Mid Goulburn River FLOWS study

Final report: flow recommendations

Prepared for the Goulburn-Broken Catchment Management Authority

by

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Prepared by Peter Cottingham & Associates on behalf of the Goulburn Broken Catchment Management Authority

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COVER PHOTOGRAPH:
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Executive Summary

As part of its obligation to the implementation of the Murray-Darling Basin Plan, the Victorian government has requested that the Goulburn Broken Catchment Management Authority (GB CMA) prepare an environmental water management plan for the mid Goulburn River for inclusion in a long-term watering plan. While environmental flow recommendations have previously been developed for the mid Goulburn River below Lake Eildon to Goulburn Weir (Cottingham et al. 2003), these have not been implemented because of the disruption that would occur in the delivery of irrigation water and the potential for third party impacts by flooding of private and public assets at flows greater than approximately 10,000 ML/d. Overcoming constraints to environmental watering is a current area of interest for the Murray-Darling Basin Authority. This project revisits the environmental flow recommendations for the mid Goulburn River under the assumption that flows of up to 20,000 ML/d can be delivered if current constraints on inundating private land and private and public infrastructure can be resolved. The environmental objectives and flow recommendations developed during the project were designed to:

- Maximise environmental outcomes given constraints such as the cold and unseasonal flows in summer-autumn to meet downstream consumptive demands; and
- Be compatible with maintaining trout populations.

The activities carried out as part of this project have been consistent with the Victorian FLOWS method, which is the standard method for the development of environmental flow recommendations in Victoria (DEPI 2013). There are three important documents that report on the application of the FLOWS method:

- A site paper that outlines the process for assigning representative reaches and identifying sites at which cross-section surveys will be undertaken (Cottingham et al. 2014a).
- An issues paper that considers the condition of assets and values associated with the reaches of river(s) that are the focus of the study, key threats to the environmental assets and values resulting from consumptive water use, and flow-related ecosystem objectives (Cottingham et al. 2014b).
- A final report that summarises the above and provides environmental flow recommendations required to meet flow-related ecosystem objectives (this report).

The environmental watering needs of the river have been considered for three study reaches:

1. Goulburn River from Lake Eildon to the Yea River (85 river km);
2. Goulburn River from the Yea River to Sunday Creek (Seymour) (45 river km);
3. Goulburn River from Sunday Creek (Seymour) to Goulburn Weir (65 river km).

Flows along the mid Goulburn River are heavily influenced by the presence and operation of Lake Eildon, which is managed according to the Goulburn System Bulk Entitlement. The Bulk Entitlement includes provision for minimum flow releases from Eildon Pondage Weir of 120 ML/d or greater, as required. Environmental water releases from Lake Eildon are also made as part of the deployment of the Commonwealth water managed on behalf of the Commonwealth Environmental Water Holder. All of these arrangements will be captured in long-term watering plans to be developed as part of the Murray-Darling Basin Plan (Commonwealth of Australia 2012).

Environmental values associated with the mid Goulburn River include:

- Status as a Heritage River,
- High ecological value floodplain wetland systems, such as Tahbilk Lagoon (a biological hotspot of regional importance) and Horseshoe Bend,
- The presence of significant (e.g. threatened) flora and fauna species and communities, including riparian vegetation, native fish, birds and invertebrates.

The main channel of the mid Goulburn River also supports beds of submerged and emergent aquatic vegetation, such as Eelgrass (*Vallisneria australis*), Common reed (*Phragmites australis*) and Water milfoil (*Myriophyllum* spp.). The extent of aquatic and emergent vegetation in Reach 1 is a notable difference in the observations recorded in 2002/03 (Cottingham et al. 2003) and the current study. An increase in the diversity and extent of aquatic macrophytes is to be welcomed.

In addition to its environmental and ecological values, the mid Goulburn River is also rated highly for its social and economic values, including:

- Cultural values;
- Amenity and recreation values (e.g. fishing, camping, boating, walking, sight-seeing, picnicking);
- Economic values (e.g. water storage and delivery, town water supply; includes the river and infrastructure such as Lake Eildon, Eildon pondage and Goulburn Weir).

In undertaking this flows study, the project team was guided by the desire of the catchment community for maintaining or improving healthy and diverse aquatic ecosystems expressed in the Goulburn Broken Regional Waterway Strategy, the Goulburn Broken Biodiversity Strategy, the Northern Region Sustainable Watering Strategy, as well as by the EPA Victoria biological and water quality objectives. The project team also looked for commonalities in the watering recommendations that help deliver resilient waterway and wetland ecosystems and that help maintain trout populations, recognising the important recreational value of trout fishing to the catchment community. The condition, structure and function of river attributes are affected by many factors (often at multiple scales). The main factors likely to restrict our ability to achieve flow-related ecological objectives in this study were considered to be:

- Altered hydrology, particularly unseasonal flows and reduced frequency of river-floodplain connection;
- Altered water temperature;
- Loss of riparian and floodplain vegetation (along with a Victorian government commitment that environmental watering will not inundate private land and infrastructure);
- Reduced coarse-grained sediment supply.

This study assumes that unseasonal flow releases from Lake Eildon will continue due to obligations to deliver water for irrigation; so too will instances of altered water temperature, particularly cold water releases in summer-autumn, especially when storage levels in Lake Eildon are high. Sediment trapping behind Eildon Dam will also continue. Thus the main impacts that can be addressed are the reduced connection between the river and wetland habitat and altered riparian and floodplain vegetation patterns. This assumes that the constraints on flooding private land as well as confounding factors such as grazing and physical impacts from livestock can be overcome in the medium term. Given these factors, the project team recognises that the mid Goulburn River is likely to be managed in the future according to the following premises:

- Reach 1 will be continue as a trout fishery, given that the colder summer-autumn temperature regime that persists (particularly when storage levels in Lake Eildon are high) favours trout and that large-bodied native fish species such as Murray cod, Trout cod and Macquarie perch generally avoid the reach. Small-bodied native fish adapted to cold water, however, are also likely to persist in Reach 1.
- Reaches 2 and 3 will be considered candidates for rehabilitation to support large-bodied native fish adapted to a warmer temperature regime than persists in Reach 1.
- Opportunities to connect anabranches, the riparian zone and low-lying wetlands will be pursued along all reaches over the medium to long term if and when constraints on bankfull and overbank flows are addressed. This is to maintain diversity in riparian and wetland vegetation, provide opportunities for vegetation recruitment, and contribute external (allochthonous) sources of carbon to the river to help drive riverine productivity.

A series of flow-related ecosystem objectives were developed to provide the basis from which to develop environmental watering recommendations. Hydrological modelling was undertaken to provide time series that enables comparison of the current flow regime with a flow regime that would result if the river system were unimpacted by the presence and operation of Lake Eildon. The hydrological series included climatic scenarios ranging from worst drought on record through to average and wet years. This information, along with 1-dimensional HEC-RAS hydraulic models and wetland commence-to-flow assessments, was combined with an understanding of the ecological and biological functioning of the mid Goulburn River to arrive at a series of environmental watering recommendations for each reach of the river.

The Victorian FLOWS method focuses on recommendations for various components within the flow regime: cease to flow periods, baseflow, freshes, bankfull and overbank flows. Modelling data showed that cease to flow periods do not occur along the mid Goulburn river, so flow recommendations to achieve ecological objectives have been developed for baseflow, freshes, bankfull and overbank flow events. These are summarised in Table ES1. Further information on the rationale and details of the flow recommendations is provided in Chapter 6.

Table ES1: Summary of environmental flow recommendations for the mid Goulburn River and flows compatible with maintaining trout in Reach 1 (see Chapter 6 for the rationale and further details on flow specifications

Component	Season	Climate	Component Detail	Reach 1	Reach 2	Reach 3
Baseflow (support riverine vegetation, native fish, invertebrates)	All	All	Magnitude Frequency	400 ML/d or natural, whichever is lower Continuous	500 ML/d or natural, whichever is lower Continuous	800 ML/d or natural, whichever is lower Continuous
Baseflow (support trout)	Winter	All	Magnitude Frequency	>500 ML/d Continuous	-	-
Baseflow (support trout)	Spring-summer (Sept-Feb)	All	Magnitude Frequency	<3,000 ML/d As long as possible into the irrigation season	-	-
Baseflow (support trout)	Summer-autumn	All	Magnitude Frequency	>4,000 ML/d 1 year in 3-4 years	-	-
Fresh (support geomorphology, invertebrates)	Winter-spring	All	Magnitude Duration Frequency	900 ML/d 1 day Depends on antecedent conditions	See bankfull	See bankfull
Fresh (support invertebrates, native fish growth)	Summer-autumn Winter-spring	All	Magnitude Duration Frequency	2,500 ML/d 5 days (dry years), 7 days (average and wet years) 2 per year (1 in each season)	2,500-3,500 ML/d 5 days (dry years), 7 days (average and wet years) 2 per year (1 in each season)	As per Reach 2
Fresh (support native fish)	Spring (Oct-Dec)	All	Magnitude Duration Frequency	-	0.5 m increase in river height 1 week of rise and 2 days at target flow	0.5 m increase in river height 1 week of rise and 2 days at target flow

Component	Season	Climate	Component Detail	Reach 1	Reach 2	Reach 3
Bankfull (support geomorphology, riverine and riparian vegetation, native fish, invertebrates)	Winter-spring	All	Magnitude Duration Frequency	11,000 ML/d 4 days Dry years: 1 in 3 years Average and wet years: 1 in 2 years	11,000 ML/d 4 days Dry years: 1 in 3 years Average and wet years: 1 in 2 years	14,000 ML/d 4 days Dry years: 1 in 3 years Average and wet years: 1 in 2 years
Overbank (support geomorphology, riverine and riparian vegetation, native fish, invertebrates)	Winter-spring	All	Magnitude Duration Frequency	Up to 20,000 ML/d 4 days Dry years: 1 in 3 years up to 15,000 ML/d Average and wet years: 1 in 2 years for events up to 15,000 ML/d, 1 in 5 years for events up to 20,000 ML/d Maximum interval between (any) events 7 years.	Up to 20,000 ML/d 4 days Dry years: 1 in 3 years up to 15,000 ML/d Average and wet years: 1 in 2 years for events up to 15,000 ML/d, 1 in 5 years for events up to 20,000 ML/d Maximum interval between (any) events 7 years.	Up to 20,000 ML/d 4 days Dry years: 1 in 3 years up to 15,000 ML/d Average and wet years: 1 in 2 years for events up to 15,000 ML/d, 1 in 5 years for events up to 20,000 ML/d Maximum interval between (any) events 7 years.

While environmental watering recommendations have been made using best available information, it is important to acknowledge that gaps in information exist. This, along with an incomplete knowledge of ecological or biological processes and their response to watering events mean that there can be uncertainty in relation to the ecological outcomes expected with the delivery of environmental watering recommendations. These issues were considered for the various flow components. In addition, a series of complementary measures were identified that would increase the likelihood of environmental flows achieving their stated ecological objectives. These include:

- Testing the assumptions of the environmental flow recommendations;
- Reviewing barriers to the movement of water through riparian and floodplain areas;
- Continued implementation of catchment management strategies and programs;
- Water quality investigations;
- Fisheries management investigations.

It is anticipated that the insights and recommendations generated by this study will provide valuable information for inclusion in the long-term watering plans being developed as part of the Murray-Darling Basin Plan.

CONTENTS

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FIGURES

TABLES

1 INTRODUCTION

1.1 Background

As part of its obligation to the implementation of the Murray-Darling Basin Plan, the Victorian government is to prepare a long-term watering plan for northern Victoria by 2015. The watering plan will include ecological objectives and identify the environmental water requirements for priority water-dependent environmental assets across northern Victoria. Consequently, the Victorian government has requested that the Goulburn Broken Catchment Management Authority (GB CMA) prepare an environmental water management plan for the mid Goulburn River for inclusion in the long-term watering plan. While environmental flow recommendations have previously been developed for the mid Goulburn River below Lake Eildon to Goulburn Weir (Cottingham et al. 2003), these have not been implemented because of the disruption that would occur in the delivery of irrigation water and the potential for third party impacts by flooding of private and public assets at flows greater than approximately 10,000 ML/d. These socio-economic implications were identified as significant limitations to the implementation of the recommendations in the 2003 study (Cottingham et al. 2003). The 2003 study also noted the issue of cold water releases from Lake Eildon in summer and their potential to affect potential ecological responses to environmental flows.

Since the 2003 study, the GB CMA has compiled a substantial body of additional information on the nature and condition of the river as part of local and regional management initiatives. These include:

- A review of constraints that limit watering of the floodplain (MDBA 2013);
- Reviews of environmental water management in light of continuing drought (e.g. Cottingham et al. 2007, 2009);
- Aerial imagery of the study area;
- Hydrological and water quality investigations (e.g. Water Technology 2012; Thiess Services 2011; Tenant et al. 2012);
- Wetland condition (Australian Ecosystems 2012) and surveys of native fish populations (e.g. Kearns et al. 2014).

This information and data provides a valuable basis from which to review the ecological objectives and develop flow recommendations for the mid Goulburn River for inclusion in the northern Victoria long-term watering plan.

1.2 Project objectives

The primary objective for this project is to undertake a flow study that will identifies a set of environmental objectives for the management of water-dependent assets and values associated with the mid Goulburn River, and develops flow recommendations aimed at meeting the stated environmental objectives. The environmental objectives and flow recommendations will be designed to:

- Maximise environmental outcomes given constraints such as the cold and unseasonal flows in summer-autumn to meet downstream consumptive demands; and
- Be compatible with existing trout fishing opportunities.

1.3 General approach

The project has been undertaken according to the general steps outlined in the Victorian FLOWS method (DEPI 2013), which provides the basis from which to describe and confirm environmental flow objectives, and then develop recommendations for the mid Goulburn

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

- Cease to flow,
- Low flow,
- Freshes,
- High flow,
- Bank full,
- Overbank.

1.3.1 Project activities

The activities carried out as part of this project have been consistent with the Victorian FLOWS method, which is the standard method for the development of environmental flow recommendations in Victoria (DEPI 2013). There are three important documents that report on the application of the FLOWS method:

- A site paper that outlines the process for assigning representative reaches and identifying sites at which cross-section surveys will be undertaken. Cross-section surveys are a crucial input to hydraulic models that will be developed to support decision-making later in the project.
- An issues paper that considers:
  - The condition of assets and values associated with the reaches of river(s) that are the focus of the study;
  - System hydrology including comparison of current and unimpacted (i.e. by water resource development)[1] streamflow regimes and potential future water demands;
  - Key degrading factors, focussing on flow-related and non-flow related issues;
  - Current threats to the environmental assets and values resulting from consumptive water use;
  - The implications of current water resource management; and
  - Flow-related ecosystem objectives consistent with the Regional River Health Strategy.
- A final report that summarises the above and provides environmental flow recommendations required to meet flow-related ecosystem objectives. The threats posed to ecosystem values and assets of not delivering the recommended environmental flows will also be identified.

The site paper (Cottingham et al. 2014a) and the issues paper (Cottingham et al. 2014b) described above have been completed. This final report should be read in conjunction with the issues paper; it represents the final stage of the FLOWS method and provides:

- A description of the catchment setting,
- A summary of the key values and issues in the catchment,
- Management objectives and environmental flow objectives,
- Flow recommendations and an assessment of performance against the flow recommendations (i.e. assessment of compliance of the current flow regime with the flow recommendations), and

[1] The 'unimpacted' flow regime is shorthand for the flow regime that would occur without the presence or influence of large reservoirs, farm dams, diversions for urban and agricultural supply (surface or groundwater), and with catchment condition consistent with recent water years. But it does not take into account changes in vegetation and land-use in the catchment, so is 'natural' in only a limited sense.

- Supporting recommendations for (non-flow) river management and rehabilitation activities that will complement the outcomes expected with delivery of the recommended flow regime.

Additional activities conducted to support the development of flow recommendations include such things as:

- Refinement of modelled flow series for the mid Goulburn River, providing 114 years of modelled data for the unimpacted and current flow regime (Appendix 1);
- A resurvey of selected river cross-sections for comparison with those measured in 2002/03, and for the preparation of 1-dimensional HEC-RAS hydraulic models (see Cottingham et al. 2014b);
- The use of wetland mapping (Water Technology 2012) and LiDAR data (supplied by the GB CMA) to assess commence-to-flow (CTF) levels whereby wetlands become connected to the main river channel (Appendix 3);
- Discussions with the project steering committee and community advisory committee on both flow-related objectives and flow recommendations suitable for the mid Goulburn River.

2 CATCHMENT SETTING: GOULBURN RIVER FROM LAKE EILDON TO GOULBURN WEIR

2.1 Overview

The Goulburn River rises near Woods Point in the highlands of central Victoria and flows in a north direction to Lake Eildon. The river then flows west to Yea, approximately north-west to Seymour and then north to Nagambie and on to Shepparton, after which it flows north-westerly again before it discharges to the Murray River near Echuca. The study area is the Goulburn River downstream from Lake Eildon to the tail waters of Goulburn Weir near Nagambie. The environmental watering needs of the river have been considered for three study reaches (Cottingham et al. 2014a) (Figure 1):

1. Goulburn River from Lake Eildon to the Yea River (85 river km);
2. Goulburn River from the Yea River to Sunday Creek (Seymour) (45 river km);
3. Goulburn River from Sunday Creek (Seymour) to Goulburn Weir (65 river km).

The Goulburn River has the characteristics of a relatively steep foothills stream immediately below Lake Eildon. The river then takes on the characteristics of a lowland river with a relatively lower gradient and more extensive floodplain downstream of Seymour. The main tributaries of the Goulburn River in the study area include the Acheron and Yea Rivers, as well as Snobs, Ultima Thule (UT), Merton, King Parrot, Sunday, Sugarloaf and Hughes creeks. Most of the floodplain in the study area has been cleared for agriculture, being predominantly dryland (e.g. livestock grazing) but with some irrigated agriculture (e.g. tea and turf farming). Major urban areas in the study area include Alexandra, Yea and Seymour. Land tenure is mostly a narrow crown land reserve associated with the main river channel, but with instances where private land intersects the river (Water Technology 2012).

The river retains an almost continuous riparian canopy although the width of the riparian zone is generally narrow (e.g. one to a few trees wide). Riparian vegetation is dominated by the Ecological Vegetation Class (EVC) 56: Floodplain Riparian Woodland (see issues paper, Cottingham et al. 2014b, for more information). This EVC occurs along each reach and is characterised by a canopy layer dominated by two species of eucalypt: *Eucalyptus camaldulensis* (River Red Gum) and *Eucalyptus melliodora* (Yellow Box). The EVC describes an open woodland or forest to ~20 m tall, with ~20% tree canopy cover and a ground-layer of amphibious and aquatic herbs and sedges (DSE 2004). The EVC is listed as 'endangered' or 'vulnerable' in two relevant bioregions (Central Victorian uplands, Victoria riverina, respectively) as vegetation clearing for agriculture has reduced the pre-European cover of EVC 56 along the river considerably, and it is often narrower and much less continuous than in pre-European times[2].

Overall, the mid Goulburn River is recognised as a heritage river, and for the presence of threatened fish species (e.g. Murray cod, Macquarie perch) and vulnerable vegetation classes, which are high value assets whose protection is addressed in management planning (GB CMA 2013). The ecological values associated with the river are described in more detail in Chapter 3. The mid Goulburn River is also widely recognised for its recreational value, in particular for its trout fishing opportunities.

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[2] Based on comparison of the 2005 vegetation layers and modelled 1750 layers – not shown (http://mapshare2.dse.vic.gov.au/MapShare2EXT/imf.jsp?site=bim)

Figure 1: Reaches within the mid Goulburn River study area.

2.2 River operations

Mean annual streamflow for the Goulburn Basin is approximately 3,040 GL (GB CMA 2013). Streamflow is variable, both across years and across seasons, and is modified by:

- The presence and operation of Lake Eildon;
- Diversion of water at Goulburn Weir from the Goulburn River to the East Goulburn Main Channel and Stuart Murray Canal to supply irrigation areas;
- Diversion of water to Waranga Basin (432 GL) via the Cattanagh and Stuart Murray canals;
- Changes to floodplain drainage through changed land use;
- Private diversions throughout the Goulburn River catchment;
- Potential diversion via the North-South Pipeline to Sugarloaf Reservoir for urban use in Melbourne (has not operated since 2010).

Lake Eildon (features are presented in Table 1) is located in the river's upper catchment, immediately below the Goulburn River confluence with the Delatite River. On average, 91% of water released from Lake Eildon is diverted for irrigation purposes and supplies about 60% of water used in the Goulburn Murray Irrigation District (G-MW n.d.). The large storage capacity of Lake Eildon means that its operation fully regulates downstream flows in all but wet years. The operation of Lake Eildon and water management along the Goulburn River is governed by the Bulk Entitlement for the Goulburn System (Government of Victoria 2014).

The Goulburn Weir (25 GL capacity) is approximately 235 km downstream of Lake Eildon, and north of Nagambie. The weir is usually held close to full capacity to facilitate the diversion of water into irrigation channels and to supply Waranga Basin (432 GL capacity).

Table 1: Summary features of Lake Eildon

Location	Capacity at FSL (ML)	Outlet Capacity (ML/d)	Spillway Capacity (ML/d)
95 km east of Seymour, 55 km east of Yea. Present form completed in 1955	3,334,000	17,500 (at FSL)	300,000 (approx.)

2.2.1 Bulk Entitlement and environmental watering setting

Goulburn System Bulk Water Entitlement

Whilst the mid Goulburn River is operated to meet a number of irrigation, consumptive and environmental demands, the minimum flow requirements for releases from Lake Eildon are governed by the Bulk Entitlement for the Goulburn System (Government of Victoria 2014; consolidated in May 2012). The Bulk Entitlement states that Goulburn-Murray Water must provide the following passing flows:

(a) A minimum flow of 120 ML/d from the Eildon Pondage Weir, or such greater flow as is required by Schedule 6; and
(b) A minimum average weekly flow of 250 ML/d from Goulburn Weir over any seven day period, at a daily rate of no less than 200 ML/d; and
(c) Any additional flow necessary to maintain a minimum average monthly flow at the McCoy Bridge gauging station of -
    (i) 350 ML/d for the months of November to June inclusive, at a daily rate of no less than 300 ML/d; and

(ii) 400 ML/d for the months of July to October inclusive, at a daily rate of no less than 350 ML/d.

Other management initiatives

In addition to the Bulk Entitlement for the Goulburn System, there are a number of other water resource management initiatives that influence the management or condition of the mid Goulburn River (see Chapter 4), including decisions on environmental watering. These occur at various scales and include:

- Sub-catchment and catchment scale
    - Goulburn Broken Waterway Strategy (GB CMA 2013);
    - Goulburn Broken Biodiversity Strategy (Miles 2010);
    - State environment protection policy: Waters of Victoria (Government of Victoria 2003);
- Regional scale
    - State environment protection policy: Waters of Victoria (Government of Victoria 2003);
    - Northern region sustainable watering strategy (NRSWS) arrangements (DSE 2009);
- State scale
    - State environment protection policy: Waters of Victoria (Government of Victoria 2003);
    - Victorian environmental water holder (VEWH) decisions on environmental water allocations (VEWH 2014);
- Murray-Darling Basin scale
    - Commonwealth Environmental Water Holder (CEWH) portfolio (CEWO 2013);
    - Murray-Darling Basin Plan.

Whilst this study identifies environmental flow recommendations for the mid Goulburn River at the catchment scale, it will also contribute to regional water planning as part of the NRWS and at the State scale via the management of Victorian water managed by the VEWH. Environmental water releases from Lake Eildon are also made as part of the deployment of the Commonwealth water managed on behalf of the CEWH. All of these arrangements will be captured in long-term watering plans to be developed as part of the Murray-Darling Basin Plan (Commonwealth of Australia 2012).

The environmental water entitlements that may be deployed along the mid Goulburn River are summarised in Table 2. Although the entitlements are often destined to areas outside the Goulburn system, its importance as a conduit for delivery means that inter-valley transfers (e.g. to the Murray River) can be used to achieve ecological outcomes in the mid Goulburn River *en route* to other environmental assets.

Table 2: Summary of environmental water entitlements available in the Goulburn system 2013-14 (from GB CMA 2013b).

Entitlement	Agency	Description	Conditions
Victorian River Murray Flora and Fauna Entitlement	VEWH	27,600 ML high reliability entitlement.	Murray System
Goulburn Environmental Water Savings Supply Deed	VEWH	One-third of water savings created in the Goulburn System as a result of modernisation works completed as part of Stage 1 of the Northern Victorian Connections Project.	Volume based on works implemented and water losses saved in previous year's climate.
Environmental Entitlement (Goulburn-System – Living Murray) 2007	MDBA	39,625 ML high reliability entitlement and 156,980 ML low reliability entitlement.	Water allocated to this entitlement must be used for the Living Murray 'icon sites'. However, this water can provide environmental benefits in the Goulburn River en route to the Murray River.
Commonwealth Environmental Water Holdings	CEWH	203,539 ML Goulburn high reliability water share and 11,765 ML Goulburn low reliability water share as at 31 January 2013.	Water use is subject to agreement with the CEWH.

3 KEY VALUES AND ISSUES

The assets and values associated with the mid Goulburn River were described in the issues paper (Cottingham et al. 2014b) and are restated in the following sections, along with overarching vision and objectives used as the basis for environmental flow recommendations.

3.1 Riverine ecosystem assets and values

Environmental values associated with the mid Goulburn River were detailed in Cottingham et al. (2014b). They include:

- Status as a Heritage River,
- High ecological value floodplain wetland systems, such as Tahbilk Lagoon (a biological hotspot of regional importance) and Horseshoe Bend,
- The presence of significant (e.g. threatened) flora and fauna species and communities, including riparian vegetation, native fish, birds and invertebrates.

The main channel of the mid Goulburn River also supports beds of submerged and emergent aquatic vegetation, such as Eelgrass (*Vallisneria australis)*, Common reed (*Phragmites australis)* and Water milfoil (*Myriophyllum* spp.). The extent of aquatic and emergent vegetation in Reach 1 is a notable improvement in the observations recorded in 2002/03 (Cottingham et al. 2003) and the current study.

3.2 Social and economic values

In addition to its environmental and ecological values, the mid Goulburn River is also rated highly for its social and economic values. For example, information in the RIVERS data base (W. Tennant, GB CMA, pers. comm.) indicates that the river rates highly for:

- Amenity and recreation values (e.g. fishing, camping, boating, walking, sight-seeing, picnicking);
- Economic values (e.g. water storage and delivery, town water supply; includes the river and infrastructure such as Lake Eildon, Eildon pondage and Goulburn Weir).

3.3 Key issues

The Issues Paper (Cottingham et al. 2014b) considered the current condition of the environmental assets and values (attributes) associated with the mid Goulburn River and potential threats to the assets, with particular reference to flow-related stressors. The condition, structure and function of river attributes are affected by many factors (often at multiple scales), of which management of the flow regime is one and channel morphology is another . Conceptual models and reviews of the ecological effects of large dams were used to identify changes to the river ecosystem structure and function for the Goulburn River and its floodplain below Lake Eildon. These include impacts such as:

- First order impacts
    - Alteration of daily, seasonal and annual flows;
    - Changed water quality composition and thermal character;
    - Changes in sediment load;
- Second order impacts
    - Altered patterns of primary production;
    - Altered aquatic and riparian vegetation patterns;
    - Changes to channel and floodplain morphology;
- Third order impacts
    - Altered flora and fauna species diversity;
    - Vegetation encroachment.

Further, the Issues Paper noted that the main factors likely to restrict our ability to achieve the flow-related ecological objectives in this study were:

- Altered hydrology, particularly unseasonal flows and reduced frequency of river-floodplain connection;
- Altered water temperature;
- Loss of riparian and floodplain vegetation (along with a Victorian government commitment that environmental watering will not inundate private land and infrastructure);
- Reduced coarse-grained sediment supply.

As this study assumes that unseasonal flow releases from Lake Eildon will continue due to obligations to deliver water for irrigation, so too will instances of altered water temperature, particularly cold water releases in summer-autumn, especially when storage levels in Lake Eildon are high. Sediment trapping behind Eildon Dam will also continue. Thus the main impacts that can be addressed is the reduced connection between the river and wetland habitat and altered riparian and floodplain vegetation patterns. This assumes that the constraints on flooding private land as well as confounding factors such as grazing and physical impacts from livestock can be overcome in the medium term.

In summary, issues that are likely to have a direct bearing on flow recommendations include:

- Changed hydrology, including an unseasonal flow regime and reduced frequency of connection to the riparian zone and low-level floodplain-wetland features;
- Armouring of the river bed and reduction in fine-scale (e.g. interstitial spaces) habitat availability and quality;
- Maintenance of riffle habitat, surface water area and refugia for macroinvertebrates and fish during extended periods of low flow;
- The frequency and duration of floodplain/wetland inundation events to provide organic matter (to drive productivity) and provide habitat for invertebrates and fish;
- Provision of flow cues to stimulate the movement of native fish (Reaches 2 and 3);
- Encroachment of non-native (terrestrial) vegetation if the frequency and duration of low flow events is increased.

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

- Cold water releases from Lake Eildon, which may preclude biota such as native fish from persisting across their natural range.
- Changes to riparian vegetation patterns with changed land use, changing the nature of carbon inputs that support river and wetland foodwebs;
- Natural and human induced bank, hill slope and gully erosion that results in high sediment inputs to the river (a result of both natural (e.g. bushfires) and anthropogenic disturbance);
- Previous desnagging that has decreased in-channel diversity and associated habitat for biota such as fish;
- Contaminant (e.g. fine-grained sediment, turbidity, nutrient) loading, that can result in water quality decline that affects pollutant-sensitive macroinvertebrate taxa and contribute to eutrophication in downstream areas (e.g. Goulburn River, Murray River);
- Alteration of riparian and floodplain connection and flow paths due to the installation of block banks, levees, tracks, roads and other infrastructure.

4 MANAGEMENT OBJECTIVES

4.1 Guiding vision and objectives

The vision and objectives that guide this study are those stated in the Goulburn Broken Regional Waterway Strategy (RWS) (GB CMA 2013). The vision developed by the catchment community is one of:

- ‘Resilient waterways and wetlands, vibrant communities’.

The RWS promotes the following regional goals that are applicable to the mid Goulburn River, and consistent with national, Murray-Darling Basin and Victorian initiatives (e.g. EPBC Act, Native Fish Strategy, State Environment Protection Policies):

- Maintain resilience of the region’s waterways, wetlands and communities (within a catchment context) so that: populations of threatened aquatic dependent species will be maintained or improved- including Trout cod, Macquarie perch, Murray cod, Eel tailed catfish, Barred galaxias, Golden perch;
- Maintain or improve the values associated with Heritage River status;
- Maintain or improve wetlands with formally recognised conservation significance;
- Maintain and improve water quality in priority water supply catchments;
- Maintain and improve waterways and wetlands of high community value.

Further, the Northern Region Sustainable Water Strategy (NRSWS) (DSE 2009) outlines environmental watering objectives within a ‘seasonally adaptive’ approach, whereby short-term objective priorities are set to account for climatic conditions ranging from drought to very wet, while seeking to achieve the long-term objective of moving towards an ecologically healthy rivers. For example, the short-term objective for rivers during drought is to ensure that priority (high value) sites avoid irreversible losses (e.g. of species or communities) and have the capacity to recover.

Another pertinent management initiative is the Goulburn Broken Biodiversity Strategy (Miles et al. 2010), which is consistent with the requirements of the Commonwealth Environment Protection and Biodiversity Conservation (EPBC) Act and contains biodiversity targets[3] in terms of vegetation that when achieved will:

- Target 1: Maintain the extent and quality of all native vegetation at 2005 levels;
- Target 2: Increase the extent of native vegetation in fragmented landscapes by 70,000ha by 2030 in order to restore threatened EVCs and improve landscape connectivity (relative to 2005 levels);
- Target 3: Improve the quality of 90% of existing (2005) native vegetation by 10% by 2030.

EPA Victoria has established biological objectives for freshwaters based on macroinvertebrate communities across five Victorian aquatic bioregions (Metzeling et al. 2004). The mid Goulburn River lies within two of these bioregions: (i) Reach 1 falls within Bioregion B2 – Forests (A), while Reach 2 and 3 fall within Bioregion B4 - Cleared Hills and Coastal Plains. In addition, the State Environment Protection Policy (SEPP) Waters of Victoria includes physico-chemical water quality objectives for nutrients (nitrogen and

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[3] These targets are in-keeping with the goal of ‘net gain’ listed in Victoria’s Biodiversity Strategy 1997 (DNRE 1997).

phosphorus) (Tiller and Newall 2003), dissolved oxygen (DO), pH, salinity (electrical conductivity) and turbidity (Goudy 2003).

An important guide to the social, economic and environmental values of the Goulburn catchment community is information held by the GB CMA on its RIVERS data base (W. Tennant, GB CMA, pers. comm.). The information in the database suggests that fish, waterbird and vegetation species and communities are considered high-value assets within and along the Goulburn River. The river is also noted for its heritage river status, as well as its social and economic values (e.g. recreational values, source of water for consumption, irrigation and industry).

In undertaking this flows study for the mid Goulburn River, the project team was guided by the desire of the catchment community for maintaining or improving healthy and diverse aquatic ecosystems expressed in the RWS, the GB biodiversity strategy, the NRSWS, as well as by the EPA Victoria biological and water quality objectives. The project team also looked for commonalities in the watering recommendations that help deliver resilient waterway and wetland ecosystems and that help maintain trout populations, recognising the important recreational value of trout fishing to the catchment community.

The issues paper (Cottingham et al. 2014b) identified a series of flow-related threats to ecosystem values and flow-related ecological objectives. This information is presented in Table 3 and provides the basis of the detailed environmental flow recommendations that are presented in Chapter 6, which seek to maintain or improve the resilience of the mid Goulburn River and its wetlands through:

- Maintenance of the frequency or magnitude of flows required to maintain or improve in-channel geomorphic and habitat diversity;
- The maintenance of baseflow to provide habitat for instream aquatic and emergent vegetation, which in turn provides habitat for invertebrates and fish;
- Maintenance of the frequency, depth and duration of events required to inundate floodplain and wetland areas and associated threatened EVC or plant species;
- Maintenance of riffle, run and pool habitat, surface water area and refugia for macroinvertebrates and native fish during extended periods of low flow;
- Maintenance of the frequency and duration of floodplain/wetland inundation events to provide organic matter (to drive productivity) and habitat for invertebrates;
- Provision of flow cues to stimulate the movement of native fish;
- Provision of sufficient depth to allow the movement of fish along their natural range.

4.2 Implications of the operation of Lake Eildon on ecological objectives

As described in the Issues Paper (Cottingham et al. 2014b), such things as the presence and operation of Lake Eildon, and changed catchment land use introduce a number of factors that are likely to restrict our ability to achieve the overarching objectives stated in the RWS and elsewhere. These include:

- Altered hydrology, particularly unseasonal flows and reduced frequency of river-floodplain connection;
- Altered water temperature;
- Loss of riparian and floodplain vegetation (along with a Victorian government commitment that environmental watering will not inundate private land and infrastructure);
- Reduced coarse-grained sediment supply.

It is important to note that the flow-related ecological objectives that can be realistically pursued will be greatly influenced by (and seek to compensate for, at least in part) the factors listed above, and whether or not it is feasible to ameliorate them and other constraints such as the obligation that environmental water releases not inundate private land and private and public infrastructure. While overcoming constraints, such as inundating private land and infrastructure, is an active area of investigation (MDBA 2013), it might be some time before the constraints can be overcome.

For the purposes of this study it has been assumed that unseasonal flow releases from Lake Eildon will continue due to obligations to deliver water for irrigation. This also means that altered water temperature, particularly cold water releases in summer-autumn, will continue when storage levels in Lake Eildon are high (Cottingham et al. 2014b). Given these factors, the project team recognises that the mid Goulburn River is likely to be managed in the future according to the following premises:

- Large-bodied native fish species such as Murray cod, Trout cod and Macquarie perch generally avoid Reach 1, presumably because of cold water regime that can persist during summer-autumn (particularly when storage levels in Lake Eildon are high). The prevailing temperature and flow regime makes river rehabilitation focussing on large-bodied native fish problematic. The temperature and flow regime does, however, favour trout. Small-bodied native fish adapted to cold water are also likely to persist.
- Reaches 2 and 3 will be considered candidates for rehabilitation to support large-bodied native fish adapted to a warmer temperature regime than persists in Reach 1.
- Opportunities to connect anabranches, the riparian zone and low-lying wetlands will be pursued along all reaches over the medium to long term as constraints on bankfull and overbank flows are addressed (see section 4.3). This is to maintain diversity in riparian and wetland vegetation, provide opportunities for vegetation recruitment, and contribute external (allochthonous) sources of carbon to the river to help drive riverine productivity.

The final point (above) is particularly important, as it is a mechanism for driving riverine productivity that supports populations and communities of riverine biota. In its unimpacted state, the mid Goulburn would have had multiple inputs and diverse forms of carbon, including:

- From upstream riparian communities along the Goulburn River and tributaries;
- Direct litterfall from riparian River red gums overhanging the main channel;
- Woodland and understorey litter and standing dead material on the floodplain, in anabranches, in wetlands, and on in-channel benches;
- In-channel producers such as biofilms on fallen timber (snags), benthic macrophytes and phytoplankton.

Under current conditions, the carbon inputs are fewer, reduced or happen much less frequently, as (Cottingham et al. 2014b):

- Lake Eildon intercepts much of the downstream load of particulate organic matter;
- A previous history of de-snagging means the area of large wood substrate available for biofilms is smaller;
- Benthic macrophytes are generally sparse downstream of Reach 1;
- Floodplain woodlands are largely cleared and the woodland litter is entrained much less frequently.

Under these circumstances of reduced allochthonous (external) inputs, autochthonous (in-stream) production becomes relatively more important. In the mid Goulburn, however, in-stream production is likely to be inhibited, at least for part of the year, by fast cool flows.

Given the above, then to maximise the environmental outcomes of water delivery will require an over-arching objective to maintain or improve the number and diversity of allochthonous carbon inputs, so that in-channel food-webs are maintained or improved (Gawne et al. 2007, McGinness and Arthur 2011). Under the current flow regime, anabranches, in-channel benches and low-lying wetlands are all potential sources of allochthonous carbon. In-channel benches also influence hydraulic habitat (Poff and Zimmerman 2010; Vietz et al. 2013), biotic zonation, and distribution (Junk et al. 1989; Steiger et al. 2001) and provide denitrification zones (Groffman et al. 2005). To utilise these sources means increased flow variability for flow events, such as freshes, bankfull and overbank flows, which have been much reduced infrequency and duration since river regulation (see Chapter 5).

4.3 Constraints on floodplain and wetland watering

Goulburn-Murray Water (G-MW) generally operates Lake Eildon so that flows along the mid Goulburn River in Reach 1 do not exceed approximately 9,500 ML/d in order to avoid inundation of private land and private and public infrastructure. This constraint, combined with an obligation to avoid overbank flows when delivering environmental water constrains environmental releases to the river channel. As noted in the previous section, maximising the benefits of environmental water delivery in alluvial systems includes connection of river channels to their floodplains. This contributes to the overall diversity of river-floodplain systems and contributes allochthonous sources of carbon to the river, thus contributing to in-stream productivity.

Given the above, overcoming constraints to the watering of floodplain (and associated wetland) areas is, therefore, an issue currently being considered under the Murray-Darling Basin Plan (MDBA 2013), to which this project will input. In the case of the mid Goulburn River, this means exploring how best to overcome constraints in environmental water delivery from the current upper limit of 9,500 ML/d up to 20,000 ML/d.

The environmental watering recommendations developed as part of this project have been based on the premise that constraints to overbank flows (e.g. inundation of private land and public and private infrastructure, effect of blockbanks and levees) could be overcome in the medium term (e.g. 5-10 years), but makes no assumptions on the manner in which constraints will be overcome. Despite this, however, we recognise that delivery of overbank flows will not occur until such time as the constraints have been removed.

Table 3: Summary of flow-related ecosystem objectives and associated flow components.
Note: the geomorphology objectives have been recast and re-ordered since publication of the Issues Paper, following further consideration of potential flow-related threats.

Ecosystem Attribute	Environmental or Ecological Values	Potential flow related threats	Flow-related ecological objectives	Reach	Flow Component to be considered	Mechanism	Season
Geomorphology	Geomorphic processes contribute to the availability and quality of in-channel and riparian habitat	• Reduced frequency of flow events capable of providing diverse bed morphology • Reduced frequency of flow events that maintain connectivity with riparian and floodplain habitats	**G1**: Scour surficial and interstitial fine sediment from riffles.	All	Freshes	Flows of sufficient magnitude to provide critical shear stress to periodically mobilise fine sediments.	Win, Spr
			G2: Overturn of bed substrate (gravels to cobbles).	All	Bank full, Overbank	Flows of sufficient magnitude to provide critical shear stress to periodically disrupt pebbles and cobbles.	Win, Spr
			G3: Maintain channel form and key habitats, including in-channel benches.	All	High flows, Bank full	Flows of sufficient magnitude and duration to maintain channel form.	Win, Spr
			G4: Movement of bed material to maintain bed diversity for water depth variation, including scour of sediments from base of pools, to maintain quantity and quality of habitat for flora and fauna.	All	High flows, Bank full, Overbank	Flows of sufficient magnitude to provide critical shear stress to scour sediments from pools.	Win, Spr
			G5: Maintain channels and inlets for connectivity of main channel with important floodplain and wetland zones and tributaries.	All	High flows, Bank full, Overbank	Flows of sufficient magnitude to provide critical shear stress to periodically mobilise sand.	Win, Spr

Ecosystem Attribute	Environmental or Ecological Values	Potential flow related threats	Flow-related ecological objectives	Reach	Flow Component to be considered	Mechanism	Season
Water Quality	Integral component of aquatic habitat for flora and fauna	• Unseasonal flows combined with factors such as poor quality catchment runoff. • Most likely to be affected by localised and catchment runoff (all reaches) and operation of Lake Eildon (Reach 1)	**WQ1**: Prevent DO falling below 4 mg/L.	1	Baseflow (low flow)	Unclear and requires Investigation, including of the potential for release of high-DO water from Lake Eildon to address instances of low DO.	All (particularly Sum, Aut)
Riverine vegetation	Intrinsic value of native vegetation Preservation of endangered EVCs and species Protection against bank/channel erosion and sediment suspension Interception of catchment-derived nutrients and sediments Provision of faunal habitat	• Decreased incidence of winter-spring flows, with impacts on freshes • Decreased incidence of bankfull and overbank flows • Decrease in baseflow variability	**RV1**: Maintain existing beds of in-channel macrophytes as a habitat and for biodiversity reasons.	1, 2	Baseflow, Freshes, Bankfull flows	Provide variability in inundation to maintain adults and to permit sexual recruitment of juveniles into the population (e.g. seed generation and dispersal). Provide scouring flows to remove excessive growth of filamentous algae (Reach 1)	Win, Spr, Sum
			RV2: Provide periodic regeneration opportunities for native riparian species adapted to and dependent on the natural flow regime (riparian and floodplain wetland).	All	Bankfull flows, Overbank flows	Riparian vegetation (canopy layer as well as understory) generally requires periodic	Spr

Ecosystem Attribute	Environmental or Ecological Values	Potential flow related threats	Flow-related ecological objectives	Reach	Flow Component to be considered	Mechanism	Season
						inundation to maintain good condition of adults and to permit sexual recruitment of juveniles into the population.	
			RV3: Provide periodic overbank flows to improve in-channel carbon availability.	All	Overbank flows (to inundate floodplain more generally)	Connection to wetland and low-lying floodplain areas will add to the variety and loading of carbon in the river.	Win, Spr
			RV4: Maintain diversity among low-lying wetlands by providing different water regimes.	All	Baseflow (high flows) and variability therein, Overbank flows and variability therein (including inter-annual and within-year variability)	Increase lateral continuity to permit movement of adults and propagules for full ecological functioning, including increased productivity.	Win, Spr
Invertebrates	Important indicator of river health Food source for fish, including threatened species and important recreational species	• Reduced frequency of flow events capable of scouring sediments from pools • Longer than natural duration of low flow events,	**I1**: Maintain areas of riffle habitat.	1, 2	Baseflow (low flow)	Flows of sufficient magnitude to wet riffle habitat.	Win, Spr
			I2: Scour gravels to remove fine sediments from interstitial spaces (improve habitat quality)	All	High flow freshes	Flows of sufficient magnitude to provide critical shear stress to scour fine sediments from the substrate.	Win, Spr

Ecosystem Attribute	Environmental or Ecological Values	Potential flow related threats	Flow-related ecological objectives	Reach	Flow Component to be considered	Mechanism	Season
		resulting in excessive deposition of fine materials. • Reduced frequency of flow events that maintain connectivity with riparian and wetland habitats.	**I3**: Maintain habitat for macrophytes that provide crucial habitat for macroinvertebrates	All	Baseflow (low flow) and natural seasonality	As for RV objectives.	Spr, Sum, Aut
			I4: Scour fine sediment from the surface of the riffle substrate to maintain habitat quality	All	Freshes (low flow and high flow)	Flows of sufficient magnitude to provide critical shear stress to scour fine sediments from the substrate.	Win, Spr, Sum, Aut
			I5: Retain natural seasonality to ensure synchronicity of life cycle stages with appropriate flows	All	Baseflow (low flows and high flows)	Flow regime with components that have natural features of timing, frequency, magnitude and duration.	Win, Spr, Sum, Aut
			I6: Provide floodplain connection for exchange of organic matter and fine sediment	All	Bankfull and overbank flows	High flows into flood runners and overbank flows onto the floodplain.	Win, Spr,
			I7: Scour filamentous algae and biofilm to promote productivity	All	Spring and summer freshes	Velocity and shear stress required to disrupt filamentous algae	Win, Sum
Native fish	Native fish contribute to aquatic biodiversity, are key predator in aquatic food webs, valued for recreational fishing.	• Unseasonal flow regime (including low winter flows) that reduces habitat	**NF1**: Increase flow variability to more closely mimic natural hydrological regime	All	All	Flow regime with components that have natural features of timing, frequency, magnitude and duration.	All

Ecosystem Attribute	Environmental or Ecological Values	Potential flow related threats	Flow-related ecological objectives	Reach	Flow Component to be considered	Mechanism	Season
	In particular, Murray cod, Trout cod and Macquarie perch are listed as vulnerable or threatened and are the focus of management objectives in the Goulburn-Broken Regional Waterway Strategy.	availability and connectivity, as well as leads to miscued/lack of spawning opportunities • High summer flows which reduce riverine productivity at a range of trophic scales • Reduced frequency of connection with wetland habitats	**NF2**: Maintain or increase connection to water temperature refuges	All	Bankfull, Overbank, Low flows (summer-autumn winter-spring)	Flow of sufficient magnitude to connect channel to riparian and wetland refugia. Variability to provide connection for longitudinal movement along the river Variability to provide connection with tributaries	Win, Spr Sum, Aut Win, Spr
			NF3: Provide flows to promote colonisation by large-bodied endangered species	All	Freshes	Flow of sufficient magnitude to provide migration cues; depth across the channel sufficient for fish passage.	Spr
			NF4: Provide flows to increase recruitment of low flow specialists, primarily in off-channel areas	All	Baseflow, Bankfull, Overbank	Flow of sufficient magnitude to inundate flood runners and low-lying floodplain wetlands.	Win, Spr
			NF5: Provision of lateral connectivity to increase primary and secondary production and as habitat for small bodied fishes	All	Bankfull, Overbank	Flow of sufficient magnitude to inundate flood runners and floodplain wetlands.	Win, Spr

Ecosystem Attribute	Environmental or Ecological Values	Potential flow related threats	Flow-related ecological objectives	Reach	Flow Component to be considered	Mechanism	Season
			NF6: Maintain riffle habitat outside of the irrigation season	All	Winter-spring baseflow	Flow of sufficient magnitude to wet riffle habitat.	All
			NF7: Promote Macquarie perch spawning	2, 3	Spring fresh, Summer base flow	Fresh of sufficient magnitude to cue breeding and spawning, base flow to provide access to edge and slackwater habitat	Spr, Sum

5 RIVER HYDROLOGY AND HYDRAULICS

This chapter provides an overview of the modelled flow regime for current conditions, which includes levels of irrigation demand delivered with existing infrastructure, and the unimpacted flow regime where the influence of current irrigation demands and infrastructure have been removed (both the current and unimpacted flow regimes assume the current catchment setting). Opportunities to deliver environmental flows to achieve flow-related ecological objectives are described in Chapter 6.

5.1 Hydrological modelling

Hydrological modelling has been undertaken for the period of 1 January 1896 to 31 December 2009 (Appendix 1) to provide flow time series that represent the current operation of the river system as well as a flow regime unimpacted by the presence and operation of Lake Eildon and Goulburn Weir. The modelled current[4] flow regime included the omission of current environmental flow provisions so that it reflected the full impact of river operations to meet irrigation and consumptive demands when compared with the unimpacted flow regime.

Hydrological data were summarised for the following scenarios:

- Worst drought;
- Very dry years (driest 10% of years);
- Dry years (driest 11-30% of years);
- Average years (middle 31-70% of years);
- Wet Years (wettest 30% of years).

Flow duration curves show a general pattern reflecting the influence of Lake Eildon (Figure 2), whereby high flows expected in winter-spring are lower than would normally flow down the river, and low flows expected in summer-autumn are higher than would otherwise be the case (note: the pattern recorded for reach 1 presented in Figure 2 persists for Reaches 2 and 3 – see Appendix 1. For example in Reach 1, the current 5-25% exceedance flows are less than would occur if the river was unregulated by the presence and operation of Lake Eildon. Conversely, current flows are higher than the unregulated flows for flow exceedance of 30-95%. The current flow regime maintains the regulated flow within the river channel. This means that overbank flows rarely occur under the current flow regime except in wet years (Figure 3). Thus the frequency of overbank flows is much less than would occur under the unimpacted flow regime, where bankfull and overbank flows can occur even in dry years (see Figure 4 and section 6.2).

Interestingly, the differences in the climatic scenarios for the unimpacted flow regime presented in Figure 4 relate mainly to variability in winter-spring discharge, as the summer-autumn flows for each climatic scenario are similar and with little variability when compared with winter-spring flows. Additional details (spells analysis) on winter-spring events are provided in section 6.2.

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[4] The term 'current' flow regime used throughout this report is shorthand for the current flow rules with environmental releases (e.g. as part of The Living Murray program and the Murray-Darling Basin Plan) removed. This then equates to what would be released from Lake Eildon solely to meet irrigation and consumptive demand.

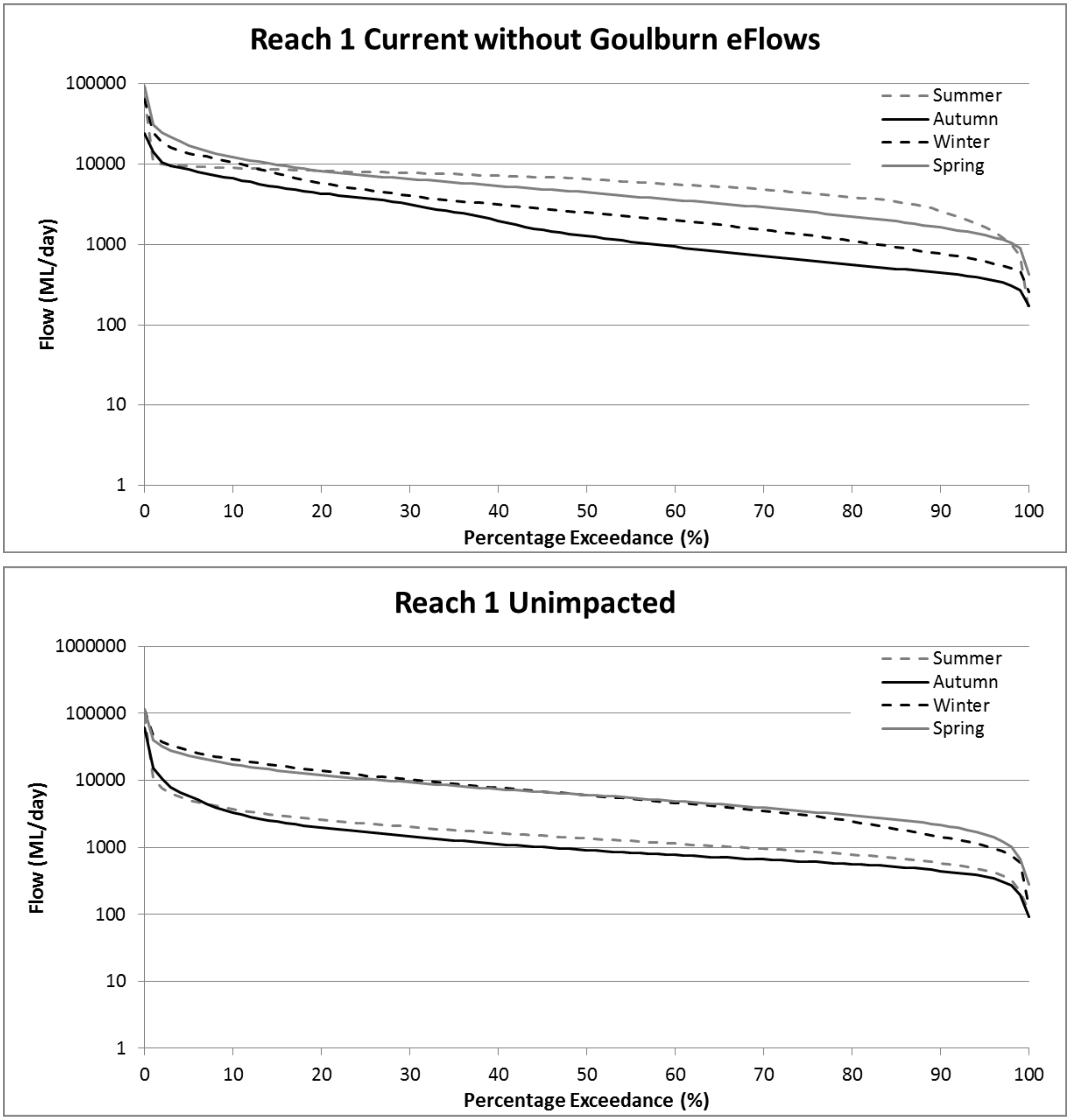

Figure 2: Flow duration curves showing seasonal patterns for modelled current and unimpacted conditions in Reach 1.

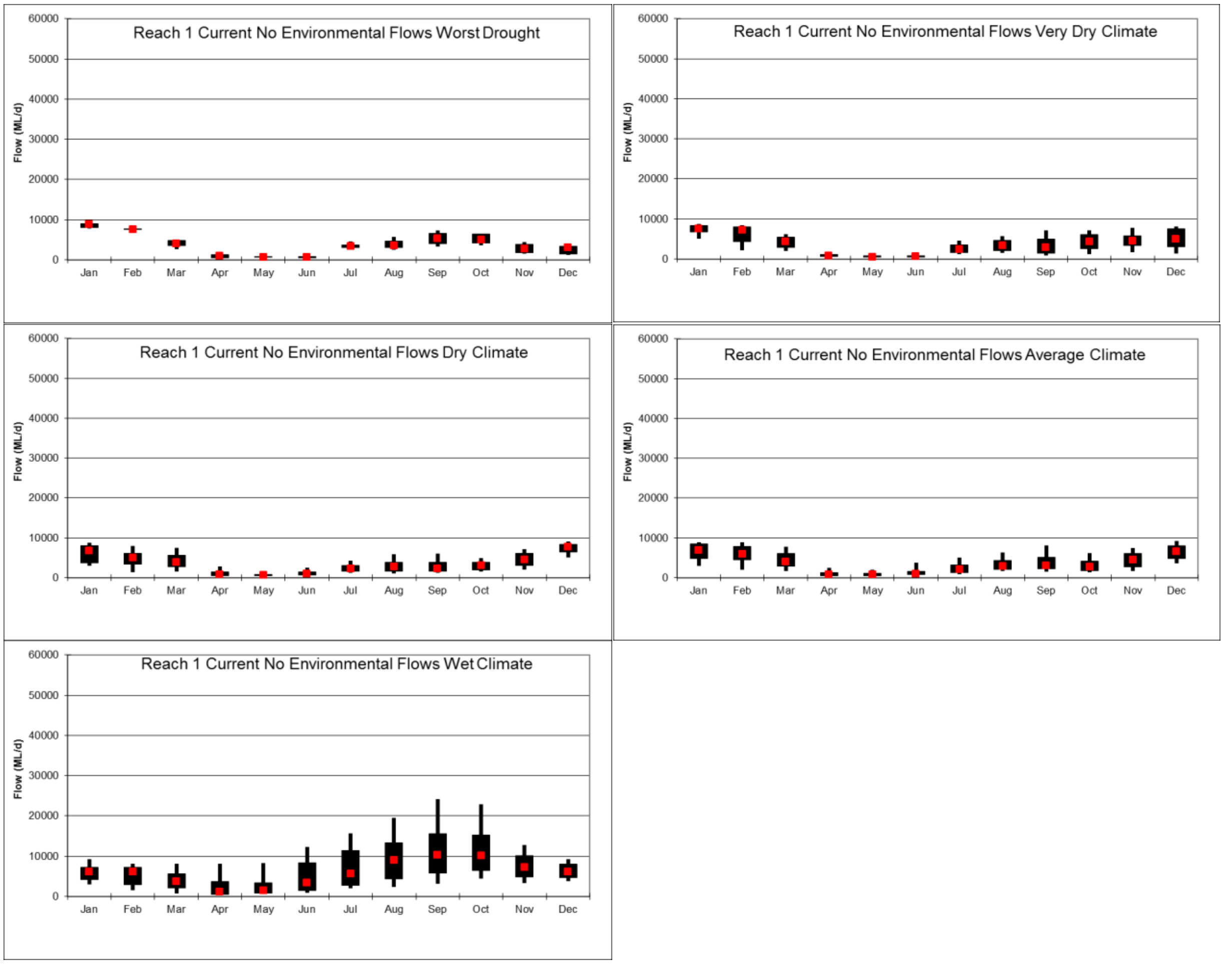

Figure 3: Plots of mean daily flow for the modelled current flow regime (with environmental releases omitted) for Reach 1 under various climatic conditions. Dots in centre of boxes are median values, boxes span the 25th to 75th percentiles, while whiskers span the 5th to 95th percentiles.

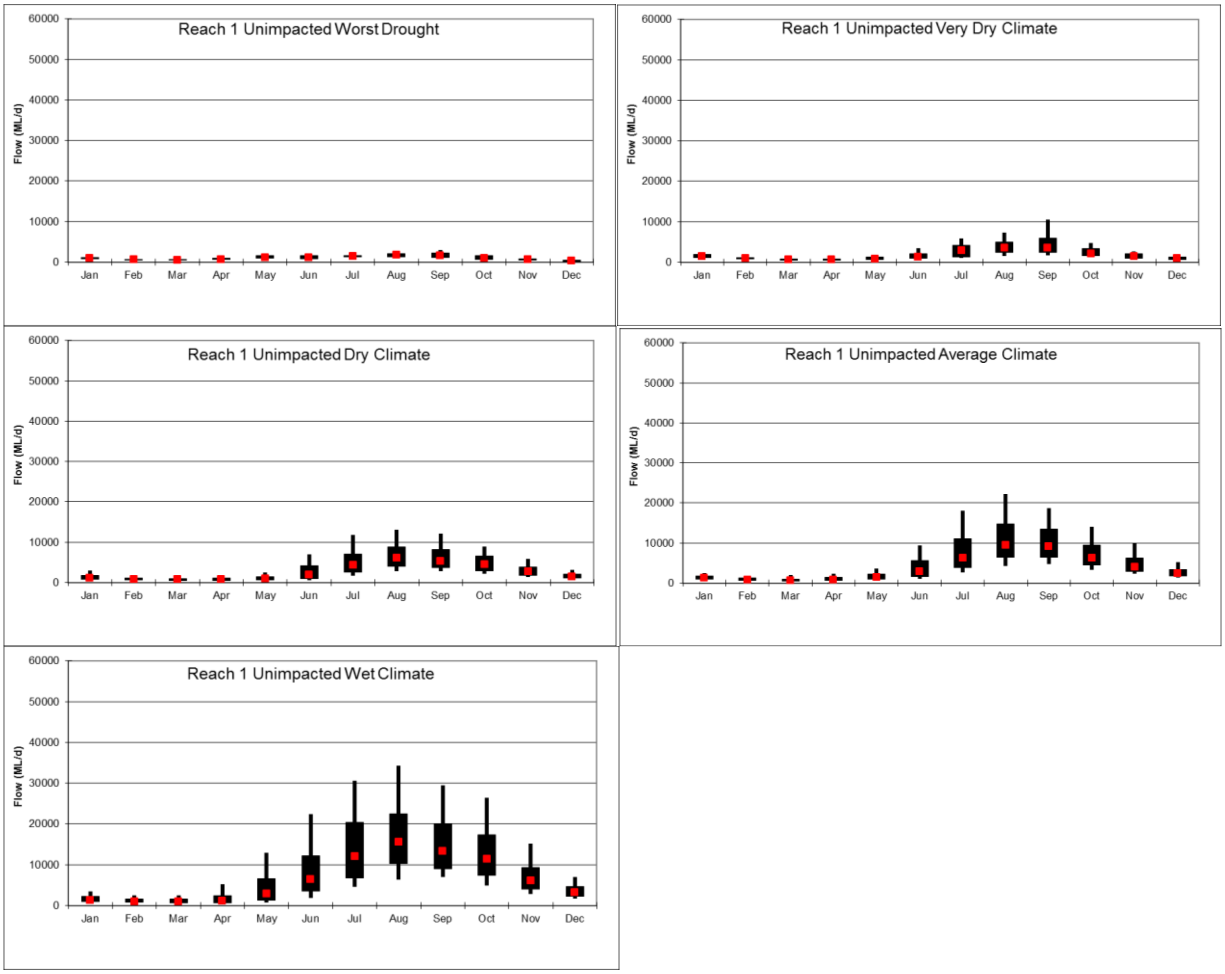

Figure 4: Plots of mean daily flow for the modelled unimpacted flow regime for Reach 1 under various climatic conditions. Dots in centre of boxes are median values, boxes span the 25th to 75th percentiles, while whiskers span the 5th to 95th percentiles.

5.2 Hydraulic modelling and wetland commence-to-flow assessment

5.2.1 Hydraulic modelling

1-dimensional HEC-RAS hydraulic models developed for the previous flows study of Cottingham et al. (2003) were revisited for the current project. The representative sites for Reaches 1 and 2 were resurveyed to establish the extent of change to channel morphology in the decade since the original cross sections were measured. While there were some anomalies found in relation to the 2003 cross-sections (see details of the hydraulic modelling undertaken, Appendix 2), the results suggested that the river has remained stable since 2003 and that the hydraulic models from 2003 provided a good basis. Models were refined and recalibrated with additional information (e.g. surveyed water levels) for the current study. Model outputs in support of flow recommendations are provided in Appendix 4.

5.2.2 Wetland commence to flow assessment

The mid Goulburn River floodplain contains more than 300 wetlands, which are an important part of the character and ecosystem values of the river system. Commence-to-flow (CTF) discharges, whereby river flows begin to spill into wetlands, can be used to inform environmental flow recommendations and assist targeted water management operations.

Available information on the connection of wetlands to the mid Goulburn River such as GIS information (Water Technology 2010) and LiDAR data (courtesy GB CMA) was used to evaluate wetland CTF elevations between the river channel and primary (directly) and secondary wetlands (connected via a primary wetland feature). These CTF elevations were translated to CTF discharges by translating rating curves from the HEC-RAS models along the reach (see details in Appendix 3). The results allowed examination of the river discharge required to reach all mapped wetlands along Reach 1 (example outputs are provided in Figure 5) and a sub-set of wetlands in the vicinity of stream gauging/rating sites in Reaches 2 and 3. Approximately 30% of the river was assessed in Reaches 2 and 3, which accounted for a similar proportion of the wetlands in each reach. In addition, the assessment identified non-flow related issues associated with wetland watering, namely direct modification of flow pathways to wetlands previously connected to the river at lower flow levels.

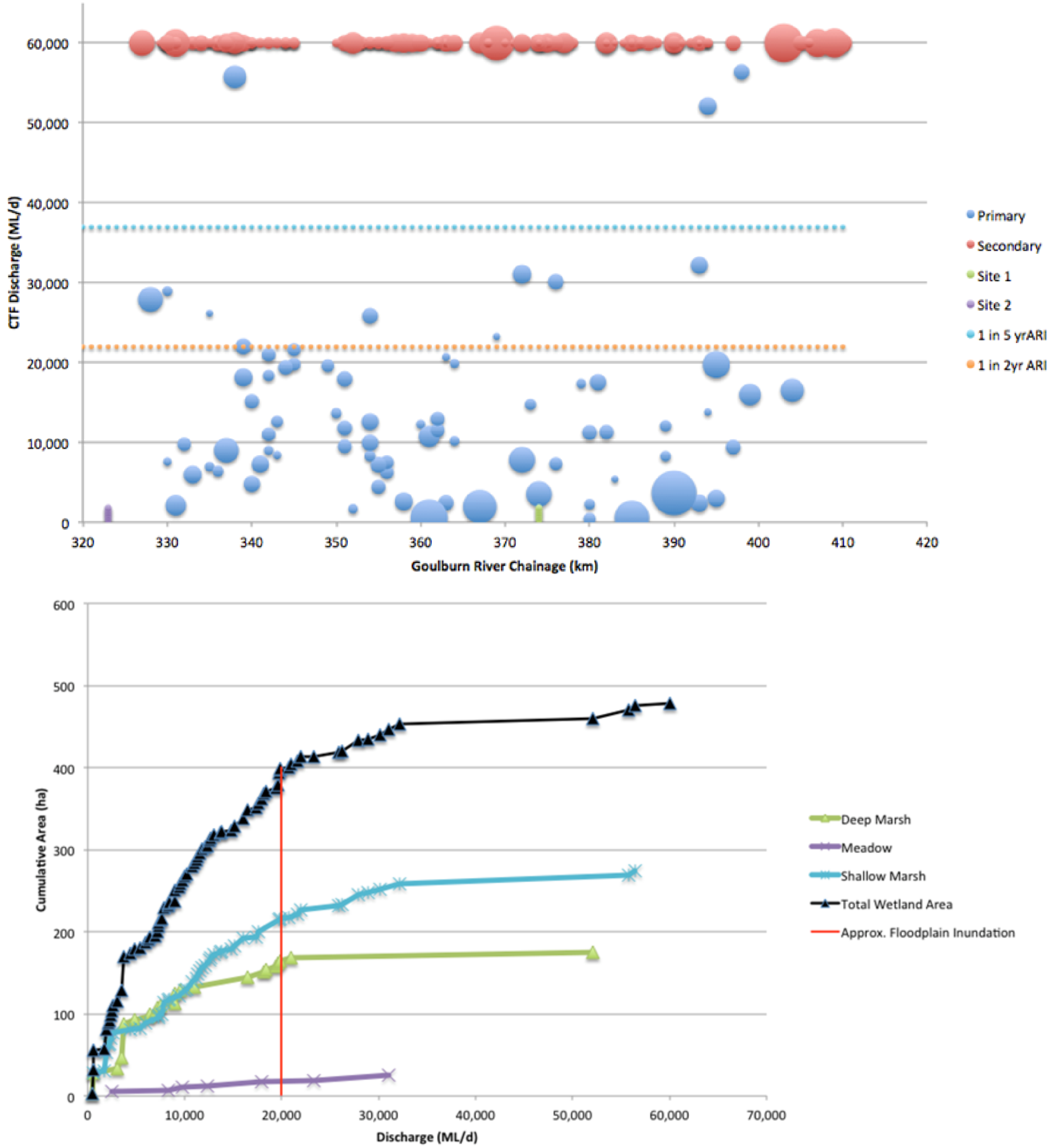

Figure 5: Example outputs of the wetland CTF assessment for Reach 1: CTF levels for selected wetlands (above) and cumulative wetland area with increasing discharge (below).

6 ENVIRONMENTAL WATER REGIME

This chapter describes the environmental flow regime required to protect or improve the environmental values described in Chapter 3 by meeting the ecological objectives presented in Chapter 4.

6.1 Flow components

The FLOWS method identifies the following flow components:

- Cease to flow;
- Baseflow;
- Freshes,
- Bankfull flows;
- Overbank flows.

The modelled current and unregulated flow series indicate that cease to flow periods do not occur along the mid Goulburn River. Thus, consideration of cease to flow periods has not been included and environmental flow recommendations contained in the following sections focus on the delivery of baseflow, freshes, bankfull and overbank flows in order to meet the listed ecological objectives. Flow recommendations are defined in terms of magnitude, frequency and duration, along with appropriate rates of rise and fall for freshes, bankfull and overbank events.

Examination of wetland CTF relationships (Appendix 3) shows that anabranch and wetland inundation flows occur at a range of flows from 500 up to 55,000 ML/d. For this study, bankfull flows in each reach are those that fill some sections of the river channel to top of bank without spilling onto any floodplain areas. These flows occur at approximately 11,000 ML/d for Reaches 1 and 2, and approximately 14,000 ML/d for Reach 3.

Overbank flows spill out of the river channel in each reach and provide local floodplain inundation. These flows occur from bankfull up to 20,000 ML/d. Both bankfull and overbank flows are considered within scope for this study, while extensive floodplain inundation events that wets the broader floodplain (above 20,000 ML/d up to 55,000 ML/d) are out of scope.

6.2 Climatic scenarios

Environmental flow recommendations establish the magnitude, frequency, duration and seasonality of flow releases to meet specific ecological objectives. An advance of this project over the previous environmental flow study (Cottingham et al. 2003) has been consideration of different climatic conditions. As described in Chapter 5, hydrological data have been generated for five climatic scenarios ranging from the worst drought on record through to wet years. As noted in section 5.1, the current flow regime maintains regulated flows within the river channel, albeit with unseasonal high flows in summer-autumn and low flows in winter-spring in all climatic scenarios except wet years. Under an unimpacted flow regime, low summer-autumn flows remain relatively constant, irrespective of the climatic scenario, with variability in winter-spring discharge being the driver between dry, average and wet years.

Details of various flow events (representing freshes, bankfull and overbank flow components) for the unimpacted and current flow regimes in Reach 1 are presented in Table 4 and Table 5, respectively. Flow events up to bankfull (11,000 ML/d) would occur for 96-100% of the time under the unimpacted flow regime, with a high frequency of such events occurring annually even in dry and very dry years. Flows up to 7,000 ML/d under the current regime occur with a similar high frequency to the unimpacted regime (although with changed seasonality), but flow events at and above bankfull are less frequent under the current flow regime (Figure 6). The pattern of flow event frequency and duration noted in Table 4 and Table 5 for Reach 1 persists for Reaches 2 and 3 also (not shown).

Given the above, the environmental flow recommendations described in the following sections focus on maintaining minimum baseflow, particularly outside of the irrigation season (May-August), and the delivery of freshes, bankfull and overbank flow events. No separation of baseflow recommendations to account for climatic differences were considered necessary, with variability in baseflow delivered by adoption of an ‘or natural’ qualification. This is often used with baseflow recommendations (e.g. ‘minimum flow of 200 ML/d or natural, whichever is lower’) and the intention is to preserve variability in the delivery of flow recommendations and prevent over- or under-watering that might result from a strict interpretation of a recommendation (e.g. ‘minimum flow 200 ML/d’ – which could see a constant flow of 200 ML/d delivered without variation; desirable natural variability in flow would be lost).

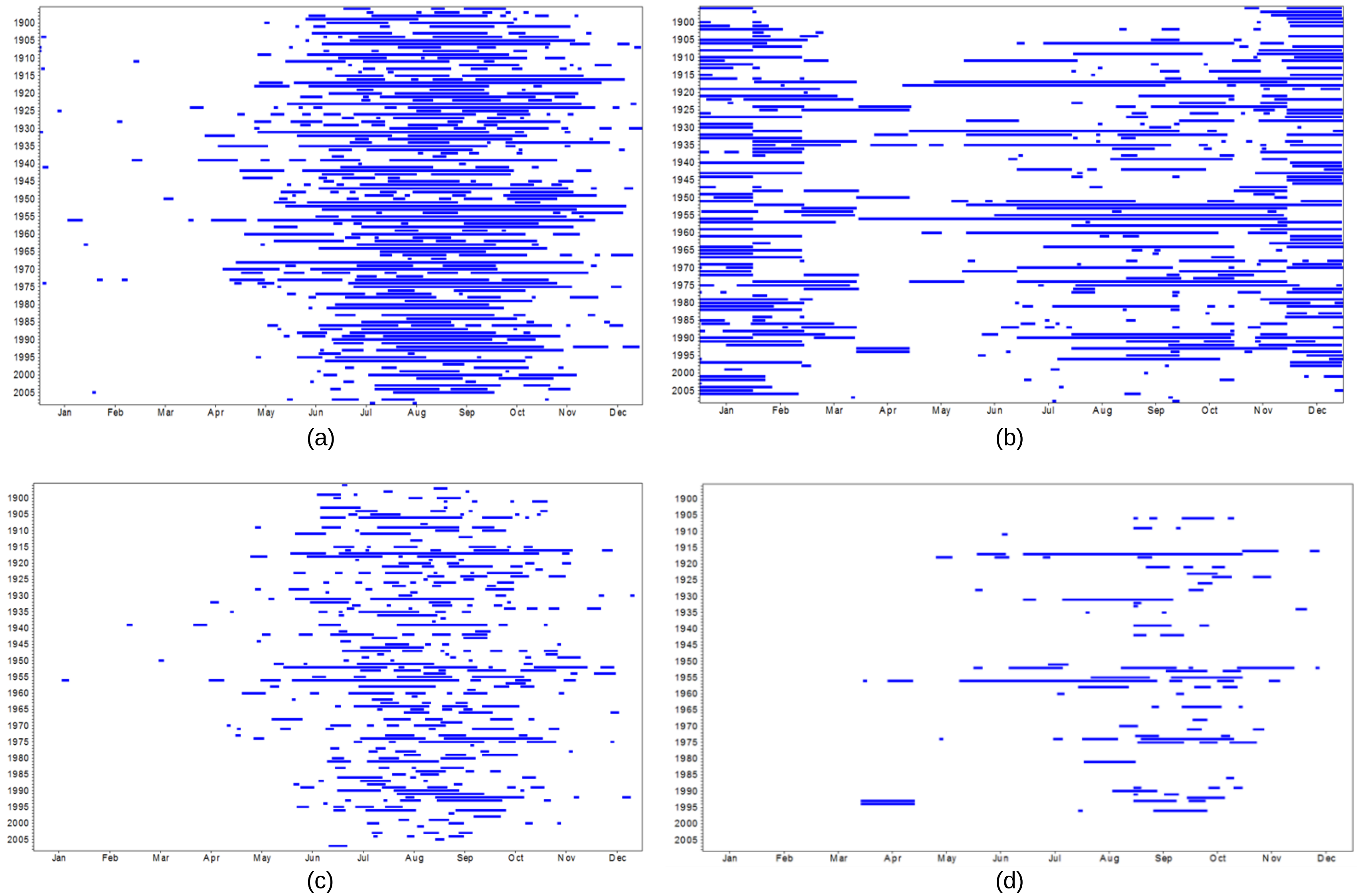

Figure 6: Comparison of flow events in Reach 1; greater than 7,000 ML/d for (a) the unimpacted flow regime and (b) the current flow regime, greater than 15,000 ML/d for (c) the unimpacted flow regime and (d) the current flow regime.

Table 4: Spells analysis for events above 4,000 ML/d in the unimpacted flow regime in Reach 1

Flow Threshold (ML/d)	20,000	11,000	9,000	7,000	5,000	4,000
All years						
Number of events per year	3	4	4	4	4	4
Percentage of years with events	88%	96%	97%	97%	99%	100%
Median duration (days)	4	6	7	7	7	7
Median interval (days)	27	23	23	23	22	22
Maximum duration (days)	83	149	192	207	245	259
Maximum interval (days)	419	391	342	330	331	376
Wet years						
Number of events per year	5	5	4	4	3	3
Percentage of years with events	100%	100%	100%	100%	100%	100%
Median duration (days)	5	8	10	10	10	10
Maximum duration (days)	83	149	192	207	245	259
Average years						
Number of events per year	3	4	4	4	4	4
Percentage of years with events	98%	100%	100%	100%	100%	100%
Median duration (days)	4	6	7	7	7	7
Maximum duration (days)	22	69	86	123	160	182
Dry years						
Number of events per year	1	3	4	4	5	5
Percentage of years with events	86%	100%	100%	100%	100%	100%
Median duration (days)	3	4	5	5	6	7
Maximum duration (days)	7	21	32	58	81	121
Very dry years						
Number of events per year	1	1	2	2	3	3
Percentage of years with events	30%	70%	90%	90%	100%	100%
Median duration (days)	2	2	3	4	5	5
Maximum duration (days)	4	8	11	14	32	60
Worst drought on record						
Number of events per year	0.00	0.00	0.00	0.00	1 in 2	2 in 3
Percentage of years with events	0%	0%	0%	0%	50%	100%
Median duration (days)	0.00	0.00	0.00	0.00	1	1
Maximum duration (days)	0.00	0.00	0.00	0.00	1	3

Table 5: Spells analysis for events above 4,000 ML/d in the current flow regime in Reach 1

Flow Threshold (ML/d)	20,000	11,000	9,000	7,000	5,000	4,000
All years						
Number of events per year	<1	1	2	3	4	5
Percentage of years with events	33%	55%	88%	100%	100%	100%
Median duration (days)	4	6	5	8	8	8
Median interval (days)	45	47.5	73	44	31	22
Max duration (days)	89	152	244	244	360	365
Max interval (days)	455	524	564	414	288	262
Wet years						
Number of events per year	2	3	3	4	4	4
Percentage of years with events	91%	100%	100%	100%	100%	100%
Median duration (days)	31	34	34	34	34	34
Maximum duration (days)	4	10	13	22.5	30	30
Average years						
Number of events per year	<1	1	2	4	5	5
Percentage of years with events	13%	49%	87%	100%	100%	100%
Median duration (days)	3.5	2	3	6	8	8
Maximum duration (days)	7	58	72	108	150	260
Dry years						
Number of events per year	0	<1	1	3	4	6
Percentage of years with events	0%	23%	82%	100%	100%	100%
Median duration (days)	0	1	3	7	12	6
Maximum duration (days)	0	30	30	62	96	139
Very dry years						
Number of events per year	0	<1	1	3	5	5
Percentage of years with events	0%	10%	80%	100%	100%	100%
Median duration (days)	0	2	3	8	13	14
Maximum duration (days)	0	2	14	60	92	106
Worst drought on record						
Number of events per year	0	0	<1	3	4	4
Percentage of years with events	0%	0%	50%	100%	100%	100%
Median duration (days)	0	0	24	5	17	54
Maximum duration (days)	0	0	24	59	65	76

6.3 Environmental flow recommendations

6.3.1 Reach 1: Lake Eildon to the Yea River

Environmental flow recommendations for Reach 1 are summarised below and in Table 6. The most salient features of the recommendations are to provide:

- Late autumn-early winter baseflow at a minimum of 400 ML/d or natural, whichever is the lesser natural, to provide habitat for native fish (small-bodied species), trout (see Section 6.4) aquatic vegetation and invertebrates;
- Spring-summer baseflow <3,000 ML/d (i.e. delay high summer flows as long as possible) to maintain habitat for native fish (small-bodied) species (see also Section 6.4 for trout);
- Winter-spring freshes above 900 ML/d to scour fine sediments from riffles;
- Winter-spring fresh above 2,500 ML/d to slough filamentous algae and reset biofilms;
- A winter-spring event approaching bankfull (7,000 ML/d – 9,000 ML/d) to maintain in-channel benches;
- A winter-spring bankfull event of 11,000 ML/d to maintain geomorphic processes, provide connection of the river channel and low-lying riparian/wetland habitat for fish and invertebrates, as well as watering riparian vegetation and maintaining wetlands as functioning systems;
- Winter-spring overbank flows (11,000 ML/d – 20,000 ML/d) to provide connection of the river channel and riparian/wetland/floodplain habitat for fish and invertebrates, water riparian/wetland/floodplain vegetation, provide regeneration opportunities for woody riparian species and entrain organic matter and nutrients back into the river channel to drive riverine productivity.

Baseflow

The current flow regime delivers higher baseflow in summer-autumn than would occur naturally as a result of water released from Lake Eildon to meet irrigation and consumptive demand. This pattern is expected to be maintained in the future. Flow along the river outside of the irrigation season is reduced to the minimum required under the Goulburn system Bulk Entitlement (120 ML/d) plus releases for electricity generation and tributary inflows.

A minimum baseflow is recommended to maintain or improve the habitat available for trout, small-bodied native fish and maintain existing beds of aquatic vegetation and invertebrates. A baseflow of 400 ML/d or natural (whichever is lower) is recommended year-round, which will wet important riffle habitat along the reach (see HEC-RAS results in Appendix 3). The recommendation applies to all climatic scenarios. Maintaining the flows across winter will also help to protect against stranding of trout redds. The 'or natural' component of the baseflow recommendation allows for flows to fall below 400 ML/d is inflows to Lake Eildon are below this figure. It is recommended that the 120 ML/d minimum flow provided under the Goulburn system Bulk Entitlement be retained as an absolute minimum flow from Lake Eildon to protect against undue threats to river condition, such as poor water quality.

Shallow, low velocity (slackwater) conditions have been shown to be important habitat for various lifecycle stages of native fish and trout (e.g. Humphries et al. 2006, Brown 2003), particularly during spring and into summer-autumn. This habitat is lost as discharge increases during the irrigation season when the velocity and depth of flow increases. Based on HEC-RAS modelling, the breakpoint in wetted perimeter-discharge relationship occurs at 2,000-3,000 ML/d. Given that summer flows will remain high due to irrigation and other releases, the intent of this recommendation is to maintain spring-summer baseflow below 3,000 ML/d to preserve slackwater habitat for as long as is possible.

Freshes

Freshes have been recommended to distribute fine sediments from habitat such as riffles and to disrupt biofilms, the subsequent regeneration of which adds to primary and secondary production (e.g. Ryder et al. 2007, Ryder 2004). Increased sedimentation can bury macroinvertebrates and their habitats (Wood et al. 2005) leading to shifts in the structure of the habitat and its associated fauna (e.g. Gayraud et al. 2002). Sedimentation can lead to a loss of species that need to feed or attach to the rocky substrata and there may be an increase in burrowing animals such as oligochaetes (Hellawell 1986). However the most common effect is a change in abundance (Weber & Post, 1985). When fine silt is deposited it is trapped by periphyton, thus reducing photosynthesis (Yamada & Nakamura, 2002) and algal food for grazers (Donohue & Irvine 2004). Sedimentation on the surface of rocky substrata in riffles can lead to a decline in habitat quality (Wood and Armitage, 1997), particularly by clogging the interstitial spaces between substrate clasts, increasing invertebrate drift and reducing the available habitat for benthic organisms (Petts 1984, Schälchi 1992). Sedimentation has long been recognized as a consequence of the elimination or reduction in the magnitude and frequency of flows (Petts 1984).

Empirical studies have shown that fine sediments can be mobilised from the substrate sediments with flows that have a shear stress above 15 Nm^2 (Wilkinson and Rutherfurd 2001). HEC-RAS modelling indicates that flows of 12,000 ML/d (i.e. approximately bankfull) are required to provide a shear stress of 15 Nm^2 more broadly along Reach 1. However the modelling, and notwithstanding the limitations of 1-dimensional modelling, identified instances where 15 Nm^2 could be achieved with relatively small magnitude freshes of 900 ML/d over some areas of riffles (although the longitudinal extent of this will be limited). Such freshes could best be deployed at the cessation of large inflows from unregulated tributaries such as the Acheron River; these tributary flows are likely to carry high sediment loads, particularly if generated in catchment that are still recovering from bushfires.

Freshes of 2,500 ML/d are also proposed to disrupt and refresh filamentous algae and biofilms; this in turn provides more palatable food for invertebrates and will, therefore, contribute to riverine productivity. The magnitude of the fresh is based on experiments conducted by Ryder et al. (2006), who found that filamentous algae growth could be sloughed when water velocity exceeded 0.55 m/s, while biofilms growth could be disrupted by velocities above 0.3 m/s. The magnitude of the event is based on the HEC-RAS model for reach average velocity of 0.6 m/s.

Bankfull and overbank flows

As noted in section 4.2, bankfull and overbank flows are important for maintaining diversity in riparian and wetland vegetation, providing opportunities for vegetation recruitment, providing habitat for native fish and invertebrates and contributing external (allochthonous) sources of carbon to the river to help drive riverine productivity. As noted in section 6.2, bankfull and overbank flows would occur for a very high proportion of years under an unimpacted flow regime, often with multiple events per year in average and wet years. The frequency of bankfull and overbank flows is much reduced from that of the unimpacted regime. Recommendations for bankfull and overbank flow events therefore aim to increase the current frequency to support riparian and wetland vegetation, provide habitat for native fish and invertebrates, and entrain organic matter that will help to increase riverine production. The bankfull flow of 11,000 ML/d and overbank flows between 11,000 – 20,000 ML/d are based on the HEC-RAS model output (Appendix 3) and acknowledging the upper constraint of 20,000 ML/d being considered in investigations currently being undertaken by the MDBA (MDBA 2013). The frequency and duration of the recommendations have been based on published information on the watering requirements of aquatic and riparian plants (e.g. Roberts and Marston 2011) and guilds such as wetland-dependent native fish[5]. While the frequency and duration of bankfull and overbank events varies depending on the ecological asset, this does not mean that each recommendation needs to be considered in isolation and a single event can achieve numerous objectives; i.e. the more frequent or larger events for one ecosystem attribute (e.g. geomorphology), will also provide events that will achieve riparian vegetation outcomes.

Interestingly, there have been anecdotal reports of wetlands filling when water levels in the river approach bankfull but have not spilled from the river bank (S. Casanelia, GB CMA, pers. comm.). It is assumed that these are instances where wetlands are connected to the river via groundwater flow away from the river, for example through alluvial gravels. Further investigations are required to confirm the filling of wetlands in such a manner and the river heights at which it occurs. Consideration can then be given as to whether these wetlands should be managed differently to other floodplain wetlands (i.e. due to their different hydrology and potentially different vegetation assemblages).

Note: it is recognised that the proposition to *actively* manage the overbank flows required for this recommendation is unlikely to be accepted due to the Victorian government policy of not inundating private land. However, it is stated here to provide completeness in terms of recommendations to achieve ecological objectives related to maintaining or improving the conditions of ecosystem assets and values associated with the mid Goulburn River.

[5] Predominantly small-bodied native species, as large-bodied species are likely to avoid the cold water that persists in the reach during the irrigation season.

Table 6: Environmental flow recommendations for Reach 1: Lake Eildon to the Yea River (see Table 3 for description of objective codes)

Objectives (features addressed in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
Recommendations for Baseflow			
NF6, RV1, I1, I2, I4 (wet riffles, maintain baseflow wetted area, maintain existing aquatic vegetation)	• Baseflow (all seasons)	Minimum flow of 400 ML/d, or natural (whichever is lower), outside of the irrigation season.	• Based on HECRAS wetted perimeter of riffle cross-sections (4.6 cumecs to inundate riffles in cross-sections) – based on the breakpoint of wetted perimeter-discharge. Provides wetted area for River blackfish and galaxids, and also supports aquatic vegetation and invertebrates (including Spiny crayfish). A baseflow of 400 ML/d in Reach 1 provides almost double the area of wetted habitat from that wetted at the current minimum flow of 120 ML/d.
Recommendations for Freshes			
G1, I3, I4 (scour fine sediments, maintain interstitial spaces for invertebrates)	• Winter-spring freshes	<u>Peak magnitude</u>: 900 ML/d. <u>Frequency</u>: depends on antecedent conditions. <u>Duration</u>: 1 day. <u>Timing</u>: depends on tributary inputs – following cessation of high tributary inflows (e.g. flows of approximately 4,000 ML/d from the Acheron River) if flows in Reach 1 are below 900 ML/d for 1 month.	• Wilkinson and Rutherfurd (2001) identified shear stress of 15 Nm^2 to scour fine sediments. HECRAS indicates this occurs at approximately 12,000 ML/d along Reach 1 generally but that 15 Nm2 can be achieved over one small riffle at 800-900 ML/d. This suggests that small pulses can still be useful for maintaining habitat quality.
I1 (sloughing filamentous algae and refreshing of biofilms)	• Summer-autumn and winter-spring freshes	<u>Peak magnitude</u>: 2,500 ML/d. <u>Frequency</u>: 2 per year <u>Duration</u>: 5 days (dry years) to 7 days (average, wet years). <u>Timing</u>: 1 in spring and 1 in summer-autumn.	• Sloughing of filamentous algae can occur at water velocity of 0.55 m/s (based on Ryder et al. 2006). From HECRAS, with reach mean velocity of 0.6 m/s. Duration of between 5-7 days represents maximum duration that

Objectives (features addressed in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
			occurs in dry years and the median that occurs in all years:
Recommendations for Bankfull and Overbank flows			
G3 (maintenance of in-channel benches)	• Close to winter-spring bankfull	Peak magnitude: 7,000 – 9,000 ML/d Frequency: as in G2 bankfull component. Duration: 2 days. Timing: as in G2 bankfull component. Rise and fall: as in G2 bankfull component.	• From HECRAS model; depth 0.0-0.5 m above bench levels (Vietz et al. 2012). • Preference is to coincide (piggy back) with or follow soon after high tributary inflows so that suspended sediment from tributary catchments is dropped onto benches (and reduce the sediment otherwise smothering the bed).
G2, G4, G5 (disruption of river channel armour layer, movement of bed material, scouring of pools)	• Winter-spring bankfull and overbank flows	**Bankfull** Peak magnitude: 11,000 ML/d Frequency: 1 event in 2 out of 3 years, but secondary to other objectives (e.g. wetland inundation). Duration: 1 day at peak flow. Rise and fall: Rise (Q_2/Q_1) = maximum of 2.0-2.7; Fall (Q_2/Q_1) = maximum of 0.8 (see description in Appendix 1). **Overbank** Peak magnitude: up to 20,000 ML/d Frequency: 1 every three years in dry years, 1 in 2 years in average and wet years. Duration: 1 day at peak flow. Timing: Any time – can coincide with other requirements such as wetland inundation. Rise and fall: Rise (Q_2/Q_1) = maximum of 2.0-2.7; Fall (Q_2/Q_1) =	• Overall, there is very little ability to change bed morphology, except at flows above bankfull up to 20,000 ML/d. • Shear stress to turn over pebbles (up to 64 mm) in riffles equals 64 Nm^2, from HECRAS model. Modelling indicates that flows greater than bankfull are required for move pebbles – in-channel flows do not have competence to move 100% pebbles. To move 50% of pebbles/cobbles in Reach 1 requires approximately 10,000 ML/d (almost bankfull). • Bankfull – Rationale for frequency – unimpacted regime gets average of 3 events per year in 96% of years. Get events in most dry years. • Overbank – rationale for frequency – unimpacted regime gets 3 events in 80% of years. Adopt 15,000 initially to avoid excessive watering, particularly in Reach 2, and measure response before moving to larger events up to 20,000 ML/d.

Objectives (features addressed in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
		maximum of 0.8 (see description in Appendix 1).	• Rise and fall – examined current G-MW rules and rates proposed by Cottingham et al. (2003); applied a more conservative rate of fall than both sources to account for variability in riparian zone condition and potential for increased rates of mass failure bank erosion. • To concomitantly reduce sediment smothering from high sediment load tributary inflows, delivery is recommended on the receding limb of tributary inflow dominance of flows along the river and just before releases from Lake Eildon start to dominate flows in the river. This timing likely to be winter-spring and can be beneficial for invertebrates and fish also.
NF1 (increased flow variability)	• All components	Covered by a combination of all previous objectives and remaining NF objectives.	• As for all previous objectives
NF2, NF4, NF5 (maintain or increase connection to fish habitats)	• Winter-spring bankfull, overbank	**Bankfull** Peak magnitude: 11,000 ML/d. Frequency and timing: Annually preferred, but accept less frequent occurrence to balance with other objectives (e.g. wetland filling only once or drying phase, Macquarie perch breeding). At least 2 events in a year (August and March/April, if not connected earlier in summer) if pursuing this objective. Duration: as for RV 2 (below). Timing: and as in rationale. Rise and Fall: As for G2 (above). **Overbank** Peak magnitude: 15,000 ML/d. Frequency: as for RV2. Duration: as for RV2.	• The intention of the bankfull flow is to connect the river to anabranches and low-lying wetlands at start and end of season the irrigation season to prevent complete wetland drying and allow fish to move between the river channel and anabranch and wetland habitat.

Objectives (features addressed in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
		Timing: winter-spring, and as in rationale. Rise and fall: as for G2.	
RV2, RV3, RV4, RV5, I5, I6 (wetting of riparian zone and wetlands, regeneration of native woody species, entrainment of organic matter)	• Winter-spring bankfull and overbank	**Bankfull** Peak magnitude: 11,000 ML/d. Frequency: Average and wet years: 1 event in 2 years Dry years: 1 event in 3 years in, Maximum interval of 1 in 7 years. Duration: 2 days (dry years) to 4 days (average and wet years). Timing: winter-spring, and as in rationale. Rise and Fall: as for G2. **Overbank** Peak magnitude: 20,000 ML/d. Frequency: Events up to 15,000 ML/d: 1 in 2 years for average and wet years, 1 in 3 years for dry years Events up to 20,000 ML/d: 1 in 5 years for average and wet years (not in dry years). Duration: 2 days (dry years) to 4 days (average and wet years). Timing: winter- early spring, with recession through October. Rise and fall: as for G2.	• The intent is to increase variability in regulated flows, and meet the needs of native woody species (Roberts and Marston 2011, Greet 2012). • The aim is to deliver events of 10,000 ML/d and greater, and then draw down to approximately 5,000 ML/d, with drawdown before Lake Eildon releases dominate river flows so that flow variability and vegetation diversity are promoted.

6.3.2 Reach 2: Yea River to Sunday Creek (Seymour)

Environmental flow recommendations for Reach 2 are summarised below and in Table 7.The most salient features of the recommendations are to provide:

- Late autumn-early winter baseflow at a minimum of 500 ML/d or natural, whichever is the lesser, to provide habitat for native fish, maintain beds of aquatic vegetation and invertebrates;
- Winter-spring fresh above 2,500 ML/d to slough filamentous algae and reset biofilms;
- A spring fresh (assuming temperature is above 16ºC) that raises water level by 0.5 metre as an attractant for large-bodied native fish species;
- A winter-spring bankfull event of 11,000 ML/d to maintain geomorphic processes (including maintaining in-channel benches), provide connection of the river channel and low-lying riparian/wetland habitat for native fish and invertebrates, as well as watering riparian vegetation;
- Winter-spring overbank flows (11,000 ML/d – 20,000 ML/d) to provide connection of the river channel and riparian/wetland/floodplain habitat for native fish and invertebrates, water riparian/wetland/floodplain vegetation and entrain organic matter and nutrients back into the river channel to drive riverine productivity.

Consideration was also given to providing freshes sufficient to inundate anabranches. The wetland CTF assessment indicated that anabranches in Reach 2 connect to the river at flows greater than 4,800 ML/d. Anabranches have been shown to be important habitat (e.g. fish, invertebrates; e.g. Saddlier et al. 2008, Leigh and Zampatti 2013), as well as providing carbon that contributes to riverine productivity (e.g. McGuinness and Arthur 2011). In the mid Goulburn, anabranches may also serve as refuge from cold water in summer-autumn irrigation season and consideration was given to provide more frequent access to this habitat to support large-bodied native fish.

However, flow through anabranches is now likely to occur frequently because of the delivery of irrigation flows over summer; further increasing this frequency of flow-through and making them flow semi-permanently risks altering the distinct ecological function of anabranches (i.e. as intermittently flowing systems) as well as developing a lower temperature regime than desired as they are continually replenished by colder irrigation releases. It is recommended that the GB CMA undertake further investigation of the temperature regime of connected anabranches during the irrigation season to confirm whether or not they serve as temperature refugia for native fish before considering this option further.

Baseflow

As for Reach 1, the baseflow recommendation has been generated from HEC-RAS based on wetting riffle areas at the base of the river channel.

Freshes

In addition to the freshes described for Reach1 (Section 6.3.1) aimed at resetting biofilms and driving productivity, a fresh is also recommended as an attractant for large-bodied native fish that inhabit tributaries and downstream areas such as Lake Nagambie and Goulburn Weir. The 0.5 m rise in water level over antecedent conditions is based on observations from the Murray River (Lyon et al. 2014, Koster et al. 2012). Antecedent conditions are where baseflow have remained at relatively low (e.g. less than 2,500 ML/d) levels in the month leading up to October.

Bankfull and overbank flows
Bankfull and overbank flow recommendations have been defined using the same approach as in Reach 1, given that such things as the frequency of these flow events in Reach 2 remains consistent with Reach 1.

Table 7: Environmental flow recommendations for Reach 2: Yea River to Sunday Creek (Seymour)

Objectives (habitat feature in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
Recommendations for Baseflow			
NF6, RV1, I2, I4 (riffles, baseflow wetted area)	• Baseflow (all seasons)	Minimum flow of 500 ML/d, or natural (whichever is lower), outside of the irrigation season.	• Based on HECRAS wetted perimeter of riffle cross-sections (4.6 cumecs to inundate riffles in cross-sections) – based on the breakpoint of wetted perimeter-discharge. Provides wetted area for Blackfish and galaxids, and also supports aquatic vegetation and invertebrates (including Spiny crayfish).
Recommendations for Freshes			
I1, NF1 (sloughing filamentous algae and refreshing of biofilms)	• Summer-autumn and winter-spring freshes	Peak magnitude: 2,500-3,500 ML/d. Frequency: 2 per year Duration: 5 days (dry years) to 7 days (average, wet years). Timing: 1 in winter-spring and 1 in summer-autumn.	• Sloughing of filamentous algae can occur at water velocity of 0.55 m/s (based on Ryder et al. 2006). From HECRAS, with reach mean velocity of 0.6 m/s. Duration of between 5-7 days represents maximum duration that occurs in dry years and the median that occurs in all years.
NF3, NF7 (attractant flows for large-bodied native fish, Macquarie perch spawning)	• Spring freshes	Peak magnitude: 0.5 m increase in stage height over one week in late spring (Oct-Dec), assuming temperature is suitable (e.g. above 16^{0}C). Duration: 1 week of rise and hold for two days at the target flow, if this does not happen earlier in spring. Rise and fall: as for G2.	• Expert opinion based on attracting flow from potential colonists noted in the Murray River (Lyon et al. 2014; Koster et al. 2012). • Macquarie perch spawning based on flow recs from the Yarra River. King et al. (2011) (cited in SKM 2012) noted that strongest recruitment occurred following spring high flows that promoted spawning (and cleaned spawning sites) followed by relatively stable (but not static) summer flows that reduced the likelihood of eggs being washed away.

Objectives (habitat feature in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
Recommendations for Bankfull and Overbank flows			
G2, G3, G4, G5 (disruption of river channel armour layer, movement of bed material, scouring of pools)	• Winter-spring bankfull and overbank flows	**Bankfull** Peak magnitude: 11,000 ML/d Frequency: 1 event in 2 out of 3 years, but secondary to other objectives (e.g. wetland inundation). Duration: 2 days at peak flow. Rise and fall: governed by Reach 1 and tributary inputs. **Overbank** Peak magnitude: 15,000 ML/d. Frequency: 1 every three years in dry and average years, 1 in 2 years wet years. Duration: 1 day at peak flow. Timing: Any time – can coincide with other requirements such as wetland inundation. Rise and fall: governed by Reach 1 and tributary inputs.	• From HECRAS model; depth 0.0-0.5 m above bench levels (Vietz et al. 2012). • Preference is to coincide (piggy back) with or follow soon after high tributary inflows so that suspended sediment from tributary catchments is deposited on benches. • Overall, there is very little ability to change bed morphology, except at flows above bankfull up to 20,000 ML/d. • Shear stress to turn over pebbles (up to 64 mm) in riffles equals 64 Nm^2, from HECRAS model. Modelling indicates that flows greater than bankfull are required for move pebbles – in-channel flows do not have competence to move 100% pebbles. To move 50% of pebbles/cobbles in Reach 2 requires approximately 11,000 ML/d (bankfull). • Bankfull – Rationale for frequency – unimpacted regime gets average of 3 events per year in 96% of years. Get events in most dry years. • Overbank – rationale for frequency – unimpacted regime gets 3 events in 80% of years. Adopt 15,000 initially to avoid excessive watering and assess response before moving to larger events up to 20,000 ML/d that could benefit Reaches 1 and 3. • Rise and fall – based on Reach 1; examined current G-MW rules and rates proposed by Cottingham et al. (2003); applied a more conservative rate of fall than both sources to account for variability in riparian zone

Objectives (habitat feature in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
			condition and potential for increased rates of mass failure bank erosion. • To concomitantly reduce sediment smothering from high sediment load tributary inflows, delivery is recommended at end of tributary inflow dominance of flows along the river and just before releases from Lake Eildon start to dominate flows in the river. This timing likely to be winter-spring and can be beneficial for invertebrates and fish also.
NF1 (increased flow variability)	• All components	Covered by a combination of all previous objectives and subsequent NF objectives.	• As for all previous objectives
NF2, NF4, NF5 (maintain or increase connection to off-channel fish habitats)	• Winter-spring bankfull, overbank	**Bankfull** <u>Peak magnitude</u>: 11,000 ML/d <u>Frequency and timing</u>: Annually preferred, but accept less frequent occurrence to balance with other objectives (e.g. wetland filling only once or drying phase, Macquarie perch breeding). At least 2 events in a year (August and March/April, if not connected earlier in summer) if pursuing this objective. <u>Duration</u>: as for RV 2 (below). <u>Timing</u>: and as in rationale. <u>Rise and Fall</u>: governed by Reach 1 and tributary inputs. **Overbank** <u>Peak magnitude</u>: 15,000 ML/d <u>Frequency</u>: as for RV2. <u>Duration</u>: as for RV2. <u>Timing</u>: winter-spring, and as in rationale.	• As for G2 • The intention of the bankfull flow is to connect the river to anabranches and low-lying wetlands at start and end of the irrigation season to prevent complete wetland drying and allow fish to move between the river channel and anabranch and wetland habitat.

Objectives (habitat feature in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
		<u>Rise and fall</u>: governed by Reach 1 and tributary inputs.	
RV2, RV3, RV4, RV5, I5 (wetting of riparian zone and wetlands, regeneration of native woody species, entrainment of organic matter)	• Winter-spring bankfull and overbank	**Bankfull** <u>Peak magnitude</u>: 11,000 ML/d <u>Frequency</u>: Average and wet years: 1 event in 2 years Dry years: 1 event in 3 years in, Maximum interval of 1 in 7 years. <u>Duration</u>: 2 days (dry years) to 4 days (average and wet years). <u>Timing</u>: winter-spring, and as in rationale. <u>Rise and Fall</u>: governed by Reach 1 and tributary inputs. **Overbank** <u>Peak magnitude</u>: 15,000 ML/d <u>Frequency</u>: 1 in 2 years for average and wet years, 1 in 3 years for dry years, maximum interval of 1 in 7 years. <u>Duration</u>: 4 days. <u>Timing</u>: winter- early spring, with recession through October <u>Rise and fall</u>: governed by Reach 1 and tributary inputs.	• The intent is to increase variability in regulated flows, and meet the needs of native woody species (Roberts and Marston 2011, Greet 2012). • The aim is to deliver events of 10,000 ML/d and greater, and then draw down to approximately 5,000 ML/d, with drawdown before Lake Eildon releases dominate river flows so that flow variability and vegetation diversity are promoted.

6.3.3 Reach 3: Sunday Creek (Seymour) to Goulburn Weir

Environmental flow recommendations for Reach 3 are summarised below and in Table 8. The most salient features of the recommendations are to provide:

- Late autumn-early winter baseflow at a minimum of 800 ML/d or natural, whichever is the lesser natural, to provide habitat for native fish and invertebrates;
- A spring fresh (assuming temperature is above 16ºC) that raises water level by 0.5 metre as an attractant for large-bodied native fish species;
- A winter-spring event approaching bankfull (12,000 ML/d – 13,000 ML/d) to maintain in-channel benches and to slough filamentous algae and reset biofilms;
- A winter-spring bankfull event of 14,000 ML/d to maintain geomorphic processes (including maintaining in-channel benches and distributing fine sediments), provide connection of the river channel and low-lying riparian/wetland habitat for native fish and invertebrates, as well as watering riparian vegetation and maintain wetland diversity;
- Winter-spring overbank flows (14,000 ML/d – 20,000 ML/d) to provide connection of the river channel and riparian/wetland/floodplain habitat for native fish and invertebrates, water riparian/wetland/floodplain vegetation and entrain organic matter and nutrients back into the river channel to drive riverine productivity.

Baseflow

As for Reaches 1 and 2, the baseflow recommendation has been generated from HEC-RAS based on wetting riffle areas at the base of the river channel.

Freshes

Recommendations for freshes have also been defined using the same approach as in Reaches 1 and 2, given that such things as the frequency of these flow events in Reach 3 remains consistent with Reaches 1 and 2.

Bankfull and overbank flows

Bankfull and overbank flow recommendations have been defined using the same approach as in Reaches 1 and 2, given that such things as the frequency of these flow events in Reach 3 remains consistent with Reaches 1 and 2. This includes the recommendation for maintaining benches, which in Reach 3 has a similar peak flow magnitude as bankfull discharge.

Table 8: Environmental flow recommendations for Reach 3: Sunday Creek (Seymour) to Lake Nagambie

Objectives (habitat feature in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
Recommendations for Baseflow			
NF6, RV1, I2, I4 (riffles, baseflow wetted area)	• Baseflow (all seasons)	Minimum flow of 800 ML/d, or natural (whichever is lower), outside of the irrigation season.	• Based on HECRAS wetted perimeter of riffle cross-sections (4.6 cumecs to inundate riffles in cross-sections) – based on the breakpoint of wetted perimeter-discharge. Provides wetted area for small-bodied fish and invertebrates.
Recommendations for Freshes			
NF3, NF7 (attractant flows for large-bodied native fish, Macquarie perch spawning)	• Spring freshes	Peak magnitude and timing: 0.5 m increase in stage height over one week in late spring (Oct-Dec), assuming temperature is suitable (e.g. above 16^{0}C). Duration: 1 week of rise and hold for two days at the target flow, if this does not happen earlier in spring. Rise and fall: as for G2.	• Expert opinion based on attracting flow from potential colonists noted in the Murray River (Lyon et al. 2014; Koster et al. 2012). • Macquarie perch spawning based on flow recs from the Yarra River. King et al. (2011) (cited in SKM 2012) noted that strongest recruitment occurred following spring high flows that promoted spawning (and cleaned spawning sites) followed by relatively stable (but not static) summer flows that reduced the likelihood of eggs being washed away.
NF1 (maintain fish growth)	• Summer-autumn freshes	As per Reach 2	• As per Reach 2
Recommendations for Bankfull and Overbank flows			
G3, I1, NF3, NF7 (maintenance of in-channel benches, slough filamentous algae and resent biofilms)	• Approaching winter-spring bankfull	Peak magnitude: 12,000 – 13,000 ML/d. Frequency: as in G2 bankfull component. Duration: 2 days. Timing: as in G2 bankfull component	• From HEC-RAS model; depth 0.0-0.5 m above bench levels (Vietz et al. 2012). • Preference is to coincide (piggy back) with or follow soon after high tributary inflows so that suspended sediment from tributary catchments is dropped onto benches.

Objectives (habitat feature in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
		Rise and fall: governed by Reach 1 and tributary inputs.	• From HEC-RAS, water velocity > 0.6 m/s requires 10,000 ML/d. This is covered by the flow required to maintain benches.
G2, G4, G5 (disruption of river channel armour layer, movement of bed material, scouring of pools,)	• Winter-spring bankfull and overbank flows	**Bankfull** Peak magnitude: 14,000 ML/d. Frequency: 1 event in 2 out of 3 years, but secondary to other objectives (e.g. wetland inundation). Duration: 1 day at peak flow. Rise and fall: governed by Reach 1 and tributary inputs. **Overbank** Peak magnitude: 20,000 ML/d Frequency: 1 every three years in dry and average years, 1 in 2 years wet years Duration: 1 day at peak flow Timing: Any time – can coincide with other requirements such as wetland inundation Rise and fall: governed by Reach 1 and tributary inputs.	• Overall, there is very little ability to change bed morphology, except at flows above bankfull up to 20,000 ML/d. • Shear stress to turn over pebbles (up to 64 mm) in riffles equals 64 Nm^2, from HECRAS model. Modelling indicates that flows greater than bankfull are required for move pebbles – in-channel flows do not have competence to move 100% pebbles. To move 50% of pebbles/cobbles requires bankfull. • Bankfull – Rationale for frequency – unimpacted regime gets average of 3 events per year in 96% of years. Get events in most dry years. • Overbank – rationale for frequency – unimpacted regime gets 3 events in 80% of years. Adopt 15,000 initially to avoid excessive watering, particularly in Reach 2, and measure response before moving to larger events up to 20,000 ML/d. • Rise and fall – examined current G-MW rules and rates proposed by Cottingham et al. (2003); applied a more conservative rate of fall than both sources to account for variability in riparian zone condition and potential for increased rates of bank erosion.

Objectives (habitat feature in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
			• To concomitantly reduce sediment smothering from high sediment load tributary inflows, delivery is recommended at end of tributary inflow dominance of flows along the river and just before releases from Lake Eildon start to dominate flows in the river. This timing likely to be winter-spring and can be beneficial for invertebrates and fish also.
NF1 (increased flow variability)	• All components	Covered by all previous objectives	• As for all previous objectives
NF2, NF4, NF5 (maintain or increase connection to fish habitats)	• Winter-spring bankfull, overbank	**Bankfull** Peak magnitude: 14,000 ML/d Frequency and timing: Annually preferred, but accept less frequent occurrence to balance with other objectives (e.g. wetland filling only once or drying phase, Macquarie perch breeding). At least 2 events in a year (August and March/April, if not connected earlier in summer) if pursuing this objective. Duration: as for RV 2 (below) Timing: and as in rationale Rise and Fall: governed by Reach 1 and tributary inputs. **Overbank** Peak magnitude: 20,000 ML/d Frequency: as for RV2 Duration: as for RV2 Timing: winter-spring, and as in rationale Rise and fall: governed by Reach 1 and tributary inputs.	• The intention is to connect the river to anabranches and wetlands at start and end of season the irrigation season to allow fish to move in and out.

Objectives (habitat feature in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
RV2, RV3, RV4, RV5, I5, I6 (wetting of riparian zone and wetlands, regeneration of native woody species, entrainment of organic matter)	• Winter-spring bankfull and overbank	**Bankfull** Peak magnitude: 14,000 ML/d Frequency: Average and wet years: 1 event in 2 years Dry years: 1 event in 3 years in, Maximum interval of 1 in 7 years. Duration: 2 days (dry years) to 4 days (average and wet years) Timing: winter-spring, and as in rationale. Rise and Fall: governed by Reach 1 and tributary inputs. **Overbank** Peak magnitude: 20,000 ML/d Frequency: Events up to 15,000 ML/d: 1 in 2 years for average and wet years, 1 in 3 years for dry years Events up to 20,000 ML/d: 1 in 5 years for average and wet years (not in dry years). Duration: 4 days Timing: winter- early spring, with recession through October Rise and fall: governed by Reach 1 and tributary inputs.	• The intent is to increase variability in regulated flows, and meet the needs of native woody species (Roberts and Marston 2011, Greet 2012). • The aim is to deliver events of 10,000 ML/d and greater, and then draw down to approximately 5,000 ML/d, with drawdown before Lake Eildon releases dominate river flows so that flow variability and vegetation diversity are promoted.

6.4 Compatibility with maintaining trout populations

A number of opportunities have been identified for managing the regulated flow regime in a manner compatible with the maintenance of trout populations in Reach 1 (Table 9). Some, such as the winter and spring-summer baseflow recommendations are also compatible with the need of small-bodied native fish species (see Section 6.3):

- Winter baseflow above 500 ML/d and up to 5,000 ML/d to protect trout redds;
- Spring-summer baseflow <3,000 ML/d (i.e. delay high summer flows as long as possible) to maintain slackwater habitat for and trout fry;
- Summer-autumn baseflow >4,000 ML/d 1 in every 3 to 4 years to promote survival of large trout.

The flow recommendations have been based on empirical studies of such things as trout spawning and rearing habitat (Brown 2003). Overall, they provide opportunities for delivering flows that will maintain the population structure of trout within the Reach 1.

6.5 Variability in irrigation releases

Water released from Lake Eildon during the irrigation season is largely governed by downstream irrigation and consumptive demand. Despite this, G-MW (in partnership with the GB CMA) have some flexibility to manage or vary releases in order to minimise risks (e.g. bank erosion) or, where opportunities arise, for environmental gain (e.g. improvement of riverine vegetation condition, provision of additional habitat, entrain organic matter to help drive riverine productivity). Variability in flow releases can be sought both within and between flow events typical of summer-autumn irrigation releases (e.g. typically within 5,000 – 9,500 ML/d). For example, variation in the delivery of prolonged flow events along the Lower Goulburn River has been proposed in order to avoid notching of the river bank (Peter Cottingham & Associates 2013). In response, G-MW and the GB CMA now seek to varying the daily water levels over an approximately 300 mm range when releasing flow pulses (e.g. of 1-2 weeks duration) along the Lower Goulburn River (G. Earl, GB CMA, pers. comm.). They also seek to vary the target range over time; i.e. avoid flow events at the same magnitude year-on-year, if possible. It is recommended that such an approach be adopted for the Mid Goulburn River should notching be observed.

Variability in the magnitude of flow pulses, both across an irrigation season as well as between irrigation seasons, can have multiple ecological benefits. Variability in the flow regime across space and time can result in a mosaic of areas with varying wetting and drying patterns, contributing to ecosystem diversity and providing multiple sources of organic matter to the river that can help productivity. Anabranch and wetlands will be watered to varying degrees due to differences in commence to flow levels along the river (see Section 5.2.2); variability in the frequency and magnitude of flow pulses (e.g. freshes) can contribute to the establishment or maintenance of dynamic and diverse vegetation assemblages within such features of the river (e.g. Abel et al. 2006, Nicol et al. 2003; Brock and Casanova 1997).

Variability in flow delivery can result in inundation of different parts of the littoral zone, which entrains organic matter that can contribute to riverine productivity. For example, Tonkin et al. (2014) found that flow variability is an important mechanism governing productivity in higher trophic order fish species. They found that growth of the nationally endangered Trout cod was positively related to river discharge and flow variability, particularly during the spring, summer and autumn periods, in both the unregulated Ovens River and the regulated Murray River. A similar pattern was also found for Murray cod and Golden perch within the Murray River.

Table 9: Flow recommendations to assist with maintaining trout populations in Reach 1

Objectives (features addressed in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
Recommendations for Baseflow			
T1 (maintain redds)	• Winter baseflow	Range: 500 ML/d - 5,000 ML/d.	• Based on Brown (2003), and spawning expected in May-June; the intention is to maintain flows to avoid drying out of redds (500 - 5,000 ML/d).
T2 (trout fry survival)	• Spring-summer baseflow	Maintain baseflow <3,000 ML/d between September and February; delay flow above this as long as possible into irrigation season.	• Peak fry habitat at 450-1,000 ML/d in Sept to Feb based on Brown (2003) habitat suitability curves for wild population recruitment. The intent is to provide flows that cover bottom of the channel. Based on break of wetted perimeter-discharge relationship from HECRAS, this requires 2,000-3,000 ML/d.
T3 (prevent angler overexploitation)	• Summer-autumn baseflow	Maintain baseflow >4,000 ML/d approximately 1 year in 3 or 4 to maintain density of larger trout in population.	• Wading depth for anglers. Based on expert opinion. Safe wading velocity (ft/sec)* depth (ft) <10. <1 m/s or less on bars and riffles for safe wading.

Opportunities for varying the pattern of releases during the irrigation season can be guided by the natural flow paradigm (Poff et al. 1997), which for the Mid Goulburn River would mean higher flows (e.g. the upper end of the 5,000 – 9,500 ML/d range) being delivered earlier in the irrigation season (spring) progressing to smaller flows, where possible, in summer-autumn. This means that parts of the river system at higher elevations (e.g. anabranches and low lying wetlands) would have a more natural pattern of wetting and then drying.

Another opportunity for managing releases from Lake Eildon to achieve both storage operation and ecological objectives occurs during wet periods when storages levels and inflows to Lake Eildon are high and there is a need to pre-release water from the dam to manage water levels and reduce the risk of flooding downstream. A pre-release peak (most likely in winter-spring) could be used to deliver a bankfull or even overbank flow (assuming constraints have been dealt with) to inundate wetlands. The wetlands could then be allowed to dry naturally, allowing the seeds of wetland and riparian plant species to germinate on wet muds during the recession phase.

6.6 Compliance points for assessing environmental flow delivery

Compliance points for assessing environmental flow delivery are proposed at:

Reach 1: Lake Eildon pondage (gauge site 405203),
Reach 2: Trawool (gauge site 405201), and
Reach 3: Seymour (gauge site 405203).

The representative site for which flow recommendations in Reach 1 were developed is downstream of tributaries such as the Acheron and Rubicon rivers and Snobs Creek, where the channel is likely to have different dimensions to that between Lake Eildon and the Acheron River. Additional channel survey between Lake Eildon and the Acheron River is recommended to define the breakpoint in the discharge-wetted area relationship in this section of the river, in the same manner as at the representative site. This will give the GB CMA greater flexibility in complying with the intent of the baseflow recommendations for Reach 1, as it may be possible that releases from Lake Eildon can be less than 400 ML/d, provide the same level of improvement in wetted area in the Goulburn River down to the Acheron River and, with tributary inputs, meet the 400 ML/d target at the representative site downstream of Alexandra.

6.7 Rationalising flow recommendations for the mid Goulburn and lower Goulburn River

In developing bankfull and overbank flow recommendations for the mid Goulburn River, consideration was given to the potentially competing demands of watering riparian and wetlands areas within the study area, providing conditions suitable for successful breeding by Macquarie perch, and providing conditions for successful breeding of Golden perch in the lower Goulburn River, the latter of which has been shown to require flows ranging from large freshes to overbank flows (Koster et al. 2012). Some recommendations, such as delivering bankfull flows 1 in 2 years in average and wet years and 1 in 3 years in dry years, represent a pragmatic approach to providing watering that promotes riparian and wetland vegetation along the mid Goulburn River and Golden perch in the lower Goulburn River, with that of providing on moderate freshes (e.g. up to 7,000 ML/d) in winter-spring that increases the chances of successful breeding by Macquarie perch in Reaches 2 and 3 of the mid Goulburn River.

6.8 Uncertainties related to flow recommendations

While environmental watering recommendations have been made using best available information, it is important to acknowledge that gaps in information exist. This, along with an incomplete knowledge of ecological or biological processes and their response to watering events mean that there can be uncertainty in relation to the ecological outcomes expected with the delivery of environmental watering recommendations. These issues are considered in the following sections on the basis of the type of flow event(s) recommended in this study.

6.8.1 Baseflows

Baseflow recommendations have been made to increase or maintain the wetted area of riffles and other shallow habitat available for trout, native fish, invertebrates and aquatic vegetation. In general. it is more usual for threats, such as poor water quality, associated with low flow regimes to emerge in summer-autumn periods, when water quality can deteriorate due to increased temperature and biochemical oxygen demand (BOD), especially if the water column stratifies (e.g. in pools). However, the risk of deteriorating water quality due to delivery of the baseflow recommendations for the mid Goulburn is considered low, as water is to be delivered in winter when there is either very little risk of temperature stratification in the river (winter) or increased flow and flow velocity at other times of the year.

Cottingham et al. (2014b) noted instances of low DO (i.e. <4 mg/L) from water quality records for the Goulburn River at Eildon in each of the past 3 years. These events occurred in the irrigation season (summer-autumn), but examination of available data found no clear relationship between the instances of low DO and factors such as timing, discharge (and by extension, retention time in Eildon pondage) and temperature. It was postulated that the low DO events were a result of the release of low DO water from deep water in stratified sections (i.e. hypolimniom) of Lake Eildon; investigation of any future low DO events (e.g. by G-MW and/or the GB CMA) is recommended to confirm this.

6.8.2 Freshes

Freshes have been recommended in each reach of the mid Goulburn River to address such things as the deposition of fine sediment and excessive growth of biofilms and filamentous algae. Fine sediments can smother habitat, such as riffles and interstitial space in river substrates that are habitats for invertebrates and small-bodied fish. Late successional stages of both filamentous algae and biofilms have also been shown to be less palatable and therefore of lower food quality for invertebrates (e.g. Cummins and Klug 1979, Sheldon and Walker 1997, Burns and Rider 2001, Treadwell 2002). The rationale for delivering freshes is, therefore, to redistribute fine sediments and maintain biofilms and filamentous algae in early succession states, thus maintaining access to habitat and food quality that in turn drive secondary production.

The magnitude of the freshes has been defined using published information on flow velocity and shear stress (e.g. Ryder et al. 2006, Wilkinson and Rutherfurd 2001). Velocity and shear stress values have been translated into discharge using the HEC-RAS models developed for this project. Because they are 1-D models, they provide reach-average velocity and shear stress values (i.e. as an average, some areas will be less that the nominated value and other will exceed the nominated value). It is recommended that the effects of the proposed freshes are assessed to confirm the extent of scouring that occurs, and whether any adjustment in the magnitude of freshes is required (see also Chapter 8). This assessment can also consider how long the effects of scouring events persist and whether changes to frequency are required. For example, nutrient concentrations above SEPP guidelines (see Cottingham et al. 2014b) may provide conditions suitable for the rapid regrowth of biofilms and filamentous algae, making the effects of biofilm and filamentous algae scour short-lived (e.g. see NSW Office of Water 2014).

6.8.3 Bankfull and overbank flows

Bankfull and CTF levels indicate the point at which water begins to leave the river channel and start to enter anabranches, wetlands and ultimately the floodplain. Providing flow along anabranches and filling wetlands requires flow events of sufficient magnitude and duration at or above the nominated threshold. For example, if the desire is to provide enough water to fill wetlands during high flow events, flow must be above the threshold to allow this within a specified time (usually days). The risk here is that flows will be provided that reach a wetland but not fill it. There is also risk to the delivery of environmental water to wetlands and other floodplain features due to changes to landscape (including roads, tracks, blockbanks and levees) that impede the movement of water across the floodplain. An assessment of this risk (e.g. survey of blockbanks) is recommended and a program for amelioration (e.g. installation of culverts) designed if necessary.

As discussed in section 6.4, meeting the environmental watering needs of wetlands along the mid Goulburn River as well as achieve objectives along the lower Goulburn River (e.g. to promote breeding of Golden perch) has the potential to affect the breeding of Macquarie perch in the mid Goulburn River. As noted previously, this has been dealt with in the frequency of bankfull and overbank flows recommended for the mid Goulburn River.

Incidences of localised bank slumping were recorded following the large floods that occurred in the lower Goulburn river in 2010/11 (Cottingham et al. 2013). To avoid the risk of mass failure bank erosion, especially at locations where riparian condition is poor, this project has recommended a slightly more conservative rate of fall for the receding limb of large events (Appendix 1) than was recommended by Cottingham et al. (2003), assuming the delivery of such events are actively managed rather than natural events. As noted previously, delivering bankfull and overbank flows will not be actively managed until current constraints to such events are addressed.

While large flow events are an important part of the life cycle of native fish, they can also benefit alien species such as carp and gambusia. The efficacy of carp control methods (e.g. carp exclusion screens, allowing access to wetlands and then drying them) in the mid Goulburn River requires further investigation.

7 PERFORMANCE AGAINST FLOW RECOMMENDATIONS

Based on the modelled flow data used in this study, the level of compliance of the current flow regime with the environmental flow recommendations presented in Chapter 6 is generally high (compliance is shown for Reach 1 in Table 10; the level of compliance in Reaches 2 and 3 are similarly high). This is due in large part to the influence of tributary inflows and because the operation of Lake Eildon has more influence on the timing of flow events, rather than the total volume of water released along the Mid Goulburn River. In addition, the very high level of compliance with the recommendation for delivering overbank flows up to 20,000 ML/d (frequency 1 in 5 years) is in part due to the application of the 'or natural' clause to the frequency of such events; i.e. the modelling assumes there is no requirement to deliver these events periods when spells analysis of the unimpacted flow regime suggests they would not have occurred.

The high level of compliance for baseflow of 400 ML/d in Reach 1 is due in large part to tributary inflows, as the flow data compliance point for the analysis is downstream of tributaries such as the Acheron and Rubicon rivers, and Snobs Creek. However, compliance along the Goulburn River between Lake Eildon and the Acheron River is low outside of the irrigation season, when releases from Lake Eildon approach the minimum flows required under the Goulburn system Bulk Entitlement. Examination of available (measured) flow data (sourced from DEPI, http://data.water.vic.gov.au/monitoring.htm) indicates that flow from Eildon pondage falls below 400 ML/d approximately 30% of the time (year round). As described in Section 6.6 (above), further cross-sectional survey work is recommended to better define the flow-wetted area relationship in this section of the river and so that the volume of water released from Eildon Pondage can be adjusted accordingly.

Table 10: Level of compliance of the (modelled) current flow regime with proposed environmental flow recommendations in Reach 1

Component	Months	From	To	Flow Recommendation					Or Natural	Compliance
Summer low	Dec - May	12	5	Magnitude	400	ML/d			Yes	*97%*
Summer fresh	Dec - May	12	5	Magnitude	2000	ML/d			Yes	*100%*
				Frequency	1	per year				
				Duration	7	days				
Winter low	Jun - Nov	6	11	Magnitude	400	ML/d			Yes	*100%*
Winter fresh	Jun - Aug	6	8	Magnitude	900	ML/d			Yes	*100%*
				Frequency	1	per year				
				Duration	1	days				
Winter fresh	Jun - Aug	6	8	Magnitude	2000	ML/d			Yes	*100%*
				Frequency	1	per year				
				Duration	7	days				
Winter high	Jun - Nov	6	11	Magnitude	7000	ML/d			Yes	*100%*
				Frequency	1	in	3	years		
				Duration	2	days				
Bankfull	Jun - Nov	6	11	Magnitude	11000	ML/d			Yes	*72%*
				Frequency	1	in	2	years		
				Duration	4	days				
Overbank	Jun - Nov	1	12	Magnitude	15000	ML/d			Yes	*70%*
				Frequency	1	in	2	years		
				Duration	4	days				
Overbank	Jun - Nov	1	12	Magnitude	20000	ML/d			Yes	*100%*
				Frequency	1	in	5	years		
				Duration	4	days				

8 SUPPORTING RECOMMENDATIONS

Achieving the best environmental outcomes for the mid Goulburn River will require additional works, measures and investigations to address or ameliorate a number of factors that may constrain the ecological effects of environmental water delivery. These are summarised in the following sections.

8.1 Testing the assumptions of environmental flow recommendations

A number of monitoring programs already exist that can be used to assess both the delivery and the effect of environmental flow releases, including:

- The Victorian Water Quality Monitoring Network;
- The Major Storages Operational Monitoring Program;
- Hydrological and temperature monitoring undertake by Goulburn-Murray Water (Lake Eildon).

In addition, monitoring of environmental watering outcomes is currently being undertaken as part of Victorian (Victorian environmental flows assessment program – VEFMAP) and Commonwealth (Long-term intervention monitoring project - LTIM) initiatives being implemented in the lower Goulburn River. The findings from these initiatives are likely to generate information of relevance to the mid Goulburn River also. For example, the LTIM project includes measuring the response of riparian vegetation to environmental watering; these results are likely to provide insights of relevance to the mid Goulburn given that vegetation communities (e.g. EVCs dominated by river red gums) are broadly similar.

More focussed investigations may be required where current monitoring and evaluation is deemed insufficient to assess the outcomes expected with environmental watering. Investigations to inform the preparation of annual water plans, as well as overall evaluation of ecosystem response and future reviews of environmental watering are recommended to.

- Confirm the wetted area inundated with baseflow outside the irrigation season (Reaches 1 and 2);
- Assess fine sediment deposition and dispersal before and after the delivery of freshes (Reaches 1 and 2);
- Assess the condition of biofilms and filamentous algae before and after the delivery of freshes (Reaches 1 and 2);
- Assess the movement of large-bodied native fish species following spring freshes (Reaches 2 and 3);
- Assess the organic matter entrained with freshes, bankfull and overbank events that flow through anabranches and wetlands (all reaches);
- Assess utilisation by native fish species of anabranch and low-lying wetland habitat following the delivery of freshes, bankfull and overbank flows (Reaches 2 and 3):
- Assess native vegetation diversity and recruitment in the riparian zone and associated with wetlands with the delivery of bankfull and overbank flows (all reaches).

8.2 Identifying barriers to the movement of water through riparian and floodplain areas

As noted in the Issues Paper and highlighted in the assessment of wetland CTF levels (Appendix 3), a long history of floodplain development and modification has resulted in altered flow patterns in riparian and floodplain areas. Features such as roads, tracks and blockbanks, as well as land management practices (e.g. grading, levelling) have blocked or changed natural features that would otherwise allow a more widespread movement of water across the landscape. So that future overbank flows can be delivered efficiently and realise the maximum ecological benefit possible, it is recommended that the GB CMA undertake a field verification survey of features such as blockbanks, roads, tracks and other features that may restrict the movement of overbank flows. The survey results can then be used to consider the best approach to overcoming barriers to the movement of water through riparian and floodplain areas.

Ascertaining the relationship between river flows and inundation levels of wetlands (rather than simply sill levels) would provide greater confidence of the inundation benefits of higher discharges, and may also assist in determining the duration of flows at sill level required to fill wetlands. A LiDAR based approach to this is described in more detail in Sammonds et al. (2013). Alternatively, the 2-dimensional hydraulic model previously developed for Reach 1 (Water Technology 2012) could be applied to the full range of discharges.

The role of groundwater in driving wetland inundation (both from river height changes and valley margins) is uncertain. Some field or satellite based testing of this would be valuable to better understand the role groundwater might play.

8.3 Continued catchment and waterway management

Many of the factors that influence the condition of the mid Goulburn River occur in its catchments and sub-catchments. Management responses at similar catchment scales will be required to complement the outcomes sought from the delivery of environmental water. These include continuation of many initiatives already being delivered under existing catchment and waterway programs (usually in partnerships with landholders), including:

- Efforts to reduce catchment inputs of sediment and turbidity (e.g. strategies to control high-sediment runoff from fire-affected catchments).
- Management of water extraction from inflowing tributaries via streamflow management plans, in particular during low flow periods.
- Reintroduction of large wood (snags) and revegetation of riparian zone to provide a future source of snags. Desnagging has occurred historically and as an important agent for river condition (e.g. physical habitat, hydraulic diversity, channel stability), the ongoing supply of wood requires consideration.
- Control of livestock access in order to minimise grazing and trampling of riparian and wetland vegetation and maximise the benefits from implementing bankfull and overbank flow recommendations.
- Control of invasive plant species (e.g. willows (*Salix* spp.) and blackberry (*Rubus anglocandicans)*), that can colonise the channel bed and lead to localised channel widening and reduced channel diversity as well reduced vegetation diversity on the banks;
    - Willow replacement with native vegetation is an active area of riparian management for the GB CMA. In some instances this may result in the loss of flow velocity refugia. It is recommended that the GB CMA consider interventions such as resnagging to accompany willow management activities, so that there is no net-loss of velocity refugia and channel banks remain stable.

8.4 Water quality investigation

Water quality management to complement environmental flows includes:

- Investigate the role of releases from the hypolimniom of Lake Eildon in future instances of DO falling to near 4 mg/L

8.5 Fisheries management

Fisheries management to complement environmental flows includes:

- Encouraging responsible recreational fishing for native species and trout;

- Investigations to better understand the relative contribution of stocked and wild-recruited populations of both (i) native fish and (ii) trout from tributaries on Goulburn River populations, and the consequences of delivering sub-optimal flows in the mid Goulburn River for egg and fry survival during critical June-September and September–February periods, respectively.
- Investigations of whether stocking of native fish has been successful and, if so, the flow condition under which it was successful.

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10 APPENDIX 1: HYDROLOGICAL MODELLING AND TIME SERIES

10.1 Approach to hydrological modelling

JACOBS

Date	24 September 2014
Project No	VW07496
Subject	**Hydrological Modelling for Mid Goulburn Environmental Watering Project**

Introduction
This file note briefly outlines method and some key findings of the hydrological analysis to inform the Environmental Watering Project for three reaches of the Goulburn River. Current and unimpacted daily flow time series were produced for each reach.

Method
The best available long-term representation of the Goulburn River system under current and unimpacted conditions, and the water resource systems that it is directly connected to, is the Goulburn Simulation Model (GSM). The model runs on a monthly time step and is applied by DEPI for water planning activities including compliance with the Murray-Darling Basin Cap.

It was agreed with the project steering committee that the version of the GSM which would be used for this project is the version which represents "Sustainable Diversion Limit" representation of GSM that has all water recovery to meet basin plan obligations. This includes connection project savings that transferred to environment plus remaining entitlement purchase of around 190 GL from the Goulburn and also environmental demands for the recovered (environment) basin plan water. This version of the GSM runs from 1895 to 2009. For the purposes of this project, this is the ‘current’ scenario.

The steering committee deemed that a current scenario that excluded Goulburn environmental flows (other than operational flows to the Murray) would also be useful in understanding the flow regime which can be influenced by environmental flows as part of this project. This project is referred to as the ‘Current, no Goulburn E-flows’.

Environmental entitlements held in the Goulburn System include entitlements for the Basin Plan, Snowy Environmental Reserve and Goulburn System – Living Murray, and Bulk Entitlement minimum flow releases. It was assumed that environmental entitlement for the Snowy was delivered as Inter-valley transfer (IVT) to the Murray and therefore part of operational flows included both scenarios. It was also assumed that the minimum bulk entitlement passing flow was to be included in both scenarios. The Goulburn System – Living Murray environmental entitlement and the Basin Plan entitlement was included in the ‘current’ scenario, but excluded from the ‘current, no Goulburn E-flows’ scenario. The simulated entitlements for the Living Murray and for Basin Plan presented are the table below (Table 11).

Table 11: Environmental water entitlements

Environmental Entitlement	High Reliability Water Share (ML)	Low Reliability Water Share (ML)
The Living Murray	45,184	156,980
Basin Plan	342,102	54,879
Total	387,286	211,859

Given the GSM is a monthly timestep model, daily variability in flows, which are important for environmental watering is not represented. A daily timestep model of the entire Goulburn system in the hydrologic modelling software Source is currently being developed by DEPI but is not yet available for use for this study. In the future it is expected that this model will be the best representation of the Goulburn system for simulating current operating rules. Ideally this would be the model which could be used for representing flow at each of the Goulburn River environmental flow sites.

As there is currently no daily timestep model of the whole of the Goulburn River and irrigation system available a method to simulate daily flows based on the GSM current monthly flows was required.

The method developed involves applying the daily timestep model of the main stem of the Goulburn River from the outlet at Lake Eildon to McCoys Bridge developed by SKM (2012b) in the Source software. This was a simple model for the purposes of simulating environmental flows in the Goulburn River itself and did not extend to simulate the irrigation channels and supply system. As this model doesn't represent the wider irrigation supply system, a method was developed for this project which utilised the monthly Lake Eildon releases as simulated in the GSM which have been disaggregated to daily.

Simulating Unimpacted Conditions

This Source model was updated to include the most recently available unimpacted time series from SKM (2012a) of all of the major tributaries from Lake Eildon to downstream of Goulburn River environmental flow site 3. It also includes the impacts of flow routing on the flows and losses. A schematic of the model is shown below in Figure 7.

Figure 7: Daily timestep Source model of the main stem of the Goulburn River

Disaggregation Process Under Current Conditions

In order to simulate current conditions using this Source model of the Goulburn main stem, the GSM, the monthly timestep Lake Eildon releases were required to be disaggregated. The disaggregation process was based on the method in SKM (2010) and was further developed as part of this project. A daily time step hydrologic model, known as the GBCL (Goulburn-Broken-Campaspe-Loddon) REALM simulates flow on a daily timestep. However, this model has not been updated for at least ten years is therefor quite out of date. The GBCL model is therefore not suitable to use directly in an environmental flow study. Rather, it was used to disaggregate the releases from Eildon in a pattern that represented the releases from Eildon that were required to supply demands downstream or for transfers to Waranga Basin.

This preserves the integrity of the data at a monthly time step, but introduces variability that is broadly reflective of daily variability of releases. Under current conditions, the daily flow pattern associated with sources of water can vary from uniform patterns (associated with releases from reservoirs minimum environmental flows) to unimpacted patterns (associated with runoff from unregulated tributaries). The method used under current conditions attempts to separate out the influence of daily variability in each of the sources of water for a given river reach.

In the GSM model there are a number of different carrier representing different types of releases from Lake Eildon (Table 12). The disaggregation method assumed either a constant, unimpacted or Lake Eildon release pattern from the GBCL for each month.

Table 12: Lake Eildon GSM releases

Release Type	GSM Carrier Name	Pattern
Eildon Spills	EILDON SPILLS	Unimpacted Eildon Inflow
Hydropower Releases	SECV REL #1	Constant
Lake Eildon Flood Prerelease	EILD FL PRE-RELEASE	Constant
Lake Eildon additional environmental flow in November as per BE	EIL#1 ENV FLOOD	Unimpacted Eildon Inflow
All other releases	EILDON REL#1	GBCL Eildon Releases

When this method was applied it was found that there were two major shortcomings. The first was that the disaggregated monthly flow of Eildon releases were sometimes less than the minimum flow requirement and sometimes greater than release rates which would cause flooding. Therefore the total of all Eildon releases excluding spills were subject to a minimum flow rate within the month of 120ML/day and a maximum release rate of 10,000ML/day was assumed.

The second shortcoming was that in some instances, for example when large Basin Plan environmental releases were made in the GSM, GBCL Eildon releases were at a minimum rate (of 120ML/day) for the entire month. This meant that the releases were disaggregated as a constant value through the month. It was judged that this was not a likely release pattern as there may be expected to be some variability in the environmental releases within a month. Therefore a criteria was included in which if the GSM Eildon releases was more than 1.5 times the GBCL releases then the unimpacted Eildon Inflow pattern would be used for that month rather than the GBCL Eildon release pattern.

Limitations of the current dataset

There are a number of potential limitations with the derived daily data set for current conditions. The sustainable diversion limit version of the GSM includes large releases to meet Basin Plan environmental flow events either in the Goulburn River or as a contribution to environmental flow events in the River Murray. The assumed rules and timing of these releases may have a large impact on the flow regime in the mid-Goulburn River.
As noted above, the GBCL model is quite out of date. It therefore does not include Basin Plan releases and a large number of policy and physical changes to the system. Therefore patterns of releases from Lake Eildon may not represent releases under current rules including the Basin Plan releases.

As noted above, ideally a daily time step model of the full Goulburn River and irrigation system would be used. It is expected that in the future the DEPI model of the full system will be available.

Summary Results

Average flow conditions over the full model period (July 1895 to June 2009) and over a concurrent period with any available data at the site of interest is shown in Table 13. It can be seen from this table that on average unimpacted flows are consistent with current flows, but are always marginally smaller. The current flows excluding Goulburn Environmental Flows are lower than current and unimpacted flows. For the two sites where sufficient gauged flow data was available, the historic flows were lower than the unimpacted flows and current flows.

Table 13: Average Annual Flows (GL/y)

Reach	Time period	Unimpacted	Current	Current no Goulburn EFlows	Historic gauge data *
1. Eildon to Yea River	Jan 1896 to Dec 2008	1,945	1,957	1717	N/a
	Concurrent with gauge 405203 (Dec 1974 – Current)	1,721	1,796	1,589	1,278
2. Yea River to Seymour at Sunday Creek	Jan 1896 to Dec 2008	2,325	2,337	2,097	N/a
	Concurrent with gauge 405201 (Dec 1974 – Current)	2,043	2,119	1,912	2,092
3. Seymour at Sunday Creek to Nagambie	Jan 1896 to Dec 2008	2,524	2,535	2307	N/a
	Concurrent with gauge 405202 (June 1975 – Current)	2,129	2,191	1987	2,158

* Note that there are no stream gauges at the locations of the three environmental flow sites and so are not directly comparable but are provided as a reference. The historic gauges are the nearest available gauge location. The reach 1 gauge is located just downstream of Eildon, whereas the environmental flow site is located downstream of Acheron and Rubicon Rivers which have a significant annual yield. The gauges for reaches 2 and 3 are closer to the environmental flow sites.

It can be seen that the average annual releases from Lake Eildon excluding the Goulburn environmental flows is 230GL/year less than the current scenario (1,957-1,727). This volume is considerably less than the long term average annual allocated volume based on the 387GL HRWS and 212GL LRWS of entitlement. The reason for this is that the delivery of environmental flows can be achieved through ceasing or reducing harvesting to Waranga Basin from Goulburn Weir or by making releases from Lake Eildon. The modelling shows that a significant proportion of environmental flow deliveries are met by reducing harvesting to Waranga Basin from Goulburn Weir and not supplied from Lake Eildon. Therefore, a significant proportion of environmental flow deliveries do not affect the Mid-Goulburn River reaches between Lake Eildon and Goulburn Weir.

Figure 8 shows the flow duration curves for the whole period of analysis for each reach, which highlights that the current flow regime lowers high flows and increases low flows. This is illustrated by the crossover of the unimpacted and current curves. Flow duration curves have also been prepared for each reach on a seasonal basis. These are presented in

Appendix 1A. These seasonal flow duration curves show that under current conditions, Autumn and Winter typically have a similar flow regime and are lower than and that Summer and Spring typically have a similar flow regime. Under unimpacted conditions, the Winter and Spring flows are typically have a similar flow regime, and are higher than Autumn and Summer flows.

Box plots have been prepared that show the median, 10th, 25th, 75th and 90th percentile values. The data for these plots was presented for five climatic conditions – worst drought (driest 1% of years), very dry (driest 10% of years excluding worst drought), dry (above the 10th percentile but below the 30th percentile), average (above the 30th percentile but below the 70th percentile), wet (above the 70th percentile). These box plots are presented in Appendix 1B.

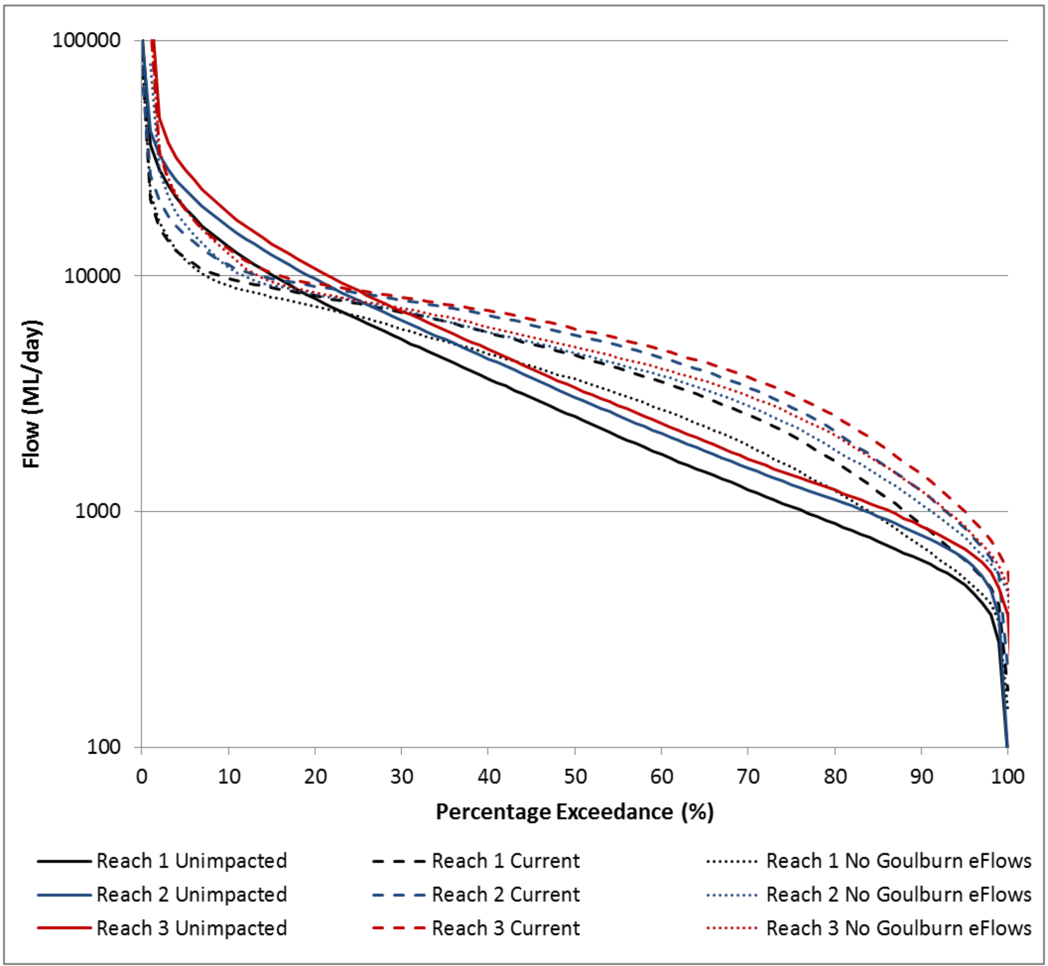

Figure 8: Flow duration curve for the whole period of record for each reach

Rates of rise and fall were calculated for each climatic condition and each reach. The statistics for these rates are shown in Appendix C. The 10th, 50th and 90th percentile values highlight how variable the rate of rise and fall can be for individual events. Low rates of rise typically occur for very small runoff events in winter/spring (when baseflows are high) and just before the flood peak is reached, whilst high rates of rise typically occur for short duration runoff events in summer and autumn. Consistent differences between rates of rise and fall under current versus unimpacted conditions are not discernible in the data. Rates of rise and fall were typically greater in percentage terms in dry climate years than wet climate years, however this is likely to be simply because of the lower baseflow from which these events are occurring rather than a different underlying hydrologic process.

For the purposes of ecological assessment, median rates of rise and fall across each of the three scenarios in Table 14 are recommended as being indicative of each reach. In practice, these rates will vary widely according to the spatial and temporal pattern of individual rainfall events. The disaggregation method will result in these rates of rise and fall being greater than expected due to potential jumps between monthly values.

Table 14: Median rates of rise and fall (of previous day's flow) of the unimpacted flow series

Reach	Rate of rise	Rate of fall
Reach 1	1.12	0.94
Reach 2	1.10	0.95
Reach 3	1.13	0.94

The partial series was analysed for each scenario. This analysis provides the average recurrence interval of peak daily flows based on the highest 228 events in each scenario flow time series. These results are presented in Appendix D. It can be seen that for Reach 1, the flow for a given annual recurrence interval greater than 3 years is higher in the 'Current no Goulburn EFlows' scenario than the 'Current' scenario. This is because if environmental flows are not released in a given month, then at times when Lake Eildon is nearly full, flood pre-releases and/or spills will be greater. The highest peak flows in Reach 1 are at times when Lake Eildon is spilling. As such, even though the average annual flow is significantly lower in the 'Current no Goulburn EFlows' scenario compared to the 'Current' scenario, the peak flows in Reach 1 are higher.

However, in Reaches 2 and 3 where tributary inflows have a greater influence on peak flows, little difference between the 'Current no Goulburn EFlows' and 'Current' scenarios is observed.

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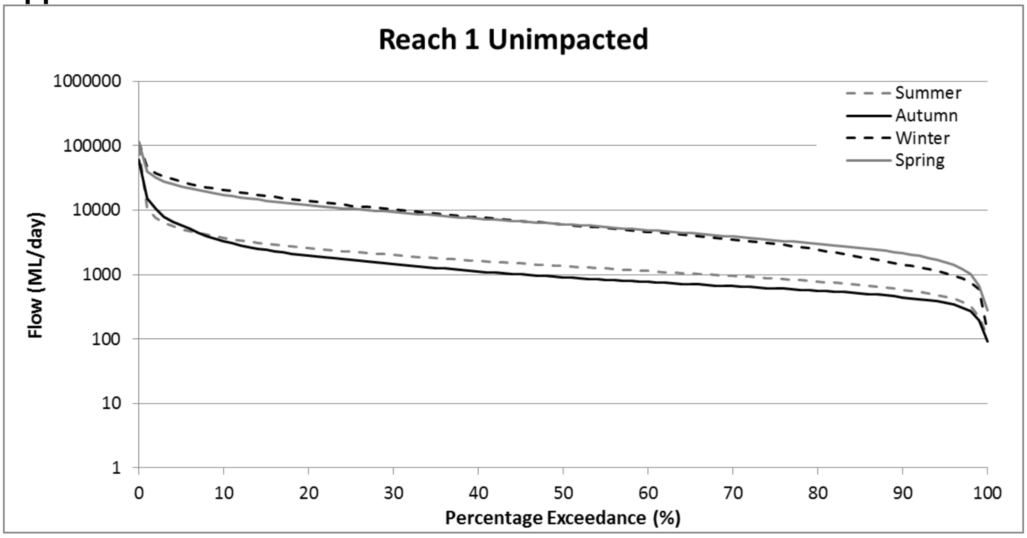
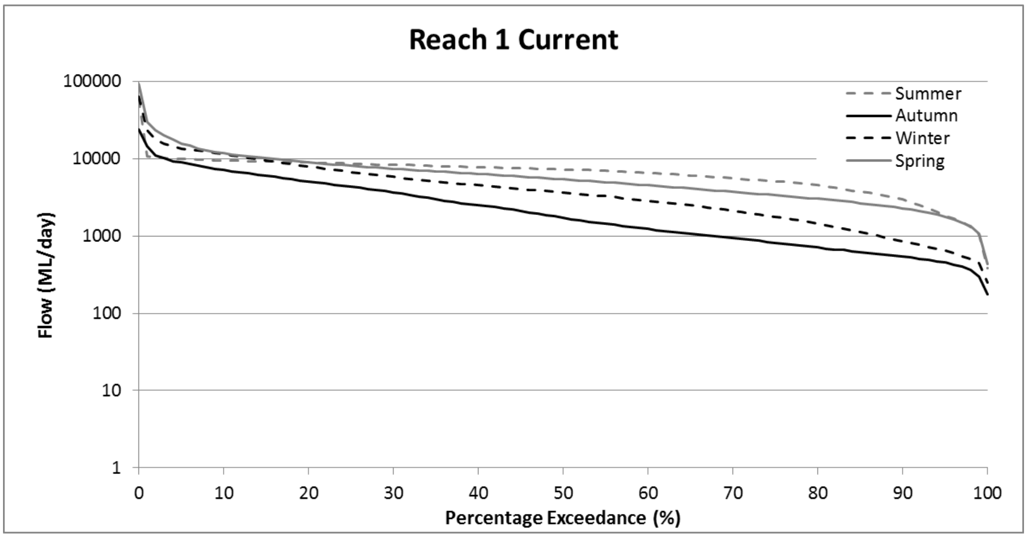
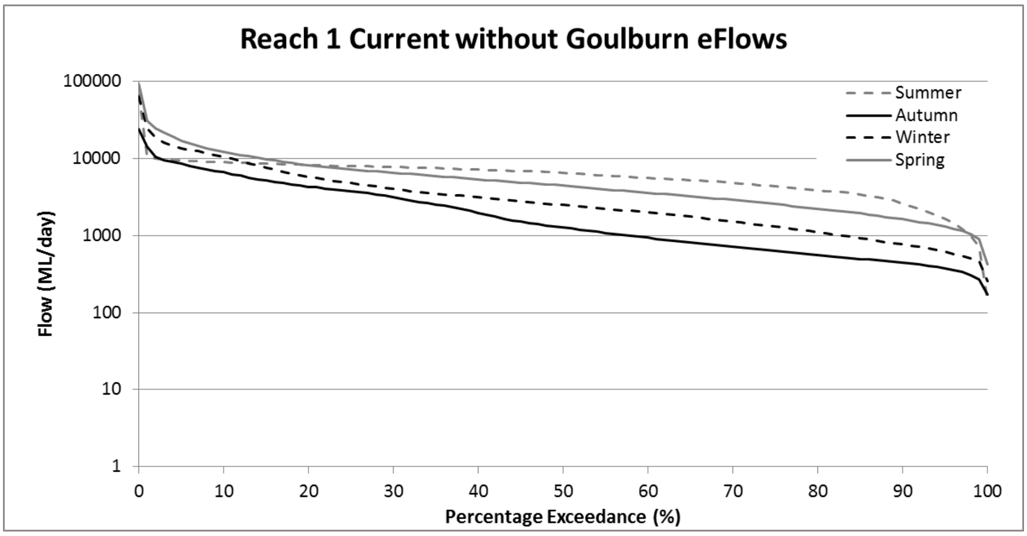
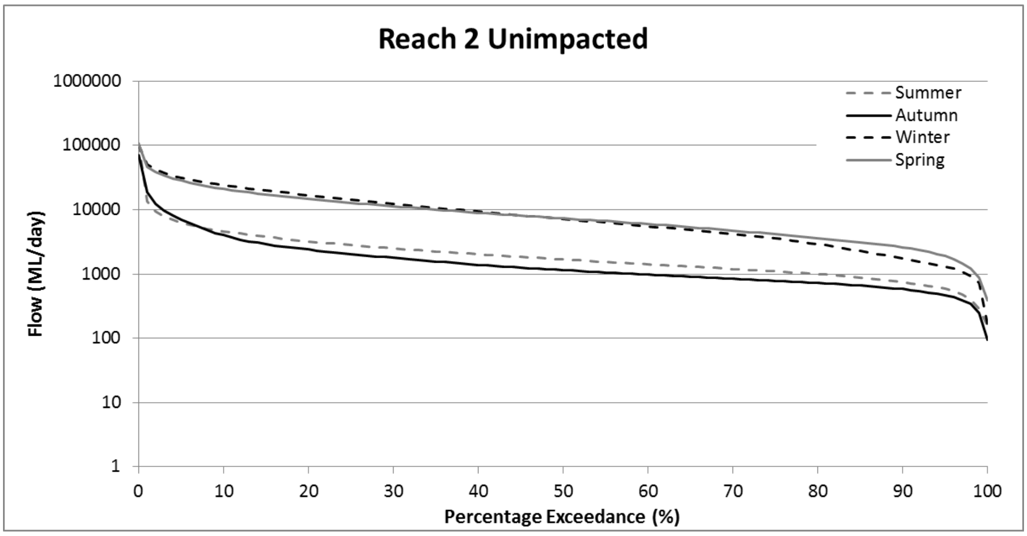
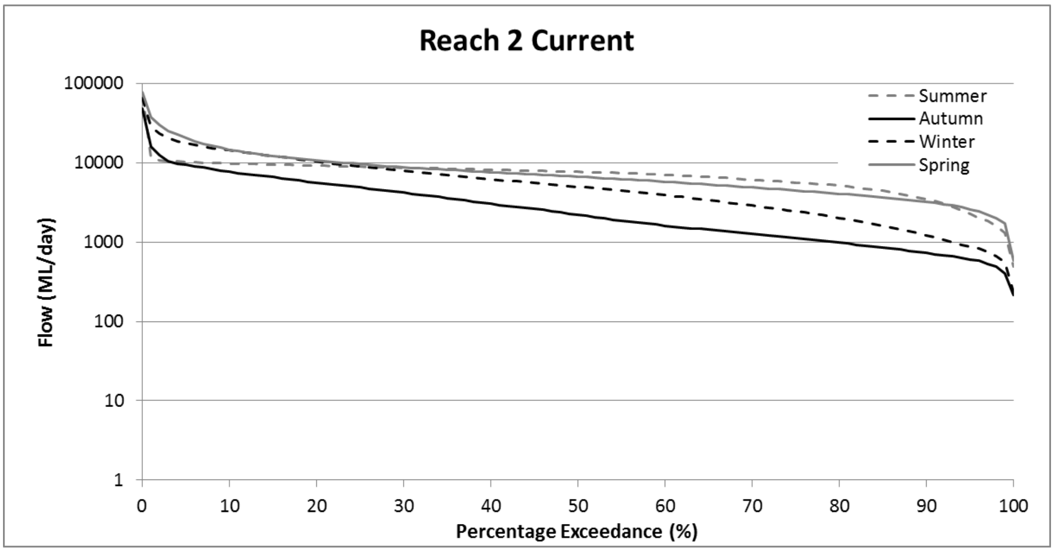
Appendix 1A – Flow Duration Curves

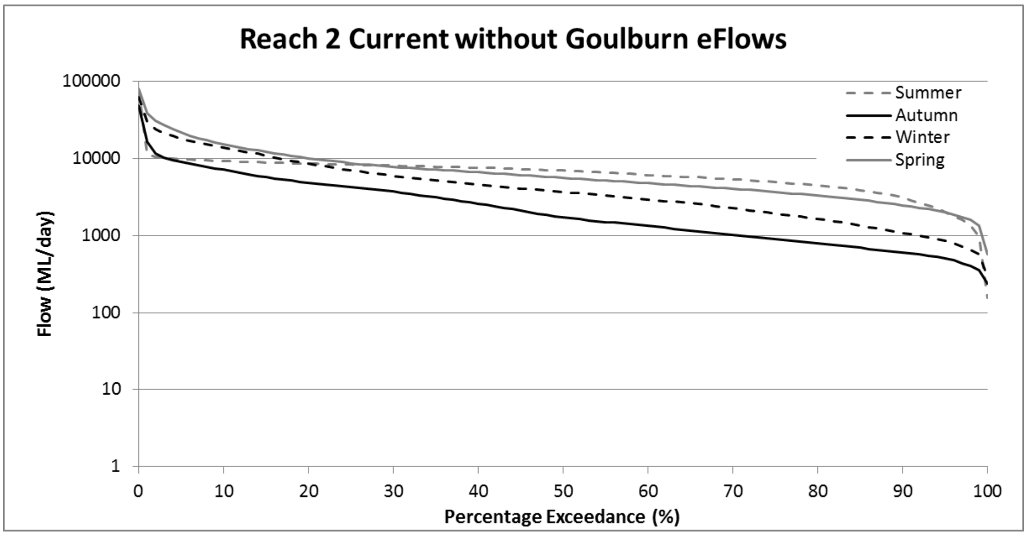


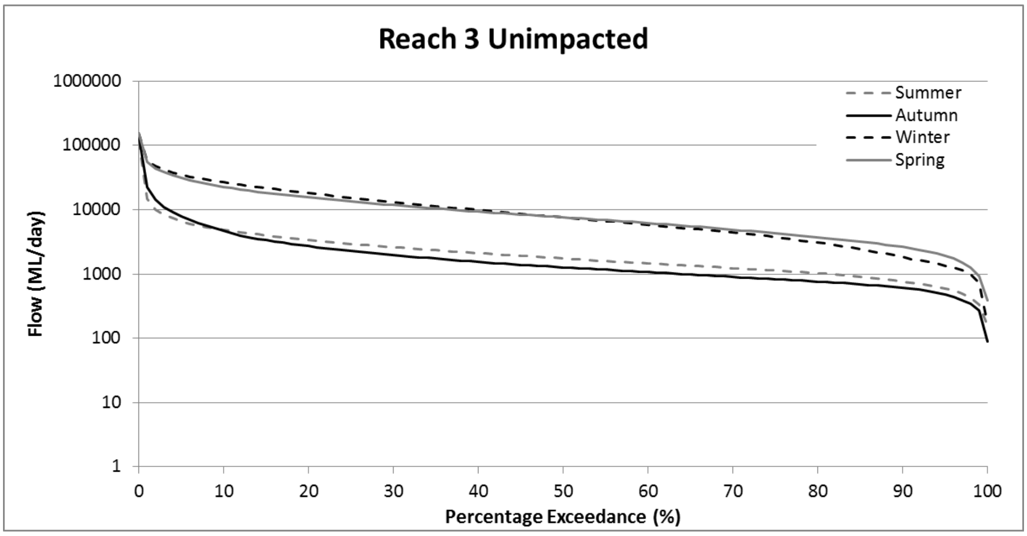


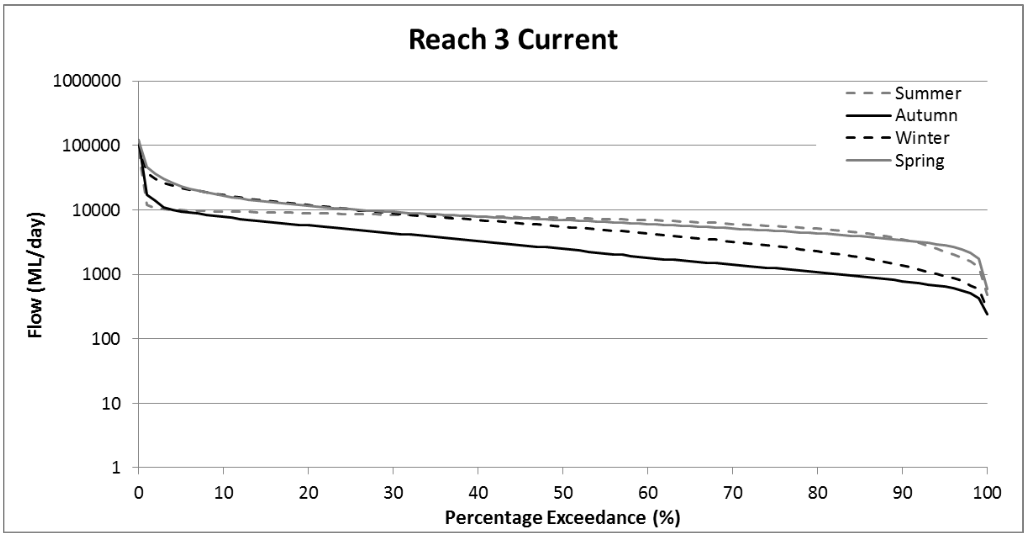


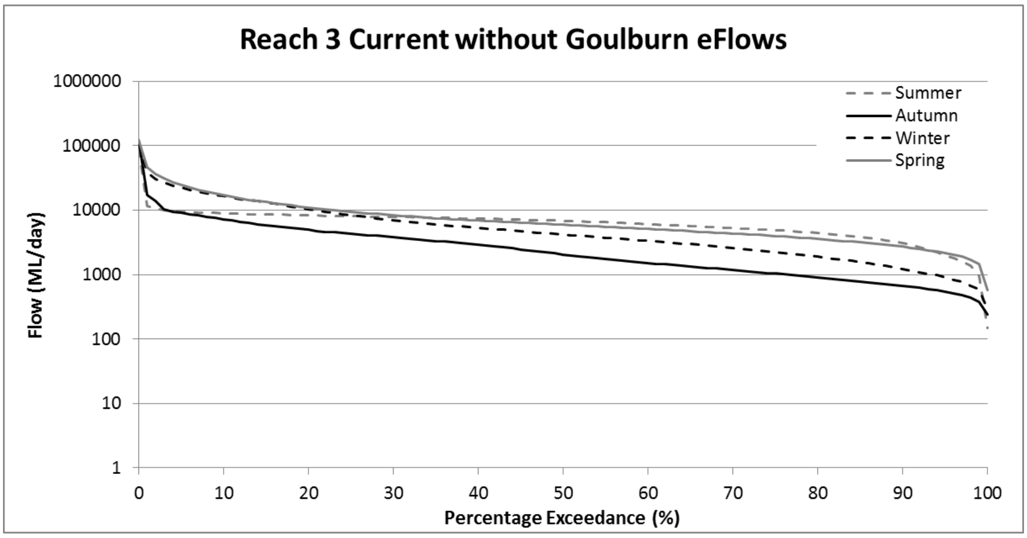

Reach 2 Unimpacted
1000000
100000
10000
1000
100
10
1
Flow (ML/day)
0 10 20 30 40 50 60 70 80 90 100
Percentage Exceedance (%)
Summer
Autumn
Winter
Spring


Reach 2 Current
100000
10000
1000
100
10
1
Flow (ML/day)
0 10 20 30 40 50 60 70 80 90 100
Percentage Exceedance (%)
Summer
Autumn
Winter
Spring


Reach 2 Current without Goulburn eFlows
100000
10000
1000
100
10
1
Flow (ML/day)
0 10 20 30 40 50 60 70 80 90 100
Percentage Exceedance (%)
Summer
Autumn
Winter
Spring

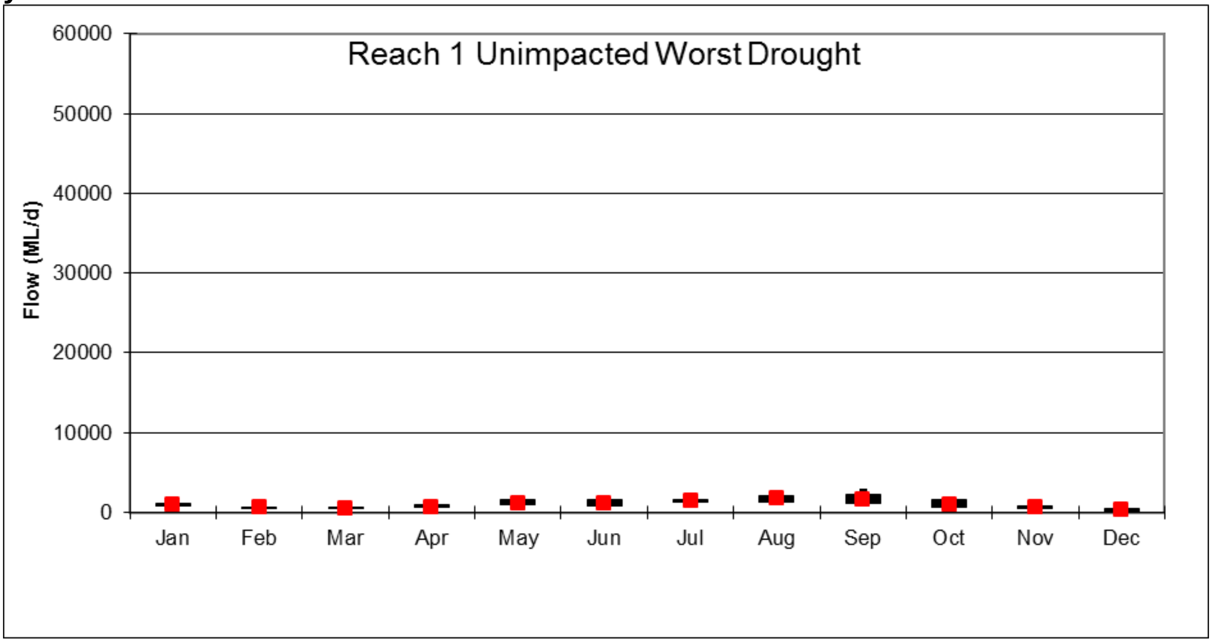

Reach 3 Unimpacted
1000000
100000
10000
1000
100
10
1
Flow (ML/day)
0
10
20
30
40
50
60
70
80
90
100
Percentage Exceedance (%)
Summer
Autumn
Winter
Spring

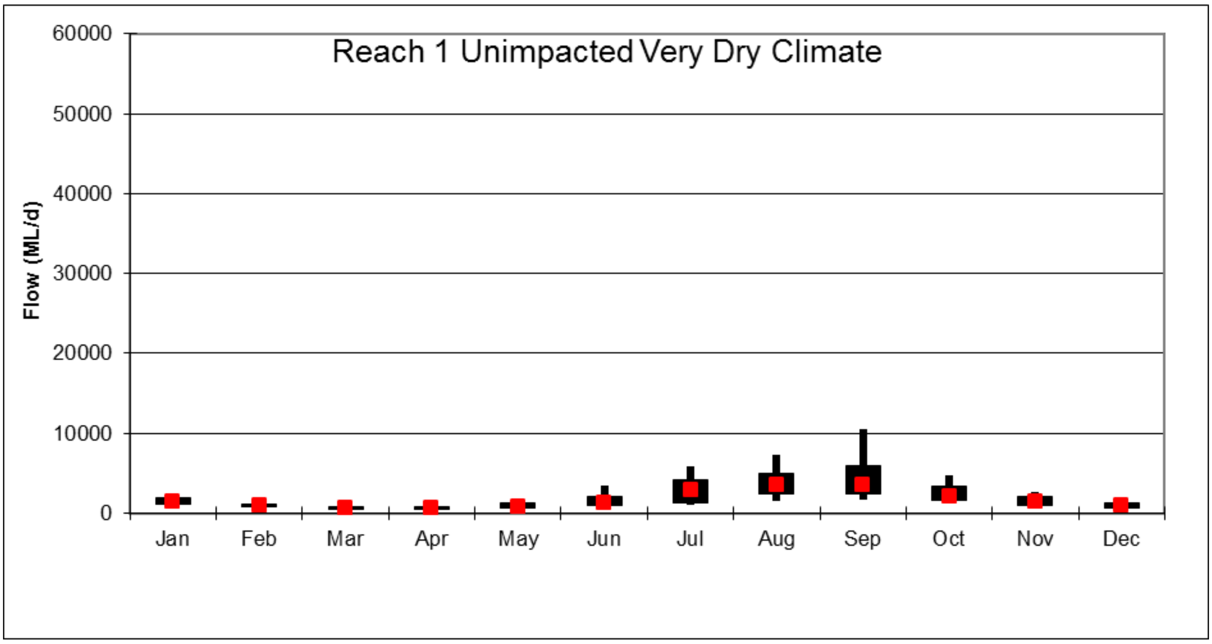

Reach 3 Current
1000000
100000
10000
1000
100
10
1
Flow (ML/day)
0
10
20
30
40
50
60
70
80
90
100
Percentage Exceedance (%)
Summer
Autumn
Winter
Spring

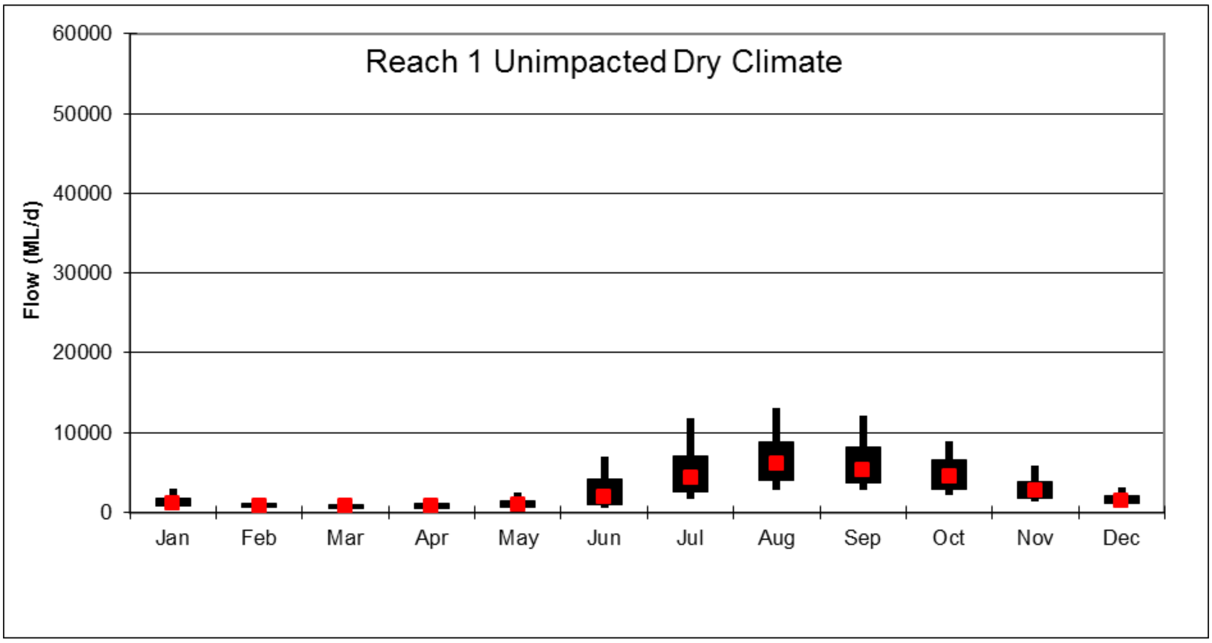

Reach 3 Current without Goulburn eFlows
1000000
100000
10000
1000
100
10
1
Flow (ML/day)
0
10
20
30
40
50
60
70
80
90
100
Percentage Exceedance (%)
Summer
Autumn
Winter
Spring

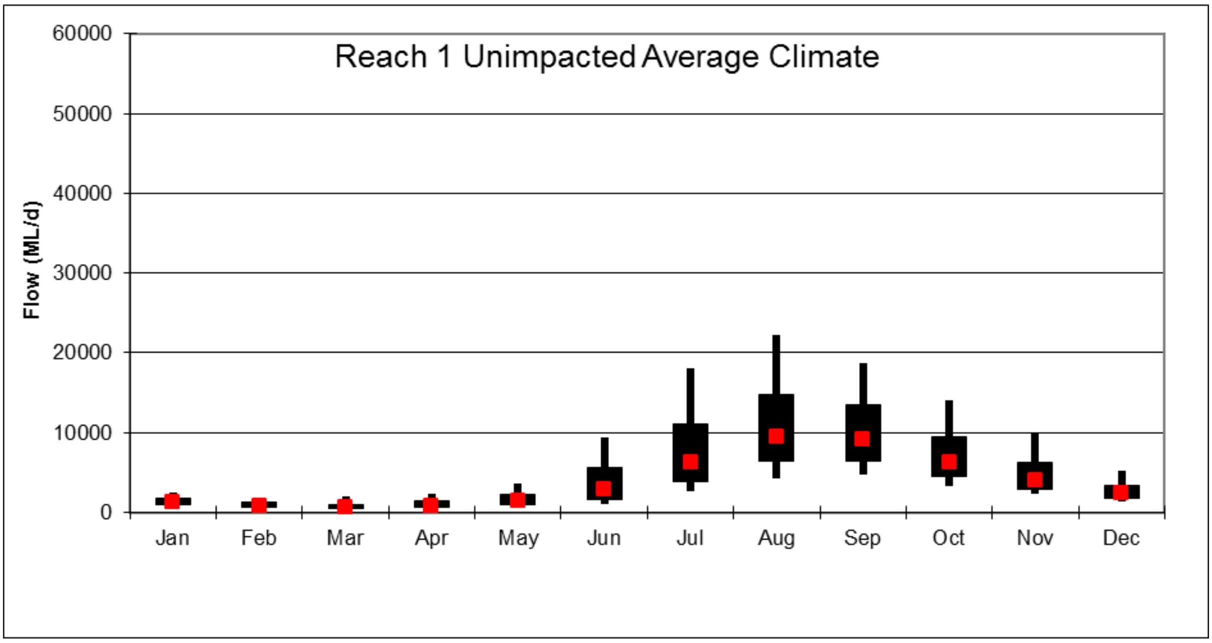
Appendix 1B – Box Plots

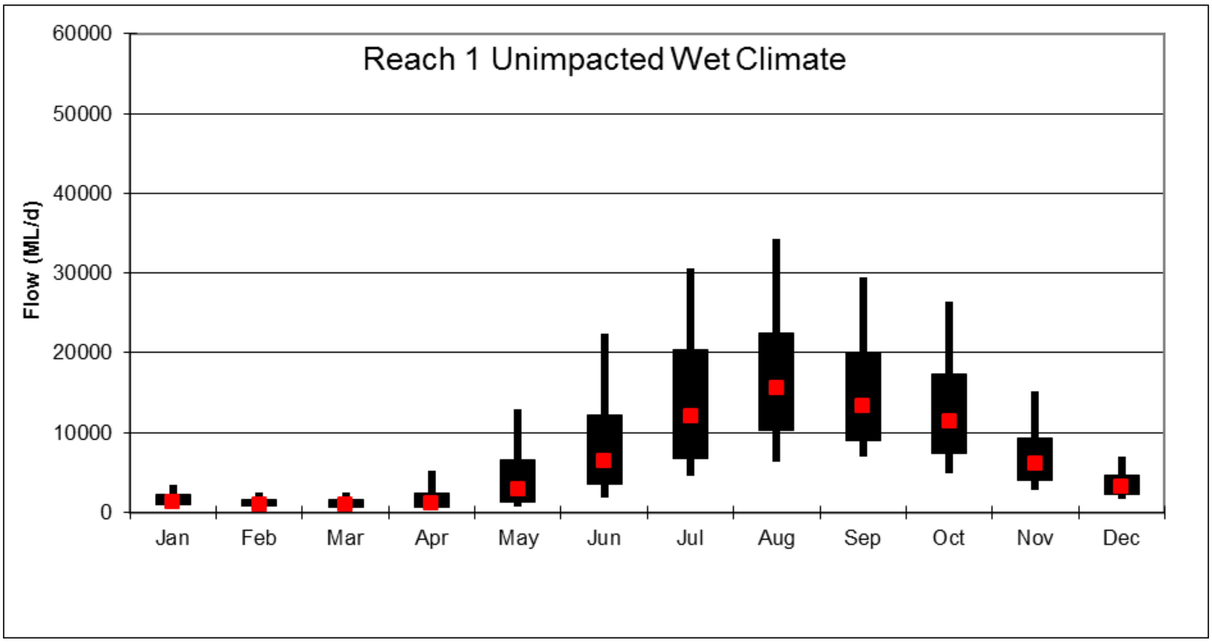
Reach 1 – Unimpacted flows split into Worst Drought, very dry, dry, average and wet years



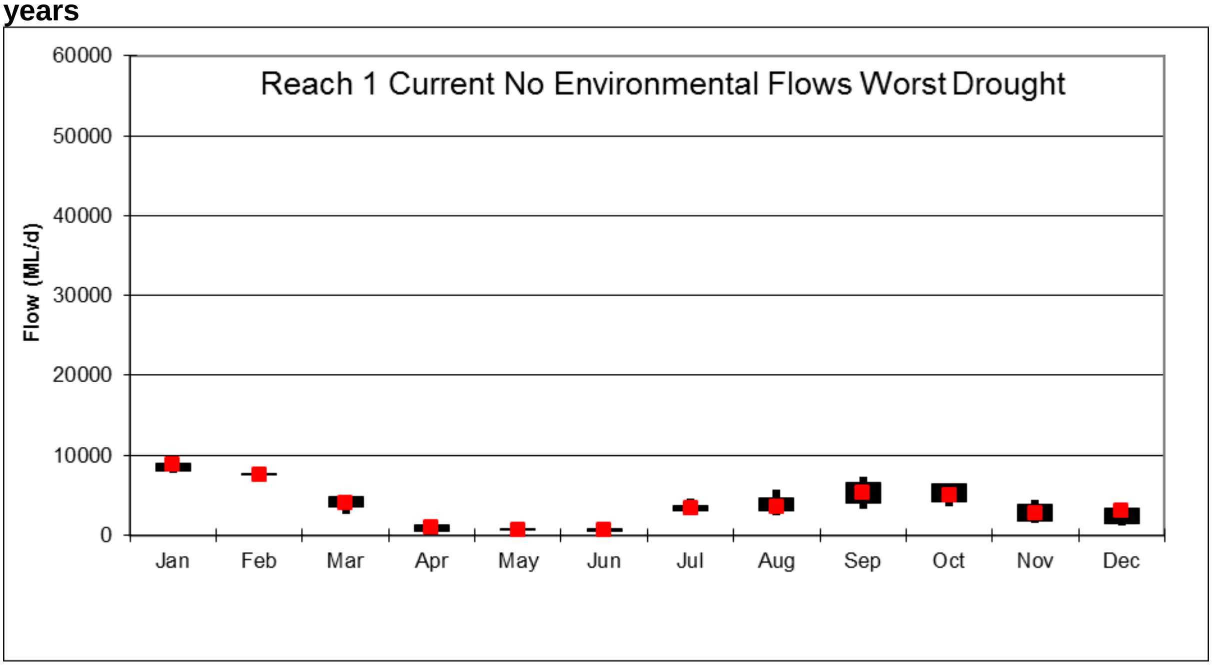


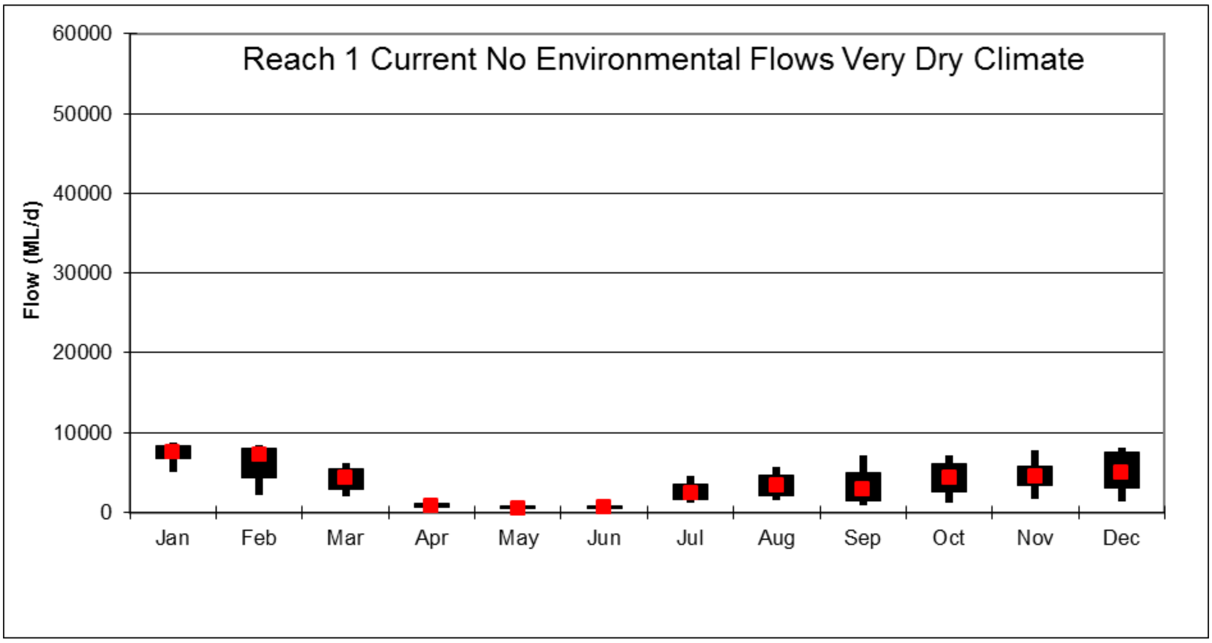

Reach 1 Unimpacted Dry Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

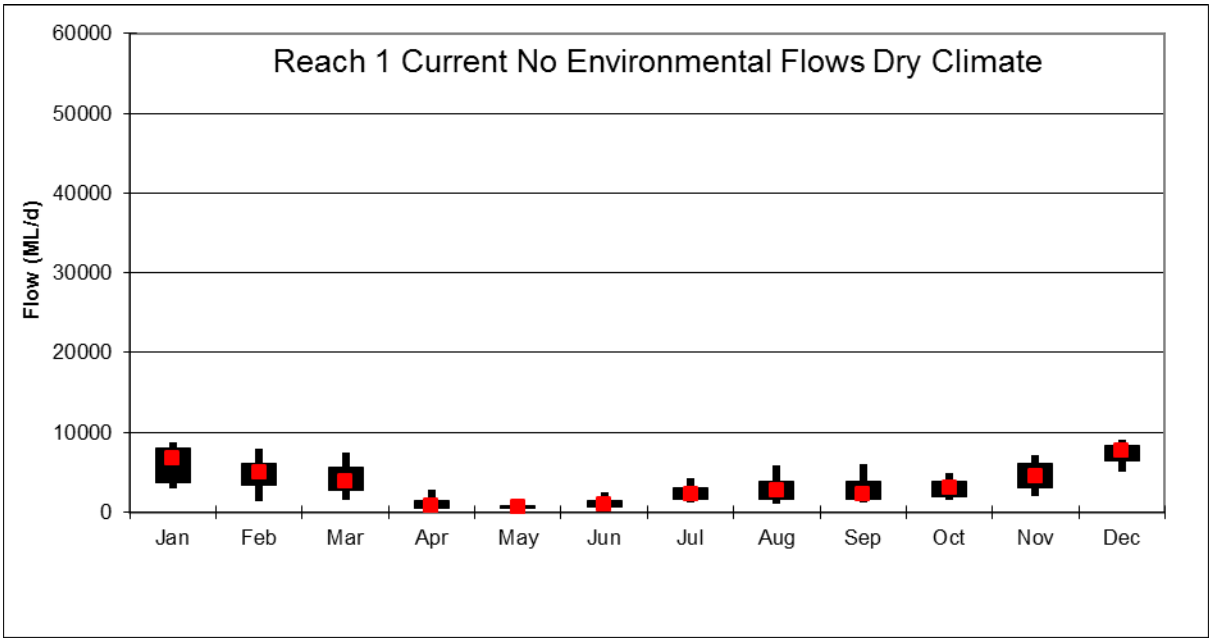

Reach 1 Unimpacted Average Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

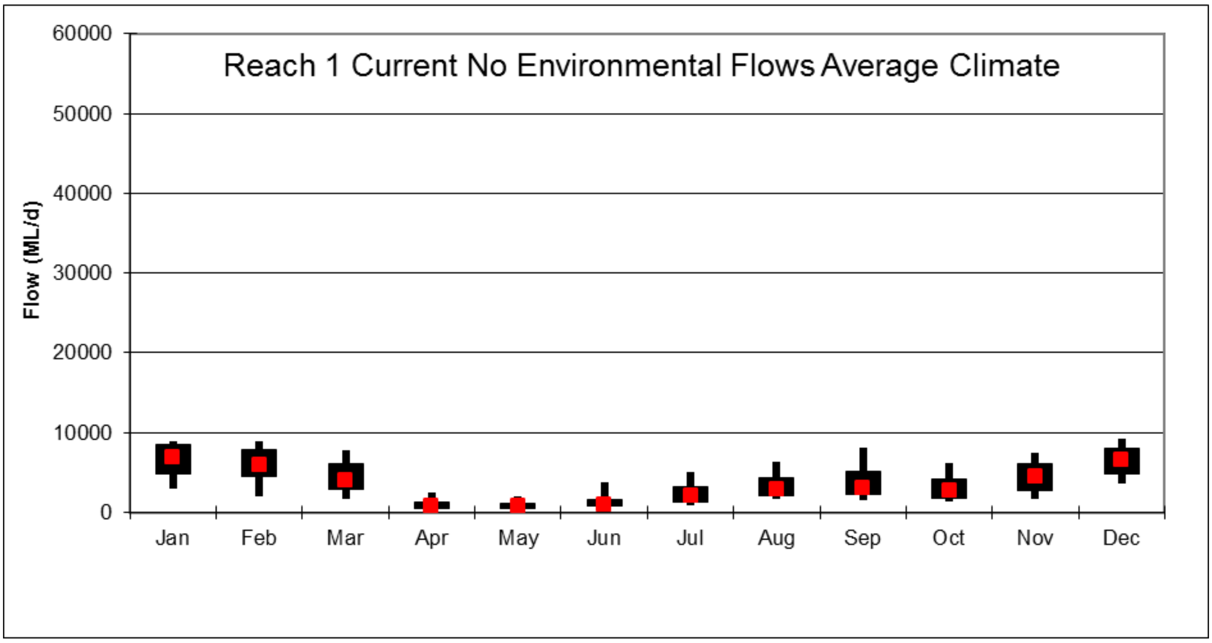


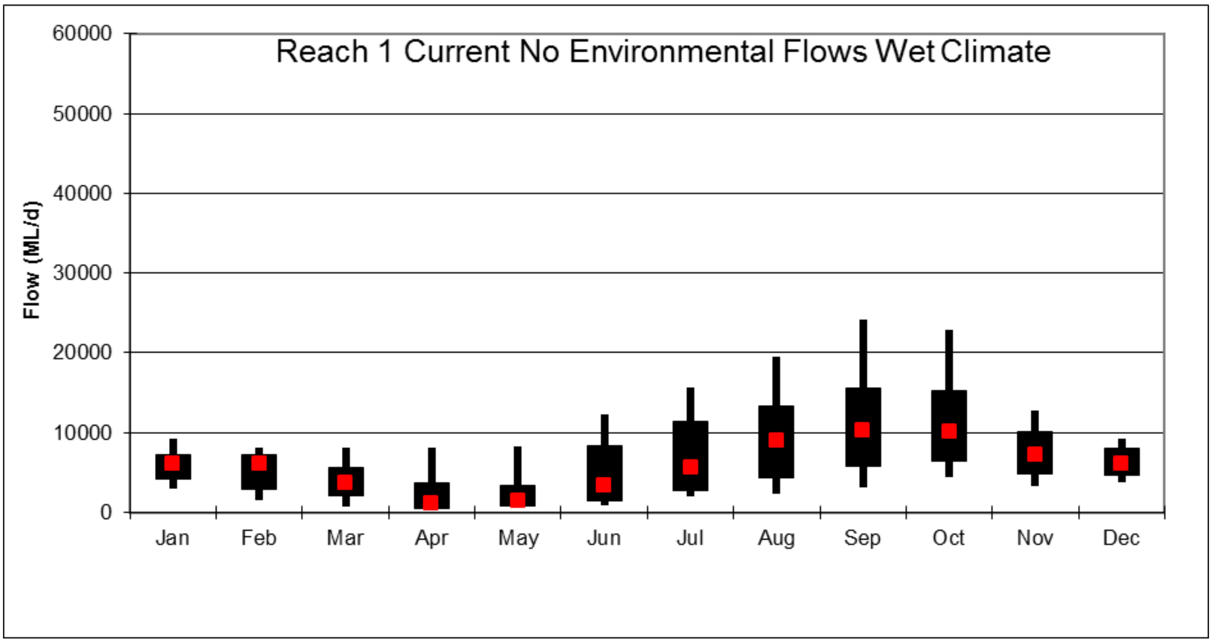
Reach 1 – Current flow regime split into Worst Drought, very dry, dry, average and wet years



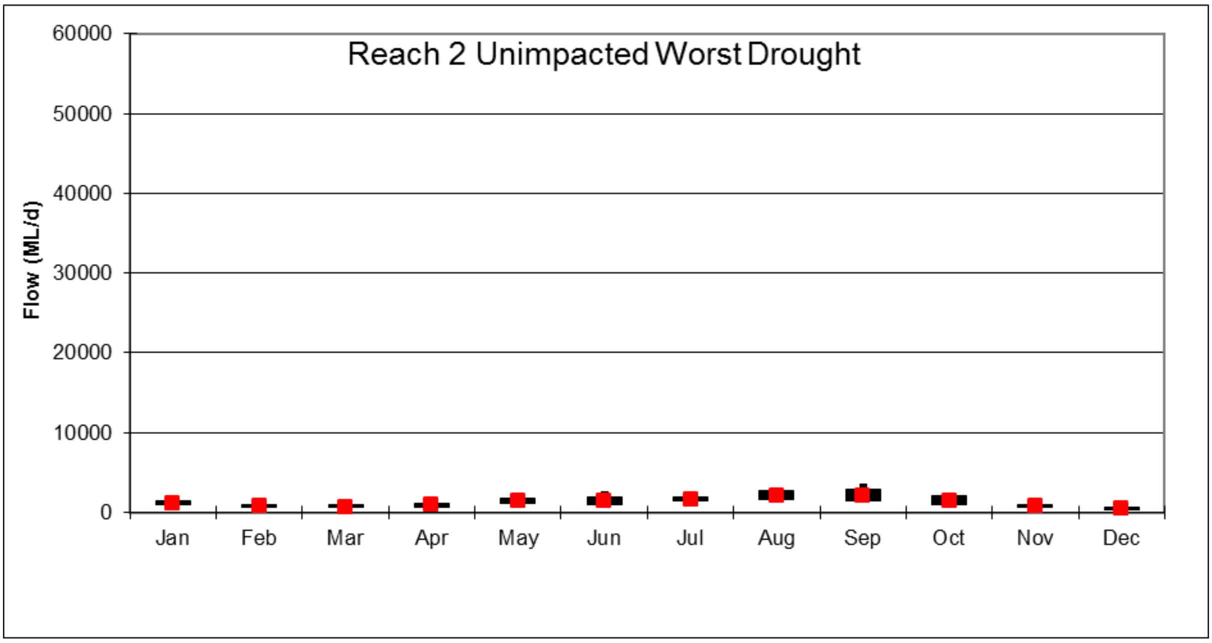

Reach 1 Current No Environmental Flows Very Dry Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

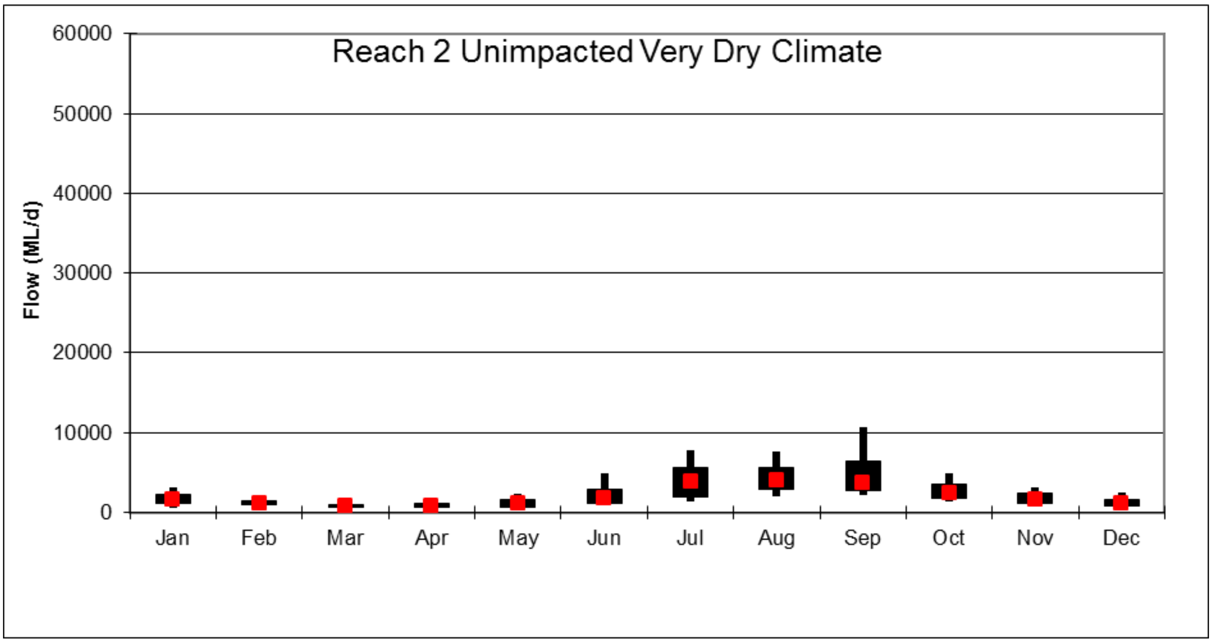

Reach 1 Current No Environmental Flows Dry Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

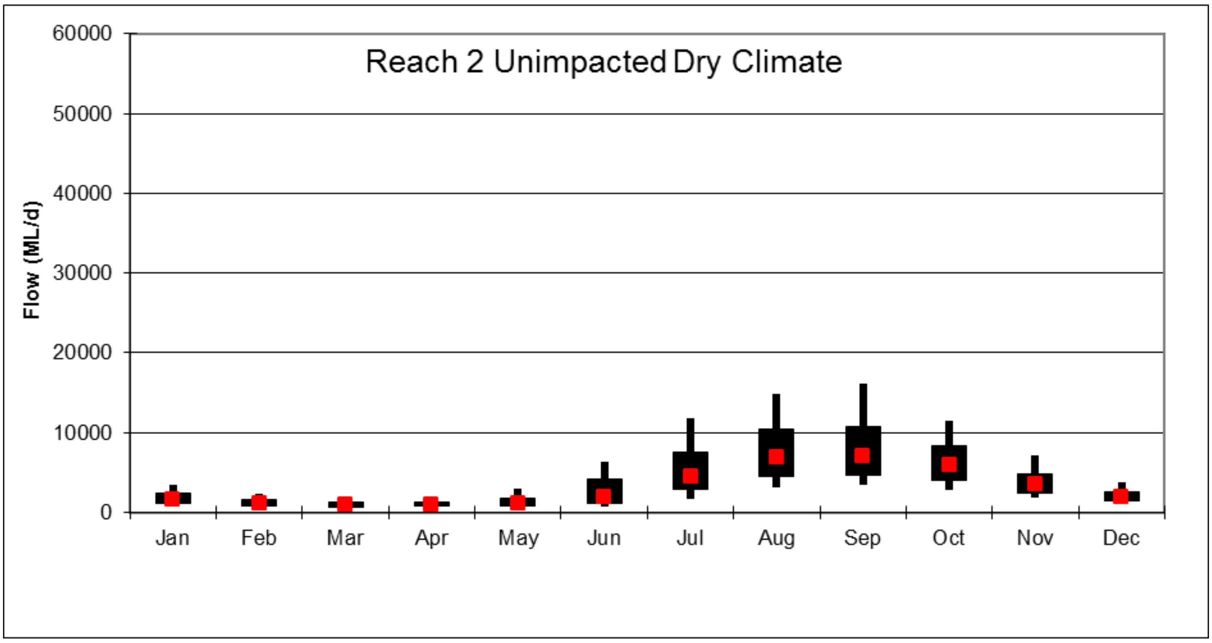


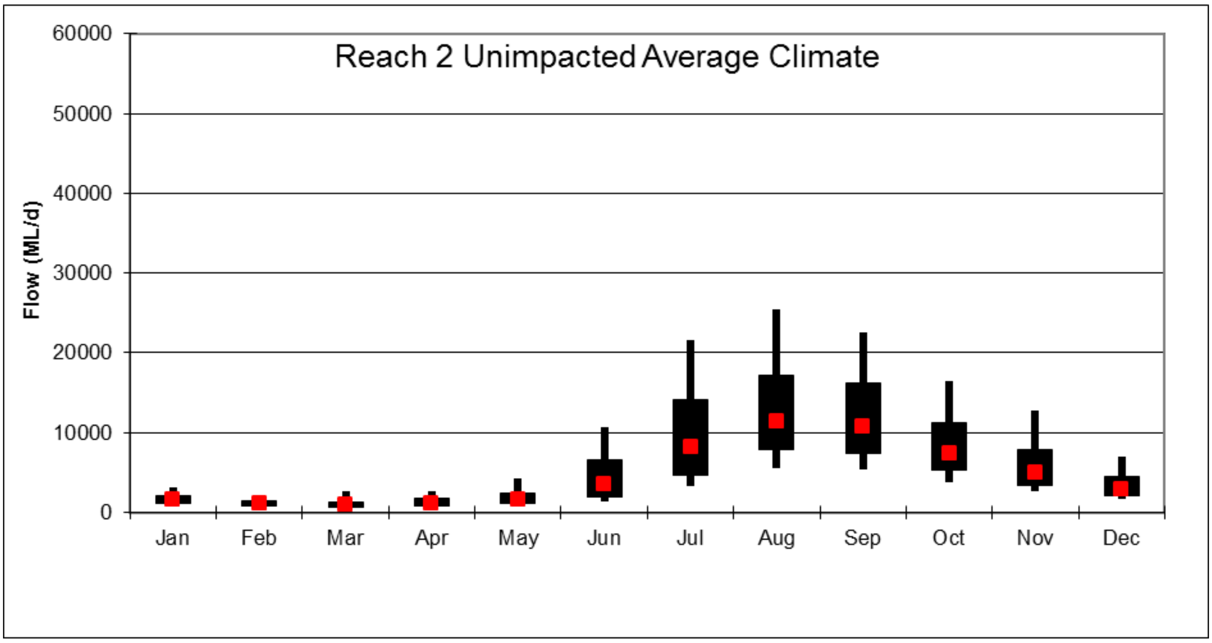


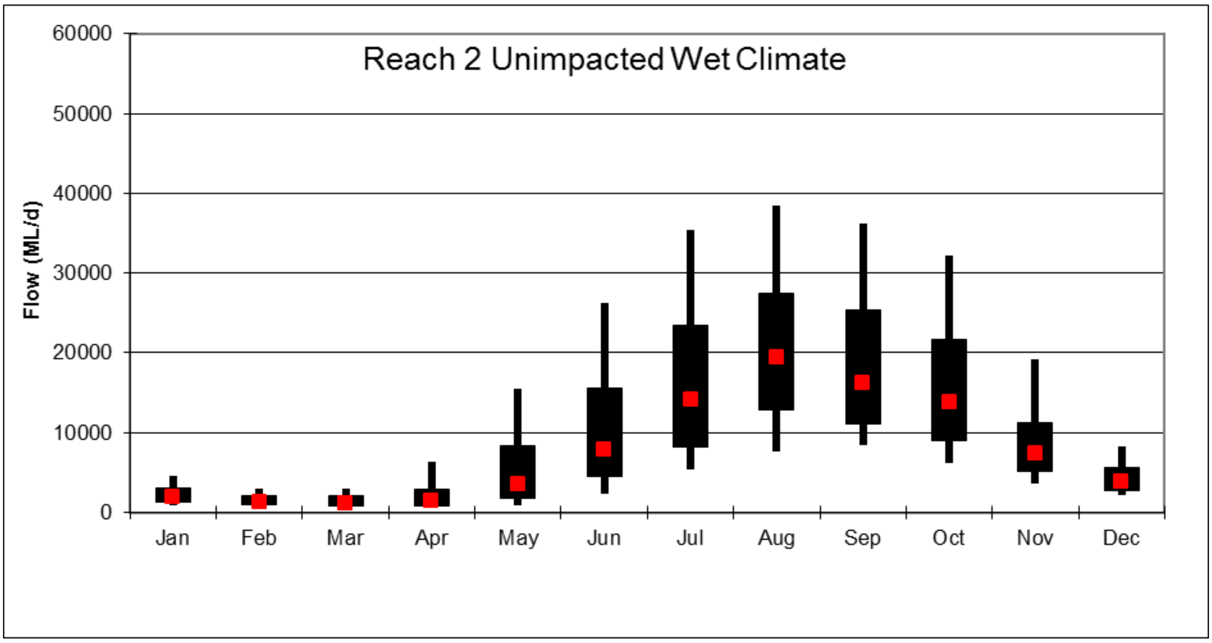
Reach 2 – Unimpacted flows split into Worst Drought, very dry, dry, average and wet years


Reach 2 Unimpacted Worst Drought
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

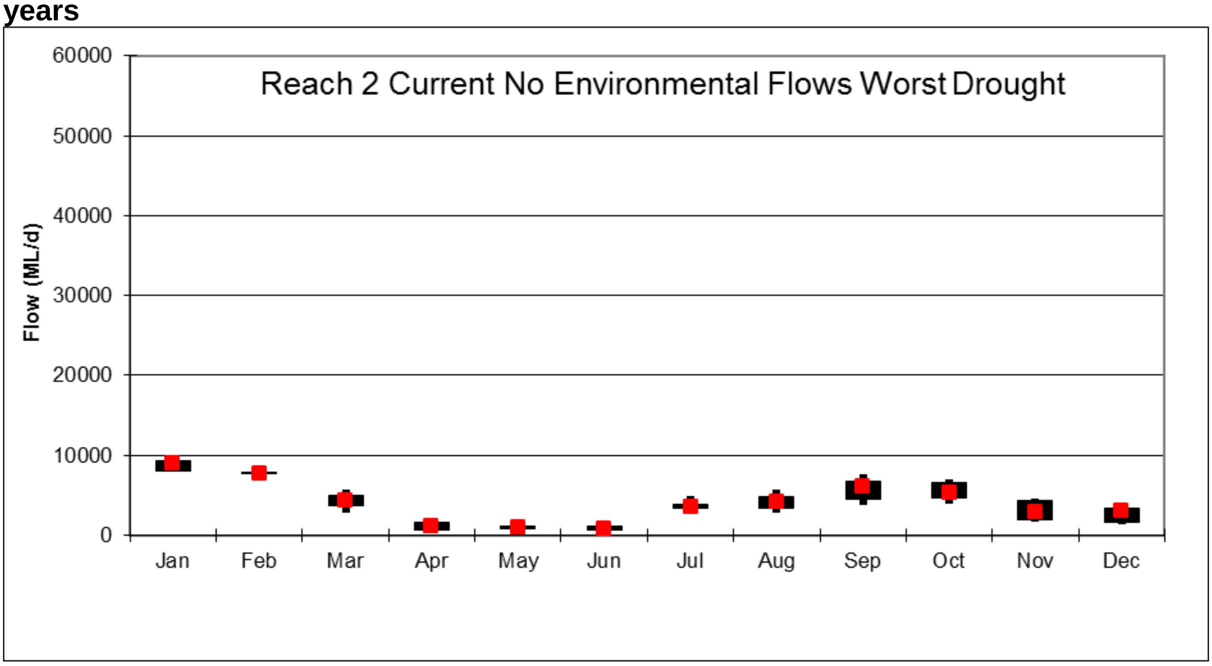

Reach 2 Unimpacted Very Dry Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

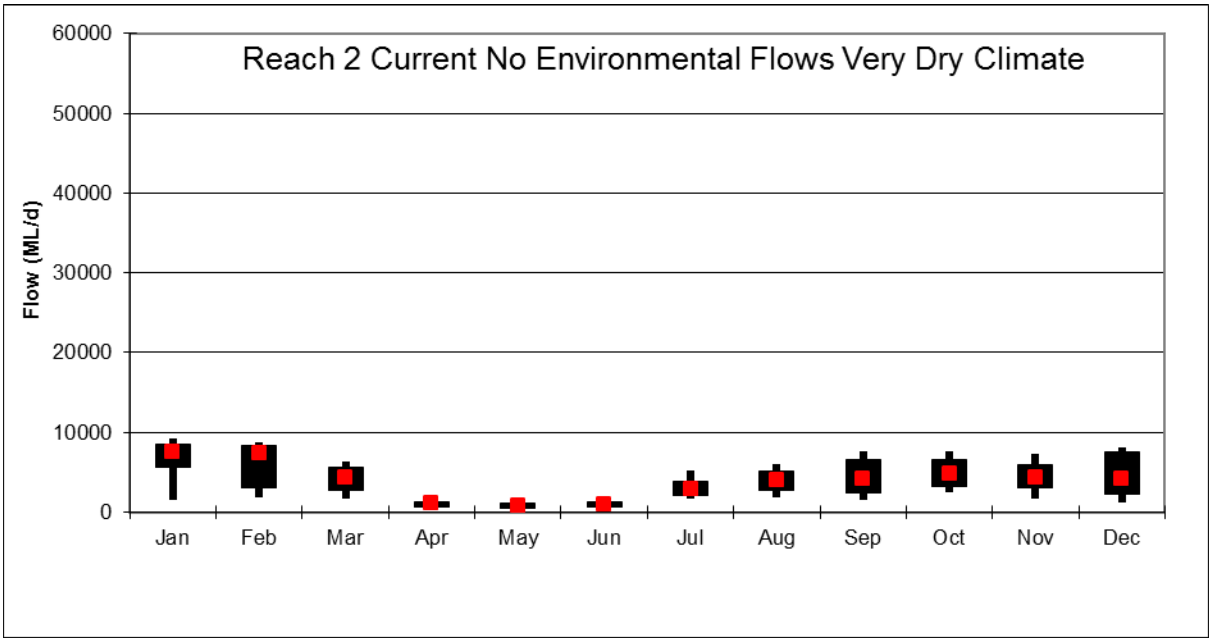

Reach 2 Unimpacted Dry Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

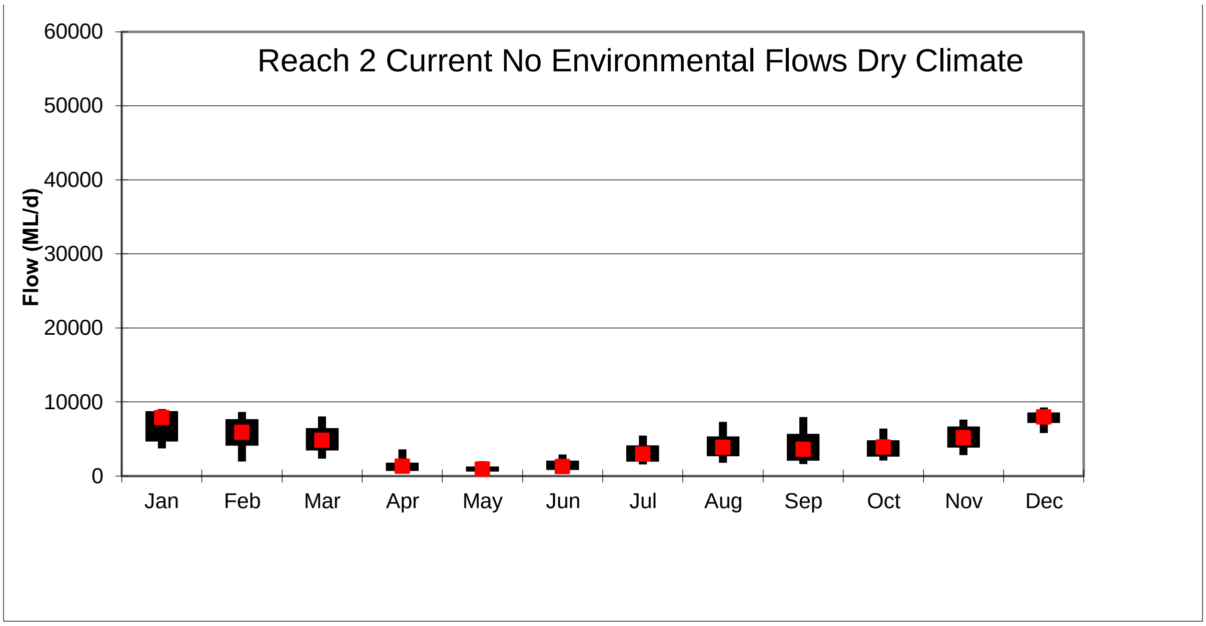

Reach 2 Unimpacted Average Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

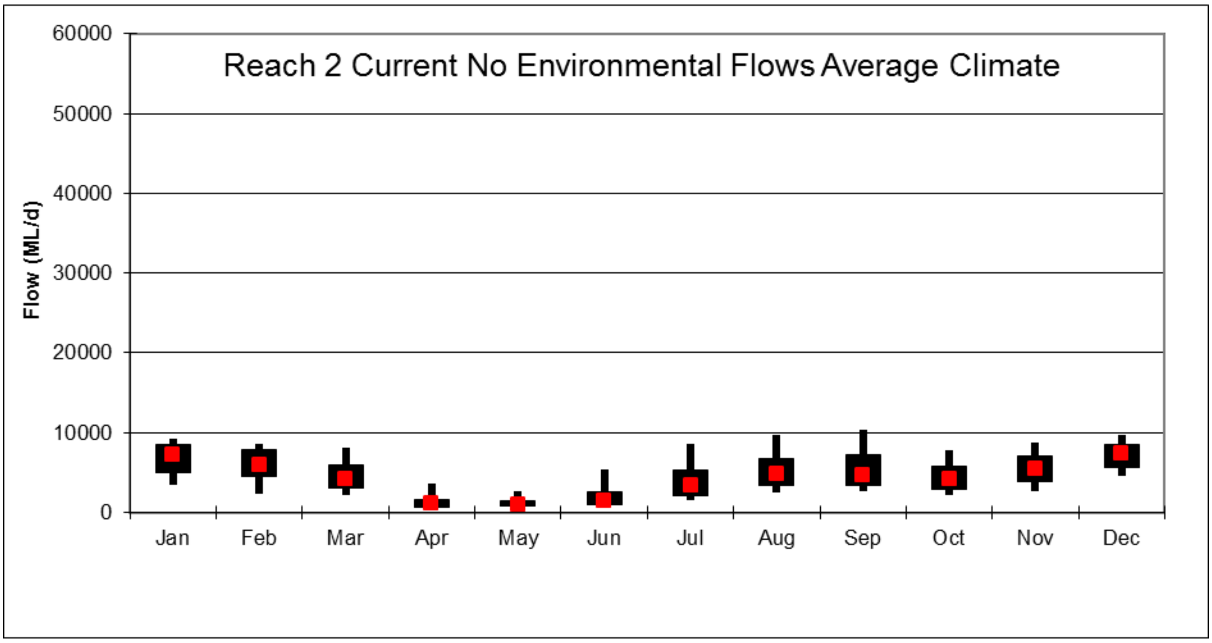


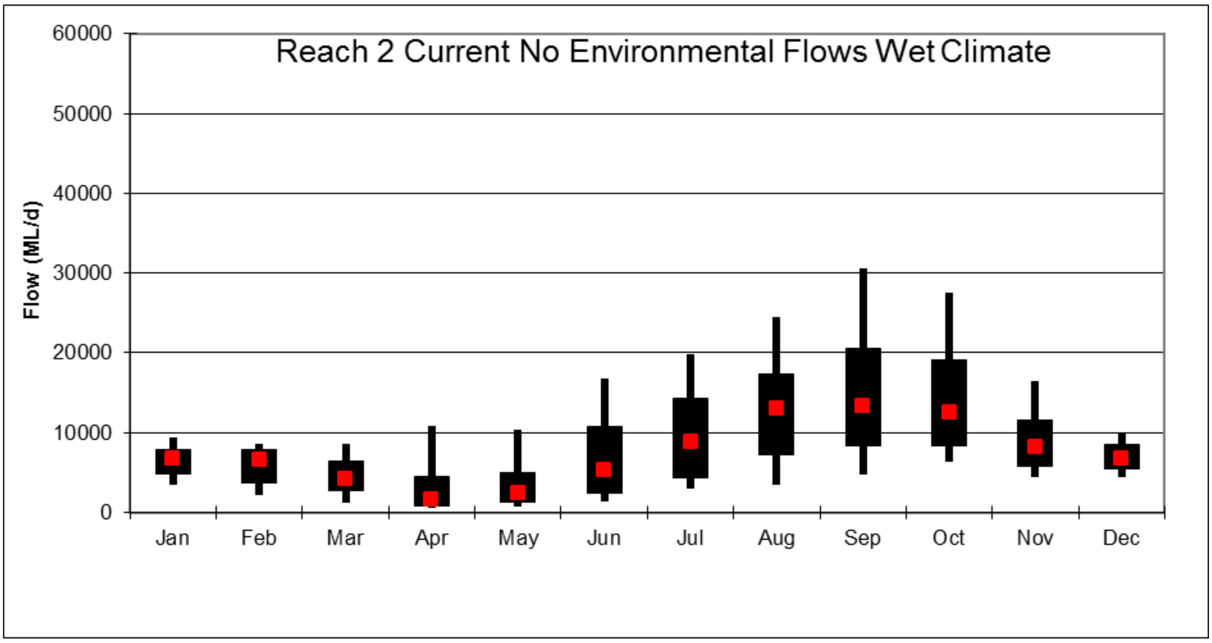
Reach 2 – Current flow regime split into Worst Drought, very dry, dry, average and wet years



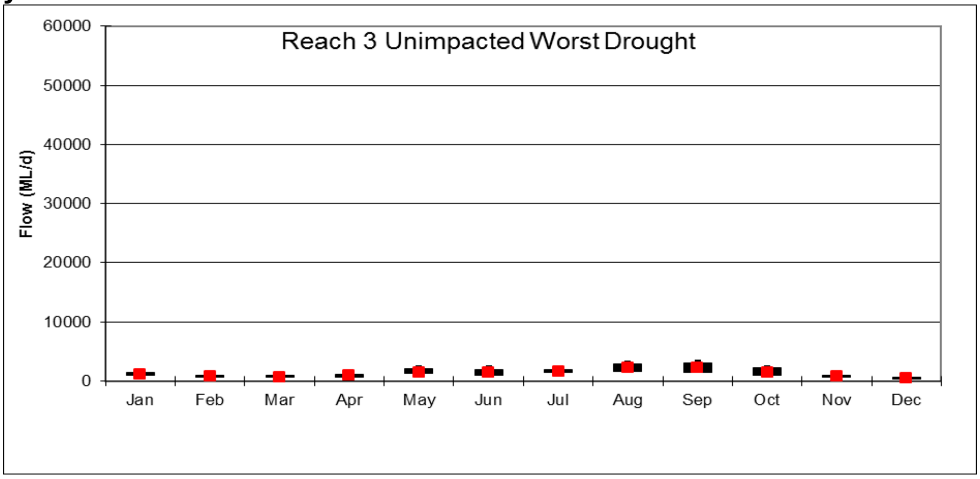

Reach 2 Current No Environmental Flows Very Dry Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

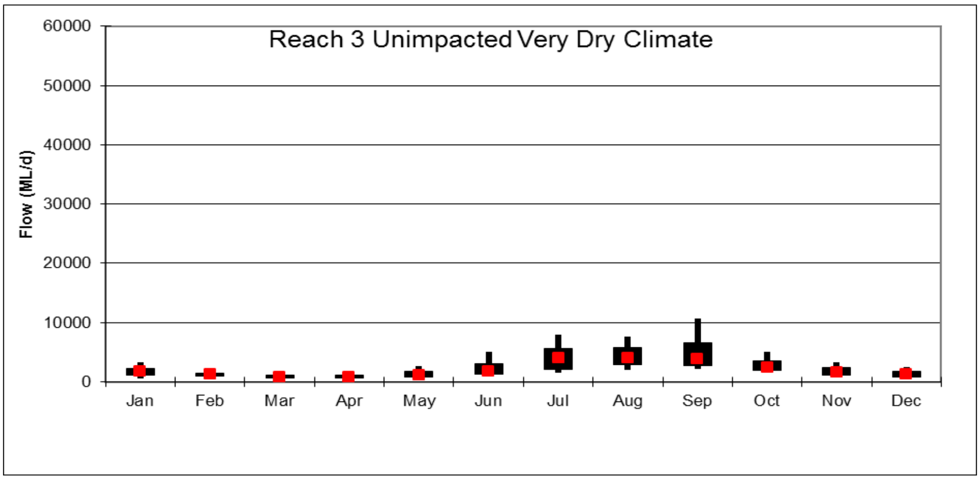

Reach 2 Current No Environmental Flows Dry Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

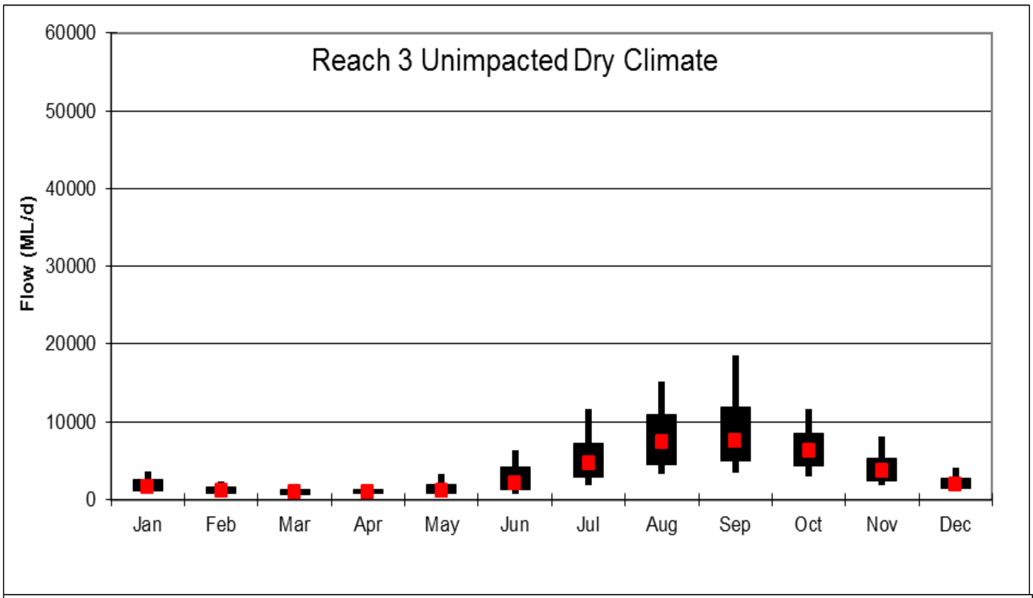

Reach 2 Current No Environmental Flows Average Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

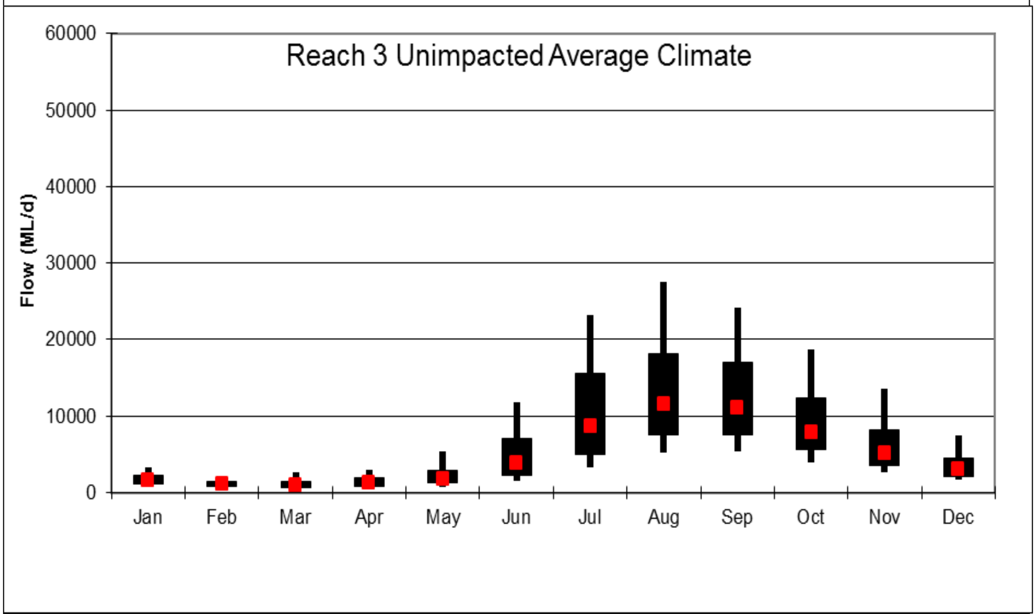

Reach 2 Current No Environmental Flows Wet Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

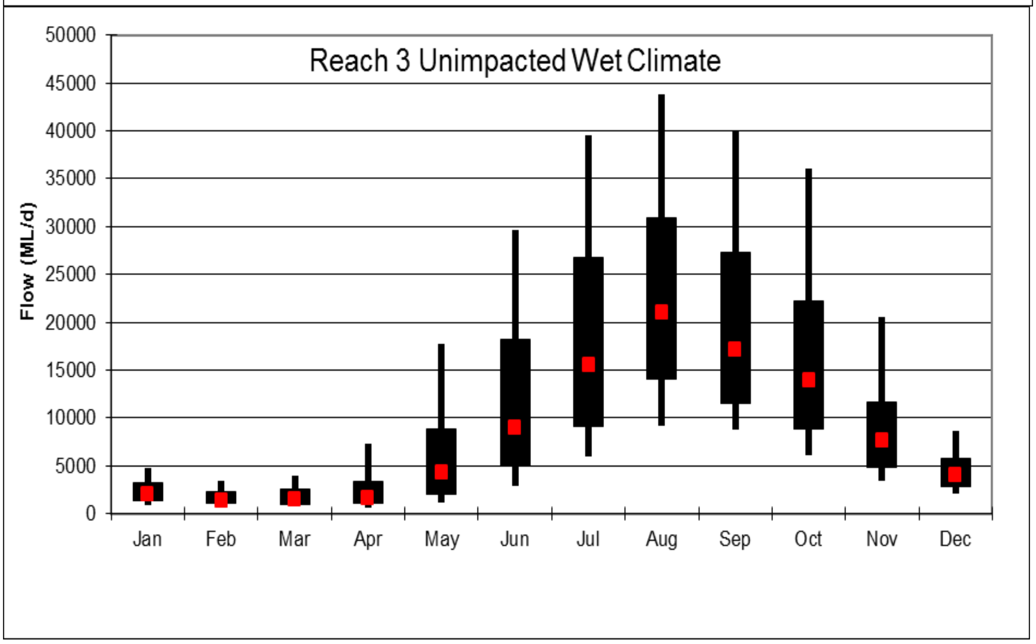
Reach 3 – Unimpacted flows split into Worst Drought, very dry, dry, average and wet years



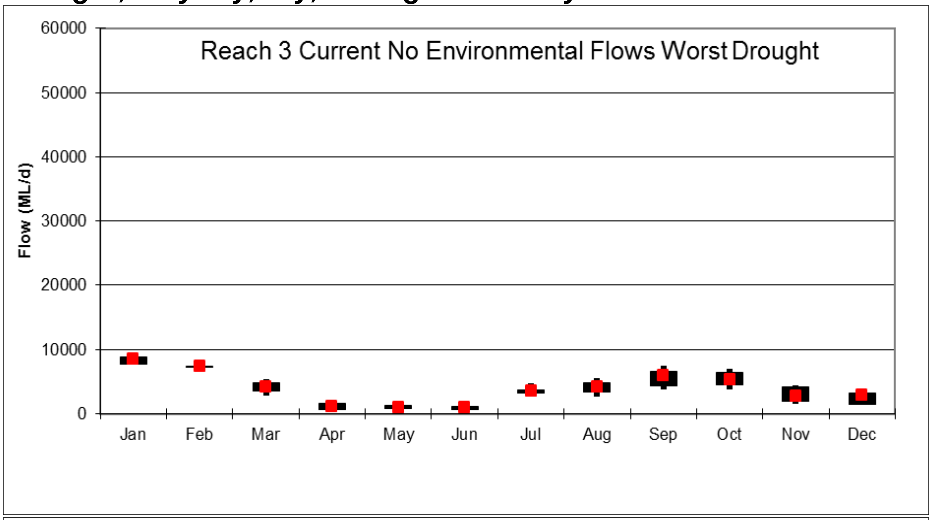


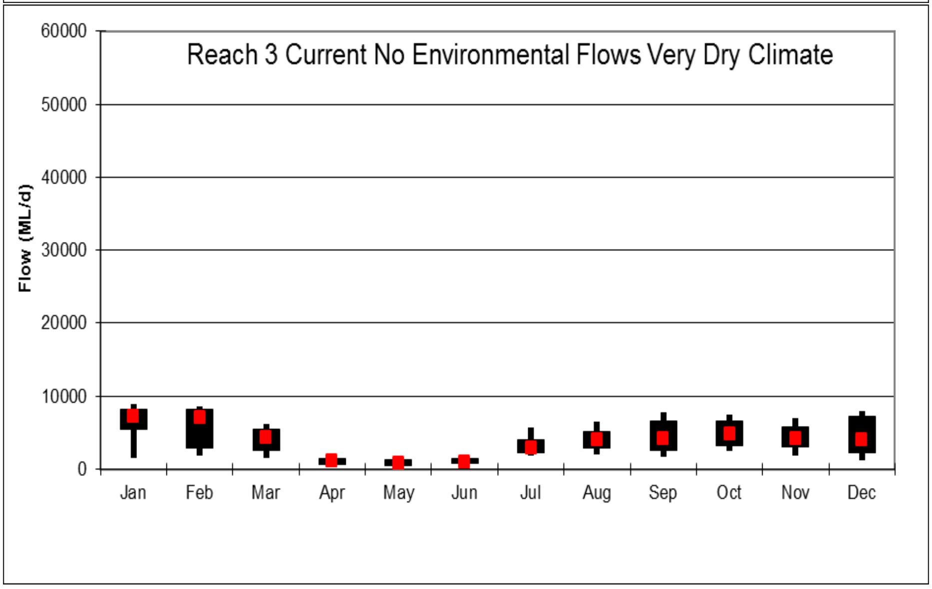

Reach 3 Unimpacted Dry Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

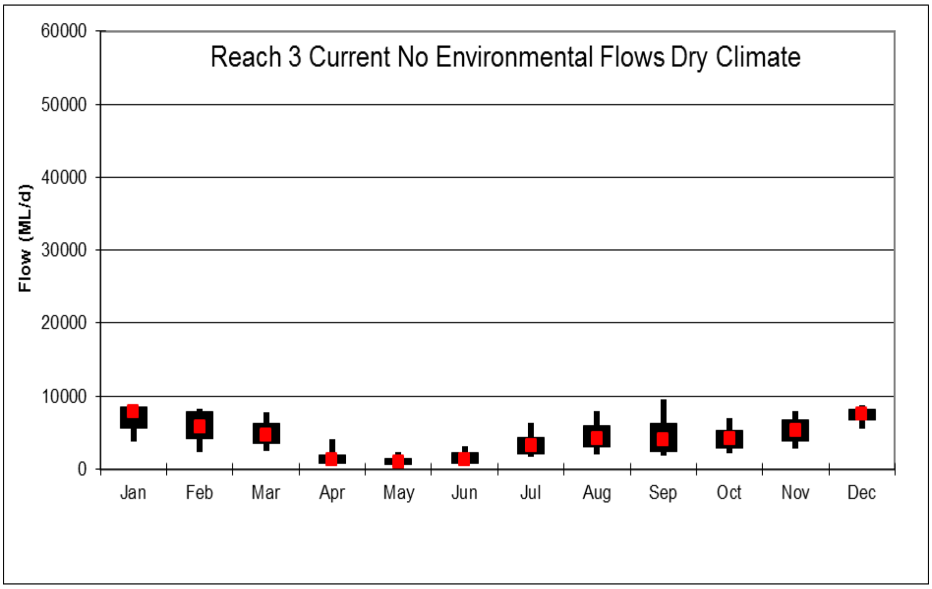

Reach 3 Unimpacted Average Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

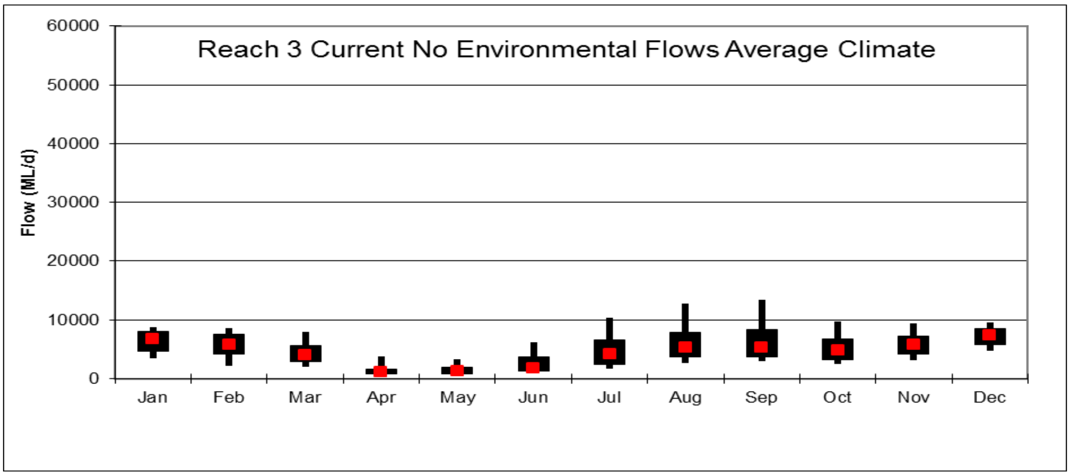

Reach 3 Unimpacted Wet Climate
Flow (ML/d)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

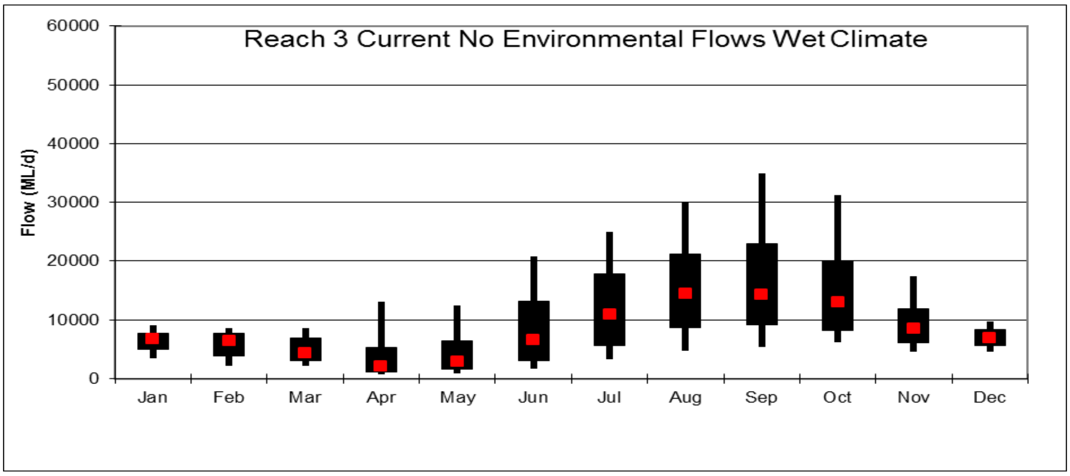
Reach 3 – Current flow regime excluding Environmental Flows split into Worst Drought, very dry, dry, average and wet years








Reach 3 Current No Environmental Flows Average Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


Reach 3 Current No Environmental Flows Wet Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Appendix 1C – Rates of Rise and Fall Table 3 Rates of rise (percentage of previous day's flow)

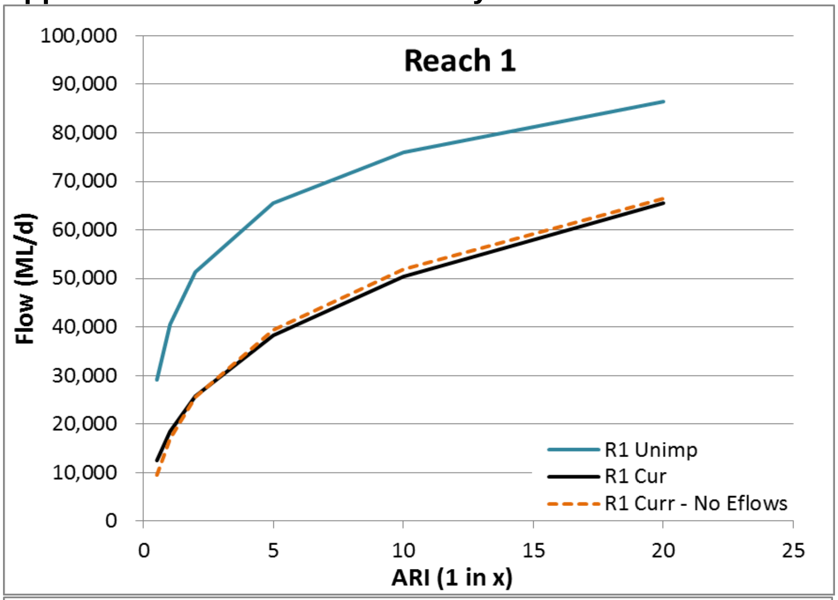
		Percentile		
Reach	**Flow**	**95th**	**Median**	**5th**
R1 unimpacted	0-1000ML/d	100%	106%	165%
	1000-5000ML/d	101%	112%	201%
	5000+ ML/d	101%	120%	271%
R1 current	0-1000ML/d	100%	108%	158%
	1000-5000ML/d	100%	107%	174%
	5000+ ML/d	100%	102%	144%
R1 Current excluding Goulburn Environmental Flows	0-1000ML/d	100%	108%	160%
	1000-5000ML/d	100%	107%	181%
	5000+ ML/d	100%	102%	134%
R2 unimpacted	0-1000ML/d	100%	105%	142%
	1000-5000ML/d	101%	110%	178%
	5000+ ML/d	101%	114%	215%
R2 current	0-1000ML/d	100%	106%	147%
	1000-5000ML/d	100%	107%	167%
	5000+ ML/d	100%	103%	147%
R2 Current excluding Goulburn Environmental Flows	0-1000ML/d	100%	107%	145%
	1000-5000ML/d	101%	111%	188%
	5000+ ML/d	101%	118%	275%
R3 unimpacted	0-1000ML/d	100%	105%	151%
	1000-5000ML/d	100%	111%	188%
	5000+ ML/d	100%	118%	275%
R3 current	0-1000ML/d	100%	107%	145%
	1000-5000ML/d	100%	108%	184%
	5000+ ML/d	100%	103%	187%
R3 Current excluding Goulburn Environmental Flows	0-1000ML/d	100%	107%	160%
	1000-5000ML/d	100%	109%	190%
	5000+ ML/d	100%	103%	186%

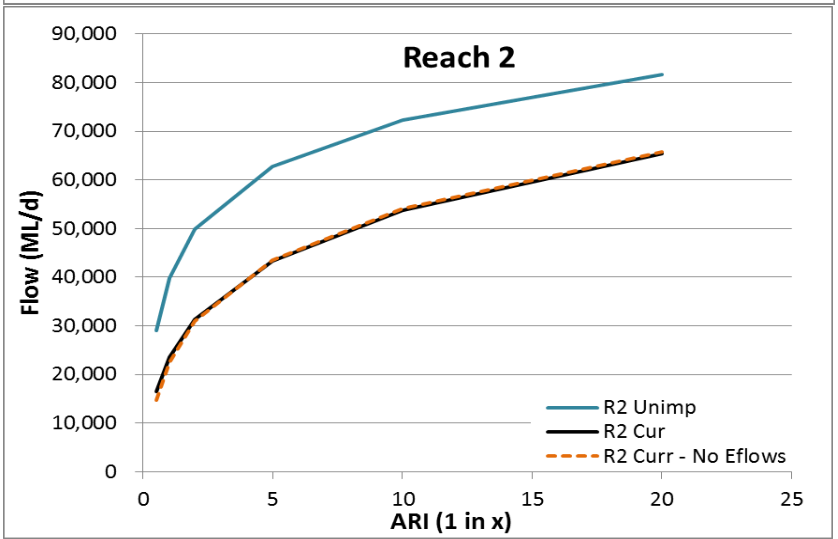
Table 4 Rates of fall (percentage of previous day's flow)

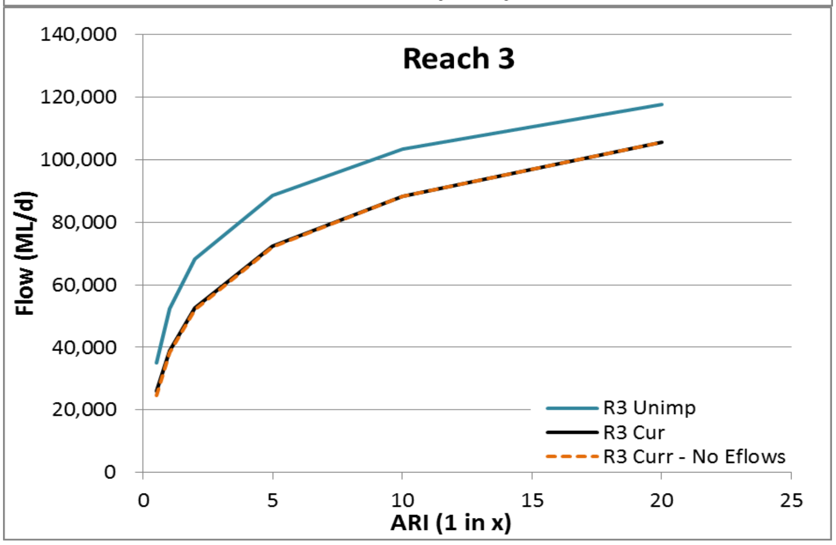
		Percentile		
Reach	**Flow**	**95th**	**Median**	**5th**
R1 unimpacted	0-1000ML/d	87%	97%	99%
	1000-5000ML/d	81%	95%	99%
	5000+ ML/d	78%	90%	97%
R1 current	0-1000ML/d	82%	96%	99%
	1000-5000ML/d	79%	94%	100%
	5000+ ML/d	81%	97%	100%
R1 Current excluding Goulburn Environmental Flows	0-1000ML/d	82%	96%	99%
	1000-5000ML/d	78%	94%	99%
	5000+ ML/d	83%	98%	100%
R2 unimpacted	0-1000ML/d	90%	97%	99%
	1000-5000ML/d	87%	95%	99%
	5000+ ML/d	84%	92%	98%
R2 current	0-1000ML/d	87%	96%	100%
	1000-5000ML/d	82%	94%	99%
	5000+ ML/d	84%	96%	100%
R2 Current excluding Goulburn	0-1000ML/d	86%	96%	99%
	1000-5000ML/d	85%	95%	99%

Environmental Flows	5000+ ML/d	80%	91%	98%
R3 unimpacted	0-1000ML/d	89%	97%	99%
	1000-5000ML/d	85%	95%	99%
	5000+ ML/d	80%	91%	98%
R3 current	0-1000ML/d	86%	96%	99%
	1000-5000ML/d	80%	94%	99%
	5000+ ML/d	78%	95%	100%
R3 Current excluding Goulburn Environmental Flows	0-1000ML/d	85%	96%	99%
	1000-5000ML/d	79%	93%	99%
	5000+ ML/d	76%	96%	100%

Appendix 1D – Partial Series Analysis







10.1.1 Addendum - Modelling the current flow regime with environmental flows excluded (Current + no eflows)

Accounting for environmental water in the Goulburn modelling required it being called out in the existing pattern of use as the current scenario. It was also necessary to keep the demand being supplied at McCoys Bridge rather than directly extracted from Eildon as the flows for the lower Goulburn River are also supplied from the mid and lower Goulburn tributaries and ceasing/reducing harvest at Waranga Basin.

A solution was applied that takes advantage of the fact that in the GSM REALM model, the flow solution is effectively solved three times per time step by including different demands up to 3 key iterations (60, 80 and final). Up to iteration 60 it solves for all orders except excluding TLM water, IVT and Basin Plan environmental flows. Then for up to iteration 80 it solves for all orders except Basin Plan environmental flows. The approach adopted was to use the results of the flow solution in REALM at the three key iterations (the 60th iteration, the 80th iteration and the final iteration) for each given time step to estimate the releases without environmental flows. By doing this it was possible to separate out just the environmental flows (and leave IVTs in). In effect, this only uses results from the current scenario, so this means that the impact of us excluding the environmental flows does not have any impact on subsequent time steps.

However, the current scenario simulation did not include output of the flows at iteration 60 and 80, so the current simulation was re-run with additional carriers which output the flow at iteration 60 and 80. An extra two simulations gave exactly the same results for flow in the final iteration but which also include the extra carriers that we needed to know at iterations 60 and 80.

The outcome of using this method for the flow solution in each time step excluding the environmental flows is that in some months flood pre-releases or spills may be higher without the environmental flows (as solved by REALM in iterations 60 and 80). A potential alternative that was considered was whether the spills and pre-releases should be assumed to be set to the final iteration; this was abandoned as it was felt there may be some inconsistency with the other release assumptions.

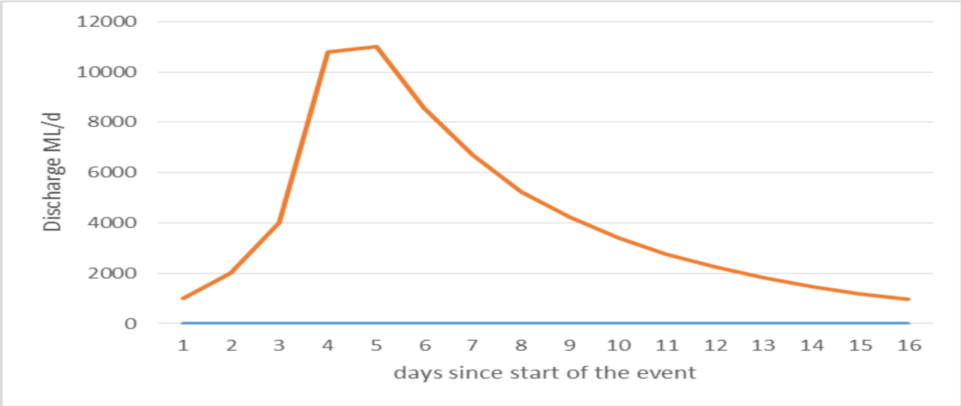
The modelling has demonstrated a number of key outcomes including the proportion of Goulburn environmental flows that are delivered to the lower Goulburn by reducing/ceasing harvest to Waranga vs delivery from Eildon. It has also shown that the behaviour of the system including spills and pre-releases is sensitive to the assumed use of the environmental water in the model.

10.2 Event rise and fall

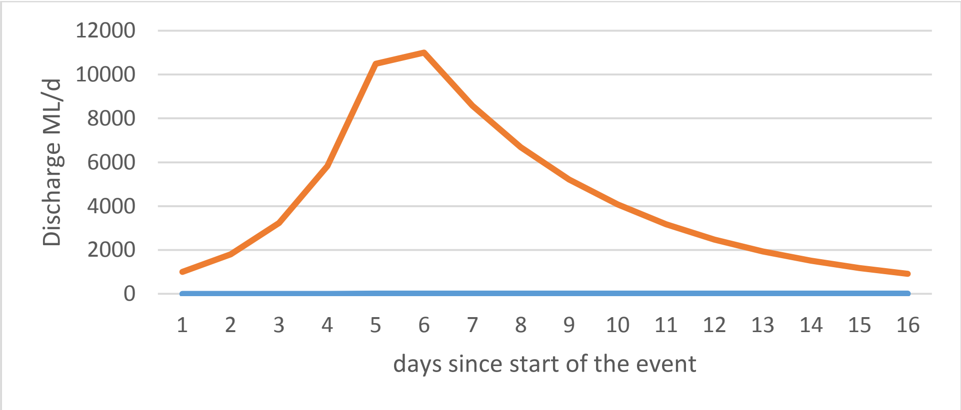
Assumes baseflow of 1000 ML/d then rise and fall of a bankfull event using rates provided by Jacob and from 2003 study. Focuses on Reach 1 – most affected by operation of Lake Eildon and Pondage. Compared with 2003 study, rate of rise is slightly higher, while rate of fall is slightly lower. Adopting slightly lower rate of fall given sensitivity to increased rates of bank erosion. Note: G-MW rate of rise is similar to that presented here, while the rate of fall is less conservative (i.e. falling limb is steeper) (G. Earl, GB CMA, pers. comm.).
Based on:

- 5th percentile rate of rise: Q_2/Q_1 up to 2.0 for flows from 1,000 to 5,000 ML/d; up to 2.7 for flows above 5,000 ML/d (i.e. flows on Q_2 can be up to 2.0 times Q_1 if between 1,000-5,000 ML/d, and up to 2.7 times Q_1 if above 5,000 ML/d.
- 95th percentile rate of fall: fall Q_2/Q_1 greater than 0.8

Current study



2003 study values (max rise = 1.8, max fall = 0.76)



11 APPENDIX 2: OVERVIEW OF HYDRAULIC MODELLING

Re-survey – Mid Goulburn Environmental Flows Project

Vietz Consulting
ABN 47 083 046 274
9 Henderson St Northcote 3070 geoff@vietzconsulting.com.au

Introduction

This report provides a concise summary of the re-survey of two of the three Mid-Goulburn River environmental flow determination sites previously surveyed in August 2002. The two sites include Alexandra (Site 1: Sheets GRS101-102) and Ghin Ghin (Site 2: Sheets GRS201-202). Sites were resurveyed to help confirm whether there has been any significant changes in channel morphology in the intervening period between 2002 and 2014, to consider whether the 2002 sections are still valid for hydraulic modelling for the project. Resurvey was undertaken between the 2nd to 4th June, using a Total Station and differential GPS.

Comments on the quality of survey data

The exercise required relocation of 2002 survey cross sections. Common practice is to leave fixed pegs or benchmarks at sites so that a number of known locations are available. Unfortunately no pegs were found for 2002 sites, even though cross section sites were identified from photographs. Photographs from 2002 indicate that temporary pegs were likely to have been used. This meant that resurvey relied on images taken by surveyors in 2002 that had been linked to cross sections (taken along the alignment of the cross section). This approach is not as reliable as having pegs on one or both banks, but we believe it allowed resurvey locations with an assumed error of between 1-3m laterally, i.e. the resurvey could be 1 to 3 metres from the 2002 survey alignment.

Four sections were resurveyed at each site. Sections were selected based on the ability to recreate the alignment from the 2002 images. For this purpose sites with well-defined features were targeted.

It is also important to note that many of the 2002 cross sections were not perpendicular to the channel. We are uncertain as to why this was the case but suggest this may have been due to the use of a slack fixed line from which the boat was attached while surveying. The problems with a non-perpendicular section is that the cross section appears wider than it is. This can influence hydraulic modelling, i.e. water depth will be represented as shallower than it is for a given discharge. For the purpose of the resurvey exercise the aim was to recreate the alignment of the 2002 survey, irrespective of the non-perpendicular nature of the alignment.

The 2002 survey data also does not appear to be georeferenced to a standard datum e.g. GDA1994. We contacted the surveyors by phone and email with no response. It was therefore impossible to accurately overlay 2002 data on the 2014 resurveyed data. Rather, comparison of survey data was achieved by matching the morphology on one bank and transposing one on another.

Data provided

Data provided with this report includes:

- 2002 survey plan form locations (GRS101, GRS102, GRS201, GRS202)
- PDF files cross section comparison between 2002 and 2014 survey data (GRS_2014_XS_Surveys.pdf) – also attached to this report
    - Note, cross sections are presented as facing downstream (river left bank on left of section)
    - Photographs (taken 2014) for Site 1 (GRS101, 102) are taken from the right bank
    - Photographs (taken 2014) for Site 2 (GRS201, 202) are taken from the left bank
- Excel data for comparison of 2002 and 2014 survey data
- Shape files of 2014 survey points and benchmarks (for use in ArcGIS or QGIS)
- Water levels on the day of survey for a stream gauge level of 3.10m at Ghin Ghin (rating curve to be obtained).

Comments on channel change

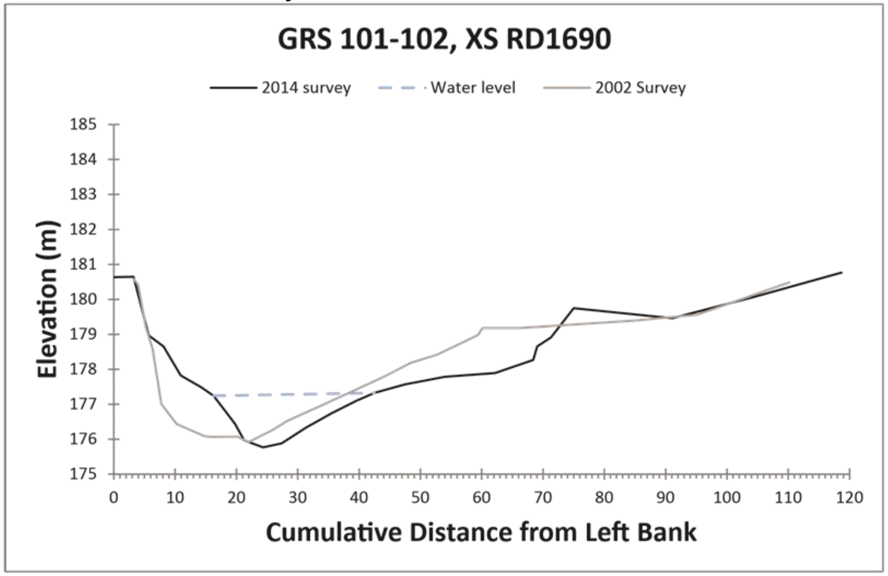
Site 1
Alignment problems with resurvey appear to plague the results at this site. Nevertheless, there are no consistent trends of aggradation (infilling) or degradation (erosion) to suggest that there is wholesale channel change. Sections RD1600 and RD1690 had a similar extent of aggradation or degradation. Section 2600 indicates significant aggradation on the left bank, but this is highly unlikely considering the left bank is the outer bank (a zone more conducive to degradation). Section RD2600 is highly skewed (GRS102) and as much as we tried to emulate this skew in 2014 it was obviously not to the same extent. Section RD2200 shows bed aggradation but it is also likely that the lack of floodplain points from the 2002 study means that the alignment is off.

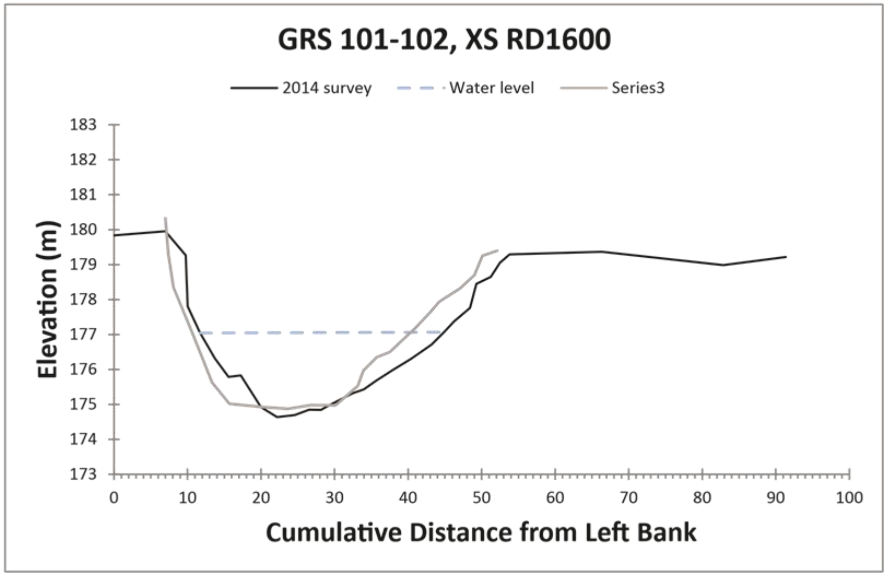
Site 2
There was close alignment between the 2002 and 2014 survey at this site suggesting very little channel change. If anything there are some minor changes in the thalweg with degradation (RD2325, RD2400) or aggradation (RD2600). Considering the similarities in bank profiles on both banks for section RD1600 the misalignment is due to higher skew on the cross section in 2002, i.e. not perpendicular.

It would be safe to suggest that there has not been any significant changes in the channel bed or banks since 2002 based on the lack of channel change at site 2, no significant changes evident in photographs from the 2002 survey compared to 2014, and little visual evidence in the field of an active channel.

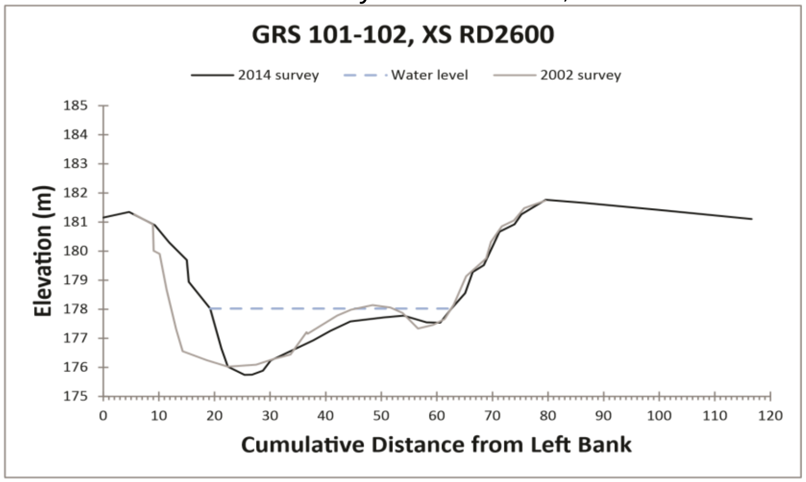
Recommendations
The lack of significant changes in channel morphology since 2002 (based mostly on Site 2) suggest the 2002 survey would be adequate for reuse. It is suggested, however, that the hydraulic models be redeveloped with a number of the misaligned cross sections removed, and be recalibrated to water levels from both 2002 as well as the 2014 survey.

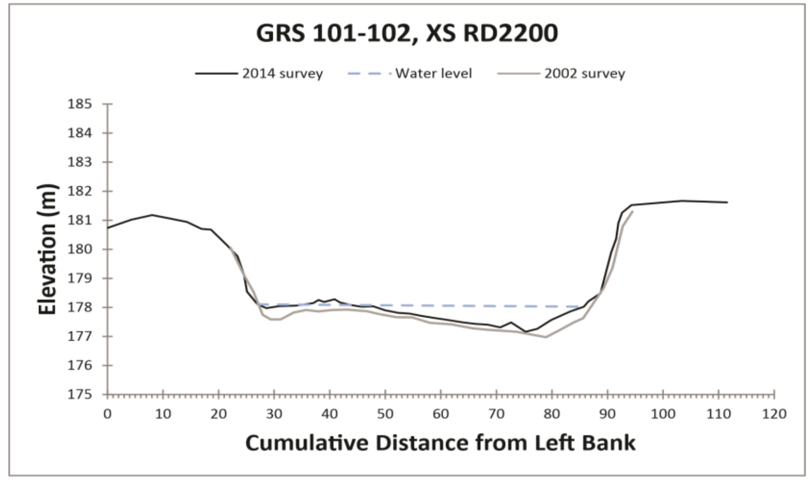
Goulburn River Survey: GRS101-102, cross sections RD1690 and RD 1600



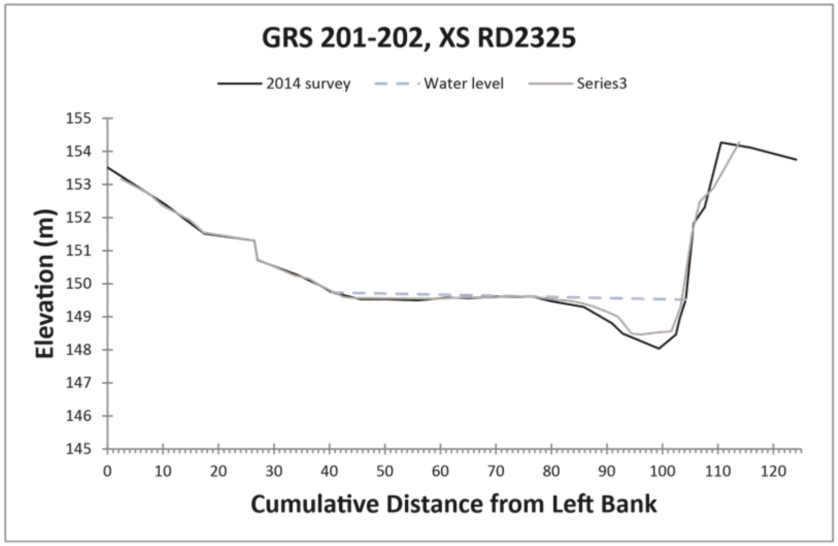


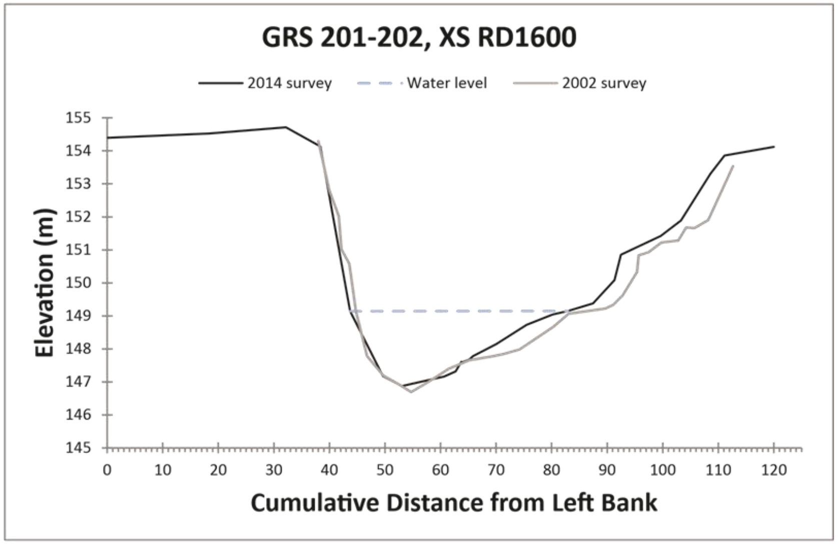
2014 Goulburn River Survey: GRS101-102, cross sections RD2600 and RD 2200



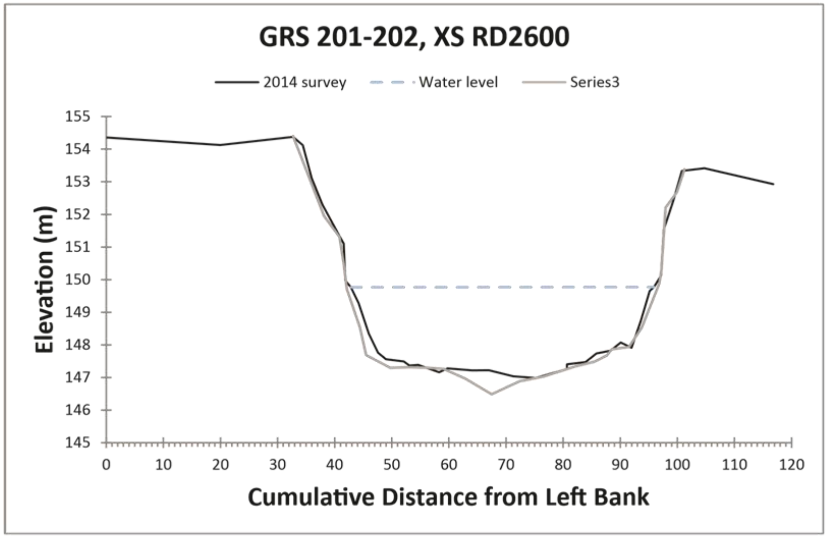


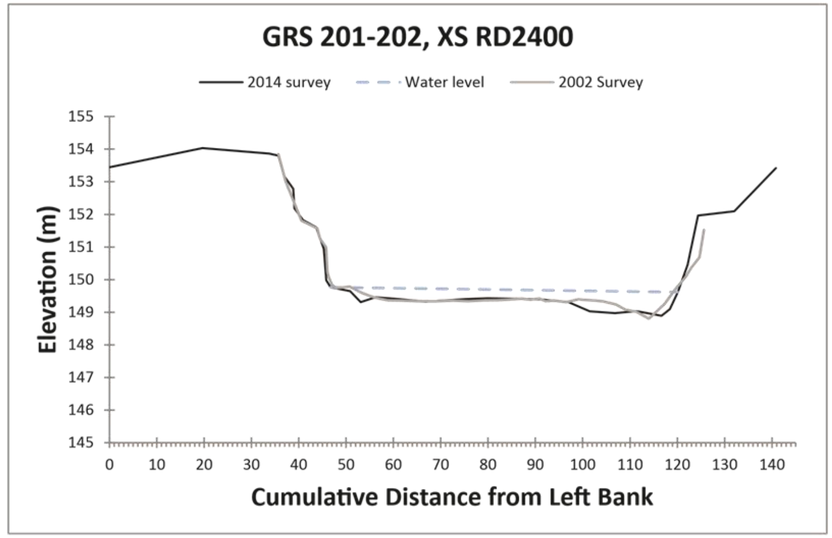
2014 Goulburn River Survey: GRS 202, cross sections RD 2325 and RD 1600

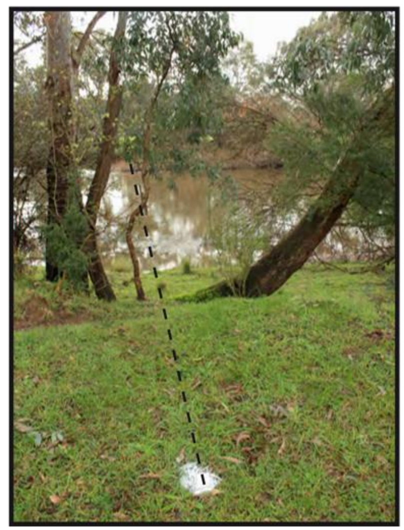




2014 Goulburn River Survey: GRS 202, cross sections RD 2600 and RD 2400







11.1 Details of hydraulic model updates

Model topography

- Substituted resurveyed sections from June 2014 (Sites 1 and 2 only)
- Checked survey plans for anomalous cross sections (e.g. oblique to flow, incomplete)
- Removed anomalous cross sections (Sites 1 and 2 only, Site 3 no anomalies found)
    - Site 1, removed 2400, 1800
    - Site 2, removed 3000, 1600 (2000 and 1800 previously removed), Section 1490 retained with caution (oblique angle, but section that is characteristic of point bar morphology)
- Added artificial data points to extend sections where they abruptly finished (presumably within dense vegetation)
- Discharges for calibration were based on data supplied by GMW and the following:
    - Site 1 - Eildon (d/s gauge) plus Acheron
    - Site 2 **–** Trawool (note that Ghin Ghin is stage height flood recording only)
    - Site 3 - Seymour

Flow profiles

- Flow scenarios (discharges) included in the model (for the benefit of calibration and familiarisation by the panel) include flows for:
    - Time of inspection
    - Time of resurvey
    - Time of original survey
    - Mean discharge
    - Annual Recurrence Intervals (up to 1 in 5 yr ARI)
- Note that high discharges (> 1 in 1 yr ARI) are of an unrealistic depth due to the extensive floodplain not being represented

Model Calibration

- Recalibrate against known water surfaces (August 2002 and June 2014)
- Water surfaces initially taken from surveyed water slope, with alteration of boundary conditions and roughness to obtain best fit
- Sensitivity analysis to be conducted

Model runs

- Models are run as mixed (sub-critical and supercritical flow regimes) for Sites 1 and 2, and sub-critical only for Site 3 (due to dominant downstream control)

Example outputs from the models are presented in Appendix 4.

12 APPENDIX 3: WETLAND COMMENCE TO FLOW ASSESSMENT

This section contains excerpts from the Streamology (2014) report: Wetland Inundation Assessment – Mid Goulburn Environmental Flows Project. The full report has been delivered to the Goulburn Broken CMA as a stand-alone document.

Introduction

This report provides a summary of the assessment of wetlands in three reaches of the mid Goulburn River between Eildon Dam and Goulburn Weir. The mid Goulburn River floodplain contains more than 300 wetlands and represent an important part of the character of the river system, as well as providing for a range of ecological and ecosystem values. CTF discharges for wetlands on the mid Goulburn River can be used to inform environmental flow recommendations and assist targeted water management operations.

The analysis aims to provide an indication of the CTF discharges for selected wetlands in the three reaches, and inform the selection of sub-bankfull discharge thresholds that could be used to target wetland watering such as with environmental water. The information in this report is to be used in conjunction with an understanding of the aims and intentions of the mid Goulburn Environmental Flows Study documentation, e.g. Issues Paper (Cottingham *et al.* 2014). This report refers to wetlands by reach as per Cottingham *et al.* (2014): Reach 1 (Eildon Dam to Yea River), Reach 2 (Yea River to Sunday Creek), and Reach 3 (Sunday Creek to Goulburn Weir).

The analysis is constrained by the use of available data, desktop analysis (i.e. no field verification), and the best approach was chosen to suit the limited time allocation (5 days). Despite these limitations the analysis is a considered and robust assessment of commence-to-flow discharge threshold that can improve confidence in environmental flow delivery to inundate wetlands of interest on the mid Goulburn River. In addition, the report identifies non-flow related issues associated with wetland watering, namely direct modification of flow pathways to wetlands previously connected to the river at lower flow levels.

Approach

Using two main tools, ArcGIS and the one-dimensional hydraulic model HEC-RAS, steps in the analysis included:

1. Linking wetlands to river chainage (distance along Goulburn River, increasing upstream)
2. Verifying CTF mAHD sill levels for ‘connector’ strings from the river to the wetland (Figure 9)
3. Linking CTF mAHD to wetlands
4. Developing elevation versus discharge relationship (rating curve) from HEC RAS models
5. Identifying water gradients upstream and downstream of HEC RAS model sites - from HEC RAS model bankfull discharge water surface slopes and LiDAR water level (water level at time of LiDAR survey, Figure 10)
6. Translating CTF mAHD into CTF Q for each site using water surface slopes and rating curve
7. Plotting cumulative area of wetlands engaged and identify points of inflection (points where beyond which increases in discharge translated to only small increases in wetland area engaged)
8. Map wetlands in different CTF Q categories based on inflection points from cumulative area for Reach 1 (0 – 3600 ML/d, 3601 – 12000 ML/d, 12001 – 20000 ML/d, > 20000 ML/d) using graduated quantities colouring and overlain on aerial imagery

Connector strings and CTF mAHD were defined for each wetland by Water Technology (2012) for Reach 1. This included 4 wetlands at the most upstream end of Reach 2. In this layer only primary wetlands (direct connector to the Goulburn River) were assessed, and as such no CTFs were available for secondary wetlands. An additional step was required for Reaches 2 and 3 at step 2 above. For these reaches wetland CTF mAHD were identified manually from analysis of the LiDAR layer. In essence a plane representing water level was increased until only connectivity between the river and wetland was visibly lost. This resulted in 34 wetlands over 13km for Reach 2 (Chainage 318 to 330 km) and 23 wetlands over 14km for Reach 3 (Chainage 262 to 275 km). A number of anabranches that could also be considered 'wetlands' were identified from the LiDAR analysis (Figure 11) but these were not classified by the wetland layer and as such have not been included here.

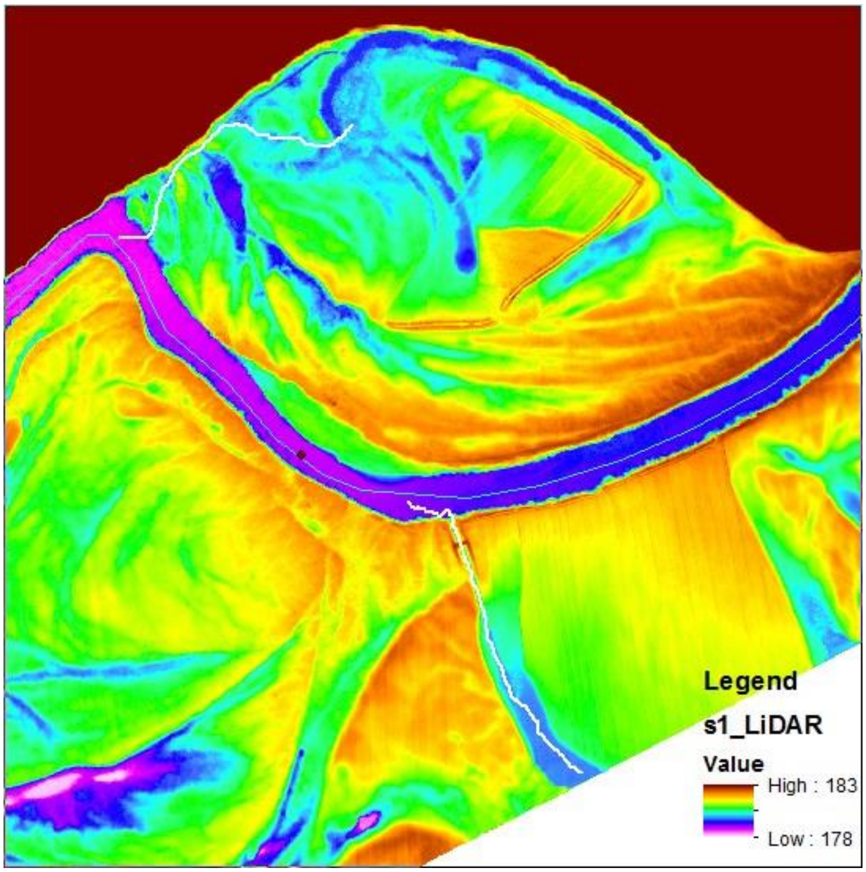


Figure 9: Example of connector string (thin white line) between the Goulburn River and wetlands e.g. 809825 to top of picture. Colour graduations represent elevation (mAHD) from low water level during time of survey (178m) to points higher than 183m as per the legend.

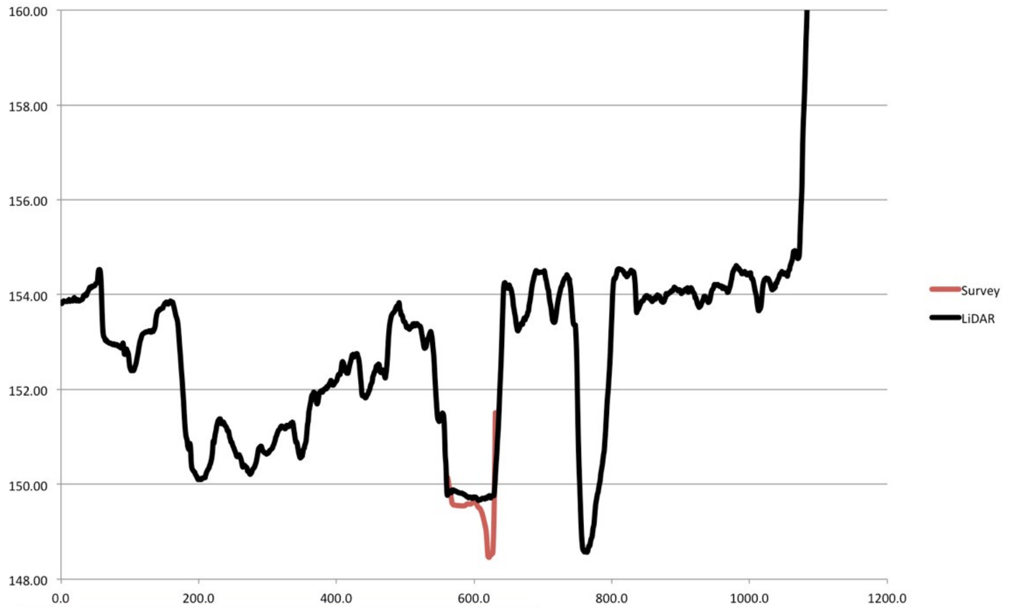
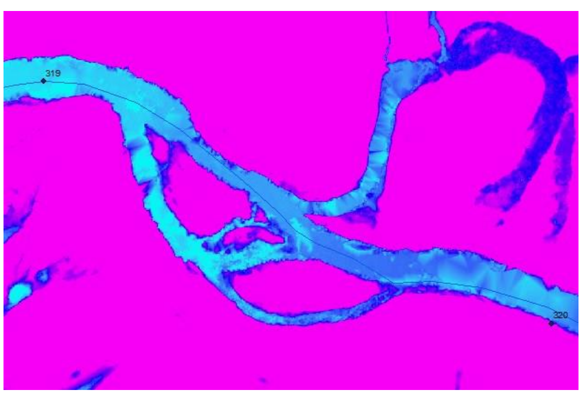
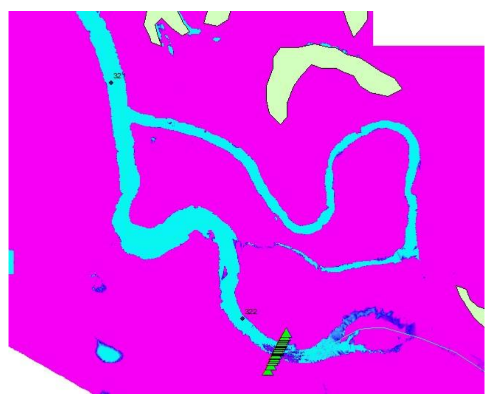


Figure 10: Cross-section 2325m (Site 1) relative to elevation (mAHD) showing multiple channels. This illustrates how the depth of the main channel captured by LiDAR (black line) is obscured by water in the bed of the channel, when compared to channel depth from one of the repeat surveys (red) conducted in 2014. This section indicates water depth at the time of survey as approximately 1.2m.



(a) note lower alternative flow path with multiple flow path entries



(b) note upper alternative

Figure 11: Anabranches that may operate as wetlands identified from the LiDAR analysis, for example, between Chainage 319 and 320 km (a) and between Chainage 321 and 322 km (b), but that are not identified on the wetland spatial layers.

Results

Wetlands appear to connect to the river channel at a range of discharges throughout the study reaches with no obvious groupings. This may represent the considerable morphologic diversity along the mid Goulburn River and the range of stages of development of anabranches and flood runners on the floodplain.

The presence of a number of wetlands at high elevations on the floodplain in Reach 1 (Figure 12) may reflect an incised channel disengaged from floodplain wetlands, but also an indiscriminate use of the wetland layer to include wetlands that are poorly connected to the current flow regime. Many higher level wetlands (in all reaches), have been formed into farm dams and are unlikely to be connected to river flows in any but the very rare events. The loss of ecological values in these wetlands is an important consideration in any attempt to reinstate via river flow.

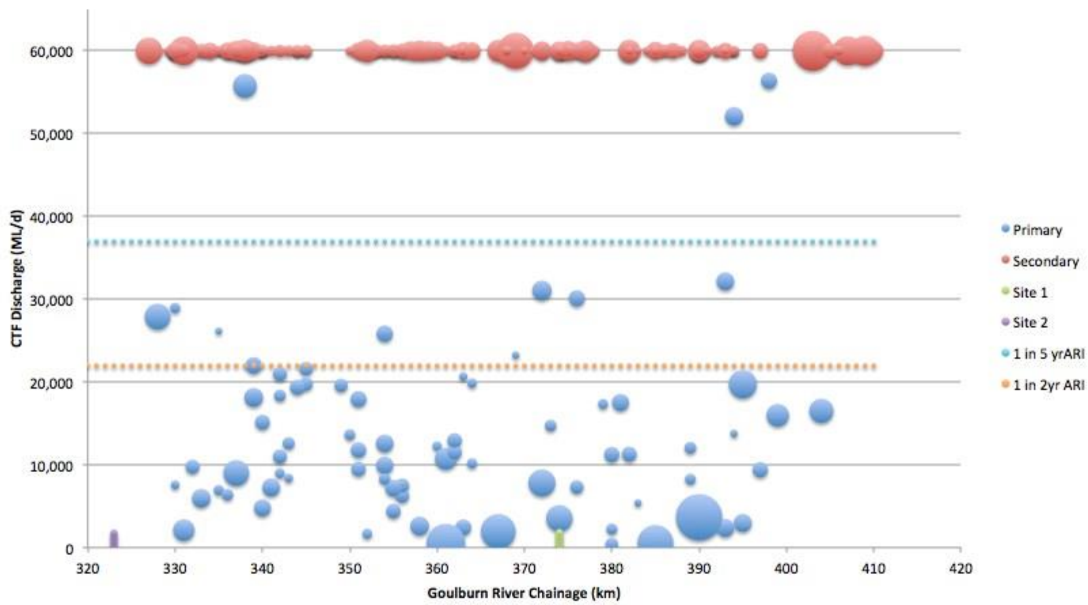


Figure 12: Reach 1 wetlands with primary connections (blue) to the Goulburn River and their CTF discharges relative to their river chainage. Wetlands with secondary connections (red) are displayed with a nominal CTF, as these were not available. Bubble size represents relative wetland size.

An increasing number of wetland sills are engaged as discharge in the mid Goulburn River increases and this can be related to the area of these wetlands as defined by the wetland spatial layer: defined as Cumulative Area. For Reach 1 wetland type was also identified (Figure 13). In Reach 1 points of inflection (e.g. top of high gradient increases in cumulative area) occur at discharges of approximately 3,600 ML/d, 12,000 ML/d and at approximate floodplain inundation (roughly 20,000 ML/d). Beyond a discharge of 32,000 ML/d little wetland engagement occurs until more than 50,000 ML/d is reached, highlighting that the upper few wetlands are very rarely engaged by river flow.

For Reaches 2 and 3 the total cumulative area engaged (Figure 14) indicates that wetlands in Reach 3 are inundated by lower discharges. This reflects a number of anabranches that have been delineated as wetlands in Reach 3, and the fact that these anabranches are engaged at very low levels. This includes one wetland that is defined as the main channel by the chainage layer between chainage 266 and 269m. The low discharges may also reflect the role of Goulburn Weir in producing a backwater effect and pushing water into wetlands at lower discharges. The role of anabranches in providing wetland values at low discharges requires further consideration and improved consistency in the delineation of low level anabranches, as wetlands should reflect this.

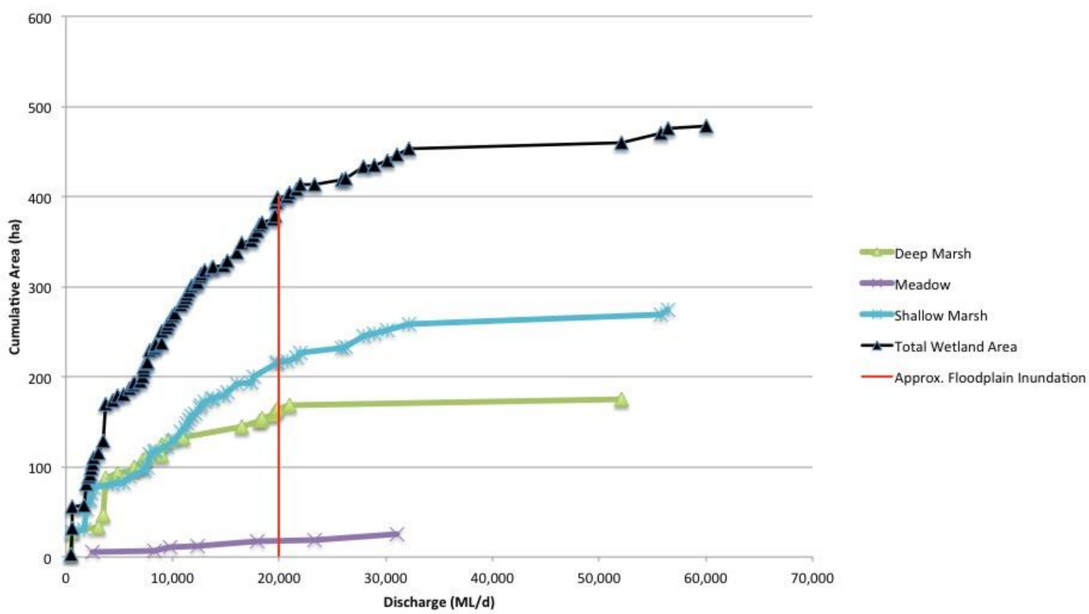


Figure 13: Reach 1 cumulative area of wetlands relative to the discharge at which those wetlands are engaged for all wetlands (dark blue) and by type: Shallow Marsh (light blue), Deep Marsh (green) and Meadow (purple). Approximate floodplain inundation discharge is labelled in red.

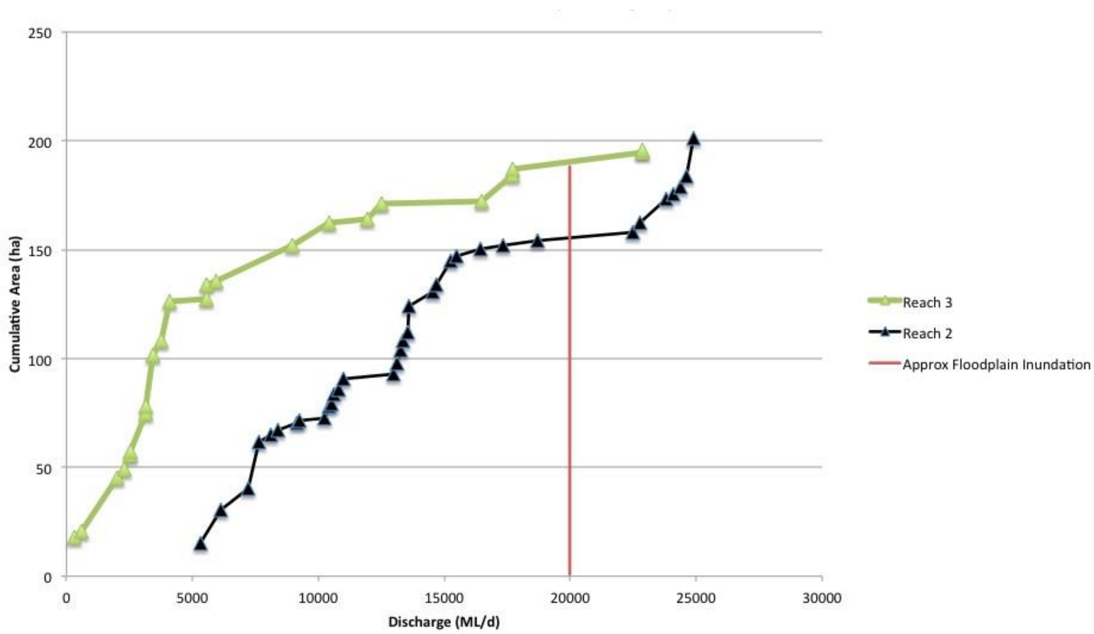


Figure 14: Reach 2 and 3 cumulative area of wetlands relative to the discharge at which those wetlands are engaged for all wetlands assessed. Approximate floodplain inundation discharge is labelled in red.

Modifications to CTF levels

Direct modifications to sill levels and connectors, such as through the construction of tracks and levee construction, has a significant impact on the inundation levels of many wetlands (Figure 15). This was not a focus of this investigation but is likely to play such a significant role that it requires further consideration. The influence of these modifications, such as a 1m high track through a connector, could lead to CTF levels for inundation of more than 10,000 ML/d greater than otherwise identified. One of the main uncertainties not ascertainable from a desktop study is whether some of these obstructions have culverts that enable flow to pass through. Nevertheless, the modification of connectors appears to be so prevalent that it could potentially be having a greater impact on the inundation frequency of wetlands than changes in flow.

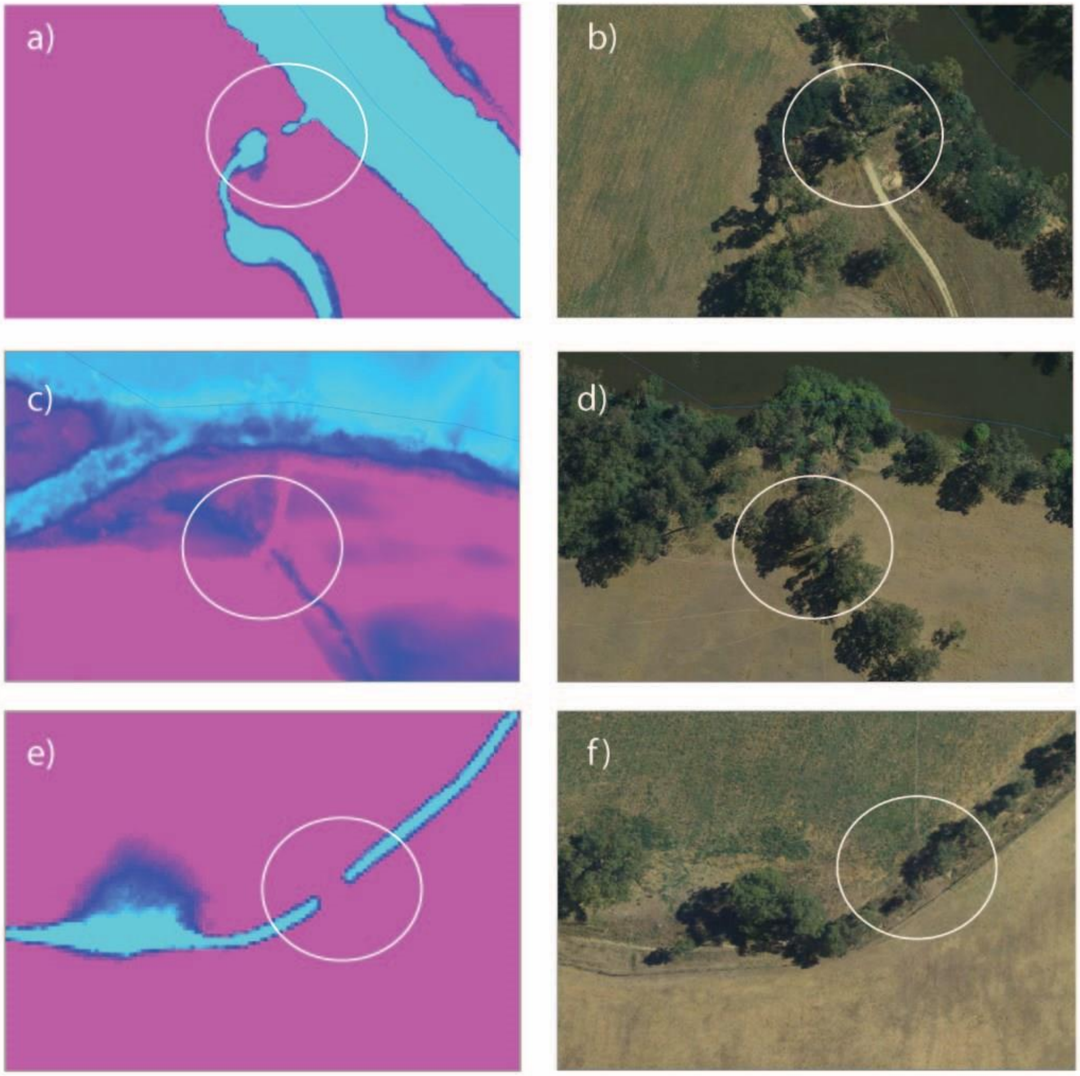
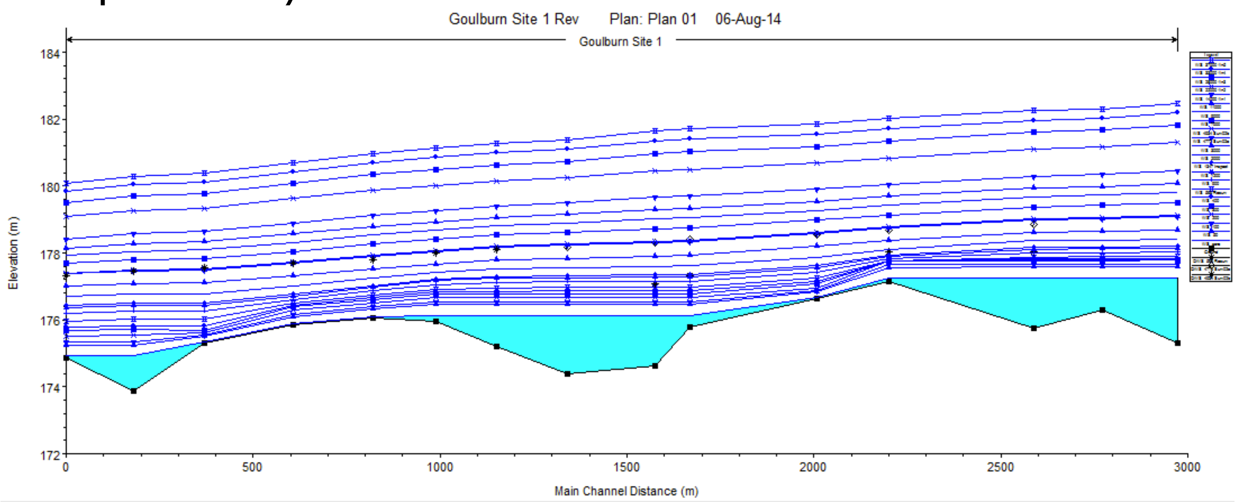


Figure 15: Significant changes to CTF levels occurs as a result of direct modification in many ways such as through: road construction (a-b, LiDAR-aerial image), the construction of levees to reduce inundation of land (c/d) and cattle tracks (e-f). In the LiDAR images (left) light blue represents low elevations and pink the highest.

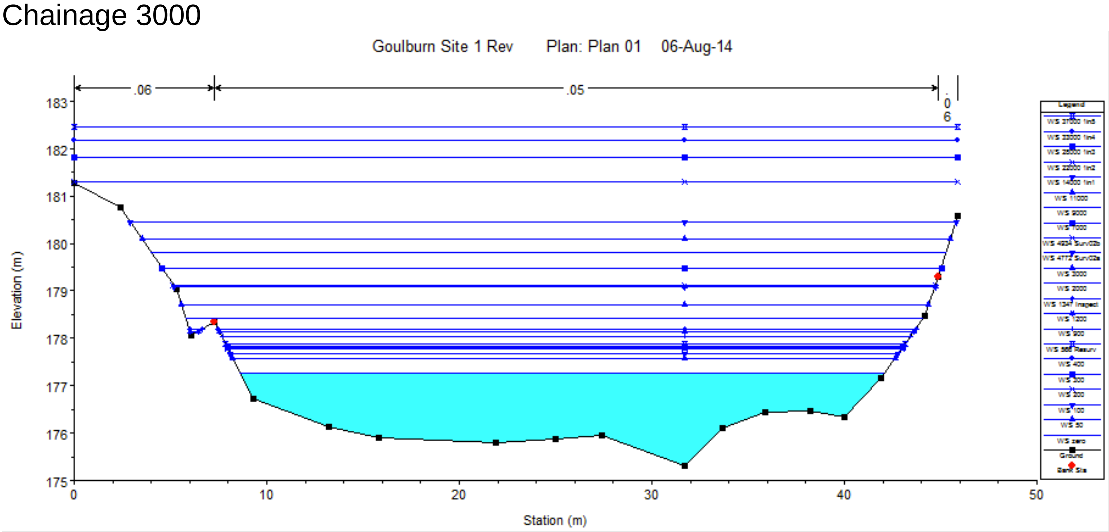
13 APPENDIX 4: EXAMPLE HEC-RAS JUSTIFICATIONS FOR ENVIRONMENTAL FLOW RECOMMENDATIONS

Water levels at various discharge along the longitudinal section at Site 1(gauged data Eildon plus Acheron)

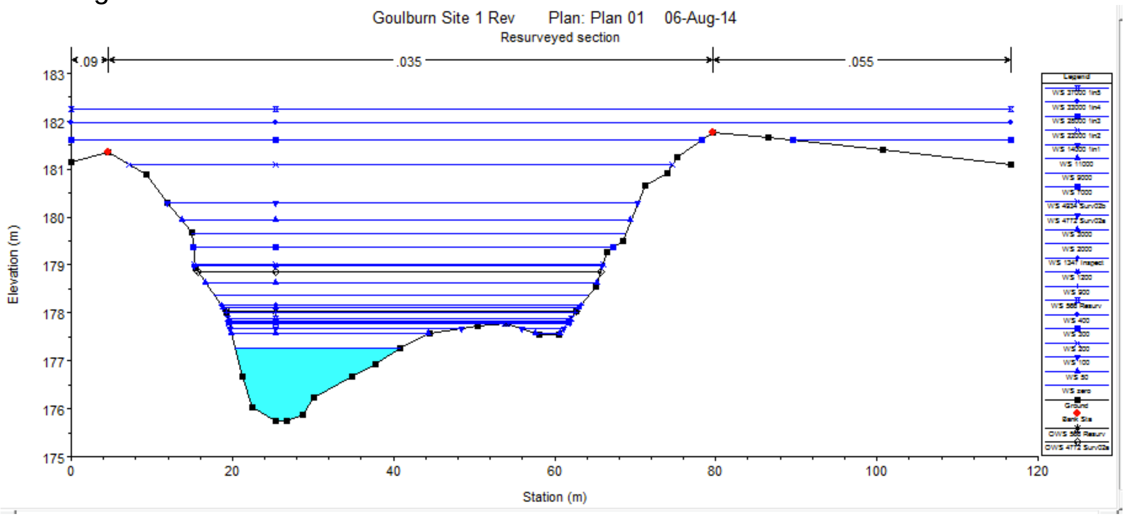


Example cross sections at Site 1

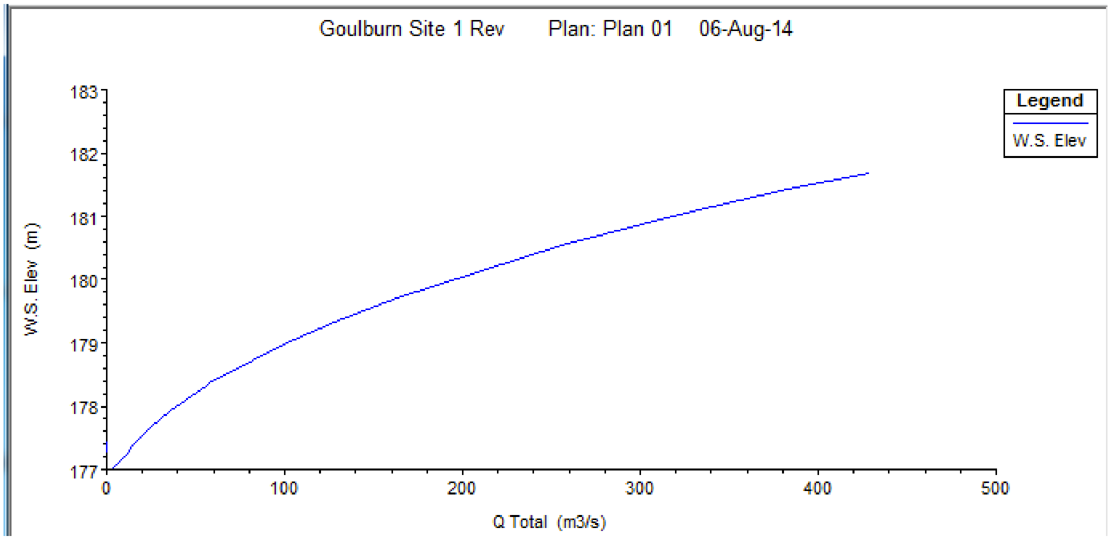
Chainage 3000



Chainage 2600



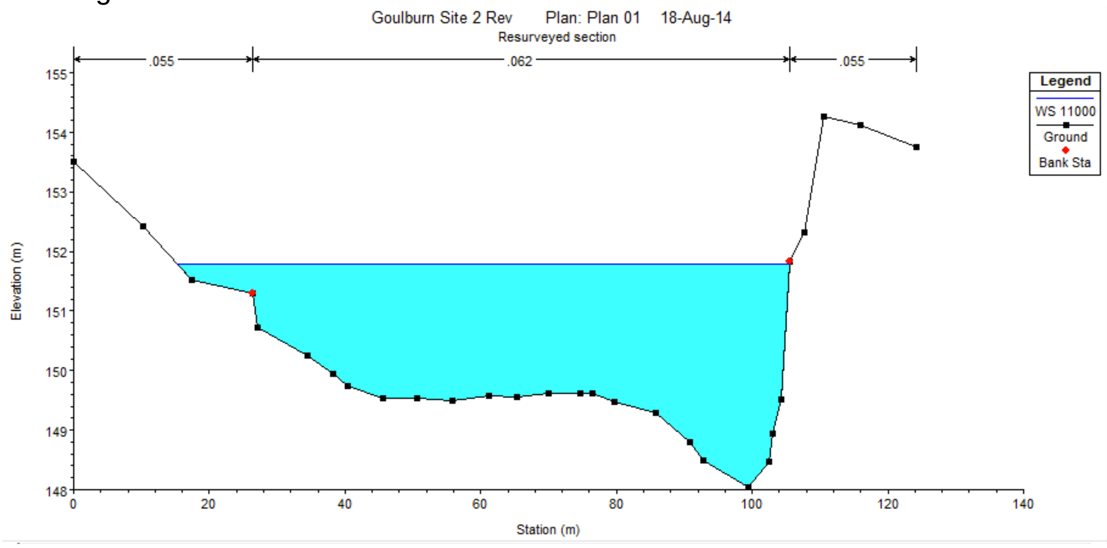
Rating curve for Site 1



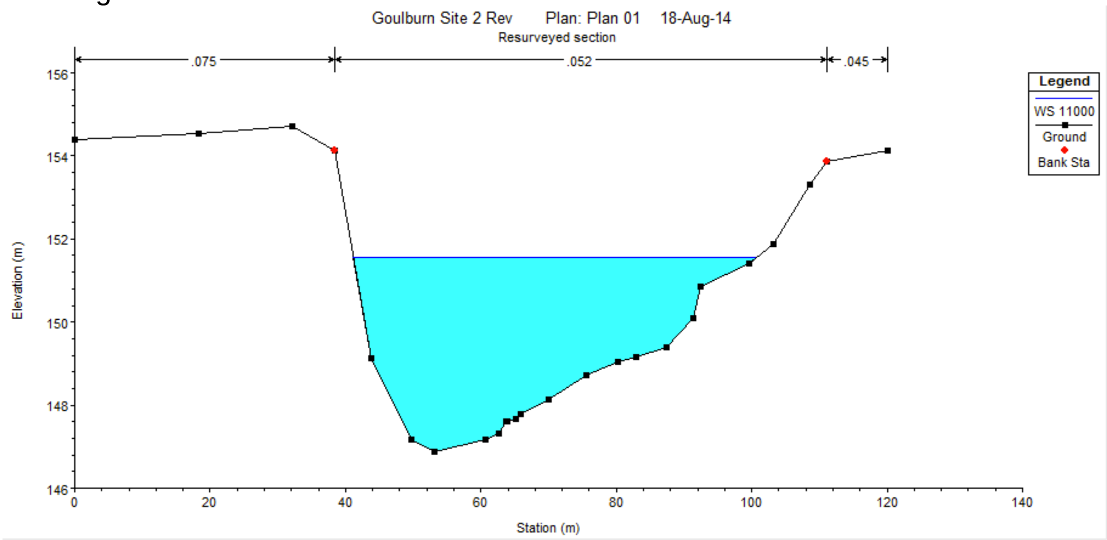
Example: Discharge required to provide 0.5 m depth over bench

Reach 2

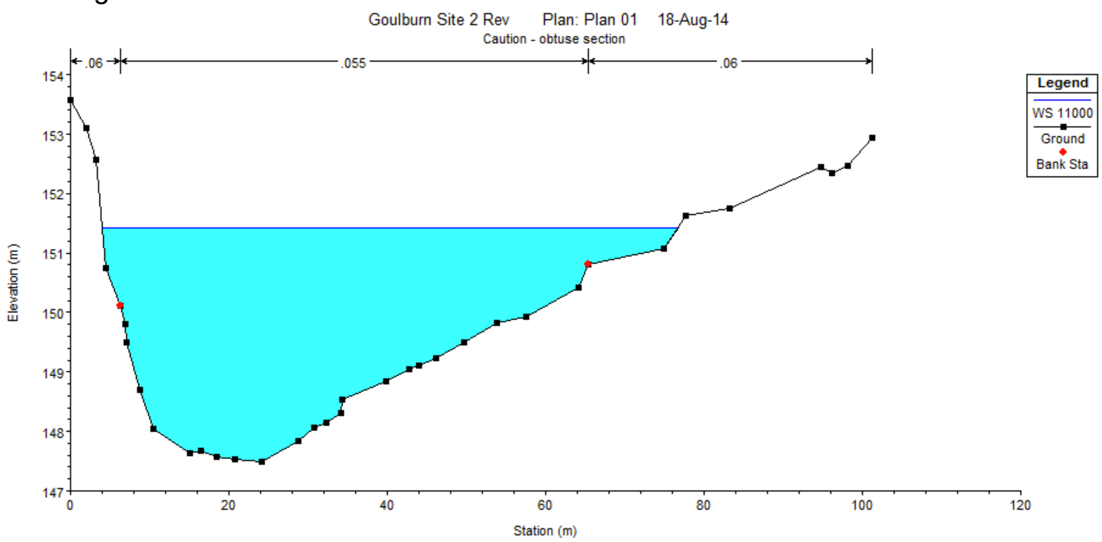
Chainage 2325



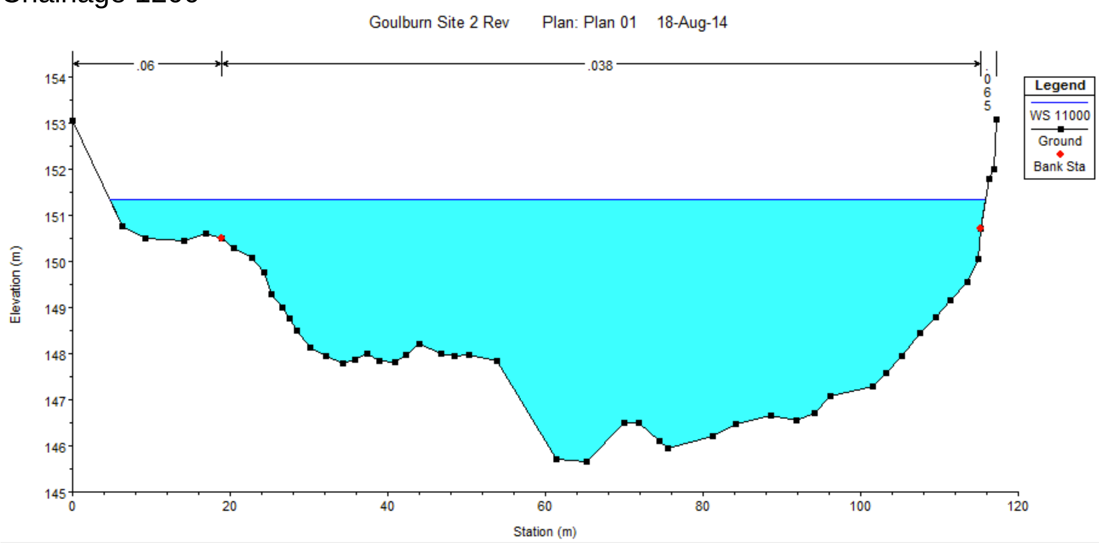
Chainage 1600



Chainage 1490

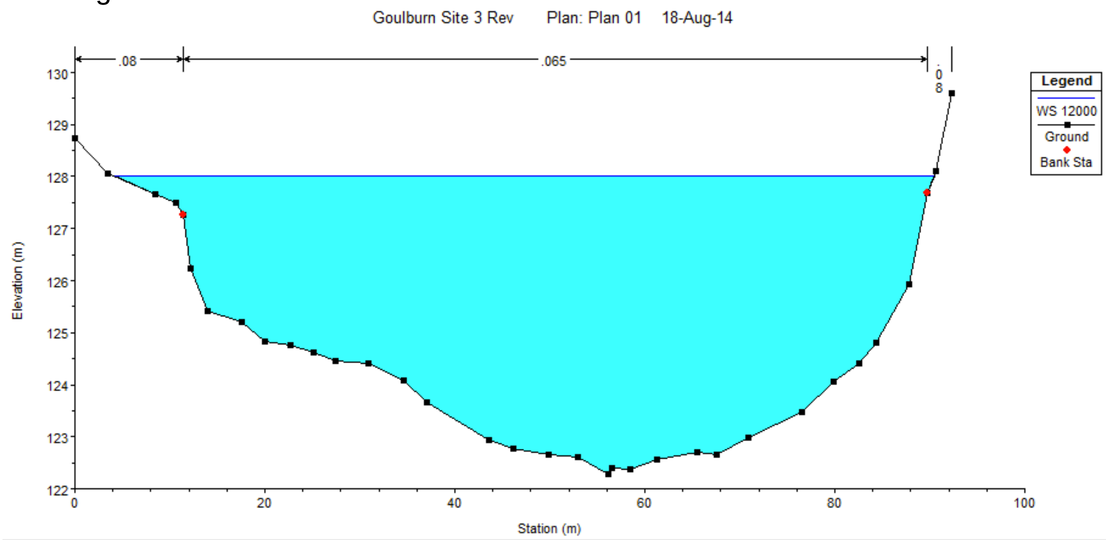


Chainage 1200



Reach 3

Chainage 1400



Chainage 1200