Serpentine Creek Environmental FLOWS Study

NORTH CENTRAL CMA

Environmental Flow Recommendations Report

0004 | Final

24November 2014

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Serpentine Creek Environmental FLOWS Study

Project no:	WT02553
Document title:	Environmental Flow Recommendations Report
Document no:	0004
Revision:	Final
Date:	24 November 2014
Client name:	North Central CMA
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File name:	C:\Users\PSandercock\Documents\SKM Drive\WTAT\Projects\WT02553\Final Reporting\Serpentine_Final_Environmental_Flow_Recommendations_Report.docx

Cover Photo: Red Gum Woodland along Nine Mile Creek

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Document history and status

Revision	Date	Description	By	Review	Approved
0001	26/8/2014	Draft Report for Project Director Review	P. Sandercock	A. Sharpe	3/9/2014
0002	03/9/2014	Draft Report submitted to North Central CMA	P. Sandercock	NCCMA	11/9/2014
0003	18/9/2014	Draft Report submitted to North Central CMA	P. Sandercock	NCCMA	
0004	24/11/2014	Final Report submitted to North Central CMA	P. Sandercock	P. Sandercock	24/44/2014

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Study Overview

Serpentine Creek has been identified by North Central CMA as a waterway with high environmental values, potentially requiring the development of an environmental water management plan. An environmental flows assessment of Serpentine Creek is required to confirm the status of environmental values and define the water requirements of water dependant values.

The environmental flows assessment follows the FLOWS method. 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, Serpentine Creek has been divided into six reaches, but the FLOWS assessment will only focus on Reaches 1, 3, 5 and 6 (see Table E-1). Reaches 2 and 4 carry irrigation water and are effectively managed as permanent weir pools. They support important populations of native fish and other biota, but we have not specifically included them in the assessment because there is little scope to change their flow regime.

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

Environmental flow reach		Flows assessment site
1	Serpentine Creek from downstream of Serpentine Weir to connection with Waranga Western Channel	Serpentine Creek, downstream of Old Boort Road and Knife Edge Weir
2	Serpentine Creek from Waranga Western Channel to No 2 Weir	None
3	Serpentine Creek downstream from No 2 Weir to outfall from Irrigation Channel 7/10/1 (600 m upstream of Durham Ox Road)	Serpentine Creek, approximately 3km upstream from Irrigation Channel 7/10/1
4	Outfall from Irrigation Channel 7/10/1 (600m upstream of Durham Ox Road) to No 12 Channel	None
5	Nine Mile Creek from Nine Mile Regulator to River Red Gum Forest and Woodland	Nine Mile Creek at Nine Mile Regulator
		Nine Mile Creek at River Red Gum Forest and Woodland
6	Pennyroyal Creek downstream from Channel No 12 Outfall to downstream of Hopefield Road	Pennyroyal Creek downstream from Channel No 12 Outfall
		Pennyroyal Creek at Leaghur Road
		Pennyroyal Creek downstream of Hopefield Road

Water management goals

The water management goals for the Serpentine Creek and Nine Mile Creek FLOWS Reaches are outlined in Table E-2. The water management goal for Pennyroyal Creek has been developed for the expansive plain of Lignum and network of distributary channels, which cannot necessarily be watered by environmental water and existing infrastructure. The vegetation that fringes the dredged drainage lines along Pennyroyal Creek is currently maintained by outfall water. These wetter sections would provide some value to frogs, turtles, woodland and waterbirds, however they only exist as a result of the current operational regime.

Table E-2 Water management goals for Serpentine Creek, Nine Mile Creek and Pennyroyal Creek.

Environmental flow reach		Water Management Goal
1	Serpentine Creek from Serpentine Weir to connection with Waranga Western Channel	To improve the quality of emergent fringing and riparian vegetation along the creek to enhance habitat for native fish and Platypus.
3	Serpentine Creek downstream from No 2 Weir to Irrigation Channel 7/10/1 (i.e. 600 m upstream of Durham Ox Road)	To enhance the ecological value of the creek through the recruitment and succession of emergent vegetation communities, maintaining the health and facilitating the recruitment of River Red Gum trees and enhancing habitat for native fish, specifically River Blackfish and Platypus.
5	Nine Mile Creek from Nine Mile Regulator to River Red Gum Forest and Woodland	To maintain and enhance current vegetation values in Nine Mile River Red Gum Forest and Woodland.
6	Pennyroyal Creek downstream from Channel No 12 Outfall to downstream of Hopefield Road	To maintain the expansive plain of Lignum and network of distributary channels.

Environmental flow objectives

Serpentine Creek is a highly regulated system. Some sections of the creek are effectively managed as weir pools and are conduits for the distribution of irrigation water. Nine Mile and Pennyroyal Creeks have been extensively modified through the construction of irrigation channels, levees and floodplain drainage works. This environmental flow study focuses on maintaining and rehabilitating those environmental values that can persist or thrive in this regulated and modified system.

The highest priority environmental flow objectives for Serpentine Creek include:

1) Maintaining a viable breeding population of Platypus along Serpentine Creek that can disperse to the lower Loddon River and adjoining Murray River thereby contributing to a larger regional metapopulation.
2) Maintaining and enhancing native small and medium-bodied fish populations such as River Blackfish along Serpentine Creek.
3) Maintaining and enhancing the diverse aquatic and riparian vegetation communities present instream and on low lying banks and benches along Serpentine Creek.
4) Preventing blackwater events that lead to fish kills along Serpentine Creek by entraining leaf litter and limiting build-up of organic material in the channel over winter and providing flushing flows during summer.
5) Maintaining and improving the remnant River Red Gum Forest and Woodland along Nine Mile Creek and Tangled Lignum along Pennyroyal Creek.
6) Maintaining the current condition of the populations of turtles, frogs, woodland and waterbirds along Serpentine Creek, Nine Mile Creek and Pennyroyal Creek.

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 and Platypus populations to thrive in wet years, in order to increase their resilience to naturally lower flows in dry year.

The environmental flow recommendations for Reach 1 and Reach 3 of Serpentine Creek and the specific objectives they are intended to meet are summarised in Table E3 and Table E4.

Table E-3 Environmental flow recommendations for Serpentine Creek Reach 1.

Waterway	**Serpentine Creek from Serpentine Weir to Waranga Western Channel**		**Regime**	**Flow recommendations**			
Season	**Flow**	**Objective**	**Wet/Average/Dry**	**Magnitude**	**Frequency and timing**	**Duration**	**Rise/Fall***
Summer / Autumn (Dec–May)	Low flow	Maintain spawning habitat and water levels for River Blackfish Maintain pool and run habitats for fish, macroinvertebrates, Platypus, turtles, birds and submerged aquatic vegetation. Prevent low dissolved oxygen during low flow periods.	All years	10 ML/day	10 ML/day January to May		NA
				20 ML/day	Required throughout December to maintain spawning habitat for River Blackfish		NA
	Fresh	Allow fish, Platypus and turtle movement through reach Inundate benches and water fringing vegetation Inundate wood and promote biofilm development Maintain water quality and prevent low dissolved oxygen conditions	Wet / Average	40 ML/day	4 events	2-3 days	140%/88%
			Dry	40 ML/day	2 events	1-2 days	140%/88%
Winter / Spring (Jun-Nov)	Low flow	Maintain spawning habitat and water levels for River Blackfish Maintain pool and run habitats for fish, macroinvertebrates, Platypus, turtles, birds and submerged aquatic and fringing vegetation.	Wet / Average	30 ML/day	Whole season		NA
			Dry	20 ML/day	Whole season (but for no more than 3 consecutive years, after which time the flow should be raised to 30 ML/day for at least one year).		NA

Waterway	Serpentine Creek from Serpentine Weir to Waranga Western Channel		Regime	Flow recommendations			
Season	**Flow**	**Objective**	**Wet/Average/Dry**	**Magnitude**	**Frequency and timing**	**Duration**	**Rise/Fall***
	Fresh	Flush organic material from banks to prevent risk of blackwater during summer Inundate benches and water fringing vegetation Inundate wood and scour biofilms from stream bed Inundate benches to provide breeding habitat for frogs	Wet / Average	120-150 ML/day	1 event. 150 ML/day ideally needs to be delivered before start of August. If not delivered by start of August, limit to 120 ML/day to avoid disrupting Platypus feeding or burrows when they have young.	1 day	180%/50%
			Dry	40 ML/day	1 event Increasing flow slightly in dry years provides important flow variability and flushes organic material from the bank to reduce risk of blackwater in summer, but it doesn't water plants on low benches.	2 days	140%/88%

*Reccomended rates of Rise/Fall are a percentage of the previous days flow and have been determined based on assessment of representative fresh/high flow events for the current flow regime.

Table E-4 Environmental flow recommendations for Serpentine Creek Reach 3.

Waterway	Serpentine Creek from No. 2 Weir to outfall from Irrigation Channel 7/10/1		Regime	Flow recommendations			
Season	**Flow**	**Objective**	**Wet/Average/Dry**	**Magnitude**	**Frequency and timing**	**Duration**	**Rise/Fall***
Summer / Autumn (Dec–May)	Low flow	Maintain spawning habitat and water levels for River Blackfish Maintain pool and run habitats for fish, macroinvertebrates, Platypus, turtles, birds and submerged aquatic vegetation Prevent low dissolved oxygen during low periods	Wet / Average	10 ML/day	10 ML/day January to May		NA
				30 ML/day	Required throughout December to maintain spawning habitat for River Blackfish.		NA
			Dry	5 ML/day	5 ML/day January to May		NA
				30 ML/day	Required throughout December to maintain spawning habitat for River Blackfish.		NA
	Fresh	Allow fish, Platypus and turtle movement through reach Inundate low benches and backwaters Water fringing vegetation Maintain water quality and prevent low	Wet / Average	30-40 ML/day	4 events	2 days	150%/55%
			Dry	30-40 ML/day	4 events in dry years when plants are establishing, 2 events in dry years once plants are established	2 days	150%/55%

Waterway	Serpentine Creek from No. 2 Weir to outfall from Irrigation Channel 7/10/1		Regime	Flow recommendations			
Season	**Flow**	**Objective**	**Wet/Average/Dry**	**Magnitude**	**Frequency and timing**	**Duration**	**Rise/Fall***
		dissolved oxygen conditions					
Winter / Spring (Jun-Nov)	Low flow	Maintain spawning habitat and water levels for River Blackfish Inundate low benches and backwaters for fish and Platypus Flush organic material from benches to prevent risk of blackwater during summer	All years	30-40 ML/day	Whole season		150%/55%
	Fresh	Flush organic material from banks to prevent risk of blackwater during summer Wetting of wood for bugs and biofilms and provision of fish habitat Inundate benches to provide breeding habitat for frogs	Wet / Average	Min 100 ML/day. Could go as high as 200 ML/day in September/ October	1 event, 3 out of 4 years	2-3 days	180%/70%
			Dry	Not expected	No more than 3 years without an event		NA
	High flow	Maintain channel and scour pools Provide cues for recruitment of River Red Gums	Wet / Average	≥ 500 ML/day	For River Red Gum recruitment and maintenance 2 events per year in 2 consecutive years twice per decade, with no more than 4 years without an event. First event each year in Jul-Aug (preferably Aug) to wet the bank and benches, second event each year in Sep-Nov to stimulate RRG recruitment.		200%/50%
			Dry	Not expected			NA
	Overbank	Maintain channel and scour pools Provide cues for recruitment of River Red Gums	Wet / Average	>1000 ML/day	For River Red Gum recruitment and maintenance 2 events per year in 2 consecutive years twice per decade, with no more than 4 years without an event. First event each year in Jul-Aug (preferably Aug) to		NA

Waterway	Serpentine Creek from No. 2 Weir to outfall from Irrigation Channel 7/10/1		Regime	Flow recommendations			
Season	**Flow**	**Objective**	**Wet/Average/Dry**	**Magnitude**	**Frequency and timing**	**Duration**	**Rise/Fall***
					wet the bank and benches, second event each year in Sep-Nov to stimulate RRG recruitment.		
			Dry	Not expected			NA

*Reccomended rates of Rise/Fall are a percentage of the previous days flow and have been determined based on assessment of representative fresh/high flow events for the current flow regime.

The environmental flow recommendations that have been developed for Nine Mile and Pennyroyal Creek are not as specific as those developed for Serpentine Creek. Setting flow recommendations for these distributary streams would require the development of complex two-dimensional hydraulic models, which is beyond the scope of this FLOWS study. The generic water requirements of Nine Mile and Pennyroyal Creek have been identified and these are outlined in this report.

This project assessed the water requirements of the River Red Gum Forest and Woodland areas in the upper 1.5 km of Nine Mile Creek. The River Red Gum Forest areas are low lying and will be inundated by moderate floods which occur more frequently than the River Red Gum Woodland areas which occoup slightly higher ground. River Red Gum forest areas require one inundation event in winter/spring every 2-3 years in wet and average conditions, for a duration of 2-6 months with water depths ranging from 200-500 mm. River Red Gum Woodland areas require one inundation event in winter/spring every 3-5 years in wet and average conditions, for a duration of 2-4 months with water depths of 200-500 mm. The River Red Gum Forest and Woodland areas would not be inundated at all in dry years and therefore we do not recommend delivering any environmental water to Nine Mile Creek in dry years.

Overbank flows, every 3 to 10 years for a duration of 1-6 months are recommended to maintain the distributary channel network and water Tangled Lignum along Pennyroyal Creek. Short duration flows of 30-100 ML/day provided by Channel No 12 outfall to Pennyroyal Creek maintain the submerged aquatic and fringing vegetation along the dredged drainage channels. Suitable habitat for Bibron's Toadlet (FFG listed) exists along Pennyroyal Creek. Bibron's Toadlet lay eggs in dry channels and need inundation in April-May to facilitate tadpole metamorphosis. Flows that inundate seasonally dry channels every one to two years are required to promote and support frog breeding events. The current outfall flows maintain instream values along Pennyroyal Creek. Any proposed changes to outfall operations should trigger a separate investigation to determine whether any actions are required to mitigate the effect of such changes.

Current achievement of environmental flow recommendations

An assessment of how well the flow recommendations for Reach 1 and 3 of Serpentine Creek are currently met in wet, average and dry years has been provided in this study.

In Reach 1 the low rate of compliance with the recommended flow regimes for average and dry years is likely to place significant stress on environmental values. Maintaining a minimum summer/autumn low flow of 10 ML/day throughout the months of January to May and a higher flow of 20 ML/day in December is critical to maintain adequate water quality and habitat for existing environmental values such as River Blackfish and Platypus. Increasing the magnitude of the winter/spring low flow and the frequency of freshes throughout the year has the potential to improve the condition of existing environmental values and facilitate the recruitment and recolonisation of some native flora and fauna that are currently in very poor condition or absent.

As with Reach 1, in Reach 3 summer/autumn low flow and winter/spring low recommendations are critical events for maintaining access to habitat for fish and Platypus throughout the year. The poor compliance with recommended low flows, especially the winter/spring low flow, indicate that there is a need to increase low flows through this reach in order to improve conditions for fish and Platypus. The frequency of fresh events in this reach is too high and is considered to have a disturbing influence on vegetation recruitment in the littoral zone and higher on the banks. Implementing a flow regime with more constant low flows and less frequent freshes presents a significant opportunity to improve the conditions for vegetation recruitment within the littoral zone and on the banks.

Management and monitoring recommendations

Changes to the existing flow regime are unlikely to significantly improve the ecological condition of Serpentine 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 monitoring the effectiveness of existing riparian management agreements and community engagement activities that increase landholders skills and awareness in riparian management practices.
- Investigation and treatment of urban water pollution from Serpentine Town.

A number of knowledge gaps were identified that need to be addressed as part of future investigations that consider the potential for watering the River Red Gum Forest and Woodland areas along Nine Mile Creek. These include:

- An assessment into the causes of any variance in the condition of vegetation along Nine Mile Creek.
- Detailed hydrological modelling of Nine Mile Creek to determine the magnitude of flows required to water different parts of the forest and woodland areas and the potential salinity impacts on downstream Accountable Actions (under the Murray-Darling Basin Salinity Management Strategy) of watering events.
- Assessment of options for watering the River Red Gum Forest and Woodland areas along Nine Mile Creek and any additional works and measures required to implement a particular watering regime (i.e. levees, regulator structures).

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:

- Water quality monitoring stations in the lower sections of Serpentine Creek in Reaches 1 and 3 to confirm that recommended low flows meet minimum depth and quality requirements during low flow periods.
- Further monitoring of water levels along Nine Mile Creek flow paths in response to variations in flow at Serpentine offtake would assist in developing an understanding of the magnitude of flows that are required to inundate different areas of the River Red Gum Forest and Woodland areas and how water gets into different parts of the forest and woodland.
- Aquatic fauna surveys to monitor populations of native fish, platypus and turtles along Serpentine Creek. Frog surveys are also recommended to inform the contemporary composition and abundance of the frog fauna and guide future watering plans in the Serpentine Creek catchment.
- Waterbird surveys in Nine Mile Creek during inundation events to develop a better understanding of the flows that are needed to ensure breeding success.

Development of an Environmental Watering Management Plan

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

- Nine Mile Creek represents a natural or near-natural example of River Red Gum Forest/Woodland as evidenced by a relative lack of post-1788 human induced hydrologic disturbance or adverse impacts on ecological character [Criterion 2(a)].

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

- Serpentine Creek provides vital habitat including: refuges for native water-dependant biota during dry spells and droughts; pathways for the dispersal and movements of native water-dependant biota; important feeding, breeding and nursery sites for native water-dependent biota [Criterion 3(a)].
- Serpentine Creek is essential for maintaining, and preventing declines of, native water-dependant biota such as native fish, platypus and turtles [Criterion 3(b)]. The population of River Blackfish is considered regionally significant (DSE, 2013).
- Serpentine Creek supports one or more native-water-dependant species treated as threatened or endangered under State or Territory law [Criterion 4(c)]. The River Red Gum Forest and Woodland in Nine Mile Creek and Lignum plains along Pennyroyal Creek potentially supports the FFG listed Brolga. Pennyroyal Creek may also support FFG listed and endangered Bibron's Toadlet.
- With environmental watering Serpentine Creek is capable of supporting, significant numbers of individuals of native water-dependant species [Criterion 5(b)], including Platypus, River Blackfish and Eastern Long-necked Turtles.

We consider that Serpentine Creek meets the criteria established in Schedule 8 of the Basin Plan, therefore an EWMP should be developed. The technical work presented in this report is sufficient to develeop an EWMP for Reaches 1 and 3. However, as discussed further technical work needs to be undertaken before an EWMP can be developed for Nine Mile and Pennyroyal Creek.

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to describe the specific flow components, including the magnitude, timing, duration and frequency of flow events that are required to meet the environmental flow objectives developed for Serpentine Creek 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 29th and 30th April 2014 as well as the 19th to 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 the 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, 2014b).

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.

Serpentine Creek has not received environmental water due to legal constraints on where water can be delivered under the Bulk Entitlement (Loddon River – Environmental Water Reserve) and a general lack of knowledge about required Environmental Flows. The legal constraints are currently being resolved and will create the opportunity to deliver environmental water to Serpentine Creek if deemed to be a high value environmental asset (North Central CMA, 2014b).

Serpentine Creek has been identified as a waterway that supports high environmental values (North Central CMA, 2014b). The creek supports a number of water dependant flora and fauna, including a regionally significant population of River Blackfish (SKM, 2013) and a well-established breeding population of Platypus (M. Serena pers. comm.).

About 1.5 km downstream of its divergence from Serpentine Creek, the Nine Mile Creek broadens and flattens out into a low lying barely distinguishable drainage line. This area supports a mixed age River Red Gum floodplain riparian forest and woodland with a diverse understorey of flood dependant and tolerant herbs, including three rare species and sedges (Campbell et al., 2009). Pennyroyal Creek receives outfall water from Serpentine Creek through an automated gate and flows in a north-westerly direction. Pennyroyal Creek traverses an extensive plain of Lignum (Foreman & Westerway, 1994).

An environmental flow study is required to confirm the environmental values, establish a water management goal, ecological objectives and hydrological regimes for Serpentine Creek. This project uses the FLOWS method to determine the environmental flow requirements for Serpentine 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.

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

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

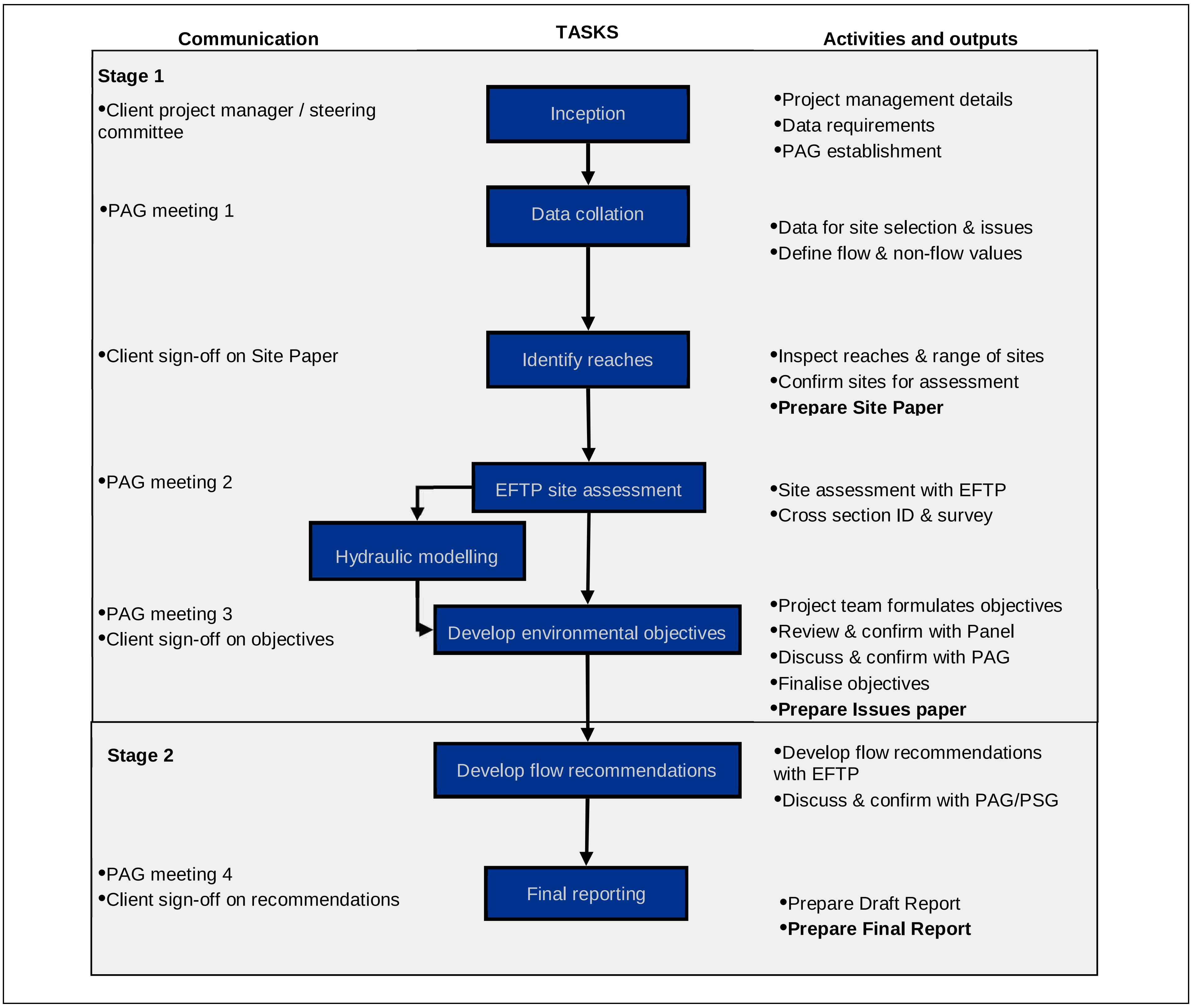

Figure 1-1 Outline of the tasks, activities and communications involved in the FLOWS method. (Note the following abbreviations: EFTP – Environmental Flows Technical Panel, PAG – Project Advisory Group, PSG – Project Steering Group).

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 Issues Paper, which outlines the expected flow requirements and ecological responses to particular flow components.

Stage 2 uses the results of detailed channel surveys and hydraulic models (mostly using HECRAS) 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) has been established to provide a forum in which Serpentine 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 Serpentine Creek to the local community and the PAG's endorsement of this environmental flows study:

"Fifteen years of well below average rainfall and probable climate change has caused the shrinking of the irrigation district resulting in monumental change to Durham Ox and districts. Further irrigation efficiency programs have caused some of our greatest natural resources to become drier and under threat. The PAG as representatives of the local community, sees this comprehensive study as a way of measuring and quantifying environmental sites such as the Serpentine Creek. It is also hoped by the community that these assets, that are of immense importance and value, will be protected in the future. We recognise that these assets have been

deprived of water, and some of the savings achieved by the efficiency programs in the irrigation districts may be returned to this natural resource. The identity of the people of Serpentine to Loddon Vale is linked to our love of the flora and fauna that exists and always has existed along the Serpentine Creek (Chairperson – Laurie Maxted, 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 each reach of Serpentine 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 the catchment and provides a rationale for dividing Serpentine 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 throughout the catchment and the specific environmental flow objectives for each reach;
- Field observations made by the EFTP during the site assessments which were conducted on the 19th, 20th and 22nd 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 under wet, average and dry conditions and current levels of licenced water extraction;
- Discussions with river managers and scientists who have relevant experience in Serpentine Creek; and
- Information and feedback provided by the Project Advisory Group.

1.6 Report structure

Following this introduction:

- Section 2 described the breakdown of Serpentine Creek into FLOWS reaches and assessment sites.
- Sections 3, 4, 5 and 6 describe the flow recommendations for Reach 1, 3, 5 and 6 respectively.
- Section 7 recommends complementary waterway works that need to be implemented along with the recommended flow regime to help meet the agreed environmental flow objectives.
- Section 8 outlines recommended monitoring activities.
- Section 9 documents our recommendation that an Environmental Watering Management Plan is developed for Serpentine 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 Serpentine Creek;
- Appendix C summarises the overall flow related issues and objectives for Serpentine Creek; and
- Appendix D documents the development of hydraulic models for Serpentine Creek.

2. FLOWS Reaches and Assessment Sites

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 the Serpentine Creek system into six FLOWS reaches (see Table 2-1 for breakdown of reaches, corresponding FLOWS assessment sites and flow gauges). We have not assessed the environmental flow requirements of the heavily regulated sections of Serpentine Creek (Reaches 2 and 4), which are effectively managed as weir pools to distribute water to irrigation channels. We recognise that there is little opportunity to change the flow regime through these reaches. A more detailed rationale for the reach and site selection is provided in the *Site Paper* (Jacobs, 2014b).

Table 2-1 Selected environmental flow reaches and corresponding flow assessment sites and flow gauges in Serpentine Creek. Refer to Figure 2-1 for schematic of Serpentine Creek showing selected FLOWS Reaches.

Environmental flow reach		Flows assessment site	SCADA Site Number/Gauge
1	Serpentine Creek from downstream of Serpentine Weir to connection with Waranga Western Channel	Serpentine Creek, downstream of Old Boort Road and Knife Edge Weir	PH2012
2	Serpentine Creek from Waranga Western Channel to No 2 Weir	None	None
3	Serpentine Creek downstream from No 2 Weir to outfall from Irrigation Channel 7/10/1 (600 m upstream of Durham Ox Road)	Serpentine Creek, approximately 3km upstream from Irrigation Channel 7/10/1	PH894
4	Outfall from Irrigation Channel 7/10/1 (600m upstream of Durham Ox Road) to No 12 Channel	None	None
5	Nine Mile Creek from Nine Mile Regulator to River Red Gum Forest / Woodland	Nine Mile Creek at Nine Mile Regulator	PH896
		Nine Mile Creek at River Red Gum Forest / Woodland	None
6	Pennyroyal Creek downstream from Channel No 12 Outfall to downstream of Hopefield Road	Pennyroyal Creek downstream from Channel No 12 Outfall	PH895
		Pennyroyal Creek at Leaghur Road	None
		Pennyroyal Creek downstream of Hopefield Road	None

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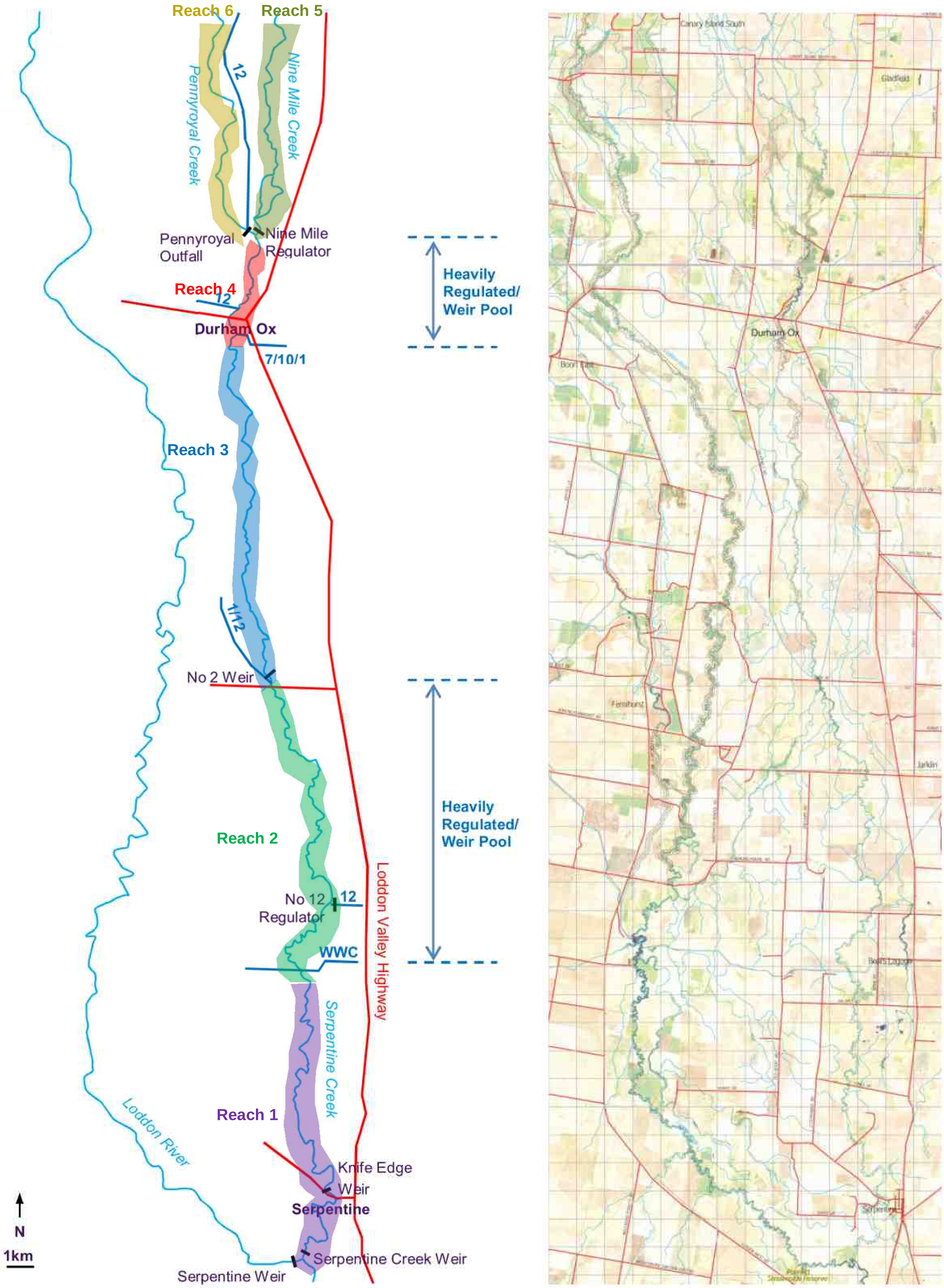

Figure 2-1 Schematic diagram of Serpentine Creek and map showing stream network, weirs and irrigation channels. The extent of selected FLOWS Reaches are also shown.

3. Reach 1 – Serpentine Creek from Serpentine Weir to Waranga Western Channel

3.1 Description

Reach 1 of Serpentine Creek extends from Serpentine Weir to the connection with Waranga Western Channel. The creek in this reach has a high sinuosity and is relatively confined within the alluvial plains. The channel has diverse instream habitat, with low lying benches, pools, shallow runs/glides and large woody debris (Figure 3-1).

The reach has diverse in-stream habitats that are suitable for macroinvertebrates, fish, Platypus, turtles, frogs and birds. The reach supports small/medium bodied fish including River Blackfish, and a small population of Platypus. Eastern Long-necked turtles are also likely to be present in this reach, although the steep banks along most of the reach may make it difficult for these animals to enter and exit the water. The riparian zone is dominated by River Red Gum but the understorey is frequently missing or depauperate. It is difficult to confidently predict what the understorey would have naturally looked like, but it is likely that a combination of grazing by native animals, exotic species and livestock (e.g. kangaroos, rabbits, sheep and cattle) and invasion by terrestrial weeds have reduced the diversity and cover of native vegetation.

Goulburn-Murray Water (G-MW) delivers a passing flow of 7 ML/day, and larger flows up to 50 ML/day, into Serpentine Creek from the Loddon River at Serpentine Weir to meet private diverter and stock and domestic demands between the Loddon River and the Waranga Western Channel. In addition, this reach receives high flows when floods break out from the Loddon River.

The Project Advisory Group highlighted poor water quality during low flow periods as a particular concern in this reach, especially near Serpentine with reports of urban water pollution and the appearance of blackwater. It is worth noting that the blackwater issues raised by the PAG relate to dark, tannin-stained water during low flow or cease-to-flow events rather than blackwater events that follow high flow events and contribute to widespread fish kills and other acute events. There have been no recorded widespread fish kills in Serpentine Creek. Further details on the mechanisms that cause blackwater events and their likely incidence in Serpentine Creek are presented in the *Issues Paper* (Jacobs, 2014a).

	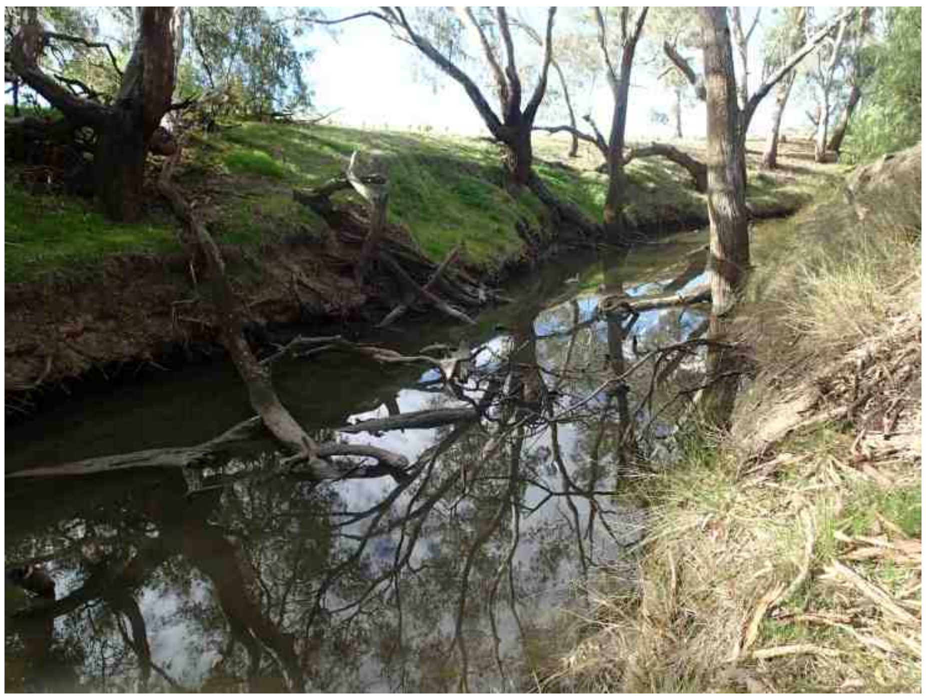
Shallow glide with water ribbon and narrow bench with emergent vegetation.	Long pool with large woody debris, undercut and exposed roots at channel margin.

Figure 3-1 Selected photographs of Reach 1 FLOW assessment site – Serpentine Creek, downstream of Old Boort Road and Knife Edge Weir.

The FLOWS assessment site for this reach is immediately downstream of Old Boort Road (Figure 3-1). This site is close to an existing flow gauge (Knife Edge Weir) and was selected because it has a mix of run and pool habitats, large woody debris and undercut banks that are typical features of the in-stream habitat throughout the whole reach. The site also has distinct bench habitats that support a mosaic of plant species with different flow requirements.

3.2 Water management goal for this reach and environmental flow objectives

Reach 1 of Serpentine Creek has good instream habitat, with large woody debris and undercut banks. The proximity to Loddon River and downstream Weir Pool provides opportunities for dispersal of River Blackfish, Flat head Gudgeon, Australian Smelt, Carp Gudgeon and Platypus. The extent and diversity of emergent fringing and riparian vegetation could be enhanced through control of grazing pressures and provision of a more variable flow regime.

The water management goal developed for Reach 1 of Serpentine Creek is '***to improve the quality of emergent fringing and riparian vegetation along Serpentine Creek so as to enhance habitat for native fish and Platypus'*****.**

Low flows will be important in providing permanent habitat for fish and Platypus. Cease-to-flow events are not considered an option as a continuous flow is required to meet private diverter and stock and domestic demands. Freshes and higher flows will be important for wetting large woody debris and scouring biofilms from the stream bed, watering vegetation, scouring pools and maintaining channel form.

The environmental flow objectives for this reach are documented in Table C-1 in Appendix C. High priority environmental flow objectives include:

1) Maintaining a viable breeding population of Platypus that can disperse to the lower Loddon River and adjoining Murray River thereby contributing to a larger regional metapopulation.
2) Maintaining and enhancing native small and medium-bodied fish populations such as River Blackfish.
3) Maintaining and enhancing the diverse aquatic and riparian vegetation communities present instream and on low lying banks and benches.
4) Preventing blackwater events that lead to fish kills by entraining leaf litter and limiting build-up of organic material in the channel over winter and providing flushing flows during summer.
5) Maintaining the current condition of the populations of turtles, frogs, woodland and waterbirds.

3.3 Flow recommendations and rationale

3.3.1 Summary of flow recommendations

The environmental flow recommendations for Reach 1 and the specific objectives they aim to meet are summarised in Table 3-1.

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

Waterway	**Serpentine Creek from Serpentine Weir to Waranga Western Channel**		**Regime**	**Flow recommendations**			
Season	**Flow**	**Objective**	**Wet/Average/Dry**	**Magnitude**	**Frequency and timing**	**Duration**	**Rise/Fall***
Summer / Autumn (Dec–May)	Low flow	Maintain spawning habitat and water levels for River Blackfish Maintain pool and run habitats for fish, macroinvertebrates, Platypus, turtles, birds and submerged aquatic vegetation. Prevent low dissolved oxygen during low flow periods.	All years	10 ML/day	10 ML/day January to May		NA
				20 ML/day	Required throughout December to maintain spawning habitat for River Blackfish		NA
	Fresh	Allow fish, Platypus and turtle movement through reach Inundate benches and water fringing vegetation Inundate wood and promote biofilm development Maintain water quality and prevent low dissolved oxygen conditions	Wet / Average	40 ML/day	4 events	2-3 days	140%/88%
			Dry	40 ML/day	2 events	1-2 days	140%/88%
Winter / Spring (Jun-Nov)	Low flow	Maintain spawning habitat and water levels for River Blackfish Maintain pool and run habitats for fish, macroinvertebrates, Platypus, turtles, birds and submerged aquatic and fringing vegetation.	Wet / Average	30 ML/day	Whole season		NA
			Dry	20 ML/day	Whole season (but for no more than 3 consecutive years, after which time the flow should be raised to 30 ML/day for at least one year).		NA
	Fresh	Flush organic material from banks to prevent risk of blackwater during summer Inundate benches and water fringing vegetation Inundate wood and scour biofilms from stream bed	Wet / Average	120-150 ML/day	1 event. 150 ML/day ideally needs to be delivered before start of August. If not delivered by start of August, limit to 120 ML/day to avoid disrupting Platypus feeding or burrows when they have young.	1 day	180%/50%

Waterway	Serpentine Creek from Serpentine Weir to Waranga Western Channel		Regime	Flow recommendations			
Season	**Flow**	**Objective**	**Wet/Average/Dry**	**Magnitude**	**Frequency and timing**	**Duration**	**Rise/Fall***
		Inundate benches to provide breeding habitat for frogs	Dry	40 ML/day	1 event Increasing flow slightly in dry years provides important flow variability and flushes organic material from the bank to reduce risk of blackwater in summer, but it doesn't water plants on low benches.	2 days	140%/88%

*Reccomended rates of Rise/Fall are a percentage of the previous days flow and have been determined based on assessment of representative fresh/high flow events for the current flow regime.

3.4 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 would have naturally occurred in Serpentine Creek, they are not recommended. A continuous low flow is required to meet private diverter and stock and domestic demands between Serpentine Weir and Waranga Western Channel. Nutrient enrichment and high salinity levels in the Serpentine Creek are likely to be exacerbated by cease-to-flow events. Increased sedimentation along the creek as a result of flow regulation may have also reduced the abundance and quality of pool habitats that are likely to persist in low and cease-to-flow periods. For these reasons, cease-to-flow events have not been recommended.

Summer/Autumn Low flow

The summer/autumn low flow recommendation aims to maintain a depth of at least 100 mm at the downstream end of the reach to allow fish and Platypus movement to the weir pool upstream of No 2 Weir. For Serpentine Creek we have assumed a minimum riffle depth of 100 mm and a minimum pool depth of 300 to 500 mm will be sufficient for the native fish that are likely to be present in the system (River Blackfish, Flat head Gudgeon, Australian Smelt and Carp Gudgeon). A minimum channel depth of 200-300 mm should ideally be maintained along the creek for Platypus throughout the year to reduce predation risk and a minimum depth of 500-1000 mm is recommended to maintain aquatic and fringing emergent vegetation.

Sufficient low flow is also required to maintain water quality and provide connecting flow between pools along this section of creek. The current flow management regime for this reach provides for a passing flow of 7 ML/day, and larger flows up to 50 ML/day, to meet private diverter and stock and domestic demands. Based on discussions with G-MW diversion operator staff, this flow management regime is said to be sufficient to maintain water quality conditions with salinity levels at an acceptable level for diverters (D. Ferguson pers. comm.). A flow of 7 ML/day results in water depths of approximately 100 mm at the lower end of the reach (D. Ferguson pers. comm.).

However, a low flow of 7 ML/day is not considered sufficient to maintain a constant flow at the lower end of Reach 1 during the Summer/Autumn period. The community have reported that the water levels over summer periods are often very low, with water turning stagnant and tannin stained. It was agreed following discusions with members of the North Central CMA, the Project Steering and Advisory Group that 10 ML/Day is considered as an appropriate minimum flow over this period.

Therefore, the summer/autumn low flow recommendation for this site is 10 ML/day and it is recommended that this is maintained from January to May in wet, average and dry years. A flow of 10ML/day ensures a depth of

140 mm in shallow riffle/run habitat areas and a depth of 1000 mm in pool habitats at the FLOWS assessment site (see Figure 3-2). Additional flows that G-MW deliver during summer and autumn to meet irrigation and stock and domestic demand will provide important flow variation throughout the reach.

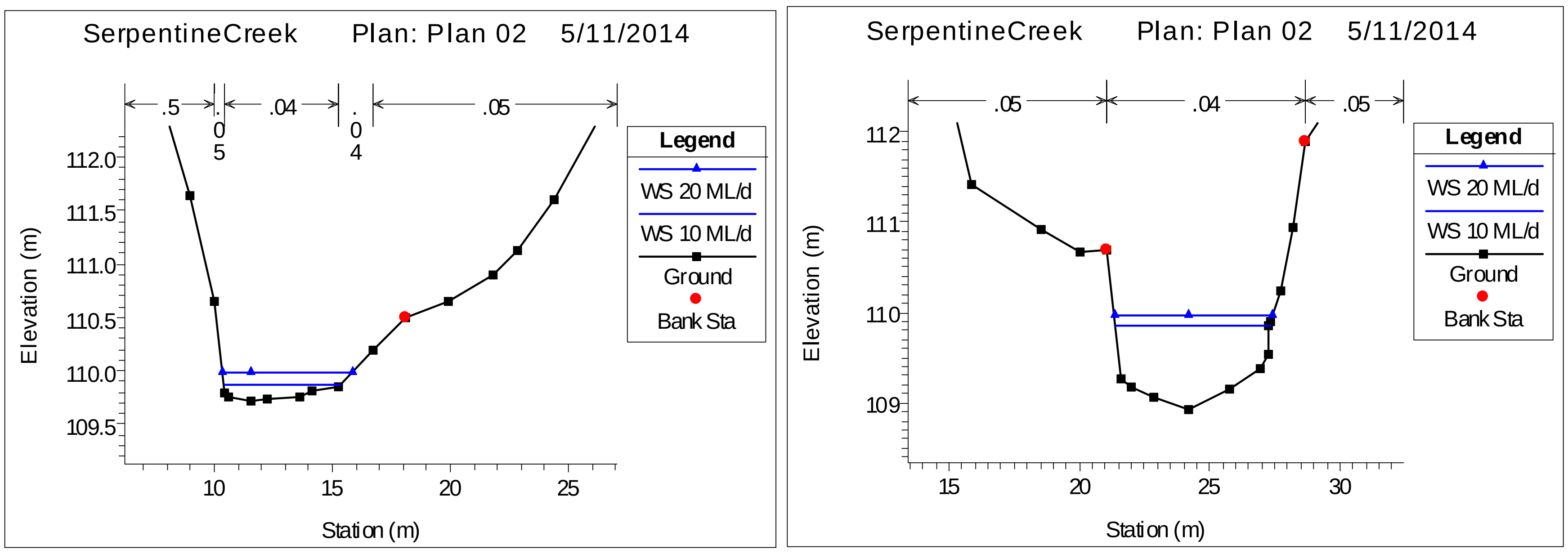

Figure 3-2 Summer/autumn Low Flow in cross-section 1 (left) and cross-section 7 (right) for all years. Flow provides flow depths ranging from 140 mm to 1000 mm.

The low flow should be 20 ML/day through December in wet, average and dry years to provide a gradual fall from the winter low flow level and ensure that developing River Blackfish eggs and larvae are not stranded. River Blackfish spawn in spring and lay their eggs in submerged hollow logs or among snags, the developing larvae also use these habitats and it is important that these nursery habitats remain inundated throughout spring and early summer and that any reduction in flow is not too sudden. By mid-summer, juvenile River Blackfish should be sufficiently competent swimmers to leave their nursery habitats and will therefore be able to move to alternative habitats as water levels drop.

In dry years, flow at Knife Edge Weir drops below 10 ML/day for periods of a month or more (Figure 3-3). In three of the seven dry years, flow drops below 10 ML/day for practically the entire summer/autumn period. Similarly in average years, there are some years in which flow drops below 10 ML/day for weeks or months at a time. During wet years, of which there is only one representative year flows do not drop below the low flow of 10 ML/day. In wet, average and dry years, flows frequently fall below the recommended 20 ML/day during the month of December (Figure 3-4).

Further water quality and depth monitoring is recommended of flow levels through this reach to confirm that 10 ML/day at Knife Edge Weir is sufficient to maintain water quality and provide a continuous flow through the whole reach with a minimum depth of 100 mm in the shallowest habitats at the downstream end of the reach. Water levels and quality may vary from year to year with changes in climatic conditions and groundwater levels, and this has implications for flow management along the creek. These interactions are summarised below; for further details, refer to the criteria for setting low flows and freshes in Table B-2 and further discussion of groundwater in the *Issues Paper* (Jacobs, 2014a).

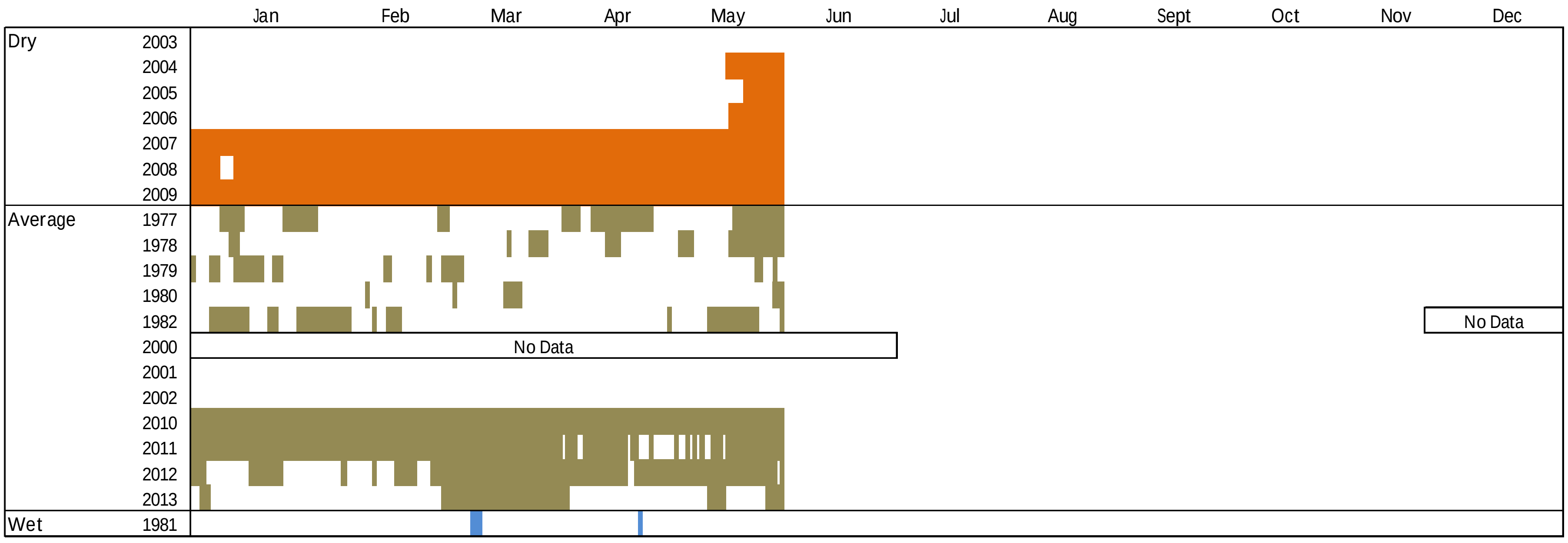

Figure 3-3 Spells analysis of current flows below 10 ML/day in wet, average and dry years.

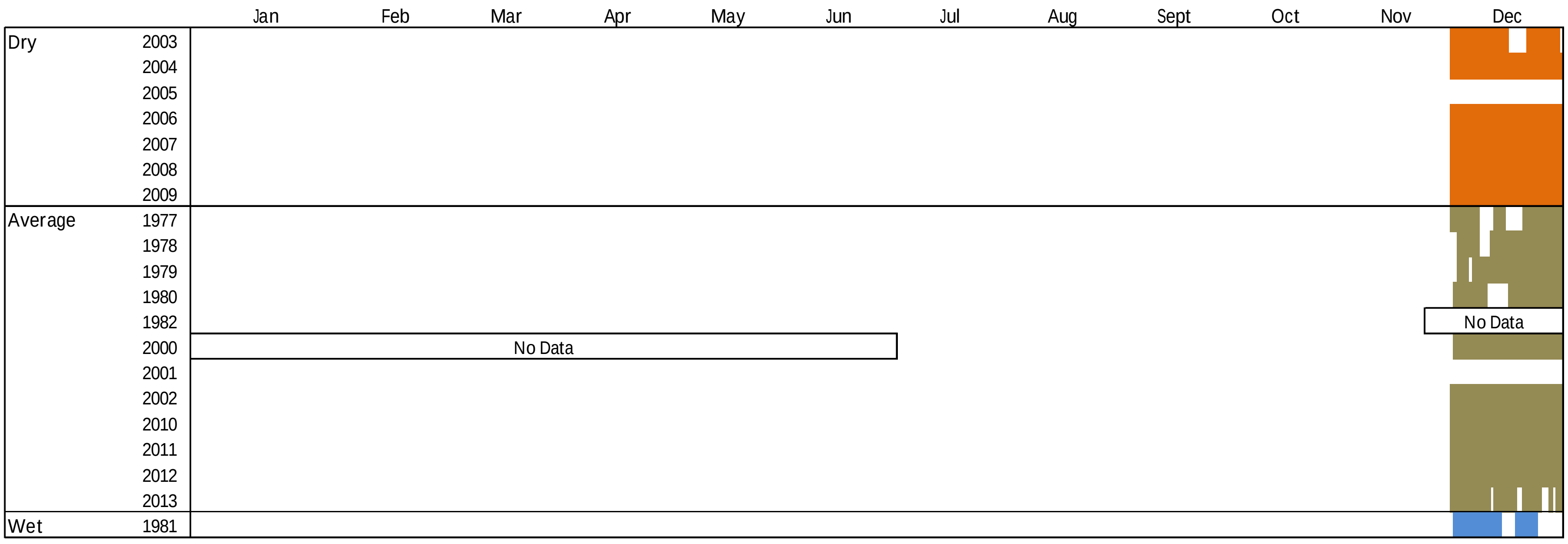

Figure 3-4 Spells analysis of current flows below 20 ML/day during the month of December in wet, average and dry years.

In wet periods, high groundwater levels may lead to saline groundwater inflows to the stream. During this period, the saline flow is generally washed downstream during seasonal slows, however, when a dry year occurs saline flows may not be flushed downstream. Therefore, if a low flow occurs during a wet period, delivering freshes to maintain water quality may become a management consideration.

During dry periods when groundwater levels fall below the stream bed and the stream is losing to groundwater, 10 ML/day may not provide sufficient flow to maintain minimum depths of 100 mm throughout the whole reach. The magnitude of the low flow may need to be increased to take into account potential losses in streamflows and the affect that has on reducing flow depths and water quality throughout the reach. Following an extended dry period groundwater levels may begin to rise, with the potential for saline groundwater inflows into the stream. During this time of transition between wet and dry periods, delivery of freshes to maintain water quality may need to be considered to maintain water quality conditions.

Summer/Autumn Freshes

Summer/autumn freshes temporarily increase the water depth in all habitats, which will allow River Blackfish, Flat head Gudgeon, Australian Smelt, Carp Gudgeon, turtles and Platypus to move more readily between pools. These higher flows will also inundate in-channel low-flow benches to water Juncus and Typha and improve the diversity and density of fringing vegetation and inundate large wood within the channel to promote biofilm development. Summer/autumn freshes will also flush poor quality water from pools and at least temporarily increase dissolved oxygen concentrations, which can drop during prolonged periods of low flow.

Freshes that inundate low benches at the edge of the channel will have the greatest effect on littoral and fringing vegetation. A flow of 40 ML/day inundates low benches and provides a depth of 250-270 mm above the summer low flow recommendation of 7 ML/day (see Figure 3-5). The frequency and duration of summer/autumn freshes is expected to vary in wet/average and dry years as shown in the Spells analysis (Figure 3-6). In order to maintain that flow variability we recommend that at least four freshes should be provided between December and May in wet/average years. Freshes in wet and average years should remain close to 40 ML/day for two to three days. Only two freshes are needed in dry years, and they only need to remain close to 40 ML/day for one to two days.

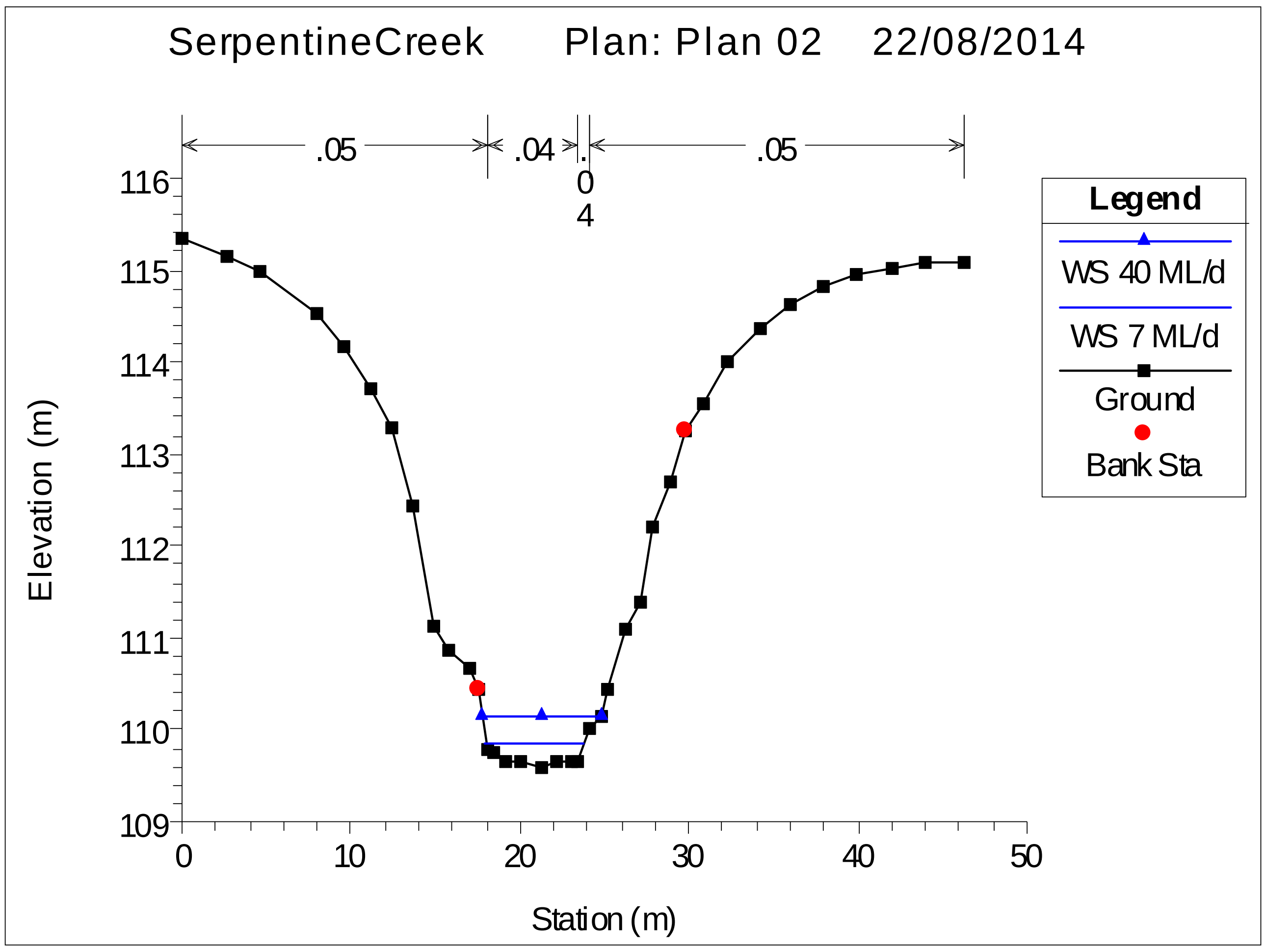

Figure 3-5 Increased depth of summer/autumn fresh compared to the summer low flow at cross-section 2.

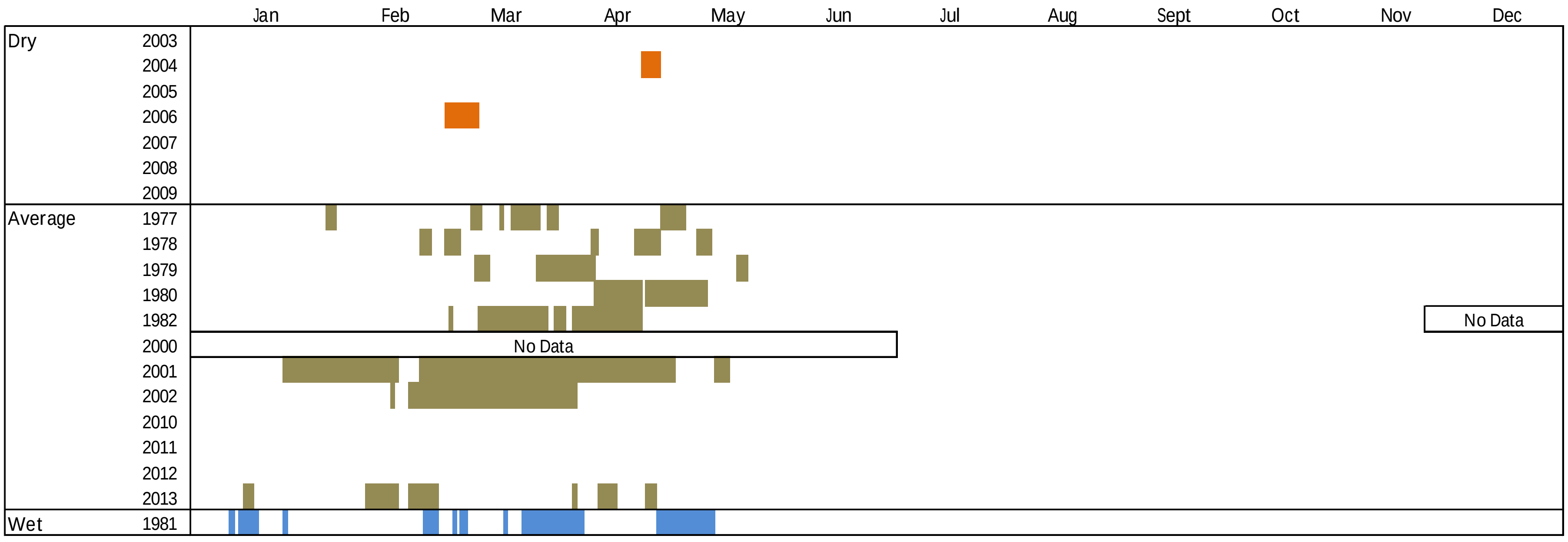

Figure 3-6 Spells analysis of current flows above summer fresh of 40 ML/day in wet, average and dry years.

Winter/Spring low flow

The winter/spring low flow should have a sufficient magnitude of flow to allow fish and Platypus to move through and forage in all shallow riffle and run habitats in the reach and to increase the abundance of pool habitat greater than 500 mm deep for Platypus to forage in. The winter/spring low flow should also provide sufficient water depth to inundate fallen wood in the channel and maintain spawning habitat for River Blackfish in October and November. The magnitude of the winter/spring low flow may vary from year to year but it is important that a target flow is maintained throughout the season to avoid reducing or isolating fish nursery habitats that are likely to contain developing eggs and larvae.

In wet or average years it is expected that the winter low flow will be 30 ML/day. A 30 ML/day flow provides a depth of 200 mm greater than the summer low flow recommendation, inundates undercut banks and the majority of large woody debris. In dry years the winter/spring low flow recommendation can drop to 20 ML/day. A 20 ML/day flow will increase the average water depth through most habitats by approximately 140 mm compared to the recommended summer low flow and partly inundates undercut banks. It does not however inundate as much habitat as the 30 ML/day flow (see Figure 3-7) and therefore will not provide the same quality or quantity of habitat and feeding opportunities for macroinvertebrates, fish and Platypus.

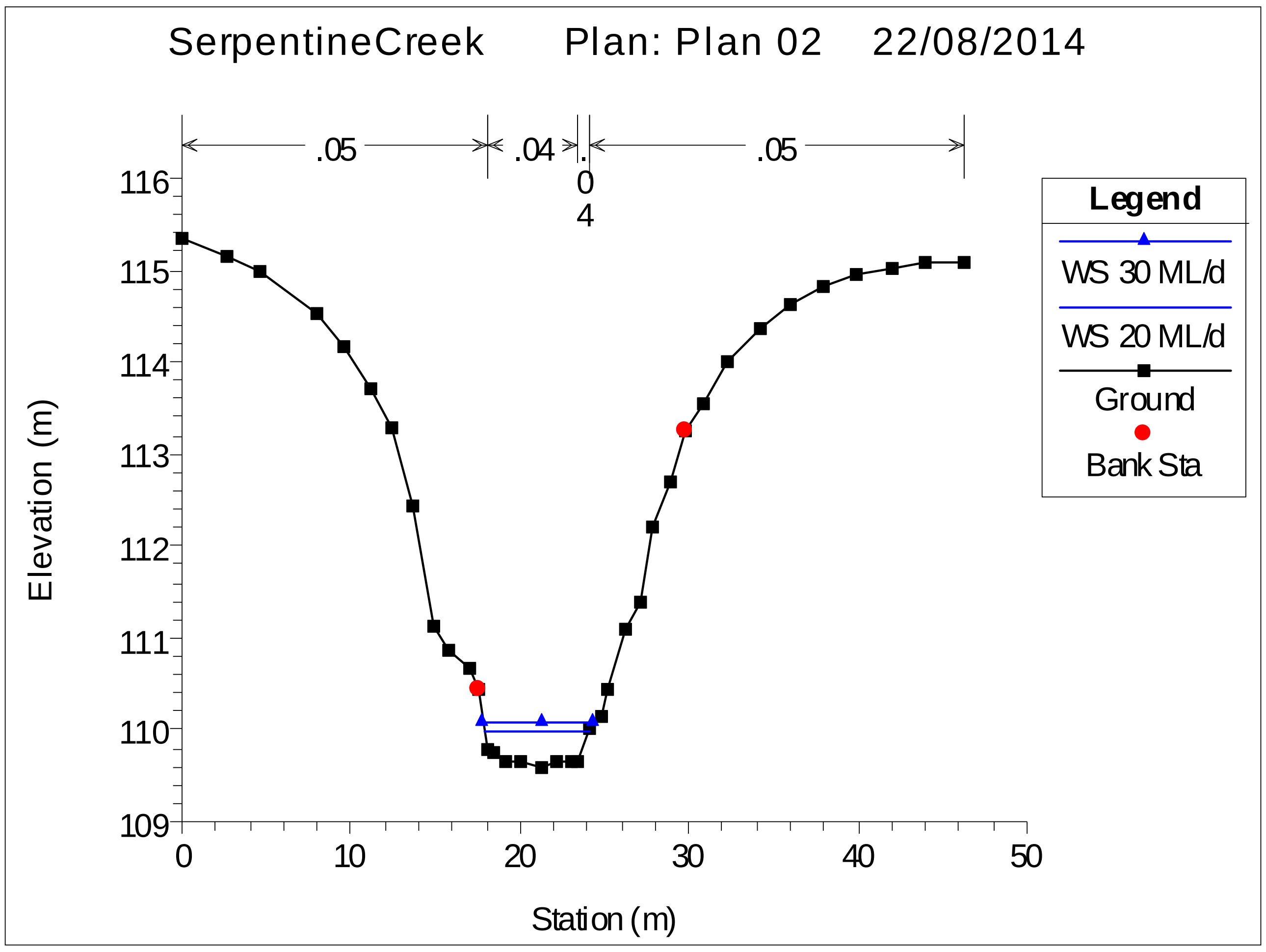

Figure 3-7 Winter/spring low flow for wet/average (30 ML/day) and dry years (20 ML/day) at cross-section 2.

The 20 ML/day winter low flow should not be delivered for more than three consecutive years to ensure that good breeding conditions are provided for River Blackfish and Platypus, as well as other biota, at least once every four years even during drought. Providing a winter low flow of 30 ML/day in wet and average years should facilitate the recruitment of native fish and Platypus in those years and increase the resilience of those populations to less favourable conditions and lower recruitment in dry years.

The spells analysis is presented in Figure 3-8 for 30 ML/day and in Figure 3-9 for 20 ML/day. Under current conditions, flow is less than 20 ML/day for most of winter and spring in dry and average years and for nearly half the time in wet years. Therefore the current releases will need to be significantly augmented to meet the recommended flows.

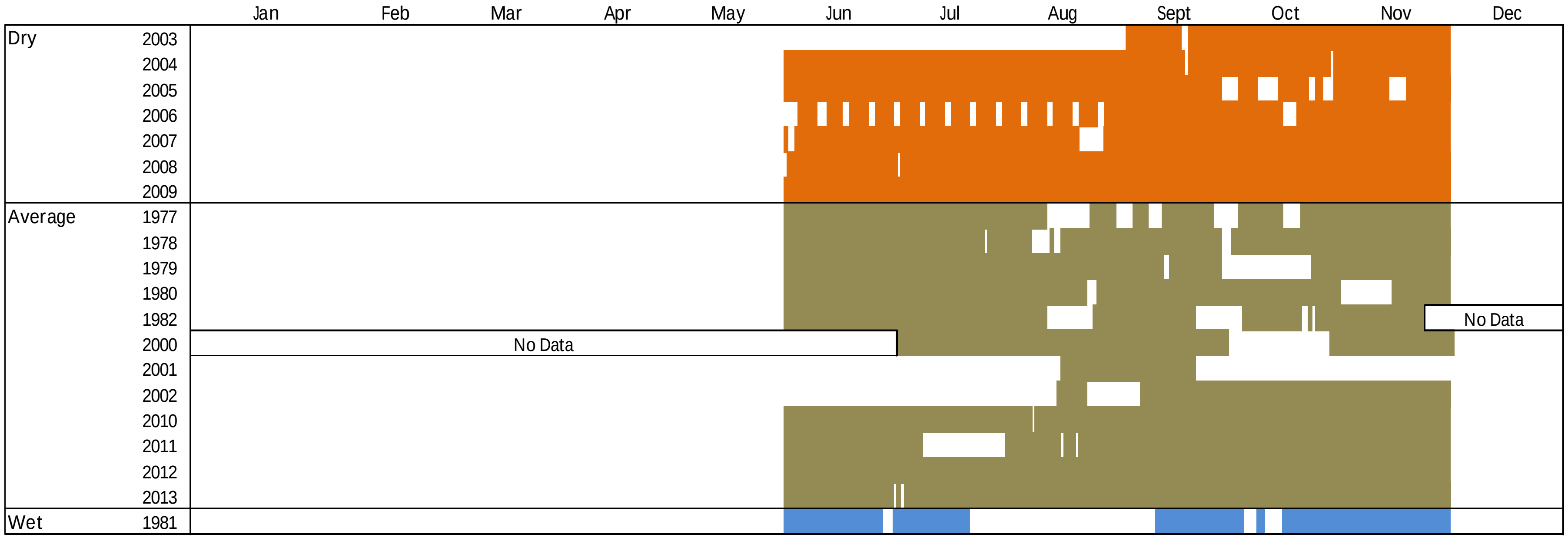

Figure 3-8 Spells analysis of current flows below 30 ML/day in wet, average and dry years.

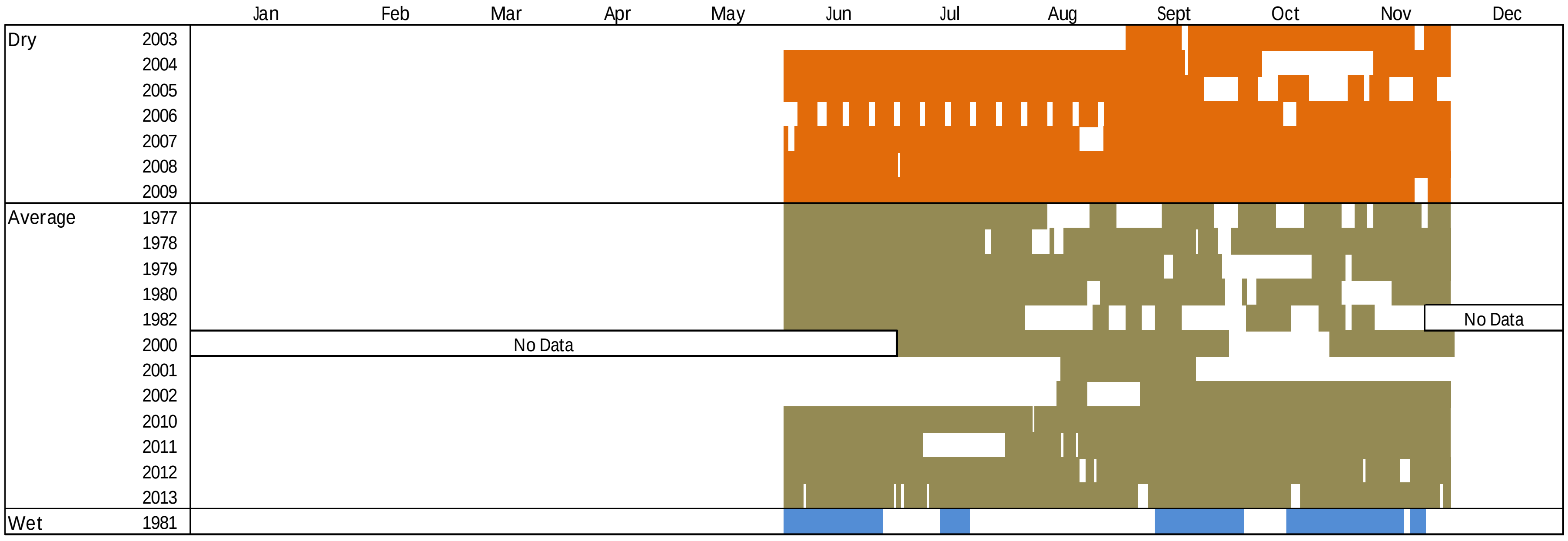

Figure 3-9 Spells analysis of current flows below 20 ML/day in wet, average and dry years.

Winter/Spring fresh

Winter/Spring freshes assist in entraining leaf litter that has accumulated on the banks above the normal winter low flow level. Entraining this leaf litter and limiting the build-up of organic material in the channel over winter/spring will help to prevent the risk of blackwater events occurring during summer. These flows will also scour biofilms, inundate large woody debris and provide the variability in flows required to maintain and increase fringing emergent vegetation on low benches.

In wet and average years a winter/spring fresh of 120-150 ML/day with a duration of one day is recommended to flush organic matter from banks, scour biofilms and inundate large woody debris. This will result in water levels 400–600 mm higher than the winter/spring low flow. Flows that increase water levels by more than 500 mm compared to the winter low flow level would potentially be a risk to Platypus during breeding season as they could lead to drowning of young Platypus in burrows. It is recommended that the magnitude of winter/spring freshes should not exceed 120 ML/day between August and November so that the water level rise relative to the winter low flow remains less than 500 mm.

In dry years, high flows are not expected, but a fresh of 40 ML/day with a duration of two days is recommended to flush organic matter from benches. The 40 ML/day flow is the same magnitude as the recommended summer fresh and will therefore clear accumulated organic material from any habitats that are likely to be inundated by planned summer/autumn flow releases and therefore reduce the likelihood that the summer/autumn flows will trigger a blackwater event. These flows will also inundate benches and provide breeding habitat for frogs.

Under the current operation, winter/spring flows greater than 150 ML/day are more common in wet years than average years and do not occur in dry years over the period of record assessed (Figure 3-11).

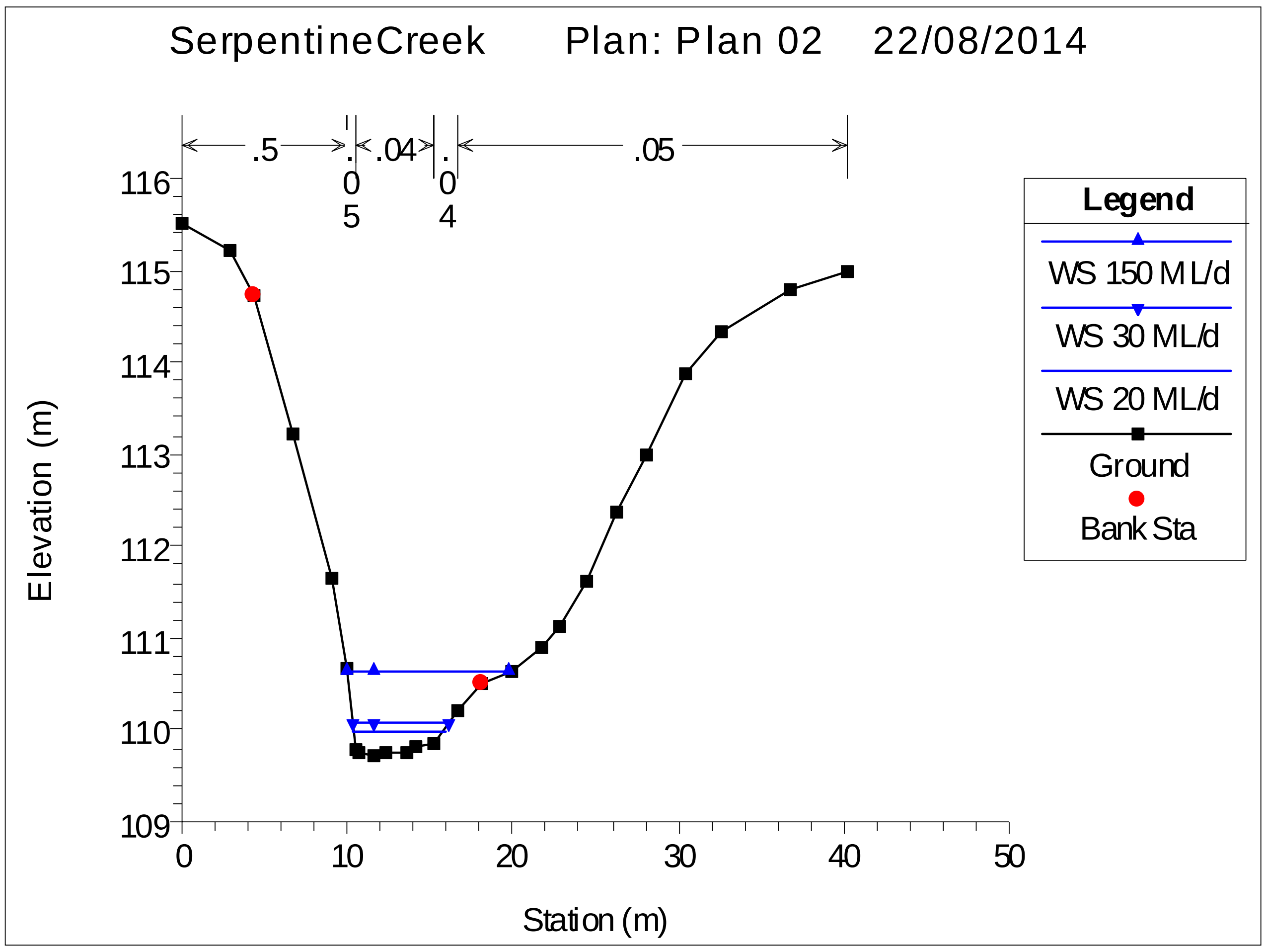

Figure 3-10 Increased depth of winter/spring fresh compared to the winter low flow at cross-section 1.

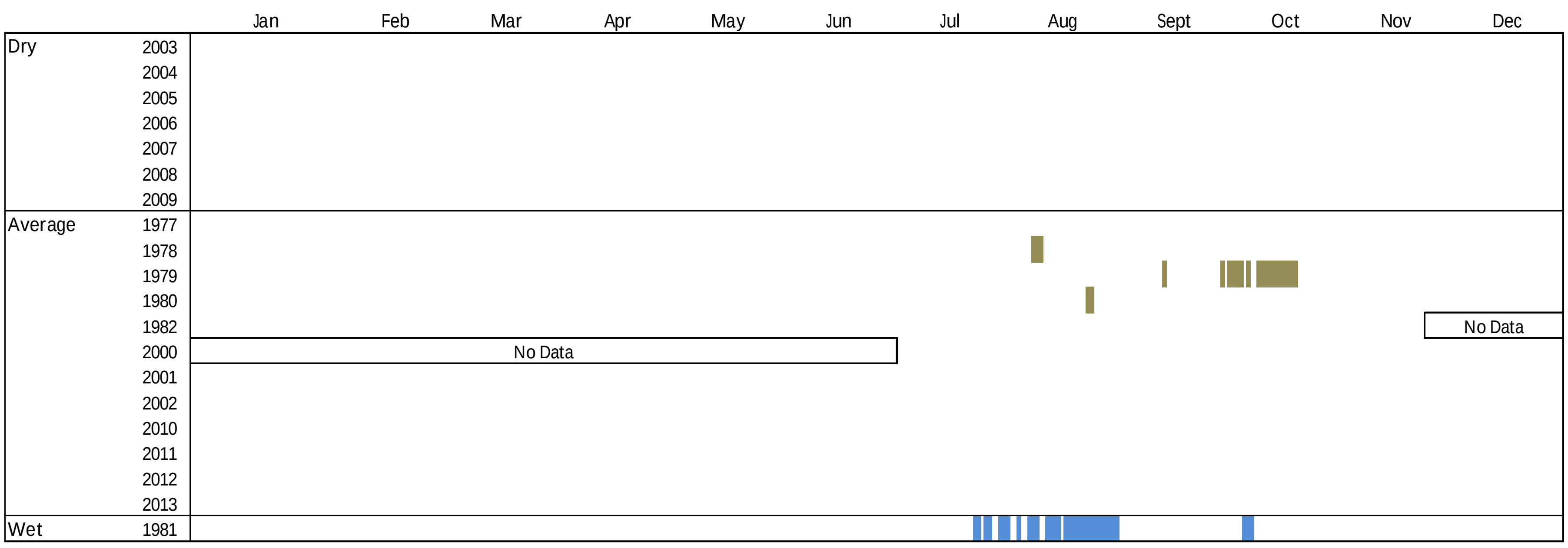

Figure 3-11 Spells analysis of current flows above winter/spring fresh of 150 ML/day in wet, average and dry years.

High flows, bankfull and overbank flows

We have not made specific recommendations for flows greater than 150 ML/day because that is the maximum managed flow that can be delivered into the reach from Serpentine Weir. Larger flows will occur from time to time due to extremely high rainfall that causes storages in the upper reaches of the Loddon Catchment to fill and spill. Those larger flows will fulfil important ecological and physical processes and functions including scouring the bed and banks of the channel, entraining sediments, deepening pools and facilitating the recruitment of River Red Gum on the river bank and surrounding floodplain. Flows that drown the existing structures at the upstream and downstream end of Reach 1 will also allow fish to disperse into and out of this reach and may facilitate re-colonisation from the Loddon River. For interest sake we note that flow will need to exceed approximately 10,000 ML/day to break out of the channel at the FLOWS assessment site (see Figure 3-12), but because there is no ability to influence these flows we have not specified the frequency, timing or duration of these or other flows greater than 150 ML/day. We also note that the existing flow gauges in Reach 1 of Serpentine Creek cannot reliably measure very large flows (for example, the largest recorded flow between 2000 and 2013 was 100 ML/day, despite record floods occurring in that period) and therefore any analysis of existing data would be meaningless.

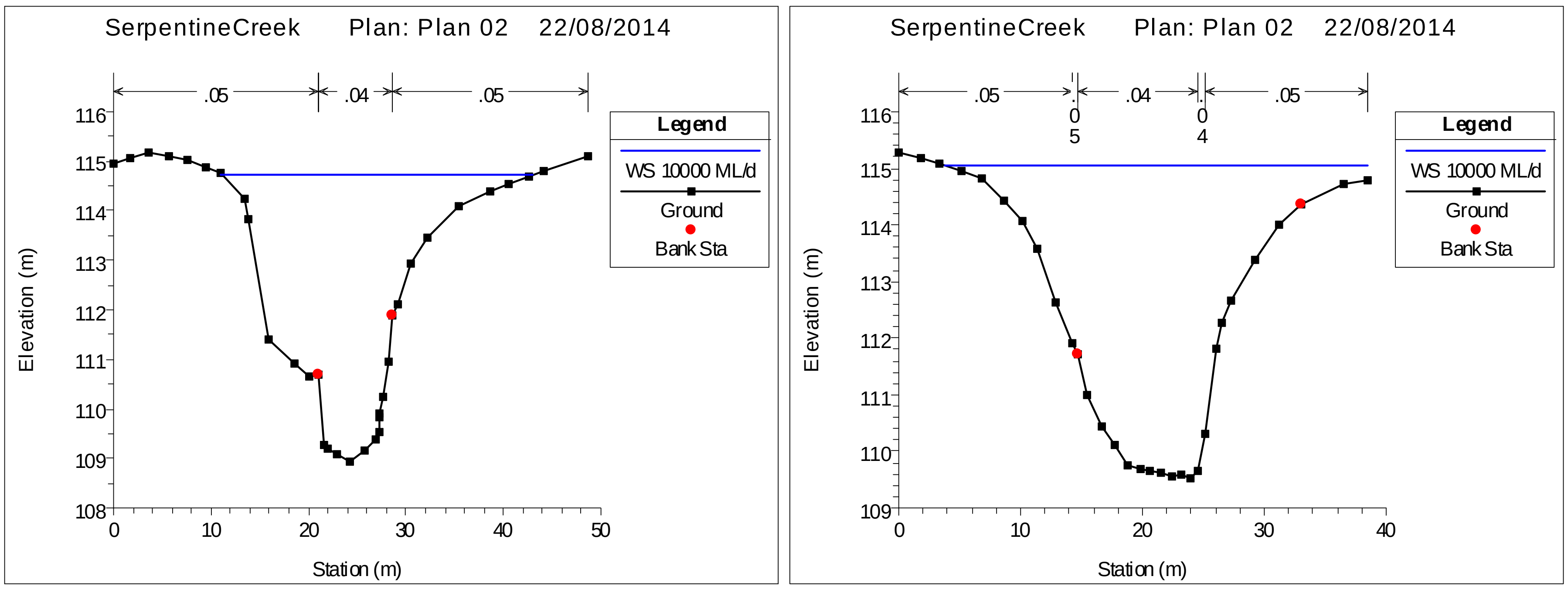

Figure 3-12 Bankfull and overbank flow threshold presented at cross-section 7 (left) and cross-section 3 (right).

3.5 Current achievement of flow recommendations

This reach currently experiences a passing flow of 7 ML/day with additional flows up to 50 ML/day to meet private diverter and stock and domestic demands. High flows also occur when floods break out from the Loddon River. Figure 3-13, Figure 3-14 and Figure 3-15 show the variation in flows experienced in this reach for a typical wet, average and dry year. Recommended low flows for summer/autumn and winter/spring are also overlaid on these plots to highlight the differences between actual and recommended flows. Figure 3-13 shows that in a typical wet year flows through summer/autumn remain higher than the low flow recommendation, with the exception of December where they drop below the recommended flow. During winter/spring, flows drop below the recommended low flow in the periods between high flow events. In an average and dry year flows frequently fall below the low flow recommendations, particularly in winter/spring (see Figure 3-14 and Figure 3-15).

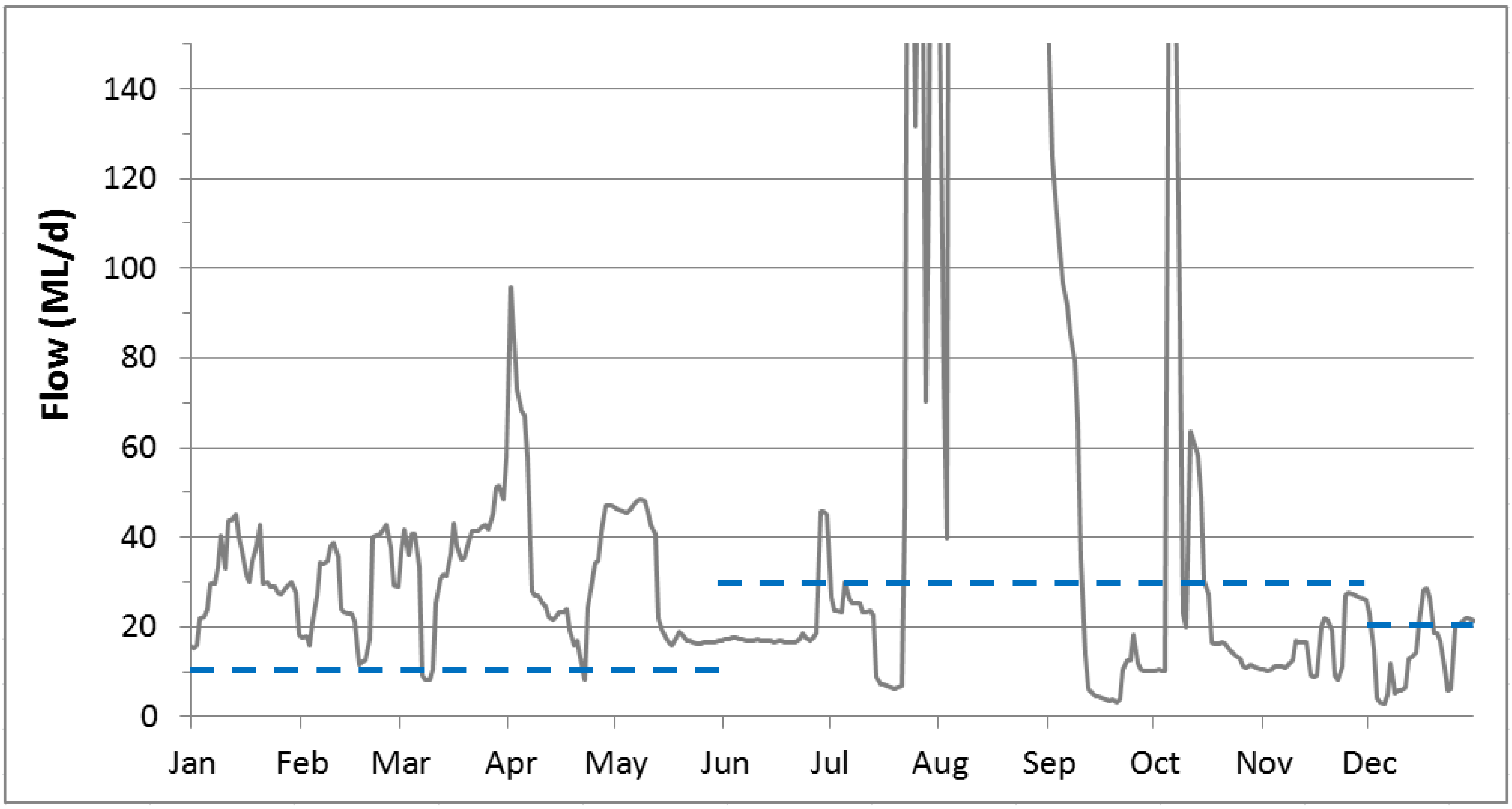

Figure 3-13 Daily flows in Reach 1 for a typical wet year as represented by the year 1981. Wet year low flow recommendations for Summer/Autumn (10 ML/day January-May and 20 ML/Day in December) and Winter/Spring (30 ML/Day June-November) are also shown.

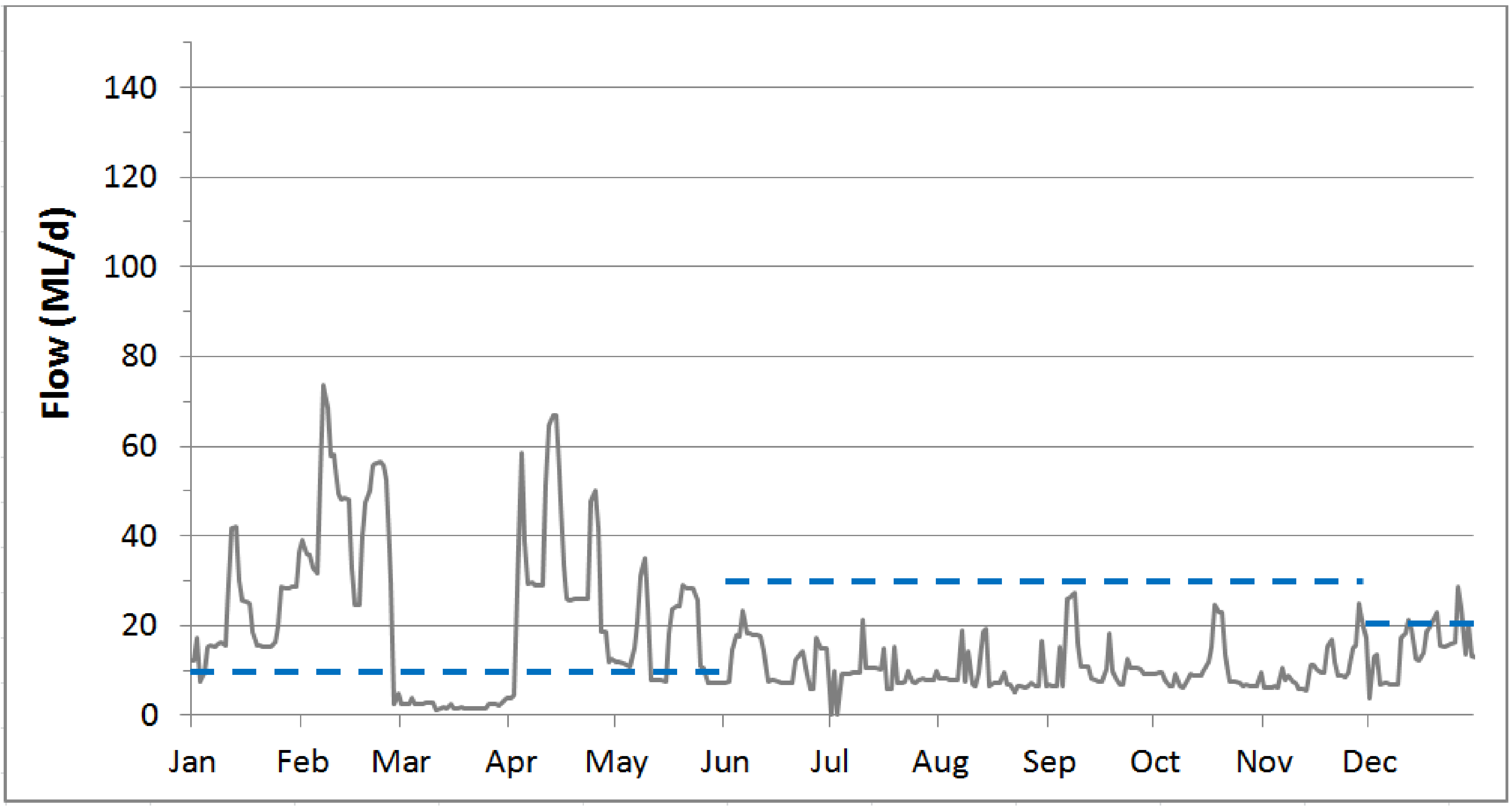

Figure 3-14 Daily flows in Reach 1 for a typical average year as represented by the year 2013. Average year low flow recommendations for Summer/Autumn (10 ML/day January-May and 20 ML/Day in December) and Winter/Spring (30 ML/Day June-November) are also shown.

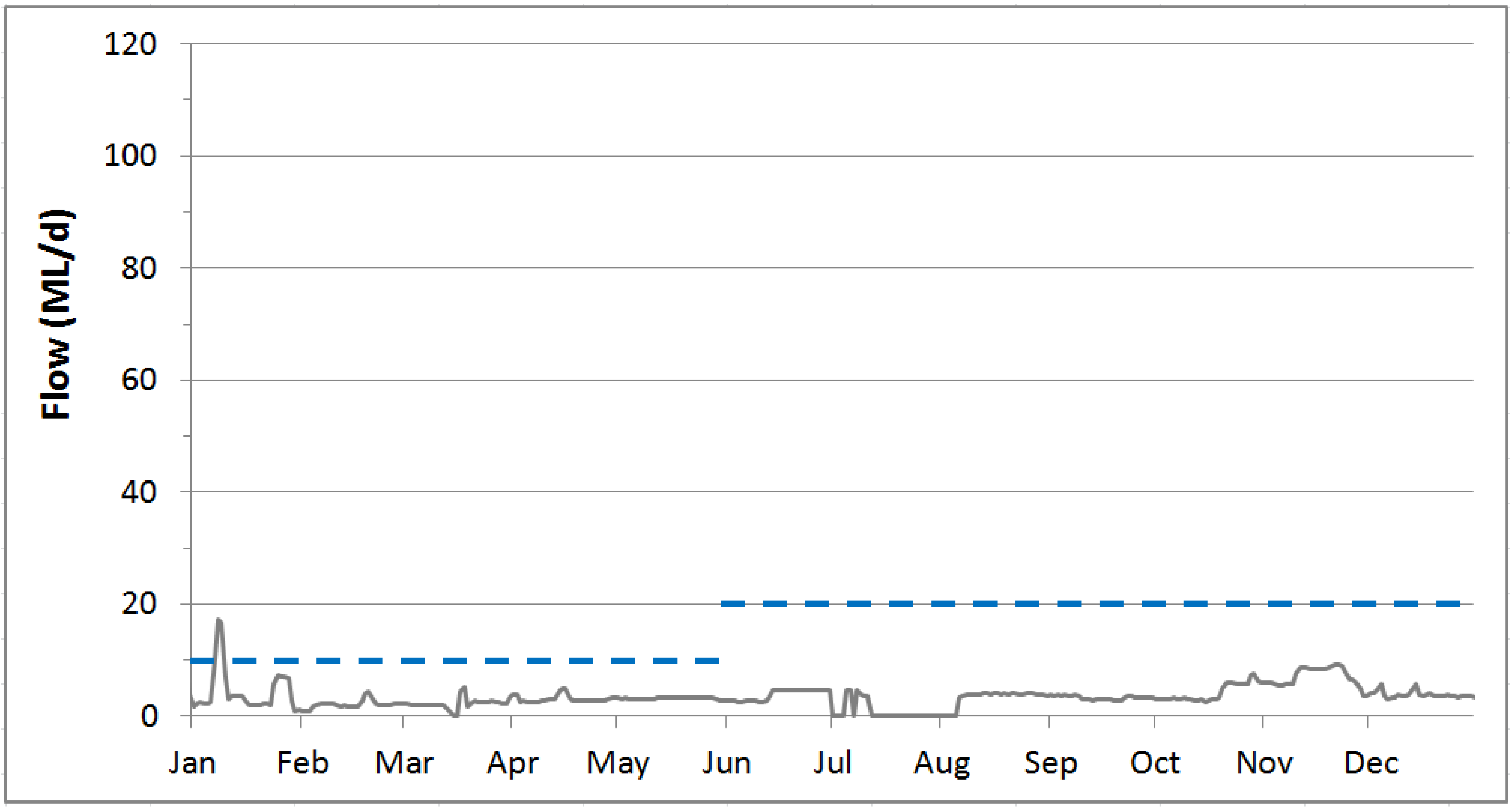

Figure 3-15 Daily flows in Reach 1 for a typical dry year as represented by the year 2008. Dry year low flow recommendations for Summer/Autumn (10 ML/day January-May and 20 ML/Day in December) and Winter/Spring (20 ML/Day June-November) are also shown.

An assessment of how well the flow recommendations for Reach 1 are currently met in wet, average and dry years is presented in Table 3-2,Table 3-3 and Table 3-4, respectively. It should be noted that these assessments do not include an 'or natural' clause, because there are no hydrological models for Serpentine

Creek that can estimate what the flow regime would be without the influence of reservoirs, farm dams and other water harvesting and water delivery operations.

Reliable flow records are only available for one wet year (1981), therefore we cannot make any definitive statements about how well the recommended flows are met in all or most wet years. The recommendations for summer/autumn low flows of 10 ML/day throughout the months of January to May were met 92% of the time, and the winter/spring freshes were met 100% of the time in 1981. The recommended December low flow of 20 ML/day was only met for 45 % of the time and the winter/spring low flow was much less than 30 ML/day for 32 % of the time (See Table 3-2).

Our assessment of compliance in average years is based on flow records for 10 years. In average years the recommended summer/autumn low flow of 10 ML/day throughout the months of January to May is met 60 % of the time and the recommended winter/spring low flow is met only 9 % of the time. The recommended December low flow of 20 ML/day was only met 25 % of the time. Four summer/autumn freshes have occurred in only 20% of the years in the available record, and each event rarely lasted for more than two days (Table 3-3). The recommended number of winter/spring freshes is met in 30 % of years. We note that these events usually exceed 150 ML/day, rather than the minimum recommended magnitude of 120 ML/day, which will be good for most environmental values in the reach (Table 3-3).

Our assessment of compliance in dry climate years is based on flow records for seven years. In dry climate years, the recommended summer/autumn low flow of 10 ML/day throughout the months of January to May is met 53 % of the time and the recommended winter/spring low flow of 20 ML/day is met only 6 % of the time (Table 3-4). The recommended December low flow of 20 ML/day is only met 11 % of the time. Fewer summer/autumn and winter/spring freshes are needed in dry years compared to wet and average years, but the available records show that the reduced recommendations are only met in one of the seven dry years that have reliable flow records (Table 3-4). Summer/autumn freshes in dry years should have a duration of between 1-2 days, and our analysis shows that when these events occur they nearly always last for two days (Table 3-4), which is likely to benefit ecological values.

The low rate of compliance with the recommended flow regimes for average and dry years is likely to place significant stress on the ecological values in Reach 1. Maintaining a minimum flow of 10 ML/day throughout the months of January to May and a higher flow of 20 ML/day in December is critical to maintain adequate water quality and habitat for existing environmental values such as River Blackfish and Platypus. Increasing the magnitude of the winter/spring low flow and the frequency of freshes throughout the year has the potential to improve the condition of existing environmental values and facilitate the recruitment and recolonisation of some native flora and fauna that are currently in very poor condition or absent.

Table 3-2 Achievement of environmental flow recommendations for Reach 1 for wet years.

Component	Months	From	To	Flow Recommendation			Or Natural	Compliance Lower	Compliance Upper
Summer/Autumn low	Jan - May	1	5	Magnitude	10	ML/d	No	92%	
	Dec	12	12	Magnitude	20	ML/d	No	56%	
Summer/Autumn fresh	Dec - May	12	5	Magnitude	40	ML/d	No	100%	100%
				Frequency	4	per year			
				Duration	2-3	days			
Winter/Spring low	Jun - Nov	6	11	Magnitude	30	ML/d	No	32%	
Winter/Spring fresh	Jun - Nov	6	11	Magnitude	120-150	ML/d	No	100%	100%
				Frequency	1	per year			
				Duration	1	days			

Table 3-3 Achievement of environmental flow recommendations for Reach 1 for average years.

Component	Months	From	To	Flow Recommendation			Or Natural	Compliance Lower	Compliance Upper
Summer/Autumn low	Jan – May	**1**	**5**	Magnitude	**10**	ML/d	**No**	*60%*	
	Dec	**12**	**12**	Magnitude	**20**	ML/d	**No**	*25%*	
Summer/Autumn fresh	Dec - May	**12**	**5**	Magnitude	**40**	ML/d	**No**	*20%*	*0%*
				Frequency	**4**	per year			
				Duration	**2-3**	days			
Winter/Spring low	Jun - Nov	**6**	**11**	Magnitude	**30**	ML/d	**No**	*9%*	
Winter/Spring fresh	Jun - Nov	**6**	**11**	Magnitude	**120-150**	ML/d	**No**	*30%*	*30%*
				Frequency	**1**	per year			
				Duration	**1**	days			

Table 3-4 Achievement of environmental flow recommendations for Reach 1 for dry years.

Component	Months	From	To	Flow Recommendation			Or Natural	Compliance	
Summer/Autumn low	Jan - May	**1**	**5**	Magnitude	**10**	ML/d	**No**	*53%*	
	Dec	**12**	**12**	Magnitude	**20**	ML/d	**No**	*11%*	
Summer/Autumn fresh	Dec - May	**12**	**5**	Magnitude	**40**	ML/d	**No**	*13%*	*13%*
				Frequency	**2**	per year			
				Duration	**1-2**	days			
Winter/Spring low	Jun - Nov	**6**	**11**	Magnitude	**20**	ML/d	**No**	*6%*	
Winter/Spring fresh	Jun - Nov	**6**	**11**	Magnitude	**40**	ML/d	**No**	*13%*	
				Frequency	**1**	per year			
				Duration	**2**	days			

No assessment of bankfull/ overbank flows has been undertaken because flows of that magnitude have never occurred in the available flow record from 1975-1982 and 2000-current.

4. Reach 3 – Serpentine Creek from No. 2 Weir to outfall from Irrigation Channel 7/10/1

4.1 Description

Reach 3 of Serpentine Creek extends from No 2 Weir to the outfall from Irrigation Channel 7/10/1. The creek in this section has a low gradient channel that is notably less confined than the reach upstream of Waranga Western Channel. The channel has a diverse instream habitat, with low lying benches, backwaters, shallow pools and runs, anabranches and secondary channels. This reach is likely to support small populations of small-bodied native fish, turtles, frogs and Platypus. Stock access and land clearing have reduced the quality of instream habitat available in this reach for fish and macroinvertebrates. Fish may be expected to move into this reach from Durham Ox weirpool downstream when flows permit.

Flows during the irrigation season are regulated by G-MW between approximately 20 ML/day and 120 ML/day to meet consumptive demands within the reach, maintain water quality, and to deliver water further downstream when the adjacent 1/12 channel is at capacity. The reach experiences marked fluctuations in flows during the irrigation season, with flow rates switching from <5 ML/day to > 50 ML/day every few weeks. Flood outbreaks from the Loddon River also contribute to occasional high flows in this reach, ranging from approximately 500 ML/day to 3,000 ML/day. The marked fluctuations in flow during the irrigation season represent frequent disturbances that probably contribute to the low cover of instream or riparian vegetation throughout the reach. An objective of the environmental flow recommendations should be to reduce the frequency of rapid flow fluctuations.

No water quality data are available for this reach, however water quality is likely to decline over summer as flows drop and the stream contracts to a series of pools. Poor water quality during low flow periods may be exacerbated by run-off from local farms or by livestock that trample the stream. Blackwater events are less likely in Reach 3 than Reach 1, because the riparian zone is more degraded and therefore the potential leaf litter load is less.

The FLOWS assessment site for this reach is located 3 km upstream from Irrigation Channel 7/10/1 (600 m upstream of Durham Ox Road). This site was selected because it has a range of channel features (benches, bars) and a good mix of vegetation with different flow requirements (Figure 4-1). G-MW has recorded flow in this reach at site PH894 between 2002 and 2014.

	
Pool and vertical banks on outer meander bend with fringing emergent vegetation on inside meander bend.	Channel with a vegetated island

Figure 4-1 Selected photographs of Reach 3 FLOWS assessment site – Serpentine Creek, approximately 3 km upstream from Irrigation Channel 7/10/1.

4.2 Water management goal for this reach and environmental flow objectives

Reach 3 of Serpentine Creek has a notably different channel morphology and diversity of habitats compared to Reach 1. The channel through Reach 3 is less incised within its surrounding floodplain, and has numerous anabranches and secondary channels that provide a range of backwaters and shallow habitats. This reach is likely to support small populations of small-bodied native fish, turtles, frogs and Platypus. Cattle access was noted as a threat to the channel condition and the recruitment and quality of vegetation.

The water management goal developed for Reach 3 of Serpentine Creek is *'**to enhance the ecological value of the Serpentine Creek through the recruitment and succession of emergent vegetation communities, maintaining the health and facilitating the recruitment of River Red Gum trees and enhancing habitat for native fish, specifically River Blackfish and Platypus'***.

Low flows will be important in providing permanent habitat for fish and Platypus. Cease-to-flow events are not desirable as they will create too much stress on aquatic communities. Freshes and higher flows will be important for wetting large woody habitat and scouring biofilms from the stream bed, watering vegetation, engaging benches and secondary channels, scouring pools and maintaining channel form.

The environmental objectives for this reach are summarised in Table C-2 in Appendix C. High priority environmental flow objectives include:

1) Maintaining a viable breeding population of Platypus that can disperse to the lower Loddon River and adjoining Murray River thereby contributing to a larger regional metapopulation.
2) Maintaining and enhancing native small and medium-bodied fish populations such as River Blackfish.
3) Maintaining and enhancing the diverse aquatic and riparian vegetation communities present instream and on low lying banks and benches.
4) Preventing blackwater events that lead to fish kills by entraining leaf litter and limiting build-up of organic material in the channel over winter and providing flushing flows during summer.
5) Maintaining the current condition of the populations of turtles, frogs, woodland and waterbirds.

4.3 Flow recommendations and rationale

4.3.1 Summary of flow recommendations

The environmental flow recommendations for Reach 3 and the specific objectives they aim to meet are summarised in Table 4-1.

Table 4-1 Summary of environmental flow recommendations for Serpentine Creek Reach 3.

Waterway	**Serpentine Creek from No. 2 Weir to outfall from Irrigation Channel 7/10/1**		**Regime**	**Flow recommendations**			
Season	**Flow**	**Objective**	**Wet/Average/Dry**	**Magnitude**	**Frequency and timing**	**Duration**	**Rise/Fall***
Summer / Autumn (Dec–May)	Low flow	Maintain spawning habitat and water levels for River Blackfish Maintain pool and run habitats for fish, macroinvertebrates, Platypus, turtles, birds and submerged aquatic vegetation Prevent low dissolved oxygen during low	Wet / Average	10 ML/day	10 ML/day January to May		NA
				30 ML/day	Required throughout December to maintain spawning habitat for River Blackfish.		NA
			Dry	5 ML/day	5 ML/day January to May		NA
				30 ML/day	Required throughout December to maintain		NA

Waterway	Serpentine Creek from No. 2 Weir to outfall from Irrigation Channel 7/10/1		Regime	Flow recommendations			
Season	**Flow**	**Objective**	**Wet/Average/Dry**	**Magnitude**	**Frequency and timing**	**Duration**	**Rise/Fall***
		periods			spawning habitat for River Blackfish.		
	Fresh	Allow fish, Platypus and turtle movement through reach Inundate low benches and backwaters Water fringing vegetation Maintain water quality and prevent low dissolved oxygen conditions	Wet / Average	30-40 ML/day	4 events	2 days	150%/55%
			Dry	30-40 ML/day	4 events in dry years when plants are establishing, 2 events in dry years once plants are established	2 days	150%/55%
Winter / Spring (Jun-Nov)	Low flow	Maintain spawning habitat and water levels for River Blackfish Inundate low benches and backwaters for fish and Platypus Flush organic material from benches to prevent risk of blackwater during summer	All years	30-40 ML/day	Whole season		150%/55%
	Fresh	Flush organic material from banks to prevent risk of blackwater during summer Wetting of wood for bugs and biofilms and provision of fish habitat Inundate benches to provide breeding habitat for frogs	Wet / Average	Min 100 ML/day . Could go as high as 200 ML/day in September/ October	1 event, 3 out of 4 years	2-3 days	180%/70%
			Dry	Not expected	No more than 3 years without an event		NA
	High flow	Maintain channel and scour pools Provide cues for recruitment of River Red Gums	Wet / Average	≥ 500 ML/day	For River Red Gum recruitment and maintenance 2 events per year in 2 consecutive years twice per decade, with no more than 4 years without an event. First event each year in Jul-Aug (preferably Aug) to wet the bank and benches, second event each year in Sep-Nov to stimulate RRG recruitment.		200%/50%
			Dry	Not			NA

Waterway	Serpentine Creek from No. 2 Weir to outfall from Irrigation Channel 7/10/1		Regime	Flow recommendations			
Season	**Flow**	**Objective**	**Wet/Average/Dry**	**Magnitude**	**Frequency and timing**	**Duration**	**Rise/Fall***
				expected			
	Overbank	Maintain channel and scour pools Provide cues for recruitment of River Red Gums	Wet / Average	>1000 ML/day	For River Red Gum recruitment and maintenance 2 events per year in 2 consecutive years twice per decade, with no more than 4 years without an event. First event each year in Jul-Aug (preferably Aug) to wet the bank and benches, second event each year in Sep-Nov to stimulate RRG recruitment.		NA
			Dry	Not expected			NA

*Reccomended rates of Rise/Fall are a percentage of the previous days flow and have been determined based on assessment of representative fresh/high flow events for the current flow regime.

4.4 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 would have naturally occurred in Serpentine Creek, they are not recommended. Nutrient enrichment and high salinity levels in the Serpentine Creek 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.

Summer/Autumn low flow

The summer/autumn low flow recommendation aims to maintain a minimum riffle depth of 100 mm and a minimum pool depth of 300 to 500 mm, which is considered sufficient for the native fish that are likely to be present in the system (e.g. River Blackfish, Flat head Gudgeon, Australian Smelt and Carp Gudgeon). A minimum channel depth of 200-300 mm should ideally be maintained along the creek for Platypus throughout the year to reduce predation risk and a minimum depth of 500-1000 mm is recommended to maintain aquatic and fringing emergent vegetation.

Sufficient low flow is also required to maintain adequate water quality and provide connecting flow between pools throughout the reach. A flow of 5-10 ML/day will provide a depth of 150 mm through the shallowest cross-section and a depth up to 800 mm in pool habitats at the FLOWS assessment site (see Figure 4-2). Therefore, the summer/autumn low flow recommendation for this site is 10 ML/day in wet/average years and 5 ML/day in dry years. It is recommended that these low flows extend from January to May inclusive.

The low flow should be 30 ML/day through December in all years to provide a gradual fall from the winter low flow level and ensure that developing River Blackfish eggs and larvae are not stranded. River Blackfish spawn in spring and lay their eggs in submerged hollow logs or among snags, the developing larvae also use these habitats and it is important that these nursery habitats remain inundated throughout spring and early summer and that any reduction in flow is not too sudden. By mid-summer, juvenile River Blackfish should be sufficiently competent swimmers to leave their nursery habitats and will therefore be able to move to alternative habitats as water levels drop.

Under the current flow regime, flow frequently falls below 5 ML/day between January and May, especially in dry years (Figure 4-3). Flows frequently fall below 30 ML/day in December in dry and average years for days/weeks at a time (see Figure 4-4). The lack of continuous flow greater than 30 ML/day in December may negatively impact on River Blackfish spawning. There are no reliable flow records for wet years in this reach.

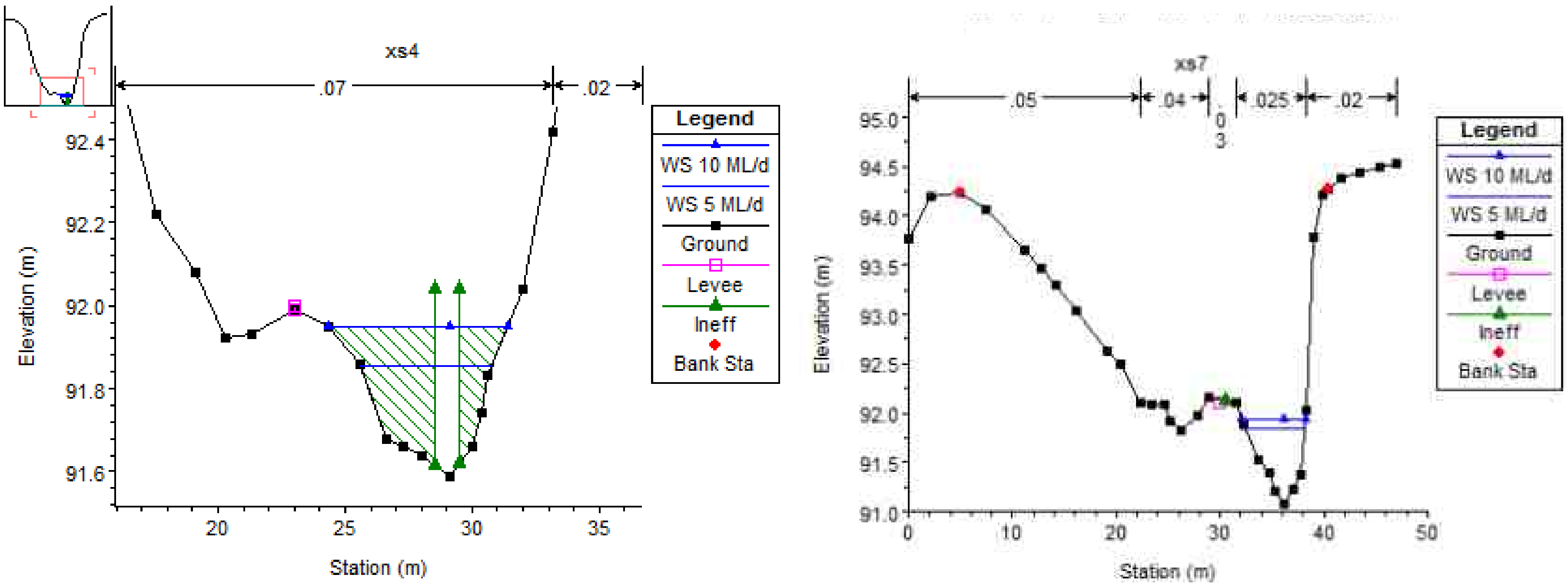

Figure 4-2 Summer/Autumn Low Flow in cross-section 4 (left) and cross-section 7 (right). Flow provides flow depths ranging from 150 mm to 800 mm.

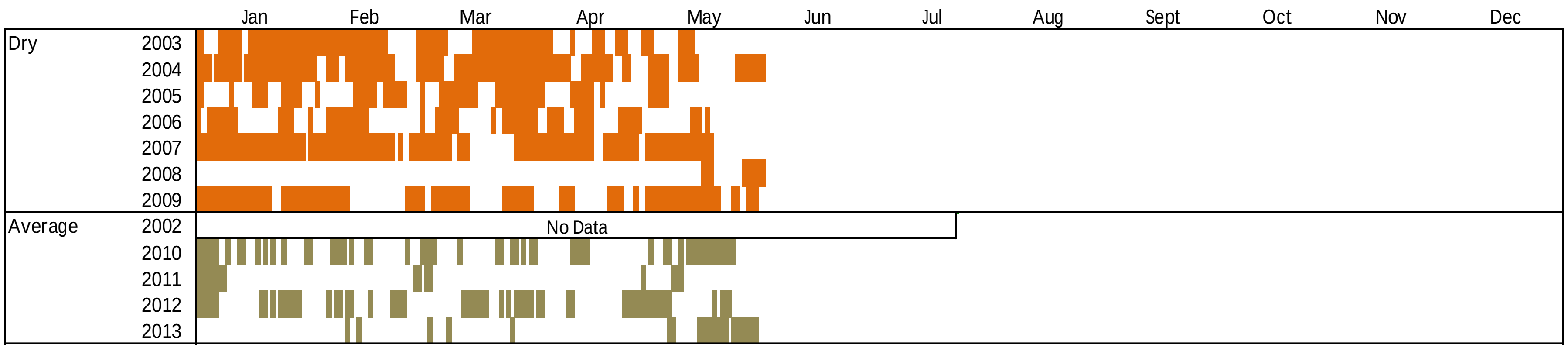

Figure 4-3 Spells analysis of current flows below 5 ML/day in dry and average years. There are no reliable flow records for wet years in this reach.

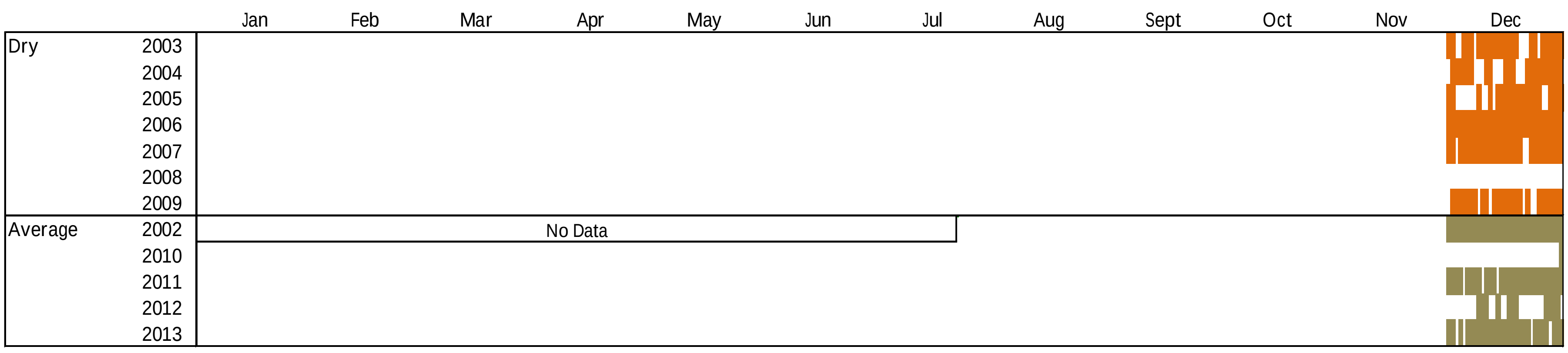

Figure 4-4 Spells analysis of current flows below 30 ML/day during the month of December in dry and average years. There are no reliable flow records for wet years in this reach.

Summer/Autumn freshes

Summer/autumn freshes are important for providing greater depth in all habitats that will allow River Blackfish, Flat head Gudgeon, Australian Smelt, Carp Gudgeon, turtles and Platypus to move more readily between pools.

These higher flows will also inundate benches near the bottom of the channel to water Juncus and Typha and improve the diversity and density of fringing vegetation. Higher flows will inundate large woody debris and promote biofilm development. Prolonged periods of low flow are likely to lead to poor water quality and cause stress on aquatic biota. Summer/autumn freshes will also assist in maintaining water quality and preventing low dissolved oxygen concentrations during low flow periods.

A specific objective of summer/autumn freshes in this reach is to inundate low lying benches and backwater habitats. A flow of 30-40 ML/day inundates low benches and backwaters in all cross-sections at the FLOWS assessment site (see for example Figure 4-5). The frequency and duration of summer/autumn freshes is expected to vary in wet and dry years, with less freshes in dry years (Figure 4-6 and Figure 4-7). We recommend four summer/autumn freshes of 30-40 ML/day between December and May in wet/average years, with each event having a duration of two days. Four events are also recommended in dry years in the short to medium term on the expectation that the full range of recommended environmental flows will promote the recruitment of littoral and riparian vegetation and those plants will require regular watering while their root systems become established. Once littoral and riparian plants are established, it will only be necessary to deliver two summer/autumn freshes per year in dry years. Under the current flow regime there are too many events greater than 30-40 ML/day during summer and autumn, particularly during average climate years (see Figure 4-6 and Figure 4-7). These flows are delivered to meet irrigation demand, but their high frequency is likely to hinder the growth and recruitment of littoral and riparian vegetation. The flow recommendation described here aims to cap the number of such events each season.

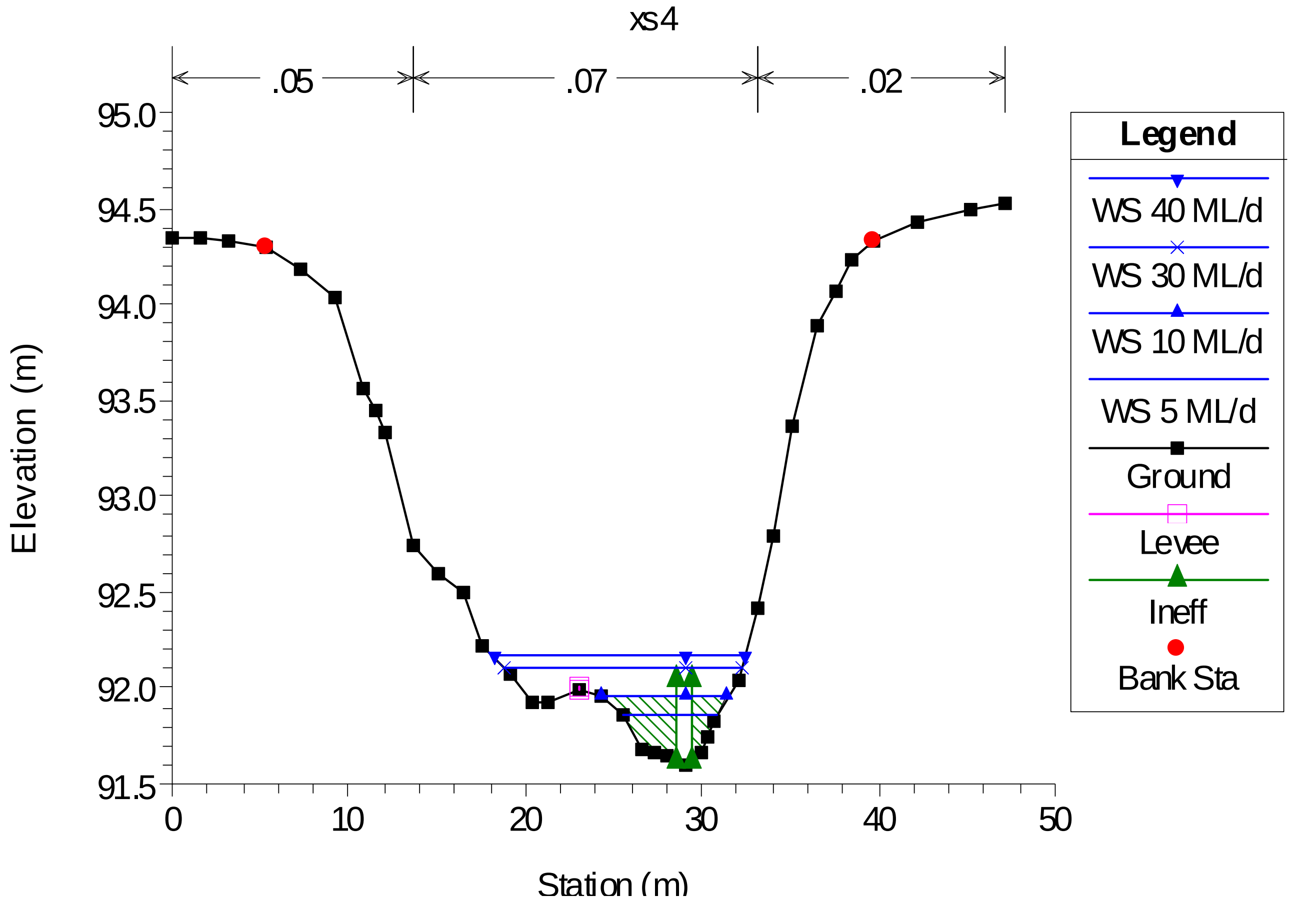

Figure 4-5 Increased depth of summer/autumn fresh compared to the summer low flow at cross-section 4.

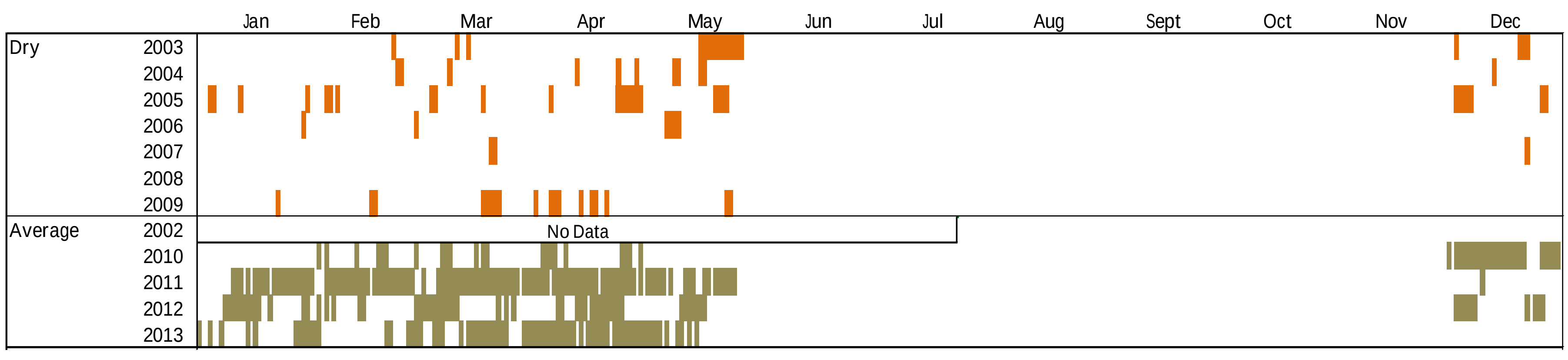

Figure 4-6 Spells analysis of current flows above summer/autumn fresh of 30 ML/day in dry and average years. There are no reliable flow records for wet years in this reach.

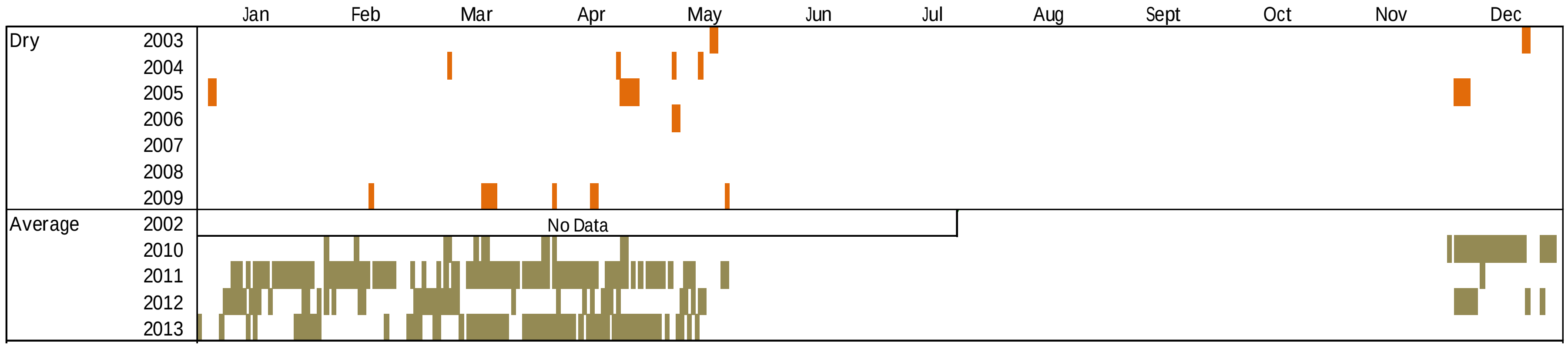

Figure 4-7 Spells analysis of current flows above summer/autumn fresh of 40 ML/day in dry and average years. There are no reliable flow records for wet years in this reach.

Winter/Spring low flow

The winter/spring low flow should have a sufficient magnitude to allow fish and Platypus to move through and forage in shallow run and backwater habitats in the reach and to increase the abundance of pool habitat greater than 500 mm deep for Platypus to forage in. The winter/spring low flow should also provide the necessary water depth to inundate wood and maintain spawning habitat for River Blackfish in October and November. The magnitude of the winter/spring low flow may vary from year to year, but it is important that a target flow is maintained in any given year to avoid stranding eggs and larvae in nursery habitats part way through the breeding season.

The winter/spring low flow recommendation is 30-40 ML/day for wet, average and dry years. This is the same magnitude as the recommended summer/autumn fresh. A flow of 30-40 ML/day will inundate benches, backwaters and LWD (see Figure 4-8), providing necessary flow depths to allow access for fish and Platypus and spawning habitat for River Blackfish. Having the winter low flow that is the same magnitude as the summer fresh will significantly reduce the likelihood of a blackwater event, because it will clear organic material from the banks and limit the amount of organic material that can be entrained by managed environmental flows in warmer months.

Under the current flow regime, winter/spring flows in Reach 3 are less than 30-40 ML/day for nearly all of the time in dry years and for extended periods in average climate years (see Figure 4-9 and Figure 4-10). No flow data are available for wet climate years.

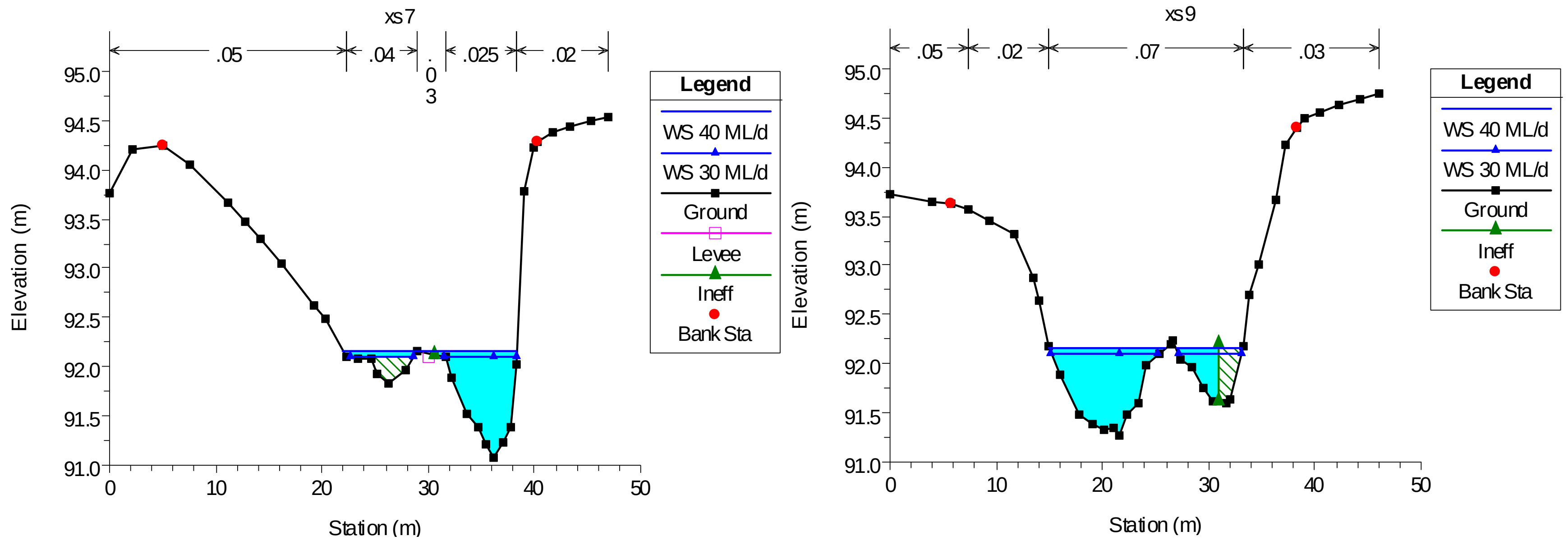

Figure 4-8 Winter/Spring Low Flow in cross-section 7 (left) and cross-section 9 (right) showing inundation of benches, backwaters and LWD.

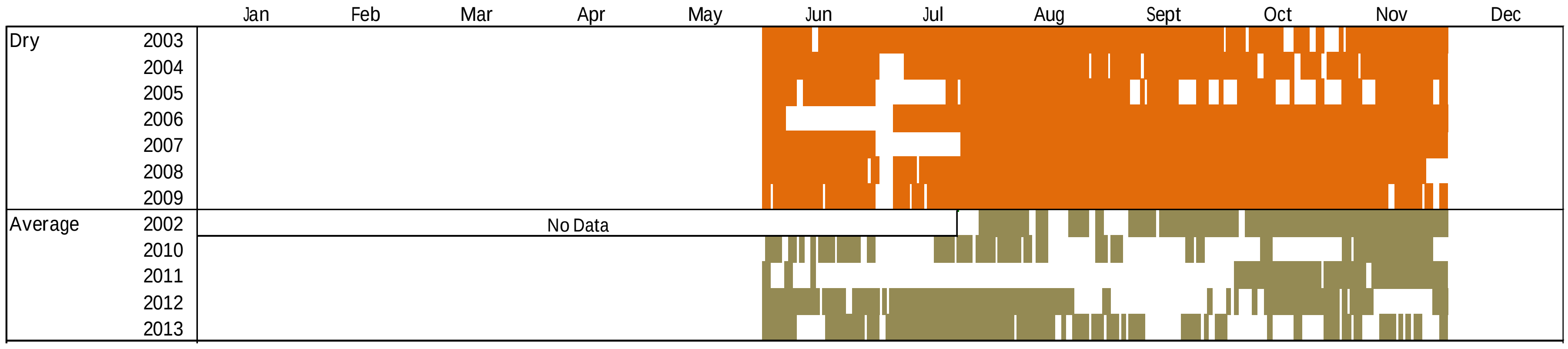

Figure 4-9 Spells analysis of current flows below 30ML/day in dry and average years. There are no reliable flow records for wet years in this reach.

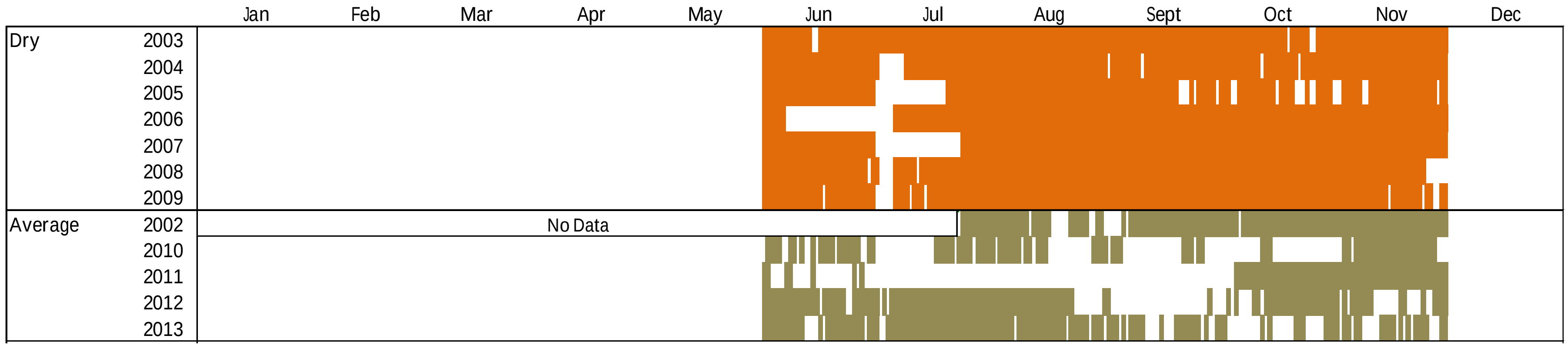

Figure 4-10 Spells analysis of current flows below 40ML/day in dry and average years. There are no reliable flow records for wet years in this reach.

Winter/Spring fresh

Winter/spring freshes help reduce the risk of blackwater events occurring in summer by reducing the amount of organic material (e.g. leaf litter) that accumulates on the river banks and therefore reducing the amount of organic material that can be washed into the channel during summer freshes or summer high flow events. Winter/spring freshes also serve to scour biofilms, inundate large woody debris and provide the variability in flows required to maintain and increase emergent vegetation on low benches and in secondary flow channels. Winter/Spring freshes will also inundate benches providing slow to no-flow breeding habitats for frogs.

A flow of 100 ML/day would inundate the back of low benches and secondary flow channels at the FLOWS assessment site (see Figure 4-11), with water levels 300 mm higher than the winter low flow. Completely inundating these habitats will help prevent the encroachment of pasture grasses and promote the establishment of native riparian vegetation.

Larger magnitude flows could promote the growth of native riparian vegetation further up the bank and on a greater number of low channel features. High freshes in September/October when it is warmer would be beneficial for River Red Gum recruitment. However, high flows in Spring are a risk to Platypus as they could lead to drowning of young Platypus in burrows. A potential trade-off exists between recommending larger freshes that inundate a greater area of bank and improving conditions for vegetation recruitment versus the higher risk that these larger freshes pose to Platypus.

Flows that increase water levels by more than 500 mm compared to the winter/spring low flow level are potentially a risk to Platypus during breeding season as they could lead to drowning of young Platypus in burrows. A flow of 200 ML/day at the FLOWS assessment site would raise water levels 500 mm higher than the winter low flow, which is at the upper limit of water level rise considered acceptable for Platypus during their breeding season.

In wet and average years a winter/spring fresh of 100-200 ML/day with for 2-3 days duration is recommended. This will results in water levels 300-500 mm higher than the winter/spring low flow. The magnitude of this flow should not exceed 200 ML/day between August and November to avoid disrupting Platypus feeding or Platypus burrows when they have young. The recommended frequency of winter/spring fresh is three out of four years in wet and average years. In dry years, no more than three years without an event is recommended.

Spells analysis shows that winter/spring freshes above 100 ML/day in average years occur three times in 2011 and 2012, 6 times in 2010 and not at all in the other two years (2002 and 2013, see Figure 4-12). Winter/spring freshes above 200 ML/day occur five times in 2010, once in 2012 and not at all in the three years (2002, 2011 and 2013, Figure 4-13).

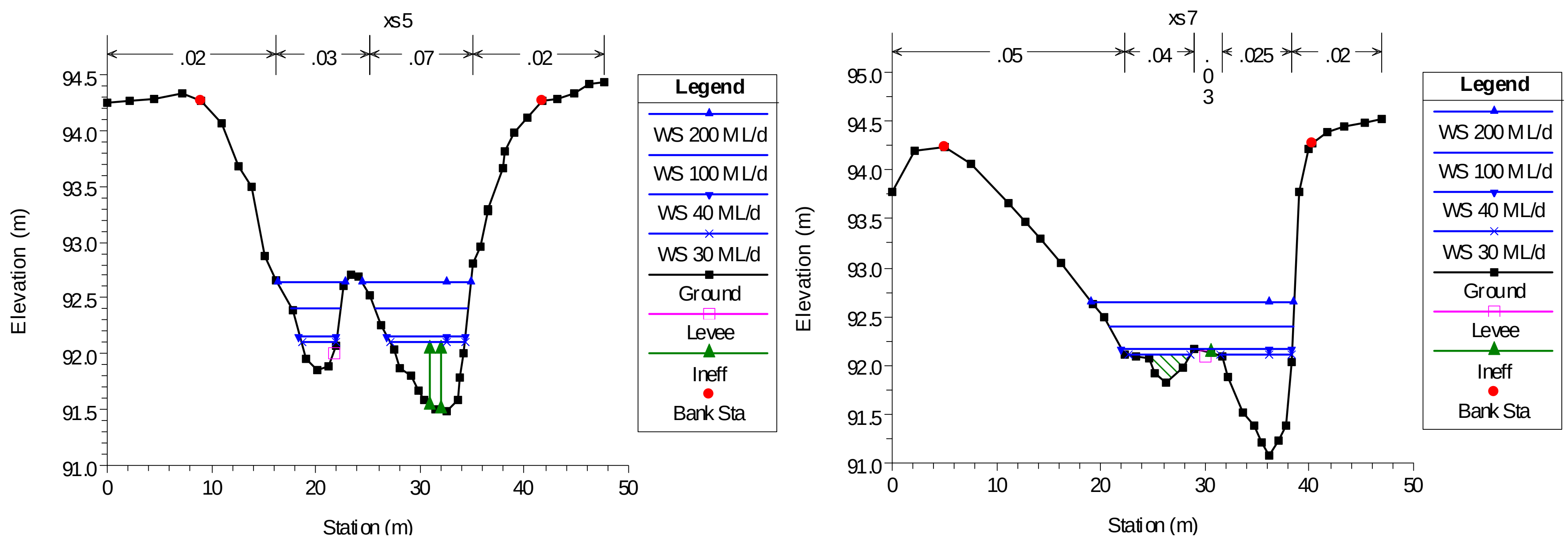

Figure 4-11 Increased depth of winter/spring fresh (100-200 ML/day) compared to the winter/spring low flow (30-40 ML/day) at cross-section 5 (left) and cross-section 7 (right).

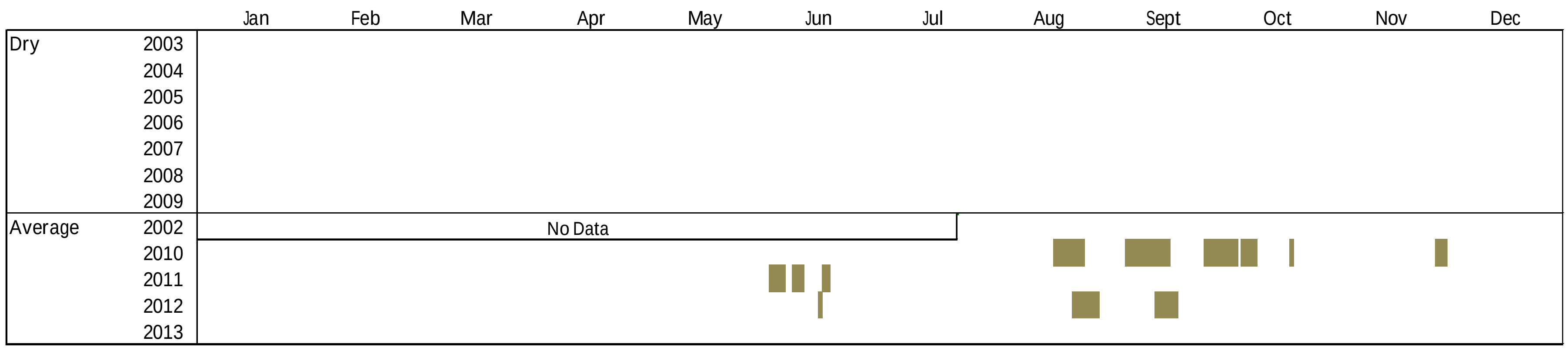

Figure 4-12 Spells analysis of current flows above winter/spring fresh of 100 ML/day in dry and average years. There are no reliable flow records for wet years in this reach.

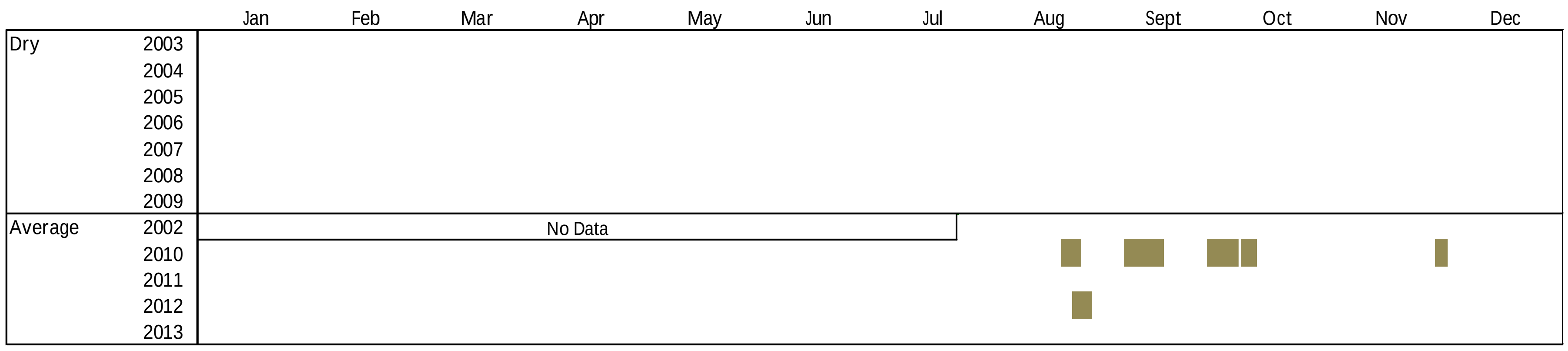

Figure 4-13 Spells analysis of current flows above winter/spring fresh of 200 ML/day in dry and average years. There are no reliable flow records for wet years in this reach.

High Flow/Overbank

Bankfull and overbank flows help to maintain the channel form and dimensions as the velocity and shear stresses associated with these flows will scour the channel bed and banks of the channel, entraining sediments and deepening pools and secondary channels. These events also help to promote river red gum recruitment and maintenance. For river red gum recruitment and maintenance, two events each year (July-August and September-November) in two consecutive years twice per decade are recommended, with no more than four years without an event. Bankfull and overbank flows are most likely to occur in the winter months, and will have the greatest effect on riparian plant communities if they occur in the Spring.

Analysis of HEC-RAS model shows that flows > 500 ML/day would result in a flow depth of 1.5 m with flow inundating low-lying in-channel benches and secondary flow channels at the FLOWS assessment site (see Figure 4-14). Increasing this flow to 1,000 ML/day would result in a greater depth of flow but no significant change in channel features inundated. Flows greater than 3,000 ML/day would be required to engage the broader floodplain adjacent to the channel (see Figure 4-14). Table 4-2 presents average velocity and shear stress values for flow rates of 500, 1,000 and 3,000 ML/day calculated in HEC-RAS. Calculated velocities and shear stresses for the range of flows modelled are quite low, this is a reflection of the low stream bed gradient in this reach. It is really only at the very highest flows > 3,000 ML/day that water velocities are approaching the threshold levels (at least 1 m/s) considered necessary to move sediment and maintain channel capacity.

A specific bankfull recommendation has not been made for this reach. Based on a review of the hydraulic geometry of the channel, the range of flows that are required to inundate different channel features and the distribution of vegetation in the riparian zone, there is no clear justification to set a morphological bankfull flow. Instead, we have chosen to specify a high flow and overbank flow for this reach for the reasons outlined below.

For this reach, a high flow > 500 ML/day is recommended to inundate low-lying in-channel benches and secondary flow channels at the FLOWS assessment site. This will also inundate higher parts of the banks that are not reached by the winter freshes. Flows of this magnitude will help promote the recruitment and maintenance of river red gum stands in the areas. Two high flow events each year (July-August and September-November) in two consecutive years twice per decade are recommended, with no more than four years without an event. Flow events larger than the recommended high flow will inundate a larger proportion of the channel and at some point break out across the broader floodplain. We have set an overbank flow recommendation of >1,000 ML/day, whilst recognising that flows >3,000 ML/day may be required to inundate the floodplain.

Spells analysis for flows greater than 500, 1,000 ML/day and 3,000 ML/day are presented in Figure 4-14, Figure 4-15 and Figure 4-16. Flows greater than 500 ML/day occur in three out of four average years (Figure 4-14), but the number and timing of events varies in different years. In 2010, flows are recorded in August/September and November/December. In 2011, a number of events were recorded in January and February, but no events occurred later in the year. In 2012 only one event occurred in August. No events were recorded in dry years.

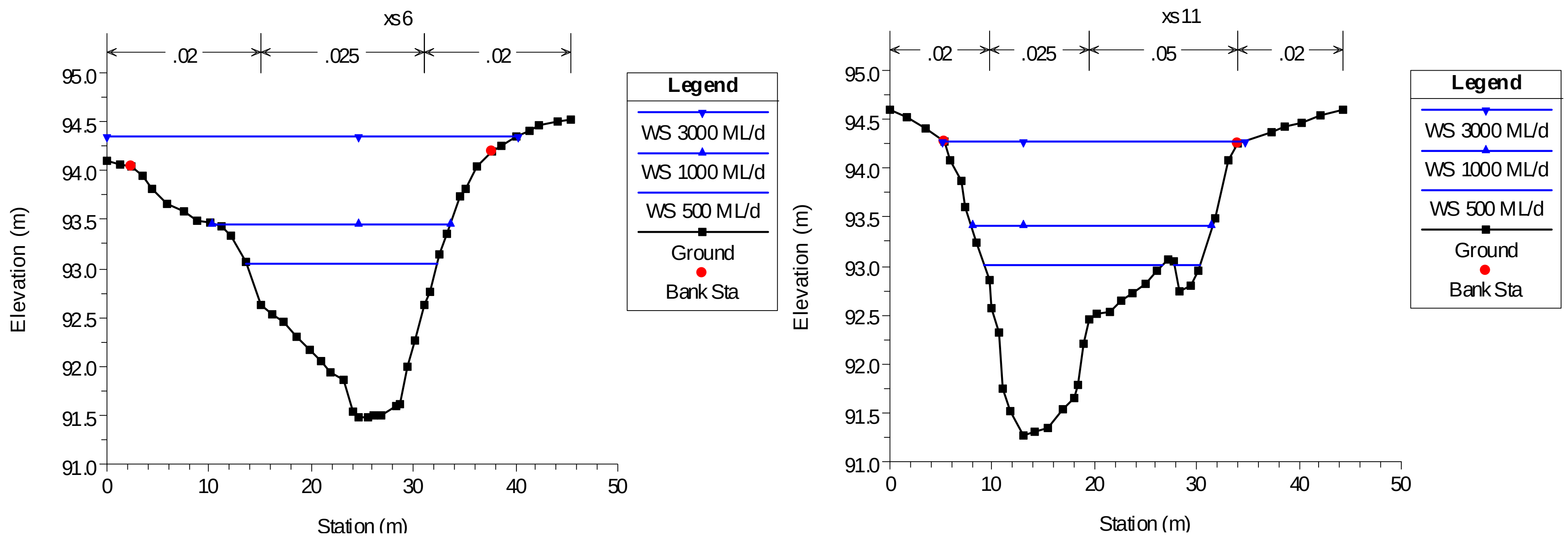

Figure 4-14 Cross-section plots showing different levels of inundation for flows of 500, 1,000 and 3,000 ML/day.

Table 4-2 HEC-RAS calculated velocities and shear stresses for flow rates of 500, 1,000 and 3,000 ML/day.

Flow (ML/day)	Velocity (m/s)	Shear Stress (N/m^2)
500	0.2 - 0.7	0.5 – 12.8
1,000	0.3 – 0.7	1.0 -14.7
3,000	0.5 – 1.0	2.7-20.7

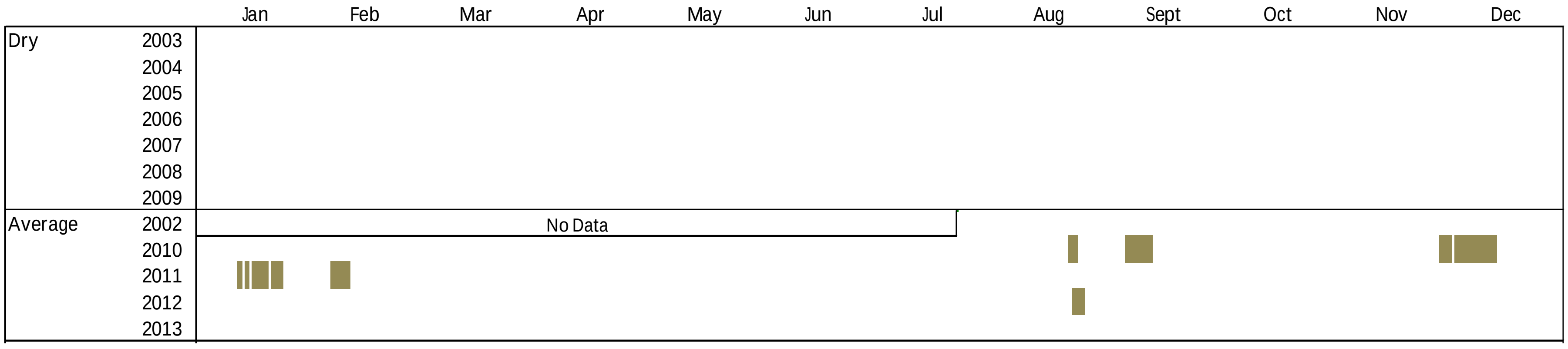

Figure 4-15 Spells analysis of current flows above high flow of 500 ML/day in dry and average years. There are no reliable flow records for wet years in this reach.

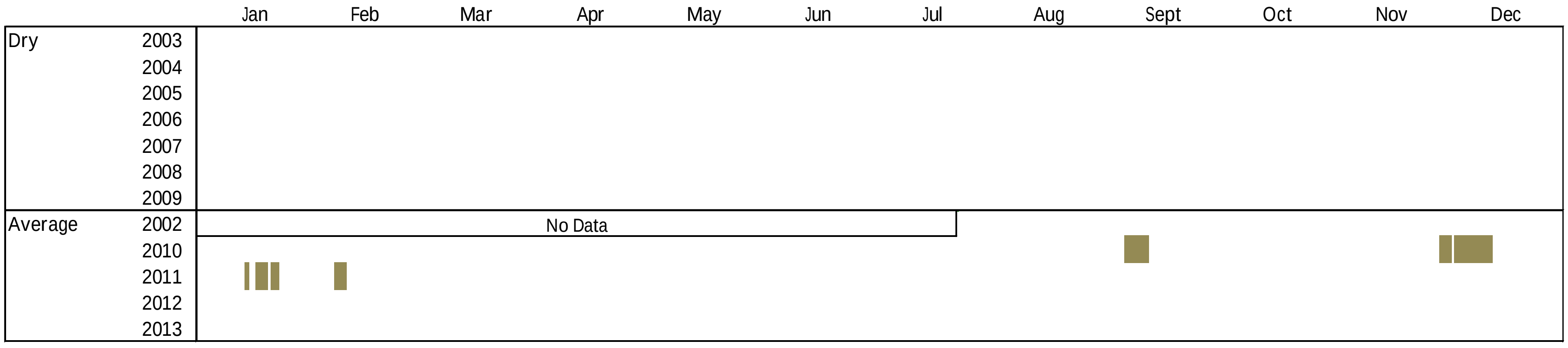

Figure 4-16 Spells analysis of current flows above 1,000 ML/day in dry and average years. There are no reliable flow records for wet years in this reach.

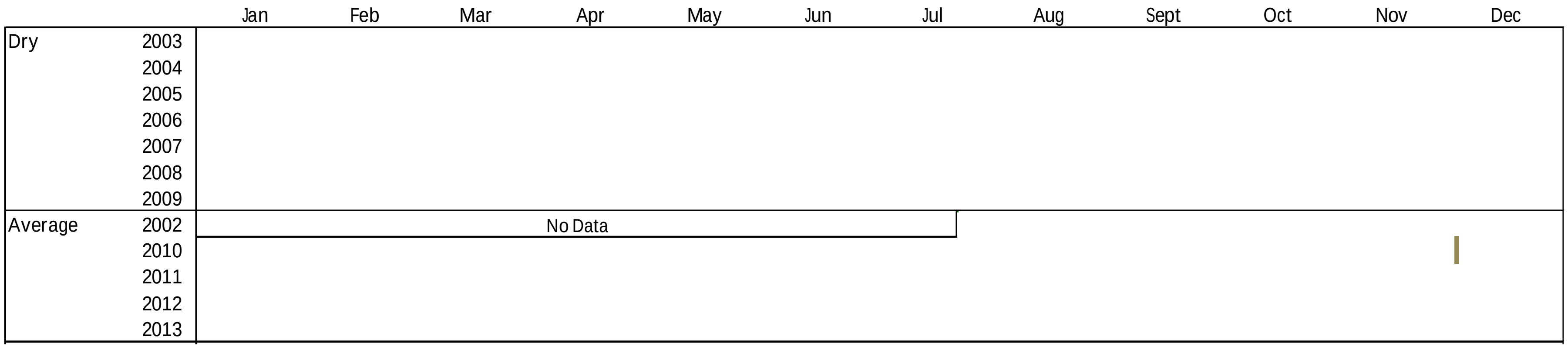

Figure 4-17 Spells analysis of current flows above 3,000 ML/day in dry and average years. There are no reliable flow records for wet years in this reach.

4.5 Current achievement of flow recommendations

The flow regime of Serpentine Creek in Reach 3 is subject to marked fluctuations throughout the year. Figure 4-18 and Figure 4-19 shows the variation in flows experienced in this reach for a typical average and dry year. Recommended low flows for summer/autumn and winter/spring are also overlaid on these plots to highlight the differences between actual and recommended flows. Flows frequently fall below the low flow recommendations throughout the year in both typical average and dry year shown. Flow fluctuations are more pronounced during the irrigation season, with flow rates switching from <5 ML/day to >50 ML/day every few weeks in an average year (Figure 4-18). The magnitude of the fluctuations is less in the dry year but there are still frequent rises and falls deviating from the recommended low flows (Figure 4-19).

An assessment of how well the flow recommendations for Reach 3 are currently met in average and dry years is presented in Table 4-3 and Table 4-4, respectively. There is no flow data for wet years in this reach and therefore the compliance during wet years is not presented. It should be noted that these assessments do not include an 'or natural' clause, because there are no hydrological models for Serpentine Creek that can estimate what the flow regime would be without the influence of reservoirs, farm dams and other water harvesting and water delivery operations. No assessment of high flow or overbank flows has been made because the period of record is too short.

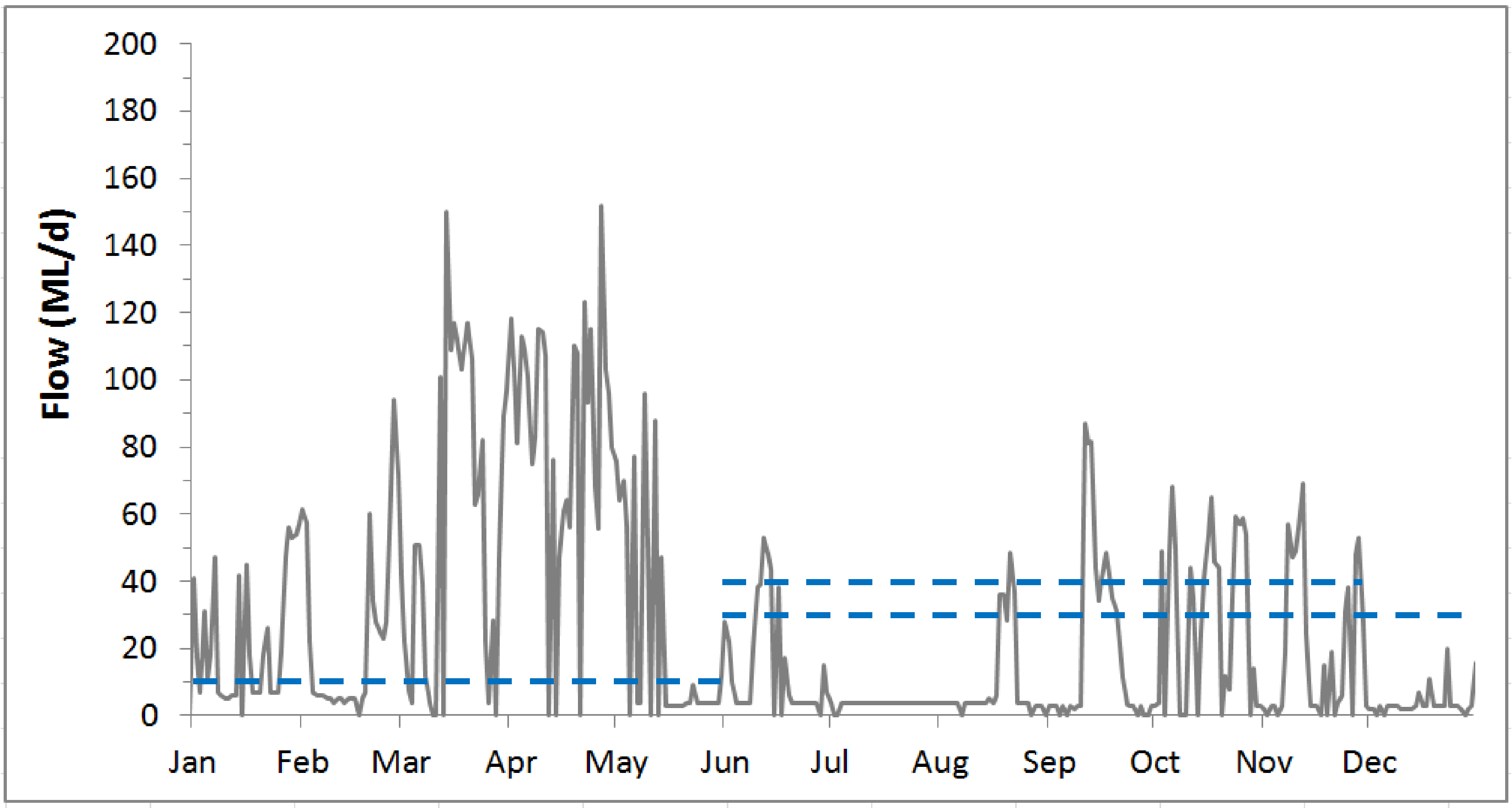

Figure 4-18 Daily flows in Reach 3 for a typical average year as represented by the year 2013. Average year low flow recommendations for Summer/Autumn (10 ML/day January-May and 30 ML/Day in December) and Winter/Spring (30-40 ML/Day June-November) are also shown.

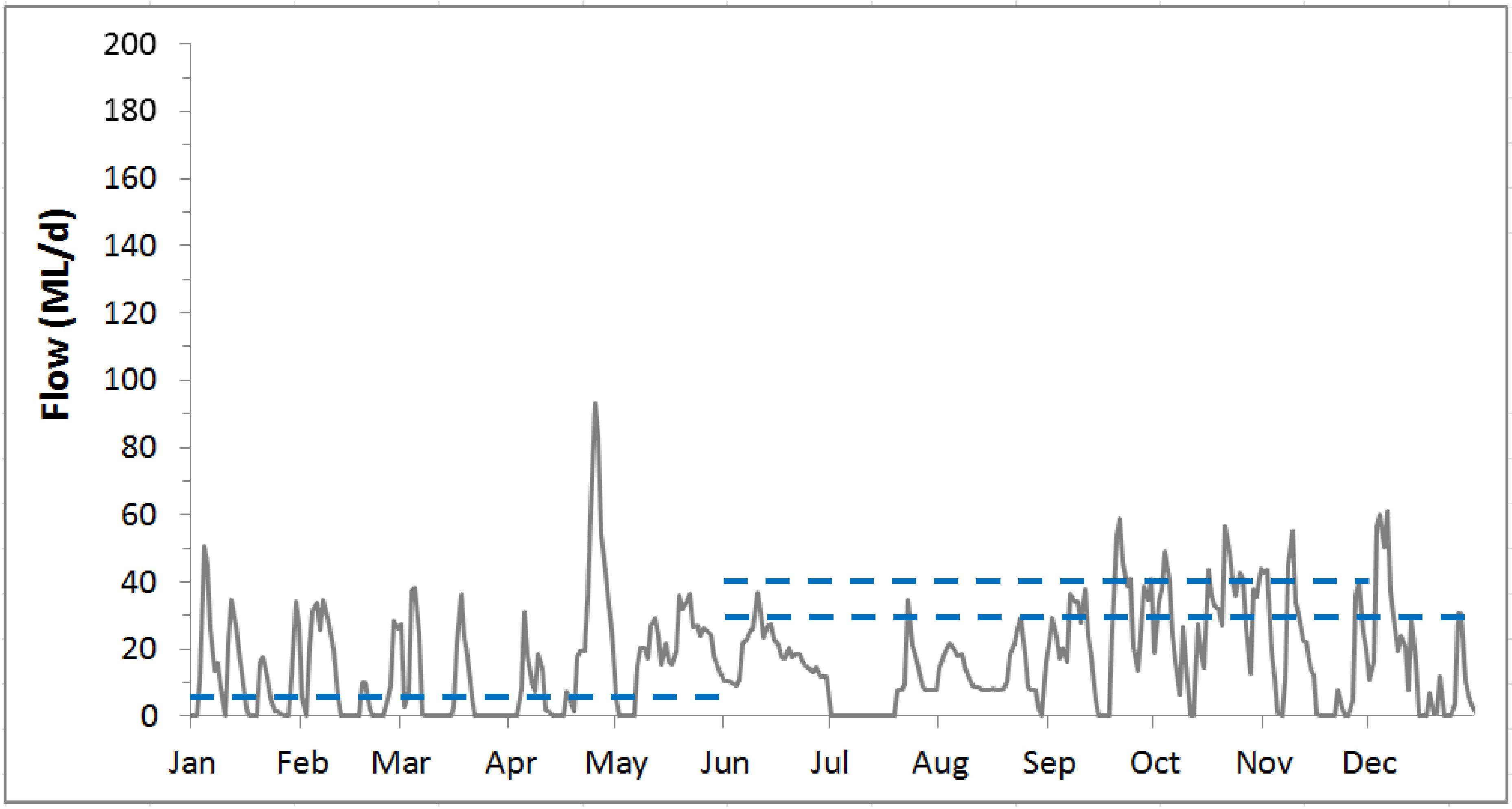

Figure 4-19 Daily flows in Reach 3 for a typical dry year as represented by the year 2005. Dry year low flow recommendations for Summer/Autumn (5 ML/day January-May and 30 ML/Day in December) and Winter/Spring (30-40 ML/Day June-November) are also shown.

Our assessment of compliance in average climate years is based on flow records for four years. In average climate years the recommended summer/autumn low flow of 10 ML/day during the months of January to May is met 54 % of the time and the recommended winter low flow of 30 ML/day is met 26 % of the time (Table 4-3). The recommended December low flow of 30 ML/day is only met 33 % of the time. The minimum summer/autumn fresh recommendation (i.e. four events of 30 ML/day that last for two days each season) was met in three out of the four average climate years that we have data for, but four freshes with a magnitude of 40 ML/day were recorded in only two out of the four years (Table 4-3). Winter freshes of 100 ML/day were recorded in three out of the four years and freshes of 200 ML/day occurred in two years (Table 4-3).

Our assessment of compliance in dry climate years is based on flow records for seven years. In dry climate years, the recommended summer/autumn low flow of 5 ML/day during the months of January to May is only met 48 % of the time and the minimum winter/spring low flow of 30 ML/day is only met 5 % of the time (Table 4-4). Two summer freshes of at least 30 ML/day occurred in 71 % of year. The recommended December low flow of 30 ML/day is only met 6 % of the time. Winter/spring freshes were not recommended for dry years and therefore were not assessed as part of the compliance.

As with Reach 1, in Reach 3 summer/autumn low flow and winter/spring low recommendations are critical events for maintaining access to habitat for fish and Platypus throughout the year. The poor compliance with recommended low flows, especially the winter/spring low flow, indicate that there is a need to increase low flows through this reach in order to improve conditions for fish and Platypus. A moderate compliance is documented for freshes, however this result is deceptive. As previously highlighted, an issue with current management of flows in this reach is that there are frequent rises and falls in flow. Overall, the frequency of fresh events in this reach is too high and is considered to have a disturbing influence on vegetation recruitment in the littoral zone and higher on the banks. Implementing a flow regime with more constant low flows and less frequent freshes presents a significant opportunity to improve the conditions for vegetation recruitment within the littoral zone and on the banks.

Table 4-3 Achievement of environmental flow recommendations for Reach 3 for average years.

Component	Months	From	To	Flow Recommendation			Or Natural	Compliance Lower	Compliance Upper
Summer/Autumn low	Jan - May	1	5	Magnitude	10	ML/d	No	54%	
	Dec	12	12	Magnitude	30	ML/d	No	33%	
Summer/Autumn fresh	Dec - May	12	5	Magnitude	30-40	ML/d	No	75%	50%
				Frequency	4	per year			
				Duration	2	days			
Winter/Spring low	Jun - Nov	6	11	Magnitude	30-40	ML/d	No	26%	22%
Winter/Spring fresh	Jun - Nov	6	11	Magnitude	100-200	ML/d	No	75%	50%
				Frequency	1	per year			
				Duration	3	days			

Table 4-4 Achievement of environmental flow recommendations for Reach 3 for dry years.

Component	Months	From	To	Flow Recommendation			Or Natural	Compliance Lower	Compliance Upper
Summer/Autumn low	Jan - May	1	5	Magnitude	5	ML/d	No	48%	
	Dec	12	12	Magnitude	30	ML/d	No	6%	
Summer/Autumn fresh	Dec - May	12	5	Magnitude	30-40	ML/d	No	71%	57%
				Frequency	2	per year			
				Duration	2	days			
Winter/Spring low	Jun - Nov	6	11	Magnitude	30-40	ML/d	No	5%	2%

5. Reach 5 – Nine Mile Creek

5.1 Description

Nine Mile Creek is a distributary stream that flows from Serpentine Creek approximately 3 km downstream from Durham Ox. Currently, Nine Mile Creek does not receive flows except for large flood flows and leakage from an old drop bar gate that historically was operated to deliver outfall flows from Serpentine Creek.

Nine Mile Creek is quite confined in its upper parts and it is likely that this section was historically dredged (Figure 5-1). Downstream from the confined section, a large area of River Red Gum Forest and Woodland with various age stands spreads across a broad drainage depression comprised of numerous anastomosing channels (Figure 5-2). Nine Mile Creek flows northwest from the River Red Gum Forest and Woodland areas through open grazing land to join Calivil Creek.

	
Dredged channel immediately downstream of regulator structure.	Further downstream looking at shallow creek traversing open River Red Gum Forest

Figure 5-1 Selected photographs of Reach 5 FLOW assessment site - Nine Mile Creek at Nine Mile Regulator.

	
Shallow depression/main flow path that directs water into River Red Gum Woodland	River Red Gum Forest with good understorey, approximately 1.5 km downstream of regulator.

Figure 5-2 Selected photographs of Reach 5 FLOW assessment site - Nine Mile Creek at River Red Gum Woodland.

The River Red Gum Forest and Woodland 1.5 km downstream of the Nine Mile Creek Regulator is the main focus for this environmental flow reach. We did not conduct a full FLOWS assessment for Nine Mile Creek because the complex distributary stream network prevent us developing reliable hydraulic models for the system that are needed to quantify flows to meet specific flow objectives. Instead, we used general site observations and a desktop review to identify environmental values at the site and to describe a general flow regime that is likely to be needed to maintain or improve those values. The results of those assessments are described below.

5.2 Water management goal for this reach and environmental flow objectives

The River Red Gum Forest and Woodland on Nine Mile Creek is one of the largest remnant River Red Gum dominated ecosystems in the region and has the potential to provide important habitat to a large number of woodland birds as well as potential breeding habitat for frogs and waterbirds. In flood, this area is likely to provide potential breeding habitat to a number of waterbird species, including the threatened Brolga which is now rare in the region (Jacobs, 2014a).

The water management goal for Nine Mile Creek is ***'to maintain and enhance current vegetation values in Nine Mile River Red Gum Forest and Woodland'.***

The environmental flow objectives for this reach are summarised in Table C-3 in Appendix C. The highest priority environmental flow objectives include:

1) Maintaining and improving the remnant River Red Gum Forest and Woodland.
2) Maintaining the current condition of the populations of turtles, frogs, woodland and waterbirds.

5.3 Flow recommendations and rationale

The environmental flow recommendations for Reach 5 and the specific objectives they aim to meet are summarised in the paragraphs below. The section of Nine Mile Creek downstream from Nine Mile Regulator is a mosaic of River Red Gum Forest and Woodland with different watering requirements.

The River Red Gum Forest areas along Nine Mile Creek are lower lying and will be inundated by moderate floods which occur more frequently. River Red Gum Forest areas and associated understorey vegetation require one inundation event in winter/spring every 2-3 years in wet and average conditions, for a duration of 2-6 months with water depths ranging from 200-500 mm. The River Red Gum Woodland areas along Nine Mile Creek occupy slightly higher ground that will be inundated by larger floods less frequently. River Red Gum Woodland areas require one inundation event in winter/spring every 3-5 years in wet and average conditions, for a duration of 2-4 months with water depths of 200-500 mm.

The primary objective of providing these inundation events is to maintain and improve River Red Gum Forest and Woodland areas and associated understorey that is present along this section of Nine Mile Creek. A secondary objective is to encourage waterbirds to breed in the low lying River Red Gum Forest areas. The River Red Gum Forest areas will hold water for longer as floodwaters gradually recede and may provide opportunities for waterbird breeding. If waterbirds nest and lay eggs, it may be necessary to prolong the period of inundation in low lying forest areas until the nesting birds successfully fledge their chicks. We do not recommend extending the inundation period for every event because regular, prolonged inundation is likely to degrade understorey vegetation and create a more homogeneous habitat.

The River Red Gum Forest and Woodland areas would not be inundated at all in dry years and therefore we do not recommend delivering any environmental water to Nine Mile Creek in dry years. Established River Red Gum trees will persist during dry periods by accessing and using groundwater, even if that groundwater is moderately saline. Studies on the Chowilla floodplain of South Australia indicate that River Red Gum trees derived nearly 80% of their water requirements from groundwater, even though the groundwater had a salinity of 11,000 ECU and the soil chloride content was 1-7 g/L in the upper 4 m (Eamus et al., 2006). The preferential use of groundwater, soil pore water, and surface water by River Red Gum does, however, vary with distance from streams. Moreover, salinity tolerance varies with provenance, with specimens coming from saline areas likely to be more salt-tolerant than those from fresher areas (Roberts & Marston, 2011). Rogers (2011) recommended that groundwater be less than 40,000 ECU for River Red Gums.

The structure of River Red Gum communities changes according to flood frequency. The condition of River Red Gum Forest and Woodland areas along Mile Creek may decline over very dry periods. River Red Gum forests can survive extended drought periods, but at the expense of regeneration and of the condition of adult trees. Rogers (2011) recommended a maximum dry period of 4 or 5 years for River Red Gum Woodlands, and 3 years for River Red Gum Forests. Roberts and Marston (2011), however, noted that River Red Gum communities with grassy understoreys may be able to survive at least 10 years without overbank flooding.

It is not possible to provide an accurate assessment of what flow is needed to inundate just the low lying River Red Gum Forest areas and what flow is needed to inundate the River Red Gum Forest and Woodland areas. Our preliminary assessment is that a flow of 800-900 ML/day is required to cause broad inundation of the forest and woodland areas along Nine Mile Creek. This is based on the local landowner's understanding of flow events that have filled this area and relating this back to the historical record of flows recorded at Serpentine Creek offtake (see Figure 5-3). The landowner stated that the areas flooded in 1996, and every 1-2 years throughout the 1990s, which is in line with a flow rate of approximately 800-900 ML/day. The landowner also stated that the areas did not flood between 1997 and November 2010, which suggests that the flow events in 1999 and 2000 of 400-700 ML/day did not inundate these areas.

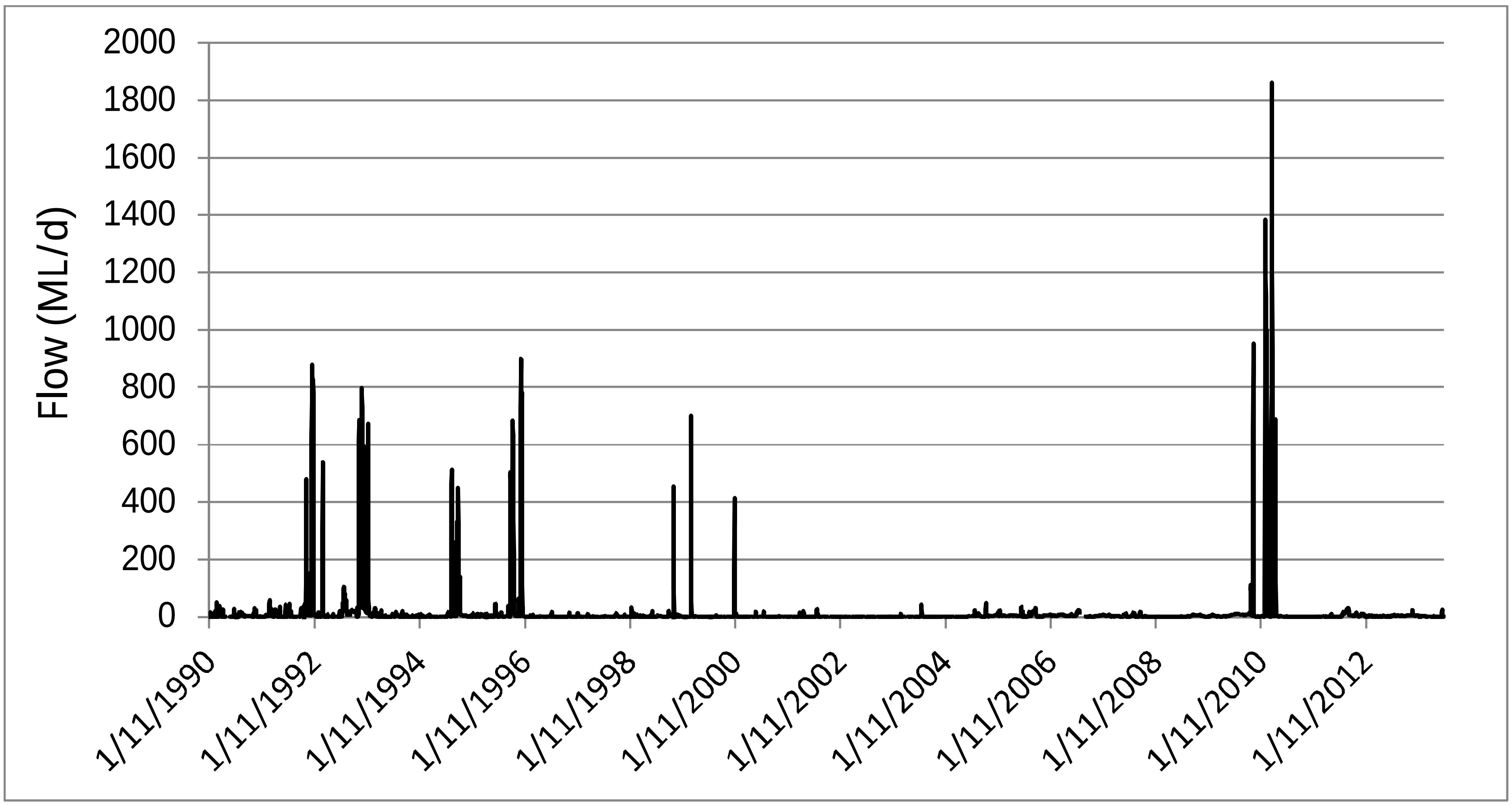

Figure 5-3 Daily Flows – Nine Mile Creek at the Serpentine Creek offtake (407289) between November 1990 and April 2014.

5.4 Knowledge Gaps

There are three key knowledge gaps that need to be addressed as part of future investigations into the potential for watering River Red Gum Forest and Woodland areas along Nine Mile Creek:

- First, the EFTP noted sections of the River Red Gum Forest and River Red Gum Woodland had varying canopy and understorey condition. Some areas had very dense and healthy canopies with dense and diverse understorey vegetation. Other areas had full canopies, but relatively bare understorey and other areas had very poor canopy condition, little or no understorey and numerous dead trees. Further investigations are recommended to determine why there is so much variation in vegetation condition across a relatively small area. Some members of the EFTP hypothesised that a combination of salt and water-logging due to nearby irrigation may be one cause, but there is currently no available data to test that hypothesis. Among other things, any future investigation should measure salt and soil water profiles throughout the reach to determine whether these factors are affecting vegetation condition.

- Second, what flow magnitude is required to water the low lying areas that support River Red Gum Forest and the higher elevation areas that support River Red Gum Woodland and what are the specific flow paths that connect and inundate these different habitats. In order to address this question it will be necessary to conduct a detailed feature survey of the site and develop a two-dimensional hydraulic model. It may also be necessary to observe the flow paths that initially connect and fill different areas within the site at the start of a high flow event.
- Third, what effect will flooding the River Red Gum Forest and River Red Gum Woodland have on salt levels in these habitats and further downstream in the Tragowel Plains?.

Once these knowledge gaps are filled, it should be possible to quantify the flows that are needed to meet the ecological objectives that we have already described for the reach and determine the extent to which managed flows from Serpentine Creek can be used to implement the recommended flow regime. It is possible that specific works and measures (e.g. upgrades to regulators and potential construction of small levees) may be needed to facilitate environmental flow releases and to ensure the flows inundate the target areas for the required duration.

5.5 Management Recommendations

We have recommended a generic watering regime to meet specific objectives of the River Red Gum Forest and Woodland vegetation areas that are present along Nine Mile Creek. The intent is that Nine Mile Creek is managed primarily to protect and maintain a healthy River Red Gum overstorey and a diverse understorey. If in delivering water, waterbirds opportunistically nest and breed, monitoring is recommended to develop a better understanding of the flows that are needed to ensure breeding success. However, at present waterbirds are not a high priority. A number of knowledge gaps have been identified. It is recommended that further investigations are completed to address these knowledge gaps.

6. Reach 6 – Pennyroyal Creek

6.1 Description

Pennyroyal Creek is a natural distributary system of Serpentine Creek that flows in a north west direction from a point on Serpentine Creek approximately 3 km downstream of Durham Ox. Pennyroyal Creek comprises a series of shallow distributary channels that cross a flat Lignum dominated floodplain between Nine Mile Creek and Bannacher Creek. The distributary channels would naturally carry water during moderately high flow events and contract to a series of disconnected pools at other times. They would have supported a range of instream and riparian vegetation that is normally associated with wetland habitats and potentially provided important refuge habitats for frogs, fish and turtles that enable those species to persist and move across the broader landscape. Large floods in Serpentine Creek and the Loddon River would inundate the whole floodplain. In flood, inundated areas are likely to provide potential breeding habitat to a number of waterbird species, including Brolga (Jacobs, 2014a).

Pennyroyal Creek now receives irrigation outfall water from an automated gate on Serpentine Creek, but nearly all of that water is directed down a single channel that has been partially dredged to increase its hydraulic capacity (see Figure 6-1). During the irrigation season, this channel frequently receives outfalls ranging from 20 ML/day to 100 ML/day. These outfalls maintain permanent pools in the dredged channel that may be suitable habitat for the FFG listed Bibron's Toadlet. Regular fluctuations in water level have created distinct bands of aquatic and semi aquatic vegetation at different bank elevation levels within the channel. The other distributary channels of Pennyroyal Creek receive much less water than they would naturally and except for a small number of pools that trap water from local rainfall, are mainly dry.

We have not conducted a full FLOWS assessment for Pennyroyal Creek because such an assessment would only focus on the distributary channel that has been dredged to carry most of the outfall water. We believe that focus is limited and does not adequately consider the importance of maintaining multiple flow paths across the floodplain and periodic overbank floods. A detailed two-dimensional hydraulic model would need to be developed to determine appropriate flow regimes for multiple channels and even if relevant flow regimes could be determined, extensive channel works would be needed to help deliver environmental flows to those flow paths. Both the two-dimensional hydraulic model and plans for associated channel works are beyond the scope of the current study.

Instead of a full FLOWS assessment, we have qualitatively described the habitat and instream values at the main distributary channel immediately downstream of the outfall regulator (Figure 6-1) and at multiple distributary channels that cross Leaghur Road, and conducted a more detailed assessment of the main distributary channel at a site downstream of Hopefield Road (Figure 6-2). We have used these observations and some semi-quantitative channel measurements that we made at the Hopefield Road site to describe general flow regimes that are needed to support floodplain and instream vegetation and maintain habitat for Bibron's Toadlet.

	
Channel No 12 outfall to Pennyroyal Creek.	Dredged channel with emergent vegetation.

Figure 6-1 Selected photographs of Reach 6 FLOW assessment site – Pennyroyal Creek downstream from Channel No 12. Outfall.

	
Downstream of Leaghur Road showing emergent vegetation	Downstream of Hopefield Road showing distinct zones of emergent vegetation

Figure 6-2 Selected photographs of Reach 6 FLOW assessment site – Pennyroyal Creek downstream from Leaghur Road and Hopefield Road.

6.2 Water management goal for this reach and environmental flow objectives

The water management goal for Pennyroyal Creek has been developed for the expansive plain of Lignum and network of distributary channels. The broad plain and network distributary channels are not necessarily able to be watered by environmental water. The fringing vegetation that is currently established along the dredged drainage lines is maintained by outfall water. These wetter sections provide some value to frogs, turtles, woodland and waterbirds, however they only exist as a result of the current operational regime. The current outfall flows will maintain these instream values, but any proposed changes to outfall operations should trigger a separate investigation to determine whether any actions are required to mitigate the effect of such changes.

The water management goal developed for Pennyroyal Creek is ***‘to maintain the expansive plain of Lignum and network of distributary channels’***.

The environmental objectives for this reach are documented in Table C-4 in Appendix C. The highest priority environmental flow objectives include:

1) Maintaining and improving the remnant Tangled Lignum.
2) Maintaining the current condition of the populations of turtles, frogs, woodland and waterbirds.

6.3 Flow recommendations and rationale

The environmental flow recommendations for Reach 6 and the specific objectives they aim to meet are summarised in the sections below. Environmental flow recommendations for vegetation are discussed separately for the Tangled Lignum on the floodplain and the in-channel vegetation that is present along the dredged drainage lines. Flow recommendations are also provided for Bibron's Toadlet.

Lignum floodplain

Overbank flows are recommended to maintain the distributary channel network and water Tangled Lignum. Tangled Lignum has a wide hydrological niche; it needs to be inundated once every 3 to 10 years, for a duration of 1-6 months. During wet and average years, one event every three years may be expected to occur. During dry periods these events may only occur once every ten years. A detailed hydraulic model is not available for this reach, but we estimate that large overbank flows (probably greater than 900 ML/day) would be required to inundate Lignum on the floodplain. Roberts and Marston (2011) suggest that the depth of inundation is not critical for this community. Land clearing and levelling is also identified is a threat to this vegetation community. Land clearing results in the loss of native vegetation and levelling flattens the land and breaks up the network of distributary channels that deliver flow during inundation events.

In-channel vegetation

Channel outfalls maintain distinct vegetation zones within the dredged drainage channel as well as aquatic biota such as frogs, turtles and macroinvertebrates. If the outfall regime is likely to change in the future as a result of the modernisation of the channel network a specific assessment will need to be completed to determine the effect of the proposed changes of flows. Short duration flows currently provided by the outfall maintain the submerged aquatic and fringing vegetation along the drainage lines. Three plant communities with differing water requirements, are present in the channel as outlined below:

- Instream vegetation – Plants such as Myriophyllum, Potomagetan and Triglochin require some water most of the time, but could withstand cease-to-flow periods as long as some permanent pools remain and sufficient soil moisture is retained within the streambed.

- Sedge community – Sedges require inundation every spring in wet and average years and at least every second year in dry years. We estimate that flows of 30-50 ML/day will be sufficient to water existing sedge communities in the main distributary channel. Approximately 4-6 events with a duration of 2-3 days are probably needed each year in wet and average years to help to maintain soil moisture.

- Higher plants, such as Juncus – This plant community benefits from lower flows maintaining some soil moisture and higher flows in the range of 80-100 ML/day to inundate benches that these plants grow on . These events are required 2-3 times per year in wet and average years and less in dry years.

Bibron's Toadlet

It is unclear if Bibron's Toadlet (FFG listed) is present in Pennyroyal Creek. The landscape contains suitable habitat with low lying tributaries that would flood in winter or spring. The specific flow objective for Bibron's Toadlet is to promote and support breeding events for the frog community. Bibron's Toadlet lay eggs in dry channels and need inundation in April-May to facilitate tadpole metamorphosis. Flows that inundate seasonally dry channels every one to two years are required, more often in wet and average years and less often in dry years. It is estimated based on a review of the stream flow record and knowledge of recent flood events, that flows with a magnitude of 700-900 ML/day are required to inundate these areas. Making changes to the landscape or flow regime that reduce the frequency of events that inundate multiple channels are likely to be a threat to Bibron's Toadlet, if present.

7. Complementary management actions

Environmental flows are one of a range of management strategies that need to be considered when managing rivers. 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 Serpentine Creek are briefly described below.

7.1 Protection of the stream-side zone

Land use, particularly grazing pressure, is contributing to the degradation of riparian vegetation and habitat along Serpentine Creek. In Reaches 1, 3 and 5 control of grazing pressures is required in order to permit the successful establishment of young River Red Gum and fringing non-woody vegetation. Preventing cattle from accessing the creek will also help protect shallow habitat areas used by a range of aquatic fauna including fish, Platypus, macroinvertebrates, and turtles.

The North Central CMA Waterway Strategy (North Central CMA, 2014a) identifies a number of management outcome targets and activities which aim to protect the stream-side zone of the Lower Loddon and Serpentine Creek program area. These activities include monitoring the effectiveness of existing riparian management agreements and community engagement activities that increase landholders skills and awareness in riparian management practices (Table 7-1).

Table 7-1 Lower Loddon River and Serpentine Creek Actions as reproduced from the North Central CMA Waterway Strategy (North Central CMA, 2014a).

Long-term Resource Condition	Management Activity/Output	Quantity	Lead agency / partners
Improve native vegetation structure and diversity	Monitor effectiveness of existing Riparian Management Agreements	At least 10% sites reviewed	CMA & Landholders
Increased landholder skills and awareness in riparian management practices	Establish Management Agreements with landholders participating in river health incentives	20 Management Agreements	CMA & Landholders
	Coordinate/attend community engagement events	10 (events)	CMA & Landholders
	Work with local Landcare groups to support the implementation and maintenance of projects	4 (events)	CMA, Landcare groups

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.

7.2 Investigate and treat urban water pollution from Serpentine Town

Urban water pollution was identified as a threat by members of the project advisory group. It is recommended that this issue is investigated in further detail and if found to be significant, measures put in place to mitigate threats to Serpentine Creek.

7.3 Nine Mile Creek investigations

A number of knowledge gaps were identified in this FLOWS study that need to be addressed as part of future investigations that consider the potential for watering the River Red Gum Forest and Woodland areas along Nine Mile Creek. Details of these investigations are outlined below.

Nine Mile Creek vegetation condition assessment

The EFTP noted in their field assessment that some areas of the forest and woodland overstorey and understorey along the creekline appeared to be in a degraded state. Further investigations are recommended to determine the cause of any variance in condition of the vegetation along Nine Mile Creek. This should include an assessment of salt and soil water profiles throughout the forest and woodland areas to determine if salt damage or water logging is contributing to the observed deterioration in vegetation condition.

Nine Mile Creek hydrological assessment

Detailed hydrological modelling is required to estimate the magnitude and duration of flows required to water different parts of the Nine Mile Creek forest and woodland areas. This hydrological assessment would require a detailed survey of the area and the development of a detailed 2-Dimensional hydraulic model. This modelling study should also consider the potential impact that flooding of forest and woodland areas may have on salt levels and the potential for flow to mobilise and transport this salt further downstream across the Tragowel Plains.

Assessment of options for watering Nine Mile Creek

The understanding gained from the vegetation condition assessment and hydrological assessment will form inputs into this study which would assess the options for watering the River Red Gum Forest and Woodland areas along Nine Mile Creek and any additional works and measures required to implement a particular watering regime (i.e. levees, regulator structures).

8. 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.

8.1 Water quality monitoring

No active water quality monitoring stations are available along the main stem of Serpentine Creek. This is particularly an issue for Reach 1 and 3, where low flow recommendations aim to provide minimum depths for passage of fish and Platypus from downstream weir pools and to maintain adequate water quality during low flow periods. It is recommended that additional water quality monitoring stations are established in the lower sections of these flow reaches to confirm that recommended flow rates at the FLOWS assessment sites do meet the minimum flow depths and acceptable water quality conditions further downstream.

Flow in Nine Mile Creek is monitored at the Serpentine offtake and further downstream at Coads Road. It was noted during this FLOWS study that leakage and flows from Serpentine offtake results in some water flowing downstream and inundating parts of the River Red Gum Forest and Woodland. Further monitoring of water levels along flow paths in response to variations in flow at Serpentine offtake would assist in developing an understanding of the magnitude of flows that are required to inundate different areas of the River Red Gum Forest and Woodland areas and how water gets into different parts of the forest and woodland.

8.2 Aquatic fauna surveys

Very limited information is available on aquatic fauna for Serpentine Creek. Aquatic fauna surveys are recommended to monitor populations of native fish, Platypus and turtles along Serpentine Creek. A base line live-trapping survey of Platypus and turtles is recommended in Reach 1 and 3 with repeat surveys every 5 years.

Fish surveys have been conducted at a single site in Reach 2 of Serpentine Creek over a number of years to supplement monitoring conducted for the Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP). It is recommended that targeted repeat annual fish surveys are undertaken in Autumn for River Blackfish, Flat head Gudgeon, Australian Smelt and Carp Gudgeon. For short lived fish species, repeat survey should be completed with the objective of assessing changes in the proportion of sampling sites in each reach where they are caught. For long lived species, such as River Blackfish repeat survey should assess the number of sites where they are caught, their size class, distribution and relative abundance. Repeat assessment of size distribution will assist in determining if there are recruitment cohorts.

The current lack of frog surveys in the area means that it is not possible to determine which frog species are present in the Serpentine Creek catchment. It is possible that the FFG listed Bibron’s Toadlet is present in the Pennyroyal Creek. Additional frog surveys are recommended to inform the contemporary composition and abundance of the frog fauna and guide future watering plans in the Serpentine Creek catchment.

8.3 Waterbird surveys in Nine Mile Creek

We have recommended a generic watering regime to meet specific objectives of the River Red Gum Forest and Woodland vegetation areas along Nine Mile Creek. The main environmental flow objectives for Nine Mile Creek focus on maintaining a healthy River Red Gum overstorey and a diverse understorey. If in delivering water, waterbirds opportunistically nest and breed, monitoring is recommended to develop a better understanding of the flows that are needed to ensure breeding success.

9. Development of an Environmental Watering Management Plan

Serpentine 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 Serpentine Creek. An EWMP is needed to meet the requirements of the water management goals and environmental flow objectives that have been developed in this FLOWS study.

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

- Nine Mile Creek represents a natural or near-natural example of River Red Gum Forest/Woodland as evidenced by a relative lack of post-1788 human induced hydrologic disturbance or adverse impacts on ecological character [Criterion 2(a)].
- Serpentine Creek provides vital habitat including: refuges for native water-dependant biota during dry spells and droughts; pathways for the dispersal and movements of native water-dependant biota; important feeding, breeding and nursery sites for native water-dependent biota [Criterion 3(a)].
- Serpentine Creek is essential for maintaining, and preventing declines of, native water-dependant biota such as native fish, Platypus and turtles [Criterion 3(b)]. The population of River Blackfish is considered regionally significant (DSE, 2013).
- Serpentine Creek supports one or more native-water-dependant species treated as threatened or endangered under State or Territory law [Criterion 4(c)]. The River Red Gum Forest and Woodland in Nine Mile Creek and Lignum plains along Pennyroyal Creek potentially supports the FFG listed Brolga. Pennyroyal Creek may also support FFG listed and endangered Bibron's Toadlet.
- With environmental watering Serpentine Creek is capable of supporting, significant numbers of individuals of native water-dependant species [Criterion 5(b)], including Platypus, River Blackfish and Eastern Long-necked Turtles.

We consider that Serpentine Creek meets the criteria established in Schedule 8 of the Basin Plan, therefore an EWMP should be developed. The technical work presented in this report is sufficient to develeop an EWMP for Reaches 1 and 3. However, as discussed further technical work needs to be undertaken before an EWMP can be developed for Nine Mile and Pennyroyal Creek.

[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 an unimpacted flow regime influence various biological, geomorphological and physicochemical processes in waterways. Key flow components are likely to vary between river systems, but every stream system has some key flow components that are essential to maintain a healthy functioning aquatic ecosystem.

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:

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

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

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

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).

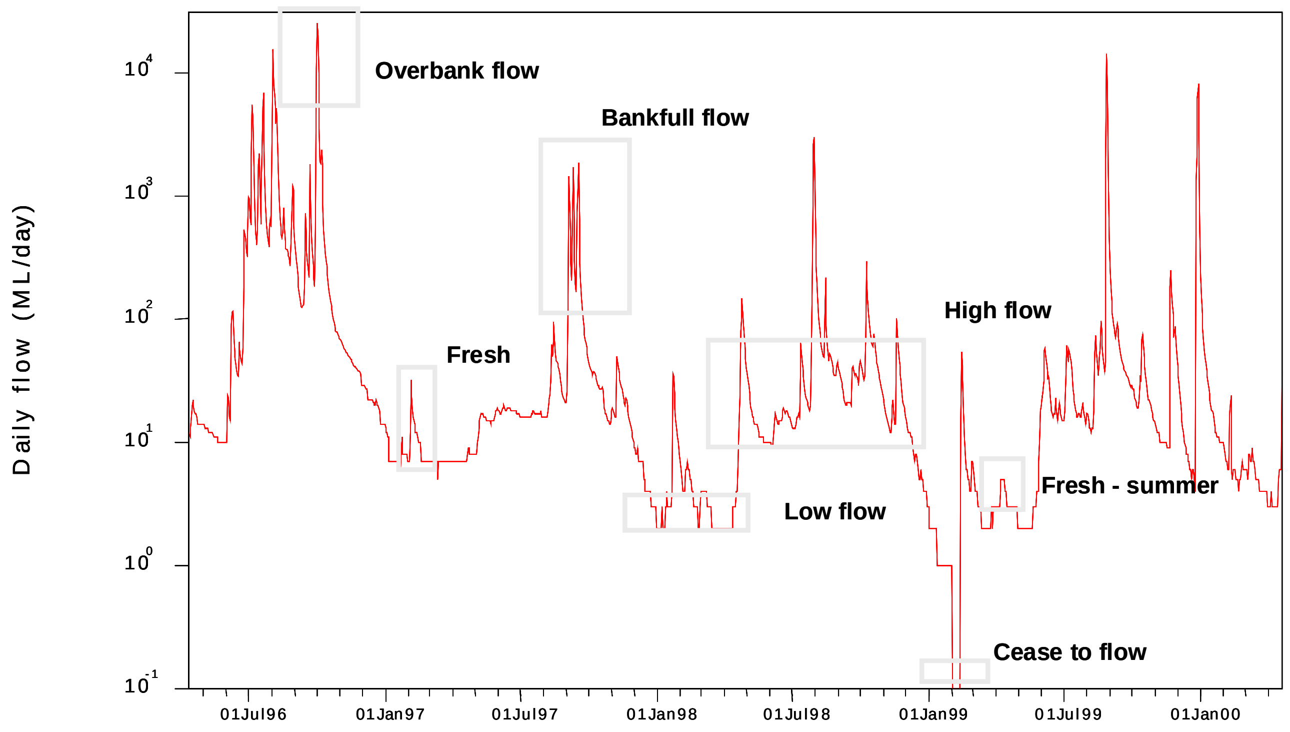


Figure B-1 Typical daily flow series for a perennial stream. Note, in intermittent or ephemeral streams the cease-to-flow period is longer and there is often more variability in the frequency of higher flow events.

Table B-1 Environmental functions of different flow components.

Flow component	Response 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. • Maintain riffle habitats with a variety of fast and slow flowing areas, adequate width and depth for colonisation by macroinvertebrates and foraging by fish and exposes some large rocks that are likely to be important for insect oviposition. • 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. • Promote development of larval and juvenile fish that require shallow, slow flowing backwater habitats (e.g. River Blackfish, Flat head Gudgeon, Smelt and Carp Gudgeon). • Promote recruitment for fish that spawn during low flow periods (e.g. Smelt, gudgeons).
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. • Provide flow variability to maintain species diversity of emergent and littoral aquatic vegetation and to drive vegetation zonation patterns across the channel. • Engage anabranches and secondary channels. • 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.
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. • Engage the riparian zone and wetlands located within the meander train. • 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 through scour and deposition (i.e. levees, secondary flood channels, billabongs)

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 Survey of selected reaches

The EFTP selected channel cross-sections at hydraulic control points (e.g. a riffle) or at the location of specific channel features (e.g. mid channel benches or a low point where flow will break out of a primary channel into a secondary channel) at each FLOWS assessment site on Serpentine Creek during their site visit in May 2014. The number of cross-sections selected varied between sites depending on the level of channel complexity. More cross-sections are needed to model hydraulic conditions and capture relevant channel features at physically complex sites compared to sites that are more homogeneous.

The EFTP selected and marked eight cross-sections at the FLOWS assessment site in Reach 1 (downstream of Knife Edge Weir) and eleven cross-sections at the second FLOWS assessment site in Reach 3 (approximately 3 km upstream from Irrigation Channel 7/10/1). Full FLOWS assessments were not conducted in the Nine Mile Creek and Pennyroyal Creek because the complex distributary stream network in each reach will prevent us setting reliable inundation levels and developing detailed hydraulic models. At Pennyroyal Creek, downstream of Hopefield Road the EFTP used a hand-held laser range-finder to estimate channel dimensions and sketched the channel cross-section to highlight the relative elevation of different vegetation zones.

Detailed feature surveys of the selected cross-sections and other site features at the Serpentine 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.4 Hydrology

There are no long-term hydrological data available for Serpentine Creek. Flow gauges were installed at various sites (mainly regulators) throughout Serpentine Creek over the last 15 years to support the Goulburn-Murray Water (G-MW) irrigation modernisation program. Flow data is frequently recorded at these gauges and provides a good measure of current water use and the impact of impoundments (e.g. farm dams) and diversions, but it does not provide a long-term history of flow events throughout the catchment. No hydrological models have been developed for Serpentine Creek and therefore current and unimpacted flow series for an extended period of time are not available. A detailed analysis of the Serpentine Creek system hydrology is provided in the *Issues Paper* (Jacobs, 2014a).

B.5 Hydraulic modelling

A one-dimensional hydraulic model of each site (with the exception of Nine Mile Creek) 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. The Pennyroyal Creek model was based on one cross-section, which was measured using a laser rangefinder, capable of horizontal and vertical measurements. There is no model for Nine Mile Creek, as the modelling required is a detailed two-dimensional model which is outside the scope of this study.

B.5.1 Model limitations

Significant effort has been made to ensure the hydraulic models are accurate, however it should be noted that the models have been calibrated 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 flower 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 within the catchment are available for each reach from a combination of long-term flow gauges and recently installed operational flow gauges. 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 the hydraulic models were obtained from gauged data.

B.5.2 Model outputs

A key output from the hydraulic model is a graphical representation of each cross-section (see Figure B-2 for an example). The black line in the example ('ground' in the legend) represents the ground surface, reflecting the channel shape at that cross-section. Small black squares on the ground line show the exact points where field survey measurements were taken. Horizontal blue lines within the cross-section represent the estimated water surface at various modelled flows (which are detailed in the legend).

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

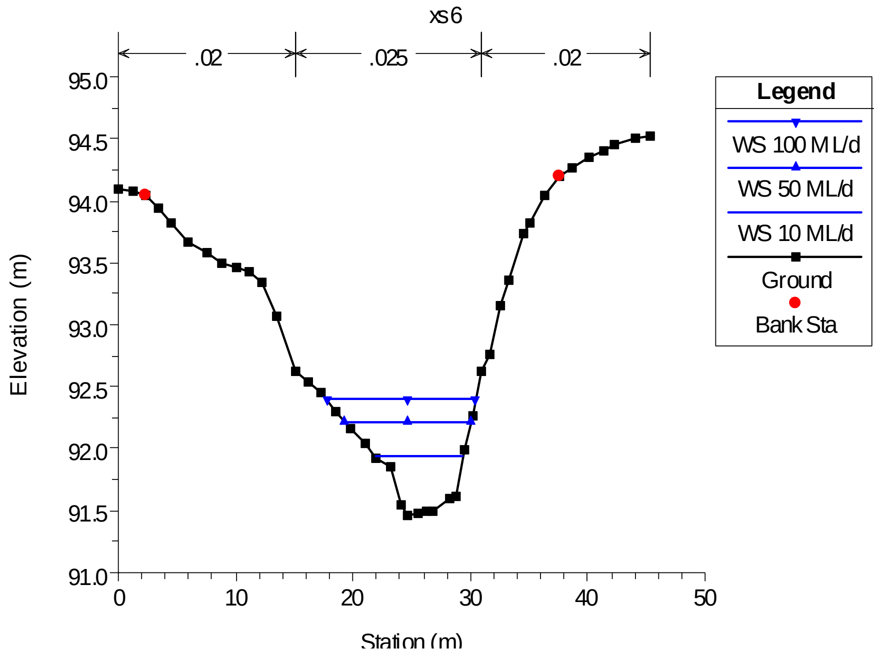


Figure B-2 Example cross-section output from the hydraulic model for Serpentine Reach 3 cross-section 6, showing channel profile and modelled water surface levels at various flow magnitudes.

B.6 Development of environmental flow recommendations

Environmental flow recommendations for Serpentine Creek were determined by the EFTP in a workshop conducted on 22 July 2013. The workshop was also attended by Louissa Rogers from North Central CMA.

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

Within each reach, each flow component was considered in turn. A range of criteria were used to determine suitable flows (Table B-2). These criteria are reach specific and vary according to the species present and channel features. For each flow component the desired volume threshold, frequency of occurrence and duration was determined (although see Section B.6.3 for a discussion of uncertainty in recommendations and the use of elements of the current regime to inform some recommendations). Consideration was given to the acceptable level of variability in flow components and differences between wet, average and dry years.

B.6.1 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-3 shows the median daily flow in reach 1 for each month over the period of record (August 1975 to November 1982 and July 2000 to May 2014) under the currently flow regime.

It can be seen that flows in summer/autumn are much higher than those in winter/spring, due to irrigation flows. The summer/autumn and winter/spring flow seasons adopted in this environmental flow study reflect the irrigation season, and therefore align with the operational requirements of the river.

A more detailed description of the hydrology of Serpentine Creek is provided in the *Issues Paper* (Jacobs, 2014a).

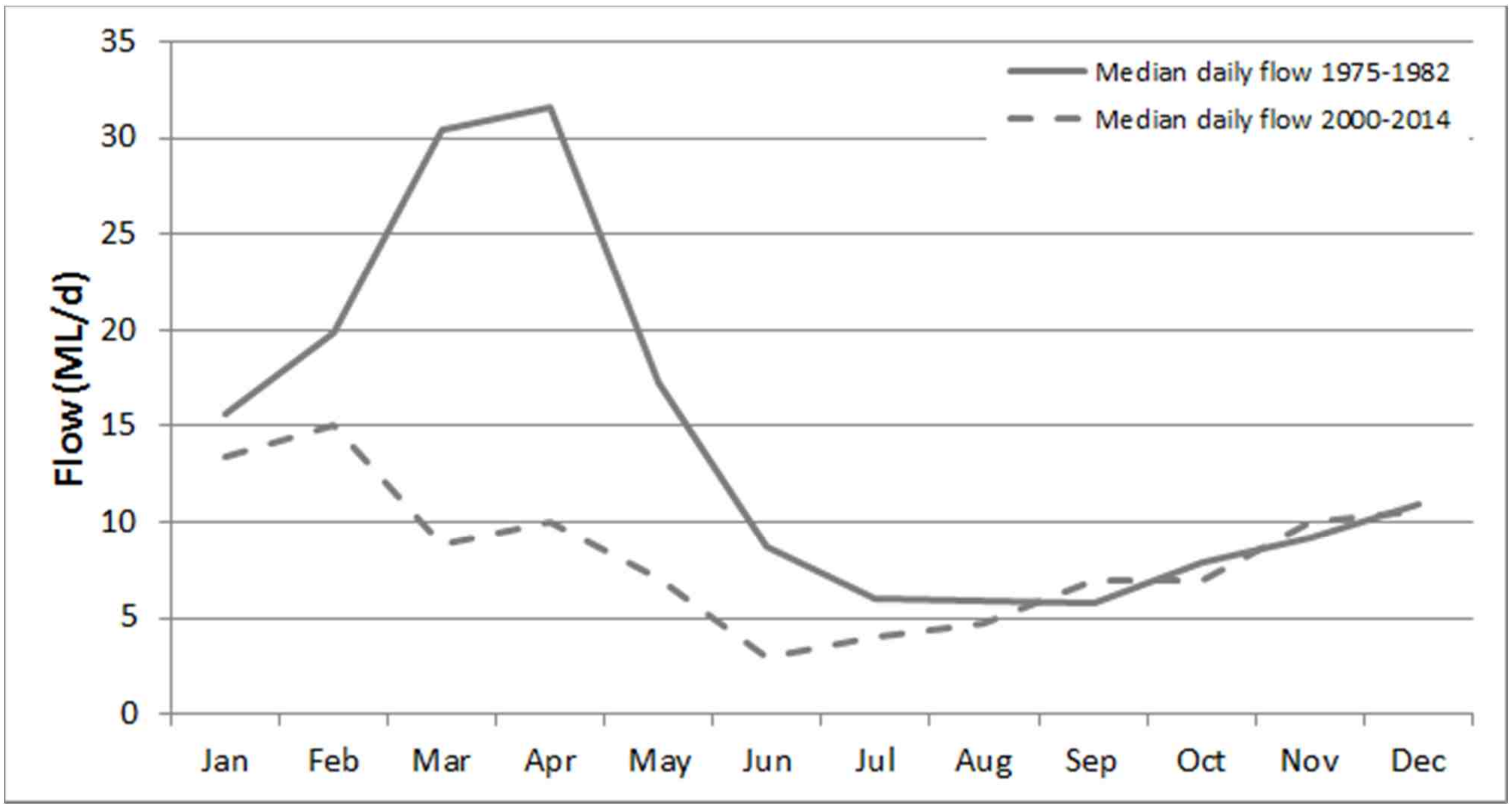
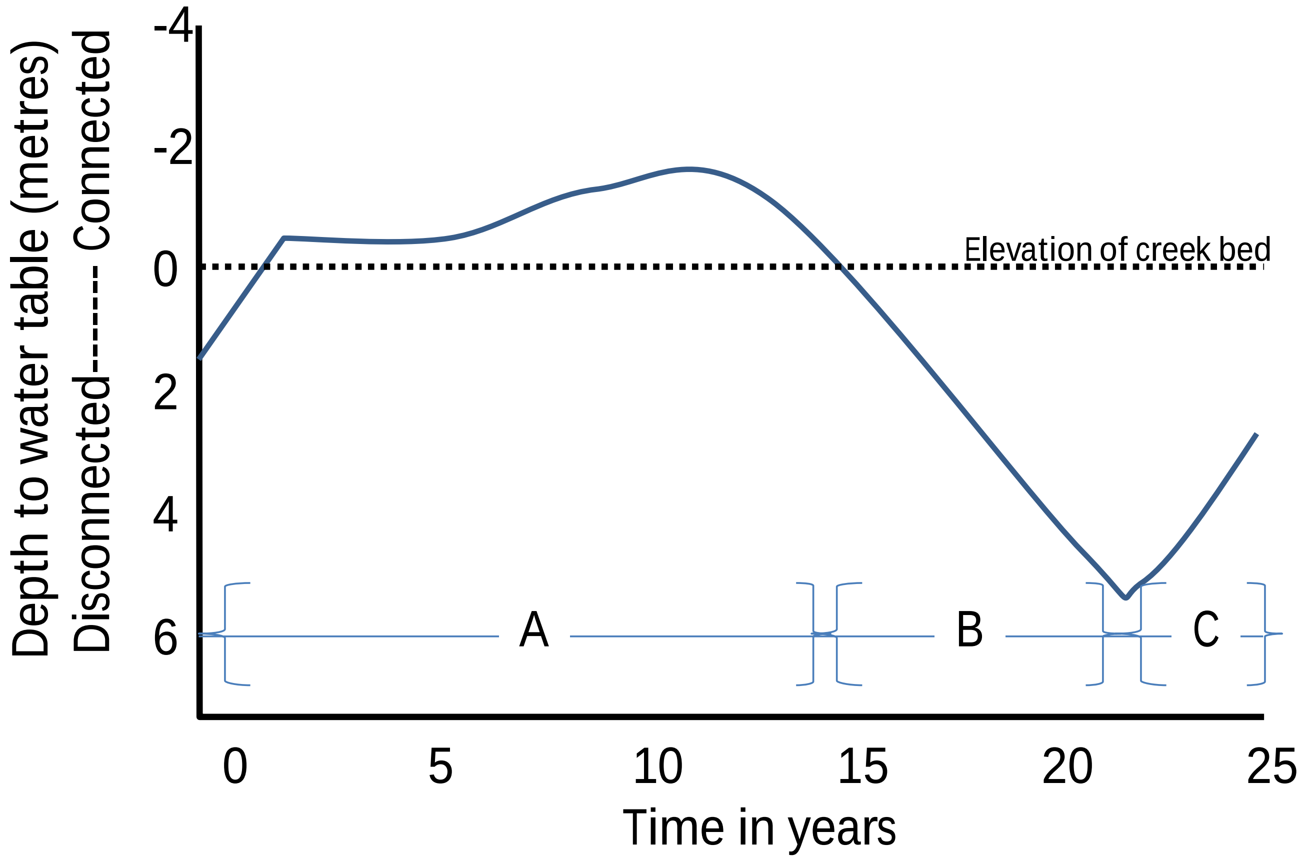


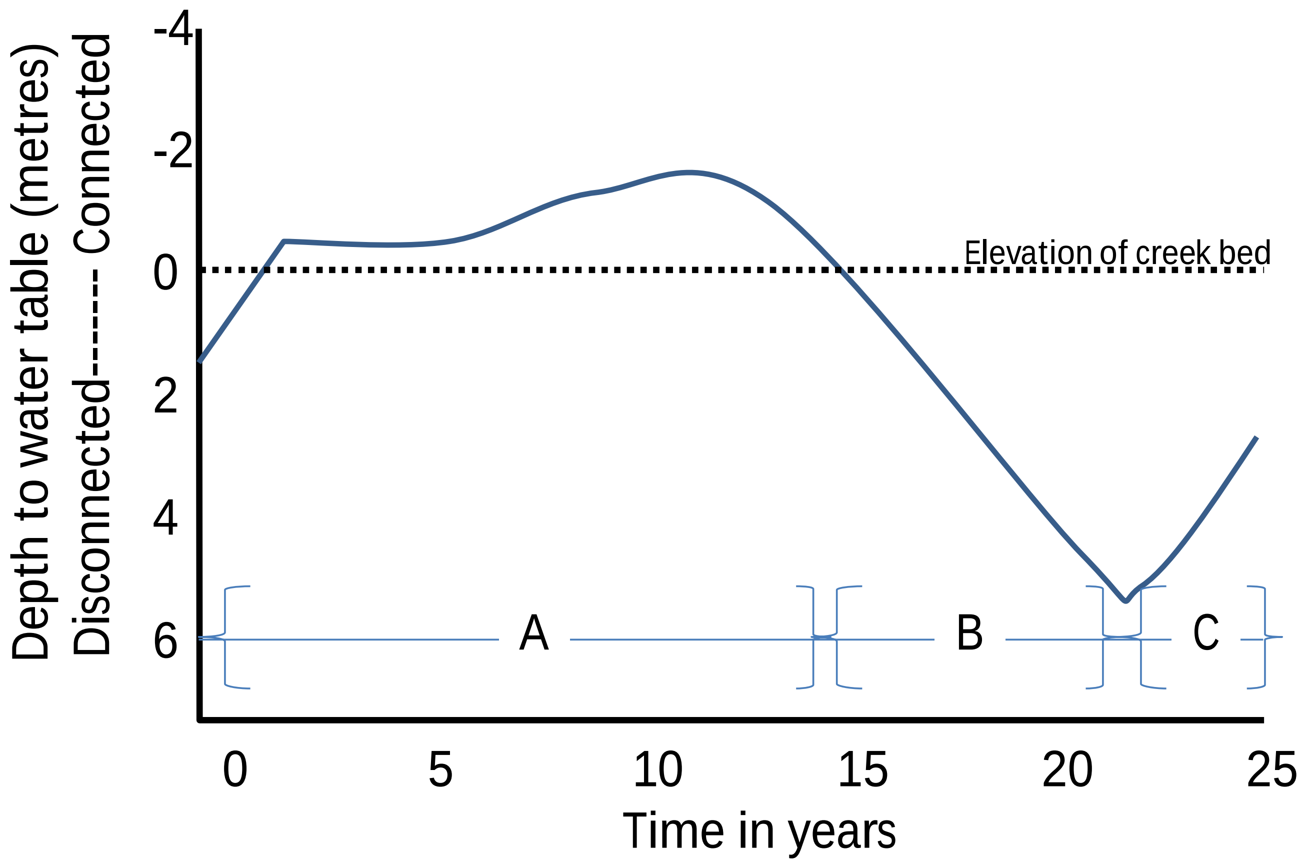
Figure B-3 Median daily current flows for each month of the year in Serpentine FLOWS Reach 1, showing the seasonality of flows.

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

Function	Criteria for determining recommendation
Low flow	
Minimum flow that provides a continuous flow throughout the channel (maintains permanent pools with an adequate depth of water to provide habitat for aquatic biota and adequate depth in riffle/run habitats to allow fish and Platypus to move through these habitats).	**Platypus** Minimum depth of 200-500 mm in pool and run habitats to satisfy foraging requirements and reduce predation risk. **Fish** Dependent on size and therefore height of individual fish species. Depth needs to be sufficient such that each fish species remains wholly submerged. Small River Blackfish (i.e. up to 150 mm long) have a preference for pool depths ranging from 100-200 mm (J. Koehn, 1986; J. D. Koehn et al., 1994). Minimum depth for general fish movement through riffles is around 120 mm for small-bodied fish (Starrs et al., 2011) and greater for large bodied fish. Tolerable velocity for small fish movement is 0.15 – 0.30 m/s (Doehring et al., 2011; Mitchell, 1989). For the purposes of the Serpentine Creek flow study, we have assumed a minimum pool depth of 300 to 500 mm and a minimum riffle depth of 100 mm will be sufficient for the native fish that are likely to be present in the system. River Blackfish require elevated flows over the period October, November and December to inundate habitat areas suitable for spawning. **Macroinvertebrates** Macroinvertebrates should be able to tolerate the same low flow conditions as fish in Serpentine Creek. Low flows should inundate woody debris and maintain submerged and emergent macrophytes that provide habitat and substrates for biofilms.
Minimum flow that provides a continuous flow throughout the channel for the inundation of habitat elements (e.g. aquatic and fringing vegetation).	Minimum depth of 500 -1000 mm in pools to maintain dense beds of Water Ribbons (*Triglochin*) and Eel Weed (*Vallisneria*) and diversity and abundance of microbial biofilms growing on submerged wood (Rogers, 2011; Victorian Environmental Assessment Council, 2006).
Minimum flow sufficient to maintain water quality and prevent low dissolved oxygen conditions	Continuously flowing water and occasional freshes are required to ensure that adverse water quality conditions do not develop (e.g. low DO, high temperatures). Relationships between water quality and flow will vary between different waterways. Any water quality recommendations will be based on an analysis of available data from the assessment reach (e.g. the flow magnitude below which low dissolved oxygen conditions are likely to occur). Groundwater in the region is relatively saline and therefore groundwater discharge does not necessarily support or contribute to the environmental values within Serpentine Creek. The groundwater system underlying the creeks responds to extended periods of wet and or dry rainfall, such that within extended wet periods, groundwater levels rise and the creeks are gaining (connected to the groundwater), and during extended dry periods groundwater levels fall away from the creeks and become losing (disconnected to the groundwater). The temporal nature of groundwater within the reaches assessed is described in more detail in the *Issues Paper* (Jacobs, 2014a). The influence groundwater has on providing environmental flows for the values within the creeks, depends on the temporal nature of the groundwater connection with the creek beds. Groundwater monitoring within the region indicates that there are three different periods, each period has different ramifications to delivering environmental flows, they are with reference to the diagram below: 1) Gaining – Period A When high groundwater tables persist during wet periods and the stream bed is connected and receiving saline groundwater inflows. During this period, the saline inflow is generally washed downstream during seasonal flows; however, when a very dry year occurs, saline inflows may not be flushed downstream and can cause a negative impact to in stream ecosystems. Therefore, if we get low flow during a wet period, delivering freshes/high flows to maintain water quality may become a management consideration. 2) Falling and disconnected - Period B During extended dry periods groundwater levels will fall below the stream bed such that no

Function	Criteria for determining recommendation
	groundwater inflows occur, during this period, groundwater does not need to be a consideration when delivering environmental flows. However, the stream may lose flow to groundwater which could impact on the ability to maintain minimum depths throughout the whole reach and maintain water quality. 3) Rising and disconnected – Period C After an extended dry period groundwater levels may begin to rise. In the advent of rising water tables, the consideration of delivering freshes/high flows to maintain water quality should be considered on a year by year basis as a pro-active step in anticipation of returning to period A, where saline groundwater inflows occur.  Schematic of groundwater periods that require different considerations for delivering environmental flows. Period A = connected gaining with saline groundwater inflows, Period B = disconnected falling groundwater levels no saline groundwater inflows and period C, disconnected rising water groundwater levels, potential saline groundwater inflows in future years.
Minimum flow that provides a continuous flow throughout the channel, but allows the lower banks, benches and bars to dry	Morphological features defined by individual cross-sections. Flow can be determined that inundate the channel bed but does not inundate other channel features (i.e. banks and benches).
Freshes/High flow	
Disturbance to scour biofilms and filamentous algae and flush fine sediments.	A velocity greater than 0.4 m/s is considered sufficient to scour biofilms and filamentous algae (Biggs et al., 1999). Shear stress: >8 N/m^2 to scour silt from sand, >15 N/m^2 to scour silt from cobble and to scour sand and > 45 N/m^2 to scour coble (based on criteria adopted by Ecological Associates, 2005).
Access to habitat – between pools.	**Fish** Availability of fish passage in the shallowest cross-section. Minimum depth for general fish movement is around 120 mm for small bodied fish (Starrs et al., 2011), at least 200 mm for adult River Blackfish, and greater for large bodied fish. Maximum tolerable velocity for small fish movement is between 0.15 – 0.30 m/s (Doehring et al., 2011; Mitchell, 1989). **Platypus** Minimum depth of 200-500 mm in run and pool habitats to satisfy foraging requirements and reduce predation risk.

Function	Criteria for determining recommendation
	Spring and Summer freshes should be lower than Winter freshes to avoid disrupting Platypus feeding or Platypus burrows when they have young (limit duration to 12 -24 hours). As a general rule, flows that increase water levels by more than 500 mm compared to the Winter low flow level are potentially a risk to Platypus during their breeding season as they could lead to drowning of young Platypus in burrows. If a spring or summer high flow event (> 500 mmetres above base flow) is considered desirable to assist other biological functions, it should ideally be coupled to a preceding event of similar or greater magnitude in early August, i.e. around the time that breeding females are choosing nursery burrow sites.
Maintenance of fringing emergent (non woody) vegetation on low benches.	The EFTP used the inundation of in-channel low-flow benches as morphological features and relative water level increases of approximately 200 mm above the recommended summer / autumn low flow to set flow levels to water littoral vegetation. Hydrological requirements to maintain broad groups of plants are outlined below (Roberts & Marston, 2011; Rogers, 2011; Victorian Environmental Assessment Council, 2006): • Minimum depth of 200 mm to maintain rushes and sedges (*Eleocharis* spp. *Cyperus* spp) for 2-4 months over Spring and Summer (Fluctuating water levels with regular flooding and drying) • Minimum depth of 300 mm to maintain reeds (*Phragmites australis*, *Eleocharis* spp., *Cyperus* spp.) for 6 months over Spring and Summer (Shallow fluctuating and drying) • Minimum depth of 0-200 mm to maintain Cambungi (*Typha* spp., *Juncus* spp., *Eleocharis* spp.) for 9-12 months over Spring to Summer (Permanent to regular flooding with some depth)
Access to habitat – increase flow width and depth, inundation of benches	The EFTP used an increase in habitat area (compared to low flows) and the inundation of in-channel benches and high flow channels as morphological features. **Frogs** Flooding the benches in later winter/early spring to provide breeding habitat for frogs. **Birds** Inundation of in-channel benches to maintain vegetation will also favour birds.
Fresh to maintain water quality	Relationships between water quality and flow will vary between different waterways and reaches along a waterway. Any water quality recommendation will be based on an analysis of available data from the assessment reach (e.g. the flow magnitude below which low dissolved oxygen conditions are likely to occur). A winter high flow needs to precede a summer fresh to minimise potential for blackwater events. Groundwater in the region is relatively saline and therefore groundwater discharge does not necessarily support or contribute to the environmental values within Serpentine Creek. The groundwater system underlying the creeks responds to extended periods of wet and or dry rainfall, such that within extended wet periods, groundwater levels rise and the creeks are gaining (connected to the groundwater), and during extended dry periods groundwater levels fall away from the creeks and become losing (disconnected to the groundwater). The temporal nature of groundwater within the reaches assessed is described in more detail in the *Issues Paper* (Jacobs, 2014a). The influence groundwater has on providing environmental flows for the values within the creeks, depends on the temporal nature of the groundwater connection with the creek beds. Groundwater monitoring within the region indicates that there are three different periods, each period has different ramifications to delivering environmental flows, they are with reference to the diagram below: 1) Gaining – Period A When high groundwater tables persist during wet periods and the stream bed is connected and receiving saline groundwater inflows. During this period, the saline inflow is generally washed downstream during seasonal flows; however, when a very dry year occurs, saline inflows may not be flushed downstream and can cause a negative impact to in stream ecosystems. Therefore, if we get low flow during a wet period, delivering freshes/high flows to maintain water quality may become a management consideration. 2) Falling and disconnected - Period B During extended dry periods groundwater levels will fall below the stream bed such that no groundwater inflows occur, during this period, groundwater does not need to be a consideration

Function	Criteria for determining recommendation
	when delivering environmental flows. However, the stream may lose flow to groundwater which could impact on the ability to maintain minimum depths throughout the whole reach and maintain water quality. 3) Rising and disconnected – Period C After an extended dry period groundwater levels may begin to rise. In the advent of rising water tables, the consideration of delivering freshes/high flows to maintain water quality should be considered on a year by year basis as a pro-active step in anticipation of returning to period A, where saline groundwater inflows occur.  Schematic of groundwater periods that require different considerations for delivering environmental flows. Period A = connected gaining with saline groundwater inflows, Period B = disconnected falling groundwater levels no saline groundwater inflows and period C, disconnected rising water groundwater levels, potential saline groundwater inflows in future years.
Bankfull flow	
Maintain channel and scour pools	The magnitude of these flows is determined primarily by channel morphology, with some interpretation required as cross-sections may differ in capacity. Water velocity (at least 1 m/s) and shear stress (approximately 30 N/m^2) may be used to estimate the magnitude of flow required to move sediment and maintain channel capacity.
Maintain adult riparian trees and provide cues for successful recruitment of juveniles	Two events per year in two consecutive years twice per decade. First event each year in July/August (preferably Aug) to wet the bank and benches, second event each year in September/November to stimulate River Red Gum recruitment.
Overbank flow	
Inundate floodplain features and wetlands by engagement with flood-runners and distributary channels	The magnitude of these flows is determined primarily by channel morphology, with some interpretation required as cross-sections may differ in capacity. The volume required for the engagement of flood-runners and distributary channels is determined by the invert or commence to flow in these channels and the flooding/drainage characteristics of the floodplain.
Engage riparian zone and wetlands to water riparian forest and woodland	The hydrological requirements to maintain different vegetation assemblages are outlined below: • River Red Gum Forest – one inundation event every 2-3 years with a duration of 2-6 months • River Red Gum Woodland - one inundation event every 3-5 years with a duration of 2-4 months • Tangled Lignum - one inundation event every 3 years with a duration of 1-6 months.

B.6.2 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.

The division of wet, average and dry years was based on the long-term streamflow record of the Loddon River at Serpentine (407229), which has 38 years of record. We used streamflow rather than rainfall to determine which years were wet, dry or average because flow in the Loddon River and Serpentine Creek is influenced more by the volume of water held in storages such as Cairn Curran Reservoir and Tullaroop Reservoir than local rainfall. Annual flows in the Loddon River at Serpentine were plotted and ranked from smallest to largest and visually inspected. Clear jumps in annual flow are apparent at the 25th percentile and 85th percentile (see Figure B-4) and therefore we used those statistics as the threshold for wet, average and dry years. The 25% of years that had the lowest annual flow were classified as dry years, the 15% of years with the highest annual flow were classified as wet years and the other 60% of years were classified as average years. The specific years allocated to each category are shown in Table B-3. Given the main flow record for Serpentine Creek commenced in 2000, most of the years are classified as dry years. Whenever assessment is made regarding wet, average or dry years, we will state the number of years in the dataset.

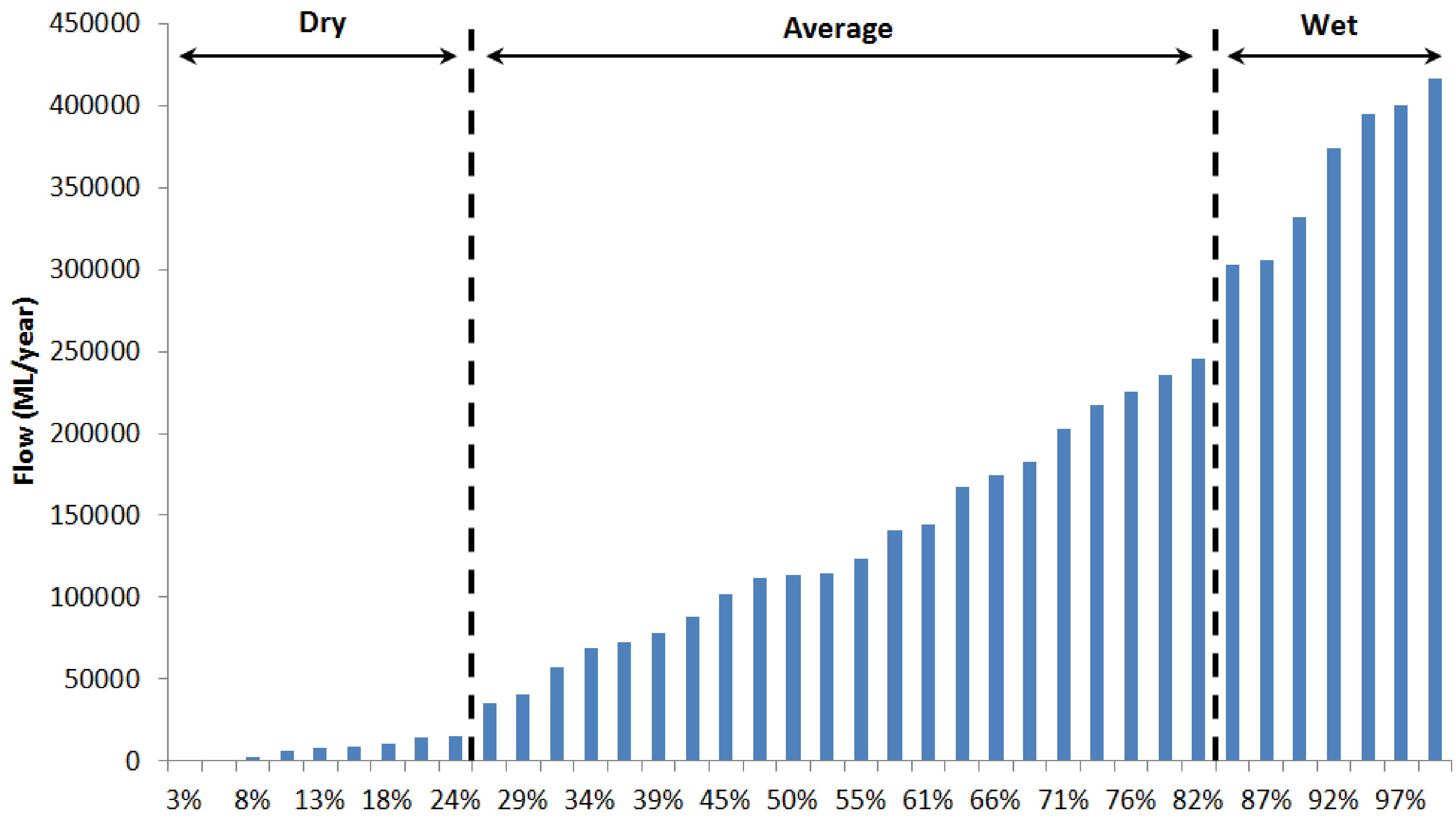


Figure B-4 Plot showing how statistics were used to assign dry, wet and average years.

In wet years it is likely that streamflow will be higher than the recommended environmental flows. Under these circumstances it is not necessary to reduce flows 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.

Table B-3 Dry, Average, Wet assignment.

Dry	Average		Wet
1998	1977	1994	1981
2003	1978	1995	1983
2004	1979	1997	1988
2005	1980	1999	1989
2006	1982	2000	1992
2007	1984	2001	1993
2008	1985	2002	1996
2009	1986	2010	
	1987	2011	
	1990	2012	
	1991	2013	

B.6.3 Current achievement of the environmental flow recommendations

The current level of achievement of the environmental flow recommendations for each reach was assessed separately for wet, average and dry years. The assessment is based on an analysis of the historical flow record in wet, average and dry years in each reach under current conditions. The level of achievement is presented as the ratio of the events that have occurred in the historical record compared to the environmental flow recommendations.

B.6.4 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.

Many of the flow recommendations are based on maintaining elements of the current flow regime (i.e. the current magnitude, frequency and duration of various events), especially if there is no clear justification for a particular flow recommendation. For example, where there is an understanding of the general flow requirements (e.g. for fish spawning) but no site specific data to support a specific recommendation, we have resorted to using elements of the current regime to inform the recommendation.

The 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 Serpentine Creek, Nine Mile Creek and Pennyroyal Creek. More details are provided in the *Issues Paper* (Jacobs, 2014a).

Serpentine Creek is a highly regulated system. Some sections of the creek are effectively managed as weir pools and are conduits for the distribution of irrigation water. Nine Mile and Pennyroyal Creeks have been extensively modified through the construction of irrigation channels, levees and floodplain drainage works. This environmental flow study focuses on maintaining and rehabilitating those environmental values that can persist or thrive in this regulated and modified system.

Reach 1 of Serpentine Creek has good instream habitat with large woody debris and undercut banks. The proximity to Loddon River and downstream weir pool provides opportunities for the dispersal of small/medium bodied native fish and Platypus. The extent and diversity of emergent fringing and riparian vegetation could be enhanced for its own value and to improve habitat for fish, Platypus and birds. The main threats to this reach include point source pollution from Serpentine and the potential for blackwater events during sustained low flow conditions. Poor water quality during very low flow conditions may be exacerbated by run-off from local farms that carry high nutrient loads into the stream or by livestock that trample the stream.

Reach 3 of Serpentine Creek has more backwaters and shallow habitats compared to Reach 1. This reach is likely to support small populations of small-bodied native fish and turtles; it may also support a small number of Platypus. Fluctuating water levels during the irrigation season probably limit the establishment and growth of instream and fringing emergent vegetation. As with Reach 1, run-off from local farms and livestock trampling the stream may exacerbate poor water quality during low flow conditions. Grazing pressures are also likely to limit the extent, diversity and condition of fringing emergent and riparian vegetation.

Nine Mile Creek, particularly the area approximately 1.5 kilometres downstream of Nine Mile Creek regulator, supports a high value River Red Gum Forest and Woodland with diverse and mostly healthy understorey. At a landscape scale, it is one of the largest remnants of River Red Gum Forest and Woodland within the region and is likely to provide important habitat to a large number of woodland birds as well as potential breeding habitat for waterbirds. Some concerns were raised during the EFTP field inspection about the current condition of vegetation in this area, particularly near the influent channel, where there are a large number of fallen dead trees and a sparse or dead understorey. A more detailed investigation into causes of degradation may be warranted. Further work is also recommended to develop a better understanding of the magnitude of flows required to inundate different areas of the River Red Gum Forest and Woodland and any issues associated with these inundation events (e.g. drainage and flooding of adjacent land, impacts on salinity levels).

Pennyroyal Creek is a series of distributary channels that traverse a flat plain of Lignum and naturally flow only during high flows or floods. Sections of Pennyroyal Creek have been dredged to improve drainage. These dredging works have directed flows into a small number of dredged channels and isolated parts of the distributary channel network. Outfalls associated with the current operating regime deliver a relatively predictable flow regime to these channels, which support distinct bands of instream and fringing vegetation at different elevations on the bank and possibly provide important habitat for frogs, turtles, woodland birds and waterbirds. Any proposal to change the current outfall flow regime to meet operational objectives (e.g. for water savings associated with irrigation system modernisation) should trigger the need for an impact assessment to quantify likely changes in flow regime in Pennyroyal Creek, the effect of those flow changes on existing values and any measures that may need to be implemented to mitigate the impacts.

The highest priority environmental flow objectives for Serpentine Creek include:

1) Maintaining a viable breeding population of Platypus along Serpentine Creek that can disperse to the lower Loddon River and adjoining Murray River thereby contributing to a larger regional metapopulation.
2) Maintaining and enhancing native small and medium-bodied fish populations such as River Blackfish along Serpentine Creek.

3) Maintaining and enhancing the diverse aquatic and riparian vegetation communities present instream and on low lying banks and benches along Serpentine Creek.

4) Preventing blackwater events that lead to fish kills along Serpentine Creek by entraining leaf litter and limiting build-up of organic material in the channel over winter and providing flushing flows during summer.

5) Maintaining and improving the remnant River Red Gum Forest and Woodland along Nine Mile Creek and Tangled Lignum along Pennyroyal Creek.

6) Maintaining the current condition of the populations of turtles, frogs, woodland and waterbirds along Serpentine Creek, Nine Mile Creek and Pennyroyal Creek.

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 objectives for each reach are documented in Table C-1, Table C-2, Table C-3 and Table C-4. More detail is provided in the *Issues Paper* (Jacobs, 2014a). The specific flow recommendations that, if delivered, will maximise the likelihood of these objectives being achieved are described for each reach in subsequent Sections.

Table C-1 Environmental objectives for Reach 1 – Serpentine Creek from Serpentine Weir to Waranga Western Channel.

Asset	Objective	Function	Flow component	Timing	Expected response
Geomorphology	Maintain channel form and processes along Serpentine Creek.	Variable low flow to prevent notching.	Low flow	Summer/autumn	Maintain channel complexity, pools and benches.
		Engage benches.	Freshes/High flows	Anytime	
		Maintain channel and scour pools.	Bankfull and Overbank flows	Anytime	
Fish	Maintain and increase remnant populations of River Blackfish, Flat head Gudgeon, Australian Smelt and Carp Gudgeon.	Connectivity between pools (10cm), inundation of LWD and leaf packs.	Low flow	Summer/autumn	Provide pools and debris in channel that will improve the quality of fish habitat.
		Access different habitat areas.	Freshes/High flows	Summer/autumn/winter	
		Maintain spawning habitat, water levels for Blackfish (less variability in levels to maintain habitat areas).	Low flow	Winter/spring	
Macroinvertebrates	Maintain tolerant macroinvertebrate community.	Inundate exposed roots, woody debris, emergent vegetation and leaf packs and maintain water quality.	Low flow	All seasons	Maintain abundance and biomass of macroinvertebrates throughout the reach.
		Flush fine sediment and scour biofilms to replenish food supply.	Freshes	All seasons	
Water quality	Prevent blackwater events that lead to fish kills Prevent low dissolved oxygen during low flow periods.	Transport organic matter that has accumulated in the channel over Winter and Summer periods.	Freshes/High flows	Winter	Winter fresh needs to precede Summer fresh to minimise potential for blackwater events. Continuously flowing water and occasional freshes will prevent algal blooms and ensure that adverse water quality conditions do not develop (e.g. low DO, high temperatures).
			Freshes/High flows (min. 7 days)	Summer	
		Connecting flow sufficient to maintain water quality and prevent low dissolved oxygen conditions.	Low flow	All seasons	
Aquatic and riparian vegetation	Maintain instream vegetation	Provide sufficient depth of water to maintain dense beds of Water Ribbons (*Triglochin*) and Eel Weed (*Vallisneria*).	Low flow	All seasons	Maintain extensive and healthy beds of submerged in-stream vegetation.
	Maintain and where possible increase fringing emergent (non woody) vegetation on low benches.	Provide flow variability to maintain species diversity of fringing vegetation – sedges (*Cyperus* and *Scirpus*), spike-rushes (*Eleocharis*), reeds (*Juncus*), Common Reed (*Phragmites*) and Cumbungi (*Typha*).	Low flow	All seasons	Maintain / promote growth of extensive and healthy beds of fringing emergent (non woody) vegetation.
			Freshes / High flow	All seasons	

Asset	Objective	Function	Flow component	Timing	Expected response
	Maintain riparian trees - River Red Gum (*Eucalyptus. camaldulensis*) and Black Box (*E. largiflorens*).	Maintain adult specimens and provide cues for successful recruitment of juveniles.	Bankfull and Overbank flows	Winter/spring	Maintain adult eucalyptus in riparian zones and on floodplain, plus successful recruitment of juveniles into the population. Water regime will also help improve the floristic diversity and health of the shrub and ground layer.
	Maintain diversity and abundance of microbial biofilms growing on submerged wood.	Provide sufficient depth of water and variability of flow to maintain microbial biofilms.	Low flow	All seasons	Maintain active layers of microbial biofilms on submerged surfaces.
			Freshes	All seasons	
Platypus	Maintain Platypus population.	Provide sufficient flow depth (20-50 cm) to maintain access to foraging habitat and maintain water quality.	Low flow	Summer/autumn	Should be capable of supporting 20 resident Platypus, with flow conditions suitable for successful reproduction in 2 years out of 3. Avoid flows higher than Winter flow in Spring and Summer to minimise risk of inundating nests, limit duration to 12-24 hrs. Avoid high flows in January/February as juveniles will be emerging from burrows and learning to swim
		High flow to help set level at which nesting burrows should be constructed.	Freshes/High flow	Winter (early August)	
	Maintain habitat areas such as pools.	High flows capable of scouring pools.	Bankfull and Overbank flows	Winter	
Turtles	Maintain Eastern Long-necked Turtle population.	Avoid flows higher than the winter flow from October onwards to minimise risk of inundating nests.	Freshes/High flow	Winter/spring	Turtles will use this reach but steep banks may restrict dispersal.
Frogs	Maintain frog populations.	Flood the benches in late winter / early spring to provide breeding habitat for frogs.	Freshes/High flow	Winter/early spring	Maintain abundance and diversity of frog populations. Limit the release of large flows in Summer that may flush tadpoles downstream.
Birds	Improve instream and riparian vegetation.	Maintain aquatic environment for instream aquatic vegetation	Low flow	All seasons	Range of birds will use water. Flows that maintain vegetation, fish and macroinvertebrates will also favour birds. Creek is an important corridor for birds to disperse.
		Establish variable water regime to inundate emergent vegetation on low benches	Freshes/High flow	All seasons	
		Maintain adults of plant species in relevant riparian and floodplain EVCs. Spring floods over consecutive years for recruitment of River Red Gum.	Bankfull and Overbank flows	Winter/spring	

Table C-2 Environmental objectives for Reach 3 – Serpentine Creek downstream from No 2 Weir to outfall from Irrigation Channel 7/10/1.

Asset	Objective	Function	Flow component	Timing	Expected response
Geomorphology	Maintain channel form and processes along Serpentine Creek.	Engage benches , anabranches and secondary flow channels.	Freshes	Anytime	Maintain channel complexity, pools, benches, anabranches and secondary channels.
		Maintain channel and scour pools.	Bankfull and Overbank flows	Anytime	
Fish	Maintain and increase remnant populations of River Blackfish, Flat head Gudgeon, Australian Smelt and Carp gudgeon.	Connectivity between pools (10 cm), inundation of LWD and leaf packs.	Low flow	Summer/Autumn	Provide pools and debris in channel that will improve the quality of fish habitat.
		Access different habitat areas.	Freshes/High flows	All seasons	
		Maintain spawning habitat, water levels for Blackfish (less variability in levels to maintain habitat areas).	Low flow	Winter/Spring	
Macroinvertebrates	Maintain tolerant macroinvertebrate community.	Inundate exposed roots, woody debris, emergent vegetation and leaf packs and maintain water quality.	Low flow	All seasons	Maintain abundance and biomass of macroinvertebrates throughout the reach.
		Flush fine sediment and scour biofilms to replenish food supply.	Freshes/High flows	All seasons	
Water quality	Prevent blackwater events that lead to fish kills. Prevent low dissolved oxygen during low periods.	Transport organic matter that has accumulated in the channel over Winter and Summer periods	Freshes/High flows	Winter	Winter high flow needs to precede Summer fresh to minimise potential for blackwater events. Continuously flowing water and occasional freshes will ensure that adverse water quality conditions do not develop (e.g. low DO, high temperatures).
			Freshes/High flows (min. 7 days)	Summer	
		Connecting flow sufficient to maintain water quality and prevent low dissolved oxygen conditions.	Low flow	All seasons	
Aquatic and riparian vegetation	Increase diversity and extent of fringing emergent (non woody) vegetation on margins and benches	Provide flow variability to maintain species diversity of fringing vegetation - sedges (Cyperus and Scirpus), spike-rushes (Eleocharis), reeds (Juncus), Common Reed (Phragmites) and Cumbungi (Typha), etc.	Low flow	All seasons	Maintain extensive and healthy beds of fringing emergent (non woody) vegetation.
			Freshes	All seasons	

Asset	Objective	Function	Flow component	Timing	Expected response
	Maintain riparian trees - River Red Gum (*Euc. camaldulensis*) and Black Box (*Euc. largiflorens*).	Maintain adult specimens and provide cues for successful recruitment of juveniles.	Bankfull and Overbank flows	Winter/Spring	Maintain adult eucalyptus in riparian zones and on floodplain, plus successful recruitment of juveniles into the population. Water regime will also help improve the floristic diversity and health of the shrub and ground layer.
Platypus	Maintain Platypus population.	Provide sufficient flow depth (20-50 cm) to maintain access to foraging habitat and maintain water quality.	Low flow	Summer/Autumn	Should be capable of supporting 20 resident Platypus, with flow conditions suitable for successful reproduction in 2 years out of 3. Avoid flows higher than the winter flow in Spring and Summer to minimise risk of inundating nests, limit duration to 12-24 hrs. Avoid high flows in January/February as juveniles will be emerging from burrows and learning to swim.
		High flow to help set level at which nesting burrows should be constructed.	Freshes/High flow	Winter (early August)	
	Maintain habitat areas such as pools.	High flows capable of scouring pools.	Bankfull and Overbank flows	Winter	
Turtles	Maintain Eastern Long-necked Turtle populations.	Avoid flows higher than the winter flow from October onwards to minimise risk of inundating nests.	Freshes/High flows	Winter/Spring	Turtles will utilise this reach and nest along the banks
Frogs	Maintain frog populations.	Flood the benches in late winter / early spring to provide breeding habitat for frogs.	Freshes/High flows	Winter/early Spring	Maintain abundance and diversity of frog populations. Prevent the release of large flows in Summer that may flush tadpoles downstream.
Birds	Improve instream and riparian vegetation	Maintain aquatic environment for instream aquatic vegetation	Low flow	All seasons	Range of birds will use water. Flows that maintain vegetation, fish and bugs etc. will also favour birds. Creek is an important corridor for birds to disperse.
		Establish variable water regime to inundate emergent vegetation on low benches	Freshes/High flows	All seasons	
		Maintain adults of plant species in relevant riparian and floodplain EVCs. Spring floods over consecutive years for recruitment of River Red Gum.	Bankfull and Overbank flows	Winter/Spring	

Table C-3 Environmental objectives for Reach 5 – Nine Mile Creek River Red Gum Forest and Woodland.

Asset	Objective	Function	Flow component	Timing	Expected response
Geomorphology	Maintain distributary network.	Engage distributaries and maintain channel/floodplain processes.	Overbank	Anytime	Maintain complexity of channels across the alluvial plain.
Macroinvertebrates	Macroinvertebrates will colonise the forest and woodland areas when inundated, but environmental flows will not be delivered to specifically target macroinvertebrate communities in the reach.	Periodic inundation of flow paths through forest and woodland areas.	High	As needed for Vegetation and Bird objectives.	Macroinvertebrates will opportunistically use Nine Mile Creek forest and woodland areas when inundated.
Water quality	Prevent mobilisation of salt.	Ensure that managed flows are either not large enough to flush salt into the Tragowel Plains or are large enough to dilute any salt that is flushed through the system.	High (controlled volume).	Summer and Winter.	Extremely high salinity levels in the lower end of Nine Mile Creek should not be flushed into the downstream environments without significant dilution, or it may adversely impact on other environmental values.
Aquatic and riparian vegetation	Maintain and where possible improve canopy trees in remnant riparian forest and woodland. Maintain and where possible improve understorey of the remnant eucalypt forest and woodland.	Engage riparian zone and wetlands to water riparian forest and woodland - River Red Gum (*Euc. camaldulensis*) and Black Box (*Euc. largiflorens*); includes maintenance of adult specimens and successful recruitment of juveniles.	Bankfull and overbank	Winter/Spring	Maintain adult Eucalypts in riparian zones and on the floodplain, plus successful recruitment of juveniles into the population. Maintain floristically rich understorey.
Turtles	Promote dispersal of the Eastern Long-necked Turtle population.	Inundate the River Red Gum Forest	Floodplain inundation	Late Winter/early Spring	Turtles will use the available habitat when inundated and disperse to other habitats as conditions allow.
Frogs	Maintain frog populations.	Inundate the River Red Gum Forest to promote and support breeding events.	Floodplain inundation	Late Winter early Spring	The frog community will breed in the floodplain habitat.

Asset	Objective	Function	Flow component	Timing	Expected response
Birds	Maintain and improve remnant riparian forest and woodland.	Maintain adults of plant species in relevant riparian and floodplain EVCs (e.g. River Red Gum, Blackbox, Lignum).	Bankfull and overbank	Winter, spring or early summer ideally inundate wetland for 5-6 months to facilitate waterbirds breeding	Range of birds will use water and some waterbirds may breed if inundation period is long enough. Flows that maintain vegetation and macroinvertebrates will also favour birds. Nine Mile Creek is an important corridor for birds to disperse throughout the region.

Note: No environmental flow objective have been set for fish or Platypus as conditions are unlikely to be suitable for permanent occupancy.

Table C-4 Environmental objectives for Reach 6 – Pennyroyal Creek at Leaghur Road.

Asset	Objective	Function	Flow component	Timing	Expected response
Geomorphology	Maintain distributary network	Engage distributaries and maintain channel/floodplain processes	Overbank	Anytime	Maintain complexity of channels across the alluvial plain.
Fish	No fish objectives - currently contains very little water and no flow.				
Macroinvertebrates	Maintain tolerant macroinvertebrate community.	Macroinvertebrates are not a high priority for this reach, but if permanent or near permanent aquatic habitats are maintained then macroinvertebrates will colonise it.	Low flow	Summer and Winter	Maintain some permanent aquatic habitats that macroinvertebrates can colonise.
			High flows	Summer and winter	Flush permanent pools and maintain diverse aquatic flora and therefore habitat for macroinvertebrates.
Water quality	N/A				
Vegetation	Maintain Tangled Lignum	Engage plains to water Tangled Lignum (*Muehlenbeckia florulenta*); includes maintenance of adult specimens and successful recruitment of juveniles.	Overbank	Summer /Autumn/Spring	Maintain adult Tangled Lignum, plus successful recruitment of juveniles into the population.
Platypus	Unlikely to be suitable for permanent occupancy so no environmental objectives set for Platypus.				
Turtles	Promote dispersal of the Eastern Long-necked Turtle population.	Provide low flows to inundate the low lying channels.	Low flows	Early Spring	Turtles will use the available habitat to disperse between the Loddon River, Serpentine Creek and other nearby waterways.
Frogs	Promote and support breeding events for the frog community	Provide flows to inundate the low lying channels	Freshes / High flows	Autumn, Late Winter / early Spring	Maintain abundance and diversity of frog populations. Frogs may breed in the inundated channels.

Asset	Objective	Function	Flow component	Timing	Expected response
Birds	No unequivocal objective devised during objective-setting workshop.				

Appendix D. Hydraulic models

D.1 Introduction

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

Two models were developed for the Serpentine Creek, and one for Pennyroyal Creek:

- The Reach 1 site for Serpentine Creek is located downstream of the Knife Edge Weir, downstream of Old Boort Road.
- The Reach 3 site for Serpentine Creek is located approximately 3km upstream from Irrigation Channel 7/10/1.
- The Penny Royal Creek site is located downstream of Hopefield Road.

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 Figure 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

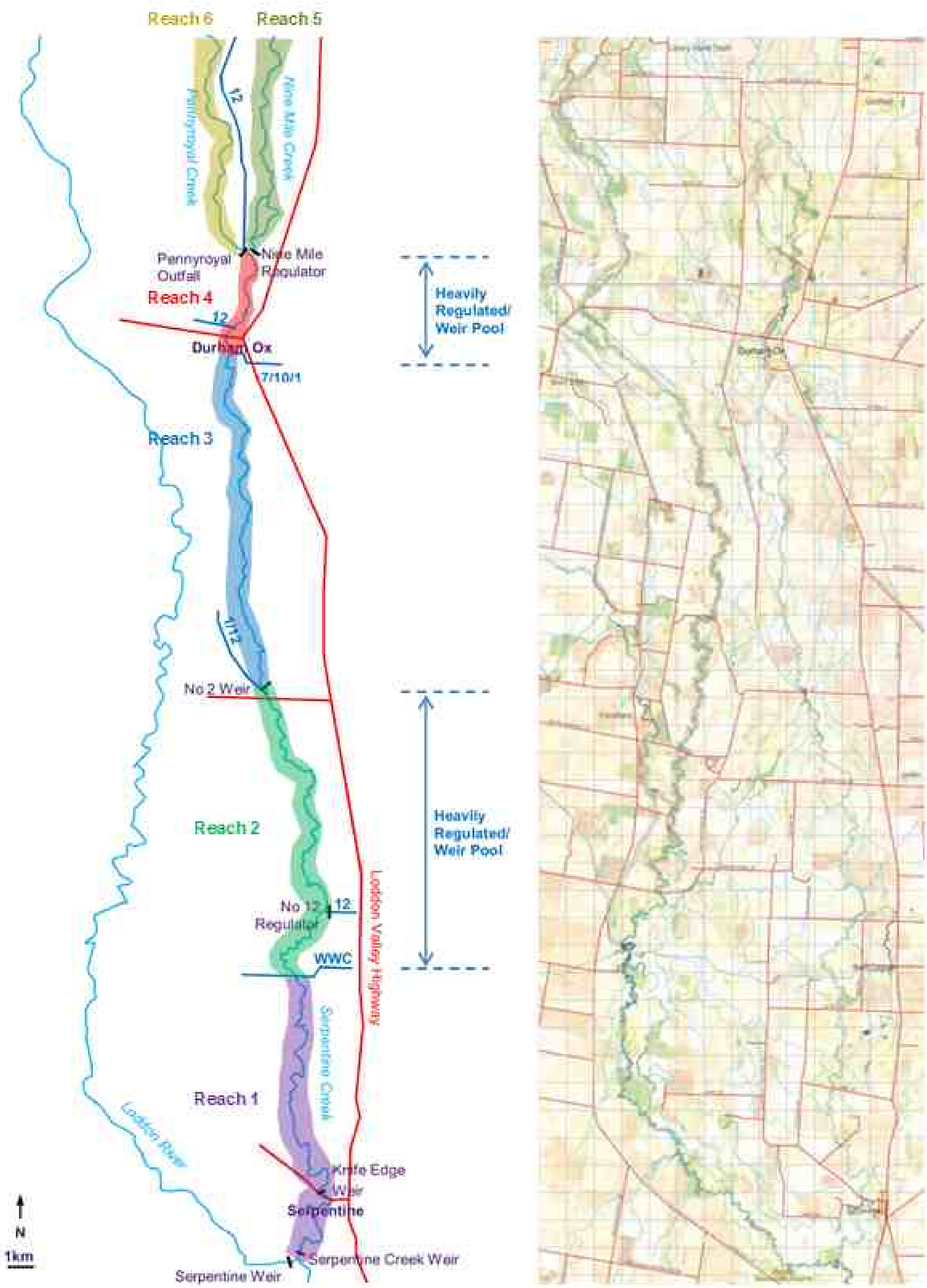


Figure D-1 Schematic map of Serpentine Creek.

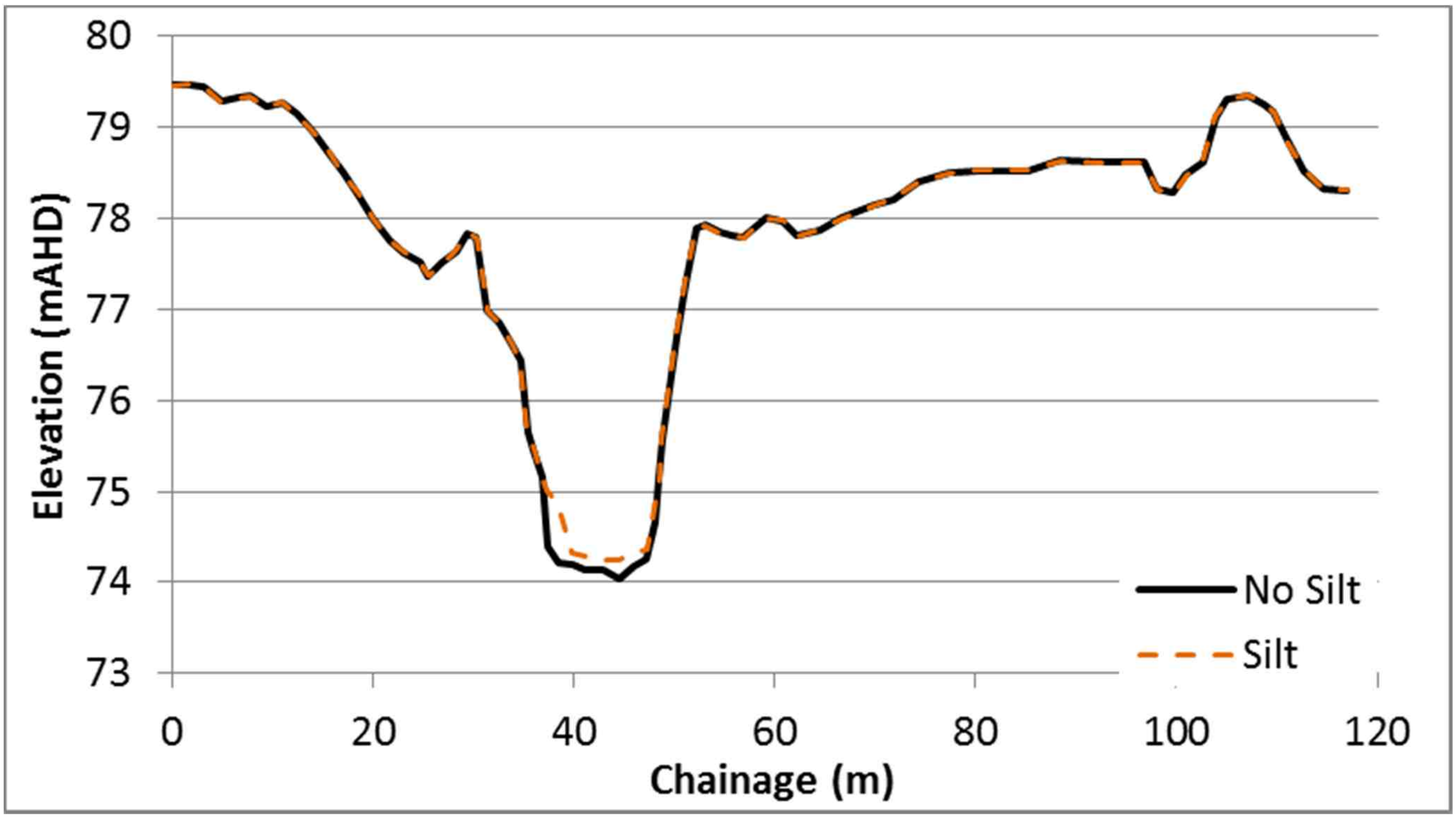


Figure D-2 Surveyed cross-section showing an example of the silt level and no silt (bed) level. The silt levels were adopted for all cross-sections for this study.

D.2 Serpentine Creek Reach 1

D.2.1 General

This site is located on Serpentine Creek downstream of the Knife Edge Weir, downstream of Old Boort Road. The site contains 8 surveyed cross-sections which represent some runs, but predominantly pool and bench habitat. A schematic of the site is shown in Figure D-3. Water flows from cross-section 1 (right) to cross-section 8 (left).

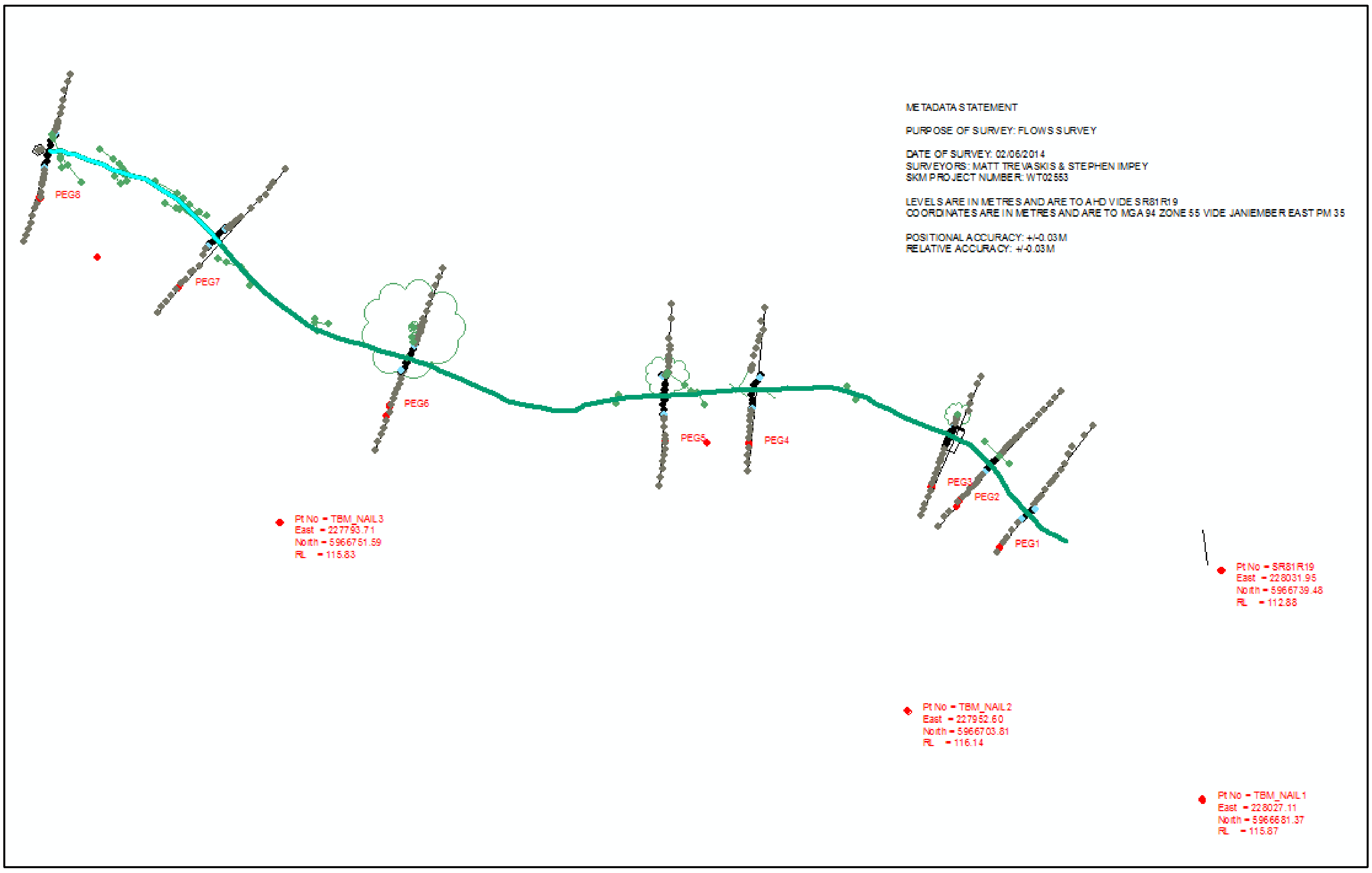
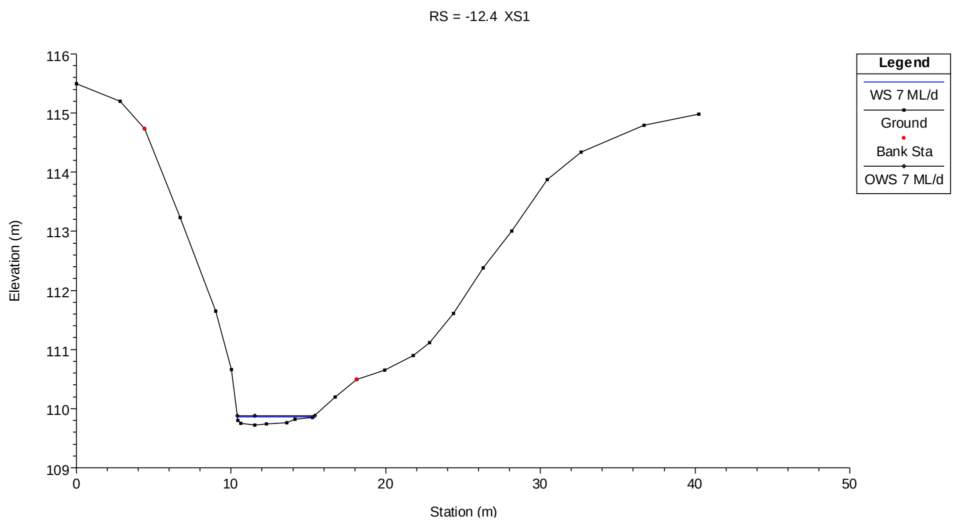


Figure D-3 Schematic of survey data at Serpentine Reach 1.

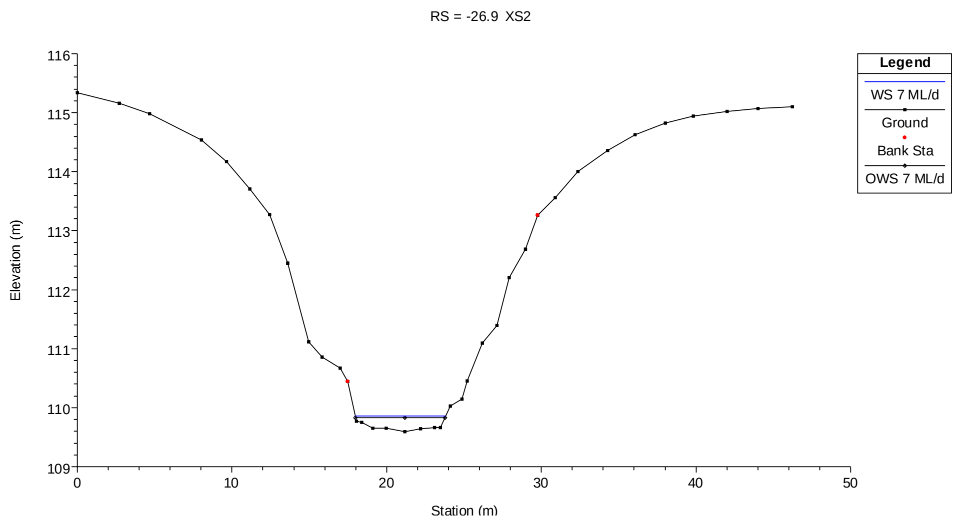
D.2.2 Cross-sections

The cross-sections are presented in Table D-1. All eight cross-sections were surveyed. An additional three cross-sections were added to represent fallen trees and other features affecting water level in the creek.

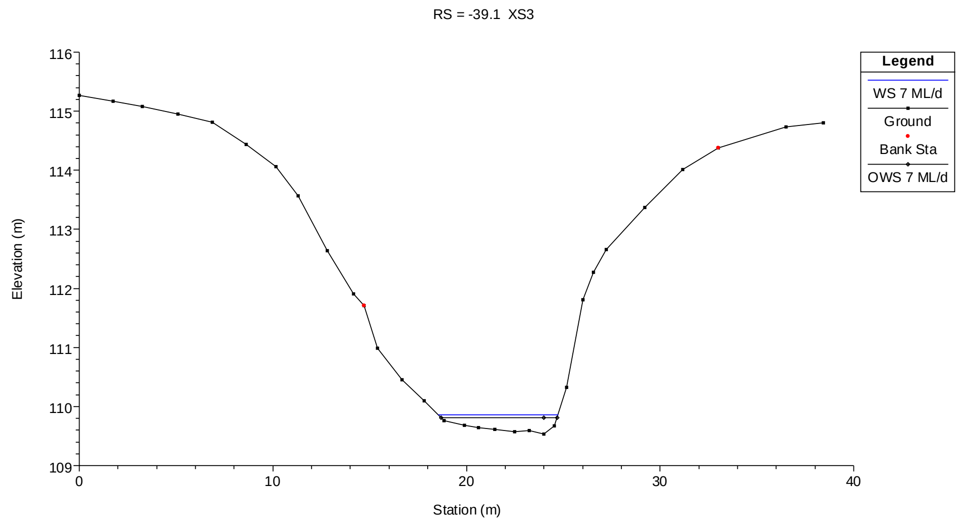
Table D-1 Cross-sections for Reach 1 of the Serpentine Creek.

Cross-section	Photo
XS1 – Most U/S 	

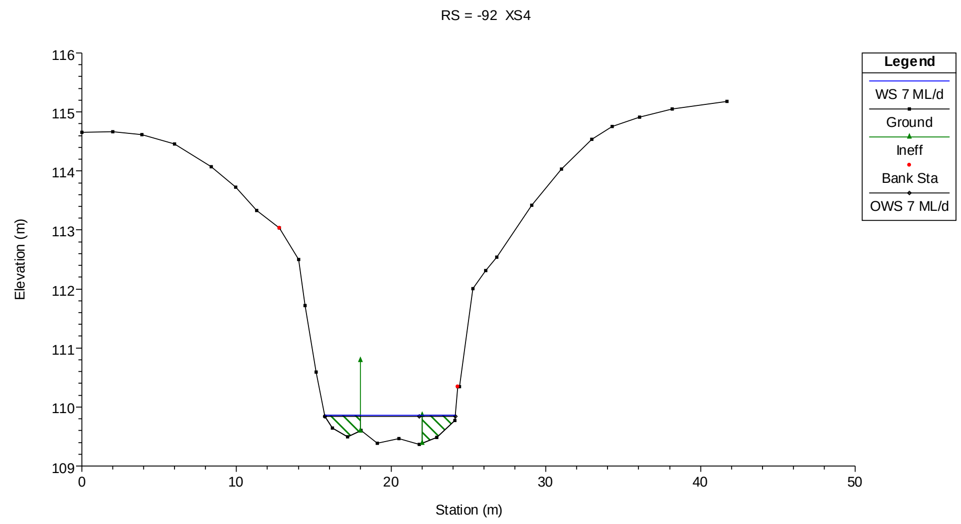
XS2


RS = -26.9 XS2
Legend
WS 7 ML/d
Ground
Bank Sta
OWS 7 ML/d
Elevation (m)
116
115
114
113
112
111
110
109
0
10
20
30
40
50
Station (m)

XS3


RS = -39.1 XS3
Legend
WS 7 ML/d
Ground
Bank Sta
OWS 7 ML/d
Elevation (m)
116
115
114
113
112
111
110
109
0
10
20
30
40
Station (m)

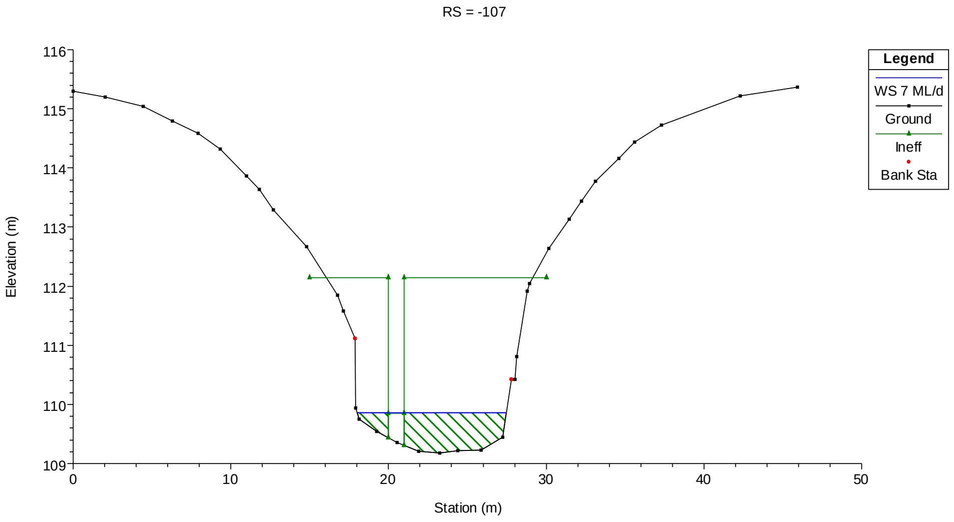
XS4


RS = -92 XS4
Legend
WS 7 ML/d
Ground
Ineff
Bank Sta
OWS 7 ML/d
Elevation (m)
116
115
114
113
112
111
110
109
0
10
20
30
40
50
Station (m)

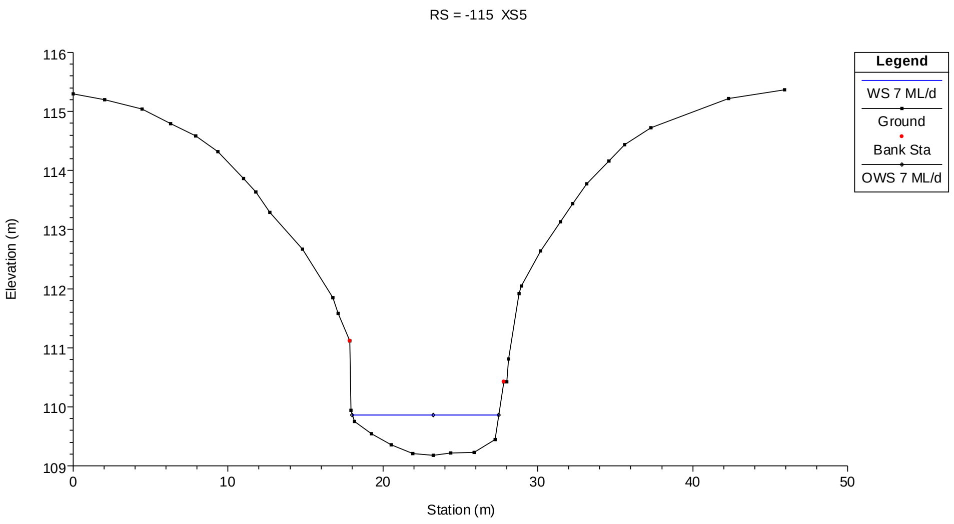
XS 14.5 m downstream of XS4 – Log across full width of channel, with field note:

Flow over middle where log has slumped/broken

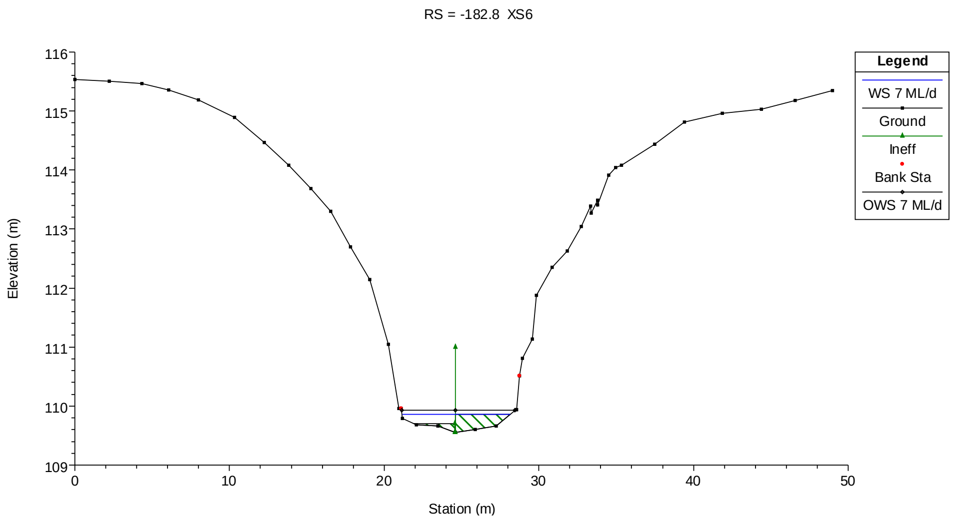
Levels from survey. Flow area in middle assumed.



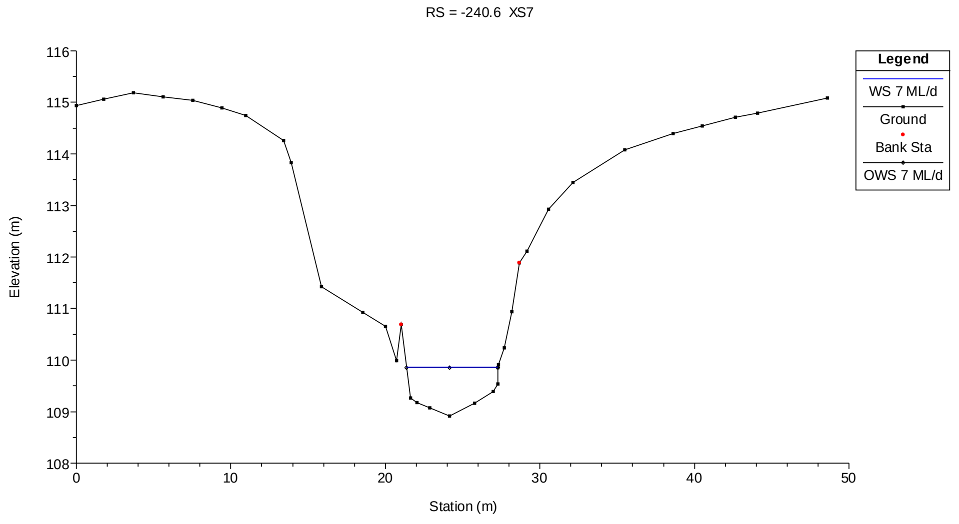
XS5



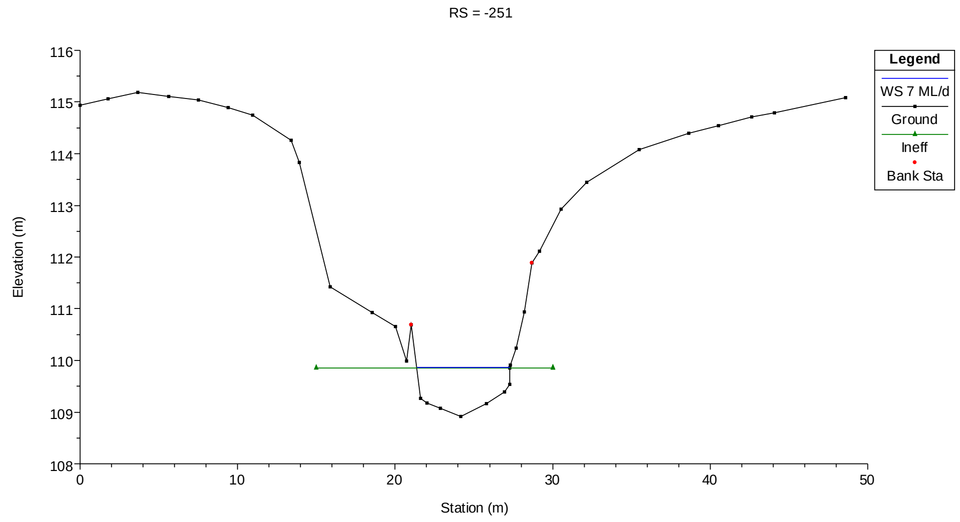
XS6 – Ineffective area to represent the logs in the channel – the extents are based on the survey data.



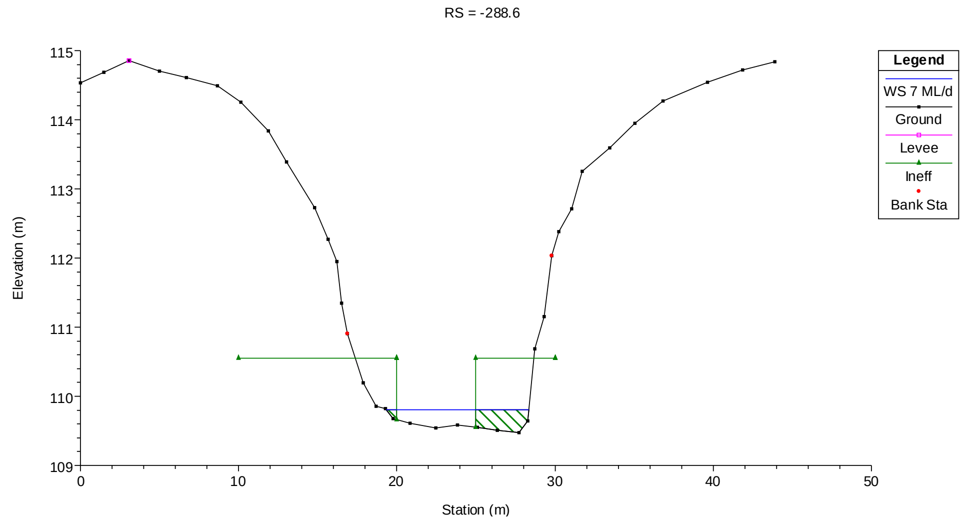
XS7



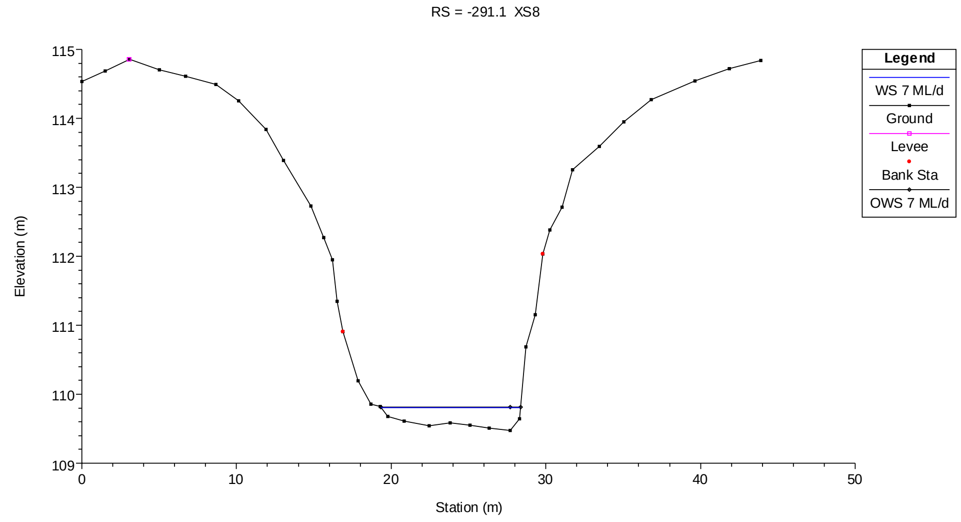
XS 10.4m downstream of XS7 – entered to capture log across creek bed. Levels from survey. Modelled water level is sensitive to the elevation of this ineffective elevation.



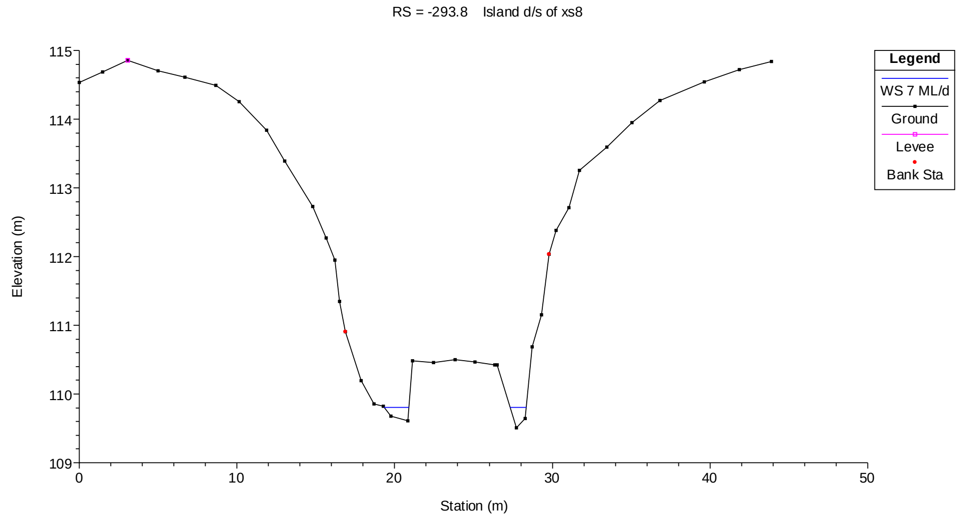
XS 2.5 m upstream of XS8 – captures log across channel. Elevation taken from survey.



XS8 – Modelled water level dictated by downstream boundary condition



XS 1.8m downstream of XS8 – captures island. Elevation & size from survey.



D.2.3 Adopted Mannings Roughness

The adopted Mannings roughness values are shown in Table D-2.

Table D-2 Mannings roughness values for Serpentine Reach 1.

Description	Value
Banks – light brush with some trees	0.05
Instream – some winding, some weeds, some LWD	0.04

D.2.4 Calibration Data

The calibration data is presented in Table D-3. It can be seen that the model calibrates well, ranging between an exact match and 5cm variation from the observed water levels.

Table D-3 Calibration data Serpentine Reach 1.

Parameter	Actual Data (gauge or surveyed)	Modelled data	Comment
Date of survey	2/6/2014		
Representative flow gauge	407294		
Mean Flow (ML/d)	7		Next day's average flow was 17.75ML/d
Mean Flow (m3/s)	0.081		
XS 1 level (mAHD)	109.9 109.86	109.86	

Parameter	Actual Data (gauge or surveyed)	Modelled data	Comment
XS 2 level (mAHD)	109.84 109.82	109.86	
XS 3 level (mAHD)	109.81	109.86	
XS 4 level (mAHD)	109.85 109.83	109.86	
XS 5 level (mAHD)	109.87 109.85	109.86	
XS 6 level (mAHD)	109.94 109.91	109.86	The reported observed levels here are higher than those upstream, and were deemed to be inaccurate. The photos do not show any sign of a change in water profile.
XS 7 level (mAHD)	109.84 109.85	109.86	
XS 8 level (mAHD)	109.819 109.796	109.81	

D.2.5 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-4. This downstream boundary condition was applied to the most downstream surveyed cross-section at the site.

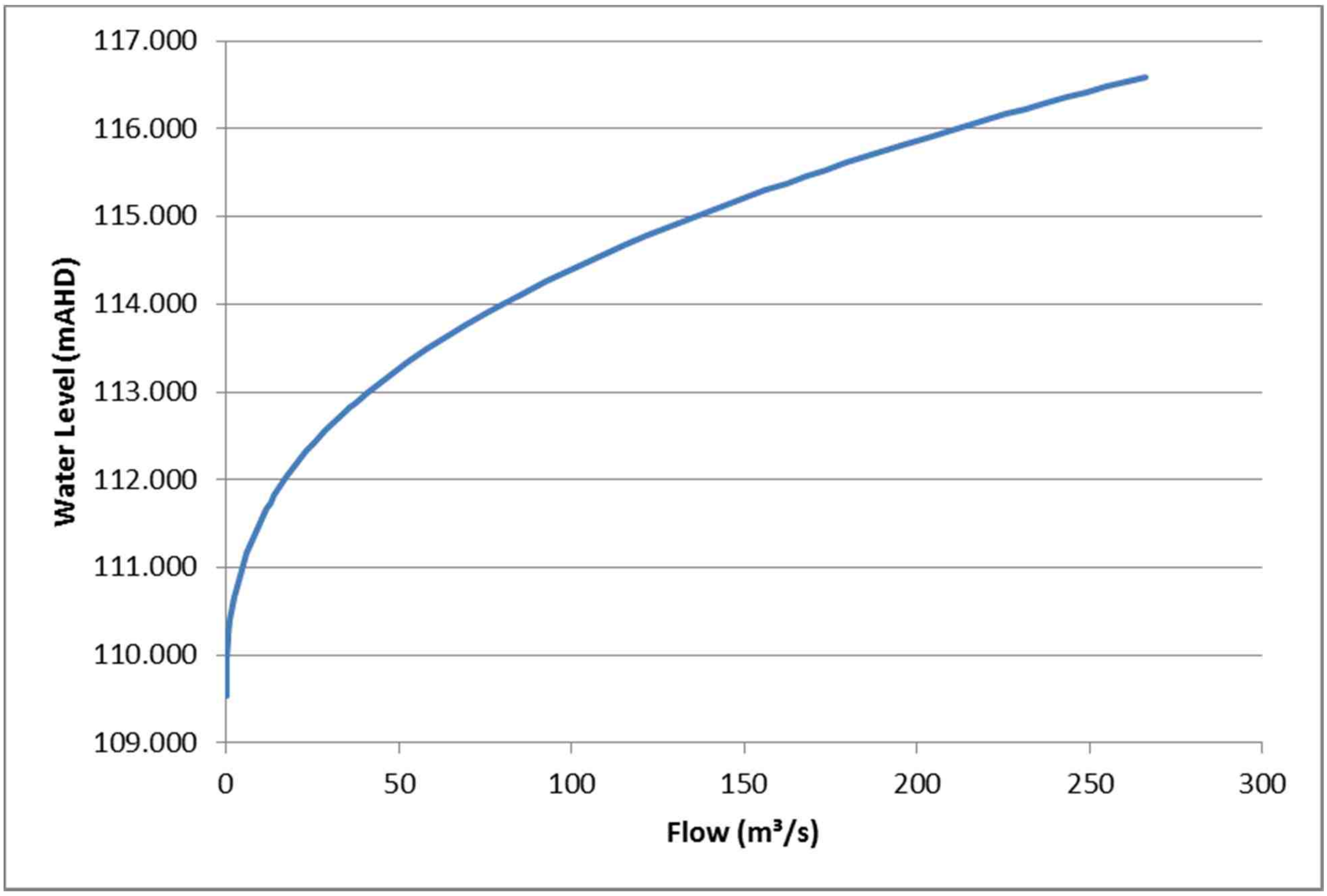


Figure D-4 Downstream rating curve boundary condition.

D.2.6 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 D-5. The low point for the 75 ML/day profile is expected due to a log over the creek, which creates a constriction in the river.

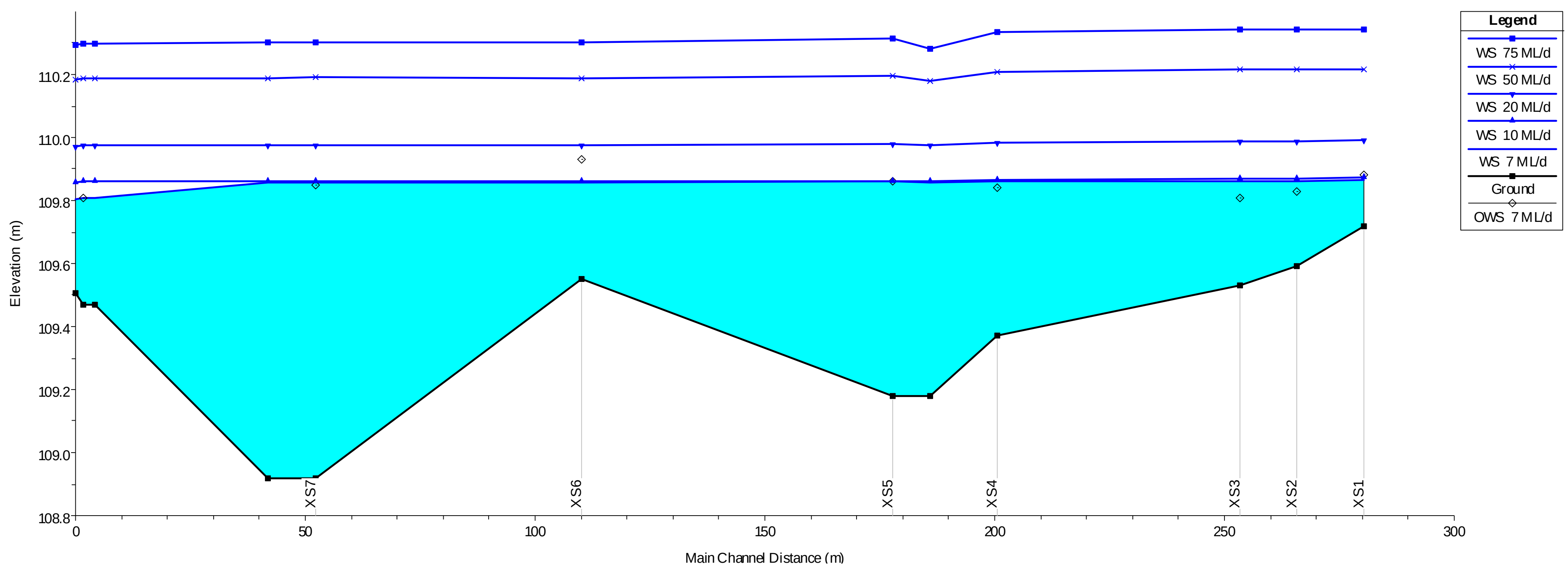


Figure D-5 Modelled water surface profiles for Reach 1 of Serpentine Creek.

D.3 Serpentine Creek Reach 3

D.3.1 General

This site is located approximately 3km upstream from Irrigation Channel 7/10/1, and can be accessed via a gate on the western side of the Loddon Valley Highway, 3.5 km south of Durham Ox. The site contains 11 surveyed cross-sections which represent some runs, pool and bench/island habitat as well as heavily vegetated sections of the river. A schematic of the site is shown in Figure D-6. Water flows from cross-section 1 (bottom) to cross-section 11 (top).

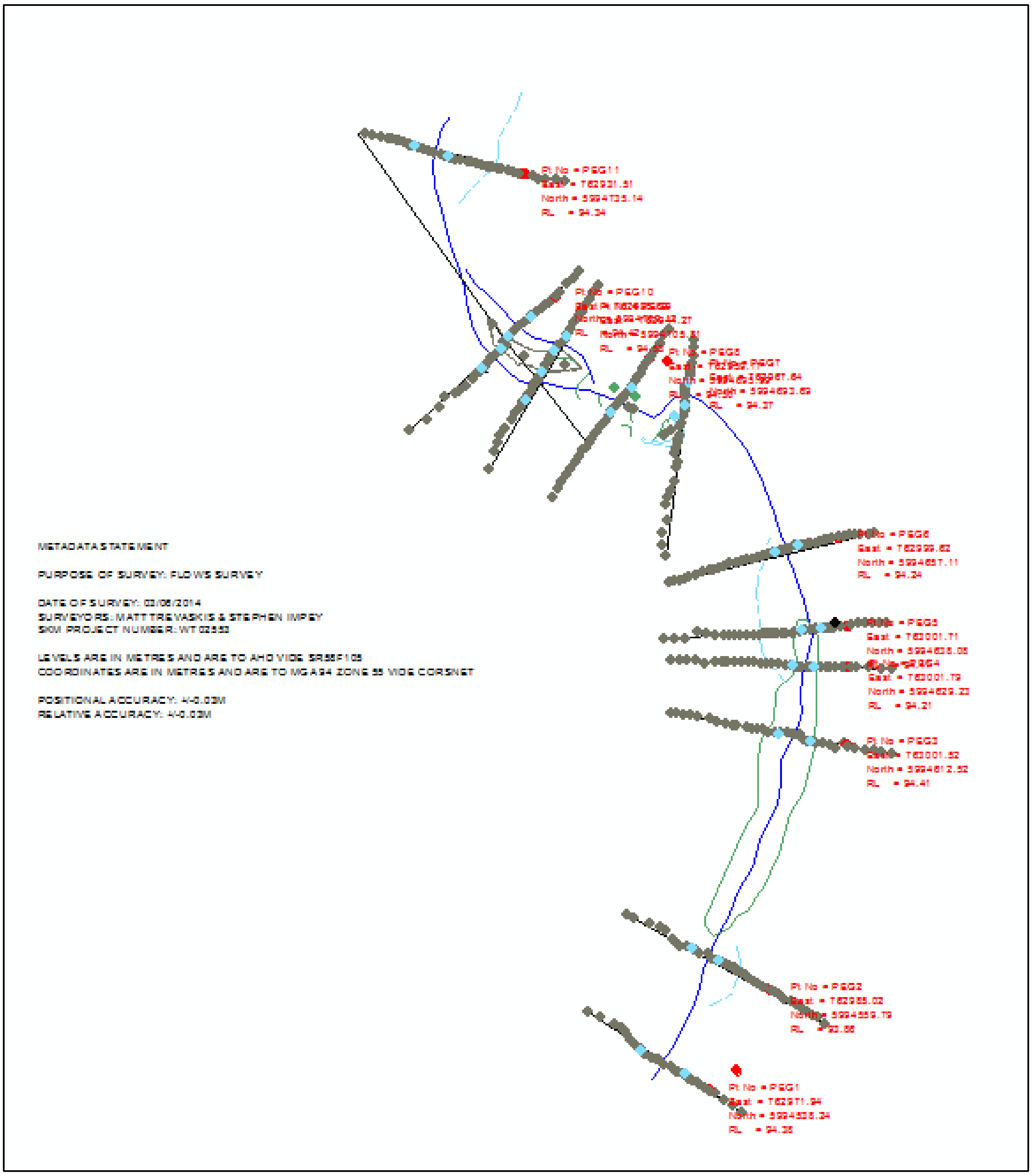


Figure D-6 Schematic of survey data at Serpentine Reach 3.

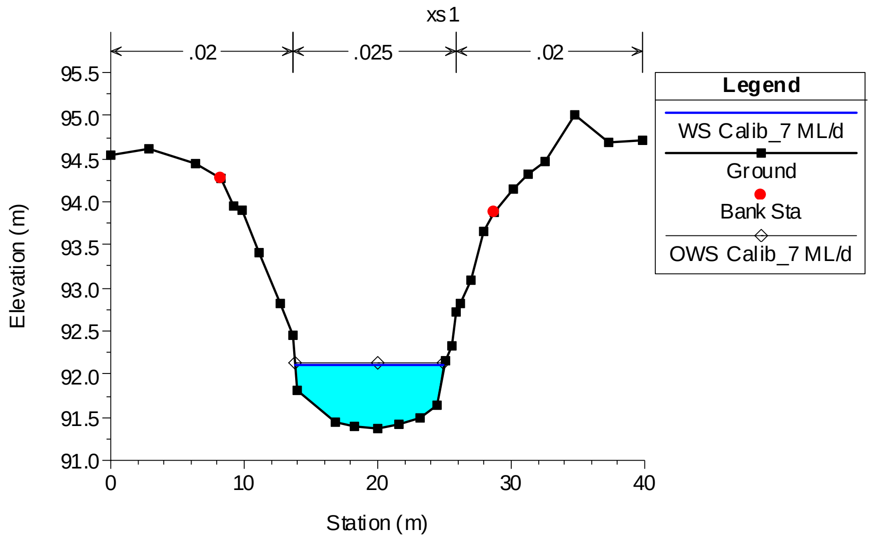
D.3.2 Cross-sections

The cross-sections are presented in Table D-4. 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 longitudinal survey data.

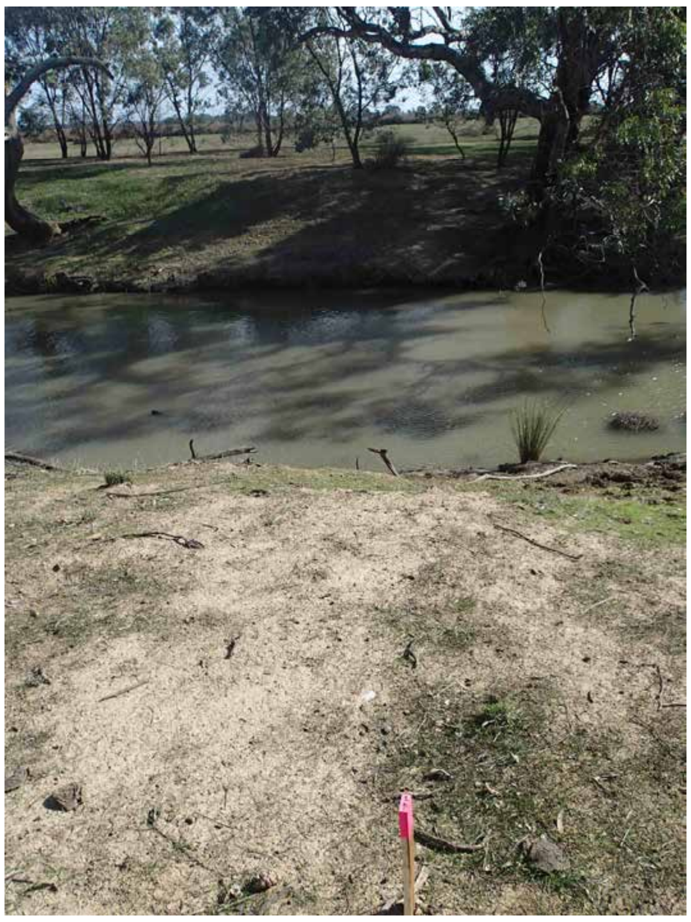
Table D-4 Cross-sections Serpentine Reach 3.

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

XS1

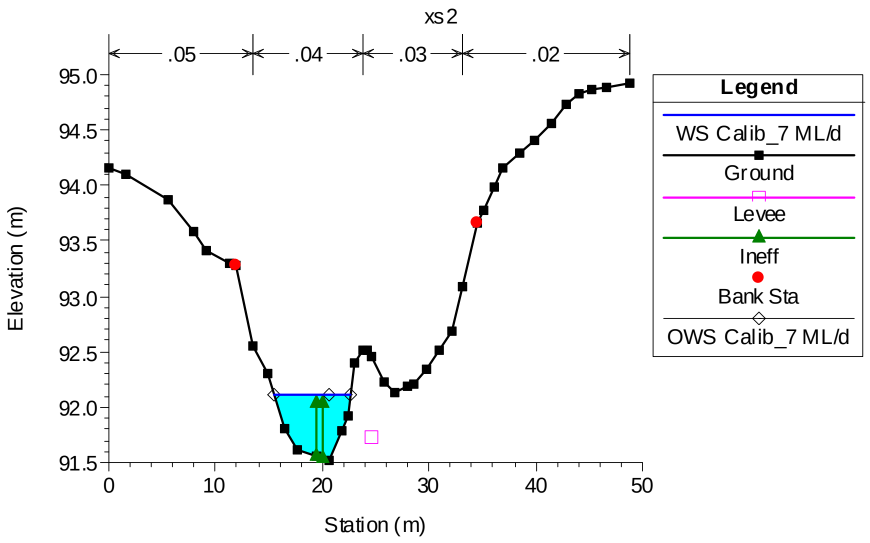


</td><td>



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

XS2

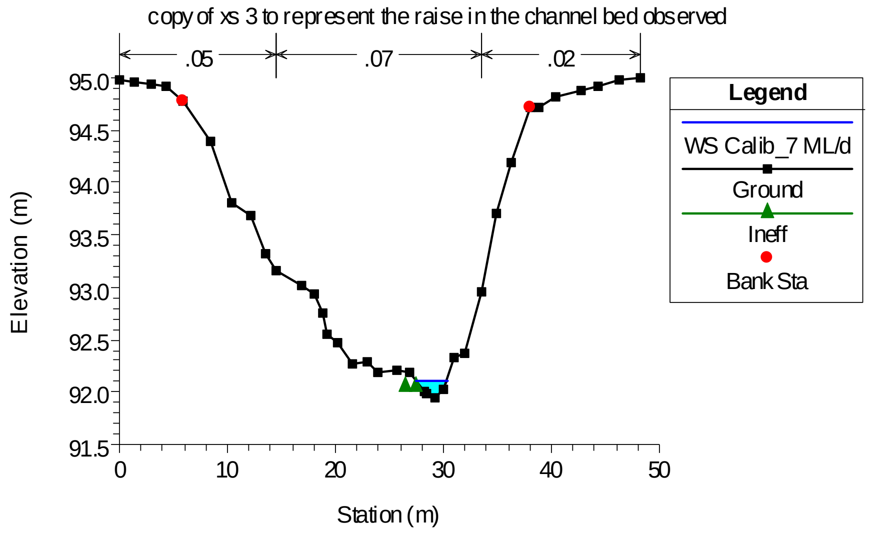


</td><td>

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

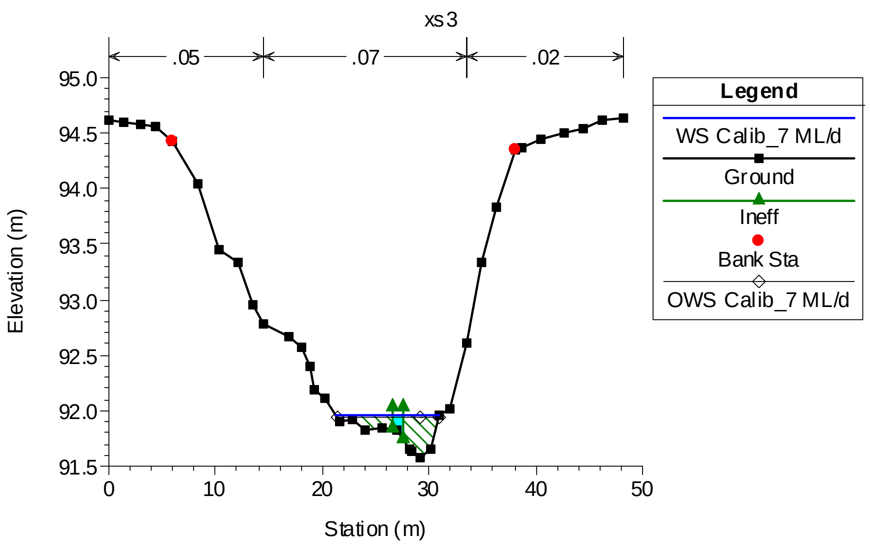
<table>
<tr><th>Cross-section</th><th>Photo</th></tr>
<tr><td>

XS between XS2 and XS3 to represent to increase in bed height identified in the long section survey. Cross-section 3 was copied and then the elevations were adjusted to reflect the increased bed height.



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

XS3

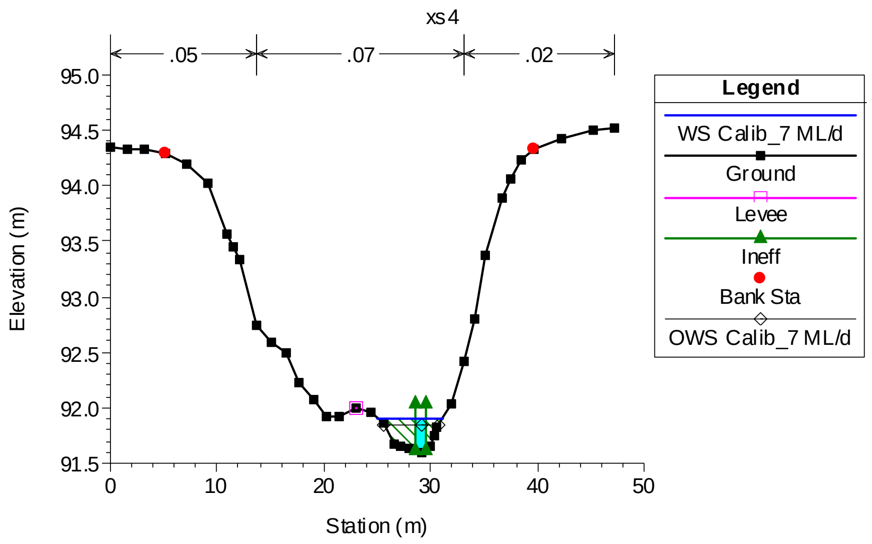


</td><td>

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

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

XS4



</td><td>

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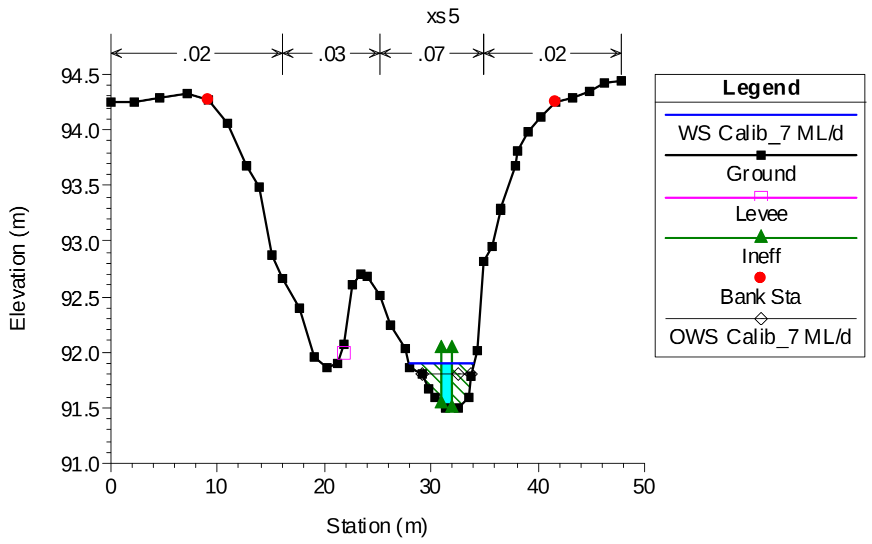
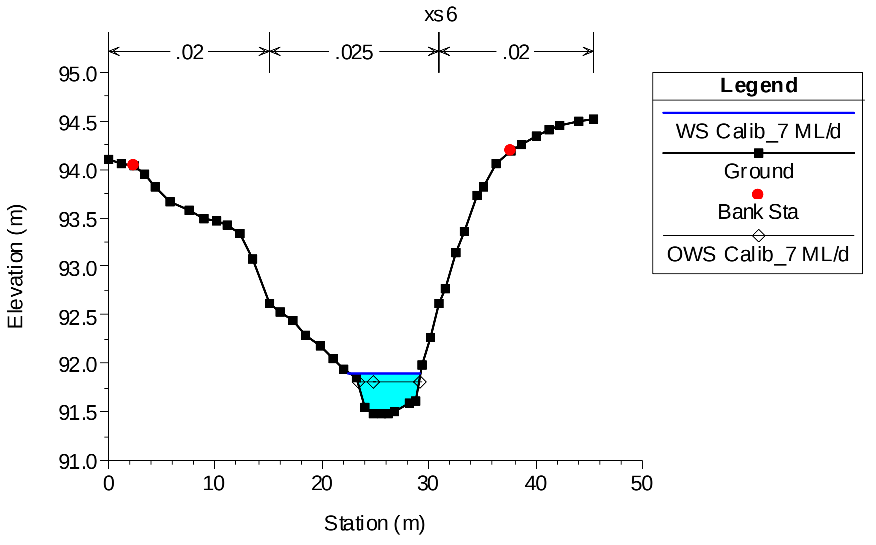
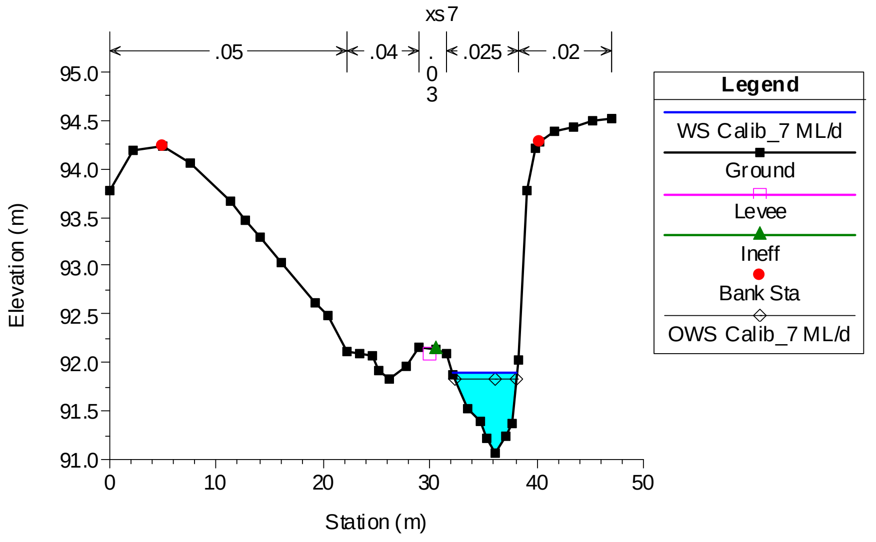
<tr><td>

XS5



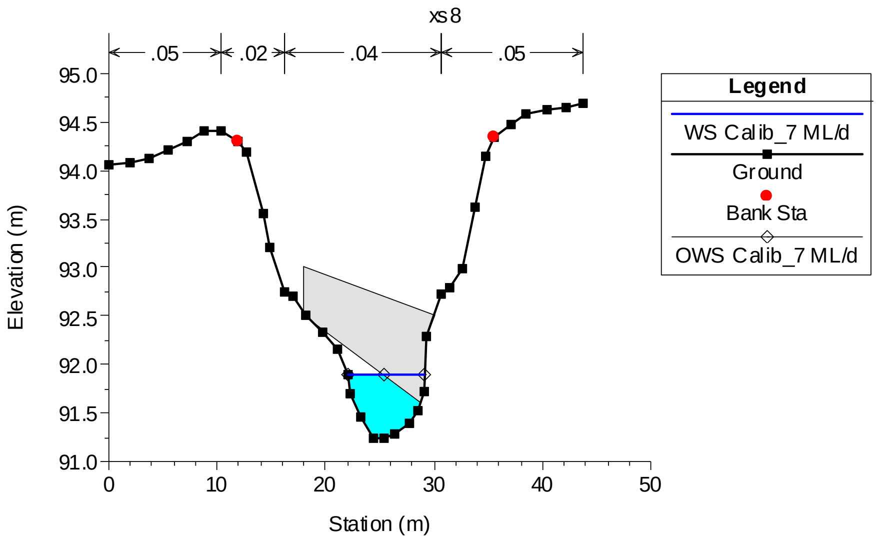
</td><td>

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

Cross-section	Photo
XS6 	
XS7 	

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

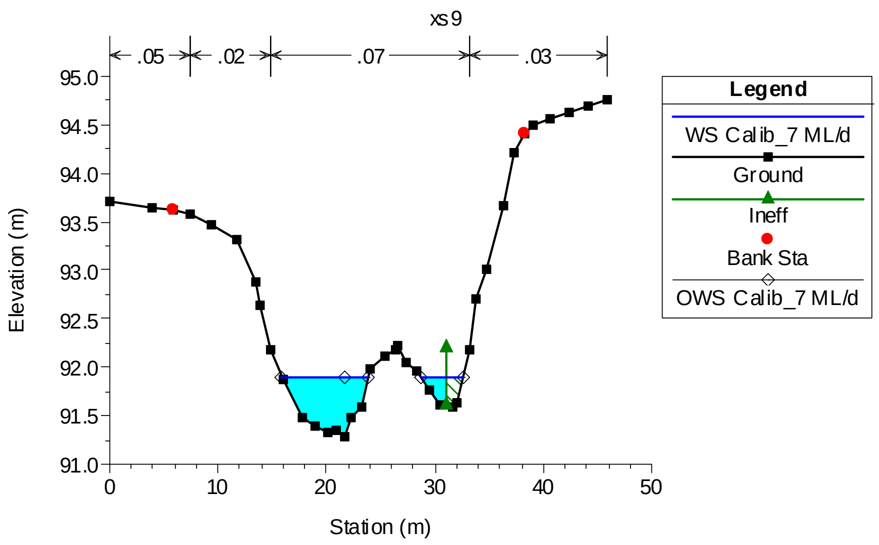
XS8



</td><td>

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

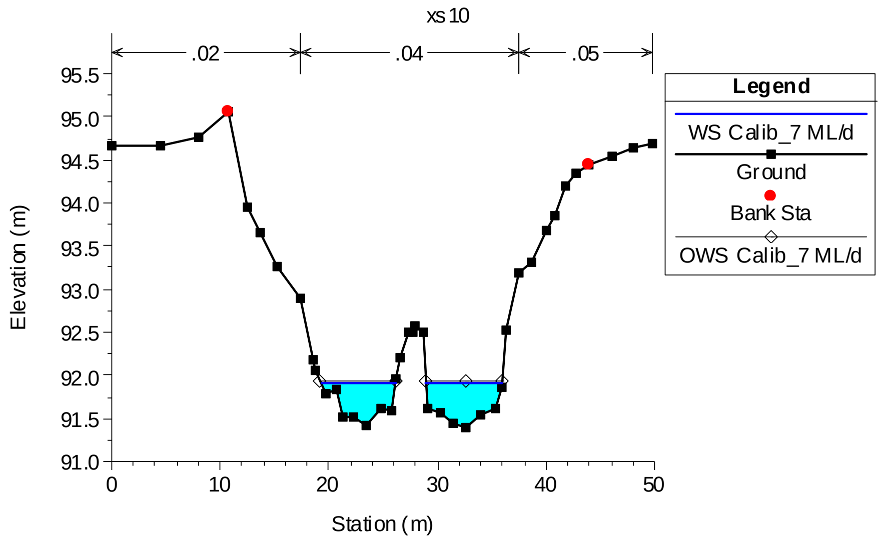
XS9



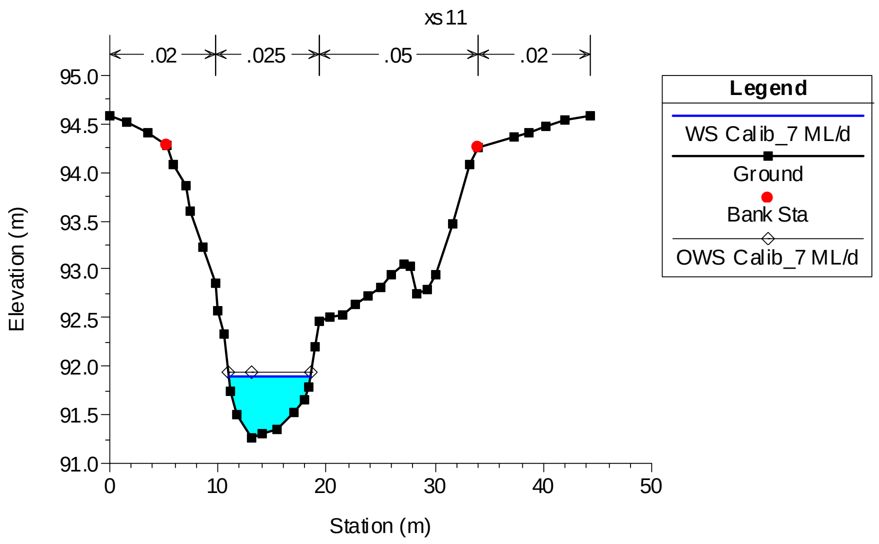
</td><td>

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

<table>
<tr><th>Cross-section</th><th>Photo</th></tr>
<tr><td>XS10



</td><td></td></tr>
<tr><td>XS11



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

D.3.3 Adopted Mannings Roughness

The adopted Mannings roughness values are shown in Table D-5.

Table D-5 Mannings roughness values for Serpentine Reach 3

Value	Description
0.02	Bare ground
0.03	Short length grass
0.05	Cleared land with some trees and some sprouts

Value	Description
0.025	Instream – uniform section, clean
0.04	Instream – some winding, some weeds, some LWD
0.07	Instream – sluggish reaches, weedy

D.3.4 Calibration Data

The calibration data is presented in Table D-6. It can be seen that the model calibrates well, ranging between an exact match and 9 cm variation from the observed water levels.

Table D-6 Calibration data for Serpentine Reach 3.

Parameter	Actual Data (gauge or surveyed)	Modelled data	Comment
Date of survey	2/6/2014		
Representative flow regulator	PH 894		Located at the upstream end of Reach 3
Mean Flow (ML/d)	7		Next day's average flow was 3 ML/d
Mean Flow (m3/s)	0.081		
XS 1 level (mAHD)	92.13	92.11	
XS 2 level (mAHD)	92.11	92.11	
XS 3 level (mAHD)	91.94	91.96	
XS 4 level (mAHD)	91.85	91.91	
XS 5 level (mAHD)	91.81	91.9	
XS 6 level (mAHD)	91.81	91.9	
XS 7 level (mAHD)	91.84	91.9	
XS 8 level (mAHD)	91.89	91.9	
XS 9 level (mAHD)	91.9	91.9	
XS 10 level (mAHD)	91.93	91.9	
XS 11 level (mAHD)	91.95	91.9	

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-7. This downstream boundary condition was applied to the most downstream surveyed cross-section at the site.

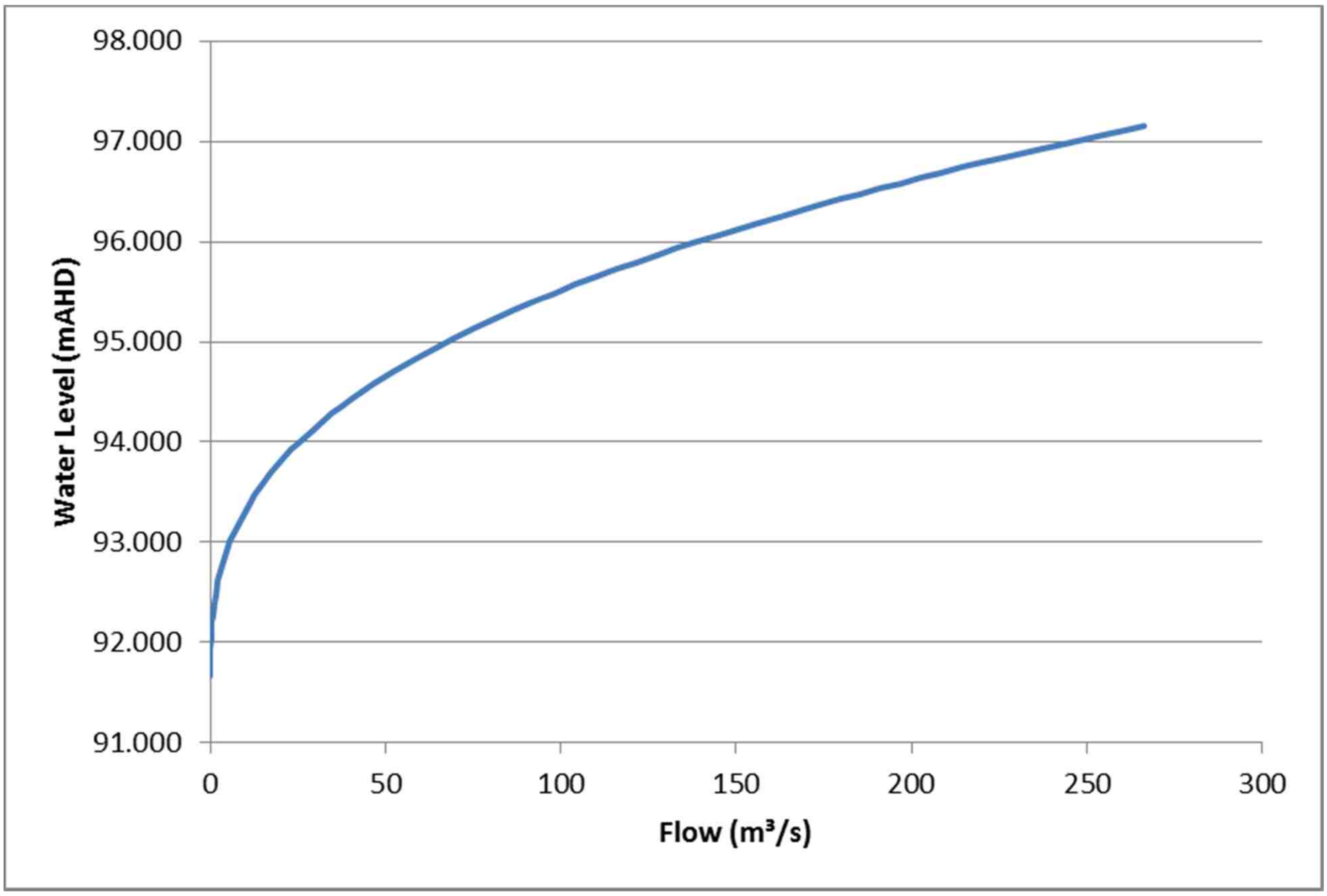


Figure D-7 Downstream rating curve boundary condition

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 D-8. The line at cross-section 8 represents a log. The cross-section data provides more detail about this flow obstruction.

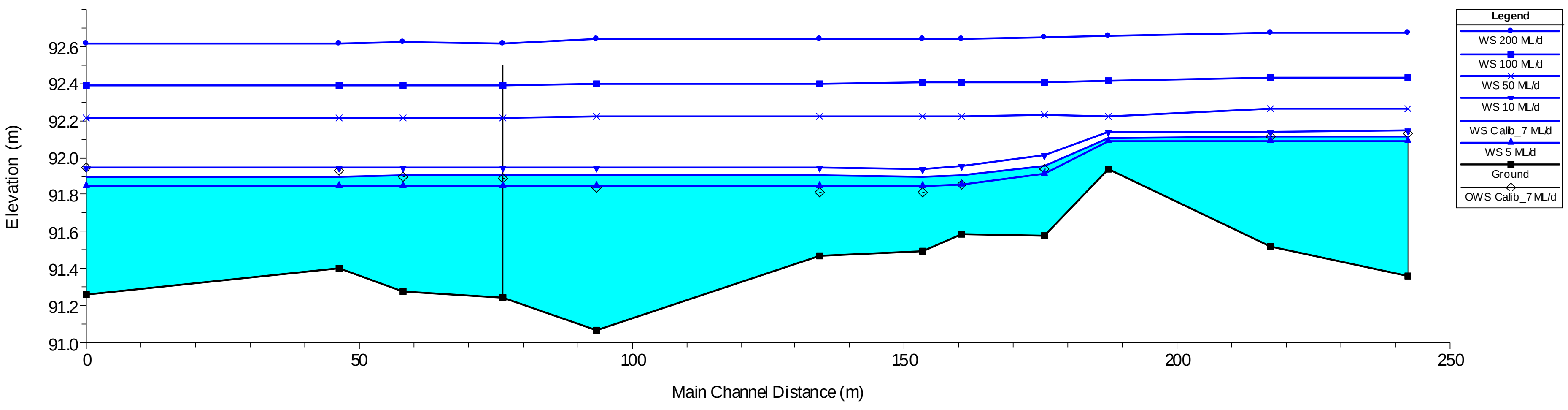


Figure D-8 Modelled water surface profiles for Reach 3 of Serpentine Creek.