Environmental Flow Determination for Painkalac Creek

Final Recommendations

Prepared by
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for the
Corangamite Catchment Management Authority

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The Painkalac Creek Environmental Flows Technical Panel

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Geoff Vietz	Geomorphology, Hydraulic Modelling

Paul Boon	Vegetation Ecology, Wetland Ecology, Water Quality

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The Painkalac Creek Steering Committee

Greg Williams	Corangamite Catchment Management Authority
Rowan Mackenzie	Barwon Water
Frances Northeast	Surf Coast Shire

The Painkalac Creek Community Advisory Committee

Rachel Faggetter, Michael Noelker, Dale Antonyson, Tim Gibson, Ros Gibson, Dennis Leavesley, Graeme McKenzie, Greg Day, Tim Wood.

Abbreviations used in this report

CMA	Catchment Management Authority
DPI	Department of Primary Industries
DSE	Department of Sustainability and Environment
EPA	Environment protection Authority
EVC	Ecological Vegetation Class
ha	hectares
ML	Megalitres (1,000,000 litres)
NRE	Department of Natural Resources and Environment

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Cover Photo: Painkalac Creek – photo from G. Vietz

Summary

This report contains the environmental flow recommendations for the freshwater reach of Painkalac Creek, Aireys Inlet, between the Painkalac Reservoir and the head of the estuary. The recommendations are designed to provide a flow regime to achieve a series of Environmental Objectives in Painkalac Creek.

Eight Environmental Flow Objectives were proposed for Painkalac Creek[1]:

- *Maintain or improve channel form and processes for ecological benefit.*
- *Restore self-sustaining populations of migratory fish species (Short-finned eels, Common galaxias, Spotted galaxias, Broad-finned galaxias, Pouched lamprey and Tupong) in Painkalac Creek.*
- *Restore self-sustaining populations of non-migratory fish species (Flat-headed gudgeon and Australian smelt) in Painkalac Creek.*
- *Restore macroinvertebrate communities to meet SEPP (Waters of Victoria) environmental quality objectives for Forest-B segments*.
- *Maintain and enhance healthy and diverse communities of native aquatic vegetation in the in-stream and fringing zones.*
- *Maintain and enhance biofilms on submerged surfaces, particularly coarse woody debris; and*
- *Maintain and enhance healthy and diverse communities of native vegetation in the riparian zone.*
- *Entrain terrestrial organic matter from the benches into the stream.*

For each objective, a series of flow functions has been determined – flow-dependent processes that must occur in the creek in order to achieve the objectives. Flow functions include measures such as the provision of adequate habitat, flushing excess silt of habitat surfaces, preventing summer water quality decline, and stimulating fish spawning migrations.

For each of these functions, the types of flows required have been determined. These include the flow component (low flow, high flow, flood flow), time of year, the frequency (if known) and the duration (if known). For each flow type, criteria for assessment have been developed (e.g. depth of water required to allow fish passage for certain species, velocity of water to prevent water quality decline in pools).

A single "Representative Site" was selected just upstream of the Old Coach Road crossing. The representative site was chosen as it contains the physical features (e.g. pool-run sequences, in-channel benches) that have ecological value and are common to the entire reach.

Eleven cross-sections were surveyed across the creek at the representative site. Cross sections were chosen to include particular channel features which have environmental significance (e.g. pools, riffles, in-channel benches).

A hydraulic model interpreting the effects of different flow rates in the site (e.g. depth, velocity) was produced using the one-dimensional steady-state backwater analysis model HEC-RAS.

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[1] Doeg, T.J., Vietz, G.J. and Boon, P.I. (2007) Painkalac Creek *Environmental Flow Investigation: Issues Paper*. Prepared for the Corangamite Catchment Management Authority, Colac.

At a workshop held on 27 November 2007, suitable flow recommendations to achieve the environmental objectives were derived using a number of analysis tools, including:

- Criteria or definitions for each flow components to achieve the flow related processes;
- The hydraulic model developed for the reach;
- Drawings and notes taken during the field inspection; and
- Photos taken during the field inspection, and those taken of each transect during the survey.

Eight flow components were considered.

Flow component	General Description
Cease-to-flow	Periods where no flows are recorded in the channel.
Low Summer Flows	The baseflow during the dry season that maintains water flowing through the channel.
Low Flow Freshes	Small and short duration increases in flow as a result of localised rainfall.
Transitional Freshes	High flows around the Low-High Flow Season to stimulate fish breeding and migration.
Low Winter Flows*	The persistent increase in baseflow that occurs with the onset of the wet season.
High Flow Freshes	Long sustained increases in flow during the high flow period as a result of heavy rainfall.
Bankfull flow	Flows that completely fill the channel, but do not spill onto the floodplain.
Overbank flows	Flows greater than Bankfull that result in surface flow on floodplain habitats.

From these considerations, the following environmental flow recommendations were developed for the freshwater sections of Painkalac Creek.

<table>
<tr><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th></tr>
<tr><td colspan="4">Low Flow Season</td><td colspan="2">T (L-H)[2]</td><td colspan="5">High Flow Season</td><td>T (H-L)[2]</td></tr>
<tr><td colspan="12">Cease to Flow: No more than 2 spells per year, maximum spell length of 7 days</td></tr>
<tr><td colspan="5">Low Summer Flow: 0.5 ML/day (or natural[3])</td><td colspan="7">Low Winter Flow: 2 ML/day (or natural[4])</td></tr>
<tr><td colspan="4">Low Flow Freshes:
2 ML/day, 4 per year (or natural), 3 day duration (or natural)
8 day independence</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="4">Transitional Freshes:
20 ML/day, 2 per year (or natural), 1 day duration
7 day independence</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="3">High Flow Freshes:
200 ML/day, 2 per year (or natural), 1 day duration
19 day independence</td><td colspan="2">High Flow Fresh:
200 ML/day, 1 per year (or natural), 1 day duration</td><td></td></tr>
<tr><td colspan="12">Bankfull Flows:
700 ML/day, 1 in 2 years, 1 day duration</td></tr>
<tr><td colspan="12">Overbank Flows:
No recommendation</td></tr>
</table>

[2] T(L-H): Transitional between Low and High Flow Season; T(H-L): Transitional between High and Low Flow Season;

[3] But with additional Cease to Flow recommendation provisions.

[4] But with additional Cease to Flow recommendation provisions.

Contents

1. Introduction

In 2004, the Surf Coast Shire developed the Painkalac Estuary Management Plan (Surf Coast Shire, undated[5]) to help improve the health and management of the Painkalac Creek estuary. The plan also included actions to maintain and improve the health of Painkalac Creek downstream of the reservoir. During the production of the plan, the Aireys Inlet community raised concerns about the effects of the reservoir on river health.

A key action identified in the plan was to:

> *Undertake an investigation into environmental flow requirements for fresh water and estuarine systems to the Painkalac Creek from the Aireys Inlet Reservoir, with a view to reviewing the Bulk Entitlement held by Barwon Water. The investigation should also consider the potential role of the Aireys Inlet Reservoir in flood management downstream.* (p. 25)

Subsequently, Tim Doeg, Paul Boon and Geoff Vietz were contracted by the Corangamite Catchment Authority to conduct an environmental flow study of the freshwater section of Painkalac Creek using the FLOWS method – the standardised Statewide Method For Determining Environmental Water Requirements in Victoria (NRE, 2002a[6]).

1.1 Project Objectives

The objectives of the project are to:

- Identify water dependant environmental and social values within the reach;
- Gauge the current health of the environmental values;
- Recommend an environmental flow regime that will sustain the identified environmental values; and
- Develop recommendations to address issues that may complement or could reduce the effectiveness of the flow recommendations.

1.2 Outline of this report

Following this introductory section, Section 2 provides an overview of the study area. Section 3 describes the methods used in the study – the FLOWS method. Section 4 reviews the environmental objectives established for the creek, detailing the main flow-related stream processes required in the Painkalac Creek study reach. The flow recommendations with detailed justifications are presented in Section 5. The final Section 6 discusses some non-flow related catchment issues that are important if the objectives are to be achieved.

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[5] Surf Coast Shire (undated) *Painkalac Estuary Management Plan*. Surf Coast Shire.

[6] NRE (2002a) *FLOWS- a method for determining environmental water requirements in Victoria*. Catchment and Water Division, Department of Natural Resources and Environment, East Melbourne.

2. The Study Area

Painkalac Creek rises at an elevation of 430 m in the deeply-dissected rolling hills at the north-eastern end of the Otway Ranges, and flows in a generally easterly direction for about 20 km where it enters Bass Strait on the western side of the township of Aireys Inlet (Figure 2.1). The freshwater section of the catchment has a total area of 57.2 km^2, including the main stem of the creek (39.2 km^2) and the Distillery Creek sub-catchment (18.0 km^2) which meets Painkalac Creek about 200 m south west of the Old Coach Road crossing.

In 1981 Painkalac Reservoir was constructed to supply the townships of Aireys Inlet and Fairhaven. The reservoir site lies at 23 m above sea level. Downstream of the dam the channel passes through extensive alluvial valley deposits. In this section, the channel is commonly partially confined, abutting the channel margin to the north in the upper reaches, before shifting to the steep sided southern margin and following this to the south (Figure 2.1). The channel becomes unconfined for the majority of the estuarine reach.

The annual rainfall average is approximately 650 mm. Highest rainfall is in the months between April and November, with the wettest month being August and the driest being January.

The lower part of the Painkalac Creek valley was largely cleared of woody vegetation early in the 19th Century and much of the cleared land was used for grazing stock.

The boundary between the estuary reach and the freshwater reach has not been specifically delineated. GHD (2005[7]) suggests that the tidal influence of the estuary extends “approximately to the junction of Distillery and Painkalac Creek” (p. 4), and spot water quality results (GHD, 2005) show a distinct difference between the salinity at Old Coach Road and further downstream.

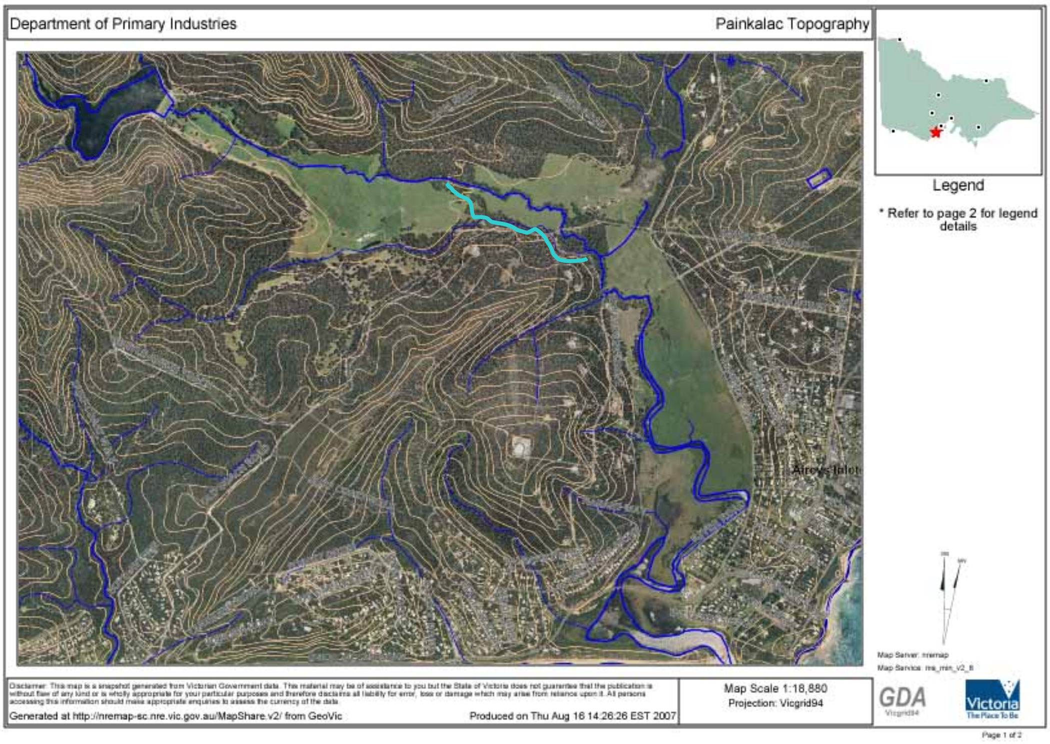


Figure 2.1 Painkalac Creek catchment map (note the light blue line represents the current channel of Painkalac Creek which has been incorrectly positioned in the previous mapping).

[7] GHD (2005) *Painkalac Creek and Estuary Pollution Source Investigation*. Report to Surf Coast Shire.

3. Description of the FLOWS method

The recommendations for environmental flows in Painkalac Creek have been developed using the 2-stage standardised Statewide Method For Determining Environmental Water Requirements in Victoria, referred to as the FLOWS method (NRE, 2002a). The major steps in applying the FLOWS method to environmental flow studies are shown in Figure 3.1.

3.1 Stage 1

Stage 1 of the FLOWS method involved the collection of available data on the ecology and hydrology of the study area, from published work, unpublished sources and local experience, that are required to develop environmental flow recommendations.

This information, presented in the **Site Paper**[8], confirmed that only a single freshwater reach needed to be selected in Painkalac Creek for further study.

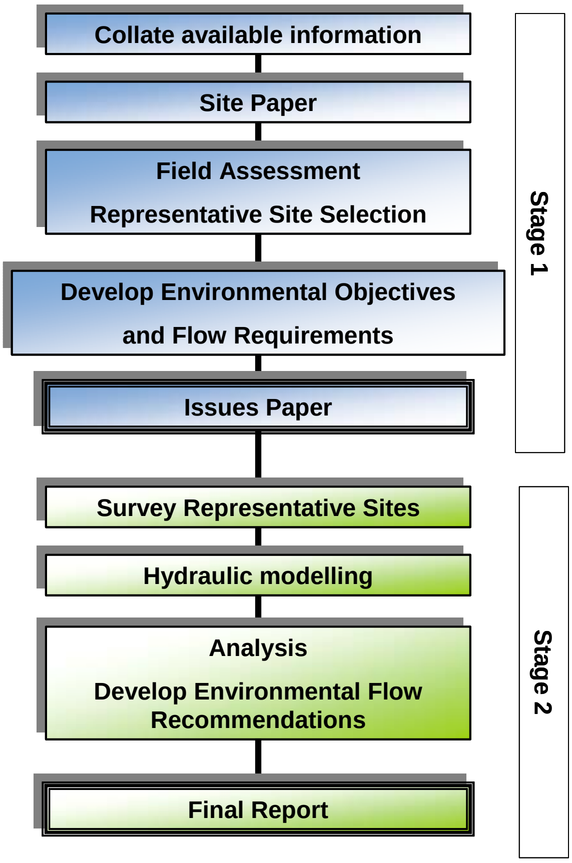


Figure 3.1 Outline of the steps in the FLOWS method. This Recommendations Paper represents the final output of Stage 2 of the process.

During a Technical Panel field inspection of the reach, a single "Representative Site" was selected just upstream of the Old Coach Road crossing. Representative Sites are those determined to have physical features (e.g. pool-run sequences, in-channel benches) that have ecological value and are common to the entire reach.

Based on the environmental assets present in the freshwater section of Painkalac Creek, Environmental Objectives were established covering the major flow-dependent environmental assets in the reach (in this case, geomorphology, fish, aquatic macroinvertebrates, in-stream and riparian vegetation).

For each objective, a series of flow-related processes were identified that would need to occur in order for the objectives to be met. The types of flows required to achieve the flow-related processes were determined. These include the flow component, time of year, the frequency (if known) and the duration (if known). For each flow type, criteria for assessment were also developed (e.g. depth of water required to allow fish passage for certain species, velocity of water to prevent water quality decline in pools).

[8] Doeg, T.J., Vietz, G.J. and Boon, P.I. (2007) Painkalac Creek *Environmental Flow Investigation: Site Paper*. Prepared for the Corangamite Catchment Management Authority, Colac.

All of this information was detailed in the **Issues Paper**[9], which completed the first stage of the FLOWS study, and is summarised in Section 4.

3.2 Stage 2

In the second stage of the study, the Representative Site is studied in more detail, with cross-sections surveyed across the creek. Cross sections include particular features identified in the field inspection which have environmental significance (e.g. pools, riffles, in-channel benches). A hydraulic model describing the effects of different flow rates in the site (e.g. depth, velocity) is produced. All the information collected is then used to determine environmental flow recommendations for the reach.

3.2.1 Surveys of selected reaches

Cross-sectional survey at the Painkalac Creek representative site was undertaken by Reed and Reed Surveying. Transects identified during the Stage 1 field inspection were surveyed using a Total Station. Cross-sections were taken perpendicular to the flow, and survey points focused on the channel detail and near channel features (such as benches), with fewer points on the floodplain.

Profiles and cross sections from the Painkalac Creek are shown in Appendix 2.

3.2.2 Hydraulic Modelling

Hydraulic modelling of the sites was undertaken using the one-dimensional steady state backwater analysis model HEC-RAS. The three main inputs required for the HEC-RAS model include: channel topography, channel roughness (Mannings *n*), and a boundary condition for calculating the water surface.

Channel topography is provided by cross-sectional field survey data. The channel roughness (Manning's *n*) is determined from appropriate manuals and the modellers experience for each cross-section, based on field observations of the reach during the field inspection, and identification of reach variability from photographs. Features such as large wood and vegetation, generally not identified by the field survey, are incorporated where appropriate.

Normal depth was used as the downstream boundary condition, with a slope determined by a combination of the water surface level and the channel invert level, particularly in the lower reaches. The use of this boundary condition allows for adjustment of flows without a corresponding adjustment of boundary condition.

Once all hydraulic model inputs are provided, the hydraulic model is calibrated to known water levels identified during surveying. Calibration improves confidence with the outputs from the model, particularly within the range of water levels surveyed (commonly low flows). Calibration of the hydraulic model is focused on the sections upstream of Old Coach Road (and upstream of the weir), Sections 1 – 8, Figure 3.2. The sections surveyed in the vicinity of the weir are used to control the downstream water level, as this structure is a major hydraulic control.

The outputs used from the model included the flows (ultimately expressed in ML/day) required to cover specified parts of the stream bed to a certain depth, or inundate identified channel units such as benches, or provide specific levels of average channel water velocity or shear stress.

[9] Doeg, T.J., Vietz, G.J. and Boon, P.I. (2007) Painkalac Creek *Environmental Flow Investigation: Issues Paper*. Prepared for the Corangamite Catchment Management Authority, Colac.

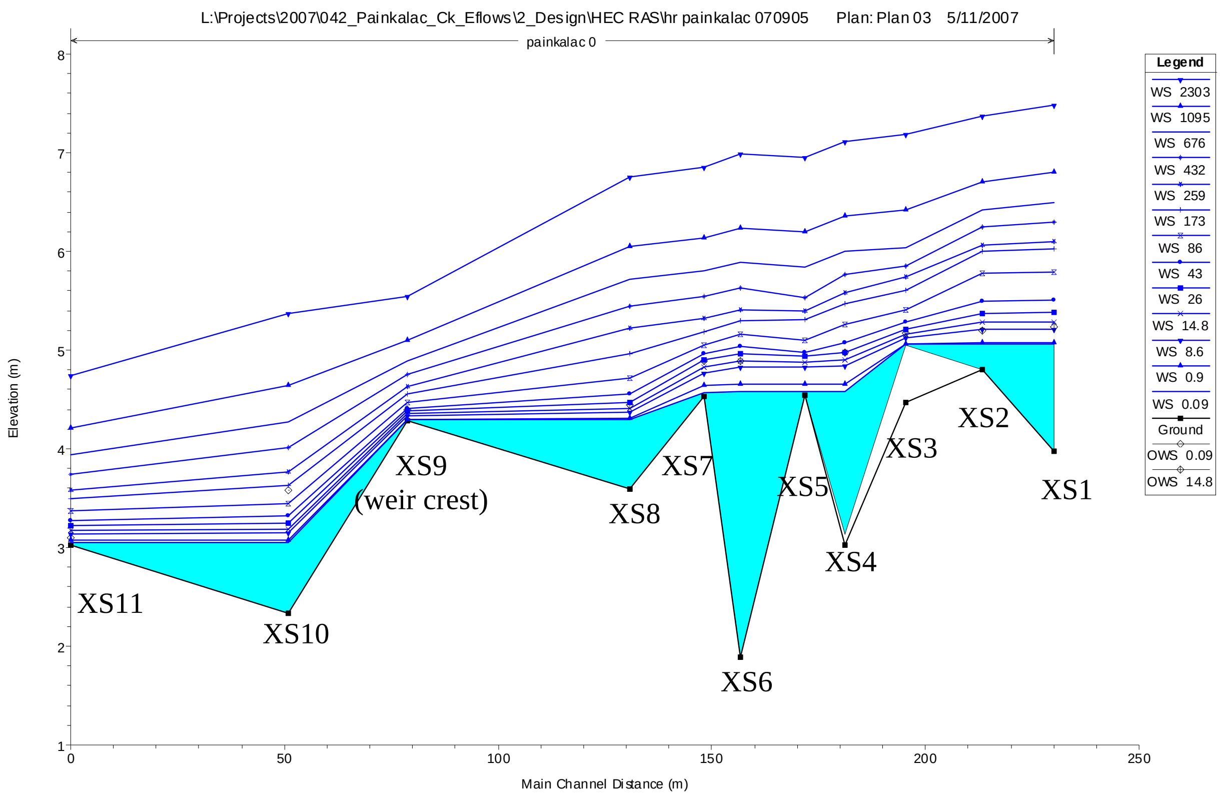


Figure 3.2. Longitudinal profile from the hydraulic model indicating pools, riffles and runs with a range of flow scenarios up to near-bankfull. Section numbering is indicated on the figure.

3.2.3 Environmental Flow recommendations

At a workshop held by the Technical Panel on 27 November 2007, the hydraulic model was examined to identify key features (pools, shallow areas, in-channel benches and banks) that could be used to assess environmental flows, based on the objectives, flow-related processes and criteria developed in the Issues Paper.

Each flow component (Table 3.1) was considered in turn. If a particular flow component was associated with any flow-related process, a suitable flow recommendation was derived by the Technical Panel using a number of analysis tools. These included:

- Criteria or definitions for each of the flow components, either from the FLOWS method or developed by the Technical Panel;
- The hydraulic model developed for the reach;
- Drawings and notes taken during the field inspection;
- Hydrologic analysis tools (both SPELLS and RAP); and
- Photos taken during the field inspection, and those taken of each transect during the survey.

Where a feature of the surveyed transects or profile was identified, a series of increasing flows were run through the hydraulic model, until a particular flow satisfied the criterion for the flow-related process. In general, the lowest flow required to achieve the criterion was selected as the recommendation for that flow-related process.

Environmental flow recommendations were based on the season in which the component should occur in order to achieve the objective. The seasonality of the flow regime in Painkalac Creek, based on the distribution of natural flows throughout the year is shown in Table 3.2 (see Appendix 1).

Table 3.1. Flow components and definitions used in environmental flow determinations

Flow component	General Description
Cease-to-flow	Defined as periods where no flows are recorded in the channel.
Low Summer Flow	Defined as "the low minimum flow that provides a continuous flow through the channel. The flow may be limited to a narrow area of the channel in the high points of the stream, but will provide flow connectivity between habitats within the channel" (NRE, 2002a, p. 22). This refers to the natural baseflow during the dry season that maintains water flowing through the channel.
Low Flow Freshes	Small and short duration increases in flow that lasts for one to several days as a result of localised rainfall during the low flow period.
Transitional Freshes	Higher flows around the Transitional Low-High Flow Season to stimulate fish breeding and migration. This is an additional flow component not included in the original FLOWS method.
Low Winter Flow*	The persistent increase in baseflow that occurs with the onset of the wet season.
High Flow Freshes	Long sustained increases in flow during the high flow period as a result of heavy rainfall events, extending over several weeks.
Bankfull flow	Flows that completely fill the channel, but do not spill onto the floodplain
Overbank flows	Flows greater than bankfull that result in surface flow on floodplain habitats

* - referred to as "High Flow" in the Flows Method

Table 3.2. Seasonality of flows adopted for Painkalac Creek.

Season	Painkalac Creek
Low Flow Season	December, January – March
Transitional: Low to High	April, May
High Flow Season	June – October
Transitional: High to Low	November

Recommendations also include a frequency and duration for a number of flow components (Low and High Flow Freshes, Bankfull, and Overbank Flows). For these, the frequency per year or season and the duration were based on either knowledge of the ecological requirements associated with the objective, or an analysis of the natural flow regime.

Where detailed ecological knowledge was not available, the frequency and duration of flows that exceed the recommended flow under natural condition was determined by a spell analysis on the natural flow regime. The frequency and duration recommendation was generally based on the median frequency of spells per year, and the median duration of spells over the period of record.

It needs to be realised that the recommendations for frequency and duration are not "fixed" requirements. Recommendations for frequency and duration are modified with an "or natural" qualification. This means that for the measurement of compliance, if the natural flows in any one year provide less events than the recommended value, then only the natural number needs to be present in the flow regime. If the natural flows result in more than the recommended value, then only the recommended value needs to be present.

For example, if a recommendation states that 6 flows above the recommended flow threshold need to occur and only 2 naturally occur in any particular year, then if 2 are provided in that year, the flows can be seen to be in compliance with the recommendation. If 10 flows occur naturally, then only 6 need to be present in the post-diversion regime for the flows to be in compliance with the recommendation.

Similarly, for the duration recommendation, if a natural flow shorter than the recommendation occurs, then as long as the flow event is not reduced in duration by diversions, the flow is in compliance with the recommendation. A flow longer than the recommended duration can be reduced by diversions, but only to the length of the recommendation.

Recommendations for Independence

It can be argued that the effectiveness of a particular higher flow event (i.e. its role in achieving a particular objective) may be reduced, depending on how soon after a similar event it occurs. Therefore, a condition is placed on recommendations for higher flow events by the determination of an “independence” value – a period of time that may elapse between similar events. Subsequent high flow events within this independence period are seen as having reduced effectiveness and are not required to achieve the objective.

For example, one objective of Low Flow Freshes is the flushing of fine sediment from in-stream habitats. A second Low Flow Fresh, soon after the first, may not have the same effect, as little or no sediment may have been deposited between the two freshes. Similarly, a function of High Flow Freshes is to entrain leaves and twigs from in-stream benches to the stream channel. A second High Flow Fresh may not have the same benefit as the first, depending on the amount of new material deposited on benches between the two events.

Hence, the independence recommendation outlines the number of days that can pass following the end of one event, before the next event is required. Higher flow events that occur during this independence period need not be provided. Applying an independence criteria also tends to space out flows over the season, so that where only a few events are recommended, they are not all provided in a group at some time in the season. The independence value was based on an assessment by the Technical Panel of the requirements of flow-related processes for a particular flow component, or from a spells analysis that determined the median interval between successive flows in the natural flow regime.

4. Painkalac Creek Objectives

Eight Environmental Objectives were established for the freshwater sections of Painkalac Creek, covering the major flow-dependent environmental assets in the reach (in this case, geomorphology, fish, aquatic macroinvertebrates, in-stream and riparian vegetation):

- *Maintain or improve channel form and processes for ecological benefit.*
- *Restore self-sustaining populations of migratory fish species (Short-finned eels, Common galaxias, Spotted galaxias, Broad-finned galaxias, Pouched lamprey and Tupong) in Painkalac Creek.*
- *Restore self-sustaining populations of non-migratory fish species (Flat-headed gudgeon and Australian smelt) in Painkalac Creek.*
- *Restore macroinvertebrate communities to meet SEPP (Waters of Victoria) environmental quality objectives for Forest-B segments.*
- *Maintain and enhance healthy and diverse communities of native aquatic vegetation in the in-stream and fringing zones.*
- *Maintain and enhance biofilms on submerged surfaces, particularly coarse woody debris.*
- *Maintain and enhance healthy and diverse communities of native vegetation in the riparian zone.*
- *Entrain terrestrial organic matter from the benches into the stream.*

To achieve these objectives, a number of flow processes or functions were proposed in the Issues Paper, along with the relevant flow component, time of year and draft criteria for assessments (Table 4.1 to Table 4.4).

Table 4.1 Summary of flow requirements to achieve geomorphology objectives in Painkalac Creek

Objective	Flow Process/Function	Flow Components	Timing	Criteria
Maintain or improve channel form and processes for ecological benefit	Maintain quantity and quality of habitat in pools by preventing siltation.	Low Flow Freshes High Flow Freshes	All year	Positive mean pool velocity.
	Movement of bed material to maintain bed diversity for water depth variation.	High Flow Freshes	Winter/Spring	Mean run scour >15 N m^{-2} .
	Control riparian vegetation encroachment to prevent catastrophic erosion processes.	High Flow Freshes Bankfull	Winter/Spring Anytime	See vegetation section.
	Maintain channel form and key habitats, including in-channel benches.	Bankfull	Anytime	Mean pool scour >15 N m^{-2}.
	Maintain channels and inlets for connectivity of main channel with important floodplain and anabranch zones.	Bankfull	Anytime	Determined from physical transects.

Table 4.2 Summary of flow requirements to achieve native fish objectives in Painkalac Creek

Objective	Flow Process/Function	Flow Components	Timing	Criteria
Restore self-sustaining populations of migratory and non-migratory fish species	Maintain habitat in pools for all species.	Low Summer Flow Low Winter Flow	All year	Median pool depth > 0.2 m.
	Provide occasional adequate depth in runs between pools for movement of all species.	Low Flow Fresh	Summer-Autumn	Median depth of runs 0.1 to 0.2 m.
	Flush sediments in lead up to spawning season.	Low Flow Freshes High Flow Fresh	Jan-Apr Oct-Nov	Mean channel scour in runs and pool edges >1.4 N m^{-2}.
	Change in flow to stimulate migration.	Transitional Freshes	March-June	No criteria available. Determined from other factors.
	Wash fish larvae downstream.	Low Winter Flow	May-July	No criteria available. Determined from other factors.
	Allow regional scale movement between freshwater and estuary for migratory species.	Low Winter flow	April –June, November	Median depth of runs 0.1 to 0.2 m.
	Prevent water quality decline.	Low Flow Freshes	Summer - Autumn	Positive mean pool velocity.

Table 4.3 Summary of flow requirements to achieve aquatic macroinvertebrate objectives in Painkalac Creek

Objective	Flow Function	Flow Components	Timing	Criteria
Restore macroinvertebrate communities to meet SEPP environmental quality objectives	Maintain habitat in pools.	Low Summer Flow Low Winter flow	All year	Lower parts of edge vegetation permanently inundated
	Maintain habitat in runs.	Low Summer Flow Low Winter flow	All year	Lower parts of edge vegetation permanently inundated (run depth >10 cm)
	Flush sediments from habitat surfaces.	Low Flow Freshes High Flow Freshes	All Year	Mean run scour >1.4 N m^{-2}
	Prevent dominance of filamentous algae.	High Flow Freshes	Winter-Spring	Mean velocity >0.3 m s^{-1}
	Prevent water quality decline.	Low Flow Freshes	Summer-Autumn	Positive mean pool velocity

Table 4.4 Summary of flow requirements to achieve vegetation objectives in Painkalac Creek

Objective	Flow function	Flow components	Timing	Criteria
Maintain and enhance native aquatic vegetation in in-stream and fringing zones	Maintain habitat in pools and runs for aquatic plants.	Low Summer Flow	Summer-Autumn	Pool depth > 20 cm. Runs with natural periods of flowing water (zero flows not extended).
	Prevent water quality decline.	Low Flow Freshes	Summer-Autumn	Positive mean water velocity.
	Inundate benches to wet emergent vegetation and maintain moist soils.	Low Flow Freshes	Summer-Autumn	Benches inundated for *ca* 1-3 days.
	Maintain pool and run depths for plant habitat.	Low Winter flow	Winter-Spring	Pool and run depth > 20 cm.
	Inundate benches and bars to prevent colonisation by exotic or terrestrial plant taxa.	Low Winter Flow High Flow Freshes	Winter-Spring	Benches and bars inundated for *ca* 1+ week.
Maintain and enhance native riparian vegetation	Maintain moist soils in riparian zones.	Bankfull	Winter-Spring	Sufficient to maintain wetted soil zone at top of bank.
Maintain and enhance biofilms on submerged surfaces	Episodically wet exposed coarse woody debris.	Low Flow Freshes	Summer-Autumn	Additional wood areas inundated *ca* 1 day.
	Episodically wet exposed coarse woody debris and remove accumulated algal growth.	High Flow Freshes and/or Bankfull	Winter-Spring	Wood inundated *ca* 1-3 days with mean pool velocity >0.3 m s^{-1}.
Entrain terrestrial organic matter into the stream	Entrain terrestrial leaves, bark and wood into the stream from channel margins.	Low Flow Freshes	Summer-Autumn	Inundate low-lying benches.
	Entrain terrestrial leaves, bark and wood into the stream from channel margins.	High Flow Freshes	Winter-Spring	Inundate higher level benches.

4.1 Summary of Flow Requirements

The following tables summarise the flow requirements and timing to achieve all of the environmental objectives in Painkalac Creek.

<table>
<tr><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th></tr>
<tr><td colspan="4">Low Flow Season (December to March)</td><td colspan="2">Transition (L-H)</td><td colspan="5">High Flow Season (June to October)</td><td>T (H-L)</td></tr>
<tr><td colspan="5">Low Summer Flow for:
• fish, macroinvertebrate and plant habitat.</td><td colspan="7">Low Winter Flow for:
• fish, macroinvertebrate and plant habitat.
• inundate low bars and low benches to deter terrestrial plant encroachment.
• upstream migration of juvenile fish and lamprey (November only).</td></tr>
<tr><td colspan="4">Low Flow Freshes to:
• maintain quantity and quality of key habitats.
• maintain summer/autumn water quality.
• allow localised fish recolonisation.
• inundate bars and low level benches/bars for semi-aquatic vegetation.
• wet exposed coarse woody debris to maintain biofilm communities.
• entrain organic terrestrial material to stream.</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2"></td><td colspan="4">Low Flow or Transitional Freshes for:
• localised migratory species movement prior to freshwater breeding (Spotted and Broad-finned galaxias).
• prepare fish breeding habitat (Spotted galaxias).</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="4">Transitional Freshes to:
• stimulate spawning (Spotted and Broad-finned galaxias).
• stimulate migration (Common galaxias, Tupong).</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="5">High flows (Transitional Freshes and Low Winter Flow) to:
• wash larvae to sea (Spotted and Broad-finned galaxias).
• allow migration to estuary (Common galaxias, Tupong).</td><td></td><td></td><td></td><td></td></tr>
</table>

<table>
<tr><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th></tr>
<tr><td colspan="4">Low Flow Season (December to March)</td><td colspan="2">Transition (L-H)</td><td colspan="5">High Flow Season (June to October)</td><td>T (H-L)</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td colspan="6">High Flow Freshes to:
• maintain bed diversity for water depth variation.
• inundate high level benches to prevent colonisation by terrestrial plants and promote restoration of natural bench vegetation zonation.
• remove accumulated filamentous algal growth from surfaces.
• flush sediment from habitat surfaces.
• wet exposed coarse woody debris to maintain biofilm communities.
• move organic terrestrial material to stream.</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="5">Bankfull flows to:
• inundate high level benches to prevent colonisation by terrestrial plants and promote restoration of natural bench vegetation zonation.
• connect side channels and old course</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="5">High Flow Freshes for:
• non-migratory species movement prior to breeding (Australian Smelt, Flat-headed gudgeon).</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="4">High Flow Freshes for:
• non-migratory fish breeding (Australian Smelt, Flat-headed gudgeon).</td></tr>
<tr><td colspan="12">Anytime - Bankfull flow for:
• channel maintenance.
• wetting top of bank for vegetation
• connectivity of main channel with important floodplain and anabranch zones</td></tr>
</table>

5. Environmental Flow Recommendations

5.1 Cease to Flows

Cease to Flows are defined as periods where no flows are recorded in the channel. There may still be water present in the pools, but connecting riffles and runs will have no surface water (but may remain damp for some time).

The natural flow data modelled for Painkalac Creek suggests that periods of cease to flow[10] occurred about 3% of the time. Over the 1970 to 2006 period, natural cease to flows occurred 45 times, and only in the period November to April (Figure 5.1).

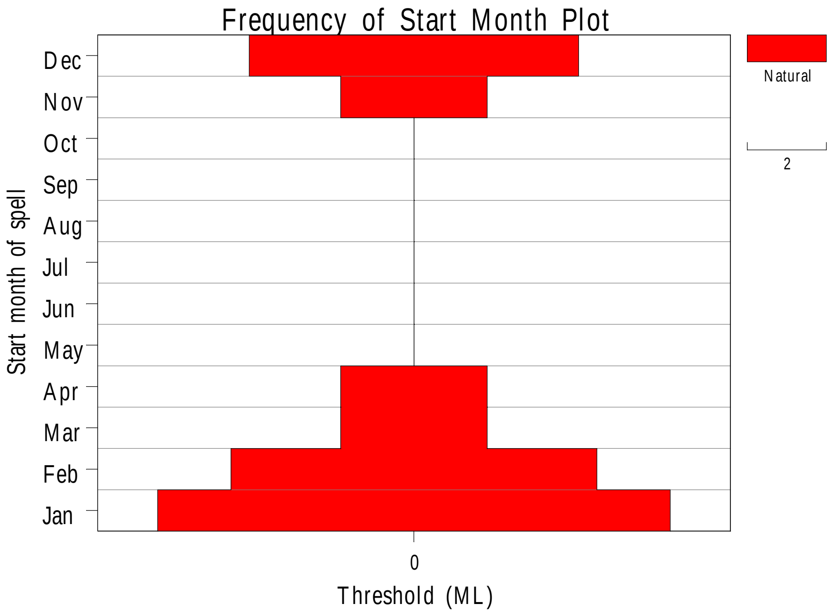


Figure 5.1 Frequency of zero flow periods that start in each month. Width of bars related to number of cease to flows in each month (Horizontal bar on right shows scale of 2 cease to flow events)

Cease to flow periods would naturally have occurred in most years (Figure 5.2), with between 1 and 3 zero flow spells in 29 of the 37 years of flow record. However, in the period leading up to the recent drought (1970 to 1999), the length of these natural zero flow spells were short (Figure 5.3), with an average length per spell of 6.1 days. Since 2000, the length of zero flow spells increased greatly, with many months of continuous no flows over the November to April period (Figure 5.3).

There are no organisms in Painkalac Creek that require cease to flows to complete their life cycle, so no specific cease to flow recommendations will be made. Under normal circumstances, natural cease to flows would be allowed in the creek by applying an “or natural” qualification to the low flow recommendation. However, cease to flow events like those experienced in 2000 and 2005–2006 (where most of the stream bed dried out completely, including most pools) are seen as undesirable in

[10] Cease to Flows were analysed as flows lower than 0.005 ML/day in the modelled flow data. This allows for some losses in the creek, including evaporation from the channel surface between the reservoir and the representative site (assuming a February evaporation of 170 mm – BOM website, accessed 24/11/07 – a creek distance of 2 km and an average width of 1 m, gives a potential loss of 0.01 ML/day).

Painkalac Creek, as they will result in massive reductions in fish and macroinvertebrate populations, with the increased potential for loss of some species. Hence, a limit on the frequency and duration of cease to flows is proposed.

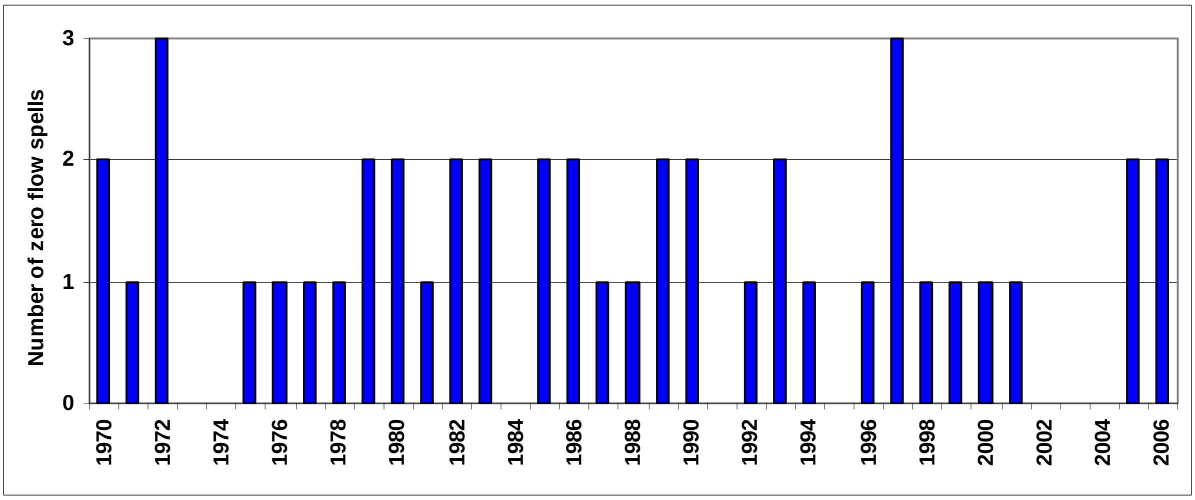


Figure 5.2 Number of natural zero flow spells each year from 1970 to 2006

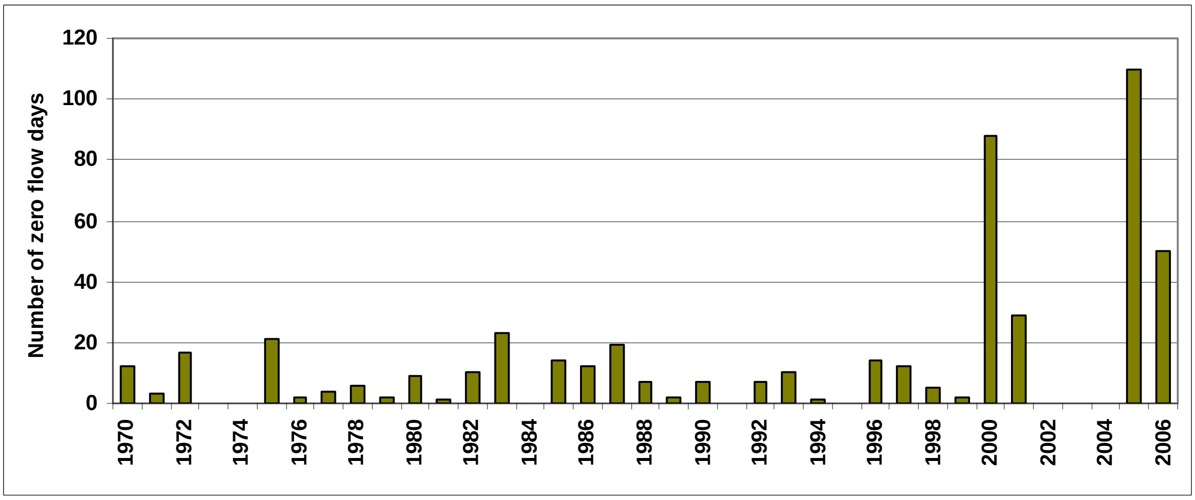


Figure 5.3 Number of natural zero flow days each year from 1970 to 2006

Cease to Flow Recommendation:

Cease to flow events downstream of Painkalac Reservoir should be restricted to a maximum of two spells per year between November and April, and a maximum length of each spell of 7 days (the average length of natural cease to flows between 1970 and 1999).

Each cease to flow event should be broken by a flow sufficient to refill pools throughout the reach, or the Low Summer Flow recommendation (see below), whichever is higher.

Cease to flow events should only occur during periods where there is no inflow to the reservoir (i.e. during natural cease to flow events).

5.2 Low Summer Flow

In Painkalac Creek, the low flow recommendation is based on providing adequate physical habitat for in-stream plants and animals during the Low Flow Season (December to March). The Low summer flow recommendation is extended to include the start of the Transitional Low to High Season (April), as baseflows are naturally low during this period (see Appendix 1).

Flow Component	Flow-related process	Assessment criteria
Low Summer Flows (Dec-Apr)	1. Maintain habitat in pools for all fish species.	1. Deep pool areas with > 20 cm depth.
	2. Maintain pool habitat for aquatic macroinvertebrates.	2. Water to inundate edge vegetation in pools.
	3. Maintain run habitat for aquatic macroinvertebrates.	3. Run areas with depth >10 cm.
	4. Maintain pool habitat for aquatic vegetation.	4. Deep pool areas with > 20 cm depth.
	5. Maintain run habitat for aquatic vegetation.	5. Runs with natural periods of flowing water (zero flows not extended).

The criteria identified to determine a suitable low summer flow recommendation were to maintain habitat availability in pools (depths >20 cm for fish and aquatic vegetation, lower parts of edge vegetation inundated for macroinvertebrates, and water depths of 10 cm in runs for macroinvertebrates).

Even at very low flows, pools in Painkalac Creek reach remain deep, with the three indicated pools (Figure 5.4, Figure 5.5) all between 0.7 and 2.6 metres deep. Therefore, no Low Summer Flow recommendation can be made based on the provision of habitat for fish, macroinvertebrates or aquatic vegetation in pools.

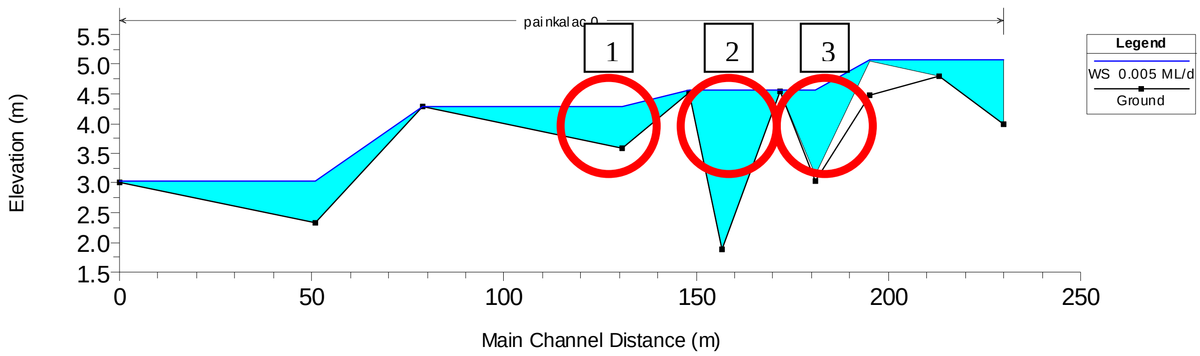


Figure 5.4 Long profile showing water depths at very low flow (0.005 ML/day) in three indicated pools.

In the main run habitat (Figure 5.6, Figure 5.7), a flow of 0.5 ML/day provides 10 cm of water depth over much of the flat-bottomed low flow channel (Figure 5.8). Higher flows examined (1 and 2 ML/day) do not provide much additional habitat of the required depth, instead only increasing the lateral extent of shallow inundation.

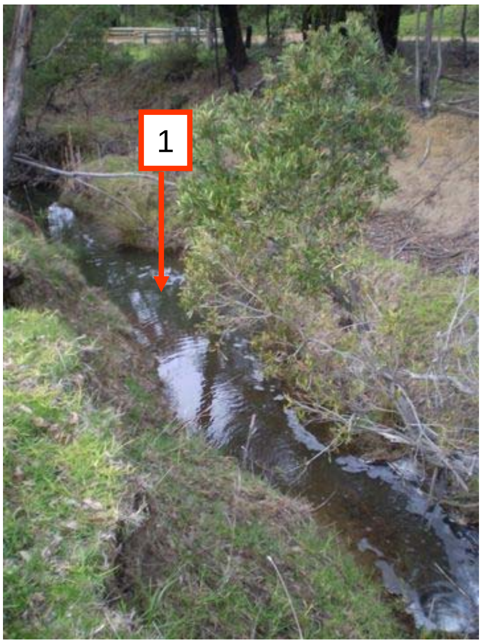


Figure 5.5. Three pools identified in Figure 5.4 (Photos: H. Reed)

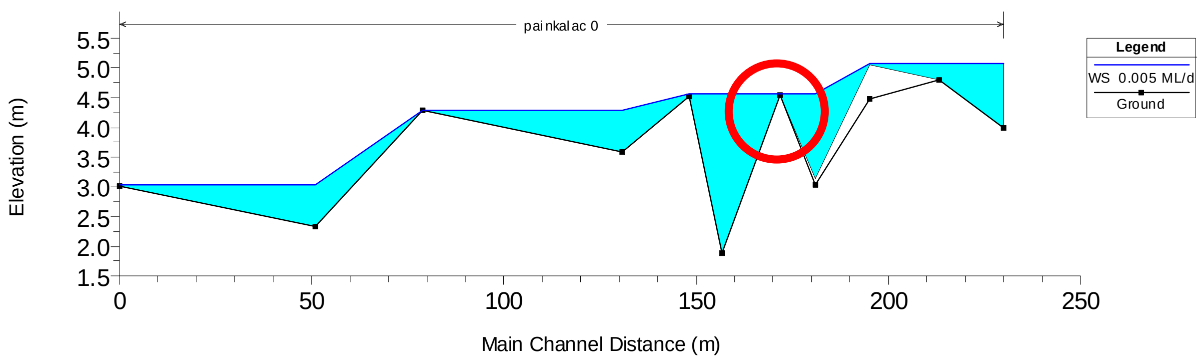
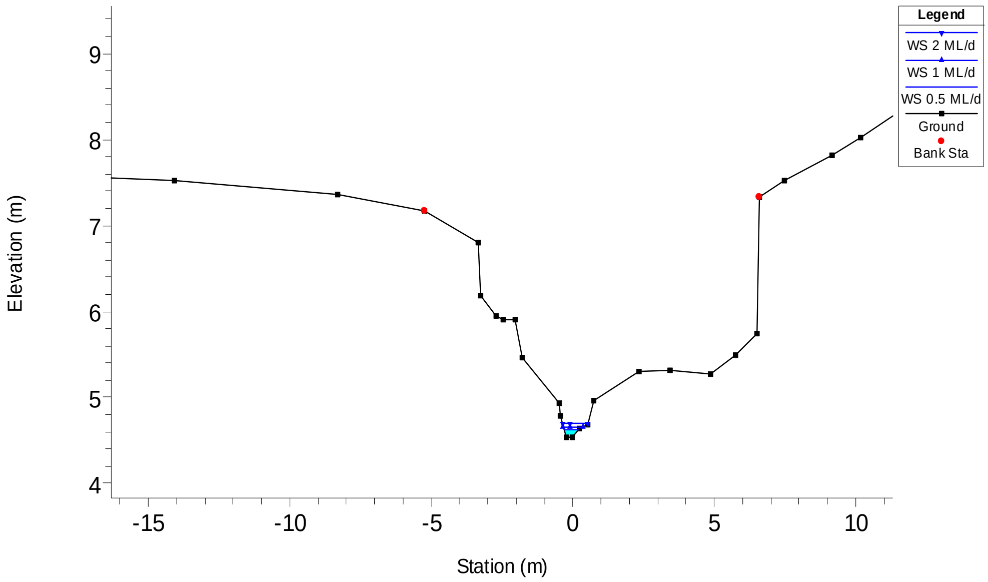


Figure 5.6 Top: Long profile showing water depths at very low flow (0.005 ML/day) with the run habitat indicated.

Figure 5.7 Photo of run habitat (Photo: H. Reed)

Low Summer Flow Recommendation:	
Flow:	0.5 ML/day or natural (with cease to flow provisions)
Timing:	December to April inclusive



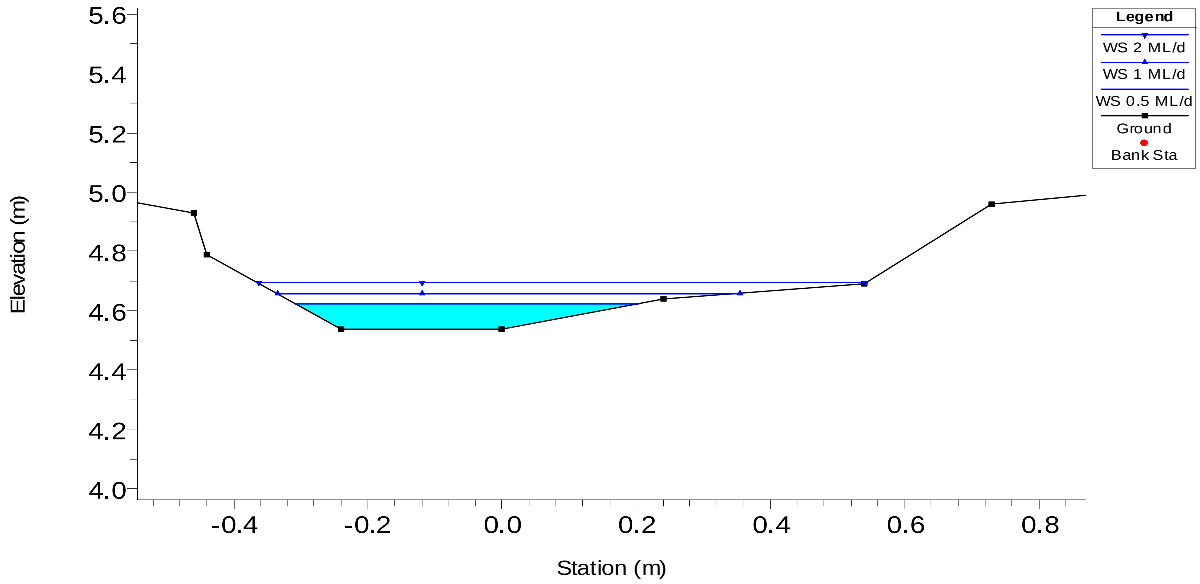


Figure 5.8 Top: Run habitat transect at flows of 0.5, 1 and 2 ML/day, indicating depth relative to the entire channel. Bottom: Detail of low flow channel at 0.5, 1 and 2 ML/day.

5.3 Low Flow Freshes

The recommended low summer flow does not provide much surface water velocity through the deeper pools (as modelled) and this may lead to periods of low water quality through the season.

The low flow fresh recommendation is based on refreshing water quality, as well as flushing sediments from potential egg laying sites in the lead up to the autumn fish breeding season (for Spotted galaxias), to inundate bars in the channel (for wetting and to entrain leaves, bark and twigs) and to provide some depth variability on the surfaces of large wood in the channel.

Flow Component	Flow-related process	Assessment criteria
Low Flow Freshes (Dec-March)	1. Maintain quantity and quality of habitat in pools by preventing siltation.	1. Positive pool velocity.
	2. Provide occasional adequate depth in runs between pools for movement of all species.	2. Run areas with depth >12 cm.
	3. Flush sediments in lead up to fish spawning season.	3. Mean channel scour in runs and pool edges >1.4 $N\ m^{-2}$.
	4. Prevent water quality decline.	4. Positive pool velocity.
	5. Inundate bars and low level benches to wet emergent vegetation and maintain moist soils.	5. Determined from cross-section morphology.
	6. Episodically wet exposed coarse woody debris.	6. Additional wood areas inundated *ca* 1 day.
	7. Entrain terrestrial leaves, bark and wood into the stream from surrounding areas.	7. Determined from cross-section morphology.

From Figure 5.8 (bottom), a flow of 2 ML/day covers the low level bar in the run habitats. This flow also provides positive mean velocity through 2 of the 3 pools[11] (Figure 5.4) and a channel shear value of over 11 $N\ m^{-2}$ in the run section, sufficient to provide sediment flushing from surfaces.

The increase in pool depth over the Low Summer Flow recommendation is about 7 cm in the pool sections, providing some variability in the wetting of large wood.

At the shallowest point in the reach (Figure 5.9), a flow of 2 ML/day provides a depth of 13 cm, allowing localised movement of small fish between pools (with depths through the run section of 15 cm).

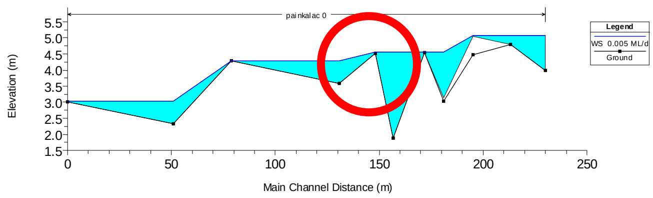


Figure 5.9. Long profile, indicating the shallowest point in the reach (Photo: G. Vietz)

[11] The deepest pool in has an average velocity less than 0.001 ms^{-1} at a flow of 2 ML/day.

Under natural flow conditions (using only flow data between 1970 and 1999), freshes of at least 2 ML/day occurred between December and March with a median frequency of 10 per year. A frequency of 1 fresh per month would seem adequate to meet the stipulated objectives, so only 4 per year are recommended. The median duration of each spell under natural conditions was 3 days. A suitable independence value cannot be determined from ecological requirements, but the median interval between freshes in the natural flow regime is 8 days.

Low Flow Fresh Recommendation:

Flow:	2 ML/day
Frequency:	4 per year (or natural)
Duration:	3 days (or natural)
Timing:	December to March inclusive
Independence:	8 days

5.4 Transitional Low to High Flow Season Freshes

Transitional freshes were not included in the original list of flow components in the FLOWS method. However, they are included here in order to stimulate spawning migrations of migratory fish species (Common galaxias and Tupong) and assist in spawning stimulation for freshwater breeding fish (Spotted and Broad-finned galaxias). In particular, Broad-finned galaxias require two periods of high flows, one to allow access to spawning habitats along the margin of the stream channel, and a second to stimulate egg hatching and wash the larvae towards the sea (O'Connor and Koehn, 1998[12]), so that two transitional freshes are recommended each year.

While the Transitional Low to High Flow Season has been identified from April to May, the two recommended flows are included for the March to June period, to allow for natural variation in the onset of higher flows (so the flows are recommended in early start and late start years).

There are no criteria that have been established to determine an appropriate flow rate (or change in flow) that stimulates spawning migrations. The suggested FLOWS surrogate of using the median flow of a season for fresh levels (the median natural April to June flow is 1.6 ML/day) does not provide access to stream edge habitats (see depths for 2 ML/day in Figure 5.10), so a suitable recommendation was based on providing access to stream margin habitats for Broad-finned galaxias.

At a flow of 20 ML/day, access to edge habitats was provided in a number of transects, and partially provided in others (Figure 5.10).

Under natural flow conditions (using only flow data between 1970 and 1999), freshes of at least 20 ML/day occurred between December and March with a median frequency of 4.5 per year. In order to separate the spells to allow for Broad-finned galaxias egg development, a 7 day independence value is applied – with the result that spells under natural conditions occur with a median frequency of 2 per year. The median duration of each spell under natural conditions was 1 day. A suitable independence value cannot be determined from ecological requirements, but the median interval between freshes in the natural flow regime is 8 days.

[12] O'Connor, W.G. and Koehn, J.D. (1998) Spawning of the broad-finned Galaxias Galaxias brevipennis Gunther (Pisces: Galaxiidae) in coastal streams of southeastern Australia. *Ecology of Freshwater Fishes* **7**:95-100.

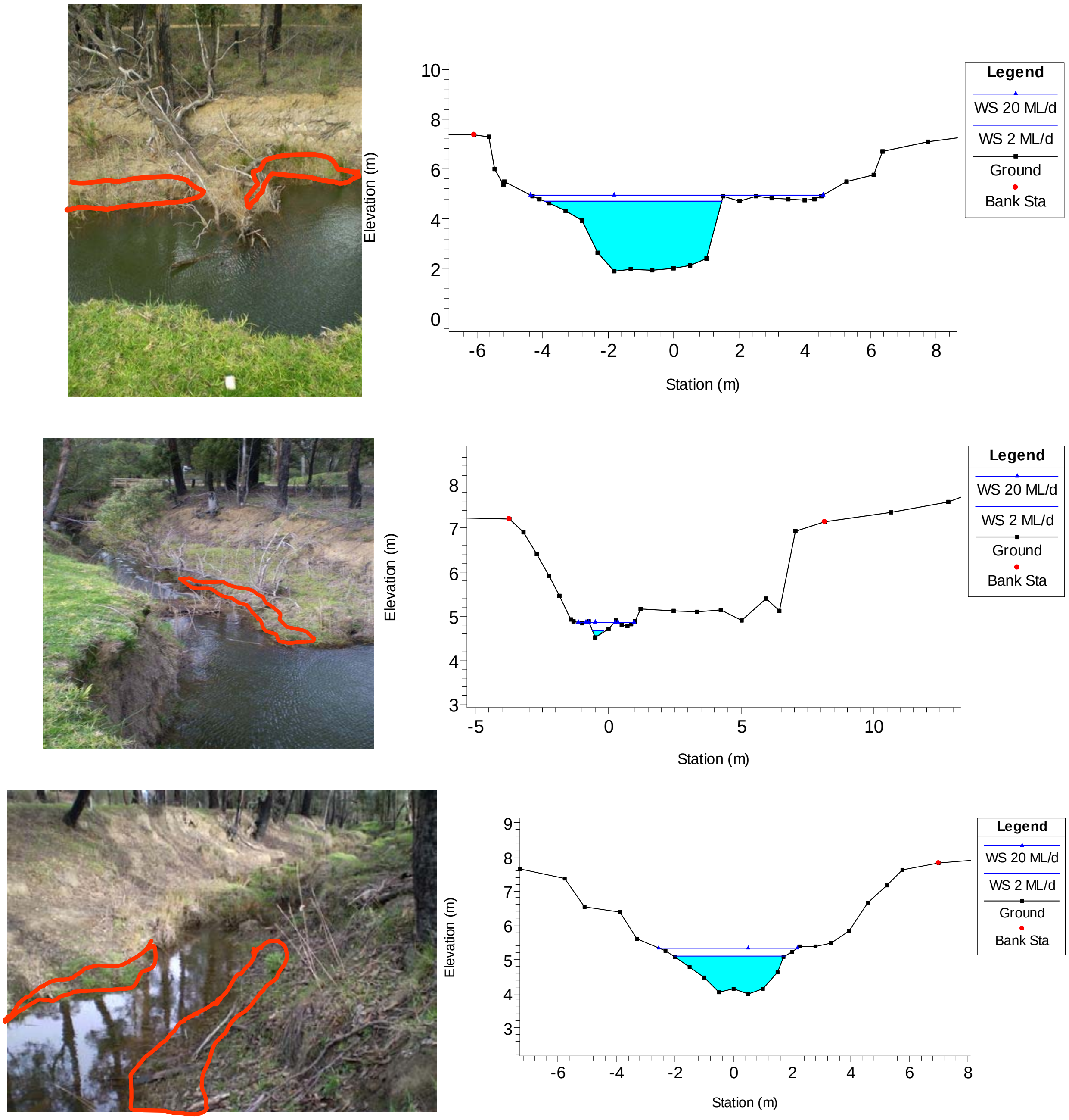


Figure 5.10. Three transects showing access to edge habitats at 20 ML/day that is not provided by the Low Flow Fresh recommendation (2 ML/day) (Photos: H. Reed)

Transitional Fresh Recommendation:

Flow:	20 ML/day
Frequency:	2 per year (or natural)
Duration:	1 day
Timing:	March to June inclusive
Independence:	8 days

5.5 Low Winter Flow

Like the low summer flow, the main functions of the low winter flow are to provide for suitable habitat availability in the creek. Adequate habitat is provided for by the low summer flow recommendation. However, another function of the higher winter baseflow is to prevent colonisation of the stream channel edges by exotic or terrestrial plant taxa. This requires that the bars along the edge of the stream are inundated for long periods of time. The suitable flow recommendation for this function is the level of the Low Flow Fresh (2 ML/day), which inundates bars (Figure 5.8).

Flow Component	Flow-related process	Assessment criteria
Low Winter Flows (May-November)	1. Maintain habitat for fish. 2. Maintain pool habitat for aquatic macroinvertebrates. 3. Maintain run habitat for aquatic macroinvertebrates. 4. Maintain habitat for aquatic vegetation. 5. Inundate benches and bars to prevent colonisation by exotic or terrestrial plant taxa. 6. Wash fish larvae to seas.	1. Deep pool areas with > 20 cm depth. 2. Water to inundate edge vegetation in pools. 3. Run areas with depth >10 cm. 4. Deep pool areas with > 20 cm depth. 5. Benches inundated for *ca* 1+ week. 6. No criteria available.

A final function of the Low Winter Flow is to provide for washing freshly hatched fish larvae towards the estuary. No criteria are available to determine a suitable flow rate, but it can be assumed that long periods of flows with positive velocity are required to prevent the settling of larvae (this can be assisted by occasional High Flow Freshes – see below – but the timing cannot be guaranteed to correspond to larval hatching). Again, the Low Flow Fresh level (2 ML/day) provides positive velocities throughout the reach.

The Low Winter Flow recommendation is extended into the Transitional High to Low Flow Season (November) to allow for upstream migration of juvenile fish and adult lamprey.

Low Winter Flow Recommendation:

Flow: 2 ML/day or natural (with cease to flow provisions)

Timing: May to November inclusive

5.6 High Flow Freshes

High Flow Freshes in Painkalac Creek have a wide variety of functions, mainly revolving around maintaining the channel shape and form (moving sediments), removing any filamentous algal build-up on surfaces in the lead up to the subsequent Low Flow Season, and wetting benches and bars to provide a watering regime on the bank that favours species adapted to periods of inundation (as opposed to terrestrial species that can colonise if higher flows are absent).

Flow Component	Flow-related process	Assessment criteria
High Flow Freshes (May-October)	1. Maintain quantity and quality of habitat in pools by preventing siltation. 2. Movement of bed material to maintain bed diversity for water depth variation. 3. Maintain channel form and key habitats, including in-channel benches. 4. Flush sediments in lead up to Spring fish spawning season (Oct-Nov). 5. Prevent dominance of filamentous algae. 6. Inundate benches and bars to prevent colonisation by exotic or terrestrial plant taxa. 7. Episodically wet exposed coarse wood and remove accumulated algal growth.	1. Positive pool velocity. 2. Mean run scour >8 N m^{-2}. 3. Mean pool scour >15 N m^{-2}. 4. Mean run scour >1.4 N m^{-2}. 5. Mean velocity >0.3 m s^{-1}. 6. Benches and bars inundated for *ca* 1+ week. 7. Wood inundated *ca* 1-3 days by water with mean velocity >0.3 m s^{-1}.

A number of benches were identified in many of the transects (Figure 5.11, Figure 5.12) – both low in the channel and at mid channel depths. Flows required to inundate these benches varied, but two flows – 35 ML/day and 200 ML/day inundated the majority of these benches (Figure 5.12).

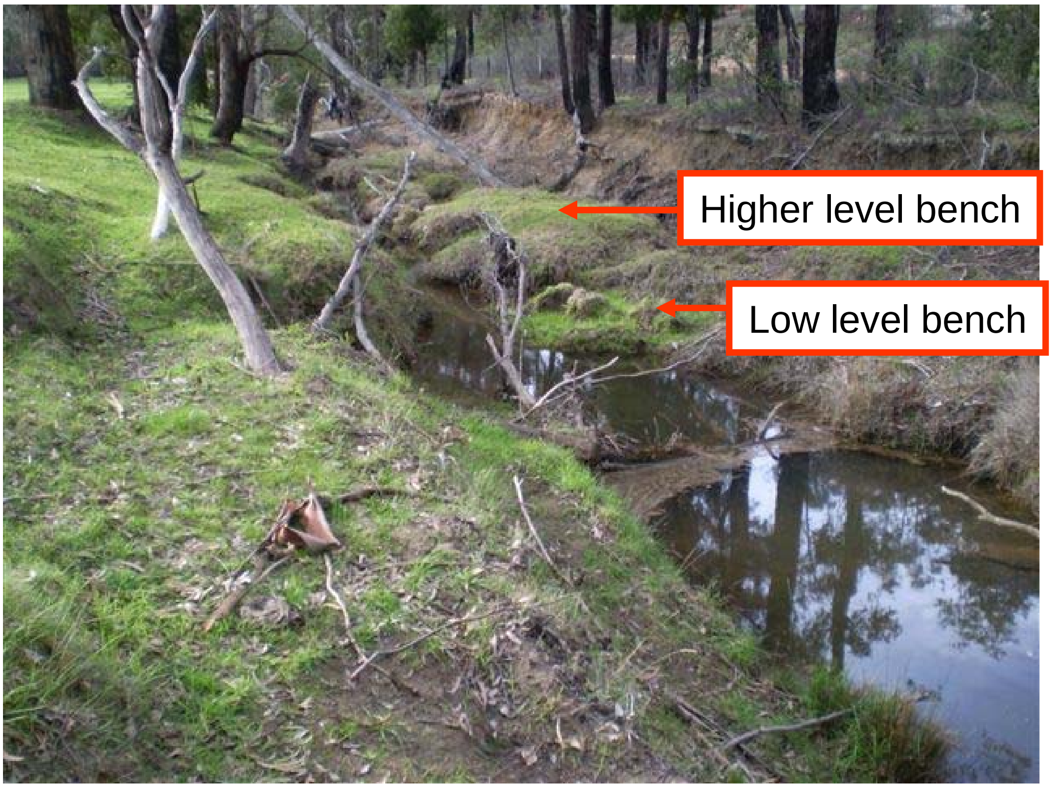


Figure 5.11. Example of two bench levels in the Painkalac Creek (Photo: H. Reed)

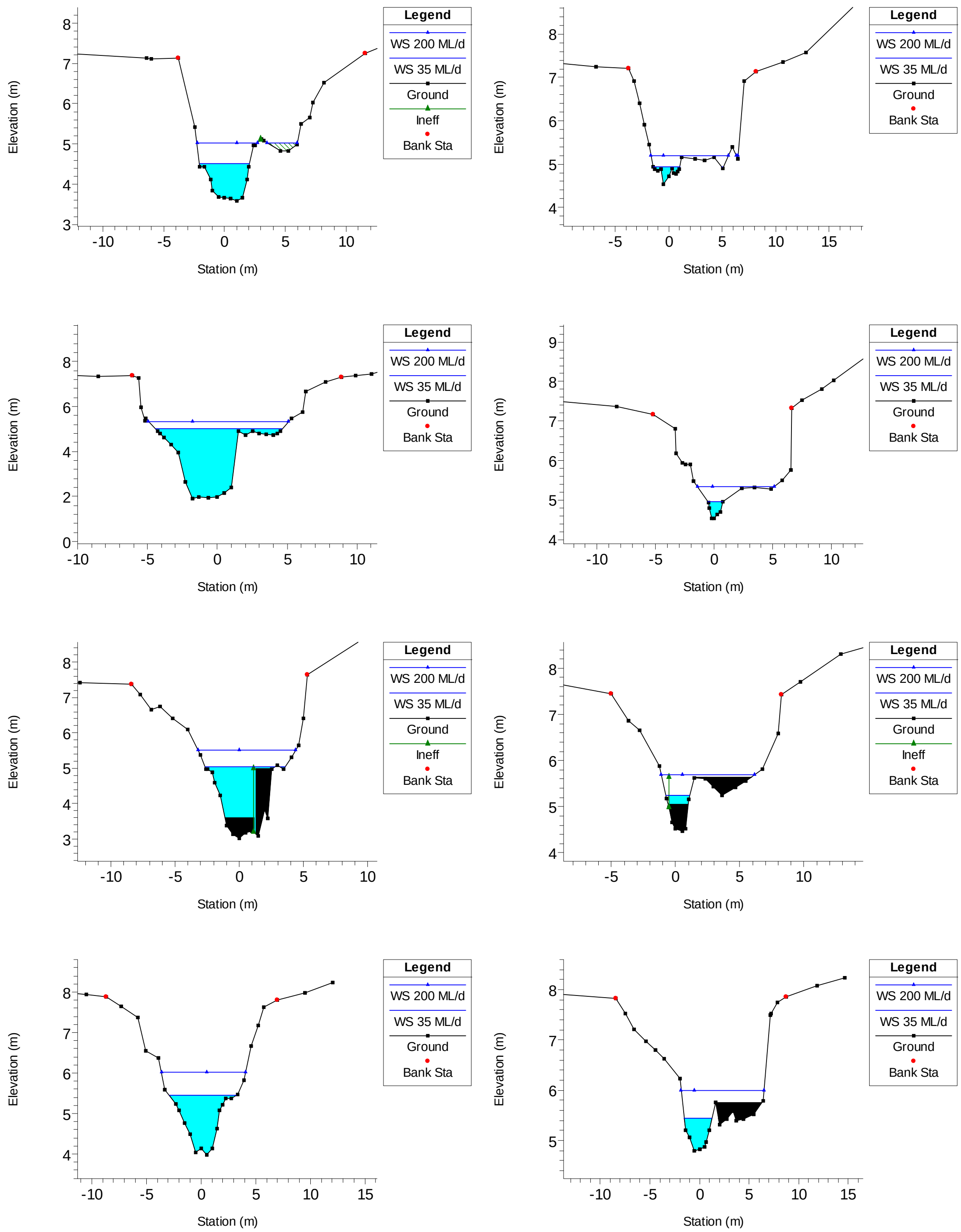


Figure 5.12. Eight transects showing inundation of various benches at 35 ML/day and 200 ML/day (note: black blocked sections indicate the presence of either large wood or changes in channel morphology immediately upstream or downstream of the cross section).

Both flow levels (35 ML/day and 200 ML/day) provided positive pool water velocity in all three pools identified in Figure 5.4. However, only at the 200 ML/day flow was average velocity in 2 pools approaching 0.3 m s^{-1}, providing for adequate scouring of filamentous algae. At 200 ML/day, there was significant levels of channel scour in the shallow reaches (>100 N m^{-2}), and high levels through pools sections 1 and 3 from Figure 5.4 (17.5 and 7.9 N m^{-2} respectively). However, scour in pools section 2 at this flow was relatively low (0.97 N m^{-2}). While this is an average level (laterally across the channel), there would be parts of the pool with much higher levels.

Flows higher than 200 ML/day occurred during the High Flow Season (June to October) under natural flows with a median frequency of 3 times per year (1970-1999), peaking over the threshold for a median duration of only 1 day.

A further requirement for this flow component is to provide sediment flushing in the lead up to the non-migratory fish species breeding season in Spring. Therefore, it is recommended that one of the three flows is to be provided in the September-October period. This has additional benefits of providing algal scour just prior to the next Low Flow Season. Under natural conditions, flows of this magnitude occur in most years at this time.

A longer independence value of 19 days (the median interval between such flows in the natural flow regime) is recommended for the two flows over 200 ML/day in the June to August period, as algal growth during this time is likely to be slow, and sedimentation will be reduced by the higher level of the low winter flow.

High flow freshes of this magnitude occurred throughout the season (Figure 5.13), so it is reasonable to expect flows to occur throughout the season. In September to October, freshes over 200 ML/day occurred in 21 out of 30 years.

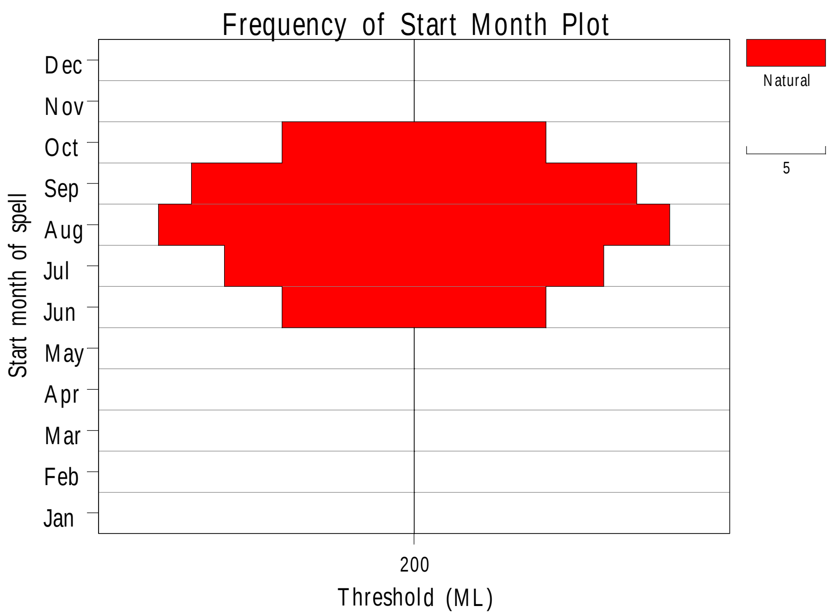


Figure 5.13. Frequency of freshes greater than 200 ML/day each month (June-October, 1970-1999). Width of bars related to number of flows in each month (Horizontal bar on right shows scale of 5 flow events).

High Flow Fresh Recommendation (1):	
Flow:	200 ML/day
Frequency:	2 per year (or natural)
Duration:	1 day
Timing:	June to August inclusive
Independence:	19 days

High Flow Fresh Recommendation (2):	
Flow:	200 ML/day
Frequency:	1 per year (or natural)
Duration:	1 day
Timing:	September to October inclusive

5.7 Bankfull Flows

Bankfull flows have similar functions to High Flow Freshes in providing a wetting regime to stream banks and providing disturbance of habitats to maintain geomorphic complexity. Under normal conditions, the flow recommended is based on modelling a flow that just fills the channel, often assumed as a surrogate for the channel forming flow (Gordon *et al*, 2004[13]). However, the incised nature of the representative reach suggests that such flows are very high and very rare, about 3,000 ML/day (Figure 5.14), a flow with a natural return time of well over 10 years (see Appendix 1).

Flow Component	Flow-related process	Assessment criteria
Bankfull Flows (May-October)	1. Maintain channel form and key habitats, including in-channel benches. 2. Control riparian vegetation encroachment to prevent catastrophic erosion processes. 3. Maintain moist soils in riparian zones. 4. Episodically wet exposed coarse woody debris and remove accumulated algal growth.	1. Flood frequency assessment or determined from transect. 2. Wetting high in the channel. 3. Wetting high in the channel. 4. Wood inundated *ca* 1-3 days by water with mean velocity >0.3 m s^{-1}.

[13] Gordon, N.D., McMahon, T.A., Finlayson, B.L., Gippel, C.J. and Nathan, R.J. (2004) Stream Hydrology: An introduction for Hydrologists (2nd Edition). John Wiley & Sons, Chichester.

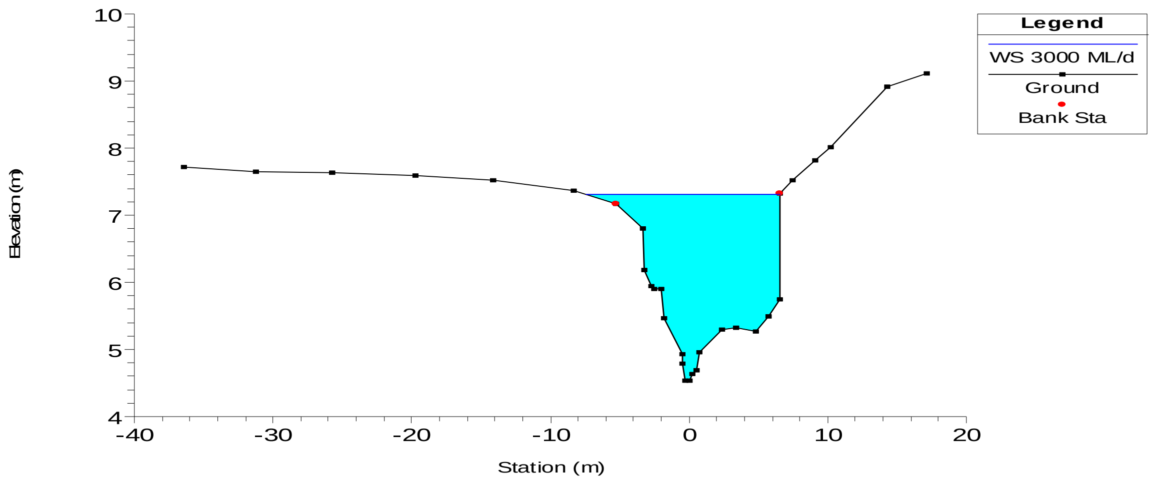


Figure 5.14. Transect showing flow at 3,000 ML/day filling the channel and about to spill onto the floodplain.

Recurrence intervals associated with bankfull are commonly in the range of 1-2 years. In this case, we have identified a flow that occurs about every 2 years as the bankfull flow recommendation – 700 ML/day.

Bankfull Flow Recommendation:	
Flow:	700 ML/day
Frequency:	1 in 2 years (or natural)
Duration:	1 day
Timing:	Any time of year

5.8 Overbank Flows

Without any major floodplain wetlands, overbank flows are not considered necessary in this reach. It is considered that the old course of Painkalac Creek will be engaged at the Bankfull Flow recommendations.

5.9 Summary of recommendations

Table 5.1 shows a summary of the environmental flow recommendations for Painkalac Creek, including time of year, flow magnitude, frequency, duration and independence between events.

Table 5.1. Summary of environmental flow recommendations for Painkalac Creek

<table>
<tr><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th></tr>
<tr><th colspan="4">Low Flow Season</th><th colspan="2">T (H-L)</th><th colspan="5">High Flow Season</th><th>T (L-H)</th></tr>
<tr><td colspan="12">Cease to Flow:
No more than 2 spells per year, maximum spell length of 7 days</td></tr>
<tr><td colspan="5">Low Summer Flow:
0.5 ML/day (or natural[14])</td><td colspan="7">Low Winter Flow:
2 ML/day (or natural[15])</td></tr>
<tr><td colspan="4">Low Flow Fresh:
2 ML/day
4 per year (or natural), 3 day duration (or natural)
8 day independence</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="4">Transitional Fresh:
20 ML/day
2 per year (or natural), 1 day duration
8 day independence</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="3">High Flow Fresh:
200 ML/day
2 per year (or natural), 1 day duration
19 day independence</td><td colspan="2">High Flow Fresh:
200 ML/day
1 per year (or natural), 1 day duration</td><td></td></tr>
<tr><td colspan="12">Bankfull Flow:
700 ML/day
1 in 2 years, 1 day duration</td></tr>
</table>

[14] But with additional cease to Flow recommendation provisions.

[15] But with additional cease to Flow recommendation provisions.

6. Comparison of Recommendations with the Current Flow

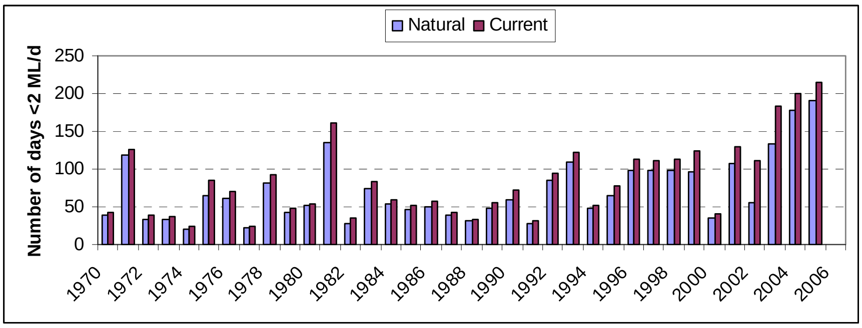
The environmental flow recommendations for Painkalac Creek (Table 5.1) were compared with the flows provided in the modelled current flow regime. As the Cease to Flow recommendation is an absolute limit for both frequency and duration, the comparison was based on the percentage of years in the current flow regime with more than the recommended frequency, and the percentage of spells that exceeded the recommended maximum duration. The Low flow comparison (summer and winter) was based on the number of days each year in the current flow regime where flows were below the recommended flow (compared with the natural flow regime).

Freshes and high flow recommendations (Low Flow Freshes, High Flow Freshes and Bankfull flows) were compared with the frequency of freshes in the current and natural flow regime in two parts. Where the natural frequency was equal to or higher than the recommended frequency in any year, the flow was considered comparable with the recommendation if the current flow regime had at least the recommended frequency. Where the natural flow regime had less than the recommended frequency, the current flow was considered comparable with the recommendation if the current flow regime had the same number of freshes (a result of the "or natural" provision). The overall comparison simply used the percentage of years that the current flow matched the recommendation.

Recommendations that involve the duration of freshes are difficult to assess. Where freshes are reduced in frequency, it is often the shorter freshes that are eliminated, so the average or median length of remaining freshes in the current flow regime are often longer than in the natural regime. In this case, a simple assessment was made as to whether the median length of remaining freshes was the same or higher than the recommended duration. If so, it is assumed that the distribution of fresh duration in the current flow regime is the same as for the natural flow regime.

Flow Recommendation	Comparison (1970-2006)
Cease to Flow: No more than 2 spells per year, maximum spell length of 7 days	The current flow regime has 2 years (5%) with more than 2 Cease to Flow spells per year. In the current flow regime, 35% of spells are longer than 7 days duration. **Conclusion:** While Cease to Flows are rarely more frequent than recommended, many spells are longer than recommended.

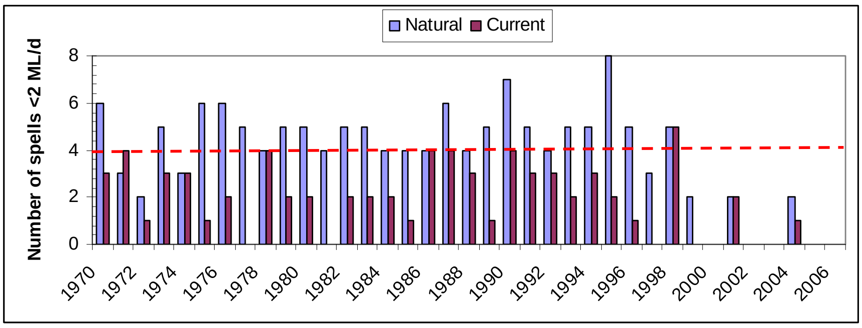
Flow Recommendation	Comparison (1970-2006)
Low Summer Flow: December to April, 0.5 ML/day (or natural)	**Natural**: Median number of spells lower than 0.5 ML/day per year – 3 per year Median duration of spells lower than 0.5 ML/day per year – 4 days Median annual days lower than 0.5 ML/day - 20 days per year **Current**: Median number of spells lower than 0.5 ML/day per year – 3 per year Median duration of spells lower than 0.5 ML/day per year – 4 days Median annual days lower than 0.5 ML/day - 20 days per year **Conclusion:** The current flow regime aligns with the recommendation as the current flow regime has been modelled with a passing flow provision of 0.5 ML/day (or natural).

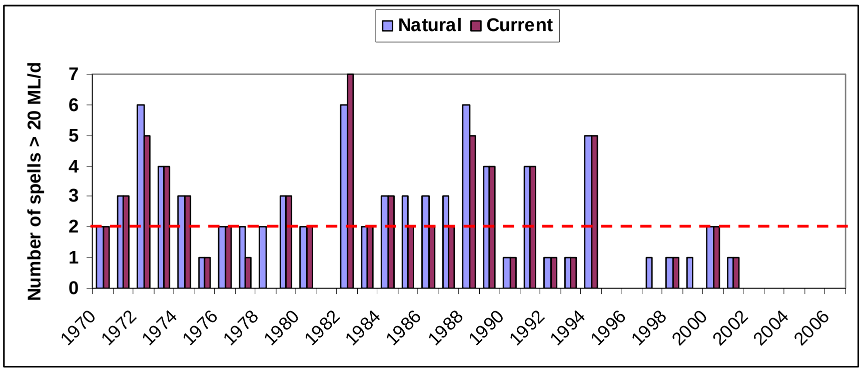
Flow Recommendation	Comparison (1970-2006)
Low Winter Flow: May to November, 2 ML/day (or natural)	**Natural**: Median number of spells lower than 2 ML/day per year – 12 per year Median duration of spells lower than 2 ML/day per year – 3 days Average annual days lower than 2 ML/day - 69 days per year **Current**: Median number of spells lower than 2 ML/day per year – 12 per year Median duration of spells lower than 2 ML/day per year – 3 days Average annual days lower than 2 ML/day - 81 days per year In all years between 1970 and 2006, the current flow regime has more days lower than 2 ML/day between May and November than in the natural flow regime. Between 1970 and 1999, the difference is relatively small (an average increase of 9 days per year), but recent years (1999-2006), the difference is much larger (25 days per year).  **Conclusion:** Longer periods with lower flows than recommended.

Flow Recommendation	Comparison (1970-2006)
Low Flow Fresh: December to March, 2 ML/day, 4 per year (or natural), 3 day duration (or natural, 8 day independence	**Natural**: Median number of spells higher than 2 ML/day per year – 4 per year[16] Median duration of spells higher than 2 ML/day per year – 3 days Median annual days higher than 2 ML/day - 35 days per year **Current**: Median number of spells higher than 2 ML/day per year – 2 per year Median duration of spells higher than 2 ML/day per year – 4 days[17] Median annual days higher than 2 ML/day - 15 days per year In the natural flow regime, there were 25 out of 37 years where 4 or more freshes occurred (all prior to 1999). In 20 of these years, less than 4 freshes were recorded in the current flow regime. Of the 12 years with less than 4 natural freshes, 4 years had less than the natural number in the current flow regime. Therefore, 24 of 37 years (65%) of years are not compliant with the frequency recommendation.

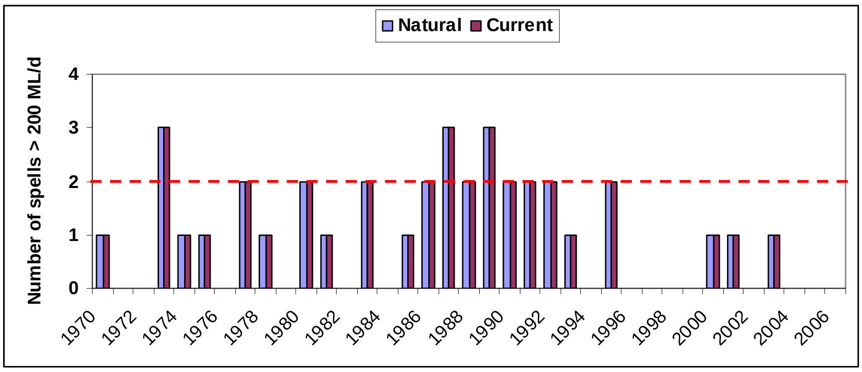
[16] With 8 day independence.

[17] The median duration of freshes in the current flow regime is higher than the natural median because it is the shorter freshes that have been eliminated from the current flow regime, leaving more of the longer natural freshes.

	 **Conclusion:** Frequency too low in most years. Freshes remaining in current flow are of adequate duration.

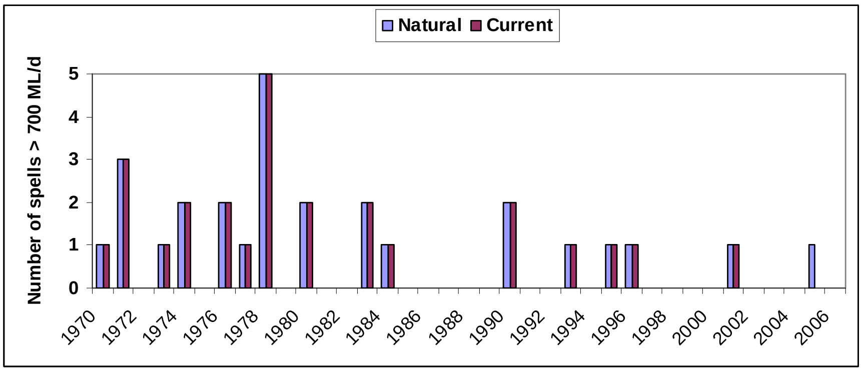
Flow Recommendation	Comparison (1970-2006)
Transitional Fresh: March to June, 20 ML/day, 2 per year (or natural), 1 day duration, 8 day independence	**Natural**: Median number of spells higher than 20 ML/day per year – 2 per year[18] Median duration of spells higher than 20 ML/day per year – 1 day Median annual days higher than 20 ML/day - 6 days per year **Current**: Median number of spells higher than 20 ML/day per year – 2 per year Median duration of spells higher than 20 ML/day per year – 1 day Median annual days higher than 20 ML/day - 6 days per year In the natural flow regime, there were 21 out of 37 years where 2 or more freshes occurred between March and April. In 2 of these years, less than 2 freshes were recorded in the current flow regime. Of the 16 years with less than 2 natural freshes, 2 years had less than the natural number in the current flow regime. Therefore, 33 of 37 years (89%) of years are not compliant with the frequency recommendation.  **Conclusion:** Frequency too low in a few years. Freshes remaining in current flow are of adequate duration.

[18] With 8 day independence.

Flow Recommendation	Comparison (1970-2006)
High Flow Fresh (1): June to August, 200 ML/day, 2 per year (or natural), 1 day duration, 19 day independence	**Natural**: Median number of spells higher than 200 ML/day per year – 1 per year[19] Median duration of spells higher than 200 ML/day per year – 1 day Median annual days higher than 200 ML/day - 1 day per year **Current**: Median number of spells higher than 200 ML/day per year – 1 per year Median duration of spells higher than 200 ML/day per year – 1 day Median annual days higher than 200 ML/day - 1 day per year  **Conclusion:** All freshes in the natural flow regime are matched in the current flow regime.

Flow Recommendation	Comparison (1970-2006)
High Flow Fresh (2): September to October, 200 ML/day, 1 per year (or natural), 1 day duration	**Natural**: Median number of spells higher than 200 ML/day per year – 1 per year Median duration of spells higher than 200 ML/day per year – 1 day Median annual days higher than 200 ML/day - 1 day per year **Current**: Median number of spells higher than 200 ML/day per year – 1 per year Median duration of spells higher than 200 ML/day per year – 1 day Median annual days higher than 200 ML/day - 1 day per year **Conclusion:** All freshes in the natural flow regime are matched in the current flow regime**.**

[19] With 19 day independence.

Flow Recommendation	Current compliance (1970-2006)
Bankfull Flow: Any time, 700 ML/day, 1 in 2 years, 1 day duration	A single bankfull flow in the natural flow regime (January 2005) appears to be missing from the current flow regime. However, the modelled current flow peaked at 627 ML/day, so is likely to have a similar ecological outcome.  **Conclusion:** All bankfull flows in the natural flow regime are matched in the current flow regime**.**

7. Other Catchment Issues

7.1 Painkalac Creek Estuary

The recommended flows in the freshwater section of Painkalac Creek are designed to provide for the requirements of environmental assets in that reach. The flow requirements of the estuary have not been assessed in this project. Whether the flows recommended are suitable to provide for environmental water requirements of estuarine assets is unknown, and may need to be investigated once suitable techniques to identify estuary environmental flow requirements are developed.

7.2 Large Woody Debris

Large Wood (LW) in Painkalac Creek is of considerable importance in maintaining channel form, stability and habitat niches. LW increases channel roughness in turn reducing the energy of the flow and the potential for reach-scale bank erosion. LW also encourages localised bed scour, which maintains diversity in the bed form and variation in water depth. Removal of LW from the channel should be prevented, unless otherwise demonstrated as a serious threat to a high value asset or human life. Riparian stands providing potential future sources of LW should be maintained or regenerated.

7.3 Riparian vegetation management

The riparian zone of the study reach shows little evidence of regeneration of overstorey trees, and little understorey (Figure 7.1), with the surrounding pasture reaching all the way to the stream bank. Any regeneration is therefore likely to be grazed by stock and/or kangaroos. Stock access to streams has a number of potential impacts, including increased soil erosion and compaction, increased nutrients from manure and urine and the spread of weed species.

Figure 7.1. Riparian zone of the study site showing little or no regeneration (Photo: P. Boon).

The local landholder has commendably introduced a number of actions to ameliorate the impacts of grazing including extensive weed control, a limit on the number of stock, the provision of reticulated water points in all paddocks which stock preferentially use, and the introduction of 8 species of dung beetle to minimise faecal contamination of the creek (Graeme McKenzie, landholder, pers. comm.).

However, it needs to be acknowledged that ecological benefits from environmental flows will be greatly increased if the riparian vegetation is rehabilitated.

This issue has been recognised in the Estuary Management Plan (Surf Coast Shire, undated) with the actions proposed to:

- Fence and rehabilitate riparian areas on private land in the Painkalac Creek catchment; and
- Fence and rehabilitate riparian areas on Council owned and managed land in the Painkalac Creek catchment. (Objective 1, p. 24).

The landholder considers that fencing may not be suitable in his part of the creek, due to the potential for damage during floods (300 m of test fencing was constructed in August/September 2007, 200 m of which was destroyed in the flood on November 2007). Should rehabilitation of the riparian zone be seen as desirable, alternative approaches to protecting regeneration may need to be investigated and implemented.

7.4 Fish passage at grade control structure

The grade control structure downstream of Old Coach Road experiences subterranean flow (through-flow) within the rocky substrate (Figure 7.2). Subterranean flow cannot be accurately modelled by the HEC RAS system so depths of water indicated by HEC RAS are likely to be relatively inaccurate at low flows (when a large proportion of the flow may pass through the rocky substrate). Therefore, fish passage recommendation from upstream cross-sections may not provide adequate flows for passage across the structure. Further investigations are required to establish whether flows recommended can provide fish passage at the structure (including between rocks), and whether the structure could be altered to include a defined low flow channel for fish passage.

Figure 7.2. Grade control structure downstream of Old Coach Road, showing no surface water on the structure, despite flows upstream of the structure (Photo: G. Vietz).

7.5 Monitoring

If the environmental flow recommendations contained in this report are implemented, monitoring the outcomes should be seen as an important component of future management of the creek. Monitoring should include three components:

- Flow monitoring to ensure compliance with the recommendations;
- Model validation – measuring the depth of water at critical points at the recommended flow to ensure that the criteria used are met in reality; and
- Monitoring of the ecological outcomes of the flows (checking whether the objectives for the creek are being met).

It is therefore recommended that a suitable monitoring program be developed and implemented.

7.6 Climate Change

The provision of water for both environment and consumptive use needs to be considered in the context of potential climate change. Predicted reductions in rainfall will mean less flow in affected rivers. CSIRO[20] estimates for the Otway Coast suggest a reduction in runoff between 5% and 30% by the year 2030.

The environmental flow recommendations should be seen as independent of climate change – the requirements of the in-stream and riparian flora and fauna will not change with the climate. However, the amount of water available to satisfy both environmental and consumptive uses will decline to some degree, which may present a challenge to the Painkalac Creek community in the future.

[20] Jones, R.N. and Durack, P.J. (2005) Estimating the impacts of climate change on Victoria's runoff using a hydrological sensitivity model. CSIRO, Melbourne.

8. References

Doeg, T.J., Vietz, G.J. and Boon, P.I. (2007) Painkalac Creek *Environmental Flow Investigation: Site Paper*. Prepared for the Corangamite Catchment Management Authority, Colac.

Doeg, T.J., Vietz, G.J. and Boon, P.I. (2007) Painkalac Creek *Environmental Flow Investigation: Issues Paper*. Prepared for the Corangamite Catchment Management Authority, Colac.

GHD (2005) *Painkalac Creek and Estuary Pollution Source Investigation*. Report to Surf Coast Shire.

Gordon, N.D., McMahon, T.A., Finlayson, B.L., Gippel, C.J. and Nathan, R.J. (2004) Stream Hydrology: An introduction for Hydrologists (2nd Edition). John Wiley & Sons, Chichester

Jones, R.N. and Durack, P.J. (2005) Estimating the impacts of climate change on Victoria's runoff using a hydrological sensitivity model. CSIRO, Melbourne.

NRE (2002a) *FLOWS – a method for determining environmental water requirements in Victoria*. Catchment and Water Division, Department of Natural Resources and Environment, East Melbourne.

O'Connor, W. G. and Koehn, J. D. (1998) Spawning of the broad-finned galaxias *Galaxias brevipennis* Gunther (Pisces: Galaxiidae) in coastal streams of southeastern Australia. *Ecology of Freshwater Fishes* **7**: 95-100.

Surf Coast Shire (undated) *Painkalac Estuary Management Plan*. Surf Coast Shire.

Appendix 1. Hydrology of Painkalac Creek

In 1981 Painkalac Creek was dammed in order to supply the townships of Aireys Inlet and Fairhaven. These two communities are entirely reliant on Painkalac Reservoir (capacity of 514 ML) for ongoing good water quality. Barwon Water's current Bulk Entitlement (BE) allows a maximum of 317 ML a year to be harvested from Painkalac Reservoir through the Bulk Entitlement (Aireys Inlet) Conversion Order 1997. The maximum diversion rate allowed through the BE is 2.94 ML/day. Passing flows are specified as follows:

- March to November, the lesser of 0.5 ML/day or inflow;
- December to February, entire flow.

Hydrological modelling for this project was provided using a water balance REALM[21] model developed for Painkalac Creek by Barwon Water. The REALM model simulated daily stream flows and water use over the period January 1970-December 2006.

Three data sets were developed for Painkalac Creek:

- Natural flows – those that would have occurred in the creek in the absence of the Painkalac Reservoir and any other diversions. Other impacts such as vegetation clearing are not considered (i.e. changes in flow due to these impacts are considered permanent and not able to be regulated).;
- Current flows – those that would have occurred in the creek under the current water resource management regime (an annual diversion of approximately 175 ML/annum);
- Full development flows – those that would have occurred in the creek if the level of water resource use was increased to approximately 270 ML/annum.

Only diversions from the reservoir for Aireys Inlet and Fairhaven are considered as other diversions (farm dams and Stock and Domestic use) are considered small.

The flow regime of Painkalac Creek

Seasonality

The natural flows in Painkalac Creek display a typical temperate seasonal pattern, with the lowest average or median monthly flows in January-March, and the highest average or median flows in August or September (Figure A1).

[21] **Re**source **Al**location **M**odel

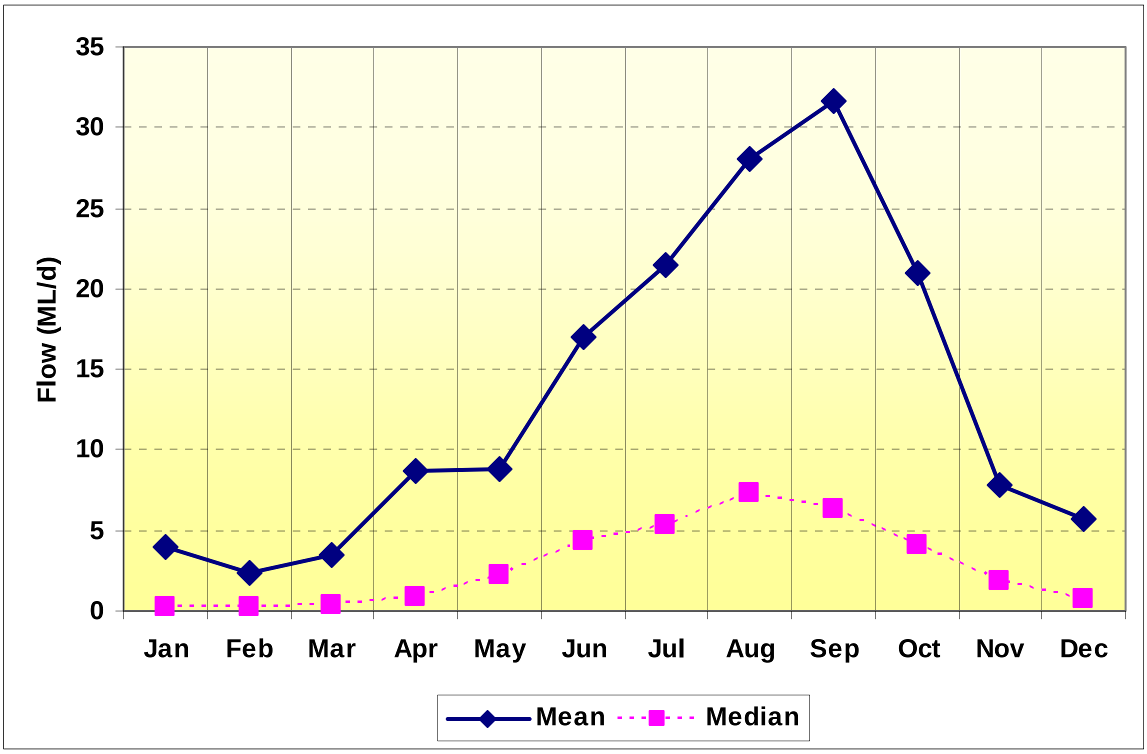


Figure A1 Mean and median natural flow for each month in Painkalac Creek

However, for environmental flow assessments, a more specific description of the seasonality is required. The flow regime is divided into four seasons, not related to the calendar seasons, but determined by characteristics of the natural flow regime:

- a Low Flow Season (with generally constant low flows – or no flow – with infrequent shorter periods of high flow – freshes – due to small localised rainfall events);
- a Transitional Flow Season from Low to High (higher flows becoming more common, due to more widespread rainfall events). Generally spread over two months, the first is characterised by increased high flows, but little change in base flows – see April in Figure A1 – while the second is characterised by a rise in baseflows – see May in Figure A1;
- a High Flow Season (higher baseflow with frequent, sometimes extended periods of higher flows from large widespread high rainfall events); and
- a Transitional Flow Season from High to Low (lower flows becoming more common as rainfall events become smaller and more localised – see November in Figure A1).

The different flow seasons in Painkalac Creek were identified from a frequency analysis was performed on the daily flow data in each month. In this, the percentage of individual daily flows in each month that lie within 10 particular flow bands (defined as the decile percentile flows over the entire year) were calculated. The most frequent flow bands, and the distribution of frequent flows can be used to identify the characteristics of the various flow seasons.

Table A1, shows the distribution of daily flows in each flow band for each month. The months of December and January to March fit the description of the Low Flow Season, with most records in the lower flow bands and few days of high flows. This pattern changes in April and May with the onset of larger proportions in the upper flow bands. June to October clearly fit the description of the High Flow Season, with a predominance of higher flow bands. November is clearly transitional between the High and Low Flow Seasons.

Table A1 Percentage of daily flow records that fall into particular flow bands in each month in Painkalac Creek. Flow bands represent flows between the indicated flow and the next lower flow. Flow bands with over 10% of records for each month are shaded yellow

Painkalac Creek													
%ile	Flow	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	0.00	7.7	13.0	6.4	2.7	0.0	0.0	0.0	0.0	0.0	0.0	1.7	5.0
0.1	0.08	19.8	16.7	13.4	9.7	2.7	0.6	0.6	1.0	0.7	3.7	5.0	10.8
0.2	0.20	16.7	17.2	19.9	18.1	10.4	4.7	1.3	0.5	1.8	3.7	7.1	18.6
0.3	0.55	13.9	14.7	13.4	13.0	11.7	6.7	5.5	3.7	5.4	7.6	13.3	11.8
0.4	1.18	10.6	11.4	11.8	10.0	11.8	9.3	8.2	5.3	8.1	9.5	13.2	10.9
0.5	2.15	7.6	8.2	10.3	9.3	12.0	10.8	9.8	8.2	10.2	11.0	12.4	9.7
0.6	3.67	6.6	6.8	7.9	9.0	11.7	12.5	12.9	11.1	10.3	11.1	11.6	8.3
0.7	6.01	4.5	4.2	6.2	8.9	10.8	14.2	14.5	14.8	12.2	13.1	10.0	6.4
0.8	10.17	5.1	3.6	4.4	6.7	11.0	12.2	13.9	16.6	14.2	13.6	9.7	8.1
0.9	19.14	3.4	2.4	3.6	7.5	9.7	15.5	16.5	18.1	16.4	12.0	9.0	5.5
1.0	2303	4.0	1.6	2.5	5.1	8.2	13.4	16.8	20.7	20.6	14.6	6.8	4.9

The seasonality adopted for this study is shown in Table A2. Of course, in individual years, the onset of the High Flow Season may be earlier or later than the April/May period, and the decline in flows to the Low Flow Season may be earlier or later than November, but this seasonality represents the case in the majority of years.

Table A2 Seasonality of flows adopted for Painkalac Creek

Season	Months
Low Flow Season	December, January – March
Transitional: Low to High	April, May
High Flow Season	June – October
Transitional: High to Low	November

Comparison of natural and current flows

The impact of the current level of diversions can be assessed from a number of viewpoints. The daily flow data from 1964-2003 was analysed to provide:

- Average daily flows for each month;
- Flow duration curves for the entire data set (1970-2006);
- Flow duration curves for each flow season identified in Table 3.2; and
- Annual maximum flood frequency distribution, plotted using Weibull plotting positions, calculated following the method described by Gordon *et al*. (1992).

Average Daily Flows

Average daily are noticeably lower than natural under the current management between January and March (Figure A2) with average flows reduced by between 25 and 33%. Flows in April and December are reduced by about 10%, with all other months showing average flow reductions of 1-5%.

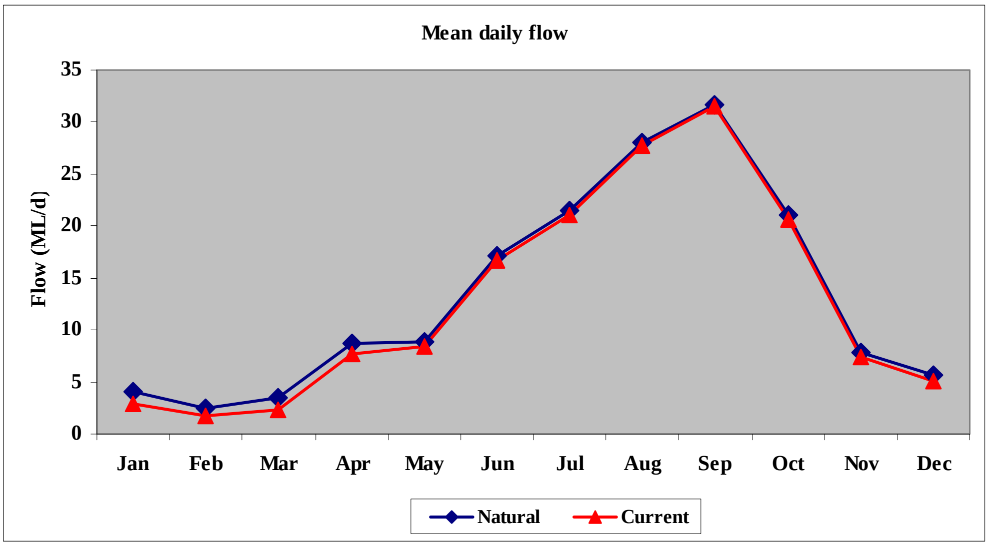


Figure A2 Average natural and current daily flows for each month in Painkalac Creek

Flow Duration Curves

The main deviations from natural flows are in the mid-range flows, between the 30th and 70th percent exceedence values over the year (Figure A3). This is due to the modelled current flow having a passing flow of 0.5 ML/day or natural proviso. This means that when natural inflows are over 0.5 ML/day, at least 0.5 ML/day is released, but when inflows fall to below 0.5 ML/day, only the inflow is released.

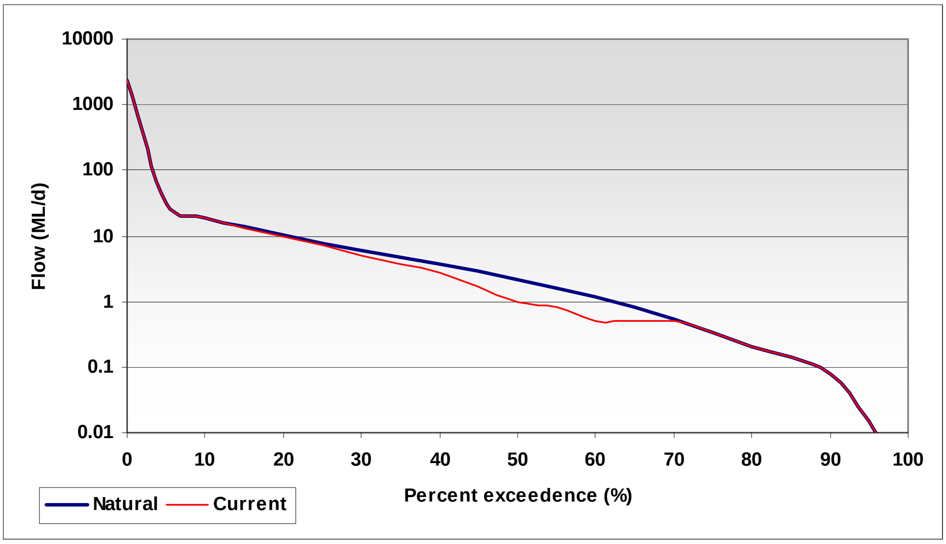


Figure A3 Natural and Current flow duration curves for the entire year in Painkalac Creek

The flow duration curves for each flow season (Figure A4) shows the effect of the passing flow rule modelled, with flows lower than 0.5 ML/day passing naturally. At the upper end of the scale, large flows are also little effected, due to the reservoir spilling and the diversion rate being small in comparison to the flow.

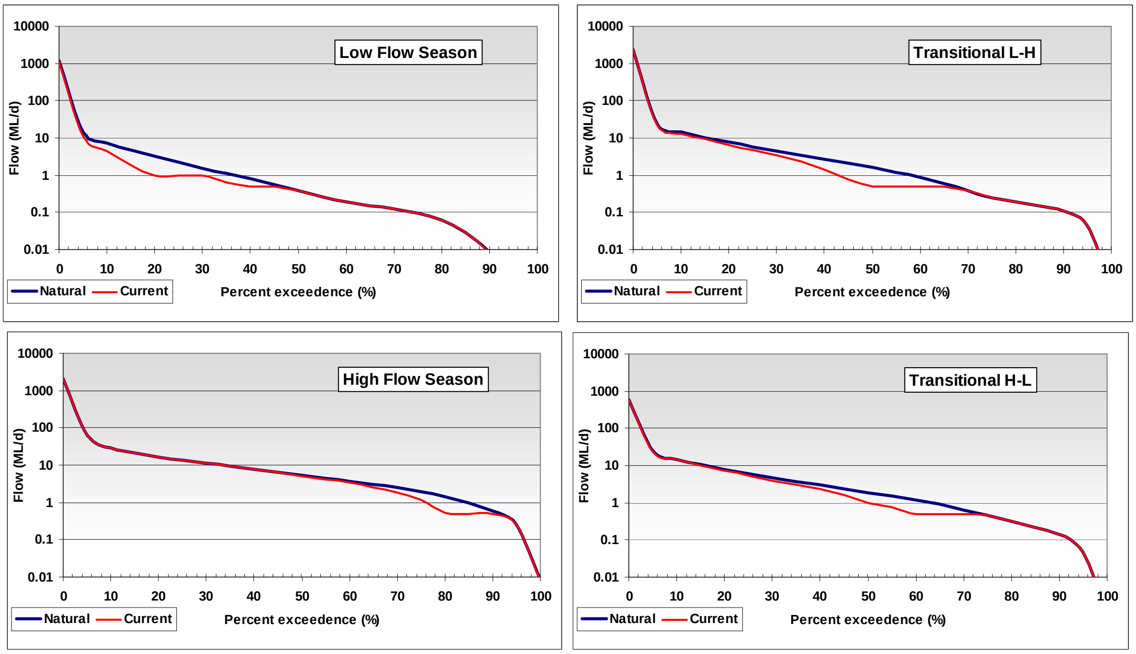


Figure A4 Natural and Current flow duration curves for curves for each Flow Season in Painkalac Creek

Flood Frequency Distribution

The annual maximum flood recurrence intervals at the Representative Site in Painkalac Creek (Table A3, Figure A5) shows almost no impact on floods with return times of two or more years. The deviation in the annual flood is due to 2006, when the only flows downstream of the reservoir were due to releases. If the 2006 data are ignored, the current annual flood is 14 ML/day, still reduced by 50% from natural.

Table A3 Natural and current flows for selected recurrence intervals for Painkalac Creek.

Recurrence interval (years)	Natural (ML/day)	Current (ML/day)
1	28	0.5
2	623	623
5	1419	1418
10	2016	2015
20	2073	2072

Summary

The low flow regime below 0.5 ML/day is not altered by the presence of the reservoir, due to the practice of releasing 0.5 ML/day or natural in the modelled current flows. This occupies about 30% of the time during the year (and about 50% of the time in the Low Flow Season).

Similarly, very high flows all through the year are little affected by the presence of the reservoir.

The main impacts of the reservoir are during periods of the Low Flow Season where the degree of variability is reduced (due to constant releases at 0.5 ML/day), and the natural flow is reduced (by on average 25-35%).

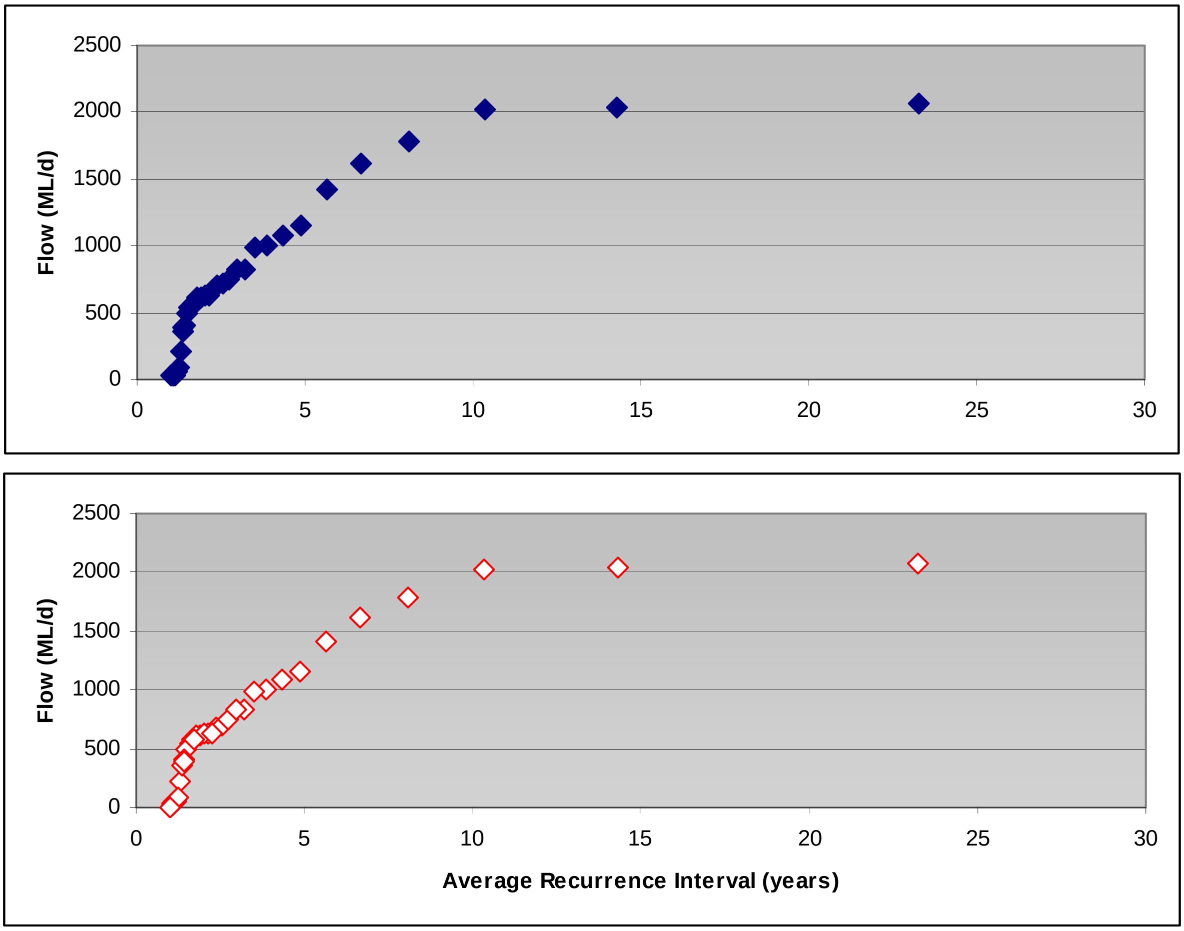
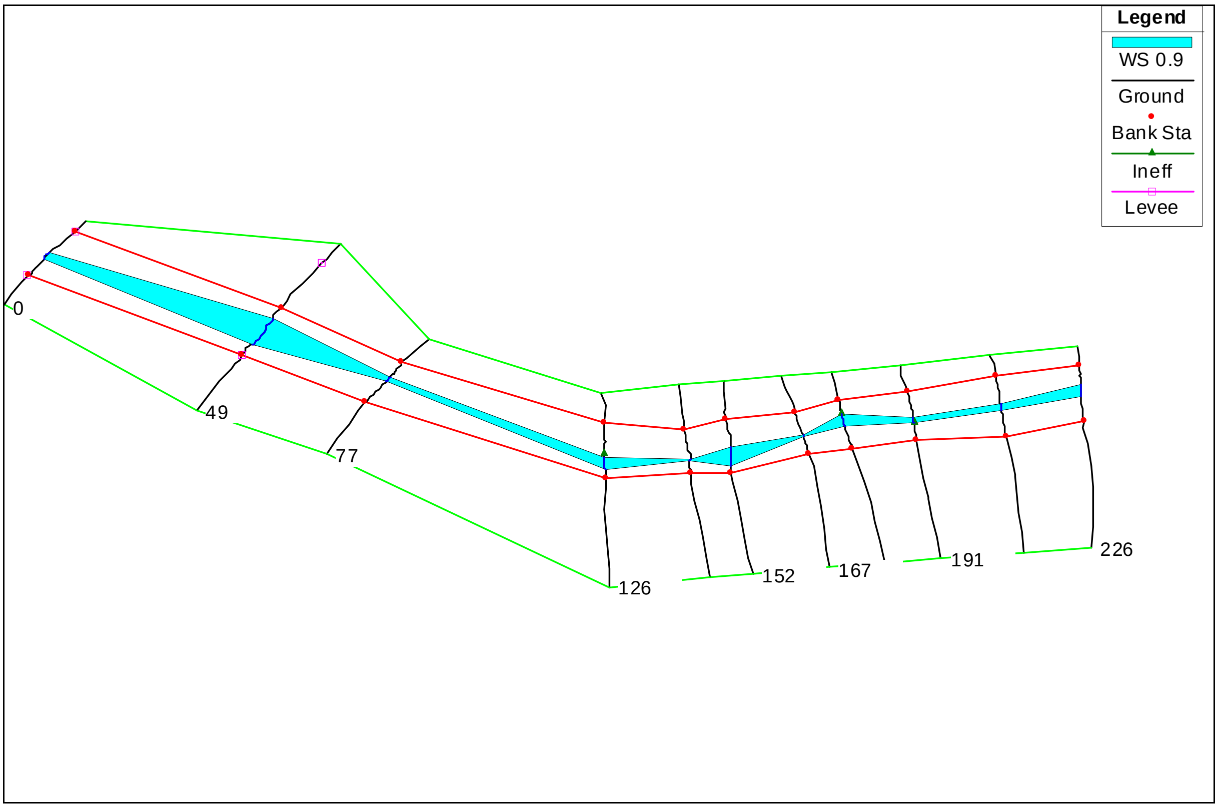


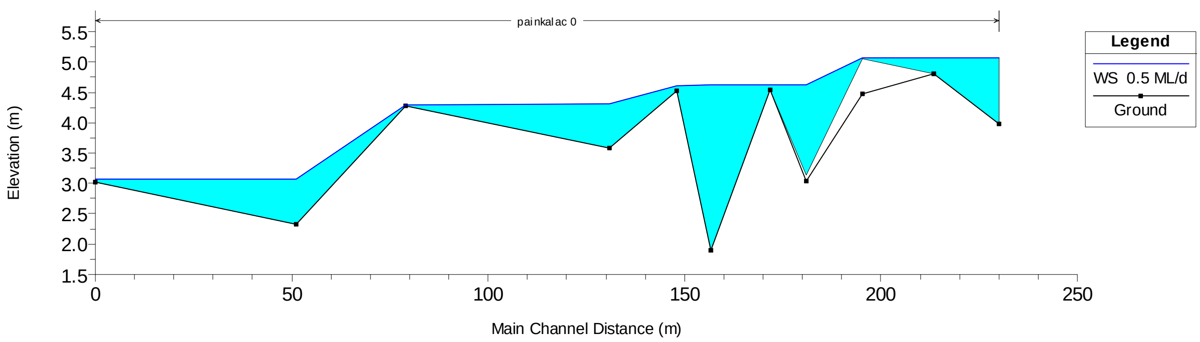
Figure A5 Recurrence intervals of the maximum annual flood flow in Painkalac Creek under natural flows (top) and current flows (bottom) at the Representative Site

Appendix 2. Cross Sections

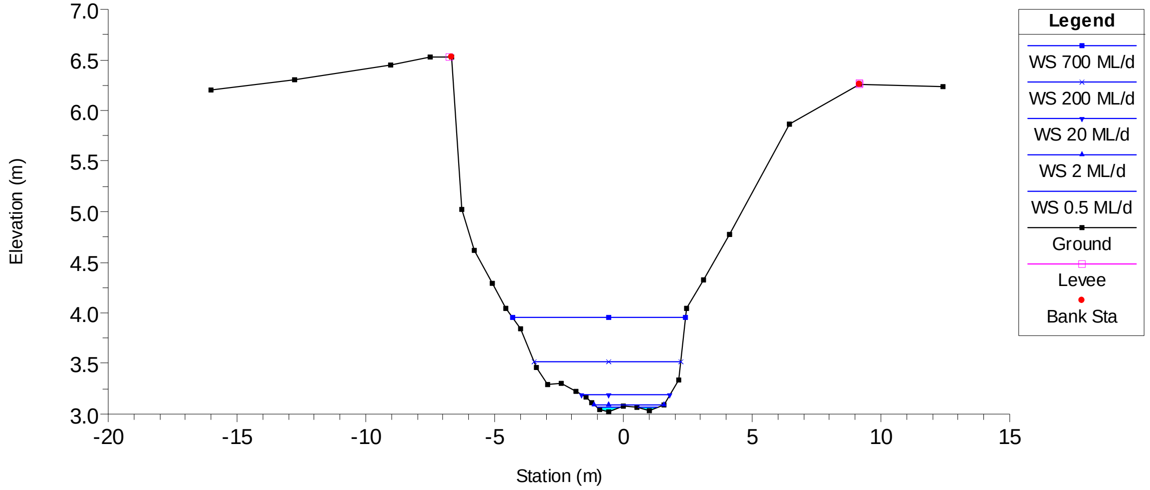
Plan View of Painkalac Creek Representative Site



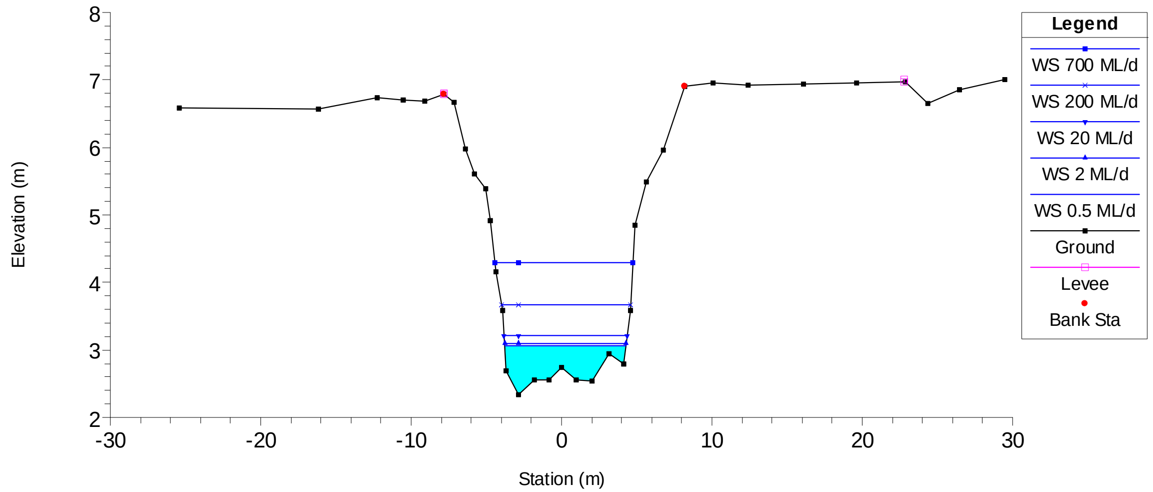
Long Profile of Painkalac Creek Representative Site



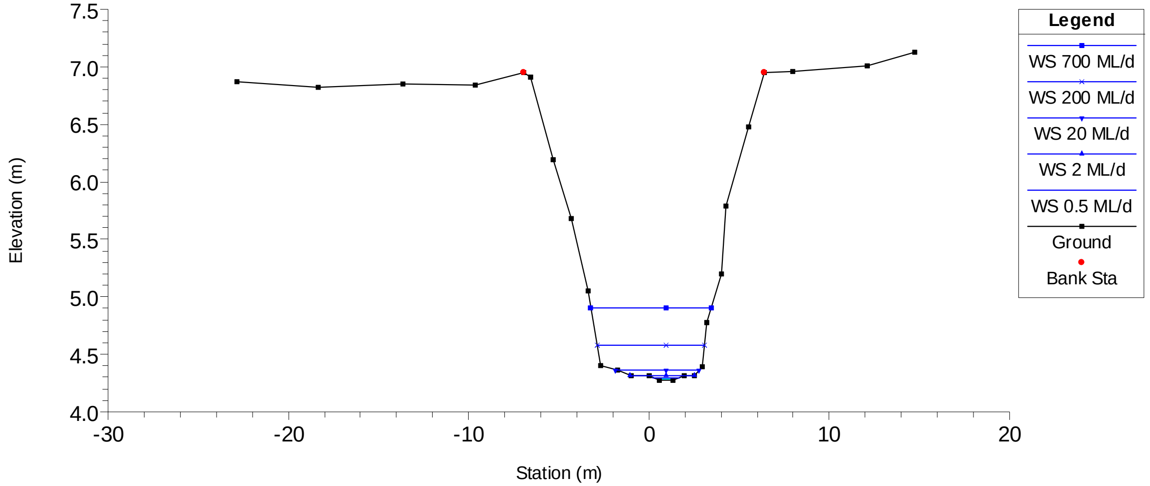
Cross Section at 0 metres



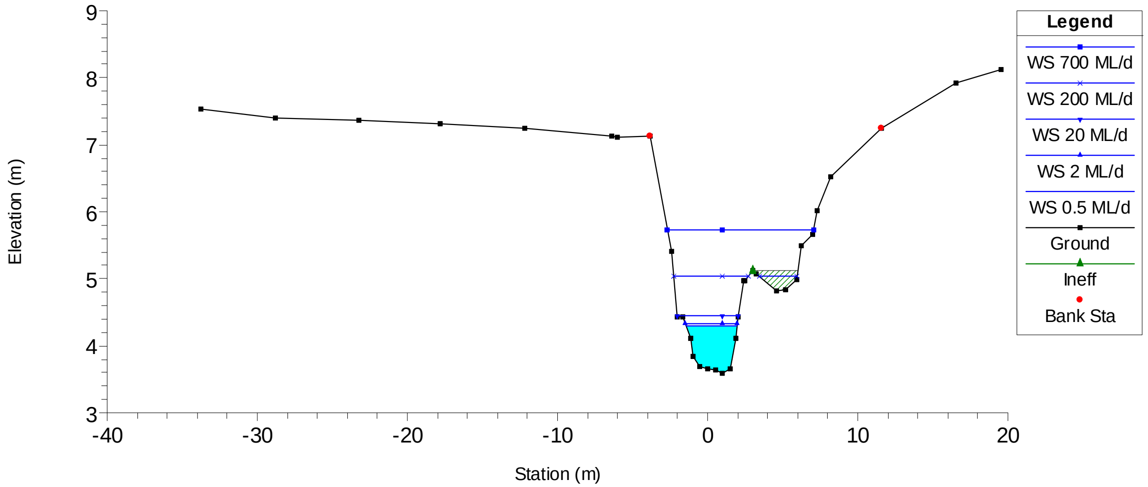
Cross Section at 49 metres



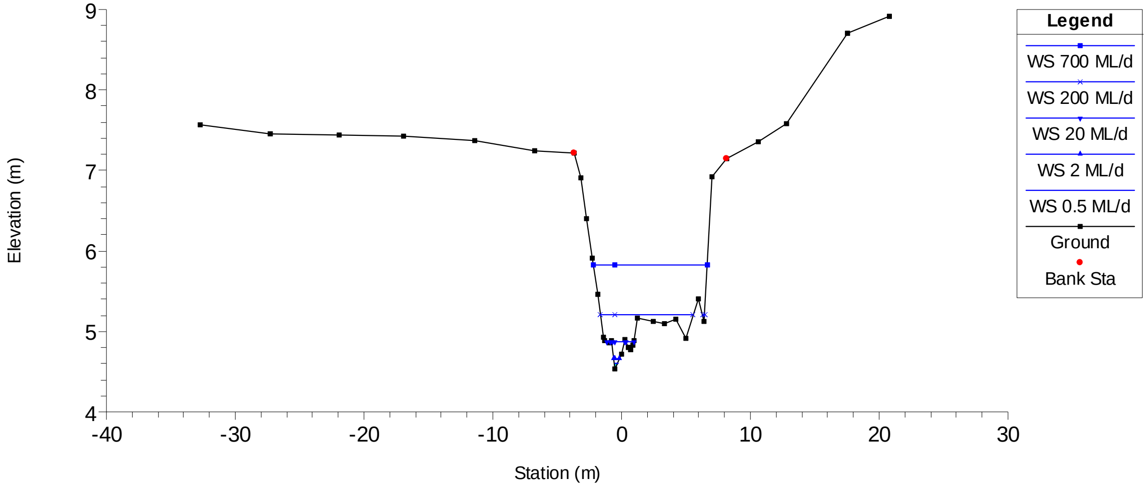
Cross Section at 77 metres



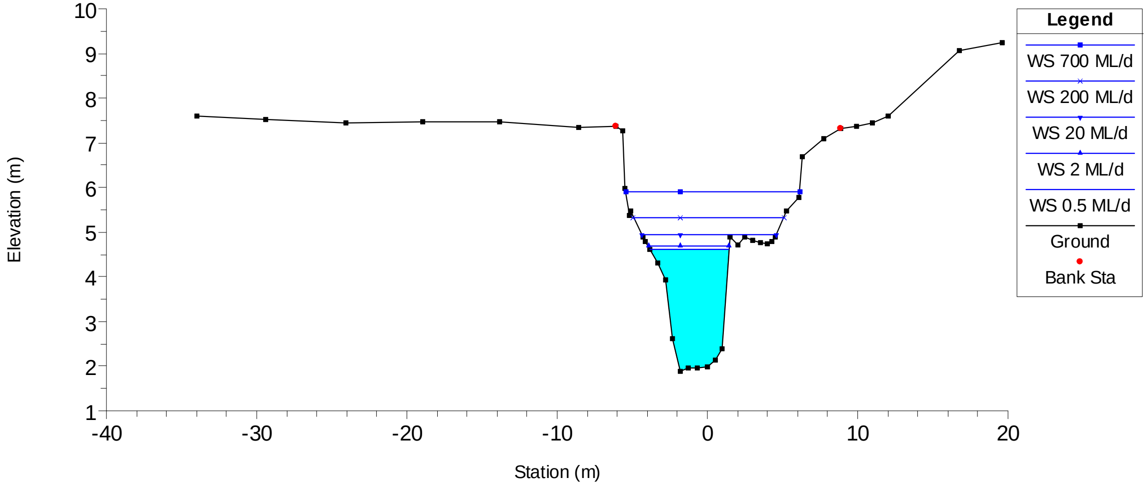
Cross Section at 126 metres



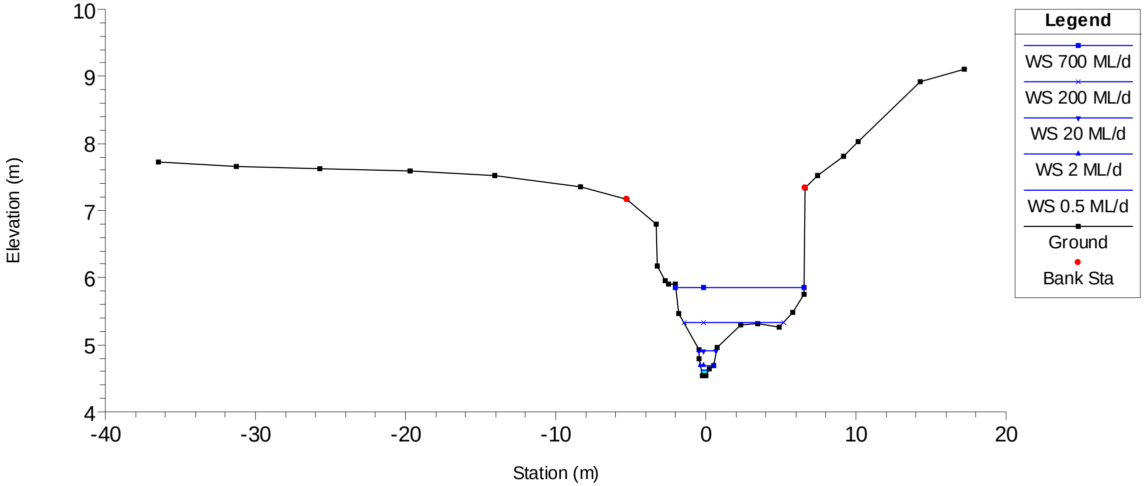
Cross Section at 144 metres



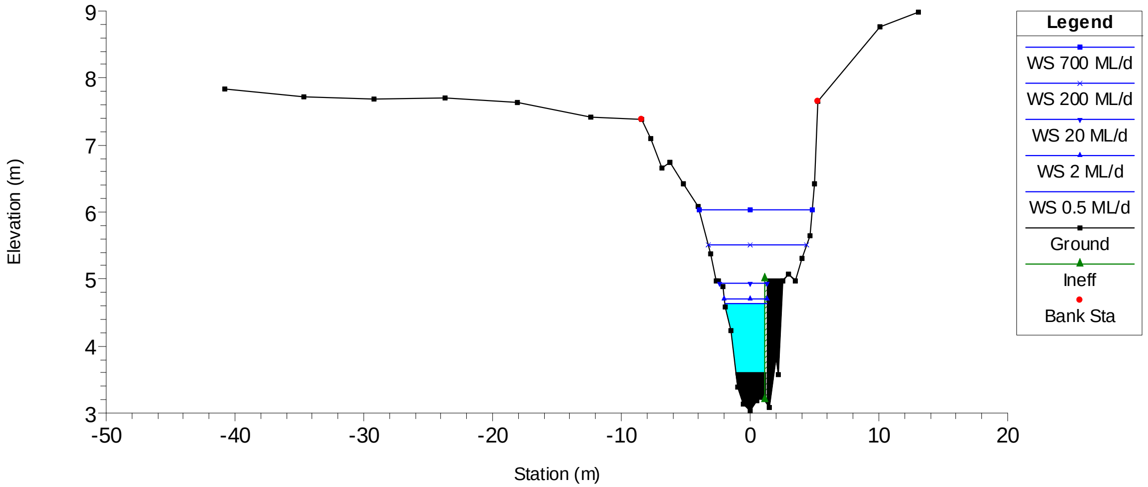
Cross Section at 152 metres



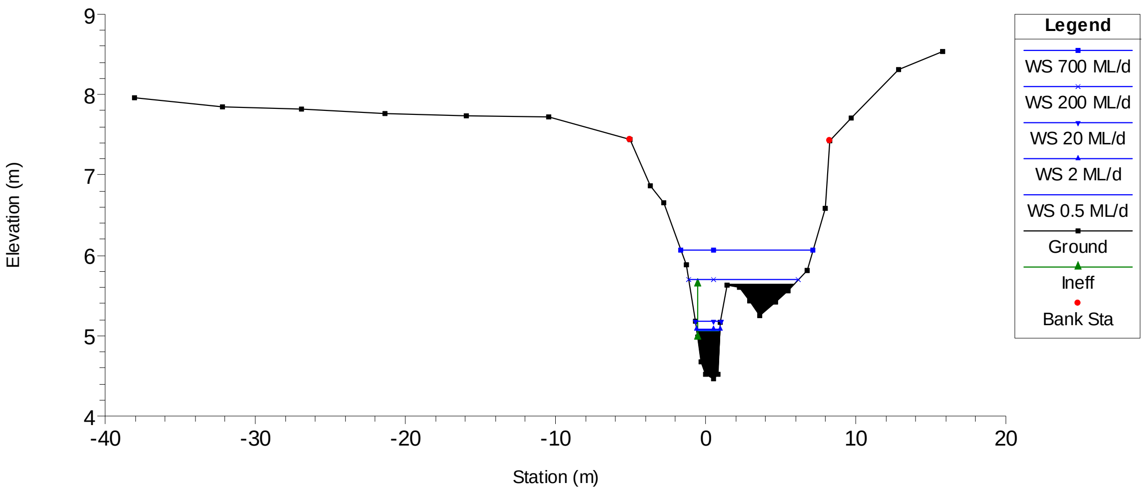
Cross Section at 167 metres



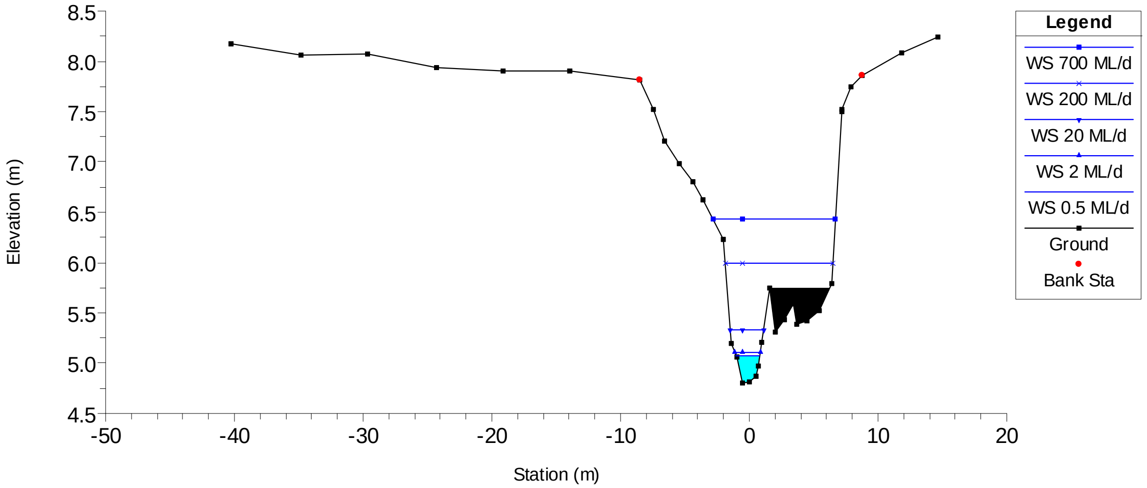
Cross Section at 177 metres

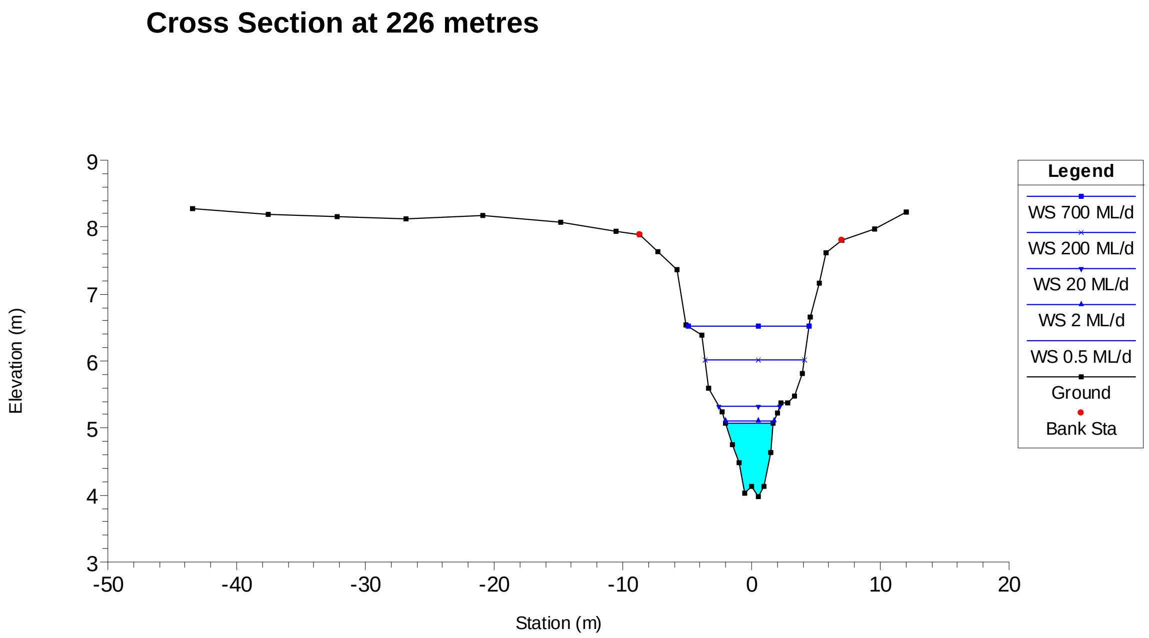


Cross Section at 191 metres



Cross Section at 209 metres




Cross Section at 226 metres
Elevation (m)
Station (m)
Legend
WS 700 ML/d
WS 200 ML/d
WS 20 ML/d
WS 2 ML/d
WS 0.5 ML/d
Ground
Bank Sta