Lower Ovens River Environmental Flows Project

Environmental flow recommendations

Submitted by:

Peter Cottingham & Associates
and the
Murray Darling Freshwater Research Centre

Lower Ovens Environmental Flows Project: Environmental flow recommendations

Prepared by Peter Cottingham & Associates and the Murray Darling Freshwater Research Centre on behalf of the North East Catchment Management Authority

CITATION:
This report can be cited as:
Cottingham P. Gawne B. Gigney H., Koehn J., Roberts J. Stewardson M. and Vietz G. (2008). Lower Ovens Environmental Flows Project: Environmental flow recommendations. Report prepared for the North Eastern Catchment Management Authority. Peter Cottingham & Associates and the Murray Darling Freshwater Research Centre.

Cover Photograph by Peter Cottingham.

EXECUTIVE SUMMARY

An environmental flows study of the regulated Ovens, Buffalo and King Rivers conducted in 2001 found that river regulation and management had relatively little impact on components of the flow regime, such as seasonal pattern and the frequency of floods and pulses. However, limited hydrological and hydraulic information meant that the study had some difficulty in arriving at detailed minimum flow recommendations (crucial to the ecological health of the rivers), which as a result were set at the 95% exceedence level, or natural. Since then, periods of drought have raised concerns about the about the effects of extreme low flow conditions on river condition in both the short and long term. This and the need to consider regional water issues has prompted the North East Catchment Management Authority (North East CMA) to commission a project that revisits environmental water requirements for the rivers. The project has used the FLOWS method that was developed to consider environmental flow issues in Victoria. The intent of the project is to identify the timing, frequency, magnitude and duration of flow components that will achieve long-term ecosystem objectives for the regulated Ovens, Buffalo and King Rivers. The project is reported in three key documents:

1. A site paper that outlines the process for assigning representative reaches and identifying sites at which cross-section surveys are undertaken.
2. An issues paper that considers:
    - The condition of assets and values associated with the rivers across the study area;
    - River hydrology and how it may have been affected by the presence of dams, the regulation of flows and extraction of water;
    - Potential threats to river condition, considering both flow-related and non-flow related issues;
    - The implications of current water resource management; and
    - Flow-related ecosystem objectives consistent with the Regional River Health Strategy.
3. A final report that summarises the above and provides environmental flow recommendations required to meet flow-related ecosystem objectives.

This Final Report is the third of the three key documents to be delivered during the project. It should be read in conjunction with the Issues Paper, which considers river condition and presents flow-related ecosystem objectives that provide the basis for the environmental flow recommendations contained in this report.

Environmental flow recommendations are developed for five study reaches:

1. Buffalo River from Lake Buffalo to the Ovens River;
2. King River from Lake William Hovell to Moyhu;
3. King river from Moyhu to the Ovens River;
4. Ovens River from the Buffalo River to Everton/Tarrawingee;
5. Ovens River from Everton/Tarrawingee to the Murray River at Lake Mulwala.

The FLOWS method was used to consider changes to the timing, frequency and duration of various flow components that make up the flow regime of each study reach:

- Cease to flow – periods of zero flow through a reach;
- Low flow – low baseflow that generally provide continuous flow through a reach;
- Freshes – small and short duration peak events;
- High flow – persistent increase in the seasonal baseflow;
- Bankfull – flow that achieves bankfull conditions with little flow onto the floodplain;
- Overbank – flows greater than bankfull that inundate the adjacent floodplain.

Modeled flow data for current (regulated) and natural (unregulated) conditions were used to assess changes to the flow regime in each reach resulting from the presence and operation of Lake Buffalo on the Buffalo River and Lake William Hovell on the King River, as well as diversions from each river reach to meet demand for stock & domestic, irrigation, and urban and industrial water supply. The modeled data were also used in 1-D hydraulic models (HECRAS) developed for each reach, which were used to related hydrology to the hydraulics that interact with geomorphic and habitat features.

River condition, structure and function are affected by many factors (often at multiple scales), of which management of the flow regime is one of the more significant. Flow-related factors that were considered to have a direct bearing on river condition were described in the Issues Paper and restated in this report:

- Potentially low DO concentration associated with cease to flow periods, particularly during drought;
- The potential for reach-scale reduction in primary production if low flow periods are more frequent of persist for longer than natural.
- Encroachment of non-native woody (terrestrial) vegetation if the frequency and duration of low flow events is increased;
- Loss of riffle habitat and other shallow habitat, surface water area and refugia for macroinvertebrates due to extended periods of low or zero flow;
- Loss of habitat for native fish due to extended periods of low or zero flow; and
- Barriers to the movement of fish if the frequency and duration of low flow events is increased.

Issues that are anthropogenic and/or catchment-based (potentially interacting with the flow regime and flow-related issues) include:

- Changes to the flow regime as a result of consumptive demand and its management (i.e. supply to meet urban and agricultural demand);
- The previous history of land clearance and other anthropogenic disturbances (e.g. mining, gravel extraction) and their effect on plant and animal community structure, habitat availability and condition, and ecosystem processes;
- Changes to riparian vegetation patterns and to the input of carbon to support foodwebs;
- Natural and human induced bank, hill slope and gully erosion that results in high sediment inputs to the rivers (a result of both natural and anthropogenic disturbance);

- The deposition of sediment, particularly sand that smothers in-stream habitat (e.g. for macroinvertebrates) and can abrade aquatic macrophytes;
- Livestock access causing damage to the riparian zone, and the river bed and banks by trampling and grazing;
- Previous desnagging that has decreased channel diversity and associated habitat for organisms such as fish.
- Contaminant (e.g. nutrient) loading, that can result in water quality decline that affects pollutant-sensitive macroinvertebrate taxa and increases the risk of nuisance algal blooms in downstream areas (e.g. Lake Mulwala);
- Cold water releases from Lake Buffalo and Lake William Hovell, which may affect metabolic function, reproduction and growth rates of aquatic organisms, or preclude biota such as native fish from persisting across their natural range.
- Levee construction, which has decreased floodplain connection and led to increased channel widening in some areas;
- The spread of willows and other alien plant species and a reduction in the ratio of native:alien species.

The Issues Paper also presented a series of flow-related ecosystem objectives that were used as the basis for environmental flow recommendations. The recommendations were developed with the intention of maintaining or rehabilitating aspects of river condition, and important ecosystem assets and values. The objectives were constructed around important ecosystem attributes:

- Water quality,
- Geomorphology,
- Aquatic and riparian vegetation,
- Aquatic macroinvertebrates, and
- Native fish.

Environmental flow recommendations were designed to:

- *Water quality*: reduce the likelihood of low dissolved oxygen conditions during periods of low inflow, and reduce the likelihood of water stratification;
- *Geomorphology*: maintain geomorphic diversity and provide habitat for aquatic, riparian and floodplain plants and animals.
- *Aquatic and riparian vegetation*: provide a flow regime that does not limit the maintenance or rehabilitation of vegetation communities, and limit the encroachment of terrestrial plant species onto features, such as benches and bars, in situations where this can ultimately increase the risk of bed and bank erosion;
- *Macroinvertebrates*: maintain the timing, natural variability and connectivity of flows that provide food resources and habitat for macroinvertebrates;
- *Native fish*: maintain in-channel and floodplain habitats for native fish, provide water of sufficient depth to allow fish movement between habitats, and provide changes in stage height that provide potential cues for breeding and movement.

The capacity of Lake Buffalo and Lake William Hovell relative to catchment discharge is relatively small. Thus the presence and operation of the dams has only a minor influence on the large flows that would naturally result in bankfull and overbank flows.

The Scientific Panel recommends that the natural frequency and duration of bankfull and overbank flows be maintained in the future. While this recommendation will have little impact on current management of the dam, it will become important should any large-scale water resource development be considered in the future. Low flow recommendations in each reach focused on ensuring sufficient depth for fish movement, and that discharge remained within a 'natural' range (defined by the p10 – p90 range of riffle and other shallow habitat) and met water quality objectives (often based on water velocity). Overall, the current operation of the water supply system results in a very high level of compliance when compared with natural conditions and the environmental flow recommendations proposed by this project.

It is widely recognized that river condition is the result of many factors, including flow regime, geomorphologic and ecological processes, habitat availability and water quality. A number of non flow-related management actions have been identified to maintain or improve the condition of ecosystem assets and values in the Ovens catchment, and so complement the flow-related objectives and environmental flow recommendations identified in this project:

- Amelioration of cold water releases from Lake Buffalo and Lake William Hovell.
- Riparian rehabilitation including;
    - Controlled access by livestock to the riparian zone;
    - Continued implementation of pest plant and animal control measures;
    - Revegetation, particularly of eroding gullies.
- Rehabilitation/protection of frequently connected wetlands.
- Control of industry and urban encroachment into the riparian zone;
- Protection of floodplain aquatic habitats, such as the protection of wetlands from livestock grazing.
- Protection of structural woody habitat in floodplain channels.
- Continuation of pest plant and animal control measures.
- Provision of fish passage past barriers such as the Wangaratta and Tea Garden Creek weirs;
- Management of the impacts of angling (especially under low flow conditions);
- Continued implementation of the Ovens water quality strategy and regional Landscape plans.

The Victorian Government has established the Victorian Environmental Flows Monitoring & Evaluation Program (VEFMAP) to evaluate the effectiveness of new flow regimes in regulated rivers across Victoria. VEFMAP is currently being deployed for a number of northern rivers in Victoria, and seeks to detect and evaluate river-specific as well as State-wide outcomes resulting from the implementation of environmental flow regimes. It is recommended that, where possible, the North East CMA seek to ensure that monitoring and evaluation of environmental flow outcomes in the Ovens River is consistent with that identified for the VEFMAP program. This will allow assessment of river-specific outcomes related to the flow recommendations proposed by this project and will add to the likelihood of detecting ecosystem responses at the State level, thus underpinning decisions on environmental flow regimes in the future. In addition, the Scientific Panel recommends that the North

East CMA undertake additional investigations and monitoring from which to assess issues specific to the Ovens River and its tributaries:

- Continuous monitoring of DO concentration in the lower Ovens River (Reach 5) when discharge falls below 65 – 85 ML/d.
- Targeted investigations of discharge-velocity-DO relationships in each reach to confirm conditions under which stratification and low DO concentration conditions become a risk to ecosystem condition.
- Basic inventories and studies of the structure and distribution of plant species that will provide basic information to assist any future review of environmental flow requirements for aquatic and riparian vegetation.
- An assessment of the potential impact of angling take on target native fish species to determine whether or not angling pressure is likely to affect the condition, distribution or recovery of native fish.
- Instream and riparian structures such as weirs, river stabilization works and levees exist that have the potential to restrict the longitudinal and lateral movement of fish and invertebrates and disrupt important ecological processes such as aquatic production and respiration and the cycling of nutrients. An audit of such structures will assist in ensuring that longitudinal and lateral connection between the river channel and riparian areas.
- Monitoring of geomorphic variables, such as bank integrity and the maintenance of bed diversity (pool depths) through observation and survey. The physical form theme of the Sustainable Rivers Audit for the Murray Darling Basin Commission is currently under preparation and is likely to include some appropriate geomorphic variables.
- Monitoring of macroinvertebrate responses to environmental flows by focusing on habitat where the macroinvertebrate communities are likely to be sensitive to changes in hydrology and hydraulics – for example on logs that make up structural woody habitat submerged in the main channel. Sampling methods such as the use of 'snag bags' have been developed for such purposes.
- Targeted investigations to confirm the conditions (shear stress) under which biofilms and deposits of fine sediments are disrupted, improving habitat conditions for macroinvertebrates.

CONTENTS

FIGURES

TABLES

1 INTRODUCTION

This project updates the environmental flow requirements of the regulated Ovens, Buffalo and King Rivers first undertaken by Cottingham et al. (2001) and as such provides information that will contribute to a review of regional water use and benefits as part of the Northern Sustainable Water Strategy, as well as any future review of the Ovens Bulk Water Entitlement.

The intent of the project is to identify the timing, frequency, magnitude and duration of flow components that will achieve long-term ecosystem objectives for the regulated Ovens, Buffalo and King Rivers, given the current level of catchment and water resource development. The project has been undertaken according to the Victorian FLOWS method (DNRE 2002) and reported in three key documents:

1. A Site Paper (PC&A and MDFRC 2007) that outlines the process for assigning representative reaches and identifying sites at which cross-section surveys are undertaken. Cross-section surveys are a crucial input to hydraulic models developed to support decision-making later in the project.
2. An Issues Paper (Cottingham et al. 2007) that considers:
    - The condition of assets and values associated with the rivers that are the focus of the study;
    - System hydrology including comparison of current and natural streamflow regimes and potential future water demands;
    - Key degrading factors, distinguishing between flow-related and non-flow related issues;
    - Current threats to the environmental assets and values resulting from consumptive water use;
    - The implications of current water resource management; and
    - Flow-related ecosystem objectives consistent with the Regional River Health Strategy.
3. A final report that summarises the above and provides environmental flow recommendations required to meet flow-related ecosystem objectives. The risks posed to ecosystem values and assets of not delivering the recommended environmental flows will also be identified.

This report of environmental flow recommendations is the third of the key documents to be delivered in applying the FLOWS method to the regulated Ovens River and its major regulated tributaries, and should be read in conjunction with the Issues Paper. The insights and recommendations developed during the project will, when implemented, ensure a flow regime appropriate for the maintenance or protection of river assets and values across the regulated part of the catchment.

2 STUDY AREA

A general overview of features (e.g. land use, geology, surface waters) of the Ovens catchment is provided in Cottingham et al. (2001) and updated in Cottingham et al. (2007). The study area is the surface waters of the Buffalo River and King River downstream of Lake Buffalo and Lake William Hovell to their respective confluence with the Ovens River, along with the Ovens River from the Buffalo River Junction to the Murray River (nominally set at the Murray Valley Highway bridge over the Ovens River). Environmental flow recommendations have been developed for five study reaches (PC&A and MDRFC 2007, Figure 1):

1. Buffalo River from Lake Buffalo to the Ovens River;
2. King River from Lake William Hovell to Moyhu;
3. King River from Moyhu to the Ovens River;
4. Ovens River from the Buffalo River to Everton/Tarrawingee;
5. Ovens River from Everton/Tarrawingee to the Murray River at Lake Mulwala.

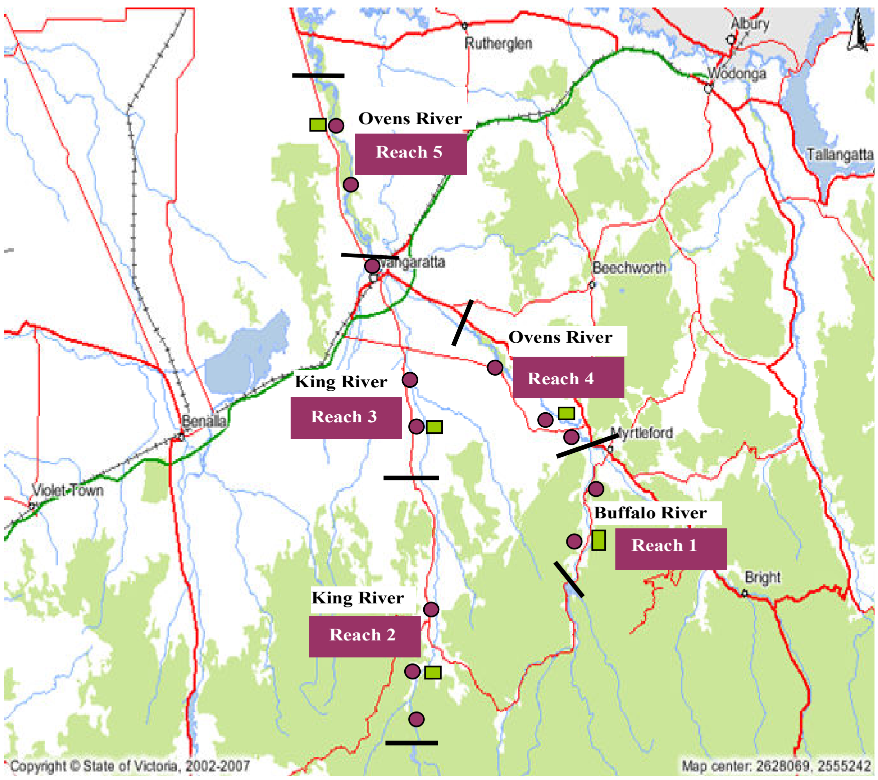


Figure 1: Reaches across the study area. Circles indicate sites visited. Squares indicate cross-section survey sites. Black lines represent boundaries between reaches.

3 METHODOLOGY

3.1 General approach

The Victorian FLOWS methodology (DNRE 2002) (Figure 2) provides a basis from which to review existing environmental flow objectives and develop recommendations for the lower Ovens River. The original study (Cottingham et al. 2001) pre-dated development of the FLOWS method and its application in this project will make the development and reporting of recommendations consistent with that for other regulated rivers across Victoria.

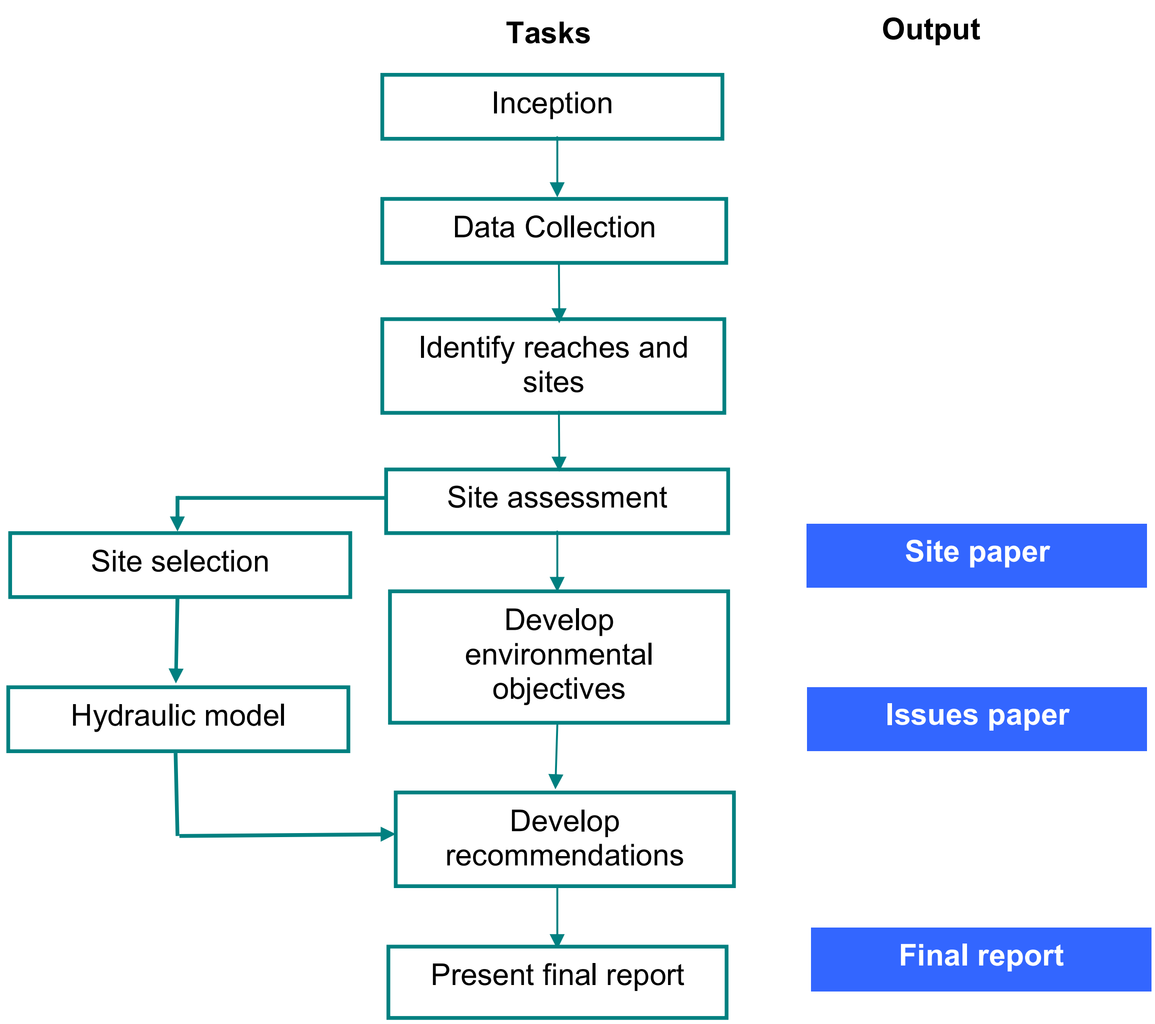


Figure 2: Outline of the FLOWS methods and key outputs (DNRE 2002)

The FLOWS method considers changes to the timing, frequency and duration of various flow components that make up the flow regime of a river:

- Cease to flow – periods of zero flow through a reach;
- Low flow – low baseflow that generally provide continuous flow through a reach;
- Freshes – small and short duration peak events;
- High flow – persistent increase in the seasonal baseflow;
- Bankfull – flow that achieves bankfull conditions with little flow onto the floodplain;
- Overbank – flows greater than bankfull that inundate the adjacent floodplain.

3.2 Hydrological and hydraulic modelling

The project utilised hydrological and hydraulic modelling to generate data and information to guide the Scientific Panel in its deliberations.

Hydrological assessment was based on modelled natural and current (regulated) daily flow data generated by the Ovens REALM model (SKM 2007). The period of record used was 1901 to 2006. The modelled natural regime describes the flow regime that would occur without the presence or influence of large reservoirs, farm dams, discharges or diversions for urban and agricultural supply (surface or groundwater), and with catchment condition consistent with the 2005/06 water year. The REALM model estimates discharge at a particular point in the system on the basis of gauged flows and tributary inflows (gauged or estimated), adjusted for demands (urban and rural) and losses. For example, discharge in the Ovens River at Peechelba under the current regulated conditions is modelled as:

$$Q_{403241} = Q_{403213} + Q_{403200} + Q_{403209} - D_{rural} - D_{urban} + I_{IWTP} - Losses$$

where:

Q_{403241} = estimated actual streamflow at gauge 403241;
Q_{403213} = gauged streamflow at gauge 403200;
Q_{403209} = gauged streamflow at gauge 403209;
D_{rural} = estimated historic rural demands in subcatchments downstream of gauge 403241;
D_{urban} = estimated historic urban demands for Glenrowan;
I_{IWTP} = historic discharges from the Wangaratta Trade Waste Treatment Plant to 15 Mile Creek at Wangaratta; and
Losses = 20% of total upstream flow when total upstream flow is less than 10,000 ML/wk.

The natural flow regime is, therefore, one where demand and losses are added to gauged flows (rather than subtracted), while industrial discharge is subtracted:

$$Q_{403241} = Q_{403213} + Q_{403200} + Q_{403209} + D_{rural} + D_{urban} - I_{IWTP} + Losses$$

Two model runs were available for natural conditions, one with no losses included and one with losses included[1]. The model run with losses included generated a flow series with a greater than expected frequency and duration of cease to flow periods, often at times when gauge records showed there was significant flow in the various study reaches. Basing flow recommendations on this flow series would inflate the frequency of very low and zero flow events and put ecosystem assets and attributes at increased risk. Accordingly, the flow series without losses was adopted for this study. Even though this flow series is more conservative in terms of low flow volumes, its use is likely to pose lower risk when developing environmental flow recommendations to maintain or protect ecosystem assets and attributes, as it better represents the low and zero flow conditions in each reach. The flow data were used to generate plots of flow exceedence, median monthly flows and partial series of flood events for both the natural and current conditions (see Issues Paper, Cottingham et al. 2007) and as an input in hydraulic models for a representative site in each reach.

Preparation of flow recommendations for each reach was aided by the use of a 1-D hydraulic model (HECRAS v 3.1.3 (USACE 2002), see Vietz (2007) in Appendix 1 for a full description of model development and calibration) based on cross-section surveys at the following sites (Figure 1):

- Buffalo River between Osbourne's Bridge and McGuffie's Bridge (Reach 1);
- King River downstream of Gentle Annie Lane road bridge, Whitfield (Reach 2);
- King River downstream of Docker Rd bridge (Reach 3);
- Ovens River downstream of the road bridge between Bowman and Whorouly (Reach 4);
- Ovens River downstream of the road bridge at Peechelba (Reach 5).

Cross-section sites were chosen based on capturing the hydraulic, geomorphic and ecological characteristics of the reach. These included lateral and vertical hydraulic constrictions (e.g. debris and riffles) as well as ecological and geomorphic points of interest (e.g. deep pools, vertical banks, riffles, runs, benches and wetlands). Cross-sections were surveyed perpendicular to the general flow path, with a greater density of survey points within the low flow channel, where detail is required, and fewer points on the floodplain where only broad-scale morphology is important. Between six and eight cross sections were surveyed at each of the five representative sites.

A key output from the modelling is a graphic presentation of each transect with water levels related to discharge. Water levels are shown for the discharge on the day of surveying and a discharge approximating bankfull. In cross-section (Figure 3a), the black line represents channel topography, with small black squares along this line identifying survey points. Horizontal blue lines within the cross-section represent the water surface at the various discharges. Long profiles (thalweg level plot) display the variability in bed levels (Figure 12b). In addition to water levels, the hydraulic models

[1] The 'losses' in the natural flow series take into account storages in the catchment. The 'natural' flow series with 'losses' has a loss function applied (losses added back into the data) to account for anthropogenically influenced losses such as evaporation from storages. However, the loss function may also account for losses which also naturally occur (e.g. loss to groundwater). The factors involved with losses have not been quantified (Heidi Ryan, SKM, pers. comm.).

are used to investigate important hydraulic parameters such as velocity and shear stress.

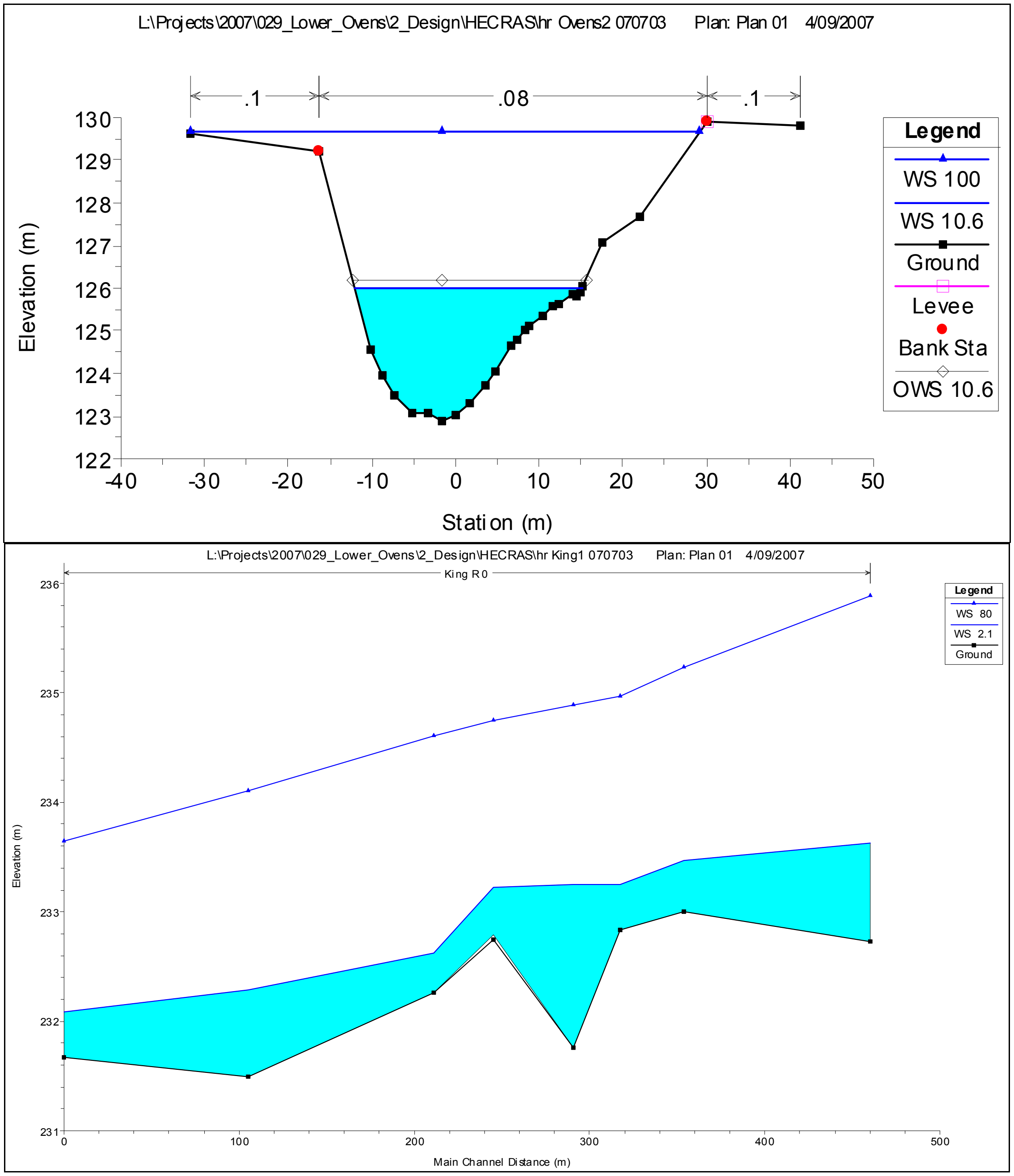


Figure 3: (a) Cross section and (b) longitudinal section displaying flow stage for the day of surveying and an approximate bankfull level.

4 FLOW-RELATED ISSUES AND OBJECTIVES

4.1 Flow-related issues

River condition, structure and function are affected by many factors (often at multiple scales), of which management of the flow regime is one of the more significant. As described in the Issues Paper (Cottingham et al. 2007), issues that have a direct bearing on the flow regime include:

- Potentially low DO concentration associated with cease to flow periods, particularly during drought;
- The potential for reach-scale reduction in primary production if low flow periods are more frequent or persist for longer than natural.
- Encroachment of non-native woody (terrestrial) vegetation if the frequency and duration of low flow events is increased;
- Loss of riffle habitat and other shallow habitat, surface water area and refugia for macroinvertebrates due to extended periods of low or zero flow;
- Loss of habitat for native fish due to extended periods of low or zero flow; and
- Barriers to the movement of fish if the frequency and duration of low flow events is increased.

Issues that are anthropogenic and/or catchment-based (potentially interacting with the flow regime and flow-related issues) include:

- The previous history of land clearance and other anthropogenic disturbances (e.g. mining, gravel extraction) and their effect on plant and animal community structure, habitat availability and condition, and ecosystem processes;
- Changes to riparian vegetation patterns and to the input of carbon to support foodwebs;
- Natural and human induced bank, hill slope and gully erosion that results in high sediment inputs to the rivers (a result of both natural and anthropogenic disturbance);
- The deposition of sediment, particularly sand that smothers in-stream habitat (e.g. for macroinvertebrates) and can abrade aquatic macrophytes;
- Livestock access causing damage to the riparian zone, and the river bed and banks by trampling and grazing;
- Previous desnagging that has decreased channel diversity and associated habitat for organisms such as fish.
- Contaminant (e.g. nutrient) loading, that can result in water quality decline that affects pollutant-sensitive macroinvertebrate taxa and increases the risk of nuisance algal blooms in downstream areas (e.g. Lake Mulwala);
- Cold water releases from Lake Buffalo and Lake William Hovell, which may affect metabolic function, reproduction and growth rates of aquatic organisms, or preclude biota such as native fish from persisting across their natural range.
- Levee construction, which has decreased floodplain connection and led to increased channel widening in some areas;
- The spread of willows and other alien plant species and a reduction in the ratio of native:alien species.

4.2 Flow-related ecosystem objectives

The Scientific Panel undertaking this project was guided by the principle of sustaining diverse and healthy ecosystems, consistent with the objectives of Ovens Regional Catchment Strategy and the Victorian River Health Strategy. The intention of the flow recommendations was to:

- Maintain or improve the condition and functioning of riverine ecosystems, and
- Maintain or improve existing populations and the distribution of native flora and fauna across their natural range.

An environmental flow study has recently been completed for the upper Ovens catchment (SKM 2006). The objectives of the upper Ovens study are consistent with this project, as they consider:

- Individual species and communities;
- Habitats; and
- Ecological (physical and biological) processes.

Thus the general approach to developing flow recommendations for the upper and lower Ovens catchment is broadly consistent and used the same method. The flow recommendations developed for the reach of the upper Ovens immediately above the regulated section of the river included in this study are listed in Table 1.

Table 1: Upper Ovens Reach 3 - Ovens River from Buckland River to Buffalo River (from SKM 2006)

Season	Component	Magnitude	Frequency	Duration
Summer	Cease-to-flow	No specific recommendation. As natural		
	Low flow	137 ML/day or natural		
	Freshes	595 ML/day	2 per year	7 days
	High	2000 ML/day	1 per year	4 days
Winter	Low flow	740 ML/day or natural		
	Freshes	1870 ML/day	1 per year	15 days
	High	8500 ML/day	1 per year	4 days
	Bankfull	As natural		
	Overbank	No specific recommendation		

A series of flow-related ecosystem objectives based on the needs of various attributes of the regulated sections of the Ovens, Buffalo and King Rivers were developed and presented in the Issues Paper (Cottingham et al. 2007). These are re-stated in Table 2 and reordered on a reach by reach basis in Chapter 5, which presents the environmental flow recommendations required to meet the stated objectives for each reach.

Table 2: Summary of flow-related ecosystem objectives and associated flow components (G = geomorphology, FP = floodplain, RB = river bank, BB = benches and bars, IC = in-channel, M = macroinvertebrate, NF = native fish)

Ecosystem Attribute	Environmental or Ecological Values	Potential flow related threats	Flow-related ecological objectives	Reach	Flow Component to be considered	Mechanism	Season
Geomorphology	Geomorphic processes contribute to the availability and quality of in-channel and riparian habitat	• Reduced frequency of flow pulses capable of scouring sediments from pools • Reduced magnitude of spring and summer base flows that allows encroachment by terrestrial vegetation • Longer than natural duration of low flow events, resulting in excessive deposition of fine materials. • Reduced frequency of flow pulses that maintain connectivity with riparian and floodplain habitats.	**G1**: Scour sediments from base of pools to maintain quantity and quality of habitat for flora and fauna.	All	High flows, Bank full, Overbank	Flows of sufficient magnitude to provide critical shear stress to scour sediments from pools.	Win, Spr
			G2: Movement of bed material to maintain bed diversity for water depth variation (pool scour).	3 and 5	High flows, Bank full, Overbank	Flows of sufficient magnitude to provide critical shear stress to periodically mobilize sand.	Win, Spr
			G3: Control riparian vegetation encroachment to prevent catastrophic erosion processes.		High flows, Bank full	Maintain high flows for sufficient time to make conditions unsuitable for flood-sensitive species.	Spr, Sum
			G4: Maintain channel form and key habitats, including in-channel benches.	All	High flows, Bank full	Flows of sufficient magnitude and duration to maintain channel form and natural rates of erosion.	Win, Spr
			G5: Maintain channels and inlets for connectivity of main channel with important floodplain and wetland zones.	3 and 5	Bank full, Overbank	Flows of sufficient stage height to connect with riparian and floodplain areas.	Win, Spr
			G6: Scour biofilms from bed	1, 2 and 4	High flow, Freshes, Bank full	Flows of sufficient velocity.	Win, Spr
Aquatic and riparian vegetation	Floodplain vegetation contributes to regional biodiversity, provides carbon that is an integral part of aquatic food webs, and is an important indicator of	Reduced frequency and duration of overbank events	**FP1**: Rehabilitate remnant native vegetation on the floodplain	1, 2, 3 and 4	Overbank	Provide inundation events to ensure maintenance or recovery of floodplain and wetland vegetation is not limited by the water regime.	Win, Spr

Ecosystem Attribute	Environmental or Ecological Values	Potential flow related threats	Flow-related ecological objectives	Reach	Flow Component to be considered	Mechanism	Season
	catchment and river health.		**FP2**: Increase the extent of native vegetation on the floodplain	1, 2, 3 and 4	Overbank	Provide inundation events to ensure maintenance or recovery of floodplain and wetland vegetation is not limited by the water regime.	Win, Spr
			FP3: Increase the width of native vegetation at the top of the riverbank to be at least 3 trees wide	1, 2, 3 and 4	Overbank	Provide inundation events to ensure maintenance or recovery of floodplain and wetland vegetation is not limited by the water regime.	Win, Spr
			FP4: Maintain the quality, extent and width of native vegetation on the floodplain	5	Overbank	Provide inundation events to ensure maintenance or recovery of floodplain and wetland vegetation is not limited by the water regime.	Win, Spr
	River bank vegetation contributes to bank stabilization and primary production, and provides food resources and habitat for other organisms such as invertebrates and fish.	Reduced frequency and duration of summer freshes that allows encroachment of terrestrial species	**RB2**: Increase the extent and diversity of native vegetation	1, 2, 3 and 4	Bank full	Provide inundation events to ensure maintenance or recovery of riparian and river bank vegetation is not limited by the water regime.	Win, Spr
			RB3: Maintain the extent and diversity of native vegetation	5	Bank full	Provide inundation events to ensure maintenance or recovery of riparian and river bank vegetation is not limited by the water regime.	Win, Spr
	Bench and bar vegetation contributes to bed and bank stabilization; it has a minor role in primary production, and as habitat for aquatic and terrestrial organisms.	Reduced frequency and duration of summer freshes allows establishment of persistent terrestrial species	**BB1**: Maintain the ruderal–temporary character of cobble and gravel bars	1, 2 and 4	Fresh	Provide summer freshes of sufficient height and duration to drown out terrestrial species.	Sum, Aut
		Reduced frequency and duration of winter freshes and floods that allows establishment of long-lived woody (native and non-native) terrestrial species.	**BB2**: Minimise the opportunities for woody species, whether native or non-native, to establish and persist on cobble and gravel bars.	1, 2 and 4	High flow	Provide winter flows sufficient to drown out woody species.	Win, Spr

Ecosystem Attribute	Environmental or Ecological Values	Potential flow related threats	Flow-related ecological objectives	Reach	Flow Component to be considered	Mechanism	Season
			BB3: Minimise the opportunities for woody species, whether native or non-native, to establish and persist on bars.	3 and 5	High flow	Provide winter flows sufficient to drown out woody species	
	In-Channel vegetation contributes to regional biodiversity, primary production, and provides food resources and habitat for other organisms such as invertebrates and fish.	Flow has a role but is not necessarily the main driver	**IC1**: Composition of macrophytes to be dominated by native species	1, 2, 3, 4 and 5	*Not known*	*To be determined*	
Macroinvertebrates	Contribute to aquatic biodiversity, integral part of aquatic food webs, and important indicator of river health.	• Reduced magnitude of base flows that limits the area of riffle habitat available for macroinvertebrates. • Extended summer low-flow events that allow excessive settling of fine sediments on in-channel habitat. • Reduced frequency and duration of events that maintain riffle and other shallow habitat. • Loss of short term variability	**M1:** Maintenance of habitat diversity	All	High flows, Bank full	Flows of sufficient magnitude and duration to maintain channel form.	Win, Spr
			M2: Maintain habitat quality by delivery of scouring flows	All	High flow and freshes	Flows of sufficient magnitude to provide critical shear stress to scour fine sediments from the substrate.	Win, Spr
			M3: Maintain seasonality	All	High flows, Low flows	Flow regime with components that have natural features of timing, frequency, magnitude and duration.	Win, Spr Sum, Aut
			M4: Maintenance of riffles and other shallow habitat	All	Low flows	Flow of sufficient magnitude to cover riffle zones (Reaches 1,2 and 4) or provide other shallow habitat (all reaches)	Sum, Aut
			M5: Maintain flood frequency to provide exchange of organic matter and fine sediment	3, 4 and 5	Bank full, Overbank	Flow of sufficient magnitude to inundate flood runners and floodplain wetlands.	Win, Spr
			M6: Maintain short-term fluctuations in discharge	All	Low flows to Bank full	Short term fluctuation to dry sediments, maintain macrophyte habitat and entrain leaf litter.	Win, Spr Sum, Aut
Native fish	Native fish contribute to aquatic biodiversity, are	• Reduced magnitude of base flows that limit the area of	**NF1**: Maintain flow regime with components that have natural	All	Seasonality, variability, volume,		All

Ecosystem Attribute	Environmental or Ecological Values	Potential flow related threats	Flow-related ecological objectives	Reach	Flow Component to be considered	Mechanism	Season
	key predator in aquatic food webs, valued for recreational fishing.	habitat available for native fish. • Reduced magnitude of base flows that limits fish passage along river reaches. • Extended low flows that result in low DO conditions. • Loss of spring flow pulses that serve as migration cues for some native fish. • Reduced frequency and magnitude of floodplain/wetland inundation events that provide habitat for some fish species and deliver food material back to the river.	features of timing, frequency, magnitude and duration		flood frequency		
			NF2: Low flows that maintain adequate habitat for native fish populations	All	Low flows	Flow of sufficient magnitude to maintain low-flow habitat and pools.	Sum, Aut
			NF3: Maintain flows sufficient to allow fish passage	All	Low flows	Flow of sufficient magnitude to depth across the channel sufficient for fish passage.	Sum, Aut
			NF4: Maintain flows sufficient to maintain DO concentration greater than 4 mg/L	All	Low flows	Flow of sufficient magnitude to maintain DO at acceptable levels.	Sum, Aut
			NF5: Maintain frequency of overbank flows that water billabongs and flood-runners	3,4 and 5	Overbank	Flow of sufficient magnitude to inundate flood runners and floodplain wetlands.	Win, Spr
			NF6: Low flows sufficient to maintain natural rates or connectivity between pools and riffles	3,4 and 5	Freshes	Flow of sufficient magnitude to maintain low-flow habitat and pools.	Sum, Aut
			NF7: Maintain flow cues to stimulate movements	All	Variability	Flow pulses of sufficient magnitude to serve as breeding and migration cues.	All

5 ENVIRONMENTAL FLOW RECOMMENDATIONS

5.1 Rationale for flow recommendations

The basis for environmental flow recommendations are described in the following sections and summarized for each reach in sections 5.2 – 5.7. No specific flow recommendations were required for objectives G3, IC1 and M3 (see tables in sections 5.2 – 5.7) under current management, as their flow requirements were addressed through other objectives. They were included as a reminder that these objectives should be reconsidered should there be any water resource development in the future (e.g. expansion of Lake Buffalo).

5.1.1 Water quality objectives

The main flow-related water quality issue is the occurrence of low dissolved oxygen (DO) recorded in Reach 5 during periods of sustained low inflows (2003 and 2006). A relationship between DO and historic flow records since 2000 was developed using daily flow and monthly DO data obtained from the Victorian data warehouse. These suggest that surface DO only falls below 4 mg/L during low flow periods (summer-autumn periods in the drought years of 2003 and 2007), and never at flows above 65 ML/d (Figure 4). In addition, DO measurements in pools along Reach 5 taken by MDFRC staff in 2006 (unpublished data) indicated that DO concentration declined to less than 4 mg/L at the pool surface during extended cease to flow periods; it is likely that DO concentration was well below 4 mg/L below the surface.

While biota such as some native fish[2] can survive at DO concentrations below 4 mg/L (McNeil and Closs 2007) for short periods, the onset of hypoxia (< 2 mg/L DO) will be harmful to many organisms and is to be avoided. A decline in DO concentration to below 4 mg/L should be taken as a warning of an increased risk of hypoxia.

Stratification of the water column (thermal or salinity induced) and reduced mixing can lead to low DO condition in bottom waters of pools, as well as contribute to conditions favourable for algal bloom formation. In an investigation of the Wimmera and Glenelg Rivers, Western and Stewardson (1999) found that thermal stratification did not usually occur when cross-section mean velocity remains above 0.01 m/s. The relationship between discharge and mean water velocity across all cross sections in the reach suggests that mean velocity exceeds 0.01 m/s at flows above 85 ML/d in Reach 5 (Figure 5), and above 10 ML/d in the other reaches (e.g. Reach 3).

Relationships between discharge and DO concentration and/or water velocity (stratification) have been used when considering low flow recommendations in each reach. These relationships have been based on empirical data, modelled relationships using HECRAS and RAP (Marsh 2004), and field observations (mainly limited surface water measurements at sites along Reach 5). It is recommended that further investigations be undertaken to explore discharge-DO relationships in more

[2] An investigation of some fish species of the Ovens River hypothesized to be tolerant of hypoxia (McNeil and Closs 2007) noted increasing evidence of stress (increased gill ventilation rates and surface breathing) as DO concentration fell below 2.55 mg/L.

detail along each reach, given limited spatial and temporal scale of data and information currently available.

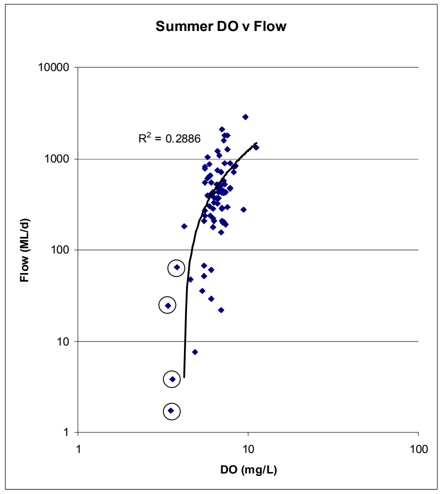
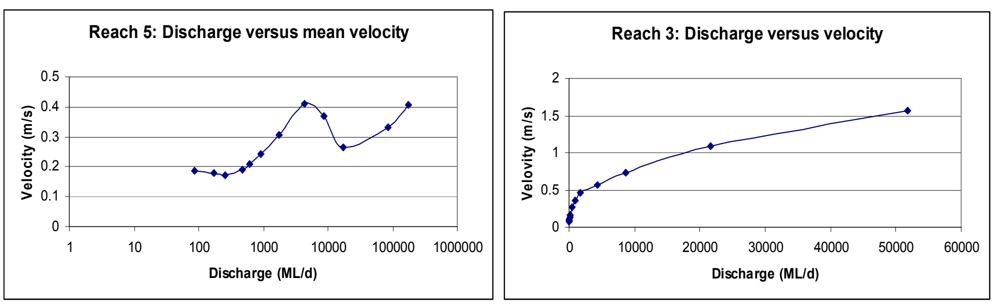


Figure 4: Relationship between discharge and DO concentration in Ovens River at Peechelba (Reach 5), 2000 – 2007. Data obtained from the Victorian data warehouse. Circled data points are those below 4 mg/L DO, all of which occur at flows below 65 ML/d.



(a) (b)

Figure 5: Relationship between mean velocity (m/s) and discharge (m^3/s) in (a) Reach 5, and (b) Reach 3.

5.1.2 Geomorphology objectives

Geomorphology objectives have been developed to maintain geomorphic diversity, to provide ecological disturbance to promote renewal of biofilms, to maintain the condition of substrate, and to provide habitat for aquatic, riparian and floodplain vegetation (Table 3). The rationale for flow recommendations to meet the stated objectives has been developed for both the cobble-bed (Reach 1, 2 and 4) and sand-bed reaches (Reaches 3 and 5). The rationale and associated metrics are based on both theoretical and empirical studies. Plots of discharge relationships with shear stress, velocity and water depth (e.g. bankfull) that underpin the flow recommendations for Reach 5 are presented in Figure 6 as an example. Similar information for the other reaches is presented in Appendix 2.

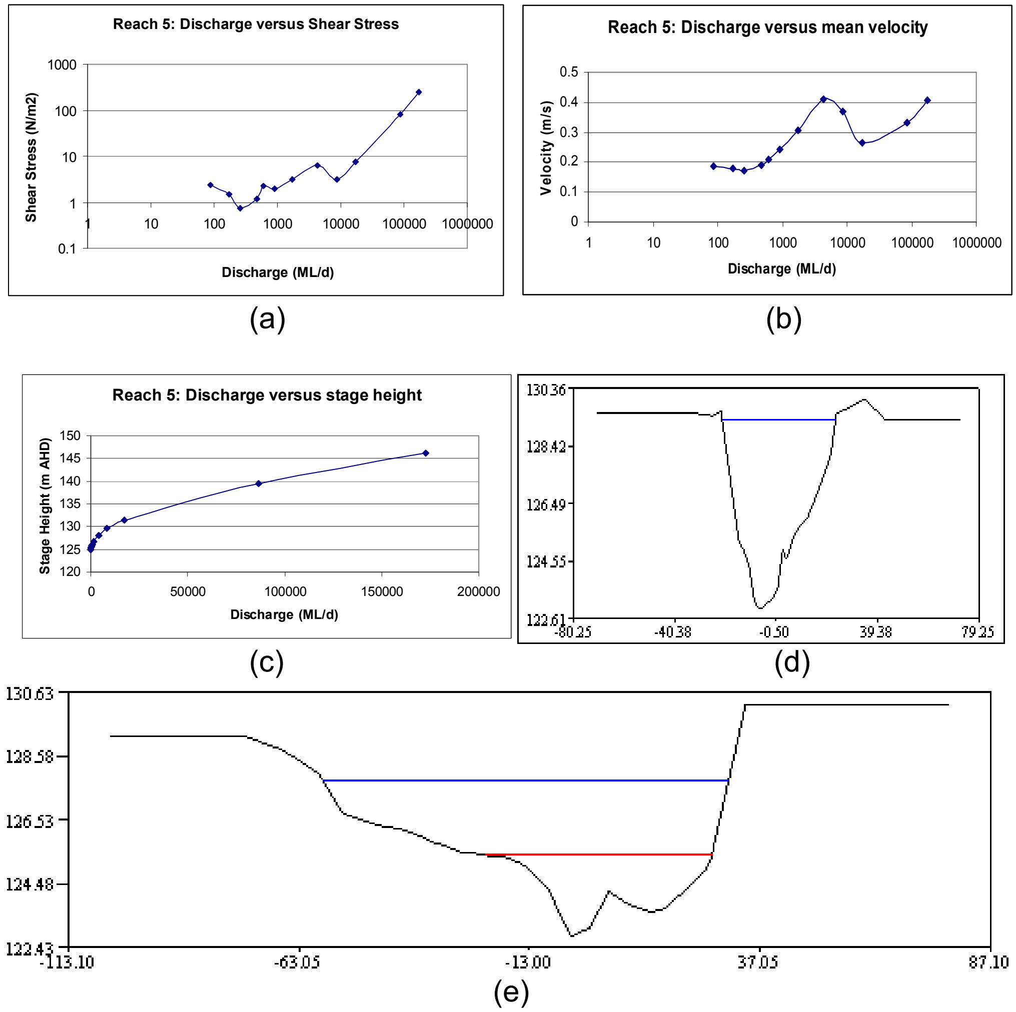


Figure 6: Relationship between discharge and (a) shear stress (N/m^2), (b) mean velocity (m/s), (c) stage height (m AHD), (d) channel depth (m AHD), and (e) inundation of a concave bench (m AHD) to a depth of 1.5m in Reach 5, Ovens River (red line shows bench level while the blue line shows level 1.5 m above the bench).

Table 3: Rationale for flow recommendations to address geomorphology objectives

Geomorphic objectives	Rationale for cobble bed (Reaches 1,2, and 4)	Rationale for sand bed (Reaches 3 and 5)
G1: Mobilise sediments in pools and riffles to remove fines from interstices	Shear stress for removing fines from cobbles in pools equal to 15 N/m^2 with 1 day duration adequate (empirically based from Wilkinson 2001)	Shear stress for pools determined by Shield's entrainment function for normally packed course sand 2mm (within which fines are present). Threshold equal to 1.1 N/m^2
G2:Movement of bed material to maintain bed diversity (pool scour)	Shear stress determined by Shield's entrainment function for d_{50} of bed material at normal packing (based on Wolman count at riffles). Shear stresses equal to 29, 176 and 57 N/m^2 for Reaches 1, 2 and 4 respectively.	In the absence of criteria for bend pool scour the bankfull discharge, often associated with channel forming, is used (USACE 2002)
G3: Control riparian vegetation encroachment to prevent catastrophic channel erosion during an event	Based on inundation of vegetation – see also BB1 and BB2 under aquatic and riparian vegetation (section 5.1.3)	Based on inundation of vegetation – see BB1 and BB2 under aquatic and riparian vegetation (section 5.1.3)
G4: Maintain channel form and key habitats including benches and bars	Not recommended	Based on inundation of in-channel benches to a depth of 1.5 m (based on investigations into sedimentation on concave benches in the Ovens River, see Vietz et al. (2006)
G5: Maintain channels and inlets for connectivity of main channel with important floodplain and wetland zones	Morphologic definition of bankfull and overbank flows	Morphologic definition of bankfull and overbank flow
G6: Scour biofilms from bed	Based on threshold velocity of 0.3 m/s (Ryder et al. 2006)	Based on threshold velocity of 0.3 m/s (Ryder et al. 2006)

5.1.3 Aquatic and riparian vegetation objectives

Vegetation objectives have been designed to maintain or improve (or at least not constrain) the condition of riparian vegetation, and prevent unnatural rates of encroachment by terrestrial vegetation into the river channel. Floodplain and riverbank objectives (Table 4) relate to the natural timing, frequency and duration of bankfull and overbank flow events (see also geomorphology objective G5). Objectives for bench and bar habitats, BB1-BB3, seek to stop terrestrial encroachment into the channel by using inundation to stress the plants: this also addresses geomorphic objective G3. Turning over the substrate, and hence effectively uprooting the plants, is effective (Biggs 1996) for shallow-rooted plants on sandy substrates and is addressed under geomorphic objective G2. The actual recommendations and flow components for BB1-BB3 are different because each objective is for a different group of plants.

Thus BB1, for cobble or gravel bench and bars, provides a disturbance (inundation) regime during the growing season to keep the vegetation at an early stage of succession and minimise the establishment of woody species. The disturbance regime means successive phases of germination, growth, and die-off. This results in bars being dominated by non-woody species (grasses, sedges, herbs) that disperse readily, and that can germinate and grow rapidly, and are pre-dominantly short-lived annuals. Woody species that are present are generally very young (i.e. short). In the absence of such disturbance, woody species continue to grow and persist, which can drastically change the ecological character of bench and bar, and alter channel hydraulics. Like BB1, objectives BB2 and BB3 aim to severely stress and eliminate woody species from establishing, but here the target is young woody species on in-channel bars, whether sandy or cobble-gravel, in the cooler months. Objective BB2 thus provide a back-up for those reaches where BB1 also applies.

The disturbance (Inundation) regime needs to be tailored for significant species in these habitats and reaches, and ideally should be based on specifying how deep, for how long, and under which season. However, because such exact Information is not available, the flow recommendations are based on interpolating what is known about inundation stress and tolerances for native species, and on general principles that are beginning to be established in the international scientific literature. Depth is important, for example, because complete submersion is more stressful than being partly submerged. Seedlings of River Red Gum can survive a long time if only partly submerged, 14 weeks according to Dexter (1978), therefore complete submergence for as long as is 'naturally' possible is needed to stress any colonising River Red Gums. Season is important because plants can tolerate submersion much longer in the cooler months outside the growing season than during the growing season (van Eck et al. 2006); this is also the season when high flows last longer. Finally, species physiology and adaptations are also important: flood sensitive species are much less tolerant of being submerged than are flood-tolerant species (van Eck 2004). The recommendation is for flows in excess of 1 m, based on observations that this should overtop recently-germinated River Red Gums, Callistemon and willows, and the duration of such flows is derived from analysis of natural flow regime supported by the literature.

Table 4: Rationale for flow recommendations to address aquatic and riparian vegetation objectives

Riparian and aquatic vegetation objectives	Rationale
FP1: Rehabilitate remnant native vegetation on the floodplain	Morphologic definition of bankfull and natural frequency, magnitude and duration of overbank flows.
FP2: Increase the extent of native vegetation on the floodplain	Morphologic definition of bankfull and natural frequency, magnitude and duration of overbank flows.
FP3: Increase the width of native vegetation at the top of the riverbank to the equivalent of at least three mature canopy trees from the relevant EVC	Morphologic definition of bankfull and natural frequency, magnitude and duration of overbank flows.
FP4 Maintain the quality, extent and width of native vegetation on the floodplain	Morphologic definition of bankfull and natural frequency, magnitude and duration of overbank flows.
RB2: Increase the extent and diversity of native vegetation	Morphologic definition of bankfull and natural frequency, magnitude and duration bankfull flows.
RB3: Maintain the extent and diversity of native vegetation	Morphologic definition of bankfull and natural frequency, magnitude and duration of bankfull flows.
BB1:Maintain the ruderal–temporary character of cobble and gravel bars	Provide summer freshes of sufficient height and duration to drown out terrestrial species.
BB2:Minimise the opportunities for woody species, whether native or non-native, to establish and persist on cobble and gravel bars.	Provide winter flows sufficient to drown out woody species.
BB3:Minimise the opportunities for woody species, whether native or non-native, to establish and persist on bars.	Provide winter flows sufficient to drown out woody species
IC1: Composition of macrophytes to be dominated by native species	There is currently insufficient knowledge available from which to develop specific flow recommendations at this stage. This is an area requiring further research and investigations.

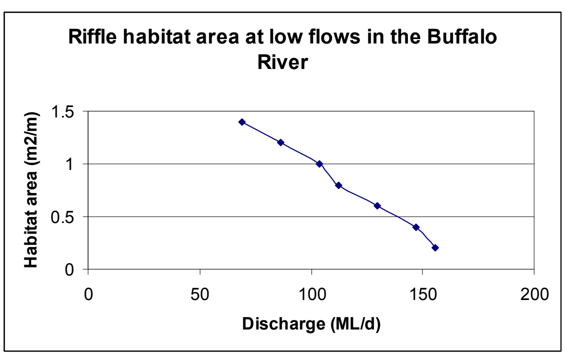
5.1.4 Macroinvertebrate objectives

Macroinvertebrate objectives (Table 5) were established to maintain the timing, natural variability and connectivity of flows that provide food resources and habitat for macroinvertebrates. Stable flows, such as can occur in highly regulated river systems, can result in low invertebrate species diversity (Johnson and Harp 2005, Rader and Belish 1999) and change the nature of biofilms, which are a food source for many invertebrates, to less palatable forms (Burns and Walker 2000, Sheldon and Walker 1997). Conversely, river systems that maintain their natural flow variability often support diverse invertebrate communities and maintain early succession biofilms that are more palatable and nutritious for invertebrates. For example, reinstating flow variability was shown to increase species diversity and SIGNAL scores when flow variability was reintroduced in the Mitta Mitta River below Lake Dartmouth (Sutherland et al. 2002, Watts et al. 2005).

Flow recommendations for objectives M1, 2, 3 and 5 are addressed by recommendations identified for geomorphology objectives. Objectives M4 and M6 relate to maintenance of shallow habitat and variability of the low flow regime. In general, there was a negative relationship between discharge and low flow habitat (shallow and riffle habitat[3]) availability; the area of habitat available declines as discharge increases (Figure 7). In some instances the current flow regime results in a lower median shallow habitat area than the natural regime in the summer-autumn low flow period (Figure 8). However, given the similarity of the variability in habitat availability, as depicted by the 10th percentile – 90th percentile (p10 – p90) range, it is unlikely that the differences in median values are ecologically significant. The Scientific Panel has adopted the p10 – p90 range (or natural) as indicative of the natural habitat variability and, therefore, upper and lower limits on discharge during summer-autumn. These values, along with information related to stratification and DO concentration, were used to develop low flow recommendations for each reach. It is likely that river operations will result in flows with less variability than natural in some reaches. Short-term variation will be achieved by delivering summer-autumn freshes to raise stage height, connect habitat and rejuvenate biofilms (i.e. disturb and allow a return of early succession biofilm communities).

Table 5: Rationale for flow recommendations to address macroinvertebrate objectives

Macroinvertebrate objectives	Rationale
M1: Maintenance of habitat diversity	Addressed by flow recommendations identified for geomorphology objective G1 (see Table 3).
M2: Scouring flows	Addressed by flow recommendations identified for geomorphology objective G1 (see Table 3).
M3: Protection of seasonality	No specific recommendation is required as seasonality remains largely intact under current management.
M4: Maintenance of riffles and other shallow habitat	Based on morphologic definition of p10 - p90 range in shallow habitat availability in summer-autumn.
M5: Floods for exchange of organic matter and fine sediment	Morphologic definition of overbank flow.
M6: Maintain short-term fluctuations in discharge	Summer freshes that raise base flows by 10cm and 30cm, typical of natural events.



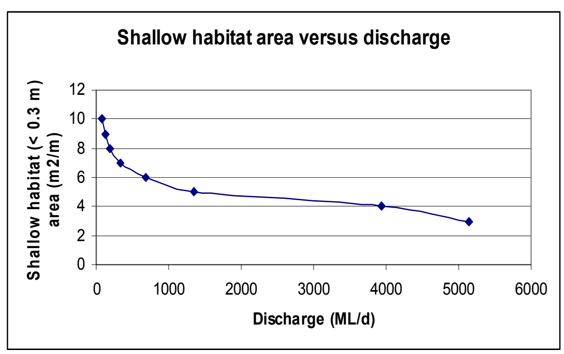


Figure 7: Relationship between discharge (ML/d) and habitat area (m^2/m) in the Buffalo River (derived from the HECRAS model for Reach 1)

[3] Riffle habitat has been defined on the basis of a Froude number > 0.41 (Jowett 1993) and depth < 0.3 m.

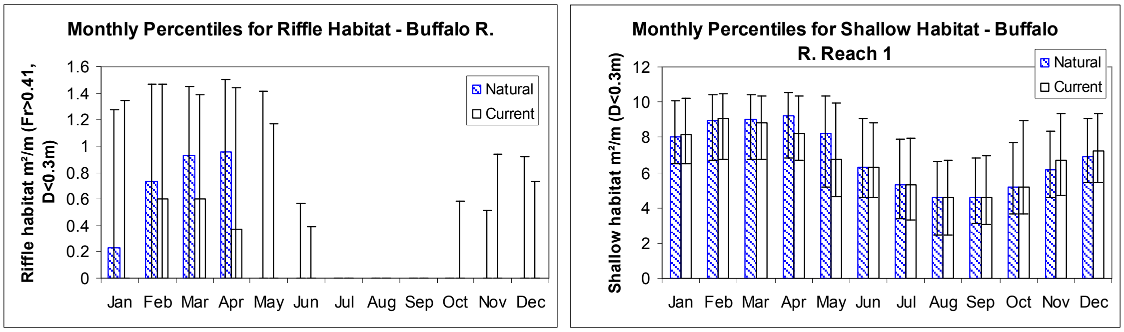


Figure 8: Riffle (Fr > 0.41, depth < 0.3 m) and shallow habitat (<0.3 m) availability for Reach 1 (habitat area as m²/m river length). The bars represent median values for the modeled natural and current flow regimes, while the upper and lower whiskers represent p90 and p10 values. Values were derived from the HECRAS model developed for Reach 1.

5.1.5 Native fish objectives

The largely natural flow regime of the Ovens River and, in its lower reach, a relatively intact and functioning floodplain provide a diversity of high quality instream habitats for native fish. This is a major contributing factor to the high native fish species diversity and abundance and recognition of the lower reach of the Ovens River in terms of Heritage River status and as a study site to test theories for fish ecology in Australia. The Ovens River also provides considerable amenity for native fish anglers and for native fish conservation. The intention of flow objectives set for native fish is to maintain the near natural flow regime as much as possible, as this contributes to:

- Maintenance of main-channel and floodplain habitats at different stage height and commence to fill levels;
- Maintenance of pools that serve as refugia during low flow periods;
- Availability of riffle and other shallow habitats, particularly during low flow periods;
- Water depths required to connect in-channel and floodplain habitats that allow fish movements and the return of floodplain resources to the main river channel;
- Changes in stage height that provide potential cues for breeding and movement.

The connection between in-channel and floodplain habitats and changes in stage height that serve as potential cues for breeding and movement are likely to be maintained with the largely natural timing, frequency and duration of bankfull and overbank flows in winter and spring. The main emphasis in terms of flow recommendations is, therefore, on ensuring sufficient low flow habitat during summer and autumn (Table 6). This is in keeping with the low flow recruitment hypotheses (Humphries et al. 2005, Humphries et al. 1999), which suggests that the availability of shallow, low-velocity (slackwater) habitats is crucial to the survival of fish larvae and juveniles, and is the preferred habitat of microinvertebrates (a crucial food resource for small fish). As for macroinvertebrate objectives, low flow recommendations for native fish have been based on the natural range (p10 – p90) of shallow water habitat and consideration of low DO concentration and stratification. Consideration has also been given to ensuring there is sufficient water depth (0.3 - 0.4 m) to provide connections for fish to move to different sections of each river reach during summer-autumn.

Table 6: Rationale for flow recommendations to address native fish objectives

Native fish objectives	Rationale
NF1: Maintain flow regime with components that have natural features of timing, frequency, magnitude and duration	Addressed by the combination of objectives NF2 – 7.
NF2: Low flows that maintain adequate habitat for native fish populations	Based on morphologic definition of p10 - p90 range in shallow habitat availability in summer-autumn.
NF3: Maintain flows sufficient to allow fish passage	Morphologic definition of 0.3 – 0.4 m depth.
NF4: Maintain flows sufficient to maintain DO concentration greater than 4 mg/L	Velocity > 0.01 m/s; discharge versus DO concentration relationship developed for Reach 5.
NF5: Maintain frequency of overbank flows that water billabongs and flood-runners	Based on morphologic definition of bankfull flow.
NF6: Low flows sufficient to maintain natural rates or connectivity between pools and riffles	Based on morphologic definition of stage height increases above minimum flows.
NF7: Maintain flow cues to stimulate movements	Addressed by objectives M6 and NF6.

As fish populations are subject to a range of impacts other than flows, these must be taken into account in their overall management (see complementary management actions). This requires the incorporation of latest knowledge and in some cases may require additional research to generate new knowledge.

5.1.6 Rate of rise and fall

It is ecologically and geomorphically important to avoid undesirable consequences of rapid rise or fall of flow events, such as the stranding of biota (e.g. invertebrates, fish) or bank slumping. Appropriate rates of rise and fall should be applied to recommended flow components when impacted by water management operations. Appropriate rates of rise and fall have been calculated for each reach, based on proportions of the previous day's flow (Q_2/Q_1). These are based on the 90^{th} percentile of the rates of rise and the 10^{th} percentile of the rates of fall for the natural flow regime (Table 7). The rationale for the percentiles is that while a rapid rate of rise is not seen as a significant concern, the rate of fall is crucial in preventing ecological concerns such as stranding of fish and invertebrates or geomorphic concerns such as bank slumping by surcharging (i.e. the appropriate rate of fall is more conservative). The rates of rise and fall are most relevant to reaches 1 and 2, immediately below Lake Buffalo and Lake William Hovell; rates of rise and fall below these reaches will be influenced by inputs from other catchment areas and tributaries.

Table 7: Rates of rise and fall (proportion of the previous day's discharge, ML/d) to be applied when managing the flow regime in each reach.

Reach	Rate of Rise	Rate of Fall
1	2.6	0.8
2	2.1	0.8
3	2.1	0.8
4	2.1	0.8
5	2.5	0.8

The rates of rise and fall listed for each reach in Table 7 have been derived hydrologically. Monitoring is required to confirm that they pose little ecological and geomorphic risk, for example by flushing or stranding of biota such as macroinvertebrates and fish, or by bank slumping.

5.1.7 Links between the Ovens and Murray River systems.

Discharge from the Ovens River represents 14% of flows entering the Murray River system from the region (OBWQWG 2000). This significant contribution means that management of water within the Ovens River valley has consequences for the rest of the Murray R valley, whether it is for environmental or consumptive use. Flows down the Ovens River have become an important driver of environmental flow management as part of The Living Murray initiative. High flows from the Ovens River can initiate flooding in the Barmah-Milawa forest, which managers can then supplement to achieve specific environmental objectives. This type of flow management occurred in 2000 when supplementary flows were used to secure a bird breeding event, and in 2005 when releases from Lake Hume were used to trigger fish spawning. The effectiveness of both these environmental flows relied on Ovens River flows for their success.

Despite perceptions that flows allowed to pass down the Oven River are 'lost', discharge during periods of low flow is integrated into the coordinated management of flows from lakes Hume, Dartmouth and Eildon to meet consumptive demand downstream. Periods of increased flow from the Ovens River allows for smaller releases from Lake Hume and Lake Eildon increasing security of supply for all stakeholders in the Goulburn-Murray supply system. Even periods of high flow may not be lost to consumptive use as these flows can be held in Lake Victoria for subsequent release during the following summer.

The Ovens River supports significant, healthy populations of Murray cod, golden perch and Murray crayfish. Ten of the native fish species in the study area have some form of threatened status, and seven of these are listed under the Flora and Fauna Guarantee Act and five have a national threatened species listing (Cottingham et al. 2007). The Ovens River populations are also likely to be important at a regional scale as source populations for other locations in the region, including Lake Mulwala, and the Murray River between Lake Hume and Lake Mulwala. If this is the case, then the loss of species from the Ovens River may have implications for regional diversity. The availability of diverse, high quality river-floodplain habitat provides opportunities for conservation or recovery of endangered or threatened species (e.g. trout cod). Once established, Ovens River based populations may provide a basis for more widespread recovery of threatened or endangered species.

The Ovens River also provides a unique combination of a flooding flow regime and a forested floodplain. As a consequence, floods down the Ovens River export a large amount of organic carbon and nutrients downstream, initially to Lake Mulwala and eventually into the main channel of the Murray River. There is mounting evidence to suggest that the Murray River is carbon limited and that the addition of floodplain derived organic matter will stimulate productivity downstream (Gawne et al. 2007). This would imply that the health and productivity of Lake Mulwala and the Murray River downstream are strongly influenced by both flow and catchment management in the Ovens valley.

There are almost certainly upstream linkages that mean that the management of the Murray River, including areas such as Lake Mulwala and Barmah-Milawa forest, will have consequences for the Ovens River. The drought and bushfires in recent years have been associated with periods of very poor water quality and loss of habitat in the Ovens River. Despite these major stresses, there have been no reports of widespread fish kills in the lower sections of the Ovens River. This is further evidence of the importance of connections between the Ovens River and the Murray River. It is likely that there is movement of fish into and out of the Ovens River and that some organisms may use the Murray River as a refuge during major disturbances. As a consequence, any downstream management activity that alters connectivity or the suitability of the Murray River as a refuge may have consequences for the persistence of species within the Ovens River.

5.1.8 Cease to flow periods

The FLOWS method identifies cease to flow periods as one of the major flow components that should be considered when developing environmental flow recommendations. Low flow recommendations are often based on a minimum flow threshold with the attached caveat ‘or natural’ (e.g. 20 ML/d or natural, whichever is lowest). This allows for discharge to fall below the stated minimum flow if this would have happened naturally (i.e. when catchment inflows are less than the stated minimum flow). In some circumstances this may result in cease to flow periods. While cease to flow periods may occur naturally (although rarely), the Scientific Panel does not recommend them as part of the environmental flow regime for this study due to their potential to contribute to, or exacerbate, risks to river condition and water quality, such as:

- Catchment disturbance and increased sediment and nutrient loads associated with runoff from urban and agricultural areas (OBWQWG 2000);
- Instances of bed, bank and gully erosion (North East CMA 2004, Gawne et al. 2005);
- Instances of poor riparian condition across the study area (Cottingham et al. 2003, 2007, Gawne et al. 2005) and the presence of alien species such as willows that can alter geomorphic conditions and have different patterns of leaf fall to that of native species;
- Instances of direct access to the rivers by livestock and associated risks to water quality, and bed and bank condition (e.g. due to trampling and pugging).

Maintaining continuous low flow (i.e. no cease to flow periods) in each reach was considered by the Scientific Panel to be prudent, given the issues stated above and especially as their impact may be exacerbated during drought. This is also consistent with the objectives of the Ovens water quality strategy (OBWQWG 2000) in managing water quality across the catchment and reducing the risks[4] associated with algal blooms in the lower Ovens River and Lake Mulwala.

5.1.9 Interrelatedness of objectives

The previous sections described flow-related objectives for the various ecosystem attributes in isolation from each other. In reality, many of the objectives will overlap. For example, a flow event that is important to achieve low flow objectives for aquatic macrophytes is also likely to contribute to low flow objectives for macroinvertebrates. Freshes that disrupt biofilms in order to achieve macroinvertebrate objectives may also provide sufficient depth for fish to move along the river. Thus the requirements for objectives listed in the tables of flow recommendations in sections 5.2-5.6 may be cross referenced to other objectives with similar flow requirements.

While multiple low flow freshes (or other flow component) may be stated for different objectives in a season, this does not necessarily mean that the total number of freshes in a season is the total of all events for all objectives. For example, an objective for one river attribute may require four low flow freshes, while an objective for another attribute may require 3 low flow freshes. Assuming that the freshes for each objective are of a similar magnitude and duration, then it will usually be the case that only four freshes are required for the season.

Recommendations related to low flow habitat for each reach are presented as a flow range (based on p10-p90 values for habitat area), rather than a single value. Low flow freshes are also recommended and in some instances the magnitude of these freshes falls within the low flow range based on habitat area, which may at first seem confusing. The Scientific Panel recognised that water managers will usually seek to meet water demand with the minimum releases possible. The expectation is that this will result in flows being predominantly held as close to the lower end of the low flow range as practicable, which may result in less variability in discharge than would naturally be the case. The low flow freshes, therefore, are designed to achieve a particular ecosystem response and add to variability in discharge and stage height (e.g. refresh biofilms as a food resource for macroinvertebrates, increase wetted area for macroinvertebrates, wet riparian plants, provide depth for fish to move to new habitat).

Lake Buffalo and Lake William Hovell have the potential to trap inflows such as occur after rainfall events, hence the specification of freshes as part of environmental flow recommendations for each reach. The best use of a fresh when released is likely when it is allowed to travel through other reaches and thus contribute to flow objectives downstream. This may require adjustment to the magnitude or duration of a release from one reach (e.g. Lake Buffalo to the Buffalo River) to account for antecedent conditions, tributary inflows, and factors such as downstream changes to river geomorphology. Thus the release of discrete flow events designed to meet

[4] As stated in section 5.1.1, instances of low DO low water velocity that can contribute to water stratification can also contribute to the formation of algal blooms.

objectives for one reach may require consideration of the requirements of multiple reaches.

Flow recommendations are expected to apply to the entire reach for which they were developed, as the cross section surveys and HECRAS models were based on information collected at sites considered representative of each reach. Points for measuring compliance should in the first instance be at the gauging stations used in developing the HECRAS models (see Site report, PC&A and MDFRC 2007). The interconnection of the various reaches and their flow recommendations should result in the flow recommendations being met along each reach (i.e. recommendations for lower reaches should ensure that environmental flows from upper reaches progress downstream).

5.2 Flow recommendations – Buffalo River from Lake Buffalo to the Ovens River

The flow recommendations for Reach 1 are described in the following sections and in Table 10. The recommendations are based on the assumption that the size and operation of Lake Buffalo will remain unchanged. Low flow recommendations should be revisited in the event that there is any future development (i.e. expansion) of Lake Buffalo. In summary, recommendations include:

Low flows:

- Operate in the range 70–680 ML/d or natural[5] to provide shallow habitat for macroinvertebrates and fish and a ensure a minimum flow 10 ML/d to maintain some wetted habitat and reduce risk of poor water quality;
- Provide up to 2 summer-autumn freshes at or above 170 ML/d to disrupt biofilm and up to 2 freshes at or above 430 ML/d to provide for fish passage and habitat for macroinvertebrates.

High flows:

- Ensure minimum flow of 130 ML/d or natural to maintain macroinvertebrate habitat and fish passage;
- Provide 1 fresh at or above 5000 ML/d to maintain geomorphic diversity;
- Provide bankfull and overbank flows (natural frequency) to maintain riparian habitat character and contribute to ecosystem processes (e.g. floodplain-channel connection, geomorphic processes).

5.2.1 Low flows and Low flow freshes

The relationship between discharge and the p10–p90 range of riffle and shallow habitat availability (Figure 7 and Figure 8) in summer - autumn, and that between water velocity and the potential for stratification have been used as the basis of low flow recommendations for Reach 1. The p90 of riffle area of 1.4 m^2/m (Figure 8) has been adopted to define low flows, equivalent to a discharge of 70 ML/d or natural (similarly, the p90 for shallow habitat is 10 m^2/m, equivalent to 75 ML/d). The p10 value of shallow habitat availability of 6.0 m^2/m provides an upper limit of 680 ML/d. Thus operating within the range of 70–680 ML/d (or natural) will provide a natural variability in shallow habitat availability in summer–autumn. Thus flow can fall below

[5] The lower end of the range should be considered as 70 ML/d or natural, whichever is lower; the upper end of the range should be considered as 680 ML/d or natural, whichever is higher.

70 ML/d or exceed 680 ML/d if this was to occur naturally, but should always remain above 10 ML/d to maintain water velocity above 0.01 m/s in order to reduce the likelihood of water stratification and any resultant decline in water quality (DO concentration).

It is possible that operation of Lake Buffalo will result in flows predominantly at the lower end of the 70 – 680 ML/d range. In order to ensure variability in the delivery of low flows, 2 low flow (summer-autumn) freshes at or above 170 ML/d and 2 freshes at or above 430 ML/d (four freshes in total) are recommended to meet geomorphology, macroinvertebrate and native fish objectives. Freshes need not be delivered at the same time as a naturally occurring event (i.e. coincident with a rainfall event that would naturally deliver a fresh – cf transparent dam approach), so long as they are delivered in the specified season (summer-autumn). This will allow water managers opportunities to deliver freshes efficiently by 'piggy-backing' on water released from Lake Buffalo to meet downstream demand. However, a trigger for delivering the freshes is if discharge remains below 170 ML/d for a continuous period of 6 weeks, assuming that freshes would have occurred naturally[6]. The trigger of 6 weeks is based on the time required for biofilm to age (i.e. approximately 4 weeks go from productive to heterotrophic) (Gawne & Lake 1995, Ryder et al. 2006, Sutherland et al. 2002) and for macroinvertebrates to recolonise disturbed areas (approximately 2 weeks) (Doeg et al. 1989, Boulton & Lake 1992).

5.2.2 High flows and High flow fresh

Minimum winter–spring high flows have been based on a maximum p90 of shallow habitat availability (9 m^2/m) that occurs in June. This is equivalent to a discharge of 130 ML/d or natural (whichever is lower) (Figure 7 and Figure 8) and would also provide suitable conditions for fish passage (minimum depth of 0.3 m requires a discharge of 120 Ml/d). High flows should also be maintained above 1,800 ML/d (> 1 m depth) for 70 or more days (80% of years) within the winter-spring period to minimise encroachment by terrestrial woody species into the river channel.

A high flow fresh of greater than 5,000 ML/d is also required to achieve the geomorphology objective of mobilising surficial and interstitial fine sediments from the cobble bed substrate (based on shear stress of 15 N/m^2, Wilkinson 2001).

5.2.3 Bankfull and overbank flows

The capacity of Lake Buffalo relative to catchment discharge is relatively small. This means that the presence and operation of the dam has only a minor influence on the large flows that would naturally result in bankfull and overbank flows. The Scientific Panel recommends that the natural frequency and duration of bankfull and overbank flows be maintained in the future. Bankfull and Overbank flows are important ecologically for:

- Maintaining the character of the riparian zone next to channel and the vigour of existing vegetation;

[6] This can be defined by using natural inflows at or above 170 ML/d, with compliance measured by comparing the percentage of years that 0, 1 or 2 freshes would have occurred for the natural and regulated regime over the period of record.

- Connecting of in-channel and riparian habitats (e.g. for macroinvertebrates and fish);
- Driving ecosystem processes (e.g. sediment erosion and deposition; aquatic production and respiration; nutrient cycling).

The magnitudes of these flows are identified in Table 8. While this recommendation will have little impact on current management of the dam, it will become important should any further water resource development occur at Lake Buffalo.

5.2.4 Rate of rise and fall

Rates of rise and fall associated with operation of Lake Buffalo are listed in Table 7. Of particular importance is the requirement to ensure that the rate of fall remains at or above 0.8 Q_2/Q_1.

5.2.5 Supplementary releases to the Murray River

G-MW currently releases surplus water held in Lake Buffalo at the end of the irrigation season as part of Victoria's contribution to flows in the Murray River. Releases have occurred in 18 of the past 20 years and are typically in the order of 300 ML/d for 3-4 weeks (Cottingham et al. 2001). The Scientific Panel considered that such releases presented little risk to the condition of the Buffalo River (falling within the recommended operating range of 70 -680 ML/d), as long as rates of rise and fall were managed appropriately. The preference would be to deliver supplementary flows as pulses consistent with low flow freshes where possible, rather than as a constant flow.

Table 8: Environmental flow recommendations for Reach 1 (shading indicates grouping of flow components)

Objective	Season*	Flow component	Magnitude (ML/day)	Frequency	Duration	Criteria
W1, NF4, M4, NF2, NF3	Sum-Aut	Low flow	Within range of 70 or natural (whichever is lower) and 680 ML/d or natural (whichever is higher), with absolute minimum of 10 ML/d (no cease to flow)	Continuous	Continuous	Natural range of riffle and shallow water habitat availability (based on range of p10–p90 habitat area, m^2/m). Absolute minimum of 10 ML/d to maintain wetted habitat and water quality during dry periods (based on velocity ≥ 0.01 m/s)
G6	Sum-Aut	Low flow fresh	≥ 170	2 per year	3 days	Based on threshold of 0.3 m/s. Freshes should be delivered should flow remain below 170 ML/d continuously for 6 weeks. Minimum 7 days duration between events.
M6, NF7	Sum-Aut	Low flow fresh	≥ 430	2 per year	3 days	Based on threshold of 0.3 m depth above minimum flow level. Freshes should be delivered should flow remain below 170 ML/d continuously for 6 weeks. Minimum 7 days duration between events.
M4, NF3	Win-Spr	High flow	Minimum 130 or natural, whichever is lower	Continuous	Continuous	Natural range of shallow water habitat availability (based on p10 habitat area in June, m^2/m).
BB2	Win-Spr	High flow	≥ 1,800	80% of years	70 days (cumulative)	≥ 1m above low flow, modelled natural duration
G1, M1, M2	Win-Spr	High flow fresh	≥ 5,000	≥ 1 per year	Minimum of 1 day	≥ 15 N/m^2
G2	Win-Spr	Bankfull	≥ 8,500	Natural	Minimum of 1 day	≥ 29 N/m^2 (for sediment size d50 of 71 mm)
RB2	Win-Spr	Bankfull	≥ 11,000	Natural	Minimum of 1 day	Natural bankfull flow regime
FP1-3, M5	Win-Spr	Overbank	≥ 15,000	Natural	Minimum of 1 day	Natural overbank flow regime
G3, IC1, M3	No specific recommendations					

* Sum-Aut = December to May, inclusive. Win-Spr = June to November, inclusive.

5.3 Flow recommendations – King River from Lake William Hovell to Moyhu

The flow recommendations for Reach 2 are described in the following sections and in Table 9. The recommendations are based on the assumption that the size and nature of operations at Lake William Hovell will remain unchanged. Low flow recommendations should be revisited in the event that there is any future development (i.e. expansion) of Lake Buffalo. In summary, recommendations include:

Low flows:

- Operate in the range 60–415 ML/d or natural[7] to provide shallow habitat for macroinvertebrates and fish and a ensure a minimum flow 10 ML/d to maintain some wetted habitat and reduce risk of poor water quality;
- Provide up to 2 summer-autumn freshes at or above 150 ML/d to disrupt biofilm and up to 2 freshes at or above 430 ML/d to provide for fish passage and habitat for macroinvertebrates;

High flows:

- Minimum 200 ML/d or natural (whichever is lower) to maintain macroinvertebrate habitat and fish passage;
- Fresh >260 ML/d to mobilise sediments in pools;
- >1500 ML/d for 70 days (cumulative) in 80% years to limit terrestrial vegetation encroachment;
- 2 freshes > 650 ML/d to disrupt biofilms;
- Bankfull and overbank flows (natural frequency) to maintain riparian habitat character and contribute to ecosystem processes (e.g. floodplain-channel connection, geomorphic processes).

5.3.1 Low flow and low flow freshes

As for Reach 1, the relationship between discharge and the p10–p90 range of riffle and shallow habitat availability (Figure 9) in summer - autumn, and that between water velocity and the potential for stratification, have been used as the basis of low flow recommendations for Reach 2. The p90 of shallow habitat area of 12 m^2/m (or natural) has been adopted to define low flow, which equivalent to a discharge of 60 ML/d or natural. The p10 value of shallow habitat availability of 6.0 m^2/m provides an upper limit of 415 ML/d, or natural. Thus operating within the range of 60–415 ML/d (or natural) will provide a natural variability in shallow habitat availability in summer–autumn. Flow can fall below 60 ML/d if this was to occur naturally, but should always remain above 10 ML/d to reduce the risk of any decline in water quality (i.e. DO concentration).

Again as for Reach 1, it is likely that operation of Lake William Hovell, will result in flows predominantly at the lower end of the 60–415 ML/d range. In order to ensure variability in the delivery of low flows, 2 low flow (summer-autumn) freshes at or above 150 ML/d and 2 freshes at or above 430 ML/d (four freshes in total) are recommended to meet geomorphology, macroinvertebrate and native fish objectives. The operational flexibility and triggers (if discharge remains below 150 ML/d for a

[7] The lower end of the range should be considered as 60 ML/d or natural, whichever is lower; the upper end of the range should be considered as 415 ML/d or natural, whichever is higher.

continuous period of 6 weeks) for delivering the freshes described in section 5.2.1 also apply to Reach 2.

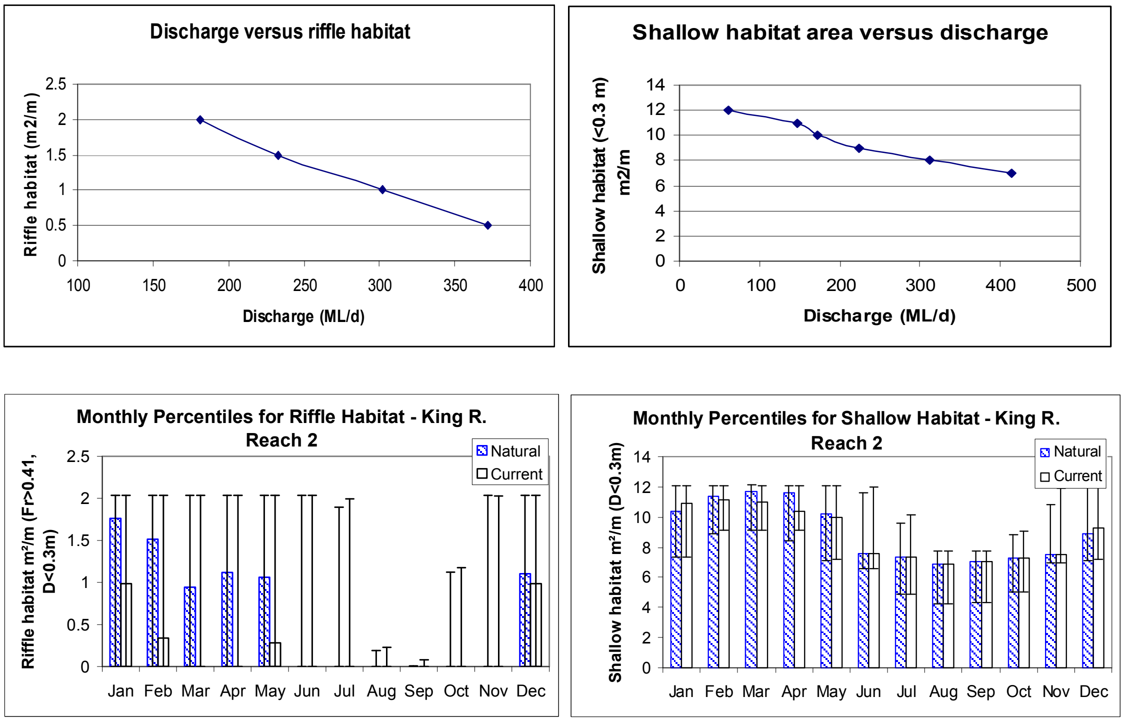


Figure 9: Riffle and shallow habitat availability in Reach 2. The bars represent median values for the modeled natural and current flow regimes, while the upper and lower whiskers represent p90 and p10 values. Values were derived from the HECRAS model developed for Reach 2.

5.3.2 High flow and high flow freshes

Minimum winter–spring high flows have been based the depth required to maintain fish passage (0.3 m) and on the p90 of shallow habitat availability (11 m^2/m) that occurs in June. A discharge of 200 ML/d is required to maintain a depth of 0.3 m in this reach, while 147 ML/d is required to inundate 11 m^2/m of shallow habitat (Figure 9). It is recommended winter-spring flows remain above 200 ML/d or natural, to permit continuous fish movement and maintain shallow habitat area within its natural range. High flows should also be maintained above 1,500 ML/d (> 1 m depth) for 70 or more days (80% of years) within the winter-spring period to minimise encroachment by terrestrial woody species into the river channel. This will also provide flows greater than 260 ML/d required to remove fines sediments and provide habitat diversity for macroinvertebrates.

5.3.3 Bankfull flow and overbank flow

Like Lake Buffalo, the capacity of Lake William Hovell relative to catchment discharge is relatively small and the presence and operation of the dam has only a minor influence on the large flows that would naturally result in bankfull and overbank flows. The Scientific Panel recommends that the natural frequency and duration of bankfull and overbank flows be maintained in the future (Table 9). As described previously, Bankfull and Overbank flows are important ecologically for:

- Maintaining the character of the riparian zone next to channel and the vigour of existing vegetation;
- Connecting of in-channel and riparian habitats (e.g. for macroinvertebrates and fish);
- Driving ecosystem processes (e.g. sediment erosion and deposition; aquatic production and respiration; nutrient cycling).

While the recommendation to maintain the frequency and duration of Bankfull and Overbank flows will have little impact on current management of the dam, it will become important should there be any further water resource development in the catchment.

5.3.4 Rate of rise and fall

The rate of rise and fall in this reach will be governed predominantly by releases from Lake William Hovell in the upper areas of the reach, with increasing influence of local tributaries progressively downstream. Of particular importance is the requirement to ensure that the rate of fall is discharge from Lake William Hovell remains at or above 0.8 Q_2/Q_1 (Table 7).

Table 9: Environmental flow recommendations for Reach 2

Objective	Season*	Flow component	Magnitude (ML/day)	Frequency	Duration	Criteria
W1, NF4, M4, NF2, NF3	Sum-Aut	Low flow	Within range of 60 or natural (whichever is lower) and 415 ML/d or natural (whichever is higher), with absolute minimum of 10 ML/d (no cease to flow)	Continuous	Continuous	Natural range of riffle and shallow water habitat availability (based on range of p10–p90 habitat area, m^2/m). Absolute minimum of 10 ML/d to maintain wetted habitat and water quality during dry periods (based on velocity ≥ 0.01 m/s)
G6,	Sum-Aut	Low flow fresh	≥ 150	2 per year	3 days	Based on threshold of 0.3 m/s. Events to be at least 7 days apart.
M6, NF7	Sum-Aut	Low flow fresh	≥ 430	2 per year	3 days	Based on threshold of 0.3 m depth above minimum flow level. Events to be at least 7 days apart.
M4	Win-Spr	High flow	Minimum of 147 or natural, whichever is lower	Continuous	Continuous	See M4 low flow
NF3	Win-spr	High flow	Minimum of 200 or natural, whichever is lower	Continuous	Continuous	≥ 0.3m depth
BB2	Win-Spr	High flow	≥ 1500	80% of years	70 days (cumulative)	≥ 1m above low flow
G1, M1, M2	Win-Spr	High flow fresh	≥ 260	≥ 4 per year	1 day	≥ 15 N/m^2
G2	Win-Spr	Bankfull	≥ 8,500	Natural	Minimum of 1 day	≥ 176 N/m^2 (for sediment size d50 of 218 mm – bankfull)
RB2	Win-Spr	Bankfull	≥ 8,500	Natural	Minimum of 1 day	Match natural bankfull flow regime
FP1-3, M5	Win-Spr	Overbank	≥ 9,500	Natural	Minimum of 1 day	Match natural bankfull flow regime
G3, IC1, M3	No specific recommendations					

* Sum-Aut = December to May, inclusive. Win-Spr = June to November, inclusive.

5.4 Flow recommendations – King River from Moyhu to the Ovens River

The flow recommendations for Reach 3 are described in the following sections and in (Table 10). In summary, recommendations include:

Low flows:

- Operate in the range 26–985 ML/d or natural[8] to provide shallow habitat for macroinvertebrates and fish and a ensure a minimum flow 10 ML/d to maintain some wetted habitat and reduce risk of poor water quality;
- Provide up to 3 summer-autumn freshes greater than 120 ML/d to provide fish passage;

High flows:

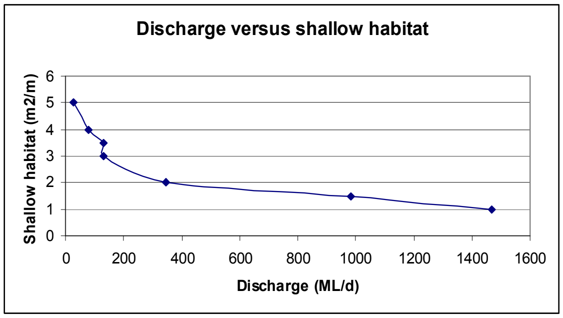
- Ensure minimum flow of 130 ML/d or natural (whichever is lower) to maintain macroinvertebrate habitat and fish passage;
- Ensure discharge at or above 430 ML/d for 70 days (cumulative) in 80% years to limit terrestrial vegetation encroachment;
- Deliver up to 2 freshes at or above 650 ML/d to disrupt biofilms;
- Allow bankfull and overbank flows (natural frequency) to maintain riparian habitat character and contribute to ecosystem processes (e.g. floodplain-channel connection, geomorphic processes).

5.4.1 Low flows and low flow fresh

The operating range in summer–autumn based on the p10–p90 values (1.5–5 m^2/m) of shallow habitat area would be 26–985 ML/d or natural (absolute minimum 10 ML/d) (Figure 10). It is interesting to note that the 26 ML/d at the lower end of the range is less than the 60 ML/d required to inundate the p90 habitat area in Reach 2. This is most likely due to factors such as natural changes in river geomorphology (i.e. transition from a shallow, cobble-bed pool and riffle river in Reach 2 to a deeper sand-bed pool and run type stream), and is consistent with the perception that this is a 'losing' reach (M. O'Connell, North East CMA, pers. comm.). It is anticipated that the river will be operated at the lower end of the operating range identified above.

Up to 3 low flow freshes greater than 120 ML/d are recommended to ensure fish passage throughout summer and autumn and to provide variability in habitat availability to meet objectives for macroinvertebrates. The operational flexibility and triggers for delivering the freshes (if discharge remains below 120 ML/d for a continuous period of 6 weeks) described in section 5.2.1 also apply to Reach 3.

[8] The lower end of the range should be considered as 26 ML/d or natural, whichever is lower; the upper end of the range should be considered as 985 ML/d or natural, whichever is higher.



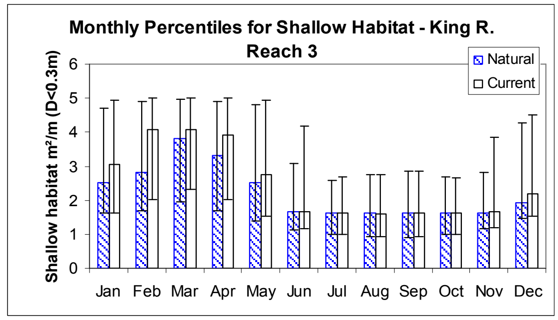


Figure 10: Shallow habitat availability in Reach 3. The bars represent median values for the modeled natural and current flow regimes, while the upper and lower whiskers represent p90 and p10 values. Values were derived from the HECRAS model developed for Reach 3.

5.4.2 High flows and high flow freshes

A minimum winter–spring flow of 130 ML/d or natural (whichever is lower) is recommended, based on the p90 of shallow habitat availability (3 m^2/m) that occurs in June. This would also provide 120 ML/d required to maintain sufficient depth for fish passage (0.4 m) and prevent unnatural rates of fine sediment deposition, meeting geomorphology and macroinvertebrate objectives. High flows should also be maintained above 430 ML/d (> 1 m depth) for 70 or more days (80% of years) within the winter-spring period to minimise encroachment by terrestrial woody species into the river channel. Two freshes of 650 ML/d are required to disrupt biofilms (> 0.3 m/s).

5.4.3 Bankfull flow and overbank flow

As is the case for other reaches, the natural frequency and duration of bankfull and overbank flows are to be maintained in the future (Table 10). This reach is more typical of a lowland river, having a wider floodplain and likely more features such as flood runners and billabongs (or at least potentially more area such features) than the upstream reach of the King River. It is likely that discharge of varying magnitude will contact varying amounts of floodplain habitat. Adopting an overbank flow recommendation with a single magnitude may increase the risk that that some portions of the floodplain will always be inundated during floods events, while other areas always remain dry. There is currently, however, insufficient information from which to relate the magnitude of discharge to floodplain habitat inundated. A conservative approach has been adopted in recommending the maintenance of the largely natural frequency, magnitude and duration of overbank flows that prevails. Two different events are presented in Table 10 to illustrate the different magnitudes and durations that might be expected. The frequency and duration of overbank events should be reviewed in the future once the relationship between event magnitude and area of floodplain inundated has been determined[9].

[9] Assessing the area of floodplain inundation will require additional survey of the floodplain. Tools such as digital elevation models linked to system hydrography and hydrology will aid this process. This and similar approaches would allow estimation of area of floodplain/wetland inundated at varying river heights and would greatly assist any future review of environmental flows.

5.4.4 Rate of rise and fall

The rate of rise and fall in this reach will be governed by the unregulated upper catchment areas and tributaries of the King River, as well as releases from Lake William Hovell (Table 7). Rates of rise and fall may also be affected by pumping from the river to meet demand for stock and domestic water, particularly at times of very low in-channel flows and low inflows from the catchment. It is recommended that rostering systems for water diversions consider the need to protect against rapid draw downs that increase the risk undue exposure of habitat and of stranding of biota such as fish and invertebrates.

Table 10: Environmental flow recommendations for Reach 3

Objective	Season*	Flow component	Magnitude (ML/day)	Frequency	Duration	Criteria
W1, NF4, M4	Sum-Aut	Low flow	Within range of 26 or natural (whichever is lower) and 985 ML/d or natural (whichever is higher), with absolute minimum of 10 ML/d (no cease to flow)	Continuous	Continuous	Natural range of riffle and shallow water habitat availability (based on range of p10–p90 habitat area, m^2/m). Absolute minimum of 10 ML/d to maintain wetted habitat and water quality during dry periods (based on velocity ≥ 0.01 m/s)
NF6, M6, NF7	Sum-Aut	Low flow fresh	≥ 120	≥ 3 per year	4 days	≥ 0.4m depth
M4	Win-Spr	High flow	Minimum 130 or natural, whichever is lower	Continuous	Continuous	p90 of shallow habitat area (m^2/m)
NF3	Win-spr	High flow	Minimum 120 or natural, whichever is lower	Continuous	Continuous	≥ 0.4m depth
BB2	Win-Spr	High flow	≥ 430	80% of years	70 days (cumulative)	≥ 1m above low flow
G1, G5, M,1 M2	Win-Spr	High flow fresh	≥ 105	≥ 4 per year	7 days	≥ 1.1 N/m^2
G6	Any time	Fresh	≥ 650	2 per year	5 days	≥ 0.3 m/s
G2, G5, RB2	Win-Spr	Bankfull	≥ 4,300	Natural	Minimum of 5 days or natural, whichever is lesser	Natural bankfull flow regime; bankfull as channel forming discharge
NF5, FP1-3, M5	Win-Spr	Overbank	≥ 7,500	Natural	Minimum of 3 days or natural, whichever is lesser	Natural floodplain flow regime
NF5	Win-Spr	Overbank	≥ 9,500	Natural	Minimum of 2 days or natural, whichever is lesser	Natural floodplain flow regime
G3, IC1, M3	No specific recommendations					

* Sum-Aut = December to May, inclusive. Win-Spr = June to November, inclusive.

5.5 Flow recommendations – Ovens River from the Buffalo River to Everton/Tarrawingee

The flow recommendations for Reach 3 are described in the following sections and in Table 11. In summary, recommendations include:

Low flows:
- Ensure low flows at or above 170 ML/d or natural (whichever is the lesser) to maintain fish passage (0.3 m) and a minimum flow 10 ML/d to maintain some wetted habitat and reduce risk of poor water quality;
- Deliver up to 4 freshes at or above 430 ML/d to provide macroinvertebrate habitat (and disrupt biofilm and stop terrestrial vegetation encroachment), with two of these freshes at or above 650 ML/d to allow fish passage (0.4 m);

High flows:
- Ensure minimum flow of 650 ML/d or natural (whichever is the lesser) to maintain macroinvertebrate habitat and fish passage;
- Provide flows at or above 1900 ML/d for 70 days (cumulative) in 80% years to limit terrestrial vegetation encroachment;
- Provide up to 2 freshes at or above 18,500 ML/d to maintain geomorphic diversity;
- Allow bankfull and overbank flows (natural frequency) to maintain riparian habitat character and contribute to ecosystem processes (e.g. floodplain-channel connection, geomorphic processes).

5.5.1 Low flow and low flow freshes

This reach is in modified condition due to past catchment and river management practices. Much of the reach either has a relatively uniform cobble/gravel bed with little geomorphic diversity or is bedrock controlled. The relationship between shallow habitat area and discharge is more complex than for the other reaches, which means that low flow recommendations based on p10 and p90 values would result in unrealistically large minimum discharge rates (in the order of 500 ML/d) (Figure 11). Minimum flow recommendations (Table 11) have, therefore, been based on ensuring sufficient water velocity (> 0.01 m/s, 10 ML/d) to reduce the likelihood of water stratification in the low flow channel and providing depth sufficient for fish movement (0.3 m, 170 ML/d). Providing depth sufficient for fish passage also links in with the intention of the MDBC Native Fish Strategy to establish this reach as one of its Demonstration Reaches for rehabilitation; fish passage would not be a factor to confound the outcomes of any river rehabilitation measures for native fish. The recommended low flows of 170 ML/d or natural (whichever is the lesser) with an absolute minimum of 10 ML/d is also broadly consistent with the combined minimum flows expected from the Buffalo River and the upper Ovens River.

Summer–autumn freshes are to be delivered to provide variability to meet objectives for bench and bar vegetation and macroinvertebrates (4 freshes > 430 ML/d), two of which should be at or above 650 ML/d to ensure depth (> 0.4 m) sufficient for large-bodied fish to move throughout the reach.

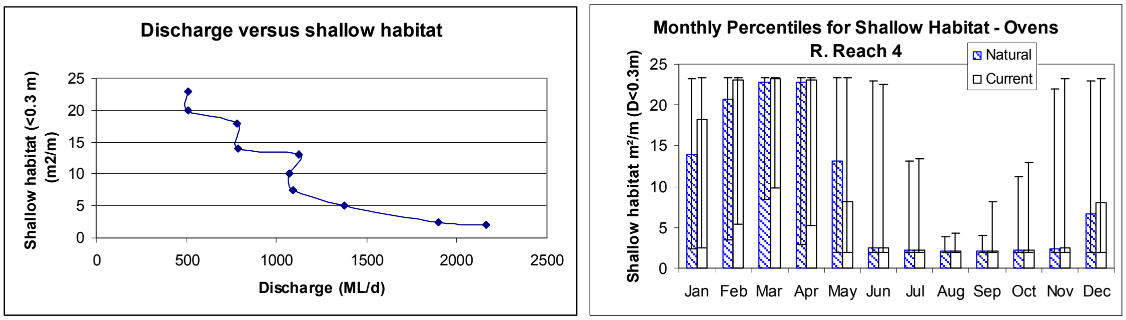


Figure 11: Riffle and shallow habitat availability in Reach 4

5.5.2 High flow and high flow freshes

High flows during winter – spring should remain above 650 ML/d or natural to ensure depth sufficient for large-bodied fish to move throughout the reach (> 0.4 m). High flows should also be maintained above 1,900 ML/d (> 1 m depth) for 70 or more days (80% of years) within the winter-spring period to minimise encroachment by terrestrial woody species into the river channel.

5.5.3 Bankfull flow and overbank flow

No specific recommendations are made for bankfull and overbank flows in Reach 4 due to the underfit (enlarged) channel present today, and the unrealistic discharges required to provide adequate depth or substrate movement. However, the channel is currently recovering (Earth Tech 2007) and it is advisable to ensure that if flows of bankfull magnitude naturally occur (bankfull is approximately 1 in 5 yr ARI) they are encouraged in this reach. These larger flows will assist the rate of recovery of the channel through the formation of within channel features, such as gravel bars and the development of a sinuous low flow channel, improving bed diversity.

5.5.4 Rate of rise and fall

The rate of rise and fall in this reach will be governed by the unregulated upper catchment areas and tributaries of the Ovens River, as well as discharge from Lake Buffalo (Table 7) and inflows from tributaries below Lake Buffalo. The distance of this reach from these sources means that large and rapid fluctuations in water level are less likely than for the reaches immediately below Lake Buffalo and Lake William Hovell.

Table 11: Environmental flow recommendations for Reach 4

Objective	Season*	Flow component	Magnitude (ML/day)	Frequency	Duration	Criteria
W1, NF4 G6, BB1, M4, upper Ovens	Sum-Aut	Low flow	170 or natural, absolute minimum of 10 ML/d	Continuous	Continuous	≥ 0.01 m/s for water velocity/stratification risk, 0.3 m above low flow for fish passage, prevention of encroachment by terrestrial vegetation
M6, BB1, G6	Sum-Aut	Low flow fresh	≥ 430	4 per year	3 days	Breakpoint in shallow habitat in low-flow channel
NF6, NF7	Sum-Aut	Low flow fresh	≥ 650	≥ 2 per year	3 days	≥ 0.4m depth for large-bodied fish
BB2	Win-Spr	High flow	1,900	80% of years	70 days	≥ 1m above low flow
NF3	Win-spr	High flow	Minimum of 650 or natural, whichever is lesser	Continuous	Continuous	≥ 0.4m depth
G1, M1, M2	Win-Spr	High flow fresh	≥ 18,500	2 per 3 years	Minimum of 1 day	≥ 15 N/m^2
G2, RB2	Win-Spr	Bankfull	≥ 25,000	1 per 3 years	Minimum of 1 day	≥ 57 N/m^2 (for sediment size d50 of 36 mm
FP1-3, M5, NF5	Win-Spr	Overbank	≥ 32,000	No specific recommendation		
G3, IC1, M3	No specific recommendations					

* Sum-Aut = December to May, inclusive. Win-Spr = June to November, inclusive.

5.6 Flow recommendations – Ovens River from Everton/Tarrawingee to the Murray River

5.6.1 Low flows and low flow freshes

Reach 5 is highly valued for its native fish community and flow objectives have been set to provide low flows necessary provide habitat availability and quality, and allow fish movement along the reach (Table 12). The flow required to meet objective of maintaining fish passage (0.4 m depth) is 130 ML/d or natural, whichever is lesser. As indicated in section 5.1, examination of DO concentration data at low flows suggests that DO remains above the critical value of 4 mg/L at flows above 65 ML/d. In addition, a flow above 85 ML/d is required to maintain velocity above 0.01 m/s to reduce the likelihood of stratification, which in turn can contribute to low DO concentration in pools and conditions favourable to nuisance algal growth. Thus maintaining a minimum flow above 85 ML/d should ensure water quality remains sufficient for native fish and other biota. Management of low flows in Reach 5 is therefore recommended as:

- Maintain a minimum flow of 130 ML/d or natural, whichever is lesser, to provide fish passage (depth > 0.4 m);
- Should flows fall below 130 ML/d, continuous DO monitoring should be deployed once discharge falls within the range 65 - 85 ML/d or routine surface water monitoring (VWQMN) indicates that DO concentration falls below 4 mg/L;
- A fresh should be delivered to improve water quality should surface DO concentration fall below 1 mg/L, with preparation for such an event commencing once DO concentration falls below 2 mg/L.

A low flow recommendation has also been developed to prevent encroachment of terrestrial woody vegetation onto in-channel benches and bars. The recommendation relates to both summer–autumn low flows and high flow freshes in winter–spring. Conditions become favourable for woody terrestrial species establishment and plants become increasingly difficult to remove the longer water levels remain below a depth of 0.3 m above benches and bars low in the channel. The following is recommended to reduce the likelihood of terrestrialisation of benches and bars (and the potential risk associated with changed hydraulic conditions and potential for bank instability):

- Maintain summer–autumn discharge above 260 ML/d (0.3 m above minimum flows);
- Ensure that the next channel forming event (see bankfull discharge to meet objective G2 in Table 12) event in winter–spring is preserved should discharge fall below 260 ML/d for more than one month in summer-autumn.

The largely natural flow regime in Reach 5 ensures that the above summer–autumn conditions are met in the majority of years and hence active management intervention to deliver a bankfull event is unlikely to be required (and likely to be impractical given infrastructure constraints and safety issues associated with large releases from the dams). The need to actively manage bankfull discharge should be considered, however, should there be large-scale water resource development in the future.

5.6.2 High flows and high flow fresh

A minimum winter–spring flow of 130 ML/d is recommended (Table 12), based on the depth required to maintain fish passage (0.4 m) and on the p90 of shallow habitat availability (3 m^2/m) that occurs in June. High flows should also be maintained above 430 ML/d (> 1 m depth) for 70 or more days (80% of years) within the winter-spring period to minimise encroachment by terrestrial woody species into the river channel.

5.6.3 Bankfull and overbank flow

The functioning of the intact floodplain in this reach with the relatively natural flow regime is an important feature of the Ovens River, including connectivity between the main channel and features such as flood runners and billabongs and stage height increases above bankfull discharge. The floodplain in this reach is complex and there is little information on the amount of wetland or floodplain habitat inundated at different water levels. The frequency and duration of flooding is provided for a number of discharges to provide an indication of the natural pattern of inundation (Table 12). It is recommended that the natural frequency and duration of bankfull and overbank flows are maintained in the future (i.e. allow the full range of magnitudes and durations that would occur naturally). Further investigation is required to confirm the magnitude and duration of events that inundate floodplain habitat at different levels and so refine overbank flow recommendations in the future (see also section 5.4.3).

5.6.4 Rate of rise and fall

The rate of rise and fall in this reach will be governed by the unregulated upper catchment areas and tributaries and releases from Lake Buffalo and Lake William Hovell, as well as diversion of water to Wangaratta. Of particular importance is the requirement to ensure that the rate of fall remains at or above 0.8 Q_2/Q_1 (Table 7) when diverting water to Wangaratta.

Table 12: Environmental flow recommendations for Reach 5

Objective	Season*	Flow component	Magnitude (ML/day)	Frequency	Duration	Criteria
NF6, NF4, NF7, W1	Sum-Aut	Low flow	The lesser of 130 or natural	Continuous	Continuous	≥ 0.4m depth
BB3**	Sum-Aut	Low flow	260**	Continuous	Continuous	0.3m above base flow
M6, NF7	Sum	Low flow fresh	130 -260	4 per year		Temporary small fluctuation 0.1m – 0.3m above low flow
NF3	Win-spr	High flow	The lesser of 130 or natural	Continuous	Continuous	≥ 0.4m depth
BB3	Win-Spr	High flow	900	95% of years	70 days	≥ 1m above low flow
G1, M1, M2	Win-Spr	High flow fresh	540	≥ 4 per year	7 days	≥ 1.1 N/m^2
G4	Win-Spr	High flow fresh	3,900	2 per year	4-6 days	1m bench inundation
G6	Any time	High flow fresh	2,500	4 per year	5 days	≥ 0.3 m/s
G2,RB3	Win-Spr	Bankfull	7,800	≥ 1 per year	5 days	Provide inundation events to ensure maintenance or recovery of riparian and river bank vegetation is not limited by the water regime.
FP1-3, M5	Win-Spr	Overbank	11,000	Natural ≈ 3.8 per year	17 days	Direct observation of floodplain inundation flow (H. Gigney, MDFRC, *pers. comm.*)
NF5, G5	Win-Spr	Overbank	12,000	Natural ≈ 1.2 per year	Natural ≈ 38 days	Natural floodplain flow regime
NF5	Win-Spr	Overbank	12,000	Natural ≈ 2.8 per year	Natural ≈ 13 days	Natural floodplain flow regime
NF5	Win-Spr	Overbank	14,000	Natural ≈ 1.3 per year	Natural ≈ 28 days	Natural floodplain flow regime
NF5	Win-Spr	Overbank	14,000	Natural ≈ 2.8 per year	Natural ≈ 13 days	Natural floodplain flow regime
NF5	Win-Spr	Overbank	16,000	Natural ≈ 1.3 per year	Natural ≈ 22 days	Natural floodplain flow regime
NF5	Win-Spr	Overbank	16,000	Natural ≈ 2.8 per year	Natural ≈ 10 days	Natural floodplain flow regime
NF5	Win-Spr	Overbank	18,000	Natural ≈ 1.3 per year	Natural ≈ 17 days	Natural floodplain flow regime
NF5	Win-Spr	Overbank	18,000	Natural ≈ 2.7 per year	Natural ≈ 9 days	Natural floodplain flow regime
NF5	Win-Spr	Overbank	20,000	Natural ≈ 1.3 per year	Natural ≈ 14 days	Natural floodplain flow regime
NF5	Win-Spr	Overbank	20,000	Natural ≈ 3.0 per year	Natural ≈ 6 days	Natural floodplain flow regime
G3, IC1, M3	No specific recommendations					

* Sum-Aut = December to May, inclusive. Win-Spr = June to November, inclusive.
** BB3: The intention of this objective is to prevent unnatural rates of encroachment by terrestrial vegetation. Should flows fall consistently below the 260 ML/d recommended during summer-autumn, then it will be important to deliver a high flow fresh in winter–spring (see also G4 and G6).

5.7 Current compliance with flow recommendations

SKM (2006) have developed and applied a ranking scheme to compare compliance of the current with the natural flow regime in terms of meeting specified objectives (Table 13). This scheme has been applied to the recommendations developed for this project, with results summarized for each reach in Table 14 to Table 18.

Compliance for minimum and low flow recommendations in each reach was calculated using data for the modeled natural and modeled current conditions generated by the Ovens REALM model using MS Excel. The compliance of events such as freshes, bankfull and overbank flows was calculated using RAP (Marsh 2004). It should be noted that presenting flow recommendations as ranges and the addition of 'or natural' qualifiers adds to the complexity of calculating compliance. The 'or natural' qualifier has been ignored when considering compliance with low flow recommendations to make calculations easier.

Compliance with minimum flow recommendations was based on the percentage of time greater than the stated minimum (e.g. % days above 10 ML/d for Reach 1). Compliance with the p10-p90 range was calculated on the percentage of time below the upper flow limit and above the minimum flow recommendation (e.g. % days below 680 ML/d) less the % days below the minimum flow. For the modeled natural flow regime for Reach 1 this was 88% - 4% = 84% compliance. In reality, % compliance would be expected to be slightly higher than 84% as there would be occasions when flows would exceed 680 ML/d naturally (e.g. after large rainfall events).

Compliance with recommendations for flow events was calculated on the basis of spells analysis for the years 1967-2005, where the number of events that occurred in each year is counted for the natural and current flow regime and compared with flow recommendations. Compliance was estimated on the basis of whether the desired number of events with the specified magnitude and duration occurred each year[10].

Table 13: Compliance scheme of SKM (2006)

	Legend	Compliance range Current:Natural
Mostly complies		**> 95%**
Frequently complies		**76 – 95%**
Often complies		**51 – 75%**
Occasionally complies		**26 – 50%**
Rarely complies		**5 – 25%**
Never complies		**0 – 5%**

In general, there is little difference between the level of compliance of both the current and natural flow regime for each recommendation (as measured by the ratio of current:natural), and a high level of compliance with recommendations overall. DSE is currently developing a tool to identify compliance levels and calculate the shortfalls in water volume that would result from environmental flow recommendations. It is recommended that this tool be used (when ready) to inform

[10] Compliance of flow events requires statements on the frequency, magnitude and duration of an event.

the Northern SWS processes in terms of implications of the flow recommendations developed for this project.

Table 14: Comparison of compliance of the current and natural flow regime with environmental flow recommendations for Reach 1

Flow component	Season	Magnitude (ML/day)	Frequency	Duration	Current compliance	Natural compliance	Ratio current:natural
Low flow	Sum-Aut	Within range of 70 or natural (whichever is lower) and 680 ML/d or natural (whichever is higher), with absolute minimum of 10 ML/d (no cease to flow)	Continuous	Continuous	95% (minimum 10 ML/d) 84% (p10-p90 range)	96% (minimum 10 ML/d) 84% (p10-p90 range)	99%
Low flow fresh	Any time	≥ 170	2 per year	3 days	100%	100%	100%
High flow	Win-Spr	Lesser of 130 or natural	Continuous	Continuous	92%	96%	96%
High flow fresh	Win-Spr	≥ 5,000	≥ 1 per year	Minimum of 1 day	Occurs 95% of years	Occurs 100% of years	95%
Bankfull	Win-Spr	≥ 8,500	Natural	Minimum of 1 day	Occurs 90% of years	Occurs 95% of years	95%
Bankfull	Win-Spr	≥ 11,000	Natural	Minimum of 1 day	Occurs 87% of years	Occurs 92% of years	95%
Overbank	Win-Spr	≥ 15,000	Natural	Minimum of 1 day	Occurs 80% of years	Occurs 85% of years	94%

Table 15: Comparison of compliance of the current and natural flow regime with environmental flow recommendations for Reach 2

Flow component	Season	Magnitude (ML/day)	Frequency	Duration	Current compliance	Natural compliance	Ratio current:natural
Low flow	Sum-Aut	Within range of 60 or natural (whichever is lower) and 415 ML/d or natural (whichever is higher), with absolute minimum of 10 ML/d (no cease to flow)	Continuous	Continuous	91% (minimum 10 ML/d) 87% (p10-p90 range)	96% (minimum 10 ML/d) 87% (p10-p90 range)	99% 100%
Low flow fresh	Any time	≥ 150	2 per year	3 days	100%	100%	100%
High flow	Win-Spr	Lesser of 147 or natural	Continuous	Continuous	92%	91%	100%
High flow	Win-Spr	Lesser of 200 or natural	Continuous	Continuous	88%	88%	100%
High flow fresh	Win-Spr	≥ 260	≥ 4 per year	1 day	84% of years	84% of years	100%
Bankfull	Win-Spr	≥ 7,500	Natural	Minimum of 1 day	Occurs 44% of years	Occurs 44% of years	93%
Overbank	Win-Spr	≥ 9,500	Natural	Minimum of 1 day	Occurs 39% of years	Occurs 39% of years	100%

Table 16: Comparison of compliance of the current and natural flow regime with environmental flow recommendations for Reach 3

Flow component	Season	Magnitude (ML/day)	Frequency	Duration	Current compliance	Natural compliance	Ratio current:natural
Low flow	Sum-Aut	Within range of 26 or natural (whichever is lower) and 985 ML/d or natural (whichever is higher), with absolute minimum of 10 ML/d (no cease to flow)	Continuous	Continuous	95% (minimum 10 ML/d) 89% (p10-p90 range)	99% (minimum 10 ML/d) 92% (p10-p90 range)	95% 97%
Low flow fresh	Any time	≥ 120	2 per year	3 days	100%	100%	100%
High flow	Win-Spr	Minimum 130, or natural	Continuous	Continuous	96%	98%	98%
High flow	Win-Spr	Lesser of 120 or natural	Continuous	Continuous	96%	98%	98%
High flow	Win-Spr	Lesser of 130 or natural	Continuous	Continuous	100%	100%	100%
High flow fresh	Win-Spr	105	≥ 4 per year	1 day	100%	100%	100%
Fresh	Any time	650	2 per year	4-6 days	100%	100%	100%
Bankfull	Win-Spr	4,300	Natural	Minimum of 5 days or natural, whichever is lesser	Occurs 82% of years	Occurs 80% of years	100%
Overbank	Win-Spr	7,500	Natural	Minimum of 3 days or natural, whichever is lesser	Occurs 28% of years	Occurs 28% of years	100%
Overbank	Win-Spr	9,500	Natural	Minimum of 2 days or natural, whichever is lesser	Occurs 10% of years	Occurs 8% of years	100%

Table 17: Comparison of compliance of the current and natural flow regime with environmental flow recommendations for Reach 4

Flow component	Season	Magnitude (ML/day)	Frequency	Duration	Current compliance	Natural compliance	Ratio current:natural
Low flow	Sum-Aut	170 or natural, absolute minimum of 10 ML/d	95% of years	Continuous	99% (minimum 10 ML/d) 96% (p10-p90 range)	100% (minimum 10 ML/d) 99% (p10-p90 range)	100% 97%
Low flow fresh	Sum-Aut	≥ 650	2 per year	3 days	92%	85%	100%
High flow	Win-Spr	Minimum 650 or natural	Continuous	Continuous	92%	93%	99%
High flow	Win-Spr	≥ 1900	80% of years	70 days (cumulative)	NA	NA	NA
High flow fresh	Win-Spr	18,500	2 per 3 years	Natural duration or 1 day, whichever is greater	Occurs 62% of years	Occurs 64% of years	97%
Bankfull	Win-Spr	25,000	1 per 3 years	Natural duration or 2 days, whichever is greater	Occurs 69% of years	Occurs 54% of years	100%

Table 18: Comparison of compliance of the current and natural flow regime with environmental flow recommendations for Reach 5

Flow component	Season	Magnitude (ML/day)	Frequency	Duration	Current compliance	Natural compliance	Ratio current:natural
Low flow	Sum-Aut	Lesser of 130 or natural	Continuous	Continuous	88%	94%	94%
Low flow	Sum-Aut	> 260	Continuous	Continuous	66%	88%	75%
Low flow fresh	Sum-Aut	130-260	4 per year	3 days	100%	100%	100%
High flow	Win-Spr	Minimum 130, or natural	Continuous	Continuous	96	98	98%
High flow	Win-Spr	Minimum 540 or natural	Continuous	Continuous	96	98	98%
High flow	Win-Spr	≥ 900	80% of years	70 days (cumulative)	NA	NA	NA
High flow fresh	Win-Spr	540	≥ 4 per year	1 day	100%	100%	100%
High flow fresh	Win-Spr	3,900	≥ 2 per year	1 day	Occurs 41% of years	Occurs 46% of years	89%
Bankfull	Win-Spr	7,800	≥ 1 per year	5 days	Occurs 85% of years	Occurs 87% of years	98%
Overbank	Win-Spr	12,000	≥ 1 per year	13 days	Occurs 67% of years	Occurs 67% of years	100%

6 COMPLEMENTARY MANAGEMENT ACTIONS

River condition is the result of the variability and interaction between hydrology, hydraulics, geomorphology and water quality. Improvements in river condition sought through various initiatives such as the Victorian River Health Strategy, the Northeast Regional catchment Strategy, the Living Murray Initiative and the MDBC native Fish Strategy are dependent on many factors; management of the flow regime being but one factor. The Scientific Panel has identified a number of non flow-related management actions required to maintain or improve the condition of ecosystem assets and values in the Ovens catchment, and so complement the flow-related objectives and environmental flow recommendations identified in this project:

- Amelioration of cold water releases from Lake Buffalo and Lake William Hovell.
- Riparian rehabilitation[11] including;
    - Controlled access by livestock to the riparian zone;
    - Continued implementation of pest plant and animal control measures;
    - Revegetation, particularly of eroding gullies.
- Rehabilitation/protection of frequently connected wetlands.
- Control of industry and urban encroachment into the riparian zone (especially Reach 3);
- Protection of floodplain aquatic habitats, such as the protection of wetlands from livestock grazing.
- Protection of structural woody habitat in floodplain channels. Large logs are of considerable importance in maintaining channel form, stability and habitat niches. This is particularly important for Reach 3 and Reach 4. Removal of structural woody habitat should be prevented, unless otherwise demonstrated as a serious threat to a high value asset or human life. Reinstatement should be considered and riparian stands providing potential future sources of logs should be maintained or regenerated
- Continuation of pest plant and animal control measures. For example, willows have colonised sections of reaches in the Ovens, King and Buffalo Rivers. Willow root mats have an extensive root system that can readily colonise stream banks and bed, creating constrictions and resulting in catastrophic erosion at higher flows. Willow colonisation should be managed to maintain natural channel form and stability. But, in line with the current North East CMA regional catchment strategy, a pragmatic approach is required to prevent the risk of catastrophic channel change in the removal of existing trees. The lower Ovens River (Reach 5) remains relatively clear of willows; maintaining this situation should be given a high priority.
- Control of alien fish species such as carp and gambusia and implementation of river rehabilitation works consistent with the MDBC native Fish Strategy (MDBC 2003).

[11] River rehabilitation best practice often focuses on giving high priority to protecting high value assets and values first, and then on works to manage risk and improve river condition. For the Ovens River, emphasis should first be placed on protecting or managing risks along Reach 5 (e.g. weed control, control of stock access) and then on minimizing risks and undertaking riparian revegetation along Reach 4. This order of priority is also consistent with the Ovens Regional River Health Strategy (North East CMA 2004).

- Generation of new knowledge into the ecological relationships between native fish and flows should continue.
- Provision of fish passage past barriers such as the Wangaratta and Tea Garden Creek weirs;
- Management of the impacts of angling (especially under low flow conditions);
- Continued implementation of the Ovens water quality strategy and regional Landscape plans.

The geomorphology of the Ovens River between Myrtleford and Wangaratta has been modified by past catchment and river management (e.g. gravel extraction, clearance). Rehabilitation of this reach would be assisted by:

- The continued suspension of gravel extraction for commercial purposes;
- Revegetation and protection of the riparian zone; and
- Reinstatement of structural wood habitat, which would assist in creating increased bed diversity.

7 MONITORING AND EVALUATION

The Victorian Government has established the Victorian Environmental Flows Monitoring & Evaluation Program (VEFMAP) (Cottingham et al. 2005) to evaluate the effectiveness of new flow regimes in regulated rivers across Victoria. VEFMAP is currently being deployed for a number of northern rivers, including the Goulburn-Broken, Loddon and Campaspe (Chee et al. 2006 a, b and c) and seeks to detect and evaluate river-specific as well as State-wide outcomes from environmental flow regimes. Assessment of Statewide outcomes will be undertaken by analyzing ecosystem responses in rivers that represent a gradient in both the degree of regulation and scale of change the environmental flow regimes represent from current management. It is recommended that, where possible, the North East CMA seek to ensure that monitoring and evaluation of environmental flow outcomes in the Ovens River is consistent with that identified for the VEFMAP program. This will allow assessment of river-specific outcomes related to the flow recommendations proposed by this project and will add to the likelihood of detecting ecosystem responses at the State level, thus underpinning decisions on environmental flow regimes in the future. The flow regime of the Ovens River has not been altered to the extent of most other regulated rivers in Victoria, and so would add to the gradient of ecosystem responses being evaluated by VEFMAP.

VEFMAP plans for each river outline the conceptual basis, study design, variables to be measured and data analysis required to assess responses such as by attributes of hydrology (have environmental flows been delivered?), geomorphology, in-channel and riparian vegetation, macroinvertebrates and native fish. In addition, the Scientific Panel recommends that the North East CMA undertake additional investigations and monitoring from which to assess issues specific to the Ovens River and its tributaries:

- Continuous monitoring of DO concentration in the lower Ovens River (Reach 5) when flows fall below 65 – 85 ML/d. This will allow for delivery of freshes to improve water quality should DO concentration fall below 1 mg/L.
- Targeted investigations of discharge-velocity-DO relationships in each reach to confirm conditions under which stratification and low DO concentration conditions become a risk to ecosystem condition.
- Flow recommendations are based on flows measured at nearby gauging stations and the geomorphology at a site considered to be representative of the reach. It is assumed that flow recommendations apply to the entire reach. It is recommended that discrete flow events are monitored to confirm that flows are delivered as described and to account for any losses or gains due to variation in geomorphology and factors such as groundwater recharge or discharge.
- The reasons for the lack of aquatic macrophytes in the Ovens River are unclear. Given the importance of macrophytes to the ecology of river systems, the lack of information on the factors affecting the structure and distribution of plant communities is an important knowledge gap, potentially limiting effective environmental flow recommendations. Basic inventories and studies of the structure and distribution of plant species will provide basic information that will assist in any future review of environmental flow requirements for aquatic and riparian vegetation.

- Angling is a very popular pastime in the Ovens catchment. An assessment of angling take on target native species would assist in determining if angling pressure is likely to affect the condition, distribution or recovery of native fish.
- Instream and riparian structures such as weirs, river stabilization works and levees exist that have the potential to restrict the longitudinal and lateral movement of fish and invertebrates and disrupt important ecological processes such as aquatic production and respiration and the cycling of nutrients. An audit of such structures will assist in ensuring that longitudinal and lateral connection between the river channel and riparian areas.
- A monitoring program for geomorphic attributes of rivers in the Murray Darling Basin is currently being developed for the Sustainable Rivers Audit. The Ovens River has been used as a pilot catchment with one site in the lower reaches of the Ovens River (Reach 5), nearby Peechelba (Vietz and Grove, unpublished data). As this project is formalised, the baseline information from this study may be useful in monitoring geomorphic change (bed diversity, channel form) over the next 5 to 10 years.
- Routine macroinvertebrate sampling usually focuses on edge and riffle (when present) samples. Macroinvertebrates that inhabit edge habitats are often relatively insensitive to changes to the flow regime. It is recommended that monitoring of macroinvertebrate responses to environmental flows focus on habitat where the macroinvertebrate communities are likely to be sensitive to changes in hydrology and hydraulics – for example on logs that make up structural woody habitat submerged in the main channel. Sampling methods such as the use of 'snag bags' (Growns et al. 1999) have been developed for such purposes.
- Targeted investigations to confirm the conditions (shear stress) under which biofilms and deposits of fine sediments are disrupted, improving habitat conditions for macroinvertebrates.
- Development of discharge-floodplain inundation relationships for lowland reaches to refine overbank flow recommendations in the future.

8 REFERENCES

Biggs B.J.F. (1996). Hydraulic habitat of plants in streams. *Regulated Rivers: Research and Management*, 12, pp. 131-141.

Boulton A. and Lake P.S. (1992). The ecology of two intermittent streams in Victoria, Australia. III. Temporal changes in faunal composition. *Freshwater Biology* 27 (1), pp. 123–138.

Burns A. and Walker K. (2000). Effects of water level regulation on algal biofilms in the River Murray, South Australia. *Regulated Rivers: Research and Management*, 16, pp. 433-444.

Chee Y., Webb A., Cottingham P. and Stewardson M. (2006a) Victorian Environmental Flows Monitoring and Assessment Program: Monitoring and assessing environmental flow releases in the Goulburn River. Report prepared for the North Central Catchment Management Authority and the Department of Sustainability and Environment. e-Water Cooperative Research Centre, Melbourne.

Chee Y., Webb A., Cottingham P. and Stewardson M. (2006b) Victorian Environmental Flows Monitoring and Assessment Program: Monitoring and assessing environmental flow releases in the Campaspe River. Report prepared for the North Central Catchment Management Authority and the Department of Sustainability and Environment. e-Water Cooperative Research Centre, Melbourne.

Chee Y., Webb A., Cottingham P. and Stewardson M (2006c) Victorian Environmental Flows Monitoring and Assessment Program: Monitoring and assessing environmental flow releases in the Loddon River. Report prepared for the North Central Catchment Management Authority and the Department of Sustainability and Environment. e-Water Cooperative Research Centre, Melbourne.

Chow V. T. (1959). Open-Channel Hydraulics, McGraw-Hill, Kogakusha.

Cottingham P., Gawne B., Gigney H., Koehn J., Roberts J. and Vietz G. (2007). Lower Ovens River environmental flows project: Issues Paper. Report prepared by Peter Cottingham & Associates and the Murray Darling Freshwater Research Centre for the North East Catchment Management Authority.

Cottingham P., Stewardson M. and Webb A. (2005) Victorian Environmental Flows Monitoring and Assessment Program. Stage 1: Statewide Framework. Report to the Dept. of Sustainability and Environment. CRC for Freshwater Ecology and CRC for Catchment Hydrology, Melbourne.

Cottingham P., Stewardson M., Crook D., Hillman T., Roberts J. and Rutherfurd I. (2003). Environmental flow recommendations for the Goulburn River below Lake Eildon. CRC Freshwater Ecology and CRC Catchment Hydrology report to DSE Victoria and the MDBC.

Cottingham P., Hannan G., Hillman T., Koehn J., Metzeling L., Roberts J. and Rutherfurd I. (2001). Report of the Ovens Scientific Panel on Environmental Condition and Flows of the Ovens River. Cooperative Research Centre for Freshwater Ecology Technical Report 9/2001, December 2001.

Dexter B.D. (1978). Silviculture of the River Red Gum forests of the central Murray floodplain. *Proceedings of the Royal Society of Victoria* 90: 175-192.

Doeg TJ, Lake PS and Marchant R. (1989). Colonization of experimentally disturbed patches by stream macroinvertebrates in the Acheron River, Victoria. *Australian Journal of Ecology,*14 (2), pp. 207-220.

DNRE (2002). Victorian River Health Strategy: Healthy Rivers, Healthy Communities and Regional Growth. The State of Victoria, Department of Natural Resources and Environment, Melbourne.

EarthTech (2007). Fluvial geomorphology of the Ovens River: Myrtleford to Wangaratta. EarthTech Pty Ltd report to the North East Catchment Management Authority.

Gawne B. and Lake P.S. (1995). Effects of microspatial complexity on a herbivore—epilithon interaction in an Australian upland stream. *Freshwater Biology* 33 (3), pp. 557–565.

Gawne B., Merrick C.J., Williams D., Rees G., Oliver R.L., Bowen P.M., Treadwell S.A., Beattie G., Ellis I., Frankenberg J., and Lorenz Z. (2007). Patterns of primary and heterotrophic productivity in an arid lowland river. *River Research and Applications*, 23(10), pp. 1070 – 1087.

Gippel C.J. (1999). Edward River: Hydraulic Effect of Snags and Management Options. Report by Fluvial Systems Pty Ltd, Melbourne, Victoria to NSW Department of Land and Water Conservation, Albury, N.S.W.

Growns J., King A., Betts F. (1999). The Snag Bag: a new method for sampling macroinvertebrate communities on large woody debris. *Hydrobiologia*, 405, pp. 67-77.

Hicks D.M. and Mason P.D. (1991). Roughness Characteristics of New Zealand Rivers – A handbook for assigning hydraulic roughness coefficients to river reaches by the “visual comparison” approach. Water Resources Survey.

Humphries P., Cook R., Richardson A. and. Serafini L. (2005). Creating a disturbance: manipulating slackwaters in a lowland river. *River Research and Applications*, 22(5), pp. 525 - 542

Humphries P., King A.J. and Koehn J.D. (1999). Fish, flows and floodplains: links between freshwater fish and their environment in the Murray-Darling River system, Australia. *Environmental Biology of Fishes,* 56, pp. 129-151.

Johnson RL, and Harp GL. 2005. Spatio-temporal changes of benthic macroinvertebrates in a cold Arkansas tailwater. *Hydrobiologia,* 537, pp. 15-24.

Jowett I. (1993). A method for objectively identifying pool, run, and riffle habitats from physical measurements. *New Zealand Journal of Marine and Freshwater Research*, 27, pp. 241—248.

Keller, R. J. (1982) Case study: Confluence of Little Murray and Murray Rivers at Swan Hill. The Association for Computer Aided Design, Ltd (ACADS) Forum/Workshop on energy loss parameters for flow profile computation programs. October 6, 1982. Melbourne, ACADS

Lang S., Ladson, A., Anderson, B. and Rutherford, I. (2005) Stream roughness. Four case studies from Victoria. *Australian Journal of Water Resources*.

Marsh N. (2004). River Assessment Package (RAP) User Guide version 1.1. CRC Catchment Hydrology, www.toolkit.net.au/rap.

McNeil D. and Closs G. (2007). Behavioral responses of a south-east Australian floodplain fish community to gradual hypoxia. *Freshwater Biology*, 52 (3), pp. 412-420.

MDBC (2003). Native fish strategy for the Murray Darling Basin, 2003-2013. Murray Darling Basin Commission, Canberra.

North East CMA (2004) North East Regional River Health Strategy 2004 - Summary. North East Catchment Management Authority, Wodonga.

OBWQWG (2000). Ovens Basin water quality strategy. Report of the Ovens Basin Water Quality Working Group.

PC&A and MDFRC (2007). Lower Ovens River environmental flows project: Site Report. Report prepared by Peter Cottingham & Associates and the Murray Darling Freshwater Research Centre for the North East Catchment Management Authority.

Rader RB, and Belish TA. 1999. Influence of mild to severe flow alterations on invertebrates in three mountain streams. *Regulated Rivers-Research & Management,* 15, pp. 353-363.

Ryder D., Watts R., Nye E. and Burns A. (2006). Can flow velocity regulate biofilm structure in a regulated lowland river? *Marine and Freshwater Research*, 59, pp. 29-36.

Sheldon F. and Walker K.F. (1997). Changes in biofilms induced by flow regulation could explain extinctions of aquatic snails in the lower River Murray, Australia. *Hydrobiologia,* 347, pp. 97-108.

SKM (2007). REALM Model Development for the

Lower Ovens River Basin. Sinclair Knight Merz report to the North East Catchment Management Authority.

SKM 2006. Upper Ovens Environmental FLOWS Assessment – flow recommendations. Sinclair Knight Merz report to the North East Catchment Management Authority.

Sutherland S, Ryder D, Watts R. (2002). Ecological assessment of cyclic release patterns (CRP) from Dartmouth Dam to the Mitta Mitta River, Victoria. Report 27, Johnson Centre research in Natural Resources Management.

Turner L. and Erskine W. (2005). Variability in the development, persistence and breakdown of thermal, oxygen and salt stratification on regulated rivers of southeastern Australia. *River Research and Applications*, 21(2-3), pp. 151 – 168.

USACE (2002). HEC-RAS river analysis system. Hydraulic reference manual version 3.1. US Army Corps of Engineers. Davis, California.

van Eck W.H.J.M., van de Steeg H.M., Blom C.W.P.M. and de Kroon H. (2004). Is tolerance to summer flooding correlated with distribution patterns in river floodplains? A comparative study of 20 terrestrial grassland species. *Oikos* 107: 393-405.

van Eck W.H.J.M., Lenssen J.P.M., van de Steeg H.M., Blom C.W.P.M. and de Kroon H. (2006). Seasonal dependent effects of flooding on plant species survival and zonation: a comparative study of 10 terrestrial grassland species. *Hydrobiologia* 565: 59-69.

Vietz G. (2007). Hydraulic Modelling Report for the Lower Ovens River Environmental Flows Project. Report P107029_R01V2 by Alluvium for Peter Cottingham & Associates, Melbourne.

Vietz, G.J., Stewardson, M.J., and B.L. Finlayson, 2006. Flows that Form: The Hydromorphology of Concave-Bank Bench Formation in the Ovens River, Australia. In Sediment Dynamics and the Hydromorphology of Fluvial Systems, Rowan, J.S., Duck, R.W. and Werritty A. (eds.), IAHS Publication 306, International Association of Hydrological Sciences, Wallingford, pp 267-276.

Vietz, G. and Grove, J. (unpublished data). Data collected for the SRA Physical Form Theme, Reach Scale Characterisation Methodology. In preparation for the Murray Darling Basin Commission.

Watts R., Nye E., Thomson L., Ryder D., Burns A. and Lightfoot K. (2005). Environmental Monitoring of the Mitta Mitta River associated with the major transfer of water resources from Dartmouth Reservoir to Hume Reservoir. Report No 97, Johnstone Centre Research in Natural Resources Management.

Western A. and Stewardson M. (1999). Thermal stratification in the Wimmera and Glenelg Rivers. Centre for Environmental Applied Hydrology report 4/99, University of Melbourne.

9 APPENDIX 1: HYDRAULIC MODELLING REPORT FOR THE OVENS ENVIRONMENTAL FLOW PROJECT

alluvium

HYDRAULIC MODELLING REPORT FOR THE:

Lower Ovens River Environmental Flows Project - Draft

7 November 2007

Document history
P107029_R01V2 Hydraulics

REVISION

ISSUE DATE	VERSION NO.	AUTHOR(S)	CHECKED	APPROVED
7 November 2007	1	G. Vietz	A. Wealands	G. Vietz

DISTRIBUTION

VERSION NO.	ISSUED TO	DESCRIPTION
1	P. Cottingham	Report for insertion into final report

CITATION

Please cite this document as: Vietz, G. (2007). Hydraulic Modelling Report for the Lower Ovens River Environmental Flows Project. Report P107029_R01V2 by Alluvium for P. Cottingham and Associates.

Introduction
This report discusses the tasks involved in producing and calibrating hydraulic models for five sites as part of the Lower Ovens River Environmental Flows Project.

Site Surveying
Cross-sectional surveys for the representative reaches on the Ovens Rivers were undertaken by the SM Urban surveying group using a Total Station and differential GPS. Transects were identified and pegged by the Technical Panel during the field inspection within each of the five reaches at the representative sites.

Cross-section locations were chosen based on capturing the hydraulic, geomorphic and ecological characteristics of the reach. The hydraulic controls include both lateral and vertical constrictions e.g. debris and riffles. The ecological and geomorphic points of interest include features such as deep pools, vertical banks, riffles, runs, benches and wetlands. Cross-sections were surveyed perpendicular to the general flow path (Figure 12). A greater density of points was identified within the low flow channel, where detail is required, and fewer points on the floodplain where only broad-scale morphology is important. Between six and eight cross sections were surveyed at each of the five representative sites.

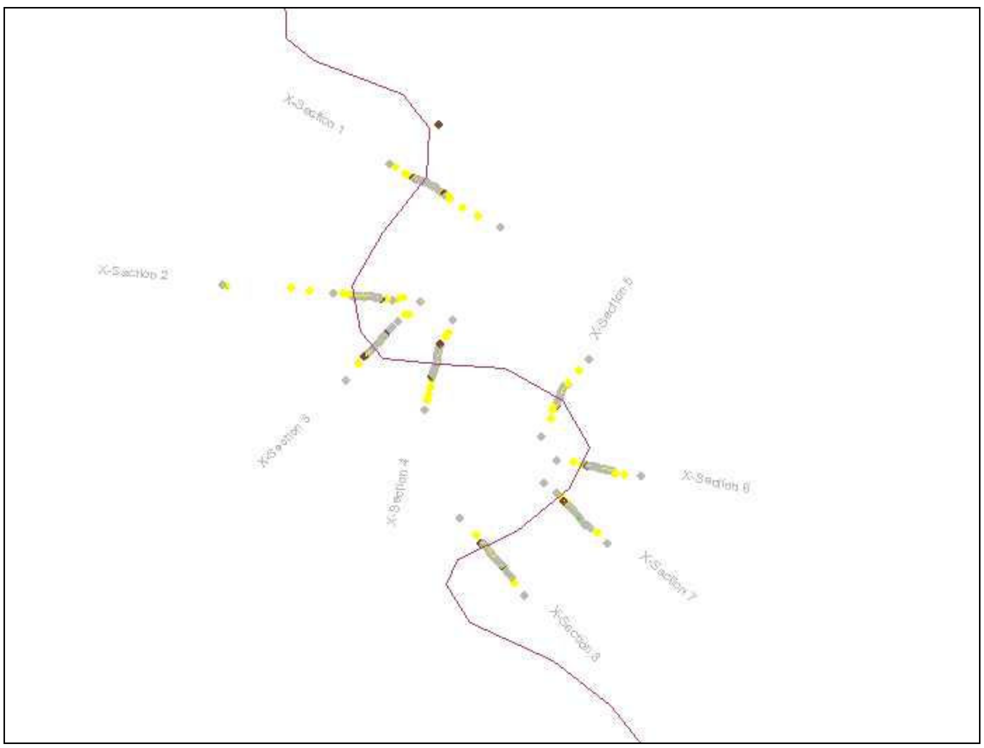


Figure 12: Surveyed points within for the Ovens River at Peechelba (exported from ArcMap GIS). Note the greater density of points representing the channel.

Hydraulic Model Construction and Calibration
Hydraulic models of the representative sites were constructed using the one-dimensional steady state backwater analysis model HEC RAS (version 3.1.3). This model was designed by the United States Army Corps of Engineers (USACE) and

has been extensively used for environmental flow studies both in Victoria and internationally. HEC RAS is well suited to the FLOWS assessment approach whereby channel morphology is related to discharge. There are three key parametric inputs to HEC RAS:

- Channel geometry;
- Hydraulic roughness; and
- A boundary condition.

Channel geometry represents the topography of the channel and is derived from the survey data. The more reliable the survey data at each cross section the lower the reliance on other parametric inputs. Generally, this equates to more reliable hydraulic outputs from the model.

The placement of the most downstream cross section is of the utmost importance when sub-critical flow is assumed, as is the case with all five models produced for this project. In a sub-critical flow regime the hydraulic model calculations begin at the downstream end (hence the term backwater model). A common error associated with hydraulic modelling in environmental flow studies is assigning a downstream cross-section within a pool or enlarged section of the channel, such that the modeller relies heavily on a downstream boundary condition to force water levels to known or 'reasonable' levels. To improve the model outputs for this project the most downstream section is:

1) Marked for surveying by the modeller at a hydraulic control (i.e. a point constricting the flow at the flow range of interest),
2) A greater distance of separation than for the other sections so that the errors in the selected boundary condition (see below) are minimised, and
3) Is not used in the output of metrics.

Hydraulic roughness is an important component in the model and is provided by Manning's *n* (a measure of channel roughness). Calibration of hydraulic roughness is highly subjective and commonly a process that requires experience and expert judgement. The approach used to determine values for Manning's *n* for this project includes:

1. Initial Manning's *n* estimate for the reach from handbook roughness tables (e.g. Chow 1959) and visual assessment guides (e.g. Hicks and Mason 1991);
2. Specific adjustment of Manning's *n* for each section based on expert judgement of the impact of obstacles such as wood, bedrock etc. with guidance from relevant literature (e.g. Gippel 1999) and interpretation from inspection and survey photographs; and
3. Calibration of the Manning's *n* value based on observed water levels and known discharges within the reasonable limits of the allocated roughness values.

This three-step process enables verification of the handbook Manning's values against observed conditions and, on the other hand, reduces the 'blind faith' often placed in calibrating modelled conditions to observed conditions. The calibration of the model to observed conditions is undertaken with an acceptable deviation from the 'reasonable' values suggested by the literature. Manning's *n* has been empirically

found to remain consistent over a range of discharges from bed level to bankfull (Hicks and Mason 1991, Lang et al. 2004) and as such were not varied with depth or discharge in these models.
The boundary conditions for the hydraulic models calibrated for this project are at the downstream end of the model, as the flow regime is assumed to be subcritical. The boundary condition of 'normal depth' is used for these models which allow the modeller to identify a water slope downstream of the site. In this case the slope for the models was determined from various characteristics of the site, such as:

- Bed slope (based on riffles at thalweg);
- Observed water slope (start to end);
- Observed downstream water slope (downstream control); and
- Valley slope.

The resulting values for each site are depicted in Table 19. Calibration of the model through known water surface elevations for a given flow assists in refining model parameters. In all cases a proximal stream gauge was used to identify the discharge on the days of surveying and the field inspection. Topographic controls missed by the surveying can also be identified and adjusted with options such as ineffective flow areas and obstructions. Since surveying was undertaken at relatively low discharges the confidence is greater at these lower levels.

Table 19: Values of Manning's roughness and downstream slope for each representative site modelled.

Reach number	Description	Channel roughness	Manning's channel roughness values	Downstream slope
1	Buffalo – Nug Nug	Low sinuosity and bed diversity with several transverse riffles and a medium wood loading	0.04 – 0.07	0.00095
2	King – Gentle Annie	Medium sinuosity, low wood loadings but course substrate and high bed diversity	0.065 – 0.085	0.005
3	King – Docker Road	High sinuosity and wood loadings	0.075 – 0.085	0.0008
4	Ovens - Whorouly	Low sinuosity, bed diversity and wood loadings	0.035 – 0.052	0.00079
5	Ovens - Peechelba	High sinuosity, bed diversity and woody loadings	0.075 – 0.08	0.00035

Hydraulic Model Outputs

A key output from the modelling is a graphic presentation of each transect with water levels related to discharge. In Figure 13, water levels are shown for the discharge on the day of surveying and a discharge approximating bankfull. In cross-section (Figure 13a), the black line represents channel topography, with small black squares along this line identifying survey points. Horizontal blue lines within the cross-section represent the water surface at the various discharges. Long profiles (thalweg level plot) display the variability in bed levels (Figure 13b). In addition to water levels, the hydraulic models are used to investigate important hydraulic parameters such as velocity and shear stress.

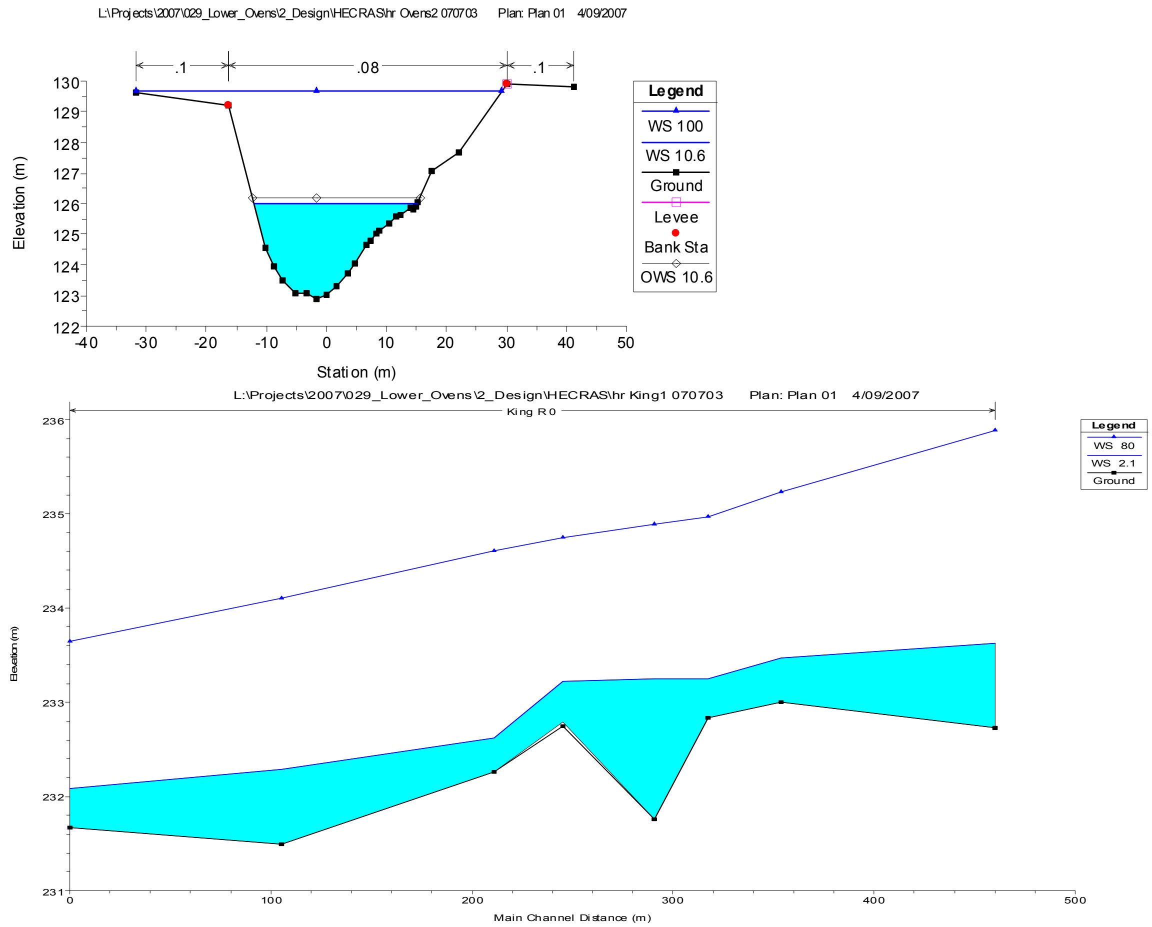


Figure 13: (a) Cross section and (b) longitudinal section displaying flow stage for the day of surveying and an approximate bankfull level.

Hydraulic Model Sensitivity Assessment

The representativeness of the cross sections in terms of site topography, and particularly reach topography, can not be easily verified. However, the two types of modelling error that can be quantified are the selection of hydraulic roughness and boundary condition parameters. The sensitivity of the model to errors in parameter selection (i.e. how wrong it can be?) is identified in the following analysis.

The sensitivity analysis is undertaken for a lowland site (Reach 5 Lower Ovens River) and an upland site (Reach 1 Buffalo River). The analysis identifies the change in discharge for one low and one high flow. The low flows used as the example in this analysis are the low flow freshes and the high flows are the bankfull flow. The metrics for both of these flow components are based on water level stage.

The hydraulics for these sites have been re-modelled for a +/-25% change in the boundary conditions of roughness and downstream slope (a significant error). The upper flow limits are based on decreased roughness and increased slope (higher water levels) and the lower flow limits are based on a 25% change for increased roughness and decreased slope (lower water levels). The flow limits relate to the discharge required to obtain the same water level as the recommended flow, when the input parameters are altered (Table 20).

Table 20: Upper and lower flow limits based on a 25% change (error) in boundary conditions for the recommended low flow and bankfull flow.

	Reach 1 Buffalo River	Reach 5 Lower Ovens River
Recommended Low Flow Fresh	230 ML/d	130 ML/d
Upper Flow Limit	264 ML/d (+15%)	189 ML/d (+45%)
Lower Flow Limit	134 ML/d (-42%)	66 ML/d (-49%)
Recommended Bankfull Flow	15,000 ML/d	7,800 ML/d
Upper Flow Limit	19,570 ML/d (+30%)	12,035 ML/d (+54%)
Lower Flow Limit	10,333 ML/d (-31%)	5,564 ML/d (-29%)

Deviations from the value of flow recommendations, based on a significant error in the hydraulic modelling boundary conditions, are between 15 to 54% (average 37%). The relative errors are similar for both low and high flows. While a 25% error in boundary conditions (particularly for roughness) should be outside the realm of an experienced hydraulic modeller, this analysis serves to put extreme bounds on potential variability in flow recommendations.

Confidence with the Hydraulic Models

Considerable confidence can be placed with the five hydraulic models because:

- Surveying was undertaken by an experienced river surveying team who has previously worked with the hydraulic modeller, and the hydraulic modeller was heavily involved in the field inspection and pegging of sections;
- The most downstream cross-section is located at a hydraulic control and is not used to determine key metrics;
- The downstream boundary condition of water slope is based on a combination of approaches, including a water surface slope surveyed downstream of the final cross section;
- Manning's roughness is determined based on various approaches and considerable experience;
- Models were calibrated to known water surface levels during survey, and observed water levels during the field inspection. At all five sites a high correlation was achieved; and
- Concerns with sections of the model likely to misrepresent actual conditions are revealed by the hydraulic modeller to the Technical Panel in a workshop

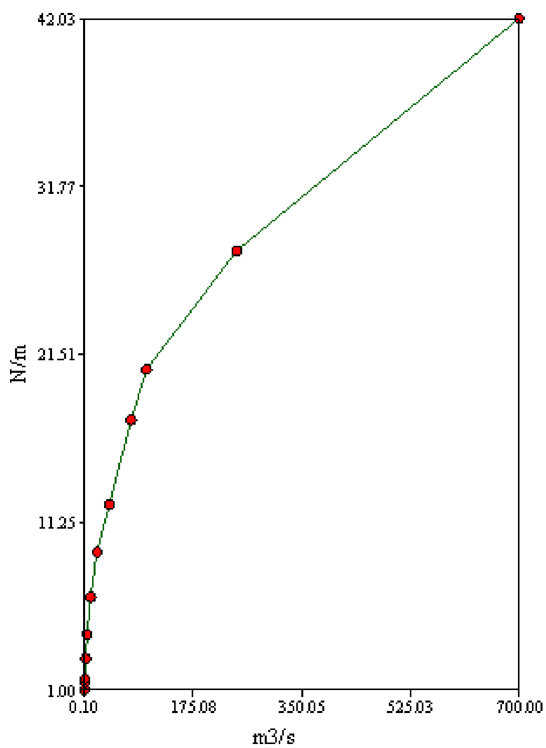
scenario e.g. the potential for the depth of passage to be indicated as greater where transverse ripples are represented in the model by cross sections perpendicular to the channel alignment.

10 APPENDIX 2: HYDRAULIC AND HYDROLOGICAL RELATIONSHIPS FOR EACH REACH.

Justifications for environmental flow recommendations for Reach 1

Note: Discharge outputs from RAP are in cubic metres per second (m^3/s). 1 m^3/s = 86.4 ML/d.

OBJECTIVE GRAPH AND RATIONALE

W1	0.01 m/s satisfied for all sections at 0.1 m/s ≈ 10 ML/d
G1	 **Figure 14: Discharge (m^3/s) versus shear stress (N/m^2)** • Pool and riffle cross-sections (excluding most d/s) • 15 N/m^2 ≈ 58m^3/s ≈ 5000ML/d
G2	• From Figure 14, 29 N/m2 ≈ 280 m3/s ≈ 24,000 ML/d

G6

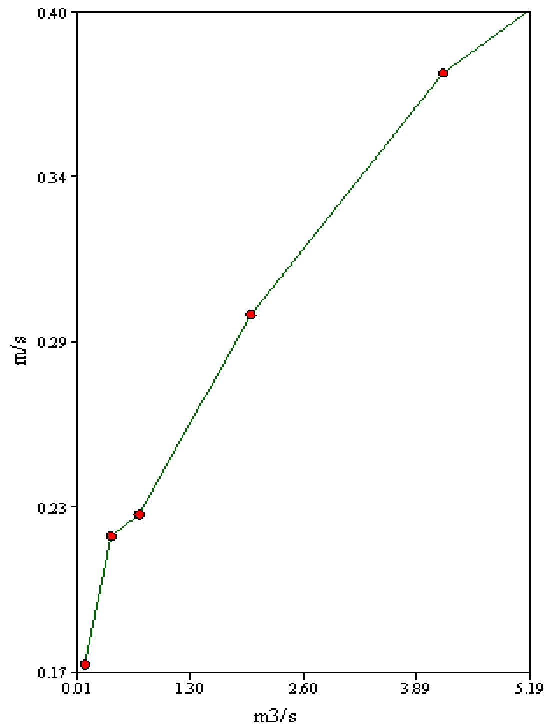


Figure 15: Discharge (m^3/s) versus velocity (m/s)

- Pool and riffle cross-sections (excluding most d/s)
- From Figure 15, 0.3m/s ≈ 2.0 m^3/s ≈ 170ML/d

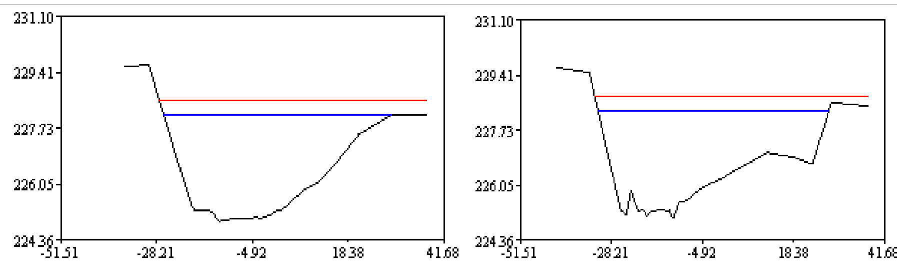
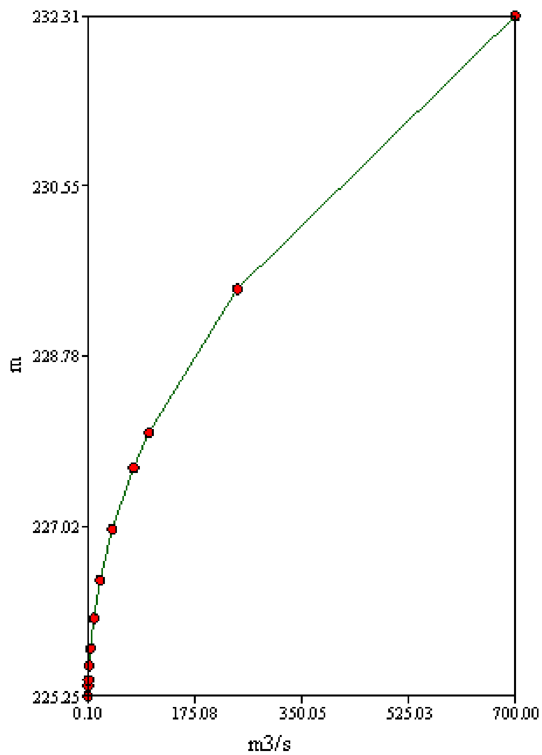


Figure 16: Height of bankfull and overbank discharge (m AHD)

- From Figure 16 and 17, Overbank flow is ≈ 173 m^3/s ≈ 15,000 ML/d

RB2	• From Figure 16, Bankfull ≈ 130m^3/s ≈ 11,000ML/d
BB1	 **Figure 17: Discharge versus stage height (m AHD)** • From Figure 17, fresh 0.3m above typical low flow (170 ML/d) ≈ 5m3/s ≈ 430ML/d
BB2	• From Figure 17, fresh 1m above typical low flow (170 ML/d) ≈ 21m3/s ≈ 1800ML/d
M4	• 80th percentile = 91.25 ML/day
M6	• 2.6 m3/s ≈ 230 ML/d

NF3

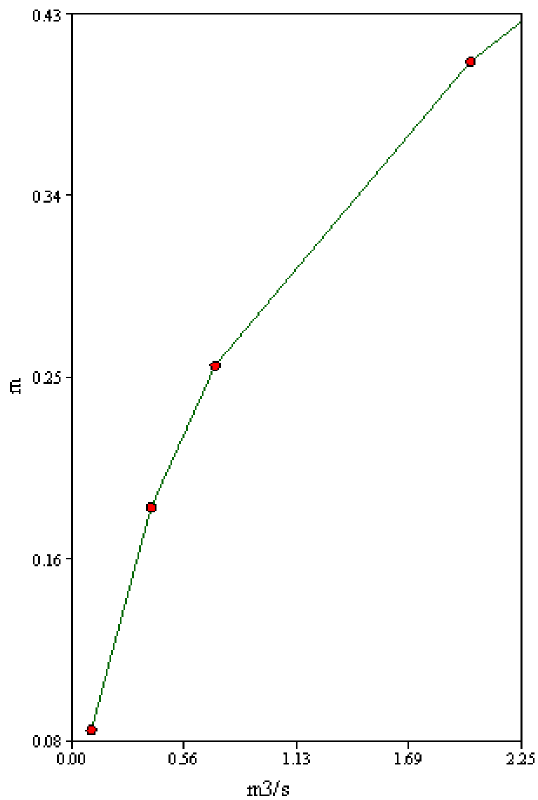


Figure 18: Discharge versus thalweg depth (m)

- From Figure 18, thalweg depth 0.3m ≈ 1.4 m^3/s ≈120ML/d

Justifications for environmental flow recommendations for Reach 2

OBJECTIVE GRAPH AND RATIONALE

G1

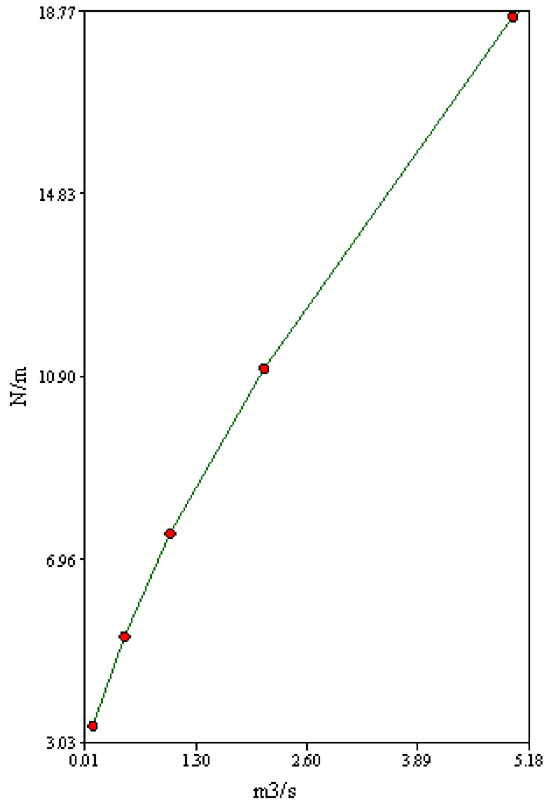


Figure 19: Discharge (m^3/s) versus shear stress (N/m^2)

- Pool and riffle cross-sections (excluding most d/s)
- From Figure 19, 15 $N/m^2 \approx 3 m^3/s \approx$ 260ML/d

G2

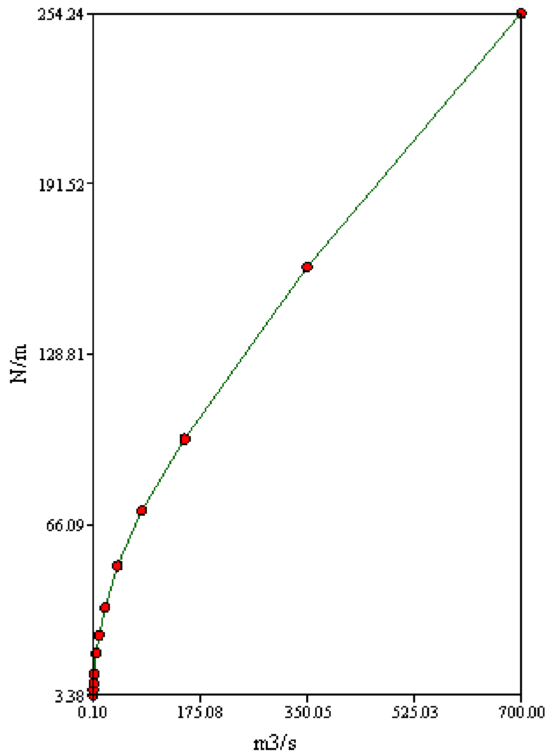


Figure 20: Discharge (m^3/s) versus shear stress (N/m^2)

- From Figure 20, 176 N/m2 ≈ 410 m3/s ≈ 35,000ML/d. This is an enormous flow, so default to bankfull – 100 m3/s ≈ 8,500 ML/d

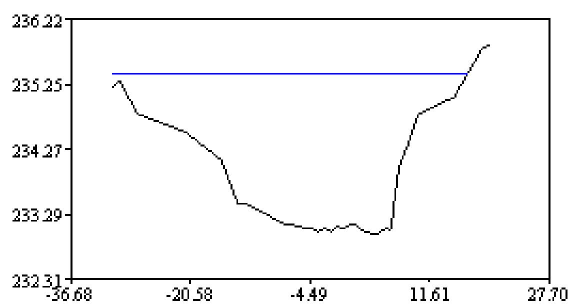


Figure 21: Height of overbank discharge (m AHD)

G6

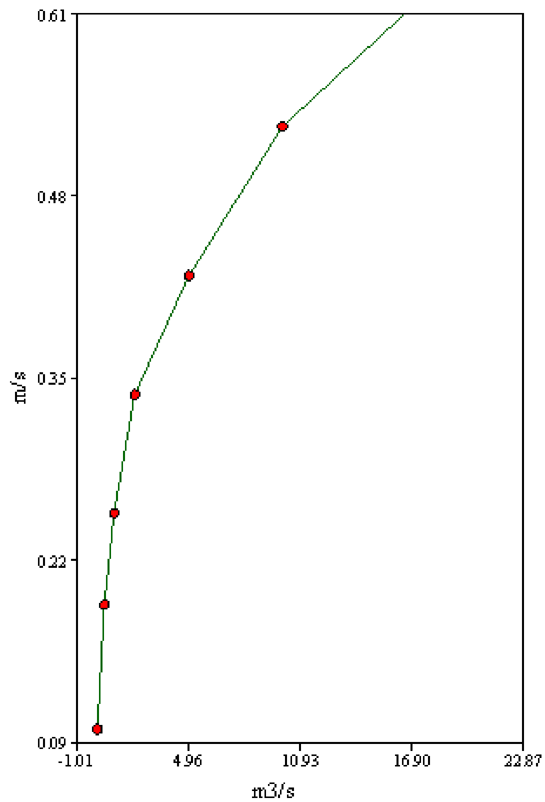


Figure 22: Discharge (m^3/s) versus velocity (m/s)

- Pool and riffle cross-sections (excluding most d/s)
- From Figure 22, 0.3m/s ≈ 1.8m^3/s ≈ 150ML/d

FP1-3

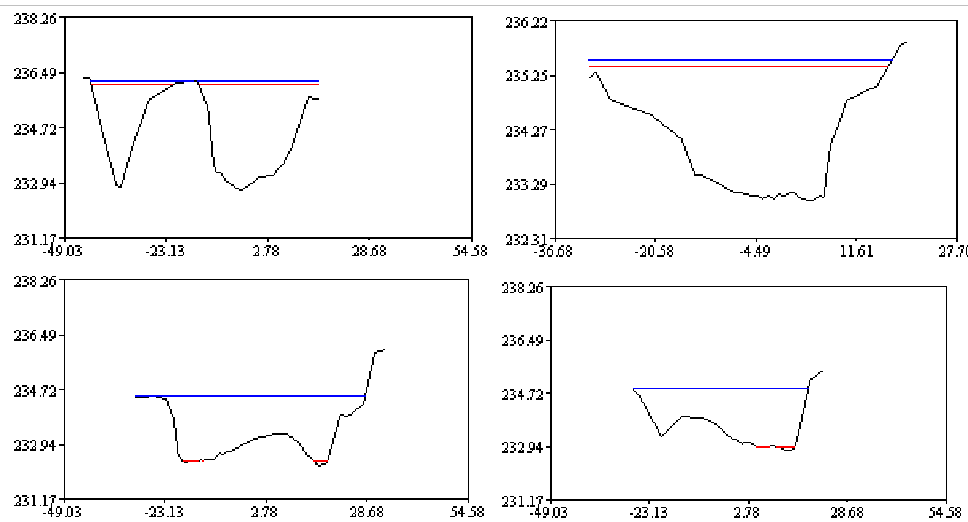
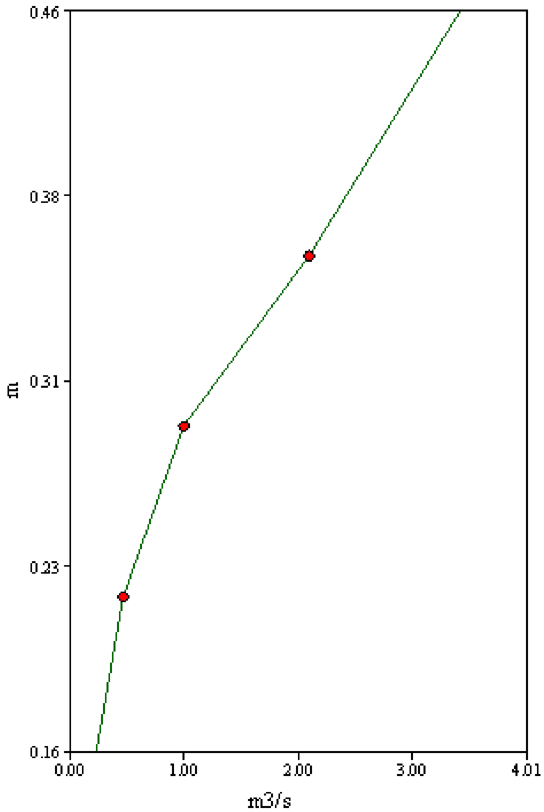


Figure 23: Height of bankfull and overbank discharge (m AHD)

- From Figure 23, overbank flow ≈ 110m^3/s ≈ 9,500ML/d

RB2	• From Figure 23, bankfull flow ≈ 75m^3/s ≈ 6,500ML/d
BB1	• From Figure 24, 0.3m above typical low flow (85 ML/d) ≈ 5m3/s ≈ 430ML/d
BB2	• From Figure 24, 1m above typical low flow ≈ 17m3/s ≈ 1500ML/d
M4	• 80th percentile = 85.31 ML/day
NF3	 **Figure 24: Discharge versus thalweg depth (m)** • Thalweg depth 0.3m ≈ 2.3 m^3/s ≈ 200ML/d

Justifications for environmental flow recommendations for Reach 3

OBJECTIVE GRAPH AND RATIONALE

W1

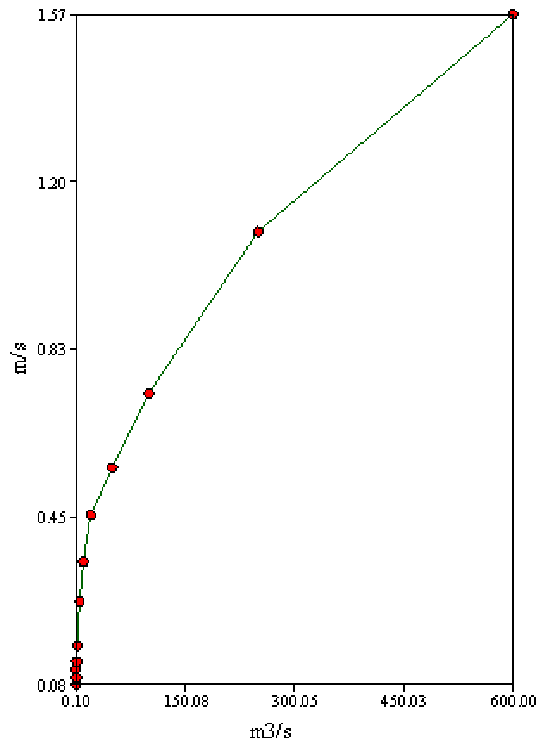


Figure 25: Discharge (m^3/s) versus velocity (m/s)

- According to model all flows modelled will achieve v > 0.01 m/s. Have nominally taken 0.1 m^3/s as lowest flow equivalent to approx 10 ML/d (this is a very narrow channel so considerably greater velocity per discharge compared with others).

G1

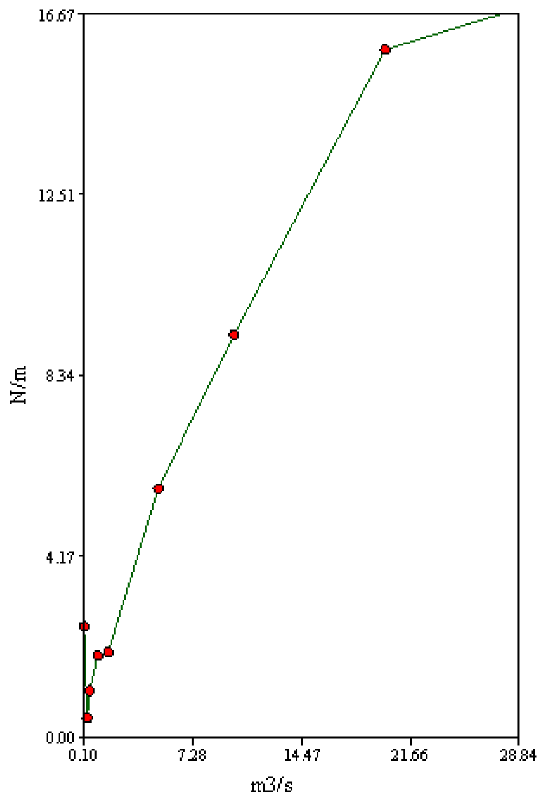


Figure 26: Discharge (m^3/s) versus shear stress (N/m^2)

- Pool and riffle cross-sections (excluding most d/s)
- From Figure 26, 1.1 $N/m^2 \approx 1.2\ m^3/s \approx$ 105ML/d

G2

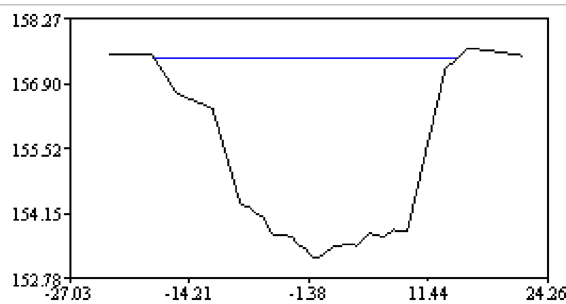


Figure 27: Height of bankfull discharge m AHD)

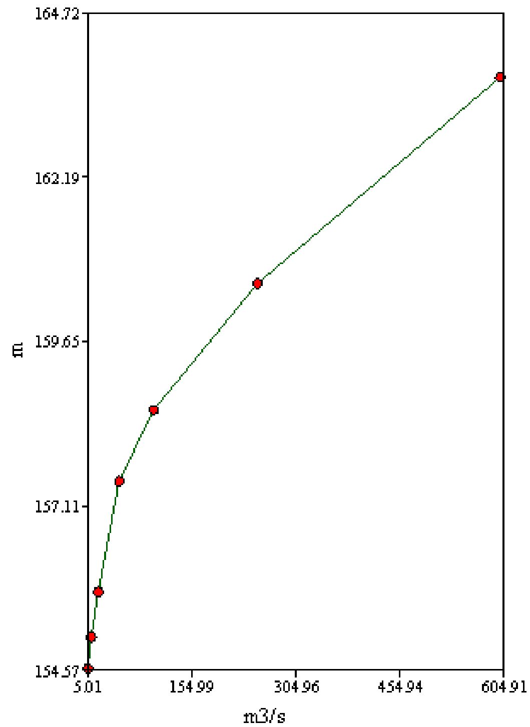


Figure 28: Discharge versus stage height (m AHD)

- Pool and riffle cross-sections (excluding most d/s)
- From Figures 27 and 28, bank full at 50m^3/s ≈ 4,300ML/d

G6

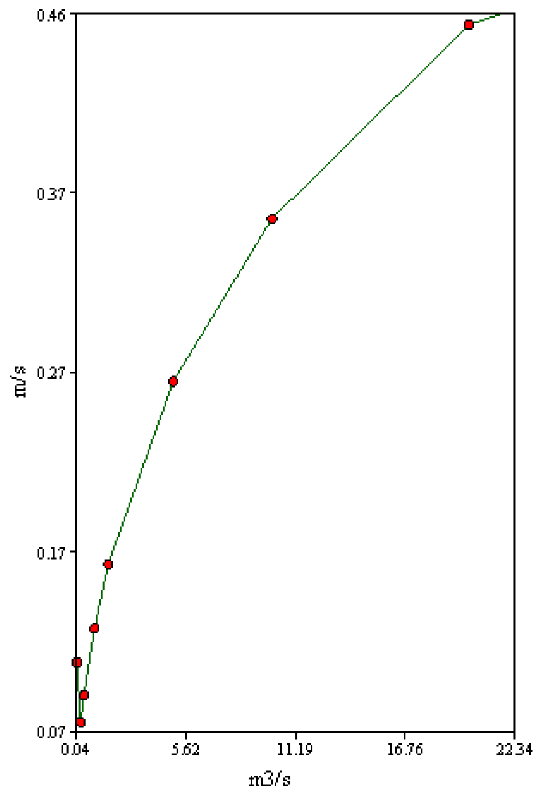


Figure 29: Discharge versus velocity (m/s)

- Pool and riffle cross-sections (excluding most d/s)
- From Figure 29, 0.3m/s ≈ 7.5m^3/s ≈ 650ML/d
- Fresh as not bankfull

FP1-3

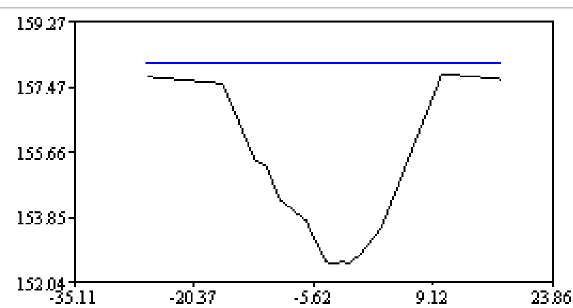


Figure 30: Stage height at overbank flow

- From Figures 28 and 30, 40 cm inundation on floodplain requires 80 m^3/s ≈ 6,900 ML/d

RB2

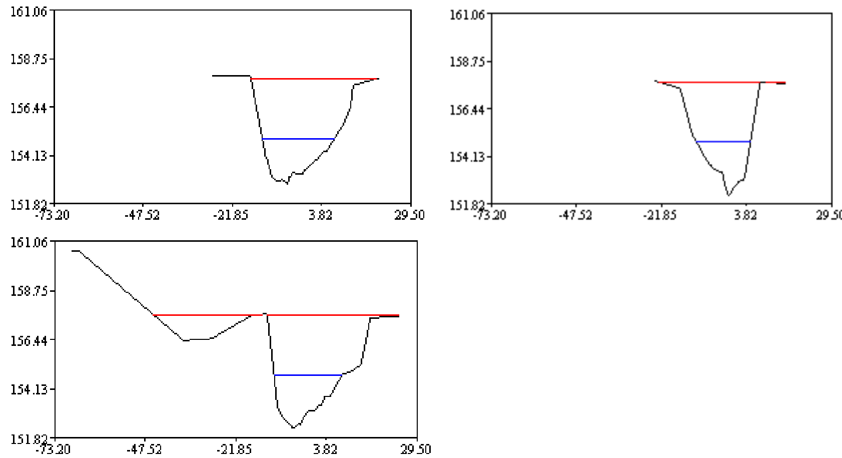


Figure 31: Stage height for bankfull discharge (m AHD)

- From Figures 28 and 31, Bankfull discharge ≈ 60m^3/s ≈ 5,000ML/d

BB2

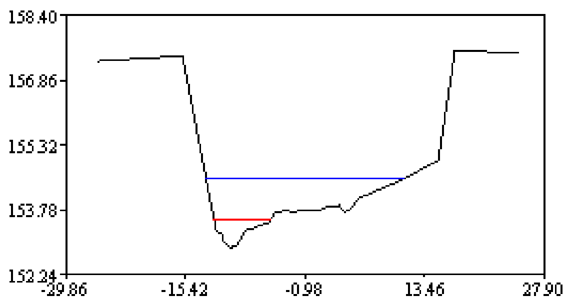


Figure 32: Stage height for low flows

- From Figures 28 and 32m 1m above low flow (10ML/d) ≈ 5 m3/s ≈ 430 ML/d

M6

- From Figures 28 and 32m, 0.3m above low flow ≈1.8 m3/s ≈ 155 ML/d)

NF3

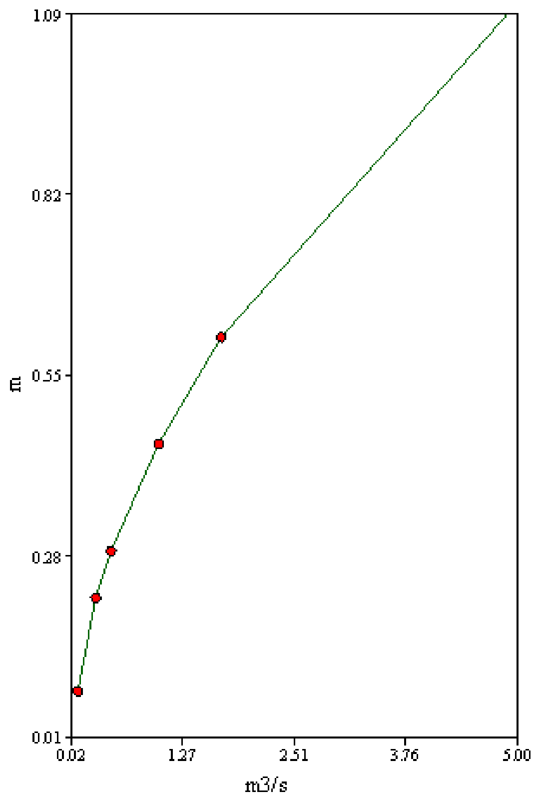


Figure 33: Discharge versus thalweg depth (m)

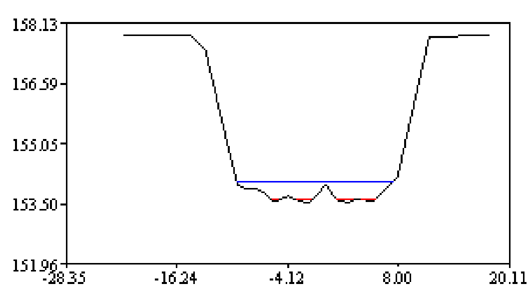


Figure 34: Stage height for low flows (m AHD)

- From Figures 28 and 34, thalweg depth 0.4m ≈ 1.4 m^3/s ≈120ML/d

NF5

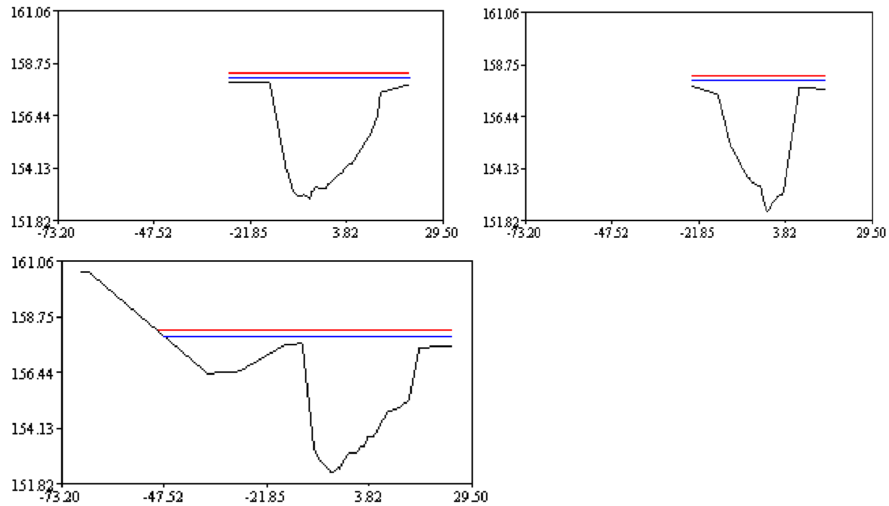


Figure 35: Stage height for overbank discharge (m AHD)

- From Figures 28 and 35, floodplain inundation ≈ 85m^3/s ≈ 7,500ML/d

Justifications for environmental flow recommendations for Reach 4

OBJECTIVE GRAPH AND RATIONALE

W1 Always satisfied (nominal 0.1 m3/s) ≈ 10 ML/d

G1

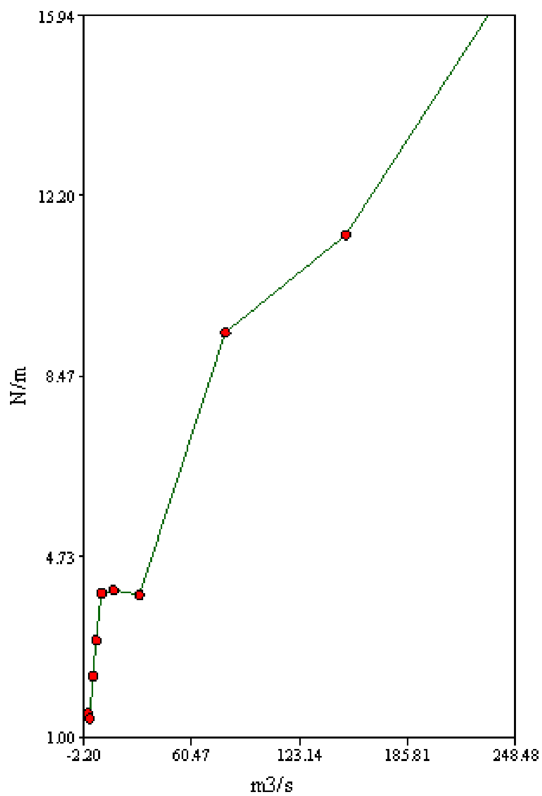


Figure 36: Discharge (m^3/s) versus shear stress (N/m^2)

- Pool and riffle cross-sections (excluding most d/s)
- From Figure 36, 15 N/m^2 ≈ 215m^3/s ≈ 18,500ML/d
- High flow fresh as not bankfull

G2

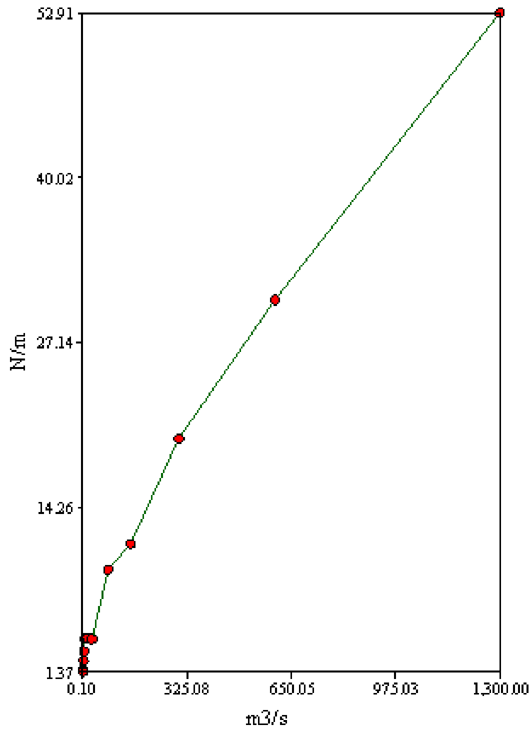


Figure 37: Discharge (m^3/s) versus shear stress (N/m^2)

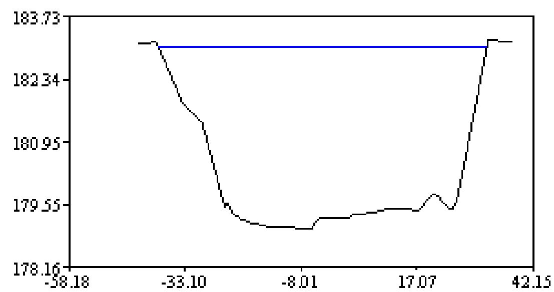


Figure 38: Stage height (m AHD) at bankfull discharge

- Shear criteria of 57 N/m2 not achieved (a result of enlarged channel and which explains the bed homogeneity – lack of diversity)
- Using bankfull as surrogate 300 m3/s ≈ 26,000 ML/d – but this rec is of low confidence and as we discussed in the panel low value (the reach is already pretty stuffed geomorphically)

G4

- No benches identified at representative site
- removed

G6

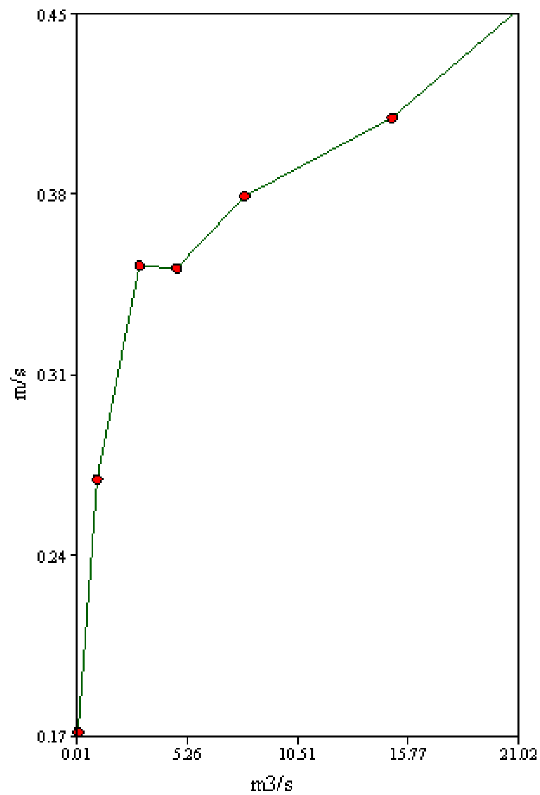


Figure 39: Discharge versus velocity (m/s)

- Pool and riffle cross-sections (excluding most d/s)
- From figure 39, 0.3m/s ≈ 1.75m^3/s ≈ 150ML/d

FP1-3

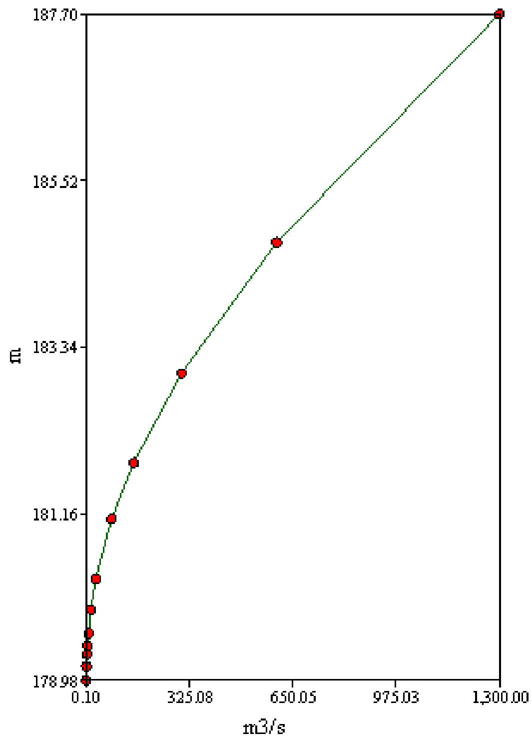


Figure 40: Discharge versus stage height (m AHD)

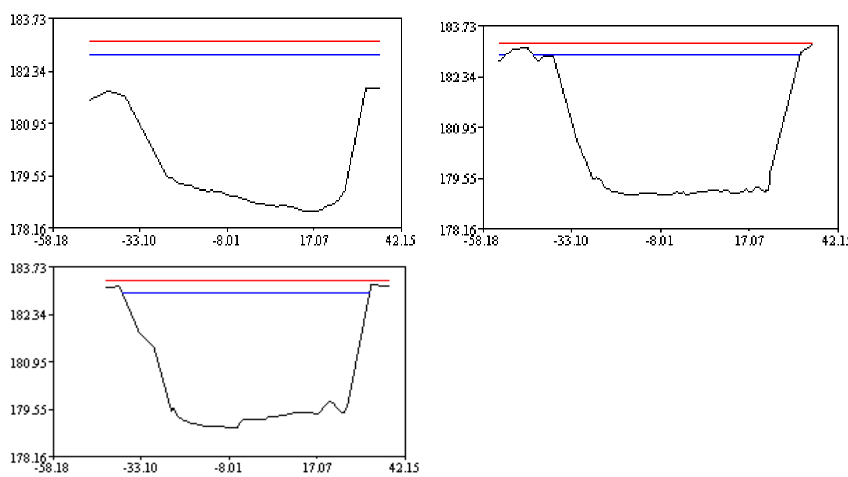


Figure 41: Stage height (m AHD) at bankfull and overbank flows

	• From Figures 40 and 41, overbank ≈ 347m^3/s ≈ 30,000ML/d
RB2	• From Figures 40 and 41, bankfull ≈ 290m^3/s ≈ 25,000ML/d
BB1	• 0.3 m above low flow (10 ML/d) ≈ 2m3/s ≈ 170 ML/d
BB2	• 1 m above low flow (10 ML/d) ≈ 22 m3/s ≈ 1900 ML/d
M6	• Same rationale as previous 0.1 m above low flow ≈ 2 m3/s ≈ 170 ML/d

M6

- 0.3 m above low flow ≈ 1 m3/s ≈ 85 ML/d

NF3

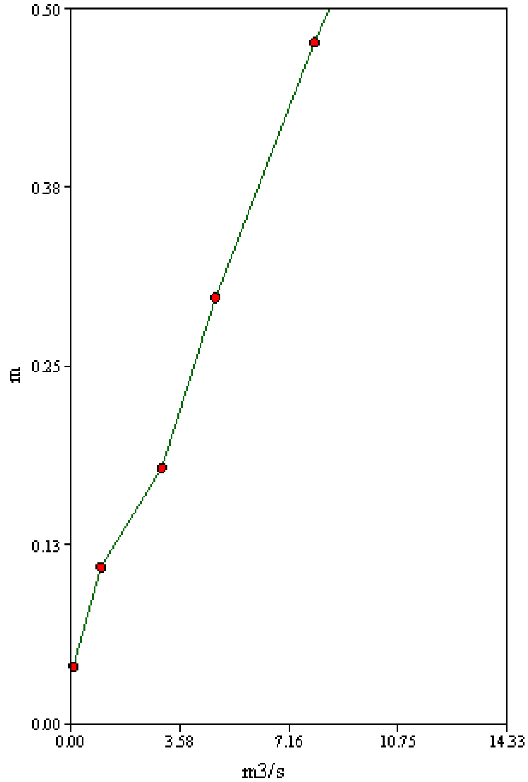


Figure 43: Discharge versus thalweg depth (m)

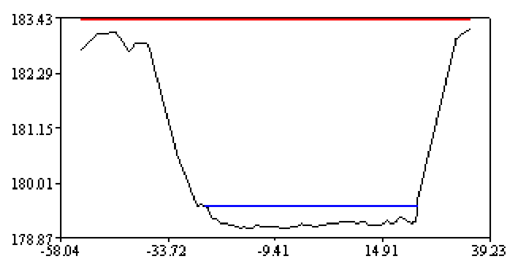


Figure 44: Stage height for low flow (0.4 m)

- Minimum thalweg depth cross-section (453)
- From Figures 43 and 44, thalweg depth 0.4m ≈ 6.5 m^3/s ≈ 560 ML/d

NF5

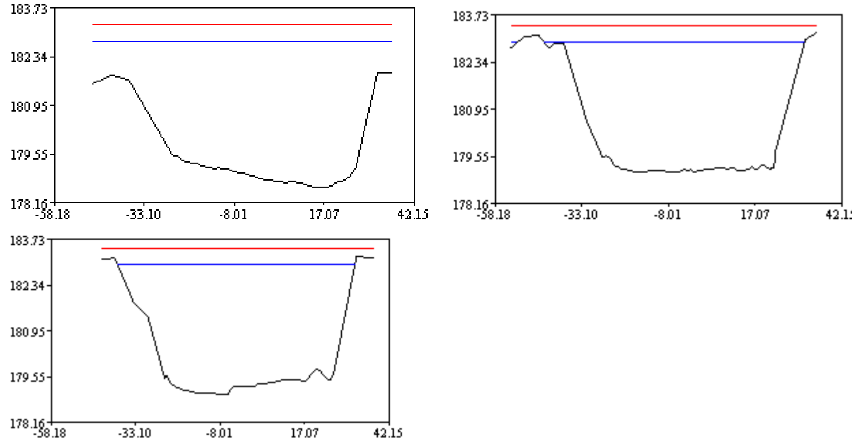


Figure 45: Stage height (m AHD) for bankfull discharge

- From Figures 40 and 45, floodplain inundation ≈ 370m^3/s + ≈ 32,000ML/d +

Justifications for environmental flow recommendations for Reach 5

OBJECTIVE GRAPH AND RATIONALE

G1

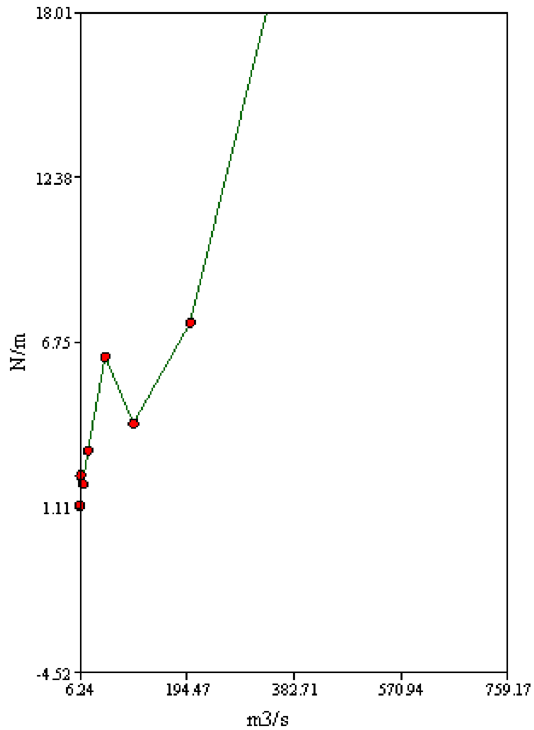


Figure 46: Discharge (m^3/s) versus shear stress (N/m^2)

- Pool and riffle cross-sections (excluding most d/s)
- From figure 46, 1.1 $N/m^2 \approx 6.2 m^3/s \approx$ 540 ML/d

W1

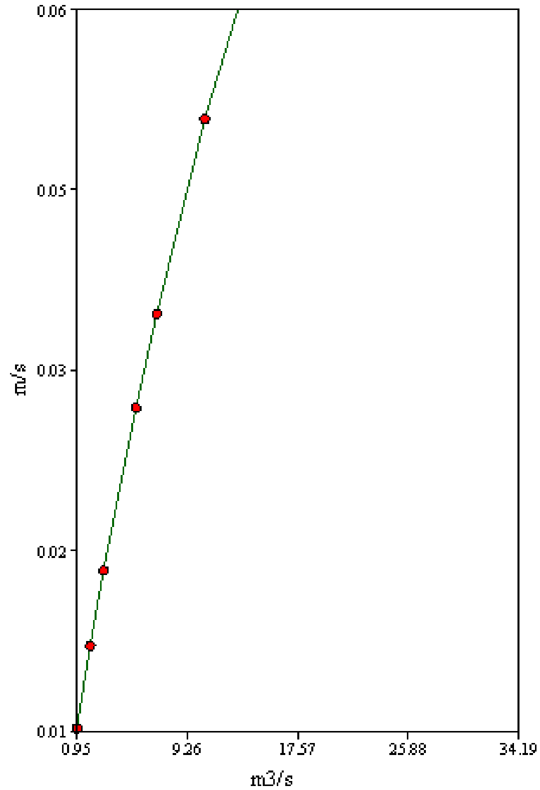


Figure 47: Discharge versus velocity (m/s)

- Pool and riffle cross-sections (excluding most d/s)
- From Figure 47, 0.01 m/s ≈ 1m^3/s ≈ 85ML/d

G2

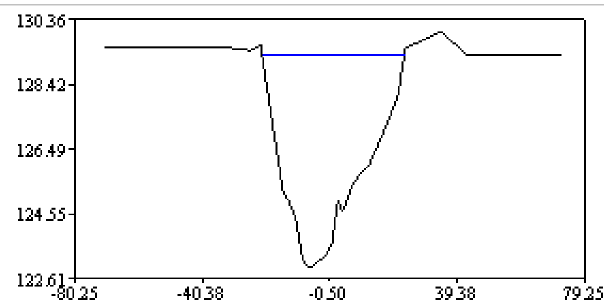


Figure 48: Stage height at bankfull discharge

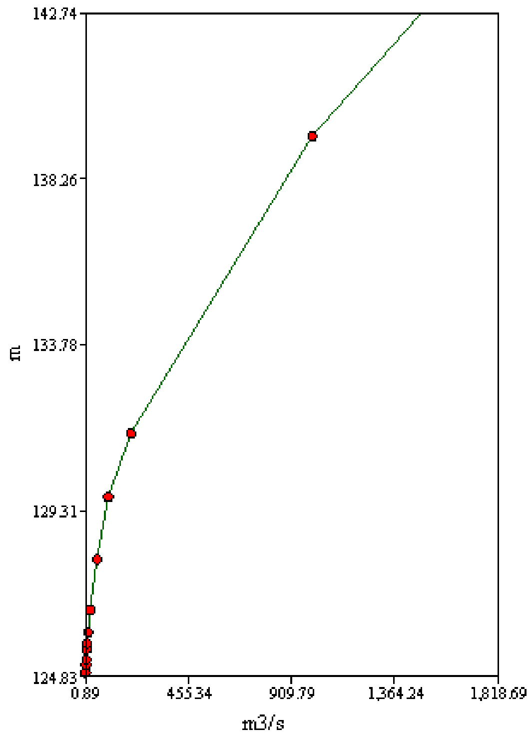


Figure 49: Discharge versus stage height (m AHD)

- From Figures 48 and 49, bankfull ≈ $90m^3/s$, ≈ 7800ML/d

G4

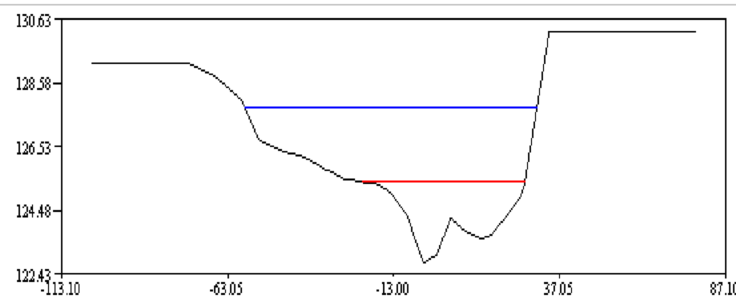


Figure 50: Stage height (m AHD) at 1 m above concave benches

- From Figures 49 and 50, 1m inundation over upper edge of bench $45m^3/s$ ≈ 3,900 ML/d

G6

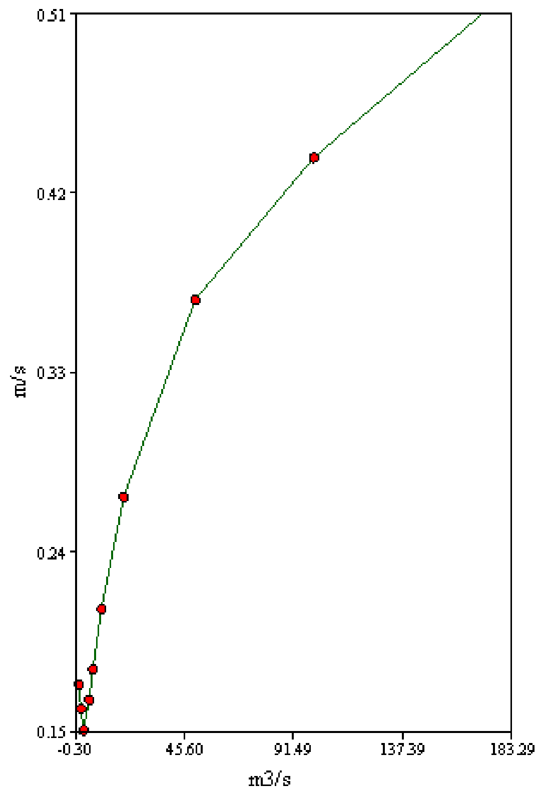


Figure 51: Discharge versus velocity (m/s)

- Pool and riffle cross-sections (excluding most d/s)
- From figure 51, 0.3m/s ≈ 29m^3/s ≈ 2,500ML/d

BB1

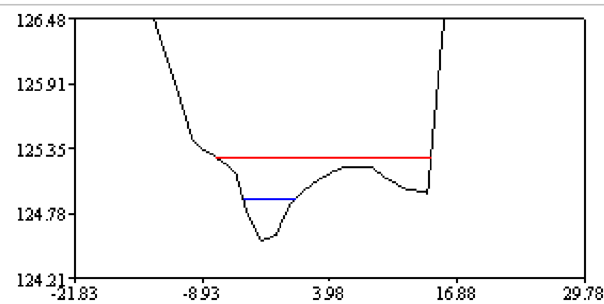


Figure 52: Stage height (m AHD) at low flows

- Based on Figures 49 and 52, 30 cm above base flow of 85 ML/d ≈ 3 m3/s ≈ 260 ML/d

BB2

- Based on Figure 49, 1m above base flow (85 ML/d) ≈ 10.5 m3/s ≈ 900 ML/d

M6

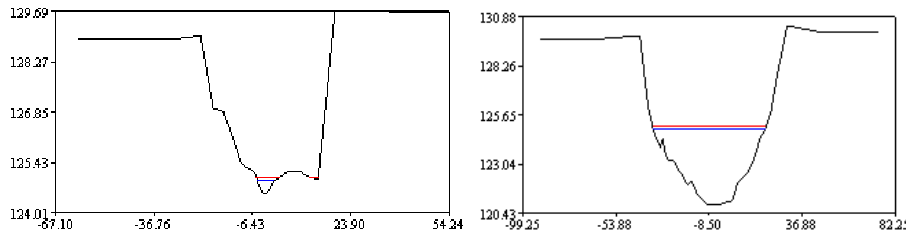


Figure 53: Stage height (m AHD) at low flows

- Based on Figures 49 and 53, flow to increase depth by 10 cm in both pools and riffles ≈ 1.5 m3/s ≈ 130 ML/d

M6

- Same as BB1

NF3

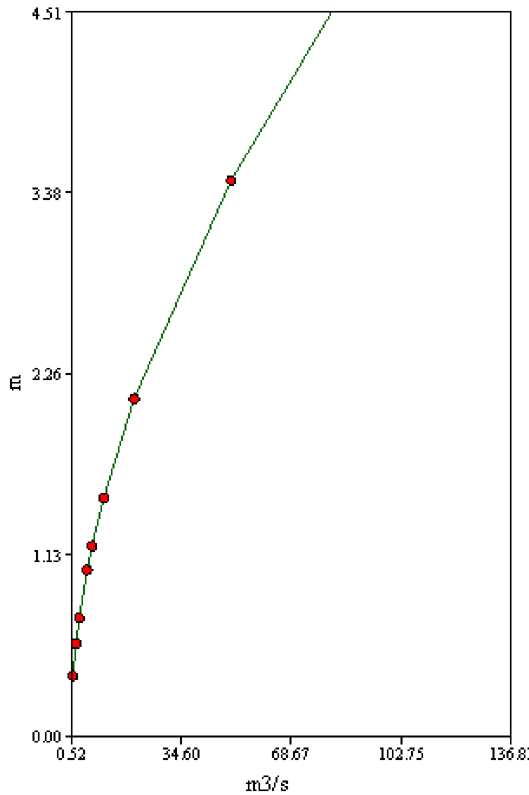


Figure 54: Discharge versus thalweg depth

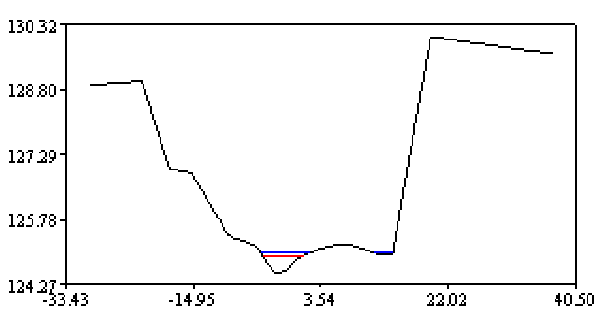


Figure 55: Stage height (m AHD) at low flow

- Based on Figures 54 and 55, minimum thalweg depth of 0.4m ≈ 1.5 m^3/s ≈130ML/d