Pyramid Creek Environmental FLOWS Study

NORTH CENTRAL CMA

Environmental Flow Recommendations Report

0004 | Final

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Pyramid Creek Environmental FLOWS Studies

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Cover Photo: Pyramid Creek at Milnes Bridge

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Executive Summary

Study Overview

Pyramid Creek has been identified by North Central CMA as a priority waterway potentially requiring the development of an environmental water management plan (North Central CMA, 2014a). An environmental flows assessment of Pyramid Creek is required to set an appropriate flow regime that will encourage fish migration and potential spawning as part of the Native Fish Recovery Plan: Gunbower and Lower Loddon (North Central CMA, 2014b).

This project has used the FLOWS method to determine the environmental flow requirements of Pyramid Creek. The FLOWS method is an expert panel format, which incorporates a desktop analysis of known environmental values, field assessments and hydraulic modelling to determine the magnitude, frequency and duration of low flows, freshes / high flows, bankfull and overbank flows that are needed to maintain or improve geomorphological and ecological condition, and water quality in rivers or streams. The FLOWS method is implemented in two stages and has three main outputs:

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

This Environmental Flow Recommendations Report uses the results of a desktop assessment, a field inspection conducted by the Environmental Flows Technical Panel (EFTP), hydraulic models developed for specific FLOWS assessment sites, an analysis of hydrological data and input from the Project Advisory Group (PAG) to recommend environmental flows that are needed to meet the agreed environmental flow objectives for each reach.

FLOWS Reaches and Assessment Sites

For the purposes of this environmental flow assessment, Pyramid Creek has been divided into two reaches (see Table E-1). Hydrologically the creek does not change significantly along its course, however 60 km is too long to be assessed as one FLOWS reach. The section from Box Creek Regulator to Hird Swamp is Reach 1 and the remainder of the length of the creek downstream from Hird Swamp is Reach 2. The confluence with the Loddon River is influenced by water backing up from the Kerang Weir weir pool and is not considered in the FLOWS study.

Table E-1 Selected environmental flow reaches and flow assessment sites in Pyramid Creek.

Environmental flow reach		Flows assessment site
1	Pyramid Creek from Box Creek Regulator to immediately upstream of Hird Swamp	Box Creek upstream of Mansfield Bridge
2	Pyramid Creek from Hird Swamp to confluence with Loddon River	Pyramid Creek downstream of No 23/1 Channel Outfall

Water management goal

The water management goal developed for Pyramid Creek is *'To enhance the value of Pyramid Creek as a conduit for the dispersal of aquatic fauna such as native fish, Platypus and freshwater turtles'*.

Environmental flow objectives

Pyramid Creek is highly modified as a result of dredging for flood control and irrigation. This environmental flow study focuses on maintaining and rehabilitating the value of the creek as a conduit for the dispersal of aquatic fauna such as native fish, Platypus and freshwater turtles.

The highest priority environmental flow objectives for Pyramid Creek include:

1) Maintaining and enhancing native fish movement, colonisation, recruitment, habitat and connectivity.
2) Maintaining and promoting fringing vegetation on the lower banks of the channel.

Maintaining and enhancing channel conditions to facilitate the dispersal of juvenile Platypus and Eastern Long-necked Turtles. The environmental flow objectives described in the *Issues Paper* and used as the basis for the recommendations in this report broadly align with the vision outlined in the 2014-2022 North Central Waterway Strategy (North Central CMA, 2014a).

Environmental flow recommendations

Separate flow recommendations have been developed for wet/average and dry years. The purpose of these separate recommendations is to provide conditions that will enable native fish, Platypus and turtle populations to thrive in wet years, in order to increase their resilience to lower flows in dry years.

The environmental flow recommendations for Pyramid Creek and the specific objectives they are intended to meet are summarised in Table E2.

Table E2: Environmental flow recommendations for Pyramid Creek.

Waterway	**Pyramid Creek**		**Regime**	**Flow recommendations**			
Season	**Flow**	**Objective**	**Wet/Average/Dry**	**Magnitude**	**Frequency and timing**	**Duration**	**Rise/Fall**
Summer / Autumn (Dec–May)	Low flow	Operate fishways, maintain connectivity and habitat for fish, Platypus and turtles Maintain and promote fringing vegetation along lower banks	All years	200 ML/day	Whole season		
	High flow	Trigger and facilitate fish movement	Wet / Average	900 ML/day	1 event in March	10 days	5/14 days
			Dry	900 ML/day	Not every year, but no more than two consecutive years without[1]	10 days	5/14 days
Winter / Spring (Jun-Nov)	Low flow	Operate fishways, maintain connectivity and habitat for fish, Platypus and turtles Maintain and promote fringing vegetation along lower banks	Wet / Average	200 ML/day	Whole season		
			Dry	90 ML/day	90 ML/Day mid June to end August (minimum)		
	High flow	Trigger and facilitate fish movement	Wet / Average	900 ML/day	1 event in September	10 days	5/14 days
			Dry	900 ML/day	Not every year, but no more than two consecutive years without[1]	10 days	5/14 days

[1]Note: High flow events not needed every year in dry years but no more than 2 years in a row without at least one event. More work needed to determine which event (i.e. Autumn/Spring) is most critical.

Current achievement of environmental flow recommendations

Low flow and high flow recommendations for Pyramid Creek are overall met well. There is at least one flow event in both March and September that exceeds the flow recommendation of 900 ML/day for 10 days duration, 98% of the time. The Summer/Autumn low flow is mostly compliant, being met 92% of the time. The Winter/Spring low flow is the least compliant flow recommendation, being met only 72% of the time when a low flow of 200 ML/day is applied, and 76% of the time when a low flow of 90 ML/day is applied.

Lower compliance of low flows could limit the movement of fish through the Box Creek and Kerang Weir fishways. It should be noted that the rate of rise/lowering of water levels is not factored into the analysis of the current achievement of flow recommendations. Rapid fluctuations in water levels are an issue along Pyramid Creek, with flows dropping >500 ML/day. These fluctuations potentially disrupt fish movement and may accentuate bank erosion along Pyramid Creek. It is recommended that the rate of fall is capped at ~100 ML/day which equates to 7-17 cm/day drop in level depending on the starting height.

The main objective for Pyramid Creek is to ensure that the flow regime is suitable to encourage native fish to move into the downstream end of Pyramid Creek from the Loddon River, to travel upstream to the Box Creek Regulator and that effective fish passage through the new fishway is provided during the times when fish are actively moving up the creek. The current level of compliance with flow recommendations is generally good, but it is critical that high flows events achieve the recommended duration to give fish sufficient time to traverse the system, that rates of rise and fall are managed to avoid triggering fish to halt any upstream movement and return downstream, and that minimum flows through the Box Creek regulator are maintained so that effective fish passage is provided. If these recommendations cannot be achieved then, the overall objective to create uninterrupted movement opportunities for fish between the Murray River, Loddon River, Pyramid Creek and Gunbower Creek will not be realised.

Management and monitoring recommendations

Changes to the existing flow regime are unlikely to significantly improve the ecological condition of Pyramid Creek unless they are accompanied by other management actions. Recommended management actions include:

- Activities that will lead to a greater level of protection of the stream-side zone, such as the installation of fencing, provision of off-stream watering points, revegetation and community engagement activities that increase landowner skills and awareness in riparian management practices.
- Habitat improvement works for aquatic biota, in particular the reintroduction of large wood structures to provide more variable hydraulic habitats and improve geomorphological processes along the creek.
- Educational and enforcement campaigns to eliminate use of illegal fish nets and yabby traps.
- Fox control programs to reduce predation risk on adult and juvenile Platypus and turtles.
- Fitting irrigation pumps with devices to exclude Platypus and turtles when pumps are operated.

This FLOWS study has made use of the most up to date information that was available at the time of the assessment, but information gaps remain. Further monitoring is recommended to fill these knowledge gaps and flow recommendations should then be revised and updated accordingly. Monitoring recommendations include:

- Fish movement and habitat studies to develop a greater understanding of the movement of fish into Pyramid Creek through fishways and along Pyramid Creek. A broad program of monitoring is recommended to investigate the movement of fish between the Murray River, Loddon River, Kow Swamp and Gunbower Creek.
- Aquatic fauna and habitat surveys are recommended to monitor populations of native fish, Platypus and turtles in Pyramid Creek. Specific surveys are also recommended within the vicinity of areas where large wood structures are being reintroduced and habitat improvement works are being completed to assess the effectiveness of these works.
- Further monitoring of the impact that different rates of rise/lowering of water levels have on fish behaviour and bank stability.

Development of an Environmental Watering Management Plan

In reference to Schedule 8 of the Basin Plan[1], Pyramid Creek is identified as an environmental asset that requires environmental watering for the following reasons:

- It provides pathways for the dispersal, migration and movements of native water-dependant biota such as native fish, Platypus and turtles [Criterion 3(ii)].
- It supports a number of listed threatened species including EPBC listed Murray Cod and FFG listed Silver Perch and Murray-Darling Rainbow fish [Criterion 4(a)].

We consider that Pyramid Creek meets the criteria established in Schedule 8 of the Basin Plan and we recommend that an Environmental Watering Management Plan is developed.

[1] See Appendix A for definitions (Schedule 8 of the Basin Plan)

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to describe the ecological values and current condition of FLOWS reaches and specific environmental flow objectives that the environmental flow recommendations will aim to meet in accordance with the scope of services set out in the contract between Jacobs and the North Central CMA. That scope of services, as described in this report, was developed with North Central CMA.

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

Jacobs derived the data in this report from information sourced from North Central CMA, the Project Steering Committee, Project Advisory Group and from field assessments on the 30th April 2014 as well as the 21st and 23rd May 2014. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report.

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

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context.

This report has been prepared on behalf of, and for the exclusive use of, North Central CMA, and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and North Central CMA. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

1. Introduction

1.1 Rationale for FLOWS study

The Department of Environment and Primary Industries (DEPI) has received funding through the Commonwealth Government's National Partnership Agreement (NPA) and the Intergovernmental Agreement (IGA) on Implementing the Water Reform in the Murray Darling Basin to develop a long-term watering plan as outlined in Chapter 8 of the Basin Plan by December 2015. To support the development of the long-term watering plans, DEPI is coordinating the 'Victorian Basin Plan Environmental Water Management Plan (EWMP) Program' (North Central CMA, 2014c).

In Victoria, EWMPs are required for all sites that receive environmental water and are a critical component of the State-wide Seasonal Watering Plan that is developed annually by the Victorian Environmental Water Holder (VEWH). The North Central CMA is contributing to the Victorian Basin Plan Environmental Water Management Plan (EWMP) Program in its region through preparing EWMP for sites:

- That do not already have an EWMP and currently receive environmental water, or will receive environmental water in the next two years; or
- Where high value environmental value(s) have been recorded at the site[2] and have the potential to receive environmental water.

Pyramid Creek would have naturally supported a diverse native fish community and provided a corridor for fish to move between the Murray River, Loddon River, Kow Swamp and Gunbower Creek (see Figure 1-1). Dredging to improve the hydraulic efficiency and capacity of Pyramid Creek has reduced the diversity of fish habitat and therefore reduced the likelihood that Pyramid Creek will support large resident populations of native fish. Nevertheless, many native fish, including EPBC listed Murray Cod and FFG listed Silver Perch and Murray-Darling Rainbowfish (North Central CMA, 2014c), move into Pyramid Creek from the Loddon River. When fish passage is provided at Box Creek Regulator and Taylor's Creek, fish will be able to move between the Loddon River and the Gunbower Creek system (including the Ramsar listed forest) (Mallen-Cooper et al., 2013; O'Connor et al., 2013). Juvenile Platypus are also likely to use the creek as a conduit for dispersal between the Gunbower Creek system and Loddon River.

Anecdotally fish are known to congregate at the bottom of the Box Creek regulator. A study was undertaken by the North Central CMA to confirm this. Twenty golden perch were acoustically tagged in the lower Loddon River in Spring/Summer 2011/12. The movements of these fish were monitored through a network of nine loggers distributed from the Loddon and Murray rivers junction through to the Box Creek Regulator. Four of 20 tagged golden perch were found to travel as far upstream as Box Creek Regulator in response to a flow event in March 2012, affirming that this structure acts as barrier to fish movement (O'Connor et al., 2013). This regulator is currently being upgraded and its design includes upstream and downstream fish passage (SKM, 2012a).

An environmental flow study is required to set an appropriate flow regime that will encourage fish migration and potential spawning as part of the Native Fish Recovery Plan: Gunbower and Lower Loddon (North Central CMA, 2014b). This project uses the FLOWS method to determine the environmental flow requirements for Pyramid Creek. If the waterway is deemed to meet the criteria established in Schedule 8 of the Basin Plan then the FLOWS study will be an input to the development of an EWMP.

1.2 Overview of the FLOWS method

The FLOWS method was initially developed in 2002 and has been improved as a result of feedback from various groups that have applied it. DEPI (2013a) formally incorporated many of those improvements in the FLOWS method Revision 2.

[2] See Appendix A for definitions (Schedule 8 of the Basin Plan)

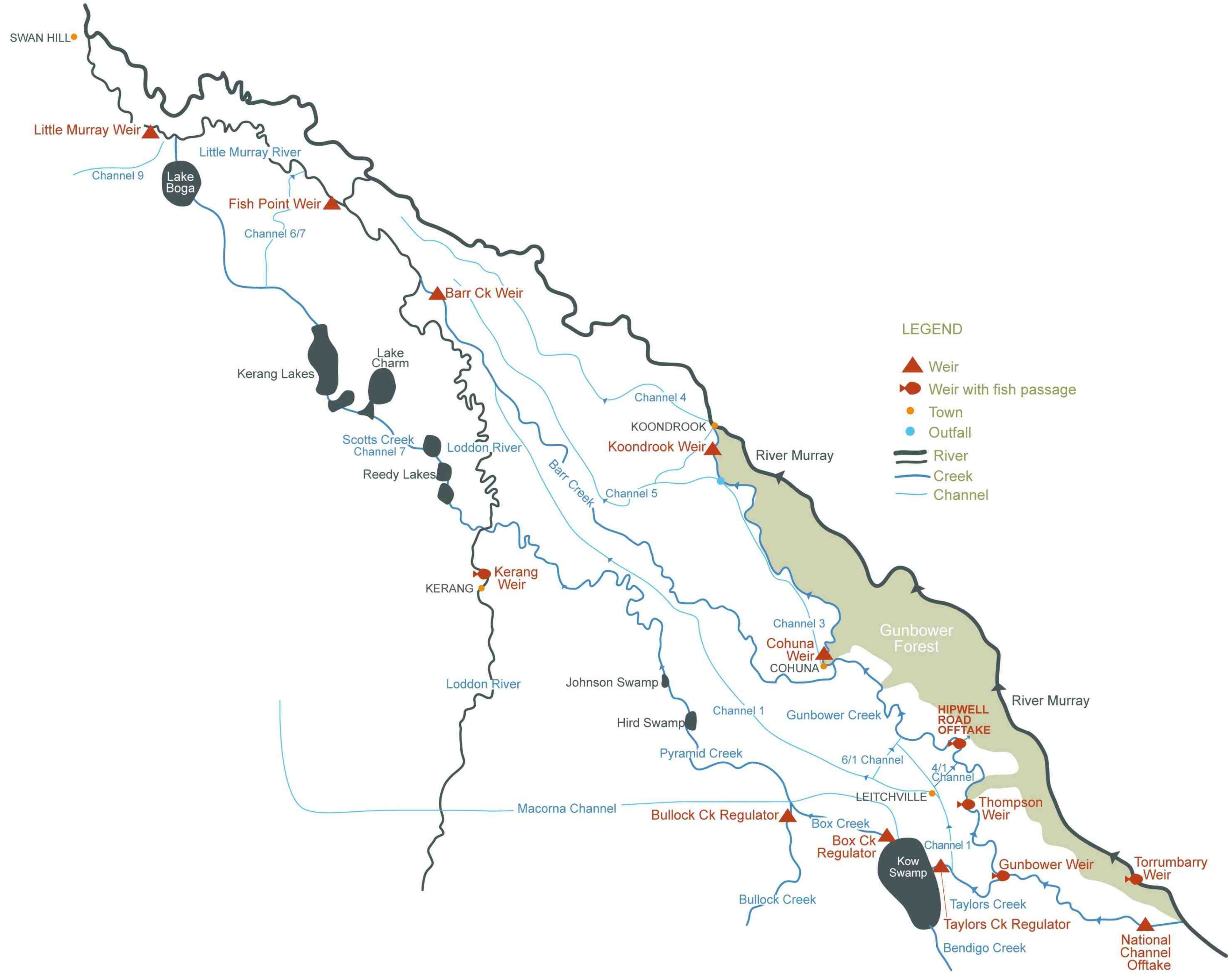

Figure 1-1 Map showing channels that provide a corridor for fish movement between the Murray River, Loddon River, Kow Swamp and Gunbower Creek (Source: North Central CMA).

The FLOWS method is implemented in two stages (Figure 1-2).

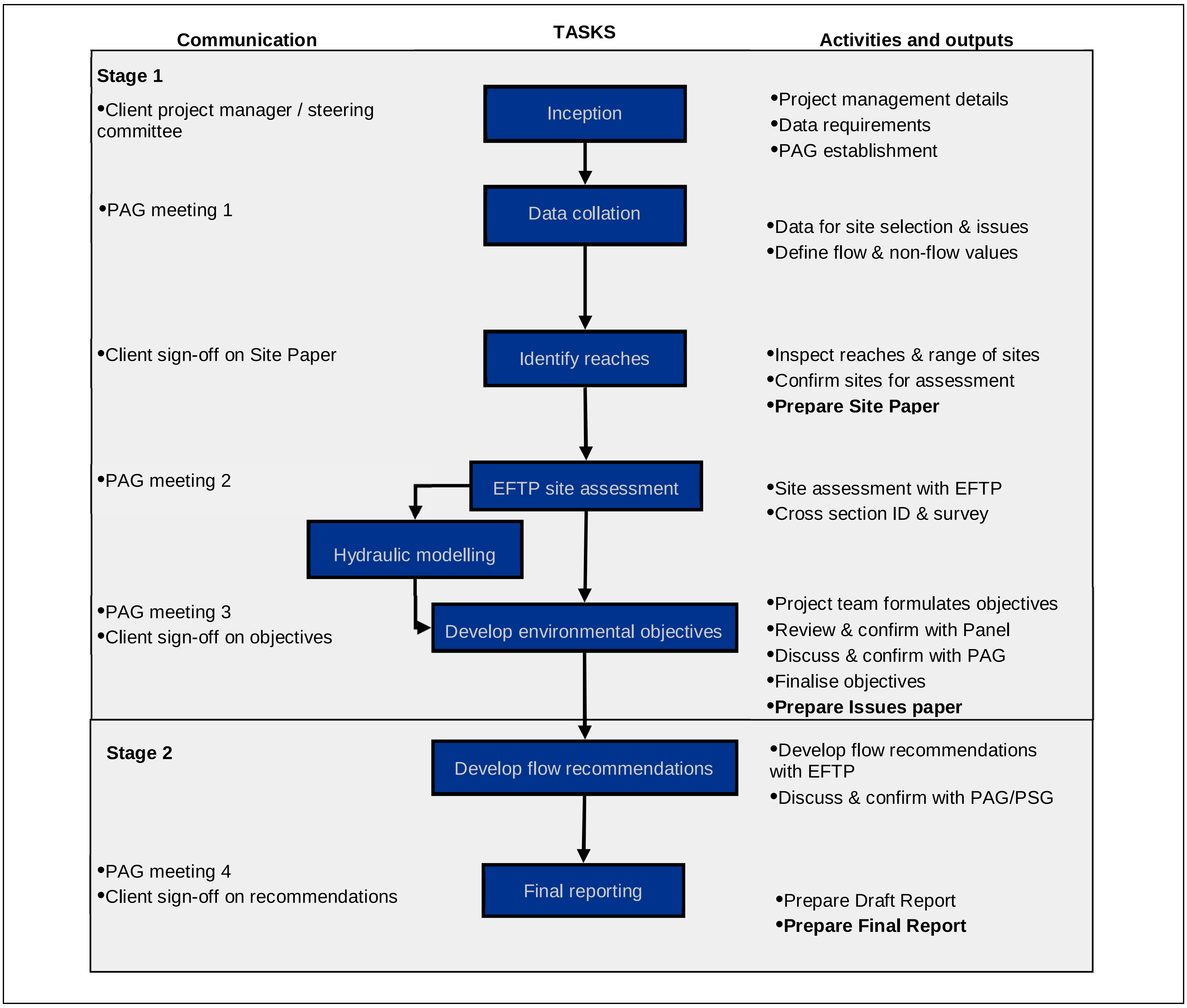

Figure 1-2 Outline of the tasks, activities and communications involved in the FLOWS method. (Note the following abbreviations: EFTP – Environmental Flows Technical Panel, PAG – Project Advisory Group, PSG – Project Steering Group).

Stage 1 describes the current condition of the system and the main flow dependent values and environmental issues within the catchment. After the project inception and an initial meeting with the Project Advisory Group (PAG), selected members of the Environmental Flows Technical Panel (EFTP) tour the catchment and conduct a preliminary review of background information to divide the catchment into reaches and to select sites within each reach where detailed assessments will be undertaken. The EFTP use observations made during the detailed site assessments and a detailed review of available literature to describe the main flow related issues for the catchment and to develop a set of environmental objectives to manage water dependent values in each reach. Qualified surveyors complete a feature survey of each FLOWS assessment site and the project hydrologist builds a hydraulic model to quantify the relationship between flow and inundation levels at each site. Two important outputs from Stage 1 are:

1) A Site Paper, which describes the reaches and sites selected for further assessment and the justification of that selection
2) An Issue paper, which outlines the expected flow requirements and ecological responses to particular flow components.

Stage 2 uses the results of detailed channel surveys and hydraulic models (mostly using HEC-RAS) to derive flow recommendations that aim to meet the flow requirements of the water dependent assets and values identified in Stage 1.

The main output from Stage 2 is a Flow Recommendations Report, which specifies the environmental flows that are required to meet the environmental flow objectives for each reach and describes any complementary management actions that may be required.

1.3 Environmental flows technical panel

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

- Dr Simon Treadwell (Jacobs) – Water quality, ecosystem processes, habitat (EFTP Chair)
- Dr Andrew Sharpe (Jacobs) – Aquatic ecology, macroinvertebrate ecology, flow monitoring
- Dr Peter Sandercock (Jacobs) – Geomorphology, physical processes, habitat
- Professor Paul Boon (Dodo Environmental) – Instream, riparian, floodplain and wetland vegetation
- Justin O'Connor (Arthur Rylah Institute) – Fish, aquatic habitat
- Katie Howard (Arthur Rylah Institute) – Turtles and frogs
- Dr Melody Serena (Australian Platypus Conservancy) – Platypus
- Dr Stuart Cooney (Ecolink) – Waterbirds
- Dr Jon Fawcett (Jacobs) – Groundwater/surface water interactions and groundwater dependant ecosystems (GDEs), acid sulphate soils
- Amanda Woodman (Jacobs) – Hydrology and hydraulic modelling
- Simon Lang (Jacobs) – Hydrology and hydraulic modelling

1.4 Project Advisory Group

A Project Advisory Group (PAG) was established to provide a forum in which Pyramid Creek's key stakeholders can provide technical input into the study by:

- helping to locate reference materials;
- providing local knowledge;
- providing technical support;
- providing local opinions about values and threats to the river and its users;
- ensuring that all important details are considered by the scientific panel developing the objectives and recommendations;
- providing an "on-ground" sanity check of the recommendations and data developed by the study;
- assisting with selection of reference sites and reaches; and
- assisting with development of flow objectives.

The following statement has been prepared by members of the PAG to highlight the value of Pyramid Creek to the local community and the PAG's endorsement of this environmental flows study:

"In its current state the Pyramid Creek is highly valued by local community for its role delivering irrigation water in the Torrumbarry Irrigation District. Before the creek was dredged 1960s, the local community also valued the creek for its environmental values such as native fish. It is recognised by the community that the dredging of the creek significantly impacted native flora and fauna, but that this action cannot be reversed. The PAG as representatives of the local community, see this comprehensive study as a way of investigating and quantifying how environmental benefits for native fish can be achieved, without reducing the value of Pyramid Creek as an

irrigation water carrier, making every drop count twice (Chairperson – Dianne Bowles, Pyramid and Serpentine Creek Project Advisory Group)."

1.5 Purpose of this report

This Environmental Flow Recommendations Report is the third output for the project. It re-states the water management goal and environmental flow objectives for Pyramid Creek and describes the specific flow components (including their magnitude, frequency, timing and duration) that are required to meet those environmental objectives.

The main inputs to this report include:

- The Site Paper (Jacobs, 2014b), which briefly describes each catchment and provides a rationale for dividing Pyramid Creek into specific reaches for the purpose of determining appropriate environmental flow recommendations;
- The Issues Paper (Jacobs, 2014a), which describes the condition and distribution of environmental values and the specific environmental flow objectives for each reach;
- Field observations made by the EFTP during the site assessments which were conducted on the 21st and 23rd May 2014;
- Hydraulic models that were developed as part of the project to determine the flow magnitude required to inundate particular habitat features within each reach;
- Hydrological analyses that were used to estimate the timing, frequency and duration of specific flow events and current levels of licenced water extraction;
- Discussions with river managers, scientists and community members who have relevant experience in Pyramid Creek; and
- Information and feedback provided by the Project Advisory Group.

1.6 Report structure

Following this introduction:

- Section 2 provides a general description of Pyramid Creek, the breakdown into FLOWS reaches and assessment sites, the water management goal and environmental flow objectives;
- Section 3 describes the flow recommendations that have been developed for Pyramid Creek;
- Section 4 recommends complementary management actions that need to be implemented along with the recommended flow regime to help meet the agreed environmental flow objectives;
- Section 5 outlines monitoring recommendations to improve our understanding of linkages between environmental flows and ecological response; and
- Section 6 documents our recommendation that an Environmental Watering Management Plan is developed for Pyramid Creek.

Additional supporting information is provided as appendices to this report:

- Appendix A outlines Schedule 8 of the Basin Plan;
- Appendix B describes the specific approach that has been used to determine environmental flow requirements for Pyramid Creek;
- Appendix C summarises the overall flow related issues and objectives for Pyramid Creek; and
- Appendix D documents the development of hydraulic models for Pyramid Creek.

2. Pyramid Creek

2.1 Catchment description

Pyramid Creek (including Box Creek) flows for 60 km in a north westerly direction from Kow Swamp to the Loddon River north of Kerang. Major tributaries include Bullock and Calivil Creeks and water can be diverted through Kow Swamp from National Channel/ via Taylor Creek (Figure 2-1). Pyramid Creek also carries water from Bendigo Creek and Mt Hope Creek, both of which flow into Kow Swamp upstream of Box Creek.

Before the introduction of flood control works, the floodplain and associated wetlands would have been regularly inundated by floods in the Loddon River and Murray River and other tributaries such as Bendigo Creek and Bullock Creek (Macumber 1969). The hydrology of Pyramid Creek and adjacent alluvial plains has been altered with the advent of flood control works, irrigation and drainage works. Regular irrigation during summer months commenced in 1884. This raised groundwater levels and caused salinity problems in the early 1930's. Dredging of the channel in the 1960s intercepted the underlying water table, which caused highly saline groundwater to discharge into the creek. The Pyramid Creek Salt Interception Scheme Drainage works between 2003 and 2009 have helped to stabilise groundwater levels and reduce salt contamination (SKM, 2010b).

The Box Creek section, which extends from the outlet of Kow Swamp to the confluence of Bullock Creek has a trapezoidal channel form with steep actively eroding banks. Further downstream at Mansfields Bridge, there is a notable change in the character of the channel banks. The channel is less incised within the surrounding plains and fencing to exclude stock has allowed more vegetation to grow on the top and walls of the banks. Narrow bench features are present at the channel margins and these have been colonised by vegetation (see Figure 2-2).

Box Creek changes its name to Pyramid Creek downstream from the confluence with Bullock Creek, and the combined stream then passes under the Macorna Channel at Flannery's Flume. Lignum and sedges are established along the edges of the channel with Black Box on the floodplain of this section of Pyramid Creek from Bullock Creek through to Rowlands Reserve. Pyramid Creek continues to flow north across flat open grazing farmland and through Hird and Johnson Swamp, located each side of the Kerang Leitchville Road. The section of creek between Hird and Johnson Swamp has been completely fenced (J. Spence, pers. comm.). Dredging and lowering of the channel bed has disconnected Pyramid Creek from both swamps, which are now watered directly from other irrigation channels.

The section of Pyramid Creek from Hirds Swamp to the confluence with the Loddon River has a homogeneous channel form with steep banks. The amount of vegetation cover on the banks through this section is strongly related to local land management. Areas that have unrestricted stock access have little vegetation cover and areas where stock has been excluded have quite dense fringing vegetation including *Phragmites* and Lignum.

2.2 FLOWS Reaches and Assessment sites

For the purposes of this environmental flow assessment, Pyramid Creek has been divided into two reaches (see Table 2-1 and Figure 2-1). Hydrologically the creek does not change significantly along its course, however 60 km is too long to be assessed as one FLOWS reach. The section from Box Creek Regulator to Hird Swamp is Reach 1 and the remainder of the length of the creek downstream from Hird Swamp is Reach 2. The confluence with the Loddon River is influenced by water backing up from the Kerang Weir weir pool and is not considered in the FLOWS study.

Table 2-1 Selected environmental flow reaches and flow assessment sites in Pyramid Creek.

Environmental flow reach		Flows assessment site
1	Pyramid Creek from Box Creek Regulator to immediately upstream of Hird Swamp	Box Creek upstream of Mansfield Bridge
2	Pyramid Creek from Hird Swamp to confluence with Loddon River	Pyramid Creek downstream of No 23/1 Channel Outfall

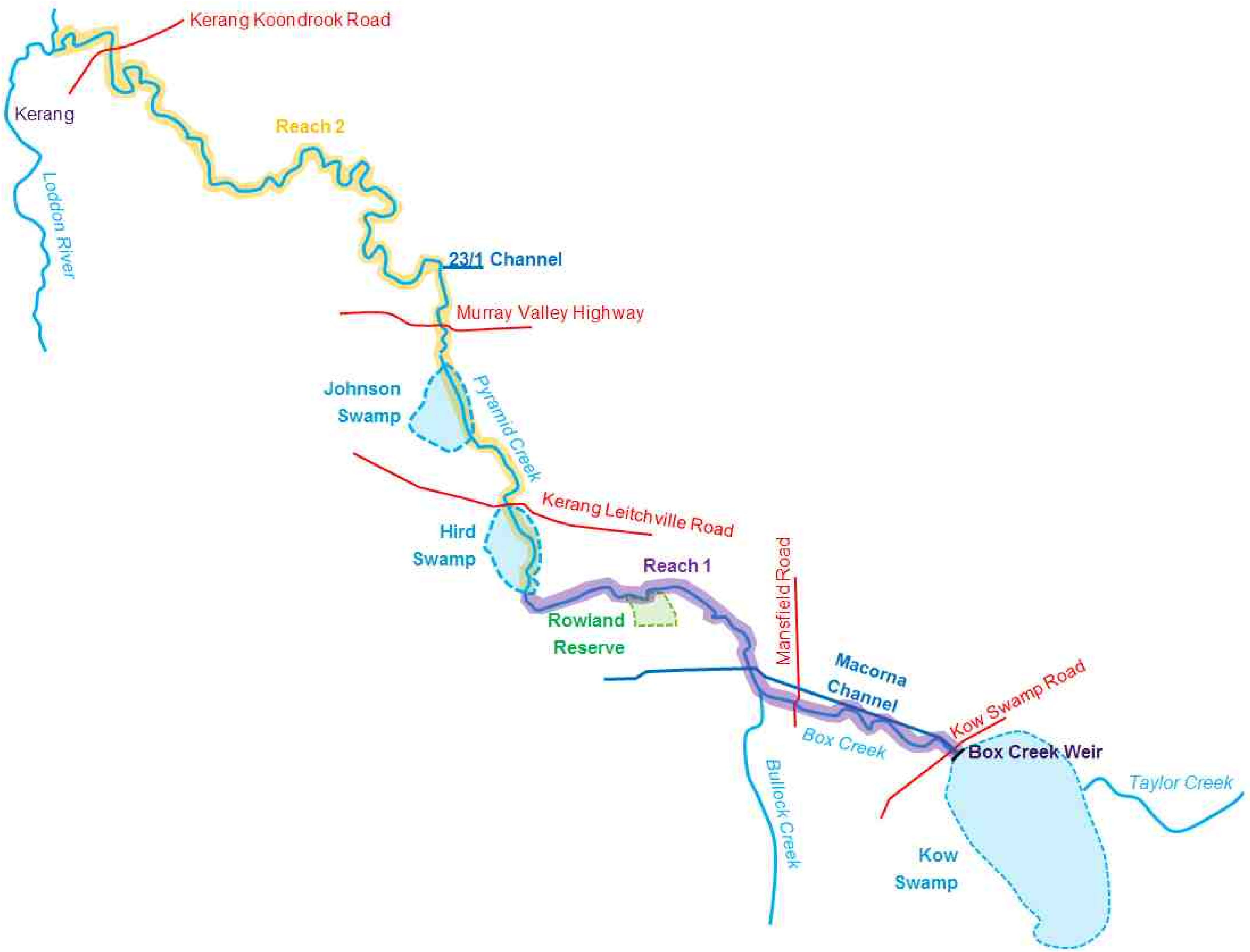

Figure 2-1 Schematic of Pyramid Creek showing layout of stream network, wetlands, irrigation and flow delivery structures and roads. The extent of the FLOWS Reaches is also shown.

Two FLOWS assessment sites were selected for Pyramid Creek. The first assessment site is located at the Mansfield Bridge flow gauge (Figure 2-2). This site was selected as there is an existing flow gauge at this location and it is representative of the channel conditions in the reach from Box Creek Weir to immediately upstream of Hird Swamp. The second assessment site is immediately downstream from No 23/1 Channel Outfall (Figure 2-3). This site was selected as the creek is accessible for survey and assessment and is representative of the reach. Bench features are present at the channel margins and there is a mixture of vegetation (Phragmites and Lignum), with Black Box located on the floodplain (Figure 2-3). Although two sites were selected for assessment, only a single set of flow recommendations have been developed that are applicable at both sites.

	
Looking upstream at homogenous channel form with steep banks and narrow benches.	Eroding bank. Material from the upper bank fails and is deposited on the lower bank/bench.

Figure 2-2 Selected photographs of Reach 1 FLOW assessment site – Box Creek upstream of Mansfield Bridge.

	
Looking upstream at channel with Lignum established on narrow benches and Black Box on the floodplain.	Phragmites established at the margins of the channel.

Figure 2-3 Selected photographs of Reach 2 FLOW assessment site – Pyramid Creek downstream of No 23/1 Channel Outfall.

2.3 Water management goal and environmental flow objectives

Pyramid Creek is valued for its significant fauna, in particular native fish. The creek would have naturally supported high environmental values. Its current condition is degraded but North Central CMA would like to rehabilitate the creek because of its value in providing connectivity between the Loddon River and Gunbower Creek. The long term goal is for there to be passage for fish into and along the Pyramid Creek between Kow Swamp and the Loddon River and that habitat conditions along Pyramid Creek are improved. The creek is also identified as a potential dispersal route for Platypus and Turtles.

A water management goal has been developed to reflect the values identified in Pyramid Creek. The water management goal developed for Pyramid Creek is ***'To enhance the value of Pyramid Creek as a conduit for the dispersal of aquatic fauna such as native fish, Platypus and freshwater turtles'.***

Low flows will be important in providing an adequate flow for movement of fish, Platypus and freshwater turtles into and along the creek, providing access to habitat at the channel margins, maintaining fringing vegetation and water quality conditions. Freshes and higher flows will encourage large bodied native fish to move upstream and enhance the recruitment of Murray Cod in the Kerang Weirpool. These flows will also assist in the maintenance of fringing vegetation and water quality conditions.

The environmental flow objectives developed for Pyramid Creek are documented in Table C-1 in Appendix C. The highest priority environmental flow objectives include:

1) Maintaining and enhancing native fish movement, colonisation, recruitment, habitat and connectivity;
2) Maintaining and promoting fringing vegetation on the lower banks of the channel; and
3) Maintaining and enhancing channel conditions to facilitate the dispersal of juvenile Platypus and Eastern Long-necked Turtles.

3. Flow recommendations and rationale

3.1 Summary of flow recommendations

The environmental flow recommendations for Pyramid Creek and the specific objectives they aim to meet are summarised in Table 3-1. Although Pyramid Creek is divided into two FLOWS reaches, a single set of flow recommendations has been developed that are applicable to both reaches as the objectives and recommended flows for the two reaches are the same for each reach. The flow recommendations developed are for the entire length of Pyramid Creek, from Box Creek Regulator to the confluence with the Loddon River.

Figure 3-1 presents the recommended flows that may be delivered for a typical wet/average or dry year with average daily flows for the year 2012 also shown to highlight differences from recommended environmental flows. Figure 3-2 highlights how flows in the year 2012 may be manipulated to achieve environmental flow recommendations.

Table 3-1 Summary of environmental flow recommendations for Pyramid Creek.

Waterway	**Pyramid Creek**		**Regime**	**Flow recommendations**			
Season	**Flow**	**Objective**	**Wet/Average/Dry**	**Magnitude**	**Frequency and timing**	**Duration**	**Rise/Fall**
Summer / Autumn (Dec–May)	Low flow	Operate fishways, maintain connectivity and habitat for fish, Platypus and turtles Maintain and promote fringing vegetation along lower banks	All years	200 ML/day	Whole season		
	High flow	Trigger and facilitate fish movement	Wet / Average	900 ML/day	1 event in March	10 days	5/14 days
			Dry	900 ML/day	Not every year, but no more than two consecutive years without[1]	10 days	5/14 days
Winter / Spring (Jun-Nov)	Low flow	Operate fishways, maintain connectivity and habitat for fish, Platypus and turtles Maintain and promote fringing vegetation along lower banks	Wet / Average	200 ML/day	Whole season		
			Dry	90 ML/day	90 ML/Day mid June to end August (minimum)		
	High flow	Trigger and facilitate fish movement	Wet / Average	900 ML/day	1 event in September	10 days	5/14 days
			Dry	900 ML/day	Not every year, but no more than two consecutive years without[1]	10 days	5/14 days

[1]Note: High flow events not needed every year in dry years but no more than 2 years in a row without at least one event. More work needed to determine which event (i.e. Autumn/Spring) is most critical.

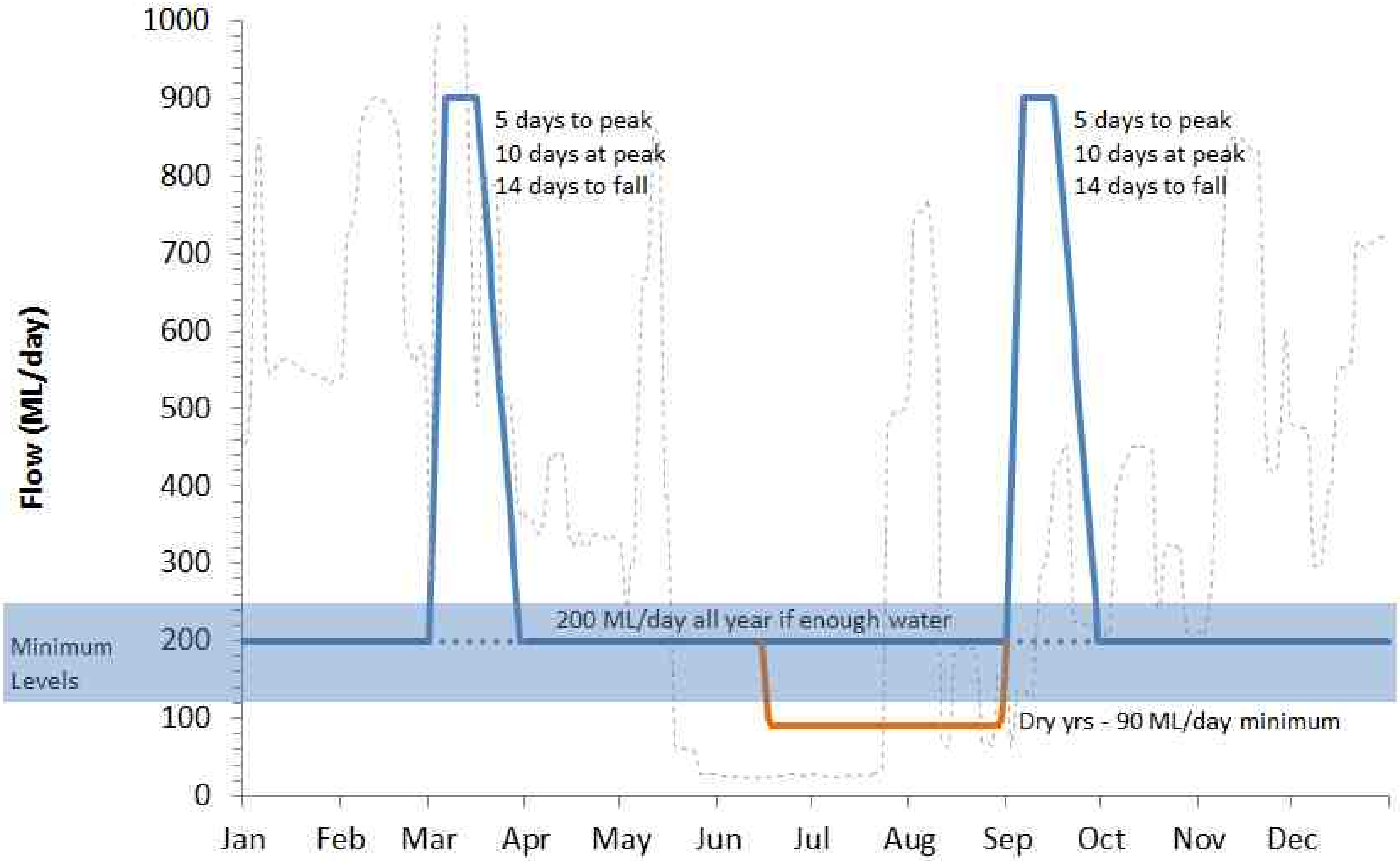

Figure 3-1 Plot illustrating flow recommendations for Pyramid Creek. Flow recommendations for wet/average year are shown in blue. In a dry year, flow levels may drop to 90 ML/day (minimum) from mid-June to end of August. Overlaid on this plot is average daily flow experienced in the year 2012 (grey dashed line). Refer also to Figure 3-2.

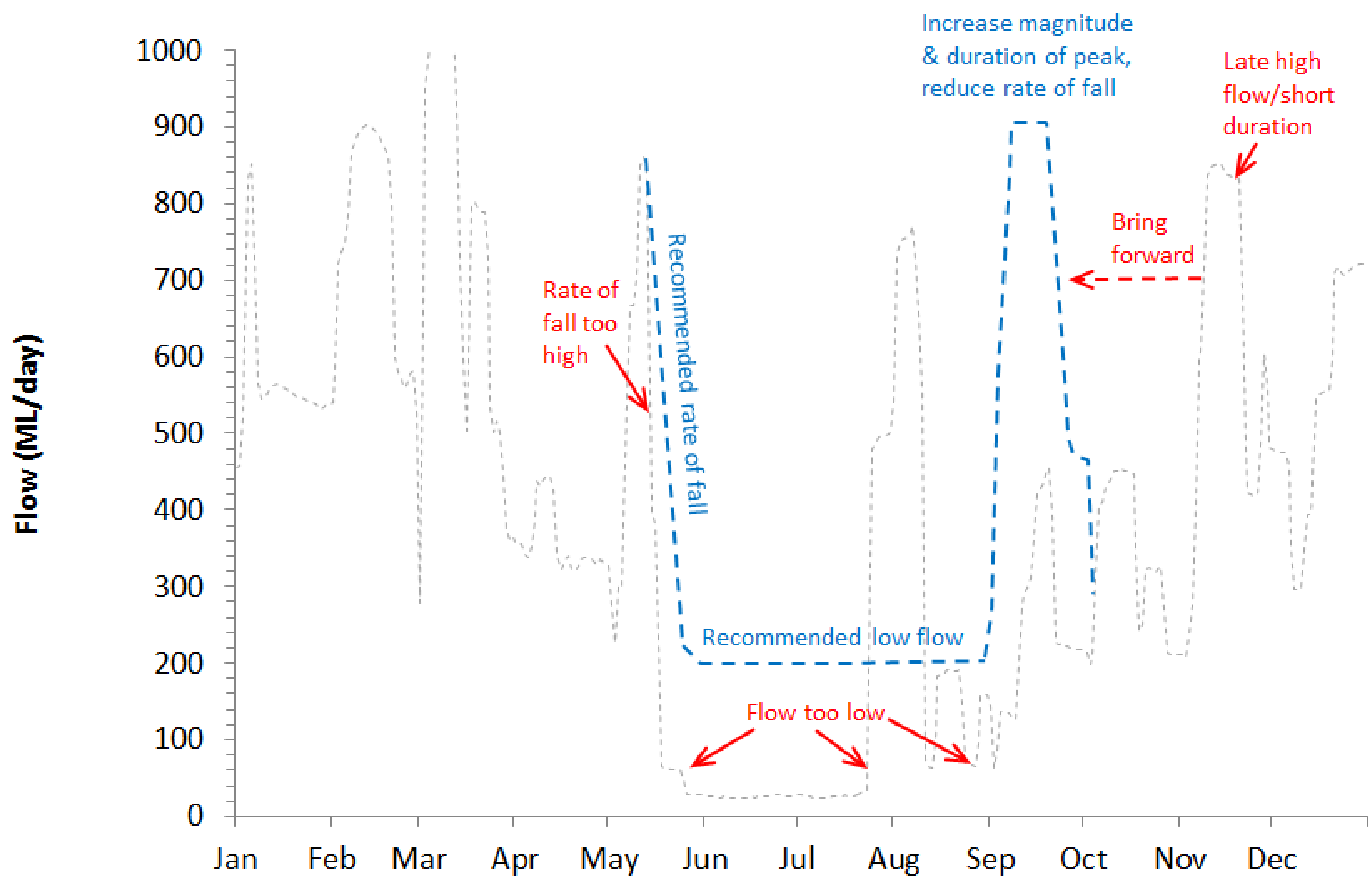

Figure 3-2 Plot highlighting how flows may be manipulated to achieve flow recommendations i.e. rate of fall of event in Autumn too high and could be lowered, higher flows in winter and changes to the magnitude, duration and timing of high flow events in Spring.

3.2 Detailed description of flow recommendations

A detailed rationale for the magnitude, frequency and duration of each flow component is provided below.

Cease-to-flow

While cease-to-flow periods are likely to have naturally occurred in Pyramid Creek, they are not recommended. The creek lacks suitable pools that could provide a refuge for aquatic biota during a cease-to-flow event. Nutrient enrichment and salinity levels are likely to be exacerbated by cease-to-flow events. Cease-to-flow periods will place too much stress for fish with reductions in available habitat and deterioration in water quality. For these reasons, cease-to-flow events are not recommended.

Low flow

The Summer/Autumn and Winter/Spring low flow recommendation aims to maintain suitable flow conditions for movement of fish through the Box Creek and Kerang Weir fishways and maintain connectivity to habitat for fish, Platypus and turtles along Pyramid Creek.

The low flow recommendation for Pyramid Creek is 200 ML/day in wet and average years. It is recommended that this low flow recommendation extends throughout the year, if there is sufficient water available. The crucial time for fish migration is September through to April. A flow of 200 ML/day will maintain suitable tailwater levels downstream of Box Creek regulator (GHD, 2013) to attract fish to the fishway and provide a suitable pool for downstream moving fish to plunge into. A flow of 58 ML/day is required to operate the Kerang fishway (Stuart et al., 2010). Key times for fishway operation are Spring and Autumn (Summer also preferable), these flows being less important during winter when fish are not likely to be moving through Pyramid Creek.

A flow of 200 ML/day also provides a minimum depth of 0.9-1 m in the channel (Figure 3-3). This will help to connect water to Phragmites and provide habitat for migrating fish, Platypus and turtles. The critical period for migration of juvenile Platypus is May to mid-June, so it is important that these flows are maintained during this time. The flow requirements for Eastern Long-necked Turtles are not known. However, flow levels that provide a connection with fringing vegetation at the channel margins are considered important in providing resting habitat areas for turtles. These flows will also be of benefit in inundating wood and maintaining substrates for biofilms and macroinvertebrates year around, which will provide food for migrating fish and Platypus.

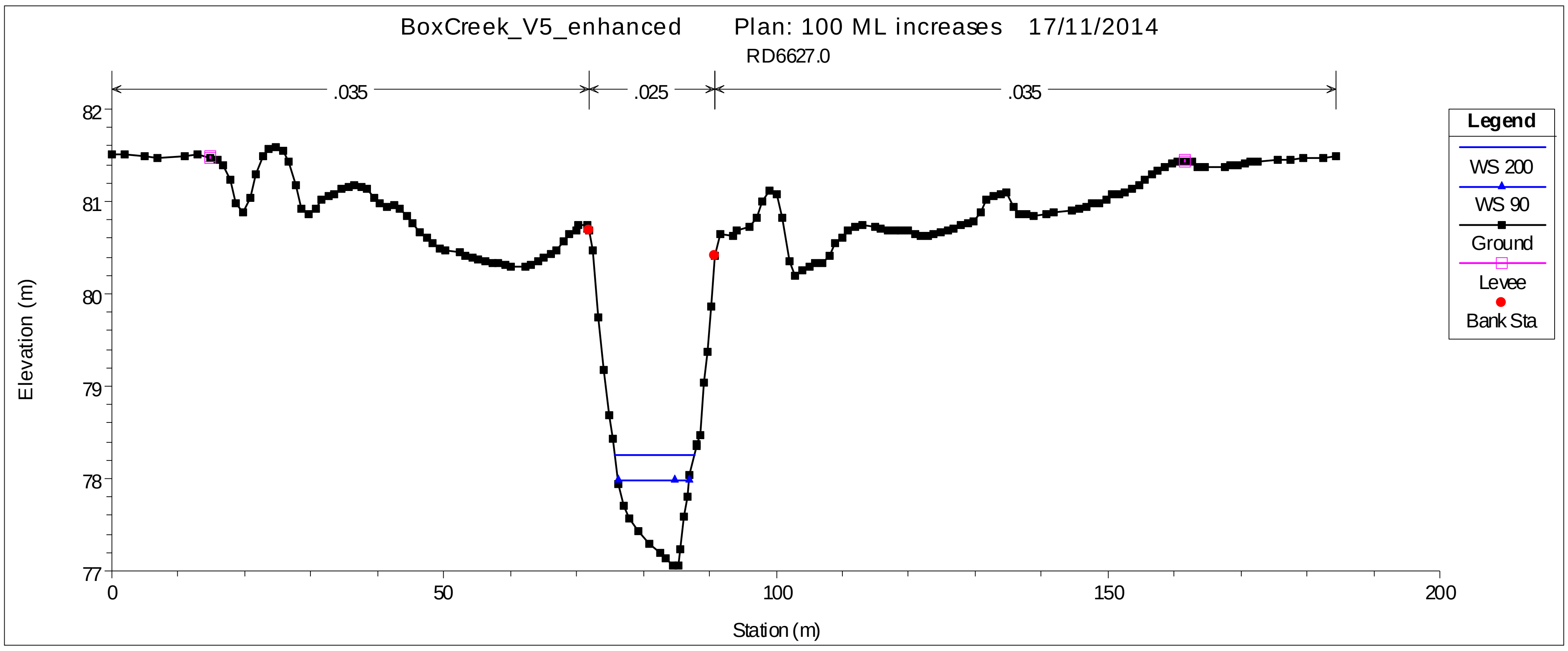

Figure 3-3 Low flow of 200 ML/day and 90 ML/ day in cross-section 1 at Mansfields Bridge.

In dry years, it is recommended that the 200 ML/day low flow is maintained throughout the Summer/Autumn season (December to May), the first half of June and from September to November. Flow levels could be reduced during the Winter period from mid-June to end of August when fish are not migrating through Pyramid

Creek. Dropping flows to 90 ML/day will still allow for movement of large bodied fish through the Box Creek fishway but tailwater levels will be low, so fishway operation is less effective at these lower flows as attracting flow to fishway and flow depths are reduced. This is the minimum level that flows are lowered to during a dry year.

Spells analysis shows that flow generally falls below the low flow recommendation of 200 ML/day outside of the irrigation season, during the winter months (mid-May to mid-August) (Figure 3-4). Flow frequently drops lower than 200 ML/day for short periods during the months of February, March and April. Flows rarely drop below 200 ML/day in the remaining months of January, September, October, November and December.

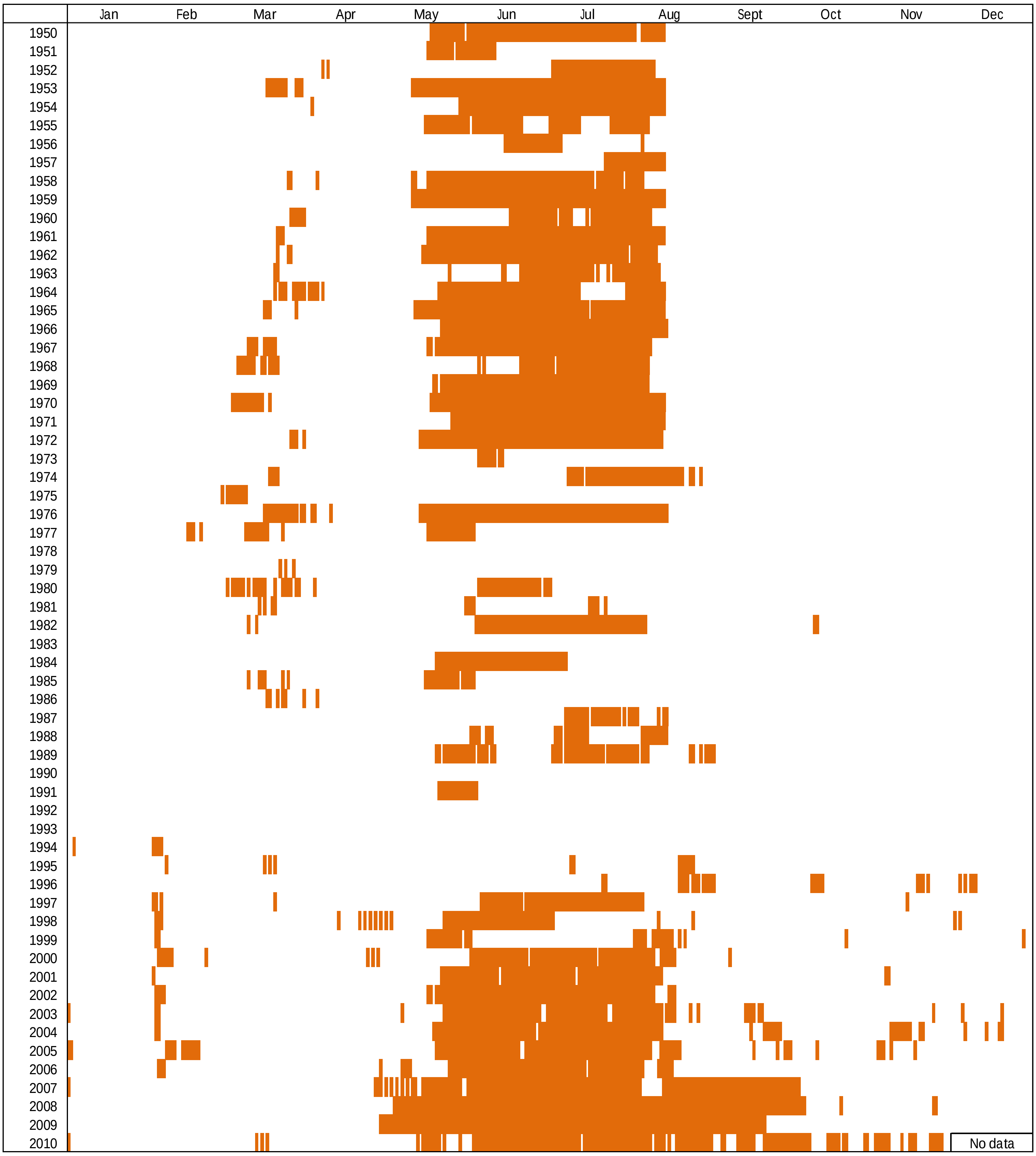

Figure 3-4 Spells analysis of current flows below 200 ML/day between 1950 and 2010.

High flows

High flows are required to initiate upstream fish movement into Pyramid Creek and Kow Swamp from the Lower Loddon River and the Murray River and to facilitate downstream fish movement from Kow Swamp. Species of most interest are Murray Cod, Golden Perch, Silver Perch and Bony Bream. A flow of 900 ML/day has been shown to attract fish from the Lower Loddon near Benjeroop to the Box Creek regulator (O'Connor et al., 2013). The duration of the high flow events are critical as it is necessary to allow sufficient time for fish to detect flow and move upstream through Pyramid Creek (O'Connor et al., 2013).

In wet and average years, two high flow events are recommended with a peak flow of 900 ML/day at Benjeroop on the Loddon River, one in Autumn (March to early April) and one in Spring (mid-September onwards). The recommended duration of the peak flow is a minimum of 10 days, with 5 days to ramp up and at least 14 days to fall. The duration and magnitude of these flow events are designed to mimic the natural high flow event which occurred in March 2012 when O'Connor et al. (2013) observed long distance movement of acoustically tagged Golden Perch. In that study four Golden Perch (20% of the tagged population) moved from Benjeroop to the Box Creek regulator. The timing of the autumn event is also based on those long distance movements observed by O'Connor et al. (2013) and while the ecological reasons behind those movements are unclear the distance fish moved and rate of that movement (~125 km in four days) suggests that they are important and should be part of the environmental flow recommendations. The timing of the spring high flow event is based on a number of previous studies where fish have undertaken long distance migrations associated with increases in flow which have been thought to be associated with spawning (Koster et al., 2014; O'Connor et al., 2013). Both events are intended to trigger and facilitate fish movement from Kerang Weirpool, Lower Loddon and Murray River into Pyramid Creek and to facilitate downstream movement from Kow Swamp. While the Spring event may also trigger Golden Perch to migrate downstream to the Murray River to spawn (Koster et al., 2014).

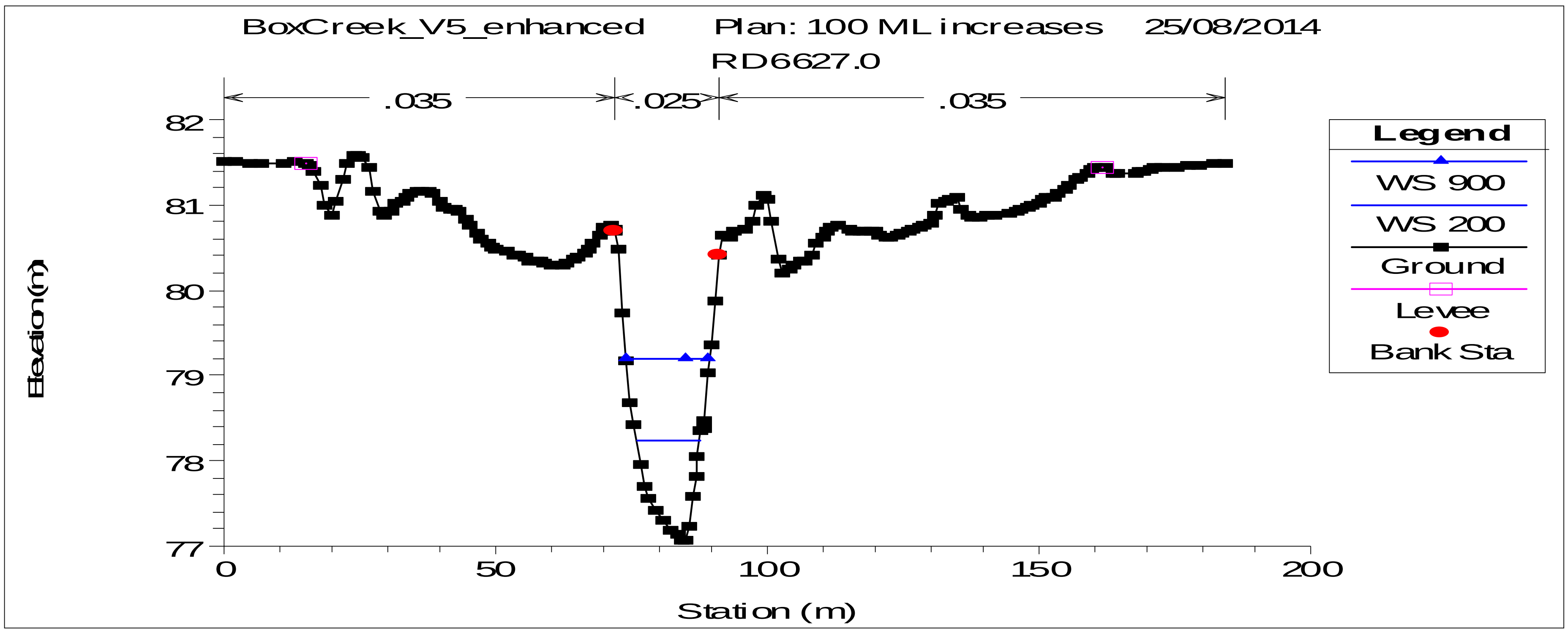

Figure 3-5 High flow of 900 ML/day in cross-section 1 at Mansfields Bridge.

Spring high flows that inundate the littoral zones and increase productivity in the waterway are thought to improve recruitment success for Murray Cod (Beesley et al., 2011; Humphries, 2005; Koehn & Harrington, 2006). The Kerang Weirpool (which extends into the lower Pyramid Creek) currently supports a population of Murray Cod and high Spring flows down Pyramid Creek may enhance future recruitment and colonists that can disperse into Pyramid Creek. Small bodied fish species are also likely to move on these flows and more opportunistically throughout the year (J. O'Connor pers. comm.).

In dry years, these high flow events are not needed every year but it is recommended that there is no more than two years in a row without at least one event. More work is required to determine which of the two recommended events (i.e. Autumn or Spring) is most critical.

Spells analysis shows that flows frequently exceed 900 ML/day throughout the year due to releases for irrigation, but the length of time in which an event exceeds this threshold can vary greatly from one day to 3 weeks (Figure 3-6). Longer duration flow events are more common in the Summer/Autumn months of January, February, March and April. Spring flows exceeding 900 ML/day in September and October tend to be much shorter, typically ranging from one day to a week in duration. Although flows often achieve the recommend threshold for fish movement, the rates of rise and fall are generally very rapid. The implications of rapid falls in water level are described in more detail below.

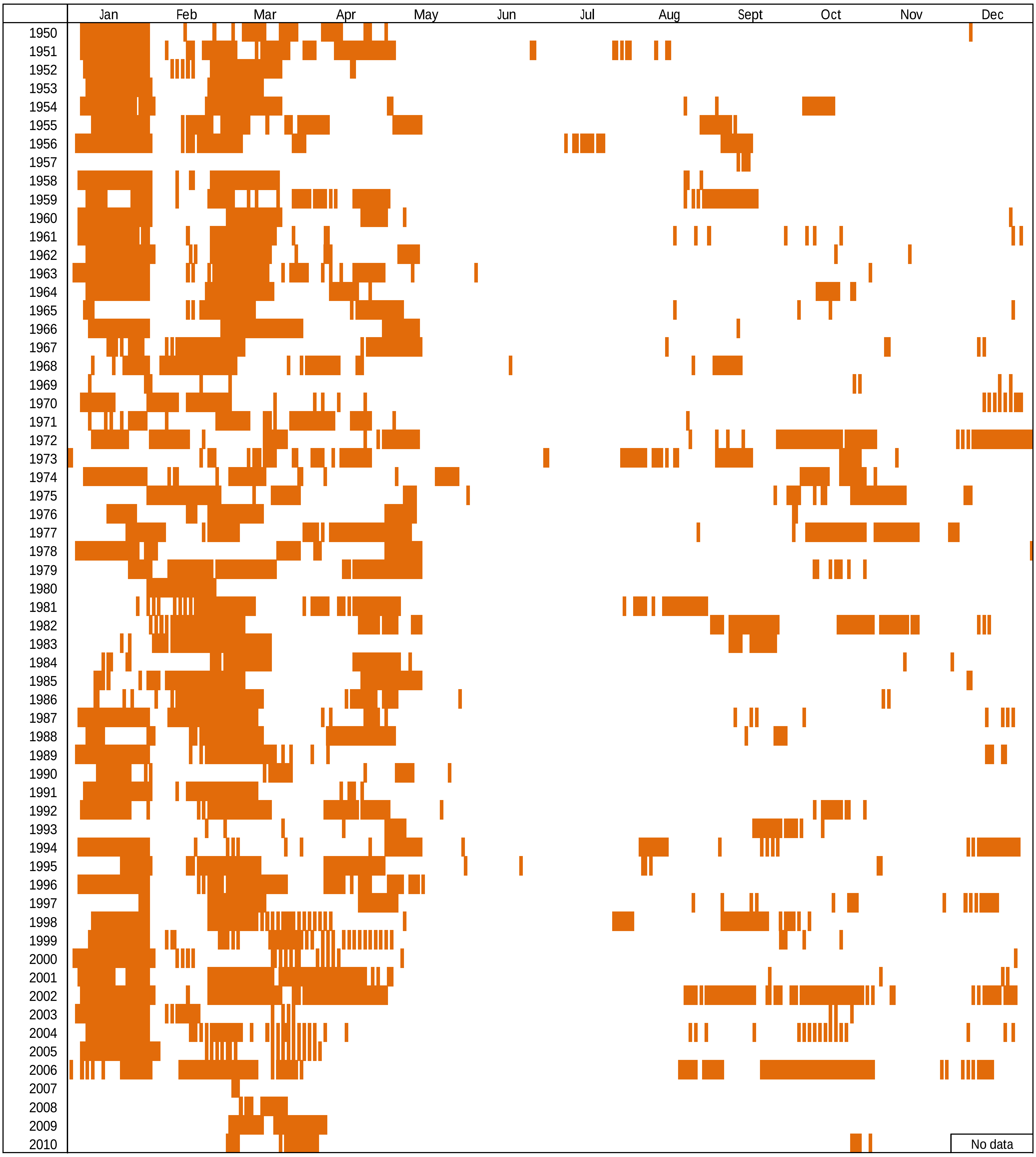

Figure 3-6 Spells analysis of current flows above 900 ML/day between 1950 and 2010.

Bankfull and overbank flows

Bankfull and overbank flows are not recommended for Pyramid Creek as there are no specific ecological objectives that will be met through the provision of the flows.

Reducing rapid fluctuations in water levels during irrigation releases

As indicated above, the current irrigation flows can see rapid drops in flow (e.g. >500 ML/day) due to fluctuating demand for irrigation water (see Figure 3-7). These fluctuations and in particular the rapid drawdown of water levels is likely to increase bank erosion because the banks are saturated and slump as a result of the additional weight and reduction in soil cohesion. Erosion is significant issue along the creek as it leads to the generation of steep banks with little vegetation cover and degraded instream habitat conditions.

Frequent rise and fall in water levels can have a disturbing influence on macroinvertebrate communities (Violin et al., 2011). These water level fluctuations are also likely to disrupt fish movement. Although there is little direct evidence to support this, individuals migrating upstream under high flows are likely to stop when flows drop and head back downstream. If this frequently occurs in the spring spawning season it may interrupt spawning and reduce recruitment success. It is recommended that the rate of fall is capped to ~100 ML/day. This equates to 7-17 cm/day drop in water level, which is in line with the falling limb of some natural flow events on the Loddon River. Monitoring is recommended to assess how the suggested rate of fall or faster rate of fall affects fish behaviour and bank erosion. More work is also required to look at the potential negative effects of infilling irrigation flows on more flashy flows in the Loddon River downstream of Kerang Weir.

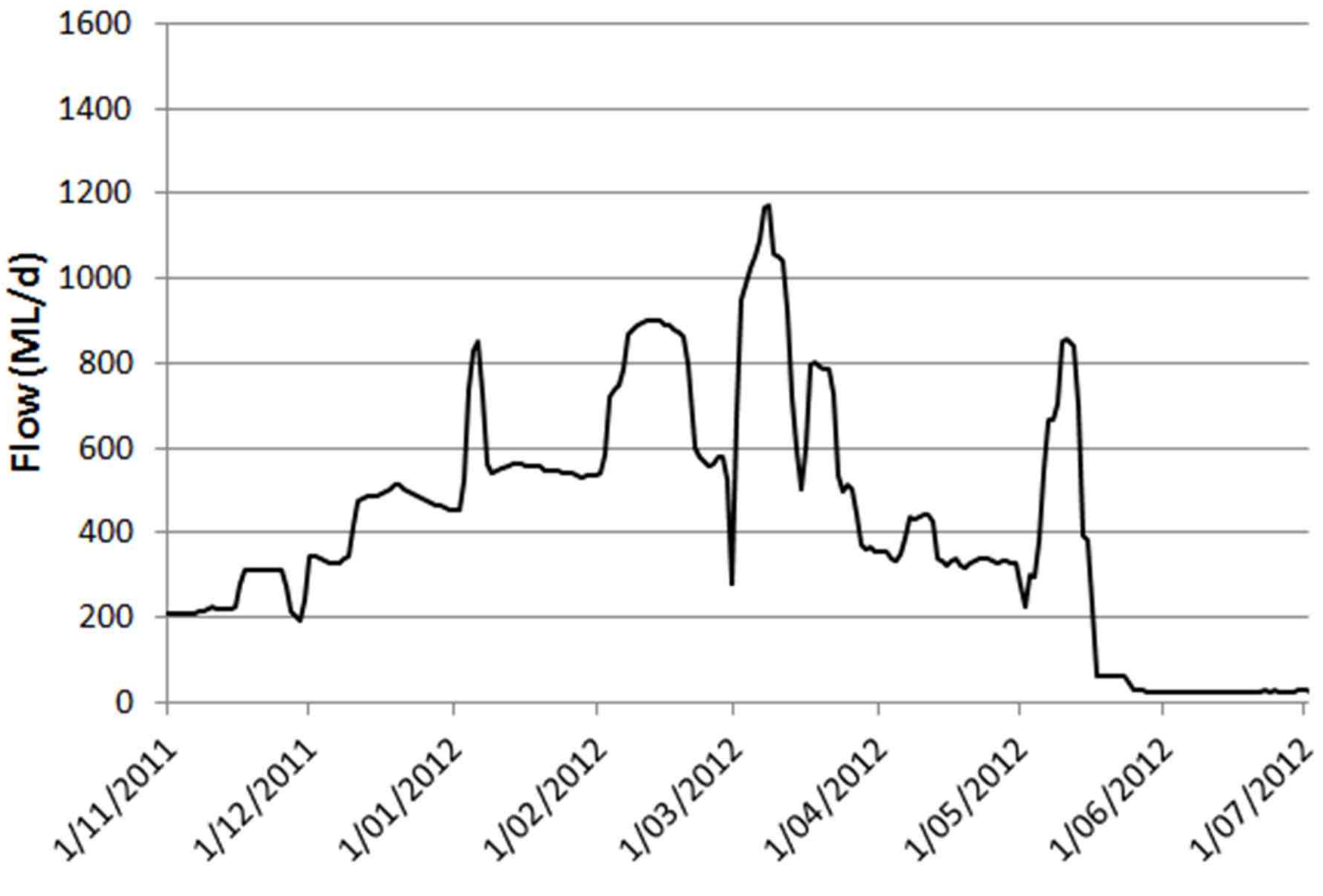

Figure 3-7 Pyramid Creek daily flows November 2011 to July 2012.

3.3 Current achievement of flow recommendations

The achievement of environmental flow recommendations for Pyramid Creek is shown in Table 3-2. Low flow and high flow recommendations for Pyramid Creek are met well overall.

The Summer/Autumn and Winter/Spring high flows are achieved 98% of the time. There is at least one flow event in both March and September which exceeds the flow recommendation of 900 ML/day for 10 days duration. However, it should be noted that the rates of rise and fall of water levels is not factored into the analysis of the current achievement of flow recommendations. Rapid fluctuations in water levels is recognised as an issue potentially disrupting fish movement and accentuating bank erosion along Pyramid Creek.

The Summer/Autumn low flow is achieved 92% of the time. The Winter/Spring low flow is achieved 72% of the time when a low flow of 200 ML/day is applied, and 76% of the time when a low flow of 90 ML/day is applied. This lower compliance throughout Winter/Spring is due to the reduced flows in the creek outside the irrigation season. Lower compliance with Winter/Spring low flows could limit the movement of fish through the Box Creek and Kerang Weir fishways.

The main objective for Pyramid Creek is to ensure that the flow regime is suitable to encourage native fish to move between the Lower Loddon and Gunbower Creek systems. The current level of compliance with flow recommendations is generally good, but it is critical that high flows events achieve the recommended duration to give fish sufficient time to traverse the system, that rates of rise and fall are managed to avoid triggering fish to halt any upstream movement and return downstream, and that minimum flows through the Box Creek regulator are maintained so that effective fish passage is provided. If these recommendations cannot be achieved then, the overall objective to create uninterrupted movement opportunities for fish between the Murray River, Loddon River, Pyramid Creek and Gunbower Creek will not be realised.

Table 3-2 Achievement of environmental flow recommendations for all years. Note: Rates of rise and fall are not considered.

Component	Months	From	To	Flow Recommendation			Or Natural	Compliance Lower	Compliance Upper
Summer / Autumn low	Dec - May	12	5	Magnitude	200	ML/d	No	92%	
Summer / Autumn high	Mar - Mar	3	3	Magnitude	900	ML/d	No	98%	
				Frequency	1	per year			
				Duration	10	Days			
Winter / Spring low	Jun - Nov	6	11	Magnitude	90-200	ML/d	No	74%	70%
Winter / Spring high	Sep - Sep	9	9	Magnitude	900	ML/d	No	98%	
				Frequency	1	per year			
				Duration	10	Days			

4. Complementary management actions

Environmental flows are one of a range of management strategies that need to be considered when managing the environmental flows of a catchment. It is rare that all of the environmental issues and threats within a catchment can be resolved by only providing an appropriate flow regime. In most catchments, other management actions need to be implemented in combination with flow management to meet the stated environmental flow objectives. The main complementary management actions for Pyramid Creek are described below.

4.1 Protection of the stream-side zone

Land use, particularly grazing pressure is contributing to the degraded and often depauperate fringing and riparian vegetation along Pyramid Creek. Fencing and revegetation programs have been effective at improving vegetation cover on the banks of Pyramid Creek but sections of river still remain that are unfenced and stock are permitted to graze on the banks.

The North Central CMA in their Waterway Management Strategy (North Central CMA, 2014a) have identified a number of management outcome targets and activities which are focused on protecting the stream-side zone along Box and Pyramid Creek. These include installation of fencing, provision of off-stream watering points, revegetation and community engagement activities that increase landowner skills and awareness in riparian management practices (see Table 4-1).

Table 4-1 Box and Pyramid Creek Actions as documented in North Central Water Strategy (North Central CMA, 2014a).

Management Outcome Target	Management Activity/Output	Quantity	Lead agency / partners
Implementation of the Native Fish Recovery Plan: Gunbower and Lower Loddon	Modify fish barriers (Taylors Creek Weir and Spittle's Regulator) and allow fish passage through Box Creek, Loddon River and Gunbower Creek.	2 barriers	CMA, GMW
	Instream Habitat improvement works (eg. reestablishment of woody debris)	5 no	CMA, GMW
	Baseline and repeat survey and monitoring to assess effectiveness of habitat improvement works	2 no	CMA, GMW
Install fencing for species control (livestock access) along riparian frontages	Construction of riparian fences	60 (km)	CMA, Landholders
	Provision of off-stream watering points	10 no.	CMA, Landholders
Improve vegetation structure and diversity through indigenous vegetation establishment	Establish native indigenous vegetation	60 (ha)	CMA, Landholders
Increase landholder skills and awareness in riparian management practices	Establish management agreements with landholders participating in river heath incentives	60 Management Agreements	CMA, Landholders
	Co-ordinate/attend community engagement events	10 (events)	CMA, Landholders
	Work with landcare groups to support the implementation and maintenance of projects	4 (events)	CMA, Landholders

Note: All actions outlined in the North Central Waterway Strategy are subject to available funding. The North Central CMA will work with partner agencies and the community to seek investment to implement the Strategy.

4.2 Habitat improvement works for aquatic biota

Pyramid Creek has very little submerged wood and most of the wood present in the stream has been found to comprise stands of dead willow trees (Kitchingman et al., 2012). The North Central CMA has recently introduced a number of large wood structures into Pyramid Creek in the area immediately downstream of Kow Swamp. This area was identified as a suitable rehabilitation reach as it would provide resting areas for native fish colonising from downstream. Going forward, habitat in this location will help to hold fish close to the Box Creek regulator fishway and maximise opportunities for movement through the fishway.

Introducing more large woody structures will provide more variable hydraulic habitats for aquatic biota and improve geomorphic processes in Pyramid Creek. Large wood structures need to be tall enough to be inundated by a range of flows for fish and Platypus habitat. Periodic exposure is also beneficial for biofilm processes.

It is understood that there has been some concern by members of the community as to the affect that large wood reintroduction may have on water levels and the stability of the channel bed and banks. Re-introduction of large wood structures is unlikely to result in significant changes in water level or destabilise the bed and bank.

SKM (2014) analysed changes in water levels associated with reintroduction of large wood structures between the outlet of Kow Swamp and the crossing of the Goulburn Murray Water Channel at Flannery's Flume. Calculated changes in water levels will vary depending on the flow. The flows of interest from a flooding perspective are 2,000–3,000 ML/day. Rises in water levels with reintroduction of large wood structures are relatively small for these flows, ranging from 0.01 to 0.10 m.

Previous studies of log structures reintroduced into the Glenelg River by SKM (2009a) concluded that the likelihood of wood moving to be very low. Partially burying the wood structures and orientating them downstream will further reduce the likelihood that they will move or cause unwanted problems.

4.3 Protection of fish, Platypus and turtle populations

There are a number of additional management actions that are recommended to provide a greater level of protection for fish, Platypus and turtle populations along Pyramid Creek:

- Implement educational and enforcement campaigns to eliminate use of illegal fish nets and yabby traps – Illegal fishing, in particular the use of drum nets and yabby traps is a threat to fish, Platypus and turtle populations. Educational awareness and enforcement campaigns are needed to address these illegal activities.
- Undertake fox control programs to reduce predation risk on adult and juvenile Platypus and turtles – Foxes are a common threat to both Platypus and turtles. Fox control programs are needed to control the numbers of these predators along Pyramid Creek.
- Fit irrigation pumps with devices to exclude Platypus and turtles when pumps are operated – Exclusion cages or mesh structures could be fitted to the end of pipes to prevent animals being trapped.

5. Monitoring recommendations

This FLOWS study has made use of the most up to date information that was available at the time of the assessment, but information gaps remain. It is important that as our understanding of biological responses to flow improves (e.g. through monitoring and scientific research) the flow recommendations are revised and updated accordingly. Monitoring recommendations are described below.

5.1 Fish movement and habitat studies

Additional fish movement studies are required to develop a greater understanding of fish movement through Box Creek and Kerang Weir fishways, and along Pyramid Creek. This is needed to confirm that fish are moving through the structures when they are in operation and to provide a greater understanding of the specific magnitude and timing of flows required to facilitate movement for different fish species. Further information is also required on where along Pyramid Creek the fish are moving to and what habitat they are using when they are moving through Pyramid Creek. Once fish passage is provided at Box Creek Regulator and Taylor's Creek, a broader program of monitoring is recommended to investigate the movement of fish between the Loddon River, the Gunbower Creek system and the Murray River.

5.2 Aquatic fauna and habitat surveys

Aquatic fauna and habitat surveys are recommended to monitor populations of native fish, Platypus and turtles in Pyramid Creek. Specific surveys are recommended within the vicinity of areas where large wood are being reintroduced and habitat improvement works are being completed. Ideally, before and after surveys should be undertaken so that the influence of large wood reintroduction/habitat improvement works can be more clearly assessed. These monitoring programs need to be carefully designed with respect to number of sites and monitoring activities completed at each site to allow a robust assessment of the effectiveness of works.

5.3 Impact of rise/lowering of water levels on fish behaviour and bank stability

This FLOWS study has highlighted some concern that rapid fluctuations in flow rates and water levels during the irrigation season may have negative impact on Pyramid Creek. Fish migrating upstream under high flows could stop with a sudden drop in water levels, turn around and head back downstream. Increased bank erosion may also occur if water levels drop too quickly.

This FLOWS study has provided recommendations on rate of water level rise/fall to minimise potential negative effects associated with rapid fluctuations in water level on fish behaviour and bank erosion. Recommended rates of rise and fall for Pyramid Creek are in part based on an analysis of natural flows for the Loddon River. Further monitoring is recommended to monitor the impact that different rates of rise/lowering of water levels have on fish behaviour and bank stability.

6. Development of an Environmental Watering Management Plan

Pyramid Creek does not currently have an Environmental Watering Management Plan (EWMP). We recommend that the North Central CMA use the outcomes of this FLOWS study to develop an EWMP for Pyramid Creek. An EWMP is needed to meet the requirements of the water management goal and environmental flow objectives.

In reference to Schedule 8 of the Basin Plan[3], Pyramid Creek is identified as an environmental asset that requires environmental watering for the following reasons:

- It provides pathways for the dispersal, migration and movements of native water-dependant biota such as native fish, Platypus and turtles [Criterion 3(ii)].
- It supports a number of listed threatened species including EPBC listed Murray Cod and FFG listed Silver Perch and Murray-Darling Rainbow fish [Criterion 4(a)].

We consider that Pyramid Creek meets the criteria established in Schedule 8 of the Basin Plan, therefore an EWMP should be developed.

[3] See Appendix A for definitions (Schedule 8 of the Basin Plan)

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Appendix A. Schedule 8 of the Basin Plan

Item	Criteria
Criterion 1: The water-dependent ecosystem is formally recognised in international agreements or, with environmental watering, is capable of supporting species listed in those agreements	
1	Assessment indicator: A water-dependent ecosystem is an environmental asset that requires environmental watering if it is: (a) a declared Ramsar wetland; or (b) with environmental watering, capable of supporting a species listed in or under the JAMBA, CAMBA, ROKAMBA or the Bonn Convention.
Criterion 2: The water-dependent ecosystem is natural or near-natural, rare or unique	
2	Assessment indicator: A water-dependent ecosystem is an environmental asset that requires environmental watering if it: (a) represents a natural or near-natural example of a particular type of water-dependent ecosystem as evidenced by a relative lack of post-1788 human induced hydrologic disturbance or adverse impacts on ecological character; or (b) represents the only example of a particular type of water-dependent ecosystem in the Murray-Darling Basin; or (c) represents a rare example of a particular type of water-dependent ecosystem in the Murray-Darling Basin.
Criterion 3: The water-dependent ecosystem provides vital habitat	
3	Assessment indicator: A water-dependent ecosystem is an environmental asset that requires environmental watering if it: (a) provides vital habitat, including: (i) a refugium for native water-dependent biota during dry spells and drought; or (ii) pathways for the dispersal, migration and movements of native water-dependent biota; or (iii) important feeding, breeding and nursery sites for native water-dependent biota; or (b) is essential for maintaining, and preventing declines of, native water-dependent biota.
Criterion 4: Water-dependent ecosystems that support Commonwealth, State or Territory listed threatened species or communities	
4	Assessment indicator: A water-dependent ecosystem is an environmental asset that requires environmental watering if it: (a) supports a listed threatened ecological community or listed threatened species; or Note: See the definitions of *listed threatened ecological community* and *listed threatened species* in section 1.07. (b) supports water-dependent ecosystems treated as threatened or endangered (however described) under State or Territory law; or (c) supports one or more native water-dependent species treated as threatened or endangered (however described) under State or Territory law.
Criterion 5: The water-dependent ecosystem supports, or with environmental watering is capable of supporting, significant biodiversity	
5	Assessment indicator: A water-dependent ecosystem is an environmental asset that requires environmental watering if it supports, or with environmental watering is capable of supporting, significant biological diversity. This includes a water-dependent ecosystem that: (a) supports, or with environmental watering is capable of supporting, significant numbers of individuals of native water-dependent species; or (b) supports, or with environmental watering is capable of supporting, significant levels of native biodiversity at the genus or family taxonomic level, or at the ecological community level.

Appendix B. Approach to setting flow recommendations

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

B.1 Environmental flow objectives

Environmental flow objectives set the direction and target for the environmental water recommendations and are clear statements of what outcomes should be achieved in providing environmental flows. The process of setting environmental objectives involves first identifying the environmental assets, setting environmental objectives against these, and then identifying the flow required to meet the environmental objectives. Environmental objectives are developed for those ecological assets that have a clear dependence on some aspect of the flow regime, and include:

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

Objectives are typically developed such that, if met, the flow could sustain an ecologically healthy waterway as defined by the Victorian Waterway Management Strategy (VWMS) (DEPI, 2013b), or could help meet the vision for waterways as described in the 2014-2022 North Central Waterway Strategy (North Central CMA, 2014a). The 2014-2022 North Central Waterway Strategy vision represents what the community value about the waterways in the North Central Region. It states:

Waterways will be managed sustainably to maintain and improve their ecological diversity and function while also supporting the regional community's economic, cultural, recreational and amenity use.

An ecologically healthy waterway will have flow regimes, water quality and channel characteristics such that, among other things:

- native riparian vegetation communities exist sustainably for the majority of the waterway's length; and
- native fish and other fauna can move and migrate up and down the waterway.

A waterway does not have to be pristine to be ecologically healthy. The definition of an ecologically healthy waterway that we use recognises that there can be some change from the natural state, and in highly developed catchments it will not be possible or desirable to return a waterway to its natural state because to do so would jeopardise some important social and economic values as is the case with Pyramid Creek. For Pyramid Creek, we are looking to develop environmental flow objectives that enhance fish populations.

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

B.2 Flow components

The FLOWS method requires the EFTP to identify specific flow components that are relevant to each objective. A flow component is a specific element of the flow regime (see Figure B-1) that fulfils a particular ecological or biophysical function (Table B-1).

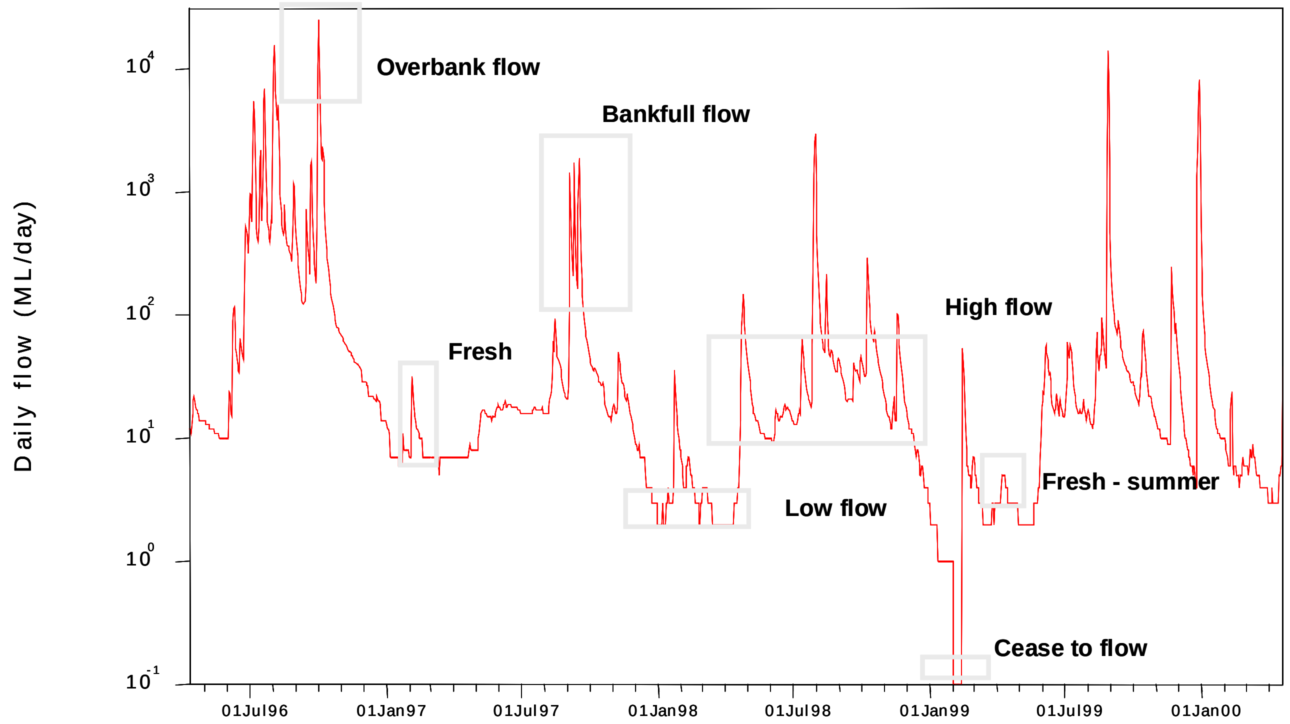


Figure B-1 Typical daily flow series for a perennial stream. Note, in intermittent or ephemeral streams the cease-to-flow period is longer and there is often more variability in the frequency of higher flow events.

Table B-1 Environmental functions of different flow components. Note, the flow components listed below are those that are typically present in perennial and ephemeral streams. In highly modified and regulated streams such as Pyramid Creek, some of these flow components are no longer considered appropriate (i.e. cease-to-flow and overbank flows).

Flow components	Function
Cease-to-flow	• Disturb lower channel features by exposing and drying sediment and bed material. • Promote successional change in community composition through disturbance. • Maintain a diversity of ecological processes through wetting and drying.
Low flow	• Allow accumulation and drying of organic matter in the higher areas of the channel such as benches. • Maintain permanent pools with an adequate depth of water to provide habitat for aquatic biota. • Slow the process of water quality degradation occurring in pools (avoid complete stagnation). • Sustain longitudinal connectivity for movement of macroinvertebrates, fish, Platypus and turtles. • Sustain inundation of lower benches to maintain habitat for emergent and marginal aquatic vegetation. • Provide passage through Kerang Weir and Kow Swamp fishways. • Promote development of larval and juvenile fish that require shallow, slow flowing backwater habitats. • Promote recruitment for fish that spawn during low flow periods.
Freshes/High flow	• Entrain terrestrial organic matter that has accumulated on benches and in the upper channel. • Erode, transport and deposit sediment across a range of channel surfaces (i.e. deposition at channel margins and formation of benches). • Provide spawning and migration cues for fish. For example, to trigger fish spawning for Murray Cod and trigger upstream movement of Golden Perch, Murray Cod, Silver Perch and Bony Herring. • Provide flow variability to maintain species diversity of emergent and littoral aquatic vegetation and to drive vegetation zonation patterns across the channel. • Instigate die back of terrestrial vegetation that has encroached down the bank during the low flow period. • Increase habitat area available for in-stream flora and fauna through inundation of benches and LWD located on banks. • Winter high flows to help set levels at which Platypus and Turtles construct their nests.

Flow components	Function
Bankfull flow	• Provide spawning cues for fish and assist in dispersal movement. • Disturb aquatic and riparian vegetation and rejuvenate successional patterns; provide cues for Riparian Forest and Floodplain Riparian Woodland EVC recruitment. • Transport organic matter that has accumulated in the riparian zone and wetlands. • Instigate die back of terrestrial vegetation that has encroached down the bank during the low flow period. • Increase habitat area, including access to large woody debris and over hanging banks for in-stream biota. • Maintain overall channel dimensions through scour of pools, formation and modification of existing bars and channel marginal elements (i.e. low lying benches)
Overbank flow	• Engage entire floodplain • Form and maintain floodplain features (i.e. wetlands)
Definition of terms: Cease-to-flow – no measurable flow in the river (although pools may retain water) Low Flow – flow that provides continuous flow through the channel within that reach Freshes – small and short duration peak flow event High Flow – large flow events with longer duration than freshes, these flows cover streambed and low in-channel benches Bankfull Flow – fill the channel and adjacent wetlands with little spill onto the actual floodplain Overbank Flow - greater than bankfull and result in inundation of floodplain habitats	

B.3 Reach and site selection

For the purpose of setting environmental flow recommendations, it is usually necessary to divide a catchment into a number of reaches. Reaches must be representative of the key features of the waterways within the study area and can be identified by major tributary inflows, changes in landform, geology, channel or floodplain morphology, points of regulation (e.g. major weirs or off-takes), or shifts in ecological processes or community structure.

For this study we have divided Pyramid Creek into two FLOWS reaches (see Table B-2 and Figure B-2). Reach 1 extends from Box Creek Weir to immediately upstream of Hird Swamp and Reach 2 extends from Hird Swamp to the confluence with the Loddon River. The channel has a uniform shape throughout both reaches, but the reach upstream of Hird Swamp has less riparian vegetation and more bank erosion than the downstream reach.

The FLOWS assessment site for the Reach upstream of Hird Swamp is the Mansfield Bridge flow gauge, and the assessment site for the Reach downstream of Hird Swamp is immediately downstream from No 23/1 Channel Outfall. A detailed rationale for the reach and site selection is provided in the *Site Paper* (Jacobs, 2014b).

Table B-2 Selected environmental flow reaches and corresponding flow assessment sites and flow gauges in Pyramid Creek.

Environmental flow reach		Flows assessment site	Active flow gauge
1	Pyramid Creek from Box Creek Weir to immediately upstream of Hird Swamp	Box Creek upstream of Mansfield Bridge	407295 Box Creek at Mansfields Bridge
2	Pyramid Creek from Hird Swamp to confluence with Loddon River	Pyramid Creek downstream of No 23/1 Channel Outfall	407294 Pyramid Creek at Flannerys Bridge

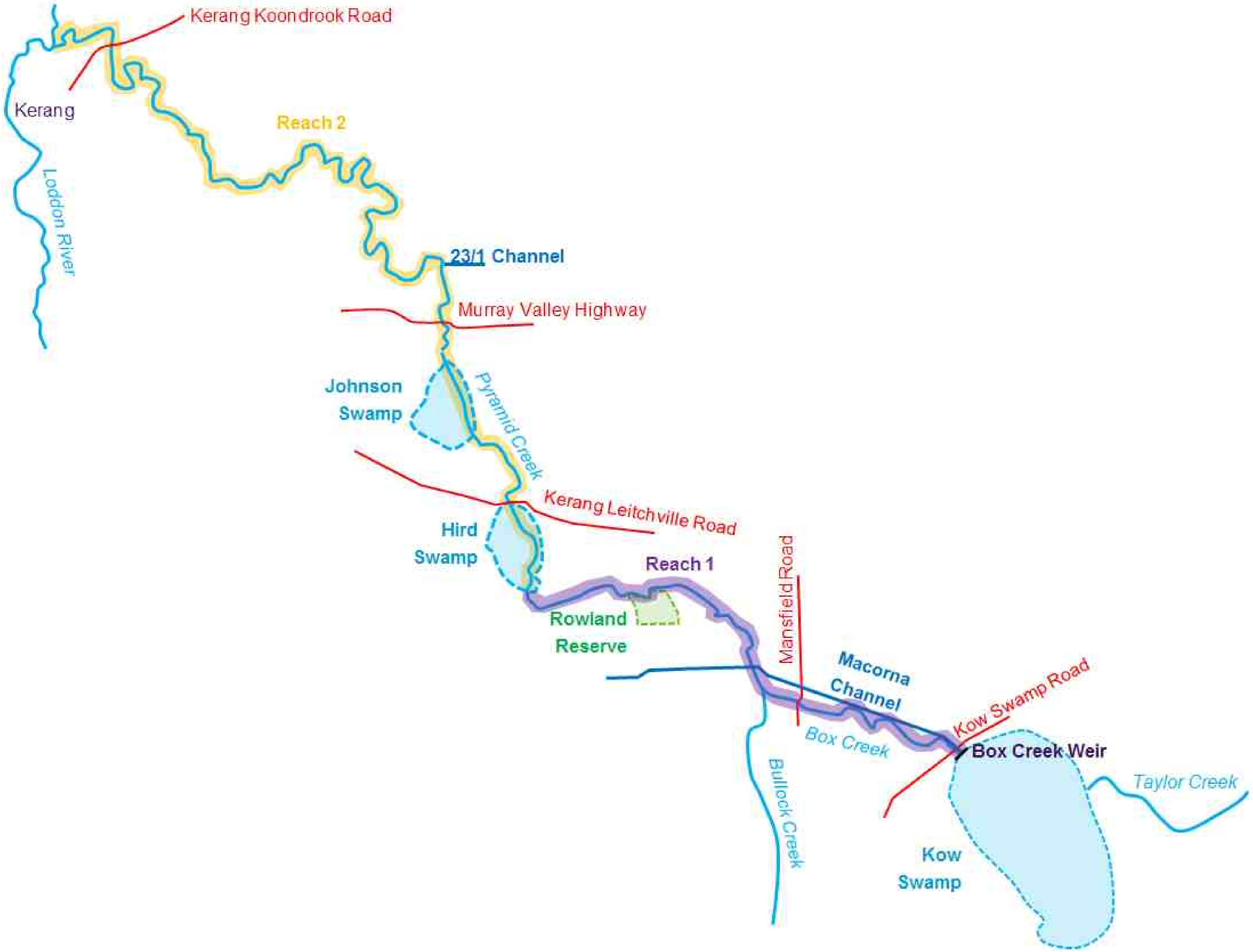


Figure B-2 Schematic of Pyramid Creek showing layout of stream network, wetlands, irrigation and flow delivery structures and roads. The extent of the FLOWS Reaches is also shown.

B.4 Survey of selected reaches

The EFTP selected four channel cross-sections at the location of specific channel features at each FLOWS assessment site on Pyramid Creek during their site visit in May 2014. Most environmental flow studies survey at least eight cross-sections at each site, but four is adequate for Pyramid Creek because the channel is very homogenous (Jacobs, 2014a; SKM, 2012b).

Detailed feature surveys of the selected cross-sections and other site features at the Pyramid Creek FLOWS assessment sites were conducted in June 2014 and the results were used to build one-dimensional hydraulic models of each site. Cross-section survey points focussed on the channel detail, with fewer points located within the riparian zone and floodplain. A total station was used to measure any significant changes in elevation, breaks in slope and the location of specific channel features across each cross-section. Water level was recorded at all cross-sections to assist in calibration of the hydraulic model. Cross-sections were surveyed to AHD (Australian Height Datum).

B.5 Hydrology

The current flow regime was developed to assist in the setting of flow recommendations. The current flow series is the flow regime that refers to current use, including the effect of impoundments (e.g. Kow Swamp) and diversions. The current flow regime was derived as part of the Kerang Lakes REALM model (SKM, 2013b), which was updated by Jacobs and DEPI in 2014 (run D217). The flow time series extends from 1990 to 2010. Ideally an unimpacted flow series would be available to provide an understanding of the flow regime that would have existed if there were no diversions or impoundments. However, the unimpacted flow regime is not appropriate for adoption in Pyramid Creek, because the system has been regulated for over 100 years, and does not represent any elements of the natural flow regime. A detailed analysis of current regime hydrology in Pyramid Creek is provided in the Issues Paper (Jacobs, 2014a). The flow recommendations make reference to wet, average and dry climate years. The hydrology is not split to reflect these differences in climate because the flow and rainfall in the catchment are very loosely related to the climate, but are related to the allocations in the Murray system.

B.6 Hydraulic modelling

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

B.6.1 Model limitations

Significant effort has been made to ensure the hydraulic models are accurate, however it should be noted that the models have been calibrated using the measured flow on the day of survey. HEC-RAS models should be accurate for flows that are relatively close to the calibrated flow magnitude, but will be less reliable for higher or lower flow magnitudes. Each model has been created so as to minimise this error, but it is not possible to avoid it entirely without surveying the water levels at each site over a wide range of different flows.

Gauged data are available for each reach from long-term flow gauges (Jacobs, 2014a). These gauges are considered to represent flows throughout the reach and are at, or close to, the actual location of the flows assessment site. Flow data applied to calibrate the hydraulic models were obtained from gauged data.

B.6.2 Model outputs

A key output from the hydraulic model is a graphical representation of each cross-section (see Figure B-3 for an example). The black line in the example (‘ground’ in the legend) represents the ground surface, reflecting the channel shape at that cross-section. Small black squares on the ground line show the exact points where field survey measurements were taken. Horizontal blue lines within the cross-section represent the estimated water surface at various modelled flows (which are detailed in the legend).

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

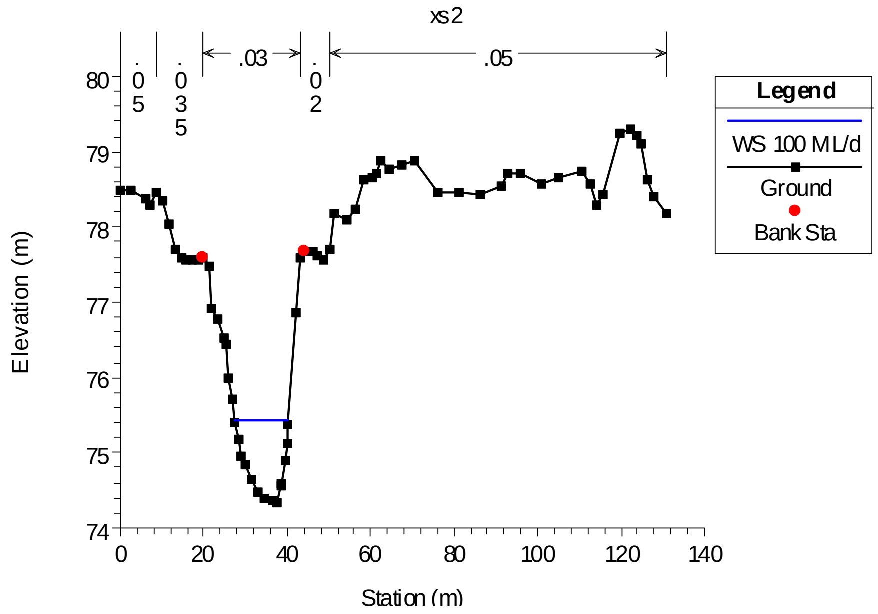


Figure B-3 Example cross-section output from the hydraulic model for cross-section 2 at Lyons Road showing channel profile and modelled water surface level for a flow of 100 ML/day.

B.7 Development of environmental flow recommendations

Environmental flow recommendations for Pyramid Creek were determined by the EFTP in a workshop conducted on 23 July 2013. The workshop was also attended by Louissa Rogers from North Central CMA.

The EFTP worked through the process of determining flow recommendations for the creek with reference to the site assessments and hydraulic models developed for the two FLOWS reaches. The environmental flow objectives documented in the *Issues Paper* (Jacobs, 2014a) were discussed. Photos and field notes taken during the field assessment were examined along with transects from the hydraulic models in order to identify key habitat features (i.e. benches). Information on the flows required for the operation of fishways was also used to set flow recommendations.

Each flow component was considered in turn. A range of criteria were used to determine suitable flows. For each flow component the desired volume threshold, frequency of occurrence and duration was determined (although see Section B.7.4 for a discussion of uncertainty in recommendations and the use of elements of the current regime to inform some recommendations). Consideration was given to the acceptable level of variability in flow components and differences between wet, average and dry years.

B.7.1 Flow seasons

Separate environmental flow recommendations are made for the dry seasons (i.e. summer / autumn) and wet seasons (i.e. winter / spring). For the purposes of this project, summer / autumn flow recommendations apply to the whole period from the start of December to the end of May. Winter / spring flow recommendations apply from the start of June to the end of November. Figure B-4 shows the average daily and median daily flow for each month over the period of record (1900 to 2014). It can be seen that flows in summer / autumn are generally higher than those in winter / spring, due to irrigation flows. A more detailed description of the hydrology of Pyramid Creek is provided in the *Issues Paper* (Jacobs, 2014a).

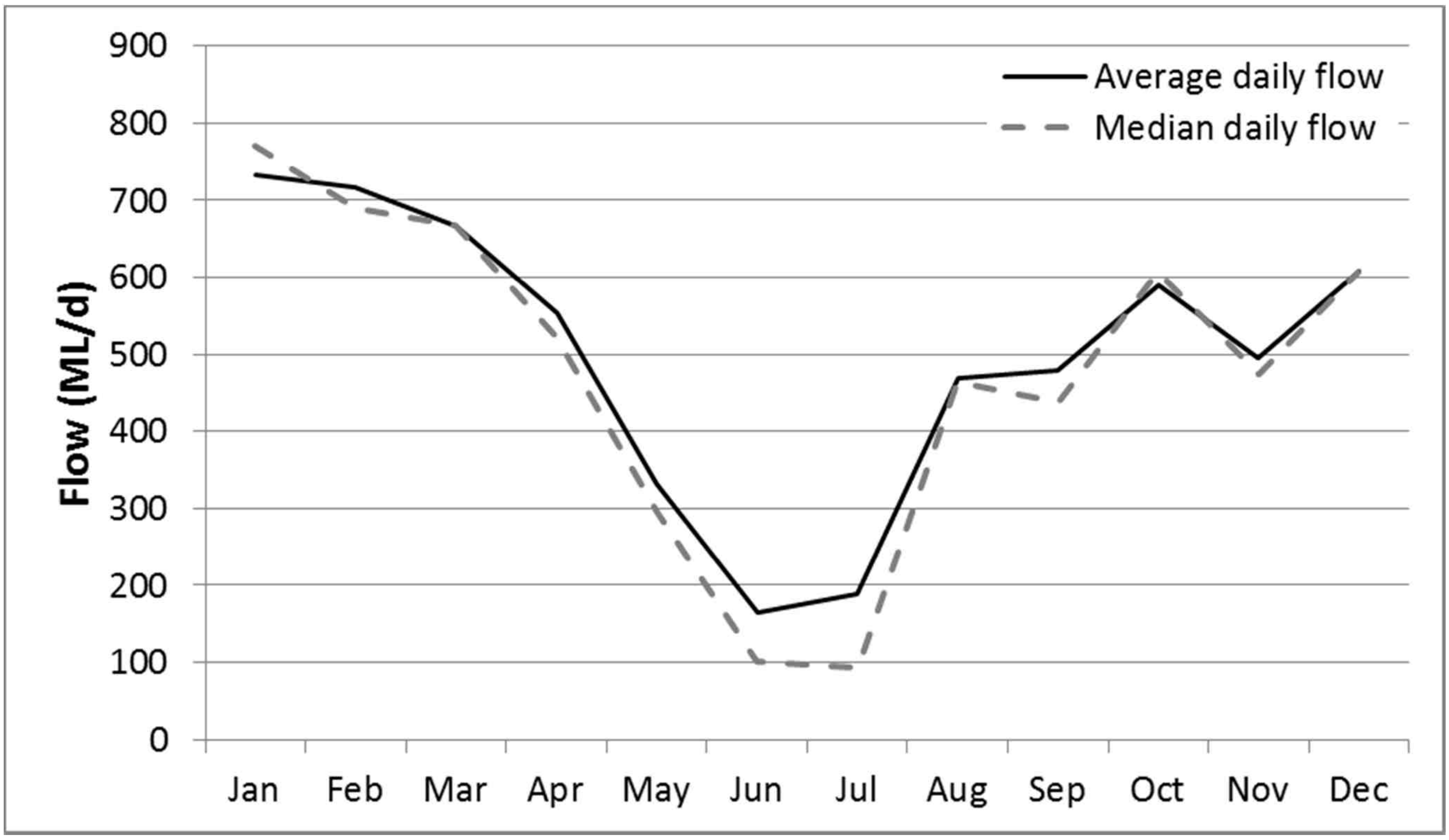


Figure B-4 Average daily and median daily flow for each month over the period of record showing the seasonality of Pyramid Creek (1900 to 2014).

B.7.2 Tailoring flow recommendations for wet, average and dry years

To assist in the understanding of environmental flow objectives, throughout this report there is reference to wet, average and dry years. This allows, for example, higher magnitude events in wet years compared to dry years, fewer freshes during dry years, or longer duration high flows during wet years.

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

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

B.7.3 Current achievement of the environmental flow recommendations

The current level of achievement of the environmental flow recommendations for each reach was assessed. The assessment is based on an analysis of the modelled current flow record under current conditions. The level of achievement is presented as the percentage of time that the current flow regime meets the recommended flow regime. It also highlights the changes required to the current flow regime to achieve full compliance of the recommended environmental flows.

B.7.4 Uncertainty in flow recommendations

As discussed in Section B.6.1 a range of uncertainties exist in the modelling of current flows and in HEC-RAS models. There are also uncertainties in the response of various physical and biological processes and functions to flow. For example, we know that some fish require an increase in flow at a particular time of the year to trigger migration or spawning, however we don't know whether the biological response is related to the rate of flow change or a specific flow threshold, whether the flow increase must be of a certain duration, or whether there are other confounding factors. These knowledge gaps introduce further uncertainties to the flow recommendations.

The environmental flow recommendations presented in this report make use of the most up to date information that was available at the time of the assessment, but many information gaps remain. It is important that as our understanding of biological responses to flow improves (e.g. through monitoring and scientific research) the flow recommendations are amended to improve overall confidence.

Appendix C. Summary of issues and objectives

Flow recommendations are underpinned by the current conditions and environmental issues identified for the creek and the objectives established to address the identified issues. Below is a summary of the critical issues and objectives for Pyramid Creek. More details are provided in the *Issues Paper* (Jacobs, 2014a).

Pyramid Creek is a highly regulated stream that is used to supply irrigation water to the Kerang Lakes in the Torrumbarry Irrigation Area and a few customers en route. Flow regulation has reversed the natural seasonal flow patterns and Pyramid Creek now consistently has high flow throughout the irrigation season (i.e. August to May), and lower than natural flow over the cooler months (May to August).

Pyramid Creek was dredged in the 1960s and consequently has a trapezoidal channel form with steep banks and narrow, if at all, benches. Dredging removed all of the large wood from the stream and created a channel with little variation in depth or hydraulic habitat. As such there is relatively little habitat for fish, macroinvertebrates, Platypus and aquatic plants. Channel banks are typically degraded, especially in the sections where stock have unrestricted access. Fencing and revegetation programs have been very effective at improving vegetation cover on the banks of Pyramid Creek.

The lack of instream habitat limits the majority of Pyramid Creek's suitability as permanent habitat for native fish. There are records of large Murray Cod in the bottom of Pyramid Creek where it is influenced by the Kerang Weir Pool (Lieschke et al., 2013; SKM, 2008, 2009b, 2010a, 2011, 2012c; 2013a, unpublished data). It is critically important as a corridor for fish movement. The North Central CMA recently installed a fishway at Kerang Weir. Construction will soon begin on a fishway at Box Creek regulator and there are plans to build a new fishway in Taylor's Creek between Kow Swamp and Gunbower Creek. Native fish such as Golden Perch, Silver Perch and Murray Cod currently move from the lower Loddon River into Pyramid Creek. When fish passage is provided at the Box Creek regulator and Taylor's Creek, these and other fish species will be able to move between the Murray River, Loddon River, Pyramid Creek, Kow Swamp and Gunbower Forest. Such movement is a critical component of the breeding cycle for several native fish and therefore is expected to significantly increase recruitment and dispersal of native fish in these waterways, the Murray River and other connected tributaries. Pyramid Creek is also a potential migration corridor for juvenile Platypus and turtles that disperse from Kow Swamp or Gunbower Creek.

The highest priority environmental flow objectives for Pyramid Creek include:

1) Maintaining and enhancing native fish movement, colonisation, recruitment, habitat and connectivity.
2) Maintaining and promoting fringing vegetation on the lower banks of the channel.
3) Maintaining and enhancing channel conditions to facilitate the dispersal of juvenile Platypus and Eastern Long-necked Turtles.

The environmental flow objectives described in the *Issues Paper* (Jacobs, 2014a) and used as the basis for the recommendations in this report broadly align with the vision outlined in the 2014-2022 North Central Regional Waterway Strategy (North Central CMA, 2014a).

Environmental flow objectives for Pyramid Creek are documented in Table C-1. More detail is provided in the *Issues Paper* (Jacobs, 2014a).

Table C-1 Environmental flow objectives for Pyramid Creek.

Asset	Objective	Function	Flow component	Timing	Expected response
Geomorphology	Maintain and improve channel form along Pyramid Creek	Engage benches	Freshes/High flows	Anytime	Maintain and improve channel complexity through creation of benches.
Fish	Operate fishways	Maintain connectivity	Low flows	Continuous	Movement of fish through fishways
	Enhance colonisation of native fish species	Enhance colonisation	Freshes/High flows	Summer/Autumn	Increased distribution, abundance and diversity of native fish populations.
	Maintain habitat, water quality and connectivity	Maintain connectivity and habitat	Low flow	Spring/Summer/Autumn	Recruitment of Murray cod.
	Enhance recruitment of Murray cod and other native species	Enhance recruitment of Murray cod	Freshes/High flows	Spring/Summer	
Water quality	Reduce salinity levels	Mitigate adverse water quality conditions developing during winter low flow.	Low flow	Winter	Reduce salinity levels below the tolerances of ecological values.
			Freshes	Winter	
Aquatic and riparian vegetation	Maintain and promote fringing emergent (non woody) vegetation along the lower banks of the channel	Provide flow variability to maintain species diversity of fringing vegetation and stabilization of channel banks - with a focus on Common Reed (*Phragmites*). Maintain Tangled Lignum (*Muehlenbeckia*) on top of banks.	Low flow	Continuous	Improved longitudinal continuity and lateral density of emergent non-woody vegetation along stream banks.
			Freshes	Summer	
Platypus	Maintain Platypus population	Provide flows to assist with dispersal of juvenile Platypus.	Freshes	Autumn/Winter	Platypus will use creek as corridor for dispersal. Minimum flow depth of 0.5 m recommended.
Turtles	Maintain Eastern Long-necked Turtle populations	Maintain variable flows to provide a refuge location for turtles and a conduit for dispersal.	Freshes	Summer	Turtles will use this reach as a refuge location and an important, but alternative habitat source.

Note: Specific flow objectives have not been set for macroinvertebrates, frogs or birds. None of the expected flow changes in Pyramid Creek are likely to affect the macroinvertebrate community and therefore no specific flows are set for macroinvertebrates. Frog occupancy will be opportunistic, some common species may exist in the downstream reaches associated with littoral vegetation. No specific flow objectives are set for birds, flow objectives set for vegetation will assist in maintaining the creek as a corridor for the dispersal of birds.

Appendix D. Hydraulic models

D.1 Introduction

This report documents the inputs and calibration of the hydraulic models adopted for the Pyramid Creeks environmental flows project.

There were two models developed for Pyramid Creek:

- The Reach 1 site is located at the Mansfield Bridge gauge, upstream of Mansfield Road, Horfield.
- The Reach 2 site is located at Lyons Road, which is located downstream of the Murray Valley Highway to the West of Cohuna.

Refer to Figure D-1 for these reach locations.

Topographic data in the hydraulic models is based on field survey. During the survey, levels of the bed were measured at the top of the silt and the bottom of the silt. The top of silt values were adopted, as these reflect the flow conditions on the day of the survey. An example cross-section showing bed and silt levels is shown in Table D-2.

The hydraulic models were developed in HEC-RAS, a one-dimensional hydraulic analysis program developed by the US Army Corps of Engineers. The steady state modelling capabilities of this program were adopted for this project.

The following sections summarise relevant details for each model, including:

- General arrangement
- Cross-sections
- Mannings roughness values
- Calibration data
- Downstream boundary condition
- Modelled water surface profiles

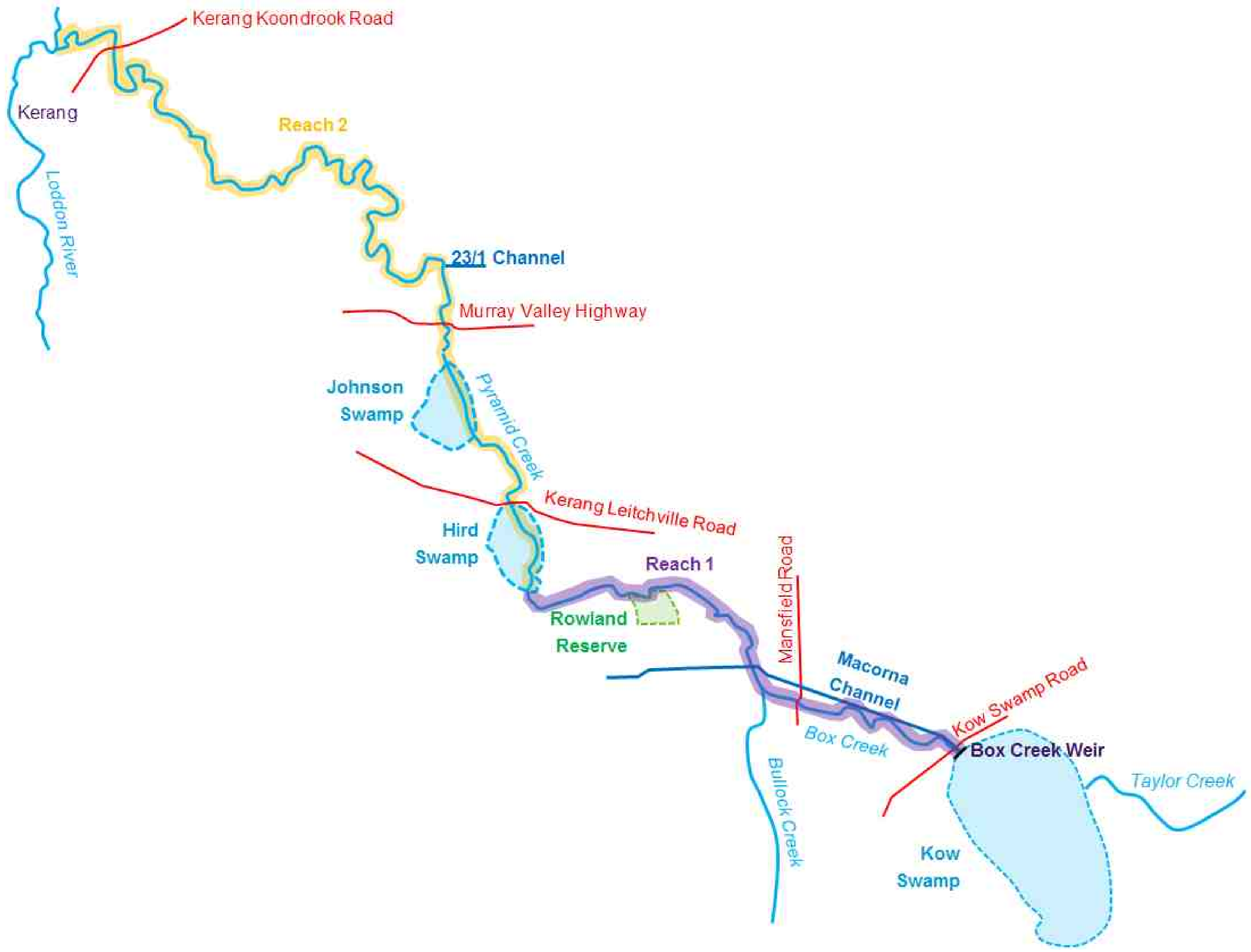


Figure D-1 Schematic map of Pyramid Creek.

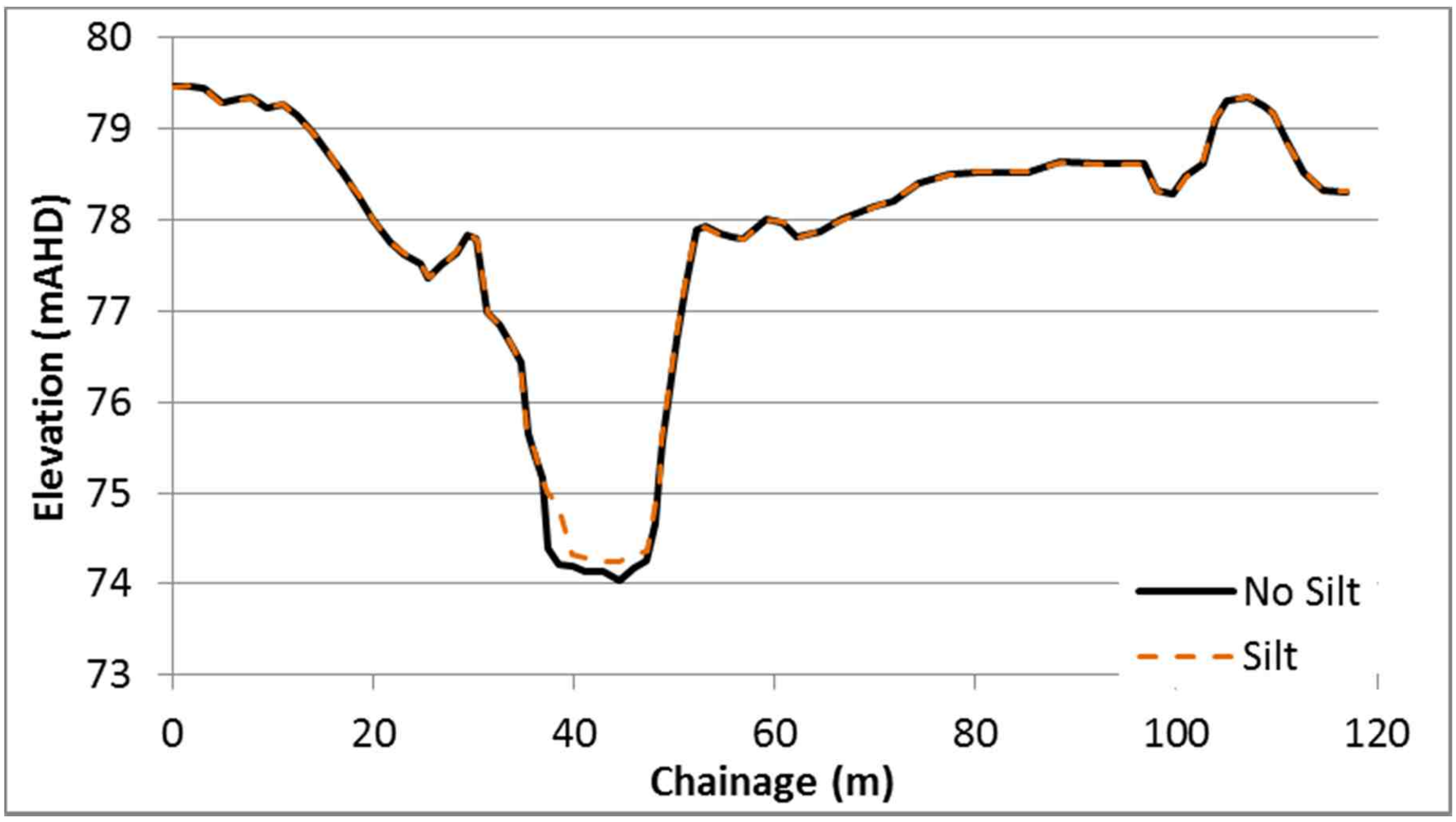


Figure D-2 Surveyed cross-section showing an example of the silt level and no silt (bed) level. The silt levels were adopted for all cross-sections for this study.

D.2 Box Creek at Mansfield Bridge

D.2.1 Previous Model

An existing model of Box Creek was created by SKM in 2012. The project number for this work was WT02389. Relevant information from the report is summarised in this section.

The model was created using survey conducted in June 2012 and LiDAR data from 2012. The model extends from upstream of the Box Creek Weir regulator at Kow Swamp to hydrographic station 407294 at Flannery's Bridge, 12 km downstream.

The structures included in the model and the basis for their geometry is:

- Box Creek Weir – this is modelled as an inline weir structure with gates
- Leitchville Road Bridge – the modelled bridge is based on surveyed dimensions and photographic record
- Mansfields Bridge – surveyed dimensions of the deck and photographic record
- Flannerys Flume – modelled as a bridge structure. Two versions of this are relevant, one with the flood relief gates open and the other with them closed.

Figure D-3 shows the locations of these structures relative to the environmental flows site.

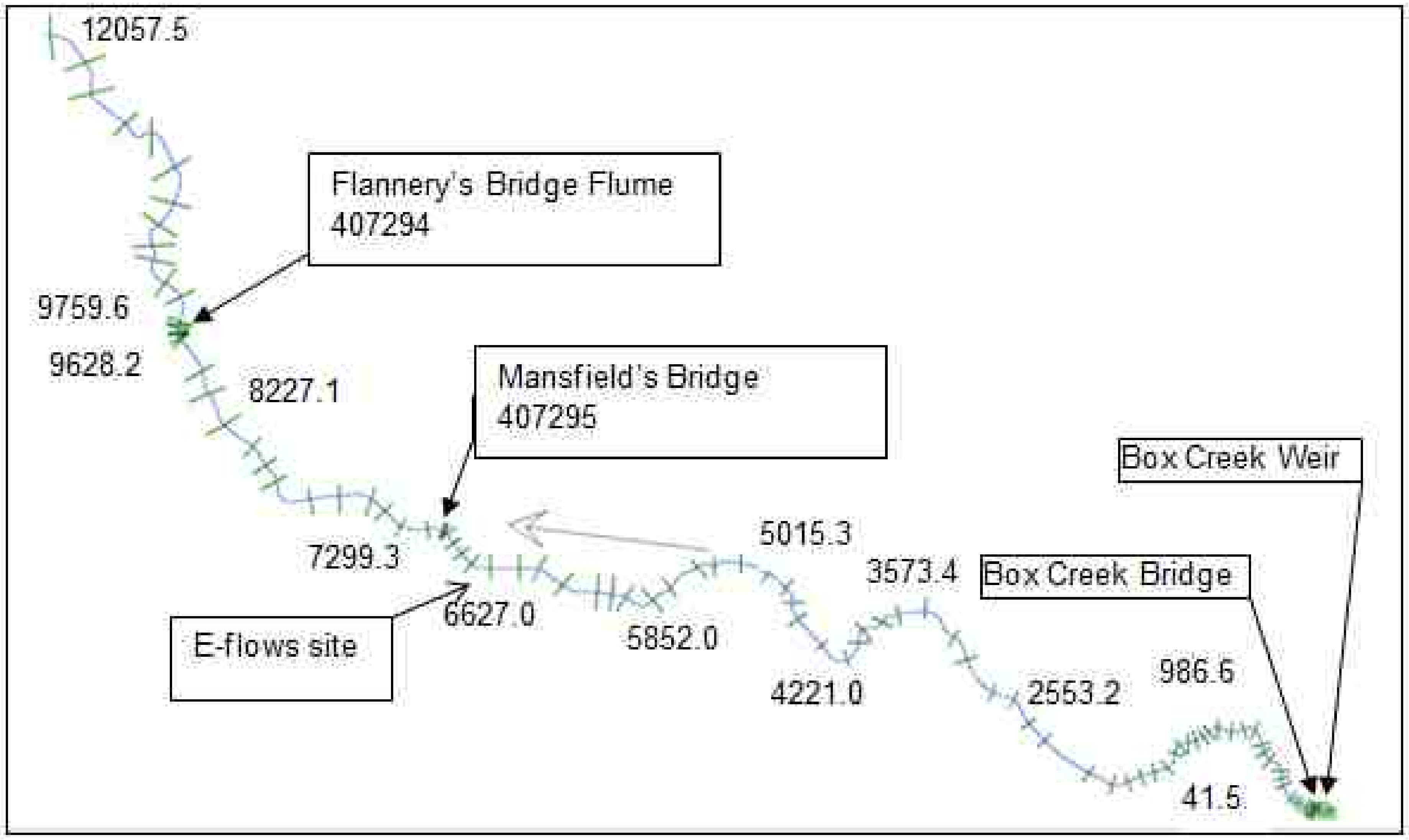


Figure D-3 Schematic of the previous Box Creek model.

D.2.2 Roughness

Mannings n values applied to the original model were:

- 0.025 for the channel
- 0.065 for the banks

D.2.3 Model Verification and Validation

Three gauges are maintained on Pyramid Creek:

- Box Creek @ D/S Kow Swamp Regulator – 407293
- Box Creek @ Mansfields Bridge – 407295
- Pyramid Creek @ Flannerys Bridge – 407294

Stage series are available for all three gauges for years 1992 to 2012, however a rating curve and gauged flow data is available at Mansfields Bridge only. This gauge was used to verify the HEC-RAS model for flows up to the highest gauged flow of 1,163 ML/day measured in 1996.

The downstream model boundary is based on a normal depth assumption with gradient 0.138/1000 (refer plan No 86181, Box Creek Remodelling Longitudinal Section). This is shown to extend through to the end of Hirds Swamp, a further 12 km downstream.

D.2.4 Comparison to Mansfields Bridge gauge (407295)

The HEC-RAS model has been verified against level and flow data available at Mansfields Bridge for low and medium flows. Figure D-4 shows that the HEC-RAS model matches the rating curve well up to flows of approximately 900 ML/day. At higher flows the HEC-RAS model predicts lower levels than the rating curve. The rating curve above the maximum measured flow of 1,163 ML/day has been extrapolated and HEC-RAS modelling results would not be expected to replicate this. Correspondence from DSE indicates that the rating is affected by back up (presumably from Bullock Creek inflows) for the higher flow. The extrapolated portion of the rating curve is not considered to be an accurate representation of the hydraulic behaviour of the creek (assuming no back up).

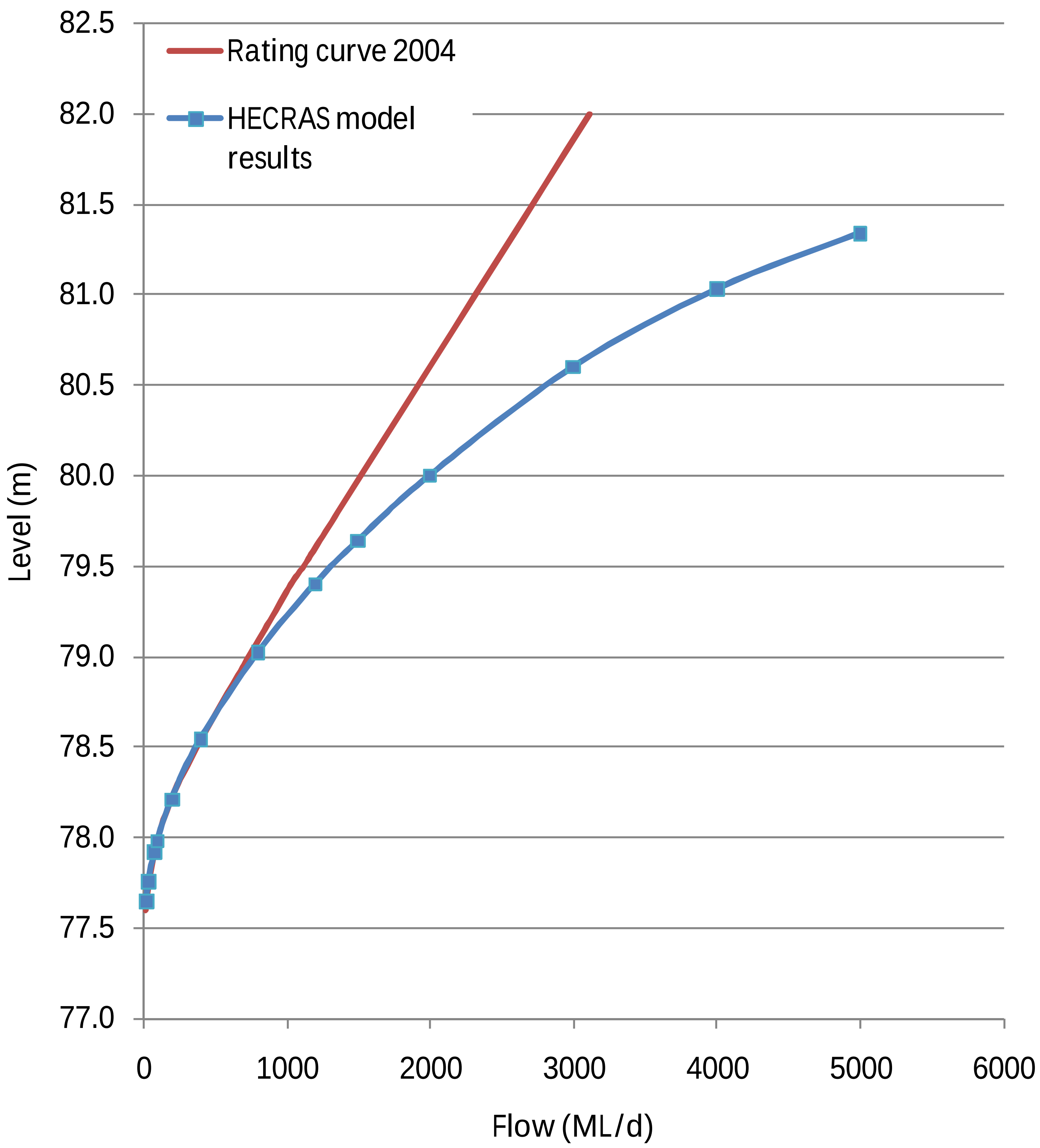


Figure D-4 Water levels based on the rating at 407295 and HEC RAS model results for flows of 17 ML/day to 5200 ML/day.

D.2.5 Model Updates

Survey for the current project was carried out on 4 June 2014 at four locations. The cross-sections and their placement in the existing model are shown in Table D-1. The site contains 4 surveyed cross-sections which represent a pool section, which is reflective of the entire reach. A schematic of the site is shown in Figure D-5 and Figure D-6. Water flows from cross-section 1 (right) to cross-section 4 (left).

Table D-1 Cross-sections entered into the existing model.

Cross-section	Previous model station	Note
XS1	-6627	Corresponds to the existing -6627 cross-section
XS2	-6897.2	Added cross-section 270.2 m downstream of XS1
XS3	-7065.7	Added cross-section 233.62 upstream of XS3 and 11.74 m upstream of the next cross-section at -7144.43
XS4	-7299.3	Corresponds to the existing -7299.3 cross-section

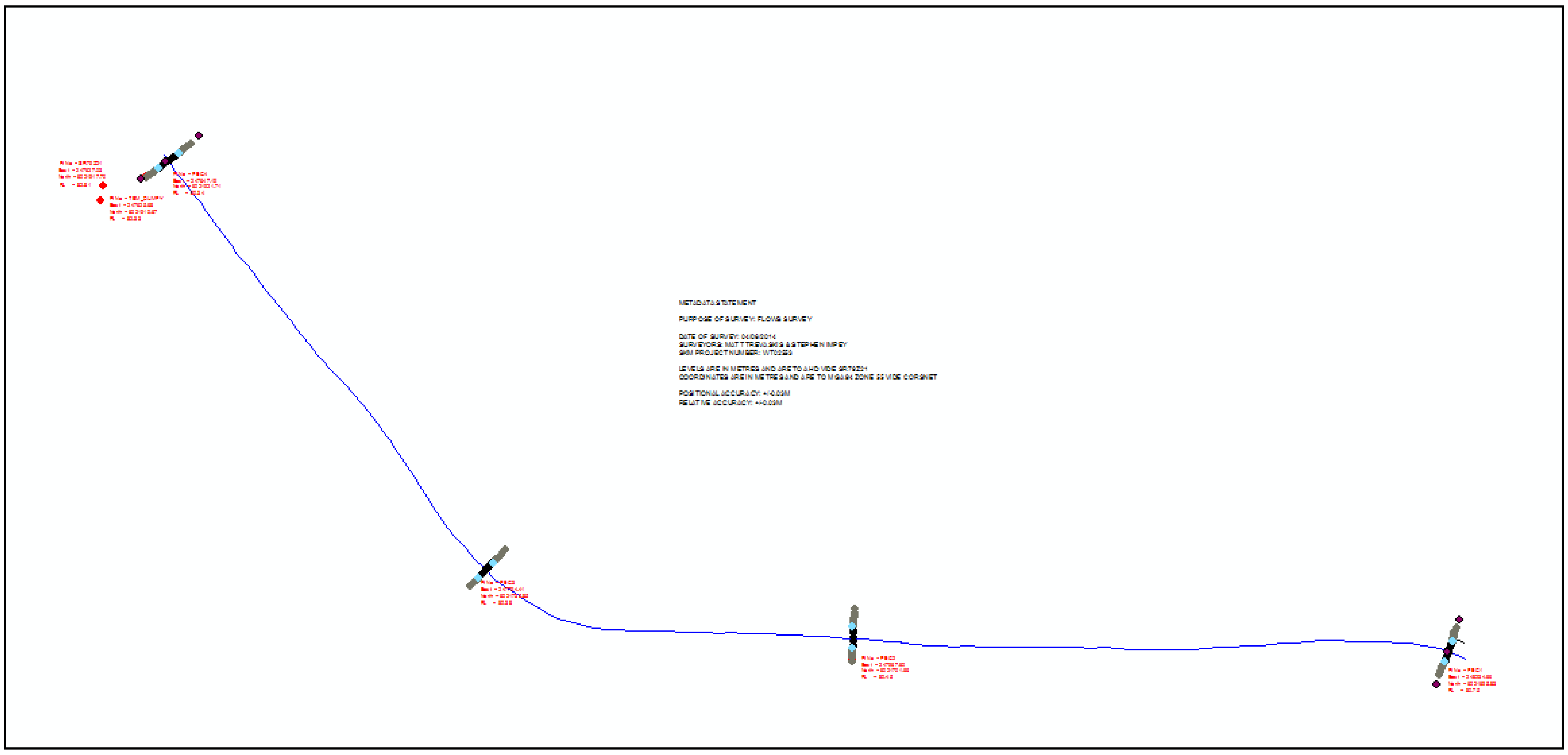


Figure D-5 Schematic of survey data for Box Creek at Mansfields Bridge.

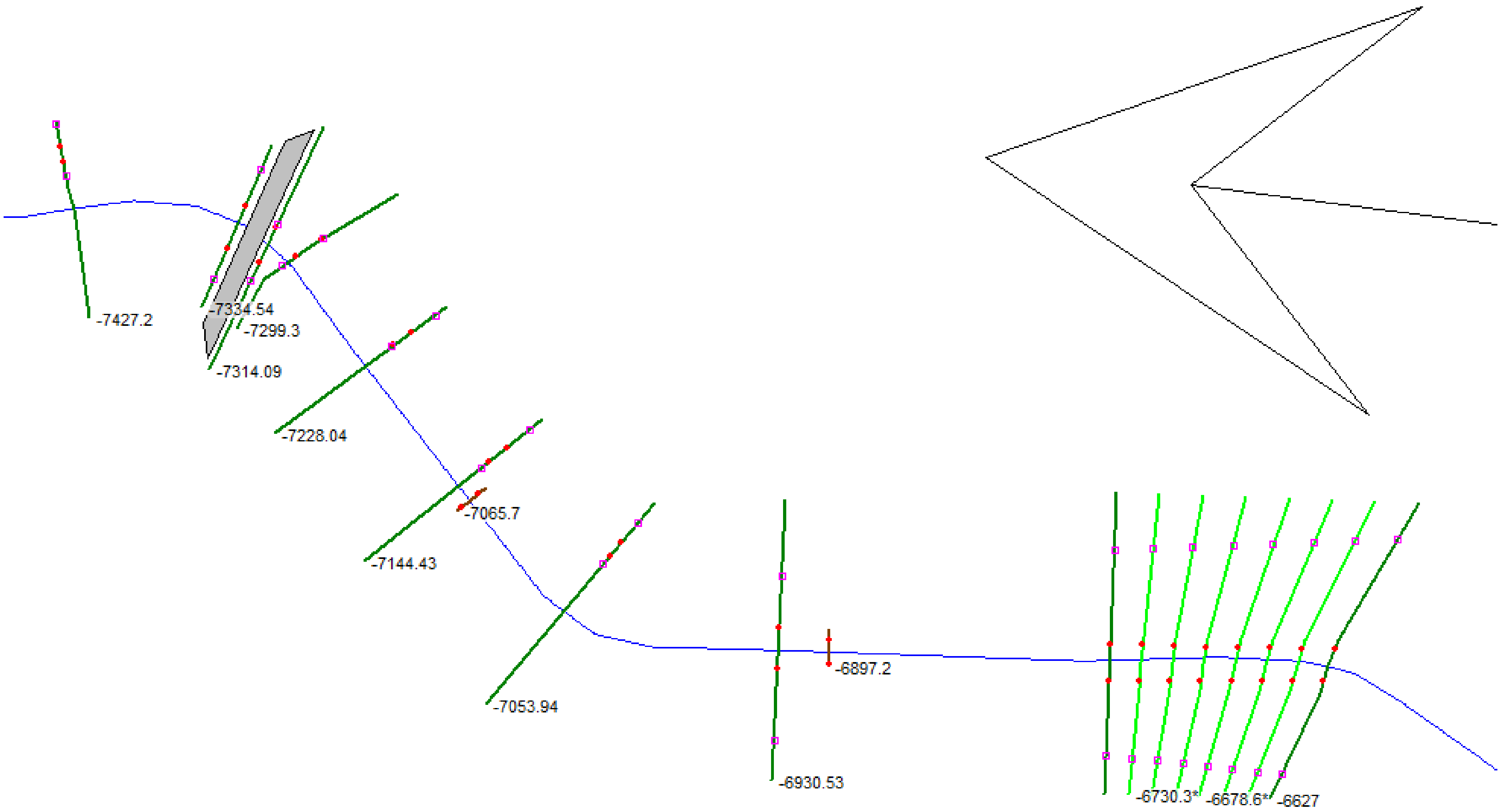


Figure D-6 Schematic of Box Creek at Mansfields Bridge, showing its location within the broader Box Creek model.

Cross-sections 1 and 4 which correspond to existing cross-sections in the model have been married to the existing cross-sections. That is, the wider LiDAR extents have been retained but the recent survey has replaced the channel part of the cross-section (as shown in the figures below). Cross-sections 2 and 3 which did not exist in the current model have not been extended to cover the wider banks. Not using LiDAR to extend cross-sections 2 and 3 onto the floodplain has no implications for the environmental flows study, because it is focusing on flows in the channel, and not onto the wider floodplain.

Bank and silt levels were picked up by the surveyors along the bottom of the channel. The silt level elevations only have been used in the model, as discussed in Section D.1.

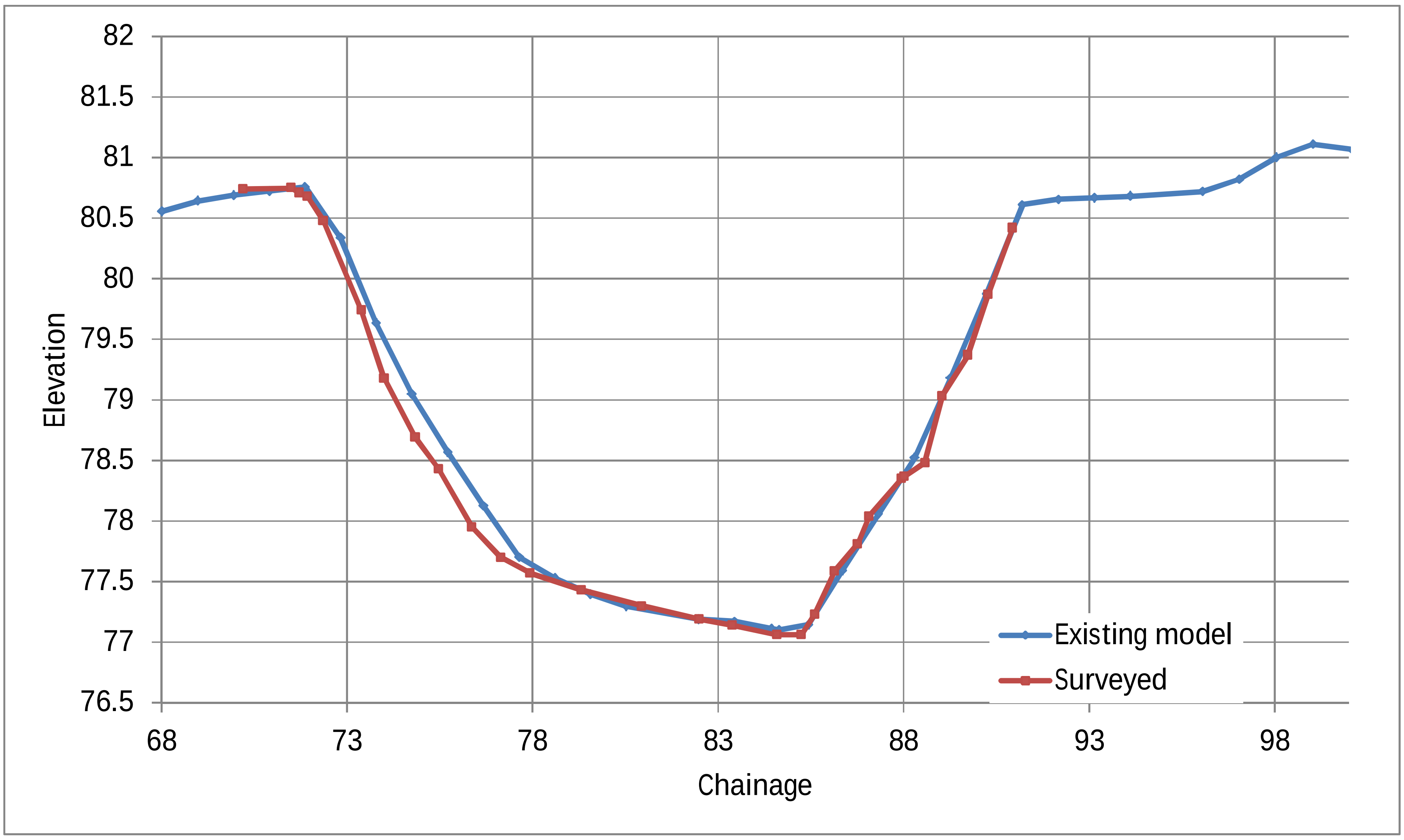


Figure D-7 XS1 surveyed cross-section and existing model cross-section comparison.

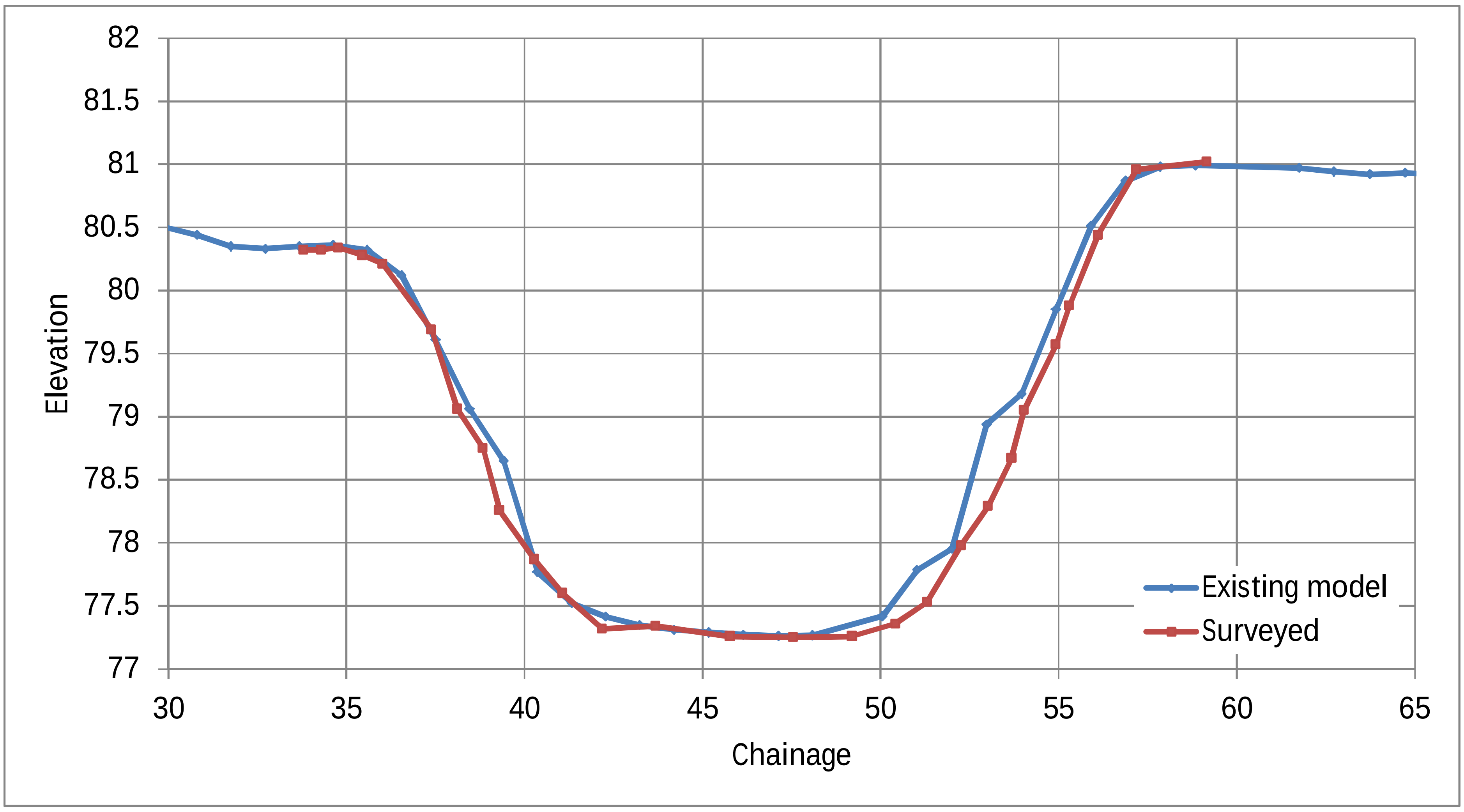


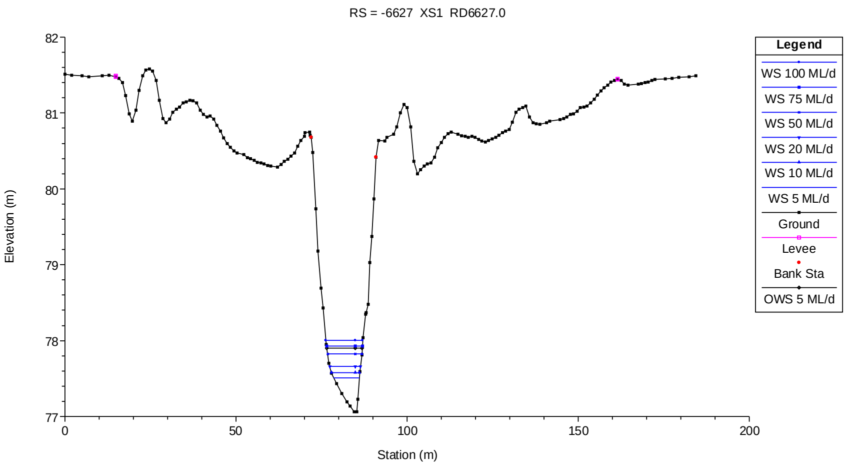
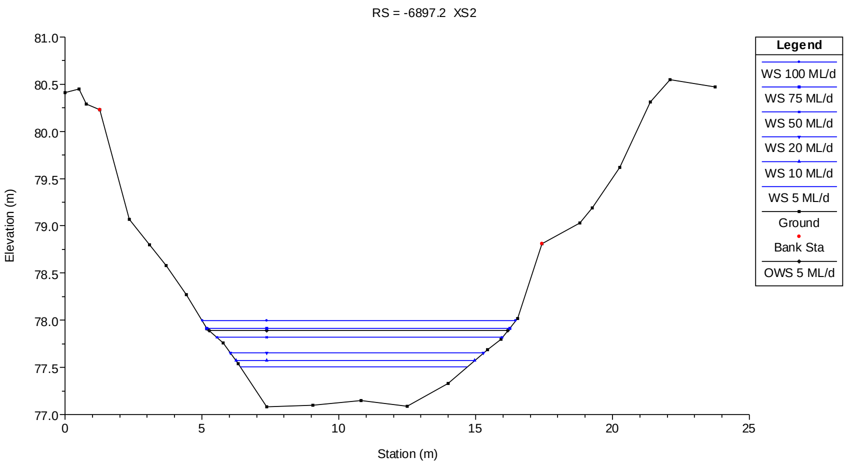
Figure D-8 XS2 surveyed cross-section and existing model cross-section comparison.

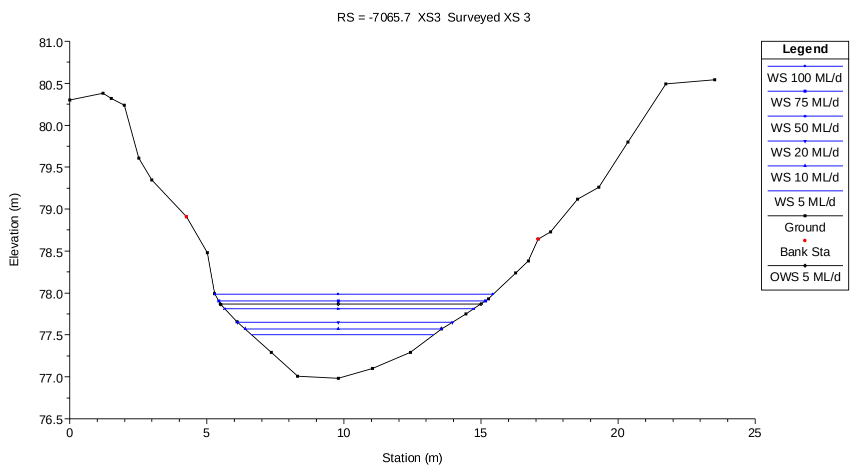
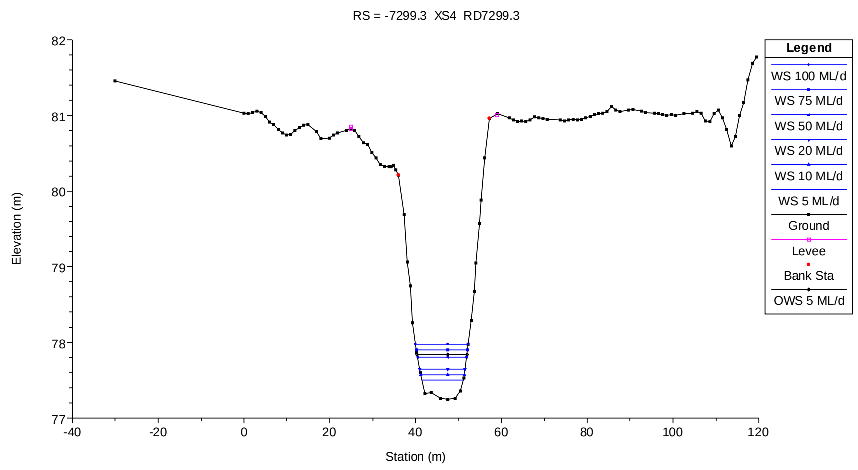
Interpolated cross-sections between stations -6627 and -6747.59 have been re-derived using the updated -6627 station, which combines the recent survey with the previous model cross-sections derived from LiDAR. Cross-section 4 from the current survey was copied for model station -7314.09, immediately upstream of Mansfields Bridge.

D.2.6 Cross-sections

The cross-sections are presented in Table D-2. All cross-sections were surveyed with the exception of one which was added to reflect a change in the channel bed elevation identified in the survey data.

Table D-2 Cross-sections Box Creek at Mansfield Bridge.

Cross-section	Photo
XS1 – Most upstream 	
XS2 	  Eroding left bank

XS3	
	
XS4	
	

D.2.7 Adopted Mannings Roughness

The adopted Mannings roughness values are shown in Table D-3.

Table D-3 Mannings roughness values for Box Creek at Mansfield Bridge.

Description	Mannings n value
Banks – short to medium grass	0.035
Instream – uniform section, clean	0.025

The Mannings roughness value adopted for the channel (0.025) is consistent with the previously developed model. In contrast, the Mannings roughness value used for the banks was reduced from the 0.065 used in the previous model to 0.035. This reduction was based on observations during site visits for the current project. The calibration of the hydraulic model to the flow on the day of survey does not involve the banks, and therefore this value does not affect the calibration. However, the Mannings value for the banks should be re-considered when running the model with higher flows, by making reference to the calibration done as part of WT02389 and site visits during the current project. For the purposes of this project, flows will not be recommended that overtop the channel, and therefore the Mannings value for the banks is not critical.

D.2.8 Calibration Data

The calibration data is presented in Table D-4 (flow data) and Table D-5 (water levels). It can be seen that the model calibrates well, ranging between an exact match and 4 cm variation from the observed water levels.

Table D-4 Model calibration information for Box Creek at Mansfields Bridge.

Parameter	Actual Data(gauge or surveyed)
Date of survey	4/6/2014
Representative flow gauge	407295A Box Creek @ Mansfields Bridge
Mean Flow (ML/d)	61.0
Mean Flow (m^3/s)	0.706

Table D-5 Water surface elevation results of calibration for Box Creek at Mansfields Bridge.

Cross-section	Observed Water Surface	Modelled Water Surface
XS1	77.91 77.89	77.87
XS2	77.89 77.88	77.87
XS3	77.87 77.86	77.86
XS4	77.83 77.85	77.85

D.2.9 Downstream Boundary Condition

The downstream boundary condition has not been changed from that applied in the previous model. A normal depth boundary was applied for the upstream and downstream boundary.

- Upstream normal depth with a slope of 0.003
- Downstream normal depth with a slope of 0.000138

Given the significant distance from the current area of interest to the upstream and downstream limits of the model, the boundary conditions have minimal impact on the hydraulic modelling results.

D.2.10 Modelled Water Surface Profiles

The water surface profiles modelled for the flow observed on the day of survey is shown in Figure D-9. Figure D-10 presents modelled profiles for a range of other flows. The vertical lines in the long section represent structures in the hydraulic model.

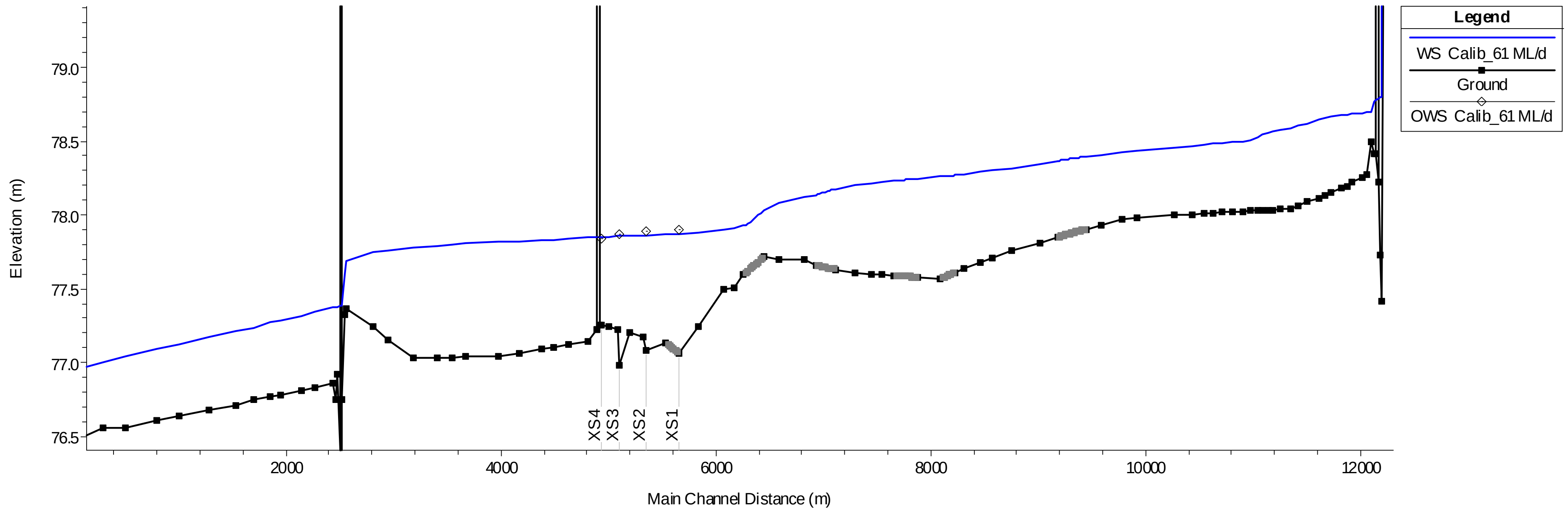


Figure D-9 Modelled water surface profile for Box Creek at Mansfield Bridge for the flow observed on the day of survey.

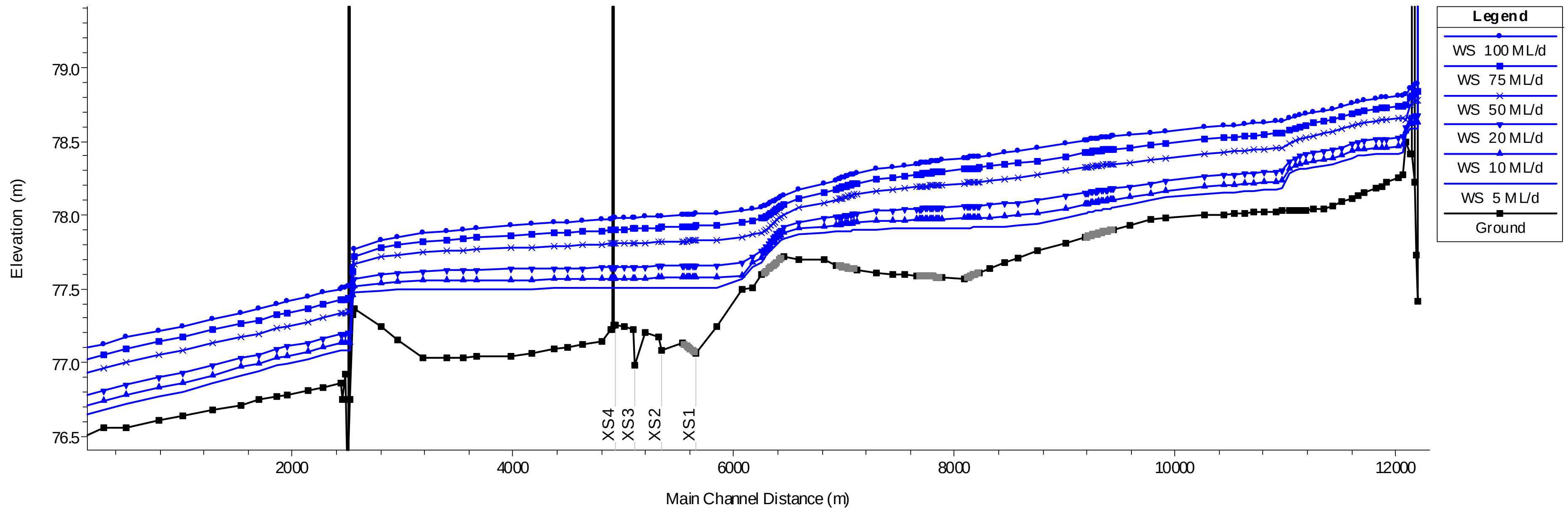


Figure D-10 Modelled water surface profiles for the Box Creek at Mansfield Bridge for a range of flows.

D.3 Pyramid Creek at Lyons Road

D.3.1 General

This site is located on Lyons Road, and is just downstream of the Murray Valley Highway to the west of Cohuna. The site contains 4 surveyed cross-sections which represent a pool section, which is reflective of the entire reach. A schematic of the site is shown in Figure D-11. Water flows from cross-section 1 (bottom) to cross-section 4 (top).

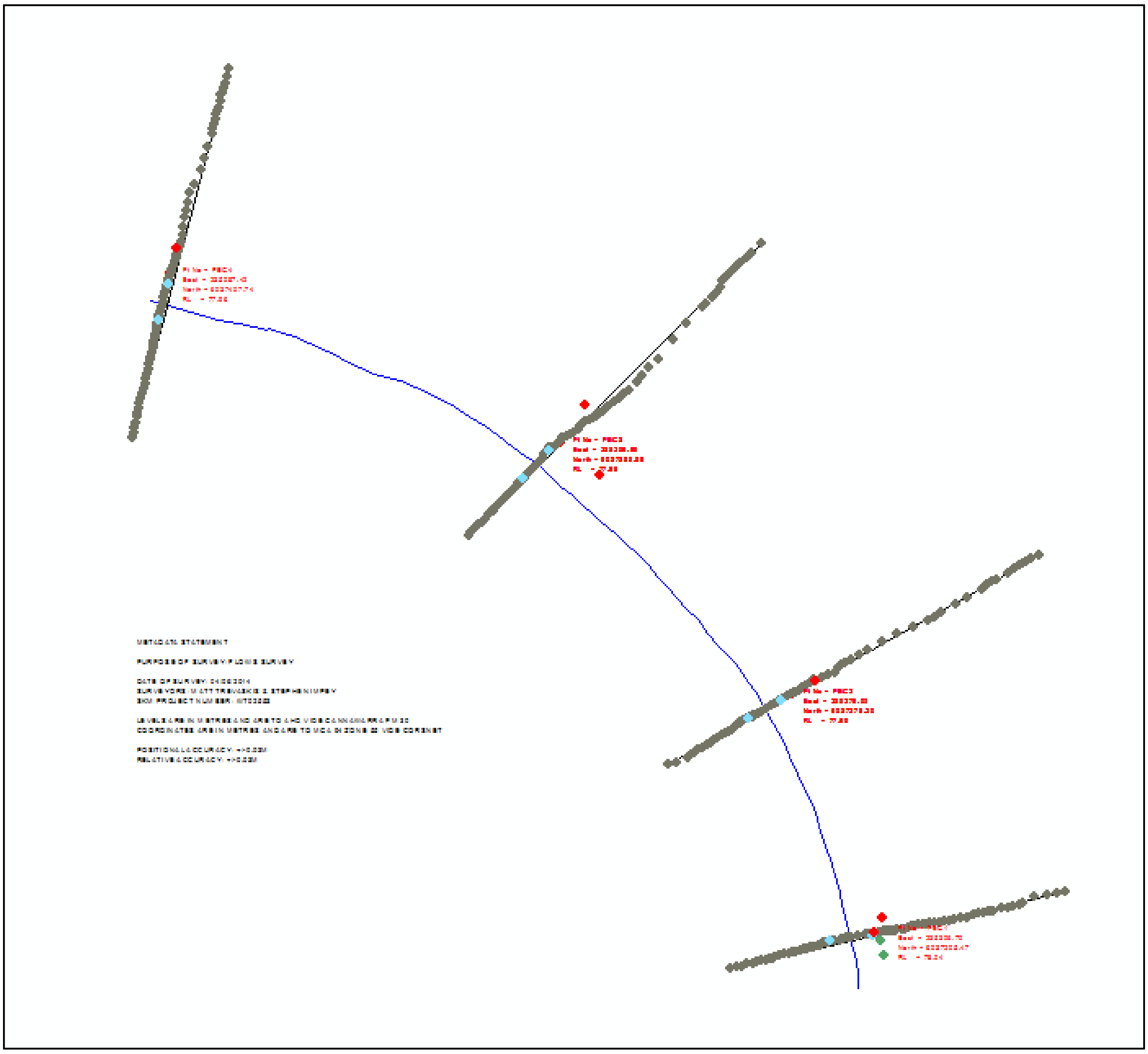
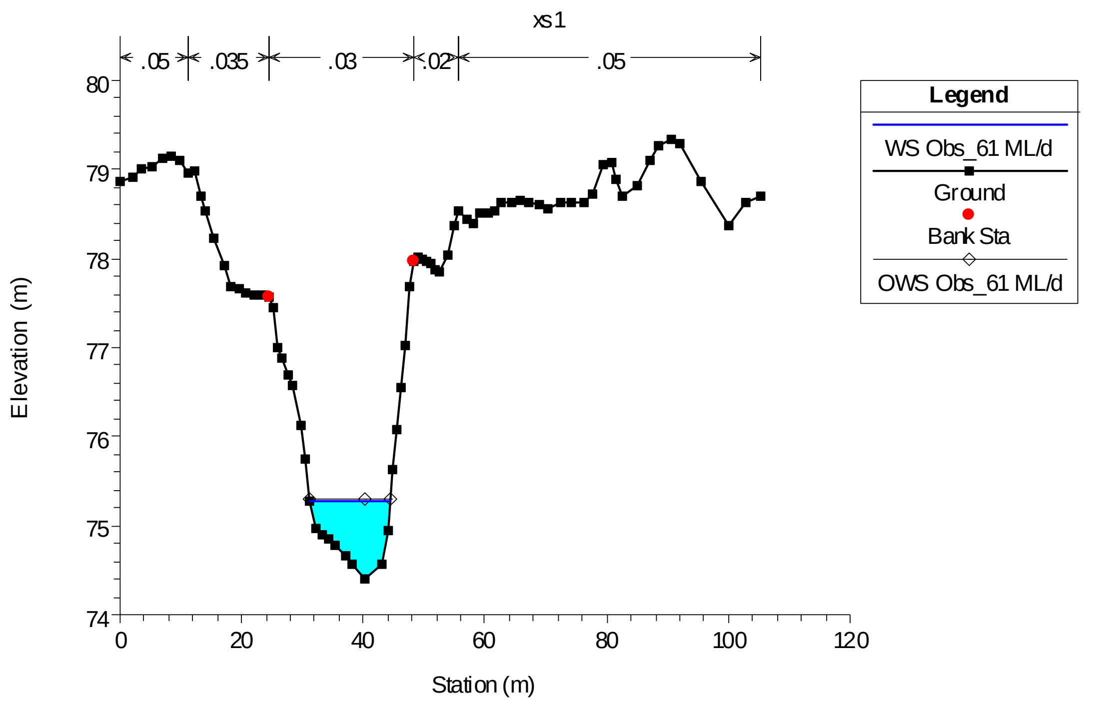
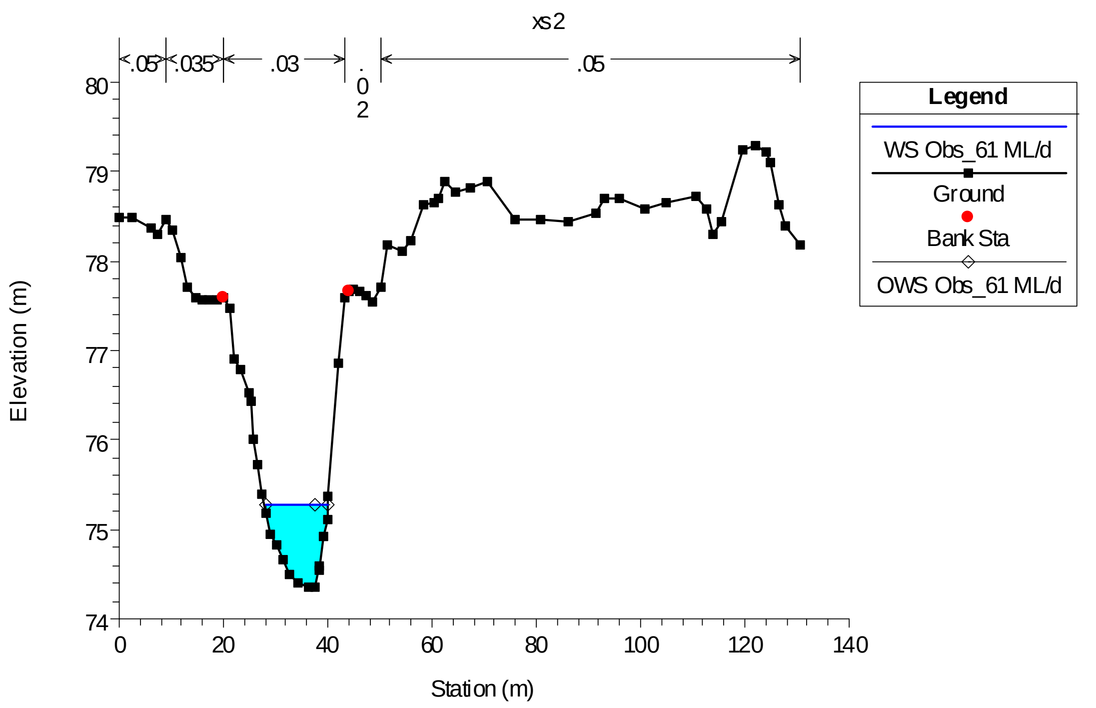


Figure D-11 Schematic of survey data at Pyramid Creek at Lyons Road.

D.3.2 Cross-sections

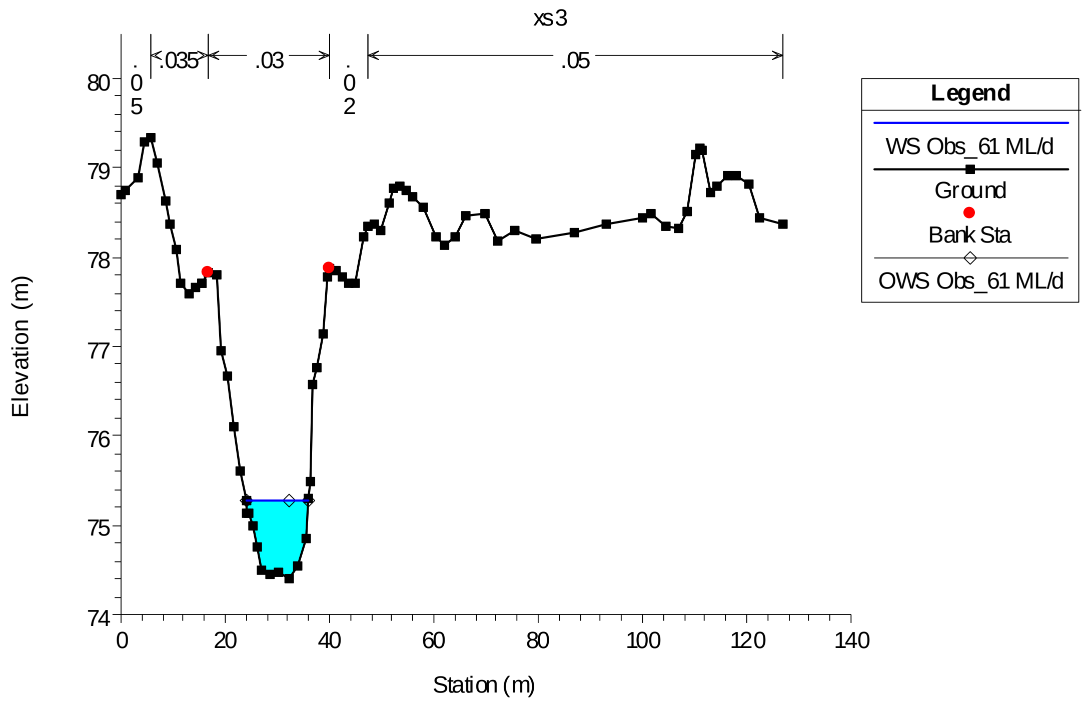
The cross-sections are presented in Table D-6. All cross-sections were surveyed.

Table D-6 Cross-sections Pyramid Creek at Lyons Road.

Cross-section	Photo
XS1 – Most Upstream 	
XS2 	

<table>
<tr><th>Cross-section</th><th>Photo</th></tr>
<tr><td>

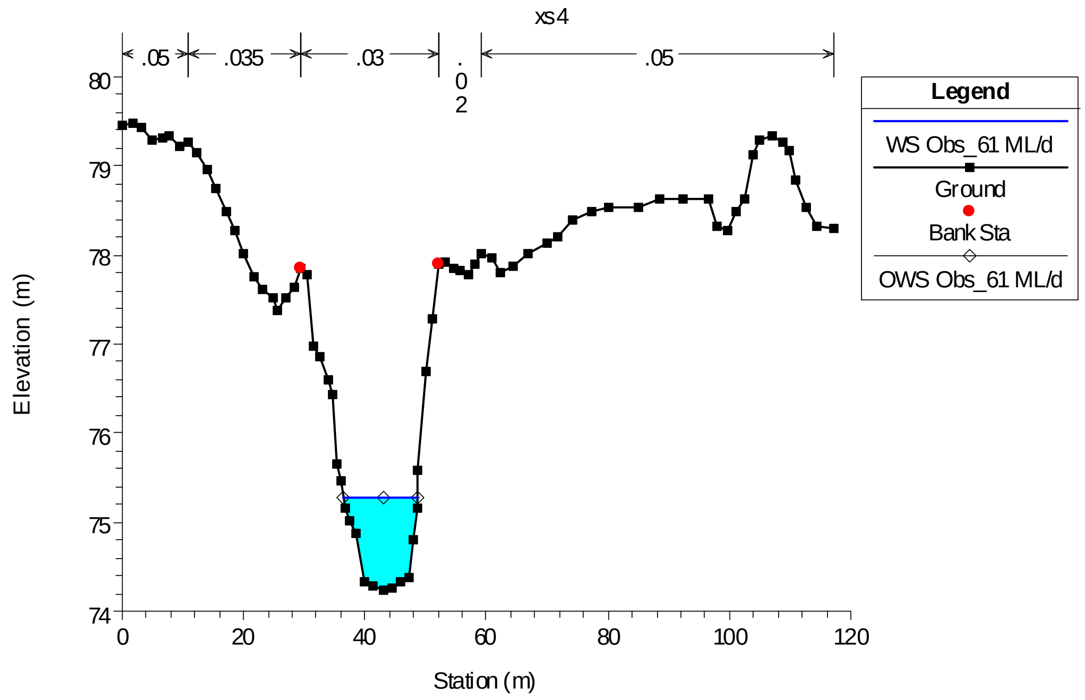
XS3



</td><td>

</td></tr>
<tr><td>

XS4 – Most Downstream



</td><td>

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</table>

D.3.3 Adopted Mannings Roughness

The adopted Mannings roughness values are shown in Table D-7.

Table D-7 Mannings roughness values for Pyramid Creek at Lyons Road.

Value	Description
0.02	Bare ground
0.035	Short to medium length grass
0.025	Instream – uniform section, clean
0.05	Light brush with some trees
0.07	Medium to dense brush

Value	Description
0.04	Instream – some winding, some weeds, some LWD

D.3.4 Calibration Data

The calibration data is presented in Table D-8 (flow data) and Table D-9 (water levels). It can be seen that the model calibrates well, ranging between an exact match and 1 cm variation from the observed water levels.

Table D-8 Mannings roughness values for Pyramid Creek at Lyons Road.

Parameter	Actual Data (gauge or surveyed)
Date of survey	4/6/2014
Representative flow gauge	407295A Box Creek @ Mansfields Bridge + 407287B Bullock Creek u/s Box Creek
Mean Flow (ML/d)	61.0
Mean Flow (m3/s)	0.706

Table D-9 Water surface elevation results for calibration of Pyramid Creek at Lyons Road.

Cross-section	Observed Water Survey	Modelled Water Surface
XS1	75.28 75.32	75.28
XS2	75.29 75.28	75.28
XS3	75.27 75.28	75.28
XS4	75.29 75.28	75.28

D.3.5 Downstream Boundary Condition

The adopted downstream boundary condition is a rating curve developed using the surveyed water levels and flow on the day of the survey along with a higher level developed using hydraulic computations based on the normal depth. This is presented in Figure D-12. This downstream boundary condition was applied to the most downstream surveyed cross-section at the site.

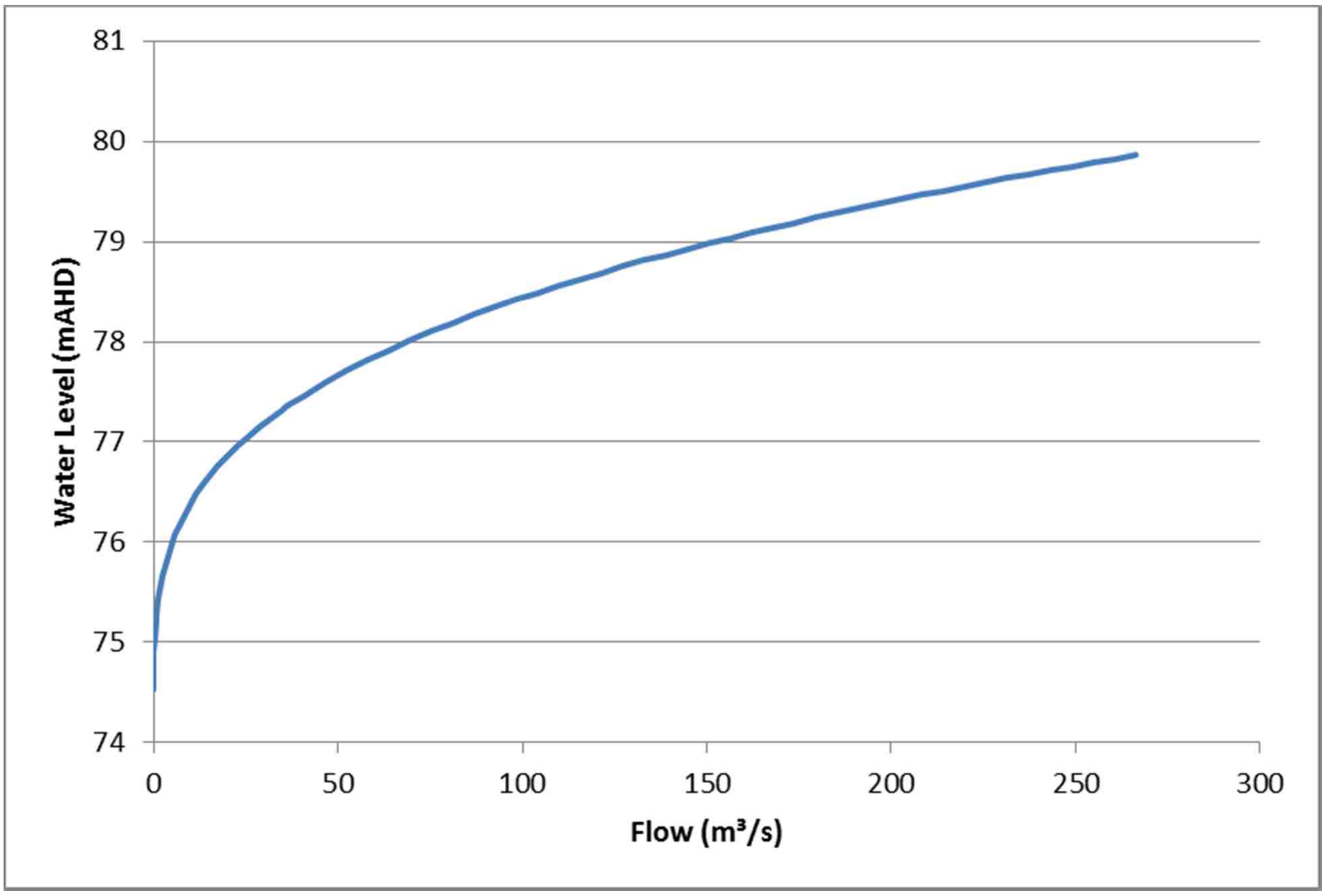

Figure D-12 Downstream rating curve boundary condition Pyramid Creek at Lyons Road.

D.3.6 Modelled Water Surface Profiles

The water surface profiles modelled for the flow observed on the day of survey, and other flows, are shown in Figure B-13.

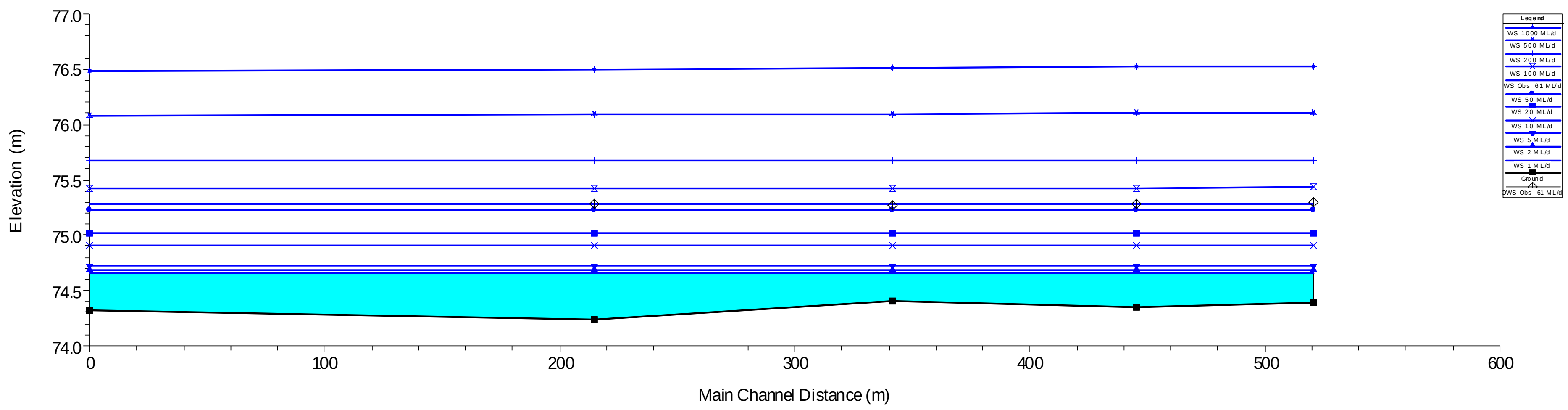

Figure D-13 Modelled water surface profiles for Pyramid Creek at Lyons Road.