Campaspe River Environmental FLOWS Assessment

FLOW RECOMMENDATIONS

- Final
- 25 July 2006

Campaspe River Environmental FLOWS Assessment

FLOW RECOMMENDATIONS

- Final
- 25 July 2006

Sinclair Knight Merz
ABN 37 001 024 095
590 Orrong Road, Armadale 3143
PO Box 2500
Malvern VIC 3144 Australia
Tel: +61 3 9248 3100
Fax: +61 3 9500 1182
Web: www.skmconsulting.com

Contents

Document history and status

Revision	Date issued	Reviewed by	Approved by	Date approved	Revision type
Draft 1	5 April 2006	A Sharpe	A Sharpe	5 April 2006	
Final	30 June 2006	B Abernethy	B Abernethy	30 June 2006	

Distribution of copies

Revision	Copy no	Quantity	Issued to
Draft 1	1	1 electronic	Catherine Fox NCCMA
Final	1	1 electronic	Catherine Fox NCCMA

Printed:	7 August 2006
Last saved:	7 August 2006 10:27 AM
File name:	I:\WCMS\Projects\WC03422\Deliverables\Flow Recommendations\R01 AKS Campaspe Flow Recommendations Final Report_final.doc
Author:	Andrew Sharpe
Project manager:	Andrew Sharpe
Name of organisation:	North Central Catchment Management Authority
Name of project:	Campaspe River Environmental FLOWS Assessment
Name of document:	Flow Recommendations
Document version:	Final
Project number:	WC03422

Executive summary

This report presents the environmental flow recommendations for the Coliban River downstream of Malmsbury Reservoir and the Campaspe River downstream of Lake Eppalock. This report is the third output of the Campaspe River Flows Assessment project and has been preceded by a *Site Paper* that outlined the site and reach selection process and described selected study sites and an *Issues Paper* that described the environmental values of the study area and environmental objectives for the system.

The specific objectives of the Campaspe River Flows assessment project were to:

- identify the water dependent environmental values of the system;
- identify suitable flow regimes for the protection/enhancement of defined environmental values;
- develop environmental flow objectives;
- develop environmental flow recommendations to meet the objectives;
- provide a clear and transparent process for assessing environmental flow requirements that can be clearly understood by all stakeholders;
- provide advice on the environmental benefits and disbenefits of various management options and operational scenarios including the use of any additional water that will be provided to the Campaspe and Coliban Rivers; and
- inform and engage the community.

The project used the FLOWS method, which has been specifically developed for determining environmental water requirements in Victoria and is based on the concept that key components of the natural flow regime influence various biological, geomorphological and physico-chemical processes in waterways. The Environmental Flows Technical Panel (EFTP) involved in this study were:

- Dr Bruce Abernethy — Geomorphology
- Dr Paul Boon — Vegetation
- Dr Paul Humphries — Fish
- Simon Lang and Robert Morden — Hydrology
- Dr Andrew Sharpe — Macroinvertebrates and water quality

The Campaspe River system was divided into four separate reaches and two representative sites were selected from each reach (Table 1). The EFTP used a desktop study and field investigation at each site to identify specific environmental assets and set environmental objectives for each reach.

SKM

Cross section and long section profiles were surveyed at each site and these results were used to develop a one dimensional hydraulic HEC-RAS model for each site. Modelled current and natural daily flow series were also developed for each reach and this information along with the HEC-RAS model were used to help determine the magnitude, frequency and duration of specific flow components that are required to maintain or rehabilitate key environmental assets within each reach.

Table 1 – Campaspe River flow assessment reaches and study sites

Reach No.	Description	Site No.	Location
1	Coliban River: Malmsbury Reservoir to Lake Eppalock	8	Phillips Road – upstream of Sandy Creek
		7	Lyell Road – 4 km upstream of Lake Eppalock
2	Campaspe River: Lake Eppalock to Campaspe Weir	6	Doak's Reserve – 5 km downstream of Lake Eppalock
		5	English's Bridge – downstream of Forest Creek confluence
3	Campaspe River: Campaspe Weir to Campaspe Siphon	4	Bryant's Lane – 2 km downstream of Campaspe Weir
		3	Spencer Rd – 5 km upstream of Campaspe Siphon
4	Campaspe River: Campaspe Siphon to River Murray	2	Strathallan Bridge – 8 km downstream of Campaspe Siphon
		1	Campbell's Road – 4 km upstream of Echuca

The main flow related issues and flow recommendations for each reach are described below. Unless otherwise stated, summer flow recommendations relate to flows between December and May, winter flow recommendations relate to flows between June and November.

Reach 1 – Coliban River: Malmsbury Reservoir to Lake Eppalock

The mean annual flow in the Coliban River has been nearly halved from 202 ML/day to 127 ML/day, due to the operation of the Upper Coliban, Lauriston and Malmsbury Reservoirs. Median and high flows have been primarily affected by this regulation, but the natural seasonal flow pattern is retained. Reduced flows have restricted aquatic habitat for aquatic flora and fauna and potentially exacerbate water quality problems such as high nutrient concentrations. However, other factors such as willows, stock access and high instream sediment loads also reduce the environmental condition of this reach. The recommended environmental flows for Reach 1 are summarised in Table 2.

- **Table 2: Summary of flow recommendations for Reach 1 – Coliban River: Malmsbury Reservoir to Lake Eppalock.**

Stream		Coliban River		Reach	Malmsbury Reservoir to Lake Eppalock.		
Compliance point		Lyell Road		**Gauge No.**	406215		
Season	**Component**	**Volume**	**Frequency**	**Duration**	**Rise**	**Fall**	**Objective**
Summer	Cease	Not Recommended					
	Low flow	5 ML/d	1 per year	6 months			V1-1, F1-1, W1-1, M1-1
	Freshes	100 ML/d & 200 ML/d	One of each per year	3 days	280%	65%	V1-2, F1-2, F1-4, M1-2
Winter	Low flow	35 ML/d (or natural)	1 per year	6 months			F1-3, F1-3, W1-1, M1-1
	Freshes	700 ML/d	4 per year	3 days	280%	65%	G1-2, V1-3, F1-4, W1-2, M1-2
	Bankfull	12000 ML/d	1 every 3 years	1 day	280%	65%	G1-1, G1-2, V1-4, F1-4
	Overbank	As natural					

Reach 2 – Campaspe River: Lake Eppalock to Campaspe Weir.

The mean annual flow in the Campaspe River between Lake Eppalock and the Campaspe Weir has been reduced from 640 ML/day to 420 ML/day. The seasonal flow pattern has also been reversed, with high flows during the summer irrigation season and low flows during winter. Land clearing and unrestricted stock access have degraded the riparian zone along much of this reach and high summer flows have contributed to excessive *Typha* growth in the main channel. High summer flows have also reduced the prevalence of slackwater habitats that are important nurseries for native fish, but restricted fish passage at the Campaspe Weir and Lake Eppalock also limit fish communities in this reach. High summer flows have also altered the composition of the macroinvertebrate community in this reach, but rapid flow fluctuations probably have an adverse effect on the health of this community. The environmental flow recommendations for this reach are summarised in Table 3.

- **Table 3: Summary of flow recommendations for Reach 2 – Campaspe River: Lake Eppalock to Campaspe Weir.**

Stream		Campaspe River		Reach	Lake Eppalock to Campaspe Weir		
Compliance point		Doakes Reserve		**Gauge No.**	406207		
Season	**Component**	**Volume**	**Frequency**	**Duration**	**Rise**	**Fall**	**Objective**
Summer	Cease to flow	0 ML/d	1 per year	14 days			F2-1
	Low flow	10 ML/d (or natural)	1 per year	6 months			V2-1, F2-2, F2-6, M2-1, W2-1

SKM

Stream		Campaspe River		Reach	Lake Eppalock to Campaspe Weir		
Compliance point		Doakes Reserve		**Gauge No.**	406207		
Season	**Component**	**Volume**	**Frequency**	**Duration**	**Rise**	**Fall**	**Objective**
	Freshes	100 ML/d	3 per year (or natural)	5 days	230%	65%	V2-2, F2-3, W2-3
Winter	Low flow	100 ML/d (or natural)	1 per year	6 months			F2-4, F2-6, M2-1, W2-1
	High flow	1000 ML/d	4 per year (or natural)	4 days	230%	65%	V2-3, V2-4, F2-5, W2-2, W2-3, M2-3
	Bankfull flow	10,000 ML/d	1 per year (or natural)	2 days	230%	65%	G2-1, V2-5, F2-5
	Overbank flow	12,000 ML/d	1 per year	1 day	230%	65%	G2-2, V2-6

Reach 3 – Campaspe River: Campaspe Weir to Campaspe Siphon.

The mean annual flow in the Campaspe River between the Campaspe Weir and Campase Siphon has been reduced from 880 ML/day to 360 ML/day. The seasonal flow pattern has also been reversed, with transfer flows delivered from the Campaspe Weir to the Western Waranga Channel in March and April in most years. The current flow regime is characterised by longer periods of low flow and shorter periods of high flow compared to natural. Reduced flows and altered seasonal patterns are likely to affect native fish movement and recruitment in this reach and the community has a high abundance of exotic species such as carp and redfin. Reduced flooding and stock access limit riparian regeneration throughout the reach and stable flows have contributed to excessive *Typha* growth within the channel. The macroinvertebrate community in this reach is dominated by pollution tolerant species indicating that nutrient enrichment is likely to be a problem in this reach, but there is little routine water quality monitoring. The environmental flow recommendations for this reach are summarised in Table 4.

- **Table 4: Summary of flow recommendations for Reach 3 – Campaspe River: Campaspe Weir to Campaspe Siphon.**

Stream		Campaspe River		Reach	Campaspe Weir to Campaspe Siphon		
Compliance point		Spencer Road		**Gauge No.**	406202		
Season	**Component**	**Volume**	**Frequency**	**Duration**	**Rise**	**Fall**	**Objective**
Summer	Low flow	10 ML/d (not more than 20 ML/d*)	1 per year	6 months			V3-1, F3-1, W3-1, M3-1
	Freshes	100 ML/d	3 per year (Feb to May**)	6 days	230%	65%	V3-2, F3-2, W3-2, M3-2
Winter	Low flow	200 ML/d (or natural)	1 per year	6 months			F3-3, W3-1, M3-1
	High flow	1500 ML/d	4 per year (or natural)	4 days	230%	65%	V3-3, F3-4, W3-2, M3-2
	Bankfull flow	8,000 ML/d	2 per year (or natural)	2 days	230%	65%	G3-1, V3-5, F3-4

SKM

Stream		Campaspe River		Reach	Campaspe Weir to Campaspe Siphon		
Compliance point		Spencer Road		Gauge No.	406202		
Season	Component	Volume	Frequency	Duration	Rise	Fall	Objective
	Overbank flow	12,000 ML/d	1 per year	1 day	230%	65%	V3-6
* This value may be reviewed after planned work assessing behaviour of saline pools and slackwaters in different flow conditions has been completed. ** Additional freshes may be released between December and February to manage water quality if required.							

Reach 4 – Campaspe River: Campaspe Siphon to River Murray.

The mean annual flow in the Campaspe River between the Campaspe Weir and Campase Siphon has been reduced from 890 ML/day to 320 ML/day. The natural seasonal flow pattern has been retained, but there are longer periods of low flow and shorter periods of high flow compared to natural. Reduced flows and the presence of barriers are likely to affect native fish movement and recruitment in this reach and the community has a high abundance of exotic species such as carp and redfin. Reduced flooding and stock access limit riparian regeneration throughout the reach and stable flows have contributed to excessive *Typha* growth within the channel. Nutrient enrichment and salinity are major water quality issues in this reach, and saline pools near Echuca are considered a major threat to the health of the reach. The macroinvertebrate community in this reach is dominated by pollution tolerant taxa and has poor overall condition. The environmental flow recommendations for this reach are summarised in Table 5.

Table 5: Summary of flow recommendations for Reach 4 – Campaspe River: Campaspe Siphon to River Murray.

Stream		Campaspe River		Reach	Campaspe Siphon to River Murray		
Compliance point		Campbells Road		Gauge No.	406265		
Season	Component	Volume	Frequency	Duration	Rise	Fall	Objective
Summer	Low flow	10 ML/d (Not more than 20 ML/d*)	1 per year	6 months			V4-1, F4-1, W4-1, M4-1
	Freshes	100 ML/d	3 per year (Feb to May**)	6 days	230%	65%	V4-2, F4-2, W4-2, M4-2
Winter	Low flow	200 ML/d (or natural)	1 per year	6 months			F4-3, W4-1, M4-1
	High flow	1500 ML/d	2 per year (or natural)	4 days	230%	65%	V4-3, V4-4, F4-4, W4-2, M4-2
	Bankfull flow	9,000 ML/d	2 per year (or natural)	2 days	230%	65%	G1-1, V4-5, F4-4
* This value may be reviewed after planned work assessing behaviour of saline pools and slackwaters in different flow conditions has been completed. ** Additional freshes may be released between December and February to manage water quality if required.							

SKM

Limitations

The environmental flow recommendations described in this report have been based on information that was available at the time. Specific summer flow recommendations in the lower reaches of the Campaspe River have balanced the need to maintain water quality with the need to retain slackwater habitats for breeding fish. In many cases there was not enough information to determine critical flow threshold limits for specific water quality parameters, nor was there information on how higher flows affect the abundance and distribution of slackwater habitats. The North Central CMA is currently undertaking studies to address these information gaps and the low flow recommendations for Reaches 3 and 4 may need to be revised based on the results of these studies.

Acknowledgements

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

Steering Committee	
Catherine Fox	North Central Catchment Management Authority
Emer Campbell	North Central Catchment Management Authority
Paulo Lay	Department of Sustainability and Environment
Amber Clarke	Department of Sustainability and Environment
Andrea Joyce	Department of Sustainability and Environment
Geoff Adams	Goulburn-Murray Water
Bill Viney	Goulburn-Murray Water
Sally-Anne Mason	Coliban Water
Consultative Committee	
Joy Sloan	DPI Fisheries
Rob Loats	VR Fish
David Major	Parks Victoria
Craig Kelly	Mt Alexander Shire
Bruce Macague	Irrigation IC
John McKinstry	Dryland IC
Geoff Elliott	Campaspe Catchment Committee
Mark Hill	Water Services Committee

Glossary of terms and abbreviations

AUSRIVAS	Australian River Grade and Assessment System.
Anastomosing	A channel that splits into several channels that rejoin regularly.
Biofilm	An organic matrix comprised of microscopic algae, bacteria and microrganisms that grow on stable surfaces in water bodies (e.g. logs, rocks or large vascular plants).
Catchment	The area of land drained by a river and its tributaries.
Current flow series	Series of streamflows which represent the current level of development.
Compliance point	Gauging station at which flows are measured to ensure compliance with recommendations.
Debouching	Emerge into larger body or area.
Dissolved oxygen (DO)	Concentration of oxygen in the water column. A measure of the amount of oxygen available to aquatic flora and fauna.
DSE	Department of Sustainability and Environment.
EFTP	Environmental Flows Technical Panel.
Environmental flow	Releases of water, periods of drying, or river flows allocated for the maintenance of aquatic and riparian ecosystem, measured in megalitres per day (ML/d).
Ephemeral stream	A waterway containing water only after unpredictable rain.
Floodplain	Temporarily inundated lateral river flats, usually of lowland rivers.
FSR	Flow Stressed Ranking.
GBCMA	Goulburn Broken Catchment Management Authority
Geomorphology	The study of the physical form of, and processes operating in, rivers. It aims to provide an understanding of the physical processes governing the current state of a river.
G-MW	Goulburn-Murray Water.
Groundwater	Water occurring below the ground surface.
Habitat	The place or environment in which a plant or animal usually lives; the subset of physical and chemical environmental variables that allow an organism to survive and persist.
Hydrology	The study of the surface and subsurface water. Sometimes used loosely to describe the water regime.
Hyporheic zone	Saturated sediment beneath and adjacent to stream or river where surface water and groundwater mix.
Instream	Of, or occurring within the wetted area of a running water body.
ISC	Index of Stream Condition. Presents an indication of the extent of change in respect of five key 'stream health' indices: hydrology, physical form, streamside zone, water quality and aquatic life.
Littoral	Edge or shore region where the water is shallow enough for continuous mixing.
Lowland waterway	A stream section at low altitude, that is sinuous and often with width to depth ratios greater than 20.
LWD	Large Woody Debris. Branches and trees that have fallen in the river channel. Often referred to as snags.
Macroinvertebrates	Aquatic invertebrates whose body length usually exceeds 1 mm.

	Includes insects, crustacean, aquatic worms, and aquatic snails.
Macrophytes	The term is used to describe water plants other than microscopic algae; they may be floating or rooted.
Mean	Average. Equally far from two extremes.
Median	The middle value in an ordered sequence of values.
Megalitre (ML)	One million litres (an Olympic size swimming pool is about two megalitres).
Natural flow series	Series of streamflows which represent what streamflows would have historically been like without man-made diversions, demands and impoundments, not withstanding changes to land use over time.
Nutrients	Natural elements (usually phosphorus and nitrogen) that are essential for plant and animal growth.
Percentile exceedence flows	The flow which is exceeded for the defined percentage of time. E.g. the 80^{th} percentile flow is exceeded 80% of the time and is therefore a low flow. Also commonly used: 20^{th} and 50^{th} percentile where 20^{th} percentile exceedence flow is a relatively high flow and the 50^{th} percentile exceedence flow may also be called the median flow.
pH	Level of acidity in a range from 0-14: low pH (values <7) refers to high acidity and high pH (values >7) refers to low acidity.
Piedmont	The foot of a mountain. Used to describe the gentle slope leading down from the steep mountain to the plains.
Pool	A stream section where there is no discernable flow and usually deep.
Reach	A length of stream that is reasonably uniform with respect to geomorphology, flow and ecology.
Recruitment	The addition of new members into a population through reproduction or immigration.
Regulated catchment/river	A river or creek where the flow of the river is controlled through the operation of large dams or weirs to meet water use demands downstream.
Riffle	A stream section with fast and turbulent flow over a pebble bed with protruding rocks. Characterised by a broken water surface.
Riparian	Vegetation found along the banks of streams and rivers.
Riparian zone	Any land which adjoins, directly influences, or is influenced by a body a water.
Run	A stream section with low to moderate laminar flow with unbroken water surface.
Water-dependent	Aquatic species or those dependent on river water for survival
SEPP	State Environment Protection Policy.
SIGNAL	Stream Invertebrate Grade Number Average Level.
SFMP	Stream Flow Management Plan.
Spawning	Production and deposition of eggs; related to fish reproduction.
SKM	Sinclair Knight Merz.
Snag	Branches and trees that have fallen in the river channel; also called Large Woody Debris (LWD).
Substrate	The base, or material, on the bed of the river.
Taxa	Any defined unit in the classification of living organisms (i.e. species, genus, family).

Thalweg	The long profile of a river valley; term used to describe the line that joins the lowest points along the entire length of the streambed.
Threatened	A generic term used to describe taxa that are rare, vulnerable, endangered or insufficiently known and are subject to a threatening process.
Transect	Line drawn across a stream channel and perpendicular to the direction of flow for standardising measurements of width, depth velocity discharge etc.
Tributary	A river or creek that flows into a larger river.
Turbidity	The cloudy appearance of water due to suspended material (sediment).
Unregulated catchment/river	A river system where no major dams or weir structures have been built to assist in the supply, or extraction of water.
Upland	A stream section at high altitudes with a river channel often less than 10 times the channel depth.
Weed	Any useless, troublesome or noxious plant, especially one that grows profusely.
VRHS	Victorian River Health Strategy.
VWQMN	Victorian Water Quality Monitoring Network.

1 Introduction

The Campaspe River catchment covers approximately 4,000 km^2 and extends for 150 km from the northern slopes of the Great Dividing Range near Trentham to the River Murray at Echuca. The Campaspe River and Coliban River are the largest rivers in the catchment, but other significant tributaries include Axe, McIvor, Mt Pleasant, Forest, Wild Duck and Pipers Creeks.

Prior to European occupation, streams in the middle and lower Campaspe River catchment would have had low energy, contained fine grained sediments and had occasional rocky outcrops. Most of the streams would have had incised channels, with deep pools, infrequent riffles over gravel, boulders or logs and an abundance of large woody debris (NCCMA 2005). Flows would have been seasonally variable, with high flows in winter and spring and low or no flow in summer and autumn (McGuckin and Doeg 2001). However, the construction of reservoirs and weirs for potable supply and irrigation has substantially reduced flows throughout the catchment and reversed seasonal flow patterns in the lower reaches.

Regulation throughout the Campaspe River catchment diverts approximately 50% of mean annual discharge for irrigation, stock and domestic use. Flow in the Coliban River downstream of Malmsbury is reduced year round, but regulation has little effect on flow in the Campaspe River upstream of Lake Eppalock. Irrigation transfers between Lake Eppalock and Campaspe Weir elevate flows from spring to autumn, while irrigation releases elevate autumn flows between Campaspe Weir and the Campaspe Siphon. Operations are planned to release an average of 15 ML/day downstream of the Campaspe Siphon during the irrigation season to maintain flow to the River Murray (Marchant *et al.* 1997). Lake Eppalock captures most of the flow from the upper part of the catchment during winter and spring and substantially reduces flow in the entire lower half of the Campaspe River at a time when flows would have naturally been at their highest.

Trial environmental flow releases for the Campaspe River downstream of Lake Eppalock were recommended in 1995. The recommendation is to pass one quarter of Lake Eppalock inflows to downstream reaches once the lake reaches 64% capacity. However, drought has ensured that Lake Eppalock has remained below 64% capacity for most years since 1995 and therefore the trial environmental flow release program has ceased.

In 1997, a scientific technical panel conducted an environmental flow assessment for the Coliban River below Malmsbury Reservoir and the Campaspe River downstream of Redesdale (Marchant *et al.* 1997) to help inform the Bulk Water Entitlement (BE) Conversion Process. However, the final BE flow provisions were ultimately less than the recommended flow requirements and reflect a decision that minimised impacts to consumptive supplies. The final BE recommendations specified passing flows for the Campaspe River below Lake Eppalock that varied depending on inflows to the lake, storage levels and season.

In 2004, the Victorian Government made a commitment to recover 212 GL of water for the Living Murray Initiative (DSE 2004), as its contribution to the 500 GL that will be recovered for the entire Murray Darling Basin. Water that is recovered in Victoria is primarily intended to deliver environmental flows to six icon sites along the River Murray, but will have secondary benefits in a number of tributaries including the Campaspe River. The Victorian Government White Paper "Our Water Our Future (OWOF)" (DSE 2004) also calls for the development of regional Sustainable Water Strategies (SWS) that will guide the long term planning of future water demand and outline mechanisms for improving the Environmental Water Reserve (EWR). The Northern Victorian SWS includes the Campaspe River system and is scheduled to be developed in 2006.

An updated environmental flows assessment is required to help inform the development of the Northern Victorian SWS and to guide the optimal use of additional water that becomes available to the Campaspe River system via the OWOF initiatives and other means. The flow assessment will adopt the FLOWS method, which was developed for Victoria in 2002 and is being used to assess environmental flow requirements for rivers throughout the state. The use of this standard approach will ensure that the Campaspe River environmental flows assessment will be comparable to flow assessments in other major Victorian rivers.

1.1 Objectives

This environmental flows assessment will focus on sections of the Campaspe River system that are likely to be affected by water recoveries gained through the water sales package. Specifically this assessment will address the following objectives in the sections of the Coliban River downstream of Malmsbury Reservoir and the Campaspe River downstream of Lake Eppalock:

- identify the water dependent environmental values;
- identify suitable flow regimes for the protection/enhancement of defined environmental values;
- develop environmental flow objectives;
- develop environmental flow recommendations to meet the objectives;
- provide a clear and transparent process for assessing environmental flow requirements that can be clearly understood by all stakeholders;
- provide advice on the environmental benefits and disbenefits of various management options and operational scenarios including the use of any additional water that will be provided to the Campaspe and Coliban Rivers; and
- inform and engage the community.

The overall objective of this report is to present the environmental flow recommendations for Coliban River downstream of Malmsbury Reservoir and the Campaspe River downstream of Lake Eppalock, and the associated level of compliance under current flow conditions. If implemented the recommended flows are expected to provide a flow regime that reflects the natural seasonal pattern and variability sufficient to maintain or enhance ecological and geomorphic processes in the Campaspe River system.

1.2 Steering Committee

The project steering committee (Table 1-1) met at key milestone stages and reviewed all project outputs. Several members of the steering committee also attended the flow determination workshop held at SKM in March.

Table 1-1: Campaspe Environmental Flows Assessment Steering Committee members

Committee Member	Affiliation
Catherine Fox	North Central Catchment Management Authority
Emer Campbell	North Central Catchment Management Authority
Paulo Lay	Department of Sustainability and Environment
Amber Clarke	Department of Sustainability and Environment
Andrea Joyce	Department of Sustainability and Environment
Geoff Adams	Goulburn Murray Water
Bill Viney	Goulburn Murray Water
Sally-Anne Mason	Coliban Water

1.3 Consultative Panel

A consultative panel (Table 1-2) was established to provide a forum for which the key stakeholders of the Coliban and Campaspe Rivers can input to the study by:

- providing local knowledge;
- providing local opinions about values and threats to the river;
- assisting with the selection of reaches and sites;
- reviewing environmental objectives;
- participating in community meetings;
- assisting in the development of flow objectives; and
- reviewing draft flow recommendations.

SKM

- **Table 1-2: Campaspe Environmental Flows Assessment Consultative Panel members.**

Panel Member	Affiliation
Geoff Elliot	Campaspe Catchment Committee
Mark Hill	Water Services Committee
Craig Kelly	Mt Alexander Shire
Rob Loats	VR Fish
Bruce Macague	Irrigation IC
David Major	Parks Victoria
John McKinstry	Dryland IC
Joy Sloan	DPI Fisheries

The consultative panel met on four occasions. The first meeting provided the consultative panel with an overview of the FLOWS process and an opportunity to comment on the preliminary environmental values and threats to the Coliban and Campaspe River systems. Information was also sought in regards to site access, site features and landholder details, which was then used as input to the selection of reaches and sites. The second meeting was undertaken whilst in the field and provided the consultative panel with an opportunity to observe the FLOWS process undertaken at a field assessment site. The third meeting was to provide the consultative panel with an overview of the *Issues Paper* and also an opportunity to discuss and confirm the environmental flow objectives. The final meeting provided the consultative panel with an overview of the *Flow Recommendations Report* and an opportunity to discuss its implications.

1.4 Report objectives

The *Flow Recommendations Report* is the third and final output from the Campaspe Flows Assessment Project and presents the environmental flow recommendations for the Campaspe River catchment. This report was preceded by a *Site Paper* and *Issues Paper*. The *Site Paper* described the process used to divide the study area into representative reaches and the rationale for specific reach and site selections (SKM 2005). The *Issues Paper* detailed the available information on the environmental values of the study area – water system management, hydrology, geomorphology, ecology and water quality – and canvasses those catchment and streamflow issues that affect the environmental condition of the study area and culminated in the determination of environmental objectives that contribute to ecologically healthy waterways (SKM 2006a). The *Issues Paper* summarises all the supporting information required to determine the environmental flow requirements for the Campaspe River catchment.

Using hydrological and hydraulic data and information contained in the *Issues Paper*, the Environmental Flow Technical Panel (EFTP) determined a series of flow recommendations. The outputs of this task are documented in this report, which summarises the key ecological values, current condition and environmental flow objectives and provides the minimum flow recommendations and the associated level of compliance under current flow conditions for each reach in the Campaspe River catchment.

1.5 Report structure

Following this introduction, Section 2 provides a summary of the method used to develop flow recommendations for the Campaspe and Coliban Rivers. Updated environmental flow objectives and their function are presented in Section 3. The flow recommendations are provided in Section 4 along with an overview of reach conditions and a brief assessment of the current degree of compliance. Section 5 provides recommendations for complementary waterway works and further investigations required to support the environmental objectives and complement the environmental flow recommendations.

2 Method

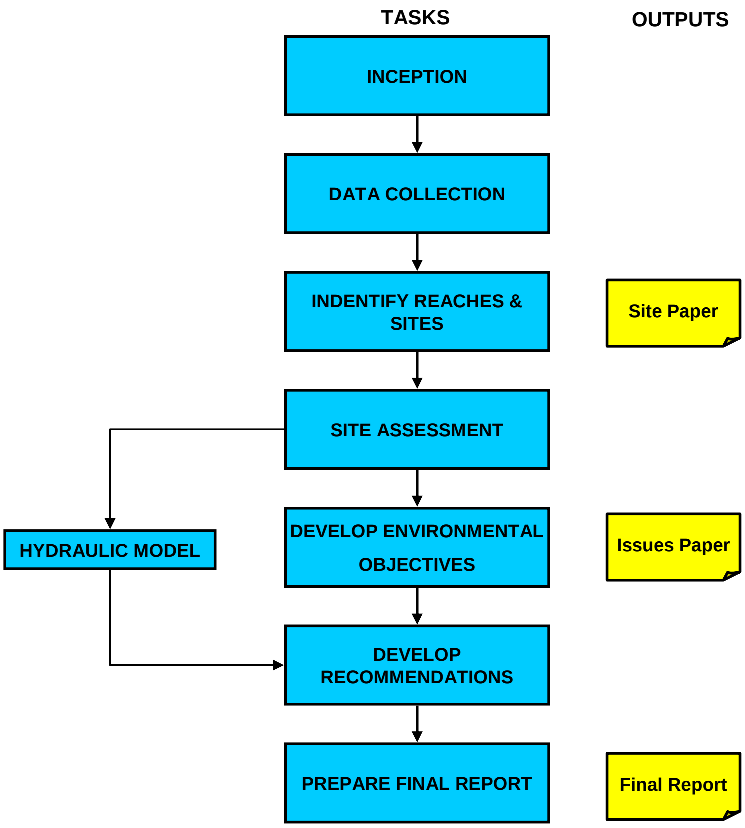
The FLOWS method (DNRE 2002a) was used to determine environmental flow recommendations for the Campaspe River system. The method has been specifically developed for determining environmental water requirements in Victoria and is based on the concept that key flow components of a natural flow regime influence various biological, geomorphological and physicochemical processes in waterways. Key flow components are likely to vary between river systems, but every stream system has some key flow components that are essential to maintain a healthy functioning aquatic ecosystem.

A key component of the FLOWS method is the constitution of an Environmental Flows Technical Panel. The EFTP consists of members that have expertise in a specific environmental discipline. Together, the EFTP conducted the field assessment and desktop review and determined environmental flow requirements for the Campaspe River system.

The EFTP members involved in this study and their particular environmental discipline are listed below in alphabetical order:

- Dr Bruce Abernethy — Geomorphology
- Dr Paul Boon — Vegetation
- Dr Paul Humphries — Fish
- Simon Lang and Robert Morden — Hydrology
- Dr Andrew Sharpe — Macroinvertebrates and water quality

The major stages of the FLOWS method are shown in Figure 2-1 and brief description of the method applied to this project is provided below. The full method and rationale is provided in (DNRE 2002a).



- **Figure 2-1: Outline of the steps involved in the FLOWS method.**

2.1 Reach and site selection

The first stage of this project was to collect and collate all available information relating to the study area so as to describe the operation of the system, hydrology, environmental values and ecological processes. The delineation of each of these characteristics was then used to separate the study area into four reaches (Table 2-1).

Reaches were determined based on points of regulation (e.g. major dams, weirs and offtakes), major tributary inflows, changes in landform, geology, channel and floodplain morphology and changes in ecological processes or communities. Information detailing physical and ecological patterns along the Coliban and Campaspe Rivers and justification of this reach selection is provided in the *Site Paper* (SKM 2006a). These reaches are the same as were used in the previous Campaspe River environmental flows assessment (Marchant *et al.* 1997).

The EFTP selected two sites within each reach for detailed flow assessment (Table 2-1 and Figure 2-2). The FLOWS method generally uses a single site in each reach, but extra sites were chosen for this study because the study reaches are particularly long. Selected sites contain examples of the major geomorphological and ecological features that typify that reach.

Table 2-1: Campaspe River and Coliban River reaches and field assessment sites.

Reach No.	Description	Site No.	Location
1	Coliban River: Malmsbury Reservoir to Lake Eppalock	8	Phillips Road – upstream of Sandy Creek
		7	Lyell Road – 4 km upstream of Lake Eppalock
2	Campaspe River: Lake Eppalock to Campaspe Weir	6	Doak's Reserve – 5 km downstream of Lake Eppalock
		5	English's Bridge – downstream of Forest Creek confluence
3	Campaspe River: Campaspe Weir to Campaspe Siphon	4	Bryant's Lane – 2 km downstream of Campaspe Weir
		3	Spencer Rd – 5 km upstream of Campaspe Siphon
4	Campaspe River: Campaspe Siphon to River Murray	2	Strathallan Bridge – 8 km downstream of Campaspe Siphon
		1	Campbell's Road – 4 km upstream of Echuca

2.2 Site assessment

Representative sites were assessed by the EFTP on 14-16 November 2005. At each site, between six and nine cross sections were identified for surveying. These cross sections were selected as representative of the range of channel and habitat features of the site, such as pools, riffles, log jams or channel benches. Photographs and sketches were used to identify important geomorphic and habitat features at each cross section. An evaluation of the key components of the flow regime at each of the sites was carried out to identify flows that would be geomorphologically or ecologically important for the creek system.

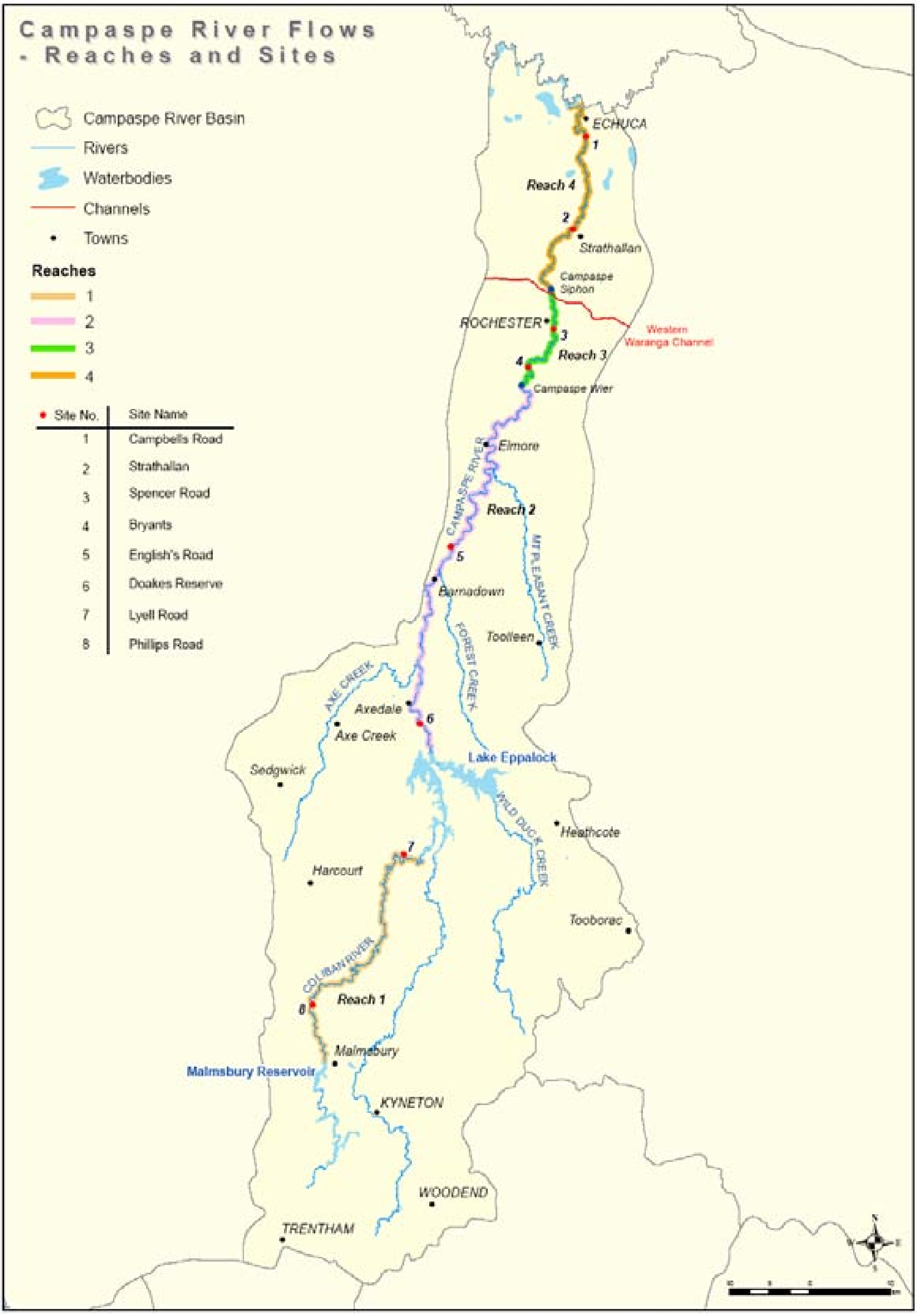
2.3 Environmental flow objectives

Environmental flow objectives were developed by the EFTP for those ecological assets that have a clear dependence on some aspect of the flow regime, such as:

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

In formulating objectives the EFTP considered outcomes from steering committee and consultative panel meetings, past information on asset values and condition within each reach and observations from the site assessments. Final environmental flow objectives for the Campaspe River system were endorsed by the steering committee and consultative panel. They are provided in the *Issues Paper* (SKM 2006a) and summarised in Section 3 of this report.

SKM



■ **Figure 2-2 Campaspe River catchment showing FLOWS assessment reaches.**

2.4 Survey of selected reaches

Cross sections identified by the EFTP were surveyed and incorporated into a hydraulic model for each site. Cross sections were surveyed to at least bankfull level on each side of the channel, but most points were surveyed within the channel to pick up details that would be inundated at lower flows. A total station was used to measure any significant changes in channel features across each cross section. Water level was recorded at all cross sections to assist in validation of the hydraulic model. A longitudinal survey was also conducted through all cross sections at each site to highlight changes in depth and the overall gradient through the site.

2.5 Hydraulic model

A one-dimensional hydraulic model of each site was prepared to develop a relationship between flow, water depth and velocity using the one dimensional steady state backwater analysis model HEC-RAS (v3.1.3). This software calculates water surface profiles and other flow characteristics using a series of surveyed transects and estimated roughness factors.

Roughness factors and other flow control features such as riffles, large woody debris (LWD), and rock or weed obstructions were noted at each cross section. Water surface levels were surveyed for each transect. Estimates of streamflow, based on data from nearby gauges, were used to calibrate each HEC-RAS model.

As part of the calibration process, the survey data was used to create interpolated cross sections, allowing each model to represent features such as riffles and LWD that occurred between the surveyed cross sections. These weir and riffle features often control water levels, and therefore their representation in the HEC-RAS models is critical. In addition, the cross sections, roughness, and riffle details were adjusted so that the modelled water levels matched the surveyed water levels. Roughness factors only affect water levels where there is significant flow velocity. In deep pools, the velocity is typically below 0.1 m/s. In these conditions, roughness factors do not significantly affect water levels.

The most important part of the calibration was the assumed water level at the downstream end of each model (the downstream "boundary condition"). For the initial calibration, the flow on the day of the survey, and the water level at the downstream end of the model were both known. On this basis, the surveyed water level was adopted as the downstream boundary condition.

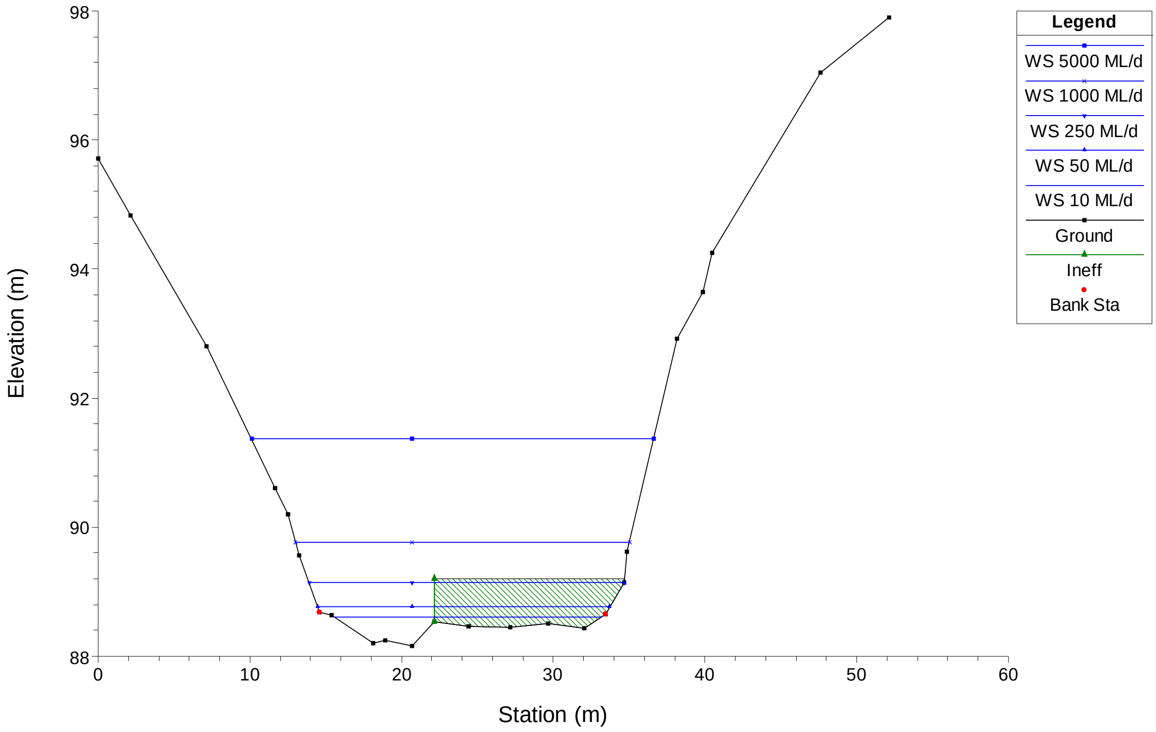
However, determining an appropriate boundary condition for a range of other flows was more difficult, because the water level for each site was only surveyed at one flow. Therefore, for any flow in the stream, it was assumed that the relationship between flow and water level at the downstream end of the model was the same as for a nearby streamflow gauge. This meant that the rating curve from a streamflow gauge was used to determine downstream water levels. Gauge rating curves were adjusted either up or down to match levels at the site.

SKM

Hydraulic output

A key output from the hydraulic model is a graphical representation of each transect. An example of a hydraulic output is provided in Figure 2-3. The black line ("ground" in the legend) represents the ground surface, reflecting the channel shape at each cross section. Small black squares on the ground line show the exact points where survey measurements were taken (note that these are more frequent within the channel than above the bank). Horizontal blue lines within the cross section represent the water surface at the various flows, which are detailed in the legend. The green hatching represents vegetation in the channel that prevents or restricts flow in that area.

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



- **Figure 2-3 Example cross section output from the hydraulic model in Reach 4 at different flows.**

2.6 Hydrology

A modelled current and natural daily flows series was developed in each reach (SKM 2006b). The current flow series is the flow regime that refers to the actual current use, including the effect of impoundments and diversions. The natural flow series is the flow regime that would exist if no diversion or storage of water occurred, assuming there have been no flow changes due to vegetation removal or landuse.

Hydrological assessment involved consideration of a range of hydrological parameters to describe the flow regime, including:

- flow duration curves that show the percentage of time that a flow of a given rate is exceeded;
- time series graphs to examine the sequence of flow events, particularly during very dry or very wet conditions; and
- flow spell analysis using GetSpells to describe the frequency, duration and start month of flow spells.

GetSpells output

GetSpells software is used to describe and compare the duration, start months and frequency of flow events (spells) that rise above, or fall below, a stipulated flow threshold under current and natural conditions. These analyses are carried out using modelled daily flow data for either the winter high flow (June to November) or summer low flow (December to May) periods but not the entire year combined. For our analyses, flow spells separated by more than seven days are considered independent of each other. It is important to note that for low flows, spells that fall *below* the threshold are evaluated. For freshes, high flows, bankfull flows and overbank flows, spells *above* the threshold are evaluated.

An example of GetSpells output using a threshold value of 100 ML/d for the summer/autumn period is provided in Figure 2-4. In this example, the percentile plot summarises the duration of flow spells over 100 ML/d. In the plot, the median spell duration (50^{th} percentile) is indicated with variation in spell durations described by the box and whiskers plots. Sixty percent of flow spells have a duration that lies within the box (20^{th} and 80^{th} percentiles) while 80 percent of the spells are described by the box plus whiskers (spells within the 10^{th} and 90^{th} percentiles). In the example provided in Figure 2-4 for spells higher than 100 ML/d that occurred during summer/autumn under natural conditions:

- the median duration of spells above the threshold is three days;
- 60% of spells above the threshold lasted between one and eight and a half days; and
- 80% of spells above the threshold lasted between one and 14 days.

Under current conditions:

- the median duration of spells above 100 ML/d is two days;
- 60% of spells above the flow threshold lasted between one and five days; and
- 80 % of spells above the flow threshold lasted between one and nine days.

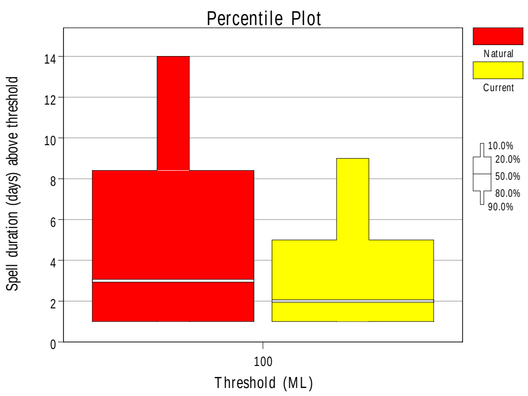
This example indicates that larger flows (i.e. above the flow threshold) generally occur for a shorter duration under the current regime compared to natural.

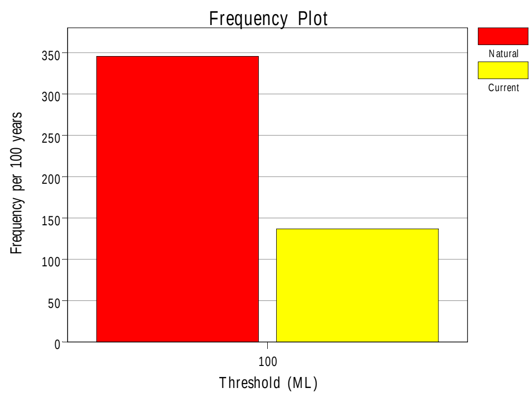
SKM

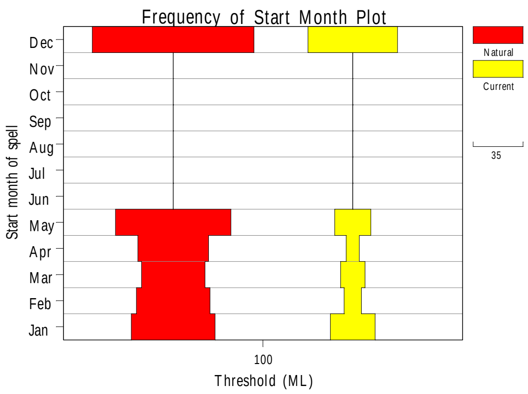
The upper box and whisker plots shown in Figure 2-4 have a greater spread than the lower box and whiskers. This indicates that the data is skewed, that is to say that spells are of a short duration and long duration spells are relatively infrequent.

The frequency plot compares the average number of times that spells will occur in any 100 year period. Flow spells that occur with a frequency of less than 100 do not occur every year while spells with a frequency greater than 100 occur more than once a year on average. Using the example in Figure 2-4, the frequency of spells above the flow threshold that occurred during the summer/autumn period under natural conditions is 350 times in every 100 years (i.e. approximately three and a half times a year). Under current conditions, flows above the threshold occur on average 125 times in every 100 years (one and a quarter times a year).

The frequency of start month plot describes the frequency distribution of the months in which flow spells have started. The width of the bars provides an indication of the number of events that start in each month and the differences in the distribution of events can be compared between natural and current. In Figure 2-4, freshes during the summer/autumn period most often start in December under natural and current conditions.







- **Figure 2-4 Duration (top left), frequency (top right) and start month (left) for flows above the summer/autumn fresh flow threshold of 100 ML/d at Lyell Road under natural and current conditions for Reach 1.**

SKM

2.6.1 Ramp rates

The rates at which flows rise and fall are known as ramp rates. These rates are environmentally significant for short duration spells such as freshes and bankfull flows. If rates of rise are too fast they may exceed the ability of biota to adapt, thereby causing stress. Rapid falls in flow can increase the risk of bank failure, increase erosion and sediment loads, or strand biota in rapidly exposed habitat areas.

Ramp rates were calculated from gauged data for each reach. The differences between flows on individual days were divided into days when flows rose and days when flows fell. The ratio of the change in flow was calculated for each rise or fall. The maximum desirable rate of rise was selected as the 90th percentile value of all recorded rates of rise (representing a high rate that was recorded naturally) and the maximum desirable rate of fall was selected as the 10th percentile value of all recorded rates of fall (representing an abrupt reduction in flow).

Gauged data was used in preference to modelled daily flows because REALM does not accurately model the routing and dampening of streamflow on a daily basis. Had modelled daily flows been used, the calculated ramp rates would exceed those realistically expected under natural conditions. Initially, in each reach the gauge most downstream of the Malmsbury and Lake Eppalock reservoirs was used, under the assumption these gauges were the best representation of the natural flow regime. However, estimated ramp rates for Reach 2 and Reach 3 appeared inconsistent with Reach 1 and Reach 4, and with ramp rates calculated for other catchments. Therefore, ramp rates for Reach 2 and Reach 3 were set to those of Reach 4. For Reach 3, this is an appropriate measure, because Reach 3 is short compared to the other reaches, and there are no tributaries between the Campaspe Weir and Campaspe Siphon. This measure is less appropriate for Reach 2, because several major tributaries join the Campaspe River downstream of Lake Eppalock. The actual rate of rise under natural conditions for Reach 2 is probably somewhere between that for Reach 1 and Reach 3.

The ramp rate recommendations are provided as a percentage of the previous days' flow. For example a recommended rate of rise of 230 % indicates that flow on a given day should not exceed 230 % of the previous day's flow (Table 2-2). Ramp rates vary for each reach due to factors such as the degree of vegetation cover, the proportion of forests, geological conditions, soil type and catchment area.

SKM

- **Table 2-2 Recommended maximum rates of rise and fall (expressed as a percentage of the previous days flow).**

Reach		Rate of rise	Rate of fall
1	Coliban River from Malmsbury Reservoir to Lake Eppalock	280%	65%
2	Campaspe River from Lake Eppalock to Campaspe Weir	230%*	65%*
3	Campaspe River from Campaspe Weir to Campaspe Siphon	230%*	65%*
4	Campaspe River from Campaspe Siphon to River Murray	230%	65%

* Based on rates of rise and rates of fall for Reach 4.

2.7 Development of environmental flow recommendations

Environmental flow recommendations for the Campaspe River system were determined by the EFTP in a workshop conducted on 9-10 March 2006. The workshop was also attended by several members of the Steering Committee (Catherine Fox from North Central Catchment Management Authority, Paulo Lay and Andrea Joyce from DSE and Bill Viney from G-MW).

The EFTP worked through the process of determining flow recommendations on a reach by reach basis. For each reach the basic ecological condition was discussed and previously determined environmental flow objectives were summarised and reviewed. Photos and field notes taken during the field assessment were examined along with transects from the hydraulic model in order to identify key environmental features (i.e. benches, riffles).

Within each reach, each flow component was considered in turn. If a particular flow component could be associated with an environmental flow objective for the reach, a flow recommendation was made. The criteria for each flow component were considered (e.g. flow that provides a depth of 100 mm at the shallowest riffle, or flow required to fill the channel) and equated to a volume using the hydraulic model. It is important to note that these criteria are reach specific depending on the species present and channel features. Spells analyses were conducted to determine the natural frequency and duration of identified flow volumes.

SKM

2.8 Compliance with recommendations

Compliance of flow recommendations to the current flow regime was determined for each recommended flow component. Compliance was based on the percentage of time that a given flow volume, frequency and duration was exceeded and is described below. Current compliance was assessed for each of the Campaspe environmental flow reaches and summarised in tables such as the one illustrated in Figure 2-5.

Flow recommendations				Percentage of years (vol & no.) or events (dur.) when flow recs are complied with for the current flow regime
Component	Time	Flow Recommendation		
Summer low	December - May	Volume	5	56
Summer fresh	December - May	Volume	100	73
		Number	2	39
		Duration	3	42
Winter low	June - November	Volume	35	48
Winter fresh	June - November	Volume	700	85
		Number	4	49
		Duration	3	57
Winterbankfull	August - September	Volume	1200	35
		Number	1 in 3	35
		Duration	1	100

The summer low flow recommendation is 5 ML/d. Under the current flow regime, the low flow recommendation is complied with 56% of the time

The summer fresh recommendation is 100 ML/d, twice a year for three days duration. Under the current flow regime, the volume recommendation is met 73% of the time, but the required number of freshes is only delivered in 39% of years and the required duration only 42% of the time.

The winter bankfull flow recommendation is 1200 ML/d once every three years. Under the current flow regime, the volume and frequency recommendations are met only 35% of the time, but when bankfull flows do occur they last for the required duration.

The winter low flow recommendation is 35 ML/d. Under the current flow regime, the low flow recommendation is complied with 48% of the time

- **Figure 2-5: Example of current compliance assessment table with explanatory notes.**

2.8.1 Volume compliance

For summer and winter low flow volumes compliance is based on the percentage of time (days) within the relevant period that the flow exceeds the recommended volume. For all other flow components (fresh, high and bankfull) the volume compliance is based on the percentage of years when the volume recommendation is met. For example, a 70% compliance with the volume recommendation for a fresh or high flow means that in 70% of years the volume recommendation was met or exceeded in the defined season.

2.8.2 Frequency compliance

Compliance with the frequency or number of events is based on the percentage of years when the recommended number of events was met. For example, if one event is required each year but currently only occurs in eight years out of ten then compliance is 80%. If two events are recommended to occur each year but currently two events only occur every second year then compliance is 50%.

Note, that for the purposes of testing compliance, frequency has been determined based on the percentage of years when the threshold was exceeded, rather than an average of the number of times that a particular threshold is exceeded in a 100 year period.

2.8.3 Duration compliance

Compliance with duration is based on the percentage of events (i.e. when the volume is met at the right time of year) where the recommended duration is met. For example, the recommended event duration may be seven days but if only 25% of events last for seven days or longer then compliance is 25%. Compliance has been colour coded according to the arbitrary ranges in Table 2-3.

Table 2-3 Key to colour coding for percentage compliance.

Component	Mostly complies	Frequently complies	Often complies	Occasionally complies	Rarely complies	Never complies
Volume (ML/d) as percentage of years (or time in the case of low flows) when recommended volume is met	>95% of years	76-95% of years	51-75% of years	26-50% of years	5-25% of years	<5% of years
Frequency (no. of events per year) as percentage of years when frequency is met	>95% of years	76-95% of years	51-75% of years	26-50% of years	5-25% of years	<5% of years
Duration (days) as percentage of events when duration is met	>95% of events	76-95% of events	51-75% of events	26-50% of events	5-25% of events	<5% of events

3 Environmental flow objectives

Environmental flow objectives set the direction and target for the environmental flow recommendations and are clear statements of what outcomes should be achieved in providing environmental flows.

The process of setting environmental objectives involves first identifying the environmental assets, setting environmental objectives against these, and then identifying the flow components required to meet the environmental objectives. For the purpose of this process, environmental objectives were developed for those ecological assets that have a clear dependence on some aspect of the flow regime. Environmental objectives were developed for:

- 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 river as defined by the Victorian River Health Strategy (DNRE 2002b). The objective of the Victorian River Health Strategy is to:

Achieve healthy rivers, streams and floodplains which meet the environmental, economic, recreational and cultural needs of current and future generations.

An ecologically healthy river will have flow regimes, water quality and channel characteristics such that:

- in the river 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 river's length;
- native fish and other fauna can move and migrate up and down the river;
- linkages between the river and floodplain and associated wetlands are able to maintain ecological processes;
- natural linkages with the sea are maintained; and
- associated estuaries are productive ecosystems.

This does not mean that a river must be pristine to be ecologically healthy. It recognises that there can been some change from the natural state but not to the point that there is a major loss of natural features, biodiversity or function.

Ultimately objectives must be developed for assets that have a clear dependence on some aspect of the flow regime, they need to provide a clear statement of what outcomes are expected (i.e. be meaningful and measurable) and that if met, mean that the flow could sustain an ecologically healthy river. Following the FLOWS method the direction of a particular objective is expressed as one of three main targets:

1) maintain – keep the condition of the asset in it’s current state;
2) restore – move the condition of the asset back to natural condition; and
3) rehabilitate – move the condition of the asset to some improved state (but different to natural).

The development of reach specific environmental objectives for the Campaspe River system is detailed in the *Issues Paper* (SKM 2006a) and tabulated in Table 3-2 to Table 3-5. For each of the listed objectives we have identified the function, specific component and timing of the flow regime that is required to support the identified function and the expected response once the recommended flow regime is implemented.

In summary, the objectives have been developed to:

- maintain current channel geometry;
- rehabilitate the native fish community through improved conditions for recruitment, maintenance and movement;
- reduce nutrient concentrations and salinity and improve dissolved oxygen concentrations; and
- rehabilitate riparian vegetation and increase diversity of instream vegetation.

For each environmental flow objective, components of the flow regime have been identified (Figure 3-1). These components perform a variety of functions, which may include providing adequate flow to maintain aquatic habitats or facilitating ecological processes such as nutrient cycling. The functions provide an important link between the environmental objectives and the components of the flow regime. The key environmental functions or processes of each of the flow components used in this assessment are described in the sections below and summarised in Table 3-1. The functions describe how each flow component acts to meet the environmental objectives and their feature.

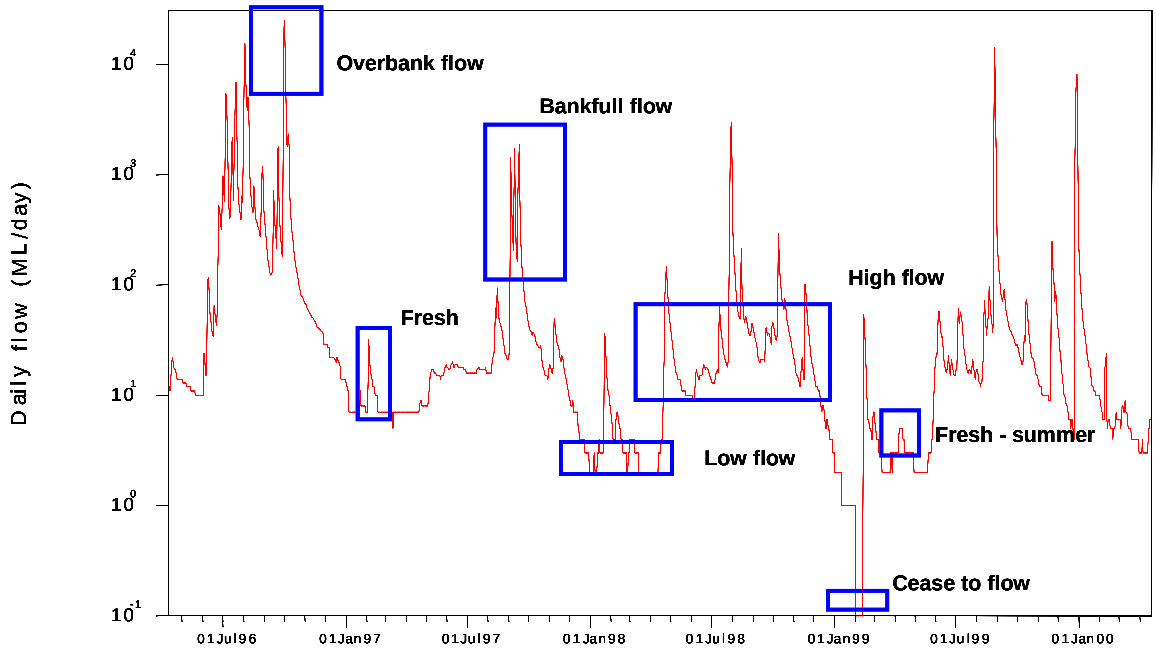


Figure 3-1 Typical daily flow series.

SKM

■ **Table 3-1 Functions or processes supported by components of the flow regime.**

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. ■ Slow the process of water quality degradation occurring in pools (avoid complete stagnation). ■ Sustain longitudinal connectivity for movement of macroinvertebrates and some fish. ■ Sustain inundation of lower benches to maintain habitat for emergent and marginal aquatic vegetation. ■ Promote recruitment for fish that spawn during low flow periods (eg carp gudgeon).
Freshes / High flow	■ Entrain terrestrial organic matter that has accumulated on benches and in the upper channel. ■ Provide sediment transport. ■ Provide movement cues for fish. For example, golden and silver perch. ■ Allow fish passage over small in-channel barriers ■ Provide flow variability to maintain species diversity of emergent and marginal aquatic vegetation and to drive zonation patterns across the channel. ■ Engage flood runners within the main river channel. ■ Instigate die back of terrestrial vegetation that has encroached down the bank during the low flow period. ■ Increase habitat area available for instream flora and fauna through inundation of benches and LWD located on banks.
Bankfull flow	■ Possibly provide spawning cues for fish and assist in dispersal movement. ■ Disturb aquatic and riparian vegetation and rejuvenate successional patterns; provide cues for Floodplain Riparian Woodland EVC recruitment. ■ Transport organic matter that has accumulated in the riparian zone. ■ Instigate die back of terrestrial vegetation that has encroached down the bank during the low flow period. ■ Scour dense stands of *Typha* and *Phragmites* within the main river channel. ■ Increase habitat area, including access to large woody debris and over hanging banks for instream biota. ■ Engage the riparian zone and wetlands located with the meander train.
Overbank flow	■ Engage entire floodplain, where it exists in a given reach, in order to encourage River red gum regeneration and effect improved wetland wetting and drying cycles. ■ Transport organic matter that has accumulated on the floodplain and in floodplain wetlands.
Definition of terms: Cease to flow – no measurable flow in the river 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 with little spill onto the floodplain Overbank Flow – inundate adjacent floodplain habitats.	

Table 3-2: Reach 1 – Coliban River between Malmsbury Reservoir and Lake Eppalock.

Asset	Objective	No.	Function	Flow component	Timing	Expected response
Geomorphology	Maintain current channel hydraulic geometry	G1-1	Channel forming processes	Bankfull	Winter	▪ Rehabilitate channel form
		G1-2	Channel maintenance	Freshes / High flows	Winter	▪ Maintain Thalweg / channel complexity
Vegetation	Rehabilitate riparian vegetation extent, structure and composition and increase diversity of instream vegetation	V1-1	Maintain aquatic vegetation	Low flow	Summer	▪ Winter and spring flows will facilitate the recruitment of native riparian species such as River Red Gum, but summer freshes will be required to water these recruits to ensure their survival and growth. Some areas of the channel have excessive Typha growth, which should be scoured by bankfull flows.
		V1-2	Maintain riparian and in channel recruits	Fresh	Summer	
		V1-3	Reduce encroachment of exotics and terrestrial species	Fresh	Winter	
		V1-4	Enhance River Red Gum recruitment and scour Typha from middle of channel	Bankfull	Winter	
Fish	Rehabilitate native fish community through improved conditions for recruitment, maintenance and movement	F1-1	Maintain habitat for survival and spawning	Low flow	Late Spring / Summer	▪ On their own the recommended flows are likely to maintain current fish communities, but movement from upper and lower reaches is limited by large dams and therefore full benefits will not occur without actions to remove or overcome these barriers.
		F1-2	Longitudinal connectivity	Freshes	Summer	
		F1-3	Maintain longitudinal connectivity	Low flow	Winter	
		F1-4	Cue upstream and downstream movement and/or spawning	High flow / Bankfull or Fresh	Winter / Spring	
Water quality	Reduce nutrient concentrations and salinity throughout the reach	W1-1	Maintain permanent connecting flow	Low flow	Summer / winter	▪ Permanent flow will prevent nutrient enrichment from increasing. Periodic freshes, especially without associated local run-off will help mix pools throughout the reach and dilute nutrient concentrations within the river. Nutrient reductions should lead to a decrease in filamentous algae throughout the reach.
		W1-2	Flush and mix pools	Freshes	Throughout year	
Macroinvertebrates	Maintain current macroinvertebrate community diversity, increase pollution sensitive taxa	M1-1	Maintain access to riffle habitat	Low flow	Summer / winter	▪ By maintaining habitat diversity, we would expect to see the diverse macroinvertebrate community through this reach persist. ▪ Improved water quality should see an increase in the abundance and diversity of pollution sensitive taxa and see an increase in the SIGNAL score for this reach.
		M1-2	Flush pools to dilute nutrient concentrations	Freshes	Throughout year	

Table 3-3: Reach 2 – Campaspe River between Lake Eppalock and Campaspe Weir.

Asset	Objective	No.	Function	Flow component	Timing	Expected response
Geomorphology	Maintain current channel hydraulic geometry	G2-1	Channel forming processes	Bankfull	Winter	■ Maintain current channel form
		G2-2	Provide lateral connection to flood runners	Overbank	Winter	
Vegetation	Rehabilitate riparian vegetation extent, structure and composition and increase diversity of instream vegetation	V2-1	Maintain aquatic vegetation	Low flow	Summer	■ Winter and spring flows will facilitate the recruitment of native riparian species such as River Red Gum, but summer freshes will be required to water these recruits to ensure their survival and growth. Some areas of the channel have excessive Typha growth, which should be scoured by bankfull flows.
		V2-2	Maintain riparian and in channel recruits	Fresh	Summer	
		V2-3	Reduce encroachment of exotics and terrestrial species	Fresh	Winter	
		V2-4	Enhance River Red Gum recruitment	High flow	Winter	
		V2-5	Scour Typha from middle of channel	Bankfull	Winter	
		V2-6	Enhance River Red Gum recruitment	Overbank	Winter	
Fish	Rehabilitate native fish community through improved conditions for recruitment, maintenance and movement	F2-1	Increase food concentration for fish larvae and juveniles	Cease to flow	Summer	■ No decline in native fish diversity and abundance – possible increase in native fish recruitment due to reinstatement of slackwaters and some movement of species between reaches.
		F2-2	Maintain habitat and re-instate slackwaters	Low flow	Summer	
		F2-3	Provide longitudinal connectivity during low flow period	Fresh	Summer	
		F2-4	Provide longitudinal connectivity	Low flow	Winter	
		F2-5	Cue fish movement and allow movement to downstream reaches	High flow / Bankfull	Winter	
		F2-6	Limit effect of cold water releases	Complementary	As part of release operations	
Water quality	Reduce nutrient concentrations and salinity downstream of Axe Creek and reduce temperature impacts	W2-1	Maintain permanent connecting flow	Low flow	Summer / winter	■ Winter flows are currently much lower than natural, increasing winter flow flows will help dilute inputs from Axe Creek and reduce stratification in deep pools. ■ Winter high flows will mix and flush deep pools
		W2-2	Flush and mix pools	High Flows	Winter	
		W2-3	Respond to potential 'blackwater' events	Freshes	As required	

	downstream of Lake Eppalock	W2-4	Limit effect of cold water releases	Complimentary	As part of release operations	downstream of Axe Creek and reduce salt, temperature and oxygen stratification. High flows will only be effective if lows flows at other times are sufficient otherwise pools will restratify. ▪ Stored water may be released as a fresh as a management response to 'blackwater' events, however time lags may limit the effectiveness of such releases depending on where 'blackwater' events occur. ▪ Temperature impacts downstream of Lake Eppalock should be managed by adjusting the water release level. This may be feasible given that Lake Eppalock already has a multi-level offtake tower.
Macroinvertebrates	Maintain current macroinvertebrate community diversity in edge habitats, increase diversity of riffle dwelling species, increase abundance of pollution sensitive taxa and reduce effect of temperature impacts downstream of Lake Eppalock.	M2-1	Maintain access to riffle habitat and maintain water quality	Low flow	Summer / winter	▪ Summer and winter low flows that maintain permanent riffle habitats combined with gradual flow changes will increase the abundance and diversity of riffle dwelling species. ▪ Improved water quality will help maintain macroinvertebrate diversity and increase the abundance and diversity of pollution sensitive taxa, which will increase the SIGNAL score for this reach particularly downstream of Axe and Mt Pleasant Creeks. ▪ Reduced temperature impacts downstream of Lake Eppalock will increase growth rates and help synchronise development times for macroinvertebrates including *Macrobrachium austrexoticse.*
		M2-2	Prevent sudden changes in flow	Ramp flows up and down	As required	
		M2-3	Flush and mix pools	High Flows	Winter	
		M2-4	Limit effect of cold water releases	Complimentary	As part of release operations	

▪ Table 3-4 Reach 3 – Campaspe River between Campaspe Weir and Campaspe Siphon.

Asset	Objective	No.	Function	Flow component	Timing	Expected response
Geomorphology	Maintain current channel hydraulic geometry	G3-1	Channel forming processes	Bankfull	Winter	▪ Maintain current channel form
Vegetation	Rehabilitate riparian vegetation extent, structure and composition, inundate and drain wetlands, and increase diversity of instream vegetation	V3-1	Maintain aquatic vegetation	Low flow	Summer	▪ Winter and spring flows will facilitate the recruitment of native riparian species such as River Red Gum, but summer freshes will be required to water these recruits to ensure their survival and growth. Some areas of the channel have excessive Typha growth, which should be scoured by bankfull flows. Winter flows will also help maintain vegetation communities in a number of perched waterbodies within the main river channel.
		V3-2	Maintain riparian and in channel recruits	Fresh	Summer	
		V3-3	Reduce encroachment of exotics and terrestrial species	Fresh	Winter	
		V3-4	Enhance River Red Gum recruitment	High flow	Winter	
		V3-5	Scour Typha from middle of channel	Bankfull	Winter	
		V3-6	Inundate wetlands and connect to main channel and enhance River Red Gum recruitment above bank	Overbank	Winter	
Fish	Rehabilitate native fish community through improved conditions for recruitment, maintenance and movement	F3-1	Maintain habitat and re-instate slackwaters	Low flow	Summer	▪ No decline in native fish diversity and abundance – possible increase in native fish recruitment due to reinstatement of slackwaters and some movement of fish from upstream reach and upstream and downstream movement over the Campaspe Siphon, which will connect Campaspe populations with River Murray populations.
		F3-2	Provide longitudinal connectivity during low flow period	Fresh	Summer	
		F3-3	Provide longitudinal connectivity	Low flow	Winter	
		F3-4	Cue fish movement and allow movement between upstream and downstream reaches	High / Bankfull flow	Winter	
Water quality	Reduce nutrient concentrations and salinity throughout the reach	W3-1	Maintain connecting flow	Low flow	Summer / winter	▪ Permanent flow will prevent nutrient enrichment from increasing and control salinity at the surface of pools. Periodic freshes, especially without associated local run-off will help mix pools throughout the reach and dilute nutrient and concentrations within the river.
		W3-2	Flush and mix pools	Freshes	Throughout year	
Macroinvertebrates	Increase macroinvertebrate diversity, especially pollution sensitive taxa.	M3-1	Maintain aquatic habitat	Low flow	Summer / winter	▪ Low flows and periodic freshes will maintain the quality and quantity of aquatic habitat, which will maintain the current macroinvertebrate community ▪ Periodic freshes will also inundate additional snag habitats that may be temporarily used by some species and will facilitate wetting and drying of biofilms, but will more importantly flush sediment from biofilms and therefore increase food availability for macroinvertebrates.
		M3-2	Inundate additional snags and flush sediments off biofilms	Freshes	Throughout year	

▪ Table 3-5 Reach 4 – Campaspe River between Campaspe Siphon and the River Murray.

Asset	Objective	No.	Function	Flow component	Timing	Expected response
Geomorphology	Maintain current channel hydraulic geometry	G1-1	Channel forming processes	Bankfull	Winter	▪ Maintain current channel form
Vegetation	Rehabilitate riparian vegetation extent, structure and composition, inundate and drain wetlands, and increase diversity of instream vegetation	V4-1	Maintain aquatic vegetation	Low flow	Summer	▪ Winter and spring flows will facilitate the recruitment of native riparian species such as River Red Gum, but summer freshes will be required to water these recruits to ensure their survival and growth. Some areas of the channel have excessive Typha growth, which should be scoured by bankfull flows.
		V4-2	Maintain riparian and in channel recruits	Fresh	Summer	
		V4-3	Reduce encroachment of exotics and terrestrial species	Fresh	Winter	
		V4-4	Enhance River Red Gum recruitment	High flow	Winter	
		V4-5	Scour Typha from middle of channel	Bankfull	Winter	
Fish	Rehabilitate native fish community through improved conditions for recruitment, maintenance and movement & link to River Murray fish communities	F4-1	Maintain habitat and re-instate slackwaters	Low flow	Summer	▪ No decline in native fish diversity and abundance – possible increase in native fish recruitment due to reinstatement of slackwaters and some movement of fish from upstream and River Murray.
		F4-2	Provide longitudinal connectivity during low flow period and cue fish movement from the River Murray	Fresh	Summer	
		F4-3	Provide longitudinal connectivity	Low flow	Winter	
		F4-4	Cue fish movement and allow movement between upstream and downstream reaches	High / Bankfull flow	Winter	
Water quality	Reduce salinity and improve dissolved oxygen throughout the reach	W4-1	Maintain constant flow	Low flow	Summer / winter	▪ Minimum low flows will need to be maintained throughout the year to prevent the formation of saline pools. Freshes can mix pools if stratification does occur, but without adequate low flows, saline pools can be expected to reform within 2 weeks.
		W4-2	Flush and mix pools	Freshes	Throughout year	
Macroinvertebrates	Increase macroinvertebrate diversity, especially pollution sensitive taxa	M4-1	Maintain aquatic habitat	Low flow	Summer / winter	▪ Low flows and periodic freshes will maintain the quality and quantity of aquatic habitat, which will

						maintain the current macroinvertebrate community
		M4-2	Inundate additional snags and flush sediments off biofilms	Freshes	Throughout year	▪ Periodic freshes will also inundate additional snag habitats that may be temporarily used by some species and will facilitate wetting and drying of biofilms, but will more importantly flush sediment from biofilms and therefore increase food availability for macroinvertebrates.

SKM

3.1 Flow components

3.1.1 Summer/autumn

Cease to flow

Cease to flow is the period of no discernable flow in a waterway, or in practice when there is no measureable flow at a stream gauge, representative of the relevant reach. This may lead to total or partial drying of the stream channel, depending on the evaporation rate, groundwater exchange, depth of pools and the duration of cease to flow. The Coliban River downstream of Malmsbury would have naturally ceased to flow for 23 days (median duration) approximately 1.5 times every year. The Campaspe River would have also ceased to flow naturally, but the frequency of cease to flow events would have decreased with downstream distance due to tributary inputs and groundwater contributions to flow. The Campaspe River between Lake Eppalock and the Campaspe Weir would have ceased to flow for approximately 17 days (median duration) 1.2 times per year. The Campaspe River downstream of the Siphon would have naturally ceased to flow less frequently (only once every 2.3 years) but would have ceased for a longer period (median 27 days) on each occasion.

Cessation of flow is a common natural occurrence in Australian streams and there are a range of ecological functions provided by this flow component (Poff and Ward 1989, Boulton *et al.* 2000). During these periods, the river may contract to a series of isolated pools. Biota that remain in these pools are likely to be subject to intensified predation and physicochemical stresses (e.g. low dissolved oxygen concentrations). However, the increased concentration of zooplankton in these pools can provide an important food source for larval and juvenile native fish. Mobile animals and rapidly dispersing plants that survive in these remnant pools are able to recolonise other sections of the stream and other habitats when flows return (Jowett and Duncan 1990). Drying of habitats and organic matter facilitates the decomposition and processing of organic matter; following rewetting this organic matter provides a fresh pool of nutrient and carbon inputs for the system (Baldwin and Mitchell 2000).

Overall there is a significant ecological benefit from this component, but there may be risks associated with introducing this flow component to a system that would not have naturally ceased to flow, or unnaturally extending the duration of the cease to flow period. Cease to flow periods represent a natural stress to the ecosystem, but can have very deleterious effects in systems that are already stressed by anthropogenic impacts. Under current flow conditions, cease to flow events are more common in the Coliban River compared to natural, but are generally less common and have a much shorter duration in all reaches of the Campaspe River downstream of Lake Eppalock.

Nutrient enrichment and high salinity levels in the Coliban and Campaspe Rivers are likely to be exacerbated by cease to flow events. High sediment loads in the Coliban River 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 only been recommended in one of the four environmental flow study reaches considered in this assessment. Cease to flow events in the Campaspe River between Lake Eppalock and the Campaspe Weir are intended to concentrate food resources for native fish and therefore enhance fish recruitment.

Low flow

The summer/autumn low flow refers to the minimum flow remaining in the channel (either after diversions are taken out, or water released from reservoirs). The objective of this flow is to maintain permanent pool and riffle habitats and expose areas of the streambed (including parts of riffles) and large woody debris (LWD). The exposure of streambed will allow the accumulation of terrestrial organic matter and act as a disturbance to reset successional processes for macroinvertebrate, biofilms and vegetation communities.

The low flow also serves to maintain minimum water levels to preserve wetted riffle areas as refuges for macroinvertebrates and provide adequate depth in pool refuges for fish. Maintaining flows over the riffles and connectivity between pools also helps to slow the deterioration of water quality that occurs in pools during low flow periods. Nutrient concentrations and salt levels can substantially increase and dissolved oxygen levels can severely drop in pools during summer cease to flow or very low flow periods. Minimum low flows are often required in areas with poor water quality to help prevent conditions deteriorating to an extent that threatens aquatic life.

Elevated flows during the summer low flow period can also represent an environmental threat. Irrigation flows currently exceed the recommended summer low flow by several orders of magnitude in the Campaspe River between Lake Eppalock and the Campaspe Siphon. Constant high flows throughout summer can destroy important slackwater habitats and also promote excessive *typha* growth. This flow study has recommended maximum and minimum summer low flows for the Campaspe River, but the specific magnitude for these thresholds may need to be revised after scheduled work investigating the behaviour of saline pools and slackwater habitats under different flow conditions has been completed.

Freshes

Summer/autumn freshes refer to the short increases in flow in the channel due to localised rainfall events. This variation in water levels is important for maintaining species diversity in the emergent and marginal aquatic vegetation communities and is the principal driver of zonation at the channel margins. Freshes also wet low-lying channel zones such as riffles and benches, and therefore help reduce drought-stress on emergent and marginal vegetation that is exposed during the low flow period. Fish and other aquatic fauna may be able to move between pool habitats during freshes because of the increased depth across riffle areas. Freshes can also desilt riffle areas and biofilms, thereby improving habitat and food resources for some macroinvertebrates. Brief increases in flow may help to improve water quality by flushing and mixing any pools that have begun to stagnate and become stratified, in particular during prolonged periods of low and/or zero flow. However, summer freshes in the Campaspe River downstream of the Campaspe Weir should not turn over saline pools, because mixed pools will quickly re-stratify when flows return to the low flow level and frequent fluctuations between stratified and non-stratified conditions are likely to stress aquatic biota.

3.1.2 Winter/spring

Low flow

Low flow during winter and spring will provide conditions of sustained water levels in the river and further increase the area and depth of riffles for macroinvertebrates. The winter low flow will also facilitate fish movement and invertebrate drift and inundate the lower parts of the banks. Prolonged inundation of the lower banks will drown encroaching terrestrial vegetation while maintaining habitat for emergent and marginal vegetation during the spring growth season. There will also be a general increase in habitat availability for aquatic biota as LWD, branch-piles and riverbanks become inundated and available for colonisation. This increase in habitat compensates for a decrease in primary production in winter (low light and low temperatures), which in turn leads to a decrease in competition for limited resources and relieves summer low flow stress. Habitat diversity will also increase as higher flows create a greater diversity of flow velocity habitats. This may be particularly important for macroinvertebrate community diversity, which can contain species specialised for high velocity habitats.

Freshes

Freshes describe short duration increases in flow that occur during the high flow period between June and November. Similar to the summer/autumn freshes, the winter/spring freshes will provide flow variability important for maintaining diverse aquatic vegetation along the edges of waterways. Freshes will entrain organic matter that has accumulated in the terrestrial channel sections, and to a lesser degree transport sediment. Entrainment and deposition of sediment is unlikely to result in a net change in channel form during these flow events. Winter freshes may be of a sufficient magnitude to turn over saline pools in the Campaspe River downstream of the Campaspe Weir, because winter low flows should be high enough to prevent pools re-stratifying.

High flow

Winter high flows are seasonal increases in flow that fill the channel to a deeper extent than winter freshes. They effectively wet and connect most habitats within the main channel and provide lateral connectivity between the main channel, high-flow channel and benches. Maintaining occasional inundation of these habitats provides significant carbon returns to the stream after a period of significant production (e.g. plants, algae and macroinvertebrates) and provides connectivity for fish to move between habitats. These flows also reduce the extent to which terrestrial vegetation can encroach on the main channel.

Bankfull

Bankfull flow essentially refers to a flood flow that fills a large proportion of the river channel without escape onto the floodplain. A bankfull flow acts as a significant disturbance to the geomorphology and ecology of the river. These large flows can reform the channel by scouring banks and transporting sediment. Ecological succession will be reset in both aquatic and riparian communities as plants and animals are swept downstream or drowned. Organic matter that has accumulated in the higher portions of the channel will be entrained and transported downstream. Included in the organic material will be large woody debris that becomes dislodged and caught up the lower channel sections.

Overbank

Overbank flows are flood flows that overtop the banks and spill onto the floodplain. Overbank flows have been recommended to enhance River Red Gum recruitment and to fill flood runners on the Campaspe River floodplain between Lake Eppalock and the Campaspe Siphon. Floodplain features in the other parts of the study area have either been lost due to land clearing or will be more affected by overbank flows in the River Murray. No specific overbank flows have been recommended for the Coliban River or the Campaspe River downstream of the Campaspe Siphon, but will naturally occur from time to time.

4 Environmental flow recommendations

This section outlines the environmental flow recommendations for each reach. A standard format is provided for each reach and includes:

- a summary of the current condition. These are a concise summary of the hydrology, geomorphology, vegetation, fish, water quality and macroinvertebrate taken from information presented in the *Issues Paper* (SKM 2006a).
- flow recommendations. A rationale of the various flow recommendations. A number of cross section photos and plots from HEC-RAS are presented with the flow recommendations that demonstrate where each flow would be expected to occur in the channel cross section.
- current compliance with recommendations. An analysis of the current frequency and duration of the recommended flows was undertaken to indicate where the recommendations are being achieved by current operational practices.

Flow recommendations were initially determined for a single site in each of the four study reaches. For each reach we selected the site that had the most diverse habitat features; where sites had similar levels of habitat complexity, the most downstream site was selected. Flow recommendations developed for the first site in each reach were then tested at the second site to confirm that the flow recommendations were appropriate for the whole reach. In each case, the equivalent flow percentile rather than the same flow volume were tested at the second site. For example, the recommended summer low flow (5 ML/day) at Lyell on the Coliban River is equivalent to the 56th percentile for flow during summer. Due to tributary inflows between Malmsbury and Lyell, the 56th percentile for summer flows at Phillips Road is only 2.5 ML/day and therefore this flow volume was used as the recommended summer low flow for this site. Using this approach, the overall flow recommendation for each reach is consistent, but the exact flow volume will vary depending on where compliance is assessed within each reach.

An ‘or natural’ proviso has been added to the flow recommendations. This proviso allows for natural variability in the flow regime and is applicable to the low flow magnitude, and the frequency and duration of freshes, high flows, bankfull flows and overbank flows. The proviso requires that the recommendations need to be measured against the natural flow frequency and duration that would have occurred without any diversions, defined as ‘natural’ in this study.

The addition of the ‘or natural’ proviso to the low flow recommendation means that cease to flows can occur at the natural frequency and duration. Cease to flows are an ecological disturbance that maintain a diverse macroinvertebrate and macrophyte community and dry habitats and substrates. If the natural flow at a compliance point in a reach is lower than the recommended flow, then the natural inflow should be released rather than the minimum flow value. In this way, the flow variability, including cease to flow, is maintained in the natural state. Significantly, it means that water does not have to be released to top up flows to the minimum value if the natural flows are lower than this. This situation does not apply to reaches where cease to flows have not been recommended due to other stressors in the system.

The addition of the ‘or natural’ proviso to freshes, high flows, bankfull flows and overbank flows means that these flows will occur at their natural frequency and duration. For example, if there is a recommendation for winter/spring freshes to exceed 15 ML/d, four times a year for a period of four days, this does not mean that flows over 15 ML/d need to occur four times every year, irrespective of natural flow conditions. If there are less than four natural flows greater than 15 ML/d in winter/spring in a particular year, then only the natural number of flows need to be present downstream for the frequency recommendation to be achieved. However, if there are more than four flow events that exceed 15 ML/d in a year, then only four of those need to be delivered to the downstream reach in order to meet the recommendation. On the other hand, if in a year when four or more such natural flows occur, only three or less flows are passed, then it should be considered that the recommended flow has not been met.

The ‘or natural’ proviso also relates to the duration of particular flow events. For example, if a natural fresh greater than 100 ML/d occurs for less than the recommended five days, then the natural duration for that fresh should be met downstream. Any natural freshes with durations over five days however, can be truncated at five days (subject to suitable rates of fall) and the remainder of the fresh can be harvested.

Flow requirements are specified separately for summer and winter in each reach. Unless otherwise stated, summer flow recommendations relate to flows between December and May, winter flow recommendations relate to flows between June and November.

SKM

4.1 Reach 1 – Coliban River: Malmsbury Reservoir to Lake Eppalock

4.1.1 Current condition

The current condition of Reach 1 is detailed in the *Issues Paper* (SKM 2006a) and summarised below in Table 4-1.

Table 4-1 Current condition of Reach 1 – Coliban River: Malmsbury Reservoir to Lake Eppalock.

Aspect	Current condition
Hydrology	▪ Mean annual flow at Lyell Road has been reduced from 202 ML/day to 127 ML/day. ▪ Median and high flows most impacted by regulation. ▪ Natural seasonal flow pattern is retained, but timing of high spring flows is delayed.
Geomorphology	▪ Well developed sand slugs indicate accelerated sediment delivery to channel, but limited transport through the channel. ▪ Floodplain generally not developed with only occasional alluvial flats.
Vegetation	▪ Possible grazing and stock access as well as reduced flooding of riparian vegetation leading to poor recruitment of juvenile natives and spread of riparian weeds. ▪ Year-round reduced flow restricts habitats for in-stream plants. ▪ Reduced overbank flows leading to less frequent wetland inundation and poor recruitment of juveniles.
Fish	▪ Sand smothers habitat in places. ▪ Lake Eppalock prevents connection of the Coliban with downstream reaches of Campaspe.
Water quality	▪ General condition – good. ▪ Relatively high salinity for position in catchment, but no evidence of saline pools. ▪ Nutrient enrichment locally severe due to agricultural run-off, leaky septic tanks and urban run-off.
Macroinvertebrates	▪ Taxa indicative of mild pollution - ISC assessment (DSE 2005). ▪ High diversity. ▪ Community composition equivalent to reference ((EPA 2000).

4.1.2 Flow recommendations

The environmental flow recommendations for Reach 1 are summarised in Table 4-2. The main assessment for Reach 1 was based on modelled flows and cross section data from Lyell, these flows were then checked at the Phillips Road site.

SKM

- **Table 4-2 Summary of flow recommendations for Reach 1 – Coliban River: Malmsbury Reservoir to Lake Eppalock.**

Stream		Coliban River		**Reach**	Malmsbury Reservoir to Lake Eppalock.		
Compliance point		Site 7 - Lyell Road		**Gauge No.**	406215		
Season	**Component**	**Volume**	**Frequency**	**Duration**	**Rise**	**Fall**	**Objective**
Summer	Cease	Not Recommended					
	Low flow	5 ML/d	1 per year	6 months			V1-1, F1-1, W1-1, M1-1
	Freshes	100 ML/d & 200 ML/d	One of each per year	3 days	280%	65%	V1-2, F1-2, F1-4, M1-2
Winter	Low flow	35 ML/d (or natural)	1 per year	6 months			F1-3, F1-3, W1-1, M1-1
	Freshes	700 ML/d	4 per year	3 days	280%	65%	G1-2, V1-3, F1-4, W1-2, M1-2
	Bankfull	12000 ML/d	1 every 3 years	1 day	280%	65%	G1-1, G1-2, V1-4, F1-4
	Overbank	As natural					

Stream		Coliban River		**Reach**	Malmsbury Reservoir to Lake Eppalock.		
Compliance point		Site 8 - Phillips Road		**Gauge No.**	NA		
Season	**Component**	**Volume**	**Frequency**	**Duration**	**Rise**	**Fall**	**Objective**
Summer	Cease	Not recommended					
	Low flow	2.5 ML/d	1 per year	6 months			V1-1, F1-1, W1-1, M1-1
	Freshes	90 ML/d & 160 ML/d	One of each per year	3 days	280%	65%	V1-2, F1-2, F1-4, M1-2
Winter	Low flow	25 ML/d (or natural)	1 per year	6 months			F1-3, F1-3, W1-1, M1-1
	Freshes	560 ML/d	4 per year	3 days	280%	65%	G1-2, V1-3, F1-4, W1-2, M1-2
	Bankfull	6000 ML/d	1 every 3 years	1 day	280%	65%	G1-1, G1-2, V1-4, F1-4
	Overbank	As natural					

Summer/autumn: cease to flow

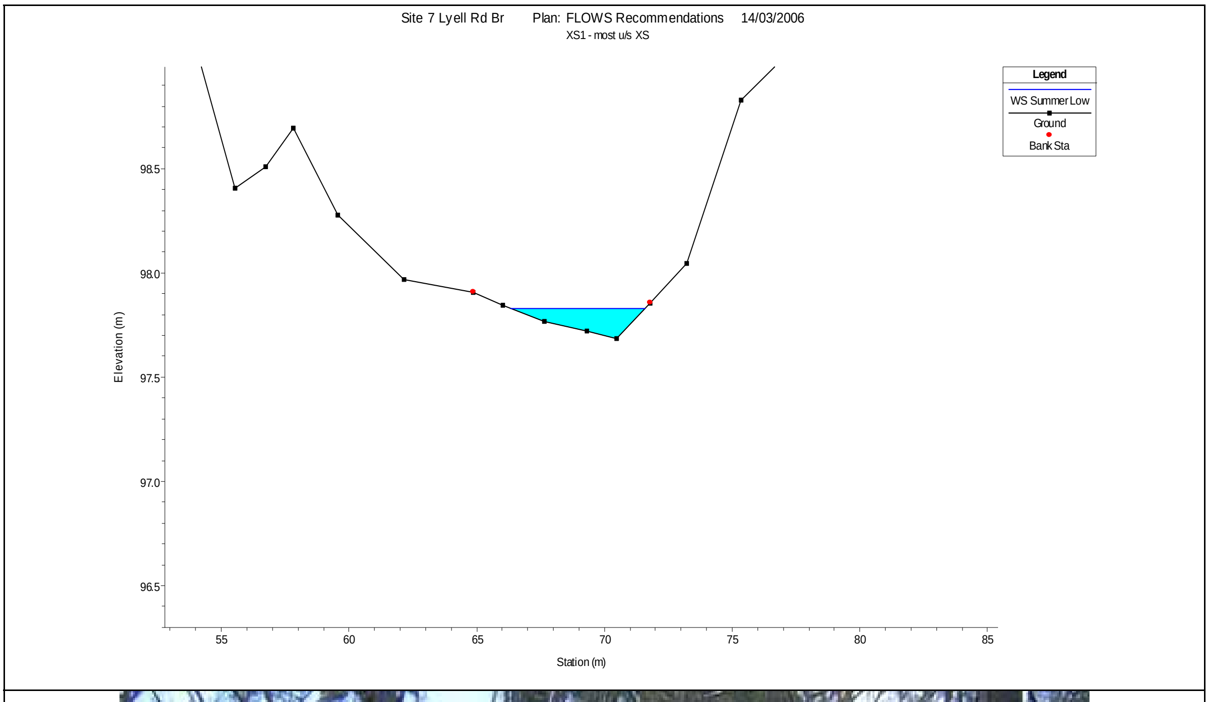
No cease to flow recommendation has been made for this reach because it would exacerbate impacts associated with high nutrient enrichment and extensive sand infilling has reduced the size and availability of pool habitats that provide refuge habitats for aquatic biota during natural cease to flow periods.

Summer/autumn: low flow

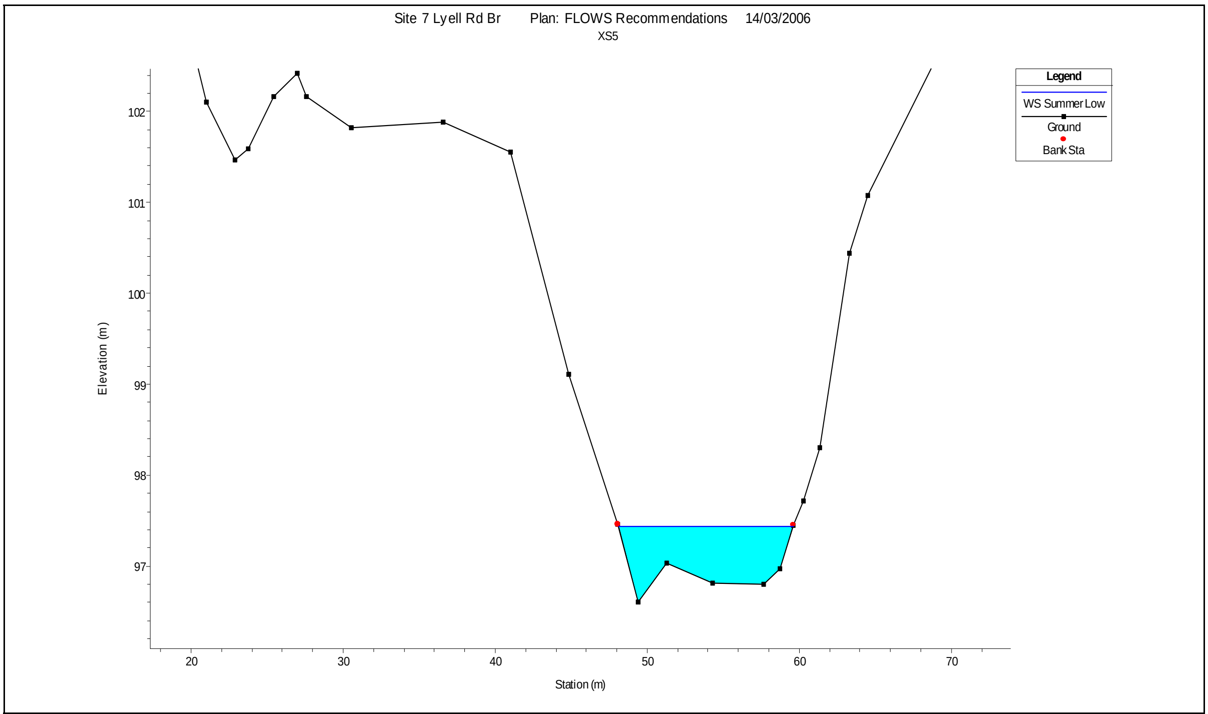
A low flow of 5 ML/day at Lyell Road is recommended for Reach 1. This flow will maintain adequate habitat through the site to ensure the survival of aquatic biota. The flow will maintain a depth of 13 cm through the riffle at Lyell Road (Figure 4-1), which will provide a variety of flow habitats and maintain macroinvertebrate communities. This low flow will also maintain a depth of 83 cm in the deepest surveyed pool at this site (Figure 4-2), which will ensure adequate habitat for native fish known to occur in this reach (SKM 2003).

The summer low flow will provide a permanent flow through the reach, which will help to maintain the quantity and quality of water in pools. However, in areas that are severely affected by sand, the flow may be through the hyporheic zone with little or no visible surface flow. The low flow will also expose large areas of the streambed, which serves as an important function for nutrient processing by allowing terrestrial organic matter to accumulate on the exposed channel and the drying of benches and banks.

Under natural conditions, flow in this reach would have fallen below the recommended low flow threshold approximately twice per year, for a median duration of approximately 20 days (Figure 4-3). This flow pattern is relatively unchanged under the current flow regime (Figure 4-3) and therefore the recommended summer low flow should maintain current conditions in this reach.

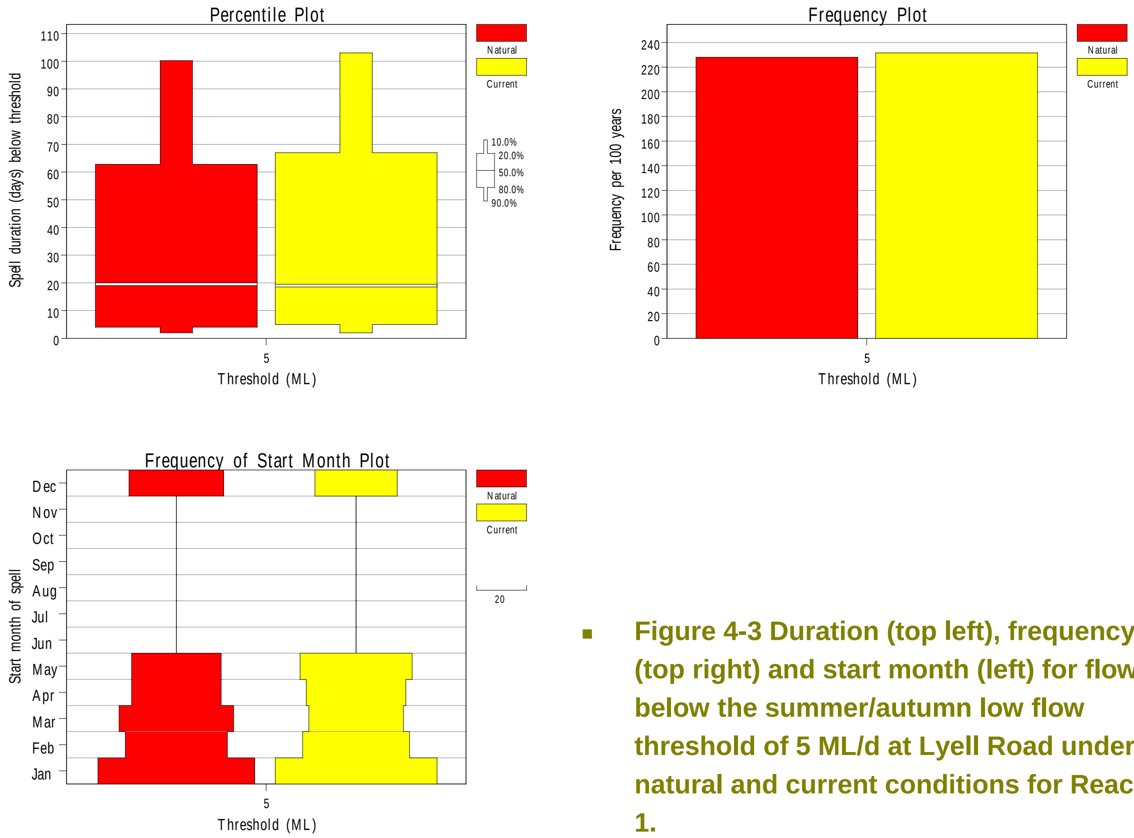


- Figure 4-1: Stage height in riffle (cross section one) for the recommended threshold for summer/autumn low flows at Site 7 (Lyells Road).



■ **Figure 4-2: Stage height in pool (cross section five) at the recommended threshold for summer/autumn low flows at Site 7 (Lyells Road).**

SKM



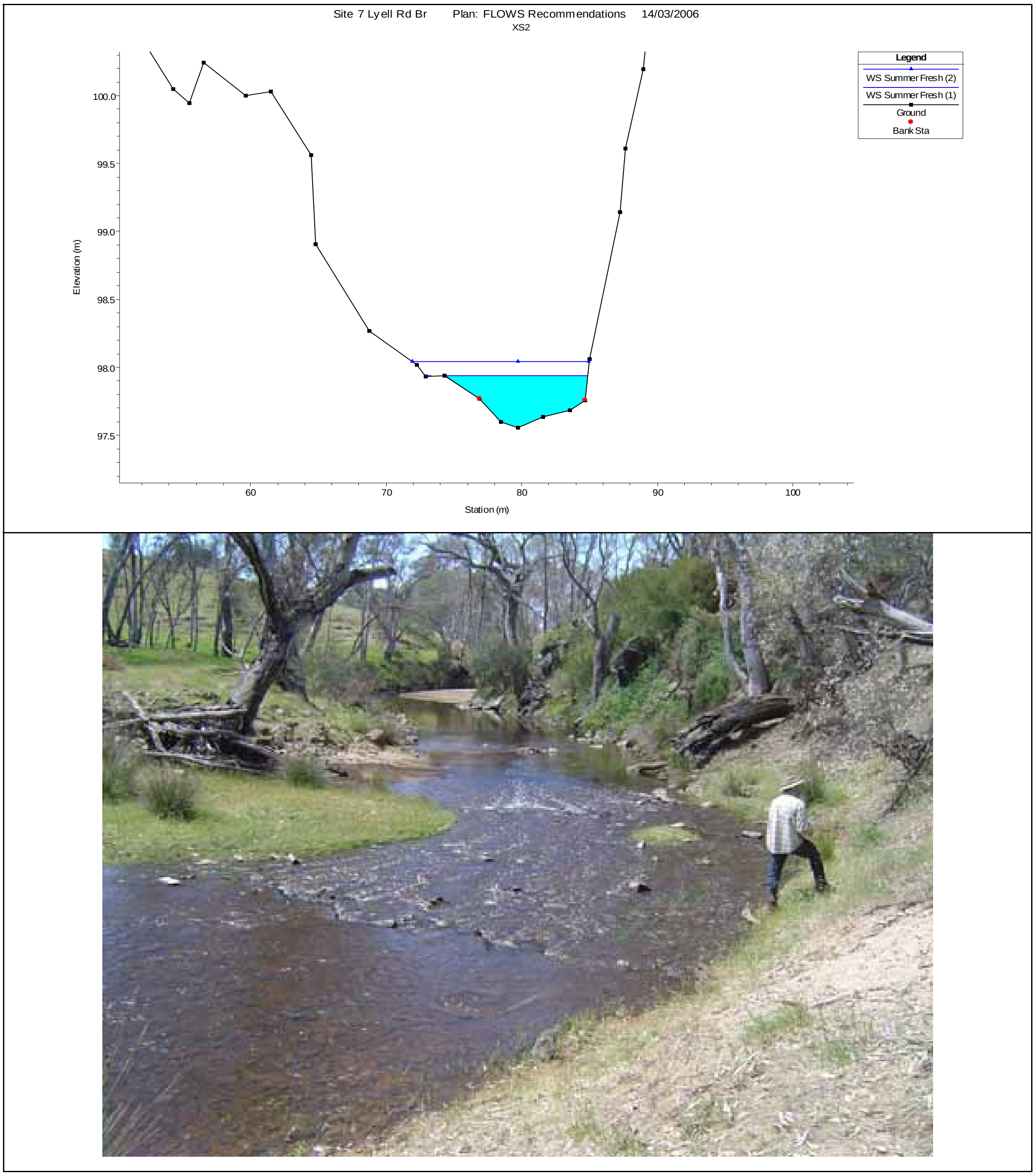
- **Figure 4-3 Duration (top left), frequency (top right) and start month (left) for flows below the summer/autumn low flow threshold of 5 ML/d at Lyell Road under natural and current conditions for Reach 1.**

Summer/autumn: freshes

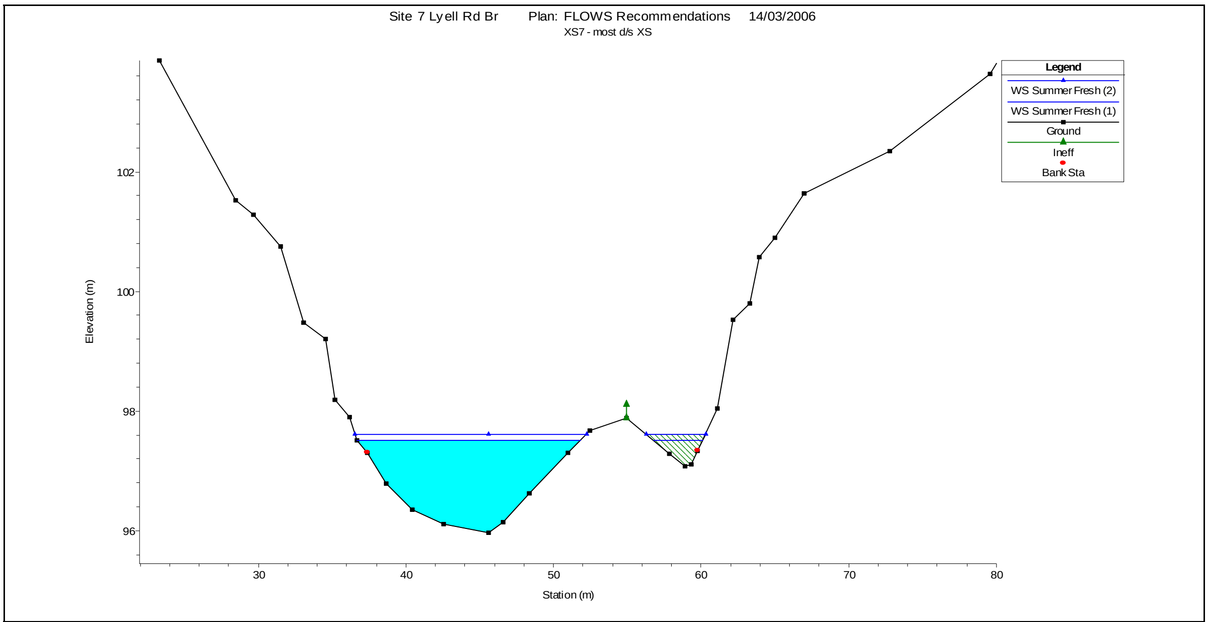
Two different summer fresh magnitudes are recommended for Reach 1. One fresh of 100 ML/day at Lyell (90 ML/day at Phillips Road) is recommended to inundate vegetated benches at the margin of the stream, deliver some organic matter to the stream and to provide full connecting flow above the hyporheic zone throughout the reach, which will aid fish movement. A larger fresh of 200 ML/day at Lyell (160 ML/day at Phillips Road) is also recommended to scour algae in areas with high nutrient loads and to maintain a thalweg in the channel in areas with very high sand loads.

The smaller fresh just wets the small bench next to the riffle at cross section 2 (Figure 4-4) and inundates an area behind the vegetated bar at cross section 7 at Lyell Road (Figure 4-5). The larger fresh completely covers benches at the bottom of the channel and increases the water depth behind the vegetated bar.

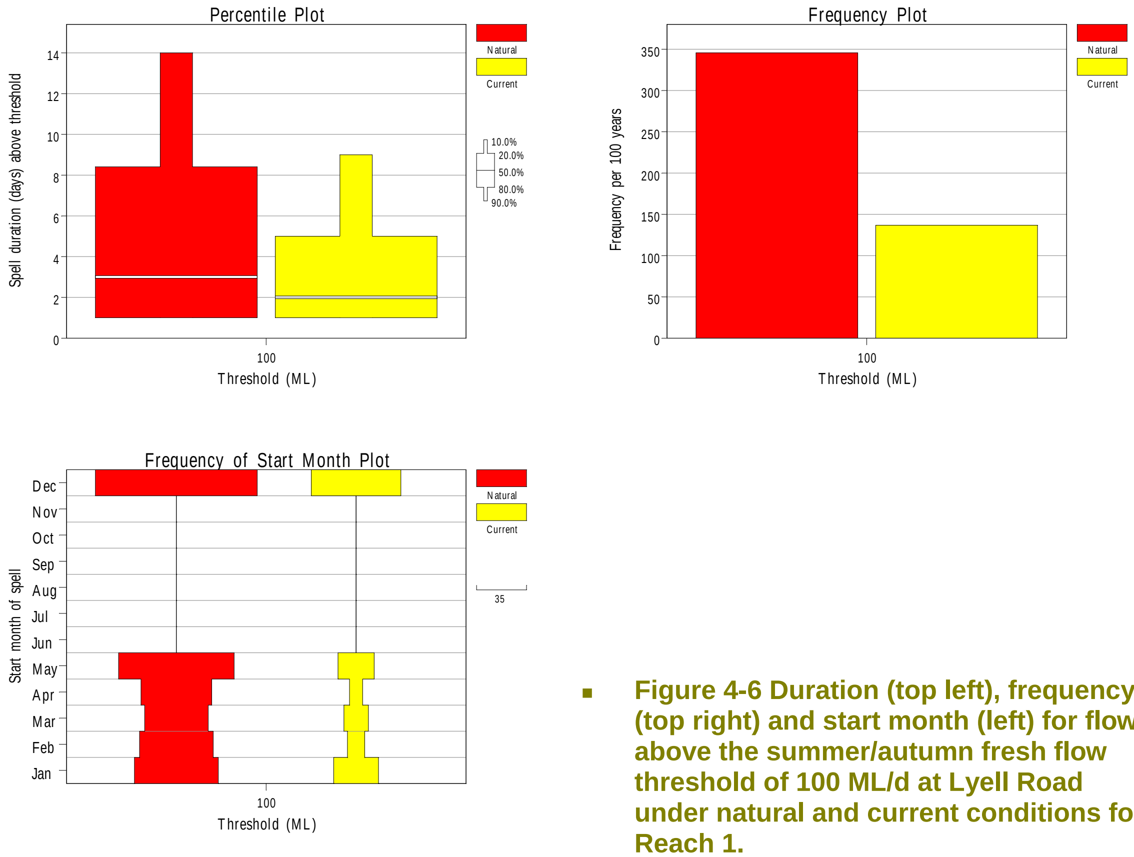
The recommended flow of 100 ML/day at Lyell would have been exceeded approximately three times per year for a median duration of three days under natural conditions, however this flow only occurs once per year for a median of two days under current conditions (Figure 4-6). These flows would have also been more common in December, than later in the summer (Figure 4-6). The recommendation for this reach is for two freshes per summer. One of these freshes should be at least 100 ML/day and last for three days, the other fresh should be 200 ML/day and last for 2 days. Rise and fall rates associated with the larger fresh will mean that both freshes will deliver at least 100 ML/day at Lyell for three days.



- **Figure 4-4: Stage height in riffle (cross section two) at recommended thresholds for summer/autumn freshes at Site 7 (Lyells Road).**



- **Figure 4-5: Stage height in pool (cross section seven) at recommended thresholds for summer/autumn freshes at Site 7 (Lyells Road).**

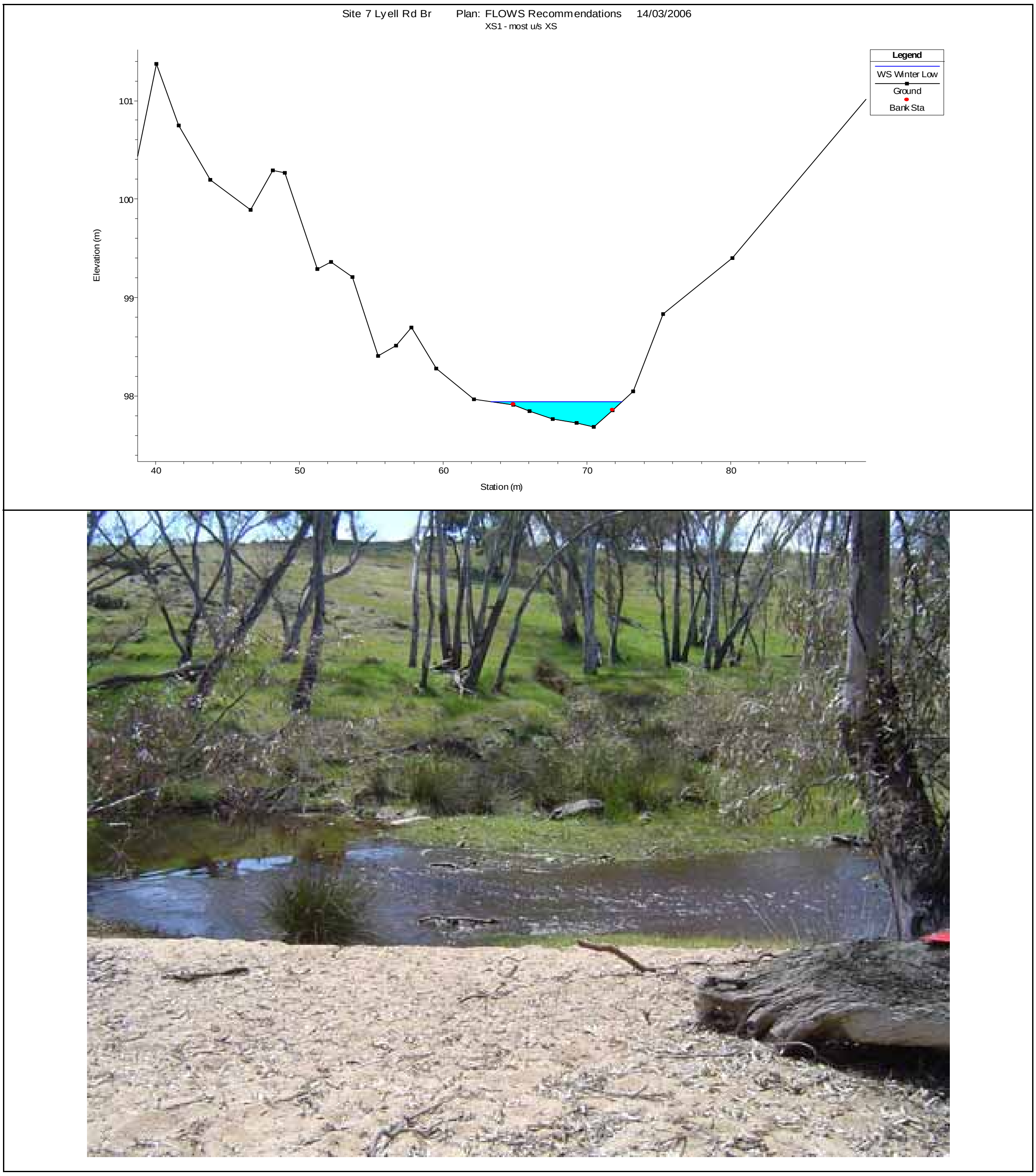


▪ **Figure 4-6 Duration (top left), frequency (top right) and start month (left) for flows above the summer/autumn fresh flow threshold of 100 ML/d at Lyell Road under natural and current conditions for Reach 1.**

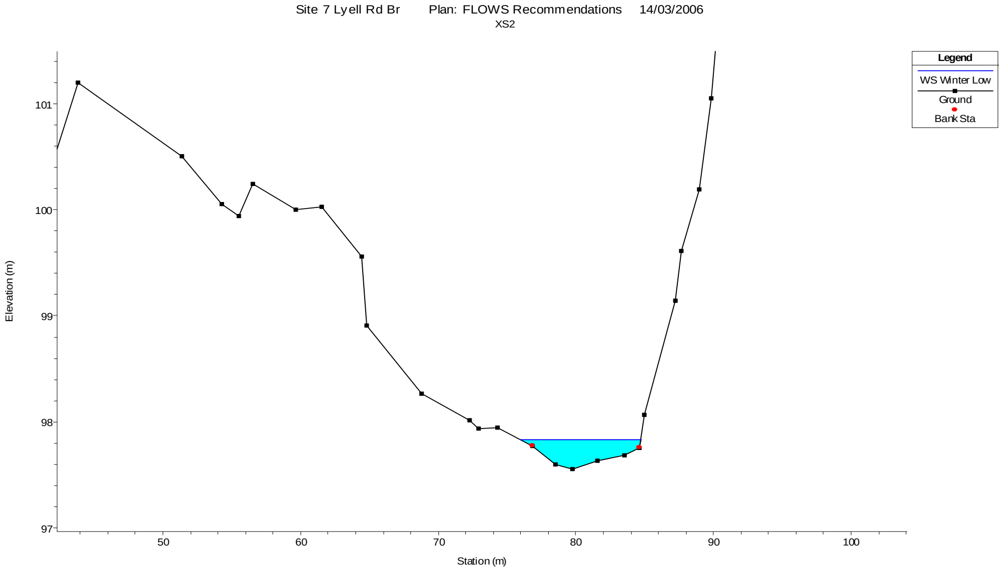
Winter/spring: low flow

A winter low flow of 35 ML/day is recommended for the Coliban River at Lyell, which corresponds with a flow of 25 ML/day at the Phillips Road site. This flow will provide fish passage through shallow riffles (i.e. provides 27 cm flow through riffle in the shallowest cross section at Lyell Road) (Figure 4-7 & Figure 4-8), but may not allow fish passage through some areas with very high sand loads. The winter low flow is not intended to flood the vegetated benches in this reach.

Flows of 35 ML/day would have naturally occurred on the Coliban River at Lyell Road at least twice a year for a median of 10 days in winter (Figure 4-9). These flows are more common under the current flow regime and on average occur 2.5 times a year for a median of 15 days each time (Figure 4-9). Flows of this magnitude most commonly occurred in June under both natural and current conditions. The recommendation for this reach therefore is to deliver a low flow through the Coliban River that ensures 25 ML/day flow at Phillips Road and 35 ML/day at Lyell from June to November each year.

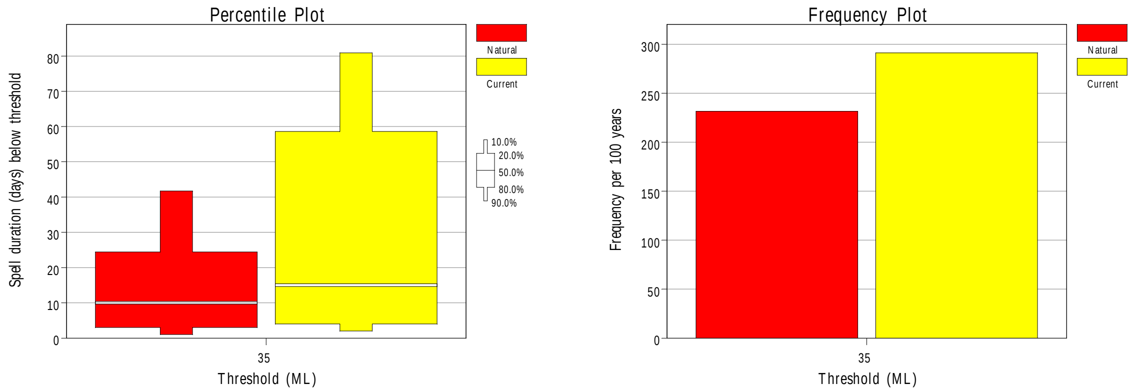


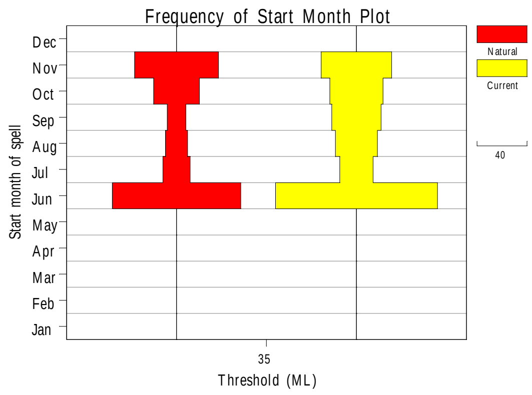
- **Figure 4-7: Stage height in riffle (cross section one) at the recommended threshold for winter/spring low flows at Lyell Road.**



- **Figure 4-8 Stage height in riffle (cross section two) at the recommended threshold for winter/spring low flows at Lyell Road.**

SKM



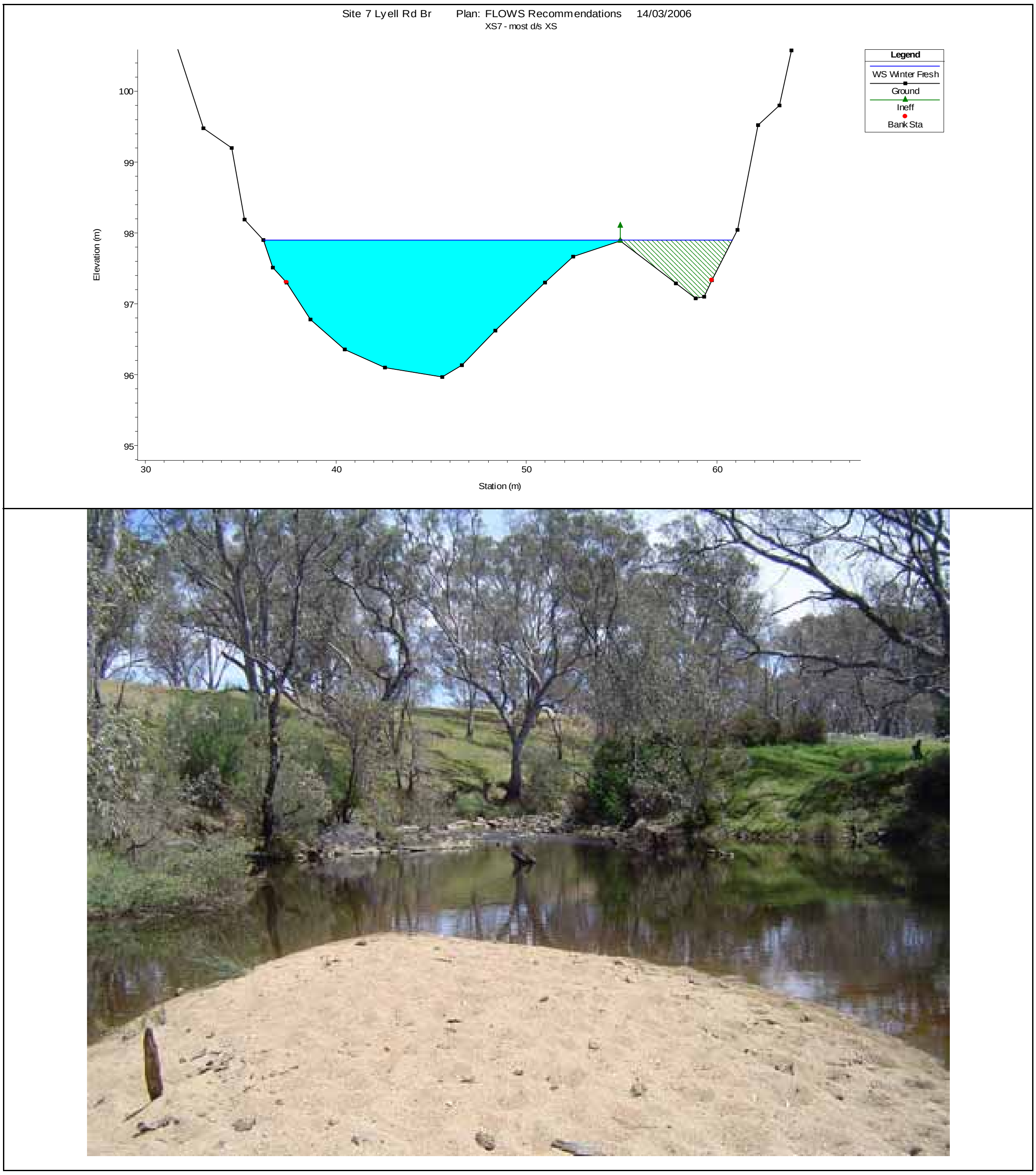


- **Figure 4-9 Duration (top left), frequency (top right) and start month (left) for flows below the winter/spring low flow threshold of 35 ML/d at Lyell Road under natural and current conditions for Reach 1.**

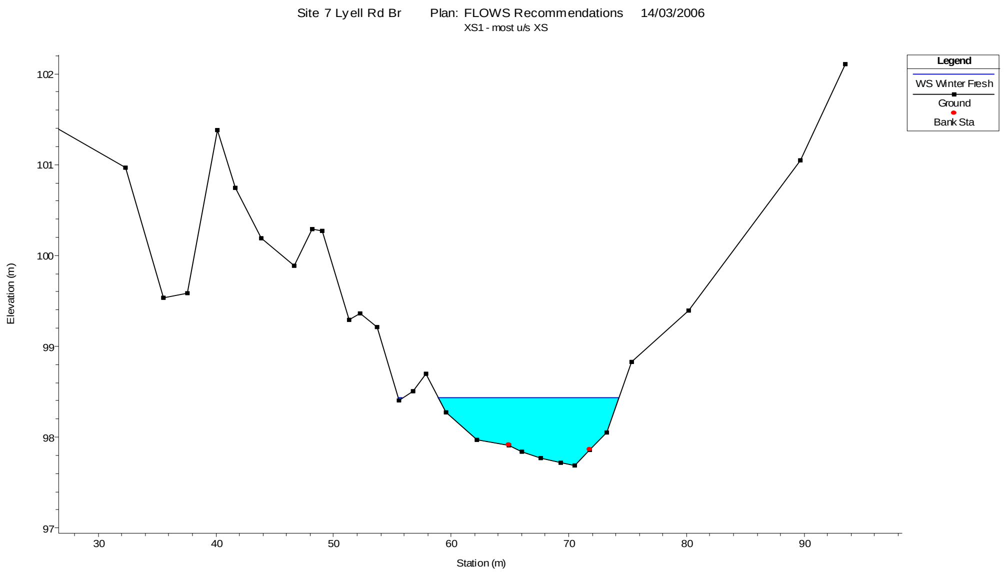
Winter/spring: freshes

The recommended winter/spring fresh for Reach 1 is 700 ML/day at Lyell and 560 ML/day at Phillips Road. This flow will completely cover all sandbars, low flow benches and boulders within the channel, but does not spill into other features higher up the bank (Figure 4-10 and Figure 4-11). Flows of 700 ML/day will also provide a velocity in excess of 1 m/s in some parts of the channel, which will move some sand (page 330 Gordon *et al.* 1992). This flow will entrain organic matter deposited on channel benches and suppress encroaching terrestrial vegetation that colonises lower channel habitats during low flows.

Flows of 500 ML/day at Lyell Road were found to inundate most of the boulders within the channel, but did not completely cover sand bars that are a major feature of the lower Coliban River. Flow of 700 ML/day at Lyell and 560 ML/day at Phillips Road would have occurred on average 4.5 times per year for a median duration of 3 days under natural conditions, but currently occur only 3 times per year (Figure 4-12). Under natural conditions, winter freshes would have been most common in July, but under the current flow regime they are more likely to occur in August or September (Figure 4-12). The recommendation for this reach is for four winter freshes of at least three days duration between June and November each year.

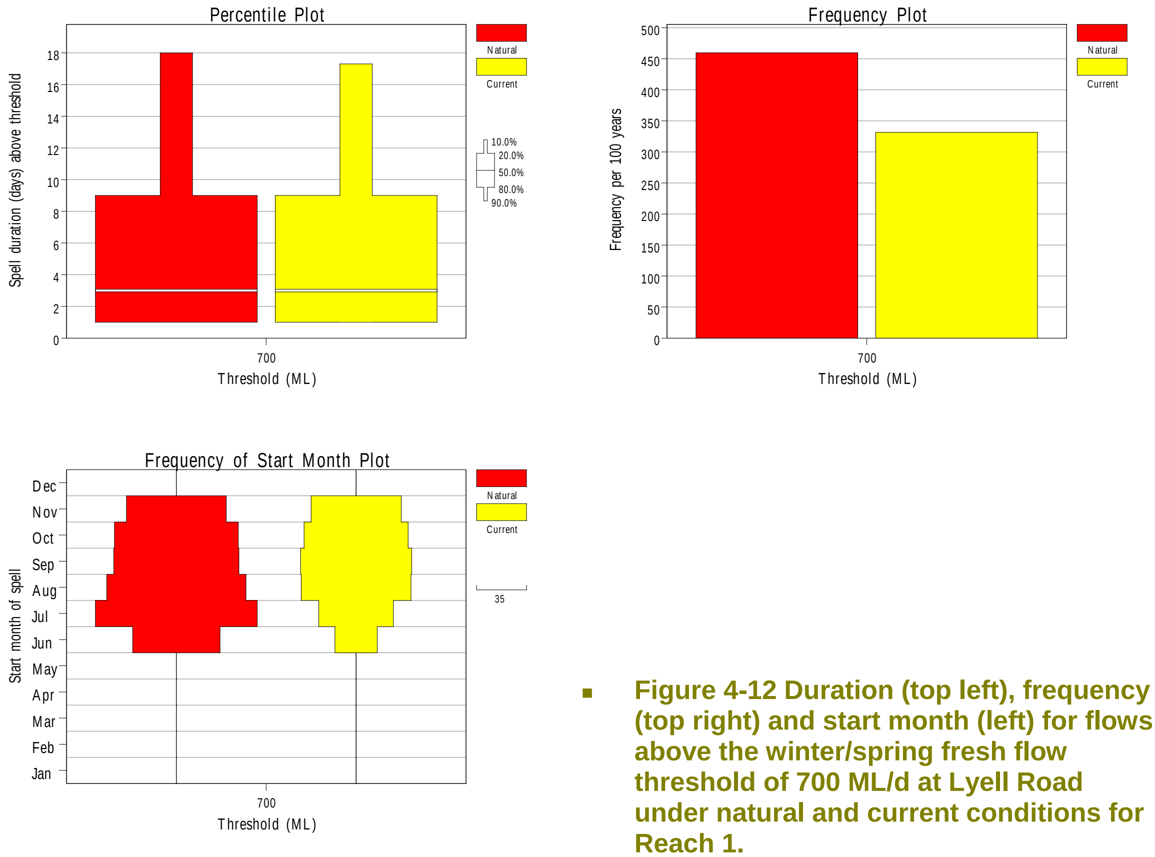


- **Figure 4-10: Stage height for winter fresh flow at Lyell Road showing inundation across sand bar in cross section 7. Photo underneath plot shows the cross section, but does not reflect conditions during a winter fresh**



- **Figure 4-11: Stage height for winter fresh flow at Lyell Road showing inundation up to secondary channel features at cross section 1. Photo underneath plot shows the cross section, but does not reflect conditions during a winter fresh.**

.



▪ **Figure 4-12 Duration (top left), frequency (top right) and start month (left) for flows above the winter/spring fresh flow threshold of 700 ML/d at Lyell Road under natural and current conditions for Reach 1.**

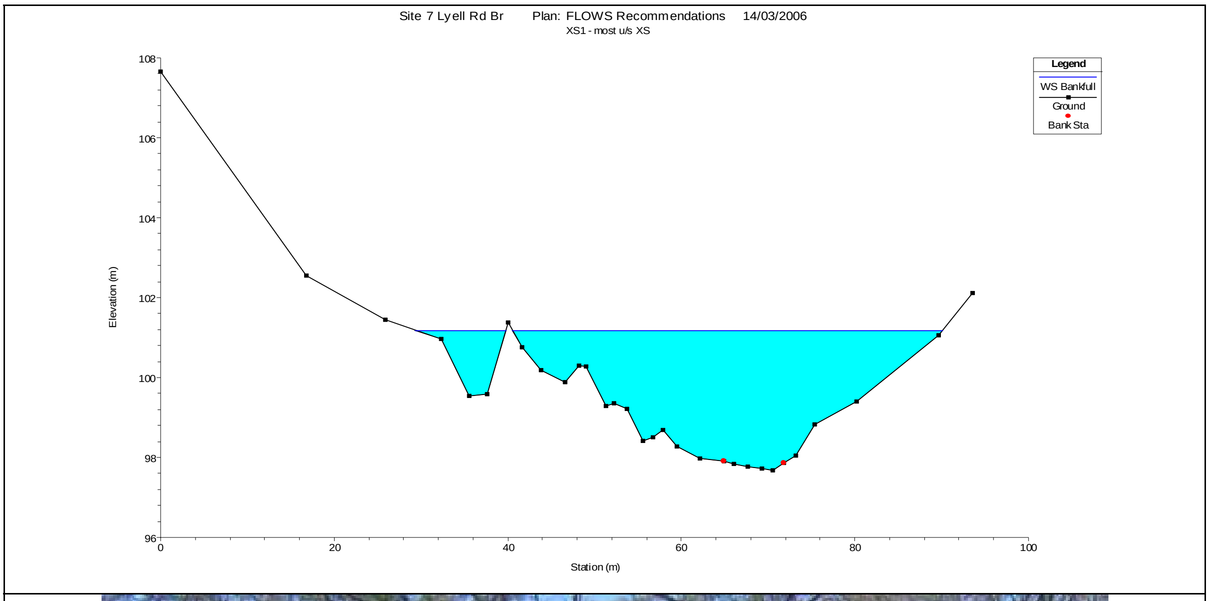
Winter/spring: high flow

The winter/spring fresh recommendation fulfils the objectives of a high flow through this reach and therefore there is no specific high flow recommendation.

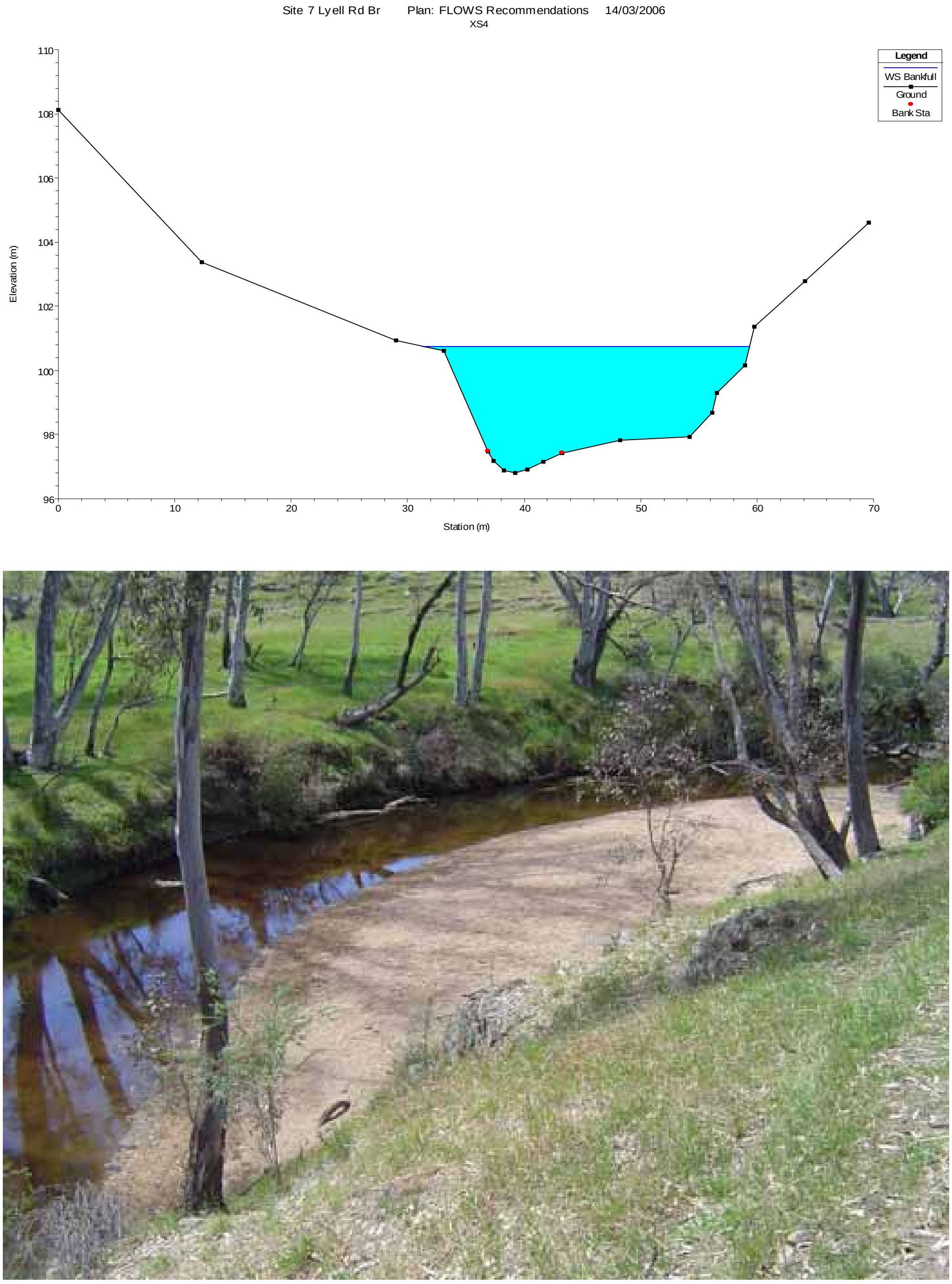
Winter/spring: bankfull

A bankfull flow of 12,000 ML/day at Lyell and 6,000 ML/day at Phillips Road is recommended for Reach 1. This flow will fill the entire channel, as determined by the lower left hand bank. It may break out to fill high flood runners in a few places (Figure 4-13), but will be contained within the channel in most places (Figure 4-14). The purpose of this flow is to entrain organic material from the riparian zone, scour sediment and fine mater and break out to fill high flood runners in a few places. HEC-RAS modelling indicates that a bankfull flow will generate velocities in excess of 2 m/s in some parts of the channel, which is sufficient to move sand around (Gordon *et al.* 1992).

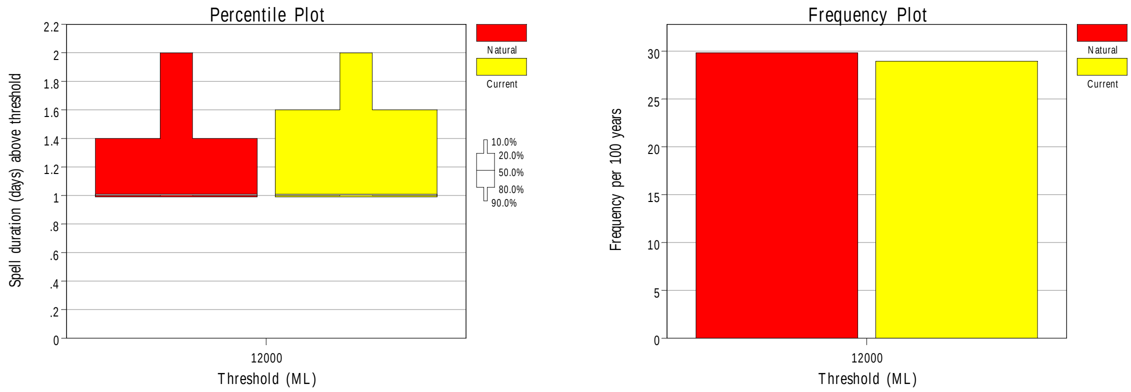
Bankfull flows around 12,000 ML/day at Lyell occur approximately once every three years for a median duration of 1 day under both natural and current flow conditions (Figure 4-15). The recommended frequency and duration of the bankfull flow therefore maintains the current conditions.

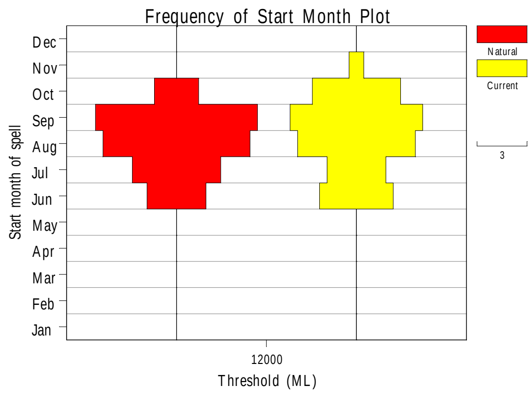


- **Figure 4-13: Stage height for bankfull flow at Lyell Road showing inundation of secondary channel in cross section 1.   Photos underneath plot shows the cross section and elements that may be inundated by a bankfull flow, but does not reflect conditions during a bankfull flow**



- **Figure 4-14 Stage height for bankfull flow at Lyell Road showing full channel capacity at cross section 4. Photo underneath plot shows the cross section and elements that may be inundated by a bankfull flow, but does not reflect conditions during a bankfull flow.**





- **Figure 4-15 Duration (top left), frequency (top right) and start month (left) for flows above the winter/spring bankfull flow threshold of 12000 ML/d at Lyell Road under natural and current conditions for Reach 1.**

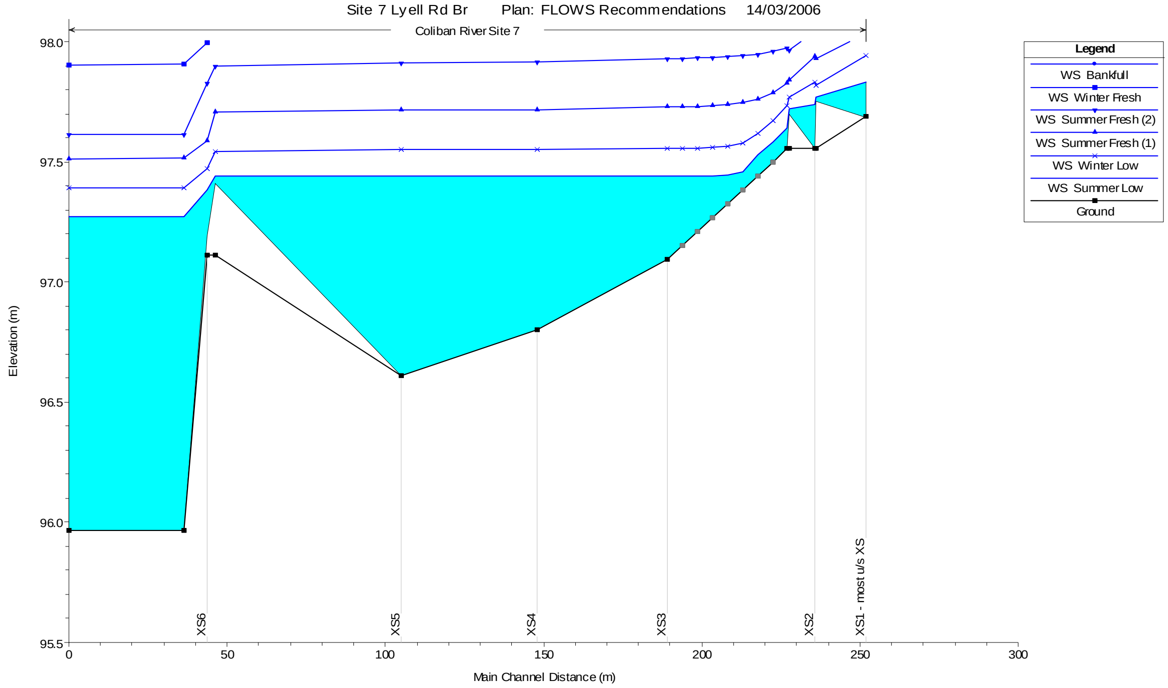
Winter/spring: overbank

No specific overbank flow is recommended for Reach 1 as no specific floodplain elements were identified that would obviously benefit. However, overbank flows will naturally occur during large floods and as the spells analyses for bankfull flows indicates; these very large flow components are not substantially affected by current regulation. Future changes to flow management in the Coliban River should not reduce the current frequency or duration of overbank flows as these flows need to be transferred downstream to water floodplain habitats in the lower Campaspe River and River Murray.

Long section

The water surface level for each flow threshold along a long section of the flows assessment site at Lyell is shown in Figure 4-16. Water surface levels indicate the variation in depth between the riffle (cross sections one and two) and the deep pool (cross sections four and five).

SKM



▪ **Figure 4-16 Long section showing water surface (WS) level for all flows in the Coliban River at Lyell. Surveyed cross sections are shown. Elevations are relative to a single high point at each site that is given an arbitrary elevation of 100.**

Comparison with previous environmental flow recommendations

The previous environmental flow assessment for the Coliban River recommended a minimum release from Malmsbury Reservoir of 8 ML/day or natural, whichever is less to maintain instream habitat and prevent deoxygenation (Marchant *et al.* 1997). During summer, the natural flow at Malmsbury is likely to be less than 8 ML/day and may be zero at times. Therefore the summer low flow recommendation for 2.5 ML/day at Phillips Road and 5 ML/day at Lyell Road are probably not much different from the previous recommendation. The overall flow regime recommended in this report incorporates freshes, winter high flows and bankfull flows, which were not considered in the previous environmental flows study. Summer freshes in particular are recommended to help maintain aquatic habitat and water quality therefore the combination of summer freshes and the recommended summer low flows through this reach address the issues identified by Marchant *et al.* (1997), but have the benefit of more natural flow variability.

4.1.3 Current compliance with recommendations

Compliance with environmental flow recommendations for Reach 1 is presented in Table 4-3. Under current conditions, the low flow recommendation is met 56 % of the time and the winter low flow recommendation 48 % of the time. Summer and winter freshes are met 73 % and 85 % of the time respectively, but the total number and duration of freshes under current conditions is less than

SKM

recommended for this reach. Winter bankfull flows only occur 35 % of the time recommended in this study, but their current duration complies with the recommendation.

In summary, the current flow regime does not comply well with the recommended flow requirements for this reach. Flow in the Coliban River is highly regulated by Malmsbury, Lauriston and Upper Coliban Reservoirs and altered release patterns will be needed in order to deliver the recommended environmental flows.

- **Table 4-3 Compliance of the current flow regime in Reach 1 with flow recommendations. Compliance is estimated by applying the current system operation to the 1891 - 2005 flow record.**

Flow recommendations				Percentage of years (vol & no.) or events (dur.) when flow recs are complied with for the current flow regime
Component	Time	Flow Recommendation		
Summer low	December - May	Volume	5	56
Summer fresh	December - May	Volume	100	73
		Number	2	39
		Duration	3	42
Winter low	June - November	Volume	35	48
Winter fresh	June - November	Volume	700	85
		Number	4	49
		Duration	3	57
Winterbankfull	August - September	Volume	1200	35
		Number	1 in 3	35
		Duration	1	100

4.2 Reach 2 – Campaspe River: Lake Eppalock to Campaspe Weir

4.2.1 Current condition

The current condition of Reach 2 is detailed in the *Issues Paper* (SKM 2006a) and summarised below in Table 4-4.

- **Table 4-4 Current condition of Reach 2 – Campaspe River: Lake Eppalock to Campaspe Weir.**

Aspect	Current condition
Hydrology	▪ Mean annual flow at Doake's Reserve has been reduced from 640 ML/day to 420 ML/day. ▪ Reversal of the natural seasonal flow regime due to controlled irrigation releases from Lake Eppalock. ▪ In wet years, Lake Eppalock has split (every 2-3 years) but this has not happened since 1996 due to the drought.
Geomorphology	▪ Channel morphology does not appear to be substantially altered by

SKM

Aspect	Current condition
	regulation. ▪ Land clearing and stock access have impacted protective riparian vegetation.
Vegetation	▪ Grazing and stock access of riparian vegetation leading to poor recruitment of juvenile natives and spread of riparian weeds. ▪ Reduced flooding and aseasonality in flow, leading to poor recruitment of juveniles. ▪ Aseasonality in flows may adversely affect growth and recruitment of desirable species of angiosperms (rooted flowering plants). ▪ Year-round reduced flow restricts habitats for in-stream plants. ▪ Reduced flows and possible nutrient enrichment encourage dense growth of *Typha* and *Phragmites*.
Fish	▪ Likely that poor native fish recruitment is a result of destruction of slackwater habitat. ▪ Reduction in frequency and duration of high flows will prevent movement of native fish upstream and downstream. ▪ Some temperature depression due to effects of deep-water releases from Lake Eppalock. ▪ Alien species are significant stressors. ▪ Campaspe Weir and Lake Eppalock are significant barriers to movement upstream and downstream of this reach.
Water quality	▪ General condition – good, although noticeable impacts immediately downstream of Axe Creek especially at times of lower flow from Lake Eppalock. ▪ High salinity and low dissolved oxygen most severe immediately downstream of Axe Creek. ▪ Blackwater events may occur downstream of Forest and Mt Pleasant Creek. ▪ Low level releases from Lake Eppalock contribute to reduced summer temperatures between the reservoir and Axe Creek.
Macroinvertebrates	▪ Community immediately downstream of Lake Eppalock is affected by flow fluctuations and riffle communities are especially poor (DSE 2005). ▪ Diversity very low on riffle habitats. ▪ Community has a high proportion of filter feeders.

4.2.2 Flow recommendations

The environmental flow recommendations for Reach 2 are summarised in Table 4-5. The main assessment for Reach 2 was based on modelled flows and cross section data from Doakes Reserve, these flows were then checked at English's Bridge. Inflows from Axe Creek ensure that recommended flows have a greater magnitude at English's Bridge than Doakes Reserve. Both sites have a large island that divides the channel into two branches. In both cases, the left hand branch is deeper and carries more flow.

SKM

- **Table 4-5 Summary of flow recommendations for Reach 2 – Campaspe River: Lake Eppalock to Campaspe Weir.**

Stream		Campaspe River		**Reach**	Lake Eppalock to Campaspe Weir		
Compliance point		Site 6 - Doakes Reserve		**Gauge No.**	406207		
Season	**Component**	**Volume**	**Frequency**	**Duration**	**Rise**	**Fall**	**Objective**
Summer	Cease to flow	0 ML/d	1 per year	14 days			F2-1
	Low flow	10 ML/d (or natural)	1 per year	6 months			V2-1, F2-2, F2-6, M2-1, W2-1
	Freshes	100 ML/d	3 per year (or natural)	5 days	230%	65%	V2-2, F2-3, W2-3
Winter	Low flow	100 ML/d (or natural)	1 per year	6 months			F2-4, F2-6, M2-1, W2-1
	High flow	1000 ML/d	4 per year (or natural)	4 days	230%	65%	V2-3, V2-4, F2-5, W2-2, W2-3, M2-3
	Bankfull flow	10,000 ML/d	1 per year (or natural)	2 days	230%	65%	G2-1, V2-5, F2-5
	Overbank flow	12,000 ML/d	1 per year	1 day	230%	65%	G2-2, V2-6

Stream		Campaspe River		**Reach**	Lake Eppalock to Campaspe Weir		
Compliance point		Site 5 - English's Bridge		**Gauge No.**			
Season	**Component**	**Volume**	**Frequency**	**Duration**	**Rise**	**Fall**	**Objective**
Summer	Cease to flow	0 ML/d	1 per year	14 days			F2-1
	Low flow	16 ML/d (or natural)	1 per year	6 months			V2-1, F2-2, F2-6, M2-1
	Freshes	125 ML/d	3 per year (or natural)	5 days	230%	65%	V2-2, F2-3, W2-3
Winter	Low flow	120 ML/d (or natural)	1 per year	6 months			F2-4, F2-6, M2-1
	High flow	1200 ML/d	4 per year (or natural)	4 days	230%	65%	V2-3, V2-4, F2-5, W2-2, W2-3, M2-3
	Bankfull flow	12,000 ML/d	1 per year (or natural)	2 days	230%	65%	G2-1, V2-5, F2-5
	Overbank flow	14,000 ML/d	1 per year	1 day	230%	65%	G2-2, V2-6

Summer/autumn: cease to flow

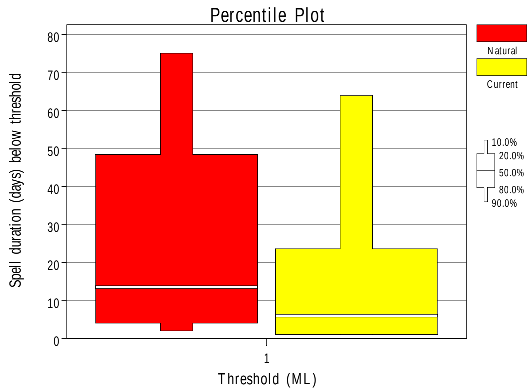
A summer cease to flow (0 ML/day) that lasts for up to two weeks is recommended for Reach 2. This recommendation contrasts with Marchant *et al.* (1997), who recommended no cease to flows between Lake Eppalock and the Campaspe Weir. Cease to flow events represent a stress on the system, but high zooplankton concentrations in permanent pools provide important feeding

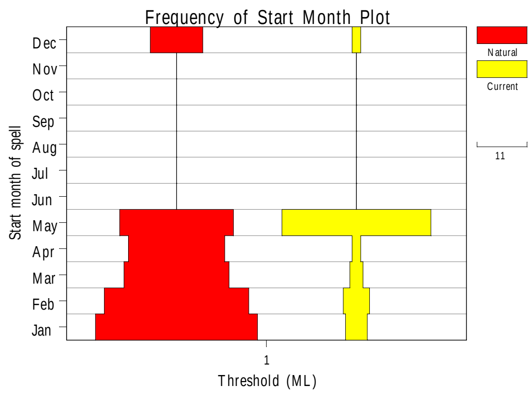
SKM

opportunities for larval and juvenile fish. Large adult fish may prey on juvenile fish in pools during cease to flow events, but increased food concentrations for early life stages can contribute to enhanced native fish recruitment after cease to flow periods (Humphries *et al*. 1999, King 2004b, a).

Under natural conditions the Campaspe River between Lake Eppalock and the Campaspe Weir would have ceased to flow 1.3 times per year for a median duration of 13 days each time (Figure 4-17).   However, regulation in this reach means that cease to flow events occur only once every two years and only for a median of five days (Figure 4-17). Regulation has also affected the timing of summer cease to flow events. Cease to flow events most commonly occurred in January and February under natural flow conditions, but they now occur most commonly at the end of the irrigation season (Figure 4-17), when discharge from Lake Eppalock is cut off for maintenance.

The recommendation for this reach is for one cease to flow that lasts for two weeks during January or February each year.





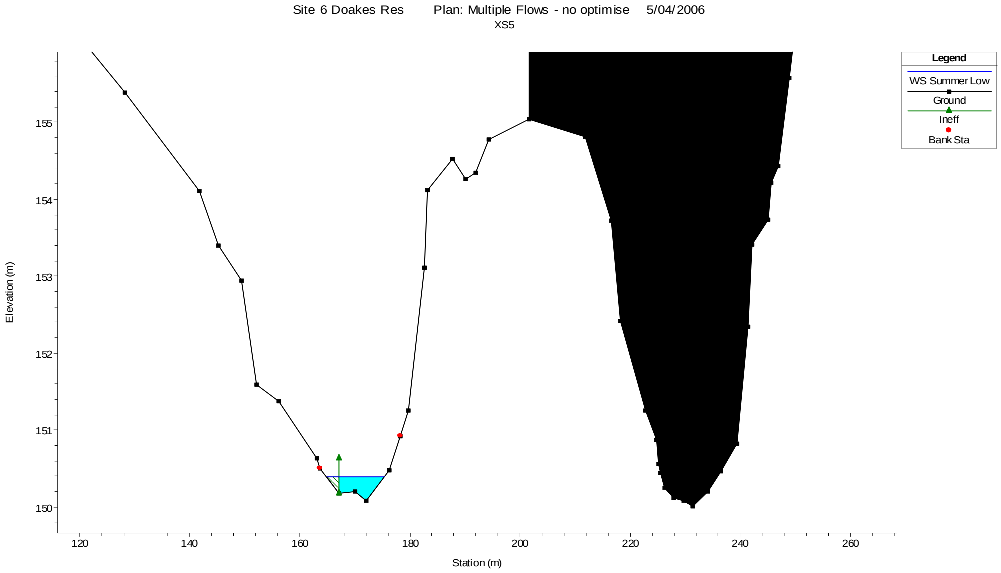
▪ **Figure 4-17 Duration (top left), frequency (top right) and start month (left) for flows below the summer/autumn cease to flow threshold (1 ML/d) at Doakes Reserve under natural and current conditions for Reach 2.**

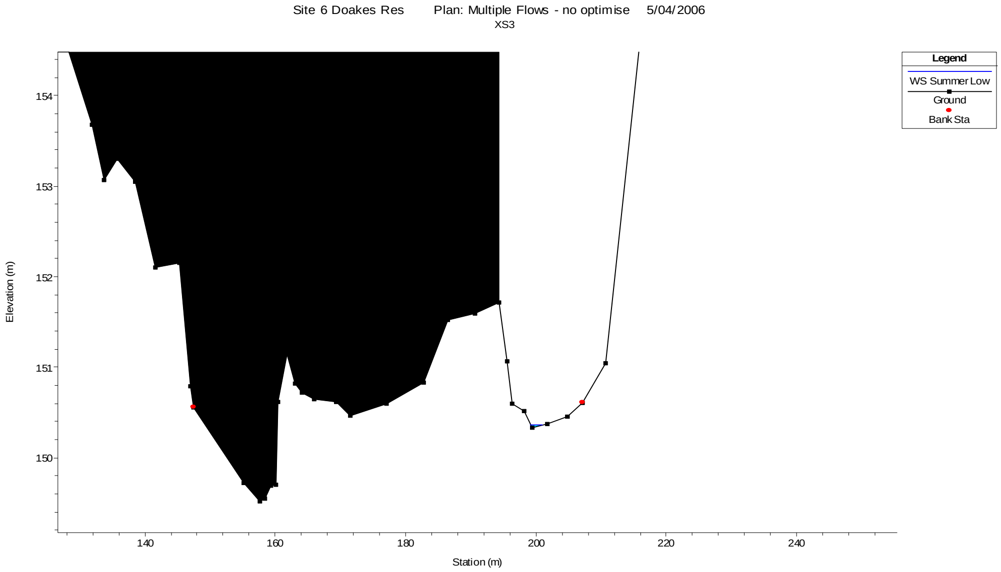
SKM

Summer/autumn: low flow

The recommended summer low flow for the Campaspe River at Doakes Reserve is 10 ML/day. This flow fills the bottom of the low flow channel and provides 30 cm flow over the deepest part of the shallowest cross section, but does not allow flow through the higher secondary channel (Figure 4-18). The secondary channel on the right hand side of the island would have naturally dried during summer, but under current conditions the channel is permanently wet and as a result is choked with *Typha*. At flows greater than 10 ML/day, the secondary channel begins to flow and therefore summer low flows should not exceed this magnitude so that T*ypha* can be controlled. This summer low flow will increase the abundance and diversity of slackwater habitats in the bottom of the channel, which are important nurseries for native fish.

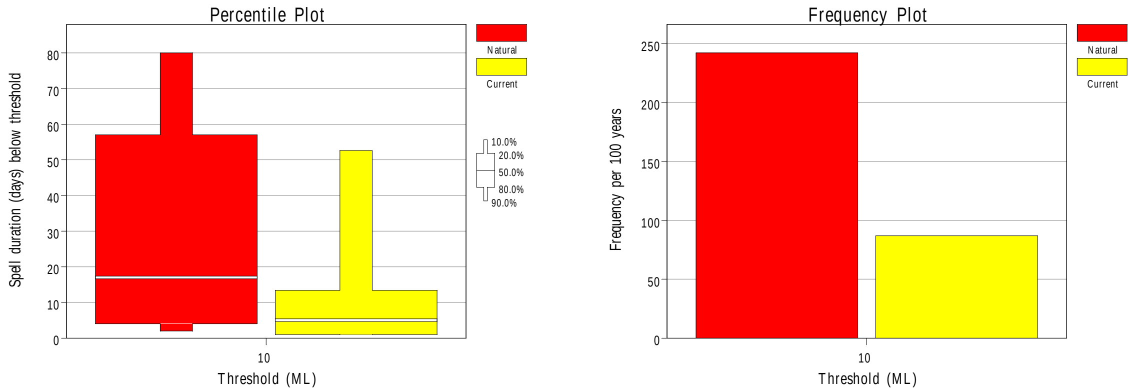
Under natural conditions, the Campaspe River at Doakes Reserve would have experienced flows less than 10 ML/day approximately 2.5 times per year for a median of 17 days each time, and these events usually occurred between December and February (Figure 4-19). Under current conditions, flows less than 10 ML/day occur less than once a year and only last for a median of five days (Figure 4-19). The current timing of these low flow events has been shifted to May, when releases from Lake Eppalock stop for maintenance purposes. The recommendation for this reach is for a constant summer low flow of 10 ML/day at Doakes Reserve between December and May except when cease to flow or freshes occur. Due to tributary inputs from Axe Creek, the summer low flow in the Campaspe River at English's Bridge should be 16 ML/day.

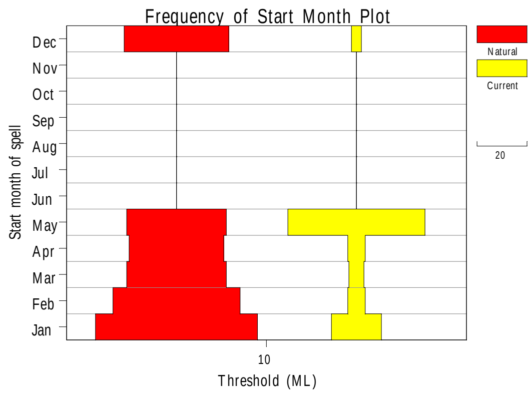




- **Figure 4-18 Stage height in shallowest riffle (cross section five, top) and at the start of the secondary channel on the right hand side of the island (cross section three, bottom) cross sections at the recommended threshold for summer/autumn low flows at Doakes Reserve.**

SKM



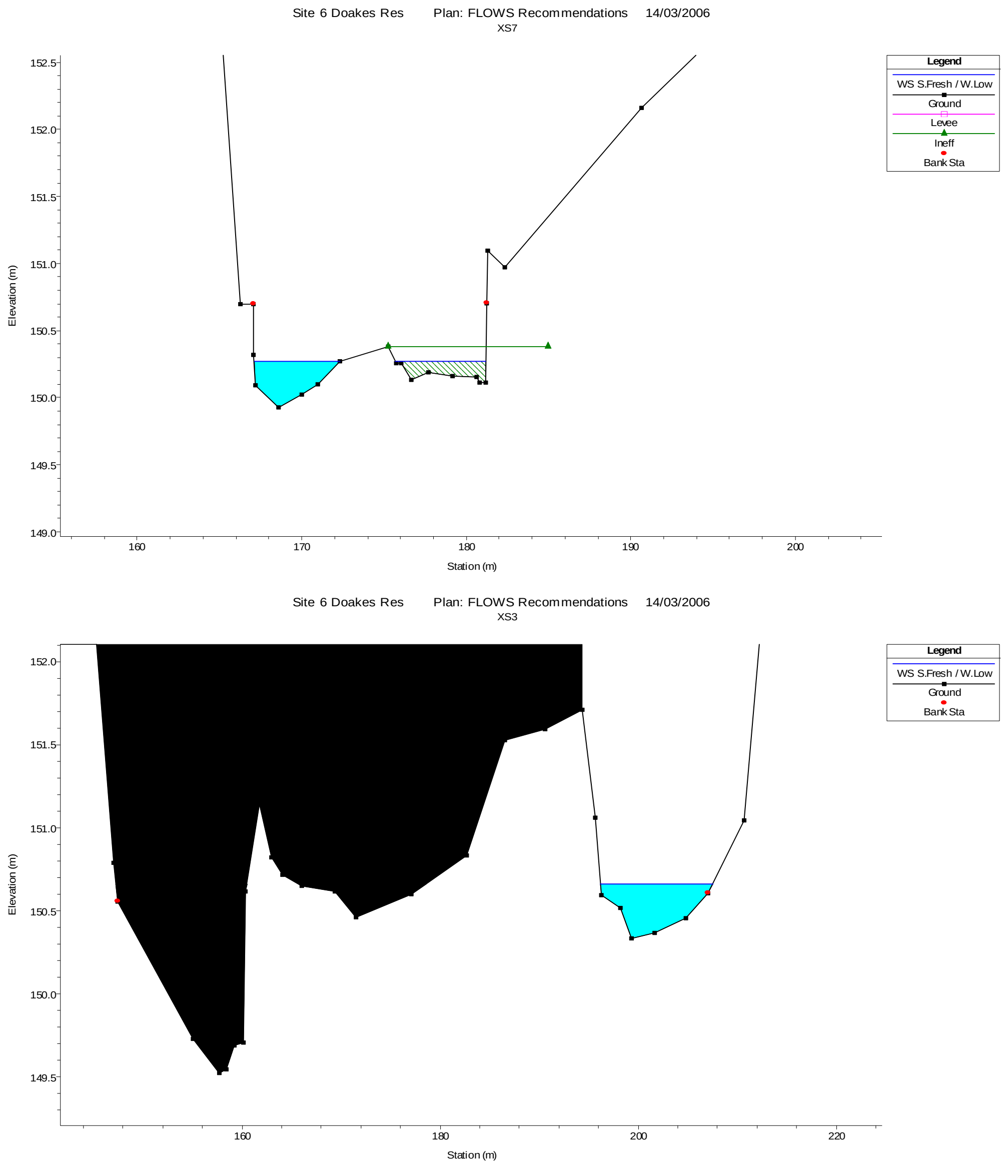


- **Figure 4-19 Duration (top left), frequency (top right) and start month (left) for flows below the summer/autumn low flow threshold of 10 ML/d at Doakes Reserve under natural and current conditions for Reach 2.**

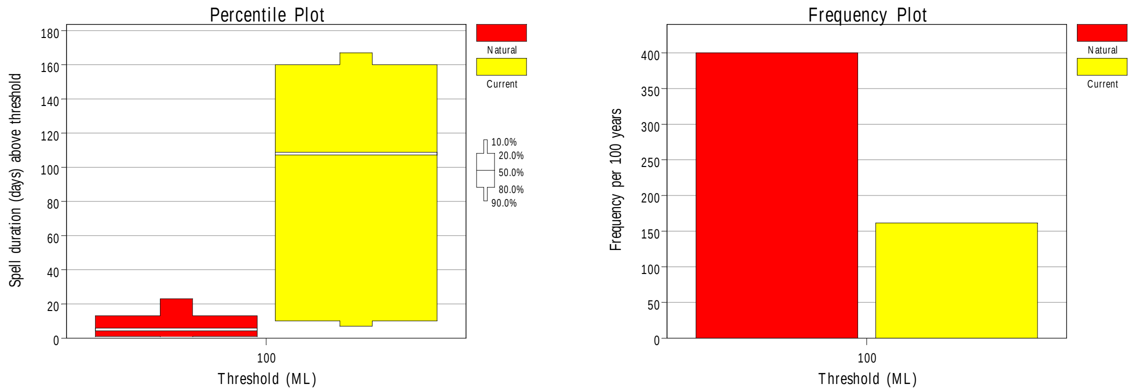
Summer/autumn: freshes

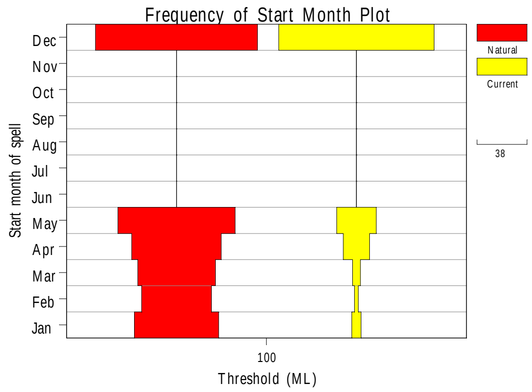
The recommended summer fresh for the Campaspe River at Doakes Reserve is 100 ML/day, which corresponds with a flow of 125 ML/day at English's Bridge. This recommended fresh will provide flow on either side of the island at Doakes Reserve and will provide a 34 cm flow depth across the shallowest riffle habitats (Figure 4-20) in both channels, which will allow longitudinal connectivity of fish movement throughout the reach (Mallen-Cooper 2001).

Under natural conditions, the recommended summer fresh at Doakes Reserve would have been exceeded four times between December and May each year and lasted for a median of five days each time (Figure 4-21). However, due to current irrigation releases, this flow is now exceeded for a median of 110 days each summer (Figure 4-21). The recommendation for this reach is that three summer freshes of 100 ML/day at Doakes Reserve (and 125 ML/day at English's Bridge) be provided each year and that each fresh last for only five days. Where possible these freshes should occur between February and May so as not to flush slackwater habitats in early summer when larval and juvenile fish are abundant.



- **Figure 4-20 Stage height in riffle in left hand channel (cross section seven, top) and through secondary channel (cross section three, bottom) cross sections at recommended threshold for summer/autumn freshes at Doakes Reserve.**



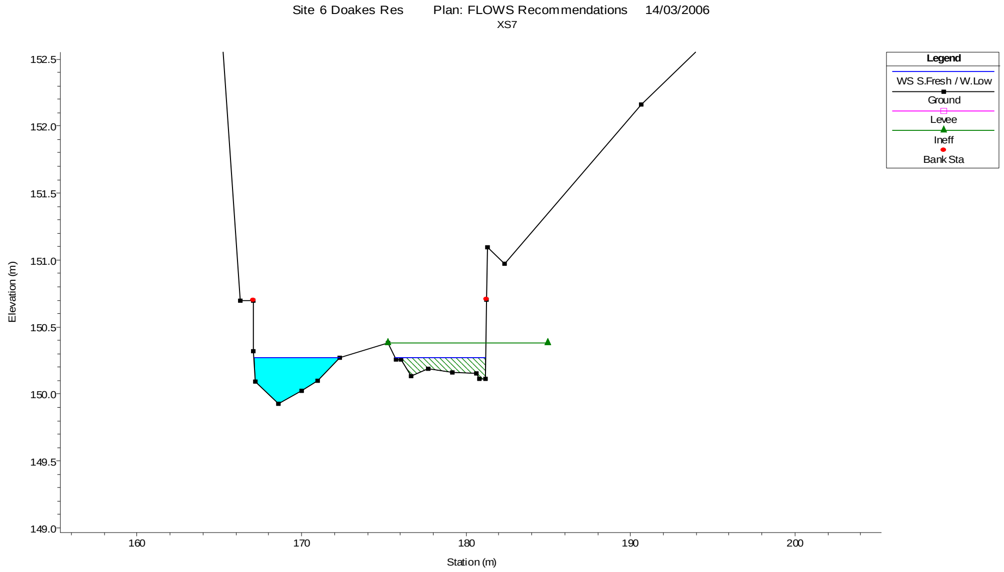


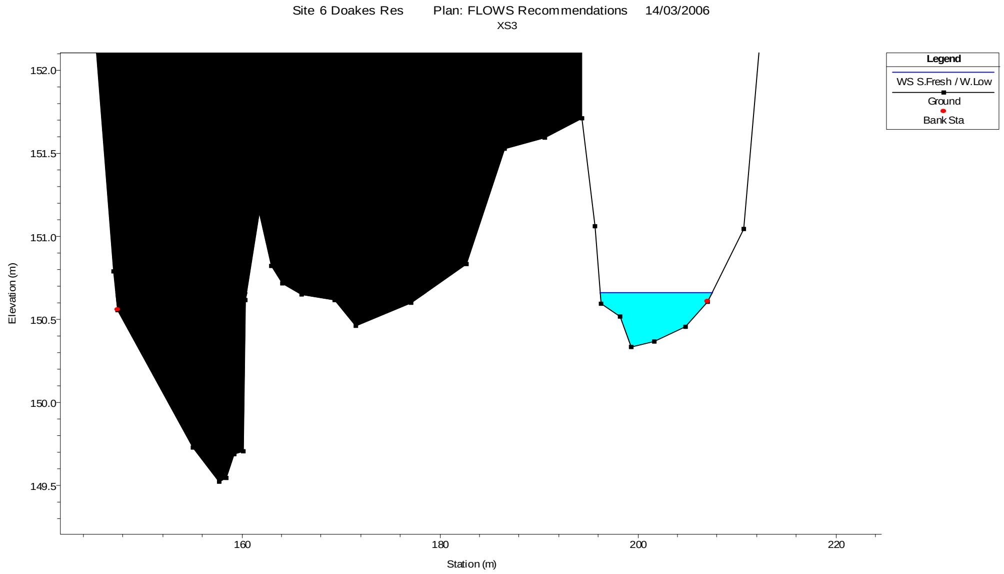
▪ **Figure 4-21 Duration (top left), frequency (top right) and start month (left) for flows above the summer/autumn fresh threshold of 100 ML/d at Doakes Reserve under natural and current conditions for Reach 2.**

Winter/spring: low flow

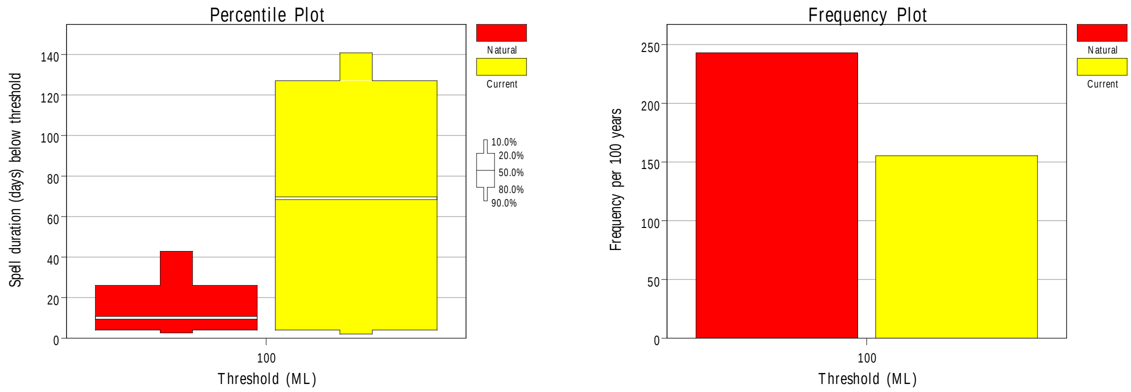
The recommended winter low flow through this reach is 100 ML/day at Doakes Reserve and 120 ML/day at English's Bridge. This flow will inundate the same areas as the summer fresh and will allow fish movement throughout the reach. Higher winter inflows from Axe Creek and Mount Pleasant Creek contribute significant salt loads to the Campaspe River and current monitoring indicates a spike in salinity in the Campaspe River for a short distance downstream of the Axe Creek confluence. The recommended winter low flow is not likely to prevent this salinity spike, but higher flows are not considered necessary because current monitoring suggests that the spike (approximately 200 EC) is not likely to threaten any aquatic biota in this reach (Hart *et al.* 1990, Hart *et al.* 2003, Nielsen *et al.* 2003). Further water quality monitoring may be warranted to assess water quality changes associated with the proposed environmental flow release throughout this reach.

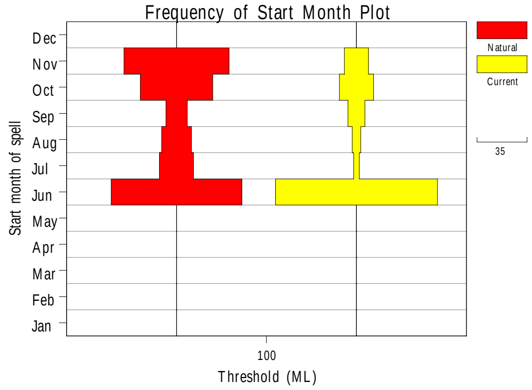
Flows less than 100 ML/day would have naturally occurred in the Campaspe River at Doakes Reserve on average 2.5 times each winter for a median duration of 8 days (Figure 4-23). Under current conditions, flows less than 100 ML/day occur approximately 1.5 times per year for a median duration of 70 days (Figure 4-23). The recommendation for this reach is that a constant low flow of 100 ML/day be provided to the Campaspe River at Doakes Reserve throughout winter.





- **Figure 4-22 Stage height in riffle in left hand channel (cross section seven, top) and through secondary channel (cross section three, bottom) cross sections at recommended threshold for winter low flows at Doakes Reserve.**



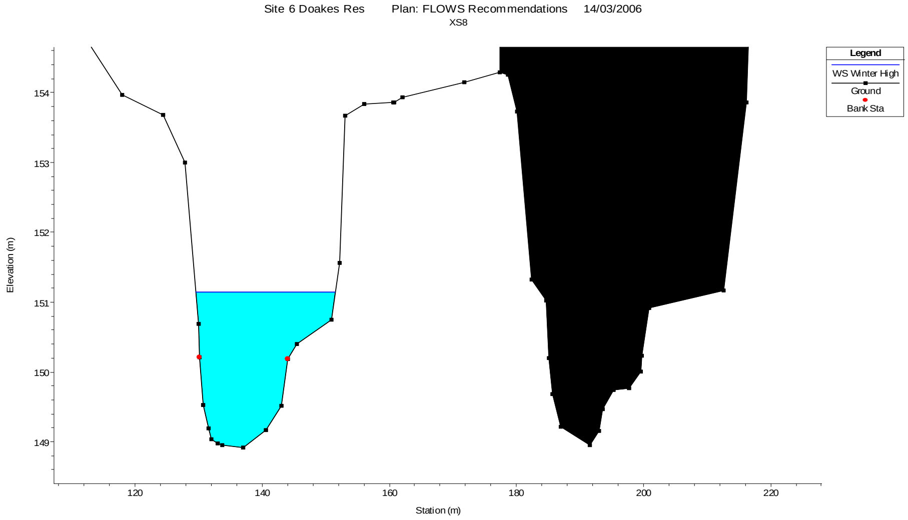


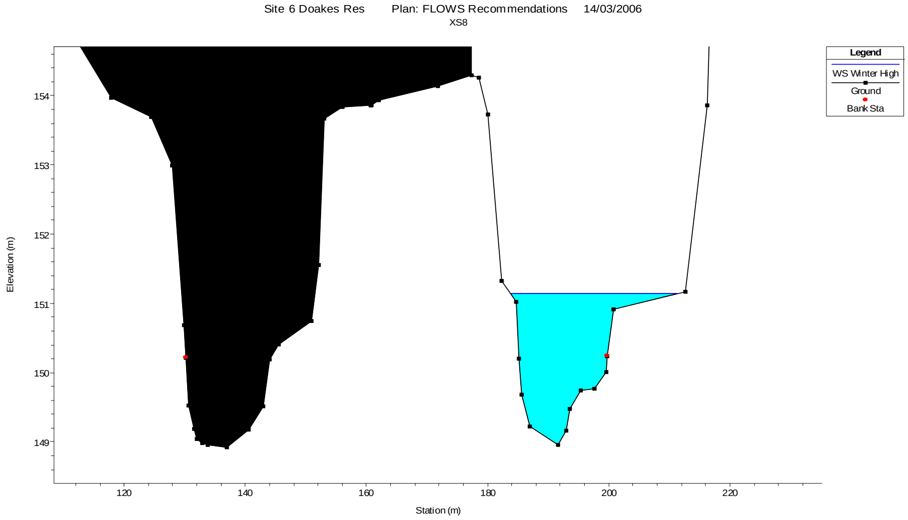
- **Figure 4-23 Duration (top left), frequency (top right) and start month (left) for flows below the winter/spring low flow threshold of 100 ML/d at Doakes Reserve under natural and current conditions for Reach 2.**

Winter/spring: high flow

The recommended winter high flow for Reach 2 is 1000 ML/day at Doakes Reserve and 1200 ML/day at English's Bridge. This flow will inundate benches in the low flow channel on either side of the island at Doakes Reserve (Figure 4-24), which will help suppress encroaching terrestrial vegetation and entrain organic matter. The winter high flow is expected to create a velocity of approximately 0.3 to 0.4 m/s through the channel, which may help cue fish migration, but substantial increases in velocity are not expected until flow exceeds 2,500 ML/day.

Under natural conditions, flows greater than 1000 ML/day would occur in the Campaspe River at Doakes Reserve on average four times per winter and last for a median duration of four days (Figure 4-25). Flow regulation through this reach has substantially reduced the frequency of large flows and therefore flows greater than 1000 ML/day occur at Doakes Reserve only once every second year on average and last for a median duration of 10 days (Figure 4-25). The recommendation for this reach is for four winter high flow events between June and November every year; these high flows should last for four days on each occasion. The winter high flows at English's Bridge should have the same frequency and duration, but should have a magnitude of 1200 ML/day.

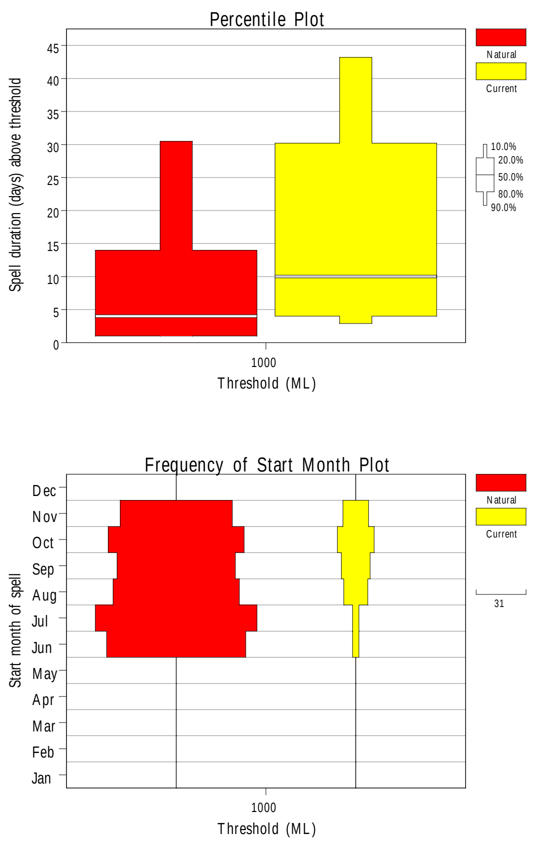


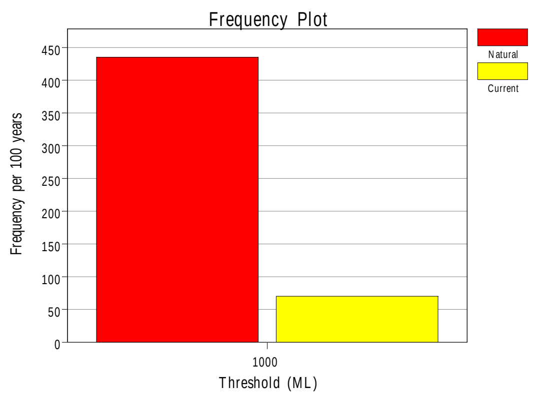


- **Figure 4-24 Plot showing stage height and inundated channel benches in left and right hand channels at cross section 8 during winter high flows at Doakes Reserve. The photo shows the left hand channel of cross section 8 including the bench that will be inundated by high winter flows.**

.

SKM



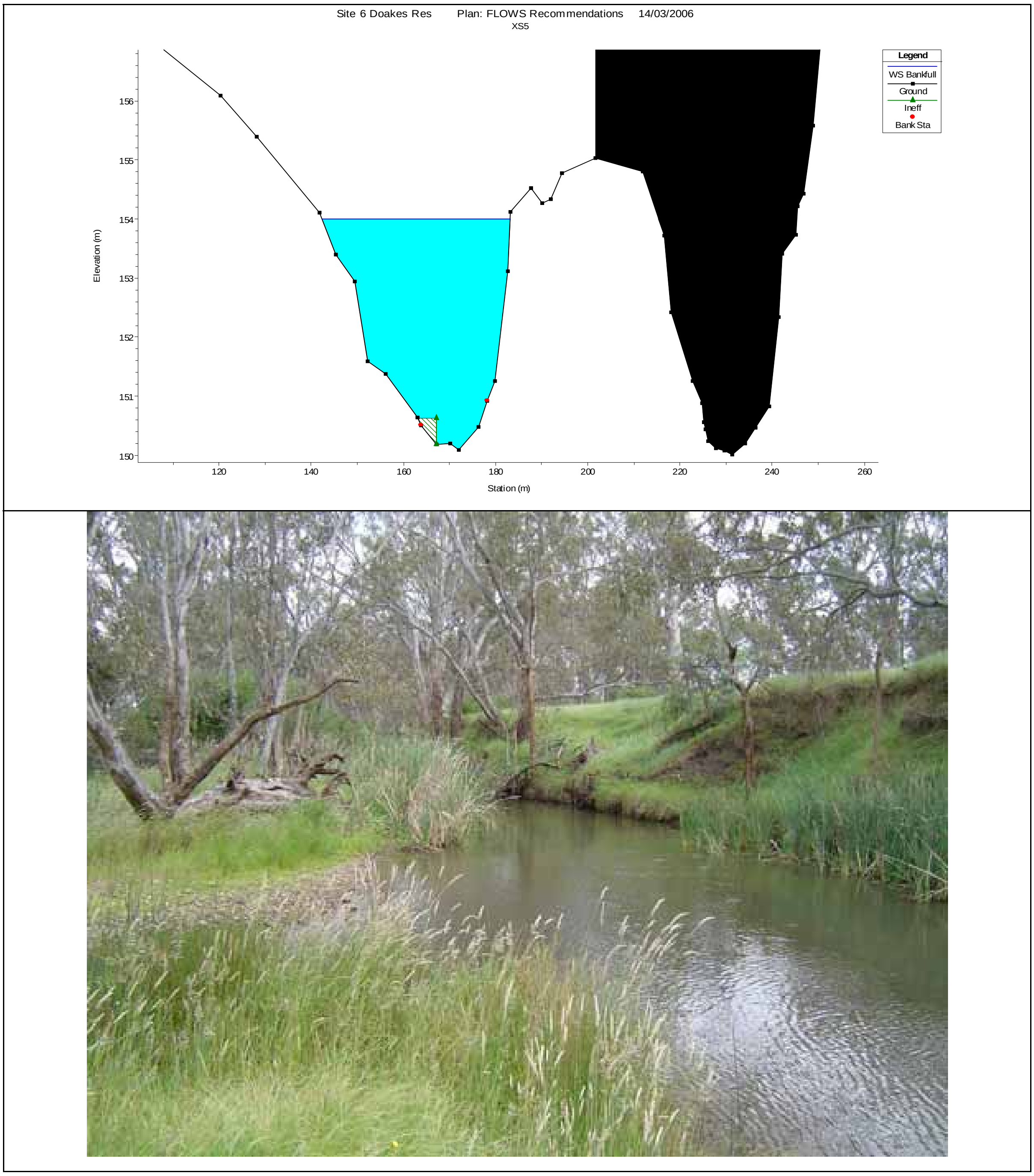


- **Figure 4-25 Duration (top left), frequency (top right) and start month (left) for flows above the winter/spring high flow threshold of 1000 ML/d at Doakes Reserve under natural and current conditions for Reach 2.**

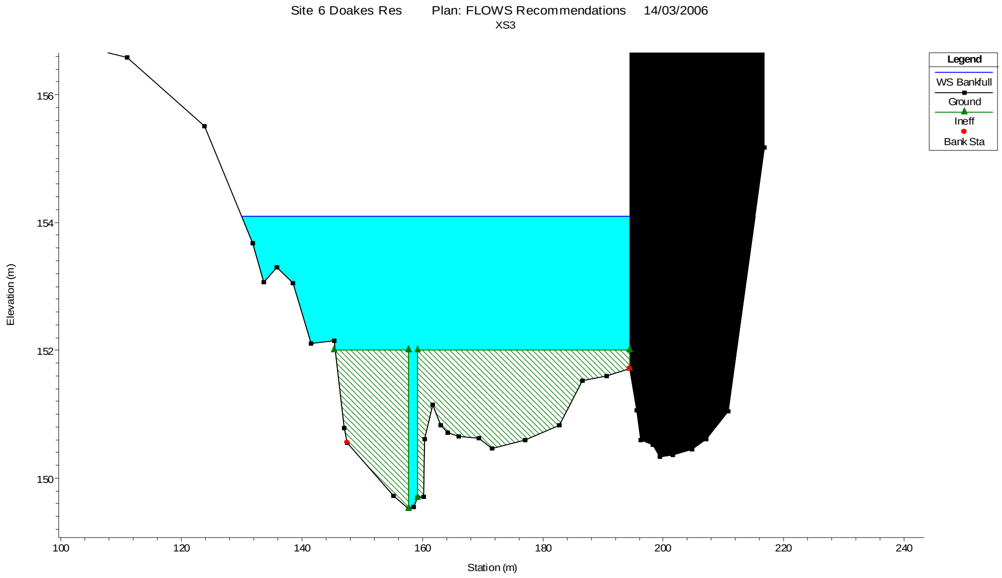
Winter/spring: bankfull

The recommended winter/spring bankfull flow for Reach 2 is 10,000 ML/day at Doakes Reserve and 12,000 ML/day at English's Bridge. This flow will be contained within the channel, but will not inundate the mid-channel islands at either of the two study sites (Figure 4-26). The bankfull flow will mobilise sediments (Gordon *et al.* 1992) and have sufficient velocity to scour stands of *Typha* (Moss 1998), such as those shown in Figure 4-27, as well as cue fish migration.

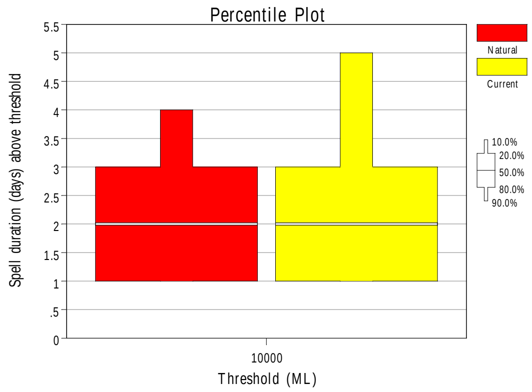
Bankfull flows through this reach would have naturally occurred approximately 1.3 times each winter and lasted for a median duration of two days (Figure 4-28). However, due to regulation, this flow now occurs on average once every two years, and generally occurs later in the season than would have naturally been the case (Figure 4-28). The recommendation for this reach is to deliver bankfull flows of 10,000 ML/day at Doakes Reserve and 12,000 ML/day at English's Bridge once during August or September each year. These flows should remain at bankfull level for two days.

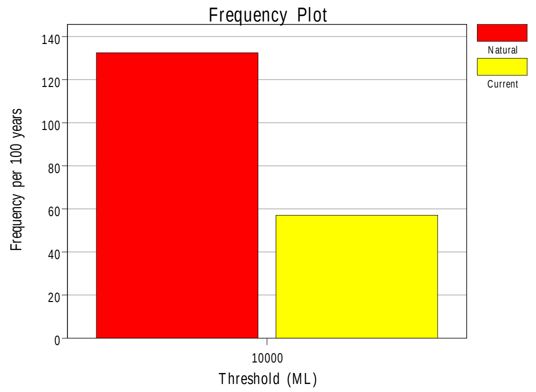


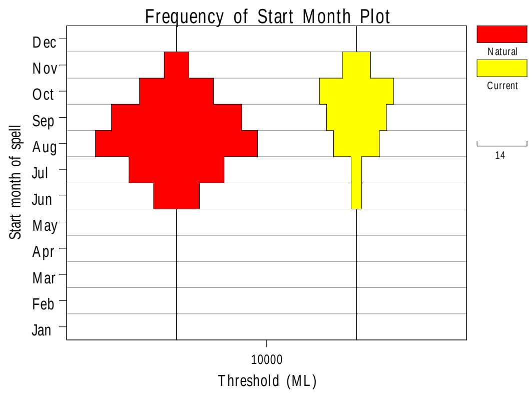
- **Figure 4-26: Stage height in channel at cross section 5 at the recommended threshold for winter/spring bankfull at Doakes Reserve. Photo shows the channel features and vegetation that will be affected by the recommended bankfull flow.**



- **Figure 4-27 Stage height across *Typha* stand at cross section 3 at the recommended threshold for winter/spring bankfull at Doakes Reserve. Photo shows the channel features and vegetation that will be affected by the recommended bankfull flow.**





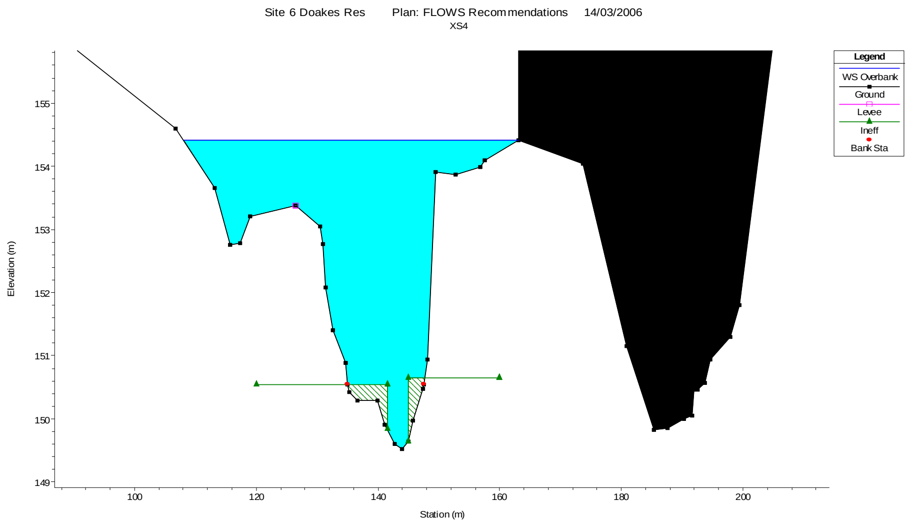


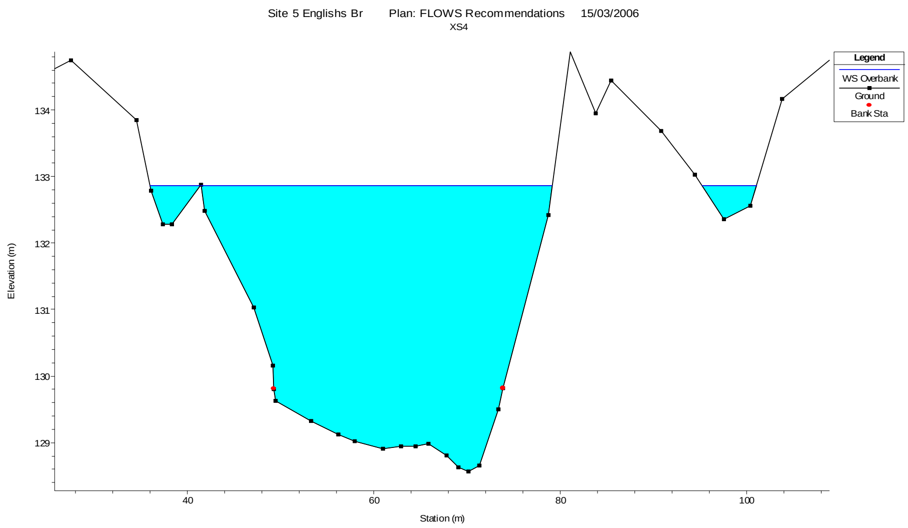
- **Figure 4-28 Duration (top left), frequency (top right) and start month (left) for flows above the winter/spring bankfull flow threshold of 10000 ML/d at Doakes Reserve under natural and current conditions for Reach 2.**

Winter/spring: overbank

An overbank flow of 12,000 ML/day at Doakes Reserve and a corresponding flow of 14,000 ML/day at English's Bridge are recommended for Reach 2. This flow would wet most of the island at Doakes Reserve and connect later flood runners, such as those observed at English's Bridge, to the main channel (Figure 4-29). Overbank flows should encourage some River Red Gum regeneration (Bren 1988, 1990, Nichol and G.G. 2000, Roberts and Marston 2000, Robertson *et al.* 2001) and deliver a large load of organic material to the river (Junk *et al.* 1989).

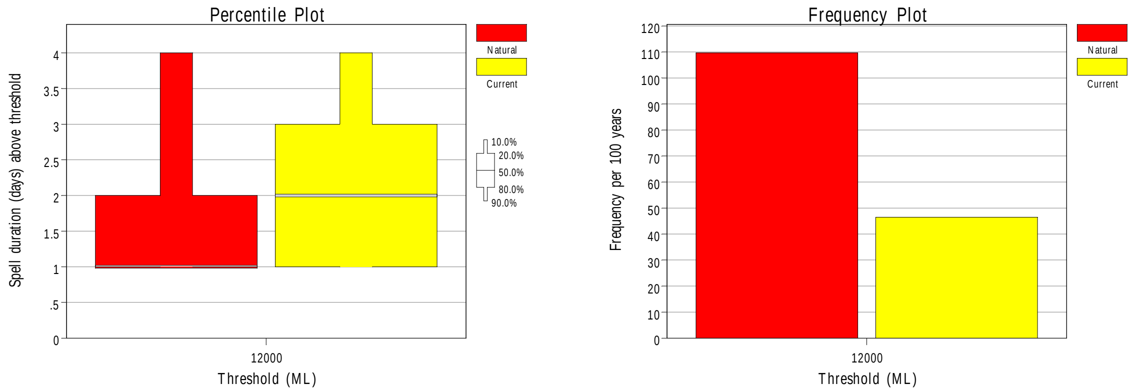
Flows greater than 12,000 ML/day would have naturally occurred at Doakes Reserve approximately once per year on average and lasted for a median of one day (Figure 4-30). Under current conditions, flows of this magnitude occur approximately once every two years and last for a median of two days (Figure 4-30). One overbank flow of 12,000 ML/day that lasts for one day at Doakes Reserve is recommended for this reach. In many cases, the natural overbank flow would have occurred at the same time as the bankfull flow event. Overbank flows will only occur in this reach when Lake Eppalock spills, therefore it is recommended that any spill events be allowed to meet the overbank flow threshold for one day where possible.

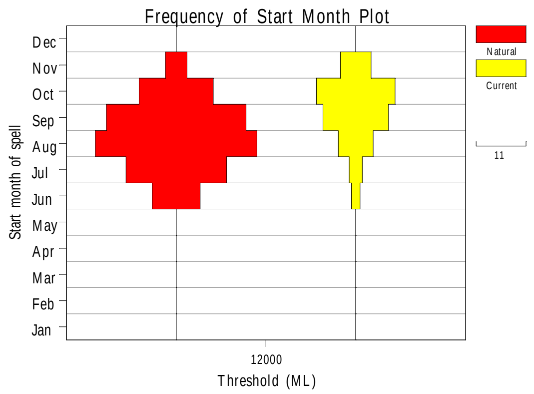




- **Figure 4-29 Stage height showing inundation across the top of the island at cross section 5 at Doakes Reserve (top) and inundation of channel and connection to the flood runner at cross section 4 (middle) at English's Bridge at the recommended threshold for winter/spring overbank flows. The photo shows the flood runner on the right hand bank that will be inundated by the proposed overbank flow.**

SKM



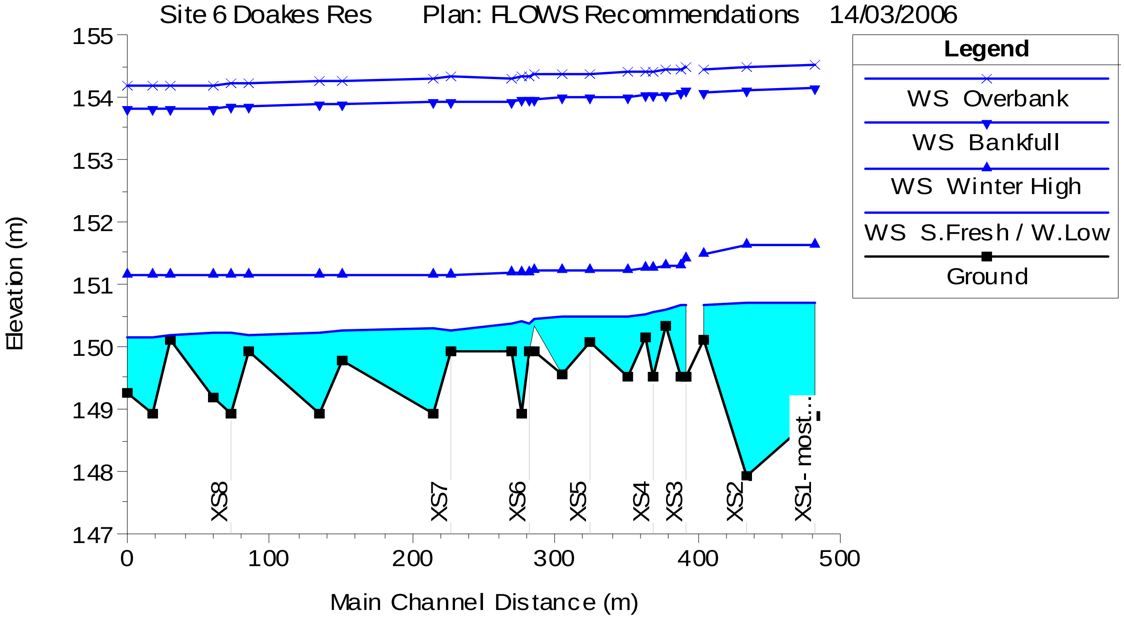


- **Figure 4-30 Duration (top left), frequency (top right) and start month (left) for flows above the winter/spring overbank flow threshold of 12000 ML/d at Doakes Reserve under natural and current conditions for Reach 2.**

Long section

The water surface level for each flow threshold along a long section of Reach 2 is shown in Figure 4-31. This long profile only includes the main channel along the left hand side of the island at this site. Water surface levels indicate the variation in depth between riffles (cross sections five and seven) and deeper pools (cross sections two and eight).

SKM



- **Figure 4-31 Long section at Doakes Reserve showing water surface (WS) level for all flows in Reach 2. Elevations are relative to a single high point at each site that is given an arbitrary elevation of 100.**

Comparison with previous environmental flow recommendations

The recommended summer environmental flows for the Campaspe River between Lake Eppalock and the Campaspe Weir are generally lower than the previous environmental flow recommendations for this reach. Marchant *et al.* (1997) did not recommend cease to flows for this reach and recommended minimum summer flows of between 80 and 90 ML/day to manage water quality in the Campaspe River. However, the summer cease to flow will provide important feeding opportunities for juvenile and larval fish and summer low flows above about 20 ML/day will lead to excessive *Typha* growth, which is considered one of the main environmental threats in this reach. The EFTP considered that the combined effect of cease to flows, low flows less than 20 ML/day and freshes will allow water quality issues in the reach to be managed and limit *Typha* growth within the channel. An environmental flow monitoring program should assess water quality in this reach during summer to ensure that the recommended flow regime does not adversely affect salinity, dissolved oxygen levels or nutrient concentration in this reach or the Campaspe Weirpool.

Marchant *et al.* (1997) also recommended winter floods of 2,000 to 3,000 ML/day that would inundate channel benches for four to six weeks, which is much longer than the high flow duration recommended in the current study. The HEC-RAS modelling used in the current FLOWS assessment indicates that flows of 1000 ML/day are required to inundate channel benches through this reach and given that bankfull and overbank flows are also recommended the duration of these high flows only needs to be several days.

4.2.3 Current compliance with recommendations

Compliance with environmental flow recommendations for Reach 3 is presented in Table 4-6. Under current conditions, the recommended summer low flow of 10 ML/day is exceeded for 93 % of the time. This increased flow through this reach reduces the amount of important slackwater habitats for larval and juvenile fish and is the main reason for excessive *Typha* growth throughout the reach. Cease to flow events occur 10% as often as required and the timing of these is generally timed to coincide with maintenance work at Lake Eppalock. Summer irrigation flows are substantially higher than the recommended summer freshes and therefore normal compliance assessments of this flow component are not possible. However, to give an indication of the problem we can compare the current monthly flows at these sites against the estimated monthly flows if the recommended flow regime were delivered. The recommended summer low flows and freshes would require approximately 600 ML/month at Doakes Bridge and 850 ML/month at English's Bridge. The current average monthly flows at these sites during summer are 11,500 ML/month and 10,700 ML/month respectively, which is more than an order of magnitude higher than that required for the recommended flows.

Current winter flows through Reach 2 are less than the natural flows through this reach and therefore compliance against the recommended flow regime can be compared using the standard approach. Winter low flows are currently met 41 % of the time. Winter high flows are only met in 37 % of years and all four of the recommended high flows only occur in 3 out of every 100 years. Bankfull and overbank flows are recommended each year but occur less than every five and less than every 15 years respectively.

In summary, irrigation flows between Lake Eppalock and the Campaspe Weir ensure that summer flows far exceed the recommended environmental flows and that winter flows are too small and infrequent. Excessive summer flows and retarded winter flows have different ecological effects on the river system, but both are detrimental to the overall health of the system.

SKM

- **Table 4-6 Compliance of the current flow regime in Reach 2 with flow recommendations. Compliance is estimated by applying the current system operation to the 1891 - 2005 flow record.**

Flow recommendations				Percentage of years (vol & no.) or events (dur.) when flow recs are complied with for the current flow regime
Component	**Time**	**Flow Recommendation**		
Summer cease to flow	**February - May**	**Volume**	0	10
		Number	1	10
		Duration	14	36
Winter low	**June - November**	**Volume**	100	41
Winter high	**June - November**	**Volume**	1,000	37
		Number	4	3
		Duration	4	83
Winter bankfull	**August - September**	**Volume**	10,000	17
		Number	1	17
		Duration	2	100
Winter overbank	**August**	**Volume**	12,000	6
		Number	1	6
		Duration	1	100

4.3 Reach 3 – Campaspe River: Campaspe Weir to Campaspe Siphon

4.3.1 Current condition

The current condition of Reach 3 is detailed in the *Issues Paper* (SKM 2006a) and summarised below in Table 4-7.

Table 4-7 Current condition of Reach 3 – Campaspe River: Campaspe Weir to Campaspe Siphon.

Aspect	Current condition
Hydrology	▪ Mean annual flow at Spencer Road has been reduced from 880 ML/day to 360 ML/day. ▪ Reversal of the natural seasonal flow regime due to irrigation diversions at Campaspe Weir and transfer flows between Campaspe Weir and Campaspe Siphon. ▪ Current flow regime is characterised by longer periods of low flow and shorter high flow periods compared to natural.
Geomorphology	▪ Slight increase in sand probably due to observable toe erosion, but gross morphology of the channel appears unaltered by regulation.
Vegetation	▪ Clearing of original riparian vegetation and presence of exotic and weedy species. ▪ Reduced flooding and aseasonality in flow, leading to poor recruitment of juveniles. ▪ Grazing and stock access, leading to poor recruitment of juvenile natives and spread of weeds. ▪ Aseasonality in flow may adversely affect growth and recruitment of desirable species of angiosperms (rooted flowering plants). ▪ Year-round reduced flow restricts habitats for in-stream plants. ▪ Reduced flows and possible nutrient enrichment encourage dense growth of *Typha* and *Phragmites*.
Fish	▪ Reversed flow seasonality (i.e. high flow in summer and low in winter) is unlikely to prevent recruitment. ▪ Reduction in frequency and extent (duration?) of high flow will prevent movement upstream and downstream. ▪ Weir pools probably conducive to occurrence of large numbers of Carp and European Perch. ▪ Campaspe Weir and Campaspe Siphon are significant barriers to movement of fish upstream and downstream. ▪ Alien species are significant stressors to this reach.
Water quality	▪ General condition – good, although little data available. ▪ Nutrient enrichment likely to be high from local grazing and irrigation run-off. ▪ No temperature effect from Lake Eppalock.
Macroinvertebrates	▪ General condition – moderate to poor and dominated by pollution tolerant taxa (ISC assessment (DSE 2005)). ▪ Moderate diversity. ▪ Community has some filter feeders, but mainly collector/gatherers.

SKM

4.3.2 Flow recommendations

The environmental flow recommendations for Reach 3 are summarised in Table 4-8. The main assessment for Reach 3 was based on modelled flows and cross section data from Spencer Road near Rochester, these flows were checked at the Bryants Lane Site downstream of the Campaspe Weir. There are no major tributary inflows between the Campaspe Weir and Campaspe Siphon, therefore recommended flows have the same magnitude at each site.

- **Table 4-8 Summary of flow recommendations for Reach 3 – Campaspe River: Campaspe Weir to Campaspe Siphon.**

Stream		Campaspe River		Reach	Campaspe Weir to Campaspe Siphon		
Compliance point		Site 4 – Bryants Lane		Gauge No.	406202		
Season	Component	Volume	Frequency	Duration	Rise	Fall	Objective
Summer	Low flow	10 ML/d (not more than 20 ML/d*)	1 per year	6 months			V3-1, F3-1, W3-1, M3-1
	Freshes	100 ML/d	3 per year (Feb to May**)	6 days	230%	65%	V3-2, F3-2, W3-2, M3-2
Winter	Low flow	200 ML/d (or natural)	1 per year	6 months			F3-3, W3-1, M3-1
	High flow	1500 ML/d	4 per year (or natural)	4 days	230%	65%	V3-3, F3-4, W3-2, M3-2
	Bankfull flow	8,000 ML/d	2 per year (or natural)	2 days	230%	65%	G3-1, V3-5, F3-4
	Overbank flow	12,000 ML/d	1 per year	1 day	230%	65%	V3-6
* This value may be reviewed after planned work assessing behaviour of saline pools and slackwaters in different flow conditions has been completed. ** Additional freshes may be released between December and February to manage water quality if required.							

Stream		Campaspe River		Reach	Campaspe Weir to Campaspe Siphon		
Compliance point		Site 3 - Spencer Road		Gauge No.	406202		
Season	Component	Volume	Frequency	Duration	Rise	Fall	Objective
Summer	Low flow	10 ML/d (not more than 20 ML/d*)	1 per year	6 months			V3-1, F3-1, W3-1, M3-1
	Freshes	100 ML/d	3 per year (Feb to May**)	6 days	230%	65%	V3-2, F3-2, W3-2, M3-2
Winter	Low flow	200 ML/d (or natural)	1 per year	6 months			F3-3, W3-1, M3-1
	High flow	1500 ML/d	4 per year (or natural)	4 days	230%	65%	V3-3, F3-4, W3-2, M3-2
	Bankfull flow	8,000 ML/d	2 per year (or natural)	2 days	230%	65%	G3-1, V3-5, F3-4
	Overbank flow	12,000 ML/d	1 per year	1 day	230%	65%	V3-6
* This value may be reviewed after work to assess the behaviour of saline pools and slackwaters in different flows is done. ** Additional freshes may be released between December and February to manage water quality if required.							

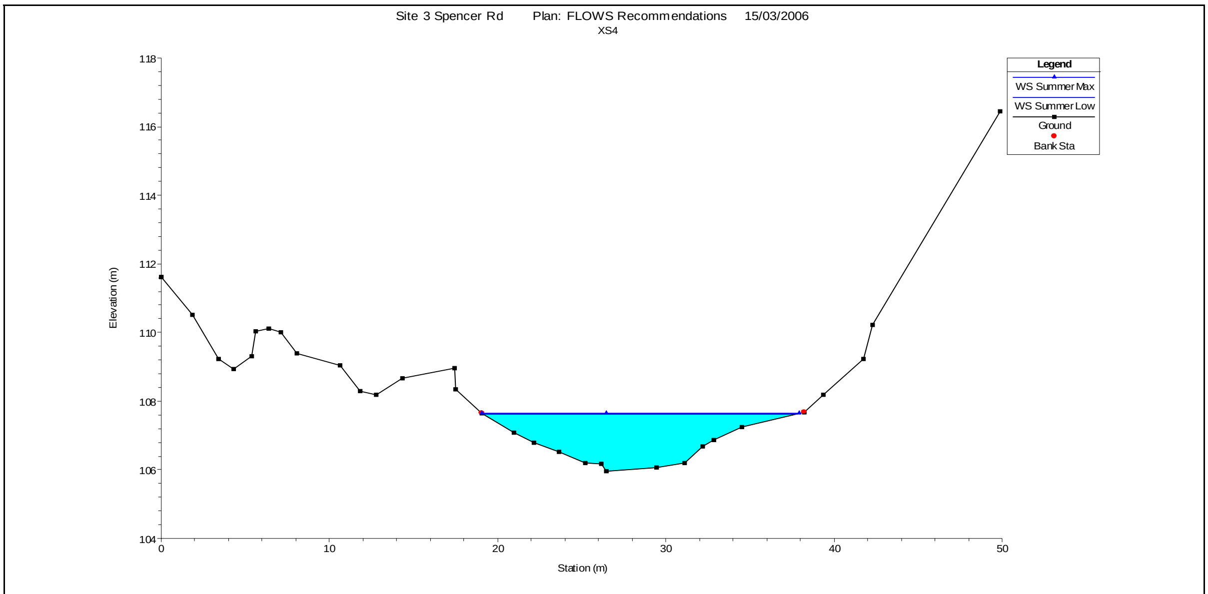
Summer/autumn: cease to flow

Cease to flow events would have naturally occurred in Reach 3. However, re-introducing cease to flow events is likely to exacerbate high salinity levels, nutrient enrichment and low dissolved oxygen levels, which would create an unnatural level of stress to aquatic biota throughout this reach. We recommend that no cease to flow period be provided in this reach until these water quality issues have been addressed and mitigated.

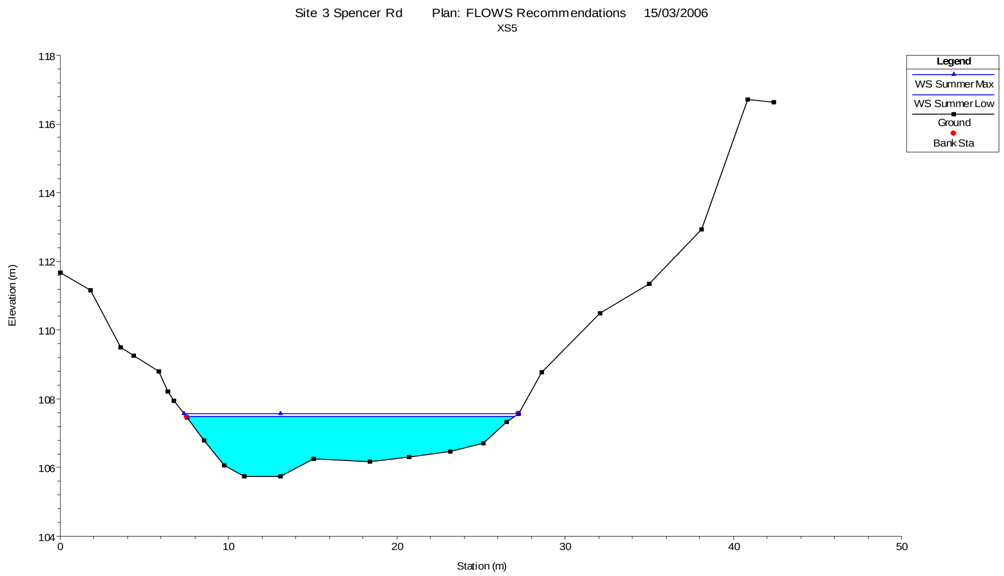
Summer/autumn: low flow

The recommended summer low flow for Reach 3 is 10 ML/day. This flow rate will maintain flow through the reach, prevent further deterioration of water quality at the surface of pools and preserve slackwater habitats for developing fish larvae and juvenile fish. The channel through Reach 3 is characterised by slow flowing pool and run habitats and the recommended summer low flow will maintain a depth of 70 cm through the shallowest cross section (Figure 4-32) and a depth of 1.7 m through the deepest cross section surveyed at Spencer Road (Figure 4-33). Modelling indicated little difference in stage height for flows between 5 ML/day and 20 ML/day, however flows above 20 ML/day are expected to create flows of more than 0.1 m/s through the slackwater habitats, which is considered likely to flush larval and juvenile fish out of these habitats. Further work is currently being conducted to assess changes to slackwater habitats under different flow conditions and the results of that study may cause the maximum summer flow recommendation for this reach to be revised. The recommended flow was set at 10 ML/day to be consistent with flow recommendations for Reach 4.

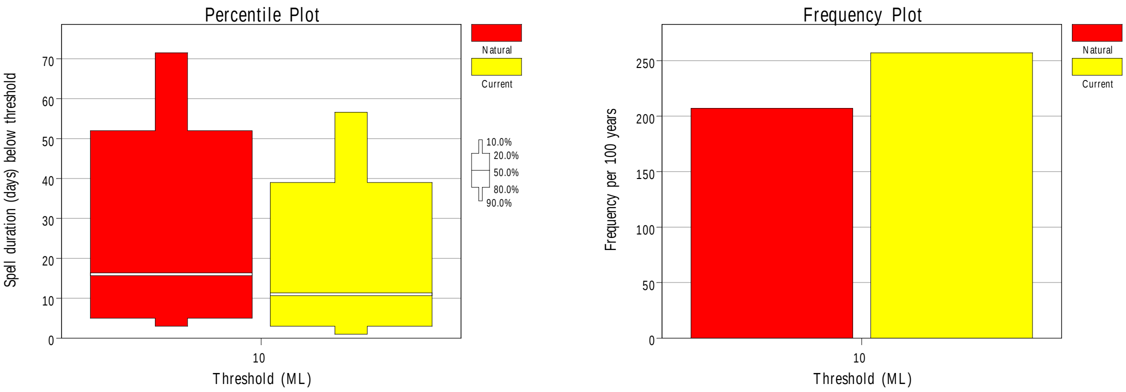
Under natural conditions, flows less than 10 ML/day would have occurred in Reach 3 twice a year on average with a median duration of 15 days. Under current conditions, flows less than 10 ML/day occur approximately 2.5 times per year, but they only have a median duration of 11 days (Figure 4-34). It is recommended that the summer low flow for Reach 3 should be 10 ML/day and should not exceed 20 ML/day.

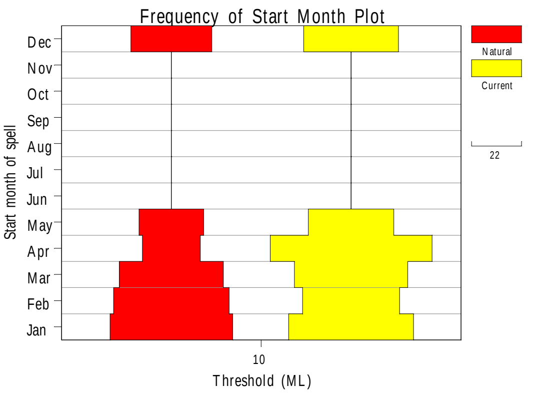


- **Figure 4-32: Stage height in the shallowest run (cross section four) at the recommended threshold for summer/autumn low flows at Spencer Road. The photo shows the channel section across cross sections four.**



- **Figure 4-33 Stage height in the deepest pool (cross section 5) at the recommended threshold for summer/autumn low flows at Spencer Road. The photo shows the channel section captured in cross section five.**



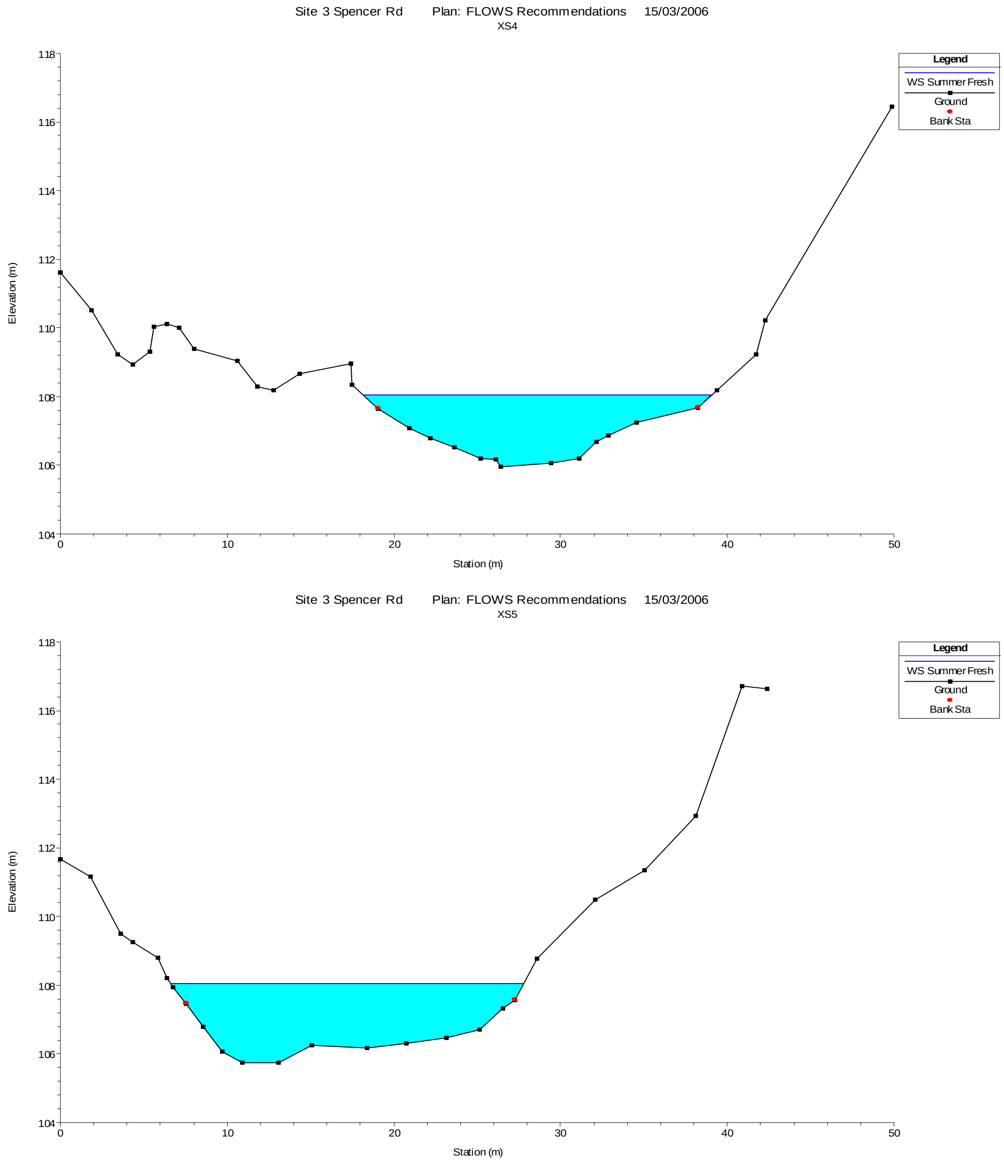


- **Figure 4-34 Duration (top left), frequency (top right) and start month (left) for flows below the summer/autumn low flow threshold of 10 ML/d at Spencer Road under natural and current conditions for Reach 3.**

Summer/autumn: freshes

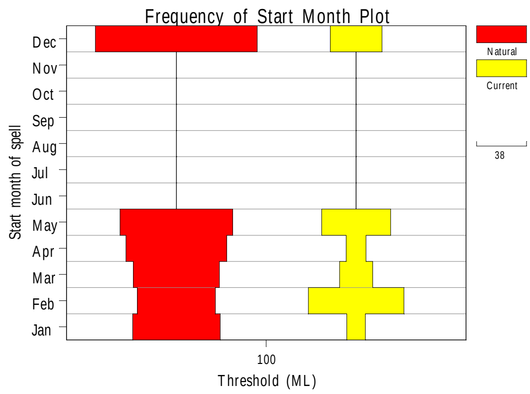
The recommended summer fresh for Reach 3 is 100 ML/day. There are relatively few low level benches in the lower half of this reach and therefore summer freshes will only serve to increase the wetted perimeter and wet large woody debris within the channel (Figure 4-35). However, summer freshes are expected to improve or help maintain surface water quality conditions; in particular help maintain dissolved oxygen levels and reduce the risk of algal blooms. The fresh is not considered large enough to turn over saline pools (McGuckin 1990) as repeated short term mixing events followed by restratification are likely to have an adverse effect on aquatic biota.

Under natural conditions, flows greater than 100 ML/day would have occurred in Reach 3 four times per summer and had a median duration of six days (Figure 4-36). Under current conditions, freshes greater than 100 ML/day occur on average twice each summer and have a median duration of eight days (Figure 4-36). Freshes would have naturally occurred throughout summer, but were most common in December and May. The recommendation for Reach 3 is to deliver three 100 ML/day summer freshes for six days. These freshes should be delivered between February and May to avoid flushing fish nursery habitats. However, freshes may be released in December and January if water quality in the reach deteriorates. At present, there is insufficient information to determine specific water quality thresholds that would trigger a release and therefore continuous probes should be used to measure dissolved oxygen and salinity to quantify temporal water quality patterns and establish reliable trigger levels. A reliable trigger value for algal blooms should also be established.



- **Figure 4-35 Stage height in cross sections four (top) and five (bottom) at recommended threshold for summer/autumn freshes at Spencer Road.**

SKM

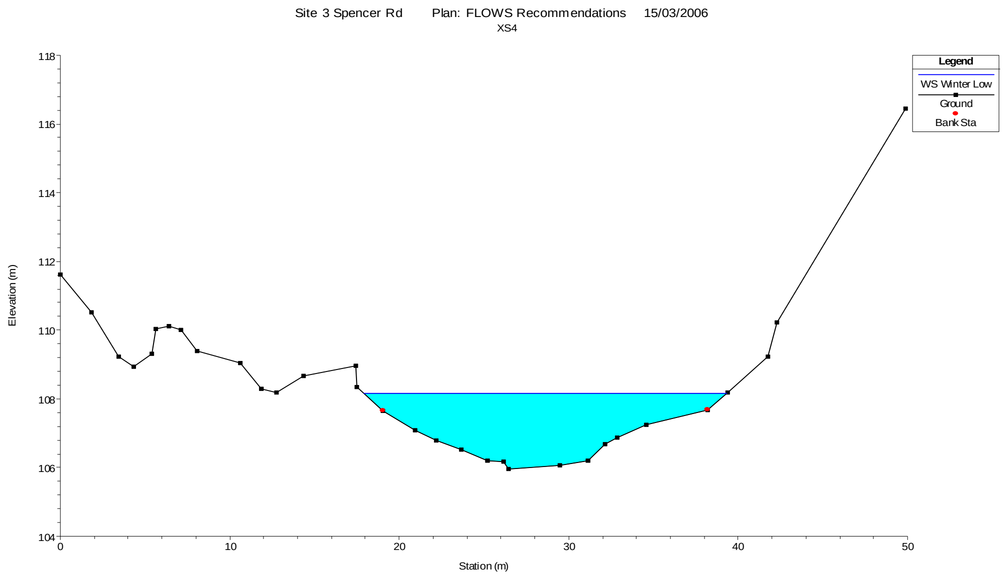


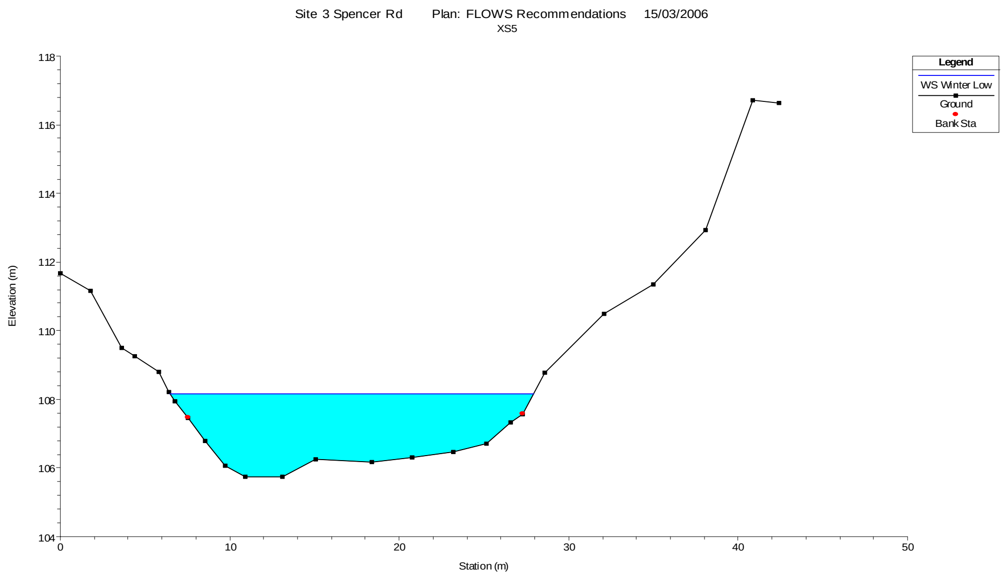
- **Figure 4-36 Duration (top left), frequency (top right) and start month (left) for flows above the summer/autumn fresh threshold of 100 ML/d at Spencer Road under natural and current conditions for Reach 3.**

Winter/spring: low flow

The recommended winter low flow for Reach 3 is 200 ML/day. This flow slightly increases the wetted perimeter in the channel compared to summer low flow and summer fresh, but does not inundate any additional channel features (Figure 4-37). The winter low flow magnitude was primarily set to address water quality issues. The winter low flow is considered to be of a sufficient magnitude to prevent saline pools from re-forming (McGuckin 1990). However, it is not clear whether this flow is sufficient to mix pools that are already stratified. The North Central CMA is currently undertaking further work to quantify the behaviour of saline pools in the lower Campaspe River under different flow conditions and the results of this work may cause this low flow recommendation to be revised.

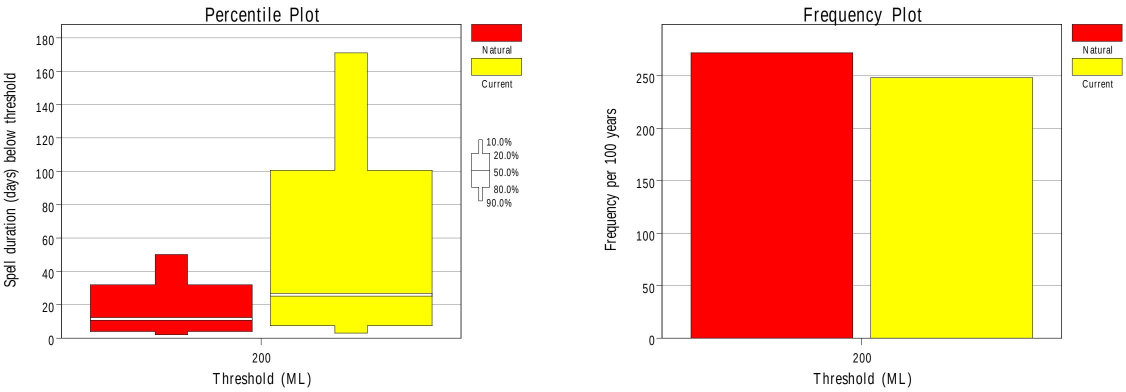
Under natural conditions, winter flows less than 200 ML/day would have occurred on average 2.5 times per year in Reach 3 for a median of 15 days (Figure 4-38). Under current conditions, winter flows less than 200 ML/day occur with similar frequency, but have a median duration of 30 days (Figure 4-38). The winter low flow recommendation of 200 ML/day therefore returns some flow through this reach.

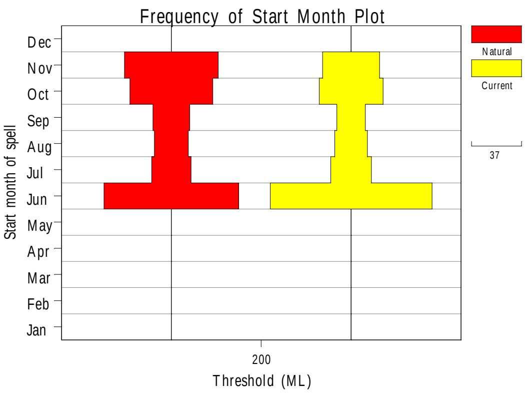




- **Figure 4-37 Stage height in cross sections four (top) and five (bottom) at recommended threshold for winter low flows at Spencer Road.**

SKM



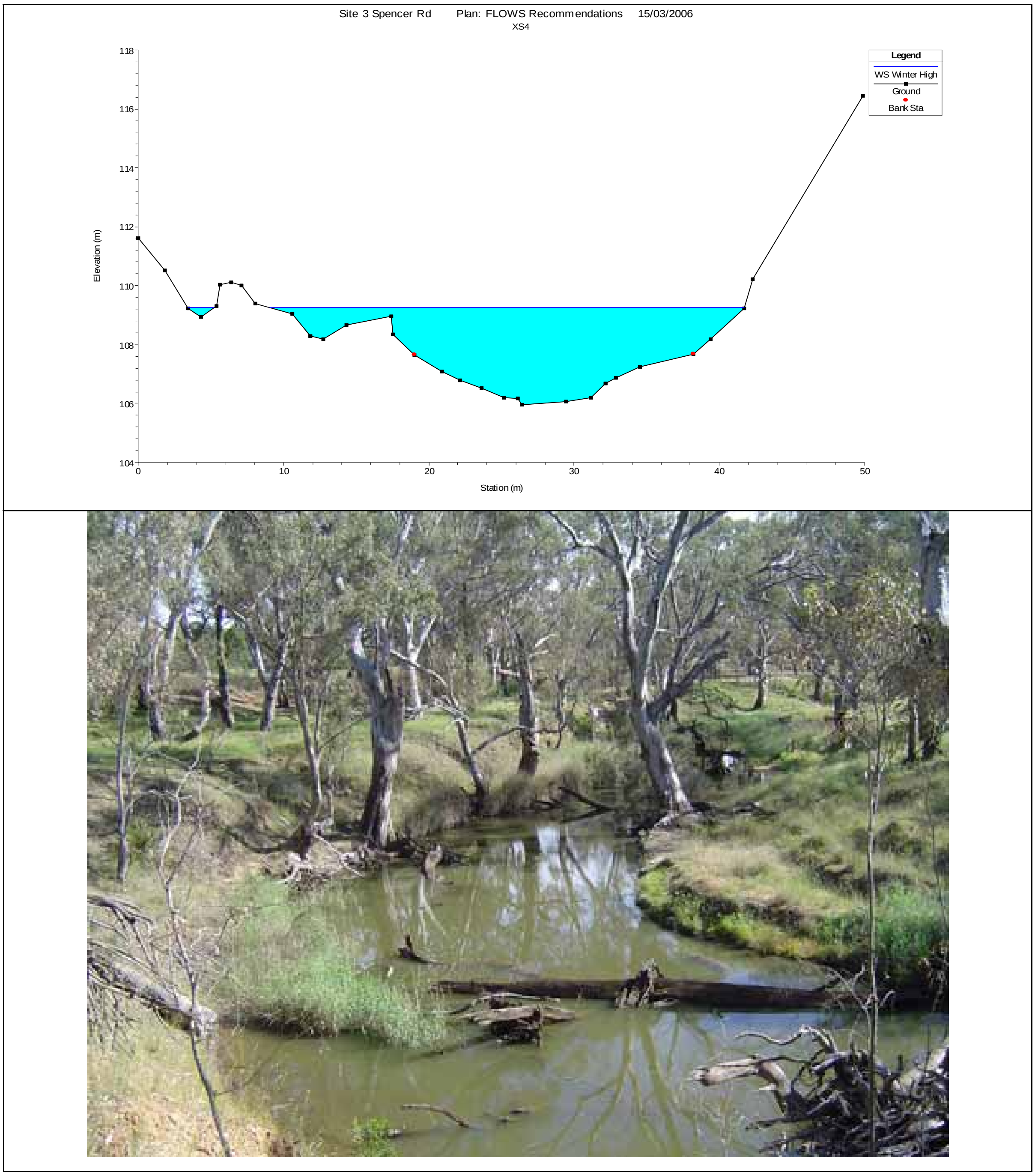


- **Figure 4-38 Duration (top left), frequency (top right) and start month (left) for flows below the winter/spring low flow threshold of 200 ML/d at Spencer Road under natural and current conditions for Reach 3.**

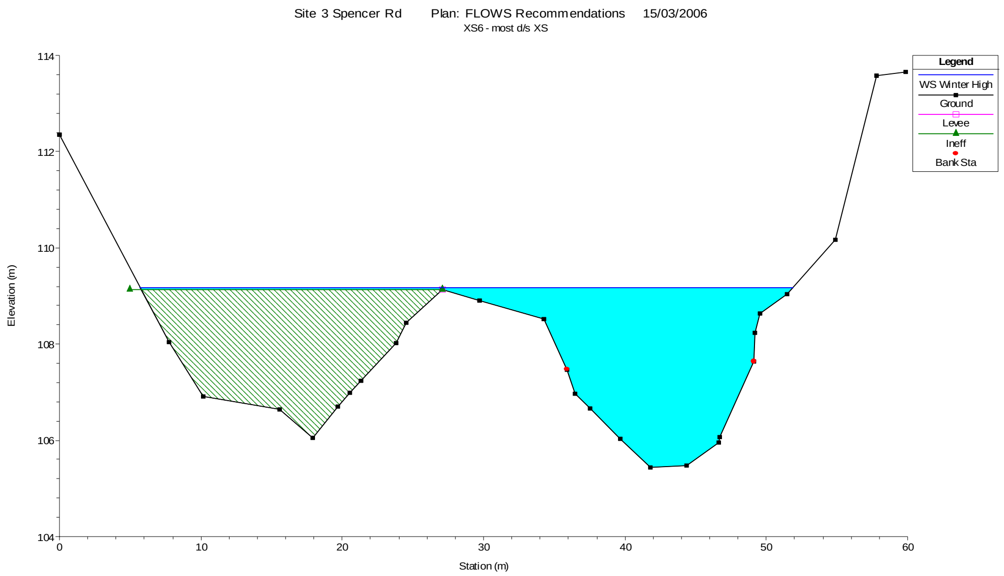
Winter/spring: high flow

The recommended winter high flow for Reach 3 is 1500 ML/day. This flow will cover benches at mid channel height (Figure 4-39) and connect other in channel features such as the perched pool in cross section six (Figure 4-40). A high flow early in winter is recommended to mix pools and help aquatic plants such as *Bolboschoenus* that cannot tolerate prolonged dry periods (Roberts and Marston 2000). High flows in late winter and spring will enhance River Red Gum and other native plant regeneration within the channel (Bren 1988, 1990, Nichol and G.G. 2000, Roberts and Marston 2000, Robertson *et al.* 2001) and help prevent encroachment by exotic terrestrial species (Frankenberg and Tilleard 1991, Buchanan 1999).

Under natural conditions flows greater than 1500 ML/day would have occurred on average four times each winter for a median duration of four days (Figure 4-41). Under current conditions, the frequency and duration of winter high flows have been halved (Figure 4-41). The recommendation for this reach restores the natural frequency of winter high flows. These flows should be spread throughout the winter/spring period as flows at the start of winter provide different ecological functions to spring flows. Under natural conditions, flows would only exceed 1500 ML/day four times per year on average, therefore it is recommended that some of these winter high flows be allowed to rise to bankfull or overbank flow levels.

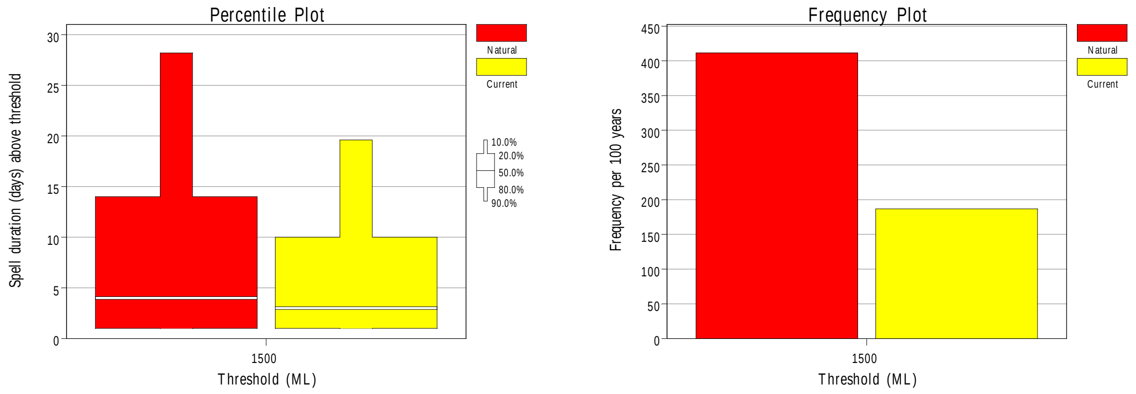


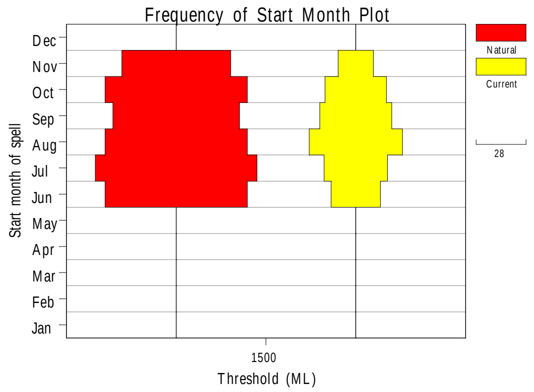
- **Figure 4-39: Plot showing stage height across channel benches in cross section four at the recommended threshold for winter high flows at Spencer Road. Photo shows areas likely to be inundated by the winter high flow.**



- **Figure 4-40 Plot showing stage height across the waterbody at cross section six at the recommended threshold for winter high flows at Spencer Road. Photo shows area likely to be inundated by the winter high flow.**

SKM



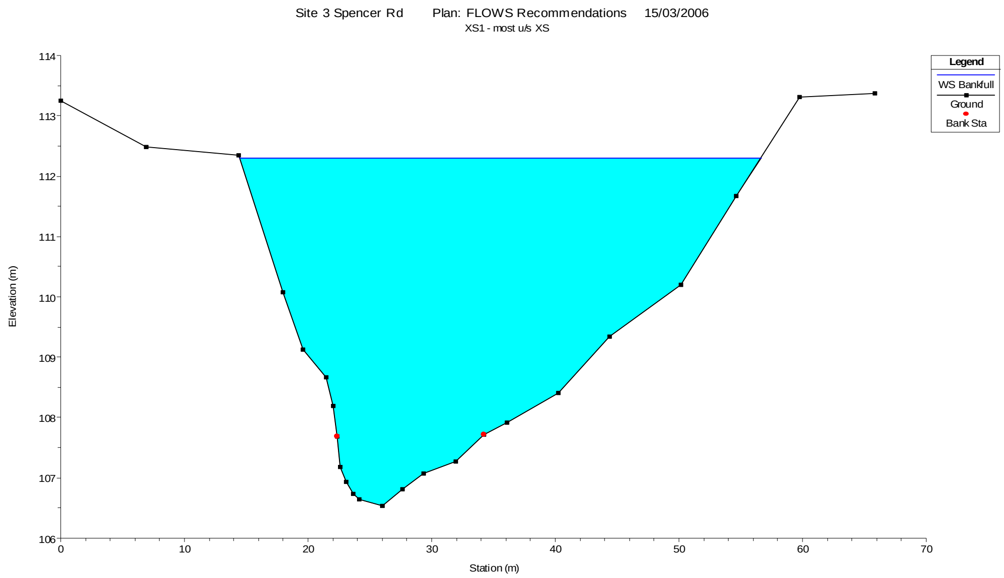


- **Figure 4-41 Duration (top left), frequency (top right) and start month (left) for flows above the winter/spring high flow threshold of 1500 ML/d at Spencer Road under natural and current conditions for Reach 3.**

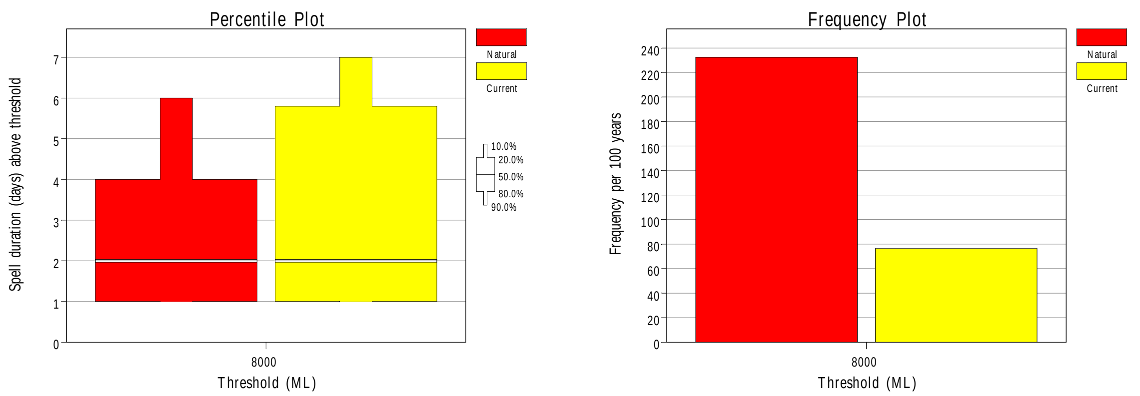
Winter/spring: bankfull

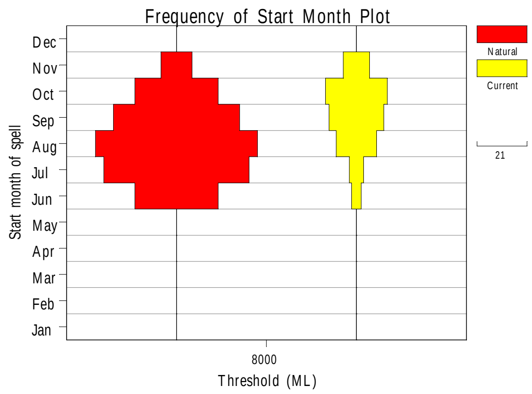
The winter/spring bankfull flow recommendation for Reach 3 is 8000 ML/day. These flows will fill the channel (Figure 4-42), mobilise sediment (Gordon *et al.* 1992) and help scour *Typha* (Moss 1998). The flows will also promote River Red Gum regeneration and other native riparian species within the channel (Bren 1988, 1990, Nichol and G.G. 2000, Roberts and Marston 2000, Robertson *et al.* 2001) and reduce encroachment from exotic terrestrial species (Frankenberg and Tilleard 1991, Buchanan 1999).

Under natural conditions, bankfull flows greater than 8,000 ML/day would have occurred on average 2.3 times per year and had a median duration of two days (Figure 4-43). Under current conditions, bankfull flows occur less than once per year on average, but they have a median duration of two days. The recommendation for this reach is to deliver two bankfull flows of 8,000 ML/day each winter and where possible to allow one of these flows to spill onto the floodplain.



- **Figure 4-42 Plot showing stage height at cross section one during a bankfull flow event in Reach 3. The photo shows the top of the bank and features that will be inundated during a bankfull flow.**



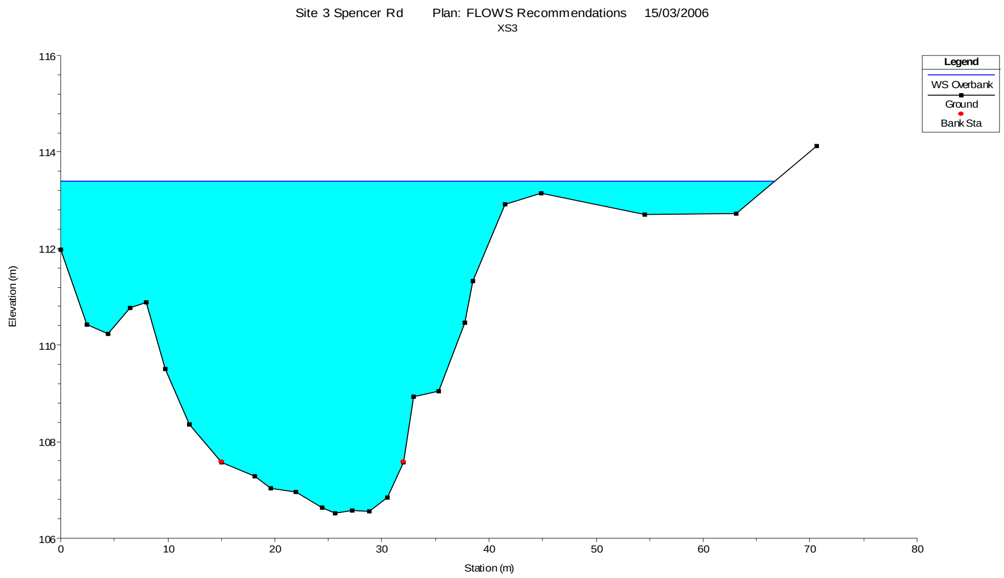


- **Figure 4-43 Duration (top left), frequency (top right) and start month (left) for flows above the winter/spring bankfull flow threshold of 8000 ML/d at Spencer Road under natural and current conditions for Reach 3.**

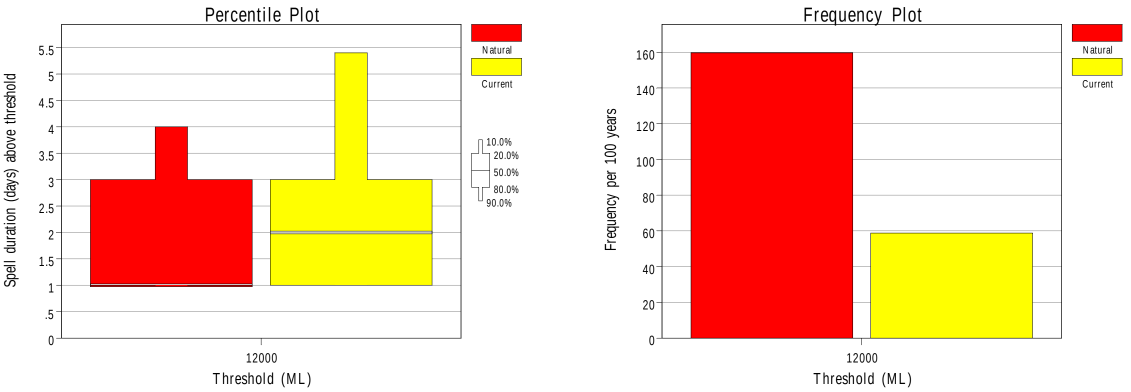
Winter/spring: overbank

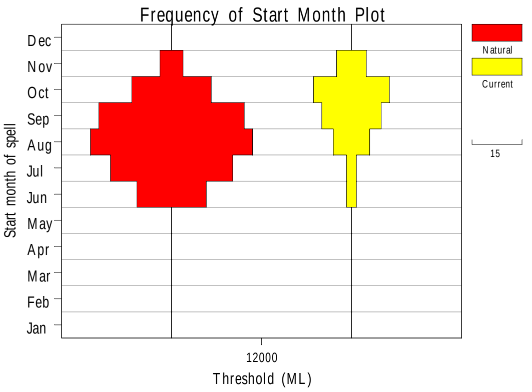
Some floodplain sections along Reach 3 contain remnant River Red Gum forest and an overbank flow is recommended to help promote regeneration in these areas. The recommended overbank flow for Reach 3 is 12,000 ML/day. This flow will inundate the wooded floodplain above the right hand bank at Spencer Road (Figure 4-44), but will not adversely affect nearby roads and farmland.

Under natural conditions, overbank flows would have occurred on average 1.5 times a year in Reach 3 for a median duration of 1 day. Under current conditions, overbank flows only occur once every two years, but they have a median duration of 2 days (Figure 4-45). The recommendation for this reach is to allow one bankfull flow to spill onto the floodplain for one day each year. If possible, this overbank flow should occur in August or Spring to coincide with the natural timing of these events and to help cue fish migration.



- **Figure 4-44 Plot showing stage height at cross section three during an overbank flow in Reach 3. The photo on the right is looking downstream through cross section three and shows the River Red Gum woodland that will benefit from overbank flows.**



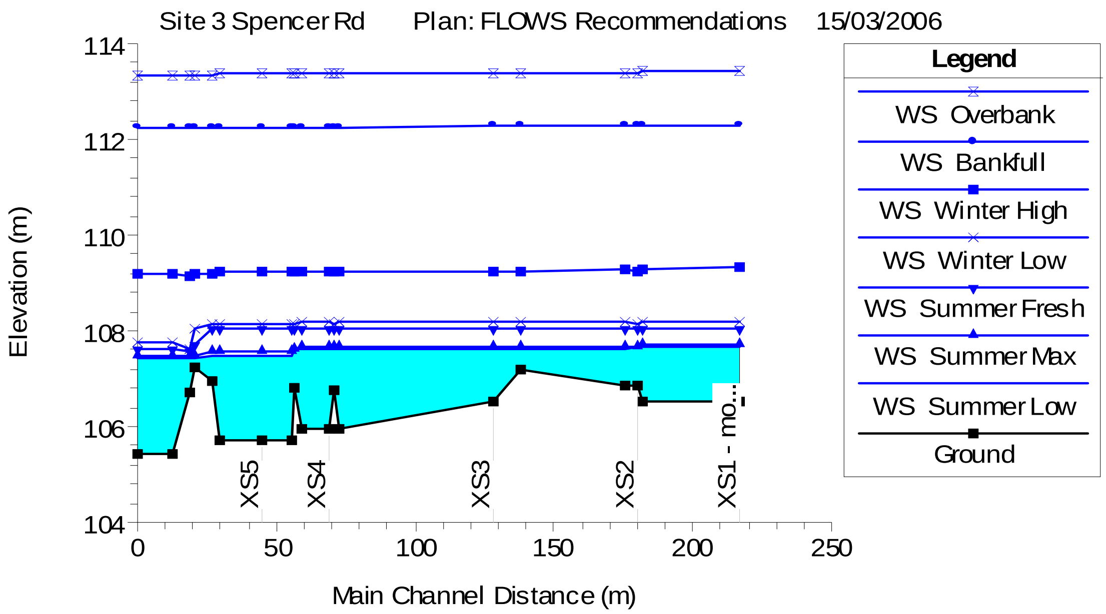


- **Figure 4-45 Duration (top left), frequency (top right) and start month (left) for flows above the winter/spring overbank flow threshold of 12000 ML/d at Spencer Road under natural and current conditions for Reach 3.**

Long section

The water surface level for each flow threshold along the Spencer Road site in Reach 3 is shown in Figure 4-46. The plot shows that the channel is characterised by a series of runs and pools of varying depth. Water surface levels indicate the variation in depth between runs (cross section four) and deeper pools (cross sections three and five).

SKM



- **Figure 4-46 Long section showing water surface (WS) level for all flows in Reach 3. Elevations are relative to a single high point at each site that is given an arbitrary elevation of 100.**

Comparison with previous environmental flow recommendations

Marchant *et al.* (1997) recommended a minimum flow of 80 ML/day or natural (whichever is less) year round for the Campaspe River between the Campaspe Weir and Campaspe Siphon to control water quality. This recommendation is higher than the summer low flow recommendation and lower than the winter low flow recommendation determined in the current environmental flow study. Hydraulic modelling used in the current environmental flow study indicated that flows greater than 20 ML/day could create velocities in excess of 0.1 m/s in some slackwater habitats, which may be too fast for larval and juvenile fish in these habitats and affect native fish recruitment in the system. The EFTP considered that summer low flows less than 20 ML/day with occasional freshes would be sufficient to control water quality without adversely affecting important fish nursery habitats. The North Central CMA is conducting follow up studies to investigate the behaviour of saline pools in the Campaspe River under different flow conditions, review velocity tolerances of larval fish and assess the likely persistence and distribution of slackwater habitats under different flow conditions. If these studies demonstrate that that higher summer flows are needed to maintain water quality through this reach and that such flows will not adversely affect fish recruitment, then the summer low flows recommended in this report may need to be revised.

4.3.3 Current compliance with recommendations

Compliance with environmental flow recommendations for Reach 3 is presented in Table 4-9. Under current conditions, the summer low flow range of 10-20 ML/day is only met 37% of the

SKM

time. Current flows through this reach are less than the recommended summer low flow for much of the time between December and February, but exceed the recommended flow in autumn when irrigation transfer flows are delivered to the Campaspe Siphon. Constant summer flows greater than 20 ML/day are considered inappropriate for this reach as they may threaten fish nursery habitats. High irrigation flows also prevent a proper assessment of compliance for summer freshes. The environmental flow recommendation requires three summer freshes of 100 ML/day that last for six days, however, irrigation transfers ensure that flows remain above this level for most of March and April and therefore the flow variation associated with delivering summer freshes is lost.

Current winter flows are less than the natural winter flows for Reach 3 and therefore compliance with the recommended environmental flows can be assessed in the normal manner. Winter low flows are only met 31 % of the time and although the recommended winter high flows occur in 61% of years, the number of events in each year and duration of these events is substantially less than recommended. Two bankfull and one overbank flow are recommended for this reach each year, but these flows are delivered less than once every five years under the current flow regime.

In summary, the current flow regime does not comply with the recommended environmental flow requirements due to elevated autumn flows and substantially reduced winter and spring flows.

- **Table 4-9 Compliance of the current flow regime in Reach 3 with flow recommendations. Compliance is estimated by applying the current system operation to the 1891 - 2005 flow record.**

Flow recommendations				Percentage of years (vol & no.) or events (dur.) when flow recs are complied with for the current flow regime
Component	**Time**	**Flow Recommendation**		
Summer low	**December - May**	**Volume**	10-20	37
Winter low	**June – November**	**Volume**	200	31
Winter high	**June - November**	**Volume**	1,500	61
		Number	4	22
		Duration	4	43
Winter bankfull	**June - November**	**Volume**	8,000	17
		Number	2	17
		Duration	2	76
Winter overbank	**August – September**	**Volume**	12,000	19
		Number	1	19
		Duration	1	100

SKM

4.4 Reach 4 – Campaspe River: Campaspe Siphon to the River Murray

4.4.1 Current condition

The current condition of Reach 4 is detailed in the *Issues Paper* (SKM 2006a) and summarised below in Table 4-10.

- **Table 4-10 Current condition of Reach 4 – Campaspe River: Campaspe Siphon to the River Murray.**

Aspect	Current condition
Hydrology	▪ Mean annual flow at Campbell Road has been reduced from 890 ML/day to 320 ML/day. ▪ The current flow regime is characterised by longer periods of low flow and shorter high flow periods compared to natural. ▪ Natural seasonal flow pattern is generally retained, but the high flow period generally persists through all of spring rather than peaking in September.
Geomorphology	▪ Slight increase in sand probably due to observable toe erosion, but gross morphology of the channel appears unaltered by regulation.
Vegetation	▪ Clearing of original riparian vegetation and presence of exotic and weedy species. ▪ Reduced flooding, leading to poor recruitment of juveniles. ▪ Grazing and stock access, leading to poor recruitment of juvenile natives and spread of weeds. ▪ Year-round reduced flow restricts habitats for in-stream plants. ▪ Reduced flows and possible nutrient enrichment encourage dense growth of *Typha* and *Phragmites*.
Fish	▪ Reduction in high flow period prevents the upstream and downstream movement of native fish species. ▪ Small gauging weir at Echuca prevents movement upstream at low flows. ▪ Saline pools may be a barrier to movement and limit habitat during low flows. ▪ Alien species are significant stressors to this reach.
Water quality	▪ General condition – poor, due to presence of saline pools. ▪ Saline pools are a major problem (EC levels increase with downstream distance from the Siphon). ▪ Nutrient enrichment due to agricultural run-off, irrigation drains, urban run-off and industry. ▪ No temperature effect from Lake Eppalock.
Macroinvertebrates	▪ General condition – moderate to poor and dominated by pollution tolerant taxa (ISC assessment (DSE 2005)). ▪ Large woody debris and reeds provide important habitat. ▪ Moderate diversity. ▪ Community dominated by collector/gatherers.

4.4.2 Flow recommendations

The environmental flow recommendations for Reach 4 are summarised in Table 4-11. The main assessment for Reach 4 was based on modelled flows and cross section data from Campbells Road, which is near Echuca but upstream of any influence from the River Murray, these flows were checked at the Strathallan Site downstream of the Campaspe Siphon. There are no major tributary inflows between the Campaspe Siphon and Echuca, therefore recommended flows have the same magnitude at each site.

- **Table 4-11 Summary of flow recommendations for Reach 4 – Campaspe River: Campaspe Siphon to River Murray.**

Stream		Campaspe River		**Reach**	Campaspe Siphon to River Murray		
Compliance point		Site 2 - Strathallan		**Gauge No.**	406265		
Season	**Component**	**Volume**	**Frequency**	**Duration**	**Rise**	**Fall**	**Objective**
Summer	Low flow	10 ML/d (Not more than 20 ML/d*)	1 per year	6 months			V4-1, F4-1, W4-1, M4-1
	Freshes	100 ML/d	3 per year (Feb to May**)	6 days	230%	65%	V4-2, F4-2, W4-2, M4-2
Winter	Low flow	200 ML/d (or natural)	1 per year	6 months			F4-3, W4-1, M4-1
	High flow	1500 ML/d	2 per year (or natural)	4 days	230%	65%	V4-3, V4-4, F4-4, W4-2, M4-2
	Bankfull flow	9,000 ML/d	2 per year (or natural)	2 days	230%	65%	G1-1, V4-5, F4-4

* This value may be reviewed after planned work assessing behaviour of saline pools and slackwaters in different flow conditions has been completed.

** Additional freshes may be released between December and February to manage water quality if required.

Stream		Campaspe River		**Reach**	Campaspe Siphon to River Murray		
Compliance point		Site 1 - Campbells Road		**Gauge No.**	406265		
Season	**Component**	**Volume**	**Frequency**	**Duration**	**Rise**	**Fall**	**Objective**
Summer	Low flow	10 ML/d (Not more than 20 ML/d*)	1 per year	6 months			V4-1, F4-1, W4-1, M4-1
	Freshes	100 ML/d	3 per year (Feb to May**)	6 days	230%	65%	V4-2, F4-2, W4-2, M4-2
Winter	Low flow	200 ML/d (or natural)	1 per year	6 months			F4-3, W4-1, M4-1
	High flow	1500 ML/d	2 per year (or natural)	4 days	230%	65%	V4-3, V4-4, F4-4, W4-2, M4-2
	Bankfull flow	9,000 ML/d	2 per year (or natural)	2 days	230%	65%	G1-1, V4-5, F4-4

* This value may be reviewed after work to assess the behaviour of saline pools and slackwaters in different flows is done.

** Additional freshes may be released between December and February to manage water quality if required.

Summer/autumn: cease to flow

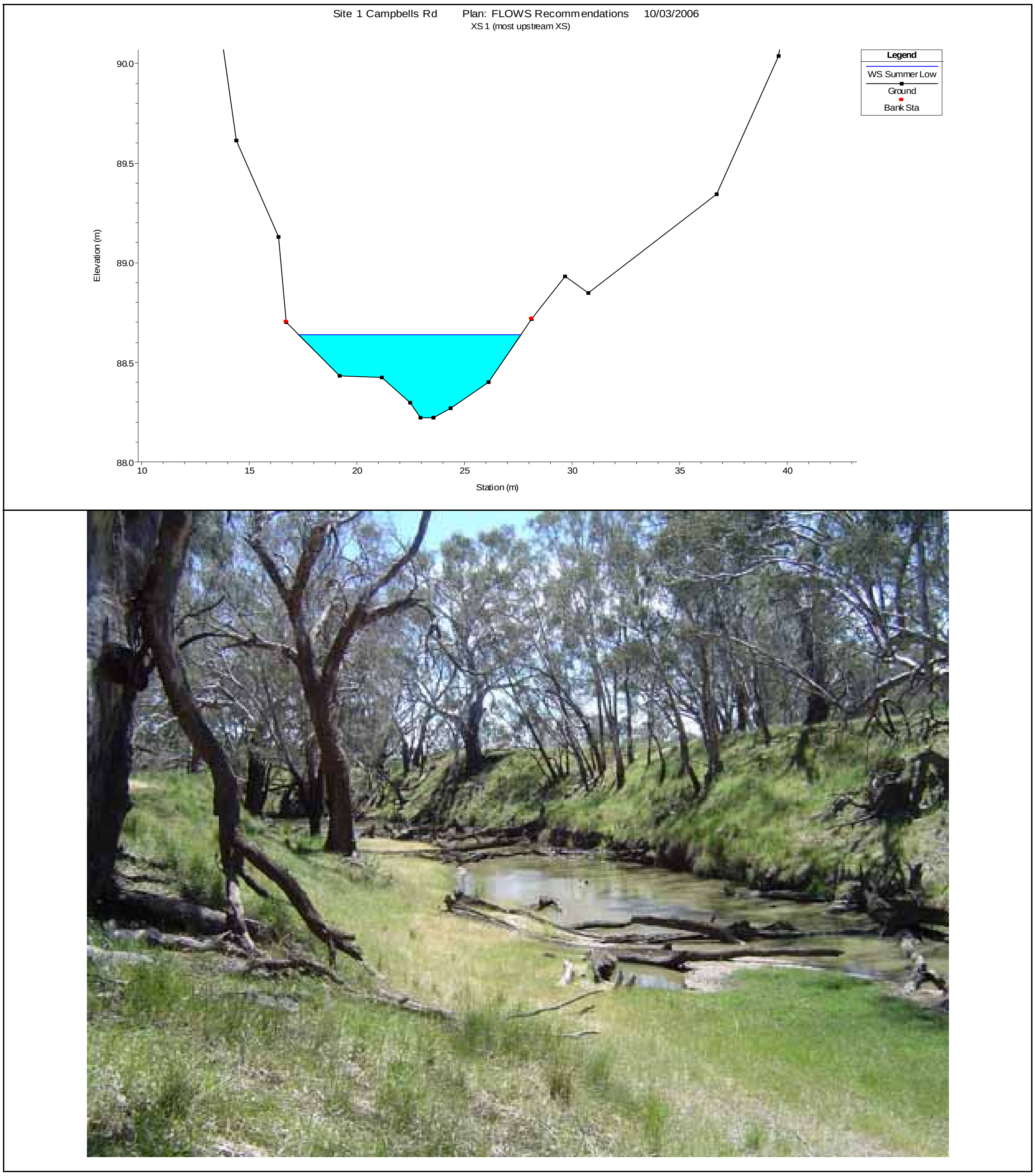
Cease to flow events would have naturally occurred in Reach 4. However, re-introducing cease to flow events is likely to exacerbate high salinity levels and low dissolved oxygen levels, particularly near Echuca (McGuckin 1990). We recommend that no cease to flow period be provided in this reach until these water quality issues have been addressed and mitigated.

Summer/autumn: low flow

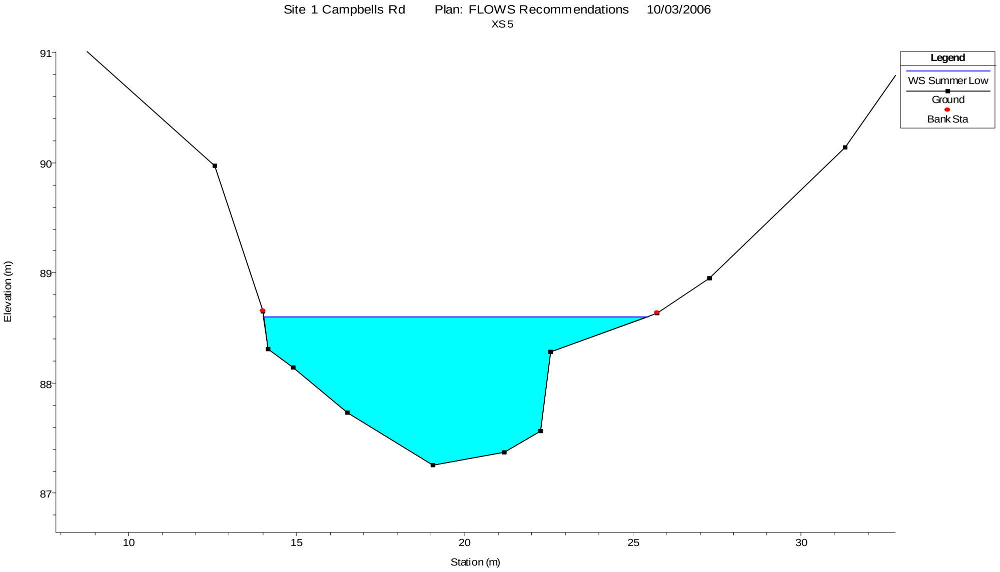
The recommended summer low flow for Reach 4 is 10 ML/day. This flow will maintain flow and aquatic habitat, including slackwaters for juvenile fish, throughout the reach. This flow is unlikely to influence groundwater intrusions, which contribute to the saline pools that occur throughout the reach and particularly near Echuca, but if the recommended summer freshes are delivered, this flow may be adequate to manage water quality through the reach. McGuckin (1990) described the effect that flows between 80 ML/day and 300 ML/day have on saline pools in the lower Campaspe River, but little is known about the behaviour of saline pools for a range of flows below 80 ML/day. The North Central CMA is conducting a study to quantify the behaviour of saline pools under a range of flow conditions in the lower Campaspe River. If this study demonstrates that the recommended summer low flow of 10 ML/day in combination with freshes do not limit salinity levels in the lower Campaspe River, then the summer flow recommendations for this reach may need to be revised.

The Campaspe River downstream of the Campaspe Siphon is characterised by pools and slow flowing run habitats, rather than shallow riffles and the recommended summer flow of 10 ML/day will maintain a depth of 40 cm in the shallowest cross section (Figure 4-47) and a depth of 1.35 m in the deepest cross section surveyed at Campbells Rd (Figure 4-48), which is expected to be adequate for most native species that occur in this reach (SKM 2003).

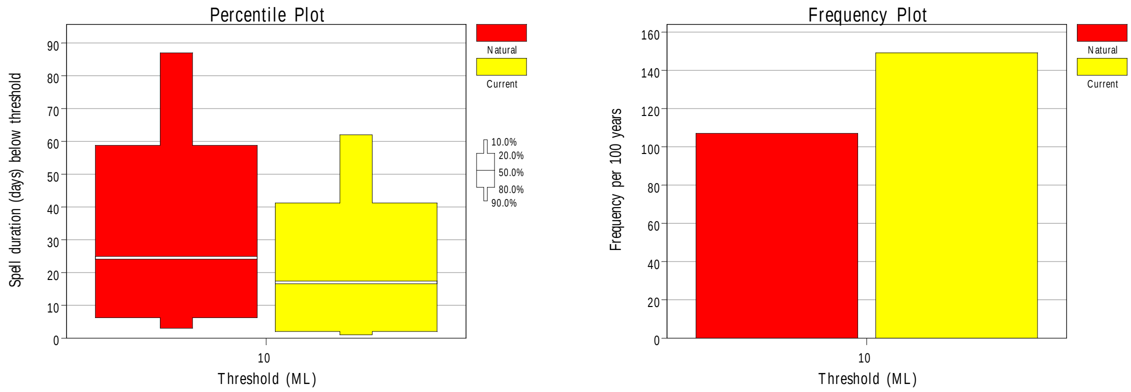
Under natural conditions, flows less than 10 ML/day would have occurred in Reach 4 once a year on average with a median duration of 25 days. Under current conditions, flows less than 10 ML/day occur approximately 1.5 times per year, but they only have a median duration of 17 days (Figure 4-49). It is recommended that the summer low flow for Reach 4 should be 10 ML/day and should not exceed 20 ML/day to preserve slackwater habitats for fish.

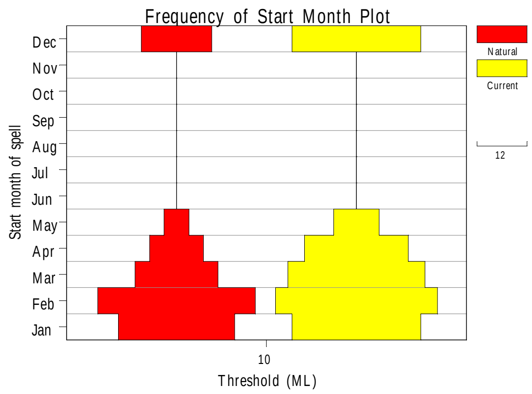


- **Figure 4-47: Stage height in run cross section (cross section one) at the recommended threshold for summer/autumn low flows at Campbells Road. Photo is view looking upstream through cross section one.**



- **Figure 4-48 Stage height in pool (cross section five) at the recommended threshold for summer/autumn low flows at Campbells Road. Photos is looking upstream through cross section five**



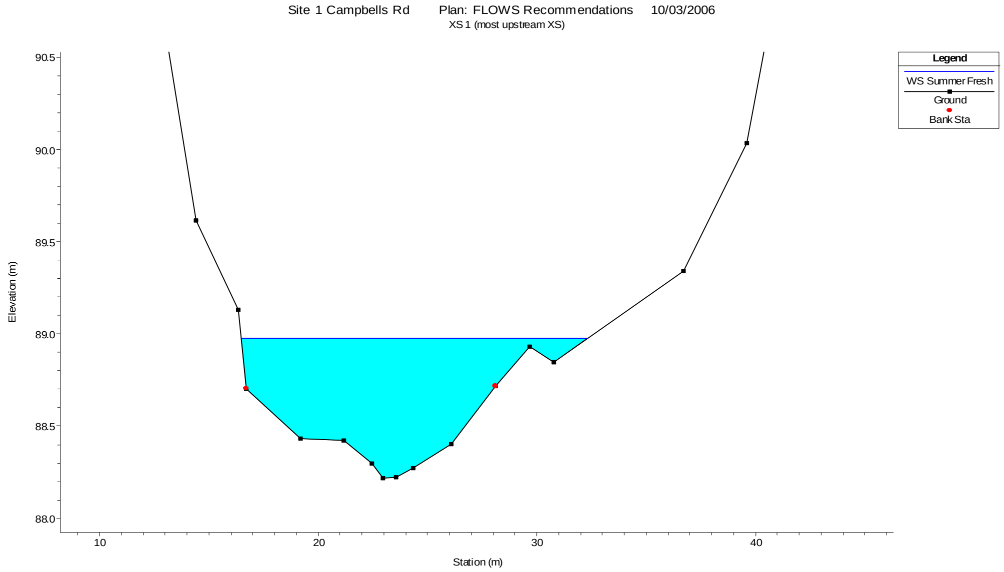


- **Figure 4-49 Duration (top left), frequency (top right) and start month (left) for flows below the summer/autumn low flow threshold of 10 ML/d at Campbells Road under natural and current conditions for Reach 4.**

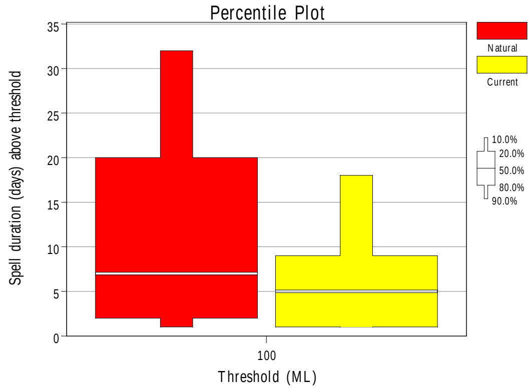
Summer/autumn: freshes

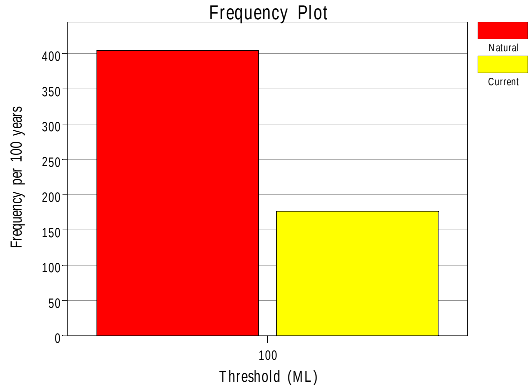
The recommended summer fresh for Reach 4 is 100 ML/day. This flow will wet very low lying benches in the bottom of the channel such as the one observed on the right hand side of the channel at cross section one (Figure 4-50), but larger benches in the bottom of the channel will not be affected. Higher flows would inundate more of the channel and may help to limit the extent of exotic vegetation in the bottom of the channel, but flows above 200 ML/day are likely to flush fish larvae from slackwater habitats and may flush saline water from pools (McGuckin 1990).

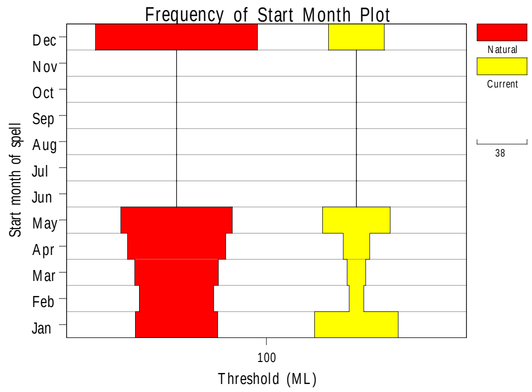
Under natural conditions, flows greater than 100 ML/day would have occurred in Reach 4 four times per summer and had a median duration of seven days (Figure 4-51). Under current conditions, freshes greater than 100 ML/day occur nearly twice each summer on average and have a median duration of five days (Figure 4-51). Freshes would have naturally occurred throughout summer, but were most common in December and May. The recommendation for Reach 4 is to deliver three 100 ML/day summer freshes with a duration of six days. These freshes should be delivered between February and May to avoid flushing fish nursery habitats. However, freshes may be released in December and January if water quality in the reach deteriorates. At present, there is insufficient information to determine specific water quality thresholds that would trigger a release and therefore continuous probes should be used to measure dissolved oxygen and salinity to quantify temporal water quality patterns and establish reliable trigger levels. The North Central CMA is currently undertaking a study that will help address these information gaps.



- **Figure 4-50 Stage height across cross section one showing inundation of shallow bench during a summer fresh. The photo shows the cross section and area affected by the flow.**





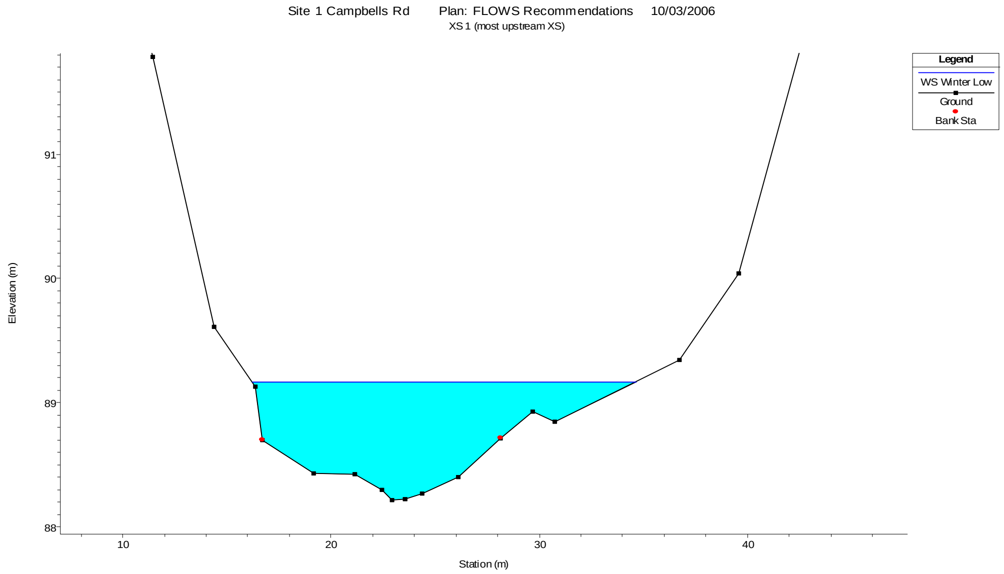


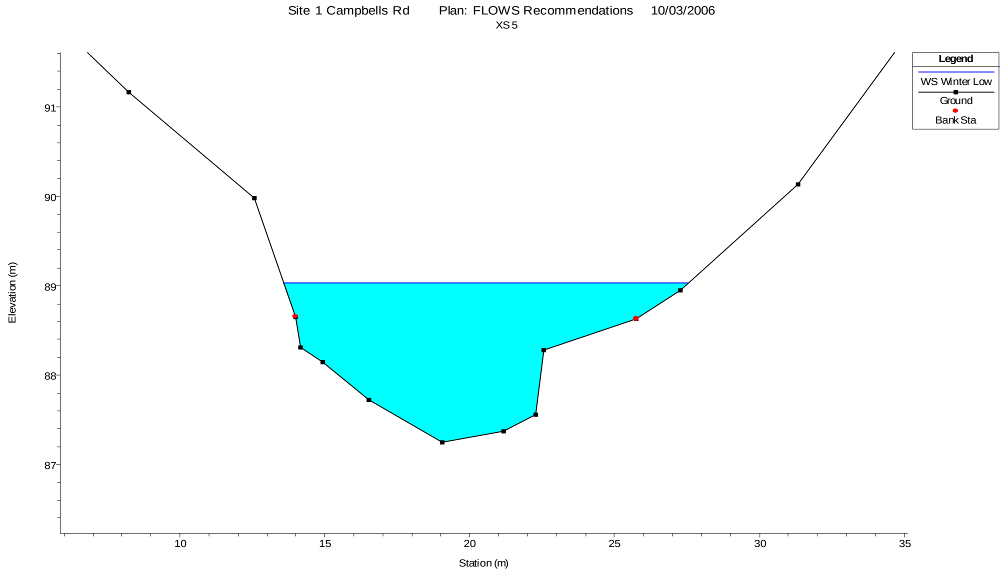
- **Figure 4-51 Duration (top left), frequency (top right) and start month (left) for flows above the summer/autumn fresh threshold of 100 ML/d at Campbells Road under natural and current conditions for Reach 4.**

Winter/spring: low flow

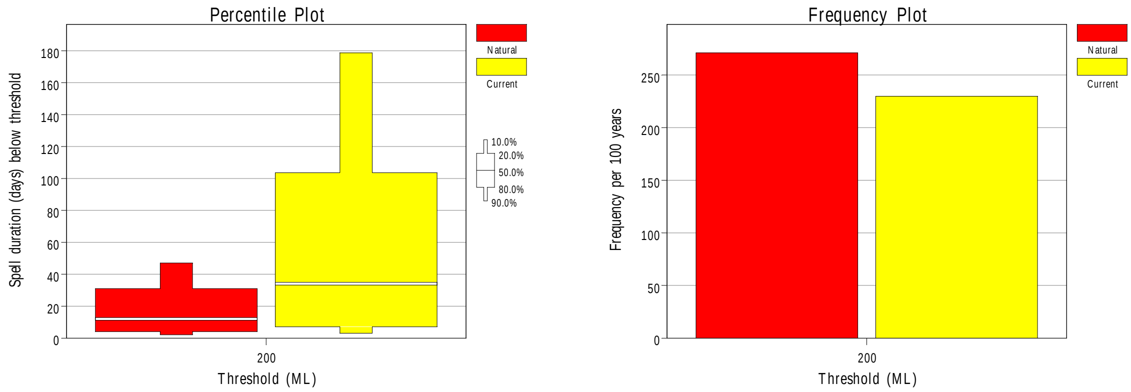
The recommended winter low flow for Reach 4 is 200 ML/day. This flow slightly increases the wetted perimeter in the channel compared to summer low flow and summer fresh, but does not inundate any additional channel features (Figure 4-52). The winter low flow provides a maximum depth of 95 cm in the shallowest glide and 1.8 m in the deepest pool captured in the physical site survey at Campbells Road (Figure 4-52) and therefore provides continuous fish passage (Mallen-Cooper 2001). The winter low flow is considered to be of a sufficient magnitude to prevent saline pools from re-forming (McGuckin 1990). However, it is not clear whether this flow is sufficient to mix pools that are already stratified.

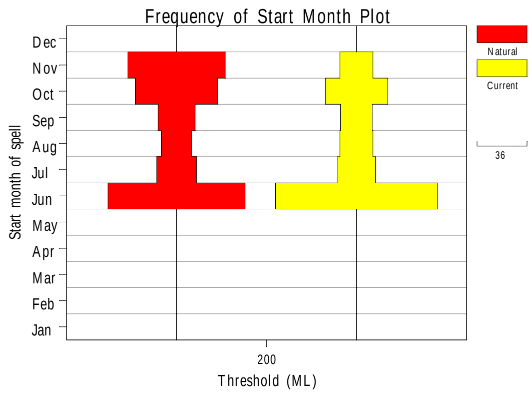
Under natural conditions, winter flows less than 200 ML/day would have occurred on average 2.5 times per year in Reach 3 for a median of 10 days (Figure 4-53). Under current conditions, winter flows less than 200 ML/day occur with similar frequency, but have a median duration of 30 days (Figure 4-53). The winter low flow recommendation of 200 ML/day therefore returns some flow through this reach.





- **Figure 4-52 Stage height in glide (cross section one, top) and pool (cross section five, bottom) cross sections at the recommended threshold for winter/spring low flows at Campbells Road.**



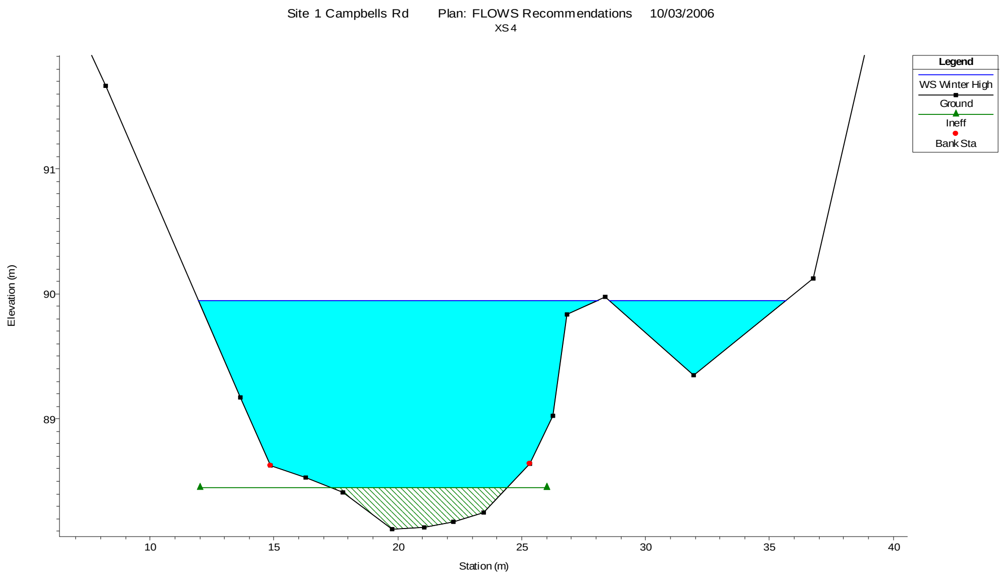


- **Figure 4-53 Duration (top left), frequency (top right) and start month (left) for flows below the winter/spring low flow threshold of 200 ML/d at Campbells Road under natural and current conditions for Reach 4.**

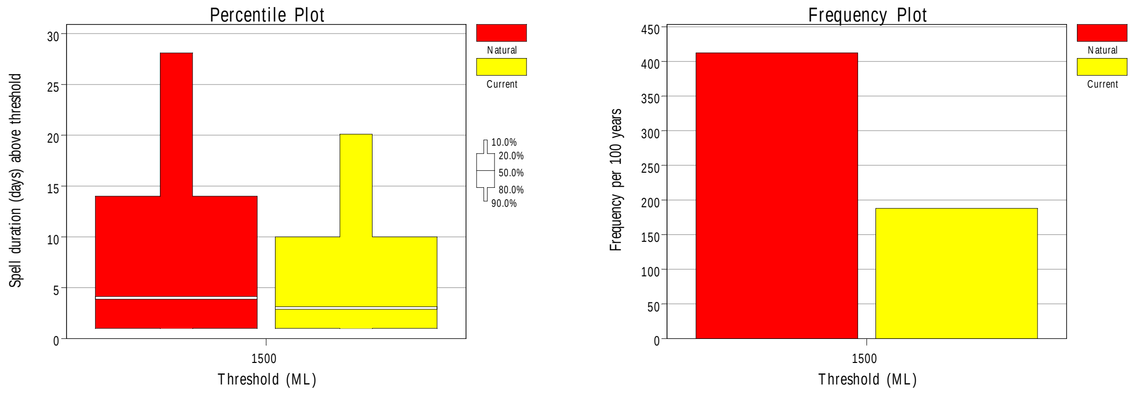
Winter/spring: high flow

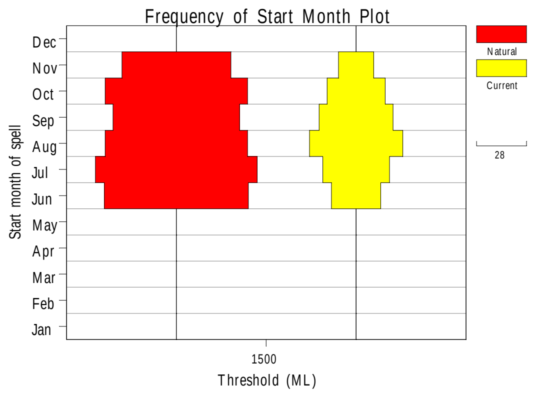
The recommended winter high flow for Reach 4 is 1500 ML/day. This flow will cover benches at mid channel height such as the one shown on the right hand bank at cross section four (Figure 4-54) and inundate all snags within the channel. A high flow early in winter is recommended to mix pools and help aquatic plants such as *Bolboschoenus* that cannot tolerate prolonged dry periods (Roberts and Marston 2000). High flows in late winter and spring will enhance River Red Gum and other native plant regeneration within the channel (Bren 1988, 1990, Nichol and G.G. 2000, Roberts and Marston 2000, Robertson *et al.* 2001), help prevent encroachment by exotic terrestrial species (Frankenberg and Tilleard 1991, Buchanan 1999) and cue fish movement.

Under natural conditions flows greater than 1500 ML/day would have occurred on average four times each winter for a median duration of four days (Figure 4-55). Under current conditions, the frequency and duration of these winter high flows has been halved (Figure 4-55). The recommendation for Reach 4 is to restore the natural frequency and duration of winter high flows, but one or two of these high flows should be allowed to progress to bankfull. Winter high flows should be spread throughout the winter/spring period as flows at the start of winter provide different ecological functions to spring flows.



- **Figure 4-54: Stage height in cross section four showing inundation of mid channel bench on right hand bank. The photo on the right is taken looking downstream through the cross section and shows the bench that will be inundated behind the exposed root mass of the River Red Gum.**



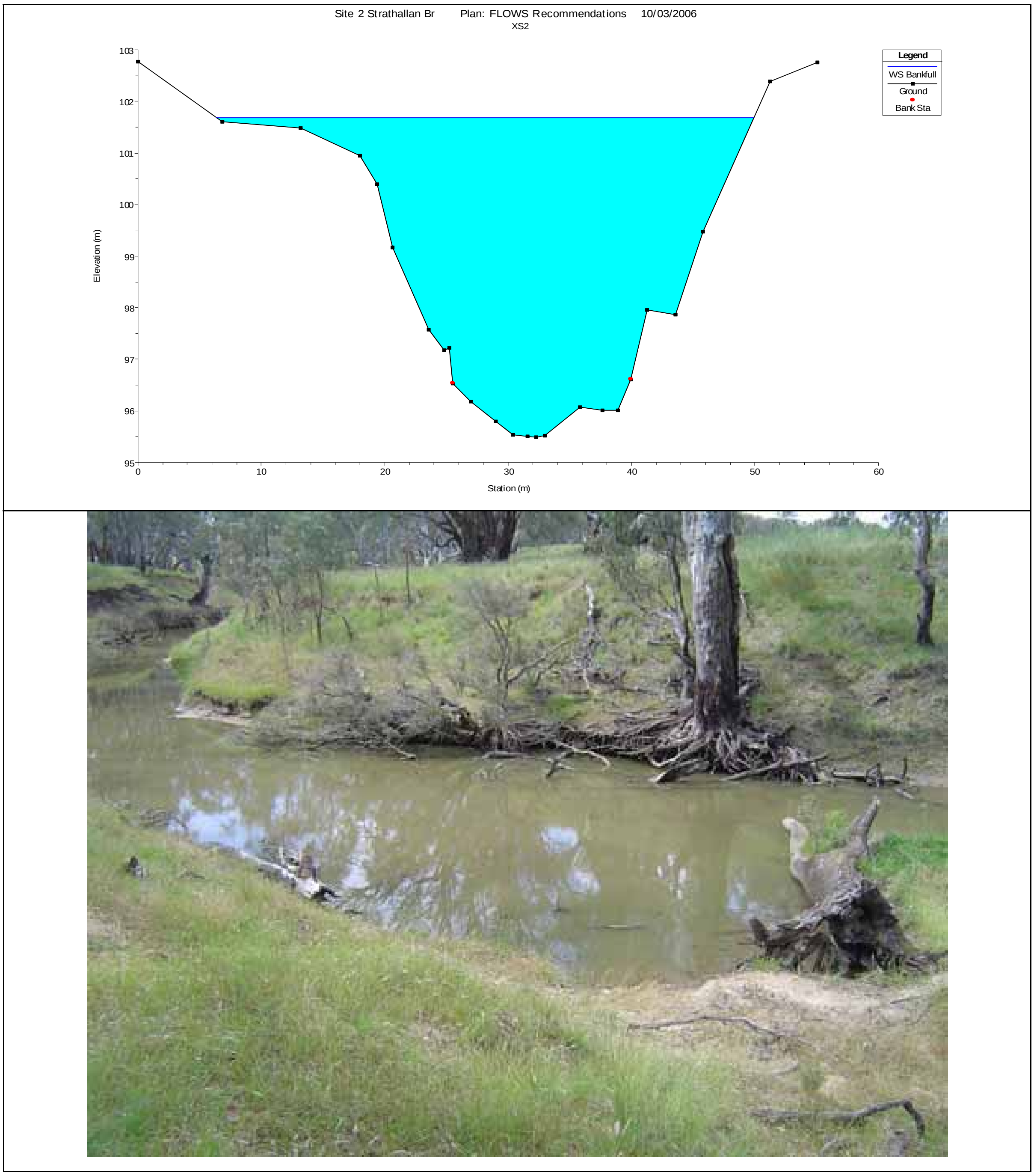


- **Figure 4-55 Duration (top left), frequency (top right) and start month (left) for flows above the winter/spring high flow threshold of 1500 ML/d at Campbells Road under natural and current conditions for Reach 4.**

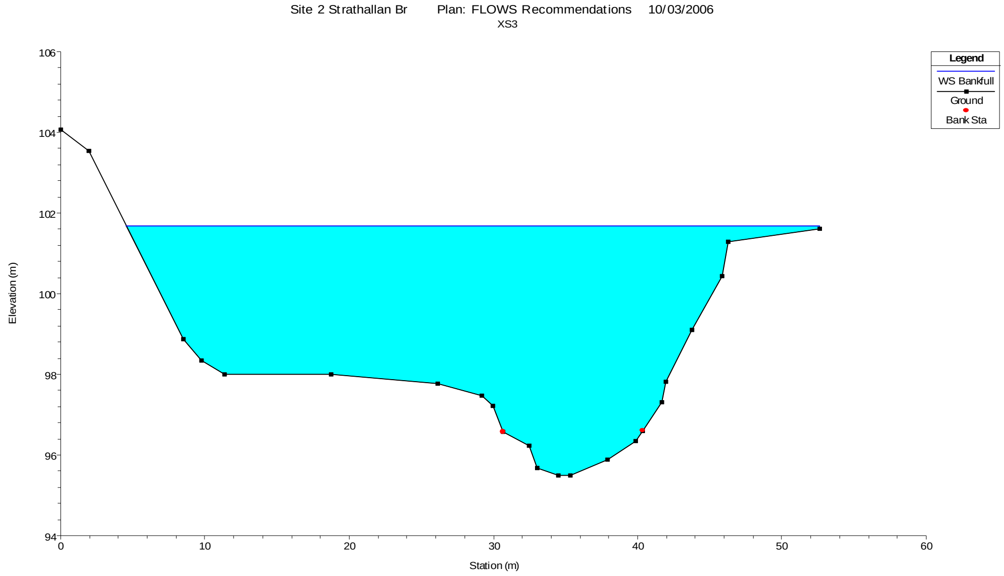
Winter/spring: bankfull

The winter/spring bankfull flow recommendation for Reach 4 is 9000 ML/day. These flows do not fill the channel at the Campbells Road site, but do equate to a bankfull flow at Strathallan (Figure 4-56 & Figure 4-57). These flows will mobilise sediment (Gordon *et al.* 1992), scour *Typha* (Moss 1998) and flush organic matter into the stream (Junk *et al.* 1989). The flows will also promote River Red Gum regeneration and other native riparian species within the channel (Bren 1988, 1990, Nichol and G.G. 2000, Roberts and Marston 2000, Robertson *et al.* 2001) and reduce encroachment from exotic terrestrial species (Frankenberg and Tilleard 1991, Buchanan 1999).

Under natural conditions, bankfull flows greater than 9,000 ML/day would have occurred on average 2 times per year and had a median duration of two days (Figure 4-58). Under current conditions, bankfull flows occur less than once per year on average, but they have a median duration of two days. The recommendation for this reach is to deliver two bankfull flows of 9,000 ML/day each winter.

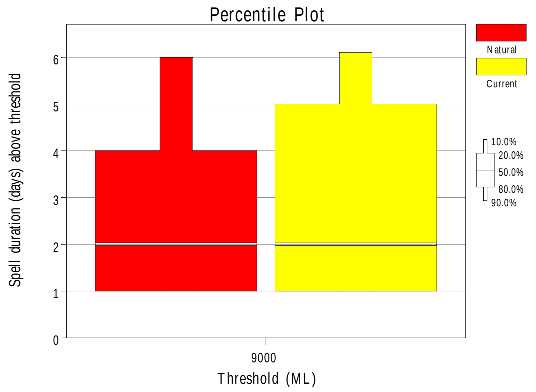


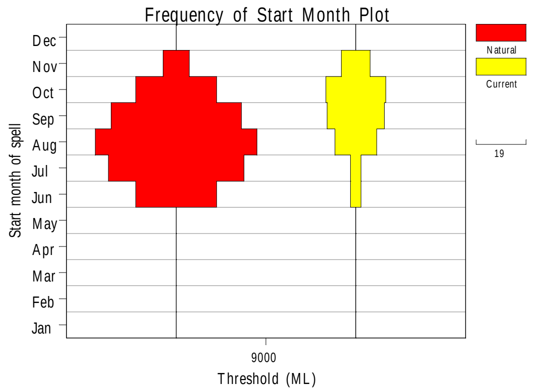
- **Figure 4-56: Plot showing stage height at cross sections 2 at Strathallan for the recommended threshold for winter/spring bankfull flows. Photo shows view looking downstream through cross section 2.**



- **Figure 4-57 Plots showing stage height at cross section three at Strathallan for the recommended threshold for winter/spring bankfull flows. Photo shows view looking downstream through the cross section.**

SKM





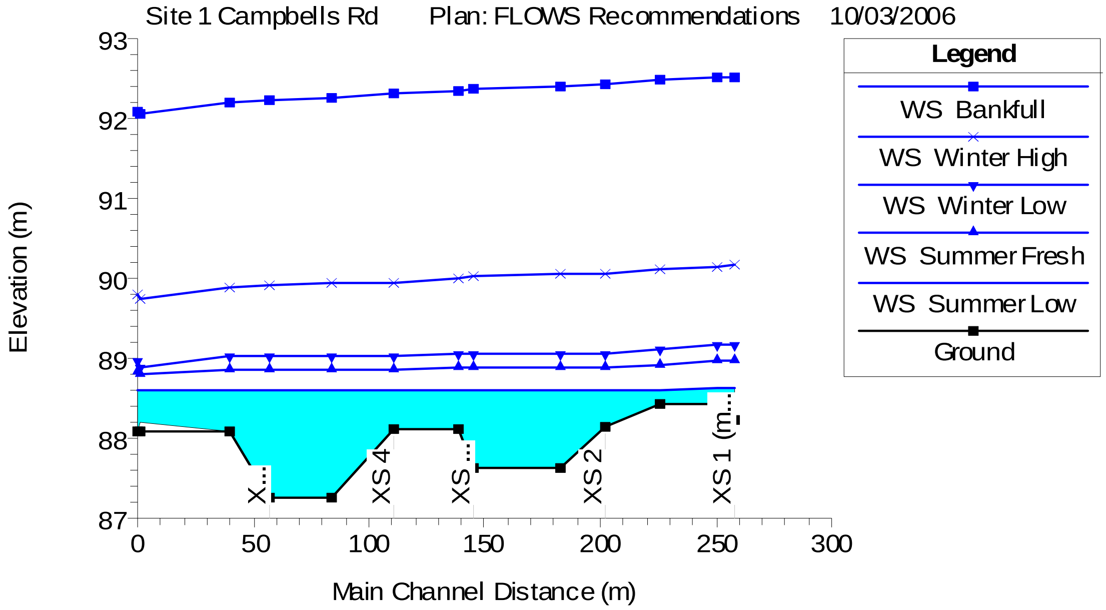
- **Figure 4-58 Duration (top left), frequency (top right) and start month (left) for flows above the winter/spring bankfull flow threshold of 9000 ML/d at Campbells Road under natural and current conditions for Reach 4.**

Winter/spring: overbank

Most of the floodplain in Reach 4 has been extensively cleared to the top of the riverbank and therefore no features were identified that would substantially benefit from an overbank flow in the Campaspe River. A number of wetlands and remnant River Red Gum forest near Echuca are predominantly associated with the River Murray floodplain and will be influenced more by overbank flows in the River Murray than flows in the Campapse River. As a result, no overbank flows are specifically recommended for this reach, however they will presumably occur from time to time and may stimulate some isolated River Red Gum recruitment (Bren 1988, 1990, Nichol and G.G. 2000, Roberts and Marston 2000, Robertson *et al.* 2001).

Long section

The water surface level for each flow threshold along a long section of Reach 4 is shown in Figure 4-59. Water surface levels indicate the variation in depth between the glide (cross section one) and deep pool (e.g. cross section five).



- **Figure 4-59 Long section showing water surface (WS) level for all flows in Reach 4. Elevations are relative to a single high point at each site that is given an arbitrary elevation of 100.**

Comparison with previous environmental flow recommendations

Marchant *et al.* (1997) recommended a minimum flow of 70 ML/day or natural (whichever is less) year round for the Campaspe River below the Campaspe Siphon. This flow was primarily set to manage water quality, in particular saline pools, throughout the reach. The summer low flow recommendation in the current study was set at 10 ML/day so as not to disturb slackwater habitats in the lower Campaspe River and provided the recommended freshes are delivered, is considered sufficient to maintain water quality at the surface of pools throughout the reach. As discussed in Section 4.3.2, the North Central CMA is currently undertaking two studies to assess the behaviour of saline pools and changes to slackwater habitats under different flow conditions in the Campaspe River and the results of these studies may cause these low flow recommendations to be reviewed.

The current environmental flow study addresses the whole flow regime and makes recommendations for high flows, freshes and bankfull flows. These flow components were not considered in the previous environmental flows study and therefore the total flow recommended flow in the current study exceeds that recommended by Marchant *et al.* (1997).

4.4.3 Current compliance with recommendations

Compliance with environmental flow recommendations for Reach 4 is presented in Table 4-12. Under current conditions, the summer low flow requirement is met most of the times, but the magnitude, number and duration of freshes is much lower than recommended. Winter low flows of 200 ML/day are only met 29 % of the time. Winter high flows are delivered in 62 % of years, but in most of these years only one high flow occurs. Two bankfull flows are recommended each year, but under the current flow regime, a single bankfull flow occurs approximately once every six years.

In summary, environmental releases downstream of the Campaspe Siphon, meet most of the summer flow requirements for Reach 4, but the operation of Lake Eppalock and the Campaspe Weir substantially reduce the magnitude and frequency of winter flows.

- **Table 4-12 Compliance of the current flow regime in Reach 4 with flow recommendations. Compliance is estimated by applying the current system operation to the 1891 - 2005 flow record.**

Flow recommendations				Percentage of years (vol & no.) or events (dur.) when flow recs are complied with for the current flow regime
Component	Time	Flow Recommendation		
Summer low	December - May	Volume	10	82
Summer fresh	February - May	Volume	100	57
		Number	3	6
		Duration	6	38
Winter low	June – November	Volume	200	29
Winter high	June - November	Volume	1,500	62
		Number	2	50
		Duration	4	42
Winter bankfull	June - November	Volume	9,000	17
		Number	2	17
		Duration	2	31

5 Complimentary waterway works and investigations

In addition to implementing environmental flow recommendations, complementary waterway works create additional opportunities for improvements in ecological health independent of flows and also maximise the opportunity to achieve the full ecological advantage of environmental flow provisions. Further investigations are needed where there is insufficient data or understanding to enable objective assessment of flow requirements or to be confident in predicted ecological responses to flow or complementary waterways works. A number of key issues are discussed in the following sections.

5.1 Land clearing and stock access

Historic land clearing and current stock access have substantially impacted the riparian vegetation throughout the Campaspe River system. In many places the floodplain has been cleared to the top of the river bank and where present, the floodplain riparian zone is only one tree wide. Many sections of the Campaspe River and Coliban River are not adequately fenced, which means that stock are eroding the river bank and trampling or grazing on riparian plant species, thereby preventing substantial regeneration. The delivery of higher flows to promote regeneration of River Red Gums and other native riparian species will have little effect unless stock are excluded from these areas.

The presence of stock and pasture has also allowed exotic grasses and other pasture species to encroach into the river channel and these plants now dominate the understorey throughout the system. Revegetation works have been implemented in various places throughout the catchment, particularly along the Campaspe River. Some of the revegetated sites now have a well developed shrub layer, but revegetation programs at other sites, including near our field assessment site downstream of the Campaspe Weir, appear to have been unsuccessful.

Stock access and land clearing have also contributed to the high sand load in the Coliban River. Sand slugs are a major feature of the lower Coliban River and have infilled pools to such an extent that low flows are conveyed entirely through the hyporheic zone in some sections. Sand slugs have also smothered important fish habitat in the Coliban River. This sand has reduced the quality and quantity of refuge pools during low or cease to flow periods and has substantially reduced fish passage throughout the reach during low flows.

5.2 Willow and weed management

Willows are present throughout the Campaspe River catchment, but are a particular problem upstream of Lake Eppalock. Most of the sites visited during our initial site inspection had extensive willow infestation and in many cases willow root masses has completely altered the morphology of the channel. The section of the Coliban River between Malmsbury and the Upper Coliban Reservoir was excluded from this flows assessment in part because of the extensive willow and blackberry infestation. A dedicated willow removal program is needed in these areas before environmental flows and other associated catchment management works are to be effective.

5.3 Fish passage

The Campaspe River and some sections of the Coliban River have a high load of large woody debris and numerous slackwater habitats, which are both key habitats for adult and laval fish. Many of the recommended environmental flows are aimed at preserving slackwater habitats and providing cues or sufficient water for fish movement. Despite the presence of good physical habitat, the fish numbers in the Campaspe and Coliban Rivers are low compared to other similar lowland rivers, and many populations are maintained primarily through stocking. Fish would have naturally migrated between the Campaspe River and the River Murray, but barriers such as Echuca Weir, the Campaspe Siphon, Campaspe Weir and Lake Eppalock restrict fish movement. Saline pools in the lower reaches of the Campaspe River may also restrict fish movement during summer. Addressing fish passage at these key points throughout the system is a priority and is essential if environmental flows are to deliver their intended benefit to native fish communities.

5.4 Water Quality

Water quality is a key issue in the Campaspe River, particularly the presence of saline pools in Reach 4 and high nutrient loads in Coliban River and lower Campaspe River. Saline pools in the lower reaches of the Campaspe River are created by groundwater intrusion and the rate of groundwater intrusion as well as the quality of groundwater is to some extent influenced by irrigation practices in the part of the catchment. Cease to flow periods have not been recommended for the lower reaches of the Campaspe River because there is a concern that they will exacerbate salinity levels in these pools. Similarly, high nutrient inputs from agricultural and urban sources have contributed to excessive algal growth in parts of the Coliban River and increases the risk of algal blooms in the lower Campaspe River. More monitoring is required to assess the response of various water quality parameters to small changes in flow. In some cases, environmental flows may be used to help relieve acute water quality events, but we need more information to determine sensible trigger levels for the release of such flows. It is recommended that continuous monitoring probes be installed to measure dissolved oxygen and salinity levels at various locations in the lower Campaspe River and that regular monitoring be undertaken to determine appropriate trigger levels.

5.5 Recommendations for further work

This flows assessment study has highlighted several knowledge gaps that have limited our assessment of environmental flow requirements for the Coliban and Campaspe Rivers and also

SKM

identified on ground works that are needed to ensure that the recommended flows have their intended effect. The main recommendations for further work are listed below:

- Fencing to exclude stock from the stream and riparian zone;
- Riparian revegetation, including follow up work to ensure that planting is successful;
- Willow removal, especially along the Coliban River and including the section between the Upper Coliban Reservoir and Malmsbury Reservoir;
- Provide fish passage at Echuca Weir as a priority and investigate the feasibility and need for fish passage at Campaspe Siphon and Campaspe Weir;
- Assess the current velocity tolerances of larval fish to refine the recommendations for maximum summer low flows;
- Investigate the availability and distribution of slackwater habitats at different flow levels in the lower Campaspe River;
- Assess the behaviour of saline pools in the lower Campaspe River under different flow conditions;
- Assess the effect of flow on dissolved oxygen in the Campaspe River and determine trigger levels for flow releases.

6 References

Baldwin, D. S., and A. M. Mitchell. 2000. The effects of drying and re-flooding in the sediment and soil nutrient dynamics of lowland river-floodplain systems: a synthesis. *Regulated Rivers: Research and Management* **16**:457-467.

Boulton, A. J., F. Sheldon, M. C. Thoms, and E. H. Stanley. 2000. Problems and constraints in managing rivers with variable flow regimes. *in* P. J. Boon, B. R. Davies, and G. E. Petts, editors. *Global perspectives on river conservation, policy and practice*. Wiley, Chichester.

Bren, L. 1988. Effects of river regulation on flooding of a riparian forest on the River Murray, Australia. *Regulated Rivers: Research and Management* **2**:65-77.

Bren, L. 1990. Red gum forests. Pages 231-242 *in* N. Mackay and D. Eastburn, editors. *The Murray*. Murray-Darling Basin Commission, Canberra.

Buchanan, R. A. 1999. *Bush regeneration: recovering Australian landscapes*. Greening Australia and NSW TAFE, Sydney.

DNRE. 2002a. *The FLOWS method: a method for determining environmental water requirements in Victoria*. Sinclair Knight Merz, CRC Freshwater Ecology, Freshwater Ecology (NRE), and Lloyd Enviornmental Consultants report to the Department of Natural Resources and Environment, Victoria.

DNRE. 2002b. *Healthy rivers, healthy communities and regional growth: Victorian River Health Strategy*. Department of Natural Resources and Environment, Victoria, Melbourne.

DSE. 2004. *Victorian Government White Paper: Our Water Our Future - Securing out water future together*. Department of Sustainability and Environment, Melbourne.

DSE. 2005. *Index of stream condition: the second benchmark of Victorian river condition*.

EPA. 2000. *The health of streams in the Campaspe, Loddon and Avoca catchments*. 704, Environment Protection Authority Victoria, Melbourne.

Frankenberg, J., and J. Tilleard. 1991. Protecting river banks from erosion. *Australian Planner* **29**:107-110.

Gordon, N. D., T. A. McMahon, and B. L. Finlayson. 1992. *Stream Hydrology: An introduction for Ecologists*, 1st edition. John Wiley and Sons Ltd, Chichester, West Sussex, England.

Hart, B. T., P. Bailey, R. Edwards, K. Hortle, K. James, A. McMahon, C. Meredith, and K. Swadling. 1990. Effects of salinity on river, stream and wetland ecosystems in Victoria, Australia. *Water Research* **24**:1103-1117.

Hart, B. T., P. S. Lake, J. A. Webb, and M. R. Grace. 2003. Ecological risk to aquatic systems from salinity increases. *Australian Journal of Botany* **51**:689-702.

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

Jowett, L. G., and M. J. Duncan. 1990. Flow variability in New Zealand rivers and its relationship to in-stream habitat and biota. *New Zealand Journal of Marine and Freshwater Research* **24**:305-307.

Junk, W. J., P. B. Bayley, and R. E. Sparks. 1989. The flood pulse concept in river-floodplain systems. *Special Publication Canadian Journal of Fisheries and Aquatic Sciences* **106**:110-127.

King, A. J. 2004a. Density and distribution of potential prey for larval fish in the main channel of a floodplain river: pelagic versus epibenthic meiofauna. *River Research and Applications* **20**:883-897.

King, A. J. 2004b. Ontogenetic patterns of habitat use by fishes within the main channel of an Australian floodplain. *Journal of Fish Biology* **65**:1582-1603.

Mallen-Cooper, M. 2001. *Fish passage in off-channel habitats of the Lower River Murray*. Fishway Consulting Services, St Ives Chase, NSW.

Marchant, R., P. Humphries, I. Rutherfurd, J. Frankenberg, J. McGuckin, and G. Smith. 1997. *Scientific Panel Environmental Flow Assessment of the Coliban River below Malmsbury Reservoir and the Campaspe River below Redesdale*. Victorian Department of Natural Resources and Environment, Melbourne.

McGuckin, J. 1990. *Environmental considerations of salinity in the Campaspe River downstream of Lake Eppalock*. Technical Report Series No. 104, Kaiela Fisheries Research Station - Department of Conservation, Forests and Lands Victoria, Shepparton.

McGuckin, J., and T. Doeg. 2001. *Investigation of Aquatic Ecosystems of the Campaspe Catchment*. Streamline Research Pty Ltd.

Moss, B. 1998. *Ecology of Fresh Waters*, Third edition. Blackwell, Oxford.

NCCMA. 2005. *Campaspe River Health Plan (Draft)*. North Central Catchment Management Authority, Huntly.

Nichol, J. M., and G. G.G. 2000. Water regime, seedling recruitment and establishment in three wetland plant species. *Marine and Freshwater Research* **51**:305-309.

Nielsen, D. L., M. A. Brock, G. N. Rees, and D. S. Baldwin. 2003. Effects of increasing salinity on freshwater ecosystems in Australia. *Australian Journal of Botany* **51**:655-665.

Poff, N. L., and J. V. Ward. 1989. Implication of stream variability and predictability for lotic community structure: a regional analysis of streamflow patterns. *Canadian Journal of Fisheries and Aquatic Sciences* **46**:1805-1818.

Roberts, J., and F. Marston. 2000. *Water regime of wetland and floodplain plants in the Murray-Darling Basion*. CSIRO Land and Water, Canberra.

Robertson, A. I., P. Bacon, and G. Heagney. 2001. The response of floodplain primary production to flood frequency and timing. *Journal of Applied Ecology* **38**:126-136.

SKM. 2003. *Review of habitat associations of native fish in the Murray Darling Basin*. Report for the Murray Darling Basin Commission, Canberra.

SKM. 2005. *Campaspe River environmental FLOWS assessment: site paper final*. Report prepared for the North Central CMA, Melbourne.

SKM. 2006a. *Campaspe River environmental FLOWS assessment: issues paper final*. Report prepared for the North Central CMA, Melbourne.

SKM. 2006b. *Derivation of current and natural flows in the Campaspe River (Draft)*. Sinclair Knight Merz, Melbourne.