. This plot shows the number and duration of flows above the recommended threshold that have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.**

5.2.4. Winter/spring low flows

The winter/spring low flow threshold is 350 ML/day. This flow is sufficient to inundate benches in the channel (see Transect 4 in Figure 5-8), which will help to promote flood-tolerant vegetation such as *Phragmites* and deter plants such as the Yellow Flag Iris that prefer stable water levels. The recommended flow of 350 ML/day is considered the minimum and tributary inflows should ensure that winter flows exceed this threshold for most of the time in average and wet climate years. In dry years, flows may not reach 350 ML/day until late June or mid July and may drop below 350 ML/day before the end of November. It is acceptable to mainly consider the period from July to October when determining whether the recommended winter low flow is met in this reach.

Under current conditions flows fall below the recommended winter/spring low flow threshold at least once per year for a median duration of four days; 20% of events that drop below 350 ML/day last for 10-18 days. Most of these events occur in June or November, which emphasises the effect that extractions from upstream reaches have had on shortening duration of the wet (winter/spring) season. Spells below 350 ML/day would rarely have occurred under unimpacted conditions.



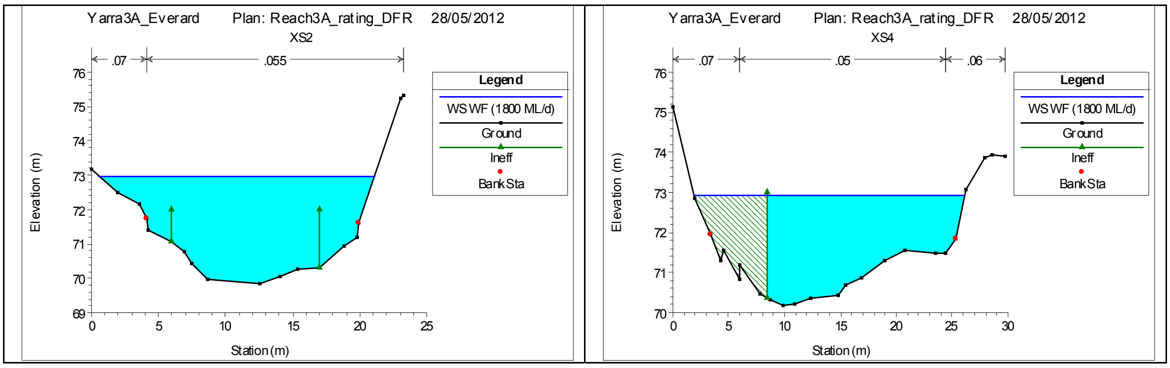
- **Figure 5-8 Stage height in pools (Transect 2, left and Transect 4, right) at the recommended threshold for winter/spring low flows in Reach 3.**

5.2.5. Winter/spring freshes and high flows

The recommended winter/spring fresh threshold is 1800 ML/day. Two events that last for seven days are recommended between June and September, but at least one of these events should occur in June or July to facilitate the downstream migration of adult Tupong and some Galaxid fish that spawn in or near estuaries. The recommended flow is considered sufficient to also scour sediment that has accumulated on LWD and rock substrates and should therefore help prepare spawning sites for Macquarie Perch in reaches further downstream. The fresh will also entrain organic material that has accumulated on the mid and upper banks (e.g. see Transect 2 in Figure 5-9).

A winter high flow event of the same magnitude, but with duration of 14 days, is also recommended for Reach 3. The flow is primarily intended to inundate vegetation on the banks and mid-channel benches during the main growing season to promote flood tolerant species and to minimise the encroachment of unwanted terrestrial vegetation such as blackberry and Wild Watsonia. A prolonged high flow in the spring growing season will also provide unfavourable conditions for the semi-aquatic weed Yellow Flag Iris, which prefers stable conditions during its growing season.

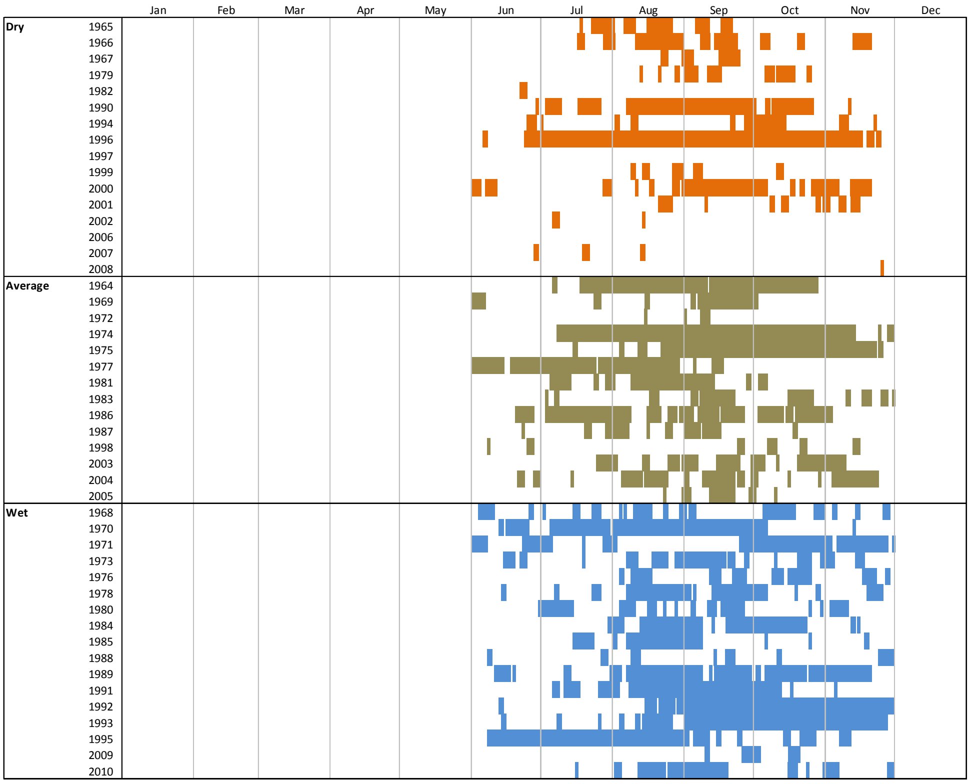
The winter high flow event is recommended for October and November, although its timing should be determined primarily by natural events. Flows in excess of 2500 ML/day at Warrandyte in late October 2009 did not adversely affect Macquarie Perch recruitment (King *et al.*, 2011), and as long as the winter high flow in Reach 3 is not much greater than 2000-2500 ML/day it should meet the objective of controlling vegetation within the channel without disturbing Macquarie Perch eggs or developing larvae. The winter high flow event may not occur in all dry climate years and it is not necessary to deliver it in those years. It is however, expected to occur naturally in most average and all wet climate years (Figure 5-10).



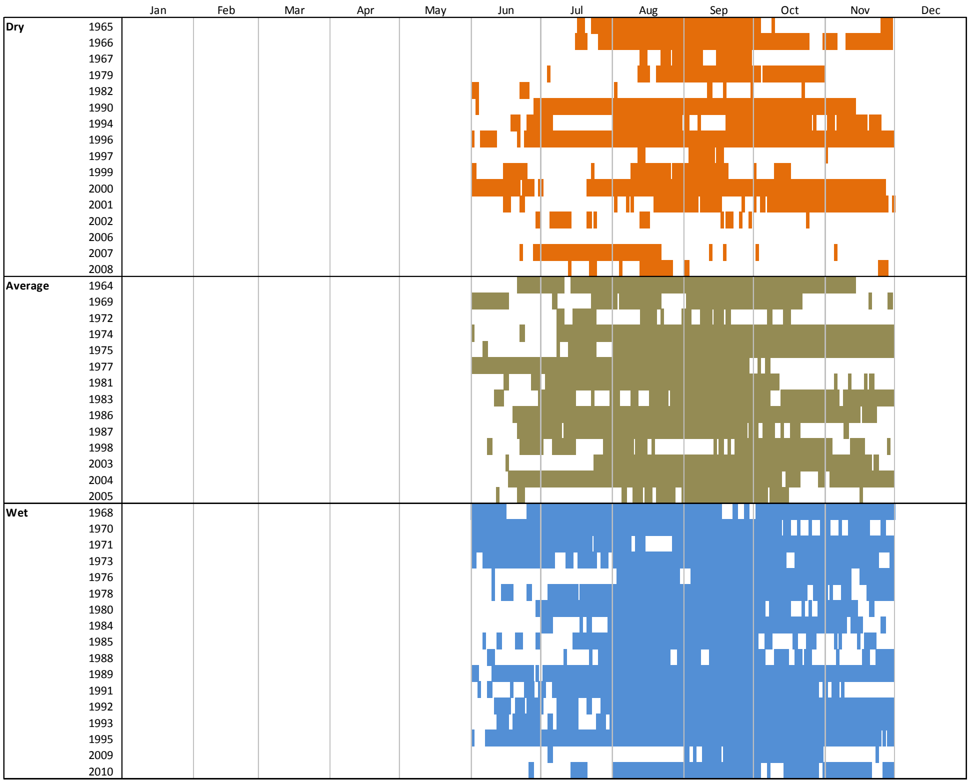
- **Figure 5-9 Stage height in pools (Transect 2, left and Transect 4, right) at the recommended threshold for winter/spring freshes in Reach 3.**

Under current conditions the winter fresh occurs several times per year with short durations (Figure 5-10). Longer duration events are rarer and typically occur between August and October (Figure 5-10). Under unimpacted conditions, flows in excess of 1800 ML/day occurred several times each year and often lasted for many weeks (Figure 5-11).

Under current conditions, the winter high flow, which has a recommended duration of 14 days is met in less than half of the dry climate years, but is met in most wet and average climate years (Figure 5-10). It may be necessary to modify harvesting operations from upstream tributaries or release patterns from the Upper Yarra or O'Shannassy Reservoirs to increase the frequency of these recommended events.



- **Figure 5-10 Characteristics of winter/spring fresh and high flow threshold for current conditions for Reach 3. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**

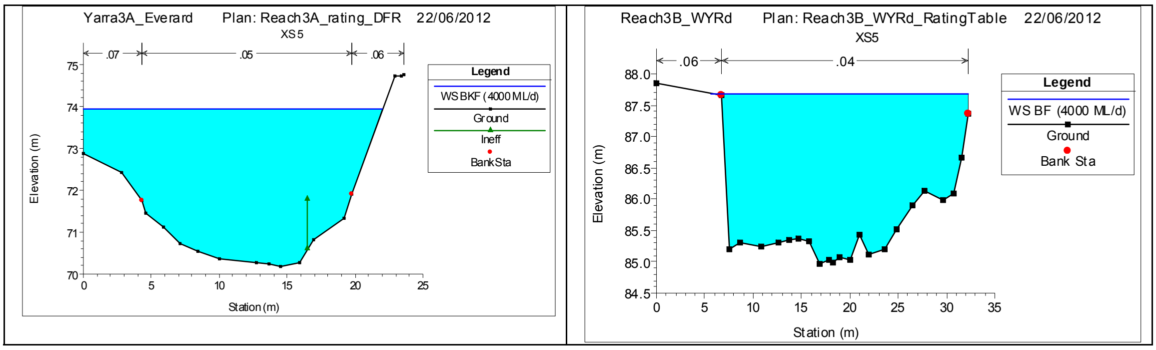


- **Figure 5-11 Characteristics of winter/spring fresh and high flow threshold for unimpacted conditions for Reach 3. This plot shows the number and duration of flows above the recommended threshold that have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.**

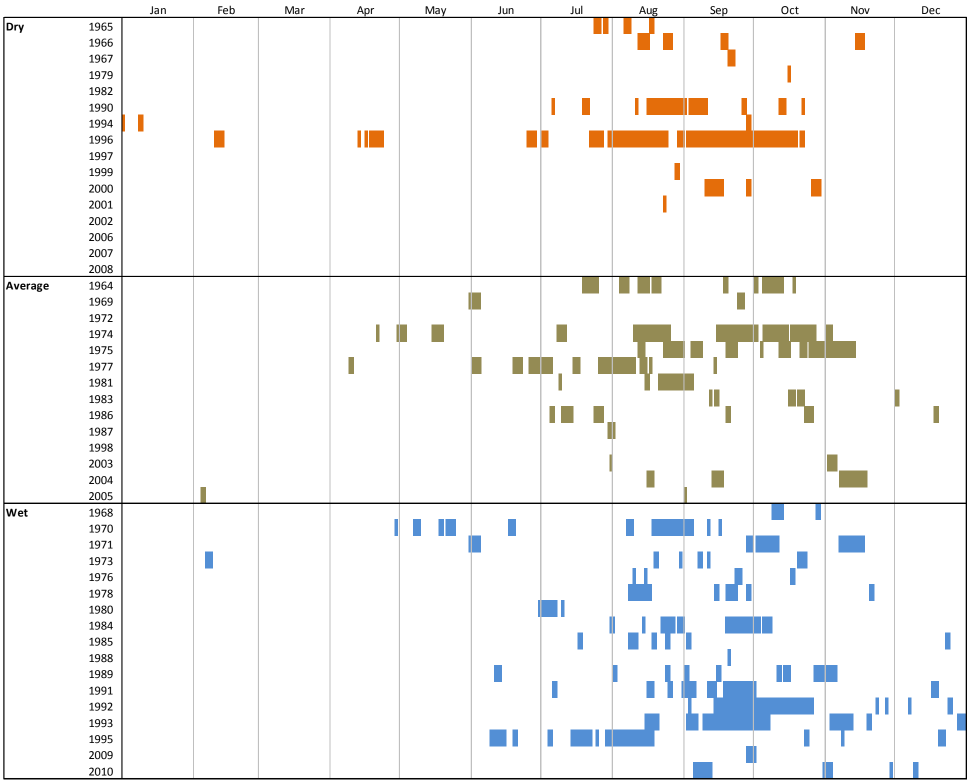
5.2.6. Bankfull flows

A peak annual flow of 4000 ML/day that lasts for 1-2 days should occur in Reach 3 in all but the driest climate years. This flow does not fill the channel, but is sufficient to water billabongs that are directly connected to the river channel via flood runners (Figure 5-12). This was confirmed via direct observation on 22 June 2012 where a flow of 4190 ML/day was delivering water into the billabong at Everard Park via a flood runner at cross section 5. The recommended flow will help to maintain desirable vegetation communities and influence macroinvertebrate community composition within near channel wetlands and billabongs (Robson and Clay, 2005), but it will not provide flow through these wetlands and therefore will not flush sediment and organic material from them.

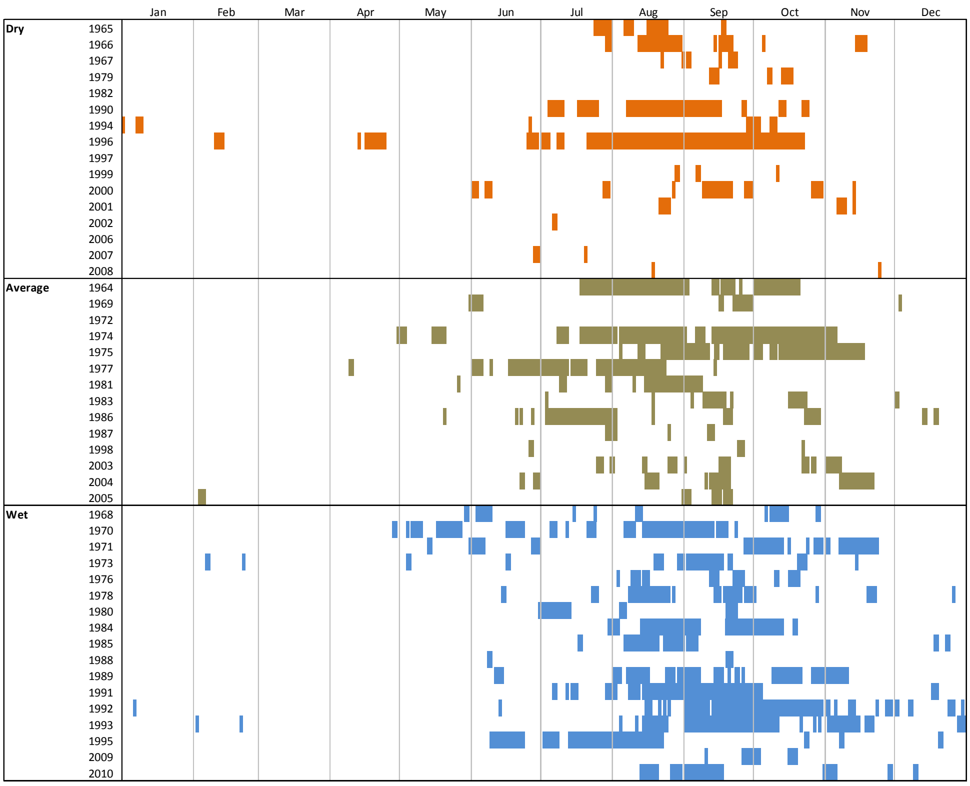
The bankfull flow recommendation is aimed at protecting existing flows when they occur rather than requiring specific releases to be made from storages. Peak flows of approximately 4,000 ML/day occur in most average and wet climate years (Figure 5-13 and Figure 5-14). They are not expected to occur every year during dry climate periods, but they should be allowed to occur naturally and will contribute to downstream flows. While the timing of bankfull flows cannot be controlled, bankfull flows in October and November are not ideal because they are likely to disturb Macquarie Perch eggs and developing larvae in downstream reaches.



- **Figure 5-12 Stage height in pools (Transect 5 at Everard Park, left and Transect 5 at Woori Yallock Road, right) at the recommended threshold for bankfull flows in Reach 3.**



- **Figure 5-13 Characteristics of bank full flow threshold for current conditions for Reach 3. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**

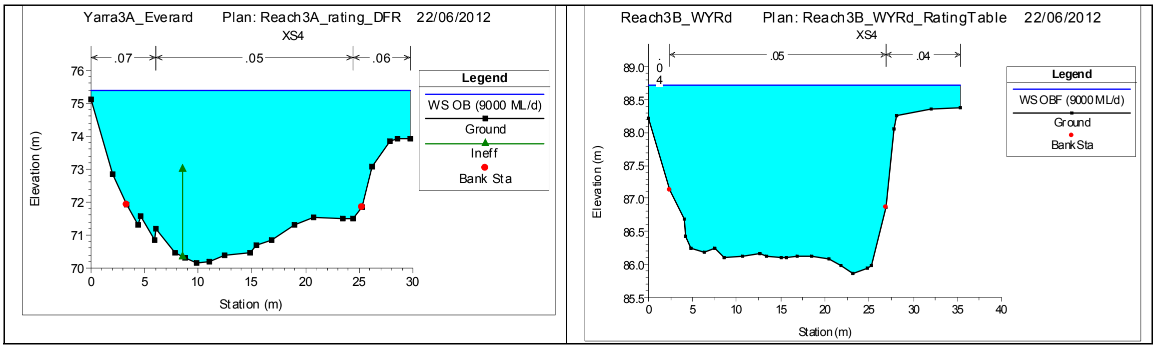


- **Figure 5-14 Characteristics of bank full flow threshold for unimpacted conditions for Reach 3. This plot shows the number and duration of flows above the recommended threshold that have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.**

5.2.7. Overbank flows

An overbank flow of 9000 ML/day with a duration of 1-2 days is recommended every 1-2 years during wet climate years. This flow is approximately 2.3 m higher than the recommended bankfull flow (Figure 5-15) and will maintain current channel geometry by scouring in-channel vegetation and sediment in pools. The overbank flow will inundate wetlands and higher parts of the floodplain not engaged at bankfull flows and will provide a flushing flow through wetlands that will transport sediment and organic material between the river channel and the floodplain.

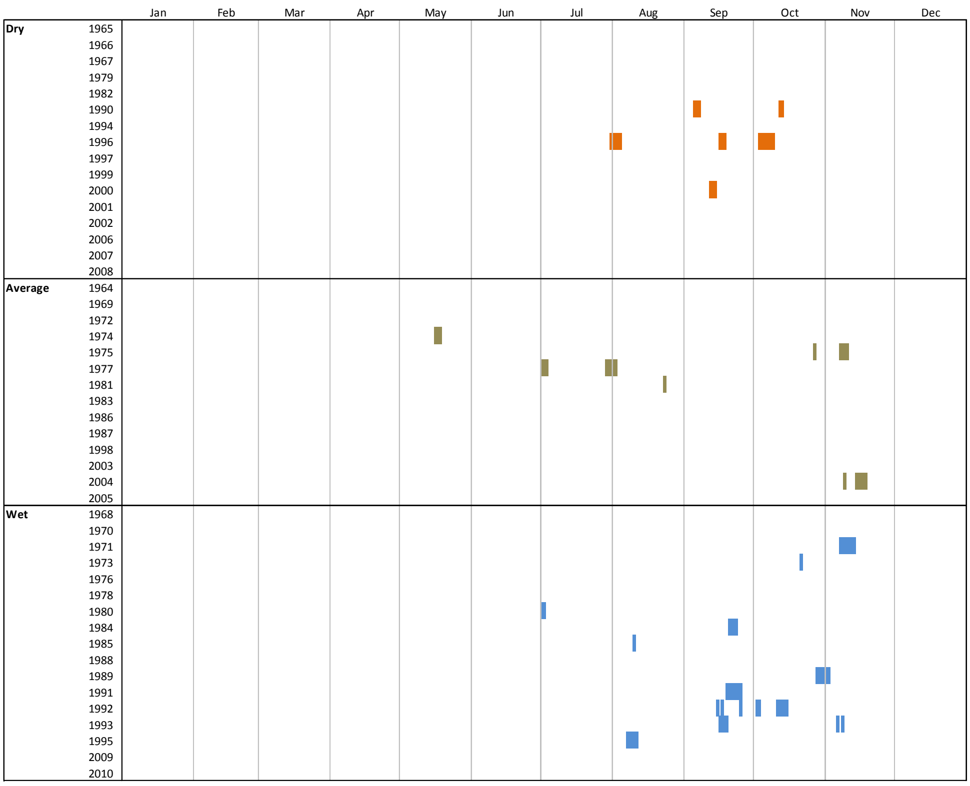
Overbank flows occur rarely during dry or average climate years, but should occur every 1-2 years during wet years (Figure 5-16 and Figure 5-17). Events longer than 1-2 days duration are not recommended because overbank flows longer than four days can kill pasture (Vogel, 1997); however natural overbank flows occasionally last for more than two days.



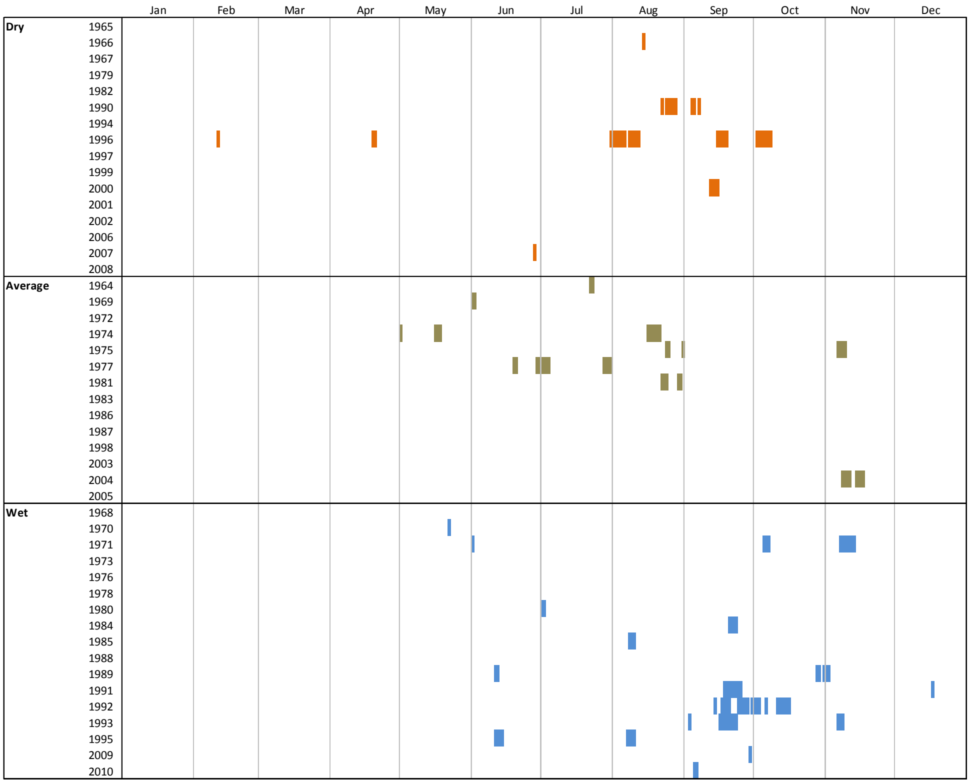
- **Figure 5-15 Stage height in pools (Transect 4 at Everard Park, left and Transect 4 at Woori Yallock Road, right) at the recommended threshold for overbank flows in Reach 3.**

As with the bankfull recommendation, the overbank flow recommendation is aimed at protecting existing flows when they occur rather than requiring specific releases to be made from storages. This will ensure there is no increased risk to pasture production over that which already occurs.

While some ecological benefits of overbank flows will be gained under current landscape conditions (e.g. see Robson and Clay, 2005), the full environmental advantage of both bankfull and overbank flows through this reach will be achieved if parts of the floodplain and some billabongs can be fenced and revegetated with species appropriate for the EVC. Cooperation with landholders is needed to take full advantage of overbank flows and to manage risks to agricultural production.



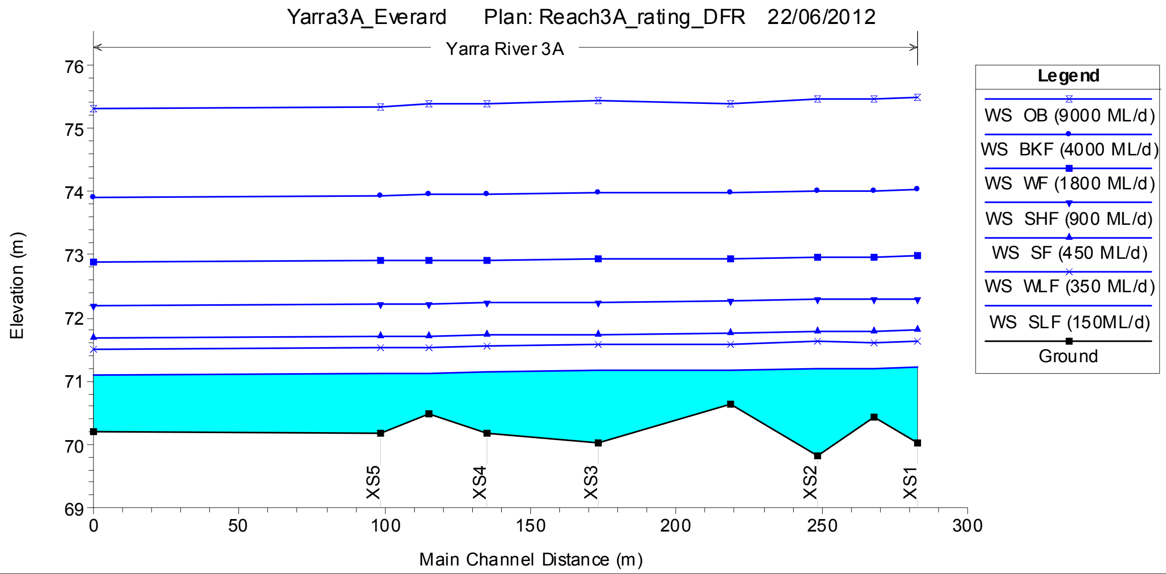
- **Figure 5-16 Characteristics of overbank flow threshold for current conditions for Reach 3. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**



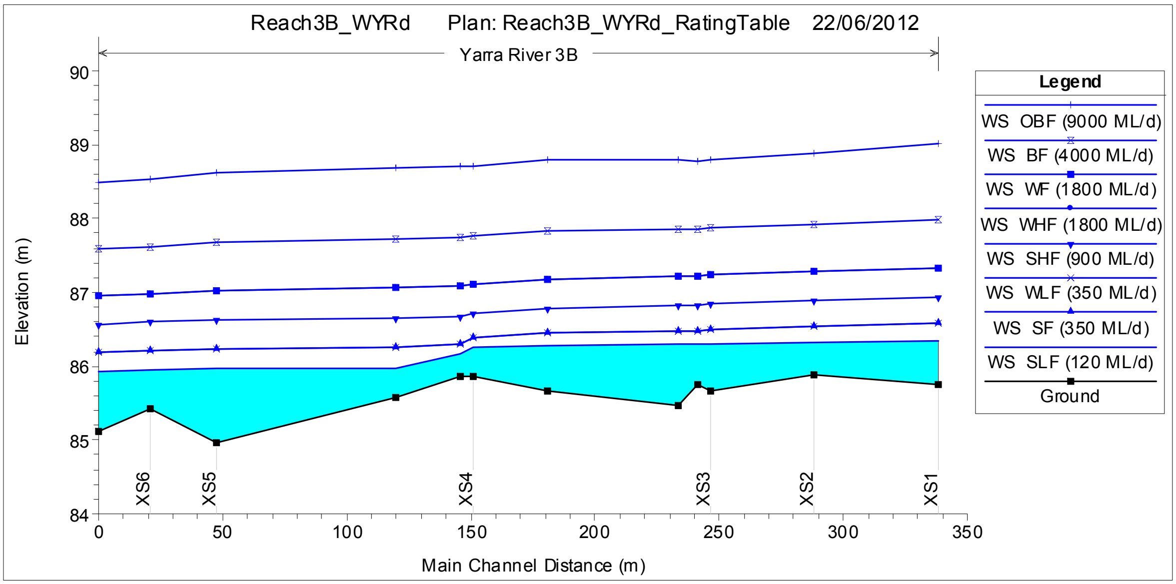
- **Figure 5-17 Characteristics of overbank flow threshold for unimpacted conditions for Reach 3. This plot shows the number and duration of flows above the recommended threshold that have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.**

5.2.8. Long section

A long section profile of Reach 3 at Everard Park shows the depth of water in pools under each flow threshold (Figure 5-18). Figure 5-19 shows the long section of Reach 3 at the site immediately upstream of Woori Yallock Road. The profile for Everard Park highlights the presence of long, uniform pools that characterise the lower half of Reach 3. Flow components such as freshes and high flows increase the depth of pool habitats and progressively wet higher sections of the bank, but there are relatively few riffles where small increases in flow are likely to have more pronounced effects.



- **Figure 5-18 Long section showing water surface level for all flows at Everard Park in Reach 3.**



- **Figure 5-19 Long section showing water surface level for all flows at Woori Yallock Road in Reach 3.**

5.2.9. Current achievement of flow recommendations

An assessment of how well the flow recommendations for Reach 3 are currently met in wet, average and dry years is presented in Table 5-2, Table 5-3 and Table 5-4. It should be noted that these assessments include an 'or natural' clause, which considers the flows that would have occurred in Reach 3 in wet, dry and average years under unimpacted conditions. For example, if the hydrological analysis shows that the recommended winter high flow would only occur in 25 out of 30 years in average years then the level of achievement is based on how many of those 25 events are delivered under the current level of development and system operation.

The summer and winter low flow recommendations and the summer fresh recommendations for Reach 3 are currently met nearly 100% of the time in wet and average years, and approximately 90% of the time in dry years. Slight adjustments to flow release patterns from upstream storages in a small proportion of dry years would ensure that these recommended flows would be achieved nearly all of the time.

The recommended summer high flow is met 63% of the time in wet and average years and 81% of the time in dry years. The higher achievement in dry years, does not indicate that more of these events occur in dry years (Summer high flows would only be expected to occur naturally in 4 out of the 30 dry climate years considered in this assessment, but would naturally occur in 14 out of the 30 wet years considered). Rather it indicates that a higher proportion of the flows that would naturally occur are still observed. It is important that summer high flows are delivered in most wet and average climate years and extra releases may need to be made from upstream storages to achieve those recommendations. The 81% achievement in dry years is likely to be sufficient, provided at least one event occurs every three years.

The recommended winter fresh is achieved 88% of the time in wet years, 69% of the time in average years and 50% of the time in dry years. Extra releases may need to be made in average and dry climate years to deliver the recommended winter fresh flows and increase flow variability.

The recommended winter high flow is achieved 56% of the time in wet years and 69% of the time in average years. Winter high flows would naturally occur more often in wet years than average years, but the current operation of the upstream reservoirs and farm dams in the catchment reduce the magnitude and/or duration of those events in wet years. In average climate years, 69% of the winter high flows that would naturally occur in Reach 3 are relatively unaffected by current reservoir operations and other harvesting actions.

Most of the recommended bankfull flows occur in wet and average years and most of the recommended overbank flows occur in wet years. It is impractical and probably undesirable from a social and economic perspective to actively deliver more frequent bankfull and overbank floods. Bankfull and Overbank flow recommendations for Reach 3 should continue to be met through protecting existing events when they occur rather than through specific flow releases.

In summary, most of the low flow and small fresh recommendations are met in wet and average climate years. Small adjustments to release rates from upstream storages are likely to deliver all of the low flow and summer fresh recommendations in dry years. Other releases may also be needed to increase the number of summer and winter high flows that are delivered. In particular, it will be essential to ensure that the recommended summer high flow is delivered in most wet and average years and at least once every three years in dry conditions. The relatively low proportion of summer high flow, winter fresh and winter high flow events that currently occur in this reach in all climate years limits the ability to achieve objectives related to Australian Grayling spawning and encroachment of terrestrial vegetation on the upper banks.

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Table 5-2 Extent to which the environmental flow recommendations for Reach 3 are currently being met during dry years.

Component	Months	Flow Recommendation			Or Natural	Achievement
Summer low	Dec - May	Magnitude	**150**	ML/d	**Yes**	*92%*
Summer fresh	Dec - May	Magnitude	**450**	ML/d	**Yes**	*88%*
		Frequency	**3**	per year		
		Duration	**2**	days		
Summer high	Apr - May	Magnitude	**1100**	ML/d	**Yes**	*81%*
		Frequency	**1**	per year		
		Duration	**7**	days		
Winter low	Jun - Nov	Magnitude	**350**	ML/d	**Yes**	*88%*
Winter fresh	Jun - Sep	Magnitude	**1800**	ML/d	**Yes**	*50%*
		Frequency	**2**	per year		
		Duration	**7**	days		
Winter high	Oct - Nov	Not expected, but allow to occur naturally				
Bankfull	Jan - Dec	Not expected, but allow to occur naturally				
Overbank	Jan - Dec	Not expected, but allow to occur naturally				

Table 5-3 Extent to which the environmental flow recommendations for Reach 3 are currently being met during average years.

Component	Months	Flow Recommendation			Or Natural	Achievement
Summer low	Dec - May	Magnitude	**150**	ML/d	**Yes**	*100%*
Summer fresh	Dec - May	Magnitude	**450**	ML/d	**Yes**	*100%*
		Frequency	**3**	per year		
		Duration	**2**	days		
Summer high	Apr - May	Magnitude	**1100**	ML/d	**Yes**	*63%*
		Frequency	**1**	per year		
		Duration	**7**	days		
Winter low	Jun - Nov	Magnitude	**350**	ML/d	**Yes**	*99%*
Winter fresh	Jun - Sep	Magnitude	**1800**	ML/d	**Yes**	*69%*
		Frequency	**2**	per year		
		Duration	**7**	days		
Winter high	Oct - Nov	Magnitude	**1800**	ML/d	**Yes**	*69%*
		Frequency	**1**	per year		
		Duration	**14**	days		
Bankfull	Jan - Dec	Magnitude	**4000**	ML/d	**Yes**	*87%*
		Frequency	**1**	in **1** years		
		Duration	**2**	days		
Overbank	Jan - Dec	Not expected, but allow to occur naturally				

Table 5-4 Extent to which the environmental flow recommendations for Reach 3 are currently being met during wet years.

Component	Months	Flow Recommendation					Or Natural	Achievement
Summer low	Dec - May	Magnitude	**150**	ML/d			**Yes**	*100%*
Summer fresh	Dec - May	Magnitude	**450**	ML/d			**Yes**	*100%*
		Frequency	**3**	per year				
		Duration	**2**	days				
Summer high	Apr - May	Magnitude	**1100**	ML/d			**Yes**	*63%*
		Frequency	**1**	per year				
		Duration	**7**	days				
Winter low	Jun - Nov	Magnitude	**350**	ML/d			**Yes**	*99%*
Winter fresh	Jun - Sep	Magnitude	**1800**	ML/d			**Yes**	*88%*
		Frequency	**2**	per year				
		Duration	**7**	days				
Winter high	Oct - Nov	Magnitude	**1800**	ML/d			**Yes**	*56%*
		Frequency	**1**	per year				
		Duration	**14**	days				
Bankfull	Jan - Dec	Magnitude	**4000**	ML/d			**Yes**	*93%*
		Frequency	**1**	in	**1**	years		
		Duration	**2**	days				
Overbank	Jan - Dec	Magnitude	**9000**	ML/d			**Yes**	*90%*
		Frequency	**1**	in	**1**	years		
		Duration	**2**	days				

6. Reach 4: Watts River to Yering Gorge

6.1. Description

Reach 4 encompasses the middle floodplain reach of the Yarra River between the Watts River confluence and the top of Yering Gorge downstream of Yarra Glen. The Watts River and several small tributaries including the Pauls, Steels, Dixons and Olinda Creeks enter this reach. The channel meanders across the floodplain, which has been predominantly cleared of vegetation for agricultural production. The environmental flows assessment site is located in the mid section of the reach at Tarrawarra. The channel here is a long pool with steep outer banks and a sandy point bar. Many billabongs and floodplain depressions are located along both sides of the river through this reach, although most have been cleared for pasture production and levee banks exist along sections of the river. Flow compliance in this reach is measured at the Yarra Glen gauge.

6.2. Flow recommendations

General objective is to maintain some variability in the summer low flow period, provide flows to assist Australian Grayling spawning in autumn and Macquarie Perch recruitment in spring, increase the vertical range and duration of bank inundation to limit growth of terrestrial species and provide appropriate bankfull and overbank flows to inundate billabongs and the floodplain.

The environmental flow recommendations for Reach 4 are summarised in Table 6-1.

Table 6-1 Flow recommendations for Reach 4.

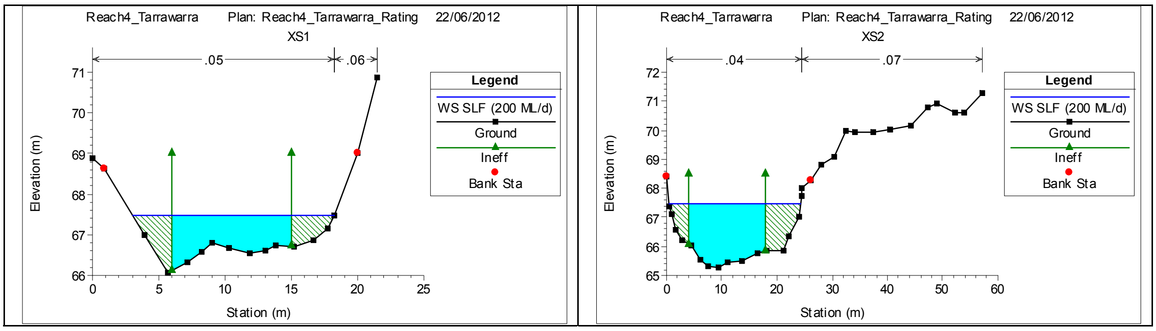
Stream		Yarra River		Reach	Watts River to Yering Gorge		
Compliance point		Yarra Glen		Gauge No.	229206		
Season	**Flow**	**Objective (refer to objectives tables for id reference)**	**Wet/Avg/ Dry**	**Volume**	**Frequency and when**	**Duration**	**Rise/Fall**
Summer / Autumn (Dec-May)	Low flow	Maintain access to habitat for bugs & fish, drying period for bank vegetation (M4-1, F4-1, V4-1)	Wet	Minimum flow of 200 ML/day, allow tributaries to provide variation above 200 ML/day in average and wet years.			
			Average				
			Dry				
	Fresh	Maintain suitable riffle and LWD habitat by periodically scouring sediment & biofilms, maintain flood-tolerant vegetation on banks and provide opportunities for local fish movement (M4-2, F4-1, V4-3)	Wet	Minimum of 450 ML/day, tributary inflows provide variation during average and wet years. Higher magnitude and longer duration flows are beneficial in average and wet years.	Minimum 3 events delivered + additional events provided by tributaries.	Min 2 day at peak, additional duration provided by tributaries. Longer duration flows acceptable in average and wet years.	1.4/0.85
			Average				
			Dry	450 ML/d	3	2	
	High	Trigger downstream migration and spawning by Australian Grayling and transport larvae to sea. (F4-3)	Wet	900-1100 ML/day to ensure minimum flow of 1300 ML/day at Chandler Hwy. Events that exceed the recommendation should be protected through downstream reaches.	1 (April/May) every year	Min 7 day at peak and event should last for 14 days from start to finish. Higher and longer duration flows are desirable in average and wet years.	1.4/0.85
			Average				
			Dry	900-1100 ML/day to ensure minimum flow of 1300 ML/day at Chandler Hwy. Larger magnitude flows should be passed and protected through downstream reaches.	1 (April/May). Must occur at least once every three years.		
Winter / spring (Jun-Nov)	Low flow	Maintain access to habitat for bugs & fish & inundate bank vegetatation (M4-1, F4-1, V4-1, V4-2)	Wet	Minimum recommendation of 350 ML/day, allow tributaries to provide additional variation above 350 ML/day in average and wet years.			
			Average				
			Dry	Minimum flow 350 ML/day, but may not reach this magnitude until late June or mid July.			
	Fresh	Maintain suitable riffle habitat by periodically scouring sediment & biofilms, maintain flood-tolerant vegetation on banks, provide fish passage, entrain organic material (M4-2, F4-1, F4-4, V4-3)	Wet	2000 ML/day- tributary inflows provide variation during average and wet years. Higher magnitude and longer duration flows are acceptable and likely to be beneficial in average and wet years.	Minimum 2 events between June and September with 1 event occurring in June or July to facilitate migration of Tupong and galaxids.	Min 7 day at peak, additional duration provided by tributaries. Longer duration flows acceptable in average and wet years.	1.4/0.85
			Average				
			Dry				
	High	As per fresh but provides prolonged disturbance to favour flood-tolerant vegetation (M4-2, F4-1, F4-4, V4-3, V4-4)	Wet	2000 ML/d	Deliver 1 event in October- November but allow to occur naturally at other times.	14 days	1.4/0.85
			Average				
			Dry	Not expected to occur in dry years, but allow to occur naturally.			

	Bankfull	Maintain existing channel geometry & prevent further vegetation encroachment in channel, entrain organic material, deliver water to billabongs via flood-runners (G4-1, G4-3, V4-4, V4-5, V4-6)	Wet	5000 ML/day	2-3 per year	2 days	1.4/0.85
			Average	5000 ML/day	1-2 per year	2 days	
			Dry	Not expected, but let it occur naturally.			
	Overbank	Engage and provide flow through billabongs and inundate low level floodplains (G4-4, V4-5, V4-6)	Wet	10,000 ML/d	Every 1-2 years but avoid during October and November if possible.	1-2 days	1.4/0.85
			Average	Not expected, but let it occur naturally.			
			Dry				

The rationale for flow recommendations in Reach 4 are the same as those in Reach 3 however the volumes have been adjusted where necessary to account for larger channel capacity. To avoid repetition the following sections only briefly describe major points associated with flow recommendations in this reach.

6.2.1. Summer/autumn low flows

The summer/autumn minimum low flow recommendation is 200 ML/day. This flow is sufficient to wet the full width of the lower channel, provide suitable pool depth for fish and inundate LWD located low in the channel (Figure 6-1). In average and wet climate years the minimum summer low flow is expected to be higher and more variable due to tributary inflows.

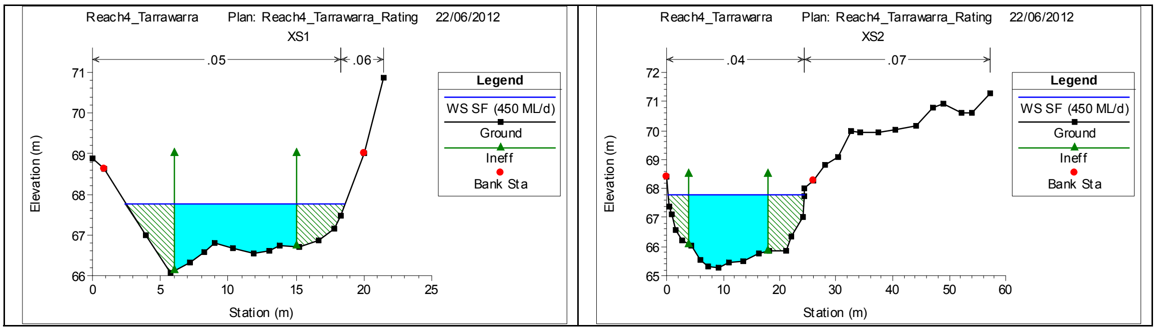


- **Figure 6-1 Stage height in pools (Transect 1, left and Transect 2, right) at the recommended threshold for summer/autumn low flows in Reach 4.**

Under current conditions summer flows fall below the low flow threshold once per year for a median duration of five days. Under unimpacted conditions the flow would have rarely fallen below the low flow recommendation.

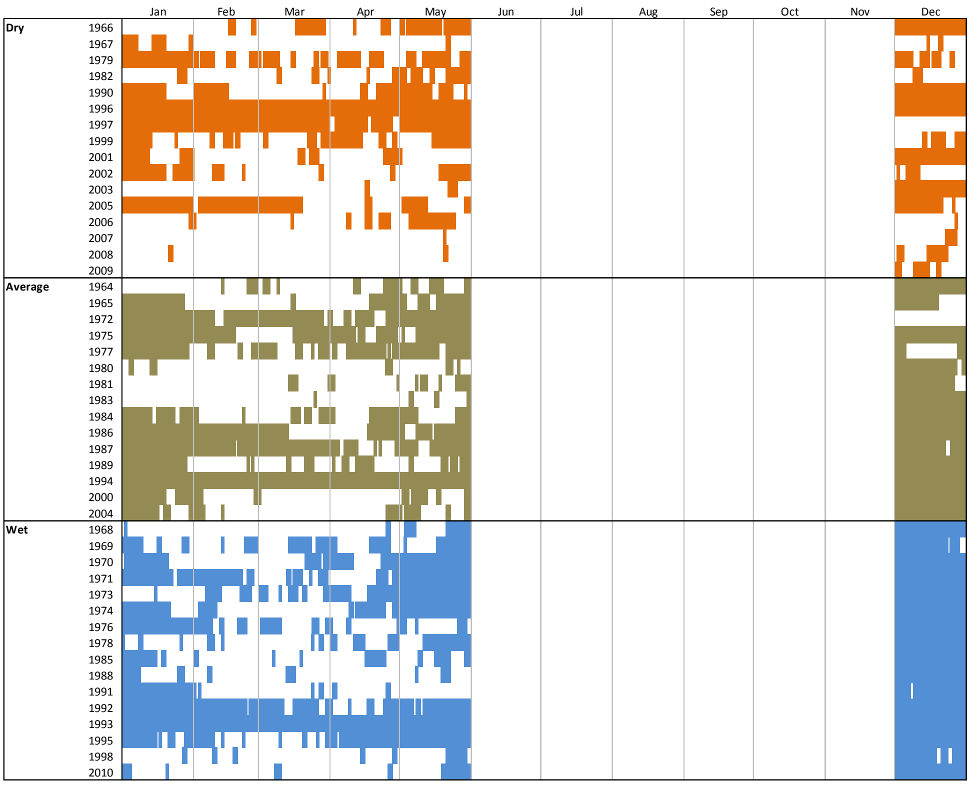
6.2.2. Summer/autumn freshes

The summer/autumn fresh recommendation is 450 ML/day. This flow wets the lower banks and inundates LWD and low level benches (see Transect 2 in Figure 6-2). Three summer/autumn freshes should occur in dry years and they should last for two days. More than three freshes are likely to occur in some average and most wet climate years and they may also last more than two days.



- **Figure 6-2 Stage height in pools (Transect 1, left and Transect 2, right) at the recommended threshold for summer/autumn fresh in Reach 4.**

Under current conditions the summer/autumn fresh occurs less frequently than under unimpacted conditions (Figure 6-3 and Figure 6-4). Under current conditions most events start in December, January or May, rather than mid-summer. This suggests that under current conditions events that exceed the fresh threshold occur in association with late spring or autumn rainfall events. Some operational intervention may be required to deliver freshes at other times to improve flow variation throughout summer and reduce the duration of prolonged low flow periods.



- **Figure 6-3 Characteristics of summer/autumn fresh flow threshold for current conditions for Reach 4. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**

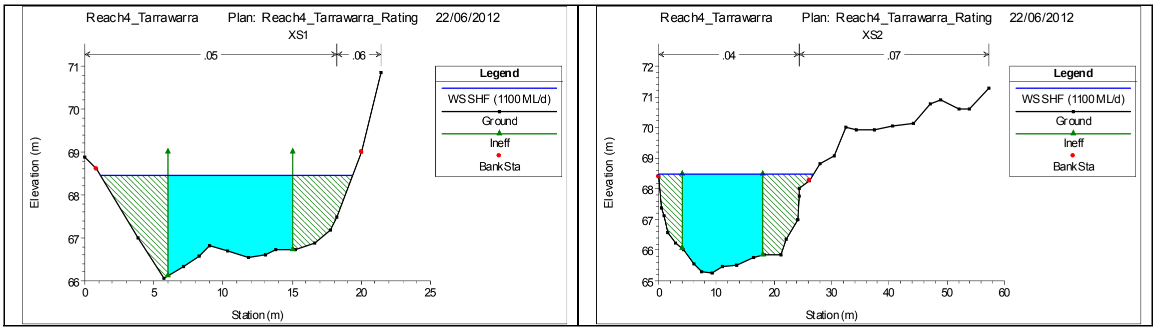
- **Figure 6-4 Characteristics of summer/autumn fresh flow threshold for unimpacted conditions for Reach 4. This plot shows the number and duration of flows above the recommended threshold that would have occurred under a unimpacted flow regime in each dry, wet and average climate year since 1964.**

6.2.3. Summer/autumn high flows

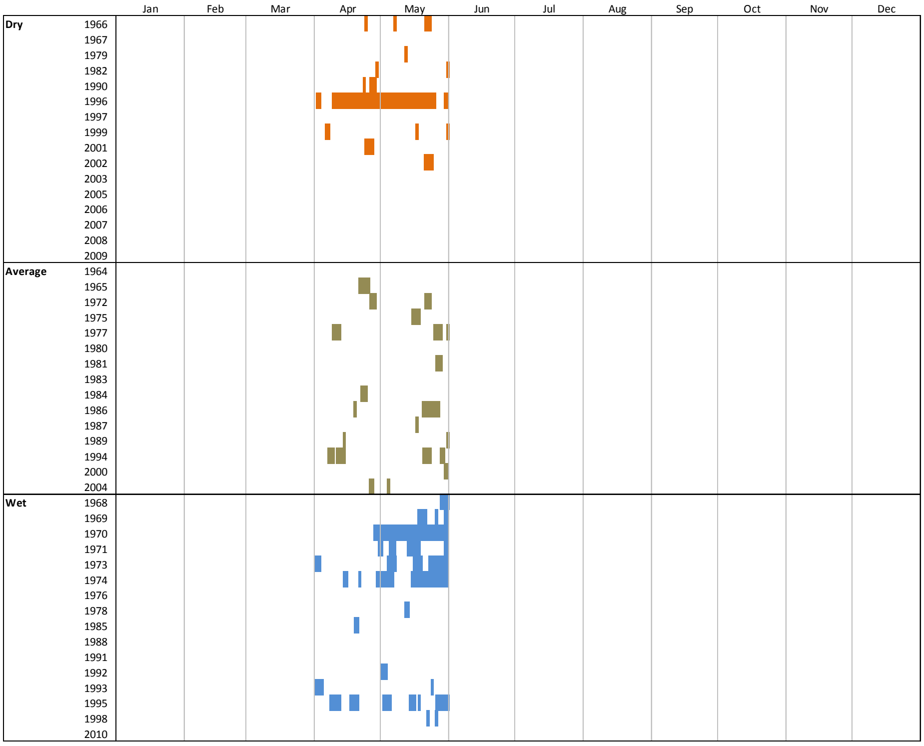
The summer/autumn high flow recommendation is between 900 and 1100 ML/day. The exact magnitude of the high flow is difficult to determine for this reach, but the objective is to deliver a flow of at least 1300 ML/day downstream in Reach 6 to provide suitable migration and spawning cues for Australian Grayling (Koster and Dawson, 2011). These high flows need to occur in April or May to coincide with the Australian Grayling spawning season and the total duration of the event from the start of the rise to the end of the fall should be 14 days to allow enough time for adult Australian Grayling to migrate to the bottom of Reach 6 and spawn. This flow also wets further up the banks (Figure 6-5) to maintain flood-tolerant vegetation and provide a disturbance to terrestrial vegetation.

In average and wet climate years, the autumn high flow event is likely to exceed the recommended magnitude. Larger flows are likely to be beneficial to Australian Grayling and therefore should be allowed to pass. These events should occur every year in average and wet climate years. They may not occur in some dry years, but it is important that at least one autumn high flow event is delivered every three years in dry years, because Australian Grayling only live for about three years, and will not spawn without the autumn high flow (Koster and Dawson, 2011).

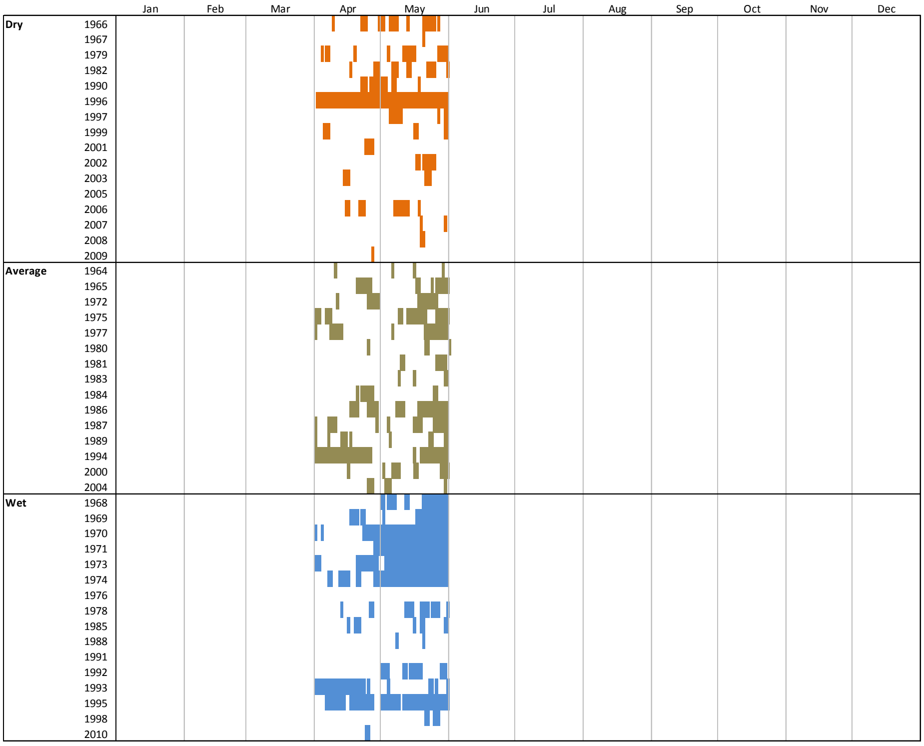
Under current conditions the summer high flow threshold is exceeded 1-2 times per year, although they would have occurred more frequently under unimpacted conditions (Figure 6-6 and Figure 6-7). Many high flow events under both current and unimpacted conditions do not exceed the recommended seven day duration. However, the events typically lasted longer under unimpacted conditions and therefore it may be reasonable to use releases from upstream storages to extend the duration of current high flow vents. If flows of this magnitude and duration do not occur during April or May there is a significant risk to spawning opportunities for Australian Grayling because they are a short lived species and frequent spawning events are required to maintain the population.



- **Figure 6-5 Stage height in pools (Transect 1, left and Transect 4, right) at the recommended threshold for summer/autumn low flows in Reach 4.**



- **Figure 6-6 Characteristics of summer/autumn high flow threshold for current conditions for Reach 4. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**



- **Figure 6-7 Characteristics of summer/autumn high flow threshold for unimpacted conditions for Reach 4. This plot shows the number and duration of flows above the recommended threshold that would have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.**

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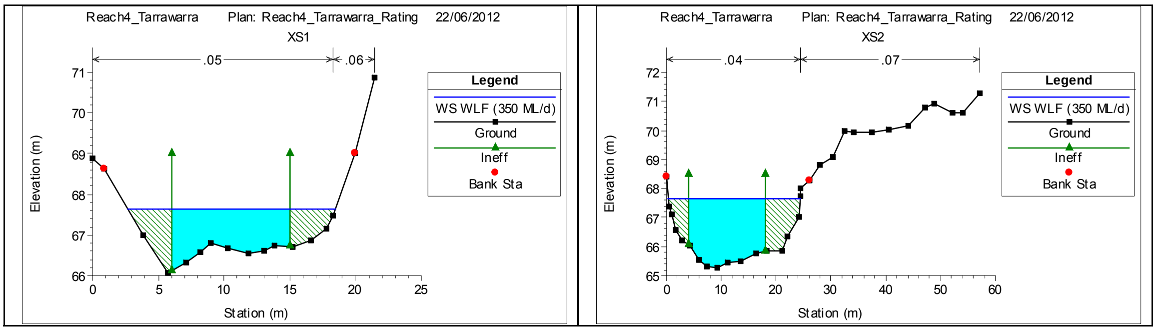
6.2.4. Winter/spring low flows

The recommended winter/spring low flow threshold is 350 ML/day. This flow is sufficient to wet the full width of the channel and lower banks (Figure 6-8). In spring these flows will help promote flood-tolerant vegetation such as *Phragmites* and deter plants such as the Yellow Flag Iris that prefer stable water levels. The recommended flow magnitude is the same as for upstream reaches even though the channel capacity is higher. The EFTP concluded that larger low flows do not significantly increase pool depth or provide access to additional habitat.

The recommended flow of 350 ML/day is considered the minimum and tributary inflows should ensure that winter flows exceed this threshold for most of the time in average and wet climate years. In dry years, flows may not reach 350 ML/day until late June or mid July and may drop below this level before the end of November. Shorter winter/spring flow seasons are not likely to be a problem if they only occur in the dry years, as long as larger flows extend well into November, (which is an important time for vegetation growth), in wet and average years.

Under current conditions flows occasionally fall below the winter low flow threshold, most often in June indicating that the summer/autumn low flow period has been prolonged under current conditions. Under unimpacted conditions flow would not have fallen below the winter low flow threshold.

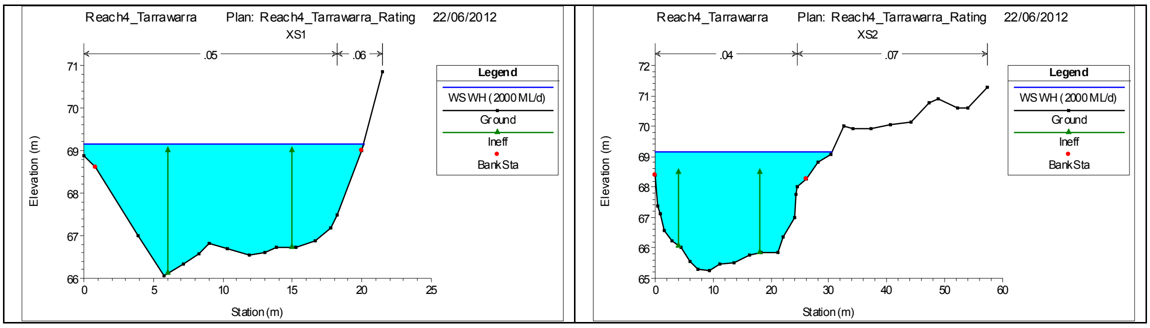


- **Figure 6-8 Stage height in pools (Transect 1, left and Transect 2, right) at the recommended threshold for winter/spring low flows in Reach 4.**

6.2.5. Winter/spring freshes and high flows

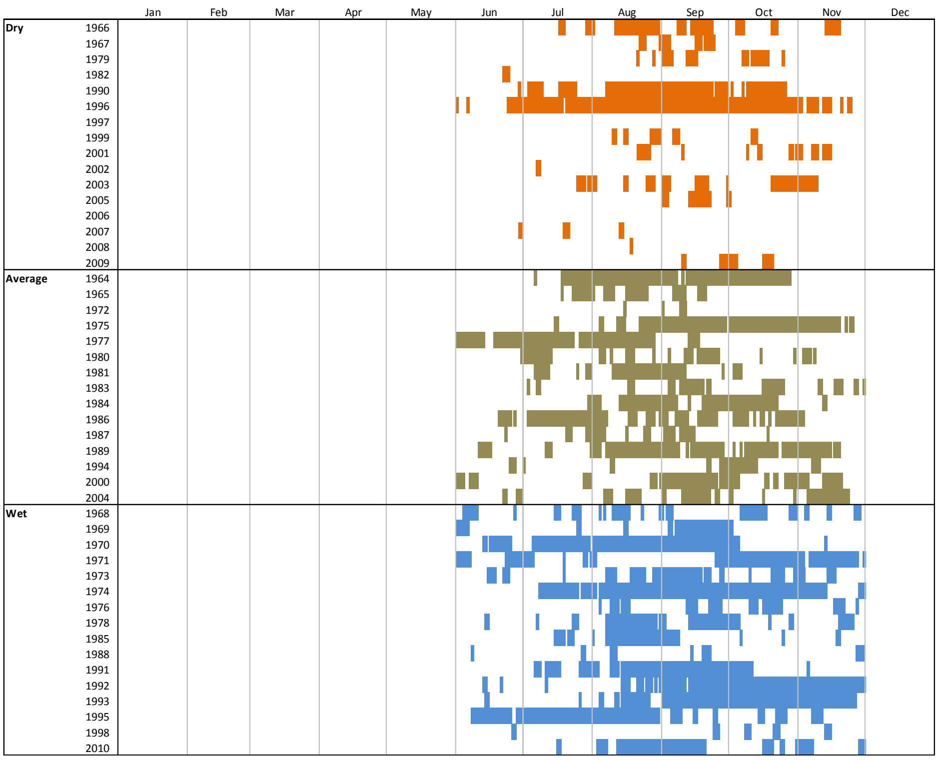
The recommended winter/spring fresh threshold is 2,000 ML/day. Two events that last for seven days are recommended between June and September, but at least one of these events should occur in June or July to facilitate the downstream migration of adult Tupong and some Galaxid fish that spawn in or near estuaries. The winter/spring high flow recommendation is for the same volume but timed to occur once in October/November and last for 14 days to promote flood tolerant vegetation within the channel. The two freshes are expected to occur in most years, but the 14 day high flow may not occur in the driest climate years. HEC RAS outputs show that flows of 2,000 ML/day are sufficient to inundate benches and a significant portion of the lower and mid banks in this reach (Figure 6-9).

Under current conditions the winter/spring fresh threshold is exceeded on average 3-4 times per year (Figure 6-10). Winter freshes would have occurred at a similar frequency under unimpacted conditions, but they would have had a much longer duration (Figure 6-11).

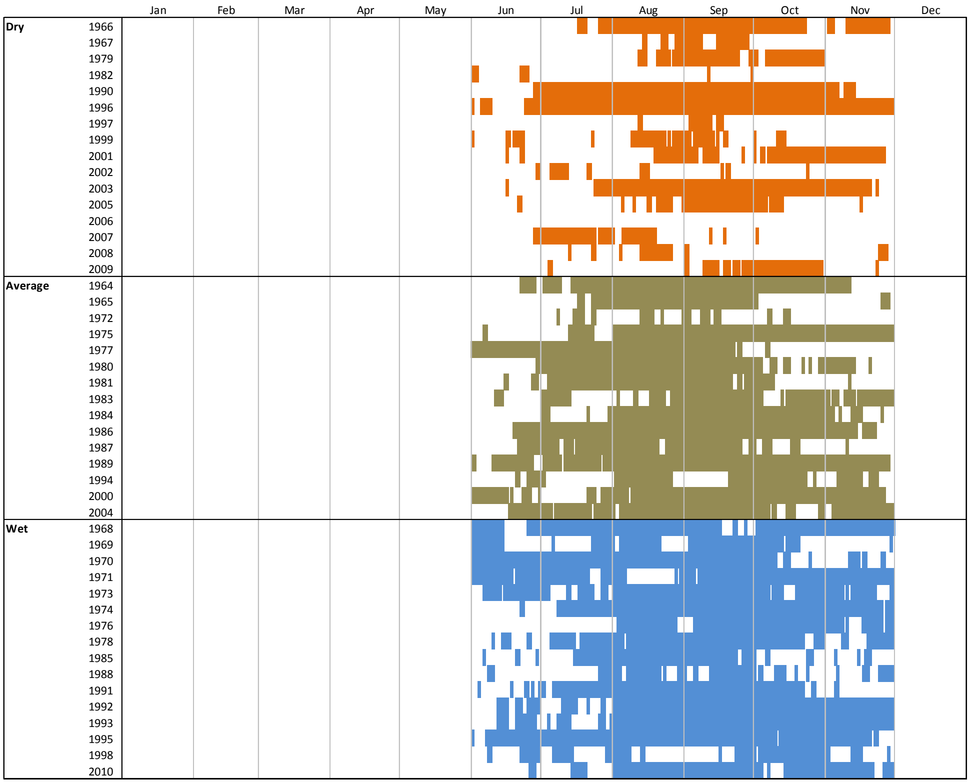


- **Figure 6-9 Stage height in pools (Transect 1, left and Transect 2, right) at the recommended threshold for winter/spring freshes and high flows in Reach 4.**

Under current and unimpacted conditions the winter high flow threshold is exceeded 1-2 times per year, but the recommended duration of 14 days is met less often under current conditions compared to unimpacted conditions (Figure 6-10 and Figure 6-11).



- **Figure 6-10 Characteristics of winter/spring fresh and high flow threshold for current conditions for Reach 4. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**

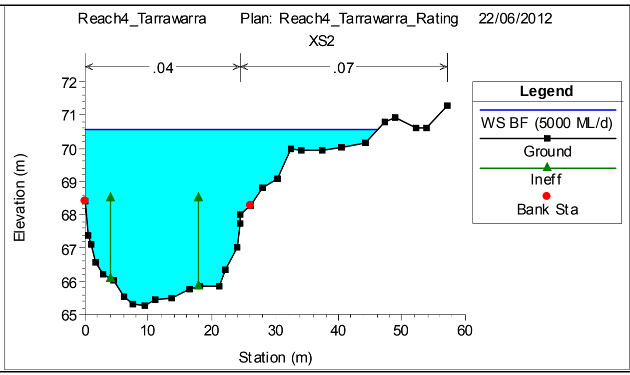


- **Figure 6-11 Characteristics of winter/spring fresh and high flow threshold for unimpacted conditions for Reach 4. This plot shows the number and duration of flows above the recommended threshold that would have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.**

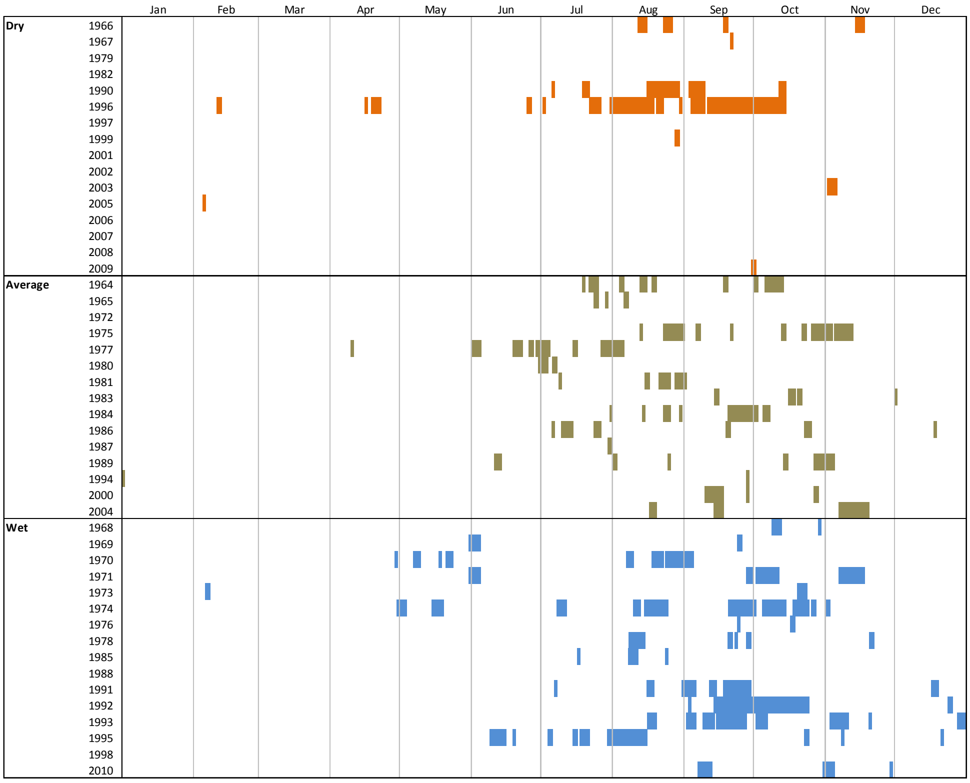
6.2.6. Bankfull flows

The recommended bankfull flow for Reach 4 is 5,000 ML/day and it should last for 1-2 days. This flow does not fill the channel, but is sufficient to water billabongs that are directly connected to the river channel via flood runners (Figure 6-12). The recommended flow will help to maintain desirable vegetation communities and influence macroinvertebrate community composition within near channel wetlands and billabongs (Robson and Clay, 2005). However, it will not provide flow through these wetlands and therefore will not flush sediment and organic material from them.

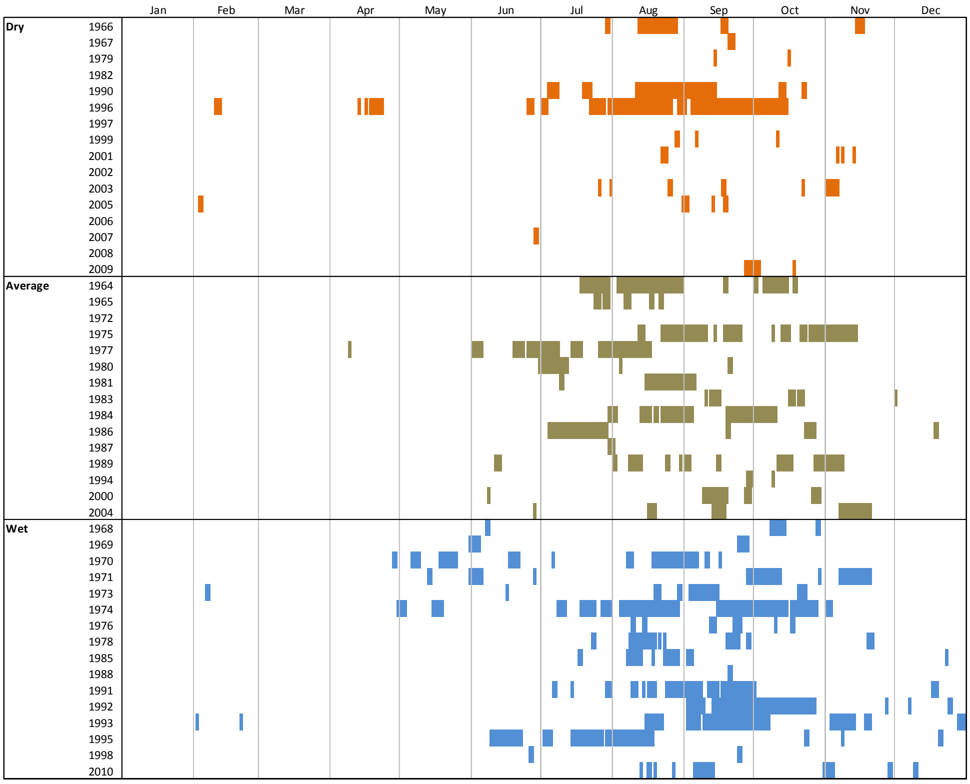
The bankfull flow recommendation is aimed at protecting existing flows when they occur rather than requiring specific releases to be made from storages. They are not expected to occur in dry climate years, but 1-2 events are expected in average climate years and 2-3 events should occur in wet climate years (Figure 6-13 and Figure 6-14). The frequency of bankfull flow events is similar under current and unimpacted flow conditions, but their duration is shorter under current conditions. While the timing of bankfull events cannot be controlled, they are likely to disturb Macquarie Perch eggs and developing larvae in downstream reaches if they occur in October and November.



- **Figure 6-12 Stage height in pools (Transect 2, right) at the recommended threshold for bankfull flows in Reach 4. Note that Lidar was used to determine the flood runner height of 70.5 that will allow water to enter the billabong just downstream of transect 2. This water level will therefore enter the billabong.**



- **Figure 6-13 Characteristics of bankfull flow threshold for current conditions for Reach 4. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**



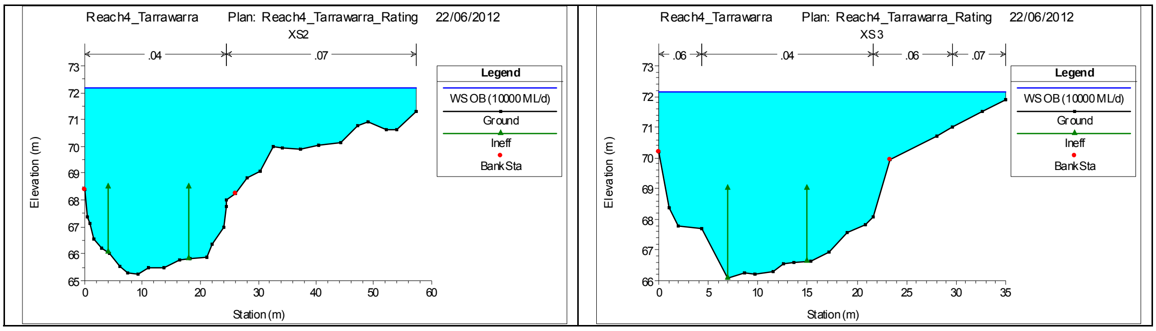
- **Figure 6-14 Characteristics of bankfull flow threshold for unimpacted conditions for Reach 4. This plot shows the number and duration of flows above the recommended threshold that would have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.**

6.2.7. Overbank flows

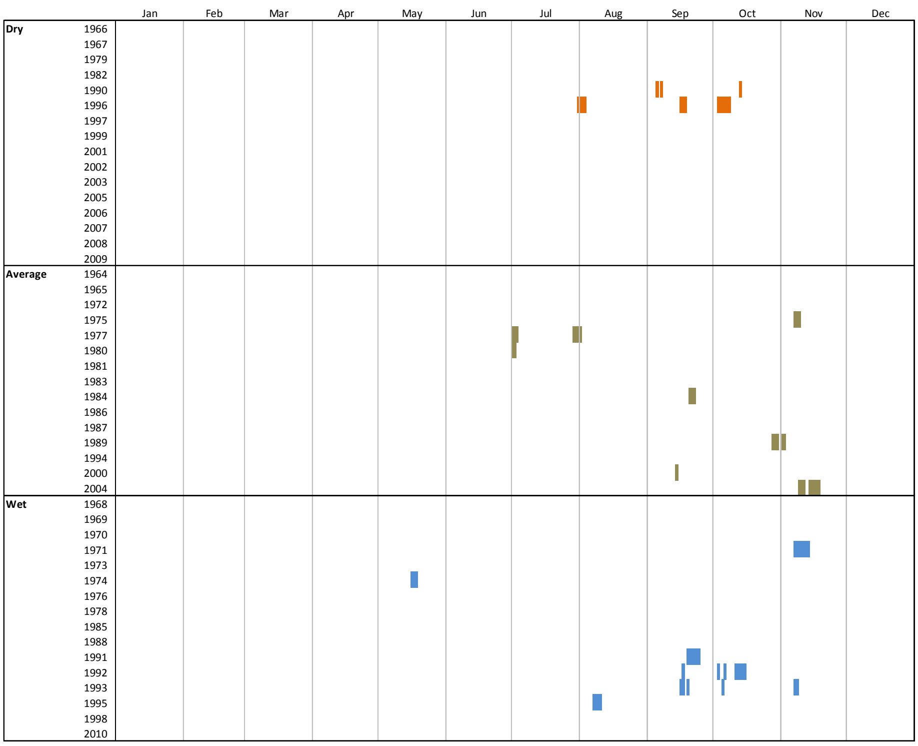
An overbank flow of 10,000 ML/day with a duration of 1-2 days is recommended every 1-2 years during wet climate years. This flow is sufficient to overtop the banks (Figure 6-15) and inundate more wetlands and more of the floodplain than the bankfull flow.

Overbank flows are not expected to occur in dry or average climate years, but should occur every 1-2 years during wet years (Figure 6-16 and Figure 6-17). Overbank flows most commonly occur in September under current and unimpacted conditions. Events longer than 1-2 days duration are not recommended because overbank flows longer than four days can kill pasture (Vogel, 1997); even under natural conditions, flows of this magnitude rarely exceed a few days duration.

The bankfull and overbank flow recommendations for Reach 4 are aimed at protecting existing flows when they occur, rather than requiring specific releases to be made from storages. While some ecological benefits of overbank flows will be gained under current landscape conditions (e.g. see Robson and Clay, 2005), the full environmental advantage of both bankfull and overbank flows through this reach will be achieved if parts of the floodplain and some billabongs can be fenced and re-vegetated with species appropriate for the EVC. There are several locations along this reach where clusters of billabongs and wetlands exist that could be targeted for rehabilitation. For example, there is a cluster of billabongs at the bottom end of the reach immediately before the river enters Yering Gorge. These wetlands are frequently inundated due to the ponding effects of Yering Gorge. Another wetland cluster is located on the south side of the river approximately 3 km upstream from Yarra Glen. Selective removal of levees, fencing and revegetation would greatly benefit the environmental value of these wetlands and take full advantage of the bankfull and overbank flows. These wetlands are located on private property so further investigations are needed to identify and prioritise wetlands and floodplain areas for rehabilitation. Such investigations also need to involve landholder input and commitment to improved environmental conditions and to manage potential risks to pasture production associated with inundation events.



- **Figure 6-15 Stage height in pools (Transect 1, left and Transect 2, right) at the recommended threshold for overbank flows in Reach 4.**



- **Figure 6-16 Characteristics of overbank flow threshold for current conditions for Reach 4. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**

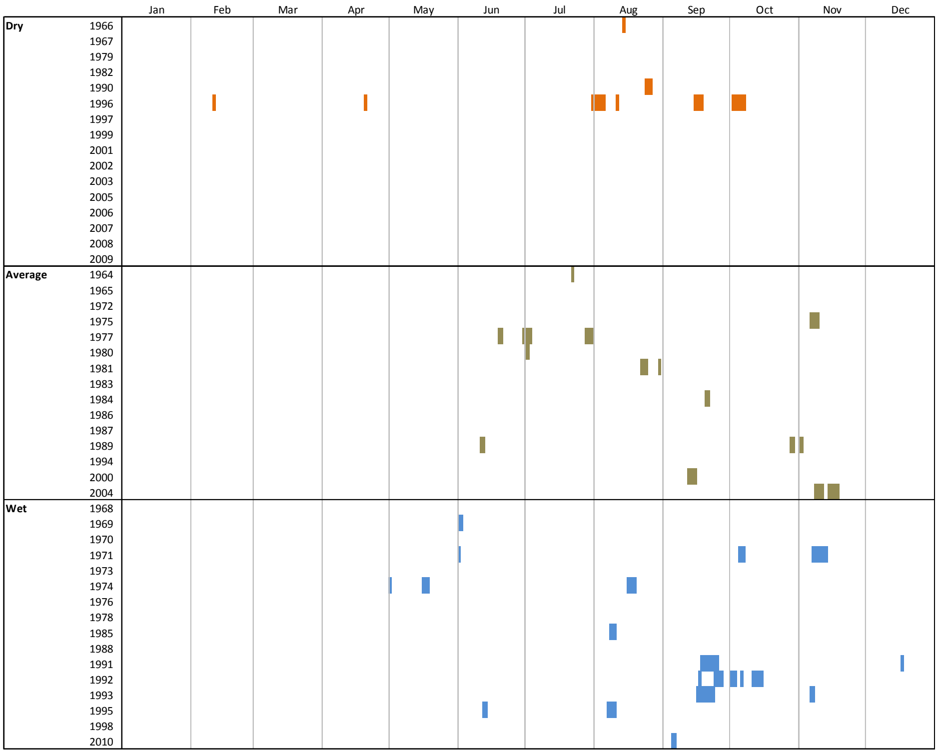


Figure 6-17 Characteristics of overbank flow threshold for unimpacted conditions for Reach 4. This plot shows the number and duration of flows above the recommended threshold that would have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.

6.2.8. Long section

Figure 6-18 shows the depth of water in pools at the flow assessment site in Reach 4 under each flow threshold. The long pool characteristics of the reach are evident and each flow threshold provides increased pool depth and progressive bank wetting.

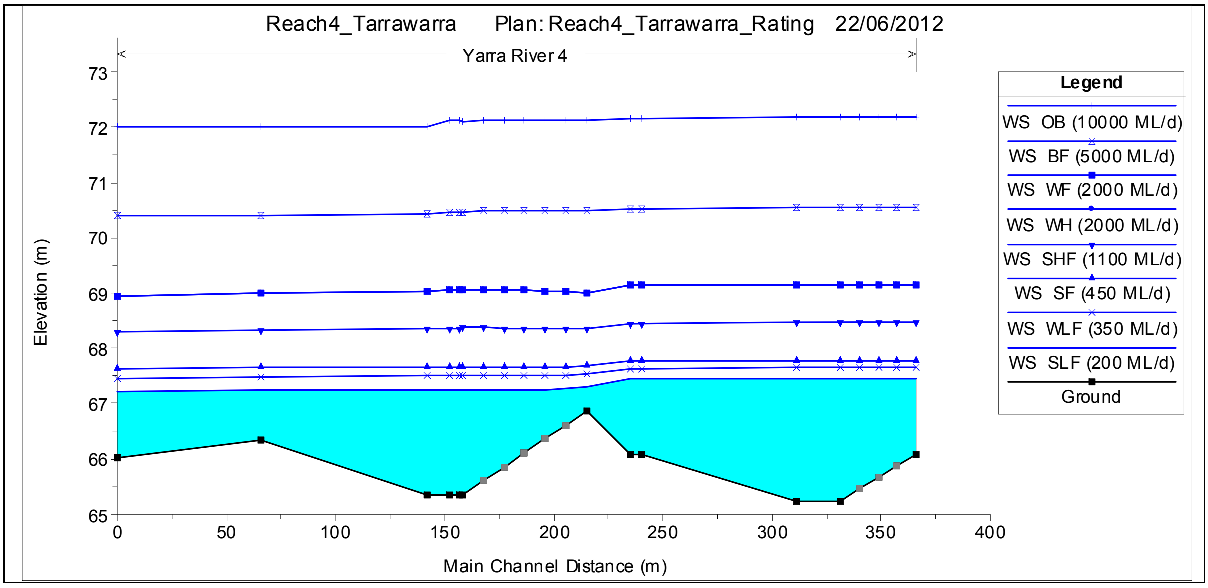


Figure 6-18 Long section showing water surface level for all flows in Reach 4.

6.2.9. Current achievement of flow recommendations

An assessment of how well the flow recommendations for Reach 4 are currently met in wet, average and dry years is presented in Table 6-2, Table 6-3 and Table 6-4. It should be noted that these assessments include an 'or natural' clause, which considers the flows that would have occurred in Reach 4 in wet, dry and average years under unimpacted conditions. For example, if the hydrological analysis shows that the recommended winter high flow would only occur in 25 out of 30 years in average years then the level of achievement is based on how many of those 25 events are delivered under the current level of development and system operation.

The summer and winter low flow recommendations and the summer fresh recommendations for Reach 4 are currently met nearly 100% of the time in wet and average years, but are only met 80-90% of the time in dry years. Slight adjustments to flow release patterns from upstream storages in a small proportion of dry years would ensure that these recommended flows would be achieved nearly all of the time.

The recommended summer high flow is met 60% of the time in wet years, 56% of the time in average years and 75% of the time in dry years. The higher achievement in dry years, does not indicate that more of these events occur in dry years (Only four summer high flow events would have naturally occurred in the 30 dry climate years considered in the current assessment). Rather it indicates that a higher proportion of the flows that would naturally occur are still observed. It is important that summer high flows are delivered in most wet and average climate years and extra releases may need to be made from upstream storages to achieve those recommendations. The 75% achievement in dry years is likely to be sufficient, provided at least one event occurs every three years.

The recommended winter fresh is only achieved between 63% and 75% of the time in any climate year. That level of achievement is acceptable as long as the recommended high flows, bankfull flows and overbank flows are delivered. Higher winter flows are not necessarily expected in Reach 4 in dry years and therefore it may be necessary to make extra releases from storages to increase the number of winter freshes and greater provide flow variability in dry years.

The recommended winter high flow is achieved 47% of the time in wet years and 81% of the time in average years. Winter high flows would naturally occur more often in wet years than average years, but the current operation of the upstream reservoirs and farm dams in the catchment significantly reduce the magnitude and/or duration of those events in wet years. In average climate years, most of the winter high flows that would naturally occur are relatively unaffected by current reservoir operations and other harvesting actions.

Most of the recommended bankfull flows occur in wet and average years. However, Upper Yarra Reservoir and Maroondah Reservoir have reduced the frequency of overbank flows in wet years by 33%. It is impractical and probably undesirable from a social and economic perspective to actively deliver more frequent overbank floods.

In summary, most of the low flow and small fresh recommendations are met in wet and average years and slight adjustments in release rates from upstream storages are likely to deliver all of the low flow and summer fresh recommendations in dry years. Other releases may also be needed to increase the number of summer and winter high flows that are delivered. In particular, it will be essential to ensure that the recommended summer high flow is delivered in most wet and average years and at least once every three years in dry conditions.

- **Table 6-2 Extent to which the environmental flow recommendations for Reach 4 are currently being met during dry years.**

Component	Months	Flow Recommendation			Or Natural	Achievement
Summer low	Dec - May	Magnitude	**200**	ML/d	**Yes**	*79%*
Summer fresh	Dec - May	Magnitude	**450**	ML/d	**Yes**	*88%*
		Frequency	**3**	per year		
		Duration	**2**	days		
Summer high	Apr - May	Magnitude	**1100**	ML/d	**Yes**	*75%*
		Frequency	**1**	per year		
		Duration	**7**	days		
Winter low	Jun - Nov	Magnitude	**350**	ML/d	**Yes**	*91%*
Winter fresh	Jun - Sep	Magnitude	**2000**	ML/d	**Yes**	*63%*
		Frequency	**2**	per year		
		Duration	**7**	days		
Winter high	Oct - Nov	Not expected, but allow to occur naturally				
Bankfull	Jan - Dec	Not expected, but allow to occur naturally				
Overbank	Jan - Dec	Not expected, but allow to occur naturally				

- **Table 6-3 Extent to which the environmental flow recommendations for Reach 4 are currently being met during average years.**

Component	Months	Flow Recommendation			Or Natural	Achievement
Summer low	Dec - May	Magnitude	**200**	ML/d	**Yes**	*98%*
Summer fresh	Dec - May	Magnitude	**450**	ML/d	**Yes**	*100%*
		Frequency	**3**	per year		
		Duration	**2**	days		
Summer high	Apr - May	Magnitude	**1100**	ML/d	**Yes**	*56%*
		Frequency	**1**	per year		
		Duration	**7**	days		
Winter low	Jun - Nov	Magnitude	**350**	ML/d	**Yes**	*100%*
Winter fresh	Jun - Sep	Magnitude	**2000**	ML/d	**Yes**	*75%*
		Frequency	**2**	per year		
		Duration	**7**	days		
Winter high	Oct - Nov	Magnitude	**2000**	ML/d	**Yes**	*81%*
		Frequency	**1**	per year		
		Duration	**14**	days		
Bankfull	Jan - Dec	Magnitude	**5000**	ML/d	**Yes**	*93%*
		Frequency	**2**	in **1** years		
		Duration	**2**	days		
Overbank	Jan - Dec	Not expected, but allow to occur naturally				

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■ **Table 6-4 Extent to which the environmental flow recommendations for Reach 4 are currently being met during wet years.**

Component	Months	Flow Recommendation					Or Natural	Achievement
Summer low	Dec - May	Magnitude	**200**	ML/d			**Yes**	*100%*
Summer fresh	Dec - May	Magnitude	**450**	ML/d			**Yes**	*100%*
		Frequency	**3**	per year				
		Duration	**2**	days				
Summer high	Apr - May	Magnitude	**1100**	ML/d			**Yes**	*60%*
		Frequency	**1**	per year				
		Duration	**7**	days				
Winter low	Jun - Nov	Magnitude	**350**	ML/d			**Yes**	*100%*
Winter fresh	Jun - Sep	Magnitude	**2000**	ML/d			**Yes**	*67%*
		Frequency	**2**	per year				
		Duration	**7**	days				
Winter high	Oct - Nov	Magnitude	**2000**	ML/d			**Yes**	*47%*
		Frequency	**1**	per year				
		Duration	**14**	days				
Bankfull	Jan - Dec	Magnitude	**5000**	ML/d			**Yes**	*87%*
		Frequency	**2**	in	**1**	years		
		Duration	**2**	days				
Overbank	Jan - Dec	Magnitude	**10000**	ML/d			**Yes**	*67%*
		Frequency	**1**	in	**1**	years		
		Duration	**2**	days				

7. Reach 5: Yering Gorge to Mullum Mullum Creek

7.1. Description

Reach 5 runs from the top of Yering Gorge to the confluence with Mullum Mullum Creek at the downstream end of the Warrandyte Gorge. The reach includes two gorges (Yering and Warrandyte) and a short floodplain (Henley floodplain). Mullum Mullum Creek represents the first major urban tributary input to the river, although a number of smaller tributary streams deliver storm water and treated sewerage effluent to the river in this reach. The Melbourne Water pumping station at Yering Gorge, which pumps water to Sugarloaf Reservoir for water supply purposes, is at the upstream end of the reach. The pumps have a maximum capacity of 1000 ML/day.

Two environmental flow sites were assessed in this reach, one in Yering Gorge just downstream of the pump station (Site 5a) and one in the Warrandyte Gorge downstream of the Warrandyte township (Site 5b). Full environmental flows assessments were conducted at both sites for the 2005 FLOWS study. The EFTP reviewed flow recommendations at both sites for the current project, but for simplicity HEC RAS outputs are only presented for the Yering Gorge site. Flow is currently measured at Warrandyte and Yering Gorge. It is recommended that Yering Gorge be used as the compliance point.

7.2. Flow recommendations

The general objective for Reach 5 is to maintain access to habitat during low flows, minimise water quality risks associated with low flows, introduce some variability in the summer low flow period, provide flows to assist Australian Grayling spawning in autumn, provide the right mix of flushing flows in spring and stable flows through late spring and early summer to enhance Macquarie Perch recruitment, increase the duration of bank inundation to limit growth of terrestrial species, manage the rate of rise and fall associated with pumping and provide appropriate bankfull flows to inundate billabongs in Henley floodplain. The main changes to the 2005 flow recommendations include a lower magnitude, but longer duration for the autumn high flow to trigger Australian Grayling spawning and more variability for the highest flows to achieve the objectives for bankfull flows. The adoption of flow recommendations for dry, average and wet years has also allowed a revision of some flow components, particularly with regard to the number of events delivered in each year. The environmental flow recommendations for Reach 5 are summarised in Table 7-1.

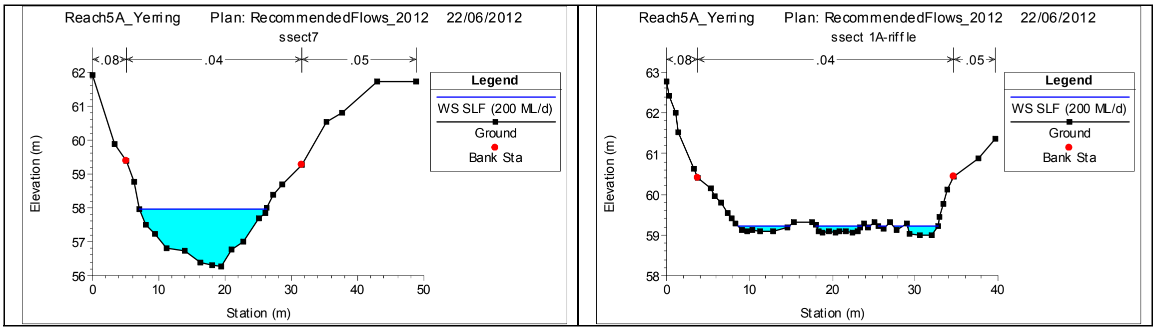
Table 7-1 Flow recommendations for Reach 5.

Stream		Yarra River		Reach	Yering Gorge to Mullum Mullum Creek		
Compliance point		**Yering Gorge**		**Gauge No.**	**229200**		
Season	**Flow**	**Objective (refer to objectives tables for id reference)**	**Wet/Avg/ Dry**	**Volume**	**Frequency and when**	**Duration**	**Rise/Fall**
Summer / Autumn (Dec-May)	Low flow	Maintain access to habitat for bugs & fish and aquatic vegetation and maintain water quality (M5-1, F5-1, V5-1, V5-2, W5-1)	Wet	Minimum flow of 200 ML/day, allow tributaries to provide additional variation above 200 ML/day in average and wet years. Note – higher flows may be needed to meet flow recommendations for water quality in the Dights Falls Weir pool (Reach 6), but 200 ML/day is adequate to meet the objectives for Reach 5.			
			Average				
			Dry				
	Fresh	Maintain suitable riffle and LWD habitat by periodically scouring sediment & biofilms, maintain flood-tolerant vegetation on banks and provide opportunities for local fish movement (M5-2, F5-1, V5-3)	Wet	750 ML/day	5	2	1.4/0.85
			Average	750 ML/day	4	2	
			Dry	750 ML/day	3	2	
	High	Trigger downstream migration and spawning by Australian Grayling and transport larvae to sea. (F5-6)	Wet	1300 ML/day. Larger magnitude flows should be passed.	1 (April/May) every year	Min 7 day at peak. Event should last for 14 days from start to finish. Higher and longer duration flows are desirable in average and wet years.	1.4/0.85
			Average				
			Dry	1300 ML/day. Larger magnitude flows should be passed.	1 (April/May). Must occur at least once every three years.		
Winter / spring (Jun-Nov)	Low flow	Maintain access to habitat for bugs & fish & wet bank vegetatation (M5-1, F5-1, V5-1, V5-2, W5-1)	Wet	Median flow 750 ML/day with a minimum flow of 350 ML/day.			
			Average				
			Dry	Median flow 600 ML/day with a minimum flow of 350 ML/day.			
	Fresh	Maintain suitable riffle habitat by periodically scouring sediment & biofilms, maintain flood-tolerant vegetation on banks, provide fish passage, entrain organic material (M5-2, F5-1, F5-4, F5-5, V5-3)	Wet	2500 ML/day- tributary inflows provide variation during average and wet years. Higher magnitude and longer duration flows are acceptable and beneficial in average and wet years.	Minimum 2 events between June and September with 1 event occurring in June or July to facilitate migration of Tupong and galaxids.	Min 7 day at peak, additional duration provided by tributaries. Longer duration flows acceptable in average and wet years.	1.4/0.85
			Average				
			Dry				
	High	As per fresh but provides prolonged disturbance to favour flood-tolerant vegetation (F5-2, F5-3, F5-5,V5-3)	Wet	2500 ML/day	Deliver 1 event in October- November but allow to occur naturally at other times.	14 days	1.4/0.85
			Average				
			Dry	Not expected to occur in dry years, but allow to occur naturally.			

	Small Bankfull	Maintain existing channel geometry & prevent further vegetation encroachment in channel, entrain organic material, deliver water to billabongs via flood-runners (G5-1, V5-4, V5-5, V5-6)	Wet	5000 ML/day	2-3 per year	2 days	1.4/0.85
			Average	5000 ML/day	1-2 per year	2 days	
			Dry	Not expected, but let it occur naturally.			
	Large Bankfull	Engage and provide flow through higher level flood runners ad billabongs (G5-1, G5-3, V5-4, V5-5, V5-6)	Wet	14,000 ML/day	Every 1-2 years	1-2 days	1.4/0.85
			Average	Not expected, but let it occur naturally.			
			Dry				

7.2.1. Summer/autumn low flows

The recommended summer low flow threshold is 200 ML/day. This wets the full width of riffles (see Transect 2 in Figure 7-1), provides oviposition sites for macroinvertebrates, allows small fish to move through riffles and maintains suitable depth in pools (see Transect 1 in Figure 7-1). The recommended flow is the minimum, because it provides a buffer against low dissolved oxygen levels in pools. It is expected that flows will vary above 200 ML/day throughout summer and autumn due to tributary inflows, and will be higher in average and wet climate years. The recommended low flow is adequate for the objectives in Reach 5, but higher flows may need to be delivered through this reach to meet the minimum summer low flow recommendations in Reach 6.



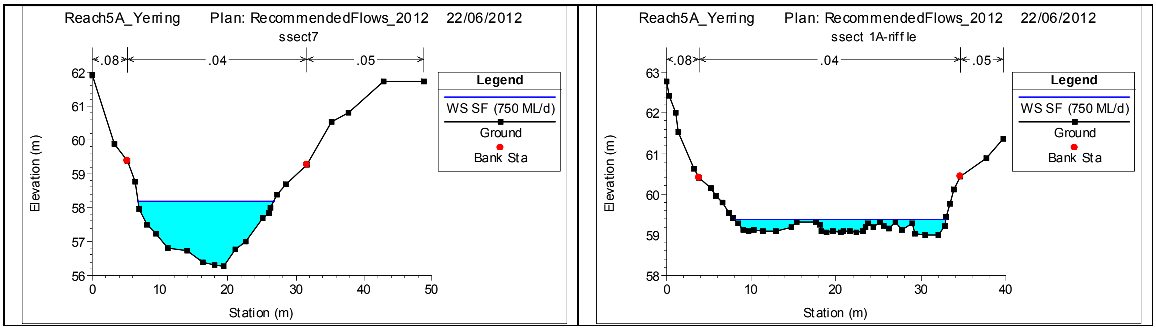
▪ **Figure 7-1 Stage height in a pool (Transect 800, left) and riffle (Transect 1420, right) at the recommended threshold for summer/autumn low flows in Reach 5.**

Under current conditions flow falls below the low flow threshold on average three times per year, typically in late autumn for a median duration of five days, although 10% of spells last for longer than 18 days. Under unimpacted conditions the flow rarely fell below the threshold, but when it did, the duration of the low flow spell was typically longer than current conditions.

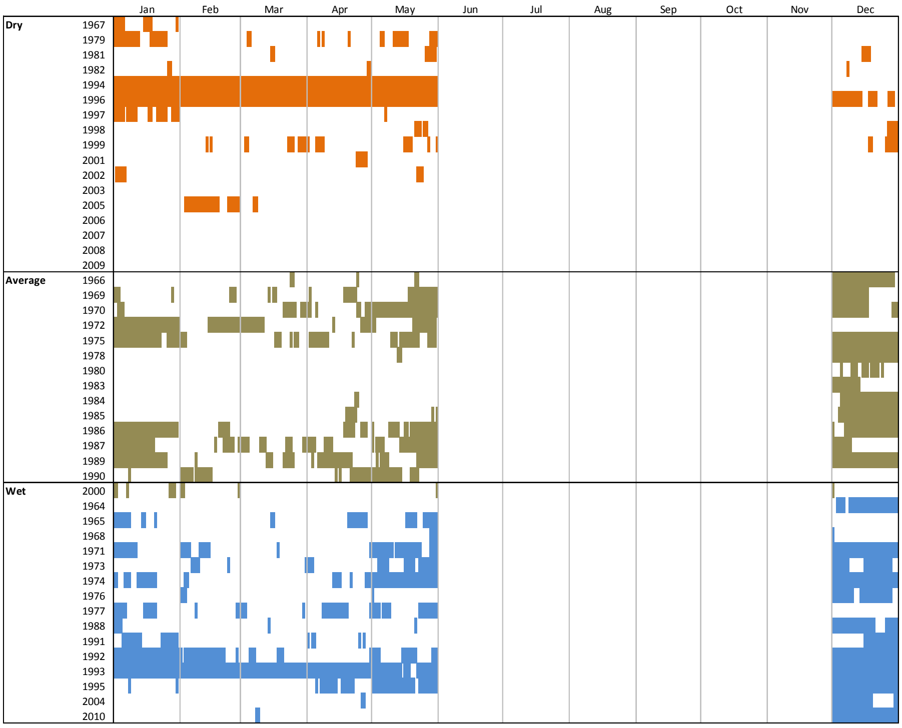
7.2.2. Summer/autumn freshes

The recommended summer/autumn fresh flow is 750 ML/day and it should last for two days. This flow fully inundates riffles and rock bars to a minimum depth of around 10 cm (see Transect 2 in Figure 7-2) and creates an average velocity of 40 cm/s to scour sediment and biofilms. These freshes also wet the lower banks in pools to maintain flood-tolerant vegetation (see Transect 1 in Figure 7-2). Three summer/autumn freshes should be delivered in dry years, but four and five freshes should be delivered in average and wet climate years respectively to provide more flow variability and to increase opportunities for Murray Cod and Macquarie Perch to move between pools.

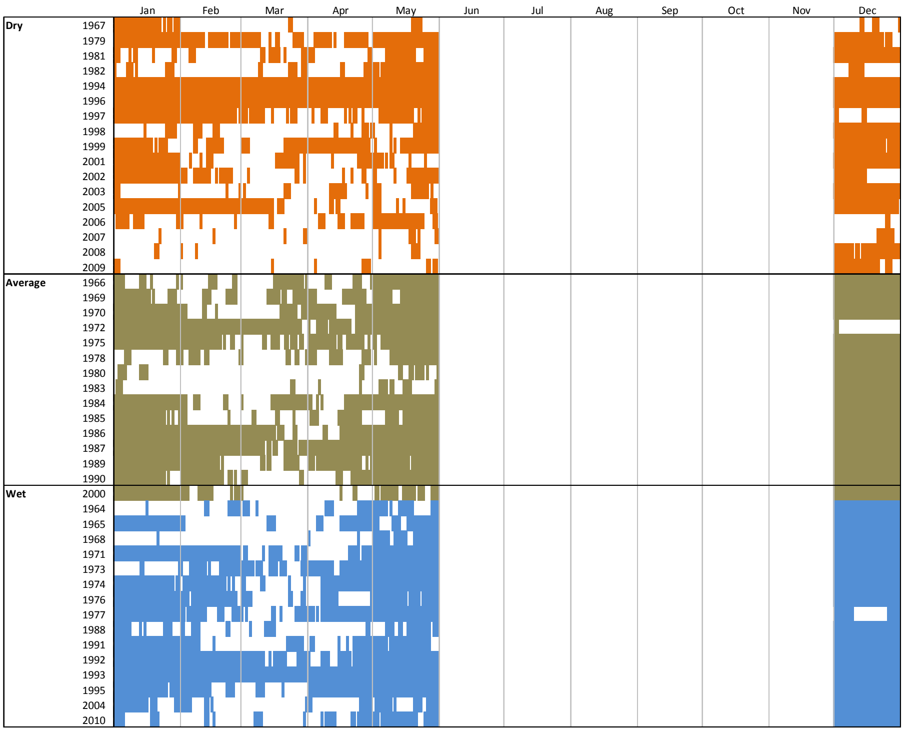
Summer freshes occur at a similar frequency under current and unimpacted conditions, but the average duration of each event is shorter under current conditions (Figure 7-3 and Figure 7-4). Under current and unimpacted conditions flows in excess of 750 ML/day have a median duration of four days, which is longer than the recommended duration. The EFTP thought that more frequent events would provide more opportunities for fish movement and therefore would be be better than fewer longer freshes. Under current conditions there has been a shift in the start month with most events now starting in December or May compared to March under unimpacted conditions.



- **Figure 7-2 Stage height in a pool (Transect 800, left) and riffle (Transect 1420, right) at the recommended threshold for summer/autumn fresh flow in Reach 5.**



- **Figure 7-3 Characteristics of summer/autumn fresh flow threshold for current conditions for Reach 5. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**



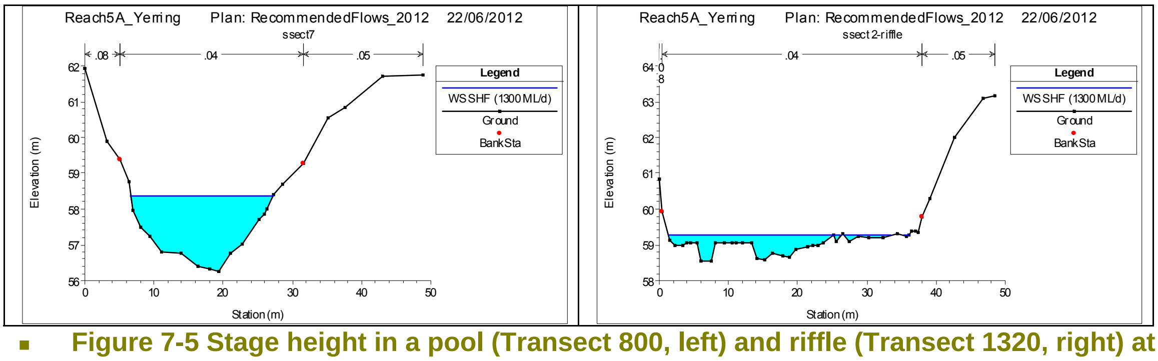
- **Figure 7-4 Characteristics of summer/autumn fresh flow threshold for unimpacted conditions for Reach 5. This plot shows the number and duration of flows above the recommended threshold that would have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.**

7.2.3. Summer/autumn high flows

The recommended summer/autumn high should have a magnitude of at least 1,300 ML/day, occur once in April or May and last for a duration of seven days. The rational for this recommendation is based on providing a suitable migration and spawning trigger for Australian Grayling. The recommended duration of this event is shorter than in upstream reaches because the adult fish will take less time to move from Reach 5 to the bottom of Reach 6 where spawning is assumed to occur. The magnitude of this flow is less than recommended in the 2005 study for two reasons. First more recent surveys have recorded Australian Grayling eggs and larvae in the Yarra River following autumn high flows around 1,300 ML/day (Koster and Dawson, 2011). Second, the lower threshold increases the likelihood that suitable events will be passed downstream of the Yering Pumps in dry years. Under the 2005 flow recommendation, high flows that were just less than the recommended 1,500 ML/day could be harvested at the Yering Pump station, which may have reduced the number of suitable spawning flows that were allowed to pass through Reaches 5 and 6. Australian Grayling spawning rates and spawning success are both likely to increase with higher autumn flows (Koster and Dawson, 2011), and therefore any events that exceed 1,300 ML/day in April or May should be passed in full.

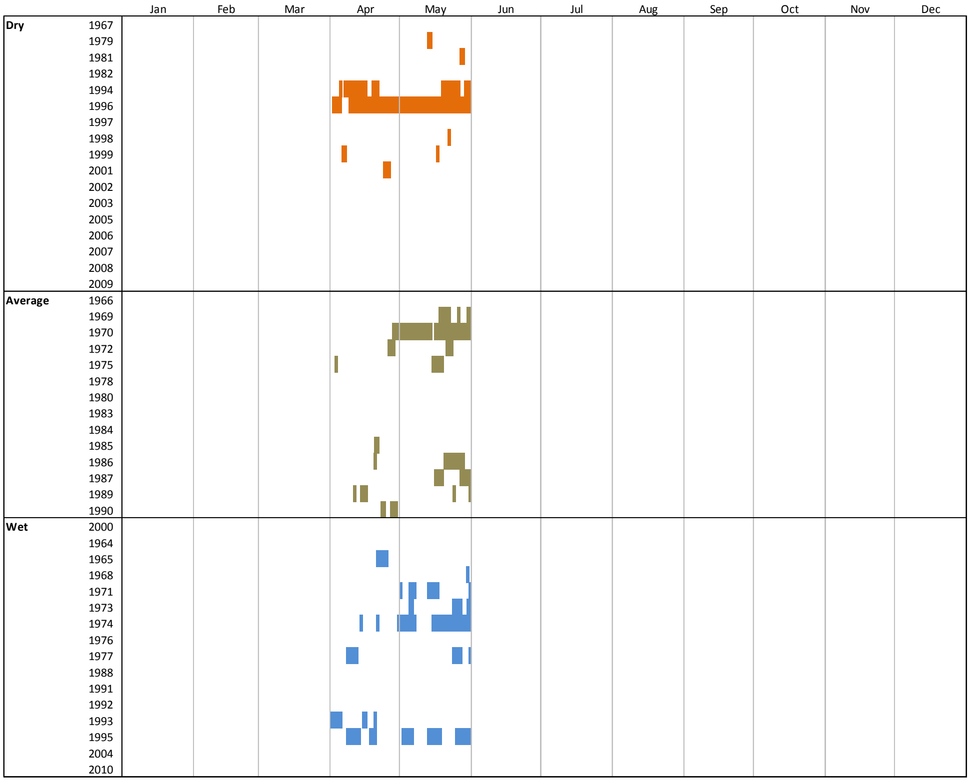
Australian Grayling are a relatively short-lived species and it is important that appropriate spawning cues are provided in most years. As a result, the recommended autumn high flow event should be delivered every year in average and wet climate years. It may not be possible to deliver the event in every dry year, but it should be delivered at least once every three years in dry climatic periods.

While the main objective for the autumn high flow is to provide spawning cues for Australian Grayling. Flows in excess of 1,300 ML/day will wet the lower banks of the channel (Figure 7-5) and will help to maintain flood-tolerant vegetation and provide a disturbance to terrestrial vegetation.



- **Figure 7-5 Stage height in a pool (Transect 800, left) and riffle (Transect 1320, right) at the recommended threshold for summer/autumn high flows in Reach 5.**

Under current conditions the summer/autumn high flow threshold is only achieved about once every two years compared to several times per year under unimpacted conditions (Figure 7-6 and Figure 7-7). Summer high flows in excess of 1,300 ML/day have a median duration of three days under current and unimpacted flow conditions, but more very long duration events would occur under unimpacted conditions. The higher likelihood of multiple high flow events and longer duration events means that spawning conditions for Australian Grayling would have been better under unimpacted flow conditions compared to the current flow conditions.



- **Figure 7-6 Characteristics of summer/autumn high flow threshold for current conditions for Reach 5. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**

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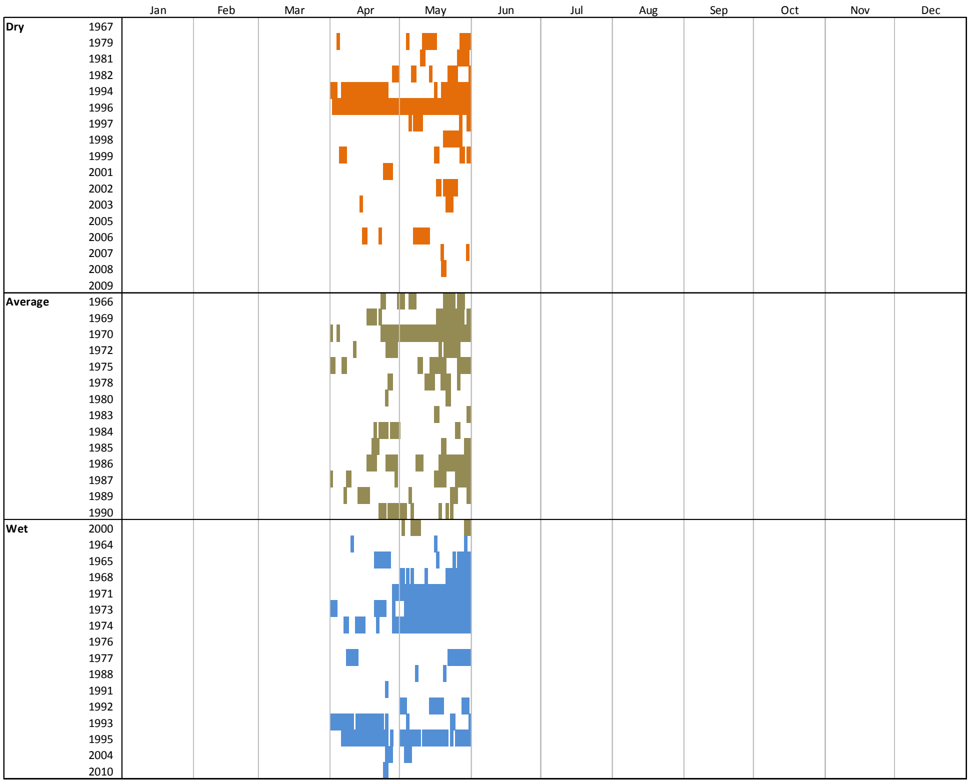
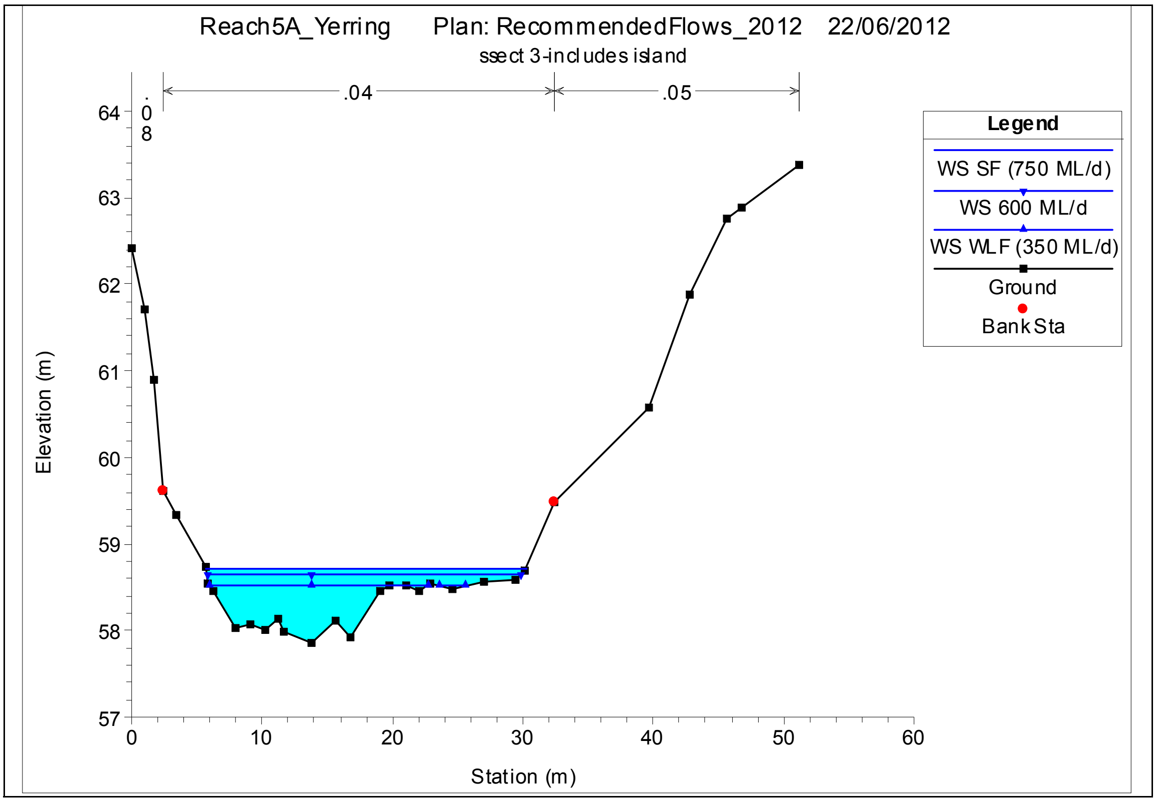


- **Figure 7-7 Characteristics of summer/autumn high flow threshold for unimpacted conditions for Reach 5. This plot shows the number and duration of flows above the recommended threshold that would have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.**

7.2.4. Winter/spring low flows

The minimum threshold for the winter/spring low flow is 350 ML/day, but a median flow magnitude of 600 ML/day has been specified for dry years and a median flow magnitude of 750 ML/day has been specified for wet and average years to introduce more variability. A flow of 350 ML/day increases riffle depth compared to the summer low flow, but higher flows will inundate more vegetation on low benches and provide more opportunities for large bodied fish to move throughout the reach (Figure 7-8). Moreover, flows between 375 and 1,000 ML/day in the reach are likely to provide good spawning conditions for Macquarie Perch (see more detailed discussion in Chapter 8).

Under current conditions the winter/spring flow falls below the threshold approximately once per year for a median duration of nine days, although 10% of spells last longer than 48 days. Most low flow events start in June indicating that the summer/autumn low flow period often extends into the winter season. The winter/spring flow would not have fallen below the 350 ML/day low flow threshold under unimpacted conditions.

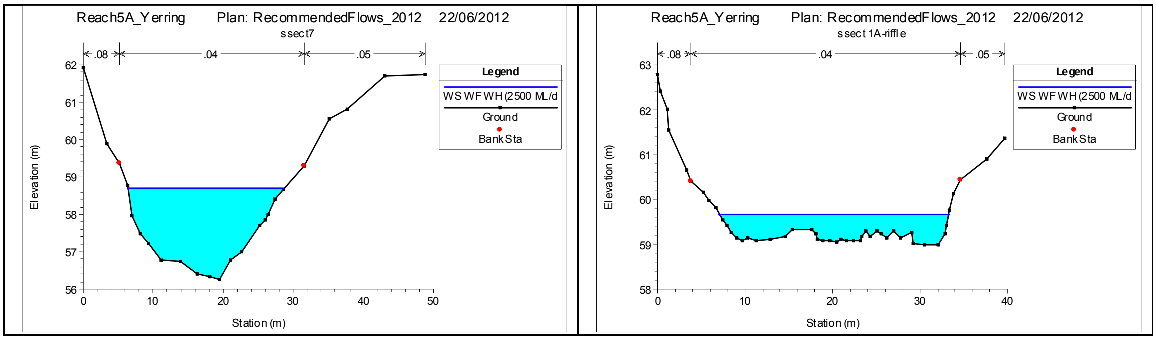


- **Figure 7-8 Stage height at a low bench(Transect 1110) at the recommended threshold for winter/spring low flows in Reach 5.**

7.2.5. Winter/spring freshes and high flows

The recommended winter/spring fresh threshold is 2,500 ML/day. Two events that last for seven days are recommended between June and September, but at least one of these events should occur in June or July to facilitate the downstream migration of adult Tupong and some Galaxid fish that spawn in or near estuaries. The winter/spring high flow recommendation is for the same volume but timed to occur once in October/November and have a duration of 14 days to promote flood tolerant vegetation within the channel. The two freshes are expected to occur in most years, but the 14 day high flow may not occur in the driest climate years.

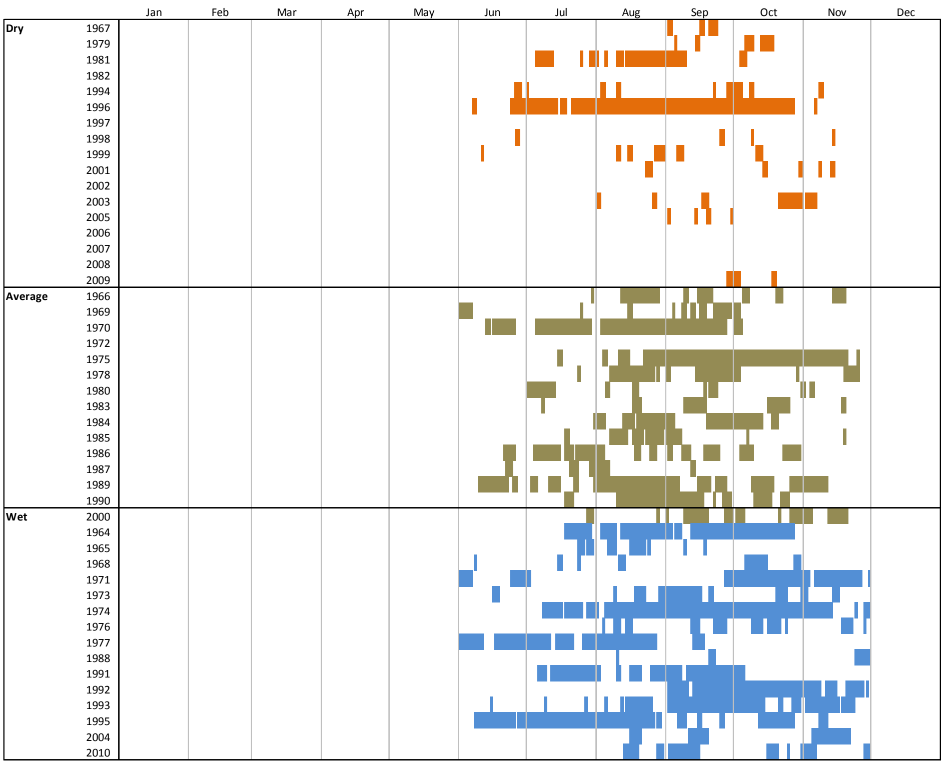
HEC RAS outputs show that flows of 2,500 ML/day are sufficient to provide more than 1 m depth over riffles for fish passage and will inundate benches and a significant portion of the lower and mid banks in this reach (Figure 7-9). These flows will also achieve a minimum velocity of 40 cm/s through riffles and runs to scour sediment and biofilms from hard substrates, which will help to clean gravel habitats prior to the Macquarie Perch spawning season.



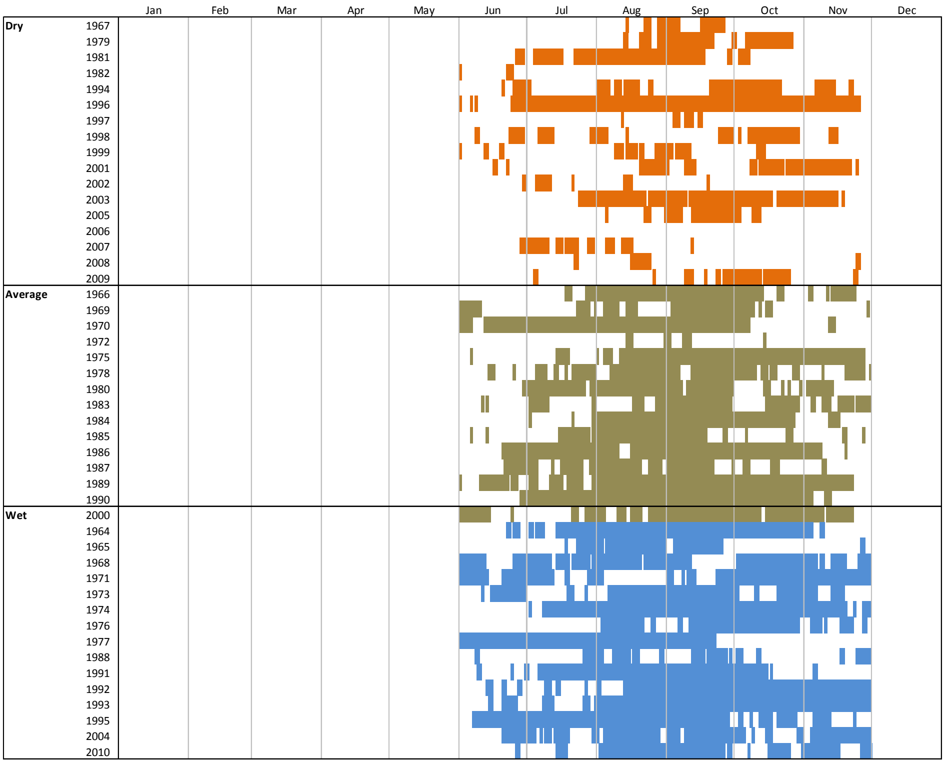
- **Figure 7-9 Stage height in a pool (Transect 800, left) and riffle (Transect 1420, right) at the recommended threshold for winter/spring freshes and high flows in Reach 5.**

Under current conditions the recommended fresh threshold is exceeded three to four times per year for a median duration of seven days (Figure 7-10 and Figure 7-11). Under unimpacted conditions fewer events above 2,500 occurred each year, but the duration was longer with 30% of events lasting between seven and 110 days and 20% of events lasting 110 to 140 days.

The high flow event occurs 1.5 times each year in October or November under both unimpacted and current conditions. However, the median duration under current conditions is only six days compared to 17 days under unimpacted conditions. Most events commence in October under both current and unimpacted conditions.



- **Figure 7-10 Characteristics of winter/spring fresh and high flow threshold for current conditions for Reach 5. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**

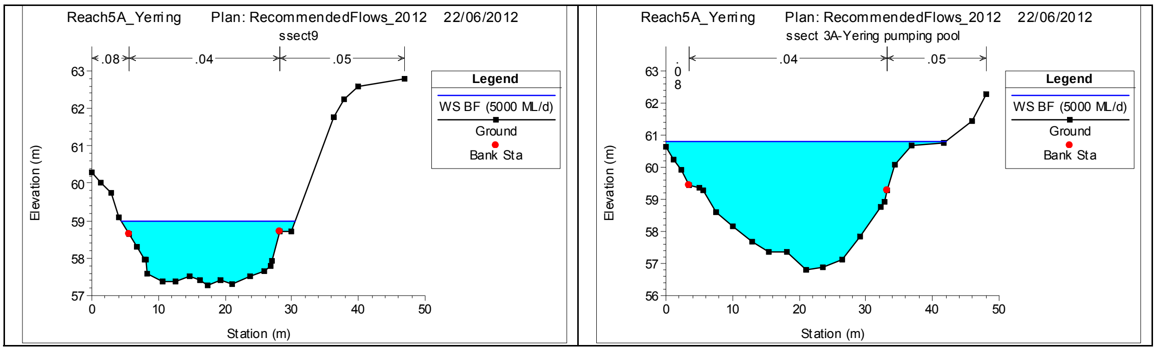


- **Figure 7-11 Characteristics of winter/spring fresh and high flow threshold for unimpacted conditions for Reach 5. This plot shows the number and duration of flows above the recommended threshold that would have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.**

7.2.6. Bankfull flows

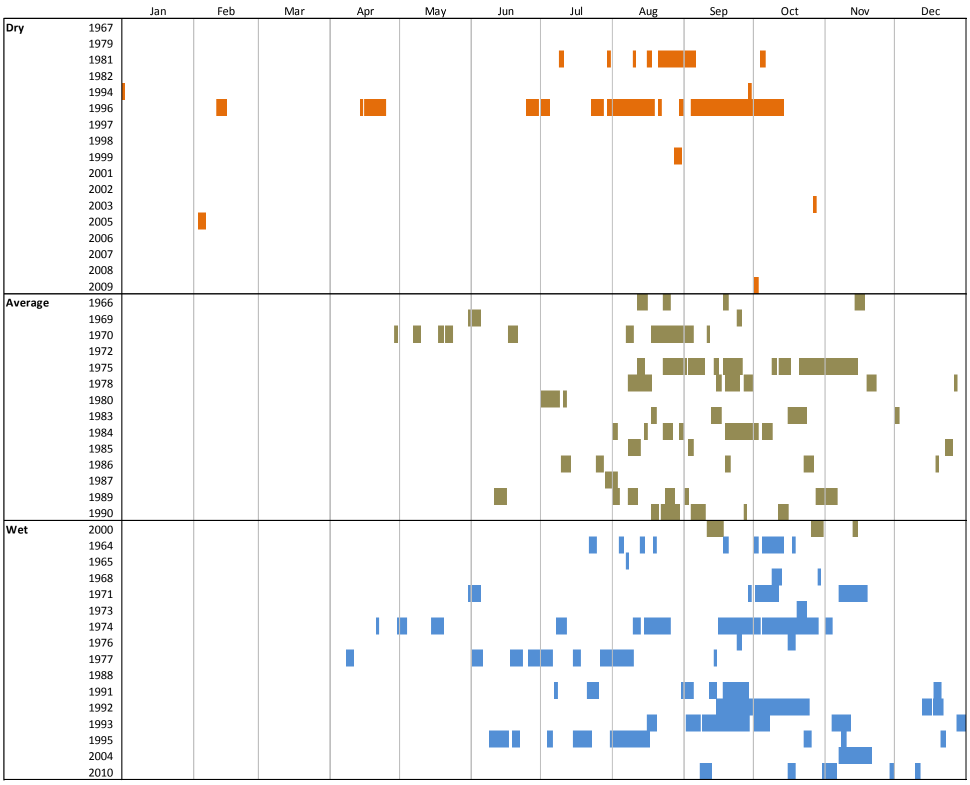
The flows required to meet the bankfull flow objectives have been broken into a lower magnitude event that occurs in most years and a much larger event that only occurs in wet years. Overbank flows are not recommended for this reach because there is relatively little floodplain habitat that relies on overbank flows. As with other reaches, the objectives is to protect very high flows that occur naturally and it is not intended that water will be specifically released from storages to create these events.

An annual peak flow of 5,000 ML/day that lasts for two days is recommended to inundate high benches within the channel (Figure 7-12) to help maintain existing channel geometry, to prevent the encroachment of terrestrial vegetation into the channel and to entrain organic material. An event of this size is unlikely to occur in dry climate years, but 1-2 events are expected in average climate years and 2-3 events may occur in wet climate years. These events are likely to overturn cobbles in riffle habitats and could disrupt Macquarie Perch spawning and recruitment if they occur in October or November. However, the timing of these events cannot be managed and Macquarie Perch do not need optimal breeding conditions every year to sustain the population.

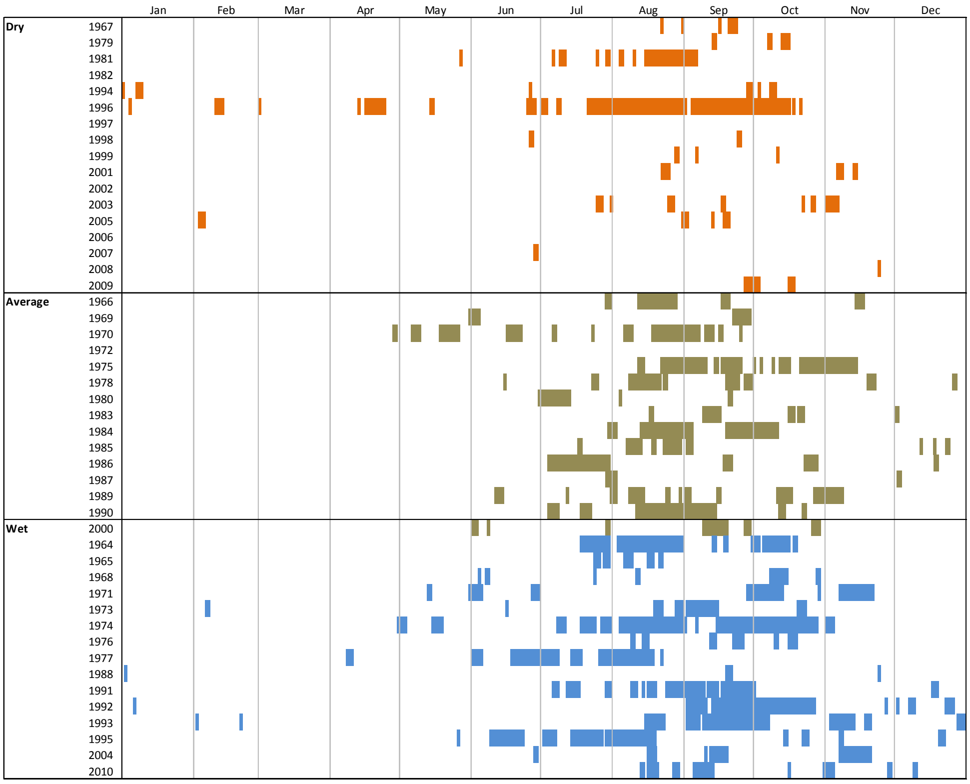


- **Figure 7-12 Stage height in a pool (Transect 600, left) and riffle (Transect 1950, right) at the recommended threshold for bankfull flows in Reach 5.**

Under current conditions flows exceed 5,000 ML/day on average once every 2 to 3 years, but rarely in dry years. Under unimpacted conditions the recommended bankfull flow would have been exceeded nearly three times every two years, and typically at least once a year (Figure 7-13 and Figure 7-14). Under both unimpacted and current conditions the median duration of the bankfull event is around two days and the majority of events commence in August, September or October.

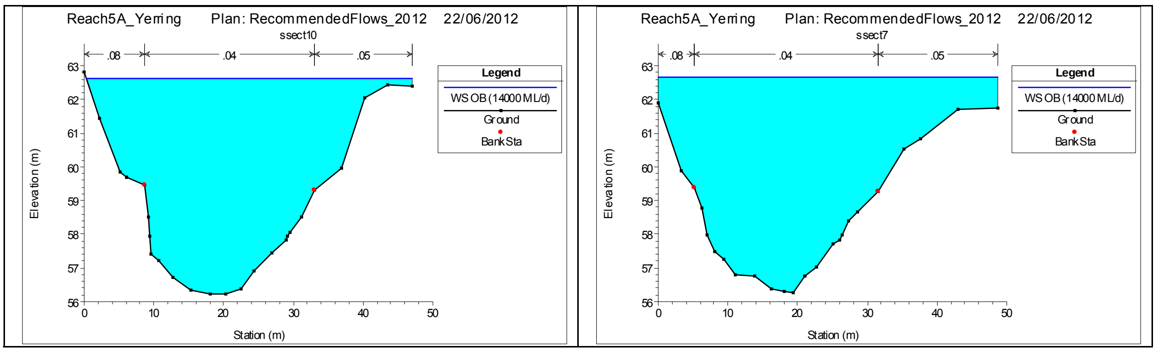


- **Figure 7-13 Characteristics of bankfull flow threshold for current conditions for Reach 5. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**



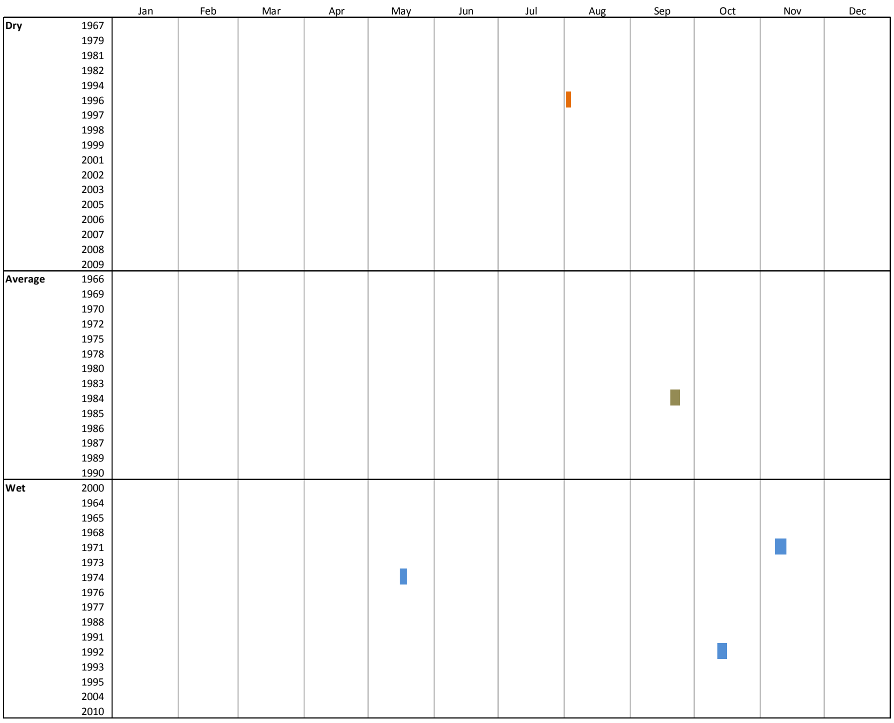
▪ **Figure 7-14 Characteristics of bankfull flow threshold for unimpacted conditions for Reach 5. This plot shows the number and duration of flows above the recommended threshold that would have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.**

The larger bankfull flow recommendation is 14,000 ML/day. This flow is only likely to occur every 1-2 years in the wettest climatic years, but is needed to inundate and maintain higher level terraces and flood runners and inundate billabongs in the Henley floodplain. Due to the confined nature of the reach, this flow provides a significant disturbance regime for vegetation growing on the banks and in riffles (Figure 7-12). Most of Reach 5 is bedrock controlled, however the large bankfull flow will help maintain pool habitat by scouring sediment in deepest pools and scouring vegetation growing in riffles.

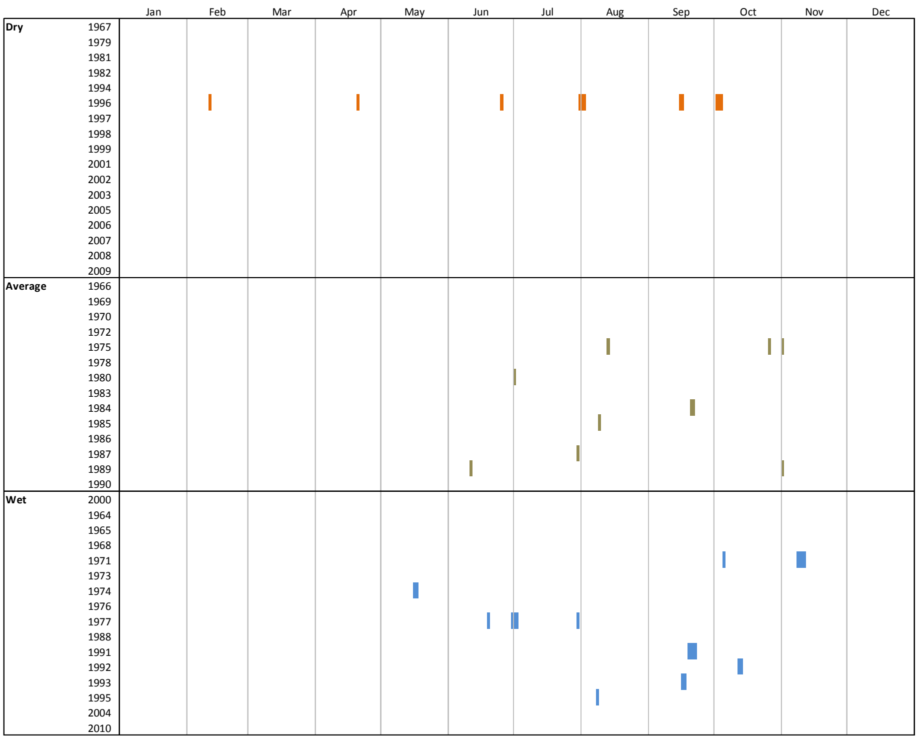


- **Figure 7-15 Stage height in a pool (Transect 500, left) and riffle (Transect 800, right) at the recommended threshold for larger bankfull flows in Reach 5.**

Under current conditions, flows of this magnitude are only likely to occur approximately one in ten years (Figure 6-16). Under unimpacted conditions, flows in excess of 14,000 ML/day occurred in about twice as many years and there were often multiple events in a particular year (Figure 6-17).



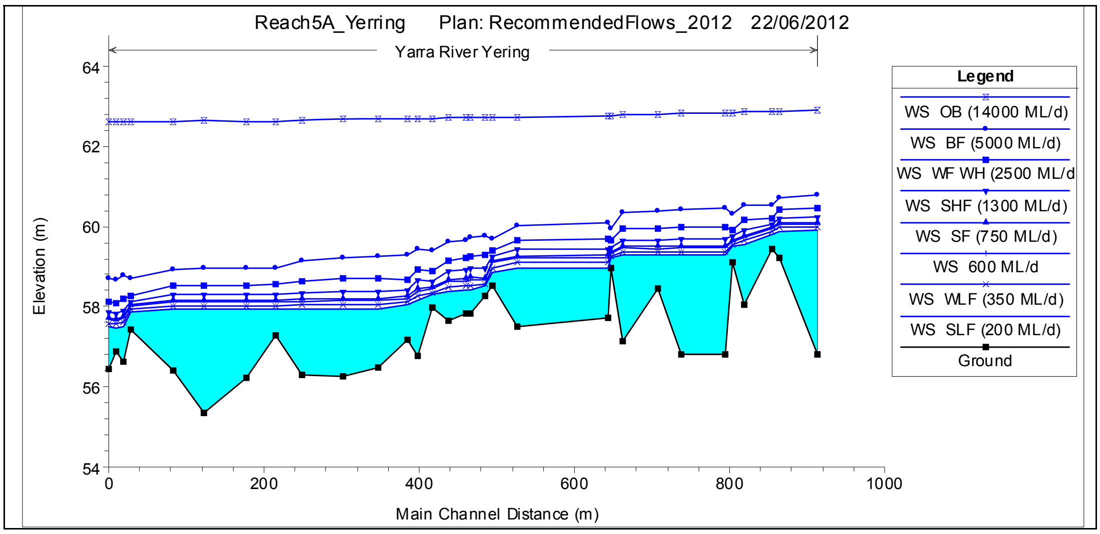
- **Figure 7-16 Characteristics of larger bankfull flow threshold for current conditions for Reach 5. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**



- **Figure 7-17 Characteristics of larger bankfull flow threshold for unimpacted conditions for Reach 5. This plot shows the number and duration of flows above the recommended threshold that would have occurred in each dry, wet and average climate year since 1964.**

7.2.7. Long section

Figure 7-18 shows the water surface level for each flow threshold along a long section of Reach 5. Low flows and freshes provide some increased depth over riffles, however the riffle at Transect 3 is not drowned until high flows and bankfull flows are reached.



- **Figure 7-18 Long section showing water surface level for all flows in Reach 5.**

7.2.8. Current achievement of flow recommendations

An assessment of how well the flow recommendations for Reach 5 are currently met in wet, average and dry years is presented in Table 7-2, Table 7-3 and Table 7-4. It should be noted that these assessments include an ‘or natural’ clause, which considers the flows that would have occurred in Reach 5 in wet, dry and average years under unimpacted conditions. For example, if the hydrological analysis shows that the recommended winter high flow would only occur in 25 out of 30 years in average years then the level of achievement is based on how many of those 25 events are delivered under the current level of development and system operation.

The summer and winter low flow recommendations for Reach 5 are currently met nearly 100% of the time in wet and average years, but are only met around 75% of the time in dry years. Slight adjustments to flow release patterns from upstream storages in a small proportion of dry years would ensure that these recommended flows would be achieved nearly all of the time.

The recommended summer fresh flow is met 73% of the time in wet years, 56% of the time in average years and 19% of the time in dry years.

The recommended summer high flow is met 53% of the time in wet years, 69% of the time in average years and 75% of the time in dry years. The higher achievement in dry years, does not indicate that more of these events occur in dry years (summer high flows would have naturally occurred in only five out of the 30 dry climate years considered in this study). Rather it indicates that a higher proportion of the flows that would naturally occur are still observed. It is important that summer high flows are delivered in most wet and average climate years and extra releases may need to be made from upstream storages to achieve those recommendations. The 75% achievement in dry years is likely to be sufficient, provided at least one event occurs every three years.

The recommended winter fresh is achieved 60% of the time in wet years, 75% of the time in average years and only 31% of the time in dry years. Winter fresh flows would naturally occur more often in wet years than average years, but the current operation of the upstream reservoirs, Yering Pumps and farm dams in the catchment significantly reduce the magnitude and/or duration of those events in wet years. The recommended winter high flow is achieved 73% of the time in wet years and 56% of the time in average years.

Most of the recommended bankfull flows occur in wet and average years. However, Upper Yarra Reservoir and Maroondah Reservoir have reduced the frequency of overbank flows in wet years by about 10% for the small bankfull flow and 50% for the large bankfull flow. It is impractical and probably undesirable from a social and economic perspective to actively deliver more frequent overbank floods.

In summary, low flow recommendations for Reach 5 are generally met in wet and average years, but the level of achievement of these flows in dry years and all other flow components in all years is less than 75%. The lower level of achievement of environmental flow recommendations in this reach compared to upstream reaches reflects the effect that the operation of the Yering Pumps has on downstream flows. The Yering Pumps can harvest up to 1,100 ML/day from the Yarra River and the current operating procedures appear to have the greatest effect on low flows in dry years and summer and winter freshes and high flows in all years. These operating rules may need to be revised to enable more of the environmental flow recommendations to be met in downstream reaches. In particular, it will be essential to ensure that the recommended summer high flow and winter fresh is delivered in most wet and average years and at least once every three years in dry conditions. Bankfull and overbank flow recommendations should be met through protecting existing events when they occur rather than through specific flow releases.

- **Table 7-2 Extent to which the environmental flow recommendations for Reach 5 are currently being met during dry years.**

Component	Months	Flow Recommendation			Or Natural	Achievement
Summer low	Dec - May	Magnitude	**200**	ML/d	**Yes**	*73%*
Summer fresh	Dec - May	Magnitude	**750**	ML/d	**Yes**	*19%*
		Frequency	**3**	per year		
		Duration	**2**	days		
Summer high	Apr - May	Magnitude	**1300**	ML/d	**Yes**	*75%*
		Frequency	**1**	per year		
		Duration	**7**	days		
Winter low	Jun - Nov	Magnitude	**350**	ML/d	**Yes**	*87%*
Winter fresh	Jun - Sep	Magnitude	**2500**	ML/d	**Yes**	*31%*
		Frequency	**2**	per year		
		Duration	**7**	days		
Winter high	Oct - Nov	Not expected, but allow to occur naturally				
Small Bankfull	Jan - Dec	Not expected, but allow to occur naturally				
Large Bankfull	Jan - Dec	Not expected, but allow to occur naturally				

- **Table 7-3 Extent to which the environmental flow recommendations for Reach 5 are currently being met during average years.**

Component	Months	Flow Recommendation			Or Natural	Achievement
Summer low	Dec - May	Magnitude	**200**	ML/d	**Yes**	*96%*
Summer fresh	Dec - May	Magnitude	**750**	ML/d	**Yes**	*56%*
		Frequency	**4**	per year		
		Duration	**2**	days		
Summer high	Apr - May	Magnitude	**1300**	ML/d	**Yes**	*69%*
		Frequency	**1**	per year		
		Duration	**7**	days		
Winter low	Jun - Nov	Magnitude	**350**	ML/d	**Yes**	*96%*
Winter fresh	Jun - Sep	Magnitude	**2500**	ML/d	**Yes**	*75%*
		Frequency	**2**	per year		
		Duration	**7**	days		
Winter high	Oct - Nov	Magnitude	**2500**	ML/d	**Yes**	*56%*
		Frequency	**1**	per year		
		Duration	**14**	days		
Small Bankfull	Jan - Dec	Magnitude	**5000**	ML/d	**Yes**	*93%*
		Frequency	**2**	in **1** years		
		Duration	**2**	days		
Large Bankfull	Jan - Dec	Not expected, but allow to occur naturally				

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Table 7-4 Extent to which the environmental flow recommendations for Reach 5 are currently being met during wet years.

Component	Months	Flow Recommendation					Or Natural	Achievement
Summer low	Dec - May	Magnitude	200	ML/d			Yes	*100%*
Summer fresh	Dec - May	Magnitude	750	ML/d			Yes	*73%*
		Frequency	5	per year				
		Duration	2	days				
Summer high	Apr - May	Magnitude	1300	ML/d			Yes	*53%*
		Frequency	1	per year				
		Duration	7	days				
Winter low	Jun - Nov	Magnitude	350	ML/d			Yes	*100%*
Winter fresh	Jun - Sep	Magnitude	2500	ML/d			Yes	*60%*
		Frequency	2	per year				
		Duration	7	days				
Winter high	Oct - Nov	Magnitude	2500	ML/d			Yes	*73%*
		Frequency	1	per year				
		Duration	14	days				
Small Bankfull	Jan - Dec	Magnitude	5000	ML/d			Yes	*87%*
		Frequency	3	in	1	years		
		Duration	2	days				
Large Bankfull	Jan - Dec	Magnitude	14000	ML/d			Yes	*50%*
		Frequency	1	in	1	years		
		Duration	2	days				

8. Reach 6: Mullum Mullum Creek to Dights Falls

8.1. Description

Reach 6 extends from the confluence with Mullum Mullum Creek to Dights Falls. Dights Falls marks the downstream freshwater extent of the Yarra River. The river through this reach flows across the lower floodplain before flowing through a short gorge section downstream of Chandler Highway to Dights Falls. The catchment is heavily urbanised through this reach and several urban tributaries enter, including Mullum Mullum Creek, Diamond Creek, Plenty River, Darebin Creek and Merri Creek. The floodplain adjacent to the river is mostly parkland and sporting facilities such as ovals and golf courses. There are several significant billabongs that retain important environmental values in an urban landscape. The environmental flows assessment site (Site 6a) was located halfway along the reach, at Banyule Flats, and included the regionally significant Banyule Billabong. In 2005 a second site was visually inspected at Dights Falls, although hydraulic surveys were not undertaken. For the 2012 review a new site was assessed, a long riffle at Finns Reserve in Templestowe. This location is considered important habitat for Macquarie perch spawning (Koster, pers. com. and see the *Site Paper*).

8.2. Flow recommendations

The general flow objective for Reach 6 is to maintain access to habitat during low flows, ensure variability in the summer low flow period, provide flows to assist Australian Grayling spawning in autumn, Macquarie perch spawning in spring and upstream migration of diadromous fish also in spring, increase the duration of bank inundation to limit growth of terrestrial species, and ensure appropriate bankfull and overbank flows for inundation of billabongs connected around bankfull. The 2005 study also considered flow to the Yarra estuary (Reach 7). The current review does not include the estuary. Recommendations for the estuary will be developed as part of a separate project.

The environmental flow recommendations for Reach 6 are summarised in Table 8-1.

■ Table 8-1 Flow recommendations for Reach 6.

Stream		Yarra River		Reach	Mullum Mullum Creek to Dights Fall Weir		
Compliance point		**Chandler Highway**		**Gauge No.**	**229143**		
Season	**Flow**	**Objective (refer to objectives tables for id reference)**	**Wet/Avg/ Dry**	**Volume**	**Frequency and when**	**Duration**	**Rise/Fall**
Summer / Autumn (Dec-May)	Low flow	Maintain access to habitat for bugs & fish, drying period for bank vegetation, minimise risk of low DO conditions (M6-1, F6-1, V6-1, W6-1)	Wet	Minimum recommendation of 300 ML/day to minimise risk of low DO in pools upstream of Chandler Highway. Minimum recommendation of 450 ML/day in December to February if considered necessary to maintain mixed conditions in the Dights Falls Weir Pool, downstream of Chandler Highway. Higher magnitude flows are acceptable.			
			Average				
			Dry				
	Fresh (Dec-Apr)	Maintain suitable riffle habitat by periodically scouring sediment & biofilms, maintain flood-tolerant vegetation on banks, provide occasional fish passage for larger bodied fish. (G6-2, F6-2, M6-2, V6-2)	Wet	750 ML/day, tributary inflows provide variation during average and wet years. Higher magnitude and longer duration flows are acceptable and beneficial in average and wet years.	Minimum 3 events delivered + additional events provided by Tributaries.	Min 2 day at peak. Longer duration flows acceptable in average and wet years.	1.4/0.85
			Average				
			Dry	750 ML/day	3	2	
	High (Apr-May)	Trigger spawning by Australian Grayling and transport larvae downstream. (F6-3)	Wet	1300 ML/day minimum flow, all events with a magnitude greater than this should be protected. This event will be higher and last longer in average and wet years.	1 (April/May). Not necessary to deliver in every dry year, but maximum duration between events in a dry sequence is 2 years.	Min 7 day at peak. Longer duration flows acceptable in average and wet years.	1.4/0.85
			Average				
			Dry				
Winter / spring (Jun-Nov)	Low flow	Maintain access to habitat for bugs & fish, wet bank vegetation (M6-1, F6-1, V6-1)	Wet	Median low flow 750 ML/day, daily minimum flow of 350 ML/day, allow tributaries to provide additional variation above 750 ML/day in average and wet years. Higher magnitude flows are acceptable. Maximises habitat availability.			
			Average				
			Dry	Median flow 600 ML/day, daily minimum 350 ML/day.			
	Fresh	Maintain suitable habitat, scour gravels to improve Macquarie perch spawning, trigger migration for winter spawning (M6-2, F6-1, V6-2, F6-2)	Wet	2500 ML/day tributary inflows provide variation during average and wet years. Do not manipulate flows down to meet recommendation. Higher and longer duration flows are acceptable in average and wet years.	Minimum 2 events between June and September, at least 1 event in June/July for downstream fish migration.	Min 7 day at peak, additional duration provided by tributaries. Longer duration flows acceptable in average and wet years.	1.4/0.85
			Average				
			Dry				
	High	As per fresh but provides prolonged disturbance to favour flood-tolerant vegetation (M6-3, F6-2, V6-3)	Wet	2500 ML/day	Deliver in October-November.	14 days	1.4/0.85
			Average				
			Dry	Not necessary to deliver but allow to occur naturally.			
	Bankfull	Maintain existing channel geometry & prevent further vegetation encroachment in channel, entrain organic	Wet	13,000 ML/day. Higher and longer duration flows are acceptable and likely to be beneficial.	1 in 2 years. May not occur in all years and not necessary to actively deliver.	1-2 days	1.4/0.85
			Average				

		material, engage high flow channels (G6-1, M6-3, V6-3)	Dry	Not necessary to deliver but allow to occur naturally.			
	Overbank	Engage billabongs and low level floodplains. (G6-3, V6-5)	Wet	21,500 ML/day. Higher and longer duration flows are acceptable.	1 in 4 years. May not occur in all years and not necessary to actively deliver.	1-2 days	1.4/0.85
			Average				
			Dry	Not necessary to deliver but allow to occur naturally.			

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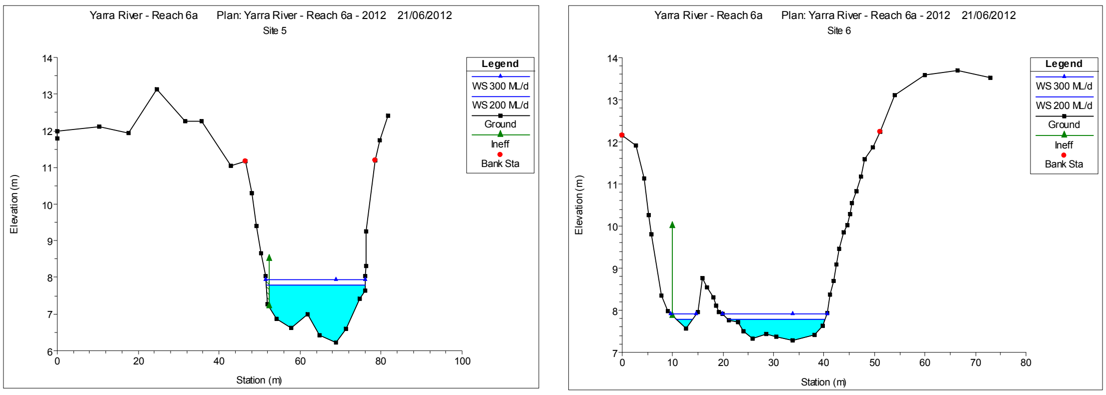
8.2.1. Summer/autumn low flow

The recommend summer/autumn low flow threshold has been increased from 200 ML/day to 300 ML/day. A flow of 200 ML/day is sufficient to inundate the full width of a gravel run at Transect 6 (see Figure 8-1), to inundate LWD located low in the channel and maintain depth of at least 1.5 m in pools to provide habitat for large-bodied fish such as Murray Cod. However, flows below 300 ML/day increase the risk of low dissolved oxygen conditions occurring in pools around and upstream of Chandler Highway during the warmer months (McGuckin, 2010, SKM, 2011b). As well as reducing risks to water quality, increasing the low flow recommendation from 200 ML/day to 300 ML/day will result in small increase in water level, which is acceptable.

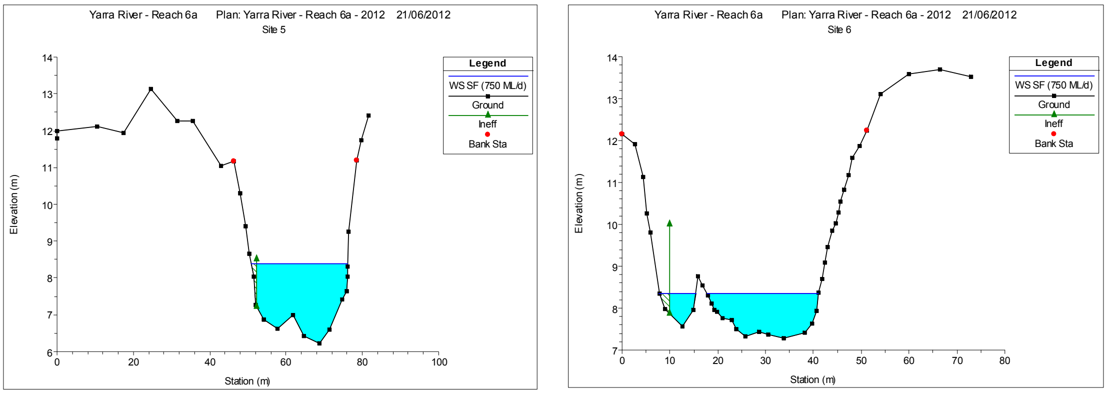
A secondary minimum flow recommendation of 450 ML/day in the months January to March is provided if it is considered desirable or necessary to ensure that the Dights Falls Weir Pool is fully mixed during the summer. Stratification is only likely to occur when water temperature exceeds 16 °C (Robinson, 2011), and therefore a low flow of approximately 300 ML/day is likely to be acceptable in December, April and May. The recommended flow of 450 ML/day should only be adopted following further investigations of the likely benefits to fish of improving water quality in the weir pool. In considering this recommendation, the amount of water required to deliver a higher flow also needs to be considered in conjunction with the impact that may have on the volume of entitlement available for critical flow components in upstream reaches.



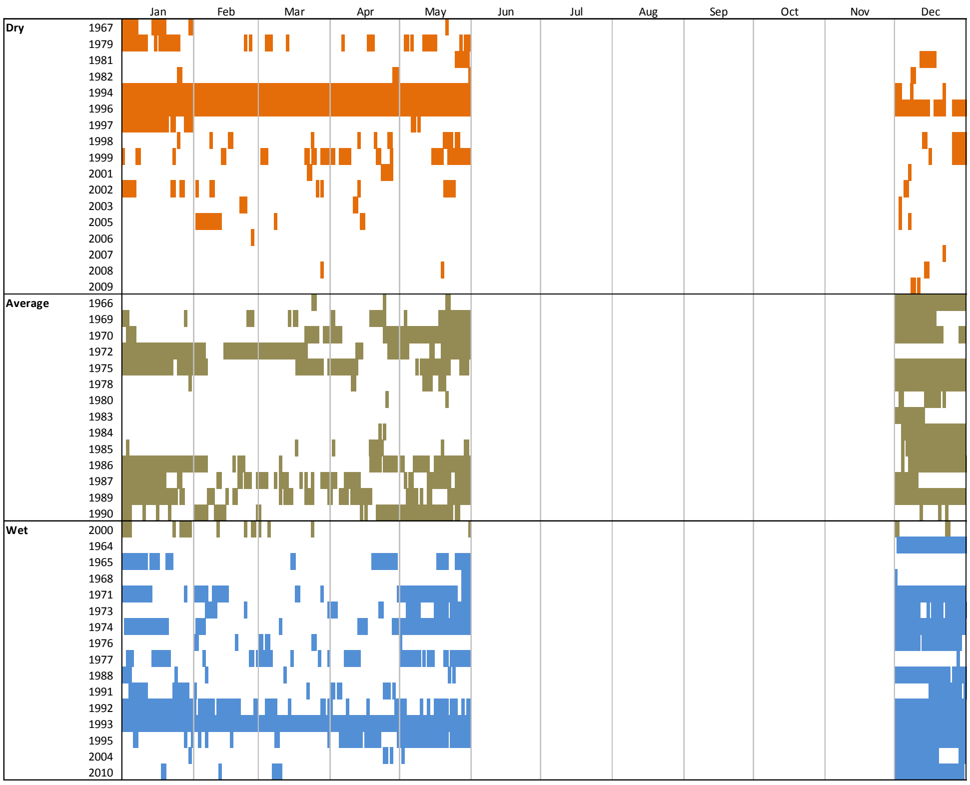
- **Figure 8-1 Stage height in a pools (Transect 5, left) and gravel run (Transect 6, right) at 200 ML/day and 300 ML/day in Reach 6.**

8.2.2. Summer/autumn freshes

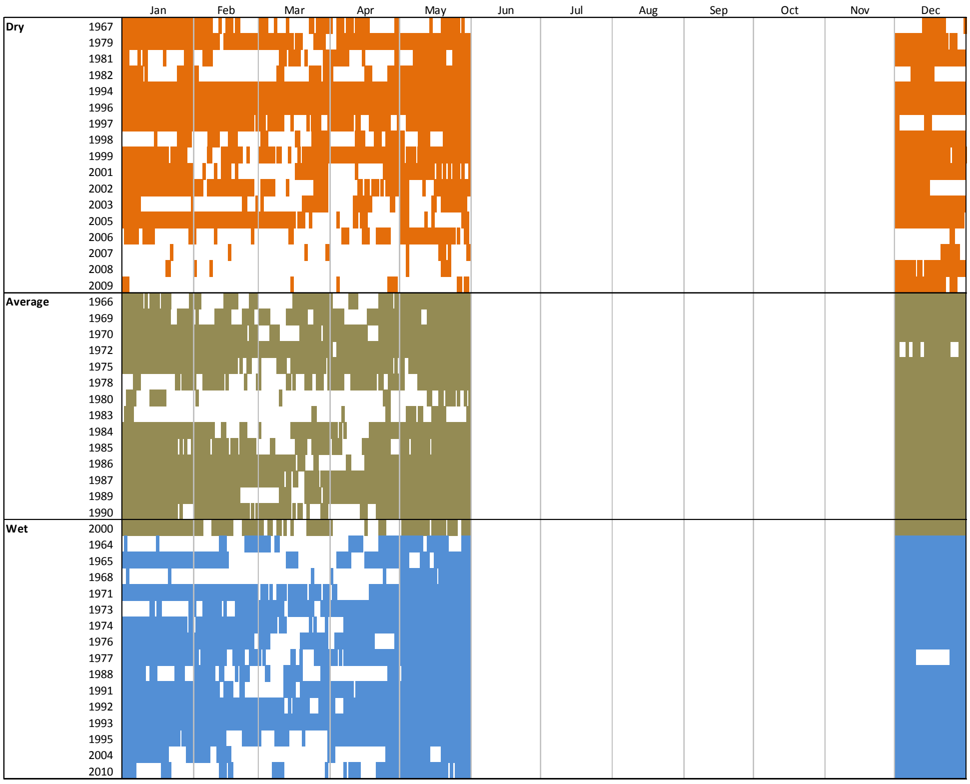
The recommended summer fresh is for three events of 750 ML/day that last for two days each, which is unchanged from 2005. The recommended flow is sufficient to achieve average velocities of 40 cm/s through gravel riffles and around LWD located low in the channel to scour sediment and excessive algal growth. However, in urban reaches the potential reduction in algal growth is likely to be relatively short lived due to elevated nutrient concentrations that contribute to rapid regrowth (Taylor *et al.*, 2004). Summer freshes will also wet the lower banks to maintain flood-tolerant vegetation. In average and wet years tributary inflows provide variation in the magnitude and duration of the summer fresh above the minimum recommended flow (Figure 8-3 and Figure 8-4).



- **Figure 8-2 Stage height in a pool (Transect 5, left) and a gravel run (Transect 6, right) at the recommended threshold for summer/autumn fresh flows (750 ML/d) in Reach 6.**



- **Figure 8-3 Characteristics of summer/autumn fresh threshold for current conditions for Reach 6. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**

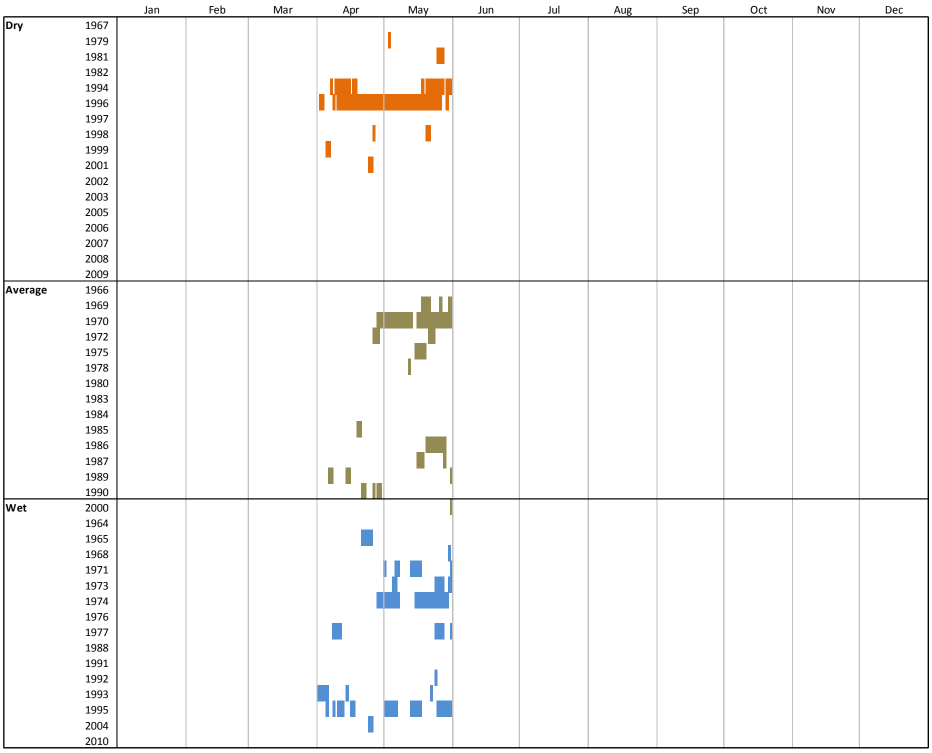


- **Figure 8-4 Characteristics of summer/autumn fresh threshold for unimpacted conditions for Reach 6. This plot shows the number and duration of flows above the recommended threshold that would have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.**

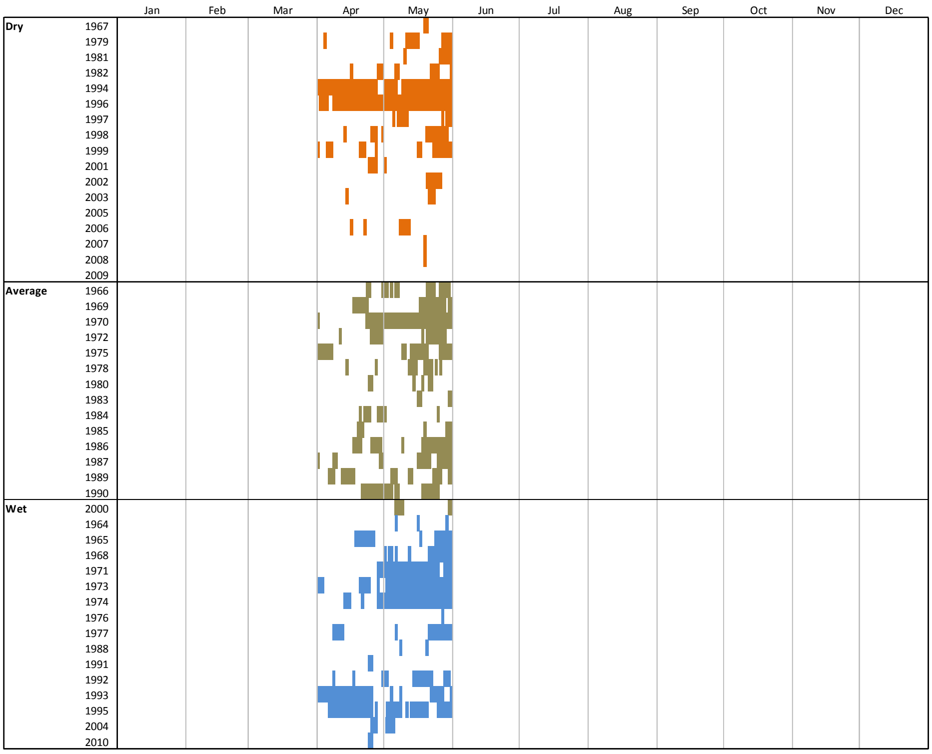
8.2.3. Summer/autumn high flows

The summer/autumn high flow recommendation has been reduced from 1,500 ML/day to a minimum of 1300 ML/day to occur once per year in April or May for a duration of seven days. This event aims to trigger migration and spawning of Australian Grayling. The revised recommendation is based on recent work by Koster (unpublished) that reported spawning by Australian Grayling in this reach after a flow event of 1,300 ML/day. There is still some uncertainty regarding the flow range required to trigger Australian Grayling spawning, so all flow above the recommended magnitude should be preserved in case a higher magnitude event is required to increase the number of individuals that spawn. In effect, the decrease in the recommended flow threshold provides protection for a larger number of events that could potentially trigger spawning. A seven day duration has been specified for this event to provide enough time to transport larvae to the estuary.

The flow recommendation would be met in average and wet climate years if the first high flow in autumn is allowed to progress down the entire system (Figure 8-5 and Figure 8-6). The event may not be achieved in all dry climate years and efforts should be made to deliver the event if it has not occurred for two consecutive years.



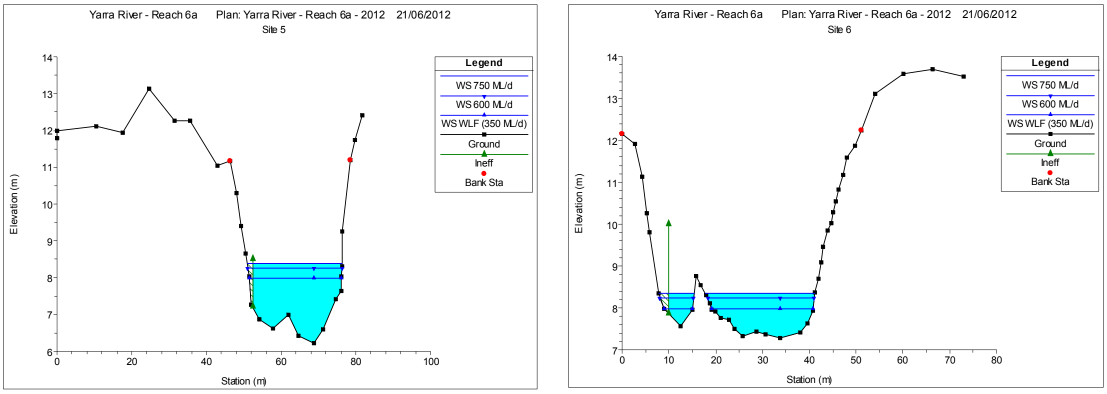
▪ **Figure 8-5 Characteristics of summer/autumn high threshold for current conditions for Reach 6. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**



▪ **Figure 8-6 Characteristics of summer/autumn high threshold for unimpacted conditions for Reach 6. This plot shows the number and duration of flows above the recommended threshold that would have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.**

8.2.4. Winter/spring low flows

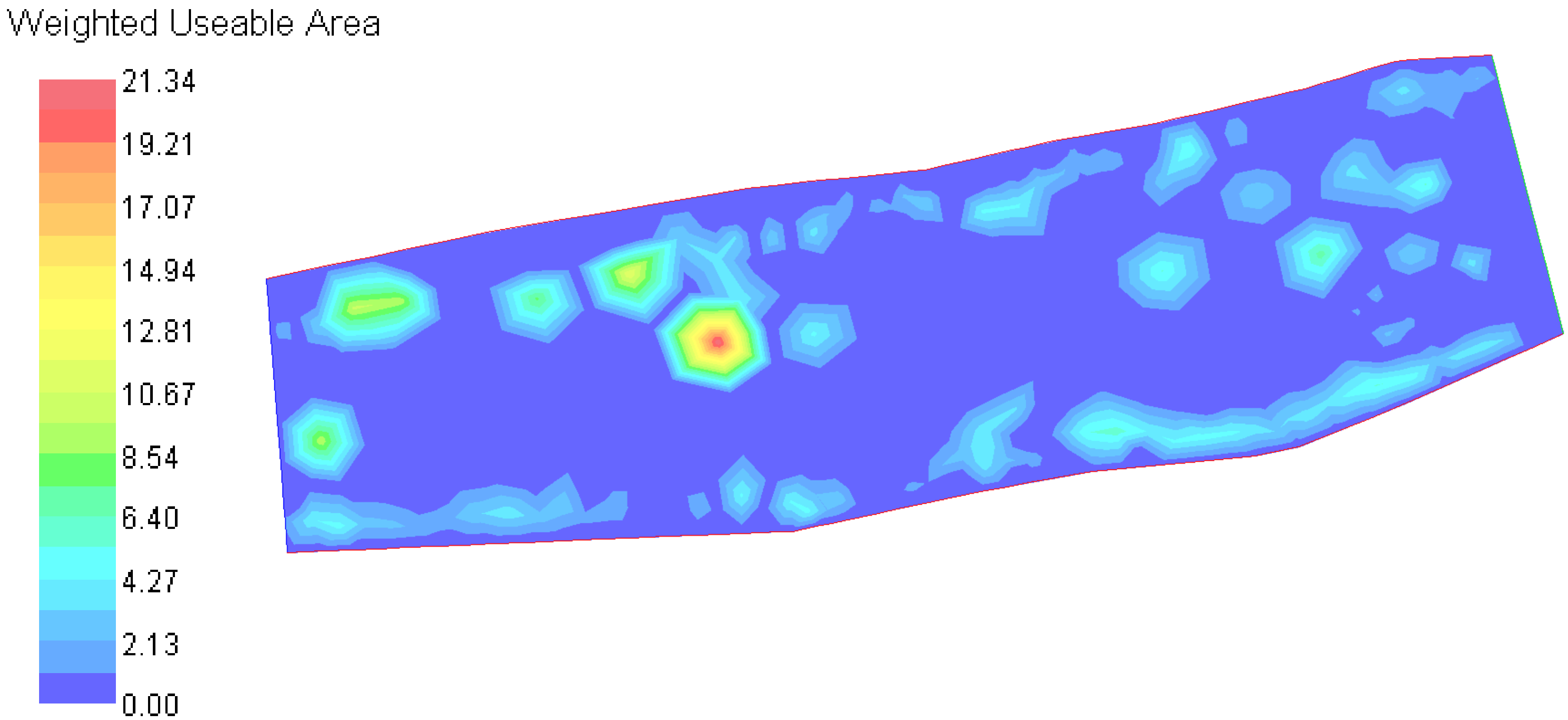
The winter/spring low flow threshold of 350 ML/day is retained as a minimum flow, but the recommendation has been modified to include a median low flow of 600 ML/day in dry climate years and a median of 750 ML/day in average and wet climate years. This revision aims to introduce additional variability in the winter low flow. This minimum flow is sufficient to inundate vegetation on the lower banks and also inundates a small backwater area at Transect 6 (Figure 8-7). Backwaters are important habitats for fish and macroinvertebrates in lowland rivers so flows that increase the area of these habitat types are important.



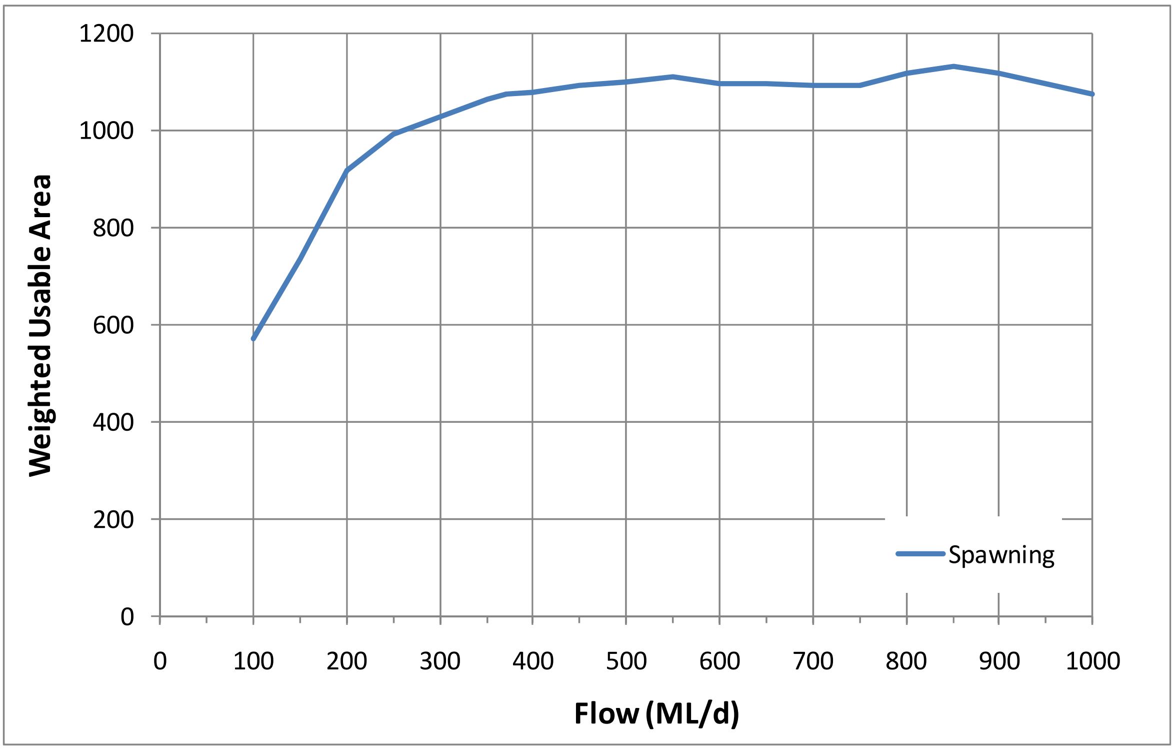
- **Figure 8-7 Stage height in a pool (Transect 5, left) and gravel run (Transect 6, right) at the recommended threshold for autumn/spring low flows (350 ML/day, 600 ML/day & 750 ML/d) in Reach 6.**

The addition of a median flow requirement improves the flow regime to better support successful spawning of Macquarie perch. Habitat preference modelling of the Finns Reserve spawning riffle site (see Figure 8-8 for an example of the model output) shows that the preferred flow range for Macquarie perch spawning is 400-1000 ML/day (Figure 8-9). Flow recommendations are based on maximising weighted useable area. Weighted useable area is a combination of velocity and depth preferences for Macquarie Perch spawning (see Table 2-3 in Section 2.6 for criteria).

The introduction of a median flow above 450 ML/day also ensures that Dights Falls Weir Pool remains well mixed through the winter and spring period in all climate years. This is particularly important in spring when juvenile diadromous fish are migrating upstream from the estuary to freshwater reaches: they need to traverse the Dights Falls Weir pool to reach all upstream reaches of the Yarra and its tributaries.



- **Figure 8-8 Weighted usable area for Macquarie perch spawning at a flow of 750 ML/day (the higher the weighted usable score the better the habitat conditions are for spawning based on spawning depth and velocity preferences for Macquarie perch – the red, yellow and green shows areas of preferred habitat).**



▪ **Figure 8-9 Distribution of weighted useable area across the flow range from 100 to 1000 ML/day for spawning Macquarie perch.**

8.2.5. Winter/spring freshes and high flows

The recommended magnitude for the winter/spring fresh and high flow is 2,500 ML/day. This is slight increase compared to the 2005 recommendation of 2,300 ML/day to allow for tributary inflows to augment matching recommendation in upstream reaches. Two freshes, which each last for seven days, are recommended between June and September. One high flow that lasts for 14 days is recommended between October and November. A flow of 2,500 ML/day is sufficient to achieve a minimum velocity of 40 cm/s through riffles and runs to scour sediment and biofilms; provide more than 1 m depth over runs for fish passage, and inundate the lower and mid banks to disturb vegetation (Figure 8-10).

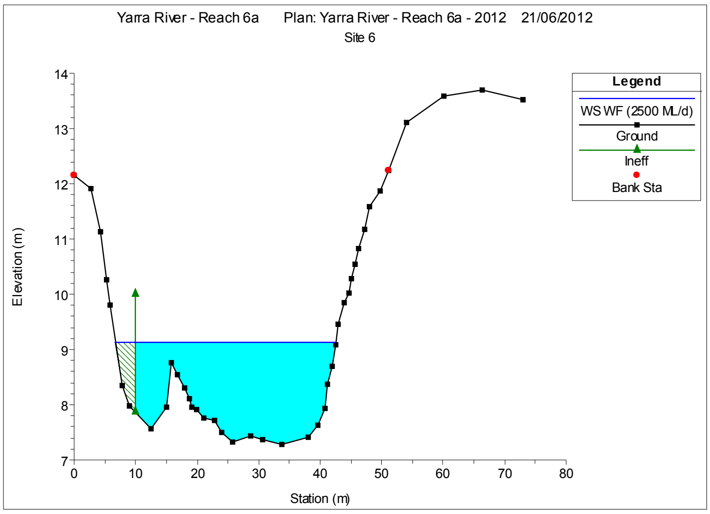


Figure 8-10 Stage height in a gravel run (Transect 6) at the recommended threshold for autumn/spring fresh/high flow in Reach 6.

Freshes and high flows in this reach also provide important flows to the Yarra estuary where they provide migration cues for diadromous fish to ascend to freshwater reaches and assist in reducing salinity by mixing the salt wedge. The newly completed Dights Falls fishway will improve upstream movement opportunities and allow diadromous fish to take advantage of the flow recommendation.

King and Mahoney (2010) suggested that high flows in the October-November period may reduce Macquarie Perch recruitment because they flush larvae and juveniles from the system. However, adverse effects were only observed for flows well in excess of 4,000 ML/day (King and Mahoney, 2010) and therefore the recommended high flow of 2,500 ML/day represents a low risk to Macquarie Perch.

The frequency of flows greater than 2,500 ML/day is similar under current and unimpacted conditions, but the events would generally have a much longer duration under unimpacted conditions (Figure 8-11 and Figure 8-12). The winter high flow that is recommended for October and November will only rarely occur in dry climate years (Figure 8-11).

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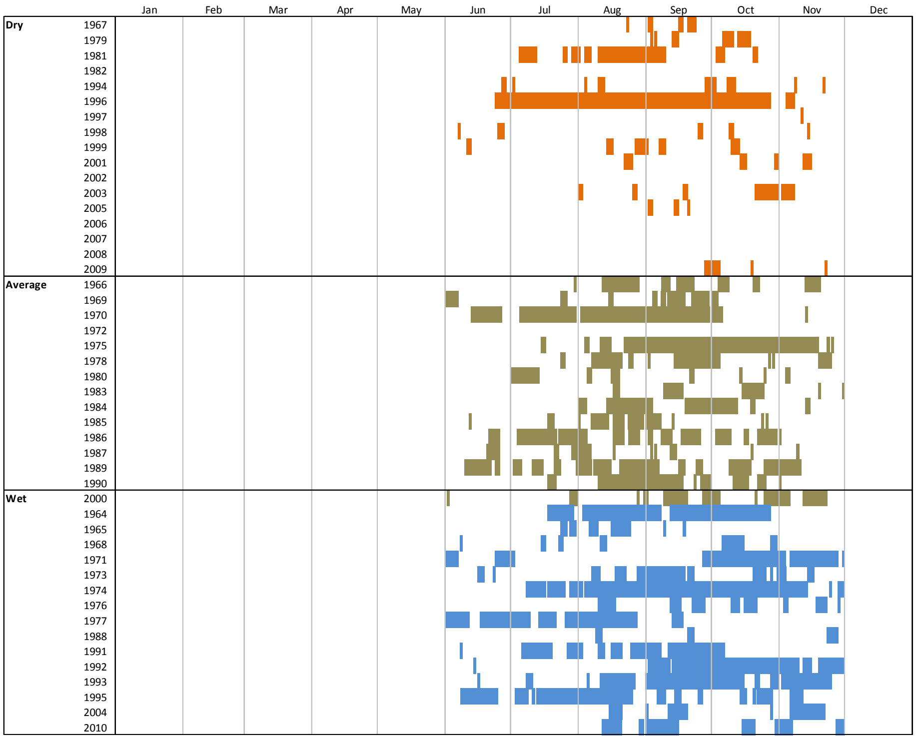
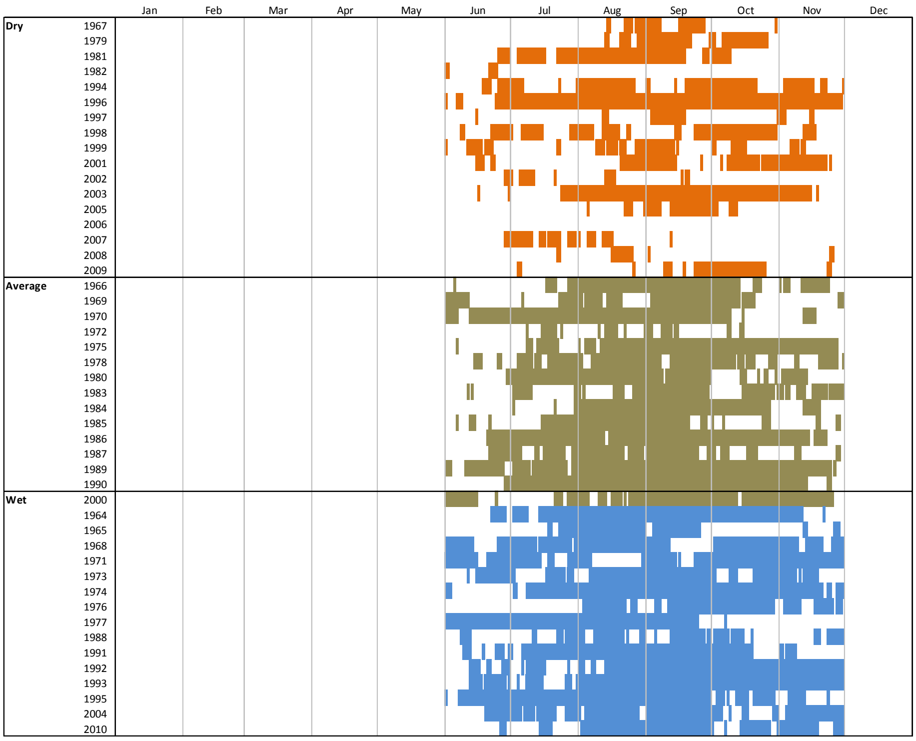


- **Figure 8-11 Characteristics of winter/spring fresh and high flow threshold for current conditions for Reach 6. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**

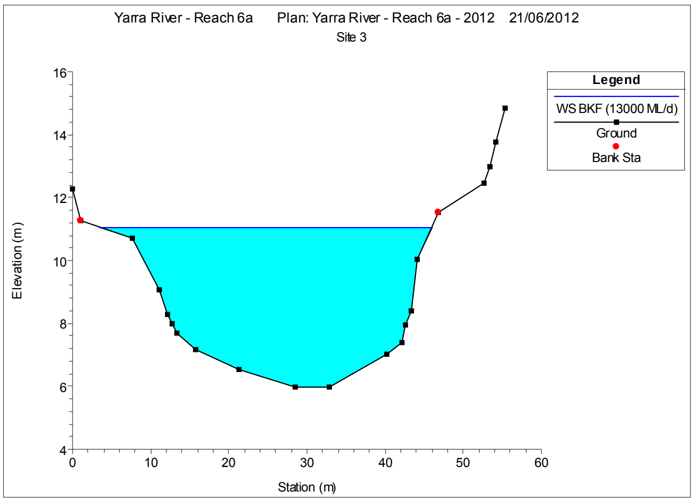


- **Figure 8-12 Characteristics of winter/spring fresh and high flow threshold for unimpacted conditions for Reach 6. This plot shows the number and duration of flows above the recommended threshold that would have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.**

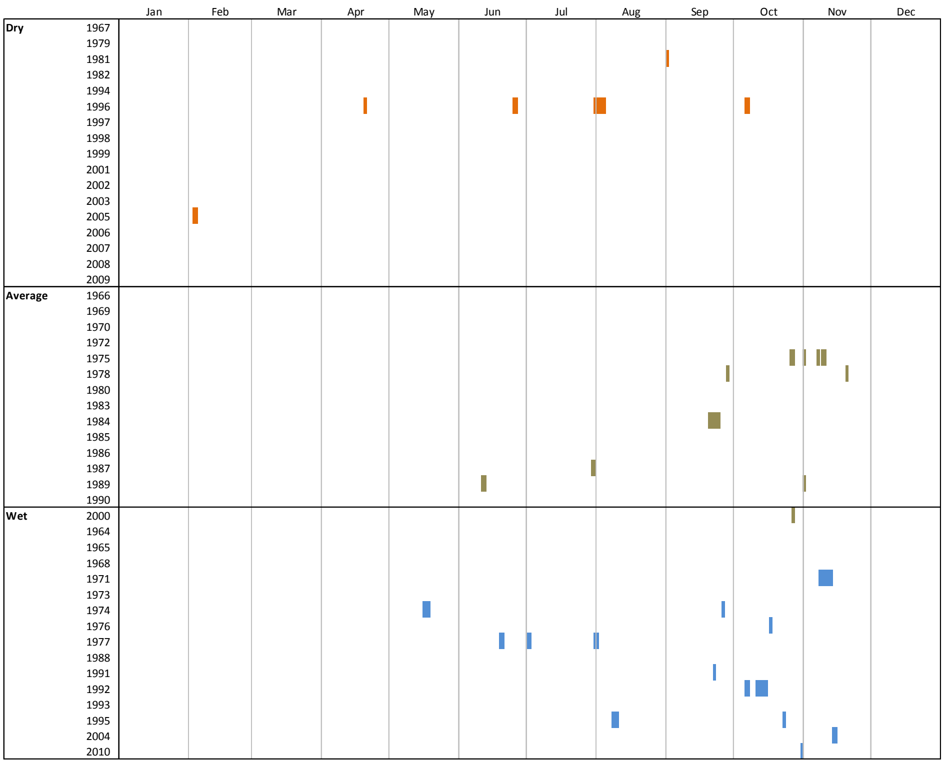
8.2.6. Bankfull flows

The bankfull flow recommendation is 13,000 ML/day once every two years for 1-2 days duration. This recommendation is unchanged from 2005. A flow of 13,000 ML/day is sufficient to reach the top of the bank at most transects and inundate high level benches and some wetlands with a direct connection to the river at around the bankfull level (Figure 8-13). Under current conditions the bankfull flow occurs once every two years on average (Figure 8-14). Under unimpacted conditions, one to two bankfull flows would have occurred each year (Figure 8-15). The median duration of these events is approximately two days under current and unimpacted conditions and most events commence in September or October (Figure 8-14 and Figure 8-15).

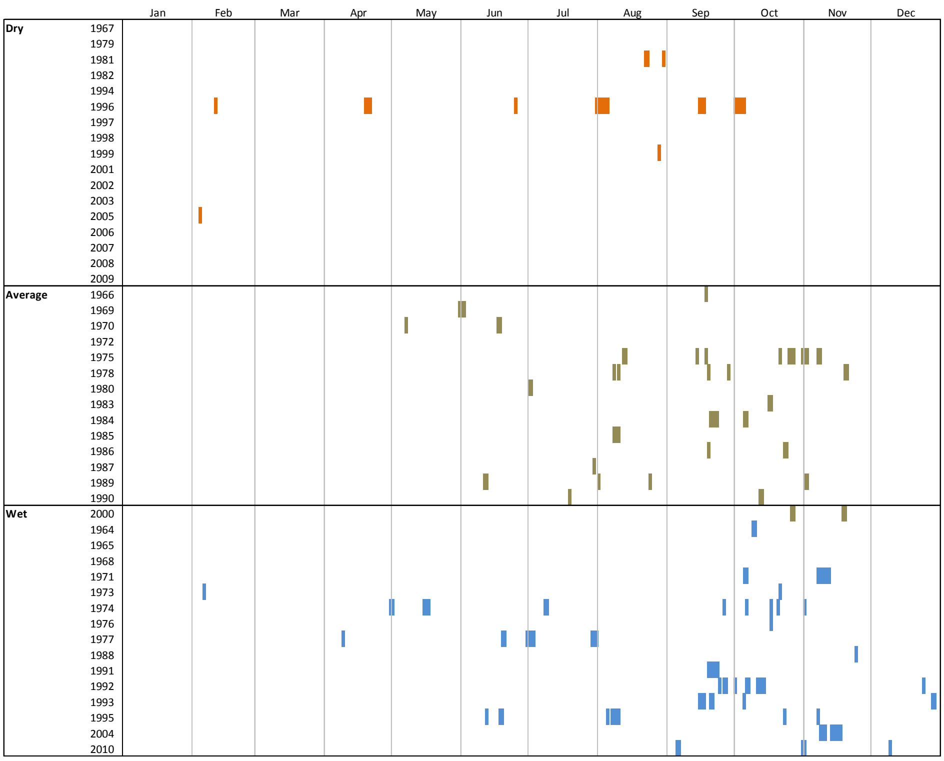
As with the upstream reaches, the bankfull recommendation is aimed at protecting existing flows when they occur rather than requiring specific releases to be made from storages.



- **Figure 8-13 Stage height in a pool (Transect 3) at the recommended threshold for bankfull flows in Reach 6.**



- **Figure 8-14 Characteristics of bankfull flow threshold for current conditions for Reach 6. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**



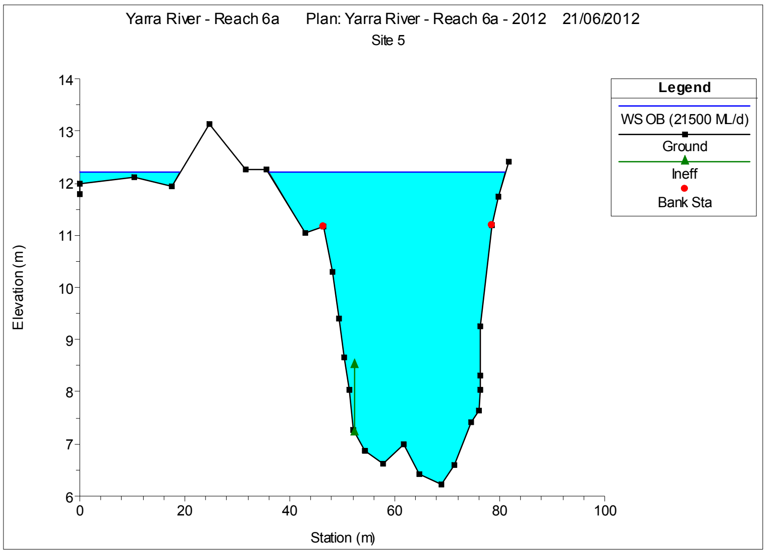
- **Figure 8-15 Characteristics of bankfull flow threshold for unimpacted conditions for Reach 6. This plot shows the number and duration of flows above the recommended threshold that would have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.**

8.2.7. Overbank flows

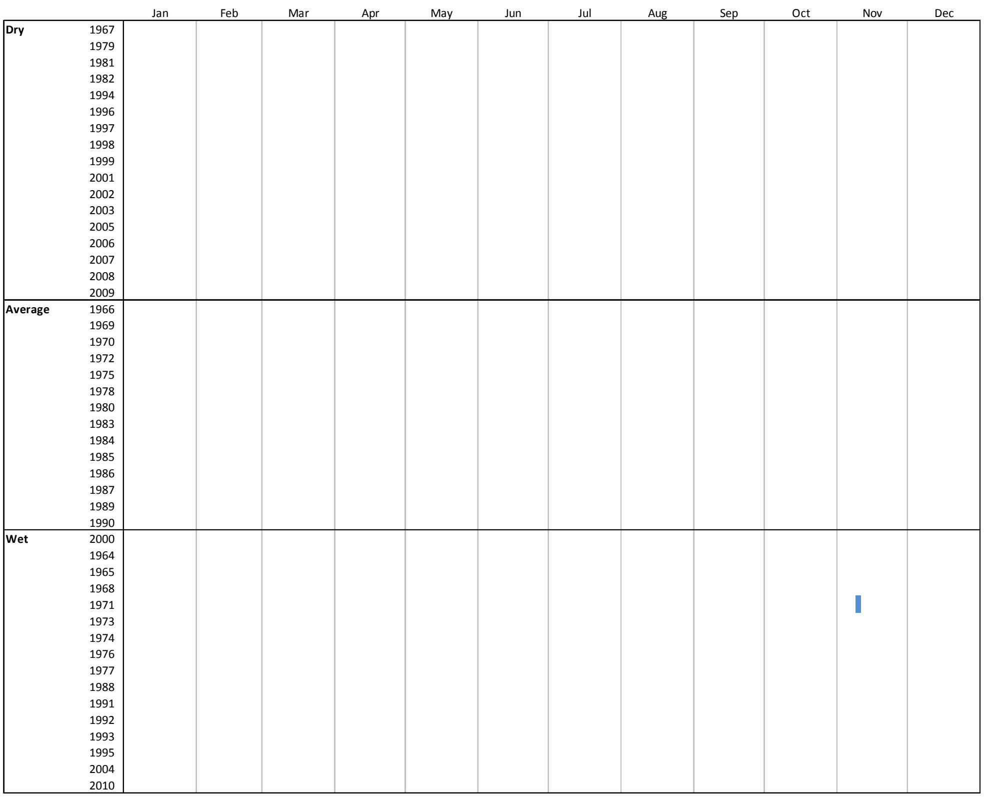
The recommended overbank flow threshold is 21,500 ML/day once every four years for a duration of 1-2 days. This recommendation is unchanged from 2005. A flow of 21,500 ML/day is sufficient to overtop banks (see Transect 5 in Figure 8-16) and spill into the Banyule Billabong. Under current conditions an overbank flow occurs on average once every 10 years (Figure 8-17). Under unimpacted conditions, overbank flows would have occurred once every two to three years (Figure 8-18). The median duration of this event is one day under current and unimpacted conditions and while most events occur in winter or spring, they can occasionally occur at other times of the year (Figure 8-17 and Figure 8-18).

Of all the bankfull and overbank flow recommendations in the Yarra River, the overbank flow threshold in Reach 6 is least often achieved. The effect of less frequent overbank flows in this reach is evident in changes to the vegetation community composition in Banyule Wetland (see Ecosystems, 2007, and discussion in Dodo Environmental, 2009). It will be difficult to increase the frequency of overbank flows in Reach 6 because it is not possible to release the required volume of water from upstream storages without causing serious flooding. Given, overbank flows cannot be actively delivered, it is critical that natural overbank flows are allowed to pass through the system when they do occur.

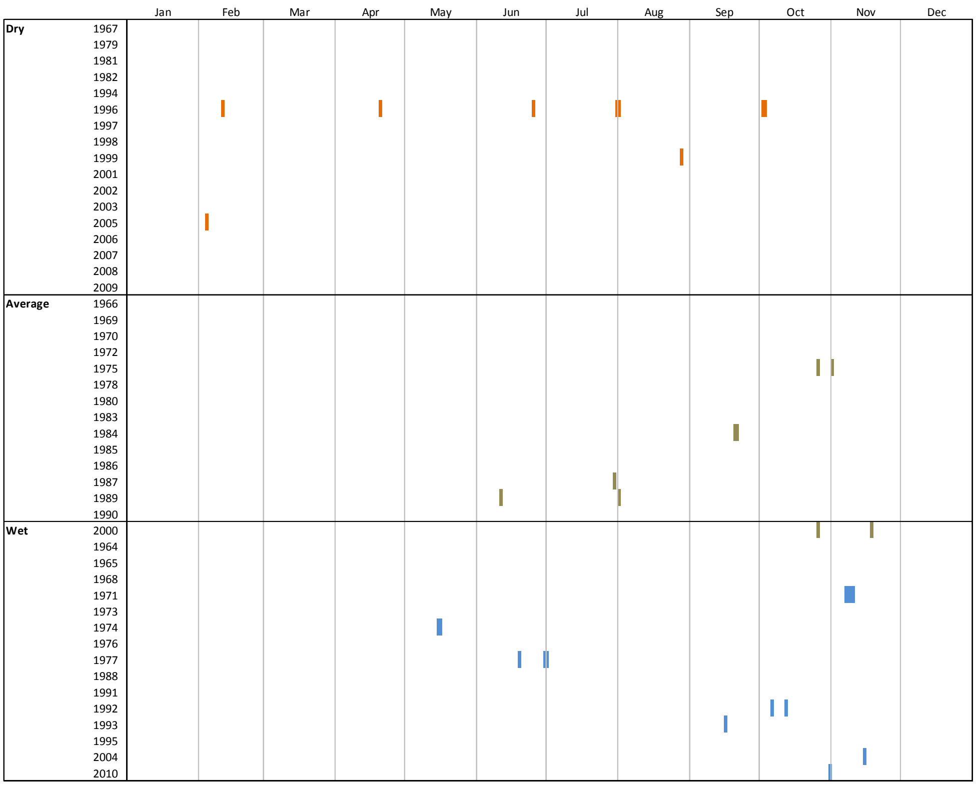
The recommended frequency of overbank flows in Reach 6 has been based on protecting the existing values associated with billabongs such as the Banyule Billabong. An inability to achieve the objective may, over time, result in a shift in the composition and structure of some wetlands that experience less frequent inundation. However, there are other mechanisms that could be used to deliver water to important wetlands at a more appropriate frequency. Specific mechanisms may include pumping or the artificial lowering of bank levels. Further recommendations for such opportunities are presented in Section 11 on complementary works.



- **Figure 8-16 Stage height in a pool (Transect 5) at the recommended threshold for overbank flows in Reach 6.**



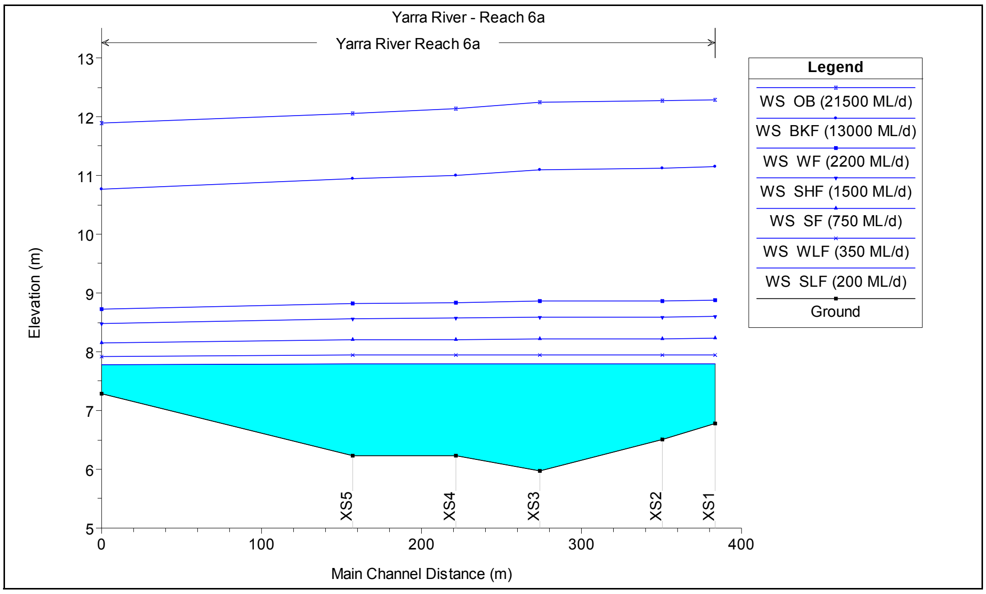
- **Figure 8-17 Characteristics of overbank flow threshold for current conditions for Reach 6. This plot shows the number and duration of flows above the recommended threshold that have occurred in each dry, wet and average climate year since 1964.**



- **Figure 8-18 Characteristics of overbank flow threshold for unimpacted conditions for Reach 6. This plot shows the number and duration of flows above the recommended threshold that would have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.**

8.2.8. Long section

Figure 8-19 shows the water surface level for each flow threshold along a long section of Reach 6. The profile highlights the predominance of long pools throughout the reach, although there is a gravel run at the lower end of the assessment site and water surface levels indicate sufficient depth is achieved over this run for fish passage at all recommended flows.



▪ **Figure 8-19 Long section showing water surface level for all flows in Reach 6.**

8.2.9. Current achievement of flow recommendations

An assessment of how well the flow recommendations for Reach 6 are currently met in wet, average and dry years is presented in Table 8-2, Table 8-3 and Table 8-4. It should be noted that these assessments include an 'or natural' clause, which considers the flows that would have occurred in Reach 6 in wet, dry and average years under unimpacted conditions. For example, if the hydrological analysis shows that the recommended winter high flow would only occur in 25 out of 30 years in average years then the level of achievement is based on how many of those 25 events are delivered under the current level of development and system operation.

The summer low flow recommendation of 300ML and winter low flow recommendations for Reach 6 are currently met more than 80% of the time in wet and average years, but are only met 44% of the time in dry years. If the summer low flow recommendation were to be increased to 450 ML/day between December and March, then the current level of achievement would drop to 60-70% for wet and average years and 24% in dry years.

The recommended summer fresh is currently met approximately in 80% of wet years, 69% of average climate years and only 44% of dry years. The recommended summer high flow is met 60% of the time in wet years, 69% of the time in average years and 50% of the time in dry years. The higher achievement in dry years, does not indicate that more of these events occur in dry years. Rather it indicates that a higher proportion of the flows that would naturally occur are still observed. It is important that summer high flows are delivered in most wet and average climate years and extra releases may need to be made from upstream storages to achieve those recommendations. The 50% achievement in dry years is likely to be sufficient, provided at least one event occurs every three years.

The recommended winter fresh is only achieved between 60% and 70% of the time in average and wet years and only 25% in dry years. The recommended winter high flow for Reach 6 is currently met in only 56% of wet years and 53% of average climate years. Bankfull flows generally occur at least once every two years in wet conditions as recommended, but they occur only half as often as recommended in average climate years. The cumulative effect of upstream storages has significantly reduced the frequency of overbank flows, which only occur in a very small proportion of very wet years. It is impractical and probably undesirable from a social and economic perspective to actively deliver more frequent overbank floods

In summary, the level of achievement with environmental flow recommendations for Reach 6 is lower in dry years compared to wet and average climate years and is very low compared to reaches upstream of the Yering Pump station. These patterns suggest that the operation of the Yering Pump station significantly reduces the magnitude of summer and winter low flows and reduces the number and magnitude of freshes and summer high flows, which in turn reduces overall flow variability. The reduced frequency of summer high flows is particularly important for Australian Grayling and the operating rules for the Yering Pump Station may need to be modified to improve low flows and moderate sized events through Reaches 5 and 6. The operation of Upper Yarra Reservoir and Maroondah Reservoir has reduced the frequency of bankfull and overbank flows in Reach 6, but increasing the frequency of these very large events is probably neither practical or desirable.

The ability to meet low flow recommendations in urban reaches may be improved through the implementation of catchment-wide low-impact stormwater drainage systems. Recent research by Walsh *et al.* (2005) suggests that low-impact urban drainage systems that result in an increase in infiltration rather than rapid runoff may lead to higher and sustained low flows through improved groundwater inflows to urban streams. In addition, low-impact drainage design reduces the 'flashiness' of flows associated with rainfall runoff in urban catchments and can help contribute to significant water quality improvements (Walsh *et al.*, 2005).

- **Table 8-2 Extent to which the environmental flow recommendations for Reach 6 are currently being met during dry years.**

Component	Months	Flow Recommendation			Or Natural	Compliance
Summer low	Dec - May	Magnitude	300	ML/d	Yes	44%
Summer fresh	Dec - Apr	Magnitude	750	ML/d	Yes	44%
		Frequency	3	per year		
		Duration	2	days		
Summer high	Apr - May	Magnitude	1300	ML/d	Yes	50%
		Frequency	1	per year		
		Duration	7	days		
Winter low	Jun - Nov	Magnitude	350	ML/d	Yes	86%
Winter fresh	Jun - Sep	Magnitude	2500	ML/d	Yes	25%
		Frequency	2	per year		
		Duration	7	days		
Winter high	Oct - Nov	Not expected, but allow to occur naturally				
Bankfull	Jan - Dec	Not expected, but allow to occur naturally				
Overbank	Jan - Dec	Not expected, but allow to occur naturally				

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Table 8-3 Extent to which the environmental flow recommendations for Reach 6 are currently being met during average years.

Component	Months	Flow Recommendation					Or Natural	Compliance
Summer low	Dec - May	Magnitude	300	ML/d			Yes	82%
Summer fresh	Dec - Apr	Magnitude	750	ML/d			Yes	69%
		Frequency	3	per year				
		Duration	2	days				
Summer high	Apr - May	Magnitude	1300	ML/d			Yes	69%
		Frequency	1	per year				
		Duration	7	days				
Winter low	Jun - Nov	Magnitude	350	ML/d			Yes	98%
Winter fresh	Jun - Sep	Magnitude	2500	ML/d			Yes	69%
		Frequency	2	per year				
		Duration	7	days				
Winter high	Oct - Nov	Magnitude	2500	ML/d			Yes	56%
		Frequency	1	per year				
		Duration	14	days				
Bankfull	Jan - Dec	Magnitude	13000	ML/d			Yes	53%
		Frequency	1	in	2	years		
		Duration	2	days				
Overbank	Jan - Dec	Magnitude	21500	ML/d			Yes	0%
		Frequency	1	in	4	years		
		Duration	2	days				

Table 8-4 Extent to which the environmental flow recommendations for Reach 6 are currently being met during wet years.

Component	Months	Flow Recommendation					Or Natural	Compliance
Summer low	Dec - May	Magnitude	300	ML/d			Yes	87%
Summer fresh	Dec - Apr	Magnitude	750	ML/d			Yes	80%
		Frequency	3	per year				
		Duration	2	days				
Summer high	Apr - May	Magnitude	1300	ML/d			Yes	60%
		Frequency	1	per year				
		Duration	7	days				
Winter low	Jun - Nov	Magnitude	350	ML/d			Yes	99%
Winter fresh	Jun - Sep	Magnitude	2500	ML/d			Yes	60%
		Frequency	2	per year				
		Duration	7	days				
Winter high	Oct - Nov	Magnitude	2500	ML/d			Yes	53%
		Frequency	1	per year				
		Duration	14	days				
Bankfull	Jan - Dec	Magnitude	13000	ML/d			Yes	80%
		Frequency	1	in	2	years		
		Duration	2	days				
Overbank	Jan - Dec	Magnitude	21500	ML/d			Yes	27%
		Frequency	1	in	4	years		
		Duration	2	days				

9. Reach 8: Watts River downstream of Maroondah Reservoir

9.1. Description

Reach 8 on the Watts River is located downstream of Maroondah Dam to the confluence with the Yarra River. There is a 1 ML/day continual release from the dam to the Watts River. The first tributary inflow (Donnellys Creek) occurs approximately 1.5 km downstream with subsequent inflows from Chum Creek and Grace Burn.

The site used for the 2005 flow assessment is located downstream of all major tributary inflows. In 2005 the site had a pool/riffle structure and willows had recently been cleared from its banks. Re-vegetation efforts in 2004 and 2005 have been successful and the site now has established wattle trees. However, the shape of the channel has changed and the riffles that were previously a feature are no longer obvious. There is a large amount of silt in the channel, which may have washed into the creek from bushfire affected areas.

The 2005 flow assessment site is not very good for assessing the minimum flows that are required to maintain riffle habitats and backwaters, nor is it likely to help determine the maximum flows that can be transferred from Maroondah Reservoir to the Yarra River without damaging low flow habitats in Watts River. Therefore a new site just downstream of the confluence with Donnelly Creek was assessed for the revised recommendations. This site has a cobble substrate, with a distinct riffle pool sequence (see Figure 9-1) and a flood runner that will fill during high flow events. The riparian vegetation at the proposed site is also more natural and has a mix of remnant eucalypt species and some native understorey species.

- **Figure 9-1 Watts River. Photo on the left shows the 2005 assessment site just downstream of the confluence with Grace Burn. Photo on the right shows the 2012 assessment site just downstream of the confluence with Donnelly Creek.**

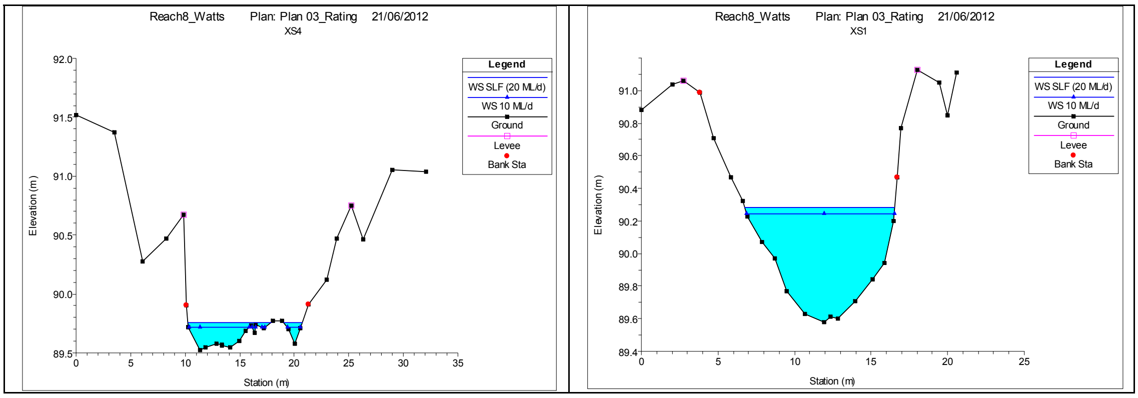
9.2. Flow recommendations

The general flow objective is to provide access to habitat for fish and macroinvertebrates, minimise prolonged stable low flow periods by ensuring some variability and to ensure appropriate high flows in the winter period. Secondary objectives are to minimise risks to the Watts River values when using the Watts River as a conduit to deliver environmental flows to reaches downstream in the Yarra River itself.

The environmental flow recommendations for Reach 8 are summarised in Table 9-1.

9.2.1. Summer/autumn low flows

The recommended summer/autumn low flow threshold is median flow of 20 ML/day with a minimum flow of 10 ML/day. The introduction of a median recommendation provides for additional variation in the summer low flow. The minimum flow ensures that riffles are sufficiently inundated to maintain habitat for macroinvertebrates, yet also provides exposed rocks for macroinvertebrates to lay eggs (see Transect 4 in Figure 9-2) and provides suitable depth to maintain access to pool habitats for fish (see Transect 1 in Figure 9-2).



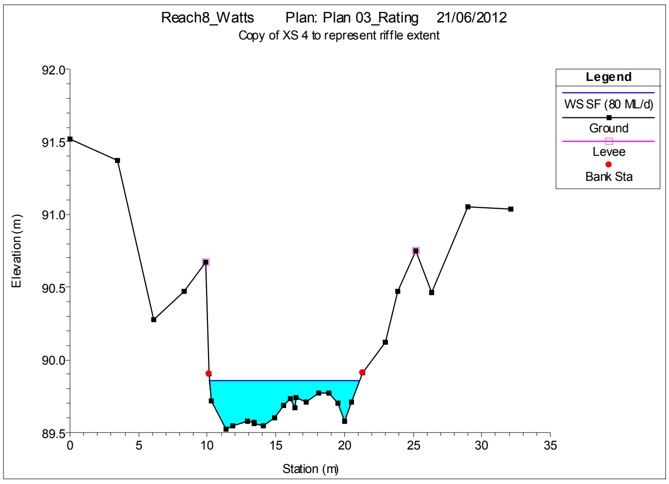
- **Figure 9-2 Stage height in a riffle (Transect 4, left) and a pool (Transect 1, right) at the recommended minimum (10 ML/d) and median (20 ML/d) threshold for summer/autumn low flow in Reach 8.**

Table 9-1 Flow recommendations for Reach 8.

Stream		Watts River		Reach	Downstream Maroondah Reservoir		
Compliance point		Healesville-Kinglake Road		Gauge No.	229144		
Season	**Flow**	**Objective (refer to objectives tables for id reference)**	**Wet/Avg/ Dry**	**Volume**	**Frequency and when**	**Duration**	**Rise/Fall**
Summer / Autumn (Dec-May)	Low flow	Maintain access to habitat for bugs & fish, drying period for bank vegetation (M8-1, F8-1, V8-1)	Wet	Median 20 ML/day, but ensure the minimum flow is greater than 10 ML/day, allow Donnelly's Creek and other tributaries to provide variation above 20 ML/day in average and wet years.			
			Average				
			Dry				
	Fresh	Maintain suitable riffle habitat by periodically scouring sediment & biofilms, maintain flood-tolerant vegetation on banks (M8-2, F8-1, V8-2)	Wet	80 ML/day, tributary inflows provide variation during average and wet years. Higher magnitude and longer duration flows are acceptable in average and wet years Maximum 250 ML/day if transferring to downstream reaches.	Minimum 4 events delivered + additional events provided by Tributaries.	Min 2 day at peak, Longer duration flows acceptable in average and wet years.	1.6/0.7
			Average				
			Dry				
	High	No specific recommendation but allow higher flows to occur naturally from tributary inflows or spills from Maroondah Reservoir.					
Winter / spring (Jun-Nov)	Low flow	Maintain access to habitat for bugs & fish (M8-1, F8-1, V8-1)	Wet	Minimum recommendation of 80 ML/day, allow tributaries to provide additional variation greater than 80ML/day in average and wet years. Maximum flow of 180 ML/day for up to 2 weeks duration if transferring to downstream reaches.			
			Average				
			Dry				
	Fresh	Maintain suitable riffle habitat by periodically scouring sediment & biofilms, maintain flood-tolerant vegetation on banks, provide local fish passage, entrain organic material (M8-2, F8-1, V8-1)	Wet	180 ML/day tributary inflows provide variation during average and wet years. Higher duration and longer duration flows are acceptable in average and wet years. Maximum 300 ML/day if transferring to downstream reaches.	4-5 per year	Min 2 day at peak. Longer duration flows acceptable in average and wet years.	1.6/0.7
			Average		3-4 per year		
			Dry		2-3 per year		
	High	No specific recommendation but allow higher flows to occur naturally from tributary inflows or spills from Maroondah Reservoir.					
	Bankfull / overbank	Maintain existing channel geometry & prevent further vegetation encroachment in channel, entrain organic material, engage high flow channels (G8-1, M8-3, V8-3)	Wet	1000 ML/day. Higher and longer duration flows are acceptable in average and wet years. Event unlikely to occur in dry years.	1 in 2 years, although may not occur in dry years and not necessary to actively deliver. Avoid delivering in November onwards to minimise risks to River Blackfish larvae.	2 days	1.6/0.7
			Average				
			Dry				

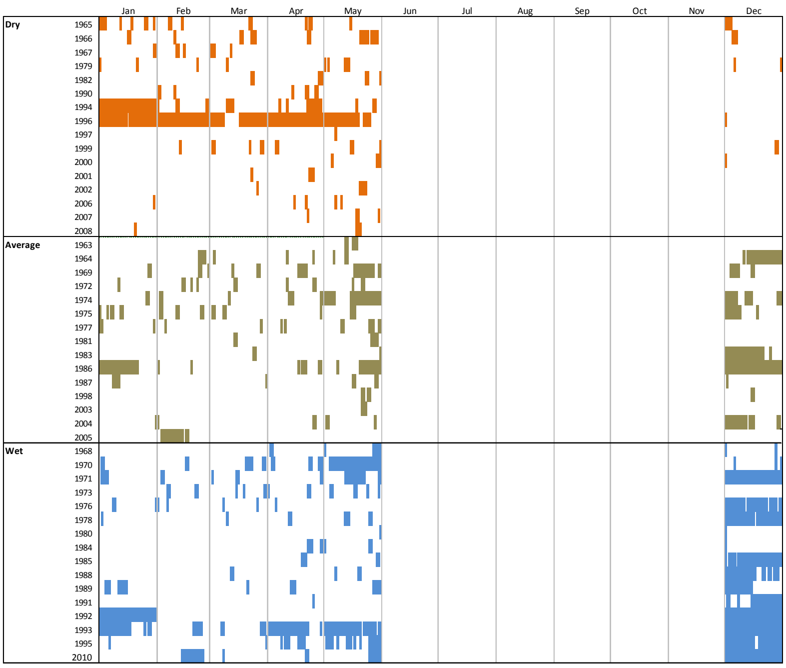
9.2.2. Summer/autumn freshes

The recommended summer/autumn fresh threshold is 80 ML/day, which should occur four times per year for a duration of two days. This recommendation is unchanged from 2005. A flow of 80 ML/day increases depth over riffles compared to the summer low flow and (Figure 9-3) should create sufficient velocity to scour sediment from riffle habitats and to mix and freshen pools.

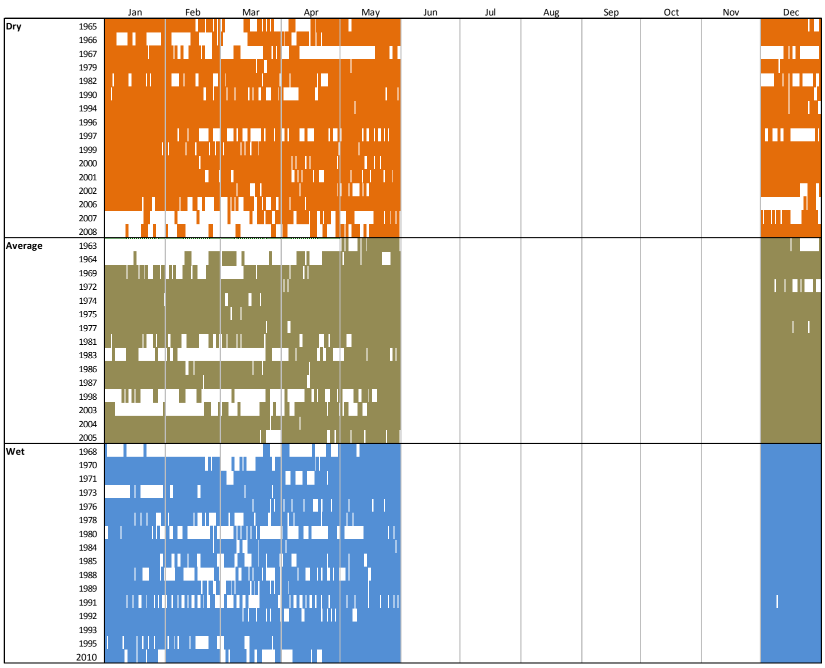


- **Figure 9-3 Stage height in a riffle (Transect 4) at the recommended threshold for summer/autumn fresh flow (80 ML/d) in Reach 8.**

The recommended number and duration of summer freshes would occur in wet years and in most average years under current flow conditions, but will not be met in all dry years (Figure 9-4 and Figure 9-5). Four summer flows greater than 80 ML/day are likely to occur in most dry years under current conditions, but these events are only likely to last for one day at a time. If there was no water harvesting in the catchment, summer flows would be expected to exceed 80 ML/day for most of the time in wet, average and dry climate years (Figure 9-5).



- **Figure 9-4 Characteristics of summer/autumn fresh threshold for current conditions for Reach 8. This plot shows the number and duration of flows above the recommended threshold that would have occurred under current flow conditions each dry, wet and average climate year since 1964.**



- **Figure 9-5 Characteristics of summer/autumn fresh threshold for unimpacted conditions for Reach 8. This plot shows the number and duration of flows above the recommended threshold that would have occurred under unimpacted flow conditions each dry, wet and average climate year since 1964.**

The magnitude of the summer fresh may be increased up to 250 ML/day if transfer flows need to be delivered from Maroondah Reservoir to meet flow recommendations in downstream reaches. Flows above 250 ML/day generate a shear stress >15 N/m^2, which is too high for a summer fresh as it would roll over cobbles and create too much disturbance of riffles and potentially flush juvenile River Blackfish from pools.

There is no specific summer/autumn high flow recommendation. In other reaches a summer high flow has been recommended to enhance opportunities for spawning by Australian Grayling. There is no specific objective for Australian Grayling in Reach 8 so a high flow has not been recommended. However, water could be released from Maroondah Reservoir to contribute to autumn high flows in downstream reaches, provided the magnitude doesn't exceed 250 ML/day as described above.

9.2.3. Winter/spring low flows

The recommended winter/spring low flow threshold has been reduced from 130 ML/day to 80 ML/day. The previously recommended 130 ML/day doesn't provide any observable benefits over 80 ML/day. A flow of 80 ML/day is sufficient to inundate vegetation on the lower banks for a prolonged period

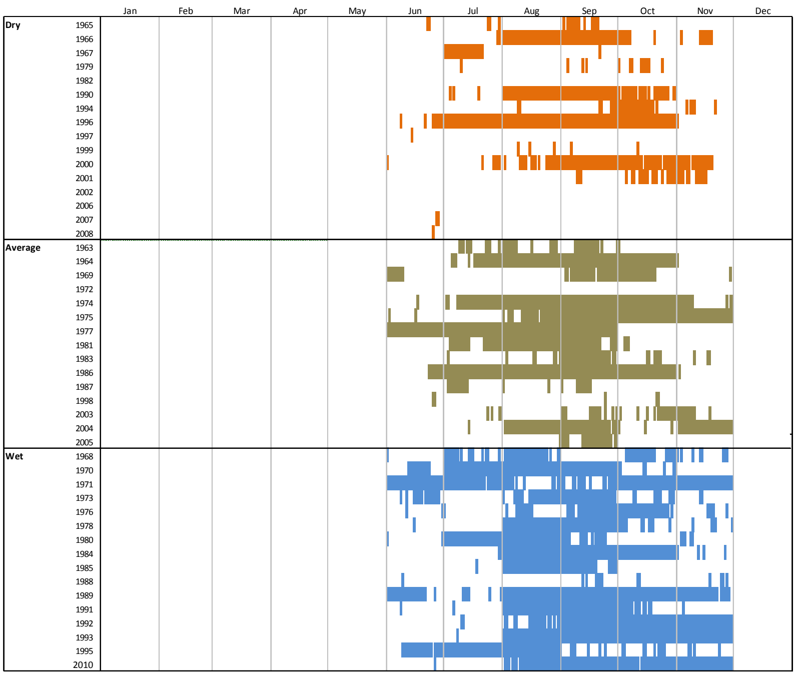
The winter flow may be increased up to 180 ML/day for up to two weeks at a time if transfers are required to meet flow recommendations in downstream reaches.

9.2.4. Winter/spring freshes

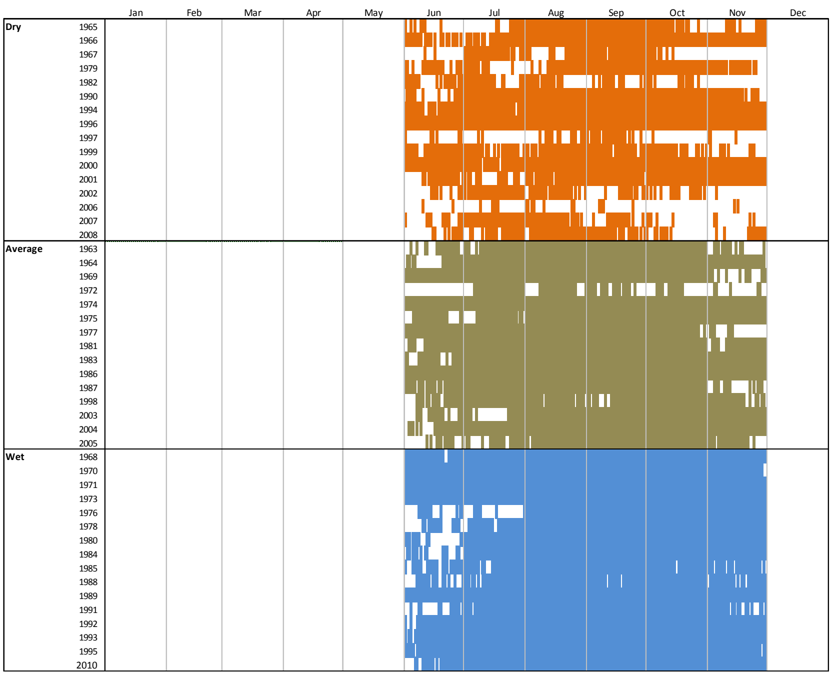
The recommended flow threshold for a winter/spring fresh is 180 ML/day. The event magnitude is unchanged from 2005. However, more variability in the number of events is required with 2-3 events in dry years, 3-4 events in average years and 4-5 events in wet years. In average and wet years, at least one of these events should occur in June or July to assist downstream migration of adult Tupong and Common Galaxias, which spawn in estuaries; and at least one event should occur in spring to attract diadromous fish back into the reach from downstream.

A flow of 180 ML/day is also sufficient to inundate low and mid level benches, reduce sediment accumulation on gravel and cobbles in riffle zones and provide increased depth over riffles for fish passage.

Under current water management and harvesting operations, winter/spring flows in excess of 180 ML/day commonly occur in most average and wet years, but not in all dry years (Figure 9-6). Under unimpacted conditions, flows in excess of 180 ML/day would have lasted for most of winter and spring in wet, average and dry years (Figure 9-7).



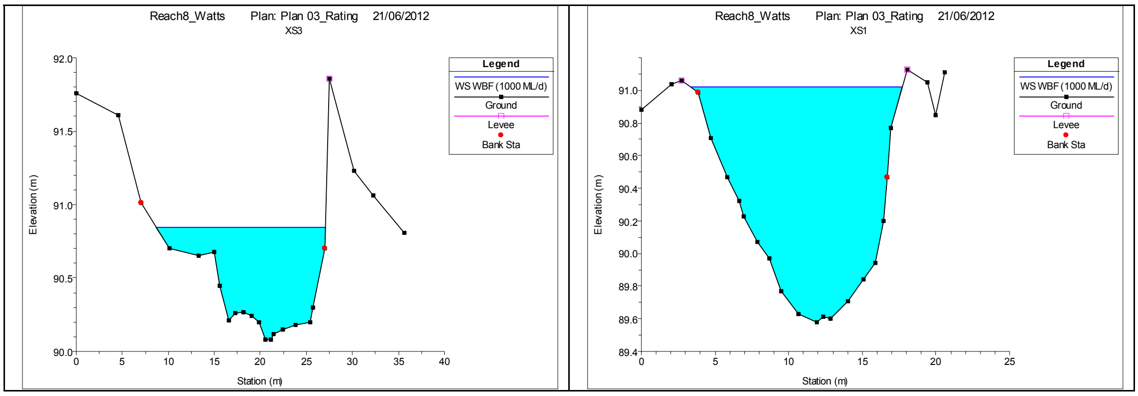
- **Figure 9-6 Characteristics of winter/spring fresh and high flow threshold for current conditions for Reach 8. This plot shows the number and duration of flows above the recommended threshold that have occurred under current flow conditions in each dry, wet and average climate year since 1964.**



- **Figure 9-7 Characteristics of winter/spring fresh and high flow threshold for unimpacted conditions for Reach 8. This plot shows the number and duration of flows above the recommended threshold that would have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.**

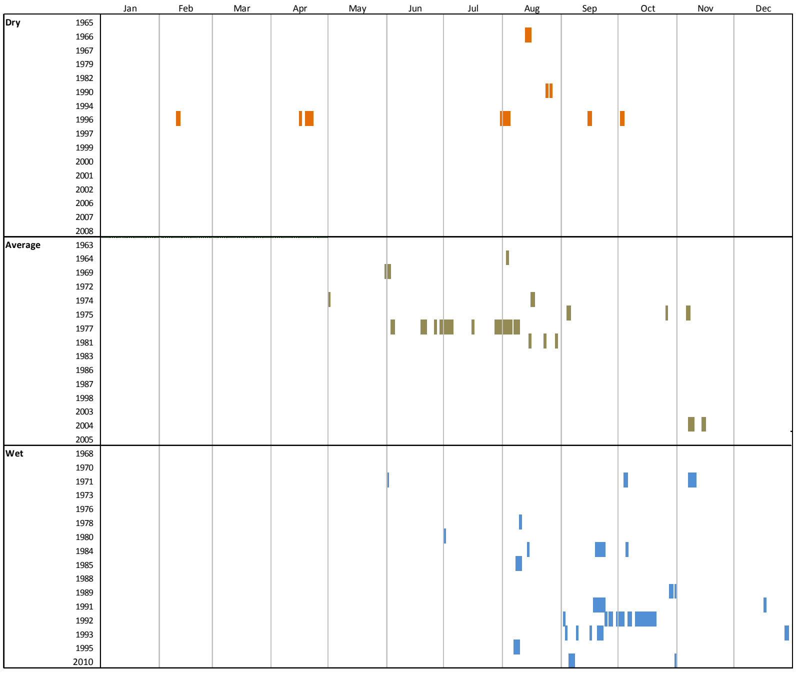
9.2.5. Bankfull flows

A bankfull flow of 1,000 ML/day is recommended once every two years for a duration of two days. This flow reaches the top of the bank along most transects in the reach and inundates a high level bench at Transect 3 (Figure 9-8). A flow of 1,000 ML/day is sufficient to maintain current channel geometry by scouring sediment in deepest pools and also inundates small low lying floodplains and high benches located along the reach.

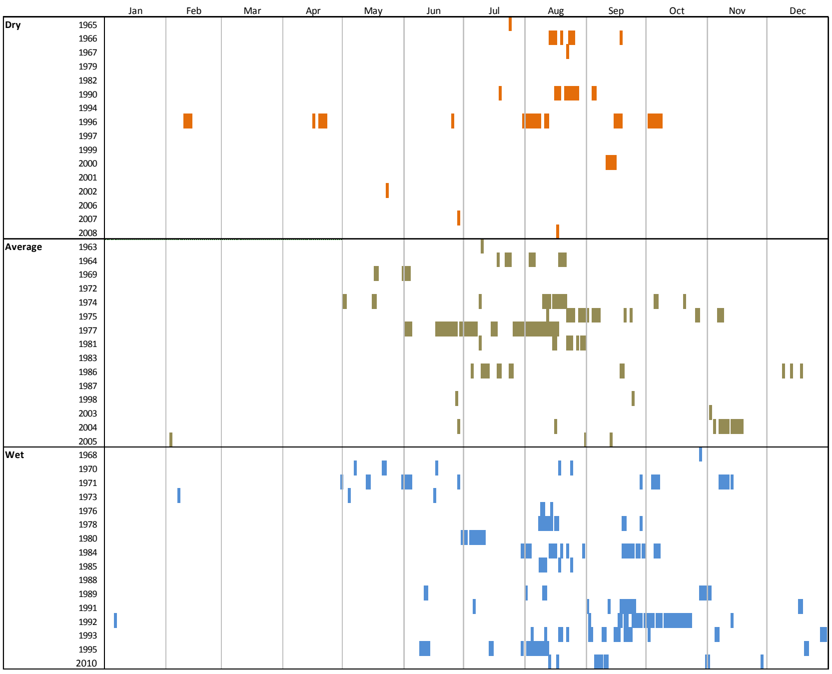


▪ **Figure 9-8 Stage height in a riffle (Transect 3, left) and a pool (Transect 1, right) at the recommended threshold for winter/spring bankfull flows in Reach 8.**

The relatively small storage capacity in Maroondah Dam means the dam spills in most years and this contributes to the bankfull flow events in many years. Under current conditions, flows in excess of 1,000 ML/day occur in more than half of wet climate years, but in less than a quarter of dry climate years (Figure 9-9). Under unimpacted conditions, bankfull flows would have occurred in Watts River multiple times in most wet and average climate years and multiple times in more than half of the dry climate years (Figure 9-10).



▪ **Figure 9-9 Characteristics of bankfull flow threshold for current conditions for Reach 8. This plot shows the number and duration of flows above the recommended threshold that have occurred under current flow conditions in each dry, wet and average climate year since 1964.**



▪ **Figure 9-10 Characteristics of bankfull flow threshold for unimpacted conditions for Reach 8. This plot shows the number and duration of flows above the recommended threshold that have occurred under unimpacted flow conditions in each dry, wet and average climate year since 1964.**

There is no overbank flow recommendation for Reach 8. The confined nature of the channel means there are few floodplain areas. Overbank flows also pose risks to built values through Healesville. The lower Watts River floodplain traverses the Yarra River floodplain and benefits from flooding in the Yarra River.

9.2.6. Current achievement of flow recommendations

An assessment of how well the flow recommendations for Reach 8 are currently met in wet, average and dry years is presented in Table 9-2, Table 9-3 and Table 9-4. It should be noted that these assessments include an 'or natural' clause, which considers the flows that would have occurred in Reach 8 in wet, dry and average years under unimpacted conditions. For example, if the hydrological analysis shows that the recommended winter high flow would only occur in 25 out of 30 years in average years then the level of achievement is based on how many of those 25 events are delivered under the current level of development and system operation.

The summer low flow recommendations and the summer fresh recommendations for Reach 8 are currently met nearly 100% of the time in wet years, and approximately 90% of the time in average years. However, in dry years the summer low flow recommendation is only met 66% of the time and the summer fresh is only met 38% of the time.

The recommended winter low flow is met 80% in wet years, 63% in average years and 38% in dry years. Similarly, the recommended winter fresh is achieved between 80% and 90% of the time in wet and average years, but only 50% of the time in dry years.

The recommended bankfull flow is met 60% of the time in wet years, 67% of the time in average climate years and 100% of the time in dry years. The greater level of achievement in dry years does not indicate that bankfull flows occur more frequently in dry years. Rather it demonstrates that under current operating rules, nearly all of the bankfull flows that would naturally occur in the Watts River in dry years cause Maroondah Reservoir to spill and create bankfull flows in the reach immediately downstream of the dam. In wet and average climate years, Maroondah Reservoir may be drawn down more frequently, which may mean that spills are less frequent.

In summary, the recommended low flows and freshes are met in most wet and average climate years, but are not achieved in dry climate years. Maroondah Reservoir is relatively small, but harvesting rules from the dam and tributary streams such as Donnelly's Creek and Grace Burn may need to be revised in dry years to improve flow delivery to section of the Watts River between the reservoir and the Yarra River.

Table 9-2 Extent to which the environmental flow recommendations for Reach 8 are currently being met during dry years.

Component	Months	Flow Recommendation					Or Natural	Compliance
Summer low	Dec - May	Magnitude	10	ML/d			Yes	66%
Summer fresh	Dec - May	Magnitude	80	ML/d			Yes	38%
		Frequency	4	per year				
		Duration	2	days				
Summer high	Apr - May	No specific recommendation but allow higher flows to occur naturally from tributary inflow or spills from Maroondah Reservoir.						
Winter low	Jun - Nov	Magnitude	80	ML/d			Yes	38%
Winter fresh	Jun - Sep	Magnitude	180	ML/d			Yes	50%
		Frequency	3	per year				
		Duration	2	days				
Winter high	Oct - Nov	No specific recommendation but allow higher flows to occur naturally from tributary inflow or spills from Maroondah Reservoir.						
Bankfull	Oct - Nov	Magnitude	1000	ML/d			Yes	100%
		Frequency	1	in	2	years		
		Duration	2	days				
Overbank	Jan - Dec	Not recommended						

Table 9-3 Extent to which the environmental flow recommendations for Reach 8 are currently being met during average years.

Component	Months	Flow Recommendation					Or Natural	Compliance
Summer low	Dec - May	Magnitude	10	ML/d			Yes	88%
Summer fresh	Dec - May	Magnitude	80	ML/d			Yes	88%
		Frequency	4	per year				
		Duration	2	days				
Summer high	Apr - May	No specific recommendation but allow higher flows to occur naturally from tributary inflow or spills from Maroondah Reservoir.						
Winter low	Jun - Nov	Magnitude	80	ML/d			Yes	63%
Winter fresh	Jun - Sep	Magnitude	180	ML/d			Yes	88%
		Frequency	4	per year				
		Duration	2	days				
Winter high	Oct - Nov	No specific recommendation but allow higher flows to occur naturally from tributary inflow or spills from Maroondah Reservoir.						
Bankfull	Oct - Nov	Magnitude	1000	ML/d			Yes	67%
		Frequency	1	in	2	years		
		Duration	2	days				
Overbank	Jan - Dec	Not recommended						

- **Table 9-4 Extent to which the environmental flow recommendations for Reach 8 are currently being met during wet years.**

Component	Months	Flow Recommendation				Or Natural	Compliance
Summer low	Dec - May	Magnitude	10	ML/d		Yes	99%
Summer fresh	Dec - May	Magnitude	80	ML/d		Yes	100%
		Frequency	4	per year			
		Duration	2	days			
Summer high	Apr - May	No specific recommendation but allow higher flows to occur naturally from tributary inflow or spills from Maroondah Reservoir.					
Winter low	Jun - Nov	Magnitude	80	ML/d		Yes	80%
Winter fresh	Jun - Sep	Magnitude	180	ML/d		Yes	81%
		Frequency	5	per year			
		Duration	2	days			
Winter high	Oct - Nov	No specific recommendation but allow higher flows to occur naturally from tributary inflow or spills from Maroondah Reservoir.					
Bankfull	Oct - Nov	Magnitude	1000	ML/d		Yes	60%
		Frequency	1	in 2	years		
		Duration	2	days			
Overbank	Jan - Dec	Not recommended					

10. Priority flow components, uncertainty and risk

While the FLOWS method provides an objective process for determining environmental flow requirements to meet reach-based environmental objectives, a number of risks and uncertainties exist in the development of flow recommendations. Flows can be determined with confidence for objectives where there is some understanding of the physical or biological response to flows. However, for some processes the response to flows is not well understood, is inferred from other systems, or is based on expert opinion. The use of a multi-disciplined technical panel and criteria that describe the relationship between ecological response and flow (see Section 2.6) is aimed at reducing the uncertainty in flow recommendations by providing a suitable level of justification for expected responses to flow. However, there are still some uncertainties in the specific flow requirements of some biota and the expected physical or biological responses to different flow components.

In addition to uncertainty of flow requirements or response, there are various levels of risks associated with not meeting certain flow recommendations. The full suite of flow recommendations at any reach are developed by considering the specific flow components that are needed to achieve all of the stated objectives for that reach. However, some objectives may be more critical than others. For example delivering flows to maintain or project threatened species, may be a higher priority than objectives for more common values. Moreover, if it is not possible to provide all flow recommendations then components that are repeatedly not delivered will become higher priorities for delivery over time. Despite this, the flow recommendations are considered the minimum required to achieve an ecologically health ecosystem as defined by the ecological objectives for the Yarra River and any reduction in the recommended flows will compromise the ability to achieve an ecologically healthy river.

In the Yarra River there are a number of risks and uncertainties associated with ecological response to flows and priorities for implementation; these are described in the following sections.

10.1. Summer low flows

10.1.1. Rationale

Summer low flows have been determined based on criteria to wet the full width of riffles, yet still provide exposed rocks for oviposition, to maintain access to habitat in pools and to minimise the risk to water quality associated with anoxia in deep pools in lower reaches. The flow threshold is based on physical characteristics of the channel with respect to availability of habitat under different flows and empirical knowledge of the potential risks to water quality if flows are too low for a prolonged period. For example, monitoring data that shows the effects of low flows on water quality in Reach 6 (Robinson, 2011, SKM, 2011b) has been used to help define the low flow thresholds in reaches where poor water quality is considered a potential risk under low flow conditions.

10.1.2. Risks and uncertainties

Channel surveys and hydraulic modelling mean that we can be confident in the water levels required to maintain the full width of riffles, to inundate specific habitats or to provide a certain depth in pools. Recent research projects have also highlighted the minimum flows required to maintain dissolved oxygen levels, prevent stratification and mix stratified pools in the lower Yarra River. However, water quality monitoring in deep pools was only conducted for a relatively short period and longer term monitoring to collect information over a wider range of temperature and flow conditions may help to refine the estimates of minimum flow requirements. Moreover, critical flow information to manage water quality in other reaches of the Yarra is not as well understood as the in the lower reaches.

There is a risk that prolonged low flows in the Yarra River may result in water quality declines under some circumstances. For this reason we have increased the recommended minimum flows in some reaches to reduce the risk of poor water quality, particularly low dissolved oxygen. Fresh flows have also been recommended to provide a periodic flushing flow that would help mix pools and improve water quality. If fresh flows are not provided as recommended there is an increased risk that water quality problems may develop. Hence the implementation of the summer low flow recommendation requires that freshes are also provided. Reaches most at risk are those in agricultural and urban areas (i.e. all reaches downstream of Millgrove, particularly Reach 6 and the Dights Falls Weir pool).

One aspect of low flow water quality management that needs further consideration is the impact of stratification and deoxygenation of the Dights Falls Weir pool in summer. A large volume of water (450 ML/d) is required to maintain a fully mixed weir pool when water temperatures exceed 18 °C (Robinson 2011). Delivering a low flow of 450 ML/day for three months during summer would use a large amount of water that would have to come out of the current Environmental Water Reserve. It is unclear what the specific benefits are of maintaining a fully mixed weir pool in summer, although it is clear that having a mixed weir pool during periods when fish are migrating between marine and freshwater environments (usually spring when higher flows are recommended) is important. A decision needs to be made as to whether the potential benefits to the weir pool are worth the amount of water needed to maintain mixing compared with the benefit that water may provide if it was used to deliver other flow components to meet other environmental objectives. If it is decided that maintaining mixed pools in the lower Yarra River is a high priority then it may be worth considering alternative management actions, such as the use of mechanical aerators, which could achieve the same outcome without the need for additional flow.

The recommended summer low flow threshold in all reaches is the minimum flow required to maintain a healthy ecosystem. Flows higher than the minimum flow threshold do not pose a risk to environmental values or objectives unless those flows are due to significant unseasonal releases from reservoirs for water supply purposes. This is currently not an issue in most reaches of the Yarra River or its tributaries. However, it may be an issue for the Watts River and Reach 1 if they are used to deliver environmental flows to downstream reaches that have much larger channel capacity. To manage this risk we have recommended maximum flow magnitudes for Reach 1 and Watts River if using these reaches as conduits to pass water to downstream reaches.

10.2. Summer freshes

10.2.1. Rationale

Summer freshes have been determined based on criteria relating to the generation of velocities and shear stress in riffles to help scour sediment and biofilms from benthic surface and around LWD and to mix pools to ameliorate any declines in water quality. The overall aim is to reduce the accumulation of sediment and excessive biofilm growth to maintain the quality of habitat for macroinvertebrates during subsequent low flows and to minimise the potential for water quality decline due to prolonged low flows. The criteria for determining fresh flows was based on generating an average velocity of 40-50 cm/s and a shear stress >15 N/m^2 in riffles or around LWD, or at achieving flows considered sufficient to mix pools.

Note that biofilms provide an important ecological function as a site for nutrient assimilation and as a food resource for microbes and macroinvertebrates. However, excessive biofilm growth can reduce access to habitats for macroinvertebrates and late successional filamentous species offer a reduced food quality to macroinvertebrates compared to early successional species (Sheldon and Walker, 1997, Lamberti, 1996, Lamberti *et al.*, 1989). Maintaining biofilms in an early successional state through frequent disturbance through scouring and wetting and drying may result in a more palatable food resource for macroinvertebrates (Treadwell, 2002).

10.2.2. Risks and uncertainties

While the summer fresh volume has been determined based on specified criteria, the variable nature of aquatic ecosystems means that responses to specific flows are not always predictable and there will always be a level of uncertainty regarding specific physical and biological responses to flows. However, fresh flow volumes, timing and duration have been based on the best available information and opinions of the EFTP at the time of the assessment. If further information becomes available or monitoring reveals the desired ecological response is not being achieved then the flow recommendation may need to be revised – this applies to all recommendations.

Specific risks associated with freshes are that the volume is insufficient to create scouring flow over a significant area of riffle or is insufficient to mix pools. While the hydraulic models suggest that the fresh flows recommended for the Yarra River are sufficient to scour riffle habitats, there is a risk that elevated nutrient levels in urban reaches may allow algae to rapidly recover, which would mean that any effect of a scouring flow will be short lived (see Taylor *et al.*, 2004). In urban reaches, seasonal factors such as light intensity and temperature are likely to be greater drivers of algal biomass accumulation than flow (Taylor *et al.*, 2004). Efforts to improve water quality, particularly by reducing nutrient concentrations and sediment inputs, are likely to have greater benefits in terms of reducing excessive algal growth and sedimentation in urban waterways. This can be achieved through the implementation of stormwater management plans and catchment-wide implementation of low-impact stormwater drainage design.

10.3. Summer high flows

10.3.1. Rationale

Summer high flows have been specified to provide a migration and spawning cue for Australian Grayling and to transport larvae to the estuary.

10.3.2. Risks and uncertainties

There has been considerable research into the life history and flow requirements of Australian Grayling in recent years (Koster and Dawson, 2011). Most of that work has been conducted in the Bunyip River (mainly because the size of the Yarra River population was considered too small during the drought). While that work has confirmed the need for high autumn flows and indicates the likely duration and timing of those flows, there is some uncertainty associated with the specific magnitude of flows that are needed in the Yarra River.

The recommended magnitude of the autumn high flow in the Yarra River has been based on recent data that shows that Australian Grayling have spawned in recent years when a flow of 1,300 ML/day was exceeded (Koster and Dawson, 2011). Recent anecdotal observations also suggest that Australian Grayling numbers are increasing in the Yarra River (Ron Lewis, Native Fish Australia Pers comm.), probably in response to good flows in the past few followings following the drought and or the temporary removal of part of the Dights Falls Weir. It may therefore now be possible to better test the critical flow threshold to trigger migration and spawning in the Yarra River.

Australian Grayling only live for 2-3 years and it was previously thought that if there was no successful spawning and recruitment for at least three years then populations could become extinct in some rivers. However, Crook *et al.* (2006) demonstrated that Australian Grayling juveniles do not necessarily return to the rivers where they were spawned and they are not thought to have high site fidelity. This is an important finding because it means that the Yarra River population has a good chance of recovery if the appropriate flow regime is provided. The other thing that may limit Australian Grayling populations in the Yarra River, and the effectiveness and value of high autumn flows is the extent to which juveniles can move through the Dights Falls fishway. The old fishway was very inefficient (Zampatti *et al.*, 2003), but a new fishway is currently being constructed, which should increase the number of Australian Grayling and other diadromous fish moving into the freshwater reaches of the Yarra. A discussion of spring flows required to enhance the upstream migration of juvenile diadromous fish is provided later in this section.

If the recommended volume is too high or duration too long there is no risk to spawning or recruitment success but the excess water may not be being used to its greatest efficiency.

10.4. Winter low flows

10.4.1. Rationale

The winter low flow is based on providing improved opportunities for local fish passage and inundating vegetation on the lower banks. The winter low flow should also be sufficient to keep riffles and LWD clear of fine sediment, which will allow biofilms and diatoms to grow and will maintain habitat and food for macroinvertebrates.

10.4.2. Risks and uncertainties

The low flow volume is based on physical characteristics of the channel and the inundation of specific habitats such as low benches, or in providing increased depth over riffles for fish passage. The FLOWS method provides an objective approach to determining flow requirements to meet objectives and on this basis the recommended flows are considered appropriate.

The winter low flow is the minimum flow required to meet objectives. Flows below this threshold represent an increased risk to achieving objectives. However, higher flows and variability above the minimum flow are not a risk and in average and wet climate years it is expected and acceptable for tributary inflows to contribute to increased winter low flows. To formalise these benefits, the recommended winter low flows for several reaches in the Yarra River specify a minimum flow magnitude and a higher median flow magnitude. If the recommended median flows for dry, average and wet climate years are met then the risks to ecological values is considered low. However, as with other flow components, if further information becomes available or monitoring reveals the desired ecological response is not being achieved then the flow recommendation may need to be revised.

10.5. Winter freshes and high flows

10.5.1. Rationale

Freshes and high flows are aimed at providing flow variability in the winter period, inundation of benches to entrain organic material, inundation of banks to provide a disturbance to vegetation and providing opportunities for fish passage. The winter/spring high flow is particularly aimed at providing a prolonged inundation of the banks to drown terrestrial vegetation where it is encroaching down the banks and to make growing conditions less favourable for semi-aquatic weeds that have colonised near the waterline in some reaches, particularly Reaches 3, 4 and 5.

10.5.2. Risks and uncertainties

The flow volume for freshes and high flows has been determined based on an assessment of physical channel features and levels of inundation required to achieve objectives. The timing and duration of the high flow is based on providing a prolonged high flow event in the main growing season for plants. Based on HEC RAS modelling the risks that important channel features are not inundated to the appropriate depth are low. There is a risk that the duration of inundation of the high flow event is insufficient to suppress the growth of terrestrial vegetation. However, the specified duration is based on the best available information at the time and opinion of the EFTP. If the duration is too short then terrestrial vegetation will not experience the appropriate disturbance regime to limit encroachment on the banks. Fortunately, this is easy to monitor, although repeated inundation over several years may be required to achieve an acceptable long-term response. As a result, infrequent delivery of the flow recommendation is unlikely to deliver an acceptable ecological response that will meet objectives.

The freshes and high flows are likely to be sufficient to assist fish passage. The old Dights Falls fishway was relatively ineffective during high flows (Zampatti *et al.*, 2003), but the new vertical slot fishway that is scheduled for completion by Spring 2012, is expected to improve fish passage from the estuary to freshwater reaches.

There is some suggestion that high flows should be avoided in spring because they could reduce the success of Macquarie Perch spawning by flushing eggs and larvae from spawning habitat (King *et al.*, 2011). However, avoiding high flows at this time may limit the ability to achieve objectives related to vegetation described above. Recent research suggests that Macquarie Perch recruitment is more successful if there is a period of stable flow in late spring following spawning (King *et al.*, 2011). That work demonstrated that good recruitment occurred in years when flows in October and November exceeded 2,500 ML/day for extended periods of time, but poor recruitment occurred when flows in October and November exceeded 4,000 ML/day. Based on those results we have concluded that high flows up to 2,500 ML/day in Reaches 4, 5 and 6 in mid to late spring are likely to promote the development of healthy riparian vegetation communities without disrupting Macquarie Perch recruitment. Macquarie Perch are a relatively long-lived species and do not need high recruitment every year, therefore occasional natural events greater than 3,000 ML/day that occur during the main spawning season are not likely to significantly reduce the Macquarie Perch population. Because our understanding of the specific requirements of Macquarie Perch is still developing, adaptive management practices should continue to be adopted so that any risks and unintended consequences of delivering high flows can be identified and managed.

10.6. Bankfull and overbank flows

10.6.1. Rationale

Bankfull flows are aimed at providing a channel maintenance flow by scouring accumulated sediment and maintaining channel geometry. Bankfull and overbank flows are also aimed at engaging wetlands and floodplains. Flows are determined by the physical characteristics of the reach, wetland inlet levels and floodplain form.

10.6.2. Risks and uncertainties

There is little uncertainty in recommended volumes, timing or duration of bankfull and overbank flow events as they are determined based on specific channel characteristics and relatively well understood physical and ecological responses. There are two main risks associated with these flows. First, the recommended flows are not delivered, which means that desirable physical and ecological responses do not occur. Second, overbank flows will flood and damage infrastructure and private assets on the floodplain. Melbourne Water does not intend to actively deliver overbank flows, and in many cases has little capacity to prevent natural floods. The bankfull and overbank flows recommended in this report will help to maintain and improve the condition of floodplain wetlands. However, Melbourne Water is also conducting other work to investigate water needs for various wetlands and billabongs on the Yarra River floodplain and to determine methods for delivering the required water.

Under current conditions the Bankfull flow recommendation is mostly met in all reaches (except Reach 1) in average and wet climate years, so there is little risk associated with failing to achieve the Bankfull flow. The frequency of overbank flows has reduced significantly since the Upper Yarra Dam was constructed, but provisioning for overbank flows from upstream storages is unfeasible. Any overbank flows that do occur play a critical role in engaging wetlands and floodplains and therefore it is critically important to protect these events when they do occur and allow them to pass through the entire river system. As a consequence, any water harvesting operations need to be undertaken in such a way that does not impact on the current frequency and duration of bankfull or overbank flows.

The main risks associated with less frequent bankfull and overbank flows are that floodplain habitats become disconnected from the main river channel, which can change the composition of wetland vegetation communities and alter other wetland processes. Less frequent bankfull and overbank flows can also have profound effects within the river channel. For example they can instigate channel contraction (which is particularly evident in Reach 1) and change the character and condition of vegetation on the banks.

Most wetlands and much of the floodplain in Reaches 3 and 4 have been cleared of vegetation and are now colonised by pasture grasses. There is some uncertainty regarding the specific benefits of providing overbank flows in these degraded systems. However, recent research in Western

Victoria has demonstrated that inundation of pasture wetlands still provide a valuable contribution to regional biodiversity and links between the river and even degraded wetland environments are important for maintaining both riverine and wetland diversity and function (Robson and Clay, 2005). To this end, inundation of the wetlands and floodplain is considered important. However, there are social and economic risks that need to be managed. For example, prolonged inundation can kill pasture grasses and cause subsequent economic loss to farmers. Moreover, to take full advantage of bankfull and overbank flows that inundate wetlands and floodplain, opportunities to restore sections of floodplain should be investigated and fencing, stock removal and revegetation undertaken in these areas.

The provision of a bankfull flow in Reach 1 is the exception to the above discussion. Bankfull flows in Reach 1 have been eliminated by the construction and operation of Upper Yarra Dam. It is undesirable to implement an annual bankfull flow to restore the natural channel geometry. However, a one in ten year bankfull event is recommended to scour sediment from pools and restore access to habitat for fish and macroinvertebrates. Failure to deliver a flow of sufficient magnitude to initially scour the pools of accumulated organic material will mean that all other flow recommendations for Reach 1 will be compromised.

11. Complementary waterway works and further investigations

Throughout the report references have been made to a range of complementary waterway works and further investigations. Complementary works are aimed at creating opportunities for improvements in ecological health independent of flows and also at maximising the environmental benefits provided by the recommended flows. Further investigations are needed where there is insufficient data or understanding to enable an objective assessment of flow requirements or to be confident in predicted ecological responses to flow or complementary works.

The environmental objectives tables presented in Appendix A list some of the complementary works that are recommended for each reach. A more detailed discussion of the priority works relating to wetland rehabilitation, riparian re-vegetation and LWD reinstatement and water quality management is presented below. Most of the recommended works and investigations are consistent with recommendations from current strategies (e.g. the Regional River Health Strategy), or are already being implemented (e.g. re-vegetation works and stormwater management plans).

11.1. Wetland rehabilitation

Significant floodplain and wetlands areas exist along Reaches 3, 4 and 6, and to a lesser extent Reach 5. In Reaches 3, 4 and 5 the floodplain and wetlands have been extensively cleared for agricultural production and converted to pasture grass. In Reach 6 a number of regionally significant wetlands remain protected within an extensive network of urban parks, but changed hydrology poses a threat to their values.

Connectivity between riverine and floodplain environments is important for a number of ecological reasons, including transfers of nutrients and sediment and contribution to life history requirements for both riverine and floodplain biota, particularly wetland plants and macroinvertebrates. The clearing of floodplains reduce the value of floodplain inundation to riverine systems, although recent research indicates that inundation of pasture dominated wetlands can still be important for regional biodiversity, particularly for water birds and macroinvertebrates (Robson and Clay, 2005).

Bankfull and overbank flows have been recommended for all floodplain reaches along the Yarra River. With the recommendations basically aimed at retaining the current frequency and duration of such events. However, to take full advantage of these flows there is a significant opportunity to rehabilitate wetlands and floodplain areas. Such works would involve fencing, removal of levees and other structures that may restrict flow paths, and re-vegetation with suitable wetland and floodplain vegetation.

Melbourne Water is assessing the environmental water requirements and associated environmental management actions for wetlands in the Yarra River catchment through a separate project and therefore specific complementary actions or monitoring for wetlands are not provided in this report.

11.2. Riparian re-vegetation and LWD reinstatement

Significant resources and effort has gone into fencing and re-vegetation of the riparian zone throughout the Yarra catchment, including tributaries. However, the riparian corridor is still discontinuous in many locations, particularly through Reaches 3 and 4. Where re-vegetation has taken place, the corridor is generally narrow and in some instances bank erosion may threaten re-vegetation works. Future re-vegetation work needs to include a wider corridor. Ideally, the whole meander train of the river will be fenced, rather than just fencing along the top of the river bank. Specific locations for riparian re-vegetation have not been identified in this project. Strategies need to be developed at a reach scale and implemented at a local level with the assistance of local landholders and facilitated through dedicated staff with appropriate resources and community support. Priority reaches for riparian re-vegetation are Reaches 3 and 4, and to a lesser extent Reach 8. Management of existing riparian vegetation, particularly weed control, is required in Reaches 2, 5 and 6.

The Yarra River has a long history of de-snagging along its entire length and this has had a significant impact on the availability of physical habitat for fish, but also on geomorphic and hydraulic processes. The protection of existing LWD habitat and supply from the riparian zone is essential. Wattle trees that were used in re-vegetation works in Reaches 3 and 4 and have reached the end of their lives have started to fall into the river. These trees provide important habitat for instream biota, but it will take much longer for recently planted or recruited eucalypt trees to contribute to the LWD load in the river. For many objectives related to fish and macroinvertebrates, the availability of suitable snag habitat is likely to be more limiting than specific flow components, particularly in low flow periods and it may be necessary to actively re-introduce LWD to the river channel. Priority reaches for LWD reinstatement are Reaches 3 and 4, and to a lesser degree Reaches 6 and 8. The protection of existing LWD habitat and supply from existing riparian vegetation is required in Reaches 2, 5 and 6.

There are a number of useful guidelines available for assisting with the planning and implementation of riparian revegetation and LWD reinstatement (e.g. Rutherfurd *et al.*, 2000b, Rutherfurd *et al.*, 2000a, Treadwell, 1999, Koehn *et al.*, 2001, Abernethy and Rutherford, 1999). It is recommended that reach scale habitat restoration and management plans be included in ongoing waterway action planning activities. The above guidelines may provide useful information for assisting with the development and implementation of such plans.

11.3. Water quality management

Poor water quality is a significant risk to ecosystem health in the Yarra catchment. Indeed, in urban reaches, such as Reach 6, water quality is likely to be a significant factor in limiting the achievement of environmental objectives. Many of the water quality issues associated with the Yarra River cannot adequately be addressed by increased flows. In fact, increased flows will only mask the problem. Water quality needs to be managed at the source, in the catchments of urban tributaries and to a lesser degree in relation to agricultural activities.

In urban areas, stormwater management plans need to be implemented, although the greatest benefit is more likely to be achieved through the implementation of catchment-wide low-impact stormwater drainage. Increased catchment imperviousness and direct connection between impervious areas and drainage networks are regarded as the greatest factors contributing to water quality decline and consequent decline in ecological condition. Catchment imperviousness levels greater than 8 to 10% appears to represent a critical threshold for a range of ecosystem processes and biological community responses (Walsh *et al.*, 2005) and sub-catchments in the Melbourne Water management area with Directly Connected Imperviousness (DCI) scores greater than 5-10% are generally considered to be heavily degraded (Danger and Walsh, 2008). To address this, Walsh *et al.* (2005) provide a model for low-impact stormwater design in urban areas that reduces the connection between impervious surfaces and the drainage network and effectively reduces the frequency of runoff from urban catchments. Design elements are based at the local scale rather than end-of-pipe solutions and are aimed at matching runoff from urban catchments to those experienced in natural catchments. Walsh *et al.* (2005) demonstrate how this can be achieved through rainwater tanks to increase local retention and infiltration through the use of porous pavements and grass swales as opposed to the standard concrete kerb and drain system. At the very least, such elements should be incorporated into new urban development but opportunities to retrofit retention elements in established neighbourhoods should also be investigated.

The other main water quality issue in the Yarra River relates to low dissolved oxygen levels and stratification in the Dights Falls Weir pool during summer. Earlier chapters of this report describe the minimum flows that are needed to manage stratification. However, these flows are larger than would naturally occur in Reach 6 of the Yarra during dry summers and if delivered would take up a large proportion of the available environmental entitlement. One of the reasons why stratification is such an issue in Reach 6 is because Dights Falls artificially raises the water level and reduces flow velocity throughout the 13 km length of the weir pool. It may be argued that a large portion of the limited environmental entitlement should not be used to manage a problem that was created by historical river engineering practices. Mechanical aerators are commonly used to prevent stratification and low dissolved oxygen conditions in wastewater treatment ponds, ornamental lakes and in Adelaide's River Torrens. It is worth investigating whether similar techniques can be applied to sections of the Dights Falls Weir pool. If mechanical aerators can be used then it may be possible to provide suitable conditions for native fish year round in the Dights Falls Weir pool, without artificially increasing the flow.

11.4. Further investigations

The 2005 FLOWS study included some general flow recommendations for the Yarra Estuary, which were based on the assumption that a flow regime that met all of the environmental objectives for the freshwater reaches of the Yarra River would probably also meet the requirements of the estuary. Since 2005, Matt Hipsey from the University of Western Australia and Perron Cook from Monash University have developed a 3-D hydro-dynamic model of the Yarra estuary and have investigated various aspects of nutrient cycling (see Bruce *et al.*, In Press, Holland and Cook, 2009). That information will significantly improve environmental flow recommendations for the Yarra estuary. Melbourne Water is currently planning a dedicated study to assess environmental flow requirements for the Yarra estuary using the Estuary Environmental Flows Assessment Method for Victoria (EEFAM) (Lloyd *et al.*, 2011). Once that project is complete, the environmental flow recommendations for the freshwater reaches can be compared against the flow requirements for the estuary and relevant adjustments can be made if necessary.

12. References

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Appendix A Environmental objectives

A.1 Reach 1 – downstream of Upper Yarra Reservoir objectives.

Asset	Objective	No.	Function	Flow component	Timing	Expected response	Response time
Geomorphology	Maintain existing channel dimensions and form	G1-1	Maintain existing channel dimensions and minimise further channel contraction	Bankfull flow	Winter / spring	▪ No further contraction in channel geometry.	Medium to long
	Rehabilitate instream habitat	G1-2	Scour fine sediment and biofilms from riffles	Freshes	Throughout year	▪ Prevent sediment build up on cobbles in riffle zone	Short
		G1-3	Scour sediment from pools	High flow	Winter / spring	▪ Flush fine sediment from pools and increased habitat availability.	Medium
		G1-4	Limit sediment sources	Complementary	Ongoing	▪ Reduced sediment input from Doctors Creek catchment Promote Best Practice Guidelines for roading & timber harvesting. Identify specific sediment sources (given impact on reach) & manage appropriately	Medium
Macroinvertebrates	Rehabilitate macroinvertebrate community to maximum diversity & abundance possible downstream of a large dam with the aim of meeting Yarra SEPP Schedule F7 objectives.	M1-1	Access to riffle habitat	Low flow	Summer / winter	▪ The objective is to increase the diversity & abundance to the maximum possible based on the assumption that flows that reduce sediment accumulation will improve access to benthic habitats will result in an increase in invertebrate biodiversity & abundance.	Short to medium
		M1-2	Clean cobbles in faster flowing reaches	Freshes	Throughout year		
		M1-3	Flush sediment from pools & entrain organic material from littoral zone	High flow	Winter		
Fish	Rehabilitate populations of non-migratory native fish, including River Blackfish and mountain galaxias with the aim of meeting Yarra SEPP Schedule F7 objectives.	F1-1	Access to habitat	Low flow	Summer / winter	▪ Increase abundance of native species including recolonisation by mountain galaxias. ▪ Self sustaining River Blackfish population with a range of age classes in population	Short to medium
				Freshes	Throughout Year		
		F1-2	Flush sediment to improve quality and availability of spawning sites and refuge habitats (i.e. pools)	High flow	Winter / spring		
Vegetation	Maintain current in channel & riparian vegetation extent, structure & composition	V1-1	Bank drying	Low flow	Summer	▪ No decline in the existing vegetation characteristics such as, structure, diversity & abundance of native species ▪ Maintenance of heterotrophic nature of Reach 1 with dominance by microbial producers	Short
		V1-2	Maintenance of flood tolerant vegetation	Freshes	Throughout year		
		V1-3	Bank wetting to promote flood-tolerant vegetation & limit terrestrial vegetation	High flow	Winter / spring		
		V1-4	Scouring of vegetation encroaching in channel	Bankfull flow	Winter / spring	▪ Maintenance of solid, clean surfaces for microbial biofilms	Short

	Limit encroachment of riparian and terrestrial vegetation into stream channel	V1-5	Limit growth of sawsedges and other fringing/riparian/terrestrial vegetation into stream channel	Low flow	All year	■ Progressive removal of emergent taxa covering much of in-stream channel and inhibition of future colonization	Medium
		V1-6	Limit growth of sawsedges and other fringing/riparian/terrestrial vegetation into stream channel	High flow	Winter / Spring		
		V1-7	Scour sawsedges and other fringing/riparian/terrestrial vegetation from stream channel	Bankfull flow	Winter / Spring		
Water quality	Maintain current water quality to meet Yarra SEPP Schedule F7 objectives	W1-1	Ecological processes & beneficial uses	Complementary	As required	■ No decline in current water quality	Short
		W1-2	Limit effect of cold water releases	Complementary	As part of release operations	■ No detrimental impacts of cold water releases from reservoir	Short

A.2 Reach 2 – Armstrong Creek to Millgrove objectives.

Asset	Objective	No	Function	Flow component	Timing	Expected response	Response time
Geomorphology	Maintain channel dimensions and form	G2-1	Maintain channel dimensions and minimise further channel contraction	Bankfull flow	Winter / spring	■ No further contraction in channel geometry.	Medium to long
	Engage low level floodplains	G2-3	Connectivity	Bankfull / low overbank flow	Winter / spring	■ Appropriate frequency of inundation of low level floodplain & billabongs achieved	Short
	Maintain access to riffle & pool habitat	G2-3	Scour fine sediment and biofilms from riffles	Freshes	Throughout year	■ Prevent sediment build up on cobbles in riffle zone	Short
		G2-4	Scour sediment from pools	High flow	Winter / spring	■ Flush fine sediment from pools and increased habitat availability.	Medium
Macroinvertebrates	Maintain current macroinvertebrate community to comply with Yarra SEPP Schedule F7 objectives	M2-1	Access to riffle habitat	Low flow	Summer / winter	■ Expect Macroinvertebrates scores to continue to meet SEPP objectives for composition, but improve with regard to SIGNAL scores	Short to medium
		M2-2	Disturbance to scour biofilms & sediment	Freshes	Throughout year		
Fish	Maintain populations of non-migratory native fish, including River Blackfish, Australian smelt & mountain galaxias and comply with Yarra SEPP Schedule F7 objectives	F2-1	Access to habitat	Low flow	Summer / winter	■ No decline in non-migratory native fish diversity & abundance – expected species include: River Blackfish, Australian smelt & mountain galaxias	Short to medium
				Freshes	Throughout year		
		F2-2	Flush sediment to improve quality and availability of spawning sites	High flow	Spring		
	Maintain populations of migratory native fish, including Australian Grayling, short-finned eel, lamprey spp., tupong, spotted galaxias & common galaxias and comply with Yarra SEPP Schedule F7 objectives.	F2-3	Provide opportunities for upstream movement of adult and juvenile migratory species	High flow	Spring	■ No decline in migratory native fish diversity & abundance – expected species include: Australian Grayling, short-finned eel, lamprey spp., tupong, spotted galaxias & common galaxias	
		F2-4	Trigger downstream migration and/or spawning, and transport of eggs/larvae to sea	Freshes	Autumn / winter		
	Rehabilitate (reinstate) populations of Australian Grayling	F2-5	Trigger downstream spawning migration & transport of eggs/larvae to sea	Freshes	Autumn	■ Increased presence & abundance of Australian Grayling through improved spawning opportunities & recruitment success	Medium to long
Vegetation	Maintain existing in-stream and fringing vegetation (including microbial biofilms on submerged	V2-1	Maintain and/or rehabilitate in-stream vegetation (microbial as well as macrophytic, e.g. Parrots Feather)	Low flow	All year	■ Improvement in the existing vegetation characteristics such as, structure, diversity & abundance of native species	Short

	surfaces)	V2-2	Maintain fringing vegetation on lower levels of bank (e.g. water ferns)	Freshes	All year	■ Maintenance of heterotrophic nature of Reach 2 with dominance by microbial producers ■ Maintenance/improvement of limited beds of submerged native vegetation in-stream, such as Parrots Feather ■ Maintenance of inundation-tolerant vegetation on lower banks, such as water ferns	
		V2-3	Remove mud and silt from subsurface cobbles and boulders	Bankfull flow	Winter / Spring	■ Maintenance of solid, clean surfaces for microbial biofilms	Short
	Maintain inundation-tolerant vegetation in riparian zone on upper banks and lower levels of riparian zone	V2-4	Maintain riparian vegetation on upper levels of bank and lower riparian zone (e.g. paperbarks)	Bankfull	Winter / Spring	■ Maintenance of inundation-tolerant riparian species, such as paperbarks	Medium
Water quality	Maintain current water quality to meet Yarra SEPP Schedule F7 objectives	W2-1	Ecological processes & beneficial uses	Complementary	Ongoing	■ No decline in current water quality. ■ Implementation of catchment strategies to limit stock access, agricultural runoff & septic tank effluent inputs to river to reduce nutrient & sediment levels & limit excessive algal growth.	Short to medium

A.3 Reach 3 – Millgrove to Watts River objectives.

Asset	Objective	No.	Function	Flow component	Timing	Expected response	Response time
Geomorphology	Maintain channel dimensions and form	G3-1	Maintain existing channel dimensions and minimise further channel contraction	High / bankfull flow	Winter / spring	■ No contraction in channel geometry.	Medium to long
		G3-2	Bank stability	Rate of fall	Following flow events	■ No increased rate or extent of bank scour above that expected naturally.	Medium
	Rehabilitate lateral connectivity with billabongs connected around bankfull	G3-3	Form and maintain billabongs and meander train	Bankfull flow	Spring	■ Maintenance of floodplain features through scour and deposition.	Short
	Rehabilitate floodplains	G3-4	Form and maintain floodplain features	Overbank flow	Spring	■ Increased frequency & duration of inundation of floodplain ■ Requires complementary works to prioritise & revegetate floodplain (see V3-6).	Short
Macro-invertebrates	Maintain and rehabilitate current macroinvertebrate community to comply with Yarra SEPP Schedule F7 objectives	M3-1	Access to LWD & edge habitats	Low flow	Summer / winter	■ Expect Macroinvertebrates scores to consistently meet SEPP objectives. ■ LWD reintroduction should be undertaken in conjunction with fencing & revegetation of riparian zone (see V3-4).	Short to medium
		M3-2	Disturbance to scour biofilm & sediment from LWD	Freshes	Throughout year		
		M3-3	Reintroduce LWD to channel	Complementary	Ongoing		
Fish	Maintain populations of non-migratory native fish, including River Blackfish, Australian smelt & mountain galaxias and comply with Yarra SEPP Schedule F7 objectives	F3-1	Access to habitat	Low flow	Summer / winter	■ No decline in non-migratory native fish diversity & abundance – expected species include: River Blackfish, Australian smelt & mountain galaxias	Short to medium
				Freshes	Throughout year		
		F3-2	Flush sediment to improve quality and availability of spawning sites	High flow	Spring		
	Maintain populations of migratory native fish, including Australian Grayling, short-finned eel, lamprey spp., tupong, spotted galaxias & common galaxias and comply with Yarra SEPP Schedule F7 objectives.	F3-3	Provide opportunities for upstream movement of adult and juvenile migratory species	High flow	Spring	■ No decline in migratory native fish diversity & abundance – expected species include: Australian Grayling, short-finned eel, lamprey spp., tupong, spotted galaxias & common galaxias	
		F3-4	Trigger downstream migration and/or spawning, and transport of eggs/larvae to sea	Freshes	Autumn / winter		
	Rehabilitate (reinstate) populations of Australian Grayling	F3-5	Trigger downstream spawning migration & transport of eggs/larvae to sea	Freshes	Autumn	■ Increased presence & abundance of Australian Grayling through improved spawning opportunities & recruitment success	Medium to long
Vegetation	Maintain/improve in-stream and fringing emergent vegetation	V3-1	Maintain and/or rehabilitate in-stream vegetation (e.g. Water Ribbons)	Low flow	All year	■ Improvement in the existing vegetation characteristics such as, structure, diversity & abundance of native species ■ Maintenance/improvement of limited beds of submerged vegetation in-stream, such as Water Ribbons	Short
		V3-2	Maintain fringing beds of Cumbungi and rehabilitate/recreate new beds of Common Reed and other reed, sedge and rush assemblages	Low flow	All year		

		V3-3	Maintain fringing beds of Cumbungi and rehabilitate/recreate new beds of Common Reed and other reed, sedge and rush assemblages	Freshes	All year	■ Maintenance of existing and re-creation of new areas of inundation-tolerant vegetation on lower banks and in-stream, such as Cumbungi and Common Reed	
	Maintain inundation-tolerant vegetation in riparian zone on upper banks and lower levels of riparian zone	V3-4	Maintain riparian vegetation on upper levels of bank (e.g. paperbarks)	Bankfull	Winter / Spring	■ Maintenance of inundation-tolerant riparian species, such as paperbarks	Medium
	Maintain and/or rehabilitate floodplain and billabong vegetation	V3-5	Inundate floodplain and/or billabongs	Bankfull and/or Overbank	Winter / Spring	■ Improvement in structure and ecological function of floodplain billabongs ■ Improved lateral connectivity between river and floodplain/billabong habitats	Medium to Long
		V3-6	Promote growth of inundation-tolerant taxa (e.g. rushes, reeds, sedges) over terrestrial taxa (e.g. Silver Wattle, Tree Violet)	Bankfull and/or Overbank	Winter / Spring		
	Rehabilitate billabong vegetation	V3-7	Revegetation, grazing control	Complementary	Ongoing	■ Complementary works required to fence meander train (billabongs / floodplain located close to channel), remove stock & revegetate with species appropriate for the EVC to take greatest advantage of provision of bankfull flows	Medium to Long
	Rehabilitate floodplain vegetation	V3-8	Revegetation, grazing control, possible levee removal	Complementary	Ongoing	■ Complementary works required to fence, remove stock & revegetate floodplain with species appropriate for the EVC & remove levees to take advantage of overbank flows.	
Water quality	Improve water quality to meet Yarra SEPP Schedule F7 objectives	W3-1	Ecological processes & beneficial uses	Complementary	Ongoing	■ Increased nutrient compliance with SEPP objectives. ■ Implementation of catchment strategies to reduce stock access, agricultural runoff & localised urban stormwater inputs to river to reduce nutrient levels & limit excessive algal growth.	Medium

A.4 Reach 4 – Watts River to Yering Gorge objectives.

Asset	Objective	No.	Function	Flow component	Timing	Expected response	Response time
Geomorphology	Maintain channel dimensions and form	G4-1	Maintain existing channel dimensions and minimise further channel contraction	High / bankfull flow	Winter / spring	■ No contraction in channel geometry	Medium to long

		G4-2	Bank stability	Rate of fall	Following flow events	■ No increased rate or extent of bank scour above that expected naturally	Medium
	Rehabilitate lateral connectivity with billabongs connected around bankfull	G4-3	Form and maintain billabongs and meander train	Bankfull flow	Spring	■ Increased frequency of inundation of billabongs & meander train	Short
	Rehabilitate floodplains	G4-4	Form and maintain floodplain features	Overbank flow	Spring	■ Increased frequency & duration of inundation of floodplain ■ Requires complementary works to revegetate floodplain (see V4-6)	Short
Macroinvertebrates	Rehabilitate macroinvertebrate community to comply with Yarra SEPP Schedule F7 objectives	M4-1	Access to LWD & edge habitats	Low flow	Summer / winter	■ Expect improvement in macroinvertebrates scores to comply with SEPP objectives, particularly towards bottom of reach. ■ LWD reintroduction to be undertaken in conjunction with fencing & revegetation of riparian zone (see V4-4).	Short to medium
		M4-2	Disturbance to scour biofilm & sediment from LWD	Freshes	Throughout year		
		M4-3	Reduce direct connectedness to impervious surfaces in urban areas	complementary	Ongoing		
		M4-4	Reintroduce LWD to channel	Complementary	Ongoing		
Fish	Maintain populations of non-migratory native fish, including River Blackfish, Australian smelt & mountain galaxias and comply with Yarra SEPP Schedule F7 objectives	F4-1	Access to habitat	Low flow	Summer / winter	■ No decline in non-migratory native fish diversity & abundance – expected species include: River Blackfish, Australian smelt & mountain galaxias	Short to medium
				Freshes	Throughout year		
		F4-2	Flush sediment to improve quality and availability of spawning sites	High flow	Spring		
	Maintain populations of migratory native fish, including Australian Grayling, short-finned eel, lamprey spp., tupong, spotted galaxias & common galaxias and comply with Yarra SEPP Schedule F7 objectives	F4-3	Provide opportunities for upstream movement of adult and juvenile migratory species	High flow	Spring	■ No decline in migratory native fish diversity & abundance – expected species include: Australian Grayling, short-finned eel, lamprey spp., tupong, spotted galaxias & common galaxias	
		F4-4	Trigger downstream migration and/or spawning, and transport of eggs/larvae to sea	Freshes	Autumn / winter		
	Rehabilitate (reinstate) populations of Australian Grayling	F4-5	Trigger downstream spawning migration & transport of eggs & larvae to sea	Freshes	Autumn	■ Increased presence & abundance of Australian Grayling through improved spawning opportunities & recruitment success ■	Medium to long
Vegetation	Improve in-stream and fringing emergent vegetation	V4-1	Rehabilitate in-stream vegetation (e.g. Water Ribbons)	Low flow	All year	■ Improvement in the currently poor characteristics of in-stream vegetation such as, structure, diversity & abundance of native species ■ Creation of beds of submerged vegetation in-	Short
		V4-2	Rehabilitate/recreate new beds of Cumbungi, Common Reed and other reed, sedge and rush assemblages	Low flow	All year		

		V4-3	Rehabilitate/recreate new beds of Cumbungi, Common Reed and other reed, sedge and rush assemblages	Freshes	All year	stream, such as Water Ribbons ■ Maintenance of the few existing areas and re-creation of new areas of inundation-tolerant vegetation on lower banks and in-stream, such as Cumbungi and Common Reed	
	Improve inundation-tolerant vegetation in riparian zone on upper banks and lower levels of riparian zone	V4-4	Maintain/rehabilitate riparian vegetation on upper levels of bank (e.g. paperbarks)	Bankfull	Winter / Spring	■ Maintenance of inundation-tolerant riparian species, such as paperbarks	Medium
	Improve and/or rehabilitate floodplain and billabong vegetation	V4-5	Inundate floodplain and/or billabongs	Bankfull and/or Overbank	Winter / Spring	■ Improvement in structure and ecological function of floodplain billabongs ■ Improved lateral connectivity between river and floodplain/billabong habitats	Medium to Long
		V4-6	Promote growth of inundation-tolerant taxa (e.g. rushes, reeds, sedges) over terrestrial taxa (e.g. Silver Wattle, Tree Violet)	Bankfull and/or Overbank	Winter / Spring		
	Rehabilitate billabong vegetation	V4-7	Revegetation, grazing control	Complementary	Ongoing	■ Complementary works required to fence meander train (billabongs / floodplain located close to channel), remove stock & revegetate with species appropriate for the EVC to take greatest advantage of provision of bankfull flows	Medium to Long
	Rehabilitate floodplain vegetation	V4-8	Revegetation, grazing control, possible levee removal	Complementary	Ongoing	■ Complementary works required to fence, remove stock & revegetate floodplain with species appropriate for the EVC & remove levees to take advantage of overbank flows.	
Water quality	Improve water quality to meet Yarra SEPP Schedule F7 objectives	W4-1	Ecological processes & beneficial uses	Complementary	Ongoing	■ Increased nutrient compliance with SEPP objectives. ■ Implementation of catchment strategies to reduce stock access, agricultural runoff & localised urban stormwater inputs to river to reduce nutrient levels & limit excessive algal growth.	Medium to long

A.5 Reach 5– Yering Gorge to Mullum Mullum Creek objectives.

Asset	Objective	No.	Function	Flow component	Timing	Expected response	Response time
Geomorphology	Maintain channel dimensions and form	G5-1	Maintain existing channel dimensions and minimise further development of vegetated bars and islands	High / bankfull flow	Winter / spring	■ No expansion in vegetated bars & island on riffles	Medium to long
	Maintain bank stability	G5-2	Bank stability	Rate of rise & fall	All year	■ Pumping induced rate of rise & fall managed to minimise stranding fauna on riffles.	Short
	Rehabilitate lateral connectivity with billabongs on Henley floodplain	G5-3	Form and maintain billabongs and meander train	Bankfull flow	Spring	■ Increased frequency of inundation of billabongs & meander train (& se V5-5).	Short
Macroinvertebrates	Rehabilitate macroinvertebrate community to comply with Yarra SEPP Schedule F7 objectives	M5-1	Access to riffle habitats	Low flow	Summer / winter	■ Expect improvement in macroinvertebrate scores to meet SEPP objectives ■ May require cease to pump in Yering Gorge to protect wetted width of riffle habitat. ■ LWD reintroduction to be undertaken in conjunction with fencing & revegetation of riparian zone (see V5-4).	Short to medium
		M5-2	Disturbance to scour biofilm & sediment from riffles & LWD	Freshes	Throughout year		
		M5-3	Reduce direct connectedness to impervious surfaces in urban areas	complementary	Ongoing		
		M5-4	Reintroduce LWD to channel	Complementary	Ongoing		
Fish	Maintain or rehabilitate populations of non-migratory native fish, including River Blackfish, Australian smelt & mountain galaxias, populations of Murray cod, and comply with Yarra SEPP Schedule F7 objectives	F5-1	Access to habitat	Low flow	Summer / winter	■ Maintain or improve non-migratory native fish diversity and abundance – expected species include: River Blackfish, Australian smelt, mountain galaxias, & Murray cod	Short to medium
				Freshes	Throughout year		
		F5-2	Flush sediment to increase availability of spawning sites	High flow	Spring		
	Maintain or rehabilitate populations of migratory native fish, including Australian Grayling, short-finned eel, lamprey spp., tupong, spotted galaxias, common galaxias & broad-finned galaxias and comply with Yarra SEPP Schedule F7 objectives	F5-3	Provide opportunities for upstream movement of adult and juvenile migratory species	High flow	Spring	■ Maintain or improve migratory native fish diversity and abundance – expected species include: Australian Grayling, short-finned eel, lamprey spp., tupong, spotted galaxias, common galaxias & broad-finned galaxias	
		F5-4	Trigger downstream migration and/or spawning, and transport of eggs/larvae to sea	Freshes	Autumn / winter		
	Maintain populations of Macquarie perch	F5-5	Flush sediment during pre-spawning period to improve quality and availability of spawning sites	High flow	Early spring	■ No decline in Macquarie perch distribution and abundance	Short to medium
	Rehabilitate populations of Australian Grayling	F5-6	Trigger downstream spawning migration & transport of eggs & larvae to sea	Freshes	Autumn	■ Increased presence & abundance of Australian Grayling through improved spawning opportunities & recruitment success	Medium to long

Vegetation	Maintain/improve in-stream and fringing emergent vegetation	V5-1	Maintain/rehabilitate in-stream vegetation (e.g. Water Ribbons)	Low flow	All year	■ Improvement in the existing vegetation characteristics such as, structure, diversity & abundance of native species ■ Maintenance/improvement of limited beds of submerged vegetation in-stream, such as Water Ribbons ■ Maintenance of existing and re-creation of new areas of inundation-tolerant vegetation on lower banks and in-stream, such as Cumbungi and Common Reed	Short
		V5-2	Maintain existing small beds of emergent taxa and recreate new beds of Cumbungi, Common Reed and other reed, sedge and rush assemblages	Low flow	All year		
		V5-3	Maintain existing small beds of emergent taxa and recreate new beds of Cumbungi, Common Reed and other reed, sedge and rush assemblages	Freshes	All year		
	Maintain/improve inundation-tolerant vegetation in riparian zone on upper banks and lower levels of riparian zone	V5-4	Maintain/rehabilitate riparian vegetation on upper levels of bank (e.g. paperbarks)	Bankfull	Winter / Spring	■ Maintenance of inundation-tolerant riparian species, such as paperbarks	Medium
	Improve and/or rehabilitate floodplain and billabong vegetation (of limited importance in this reach)	V5-5	Inundate floodplain and/or billabongs	Bankfull and/or Overbank	Winter / Spring	■ Improvement in structure and ecological function of floodplain billabongs ■ Improved lateral connectivity between river and floodplain/billabong habitats	Medium to Long
		V5-6	Promote growth of inundation-tolerant taxa (e.g. rushes, reeds, sedges) over terrestrial taxa (e.g. Silver Wattle, Tree Violet)	Bankfull and/or Overbank	Winter / Spring		
	Rehabilitate billabong vegetation (of limited importance in this reach)	V5-7	Revegetation, grazing control (including of feral animals such as deer)	Complementary	Ongoing	■ Complementary works required to fence meander train (billabongs / floodplain located close to channel), remove stock & revegetate with species appropriate for the EVC to take greatest advantage of provision of bankfull flows	Medium to Long
	Rehabilitate floodplain vegetation (of limited importance in this reach)	V5-8	Revegetation, grazing control, possible levee removal	Complementary	Ongoing	■ Complementary works required to fence, remove stock & revegetate floodplain with species appropriate for the EVC & remove levees to take advantage of overbank flows.	
Water quality	Minimise risk of stratification and low dissolved oxygen in pools through Yering and Warrandyte gorges	W5-1	Fish and macroinvertebrate health	Low flow	All year	■ Pools fully mixed at all times	Short
	Improve water quality to meet Yarra SEPP Schedule F7 objectives (nutrients and turbidity)	W5-2	Ecological processes, fish health & primary contact beneficial use	Complementary	ongoing	■ Increase nutrient compliance with SEPP objectives. ■ Continue to improve management of Sewerage Plant effluent to river, septic tank management & urban stormwater to limit nutrient levels & excessive algal growth.	Medium to long

A.6 Reach 6– Mullum Mullum Creek to Dights Falls objectives.

Asset	Objective	No.	Function	Flow component	Timing	Expected response	Response time
Geomorphology	Maintain channel dimensions and form	G6-1	Maintain existing channel dimensions and minimise further channel contraction	High / bankfull flow	Winter / spring	■ No contraction in channel geometry	Medium to long
		G6-2	Bank stability	Rate of rise & fall	Following freshes	■ No increased rate or extent of bank scour above that expected naturally. ■ Caused by increased runoff rates in urban areas - complementary works required – not a main stem flow issue	Medium to long
	Rehabilitate lateral connectivity with billabongs connected around bankfull	G6-3	Form and maintain billabongs and meander train	Bankfull flow	Spring	■ Increased frequency of inundation of billabongs & meander train	Short
Macroinvertebrates	Rehabilitate macroinvertebrate community to comply with Yarra SEPP Schedule F7 objectives	M6-1	Access to LWD, riffles & edge habitats	Low flow	Summer / winter	■ Achieve maximum possible macroinvertebrate score to the extent possible given level of urban impact ■ LWD reintroduction to be undertaken in conjunction with fencing & revegetation of riparian zone (see V6-4).	Short to medium
		M6-2	Disturbance to scour biofilm & sediment from riffles & LWD	Freshes	Throughout year		
		M6-3	Reduce direct connectedness to impervious surfaces in urban areas	complementary	Ongoing		
		M6-4	Reintroduce LWD to channel	Complementary	Ongoing		
Fish	Maintain or rehabilitate* populations of non-migratory native fish, including River Blackfish, Australian smelt &	F6-1	Access to habitat	Low flow	Summer / winter	■ Maintain or improve non-migratory native fish diversity and abundance – expected species include: River Blackfish, Australian smelt, mountain galaxias, & Murray cod	Short to medium
				Freshes	Throughout year		

* The fish community in the Yarra River at Dights Falls weirpool is considered poor (Pitman *et al.* 2007), possibly due to factors such as reduced water quality (e.g. low dissolved oxygen). The rehabilitation of populations of native fish at the site is likely dependent on improving DO levels which would require consistent large volumes (e.g. 400-500 ML/d) of water. An alternative objective could be to promote upstream movement of adult and juvenile migratory fish through the site. This objective could be addressed through the provision of high flows during spring.

	mountain galaxias, populations of Murray cod, and comply with Yarra SEPP Schedule F7 objectives	F6-2	Flush sediment to increase availability of spawning sites	High flow	Spring		
	Maintain or rehabilitate* populations of migratory native fish, including Australian Grayling, short-finned eel, lamprey spp., tupong, spotted galaxias, common galaxias & broad-finned galaxias and comply with Yarra SEPP Schedule F7 objectives	F6-3	Provide opportunities for upstream movement of adult and juvenile migratory species	High flow	Spring	■ Maintain or improve migratory native fish diversity and abundance – expected species include: Australian Grayling, short-finned eel, lamprey spp., tupong, spotted galaxias, common galaxias & broad-finned galaxias	Short to medium
Vegetation	Maintain/improve in-stream and fringing emergent vegetation	V6-1	Maintain/rehabilitate in-stream vegetation (e.g. Water Ribbons)	Low flow	All year	■ Improvement in the existing vegetation characteristics such as, structure, diversity & abundance of native species ■ Maintenance/improvement of limited beds of submerged vegetation in-stream, such as Water Ribbons ■ Maintenance of existing and re-creation of new areas of inundation-tolerant vegetation on lower banks and in-stream, such as Cumbungi and Common Reed	Short
		V6-2	Maintain existing small beds of emergent taxa and recreate new beds of Cumbungi, Common Reed and other reed, sedge and rush assemblages	Low flow	All year		
		V6-3	Maintain existing small beds of emergent taxa and recreate new beds of Cumbungi, Common Reed and other reed, sedge and rush assemblages	Freshes	All year		
	Maintain/improve inundation-tolerant vegetation in riparian zone on upper banks and lower levels of riparian zone	V6-4	Maintain/rehabilitate riparian vegetation on upper levels of bank (e.g. paperbarks)	Bankfull	Winter / Spring	■ Maintenance of inundation-tolerant riparian species, such as paperbarks	Medium
	Improve and/or rehabilitate floodplain and billabong vegetation	V6-5	Inundate floodplain and/or billabongs	Bankfull and/or Overbank	Winter / Spring	■ Improvement in structure and ecological function of floodplain billabongs ■ Improved lateral connectivity between river and floodplain/billabong habitats	Medium to Long
		V6-6	Promote growth of inundation-tolerant taxa (e.g. rushes, reeds, sedges) over terrestrial taxa (e.g. Silver Wattle, Tree Violet)	Bankfull and/or Overbank	Winter / Spring		
	Rehabilitate billabong vegetation	V6-7	Revegetation, grazing control	Complementary	Ongoing	■ Complementary works required to fence meander train (billabongs / floodplain located close to channel), remove stock & revegetate with species appropriate for the EVC to take greatest advantage of provision of bankfull flows	Medium to Long

	Rehabilitate floodplain vegetation	V6-8	Revegetation, grazing control, possible levee removal	Complementary	Ongoing	■ Complementary works required to fence, remove stock & revegetate floodplain with species appropriate for the EVC & remove levees to take advantage of overbank flows.	
Water quality	Minimise risk of stratification and low dissolved oxygen in pools upstream of Chandler Highway	W6-1a	Fish and macroinvertebrate health	Low flow	All year	■ Pools fully mixed at all times	Short
	Minimise risk of stratification and low dissolved oxygen in Dights Falls Weir Pool	W6-1b	Fish and macroinvertebrate health	Low flow	All year	■ Pools fully mixed at all times	Short
				Freshes	All year	■ Mix pools if stratification does occur	Short
	Improve water quality to meet Yarra SEPP Schedule F7 objectives (Nutrients, turbidity & bacteriological),	W6-2	Ecological processes, fish health & primary contact beneficial use	Complementary	Ongoing	■ Reduce effective catchment imperviousness in tributary streams. ■ Increase nutrient & suspended solids compliance with SEPP objectives through improved stormwater management & reduced sewerage overflows	Medium to long

A.7 Reach 8 – Watts River objectives.

Asset	Objective	No.	Function	Flow component	Timing	Expected response	Response time
Geomorphology	Maintain current channel dimensions and form	G8-1	Maintain existing channel dimensions and minimise further channel contraction	High / bankfull flow	Winter / spring	■ No contraction in channel geometry	Medium to long
	Rehabilitate lateral connectivity with small floodplains & benches connected below bankfull	G8-2	Formation and maintenance of benches	High flows	Spring	■ Increased frequency of inundation of inset floodplains & benches	Short
Macroinvertebrates	Rehabilitate macroinvertebrate community to Yarra SEPP Schedule F7 objectives	M8-1	Maintain access to riffles & LWD	Low flow	Summer / winter	■ Expect improvement in macroinvertebrates scores downstream of Donnelly Creek. ■ LWD reintroduction to be undertaken in conjunction with fencing & revegetation of riparian zone (see V8-4).	Short to medium
		M8-2	Disturbance to scour biofilms & sediment	Freshes	Throughout year		
		M8-3	Reduce direct connectedness to impervious surfaces in urban areas	Complementary	Ongoing		
		M8-4	Reintroduce LWD habitat	Complementary	Ongoing		
Fish	Maintain populations of non-migratory native fish, including River Blackfish, Australian smelt & mountain galaxias and comply with Yarra SEPP Schedule F7 objectives	F8-1	Access to habitat	Low flow	Summer / winter	■ Maintain non-migratory native fish diversity and abundance – expected species include: River Blackfish, Australian smelt & mountain galaxias	Short to medium
				Freshes	Throughout year		
		F8-2	Flush sediment to improve quality and availability of spawning sites	High flow	Spring		
	Maintain populations of migratory native fish, including, short-finned eel, lamprey spp., spotted galaxias, common galaxias & broad-finned galaxias and comply with Yarra SEPP Schedule F7 objectives	F8-3	Provide opportunities for upstream movement of adult and juvenile migratory species	High flow	Spring	■ Maintain migratory native fish diversity and abundance – expected species include: short-finned eel, lamprey spp., spotted galaxias, common galaxias & broad-finned galaxias	
		F8-4	Trigger downstream migration and/or spawning, and transport of eggs/larvae to sea	Freshes	Autumn / winter		
Vegetation	Maintain existing in-stream and fringing/riparian vegetation (including microbial biofilms on submerged surfaces)	V8-1	Maintain in-stream vegetation (microbial more than macrophytic)	Low flow	All year	■ No decline in the existing vegetation characteristics such as, structure, diversity & abundance of native species ■ Maintenance of likely heterotrophic nature of Reach 8 with dominance by microbial producers	Short
		V8-2	Maintain fringing/riparian vegetation on lower levels of bank	Freshes	All year		
		V8-3	Maintain fringing/riparian vegetation at higher levels of bank	High flow	Winter / Spring		

		V8-4	Remove mud and silt from subsurface cobbles and boulders	Bankfull flow	Winter / Spring	■ Maintenance of solid, clean surfaces for microbial biofilms	Short
	Limit encroachment of riparian and terrestrial vegetation into stream channel	V8-5	Limit growth of fringing/riparian/terrestrial vegetation into stream channel	Low flow	All year	■ Inhibition of terrestrial taxa from invading stream channel, particularly of weedy species	Medium
		V8-6	Limit growth of fringing/riparian/terrestrial vegetation into stream channel	High flow	Winter / Spring		
		V8-7	Scour fringing/riparian/terrestrial vegetation from stream channel	Bankfull flow	Winter / Spring		
Water quality	Maintain current water quality to meet Yarra SEPP Schedule F7 objectives	W8-1	Ecological processes & beneficial uses	Complementary	Ongoing	■ No decline in current water quality. ■ Implementation of catchment strategies to reduce stock access, agricultural runoff & urban stormwater inputs to river to reduce nutrient levels & limit excessive algal growth.	Short to medium

Appendix B Correlation between rainfall and streamflow

This appendix presents the correlation between rainfall and streamflow in each year of record for each reach. Wet, average and dry years for streamflow and rainfall are determined by dividing the entire record into thirds based on total annual flow or rainfall. For example, the third of years with the greatest total annual flow are classified as wet years for streamflow and the third of years with the greatest annual rainfall are classified as wet years for rainfall.

In most years there is a strong correlation between rainfall and streamflow. The main discrepancies, and greatest risk from a management perspective, occur in years that have high rainfall, but relatively low streamflow. These situations are most likely to arise when one or two large rainfall events occur in an otherwise dry year, or when there is relatively high rainfall following a period of drought and therefore run-off to the streams is relatively low. Relying on rainfall records in these years may result in management actions that do not reflect the dry conditions in the stream.

In years where the rainfall is classified dry but the streamflow represents wet conditions, the risk of making incorrect management decisions would not be as great. This is because management actions would begin for a dry season, but tributary flow would mimic the wet season and those tributary inflows would reflect wet season requirements.

B.1 Reach 1 – downstream of Upper Yarra Reservoir

Water Year	Current Flow	Unimpacted Flow	Rainfall (086090)
1963	Dry	Average	Dry
1964	Wet	Wet	Wet
1965	Average	Dry	Average
1966	Dry	Average	Dry
1967	Average	Dry	Average
1968	Average	Wet	Wet
1969	Average	Wet	Average
1970	Wet	Wet	Wet
1971	Wet	Wet	Average
1972	Average	Dry	Average
1973	Wet	Average	Wet
1974	Wet	Wet	Wet
1975	Wet	Wet	Average

1976	Average	Average	Average
1977	Wet	Average	Dry
1978	Wet	Wet	Average
1979	Dry	Dry	Dry
1980	Average	Average	Wet
1981	Dry	Average	Average
1982	Dry	Dry	Dry
1983	Average	Average	Average
1984	Average	Average	Average
1985	Average	Average	Wet
1986	Average	Average	Wet
1987	Dry	Dry	Dry
1988	Average	Dry	Wet
1989	Wet	Wet	Wet
1990	Wet	Wet	Average
1991	Wet	Wet	Wet
1992	Wet	Wet	Wet
1993	Wet	Wet	Wet
1994	Dry	Average	Dry
1995	Wet	Wet	Wet
1996	Wet	Wet	Wet
1997	Dry	Dry	Dry
1998	Average	Dry	Average
1999	Dry	Dry	Dry
2000	Dry	Average	Dry
2001	Dry	Dry	Dry
2002	Dry	Dry	Dry
2003	Dry	Average	Average
2004	Average	Average	Average
2005	Average	Dry	Dry
2006	Dry	Dry	Dry
2007	Dry	Dry	Dry
2008	Dry	Dry	Dry

B.2 Reach 2 – Armstrong Creek to Millgrove

Water Year	Current Flow	Unimpacted Flow	Rainfall (086090)
1963	Average	Average	Dry
1964	Wet	Wet	Wet
1965	Dry	Dry	Average
1966	Average	Average	Dry
1967	Dry	Dry	Average
1968	Wet	Wet	Wet
1969	Average	Average	Average
1970	Wet	Wet	Wet
1971	Wet	Wet	Average
1972	Dry	Dry	Average
1973	Average	Average	Wet
1974	Wet	Wet	Wet
1975	Wet	Wet	Average
1976	Average	Average	Average
1977	Wet	Wet	Dry
1978	Average	Average	Average
1979	Dry	Dry	Dry
1980	Average	Average	Wet
1981	Average	Average	Average
1982	Dry	Dry	Dry
1983	Average	Average	Average
1984	Average	Average	Average
1985	Average	Average	Wet
1986	Wet	Wet	Wet
1987	Dry	Dry	Dry
1988	Dry	Dry	Wet
1989	Wet	Wet	Wet
1990	Wet	Wet	Average
1991	Wet	Wet	Wet
1992	Wet	Wet	Wet
1993	Wet	Wet	Wet
1994	Average	Average	Dry
1995	Wet	Wet	Wet
1996	Wet	Wet	Wet
1997	Dry	Dry	Dry

1998	Dry	Dry	Average
1999	Dry	Dry	Dry
2000	Average	Average	Dry
2001	Dry	Dry	Dry
2002	Dry	Dry	Dry
2003	Average	Average	Average
2004	Average	Average	Average
2005	Dry	Dry	Dry
2006	Dry	Dry	Dry
2007	Dry	Dry	Dry
2008	Dry	Dry	Dry

B.3 Reach 3 – Millgrove to Watts River

Water Year	Current Flow	Unimpacted Flow	Rainfall (086070)
1963	Average	Average	Average
1964	Wet	Wet	Average
1965	Dry	Dry	Dry
1966	Average	Average	Dry
1967	Dry	Dry	Dry
1968	Average	Average	Wet
1969	Average	Average	Average
1970	Wet	Wet	Wet
1971	Wet	Wet	Wet
1972	Dry	Dry	Average
1973	Average	Wet	Wet
1974	Wet	Wet	Average
1975	Wet	Wet	Average
1976	Average	Average	Wet
1977	Wet	Wet	Average
1978	Average	Average	Wet
1979	Dry	Dry	Dry
1980	Average	Average	Wet
1981	Average	Average	Average
1982	Dry	Dry	Dry
1983	Average	Average	Average
1984	Average	Average	Wet
1985	Average	Average	Wet
1986	Wet	Wet	Average
1987	Dry	Dry	Average
1988	Dry	Dry	Wet
1989	Wet	Wet	Wet
1990	Wet	Wet	Dry
1991	Wet	Wet	Wet
1992	Wet	Wet	Wet
1993	Wet	Wet	Wet
1994	Average	Average	Dry
1995	Wet	Wet	Wet
1996	Wet	Wet	Dry
1997	Dry	Dry	Dry

1998	Dry	Dry	Average
1999	Dry	Dry	Dry
2000	Average	Average	Dry
2001	Dry	Dry	Dry
2002	Dry	Dry	Dry
2003	Average	Average	Average
2004	Wet	Average	Average
2005	Dry	Dry	Average
2006	Dry	Dry	Dry
2007	Dry	Dry	Dry
2008	Dry	Dry	Dry

B.4 Reach 4 – Watts River to Yering Gorge

Water Year	Current Flow	Unimpacted Flow	Rainfall (086066)
1963	Average	Average	Dry
1964	Wet	Wet	Average
1965	Dry	Dry	Average
1966	Average	Average	Dry
1967	Dry	Dry	Dry
1968	Average	Average	Wet
1969	Average	Average	Wet
1970	Wet	Wet	Wet
1971	Wet	Wet	Wet
1972	Dry	Dry	Average
1973	Average	Wet	Wet
1974	Wet	Wet	Wet
1975	Wet	Wet	Average
1976	Average	Average	Wet
1977	Wet	Wet	Average
1978	Average	Average	Wet
1979	Dry	Dry	Dry
1980	Average	Average	Average
1981	Average	Average	Average
1982	Dry	Dry	Dry
1983	Average	Average	Average
1984	Average	Average	Average
1985	Average	Average	Wet
1986	Wet	Wet	Average
1987	Dry	Dry	Average
1988	Dry	Dry	Wet
1989	Wet	Wet	Average
1990	Wet	Wet	Dry
1991	Wet	Wet	Wet
1992	Wet	Wet	Wet
1993	Wet	Wet	Wet
1994	Average	Average	Average
1995	Wet	Wet	Wet
1996	Wet	Wet	Dry

1997	Dry	Dry	Dry
1998	Dry	Dry	Wet
1999	Dry	Dry	Dry
2000	Average	Average	Average
2001	Dry	Dry	Dry
2002	Dry	Dry	Dry
2003	Average	Average	Dry
2004	Wet	Average	Average
2005	Dry	Dry	Dry
2006	Dry	Dry	Dry
2007	Dry	Dry	Dry
2008	Dry	Dry	Dry

B.5 Reach 5 – Yering Gorge to Mullum Mullum Creek

Water Year	Current Flow	Unimpacted Flow	Rainfall (086035)
1963	Dry	Average	Wet
1964	Wet	Wet	Wet
1965	Dry	Dry	Wet
1966	Average	Average	Average
1967	Dry	Dry	Dry
1968	Average	Average	Wet
1969	Average	Average	Average
1970	Wet	Wet	Average
1971	Wet	Wet	Wet
1972	Dry	Dry	Average
1973	Wet	Wet	Wet
1974	Wet	Wet	Wet
1975	Wet	Wet	Average
1976	Average	Average	Wet
1977	Wet	Wet	Wet
1978	Wet	Average	Average
1979	Dry	Dry	Dry
1980	Average	Average	Average
1981	Average	Average	Dry
1982	Dry	Dry	Dry
1983	Average	Average	Average
1984	Average	Average	Average
1985	Average	Average	Average
1986	Wet	Wet	Average
1987	Average	Dry	Average
1988	Average	Dry	Wet
1989	Wet	Wet	Average
1990	Average	Wet	Average
1991	Wet	Wet	Wet
1992	Wet	Wet	Wet
1993	Wet	Wet	Wet
1994	Average	Average	Dry
1995	Wet	Wet	Wet
1996	Wet	Wet	Dry

1997	Dry	Dry	Dry
1998	Dry	Dry	Dry
1999	Dry	Dry	Dry
2000	Average	Average	Average
2001	Dry	Dry	Dry
2002	Dry	Dry	Dry
2003	Dry	Average	Dry
2004	Average	Average	Wet
2005	Dry	Dry	Dry
2006	Dry	Dry	Dry
2007	Dry	Dry	Dry
2008	Dry	Dry	Dry

B.6 Reach 6 – Mullum Mullum Creek to Dights Falls

Water Year	Current Flow	Unimpacted Flow	Rainfall (086035)
1963	Dry	Dry	Wet
1964	Wet	Wet	Wet
1965	Dry	Dry	Wet
1966	Average	Average	Average
1967	Dry	Dry	Dry
1968	Average	Average	Wet
1969	Average	Average	Average
1970	Wet	Wet	Average
1971	Wet	Wet	Wet
1972	Dry	Dry	Average
1973	Wet	Wet	Wet
1974	Wet	Wet	Wet
1975	Wet	Wet	Average
1976	Average	Average	Wet
1977	Wet	Wet	Wet
1978	Wet	Average	Average
1979	Dry	Dry	Dry
1980	Average	Dry	Average
1981	Average	Average	Dry
1982	Dry	Dry	Dry
1983	Average	Average	Average
1984	Average	Average	Average
1985	Average	Average	Average
1986	Wet	Wet	Average
1987	Average	Average	Average
1988	Average	Average	Wet
1989	Wet	Wet	Average
1990	Average	Wet	Average
1991	Wet	Wet	Wet
1992	Wet	Wet	Wet
1993	Wet	Wet	Wet
1994	Average	Average	Dry
1995	Wet	Wet	Wet
1996	Wet	Wet	Dry

1997	Dry	Dry	Dry
1998	Dry	Average	Dry
1999	Dry	Dry	Dry
2000	Average	Average	Average
2001	Dry	Dry	Dry
2002	Dry	Dry	Dry
2003	Dry	Dry	Dry
2004	Average	Average	Wet
2005	Dry	Dry	Dry
2006	Dry	Dry	Dry
2007	Dry	Dry	Dry
2008	Dry	Dry	Dry

B.7 Reach 8 – Watts River

Water Year	Current Flow	Unimpacted Flow	Rainfall (086070)
1963	Average	Dry	Average
1964	Wet	Wet	Average
1965	Dry	Dry	Dry
1966	Average	Average	Dry
1967	Dry	Dry	Dry
1968	Average	Average	Wet
1969	Average	Average	Average
1970	Wet	Wet	Wet
1971	Wet	Wet	Wet
1972	Dry	Dry	Average
1973	Average	Average	Wet
1974	Wet	Wet	Average
1975	Wet	Wet	Average
1976	Average	Average	Wet
1977	Wet	Wet	Average
1978	Average	Average	Wet
1979	Dry	Dry	Dry
1980	Average	Average	Wet
1981	Average	Average	Average
1982	Dry	Dry	Dry
1983	Average	Average	Average
1984	Wet	Wet	Wet
1985	Average	Average	Wet
1986	Wet	Wet	Average
1987	Dry	Dry	Average
1988	Average	Average	Wet
1989	Wet	Wet	Wet
1990	Average	Average	Dry
1991	Wet	Wet	Wet
1992	Wet	Wet	Wet
1993	Wet	Wet	Wet
1994	Average	Average	Dry
1995	Wet	Wet	Wet
1996	Wet	Wet	Dry

1997	Dry	Dry	Dry
1998	Dry	Dry	Average
1999	Dry	Dry	Dry
2000	Average	Average	Dry
2001	Dry	Dry	Dry
2002	Dry	Dry	Dry
2003	Dry	Average	Average
2004	Wet	Wet	Average
2005	Dry	Dry	Average
2006	Dry	Dry	Dry
2007	Dry	Dry	Dry
2008	Dry	Dry	Dry

Appendix C Hydraulic Model Calibration

A one-dimensional steady state backwater analysis hydraulic model (HEC-RAS v4.1.0) was developed at each site to determine the relationship between flow, water depth and velocity. HEC-RAS calculates water surface profiles and other flow characteristics using a series of surveyed and interpolated cross-sections and estimated roughness factors. Details of the hydraulic model development, including assumptions, uncertainties and calibration are provided in this appendix.

Significant effort has been made to ensure the hydraulic models are accurate, however it should be noted that the models have been primarily calibrated to only one flow as observed on the day of the SKM survey. The flows at each site on the day of survey were relatively small, and therefore there are potentially significant errors inherent in using the HEC-RAS models to estimate water levels at high flows. In other words, while the hydraulic models are relatively accurate at the flows observed on the days of survey, they may not be accurate for higher or lower flows. Each model has been created so as to minimise this error, but it is not possible to avoid it entirely without surveying the water levels at each site over a wide range of different flows. This level of effort would be time consuming (and potentially dangerous at high flows) and is outside the scope of this project. Several of the models for this project were applied from previous projects, including the Environmental Flows recommendations (2005) and VEFMAP models. Where these models were available, calibration flows were adopted and checked with the previous studies. In some cases, we were able to combine calibrating flows from previous surveys with new readings to improve the reliability of the model outputs.

Where an existing model was applied, a site inspection was done and the model was edited as appropriate to reflect any changes that may have occurred at the site since the initial model was developed. These edits included:

- review of roughness coefficients
- ensuring that the cross-sections represented in the model represented the site
- review of vegetation present in the reach included in the model
- update of downstream boundary condition to represent new methods which apply a rating curve.

Table 12-1 presents the calibration flows applied for each of the hydraulic models.

▪ **Table 12-1 Site hydraulic model calibration details**

Reach	Site	Gauge	Date	Flow (m3/s)
1	Reefton	Yarra River at Doctors Creek (229103)	19/4/2012	0.116
2	East Warburton	Existing model calibration applied		
2	Millgrove	Existing model calibration applied		
3	Everard Park	Yarra River at Yarra Grange (229653)	2/5/2012	5.436
3	Woori Yallock Road	Yarra River at Yarra Grange (229653)	27/4/2012	11.856
4	Tarrawarra	Yarra River at Yarra Glen (229206) + Watts River at Healesville (229114)	20/4/2012	4.715+0.205
5	Yering Gorge downstream pumps	Existing model calibration applied		
5	Warrandyte Gorge	Existing model calibration applied		
6	Banyule	Existing model calibration applied		
6	Finns Reserve	Yarra River at Fitzsimons Lane (229142)	19/4/2012 16/4/2012	4.275 3.706
8	Watts River	Watts River at Healesveill (229114)	1/5/2012	0.524