Mid Goulburn River Environmental Flows Study: Issues Paper

Prepared for the Goulburn-Murray Water Connections Projectand the Goulburn-Broken Catchment Management Authority

by

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Executive summary

The Victorian government is to prepare an environmental watering plan for northern Victoria, including the Goulburn River, as part of its commitment to the Murray Darling Basin Plan. While environmental flows have, and continue to be, delivered to meet ecological objectives set for the Goulburn River below Goulburn Weir (the lower Goulburn River), previous objectives developed in 2003 for the mid Goulburn River (Lake Eildon to Goulburn Weir) 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. The 2003 study also noted the issue of cold water releases from Lake Eildon in summer and their potential to affect the distribution of native fish.

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. This includes an assessment of constraints to the delivery of environmental water and whether the constraints can be ameliorated with works and measures. This information collected since 2003 provides a valuable basis from which to review the ecological objectives and reconsider environmental watering recommendations for the mid Goulburn River for inclusion in the northern Victoria long-term watering plan. The objectives for this project are to undertake a flow study that will develop a set of environmental objectives for the management of water-dependent assets and values associated with the mid Goulburn River, and flow recommendations aimed at meeting the stated environmental objectives. The environmental objectives and flow recommendations will be designed to:

- Maximise environmental outcomes that might be possible given the constraints such as unseasonal flows (year-round) and cold water releases from Lake Eildon (summer-autumn); and
- Be compatible with existing trout fishing opportunities.

This Issues Paper is a key document required by the FLOWS method adopted to evaluate environmental watering requirements along the Goulburn River. Ultimately, environmental flow recommendations will be developed for the three study reaches:

1. Goulburn River from Lake Eildon to the Yea River;
2. Goulburn River from Yea River to Sunday Creek (Seymour);
3. Goulburn River from Sunday Creek (Seymour) to Goulburn Weir.

The flow regime of the Goulburn River is variable, both annually and seasonally, and is modified by the following processes:

- The presence and operation of Lake Eildon;
- Diversion of water at Goulburn Weir from the Goulburn River to the East Goulburn Main Channel and the Stuart Murray Canal to supply the Goulburn Murray Irrigation District and its associated irrigation supply and drainage schemes;
- Diversion of water to Waranga Basin 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 (yet to be operated).

A previous environmental flow study conducted in 2003 included flow recommendations related to upper limits to baseflow in summer-autumn and inundation of floodplain wetlands in winter spring. The upper limits were in the order of 1,000 ML/d and 3,000 ML/d and were designed to preserve important habitat such as slackwater (shallow, low flow) areas for invertebrates and fish and to reduce mean reach velocity to below 0.4 m/s to support macrophytes. However, these recommendations were not implemented due to the limitations they would place on the delivery of water to meet irrigation demand (acknowledged as a constraint at the time). As a result, flows defined in the Bulk Entitlement for the Goulburn system have since remained unchanged, being a minimum flow requirement of 120/250 ML/d from Lake Eildon.

In considering potential changes to the flow regime as part of the current study, the project team was guided by the main objectives contained in the Goulburn Broken Regional Waterway Strategy:

- 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;
- The values associated with Heritage Rivers will be maintained or improved;
- Wetlands with formally recognised significance are maintained or improved;
- Maintain and improve water quality in priority water supply catchments;
- Maintain and improve waterways and wetlands of high community value.

Other initiatives such as the Northern Region Sustainable Water Strategy, the Goulburn-Broken Biodiversity Strategy and policies such as the Commonwealth Environment Protection and Biodiversity Conservation Act and the Victorian State Environment Protection Policy (Waters of Victoria) were also influential in terms of identifying flow-related ecosystem objectives. The project team also noted that the Goulburn River from Lake Eildon to Yea is known and valued for recreational fishing, particularly trout fishing. Given this, the project team will look to emphasise commonalities, where possible, between watering needs of trout and that of other ecosystem attributes as flow recommendations are developed.

This Issues Paper considers 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 but one. Conceptual models and reviews of the ecological effects of large dams were used by the project team to identify changes to ecosystem structure and function along 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;
  - Changes to channel and floodplain morphology;
- Second order impacts
  - Altered patterns of primary production;
  - Altered aquatic and riparian vegetation patterns;
- Third order impacts
  - Altered flora and fauna species diversity.

The main factors considered likely to restrict our ability to achieve the overarching objectives stated in the RWS and elsewhere 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 sediment supply.

For the purposes of this study, it was 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. Sediment trapping behind Eildon Dam will also continue. Thus the main impacts that can be overcome to some degree is the reduced connection between the river and wetland habitat and altered riparian and floodplain vegetation patterns, assuming that the constraints on flooding private land as well as confounding factors such as grazing and physical impacts form 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 habitat availability and quality;
- Maintenance of riffle habitat (Reach 1), 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 channel diversity and associated habitat for organisms such as fish.
- Contaminant (e.g. 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.

The nature of the flow-related threats and the environmental flows required to achieve ecological objectives will be considered in greater detail by the project team in subsequent steps of the FLOWS method. Attention will focus on the ecosystem values and processes affected by the current flow regime, but recognising that a number of limitations and constraints on the flow-related objectives exist that affect what realistically be achieved in meeting objectives are likely to persist in the future.

CONTENTS

1 INTRODUCTION 1
1.1 BACKGROUND 1
1.2 PROJECT OBJECTIVES 1
1.3 GENERAL APPROACH 1
2 STUDY AREA 3
3 WATER SYSTEMS MANAGEMENT 6
3.1 OVERVIEW 6
3.1.1 Current environmental (minimum flow) requirements 6
3.2 SUMMARY OF THE CURRENT FLOW REGIME 6
4 REGIONAL POLICIES, STRATEGIES AND OBJECTIVES 13
4.1 GUIDING VISION AND OBJECTIVES 13
4.2 RIVERINE ECOSYSTEM ASSETS, VALUES AND THREATS 14
4.3 OVERVIEW OF POTENTIAL ECOSYSTEM EFFECTS OF LARGE DAMS 15
5 SUMMARY OF ECOSYSTEM ATTRIBUTES AND RATIONALE FOR FLOW-RELATED ECOLOGICAL OBJECTIVES 19
5.1 GEOMORPHOLOGY 19
5.1.1 Physical characteristics of the Mid Goulburn River and study reaches 19
5.1.2 Geomorphic and physical habitat condition 20
5.1.3 Change in channel morphology 21
5.1.4 Changes to sediment characteristics and movement 22
5.1.5 Other physical habitat considerations 23
5.1.6 Basis for assigning geomorphology objectives 25
5.1.7 Non-flow related issues 31
5.2 WATER QUALITY 33
5.2.1 Summary of condition 33
5.2.2 Other potential sources of poor water quality 35
5.2.3 Environmental objectives for water quality 40
5.3 RIVERINE VEGETATION 41
5.3.1 Overview 41
5.3.2 River Channel 41
5.3.3 The riparian zone 44
5.3.4 Wetlands on the Floodplain 45
5.3.5 Floodplain Vegetation 49
5.3.6 Summary of vegetation condition and issues 51
5.3.7 Environmental objectives for riverine vegetation 53
5.3.8 Non-flow related issues 53
5.4 INVERTEBRATES 54
5.4.1 Summary of condition 54
5.4.2 Key invertebrate species that support fisheries 55
5.4.3 Potential relationship to the regulated flow regime 56
5.4.4 Summary of macroinvertebrate condition and issues 57
5.4.5 Environmental objectives for macroinvertebrates 58
5.5 NATIVE FISH 59
Native fish populations are highly valued across the Goulburn River catchment, both in terms of their biodiversity-ecological value (including presence of threatened and icon species) and for their recreational fishing value. *59*
5.5.1 Current condition of the fish community 59
5.5.2 Fish distributions between Lake Eildon and Goulburn Weir 59
5.5.3 Summary of native fish condition and issues 62

5.5.4 Environmental objectives for native fish 63
5.5.5 Other issues relevant to native fishes in the Goulburn River between Lake Eildon and Goulburn Weir 65
5.6 TROUT 65
5.6.1 A summary of condition and major threats (flow and non-flow related) – to trout population and recreational fisheries of the Mid Goulburn River..... 65
5.6.2 A summary of potential relationships to the flow regime 67
5.6.3 Flow requirements to maintain the trout fishery..... 67
5.6.4 Summary of other relevant management issues (e.g. non-flow related and strategic) 68
5.7 SUMMARY OF ECOSYSTEM ISSUES AND OBJECTIVES AND RELATED FLOW COMPONENTS 68

6 CONSIDERATIONS FOR DEVELOPING ENVIRONMENTAL FLOW RECOMMENDATIONS 75

7 REFERENCES 76

8 APPENDIX 1: OVERVIEW OF THE VICTORIAN FLOWS METHOD 83

9 APPENDIX 2: MODELLING OF THE CURRENT AND UNIMPACTED FLOW SERIES FOR THE GOULBURN RIVER 85

10 APPENDIX 3: BIOLOGICAL OBJECTIVES RELEVANT TO THE MID GOULBURN RIVER 115

FIGURES

Figure 1: Social ecological systems of the Goulburn-Broken region (from GB CMA 2013). 3
Figure 2: Sites visited along the Goulburn River between Lake Eildon and Goulburn Weir. See Table 1 for site locations. 5
Figure 3: Flow duration curves for the modelled current and unimpacted flow series in Reaches 1-3 (see also Appendix 2). 8
Figure 4: Flow duration curves showing seasonal patterns for modelled current and unimpacted conditions in Reach 1. Flow duration curves for Reach 2 and 3 are presented in Appendix 2; each show a similar pattern to that for Reach 1. 9
Figure 5: Plots of unimpacted mean daily flow for each month in very dry through to wet climatic conditions in Reach 1 (see Appendix 2 for Reach 2 and 3 plots). 10
Figure 6: Plots of current mean daily flow for each month in very dry through to wet climatic conditions in Reach 1 (see Appendix 2 for Reach 2 and 3 plots). 11
Figure 7: Partial series (annual recurrence intervals (ARI), as 1 event per X years) of large flow events under the unimpacted and current flow regime. 12
Figure 8: Conceptual model of a meander zone (from Whittington et al. 2001). 15
Figure 9: Interdisciplinary conceptual model of the contemporary starting point for restoring instream and riparian structure and function (reproduced with permission, Mika et al. 2010). 17
Figure 10. Topographic descriptions of the mid Goulburn River (Victorian Water Resources Online, updated May 2008). 20
Figure 11. Channel contraction as evident from (a) vegetated bars (near Trawool), (b) benches (Molesworth), and (c) islands (downstream of Thornton) (May 2014). (Photos: Geoff Vietz) 21
Figure 12: Little change in bank morphology over the last decade as evident at Site 2 based on photographs from (a) August 2002, and (b) June 2014 showing intact bank vegetation and little to no active erosion. (Photos: Geoff Vietz). 21
Figure 13: Little channel change between the survey from the 2002 survey (light line) and 2014 survey (dark line) based on cross sections taken for environmental flow studies. 22
Figure 14: Block bank reducing inflows to a flood runner immediately upstream of Horseshoe Lagoon (Reach 2). (Photo: Geoff Vietz). 22
Figure 15: (a) Armoured coarse-grained layer overlying the finer gravels, sands and silts (survey Site 1, photo June 2014), and silts within and on a gravel bar (near Horseshoe lagoon, photo May 2014). (Photos: Geoff Vietz). 23
Figure 16: Desnagging in the Goulburn River, 1879 (State Library of Victoria). 24
Figure 17: Evidence of greatly reduced riparian zone pre-1940s (State Library of Victoria). 24
Figure 18: (a) Riffles and runs common (Thornton Reserve), (b) extensive pools (Killingsworth), (c) Reach 1 gravel bed and bars (Molesworth), and (d) the finer-grained sediments (silts, sands, smaller gravels) underlying the armoured gravel and cobble bed (Thornton Reserve). (Photos: Geoff Vietz). 30
Figure 19: (a) Valley margins occasionally confining channel and diverse floodplain topography with floodrunners and billabongs (Trawool Valley), (b) Reach 2 bedrock confined section (at boulder island near Horseshoe Lagoon), (c) an extensive sluggish pool (Trawool bridge), and (d) fine-grained sediment in lower velocity reaches (near Horseshoe Lagoon). 30
Figure 20: Reach 3 characteristics including (a) sluggish reaches such as in the Goulburn weir pool, (b) reaches of intact vegetation and good wood loads, (c) some localised erosion (mainly corresponding to a lack of riparian vegetation, and (d) extensive inset benches (Mitchelton). (Photos: Geoff Vietz). 31
Figure 21: Time series of monthly DO (mg/L), temperature (°C) and storage level in the Goulburn River at Eildon (Reach 1), 1990-2014 (from DEPI, http://data.water.vic.gov.au/monitoring.htm; storage level data courtesy of G-MW). 37
Figure 22: Time series of monthly DO (mg/L) and temperature (°C) in the Goulburn River at Trawool (Reach 2), 2005-2014 (from DEPI, http://data.water.vic.gov.au/monitoring.htm). 38

Figure 23: Time series of continuous DO (mg/L) and temperature (°C) in the Goulburn River at Tahbilk (Reach 3), 2008-2014 (from DEPI, http://data.water.vic.gov.au/monitoring.htm). 39
Figure 24: Abundant macrophytes at three sites upstream of the Acheron River. 43
Figure 25: Changes in floodplain woodland. 51
Figure 26: Riparian condition scores for sites along the mid Goulburn River (from Jansen et al. 2004). 52
Figure 27: Simple representation of trout survival and population dynamics in the mid Goulburn River. 67
Figure 28: Overview of the FLOWS method (from SKM 2012). 84
Figure 29: Daily timestep Source model of the main stem of the Goulburn River 86
Figure 30: Flow duration curve for the whole period of record for each reach. 89

TABLES

Table 1: Sites visited along the mid Goulburn River (May 2014). 4
Table 2: Environmental values associated with the mid Goulburn River (modified from GB CMA 2013 and DEPI 2013). 14
Table 3: ISC scores for the Mid Goulburn River reaches (from DEPI 2013). 20
Table 4: Reach summary of geomorphic character, condition and threats. 27
Table 5: Flow requirements for geomorphic objectives. 32
Table 6: Waters of Victoria water quality objectives for rivers and streams (from State of Victoria 2003, Goudy 2003). 33
Table 7: Nutrient objectives for rivers and streams (Tiller and Newall 2003). 33
Table 8: Summary of water quality data for the mid Goulburn River for the period January 2000 to December 2013, inclusive (data courtesy of DEPI; http://data.water.vic.gov.au/monitoring.htm). .. 34
Table 9: Condition and threats related to water quality in each study reach. 40
Table 10: Flow requirements for water quality objectives. 41
Table 11: ISC3 scores for Streamside Zone. For the sub-index score, the seven indicators are weighted individually and then summed. 45
Table 12: Floodplain and wetland characteristics for Reaches 1, 2 and 3. 46
Table 13: Listed wetland plants recorded during IWC assessments of February 2012. 47
Table 14: Wetland Condition scores (IWC) for 18 Wetlands in Reaches 1, 2 and 3 (Data courtesy of DEPI). 48
Table 15: IWC Sub-index scores: mean (max is 20), CV and range. 48
Table 16: Reduction in flood frequency (partial series analysis) (Appendix 2). 50
Table 17: Flow-related environmental objectives for riverine vegetation. 53
Table 18: Goulburn Valley distribution of sample sites and values of derived variables (from Davies et al. 2012). 55
Table 19: The percentage presence of shrimp, yabbies and dragonflies and damselflies collected from RBA Sweep samples in the mid Goulburn (downstream of Eildon) and lower Goulburn (downstream of the Goulburn weir) between 1998 and 2011 (unpublished EPA Victoria data; n= number of sampling events). 56
Table 20: Reach summary of the condition of macroinvertebrate populations 57
Table 21: Flow requirements for macroinvertebrate objectives. 58
Table 22: Relative abundance of fish species found in the mid Goulburn River between Lake Eildon and Lake Nagambie (from Kearns et al. 2014). Note: the comparison is for the relative abundance for individual species between reaches; it does not infer relative abundance between species. 60
Table 23: Abundance of fish species within guilds predicted to occur in the Goulburn River, and numbers of individuals of each species captured during the recent Sustainable Rivers Audit from 2005-09 (from Lieschke et al. 2014). 61
Table 24: Relative condition of native fish in each reach of the mid Goulburn River. 62

Table 25: Summary of flow requirements to achieve native fish objectives. 64
Table 26: Summary of flow-related ecosystem objectives and associated flow components......... 70
Table 27: Lake Eildon GSM releases.. 87
Table 28: Average Annual Flows (GL/yr) 88
Table 29: Median rates of rise and fall (of previous day's flow) of the unimpacted flow series....... 89

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1 INTRODUCTION

1.1 Background

The Murray Darling Basin Plan requires the Victorian government to prepare a long-term watering plan for northern Victoria by 2015. The watering plan is to include ecological objectives and environmental water requirements for priority water-dependent environmental assets. As part of their response, 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 northern Victoria long-term watering plan, building on previous environmental flow recommendations for the Goulburn River below Lake Eildon developed in 2002/03 (Cottingham et al. 2003). While environmental flow recommendations have previously been developed for the mid Goulburn River below Lake Eildon to Goulburn Weir, 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 surveys 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

As stated in the project brief, the objectives of this project are to undertake a flow study that will develop a set of environmental objectives for the management of water-dependent assets and values associated with the mid Goulburn River, and 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 team will apply the general steps outlined in the Victorian FLOWS method (SKM 2012, Appendix 1), which provides the basis from which to review existing environmental flow objectives and 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.

There are three key documents that support the FLOWS method:

1. 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.
2. An issues paper that considers:
    a. The condition of assets and values associated with the rivers that are the focus of the study;
    b. System hydrology including comparison of current and natural (i.e. unimpacted by water resource development)[1] streamflow regimes and potential future water demands;
    c. Key degrading factors, focussing on flow-related and non-flow related issues;
    d. Current threats to the environmental assets and values resulting from consumptive water use;
    e. The implications of current water resource management; and
    f. Flow-related ecosystem objectives consistent with the Regional River Health Strategy.
3. 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.

This Issues Paper is the second of the three key documents to be delivered in applying the FLOWS method to the mid Goulburn River. It is supported by a site report (Peter Cottingham & Associates 2014) and key published literature and technical reports (reported as an annotated bibliography, unpublished) relating to the environmental flow regime of the river. With the completion of this Issues Paper, the activities and outputs described in items 1 and 2 above have been completed, providing the basis for developing flow recommendations that will be presented in a final report, as identified in item 3 above. The process of developing flow recommendations is often an iterative process, as the flows required to meet objectives for river attributes (e.g. fish, macroinvertebrates, geomorphology) are refined and integrated. This process and future activities that will strengthen the scientific underpinning of the recommendations will be described in the final report.

[1] The 'natural' 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.

2 STUDY AREA

The project study area includes the Goulburn River, including its floodplain and distributary channels, downstream from Lake Eildon to Goulburn Weir. The river receives releases from Lake Eildon and inflows from tributaries such as the Acheron and Yea rivers, and numerous creeks (e.g. Snobs Creek, UT Creek, King Parrot Creek, Sunday Creek, Whiteheads Creek). A general overview of features of the Goulburn River catchment is provided in the Regional Waterway Strategy (GB CMA 2013), including the identification of 'social-ecological' zones; the study area for this project is set predominantly in the upland slopes' and commuting hills' zones therein (Figure 1).

Environmental watering recommendations will be developed for three study reaches (Peter Cottingham & Associates 2014, Table 1, and Figure 2):

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

Developing flow recommendations for each reach will be assisted by the use of a 1-D hydraulic model (HECRAS, USACE 2002) based on cross-section surveys at the following sites (Cottingham et al. 2003, Cottingham et al. 2014, and Vietz Consulting 2014) (positions for each are marked as '2003 survey site' in Table 1 and Figure 2):

- Reach 1: Goulburn River downstream of Alexandra;
- Reach 2: Goulburn River at Kerrisdale;
- Reach 3: Goulburn River at Northwood.

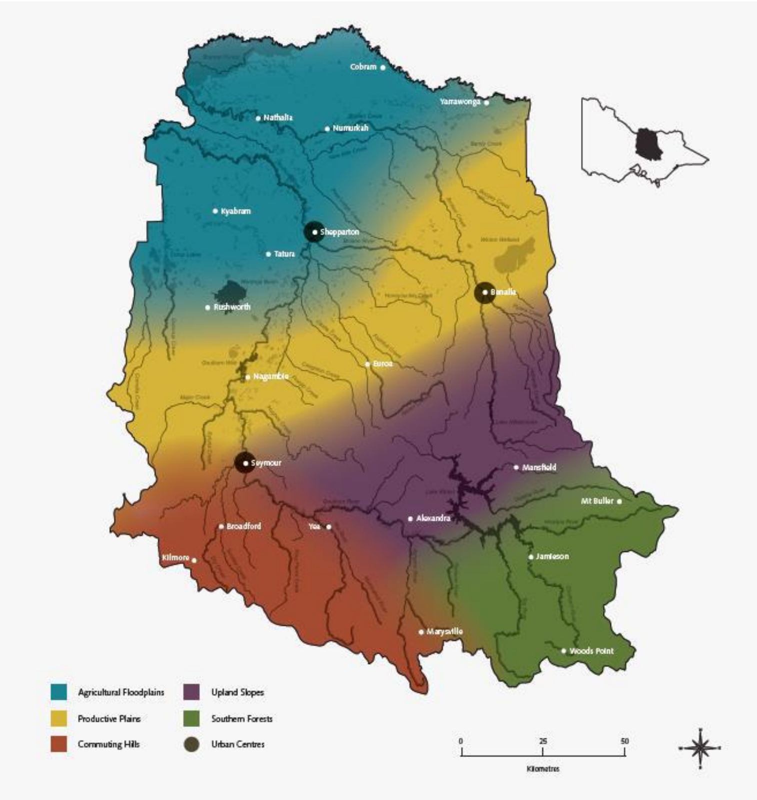

Figure 1: Social ecological systems of the Goulburn-Broken region (from GB CMA 2013).

Table 1: Sites visited along the mid Goulburn River (May 2014).

River Reach	Site	Location	Latitude & Longitude
1. Lake Eildon – Yea River	Mid Goulburn River 1 Mid Goulburn River 2 Mid Goulburn River 3 Mid Goulburn River 4 2003 survey site 1* Mid Goulburn River 5 Mid Goulburn River 6	Walnut Reserve near Snobs Creek Thornton Reserve, Thornton Goulburn Valley bridge downstream of Thornton Binns McCrae Road at UT Creek Off Brooks Cutting Road, opposite Whanregarwen Rd Alexandra Molesworth caravan park Killingworth Reserve, Killingworth	37°15'44.31"S, 145°50'44.25"E 37°15'7.88"S, 145°47'59.51"E 37°14'25.03"S, 145°46'9.70"E 37°11'43.86"S, 145°40'48.92"E 37° 12'20.87"S, 145°38'38.88"E 37° 9'37.88"S, 145°32'15.15"E 37° 9'48.01"S, 145°25'33.30"E
2. Yea River – Sunday Creek	Mid Goulburn River 7 2003 survey site 2* Mid Goulburn River 8 Mid Goulburn River 9 Mid Goulburn River 10 Mid Goulburn River 10a* Mid Goulburn River 11 Mid Goulburn River 12	Ghin Ghin Bridge & Yea River confluence End of Bryant's Lane, Kerrisdale Trawool Bridge Trawool gorge upstream of the bridge Horseshoe Lagoon bend Goulburn Valley Highway at Kerrisdale Boulder site upstream of Horseshoe Lagoon bend Seymour caravan park	37°10'53.44"S, 145°22'8.90"E 37°10'14.17"S, 145°19'36.76"E 37° 05'27.20"S, 145°12'7.16"E 37° 05'41.33"S, 145°12'53.79"E 37° 08'5.04"S, 145°14'17.63"E 37° 08'33.55"S, 145°14'35.83"E 37° 08'12.55"S, 145°14'31.68"E 37° 01'51.84"S, 145° 07'54.63"E
3. Sunday Creek – Lake Nagambie	2003 survey site 3* Mid Goulburn River 13 Mid Goulburn River 14	End of Gerrant's Lane, via Mangalore (opposite Northwood) Upstream of Hughes Creek (near O'Connor property) Mitchelstown bridge	36°55'38.31"S, 145°07'50.88"E 36°53'47.84"S, 145°07'18.59"E 36°50'48.00"S, 145°06'1.28"E

Figure 2: Sites visited along the Goulburn River between Lake Eildon and Goulburn Weir. See Table 1 for site locations.

3 WATER SYSTEMS MANAGEMENT

3.1 Overview

Mean annual streamflow for the Goulburn Basin is approximately 3,040 GL (GB CMA 2013), with an average flow of approximately 1,340 GL in the Goulburn River below Goulburn Weir. Streamflow is variable, both annually and seasonally, and is modified by the following processes:

- The presence and operation of Lake Eildon (3,334 GL, GB CMA 2013);
- 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 (423 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).

3.1.1 Current environmental (minimum flow) requirements

The unseasonal flow regime of the mid Goulburn River led Cottingham et al. (2003) to focus their flow recommendations predominantly on upper limits to baseflow in summer-autumn and inundation of floodplain wetlands in winter spring; minimum flows defined in the Bulk Entitlement for the Goulburn system remained unchanged at 120/250 ML/d (DSE 2012). Upper limits of between 1,000 ML/d and 3,000 ML/d were recommended to preserve important habitat such as slackwater (shallow, low flow) areas for invertebrates and fish and to reduce mean reach velocity to below 0.4 m/s to provide conditions suitable for macrophytes. These recommendations were not implemented due to the limitations they would place on the delivery of water to meet irrigation demand, a constraint recognized at the time (Cottingham et al. 2003).

3.2 Summary of the current flow regime

The previous environmental flow study of Cottingham et al. (2003) used existing data for the 25 year period of 1975 to 2000 to provide summary hydrological data and as the basis for hydraulic modelling. This project has used new hydrological modelling for the period of 1895 to 2009 to provide flow time series that represent the current operation of the river system, both with and without current environmental watering releases included, as well as for a flow regime unimpacted by the presence of Lake Eildon and associated flow management that meets irrigation and stock & domestic demand (note: the unimpacted flow regime assumes contemporary patterns of land use). The approach taken, as well as the resulting modelled flow regimes for each study reach is summarized and presented in Appendix 2, where hydrological data are presented for the following scenarios, consistent with the seasonal watering approach adopted by the Victorian Environmental Water Holder and Commonwealth Environmental Water Holder:

- Very dry years (< 10th percentile of years based on annual volume,
- Dry years (10th to 30th percentile of years),
- Average years (30th to 70th percentile of years),
- Wet Years (> 70th percentile of years).

Examination of flow duration curves (Figure 3 and Figure 4) show a general pattern reflecting the influence of Lake Eildon on the seasonal pattern of the flow regime, whereby winter-spring high flows and winter medium-low flows are lower than would normally flow down the river, while summer-autumn low flows are higher than would otherwise be the case. For example, the current 5-25% exceedence flows are less than would occur if the river was unimpacted by the presence and operation of Lake Eildon. Conversely, current flows are higher than the unimpacted flows for flow exceedence of 30-95%. This means that the timing, duration and heterogeneity of flow components (baseflow, freshes, bankful, overbank flows) has been substantially altered.

Other observations on the current flow regime include that:

- Summer-autumn flows remains relatively consistent for each climatic scenario for the unimpacted flow regime (Figure 5); differences between dry, wet and average climatic conditions relate mainly to increasing and more variable winter-spring discharge.
- Flow along the Goulburn River remains within the river channel (i.e. bankfull and overbank – e.g. 9,500 ML/d – 11,000 ML/d in Reach 1 - flows are rare) under the current regime for all climatic scenarios except wet years (Figure 6). Bankfull and overbank flows would occur in most average and wet years, as well as occasionally in dry years under an unimpacted flow regime.
- Large flow events such as bankfull and overbank flows are much less frequent under the current flow regime. For Reaches 1 and 2, an event that would have occurred annually under an unimpacted flow regime now occurs every five years and an event that would have occurred every five years now occurs every 20 years (Figure 7). The same pattern persists in Reach 3 but is less pronounced due to inputs from unregulated tributaries. The overall effect is that river-floodplain connection has been greatly reduced.

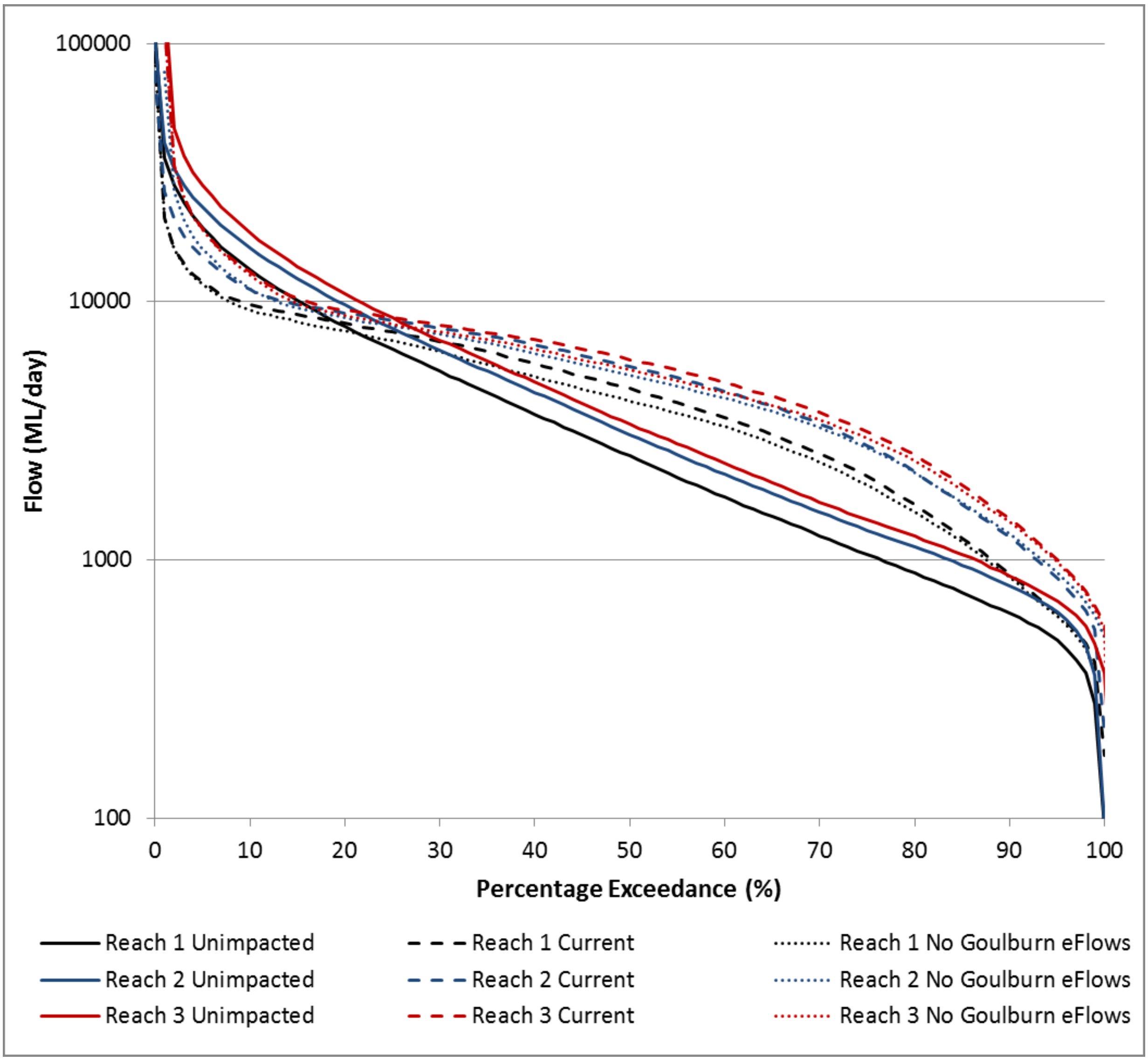

Figure 3: Flow duration curves for the modelled current and unimpacted flow series in Reaches 1-3 (see also Appendix 2).

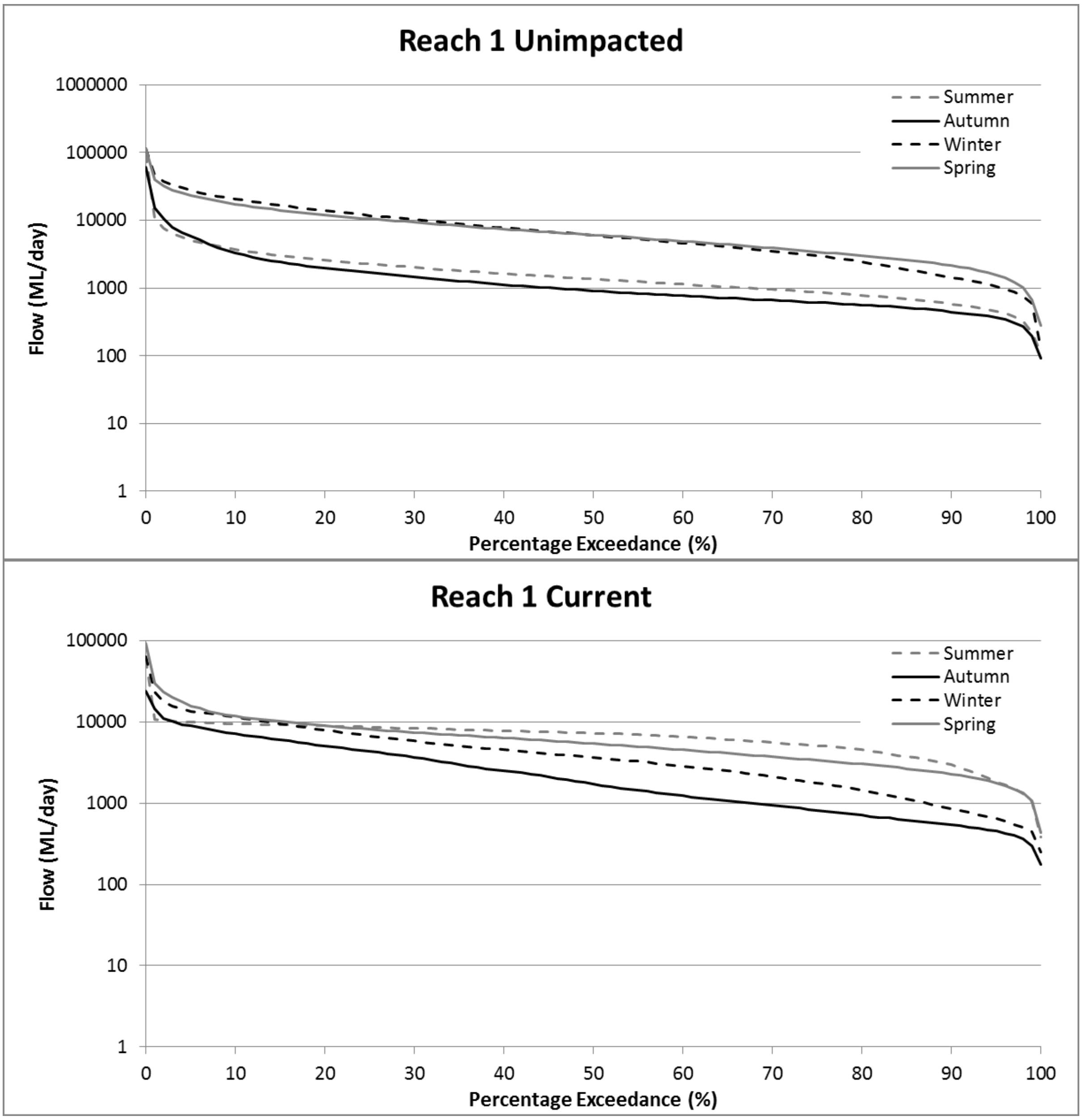

Figure 4: Flow duration curves showing seasonal patterns for modelled current and unimpacted conditions in Reach 1. Flow duration curves for Reach 2 and 3 are presented in Appendix 2; each show a similar pattern to that for Reach 1.

Note: The pattern for current without environmental flow releases is not shown here as it has a very similar pattern as for the current series, above (see Appendix 2).

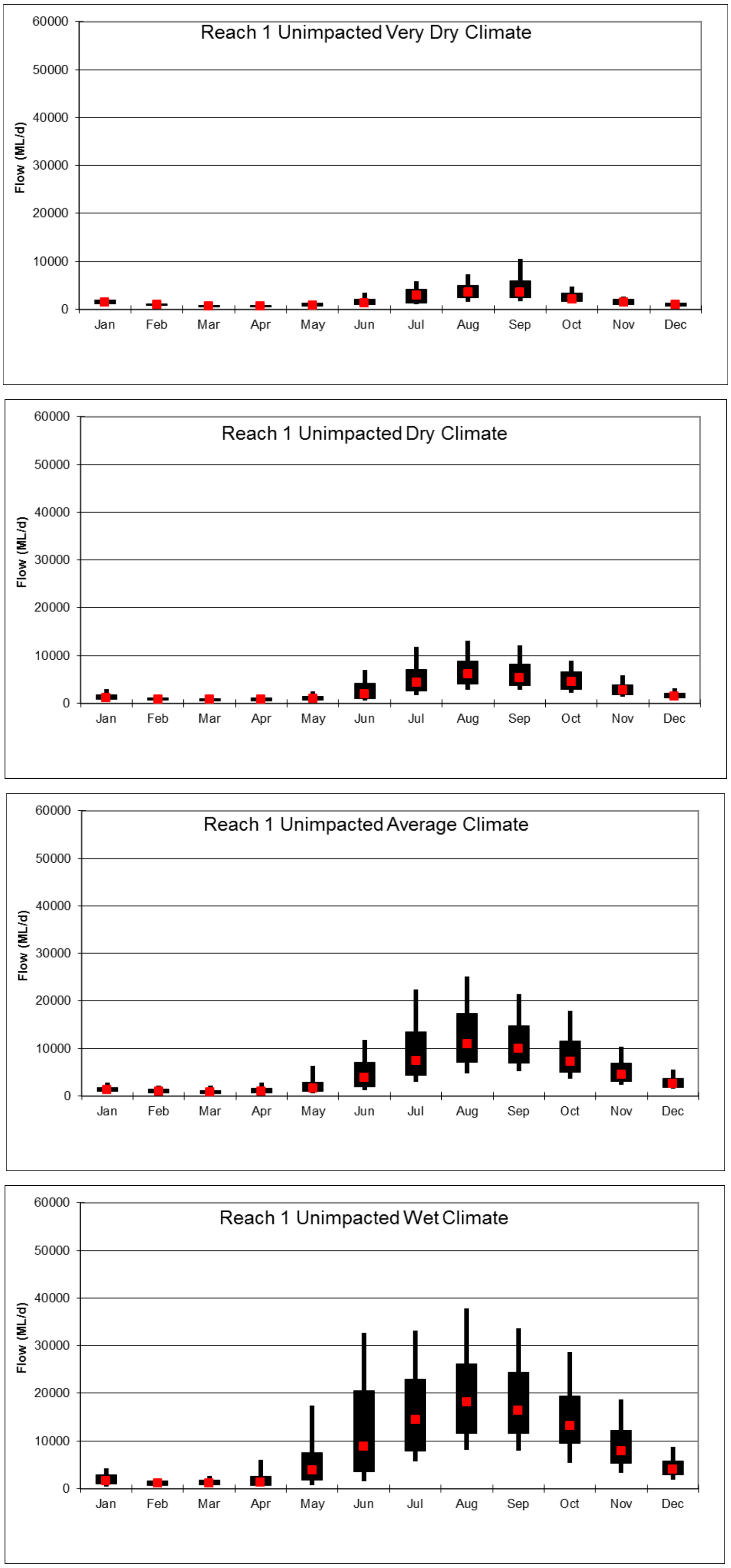

Figure 5: Plots of unimpacted mean daily flow for each month in very dry through to wet climatic conditions in Reach 1 (see Appendix 2 for Reach 2 and 3 plots).

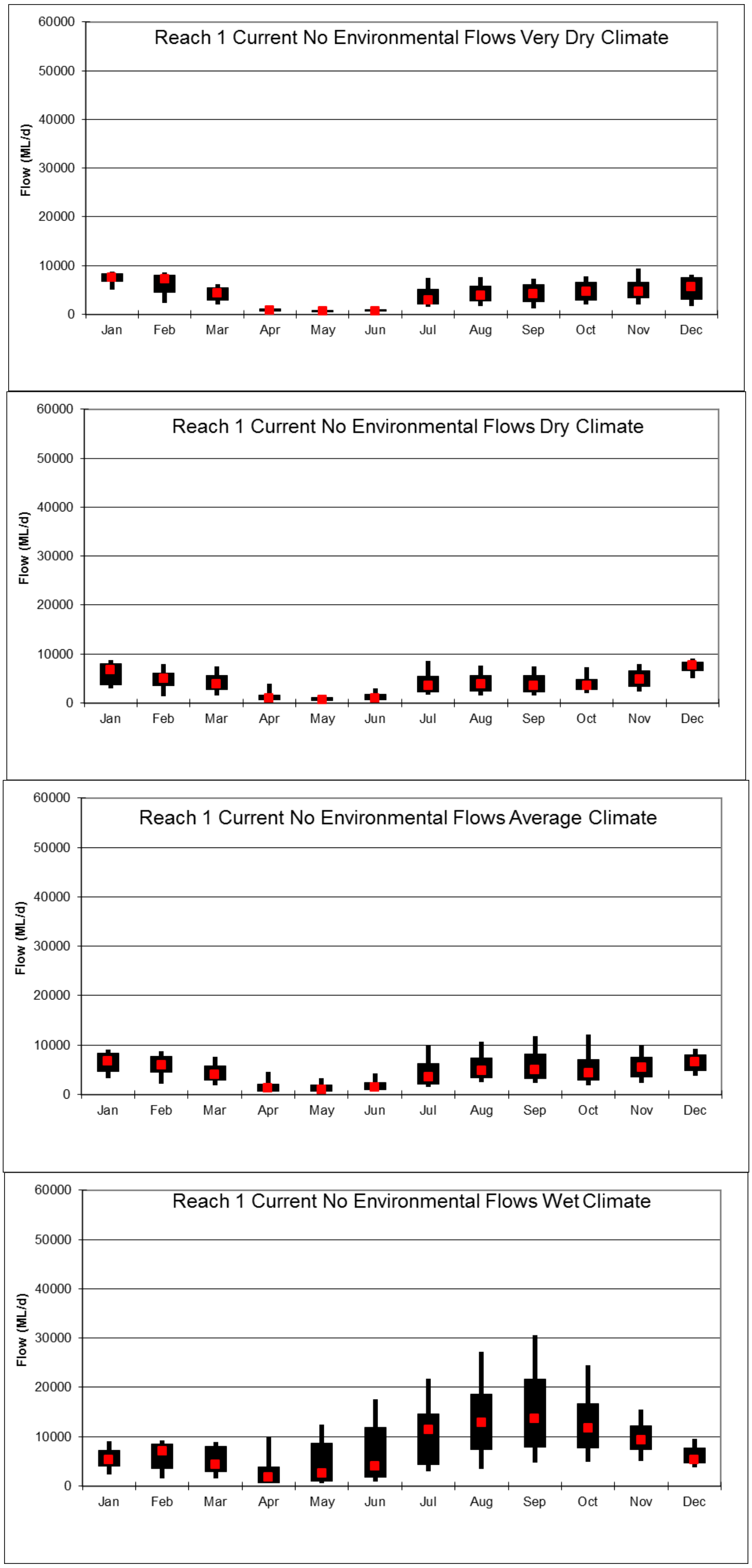

Figure 6: Plots of current mean daily flow for each month in very dry through to wet climatic conditions in Reach 1 (see Appendix 2 for Reach 2 and 3 plots).

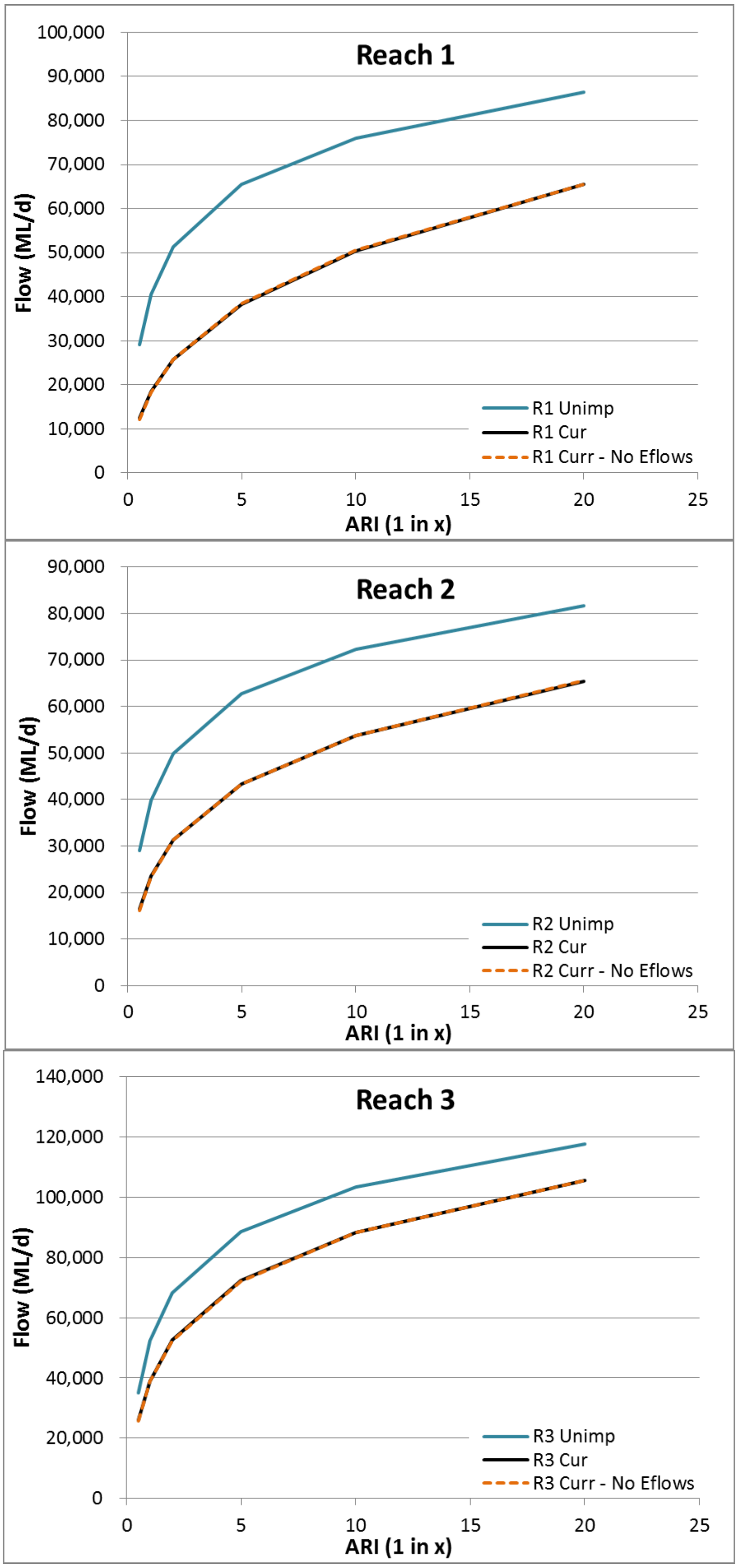

Figure 7: Partial series (annual recurrence intervals (ARI), as 1 event per X years) of large flow events under the unimpacted and current flow regime.

4 REGIONAL POLICIES, STRATEGIES AND OBJECTIVES

4.1 Guiding vision and objectives

This project has been guided by the vision and goals outlined in the Goulburn Broken Regional Waterway Strategy (RWS, GB CMA 2013). In order to achieve its vision 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 and Murray Darling Basin initiatives (e.g. EPBC Act, Native Fish Strategy):

- 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;
- The values associated with Heritage Rivers will be maintained or improved;
- Wetlands with formally recognised significance are maintained or improved;
- Maintain and improve water quality in priority water supply catchments;
- Maintain and improve waterways and wetlands of high community value.

Other management initiatives that complement the RWS and help guide natural resource management in the study area include the Northern Region Sustainable Water Strategy (NRSWS) (DSE 2009) and the Goulburn Broken Biodiversity Strategy (Miles et al. 2010). The NRSWS 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 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. The Goulburn Broken Biodiversity Strategy is consistent with the requirements of the Commonwealth Environment Protection and Biodiversity Conservation (EPBC) Act, and contains biodiversity targets 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 (Appendix 3) for freshwaters based on macroinvertebrate communities across five Victorian bioregions (Metzeling et al. 2004); the objectives are related to indices and metrics that include such things as the number of macroinvertebrate families, SIGNAL (pollution tolerant taxa) scores, an index of pollution intolerant taxa and AUSRIVAS (river health) indices. The Goulburn River between Lake Eildon and Goulburn Weir falls predominantly 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 phosphorus) (Tiller and Newall 2003), dissolved oxygen (DO) pH, salinity (electrical conductivity), and turbidity (Goudy 2003). Details of the water quality objectives are presented in section 5.2.

The project team has noted and will be guided by the desire of the catchment community for maintaining or improving healthy and diverse aquatic ecosystems, as expressed in the Goulburn Broken RWS and Biodiversity Strategy, as well as by the EPA Victoria biological and water quality objectives as it considers flow-related issues that affect river condition and with a view to developing environmental watering recommendations for the mid Goulburn River. The project team also noted that the Goulburn River from Lake Eildon to Yea is known and valued for recreational fishing, particularly trout fishing. Given this, the project team will look to emphasise commonalities, where possible, between environmental watering needs of trout and that of other ecosystem attributes as flow recommendations are developed.

4.2 Riverine ecosystem assets, values and threats

Despite having a highly regulated flow regime and often only a moderate ISC rating (Table 2), the Mid Goulburn River still retains many significant environmental, social and economic assets and values (GB CMA 2013, DEPI 2013). In terms of environmental assets and values (of most relevance to this study), the mid Goulburn River has status as a Heritage River, and is associated with high ecological value floodplain wetland systems, such as Tahbilk Lagoon (a biological hotspot of regional importance). The river and its associated riparian-floodplain areas are also valued for significant (e.g. threatened) fora and fauna species and communities, including riparian vegetation, native fish and birds.

Table 2: Environmental values associated with the mid Goulburn River (modified from GB CMA 2013 and DEPI 2013).

Waterway		Environmental Values				
Study reach	ISC Reach	2013 ISC rating	Formally recognised significance (e.g. heritage River)	Rare/threatened species/communities	Naturalness	Landscape features
Reach 1	5-14	Moderate	x	x		x
	5-13	Moderate	x	x		x
Reach 2	5-12	Good	x	x		
	5-12	Moderate	x	x	x	
Reach 3	5-10	Moderate	x	x	x	
	5-9	Moderate	x	x	x	x

In addition to the modified flow regime described in Chapter 3, the mid Goulburn River is also subjected to threats by such things as (GB CMA 2013, Cottingham et al. 2003):

- Cold water releases from Lake Eildon in summer-autumn;
- Altered land use patterns (changes to floodplain vegetation and carbon cycling);
- Invasive fauna (aquatic and terrestrial);
- Invasive flora (riparian);
- Loss of instream habitat (e.g. loss of large wood, sedimentation);
- Reduced vegetation width and limited tree layer (riparian);
- Inflows of poor quality water from tributaries (sediment, turbidity, nutrients);
- Contaminants in runoff from urban and agricultural areas;
- Localised bank instability;
- Livestock access.

The influence of the threats listed above on ecological condition is considered further by consideration of river function and disturbance drivers in section 4.3, below, as well as in Chapter 5 that deals with the condition and flow-related objectives for ecosystem attributes and assets (e.g. geomorphology, water quality, river and floodplain flora and fauna).

4.3 Overview of potential ecosystem effects of large dams

The presence and operation of flow regulating structures such as Lake Eildon and Goulburn Weir can affect river systems in many, often interacting ways. These are summarised below, starting with concepts of river function and then consideration of disturbance drivers and how they affect river condition via stressor mechanisms.

A major conceptual model of river function that may be applied to the study area is the Serial Discontinuity Concept (SDC) developed by Ward and Standford (1995), which is based on a temperate river upon which one or more large dams have been constructed. The SDC considers the potential ecosystem impacts of the dam(s) on three main river zones: (i) headwater zone, (ii) braided river zone and (iii) meandering zone. The mid Goulburn is predominantly a meander river (Figure 8) *sensu* Ward and Standford (1995); the headwater zones lies above Lake Eildon and there is very little river braiding downstream from Lake Eildon.

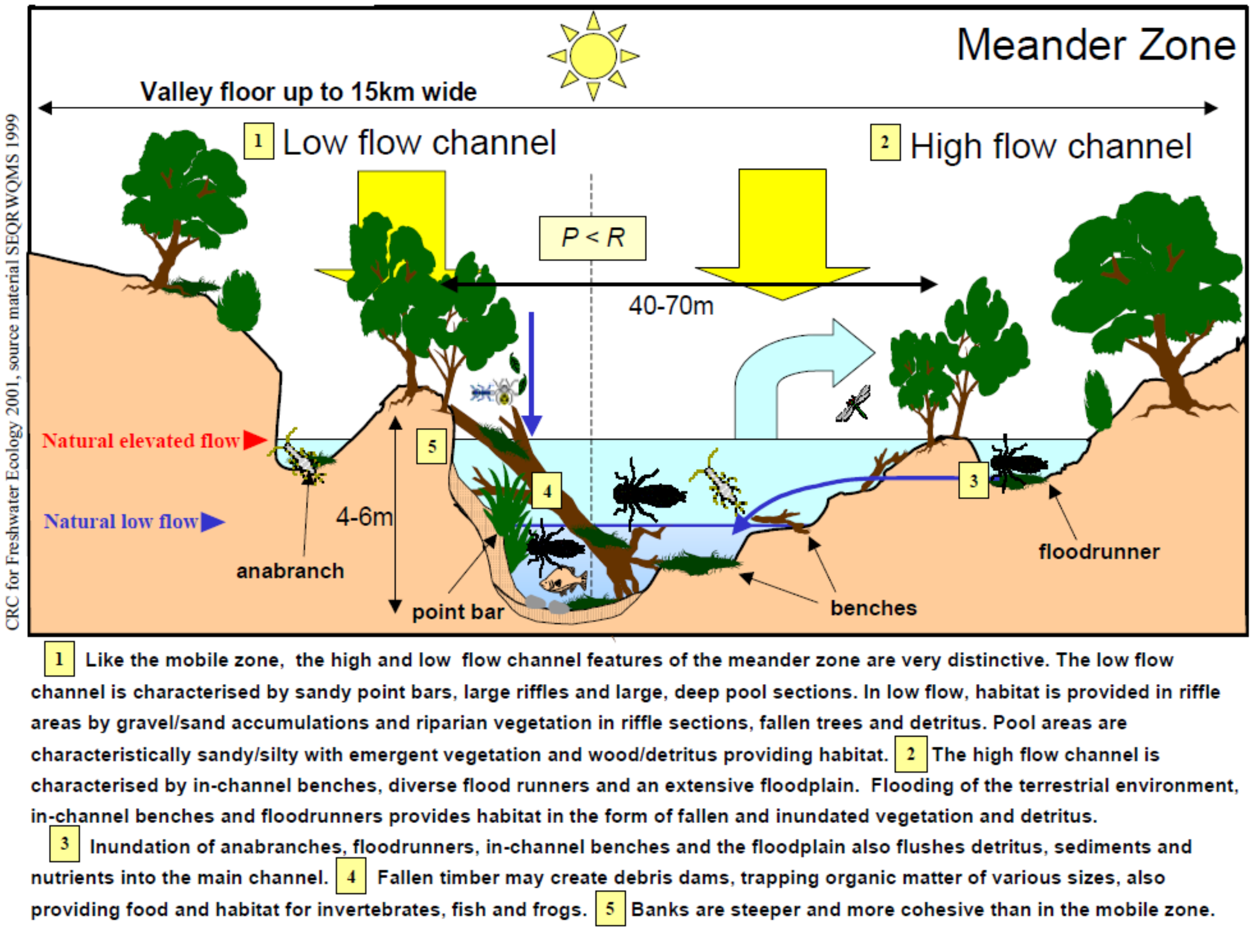

Figure 8: Conceptual model of a meander zone (from Whittington et al. 2001).

The SDC predicts a number of changes to ecosystem structure and function due to the presence of a large dam; those considered by the project team as likely to occur along the mid Goulburn River and its floodplain include:

- Increased channel stability in braided and meandering reaches due to a reduced frequency of channel-forming flows;
- Reduced thermal heterogeneity due to releases from the dam (Lake Eildon) and disconnection of the river channel with its floodplain (see also discussion of cold water releases in section 4.3.2, below);
- Reduced ecological connectivity (longitudinal due to the presence of the dam and lateral due to decreased connection between the river channel and its floodplain);
- A reduction in the ratio of coarse organic particulate matter to fine organic particulate matter and potentially the rate of riverine production;
- Reduced biodiversity due to reduced ecological connectivity and loss of habitat heterogeneity.

The changes described above have been reflected in international reviews on the impact of large dams on river ecology (e.g. Berkamp et al. 2000, McCartney et al. 2001), which describe some of the potential impacts on ecosystem drivers that can occur due to the presence and operation of large dams:

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

However, the impact of large dams do not sit in isolation of other catchment and localised disturbance drivers. For example, Mika et al. (2010) use disturbance drivers (flow regulation, catchment and riparian clearing, land use and river engineering) and their influence via ecosystem stressors to describe multiple interactions that important ecosystem attributes as the basis for considering feasible restoration approaches for the Hunter River in NSW.

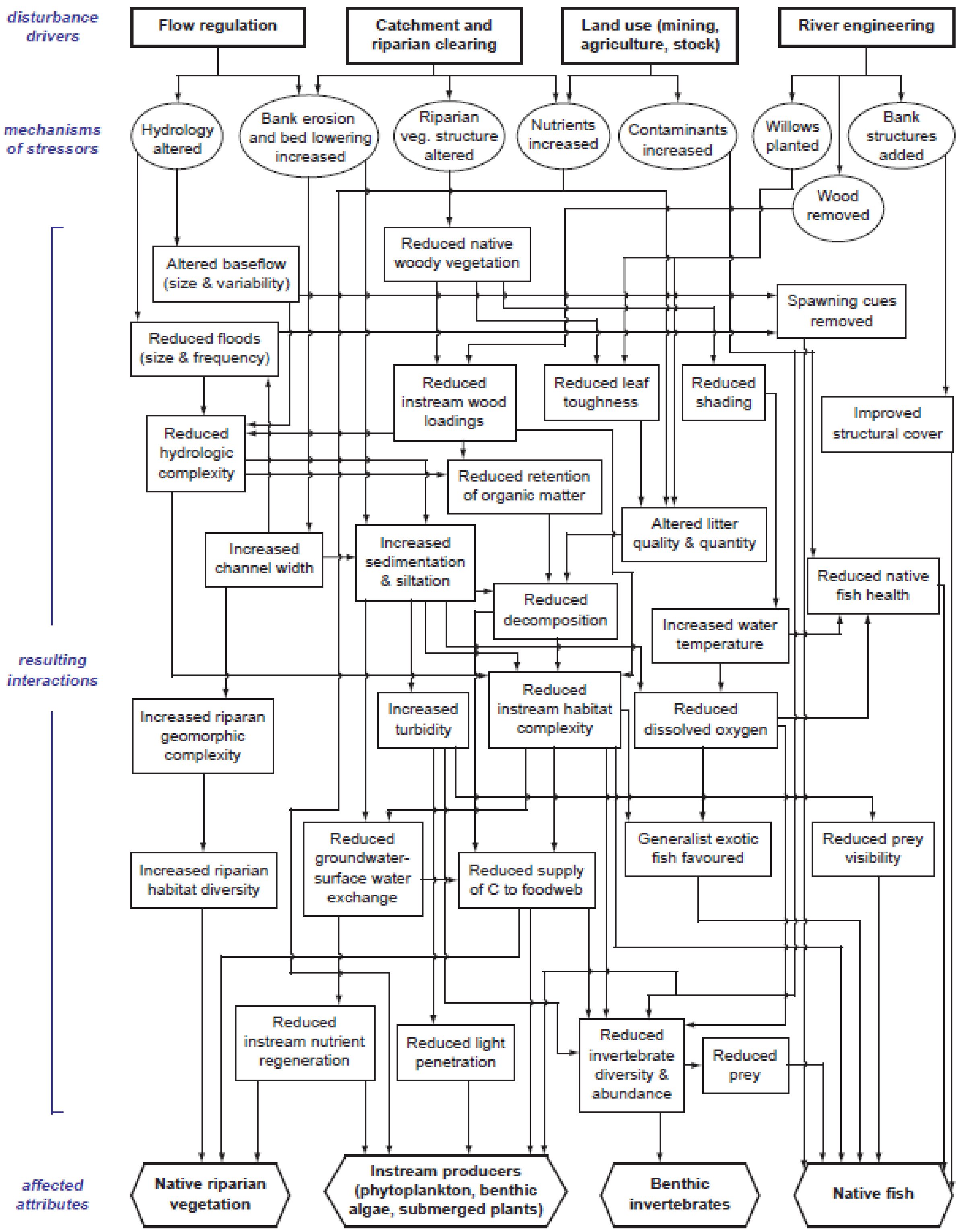

Figure 9: Interdisciplinary conceptual model of the contemporary starting point for restoring instream and riparian structure and function (reproduced with permission, Mika et al. 2010).

The main factors considered likely to restrict our ability to achieve the overarching objectives stated in the RWS and elsewhere (see section 4.1) 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 sediment supply.

These and other stressors are considered in more detail in Chapter 5. However, it is important to note here that the flow-related ecological objectives that can be realistically pursued will be greatly influenced by 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.

Implications for this study

The benefits of environmental watering is, therefore, likely to be limited to a narrow riparian zone along the river bank and low-level floodplain features such as anabranches, flood runners and low lying floodplain wetlands (e.g. that connect at minor flood levels). For the purposes of this study, it is 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 (see section 5.2). Sediment trapping behind Eildon Dam will also continue. Thus the main stressors that can be overcome to some degree are the loss of riparian and floodplain vegetation, assuming that the constraints on flooding private land can be overcome in the medium term, and to a lesser extent altered hydrology in terms of in-channel flows outside of the peak irrigation season. However, even these aspect may be limited, as changes to catchment land use since European settlement has seen a permanent change in previous riparian and floodplain areas to agricultural land.

5 SUMMARY OF ECOSYSTEM ATTRIBUTES AND RATIONALE FOR FLOW-RELATED ECOLOGICAL OBJECTIVES

Environmental flow studies often focus on the flow components (SKM 2012) deemed necessary to protect or improve the condition of various ecosystem attributes or values (e.g. geomorphic processes, native fish populations). While this is a convenient way in which to consider how changes to the flow regime can affect ecosystem attributes and from which to develop flow-related ecological objectives and environmental flow recommendations, the central role of the flow regime means that there is overlap and some repetition in the issues discussed when dealing with individual ecosystem attributes in the following sections. Flow recommendations to meet the needs of the various ecosystem attributes will be presented on a reach by reach basis in the final report for this project.

5.1 Geomorphology

Changed catchment land use since European settlement and the operation of Eildon Dam since 1955 has affected the flow and sediment regime of the mid Goulburn River. In response, the channel and floodplain has undergone a number of physical changes over time and, while these changes have not been dramatic or catastrophic, they are likely to have impacted on the quality of physical habitat and the ecological health of the river system (see section 5.1.2). The following sections outline the physical characteristics and alterations to the physical form of the mid Goulburn River based on field observations and available literature, most notably the study of the fluvial geomorphology of the Goulburn River Basin by Erskine et al. (1993). Flow-related ecosystem objectives related to river geomorphology are also proposed.

5.1.1 Physical characteristics of the Mid Goulburn River and study reaches

The mid Goulburn River is predominantly an anabranching channel that is frequently confined by resistant bedrock and valley walls that have resulted from varied topography of the basaltic and sedimentary geologies of the Goulburn Valley. The channel has a gravel bed in the upper reaches that changes to sand between Seymour and Nagambie (Erskine et al. 1993). It has occasional bedrock controls creating long pools, abundant point bars and gravel riffles (evident at lower flows), and fine-grained (silt and clay) benches in some locations. The pools, riffle and bedrock control sections are irregular (i.e. are not repeated consistently) resulting in the river being characterized by fewer pool-riffle sequences and more deeper, slower flowing sections with finer-grained sediments, interspersed with shallower, faster flowing, coarse-grained riffles and runs such as those evident near Trawool. The river has created alluvial flats within broad ridges of low to high elevation, sometimes to the point of being confined between the valley margins (Figure 10). Bedrock controls in the bed of the channel have prevented downcutting in some locations and created interesting sequences of riffles and extensive pools.

The floodplain is between 500 m to 2 km wide with ridge and swale topography, wetlands and paleo-channels (former channels) hydrologically connected to the river at a range of flows (lidar data, unpublished). Wetlands are numerous (Erskine et al. (1993) counted 400 wetlands between the Lake Eildon and Nagambie (note: approximately 300 wetlands are recorded in the Victorian Biodiversity Interactive Mapping tool – see section 5.3), with the majority in Reaches 1 and 2.

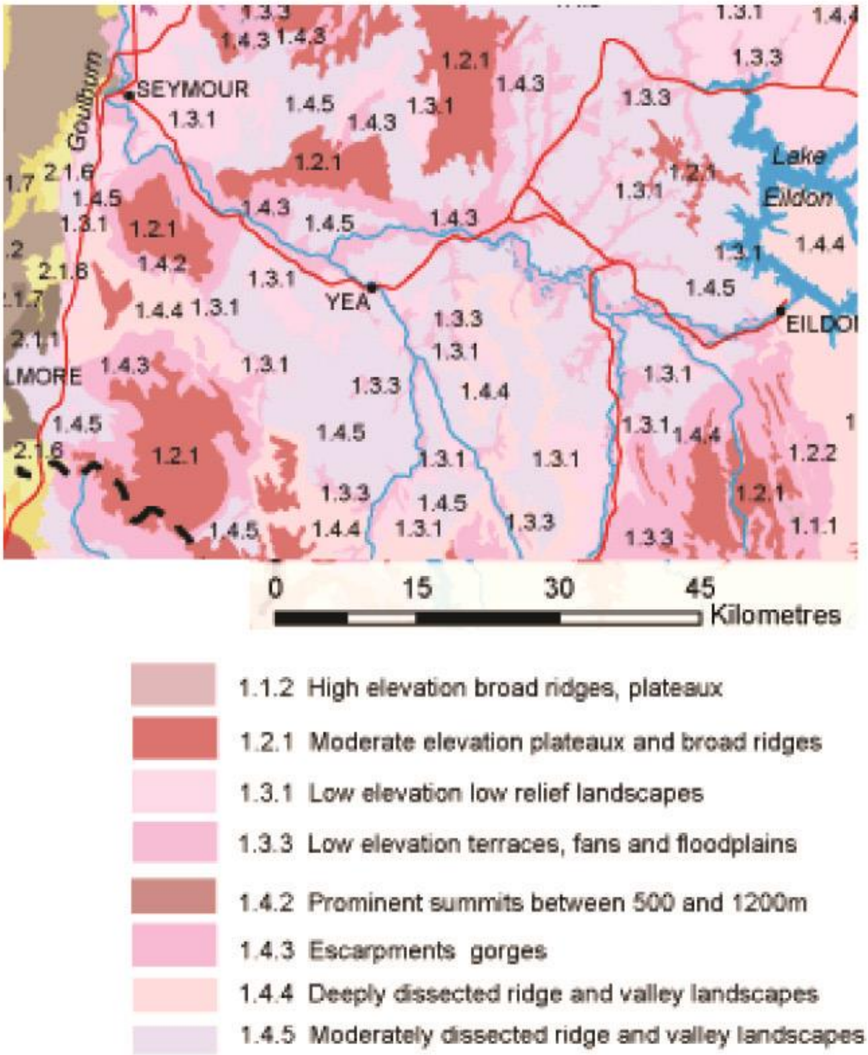

Figure 10. Topographic descriptions of the mid Goulburn River (Victorian Water Resources Online, updated May 2008).

5.1.2 Geomorphic and physical habitat condition

The most recent Index of Stream Condition (ISC) data obtained on the physical form of the mid Goulburn River (DEPI 2013, Table 3) suggests the geomorphic condition of the river is generally moderate (good rating for ISC Reach 11), which is an improvement since the previous assessment in 2004. The moderate condition means that banks are reasonably stable, wood is present but loads are not high, and barriers are not considered significant impediments to the movement of materials (e.g. sediments, carbon) and biota. The good condition for ISC Reach 11 was likely due to stable, well vegetated banks and reasonable wood loads. The 2013 ISC results suggest that the channel appears more stable than it did in the previous assessment in 2004, and as such it is in equilibrium with current flow operations.

Table 3: ISC scores for the Mid Goulburn River reaches (from DEPI 2013).

Reach	Approx. ISC Reach	Physical form condition	Overall ISC rating
1	13, 14	5-7/10	Moderate
2	11, 12	6-7/10	Moderate-Good
3	9, 10	5/10	Moderate

5.1.3 Change in channel morphology

Based on anecdotal evidence, field inspection and comparison with previous investigations, change to channel morphology (bed and banks) over recent decades (i.e. since the establishment of Lake Eildon) are likely to have been minor. Erskine (1996) suggested that bank erosion in the upper reaches of the mid Goulburn river would be 0.1 m per year at a maximum, and also suggested that there had been little channel change over many decades based on cross-sections (rating curves) at points along the river. Erskine (1996) also noted such things as well-vegetated river banks, as well as stable benches and bars supporting trees and other vegetation as indicative of minor channel contraction. Vegetated bars, benches and islands were also noted in the most recent (May 2014) field visit (Figure 11).

While there will always be localised instances of bank erosion, particularly where there is little or no riparian vegetation, there is little evidence of large-scale channel changes (e.g. erosion, deposition) in recent years and banks are generally well vegetated. For example, recent re-survey comparing sections in Reach 2 from 2002 and 2014 (Vietz 2014) found very close alignment (Figure 12 and Figure 13). This suggests little change over a 12-year period that included drought and floods, apart from some minor thalweg changes. Despite this, the recent field inspection noted instances of reduction in benches and bars at various elevations, loss of connectivity between the river channel and the floodplain, loss or simplification of riparian vegetation (i.e. decreased roughness) and homogenisation of the bed topography and surficial sediments due to armouring.

Figure 11. Channel contraction as evident from (a) vegetated bars (near Trawool), (b) benches (Molesworth), and (c) islands (downstream of Thornton) (May 2014). (Photos: Geoff Vietz)

Figure 12: Little change in bank morphology over the last decade as evident at Site 2 based on photographs from (a) August 2002, and (b) June 2014 showing intact bank vegetation and little to no active erosion. (Photos: Geoff Vietz).

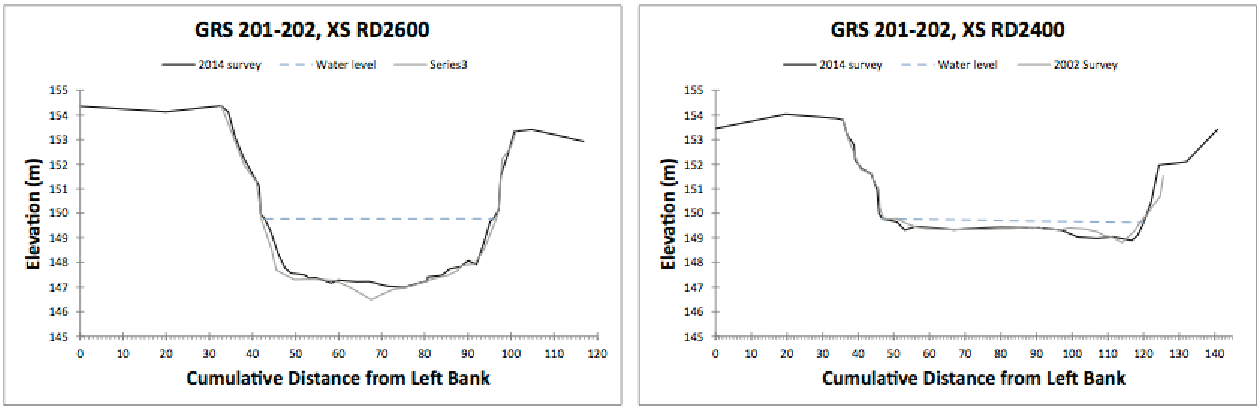

Figure 13: Little channel change between the survey from the 2002 survey (light line) and 2014 survey (dark line) based on cross sections taken for environmental flow studies.

The main geomorphic changes in the mid Goulburn River over time have been due to a number of meander cut-offs that have occurred in the last century (Erskine 1996). Direct interventions have also altered channel-floodplain connection, including bank protection and block banks on flood runners that reduce flow connectivity with wetlands (Figure 14).

Figure 14: Block bank reducing inflows to a flood runner immediately upstream of Horseshoe Lagoon (Reach 2). (Photo: Geoff Vietz).

5.1.4 Changes to sediment characteristics and movement

Lake Eildon is estimated to trap approximately 99% of bedload sediment transported in inflows (Erskine et al. 1993). This means that the mid Goulburn River immediately below the dam is starved of sediments, a situation that persists downstream until the river receives tributary sediment inflows of fine and coarse-grained sediments. The main tributary sources of sediment are likely to be the Acheron River, Yea River and King Parrot Creek, which all have catchments affected by recent (e.g. 2009) bushfires. The Sunday Creek catchment has also been predicted to be a source of moderate to high sediment load (DeRose et al. 2004). At the time of the field inspection (May 2014), the Yea River was contributing gravels and fine-grained sediments (as a visible plume) to the Goulburn River. Sources of sediment in the Yea River (both suspended and bedload sediment) could include riparian zone clearing, active avulsions, and high sand loads from the Murrindindi River catchment (Ladson et al. 2014). These sources are likely to maintain sediment loads to local sections of the Goulburn River, However, the pulsed nature of sediment delivery from the tributaries (particularly fine-grained sediments) may cause issues with regard to habitat. Large influxes of sand and suspended sediment (silts/clays) can result in homogenous bed topography that may decrease habitat suitability for biota such as macroinvertebrates.

Despite being sediment starved by Lake Eildon, the bed of the river channel is relatively stable as with a reduced frequency of large flood events, medium-sized flows have sorted the bed by removing finer material ('armouring') and aligning the coarser upper material that is most resistant to flow ('imbrication'). This creates a very stable channel bed and also means that finer sediments beneath the armoured layer (sands and silts) are likely to infill the interstices (clogging) (Figure 15a). Clogging of the bed sediments within the interstices or at the surface (Figure 15b) may reduce the habitat suitability of substrates for biota such as macroinvertebrates and fish.

The previous flow study of Cottingham et al. (2003) concluded that the disruption of the bed armour layer was not desirable as it would increase mean particle size and require successively larger flows to mobilise underlying fine sediment. This, however, presumes an adequate supply of sediment to the area scoured in order to replace lost sediments (and enable armouring). The supply-limited nature of the system means that flushing flows may end in scouring of the bed to *in situ* clay or bedrock. Erskine (1996) also indicated that releases of 10,000 ML/d (approximately bankfull flow) were not competent to mobilise the average particle size found in the river in Reach 1. The competence of managed flows and the change in bedload sediment under future flow scenarios will be tested via hydraulic modelling in subsequent stages of this project. The ecological basis and desirability of bed disturbance will also be given further consideration.

Figure 15: (a) Armoured coarse-grained layer overlying the finer gravels, sands and silts (survey Site 1, photo June 2014), and silts within and on a gravel bar (near Horseshoe lagoon, photo May 2014). (Photos: Geoff Vietz).

5.1.5 Other physical habitat considerations

While riparian vegetation is considered in detail in section 5.3, its importance is noted here in discussion of river geomorphology due to its structural role, for example in maintaining appropriate rates of channel migration and providing roughness elements (i.e. hydraulic diversity). Intact riparian vegetation can prevent excessive rates of bank erosion, and is a source of large wood that provides habitat for biota (e.g. invertebrates, fish) and increases bed diversity via the formation of scour pools. ISC assessments (DEPI 2013) and anecdotal evidence suggest that the density of large wood in the mid Goulburn River has been reduced significantly, presumably due to a previous history of extensive desnagging (existing wood) and clearance of the riparian zone (future source of wood) (Figure 16 and Figure 17).

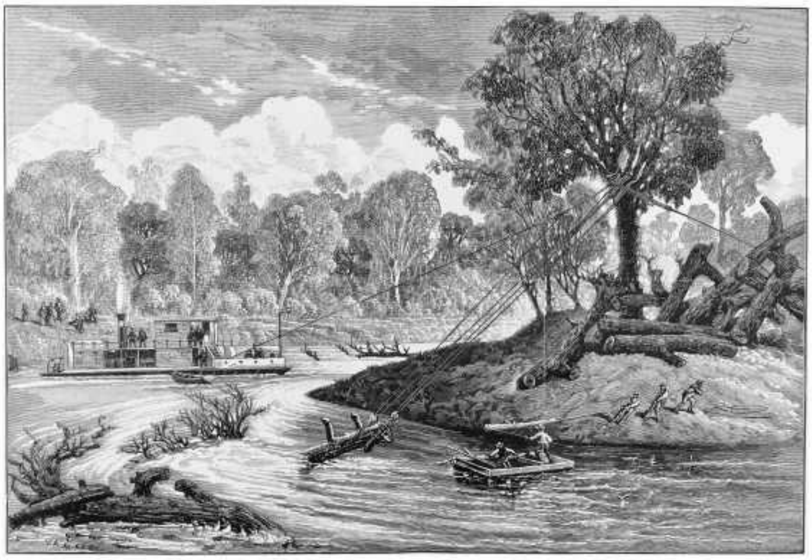

Figure 16: Desnagging in the Goulburn River, 1879 (State Library of Victoria).

Figure 17: Evidence of greatly reduced riparian zone pre-1940s (State Library of Victoria).

Vegetation encroachment has occurred along the mid Goulburn River due to factors such as a more stable flow regime, stable sediments within the channel and on mid-channel islands. This secondary response to flow regulation can be expected with a reduced frequency of disturbance events (floods) and may not necessarily be a negative outcome for a system considered as a 'working river'. Further extensive encroachment by terrestrial vegetation into the river channel is considered unlikely given the high flows that occur in the spring and summer growing seasons.

The replacement of willow trees (*Salix sp.)* with native vegetation has been an area of active management by the GB CMA and landholders over the past decade. Willows were once used extensively to control the erosion of bare river banks but have more recently been replaced due to their invasive nature and potential for altering channel morphology and river flows. While willows were still noted (May 2014) along the river by the project team, their ongoing replacement means that they appear to be less of a problem now than they were in the 90s, when they were described by Erskine et al. (1996) as “extensive but spatially disjunct”.

Finally, hydraulic conditions such as high velocity riffles, deep pools and slow, shallow areas (slackwater) can be considered physical habitat for various biota. These hydraulic habitats can be altered by flow regulation. In particular, maintaining flows at higher levels can significantly reduce the area of slackwater habitat, and size of slackwater patches (Vietz et al. 2013). The potential impact of the current flow regime on the availability of hydraulic habitat will be considered as flow recommendations are developed for the mid Goulburn River in the latter stages of this project.

5.1.6 Basis for assigning geomorphology objectives

At the catchment scale[2], the mid Goulburn River consists of a morphologically diverse channel with bars, benches, islands, riffles, runs, cascades, extensive pools, wetlands and floodplain flood runners. It has appropriate rates of channel migration (albeit slightly reduced compared to natural), armoured substrate with commonly infilled interstices, and as a result lower bed diversity than would be expected. The relative condition and threats to geomorphic values in each reach are summarised in Table 4.

Flows can be categorised as those that may be undesirable from a physical habitat or process perspective, and those flows that are considered to be beneficial. Potentially undesirable flows that may arise under potential flow management scenarios in the mid Goulburn River could include:

- Prolonged stable flows leading to bank notching, reductions in bed and bank diversity, reduced vegetation at the bank toe, and reduced hydraulic habitat diversity;
- Elevated flows during irrigation releases, i.e. above thresholds of bed mobilisation for longer periods than under a variable regime (unlikely with bed armouring);
- Rapid drawdown increasing the potential for bank surcharging and slumping;
- Extended cease-to-flows allowing colonisation of the bed by terrestrial species (unlikely under current flow management regime).

Desirable geomorphic flows could include:

- Reductions in base flows and wetted perimeter coverage (maintenance of aquatic macrophytes to stabilise bank toe);
- Low flow freshes (increased sand bed diversity around large wood);
- Low flow freshes (mobilisation of surficial fine sediment);
- High flow freshes (mobilisation of bed-load sediment to reduce ‘smothering’ of interstices);
- High flow freshes to near-bankfull flows (maintenance of bars, benches and pools);
- High flow freshes (recruitment of large wood from benches, flood runners and anabranches);
- Bankfull flows (maintenance of anabranches, flood runners and wetland sills).

It is important to note that the utility of geomorphic objectives rests with their contribution to meeting ecological and ecosystem process objectives, for example in the provision of habitat for fauna such as native fish, invertebrates and flora such as aquatic macrophytes. Guidance on geomorphic objectives is taken from the Victorian River Health Strategy (DNRE, 2002), which identifies the characteristics of an ecologically healthy river. Aspects of this strategy of particular relevance to the geomorphic objectives are:

[2] While at the catchment scale the river system has considerable geomorphic diversity, this may not be the case at the finer scale from which ecological processes occur. For example, the flow regime and resulting geomorphic processes have resulted in some in-channel habitat simplifications at fine scales (e.g. infilling of gravels and cobbles with sediment leading to loss of invertebrate habitat) – see sections 5.3 and 5.4.

- That major natural habitat features are represented and are maintained over time; and
- Linkages between river and floodplain and associated wetlands are able to maintain ecological processes.

In addition, activities for managing the river channel in order to maintain or improve channel form and processes for ecological benefit, includes maintaining:

- Substrate type and diversity;
- The presence of pools and riffles;
- Channel shape including the presence of backwaters and undercut banks;
- The presence of wood and riparian vegetation; and
- Connectivity - the degree to which there is access for biota, organic material and sediments to move both along the river and laterally into floodplains and wetlands.

An important process within rivers is *appropriate* rates of erosion and deposition, both of which are inherent within meandering rivers and have been associated with ecological attributes. Table 5 details the flow requirements to achieve various geomorphic objectives that are in turn designed to maintain natural habitat features and linkages between the river and the floodplain.

Table 4: Reach summary of geomorphic character, condition and threats.

Reach	Physical characteristics	Geomorphic Condition	Potential threats to geomorphic values and physical habitat
1 Lake Eildon to Yea River	• Diverse reach with relatively straight channel in upper reach below Dam to Alexandra, and sinuous channel in mid and lower reaches with point bars (Figure 18a) • Riffles and runs with pools (often extending for hundreds of metres) (Figure 18b) • Multiple wetlands and billabongs with varied commence-to-flow levels • Gravel/cobble armoured bed (overlying sand), Figure 18c • Vegetated gravel and cobble bars common (some terrestrialisation) • Vegetated benches (Figure 18d) and islands • Reasonable levels of large wood, mainly in lower sections	Moderate	• It is likely that the channel has contracted slightly since construction of the dam with mid-channel bars one form of this. However, sediment supply has also reduced, resulting in little further change in channel dimensions and little threat of significant change • Bed sediments are armoured (e.g. gravels and cobbles overlying finer-grained sediments) and this may reduce substrate condition for macroinvertebrates and fish as interstices are 'clogged' and unlikely to be commonly mobilised • Sediment flux from tributaries can influence substrate condition and planform change and requires monitoring • Bedload sediment supply is limited and sediment extraction will greatly impact on channel morphology and is not sustainable • Levee construction along the channel is common and this may reduce floodplain engagement and increase work done on the channel • Bank protection works may reduce system integrity and physical habitat but these works are rare • Removal of wood (desnagging) could impact on habitat availability • Lack of mature native riparian vegetation for large wood recruitment is likely to influence future wood loads • Invasive species (e.g. willows) and terrestrial vegetation encroachment is present but not a significant issue at this stage • Disturbance by livestock threatens bank condition and is likely to increase turbidity (suspended sediments)
2 Yea River to Sunday Creek (Seymour)	• Medium sinuosity reach occasionally confined by the valley margins (Figure 19a) • Reach 2 has the highest wetland number per kilometre (~13/km) and the highest wetland area,	Moderate-good	• Little channel change evident • Bed sediments are armoured (e.g. gravels and cobbles overlying finer-grained sediments) and this may reduce substrate condition for macroinvertebrates and fish as

Reach	Physical characteristics	Geomorphic Condition	Potential threats to geomorphic values and physical habitat
	with some wetlands extensive (e.g. Horseshoe Lagoon) • Gravel/cobble armoured bars evident (some sand underneath), with fine-grained sediments (silts and clays within coarser substrates (Figure 19b • Occasional bedrock controls (with boulders) creating cascades and extensive pools, particularly when confined on both margins (e.g. Trawool, Figure 19c) • Diverse sediments due to geology of sedimentary materials (predominantly north-eastern bank) and granitic materials (predominantly south-western bank) • Extensive inset-floodplains (benches) • Riffles and runs with pools, often extending for hundreds of metres (Figure 19d) • Vegetated gravel and cobble bars common (some terrestrialisation) • Vegetated islands • Reasonable levels of large wood		interstices are ‘clogged’ and unlikely to be commonly mobilised • High suspended sediment loads from tributaries (Yea River in particular) may cause high turbidity and exacerbate substrate sediment smothering • Localised bank erosion is occurring (not-excessive rates of channel migration) and some bank protection has been installed which is already leading to opposite bank failures (e.g. survey site 2) • Vegetated islands may lead to localised channel widening, but these are rare and changes are minor • Bedload sediment supply is limited and sediment extraction will greatly impact on channel morphology and is not sustainable • Removal of wood (desnagging) could impact on habitat availability • Lack of mature native riparian vegetation for large wood recruitment is likely to influence future wood loads (and increase bank erosion potential) • Invasive species (e.g. willows) and terrestrial vegetation encroachment is present but not a significant issue at this stage • Disturbance by livestock threatens bank condition and is likely to increase turbidity (suspended sediments)
3 Sunday Creek to Nagambie	• Lower gradient channel with alternating planform from straight to medium sinuosity • Extensive floodplains, some valley confinement • Significant channel change from dredging of sediment (near Seymour between 1960 to 1980) will have impacted on sediment transport through reach and is likely to continue to reduce sediment transport to lower reaches (Figure 20a) • Some wetlands but the least of the three reaches by number and area	Moderate	• Little recent channel change evident • Goulburn weir is likely to trap significant sediment loads, and maintain the lower part of this reach as a sediment sink (both gravels and fines) • Bedload sediment supply to this reach is greatly limited and sediment extraction will greatly impact on channel morphology and is not sustainable • Localised bank erosion is occurring but mainly where riparian vegetation has been removed • Wood loads are good but the lack of mature native riparian vegetation for large wood recruitment may be a future issue

Reach	Physical characteristics	Geomorphic Condition	Potential threats to geomorphic values and physical habitat
	• Deeper, wider channel well engaged with floodplain (Figure 20b) • Some historic bank erosion evident (Figure 20c, likely to be associated with low riparian vegetation density • Extensive benches in lower reaches (Mitchelton) (Figure 20d) • Bed substrates likely to be finer-grained gravels, sands and silts • High levels of large wood		• Invasive species (e.g. willows) and terrestrial vegetation encroachment is present but not a significant issue at this stage • Disturbance by livestock threatens bank condition and is likely to increase turbidity (suspended sediments)

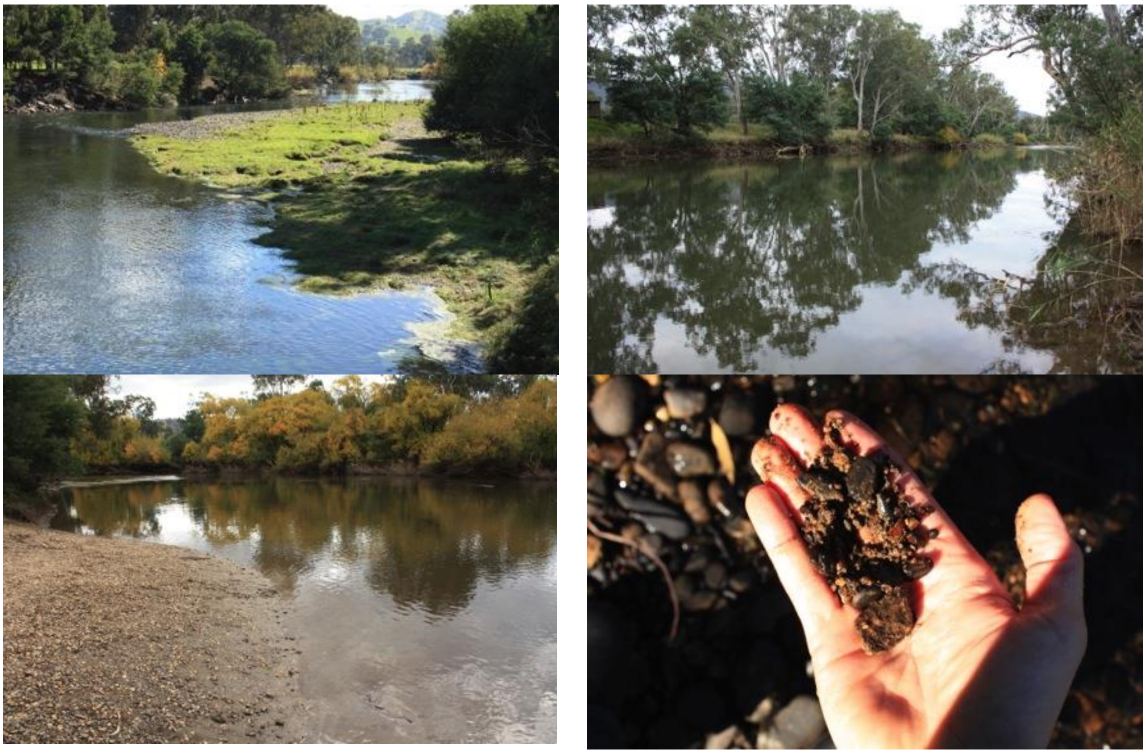

Figure 18: (a) Riffles and runs common (Thornton Reserve), (b) extensive pools (Killingsworth), (c) Reach 1 gravel bed and bars (Molesworth), and (d) the finer-grained sediments (silts, sands, smaller gravels) underlying the armoured gravel and cobble bed (Thornton Reserve). (Photos: Geoff Vietz).

Figure 19: (a) Valley margins occasionally confining channel and diverse floodplain topography with floodrunners and billabongs (Trawool Valley), (b) Reach 2 bedrock confined section (at boulder island near Horseshoe Lagoon), (c) an extensive sluggish pool (Trawool bridge), and (d) fine-grained sediment in lower velocity reaches (near Horseshoe Lagoon).

Figure 20: Reach 3 characteristics including (a) sluggish reaches such as in the Goulburn weir pool, (b) reaches of intact vegetation and good wood loads, (c) some localised erosion (mainly corresponding to a lack of riparian vegetation, and (d) extensive inset benches (Mitchelton). (Photos: Geoff Vietz).

5.1.7 Non-flow related issues

There are a number of ongoing non-flow threats to the physical condition and ongoing geomorphic processes within the mid Goulburn River:

- Invasive plant species (e.g. *Salix* (willows)) can colonise the channel bed and lead to localised channel widening and reduced channel diversity (as well reduced vegetation diversity on the banks);
- Removal of large wood items (desnagging) has occurred historically and as an important agent - for geomorphic and hydraulic diversity, and channel stability - the ongoing supply requires consideration; and
- Channel stabilisation works, which aim to reduce channel migration, often exacerbate channel instability in meandering alluvial channels by increasing stream energy in the system, and redirecting flows to the opposite bank (e.g. survey Site 2).
- Cattle access leads to reductions in bankside vegetation valuable in stabilising and directly exacerbates bank erosion;

Table 5: Flow requirements for geomorphic objectives.

Ecosystem Objective	Reach	Main Flow Components	Mechanism
Adequately persistent baseflows to prevent further terrestrial vegetation encroachment on bars	1, 2	Low flow baseflow (summer)	Periodic inundation of the wetted perimeter of the bed for adequate time to prevent terrestrial species colonising the bed and bars (leading to erosion and outflanking during higher events)
Reduce sediment smothering of substrates	All	Freshes (Low Flow)	Flows of sufficient magnitude to scour fine-grained (silt/clay) sediments from surficial coarse-grained sediments
Maintain the rates of bed material movement to maintain bed diversity for water depth variation (sand and gravel bed)	1, 2	Freshes (High Flow)	Flows of sufficient magnitude to provide critical shear stress to turnover bed sediments and scour around large wood
Bench (and island) inundation to maintain bench form (and wet vegetation and recruit organic matter and debris)	All	Freshes (High Flow)	Inundation of mid-level benches to a depth of 1m above bench surface
Maintain channel form and key habitats including riffle and pool habitat	All	Freshes (Low Flow and High Flow) Bankfull Flows	Flows of sufficient magnitude to provide critical shear stress to periodically mobilise sediments of varying size in the bed of pools
Maintain connectivity between the channel, anabranches and wetlands	All	Bankfull Flows (into floodplain connectors)	Provision of flow into mid and high-level anabranches and wetlands to maintain sill connections

5.2 Water quality

5.2.1 Summary of condition

Water quality data for the study reaches was sourced from the Victorian surface water monitoring network (http://data.water.vic.gov.au/monitoring.htm) and assessed against State Environment Protection Policy (SEPP) water quality objectives (Table 6 and Table 7).

Table 6: Waters of Victoria water quality objectives for rivers and streams (from State of Victoria 2003, Goudy 2003).

Segment	DO %saturation* (25th percentile)	Turbidity NTU (75th percentile)	Electrical Conductivity µS/cm (75th percentile)	pH pH units (25th/75th percentile)
Mid reaches in the Ovens and Goulburn catchments	>85 and <110	10	500	6.4/7.7

* At 20ºC, 85% saturation is approximately 7.5 mg/L DO

Table 7: Nutrient objectives for rivers and streams (Tiller and Newall 2003).

Segment	TP mg/L (75th percentile)	TN mg/L (75th percentile)
Goulburn to Ovens Rivers (N4 region)	0.025	0.350

Based on data accumulated from January 2000 – December 2013 (Table 8), water in the Reach 1 was generally of good quality. This is consistent with the most recent ISC assessment (DEPI 2013) that reported water quality in Goulburn River ISC Reach 14 (Lake Eildon to Molesworth) as excellent. Water quality in the Goulburn River at Eildon remained consistently good in most climatic conditions; water quality met SEPP objectives overall and in dry years (e.g. 2006), but exceeded SEPP objectives for turbidity and nitrogen in the wet year of 2010 (presumably due to poor quality tributary inflows (Tenant et al. 2012) and runoff from agricultural and urban areas – see section 5.2.2 below for further discussion on potential contaminant sources). The most notable water quality issue over the past decade has been high turbidity levels in Reaches 2 and 3 that were the result of discharge from fire-affected catchments since 2009 (Tenant et al. 2012). Tributary inflows from fire-affected areas are also likely to have contributed to the high nitrogen levels recorded in Reach 2 (and presumably persisting into Reach 3) (Table 8). However, the fact that Reach 2 nitrogen levels were high in 2006 (i.e. prior to the 2009 fires) suggests that nutrient levels were likely to be the result of numerous sources, such as runoff from agricultural and urban areas along the Goulburn River, as well as from tributaries.

Table 8: Summary of water quality data for the mid Goulburn River for the period January 2000 to December 2013, inclusive (data courtesy of DEPI; http://data.water.vic.gov.au/monitoring.htm).

Reach 1 = Lake Eildon to Yea River; Reach 2 = Yea River to Sunday Creek; Reach 3 = Sunday Creek to Goulburn Weir. Units: Turbidity = NTU; EC = µS/cm; pH = pH units; DO, Total N, Total P and TSS = mg/L. Reach 1 data are for the Goulburn River at Eildon, Reach 2 data are for the Goulburn River at Trawool, Reach 3 data are for the Goulburn River at Tahbilk. Orange cells denote exceedence of SEPP guidelines. NA = data not available.

	Reach 1	Reach 2	Reach 3	Reach 1	Reach 2	Reach 3	Reach 1	Reach 2	Reach 3
	25th percentile values			Median values			75th percentile values		
Cumulative (January 2000-December 2013)									
DO	8.0	8.4	7.8	9.2	9.5	8.9	10.1	10.5	9.8
Turbidity	2.1	6.6	11.9	3.3	9.6	18.6	5.1	15.2	31.0
EC	48.0	51.3	54.5	51.0	56.0	68.0	55.0	63.0	91.9
pH	6.6	6.6	NA	6.8	6.9	NA	6.9	7.1	NA
Total N	0.24	0.36	NA	0.28	0.47	NA	0.35	0.59	NA
Total P	0.007	0.017	NA	0.010	0.022	NA	0.010	0.030	NA
TSS	2.0	6.0	NA	2.0	10.0	NA	4.0	15.0	NA
Drought year (2006 calendar year)									
DO	8.1	8.8	NA	8.7	9.5	NA	10.0	10.6	NA
Turbidity	3.3	5.9	NA	4.1	6.8	NA	4.6	8.0	NA
EC	50.5	50.8	NA	51.5	52.0	NA	53.0	56.0	NA
pH	6.5	6.3	NA	6.8	6.5	NA	6.9	6.8	NA
Total N	0.21	0.33	NA	0.25	0.39	NA	0.29	0.47	NA
Total P	0.005	0.010	NA	0.010	0.010	NA	0.010	0.020	NA
TSS	1.0	5.0	NA	3.0	6.5	NA	4..0	10.0	NA
Wet year (2010 calendar year)									
DO	8.0	7.9	7.2	8.2	9.2	8.3	9.6	9.9	9.5
Turbidity	3.2	11.0	17.2	6.8	20.1	27.9	18.0	29.8	58.8
EC	46.7	48.1	53.7	48.0	60.6	88.6	54.3	88.5	107.1
pH	6.8	6.5	NA	6.9	6.8	NA	7.0	7.0	NA
Total N	0.17	0.29	NA	0.28	0.54	NA	0.46	1.00	NA
Total P	0.006	NA	NA	0.013	NA	NA	0.021	0.040	NA
TSS	1.0	6.0	NA	4.5	16.0	NA	6.5	17.3	NA

While many aspects of the physico-chemical quality of water in the mid Goulburn River are in good quality, there remain issues that can affect other ecological attributes and processes. A review of cold water releases from storages across Victoria (SKM 2008) noted that cold water releases from Lake Eildon affect the river from the dam down to Molesworth. Water temperature was found to be up to 8°C cooler during summer than at an upstream reference site. The cold water releases in summer-autumn can persist for some kilometres downstream until buffered by tributary inputs or until water temperature reaches equilibrium based on ambient temperature and irradiance. This has implications for the river below Lake Eildon, potentially decreasing the rates of primary production in the river, as well as affecting the breeding cycles of some native fish that require warm summer temperatures for spawning. Examination of dissolved oxygen (DO) and temperature data for the Goulburn River at Eildon from 1990 to the present highlights the influence of Lake Eildon and its operation. For example, both DO and temperature in the river remained within a relatively narrow range between 1990 and 1995, reflecting releases from Lake Eildon at a time when the reservoir was relatively full. As the Millennium Drought persisted and water levels declined from approximately 1996 to 2010, both temperature and DO became much more variable as storages levels in Lake Eildon declined (Figure 21). Interestingly, while temperature has returned to the narrow pre-drought range since Lake Eildon filled post 2010, DO levels have largely remained more variable than the pre-drought state, and have approached levels of 4 mg/L in each of the past three summer-autumn periods. The reason(s) for this are not clear but might be related to the discharge of low oxygen water from the hypolimnium of Lake Eildon, as examination of discharge, Eildon pondage storage (not shown) and DO data showed no clear relationship. The pattern of declining variability in stream temperature since 2010 also persisted down to Reach 2 (Figure 22) and Reach 3 (Figure 23), although the effects were much less pronounced.

The relative condition and a summary of threats to water quality along each study reach are provided in Table 9. Based on the previous discussion of water quality in each reach, water quality issues can be summarised as:

- Cold water releases from Lake Eildon, which may affect metabolic function, reproduction and growth rates of aquatic organisms, or preclude biota such as native fish from persisting across their natural range;
- Occasions of DO concentration less than 5 mg/L in releases from Eildon pondage in autumn in each of the past three calendar years (confirm that timing coincides with pondage drawdown);
- Poor water quality (turbidity, nutrients) in discharge from fire-affected tributary catchments.

5.2.2 Other potential sources of poor water quality

Sediment and nutrients

Sediment and nutrient inputs are mainly derived from catchment sources, such as runoff from forest, agricultural and urban areas, and direct inputs from livestock access, and are thus largely independent of management of the flow regime. Feehan and Plunkett (2003) provided an overview of the major sources of phosphorus and nitrogen in the Goulburn and Broken catchment. Irrigation drains were a major source of nutrients in the lower Goulburn contributing 45 and 21% of total phosphorus (TP) and nitrogen (TN) loads respectively. Dryland farming was also a major source of nutrients contributing 30 and 65% of TP and TN loads respectively in the catchment. In comparison nutrients generated from urban areas (TP 3%, TN 2%), wastewater treatment plants (TP 14%, TN 6%) and from aquaculture and other intensive animal industries (TP 8%, TN 5%) are comparatively low. Based on these results, runoff from dryland farming (and direct access of livestock) is likely to be the dominant source of nutrients entering the mid Goulburn either directly or via tributary streams. Discharge and runoff from intensive agriculture (e.g. fish and turf farms) and urban areas (e.g. stormwater runoff, discharge from septic tanks), is also likely to contribute nutrients to the Goulburn River (GB CMA 2013, Webb 2012). The recent field inspection (May 2014) also noted large stands of filamentous algae (often a sign of nutrient enrichment) in runs and riffles in the Goulburn River around the Goulburn Valley Highway Bridge between Thornton and Alexandra (see also section 5.3). It’s possible that any impacts from nutrient enrichment in areas downstream of Alexandra are limited due to there being deeper and moderately turbid waters that restrict the penetration of sunlight to the stream bed. Furthermore, the flows in the river appear sufficient to prevent excessive growth of phytoplankton.

Heavy metals and pesticides

Several streams (e.g. Goulburn and Big River) upstream of Lake Eildon are polluted with mercury that was brought into the region for gold mining. Recent surveys of the sediments in the upper Goulburn have shown that the mercury concentrations often exceed the Interim Sediment Quality Guideline – high value, indicating that mercury has the potential to impact ecosystem health (O'Brien, 2010). Advisories recommending limiting the consumption of fish caught from Lake Eildon are in place because of concerns of elevated concentrations of mercury in fish (DOH 2011). However, Lake Eildon is a sink for sediments and attached contaminants (including mercury), and is likely to protect the mid Goulburn River from mercury pollution.

Pesticides are another possible source of pollution that can affect biota such as invertebrates. However, there are no data on whether pesticides maybe present in the mid Goulburn River. In general, pesticide use in Victoria is more prevalent in intensive agriculture and urban areas (Shafer et al. 2011), the risk of pesticide contamination in the study area is considered low, as the dominant rural activity is livestock grazing. However, there may be local impacts in some areas of the catchment where there is intensive agriculture (e.g. upper Yea River). The most recent pesticide data collected from the study area were collected from two locations on the Goulburn River near Nagambie (Shafer et al. 2011). Surface waters and sediments were sampled from the Goulburn River at Kirwans Bridge and from the Tahbilk Wetland upstream of Nagambie on four occasions between November 2009 and April 2010. Samples were tested for almost 100 pesticides and breakdown products. Trace concentrations of seven pesticides were detected at Kirwans Bridge and nine pesticides were detected from Tahbilk Wetland. These pesticides included the herbicides simazine and atrazine, fungicides and in Tahbilk wetland, the insecticides bifenthrin and carbaryl. The study by Shafer et al. (2011) illustrates that pesticide contamination could be widespread and detrimental to macroinvertebrate communities, and highlights the need for more information on pesticide pollution to be gathered from the region.

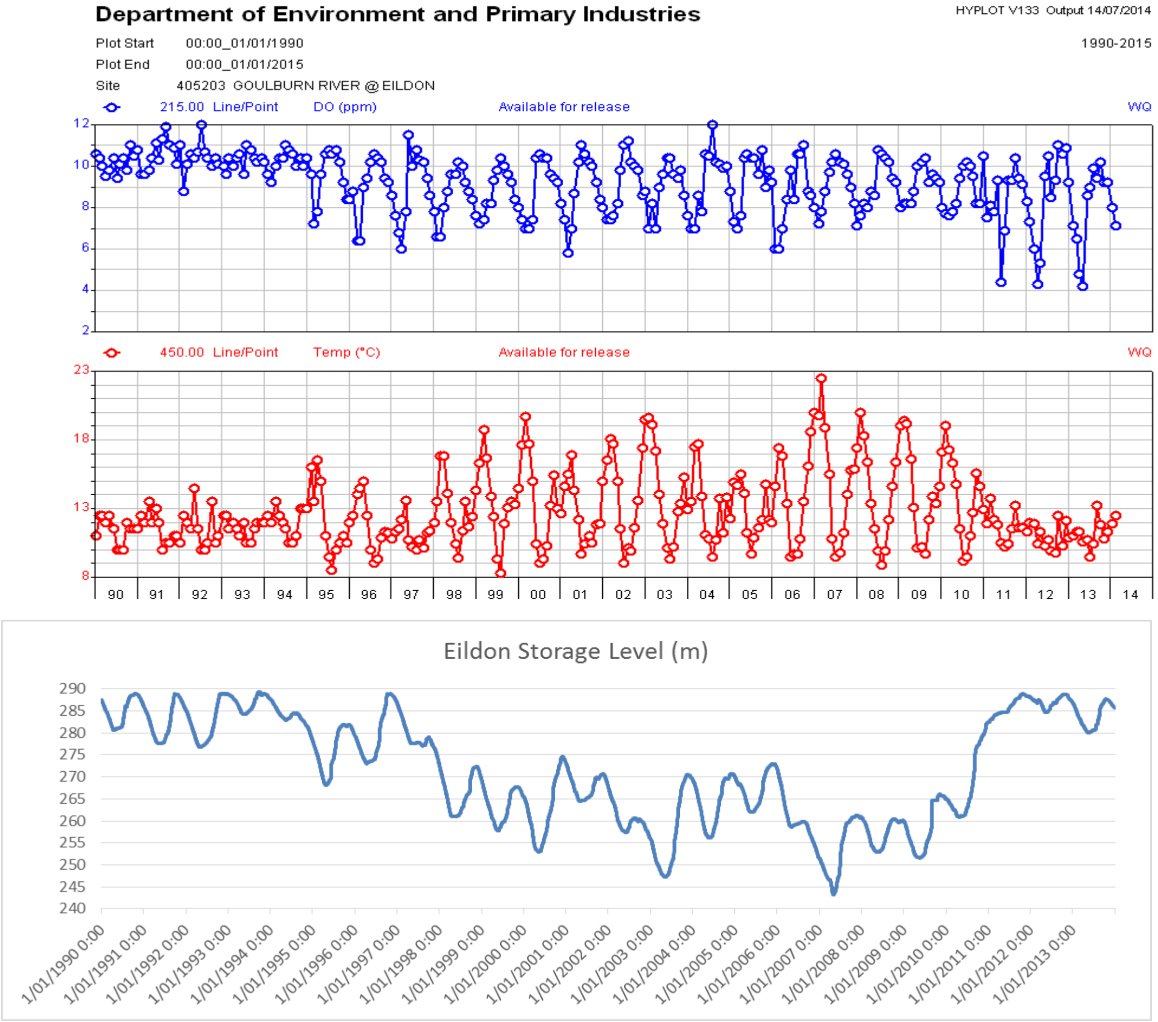

Figure 21: Time series of monthly DO (mg/L), temperature (°C) and storage level in the Goulburn River at Eildon (Reach 1), 1990-2014 (from DEPI, http://data.water.vic.gov.au/monitoring.htm; storage level data courtesy of G-MW).

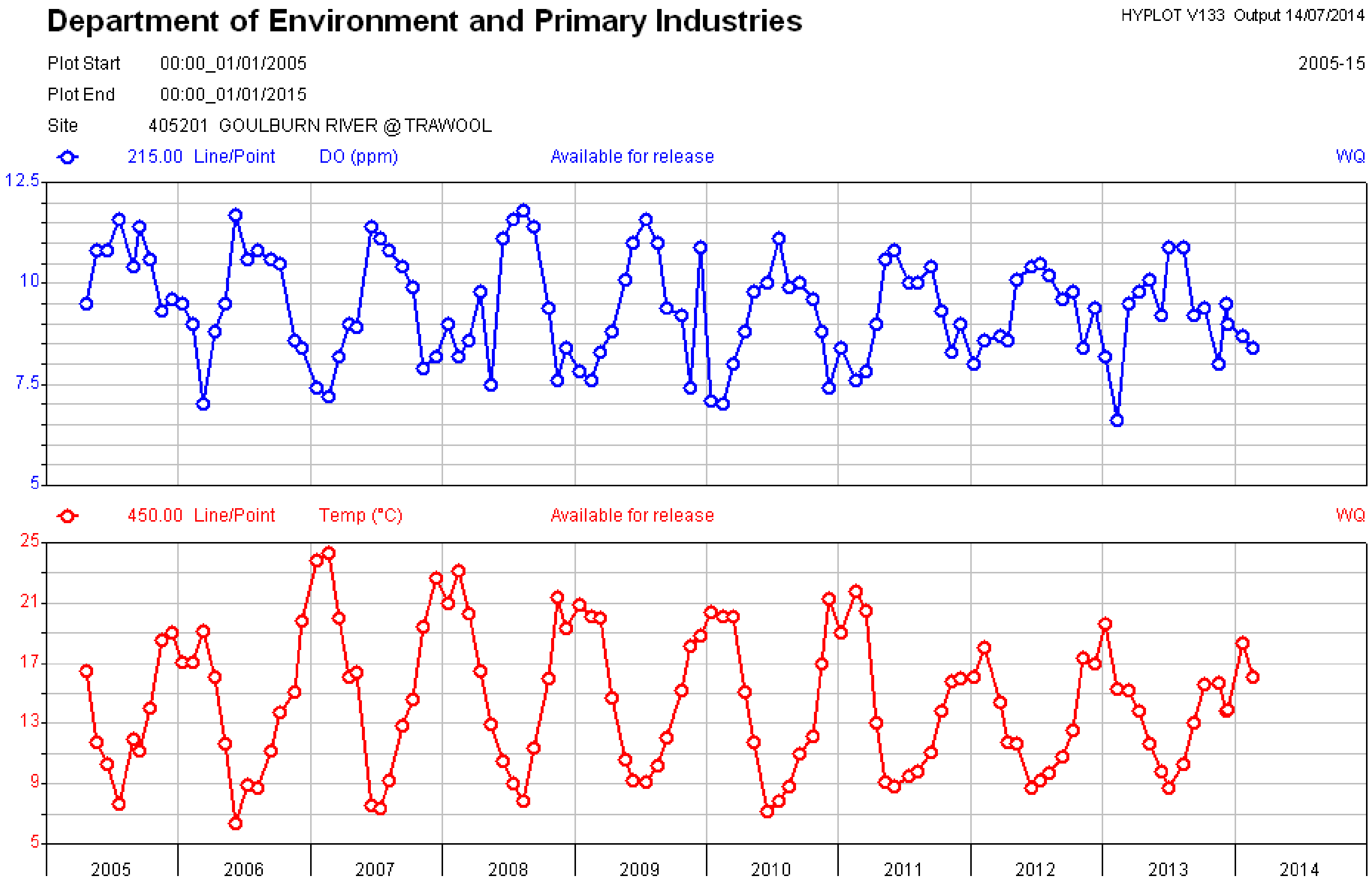

Figure 22: Time series of monthly DO (mg/L) and temperature (ºC) in the Goulburn River at Trawool (Reach 2), 2005-2014 (from DEPI, http://data.water.vic.gov.au/monitoring.htm).

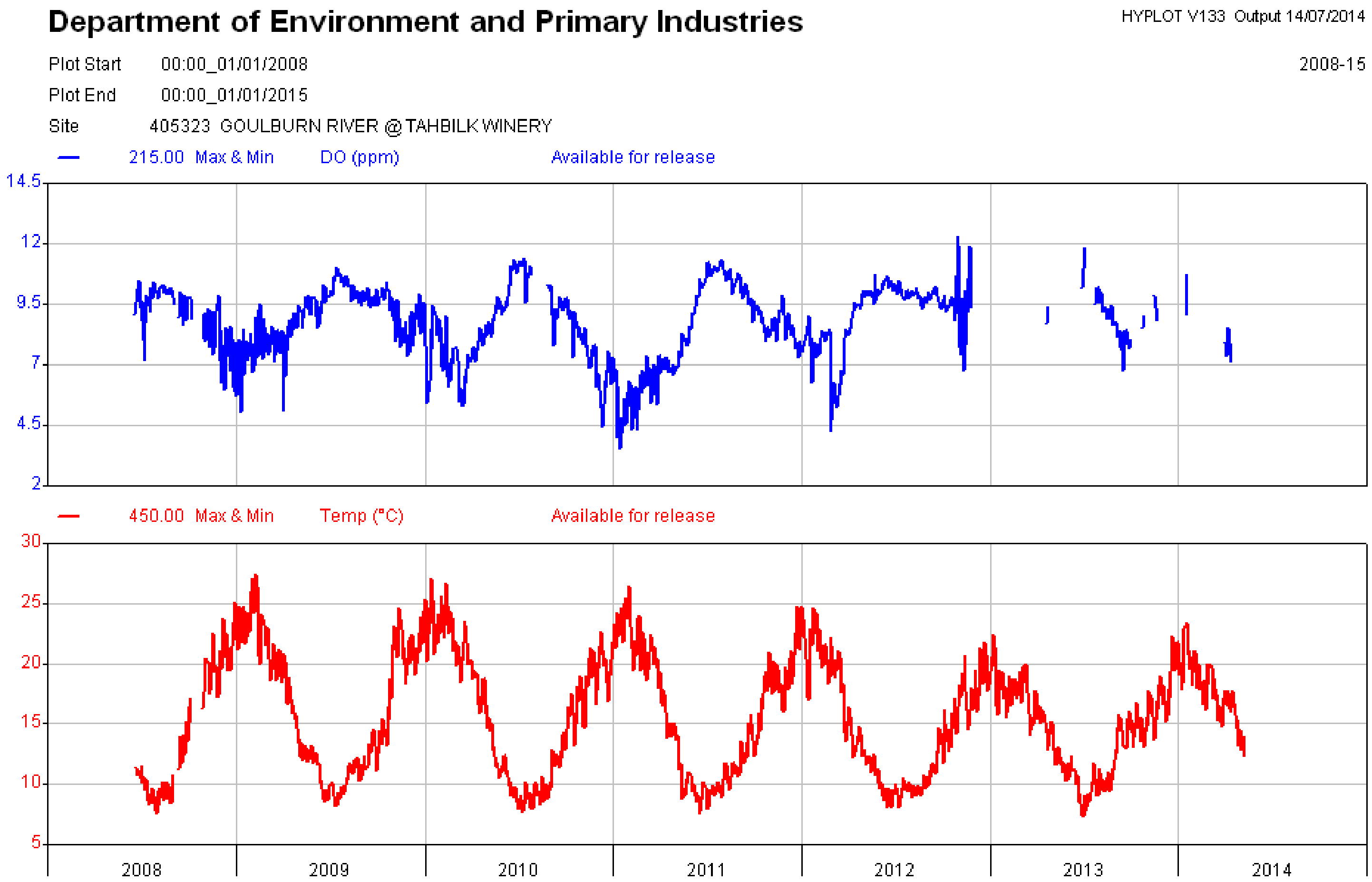

Figure 23: Time series of continuous DO (mg/L) and temperature (ºC) in the Goulburn River at Tahbilk (Reach 3), 2008-2014 (from DEPI, http://data.water.vic.gov.au/monitoring.htm).

Table 9: Condition and threats related to water quality in each study reach.

Reach	Water Quality Condition	Potential threats to water quality
1 Lake Eildon to Yea River	• Mostly meets SEPP objectives • Rated as excellent in ISC scores • Colder than natural water released from Lake Eildon during late spring and summer-autumn when storage levels are high	• Runoff from agricultural land; direct livestock access • Sediment inputs following catchment disturbances • Cold water releases from Lake Eildon in late spring and summer-autumn
2 Yea River to Sunday Creek	• Good for EC, pH and DO • Moderate to poor for turbidity, nitrogen	• Runoff from agricultural and urban land; direct livestock access • Sediment and turbidity inputs following catchment disturbances;
3 Sunday Creek to Goulburn Weir	• Good for EC, pH and DO • Moderate to poor for turbidity, nitrogen (assumed)	• Runoff from agricultural and urban land; direct livestock access • Sediment inputs following catchment disturbances.

5.2.3 Environmental objectives for water quality

While cold water has been identified as a potential threat to such things as breeding by some native fish and invertebrates, addressing this issue cannot be achieved by manipulation of the flow regime. Rather, it would require alteration to the dam offtakes, which is not considered feasible. Overall, water quality objectives relate to the continued implementation of catchment based management and emergency responses:

- Investigate the decline of DO concentration in water released from Eildon and consider whether amelioration using flow is feasible. Consideration should be given to responses should DO concentration fall below 4-5 mg/L, which is the point at which some fish can become stressed (Koehn and O'Connor 1990, ANZECC and ARMCANZ 2000).
- Continue catchment strategies to reduce or manage sediment, turbidity and nutrient inputs to the mid Goulburn River (e.g. GB CMA 2013, G-MW 2012);
- Implement emergency responses (e.g. as described by Tenant et al. 2012) to large-scale catchment inputs of sediments and turbidity, such as after bushfires.

Flow requirements to achieve flow-related objectives for water quality are listed in Table 10.

Table 10: Flow requirements for water quality objectives.

Environmental Objective	Reach	Main Flow Components
Ameliorate cold water releases from Lake Eildon. However, this is considered impractical due to the nature of the dam construction.	1 and 2	Requires changes to dam off-takes, rather than manipulation of the flow regime.
Investigate role of water releases in addressing instances of DO falling to near 4 mg/L.	1	Current information suggests low DO water may be from dam hypolimnium releases. In such circumstances, changes to the flow regime may be ineffective.
Reduce catchment inputs of sediment and turbidity (e.g. strategies to control high-sediment runoff from fire-affected catchments)	All	Management response mostly at the catchment scale, rather than by manipulation of the flow regime. Freshes may be included in emergency response in some circumstances (e.g. low DO, high turbidity and suspended solids).

5.3 Riverine vegetation

5.3.1 Overview

Riverine vegetation, as used here, means the vegetation found in various plant habitats in a river system. In a floodplain river such as the Goulburn, the principal habitats are the *floodplain* and its *wetlands*, the *riparian zone* which sometimes includes the *riverbank,* and the *river channel*, which includes the bed, edges and backwaters. Each of these habitats is affected by different parts of the river flow regime. The floodplain, for example, is inundated by overbank flows, and hence floodplain vegetation is determined by flow components such as frequency and duration of overbank flows, and the duration of the inter-flood interval; whereas the riverbank is affected by in-channel flows as well as by overbank inundation. Flow regime and hence flow management is one of the most significant environmental influences on riverine vegetation (the other being land management): river flows directly or indirectly affect the growth, vigour, survival, reproduction of riverine plants, and influence various stages in plant life cycle, such as hydrochory (seed dispersal by water), germination and seedling establishment.

Four habitats are considered here: river channel, riparian zone, wetlands and floodplain. Several of the issues discussed here are not readily resolvable for rivers that are managed primarily to serve economic demands. Nonetheless, it is important to raise these, because these place boundaries on what can be achieved.

5.3.2 River Channel

The in-channel (or river channel) vegetation of the mid Goulburn River has not been systematically assessed or described. This is not unusual: there are very few such studies in Australia (e.g. Mackay et al 2003) and possibly none in the Murray-Darling Basin. The scant information available comprises a photopoint record of a trial release in November 2011 (GB CMA n.d.), and observations and photographs made during the field inspection in May 2014, supplemented by photographs from January 2003 and description in Cottingham et al (2003). Fortuitously, the May 2014 field inspection occurred during the end-of-season drawdown, which exposed lower parts of the riverbanks and bars. The low water levels during the field inspection were 1490-1900 ML/d, which was still higher than the seasonal minimum, but nonetheless provided a strong contrast with flows in the photopoint record, of 7000 and 9000 ML day.

Description: In May 2014, in-channel macrophytes were conspicuously abundant in the Reach 1 above the Acheron River confluence. In-channel macrophytes were observed on lower parts of river banks, which had dense beds of exposed or semi-exposed submerged macrophytes stranded by the recent fall in water level. In-channel macrophytes were also observed on the channel bed amongst cobbles and gravel, and colonising gravel bars. Species richness was high at some sites, with considerable site-to-site diversity in growth forms. At Walnut Reserve, the right bank of the pool had a continuous dense fringe (at least a few hundred metres) of a submerged species of milfoil (*Myriophyllum* sp.), with Common Reed (*Phragmites australi*s) and knotweed (*Persicaria* sp.) dominant over the riverbank above summer water level (Figure 24). At Thornton Beach the river was fringed with dense masses of a delicate floating leafed macrophyte, a starwort *Callitriche* sp.; this species was also growing on the stream bed amongst cobbles and logs, with other submerged macrophytes including juvenile *Potamogeton* sp. (a tentative identification) (Figure 24). At Goulburn Valley Highway downstream of Thornton, extensive swards of vigorous submerged macrophytes almost covered the river bed, and a cobble-gravel bar on the upstream side of the bridge was covered, presumably stabilised, by an astonishingly-rich array of macrophyte species and growth forms including trees (Figure 24) and extensive patches of filamentous algae that suggest nutrient enrichment. Comparison with photos taken in 2001 suggest that the proliferation of macrophytes at this location has occurred since 2001. Large patches of submerged macrophytes were sometimes seen further downstream in Reach 1, and occasionally small patches of macrophytes were found in silty edges of Reach 2 but not in the same abundance or diversity as above the Acheron River confluence. Of interest, however, is that beds of Ribbon Weed *Vallisneria australis* were seen at Kerrisdale in the same location as in January 2003.

The abundance and diversity of in-channel macrophytes noted in May 2014 contrasts January 2003 (Cottingham et al 2003) when, in relation to the Goulburn River from Eildon to McCoys Bridge, macrophytes were described as '*relatively scarce*' and '*not very diverse*'. At the time, the principal macrophytes observed were a floating pondweed (identified in January 2003 as *Potamogeton tricarinatus*) which was noted as '*common in the upper reaches*', and Ribbon weed (*Vallisneria americana* now re-named *Vallisneria australis*). It was not possible to establish reasons for abundance and species richness being low, but the following were suggested as contributing factors: lack of suitable micro-habitats within the river, due to its lack of morphological complexity; increasing turbidity downstream; substrate mobilisation; foraging behaviour of Common carp (*Cyprinus carpio)*; armouring of the riverbed; velocity conditions.

Figure 24: Abundant macrophytes at three sites upstream of the Acheron River.

Top Left: milfoil *Myriophyllum* sp. at Walnut Reserve with *Phragmites* on the upper riverbank. Top Right: Starwort *Callitriche* amongst other macrophytes in shallow water at the toe of the bank. Middle Left: extensive beds at Goulburn Valley Highway Bridge. Middle Right: a gravel bar at the Breakaway nearly fully vegetated by aquatic, amphibious and terrestrial species. Bottom Left: Downstream of Goulburn Valley Highway Bridge 2001. Bottom Right: vegetation colonising bar near Trawool, May 2014. (Photos: all photos by Jane Roberts except Bottom left: Paul Brown).

Modelling as part of the environmental flow studies (Cottingham et al 2003) subsequently showed that velocity was plausible as an constraint on abundance in Reach 1 (Eildon to Molesworth) as the mean reach velocity in summer provided velocity conditions unsuitable for submerged macrophytes. Velocity was unlikely to be limiting growth in Reaches 2 or 3, (Molesworth to Nagambie) where mean reach velocity was slower (less than 0.6 m s-1) but water was more turbid. Here it was more likely that light limitation combined with depth during the growing season and/or benthic disturbance by foraging Common carp was limiting.

Condition: It is tempting to conclude there has been a substantive increase in macrophyte abundance since 2003. Certainly the recent flow history (2003-2014) is more conducive to macrophytes establishing and persisting in the river channel above the Acheron confluence than in the previous period (1990-2003). Flows at Eildon gauge have been much lower, barely and only briefly exceeding 5,000 ML/d in six of the last ten years (compared with up to and exceeding 8,000

ML/d nearly every year 1990-2002). As a result the period of persistent and continuous submergence on the riverbank was much shorter than typical 8 months of 1990-2002, and flows were generally shallower and slower, and even at times less than 0.6 m/s, which is widely accepted as the upper velocity limit for favourable growth of submerged macrophytes (Madsen et al. 2001; Cottingham et al. 2003).

However, such a conclusion could be misleading, as the two field inspections are not directly comparable. Different sites were visited, at different times of the year (mid-summer versus autumn) and under quite different flow conditions (high irrigation demand versus the month following the end of the irrigation season). A retrospective analysis of flow (velocity) history since 2003 compared with the preceding decades would help in understanding whether an increase in abundance was likely or merely an increase in visibility, and the role of other factors known to stimulate macrophyte growth, such as nutrients.

At the time of the 2003 flows study, understanding of ecological factors controlling macrophyte distribution and abundance in rivers was fairly rudimentary and not much understood. The velocity thresholds used in the 2003 slows study were taken from an empirical review focused on plant growth (Madsen et al. 2001). Since then, a number of ecological and cross-disciplinary studies (such as biogeomorphology, ecohydrology) have refined this understanding, but not changed the velocity thresholds critical for macrophyte growth. In general, recent studies have reinforced the significance of flow velocity as an environmental control when light is not limiting (e.g. Janauer et al. 2008), focused on plant adaptations (e.g. Puijalon et al. 2005) and investigated the functional role of macrophyte beds in physical processes such as sediment trapping (e.g. Cotton et al. 2006).

5.3.3 The riparian zone

The riparian zone is a functional part of the river, contributing carbon leachate, leaf litter and fallen wood, as well as moderating in-channel temperatures. It is important as habitat for terrestrial and floodplain fauna, often disproportionately so (e.g. Bennett et al. 2014), as well as aquatic fauna when flooded.

Description: The vegetation of the riparian zone in the mid-Goulburn has not been described, but has been assessed (see Condition below). Prior to agricultural development, the riparian zone would have changed in character and floristics, according to local geomorphological characteristics, whether reaches were relatively unconfined floodplain or constrained and in gorge. In a floodplain reach, the riparian vegetation would have been part of, and largely resembled, the dominant floodplain vegetation that was then present (i.e. Floodplain Riparian Woodland); whereas the riparian zone in constricted reaches or gorges would have had elements of the drier and more diverse vegetation from the adjacent hillslopes, such as Valley Grassy Forest, Grassy Woodland, Plains Grassy Woodland and even Box Ironbark Forest.

Field observations of the contemporary riparian zone is that it varies considerably in quality and extent (width), and that it is still strongly influenced by local geomorphology. In floodplain reaches, the riparian zone generally exists as a narrow strip, sometimes as little as 1-2 trees wide, with degraded understorey lacking a shrub layer and often dominated by pasture grasses. In extreme instances, where the floodplain had been cleared right to the top of the riverbank, the remnant Floodplain Riparian Woodland was restricted to the riverbank, and effectively within the channel. In many areas, the riparian zone in floodplain areas was exposed to stock, as fencing was not continuous. Species lists for wetlands close to the river repeatedly record blackberry (*Rubus anglocandicans)*, a WONS species (Weed of National Significance) and an array of willows (*Salix* spp.), with at least four species and hybrids (Australian Ecosystems 2012). Conversely, in constricted reaches, the riparian zone appeared to be wider and much more extensive, as well as being in better condition (floristically) and more structurally complex with shrub layers.

Condition: The condition of the woody vegetation in the riparian zone of the mid-Goulburn was recorded in 2010 as part of the third state-wide assessment of stream condition (ISC3). Unlike the first two assessments, this third assessment was done entirely remotely, using lidar, and aerial photography. This both expanded and restricted the range of indicators used relative to the two earlier assessments (ISC1 and ISC2 in 1999 and 2004 respectively), which included field-based information such as regeneration.

Table 11 below shows the mean scores for the sub-index and seven indicators for the six ISC reaches (ISC Reaches 9-14) equivalent to the mid-Goulburn study area. The average score is 6.72/10, with almost no variation between reaches (not shown). Field observations that the riparian zone was frequently very narrow were supported by the low scores for the Vegetated Width indicator and for Fragmentation indicator (which counts as a gap if woody vegetation is less than 20% cover in a 10 x 10 m area). Field observations that the understorey was weedy and grazed, with poor recruitment of native species, were not detectable using the remote sensing methods of ISC 3. The weed indicator considered only willows, and not blackberry or the nativeness of plants present. Willows, although present, are scattered rather than abundant, affecting (on average) less than 40% of the banks. A positive feature is the relatively high score for vegetation overhanging the channel, an important riparian function.

Table 11: ISC3 scores for Streamside Zone.
For the sub-index score, the seven indicators are weighted individually and then summed.

Mid-Goulburn	
Reaches 9 to 14 in ISC3	**Mean**
Riparian sub-index (max = 10)	6.72
Vegetated width (max = 5)	2.33
Shrub cover (max = 5)	4.00
Tree cover (max = 5)	4.50
Structure (max = 5)	4.33
Fragmentation (max = 5)	3.50
Large Trees (max =- 5)	1.83
Overhang of channel (max = 6)	5.17
Willows (max = 5)	3.83

5.3.4 Wetlands on the Floodplain

Description: A total of 301 wetlands are “naturally occurring” on the mid Goulburn floodplain between Lake Eildon and Nagambie (data from the Current wetlands layer, Biodiversity Interactive Mapping tool or BIM Version 3.2). All 301 wetlands are fresh (no saline wetlands), and most are palustrine (94%) rather than lacustrine (Table 12). Most (55%) are dominated by forest/woodland vegetation rather than by sedge/grass/forbs (37%); and only relatively few have no evident (emergent) vegetation (only 5%). Most of the wetlands are small, with 58% being 5 ha or less in extent. Smallness may be a natural characteristic in Reaches 1 and 2, nonetheless it is likely that numbers have been boosted by the construction of block banks and culverts that cause local disconnection and fragmentation; it was evident during the May 2014 field inspection that these were used to facilitate access around the floodplain, and to minimise high river flows onto the floodplain. Wetlands larger than 20 ha are more common in Reach 3, which also has the two biggest wetlands: an unnamed wetland (69 ha) and Tahbilk Wildlife Reserve Lagoon (106 ha).

Table 12: Floodplain and wetland characteristics for Reaches 1, 2 and 3.

		Reach 1	Reach 2	Reach 3
Reach characteristics				
Channel length (km) (approx.)		84	46	45
Floodplain width – typical (m)		Mostly 1,200-1,600	Mostly 500-900	Mostly 800-1,900
(range in m)		(400-2,300)	(300-3,400)	(200-2,150)
Wetland characteristics				
Number of wetlands		164	92	45
Area of wetlands (ha)		1016	599	544
Wetland Size categories				
<= 2 ha:	count	36	10	10
>2 - 5 ha:	count	63	44	10
>5 to 10 ha:	count	41	20	9
>10-20 ha:	count	16	16	9
>20-50 ha:	count	8	2	5
> 50 ha:	count	0	0	2
<= 2 ha:	area (ha)	56	16	15
>2 - 5 ha:	area (ha)	215	161	32
>5 to 10 ha:	area (ha)	295	147	66
>10-20 ha:	area (ha)	214	221	115
>20-50 ha:	area (ha	235	55	140
>50 ha	area (ha)	0	0	177
Types of Wetlands: Aquatic System				
Palustrine:	count	160	83	40
Lacustrine	count	4	9	5
Palustrine	area (ha)	1001	524	408
Lacustrine	Area (ha)	15	75	136
Dominant Vegetation				
Forest-Woodlands:	count	101	40	28
Sedge/grass/forb:	count	59	44	12
No emergent vegetation:	count	4	8	5
Forest-Woodlands:	area (ha)	664	265	334
Sedge/grass/forb:	area (ha)	337	244	74
No emergent vegetation:	area (ha)	15	90	136

The 301 wetlands total 2,159 ha, of which 59% is dominated by forest/woodland and 30% by sedge/grass/herb (Table 12). This breakdown by area of vegetation types does not quite parallel the breakdown by count: for example, wetlands with no emergent vegetation account for only 5% of all wetlands by count, but 11% by area, indicating that some of these are large. Given that the floodplain was probably covered by Riparian Floodplain Woodland (EVC 56) prior to agricultural development (Figure 25), it is likely that many of the wetlands currently dominated by sedge/grass/herb are derived from forest/woodland dominated wetlands that have been cleared.

The three reaches are broadly similar in the types of wetlands present, which is not surprising, given their common origin as a floodplain covered by Floodplain Riparian Woodland. Nonetheless, there are some points of difference (Table 12). Reach 1, for example, has more wetlands and more wetland area than Reaches 2 and 3: this could be due to this reach being considerably longer and generally wider rather than having a greater density of wetlands. Very small wetlands (<=5 ha) are particularly numerous in Reaches 1 and 2, and account for approximately 60% of all wetlands: they are much less numerous in Reach 3 (44%), which has more large wetlands. Small wetlands may not have high ecological value individually, but their collective value (if in moderate-good condition) can be high as a habitat mosaic.

The pattern of dominant vegetation in wetlands differs between the three reaches (Table 12). In Reach 1, the dominant vegetation for wetlands is Forest/Woodlands (664 ha) followed by sedge/grass/forb (337 ha): wetlands with no emergent vegetation are few and comprise a relatively small area (4 wetlands, 15 ha). In Reach 2, wetlands dominated by sedge/grass/forb are more numerous and cover nearly as much area as Forest/Woodland wetlands (44 wetlands, 244 ha, compared with 40 wetlands, 265 ha). Reach 3 is similar to Reach 1 in that the dominant vegetation in wetlands is Forest/Woodland (28 wetlands, 334 ha), but the presence of some large lacustrine aquatic systems means that the area with no emergent vegetation (5 wetlands, 136 ha) is more extensive than sedge/grass/forb area, which is relatively unimportant (12 wetlands, 74 ha).

Floristic surveys of wetlands are rarely done due to cost (field and processing time), and the vegetation information and floristic details provided as part of the IWC condition assessment of 12 wetlands in February 2012 (Australian Ecosystems 2012) contributes to this information gap. The most commonly recorded wetland EVC in these 12 wetlands was Billabong Wetland Aggregate, followed by Tall Marsh (EVC 821) and Floodway Pond Herbland (EVC 810), with occurrences of Wet Verge Sedgeland (EVC 932) and Aquatic Herbland (EVC 653). Riparian shrubs were frequently recorded, notably River Bottlebrush *Callistemon sieberi* and the endangered Yarran Burgan *Kunzea leptospermoides*. Especially notable was the considerable overall richness and between wetland diversity in macrophytes, with most growth forms being recorded somewhere, except for submerged species (notably absent). The assessment also recorded unusual occurrences, distributional extensions, high abundances and five listed non-woody wetland plants, including one EPBC species (Table 13). Further vegetation surveys can be expected to build on these beginnings.

Condition: Only 18 out of the 301 wetlands have been assessed using the Index of Wetland Condition (IWC), all in 2011-2012 (Australian Ecosystems 2012). Most (55%) were in Reach 1, and only 2 (11%) were in Reach 3. None were in the smallest size class (up to 2 ha) and a disproportionate number were in the 10-20 ha size class (33% as opposed to 13.6% in the population). This geographic distribution and the bias in size classes shows that the 18 wetlands are not strictly representative of the 301 wetlands on the mid-Goulburn floodplain. However the twelve wetlands assessed in February 2012 did cover a range of situations (private and public tenure; fenced, unfenced and recently fenced), and all were close to the main river channel (Australian Ecosystems 2012). Accordingly, condition results are given individually (Table 14) or as averages (Table 15) rather than being summarised at the reach-scale.

Table 13: Listed wetland plants recorded during IWC assessments of February 2012.

	Number of wetlands where recorded (max = 12)
EPBC-listed	
River Swamp Wallaby Grass *Amphiromus fluitans*	1
VROTS	
River Club-sedge *Bolboschoenus fluviatilis*	3
Green-top Sedge *Carex chloantha*	3
Veiled Fringe-Sedge *Fimbristylis velata*	1

	Number of wetlands where recorded (max = 12)
Hypsela *Hypsela tridens*	1
Yarran Burgan *Kunzea leptospermoides*	4

Table 14: Wetland Condition scores (IWC) for 18 Wetlands in Reaches 1, 2 and 3 (Data courtesy of DEPI).

Reach	Name or Corrick Number	IWC Score	IWC category
1	Mc Crackens Road	7	Good
1	7923622873	7	Good
1	Molds Billabong	7	Good
1	Zerby's Billabong	7	Good
1	Molesworth Wildlife Reserve (North)	8	Good
1	Cremona Park	5	Moderate
1	8023832813	6	Moderate
1	The Breakaway (West)	8	Good
1	Rollasons Road Evans Wetland	4	Poor
1	Taylors Breakaway	5	Moderate
2	7923374949	6	Moderate
2	Praetermissa Wetland	7	Good
2	Horseshoe Lagoon	9	Excellent
2	7923434895	7	Good
2	The Haven Billabong	7	Good
2	Homewood Swamp Wildlife Reserve	7	Good
3	7924280190	7	Good
3	7924284246	7	Good

Table 15: IWC Sub-index scores: mean (max is 20), CV and range.

	Wetland Catchment	Physical Form	Hydrology	Water properties	Soils	Biota
Mean	9.6	19.5	6.9	15.4	14.1	15.3
CV (%)	63.0	9.7	86.0	8.8	34.8	20.2
Range	2.0 to 20.0	12.0 to 20.0	0.0 to 15.0	13.7 to 20.0	0.0 to 20.0	9.4 to 19.9

The IWC scores shows that nearly all the wetlands assessed are in moderate or good condition, with just one rated as excellent (Horseshoe Lagoon in Reach 2) and just one rated as poor (Rollasons Road Evans Wetland in Reach 1). Scores for the six sub-indices contributing to the overall IWC score show some interesting patterns (Table 15) in terms of mean values, as well as variability. Average scores for sub-indices were generally moderate to high except for the Wetland Catchment and Hydrology sub-indices (which were also the most variable, with CV = 63.0% and 86.0%). Low scores for these sub-indices are indicative of clearing, and of river regulation and impeded hydrological connectivity, but although clearing and river regulation and connectivity are widely recognised as being important drivers of wetland condition, these two sub-indices have only a relatively small effect on the final IWC scores, because of how they are weighted when sub-indices are combined to give an overall score (DEPI 2013). Average scores for Physical Form and Water Properties sub-indices were high and consistent (CV = 9.7% and 8.8% respectively) suggesting these are not an issue.

The average score for the Biota sub-index is 15.3 (Table 15) indicating that wetland vegetation is generally in a good condition. The 18 wetlands assessed are all close to the Goulburn River: there are no condition assessments for wetlands set back on the floodplain.

Non-indigenous species comprised 30-57% of species recorded for these twelve wetlands for which floristic details are available (mean = 42%). This is slightly higher than for other regulated floodplains in south-eastern Australia (Roberts 2001), and can be attributed to a history of disturbance such as cattle grazing, river regulation (especially seasonally inverted flows) and edge effects resulting from clearing, all of which increase the prevalence of non-native species (e.g. Catford et al. 2011). The non-indigenous species included ten species listed under the Catchment and Land Protection Act (2004), of which five were WONS and mostly willows: S*alix babylonica*, *Salix x rubens*, *Salix cinerea*, *Salix alba* and blackberry *Rubus anglocandicans* (Australian Ecosystems 2012). Blackberry was particularly widespread, occurring at 11 of the 12 wetlands.

This average score for Biota sub-index is higher than expected given the considerable changes to hydrology and land use through most of the mid-Goulburn. It is also at odds with the interpretation given above (under Descriptions) of sedge/grass/forb dominated wetlands being cleared forms of Forest/woodland wetlands, and of ‘no emergent vegetation’ in the smaller wetlands of being a degraded form. If this interpretation is sound, then wetlands in Reach 2, which has a relatively higher proportion of sedge/grass/forb dominated wetlands, are in poorer condition than Reach 1 or Reach 3.

5.3.5 Floodplain Vegetation

Prior to the development of the Goulburn valley for agriculture, the entire floodplain from Eildon to Nagambie would have been an open woodland-forest dominated by River Red Gum *Eucalyptus camaldulensis* (EVC 56 Floodplain Riparian Woodland) except for some areas of mixed woodland (EVC 250 Floodplain Riparian Woodland Plains Grassy Woodland mosaic) downstream of the Goulburn-Yea River confluence in Reach 2. Being dominated by River Red Gum indicates the floodplain was frequently flooded. The current situation is very different. The extent of Floodplain Riparian Woodland is now much reduced, due to extensive clearing and utilisation of the rich alluvial soils for various types of agriculture, and the frequency of floods has also been reduced since the construction of Big Eildon over 60 years ago (Erskine 1996).

Precise estimates of clearing and any reach-scale variations are not currently available but can be appreciated by comparing the (modelled) pre-1750 extent of EVC 56 Riparian Floodplain Woodland with mapped extent for 2005 (Figure 25). This Riparian Floodplain Woodland once extended across the floodplain (up to 2.5 km wide in parts) and was continuous up-down the river. It is now discontinuous, and occurs either as small patches, rarely more than 600 m wide, or as strips beside the main river channel or around floodplain wetlands. The area between these woodland remnants is mostly open grassland, used for stock grazing. The reduction in flood frequency most acute immediately downstream of Eildon, in Reach 1, and is progressively attenuated downstream due to tributary inputs. For example, flows of 50,000 ML day are reduced fivefold in Reach 1 (from 1:2 to 1:10), four-fold in Reach 2, and by only a half in Reach 3 (Table 16).

A reduction in flooding frequency affects processes that are flood-dependent or flood-enhanced, such as vegetation regeneration and return of organic material to the river. Although River red gums are not dependent on flooding for regeneration, floods are important in episodic recruitment (e.g. Roberts and Marston 2011) and hence in maintaining the populations. Trees and shrubs may be regenerating in fenced areas but are unlikely to be maintaining viable populations elsewhere on the floodplain.

Table 16: Reduction in flood frequency (partial series analysis) (Appendix 2).

	Reach 1		Reach 2		Reach 3	
Flow	**Unimpacted**	**Current**	**Unimpacted**	**Current**	**Unimpacted**	**Current**
40,000 ML day	1:1	1:6	1:1	1:4	1:1	1:2
50,000 ML day	1:2	1:10	1:2	1:8	1:2	1:3
60,000 ML day	1:4	1:17	1:4	1:15	1:2	1:3.5
70,000 ML day	1:7	> 1: 20	1:9	> 1:20	1:2.5	1:5.5

It is highly likely that the combined effects of river regulation and floodplain clearing have shifted the riverine food web from heterotrophic-dominated to autotrophic-dominated. Terrestrial carbon or *allochthonous* carbon enters the river channel directly as litterfall from riparian vegetation or, more importantly, as a result of high flows. These inundate vegetation on bars, benches and floodplains and carry particulate organic carbon (POC) and dissolved organic carbon (DOC) to the river. In the river, this allochthonous carbon is broken down by heterotrophic aquatic micro-organisms, then taken up by plankton and so enters the food chain. In the absence of overbank flows, whether due to river regulation or drought, allochthonous carbon inputs are greatly reduced, and the river production is likely to become autotrophic-dominated (Westhorpe et al 2010) and may even become DOC-limited (Westhorpe et al. 2010, Hadwen et al. 2009). The carbon dynamics of the mid-Goulburn have not been studied but it is likely that autotrophic production (probably benthic algae) dominates, as shown for regulated and drought affected rivers elsewhere in the Murray-Darling basin (Westhorpe et al. 2010, Hadwen et al. 2009, Vink et al. 2005), and that productivity is both DOC limited and substrate constrained (Baldwin et al. 2014).

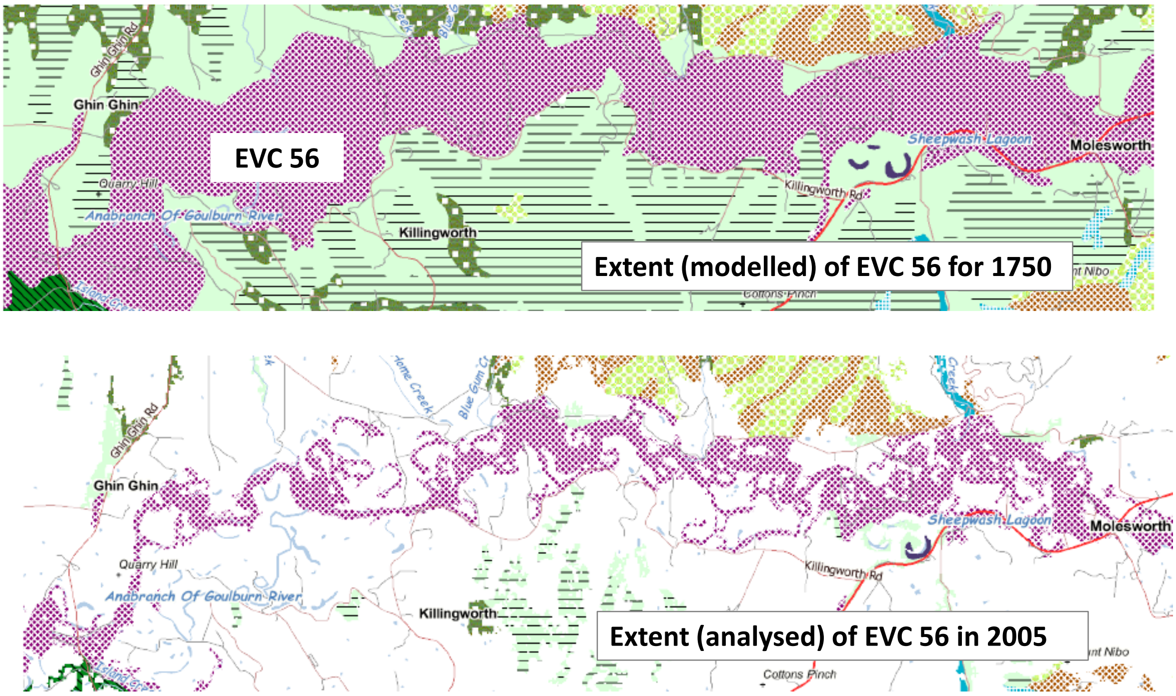

Figure 25: Changes in floodplain woodland.

Comparison of unimpacted extent of EVC 56 Floodplain Riparian Woodland (stippled purple), based on modelled vegetation patterns for pre-1750, with current mapped extent, as of 2005. This part of Reach 1, showing the floodplain between Molesworth and Yea River confluence was chosen because it appears to be fairly typical and because its horizontal format lends itself to report layout.

5.3.6 Summary of vegetation condition and issues

In-channel vegetation: The abundance and richness of macrophytes in Reach 1 above the Acheron confluence is, currently, quite a distinctive feature of the in-channel vegetation of the mid Goulburn River. Not only do these macrophyte beds provide a particular type of shelter and foraging habitat for micro-fauna and small fish that is not available elsewhere in the mid-Goulburn, but they are also significant for macrophyte biodiversity and may be acting as a source of diaspores, vegetative propagules and fragments for connected wetlands and backwaters further downstream. A detailed floristic survey was not done of this area but it did not appear to be supporting any noxious or dangerous aquatic weeds.

The ten-year persistence of submerged beds of *Vallisneria australis* near Kerrisdale in Reach 2 is of interest. Elsewhere in the Murray-Darling Basin, in-channel beds of *Vallisneria australis* are being lost (e.g. Murray River between Albury and Lake Mulwala) or declining (e.g. Broken River) leading to a homogenisation and simplification of rivers as habitat.

Maintaining these in-channel macrophytes should be an environmental objective for the mid Goulburn River, for biodiversity reasons and because they add habitat diversity to an in-channel environment that is not particularly diverse or complex.

The challenge is how to do this in a river that is highly regulated and has a seasonally inverted flow regime. The previous 2003 flow study established that summer flows of 9-10,000 ML/d produced hydraulic conditions that were marginal or even detrimental for submerged macrophytes to grow in Reach 1 (Figure 8, Cottingham et al 2003). Modelling showed that the recurrence interval for sustained periods (20-40 days) of these unfavourable conditions was now every year as opposed to being rare (1:1 versus 1:10 years) under (modelled) unimpacted conditions (Figure 7, Cottingham et al 2003). A major risk of losing beds of *Vallisneria australis* is that it is highly unlikely to re-establish, at least in a regulated river such as the Goulburn. Experimental studies suggest a drawdown, without heat stress, may be needed to promote regeneration of this submerged macrophyte from the seedbank (Salter et al 2010). It is not known if this applies to other native aquatic plants such as pondweeds (*Potamogeton* spp.), milfoils (*Myriophyllum* spp.) or other aquatic herbs.

Riparian Zone: The current condition of the riparian zone is largely a legacy of clearing, grazing, and willow planting for river improvement (Erskine et al 1993). In the absence of any field-based assessments, the ISC3 does not make explicit the role of grazing on riparian condition, specifically on regeneration of trees and shrubs and on biodiversity. However, this is already known for the Goulburn-Broken from a survey of 46 sites in 2003 (Figure 26, from Jansen et al. 2004) and can be inferred from relationships established in other agriculturally-developed lowland rivers such as the Murrumbidgee River (e.g. Jansen and Robertson 2001a, b; Jansen and Healey 2003). Improving riparian condition by fencing will take time, and an assessment of the effects of initiative of ten years ago is timely, including the re-appraisal of the 46 sites.

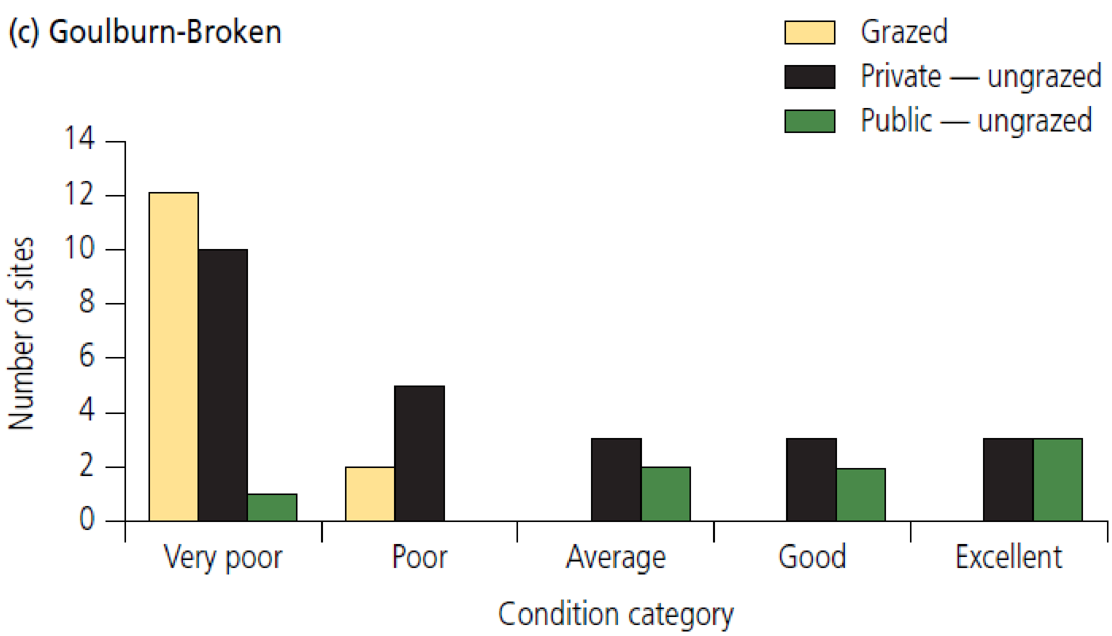

Figure 26: Riparian condition scores for sites along the mid Goulburn River (from Jansen et al. 2004).

Wetlands: The geomorphic diversity evident on the floodplains (section 5.3.5 above) results in an abundance of wetlands, mostly small. A history of river regulation especially reduced flood frequency and seasonal flow inversion, utilisation for agriculture with clearing and grazing, and small infrastructure and works on the floodplain have modified and changed the wetlands, resulting in two broad types: wetlands on the floodplain that are filled by overbank flows, and wetlands that are hydrologically connected to the river by high in-channel flows.

Under current conditions, wetlands on the floodplain now flood much less frequently (Table 16) and it is likely that for many the ratio of wet:dry time is now reversed, i.e. they are now unflooded for longer periods of time than they are flooded. Long periods without being flooded has implications for the wetland seed bank. The single Australian study of seed bank viability through time (Brock 2011) found that even though 63 out of the 64 taxa investigated were considered long-lived, viability did decline with time and that less than half (45%) were still able to germinate after 9 years in the seedbank. The implications for floodplain wetlands in Reaches 1 and 2 is they will gradually lose wetland species from the seedbank.

Conversely, the delivery of irrigation flows over the growing season means that low-lying wetlands have water regimes that track irrigation flows, with seasonally inverted flow regimes (i.e. flooding occurs in spring-summer-autumn) and incomplete drying out, due to drawdown occurring over the cooler months. Extended peak flows disadvantage native plants with life-cycles adapted to a spring flood recession, notably riparian shrubs (Greet et al 2012) and favour introduced species, such as generalists or especially winter-growing grasses. Both reduced flood frequency and seasonally inverted flow regimes (Stokes et al 2010, Greet et al 2012) are recognised as promoting non-native species in wetlands and riparian zones. The relatively high incidence of non-native species in the Goulburn is consistent with current understanding of the effects of seasonally-modified flows (see Chapter 4). The IWC assessment does not take account of floristic and structural vegetation changes induced by seasonally inverted flow regimes.

A risk associated with sustained high spring-summer-flows is that low-lying wetlands may become dominated by aggressive and invasive tall emergent macrophytes such as Cumbungi *Typha*, Giant Rush *Juncus ingens* and Common Reed or Phragmites, and lose much of their current diversity.

5.3.7 Environmental objectives for riverine vegetation

The flow-related objectives and relevant flow components to be assessed when developing environmental watering recommendations for in-channel and riparian/wetland vegetation are presented in Table 17.

Table 17: Flow-related environmental objectives for riverine vegetation.

Environmental Objective	Reach	Main Flow Components
Maintain existing beds of in-channel macrophytes as a habitat and for biodiversity reasons	1 and 2	• Flow magnitude of freshes during the growing season, specifically duration and timing, and depth and velocity.
Provide periodic regeneration opportunities for native riparian species adapted to and dependent on the natural flow regime (riparian and floodplain wetland)	All	• Recession timed to occur in spring-summer
Provide periodic overbank flows to improve in-channel carbon availability	All	• Frequency of overbank flows
Maintain diversity among low-lying wetlands by providing different water regimes	All	• Duration and timing of low-flows • Year to year variability in water levels including bankfull and overbank flows • Within-year variability in high flows

5.3.8 Non-flow related issues

There are a number of ongoing non-flow threats to riverine vegetation and hence to vegetation-related ecological processes and recovery along the mid Goulburn River:

- Abundance and prevalence of introduced woody species notably willows (*Salix* spp.) and blackberry (*Rubus anglocandicans*),
- Cattle access to riparian zone and the riverbank,
- Barriers to wetland connectivity (e.g. altered flow paths and barriers such as block banks).

5.4 Invertebrates

5.4.1 Summary of condition

The most recent and comprehensive assessment of the macroinvertebrate communities in the mid Goulburn River was conducted as part of the Sustainable Rivers Audit (SRA) that assessed the ecological health of streams in the Murray Darling Basin during the end of the Millennium drought (Davies et al. 2012, http://www.mdba.gov.au/what-we-do/mon-eval-reporting/sustainable-rivers-audit). The SRA sampling methods were those developed for the Australian River Assessment Scheme (AUSRIVAS) under the National River Health Program (Davies, 2000). The Goulburn River was sampled on three occasions between 2003 and 2008. Where possible, both riffle and edge samples were surveyed. Identification was to family level for most groups and the AUSRIVAS sampling method does not accurately represent the absolute or relative abundances of macroinvertebrates. One metric was use to summarize the data, this being the macroinvertebrate condition index, SR-MI. This index is calculated from the sum of the differences in frequency of occurrence between all macroinvertebrate families in the SRA site samples and those predicted under reference condition, divided by the sum of all taxon frequencies in both the sample and reference condition.

The SRA results (Davies et al. 2012, Table 18) indicate that the overall river ecosystem of the Goulburn Basin was in poor health generally, rating 22nd of the 23 valleys in the Basin on the basis of macroinvertebrate communities present. The macroinvertebrate community of the mid Goulburn River (predominantly Lowland) was assessed as being in poor condition, although the fauna present in tributaries streams were reported to be in moderate condition. The Goulburn River also ranked poorly for fish, having the 7th lowest biomass of fish per site amongst the 23 valleys surveyed throughout the Basin. It is possible that the type and abundance of macroinvertebrates present in the Goulburn is a major factor influencing the biomass of fish present; unfortunately, there are currently no estimates of macroinvertebrate biomass in the study area to confirm this.

The poor condition of invertebrate populations in the mid Goulburn River is likely to be the result of a number of (often interacting) factors. These include such things as the altered flow regime (e.g. changed invertebrate community structure in response to changed hydraulic habitat and changes to carbon availability), altered geomorphic conditions (see section 5.1) resulting in increased armouring and infilling of riffle and gravel habitat with sediments, cold water releases in summer-autumn affecting production rates, localised effects of contaminants such as nutrients and turbidity (see section 5.2), reduced structural habitat due to a lack of emergent macrophytes (e.g. *Phragmites*) in Reaches 2 and 3 (see section 5.3) as well as previous removal of large wood (snags) that support biofilms and provide hydraulic habitat diversity.

Table 18: Goulburn Valley distribution of sample sites and values of derived variables (from Davies et al. 2012).

Number of sites and families sampled	Valley	Zone	
		Slopes	Lowland
Sites			
Number of sites sampled	35	12	14
Number of sites with index values*	34	12	14
N sites by SR–MI condition band			
Good (80–100)	6	2	
Moderate (60–80)	8	6	2
Poor (40–60)	13	4	6
Very or Extremely Poor (0–40)	7		6
Families			
Number of families sampled	82	62	53
No. families/site (min-max)	28 (7–44)	31 (20–42)	23 (14–35)
Percent of families in Basin	87	66	56
Percent of families in valley	100	76	65

Potential flow regime impacts

Unfortunately the nature of invertebrate data collected for river health assessments, such as the SRA, are such that it is difficult to separate the effects of altered hydrology from other stressors such as altered temperature regimes, changes to habitat diversity and quality, and reduced ecosystem primary production. It is likely that all these factors are present and interacting to affect the invertebrate communities of the mid Goulburn River, given that hydrology, temperature and habitat changes below dams have been shown to affect macroinvertebrate communities (e.g. relatively more tolerant taxa such as *Chironomidae* larvae, *Oligochaeta* and *Acarina*, and fewer of the more sensitive taxa, such as *Plecoptera*, *Ephemeroptera*, *Trichoptera* and *Coleoptera*) (EPA Victoria 2004, Nicols et al. 2006).

5.4.2 Key invertebrate species that support fisheries

While it is important to have a diverse macroinvertebrate fauna, including having an array of pollution sensitive species, there are a number of key invertebrate species that are particularly important as a source of food for fish and other vertebrates. For example, yabbies, shrimp and dragonflies are recognized as being key prey for many fish (e.g. Cadwallader, 1979; Merrick & Schmida, 1984). Exploring how environmental flows and other actions may increase the presence of these key invertebrate species will also benefit other ecological attributes, such as maintaining native fish and trout populations in the mid Goulburn River.

Aquatic insects are a major component of the diet of native fish and other biota such as frogs. These include mayflies, midges, caddis flies and water beetles, and larger food sources such as dragonflies, shrimp and yabbies' (Cadwallader 1979; Merrick & Schmida 1984). While rapid bioassessment approaches do not provide quantitative macroinvertebrate data, they can provide information on the presence of taxa. Table 19 uses EPA Victoria data to summarise the presence of three key taxa in the mid Goulburn and lower Goulburn (downstream of the Goulburn Weir). Although these data are rudimentary, they strongly indicate that shrimp, yabbies, dragonflies and damselflies are more common in the lower Goulburn than in the mid Goulburn River.

Table 19: The percentage presence of shrimp, yabbies and dragonflies and damselflies collected from RBA Sweep samples in the mid Goulburn (downstream of Eildon) and lower Goulburn (downstream of the Goulburn weir) between 1998 and 2011 (unpublished EPA Victoria data; n= number of sampling events).

	n	Shrimp	Yabbies	Dragonflies and Damselflies	
		Presence	Presence	Presence	Average Abundance
Mid Goulburn	14	14	0	29	0.29
Lower Goulburn	31	31	10	48	1.26

The freshwater shrimp *Paratya australiensis* is very common in north eastern Victoria. Water temperature and hydrology seem to be most important in influencing the life history of this species. Warmer temperatures are important for embryonic and larval development and provide well-defined cues for synchronized recruitment (Bunn 1998). In Australia, members of the Atyidae (shrimps, yabbies) breed all year round in warm climates (de Silva & de Silva 1989) whereas their breeding season in temperate and subtropical regions is confined to warmer months (Williams 1977; Dudgeon 1985). It is, therefore, possible that cold-water summer-autumn temperatures in the mid Goulburn plays a major role in the low relative abundance of shrimps and yabbies.

Many Australian dragonflies are associated with streams or stream margins (Theischinger & Hawking 2006). The rate of larval growth is highly dependent on temperature (Watson et al. 1991). Some riverine dragonflies emerge early in spring and have a short emergence period. While this emergence is regulated primarily by photoperiod, the onset of emergence depends mainly on spring water temperatures (Farkas et al. 2012). The relatively low presence and abundance of Odonates in the mid Goulburn River may be attributed to the unseasonally low flows that prevail in winter-spring as a result of the modified flow regimes. Many Odonates are associated with the fringing, emergent vegetation. The banks of the middle and lower Goulburn River are typically trapezoidal, and support little fringing emergent vegetation except in the upper sections of Reach 1. This lack of fringing habitat is likely to contribute to depauperate Odonate assemblages in this system, particularly in Reaches 2 and 3.

5.4.3 Potential relationship to the regulated flow regime

The flow regime of the Goulburn River has the potential to influence invertebrate communities via:

- The modified flow regimes and associated modified water temperatures are the primary factors causing the macroinvertebrate in the Goulburn River between Eildon and Nagambie to be in poor condition. Not only is there an absence of many macroinvertebrate taxa that would be expected to occur in lowland streams, there also appears to be low numbers of large invertebrates that are major food sources for fish and other vertebrates.

Although macroinvertebrates are a key group that should be considered when determining environmental flows, there is little useful information on how they may respond to environmental flows or what water temperatures would be sufficient to stimulate breeding of key species.

Furthermore, there is no information on how the biomass of macroinvertebrates in the Goulburn River compares to other streams with larger sustainable fisheries.

The available data suggests that there is little recovery in the macroinvertebrates along the mid Goulburn reach. Inflows from tributaries may mitigate the effect of unseasonal flows and/or cold water but the current macroinvertebrate data is too coarse to distinguish any changes in the fauna. It is also unclear what effect the 2009 bushfires in tributary catchment had on macroinvertebrate communities and their potential for aiding recovery of communities in the Goulburn River.

5.4.4 Summary of macroinvertebrate condition and issues

Table 20: Reach summary of the condition of macroinvertebrate populations

Reach	Condition of Macroinvertebrates	Potential threats to macroinvertebrates
1 Lake Eildon to Yea River	Poor	• Unseasonal flows due to dam operations and rapid changes in flow (e.g. altered hydraulic habitat diversity). • Cold water releases from Lake Eildon in late spring and summer-autumn • Armouring of the river bed and Infilling of habitat by sediments. • Sediment and nutrient inputs from direct livestock access and runoff from agricultural areas. • Reduction in native riparian vegetation and proliferation of exotic vegetation changing the timing and quality of carbon inputs.
2 Yea River to Sunday Creek	Poor	• Unseasonal flows due to dam operations and rapid changes in flow (e.g. altered hydraulic habitat diversity). • Cold water releases from Lake Eildon in summer-autumn • Armouring of the river bed and Infilling of habitat by sediments. • Sediment and nutrient inputs from direct livestock access and runoff from agricultural areas. • Reduced hydraulic habitat diversity due to a lack of emergent macrophytes • Reduction in native riparian vegetation and proliferation of exotic vegetation changing the timing and quality of carbon inputs. • Previous loss of large wood.
3 Sunday Creek to Goulburn Weir	Poor	• Unseasonal flows due to dam operations and rapid changes in flow (e.g. altered hydraulic habitat diversity). • Cold water releases from Lake Eildon in summer-autumn • Armouring of the river bed and Infilling of habitat by sediments. • Sediment and nutrient inputs from direct livestock access and runoff from agricultural areas. • Reduced hydraulic habitat diversity due to a lack of emergent macrophytes

Reach	Condition of Macroinvertebrates	Potential threats to macroinvertebrates
		• Reduction in native riparian vegetation and proliferation of exotic vegetation changing the timing and quality of carbon inputs. • Previous loss of large wood.

5.4.5 Environmental objectives for macroinvertebrates

Overall ecological objectives aimed at improving macroinvertebrate diversity and biomass (Table 21) include:

- Maintain or improve hydraulic habitat diversity.
- Greater connection with floodplain wetlands. This would provide more macroinvertebrates (diversity and biomass) for the river and additional sources of carbon to drive aquatic ecosystem production, which in turn will promote breeding of shrimp, dragonflies and other macroinvertebrates in the river.
- Promoting conditions favourable for emergent macrophyte habitat along littoral zones of the river. This would provide more habitat and refugia for many macroinvertebrates including dragonflies.

Achieving the objectives listed above will require a range of flows, from base flow to overbank flows delivered at appropriate times of year. Connection between habitats is essential for sedentary biota but will be more critical to promote dispersal of new recruits and for the exchange of resources.

Table 21: Flow requirements for macroinvertebrate objectives.

Environmental Objective	Reach	Main Flow Components
Maintain areas of riffle habitat	1	Winter-spring low flows to cover areas of riffle
Scour gravels to remove fine sediments from interstitial spaces (improve habitat quality)	All	Freshes (high flow)
Maintain habitat for macrophytes that provide crucial habitat for macroinvertebrates	All	Baseflow and natural seasonality
Scour fine sediment from the surface of the substrate to promote biofilm productivity	All	Freshes (low flow and high flow)
Retain natural seasonality to ensure synchronicity of life cycle stages with appropriate flows	All	Spring-autumn low flows Winter-spring high flows
Provide floodplain connection for exchange of organic matter and fine sediment	All	Winter-spring high flows into flood runners and overbank flows onto the floodplain

5.5 Native fish

Native fish populations are highly valued across the Goulburn River catchment, both in terms of their biodiversity-ecological value (including presence of threatened and icon species) and for their recreational fishing value.

5.5.1 Current condition of the fish community

The wider Goulburn River catchment supports only a relatively depauperate native fish community. For example, recent SRA fish survey results (Davies et al. 2012) report that the basin ranked 6th lowest of the 23 catchments in the Murray-Darling Basin in terms of fish community health (as measured against expected reference condition). The results suggest that the diversity, abundance and range of many native species has declined since European settlement, while introduced species now dominate in many areas (Lieschke et al. 2014, and see Table 23 below). While the population structure of native fish in the lower Goulburn system (below Goulburn Weir) could be considered in reasonable condition, with self-sustaining populations of many species, including Murray cod and trout cod (Koster et al. 2012), the population structure between Lake Eildon and Goulburn Weir is considered to be in poor condition. Anecdotal evidence suggests that this was not always the case. For example, in his history of the catchment, Trueman (2011) provided an historical perspective of important recreational species:

> *'In 1849, it was recorded that the Goulburn River near Seymour 'abounds in fish, mostly cod and bream (Macquarie perch), also crayfish' with cod up to 43 lb. (19.5 kg) being taken at that time (Argus, 31 October 1849). In 1923, one angler caught 30 fish weighing a total of 158 lb. (71.7 kg) in one day (Argus, 13 December 1923). Further upstream at Alexandra (1868), a catch 'included two cod about 30 lb. each', and 'about a dozen smaller ones from 3 to 15 lb., and about half-a-dozen perch averaging about 3 lb. each' (Alexandra Times, 21 August 1868)'.*

5.5.2 Fish distributions between Lake Eildon and Goulburn Weir

While some broad, catchment scale surveying of fish populations have recently been undertaken (Lieschke 2014), surprisingly few systematic surveys of the Goulburn between Lake Eildon and Lake Nagambie have been undertaken in the last 30 years. However, a recent (May-June 2014) systematic survey (predominantly of Reaches 2 and 3) was undertaken as part of a study investigating the feasibility of restoring Macquarie perch populations through targeted management interventions (Kearns et al. 2014, Table 22). A total of 3,067 fish were collected and/or observed from the Goulburn River during the survey of Kearns et al. (2014). This included eight native and seven introduced species, with native fish accounting for 60.8% of the total catch. The most abundant native species captured and/or observed was Australian smelt (n = 1,613) and the most abundant introduced species was carp (n = 1,056). Native species of particular note in respect to this project were the listed species Murray cod, Macquarie perch and Golden perch, confirming that these important species (GB CMA 2013) are present in the study area. In addition, a population of Freshwater catfish exists in Tahbilk lagoon, and while the recent survey did not locate this species, previous work has found the species utilising riverine habitats in the lower end of Reach 3 (Koster et al. 2014). While Koster et al. (2014) captured some juvenile of these species, mostly the fish were large. This suggests that present conditions in the Goulburn River are not conducive to the survival and growth of smaller life history stages of this species. Other factors to note in terms of native fish community structure are that stocking of Murray cod and Golden perch occurs in Lake Nagambie, while stocking of Macquarie perch and Trout cod has commenced in the vicinity of Trawool (Reach 2) as part of recovery efforts for these species (see Kearns et al. 2014).

For comparative purposes, recent SRA survey work of Lieschke (2014) is presented in Table 23, showing the species both predicted and recorded in the slopes and lowland areas of the Goulburn Basin. Whilst this includes data from sites outside the study area, it provides an indication of the species present within the Goulburn catchment that might be expected to occur in the mid

Goulburn also. Of note from the survey of Kearn et al. (2014) and the SRA data is the low relative abundance of flood-dependent and floodplain specialist species. Whilst this will in part be due to the sampling effort of both surveys being on the main river channel, the reduced frequency of connection between the river and floodplain wetlands as well as impacts such as extensive wetland drying during the Millennium drought makes it likely that flood and wetland specialist species are indeed poorly represented along the mid Goulburn.

Table 22: Relative abundance of fish species found in the mid Goulburn River between Lake Eildon and Lake Nagambie (from Kearns et al. 2014). Note: the comparison is for the relative abundance for individual species between reaches; it does not infer relative abundance between species.

Common Name	Species name	Reach 1	Reach 2	Reach 3
Long-lived apex predators				
Murray cod	*Maccullochella peelii*	X	XX	XX
Trout cod	*Macculochella macquariensis*			
Brown trout*	*Salmo trutta**	X	XX	X
Rainbow trout*	*Oncorhynchus mykiss**	X	XX	
Redfin perch*	*Perca fluviatilis**		XX	X
Flow dependent specialists				
Golden perch	*Macquaria ambigua ambigua*	X	XX	X
Foraging generalists				
Australian smelt	*Retropinna semoni*	X	XXX	XX
Flat-headed gudgeon	*Philypnodon grandiceps*	X	XX	
Freshwater catfish	*Tandanus tandanus*			X
Macquarie perch	*Macquaria australasica*		X	
Mountain galaxias	*Galaxias olidius*		X	
River blackfish	*Gadopsis marmoratus*		X	X
Two-spined blackfish	*Gadopsis bispinosus*	X	XX	
Carp*	*Cyprinus carpio**	X	XXX	XX
Goldfish*	*Carassius auratus**		X	
Tench*	*Tinca tinca**		X	
Mosquitofish*	*Gambusia holbrooki**		X	

Note: * denotes introduced species
Sampling effort: Reach 1 = 2,171 EF seconds; Reach 2= 36,544 EF seconds; and Reach 3= 6,792 EF Seconds

Table 23: Abundance of fish species within guilds predicted to occur in the Goulburn River, and numbers of individuals of each species captured during the recent Sustainable Rivers Audit from 2005-09 (from Lieschke et al. 2014).

Common Name	Scientific Name	Lowland	Slopes
Long-lived apex predators			
Murray Cod	*Maccullochella peelii*	52	1
Trout Cod	*Maccullochella macquariensis*	0	0
Brown Trout*	*Salmo trutta*	29	112
Rainbow Trout*	*Oncorhynchus mykiss*	2	14
Redfin*	*Perca fluviatilis*	34	4
Flow dependant specialists			
Golden Perch	*Macquaria ambigua*	12	0
Silver Perch	*Bidyanus bidyanus*	2	0
Foraging generalists			
Australian Smelt	*Retropinna semoni*	107	0
Barred Galaxias	*Galaxias fuscus*		
Bony Herring	*Nematolosa erebi*	0	
Carp Gudgeon complex	*Hypseleotris* spp.	203	0
Dwarf Flat-headed Gudgeon	*Philypnodon macrostomus*	0	
Flat-headed Gudgeon	*Philypnodon grandiceps*	20	0
Freshwater Catfish	*Tandanus tandanus*	0	0
Macquarie Perch	*Macquaria australasica*	1	0
Mountain Galaxias	*Galaxias olidus*		122
Murray–Darling Rainbowfish	*Melanotaenia fluviatilis*	28	
Obscure Galaxias	*Galaxias* sp.1	4	0
Riffle Galaxias	*Galaxias* sp.2		6
River Blackfish	*Gadopsis marmoratus*	1	20
Short-headed Lamprey	*Mordacia mordax*	0	
Two-spined Blackfish	*Gadopsis bispinosus*	11	95
Un-specked Hardyhead	*Craterocephalus stercusmuscarum fulvus*	0	
Broad-finned Galaxias*	*Galaxias brevipinnis*	2	
Carp*	*Cyprinus carpio*	50	21
Eastern Gambusia*	*Gambusia holbrooki*	20	
Goldfish*	*Carassius auratus*	2	1
Oriental Weatherloach*	*Misgurnus anguillicaudatus*	1	
Roach*	*Rutilus rutilus*		28
Floodplain specialists			
Flat-headed Galaxias	*Galaxias rostratus*	0	0
Murray Hardyhead	*Craterocephalus fluviatilis*	0	
Southern Purple-spotted Gudgeon	*Mogurnda adspersa*	0	

Common Name	Scientific Name	Lowland	Slopes
Southern Pygmy Perch	*Nannoperca australis*	1	0
Total Fish		582	424

Zero scores represent zones where a species was not collected, but predicted to be collected under the Reference Condition. Blank cells indicate a species was not predicted to be collected under Reference Condition.

* introduced species.

5.5.3 Summary of native fish condition and issues

The relative condition of native fish for each reach (Table 24) was assigned after considering attributes such as the relative species diversity, species abundance, observed versus expected native species, habitat quality (substrate, diversity, wood), riparian zone, and number of alien fish species. In general, the major threats in each zone are considered to relate to the operation of Lake Eildon and its impact on the flow and temperature regimes (and thus habitat availability and quality), although other issues such as competition with introduced species and angling pressure may also influence native fish populations.

Table 24: Relative condition of native fish in each reach of the mid Goulburn River.

Reach	Condition of Native Fish	Threats
1. Lake Eildon to Yea River	Poor	• Unseasonal flow regime (including low winter flows) that reduces habitat 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 late spring and summer-autumn water temperature • Competition with introduced species • Reduced coverage of riparian vegetation and loading instream woody habitat • Increased rates of bank erosion • Reduced frequency of connection with wetland habitats • Loss of connectivity with upstream habitats
2. Yea River to Sunday Creek	Poor	• Unseasonal flow regime • Reduced frequency of connection with wetland habitats • Low winter flows that reduce habitat availability and longitudinal connectivity • High summer flows which reduce riverine productivity at a range of trophic scales • Reduced summer-autumn water temperature • Competition with introduced species • Increasing angling pressure
3. Sunday Creek to Nagambie	Moderate	• Unseasonal flow regime • Reduced frequency of connection with wetland habitats • Low winter flows that reduce habitat availability and longitudinal connectivity

Reach	Condition of Native Fish	Threats
		• High summer flows which reduce riverine productivity at a range of trophic scales • Competition with introduced species • Increasing angling pressure • Loss of connectivity with downstream habitats

5.5.4 Environmental objectives for native fish

The environmental objectives for native fish in the mid Goulburn River take into account various recovery plans (Trout cod, Macquarie perch, Murray cod, Catfish) and strategies (e.g. the MDBA Native Fish Strategy), and are aligned with objectives of the Goulburn Broken RWS. While they do not attempt to cover the breadth of issues that need to be dealt with to restore native fish in the area, they do attempt to take into account the major themes that are important in restoring native fish biodiversity – particularly as it relates to hydrological variability:

- Protecting and/or restoring populations of native fish species listed under state and national threatened species legislation;
- Protecting key fish habitats (including instream habitat, water quality, and riparian condition);
- Promoting the recruitment of native fishes by maintaining or improving lateral and longitudinal connectivity (e.g. provide a conduit for movement of Macquarie perch between 'satellite' populations in the Yea, King Parrot and Hughes catchments);
- Impeding the recruitment of alien species of non-recreational value (especially carp).

There are clear links between the flow regime of the mid Goulburn River and the 'health' of native fish populations. However, the effectiveness of any future environmental flow recommendations designed to achieve flow-related objectives for native fish will be limited by the nature of the current flow regime, which is predominantly the result of obligations to meet irrigation demand.

The use of flow as a restoration/management intervention for native fish within this reach should be considered feasible. As well as providing valuable habitat to native fish populations in its own right, appropriate flow regimes in the Goulburn River can also act as an important 'conduit' to maintain connectivity between other important tributaries, such as the Yea River, King Parrot Creek and Hughes Creek. Flows are also required to achieve ecological objectives including to enhance colonisation of various native fish species into the reach, or to enhance recruitment of some species of native fishes. Key flow components that need to be addressed include:

- Provision of an overall flow regime that more closely mimics natural variability, where possible;
- Provide for cues for movement/reproduction (flow variability and seasonality);
- Increased frequency of overbank flows and maintenance of floodplain/wetland habitats;
- Flow freshes to maintain geomorphic functions (flushing flows to maintain pools and channel morphology;
- Provision of flow and temperature 'refuges' where native species are less impacted by irrigation releases (i.e. potential reconnection of off-channel flow through habitats such as low-level anabranches, flood runners and billabongs);
- Maintenance of variability in stage height and commence to fill levels for off-channel habitats;
- Increased availability of riffle habitats for native species such as Blackfish and galaxiids (Reach 1), particularly during low flow periods in winter-spring;

- Water depth required to connect in-channel habitats and allow fish movement;
- Changes in stage height that provide cues for breeding and migration, where appropriate.

While spawning by some native fish may occur in the study area, the prevailing flow and temperature regimes mean that it is unlikely that *in situ* recruitment of Murray cod, Trout cod or Macquarie perch currently occurs in Reaches 1 and 2. Recent survey results (i.e. mostly adult fish are present; Kearns et al. 2014) suggest that any changes in the sizes of populations of these important species is currently driven by either stocking, or immigration from either Reach 3 or inflowing tributaries. Cold water releases from Lake Eildon can result in water temperatures remaining below recognised survival thresholds for Golden perch, so the presence of this species in the mid Goulburn River is most likely due to immigration from Lake Nagambie rather than localised spawning. Golden perch have been recognised as 'flood spawners' (Baumgartner *et al*. 2012) and recent research indicates that spawning and recruitment may be primarily occurring on lower reaches of rivers across the Murray-Darling Basin, after which colonisation occurs (Brenton Zampattii, pers. comm). Thus in addition to providing flows conducive to the spawning of smaller bodied fishes such as Blackfish (G*adopsis spp*.), water management that promotes immigration and movement of target large-bodied (threatened) species through the main channel is considered important for the structure of populations. In addition, ensuring variability in flow, including connectivity to productive wetland habitats, will be key in increasing productivity in the reach, thereby increasing probability of survival of all life history stages.

Macquarie perch are known to spawn in spring, when water temperatures increase to above 16^{o}C. As recent research (Tonkin et al. 2013) has shown that large variations in flow can limit recruitment success for this species, it is recommended that large variability in discharge be avoided should water temperature in the main channel exceed 16^{o}C between October and December, so as not to disturb eggs deposited in riffle areas. This may have implications for delivery of water for downstream environmental objectives (e. g. high flow freshes to promote spawning by Golden perch below Goulburn Weir).

Low flow/wetland specialists, who can recruit in late spring/summer and take advantage of the subsequent high levels of primary production (i.e. Murray River rainbowfish, Carp gudgeons and Flat headed gudgeons) may be impacted by high summer flows, and loss of connectivity with floodplain wetlands.

Table 25: Summary of flow requirements to achieve native fish objectives.

Environmental Value	Ecosystem objective	Reach	Main flow components
Ecosystem values	Increase flow variability to more closely mimic natural hydrological regime	All	• All components
Ecosystem services, fish production, fish survival	Maintain or increase connection to water temperature refuges	All	• Winter-spring bankfull and overbank flows to provide connection to riparian and floodplain features • Variability and longitudinal connectivity in summer-autumn baseflow • Winter-spring baseflow and freshes to provide

Environmental Value	Ecosystem objective	Reach	Main flow components
			connectivity with inflowing tributaries
Fish movement and population dynamics	Provide flows to promote colonisation by large-bodied endangered species	All (particularly Reaches 1 and 2)	• Winter-spring freshes (in particular to coincide with inflows from tributaries such as King Parrot Creek)
Fish recruitment	Low summer flows to enhance recruitment of low flow specialists (primarily in off-channel areas)	All (but particularly Reaches 2 and 3)	• Summer-autumn baseflow • Winter-spring freshes • Winter-spring bankfull and overbank flows
Floodplain connectivity and increased primary and secondary production	Provision of lateral connectivity to increase primary and secondary production as habitat for small bodied fishes	All	• Winter-spring bankfull and overbank flows

5.5.5 Other issues relevant to native fishes in the Goulburn River between Lake Eildon and Goulburn Weir

- Influences of other catchment processes (agriculture, sedimentation, pesticide use);
- Competition with introduced species such as carp (especially under low flow conditions and in wetland/off channel habitats);
- Management of the riparian zone and floodplain habitats, including livestock exclusion;
- Management of in channel habitats (especially structural woody habitat);
- Water extraction from inflowing tributaries, in particular during low flow periods;
- Management of recreational fishing and illegal fishing.

5.6 Trout

5.6.1 A summary of condition and major threats (flow and non-flow related) – to trout population and recreational fisheries of the Mid Goulburn River

Trout have existed in the Goulburn River catchment since their introduction sometime before the 1940s (Clements 1988). A well-patronised and high quality recreational trout fishery still exists in the Goulburn River downstream of Lake Eildon (Brown 2010; Brown & Gason 2007; Lourey & Mitchell 1994). The trout fishery persists from Lake Eildon to approximately Yea, although downstream of Alexandra the fishery is less popular and less productive than between Eildon and Alexandra. Research and monitoring of the trout populations and fisheries on the mid Goulburn River has been largely on the reach between Eildon and Molesworth and is likely to broadly represent the population downstream to Yea.

The population of Brown trout (*Salmon trutta*) and Rainbow trout (*Oncorhynchus mykiss*) is self-sustaining in the mid Goulburn River, with both species readily and regularly spawning in the main-channel and a range of tributaries. Since 2009, the productivity of the fishery has again been enhanced by stocking both species into the Goulburn River (www.depi.vic.gov.au/...fish-stocking-reporting). The Eildon Pondage, which contributes trout to the Goulburn River fishery via emigration, has also been stocked with both trout species since at least 1987. Recent studies show that stocked brown trout and stocked rainbow trout contribute around 25% of the anglers catch (www.dpi.vic.gov.au/fisheries/about-fisheries/newsletters-and-updates/angler-diary-newsletter/issue-5).

Stringent trout fishing regulations were introduced in 1996 and annual fish surveys between 1997 and 2004 reported relatively stable brown trout population with a trend for an increasing proportion of larger fish (>350 mm, fork length). Size structure and population density for rainbow trout typically fluctuates , depending upon escape-rates from the local commercial hatcheries (Brown 2008). Recent escapes of Brook Trout (*Salvelinus fontinalis*) and Atlantic salmon (*Salmo salar*) into the Rubicon River may also result in the occasional presence of these species in the adjacent mid Goulburn; however, neither species is truly established.

Fishing exploitation rate varies strongly among years and can be high enough to limit abundance at the start of the fishing season (September) in some years (Brown 2008). Factors influencing fishing exploitation include climate and flow-conditions. Estimates of total catch and fishing-effort from consecutive years 2002 and 2003 showed differences related to higher catches and fishing-effort in years when flows over summer did not exceed 4,000 ML/d and frequently dropped to ~1,500 ML/d. In a more typical year, higher flows over summer restrict access by wading anglers and reduce overall fishing-effort, probably increasing survival. The mid Goulburn River is one of many regional trout fisheries that anglers can choose to fish, and high summer flows may displace angler-effort from the mid Goulburn River to lakes and more gently-flowing wade-able tributaries such as the Rubicon and Acheron rivers.

During low summer storage levels in Lake Eildon, such as those experienced towards the end of the 'millennium drought', the temperature of water in the Mid Goulburn released from Lake Eildon approached those considered detrimental to trout health (~26 ^{o}C), and frequently exceeded temperatures at which trout are reported to feed (~20 ^{o}C) (McMichael & Kaya 1991). Non-zero catch-rates in the recreational trout fishery were sampled during the 2008-09 when river temperature at Eildon was between 12.2 and 20 ^{o}C and flows ranged 500–8600 ML/d (Brown 2010); catch-rates of zero were recorded outside these temperatures and flows. It's likely that during such warm-water challenges, health and survival of trout in the Mid Goulburn would be dependent upon adequate flow to maintain oxygenation. Bioenergetics modelling of the growth and natural mortality of brown trout in the Mid Goulburn River showed that the quality and quantity of fish sustaining the recreational fishery depended strongly upon the river temperature and the related energy-balance of the fish. Increases in modelled temperature equivalent to mean annual temperature change of 2^{o}C are enough to significantly reduce the modelled maximum potential size and significantly increase time taken to grow to sizes acceptable to anglers (Brown 2004a).

For both trout species significant spawning occurs both in the Mid Goulburn River and its tributaries (e.g. Snobs Creek, Rubicon River, Acheron River, etc.) However, the relative contribution of the tributaries and the main channel to recruitment in the Mid Goulburn River is unknown and probably varies among years. Brown and Rainbow trout spawn in the autumn and winter and bury eggs in nests in suitable gravel (known as redds). Stable or increasing flows during winter may limit egg mortality through redd stranding. Juvenile trout (fry) emerging from redds have particular depth, flow and habitat requirements requiring shallow low-velocity habitats. A study of the effects of flow variability on spawning and rearing habitat in the Mid Goulburn showed that stranding redds during variable winter flows (current conditions) is unlikely to limit the population (Brown 2004b). Estimates of suitable habitat for brown and rainbow trout redds under typical winter-flows and areas of available fry-habitat during typical spring flows suggest that it is fry-rearing habitat between September and February that is likely to be the limiting factor.

In-stream and riparian habitat management is a strong theme for management of the mid Goulburn River environment and its trout fisheries and populations (DNRE 2002) and the management (removal) of riparian willow thickets (*Salix* spp.) has been a necessary part of this. Studies of trout habitat-use showed that trout predominantly use habitat within 10 m of the bank and in high flows trout routinely used in-stream willow thickets as a ‘velocity-refuge’ (Brown 2007; Douglas 2003) as a strategy to conserve energy when flows exceed 4,000 ML/d. The inference from this is that threats to trout populations would include river management activities, including willow management, that do not include a “no-net-loss” of in-stream cover (i.e., velocity refuge) to the managed area. Trout do not have a preference for willows and using the principles outlined above, management of riparian exotic-vegetation is consistent with healthy and accessible trout fisheries on the Mid Goulburn River (Douglas & Abery 2009; Stoessel & Douglas 2007).

5.6.2 A summary of potential relationships to the flow regime

A series of simple conceptual models are presented to describe trout population dynamics in the mid Goulburn River, highlighting the interaction of factors such as river discharge and water temperature (Figure 27). These models provide the basis for flow-related objectives to maintain the trout fishery presented in section 3.6.3, below.

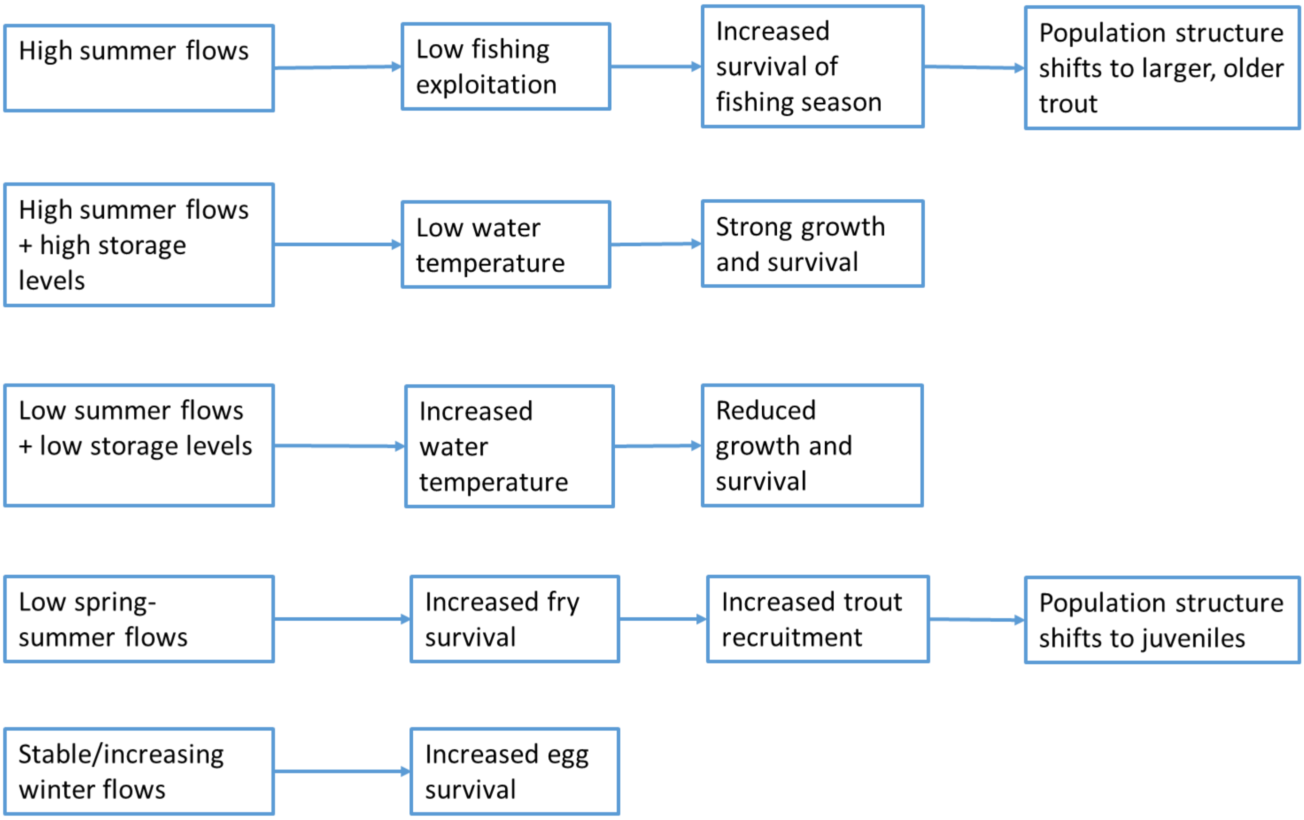

Figure 27: Simple representation of trout survival and population dynamics in the mid Goulburn River.

5.6.3 Flow requirements to maintain the trout fishery

The following flow requirements are proposed to maintain the mid Goulburn River trout fishery, based on understanding of current condition and the influence of the flow regime. The flow requirements assume that temperature and oxygen levels remain within acceptable ranges for trout survival:

- High flows (>4,000 ML/d) in December–April usefully suppress fishing over-exploitation approximately 1 year in 3 or 4 and maintain density of larger trout in population.

- Low flows (<4,000 ML/d) between September and February for good fry survival at least one year in three/four to maintain occasional good year-classes (assumes DO levels are maintained at acceptable levels).
- Stable or gradually increasing flows from June-September (for maintenance of redds and avoidance of stranding).

It is important to note that the delivering high flows in summer-autumn to alleviate fishing over-exploitation would constrain low-flow objectives for other ecological attributes such as macrophytes, macroinvertebrate and native fish. However, delivering low flows (<4,000 ML/d) in summer-autumn to maintain year-classes, as well as providing stable or rising flows from June-September to maintain redds has the potential to complement environmental flows recommendations designed to meet other ecological objectives.

5.6.4 Summary of other relevant management issues (e.g. non-flow related and strategic)

In addition to management of the flow regime, there are a number of management issues that when addressed would help maintain the trout fishery in the mid Goulburn river. These include:

- Understanding the relative contribution to trout recruitment of the tributaries and the main-channel, and of the relative contribution of stocked and wild-recruited trout, would improve understanding of the consequences of delivering sub-optimal flows for egg and fry survival during critical June-September and September–February periods, respectively.
- Maintaining instream habitat diversity and velocity refugia (e.g. large wood, boulders) will aid survival. Artificial intervention may be required during/following introduced vegetation (e.g. willow) management activities, so that there is no net-loss of velocity refugia.
- Maintain management of native riparian vegetation to improve ecosystem health while facilitating angler access.

5.7 Summary of ecosystem issues and objectives and related flow components

The condition, structure and function of river attributes listed in the previous sections are affected by many factors (often at multiple scales), of which management of the flow regime is but one. However, the current flow regime appears to have influenced ecosystem processes and habitat availability/quality such there now appears to lower rates of riverine production that in turn supports biota such as invertebrates and fish. In summary, issues that are likely to have a direct bearing on environmental watering 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 habitat availability and quality;
- Maintenance of riffle habitat (Reach 1), 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 and to the nature of carbon inputs to 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 channel diversity and associated habitat for organisms such as fish.
- Contaminant (e.g. 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.

The flow-related threats to ecosystem values, flow-related ecological objectives, and relevant flow components considered in the previous sections have been summarised in Table 26.

The nature of the flow-related threats and the environmental flows required to achieve ecological objectives will be considered in greater detail by the project team in subsequent steps of the FLOWS method. Attention will be focussed on the ecosystem values and processes affected by the current flow regime, but recognising that a number of limitations and constraints on the flow-related objectives exist that affect what realistically be achieved in meeting objectives are likely to persist in the future.

Table 26: Summary of flow-related ecosystem objectives and associated flow components

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 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
			G2: Movement of bed material to maintain bed diversity for water depth variation.	All	High flows, Bank full, Overbank	Flows of sufficient magnitude to provide critical shear stress to periodically mobilize sand.	Win, Spr
			G3: Control riparian vegetation encroachment to prevent catastrophic erosion processes.	1	Bank full, Freshes (high flow)	Maintain high flows for sufficient time to make conditions unsuitable for flood-sensitive species.	Spr, Sum
			G4: 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 and natural rates of erosion.	Win, Spr
			G5: Maintain channels and inlets for connectivity of main channel with important floodplain and wetland zones.	All	Bank full, Overbank	Flows of sufficient stage height to connect with riparian and floodplain areas.	Win, Spr
			G6: Scour surficial and interstitial fine sediment from riffles and overturn of bed substrate (gravels to cobbles).	All	High flow, Freshes, Bank full	Flows of sufficient magnitude to provide critical shear stress to periodically mobilize	Win, Spr

Ecosystem Attribute	Environmental or Ecological Values	Potential flow related threats	Flow-related ecological objectives	Reach	Flow Component to be considered	Mechanism	Season
						sediments of varying size.	
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**: Investigate role of water releases in addressing instances of DO falling below 4 mg/L.	1	Baseflow (low flow)	Investigate potential for release of high-DO water from Lake Eildon 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	• Decreased incidence of winter-spring flows, with impacts on freshes • Decreased incidence of bankfull and overbank flows • Decrease in variability in baseflows	**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)	Spr, Sum
			RV2: Provide periodic regeneration opportunities for native riparian species	All	Bankfull flows, Overbank flows	Riparian vegetation (canopy layer as well as understory)	Spr

Ecosystem Attribute	Environmental or Ecological Values	Potential flow related threats	Flow-related ecological objectives	Reach	Flow Component to be considered	Mechanism	Season
	Provision of faunal habitat		adapted to and dependent on the natural flow regime (riparian and floodplain wetland).			generally requires periodic 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, resulting in excessive	**I1**: Maintain areas of riffle habitat.	1	Baseflow (low flow)	Flows of sufficient magnitude and duration to maintain channel form.	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
		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 substrate to promote biofilm productivity	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,
Native fish	Native fish contribute to aquatic biodiversity, are key predator in aquatic food webs, valued for recreational fishing. In particular, Murray cod, Trout cod and Macquarie perch are listed as vulnerable	• Unseasonal flow regime (including low winter flows) that reduces habitat availability and connectivity, as well as leads to miscued/lack of spawning opportunities	**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
			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.	Win, Spr

Ecosystem Attribute	Environmental or Ecological Values	Potential flow related threats	Flow-related ecological objectives	Reach	Flow Component to be considered	Mechanism	Season
	or threatened and are the focus of management objectives in the Goulburn-Broken Regional Waterway Strategy.	• High summer flows which reduce riverine productivity at a range of trophic scales • Reduced frequency of connection with wetland habitats				Variability to provide connection for longitudinal movement along the river Variability to provide connection with tributaries	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: Low summer 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

6 CONSIDERATIONS FOR DEVELOPING ENVIRONMENTAL FLOW RECOMMENDATIONS

A number of significant advances have been made in understanding ecosystem-hydrology interactions since the original flow study undertaken by Cottingham et al (2003). For example, there is now better generic understanding of the hydrological requirements of biota (e.g. aquatic, riparian and wetland vegetation) in the Murray-Darling Basin (e.g. Roberts & Marston 2011, Rogers 2011, Rogers et al. 2012). There are also empirical trials, such as VEFMAP, designed to evaluate whether ecological benefits did indeed accrue from the application of environmental water to drought-stressed rivers and their floodplains/wetlands (e.g. Chee et al. 2006, Cook et al. 2009, Webb et al. 2012a, and b).

The FLOWS method currently used to determine environmental flows in Victorian streams is largely an ecology-based, building-block method (e.g. see Arthington et al. 2006) where the water requirements of individual biota, communities and critical ecological processes and environmental watering regimes are identified that best deliver those requirements (cf hydrology-driven approaches where missing elements of the pre-disturbance hydrological regime are reinstated, with the expectation that ecosystems will recover). A difficulty for building block approaches is that very often information on the watering requirements of species or communities is scant, which was certainly the case when the original flows study was conducted in 2003. However, recent surveys of such things as fish communities, the availability of vegetation mapping comparing current with pre-European extent, and more detailed topographical information (e.g. lidar) has provide an improved knowledge base from which to develop flow recommendations. The general approach to arrive at environmental flow recommendations for the mid Goulburn River will be to:

- Identify the biological and ecological processes and habitat potentially affected by the current flow regime compared with the unimpacted flow regime, with an emphasis on species and communities of native fish, macroinvertebrates and riparian and wetland vegetation;
- Relate the flow regime to the hydrological requirements of taxa and/or structural groups to identify and shortcomings in terms of the timing, frequency, magnitude and duration of flow components;
- Set flow targets to meet stated ecosystem objectives with the delivery of environmental water in the future.

The flow-related objectives and flow components identified in Table 26 provide the starting point for developing flow recommendations for each reach.

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8 APPENDIX 1: OVERVIEW OF THE VICTORIAN FLOWS METHOD

The FLOWS method (SKM 2012) 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.

There are three key documents that support 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 rivers that are the focus of the study;
- System hydrology including comparison of current and natural[3] 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.

[3] The 'natural' 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 the 2005/06 water year.

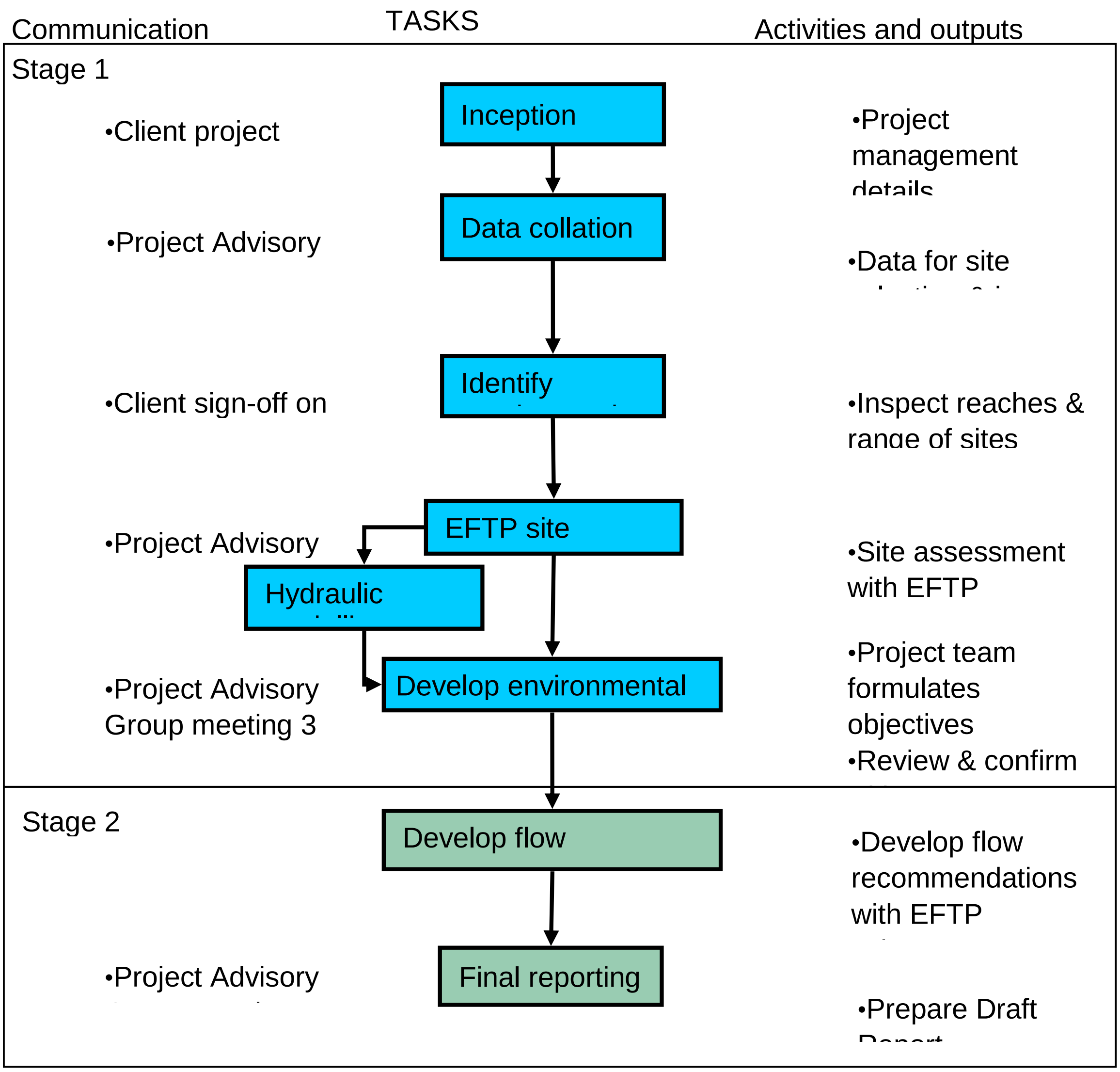


Figure 28: Overview of the FLOWS method (from SKM 2012).

9 APPENDIX 2: MODELLING OF THE CURRENT AND UNIMPACTED FLOW SERIES FOR THE GOULBURN RIVER

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 versions which represents "Sustainable Diversion Limit" representation of GSM that has all water recovery to meet basin plan obligations which 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.

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 able to be used directly to simulate unimpacted conditions by including the unimpacted inflows to Lake Eildon as derived in SKM (2012a) as the outflows from Lake Eildon. The model was also updated to include updated time series from SKM (2013) 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 1.

Figure 29: 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 therefore 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. The disaggregation method assumed either a constant, unimpacted or Lake Eildon release pattern from the GBCL for each month.

Table 27: 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 timestep 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 1. 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 28: Average Annual Flows (GL/yr)

Reach	Time period	Unimpacted	Current	Current no Goulburn EFlows	Historic gauge data *
1. Eildon to Yea River	July 1895 to June 2009	1,945	1,957	1,833	N/a
	Concurrent with gauge 405203 (Dec 1974 – Current)	1,721	1,796	1,682	1,278
2. Yea River to Seymour at Sunday Creek	July 1895 to June 2009	2,325	2,337	2,213	N/a
	Concurrent with gauge 405201 (Dec 1974 – Current)	2,043	2,119	2,004	2,092
3. Seymour at Sunday Creek to Nagambie	July 1895 to June 2009	2,524	2,535	2,418	N/a
	Concurrent with gauge 405202 (June 1975 – Current)	2,129	2,191	2,076	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.

Figure 2 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 cross-over 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 A. 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 B.

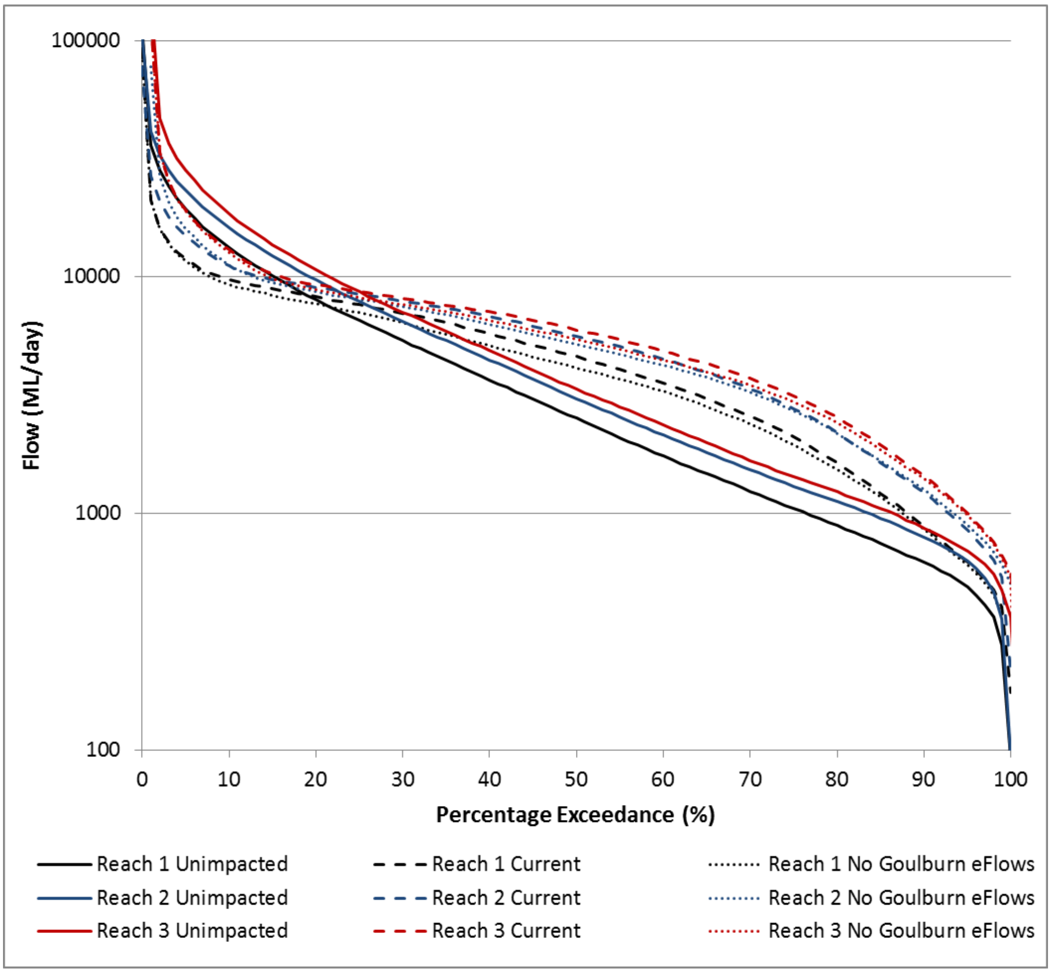


Figure 30: Flow duration curve for the whole period of record for each reach.

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 10^{th}, 50^{th} and 90^{th} 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 discernable 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 2 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 29: Median rates of rise and fall (of previous day's flow) of the unimpacted

flow series

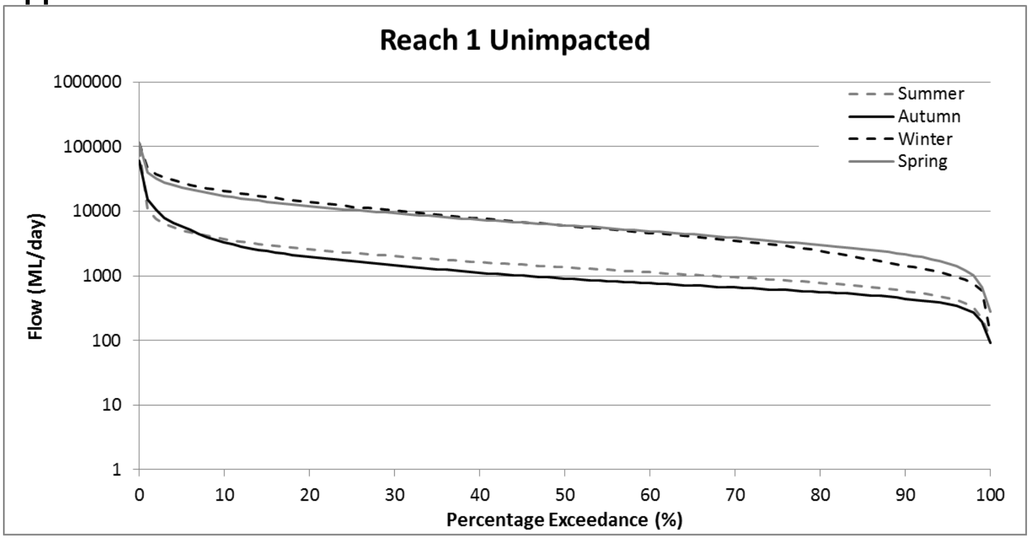
Reach	Rate of rise	Rate of fall
Reach 1	1.12	0.94
Reach 2	1.10	0.95
Reach 3	1.13	0.94

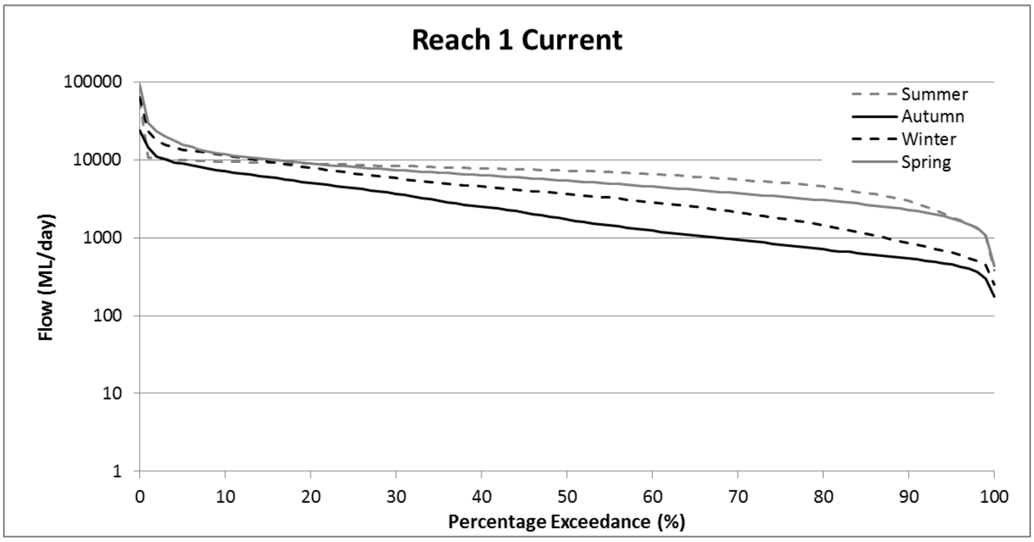
The partial series was analysed for each scenario. These results are presented in Appendix D.

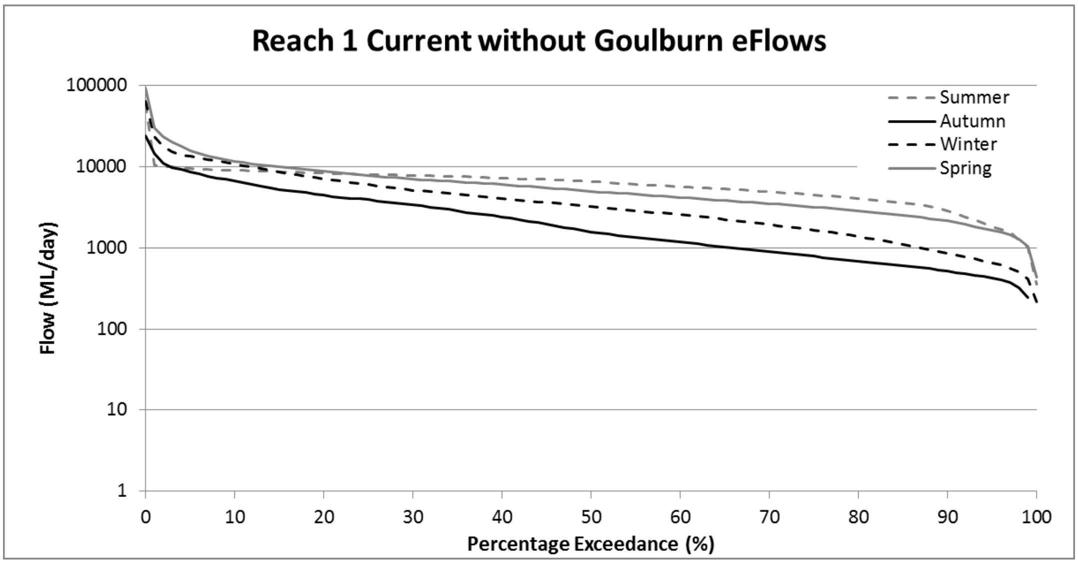
References

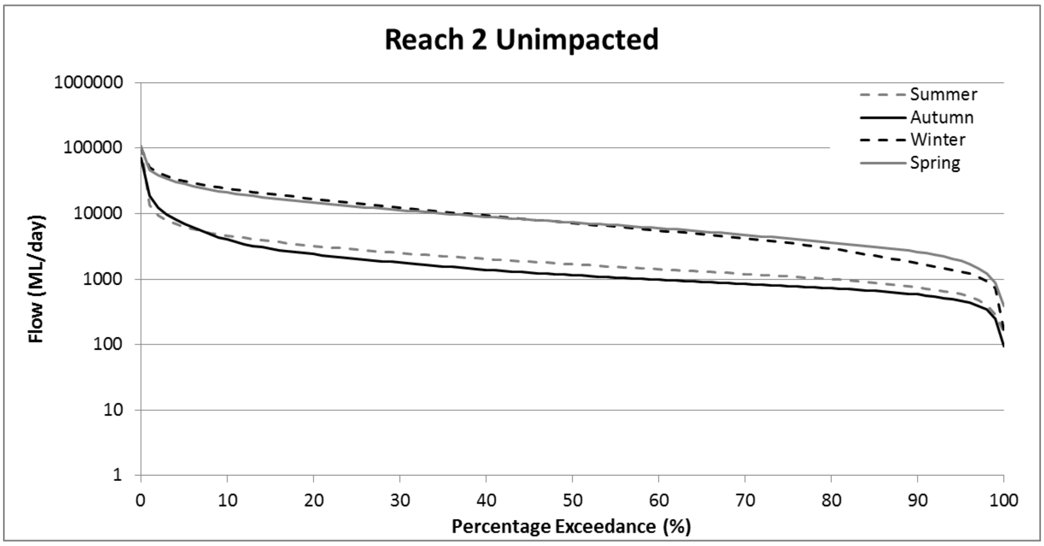
SKM (2010) *Daily disaggregation of Northern Victoria flow data.* Prepared for DSE.
SKM (2012a) *Extension of daily flow inputs to the Goulburn and Wandella Creek REALM Models to 2012.* Prepared for DSE.
SKM (2012b) *Development of a Source Rivers Model of the Goulburn River to Simulate Winter and Spring High Flows*. Prepared for Goulburn-Broken Catchment Management Authority and E-Water.

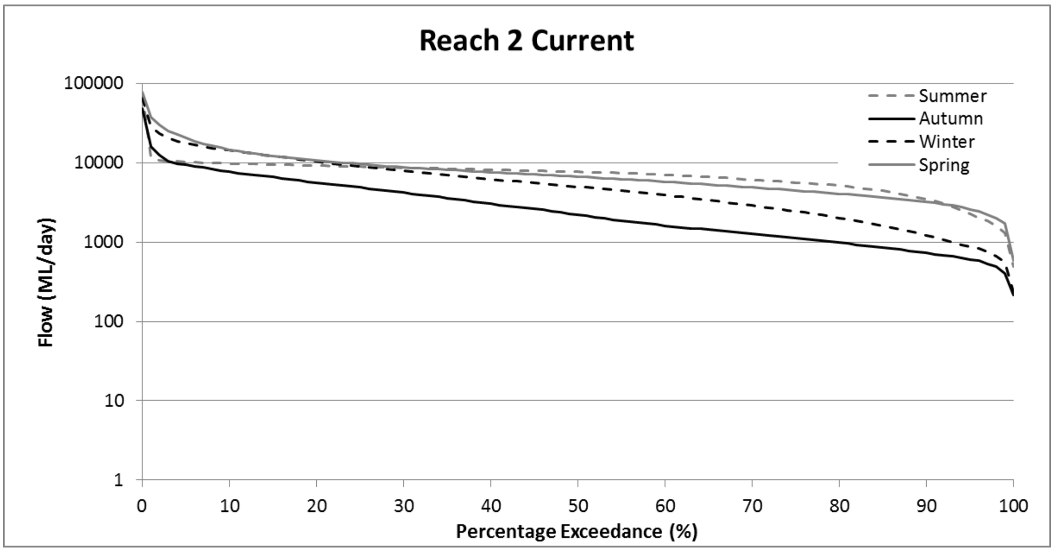
Appendix A – Flow Duration Curves

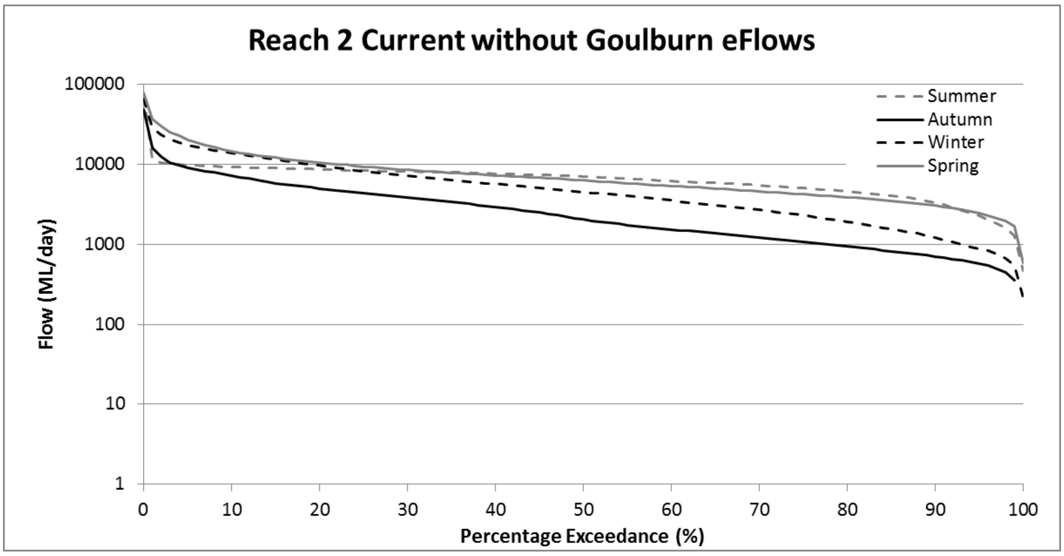


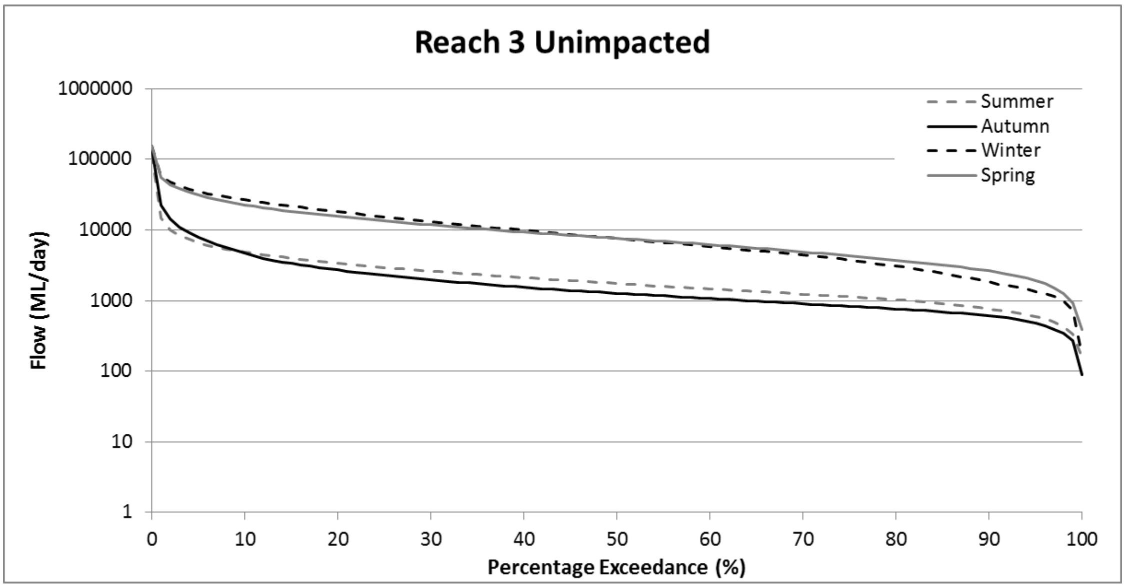


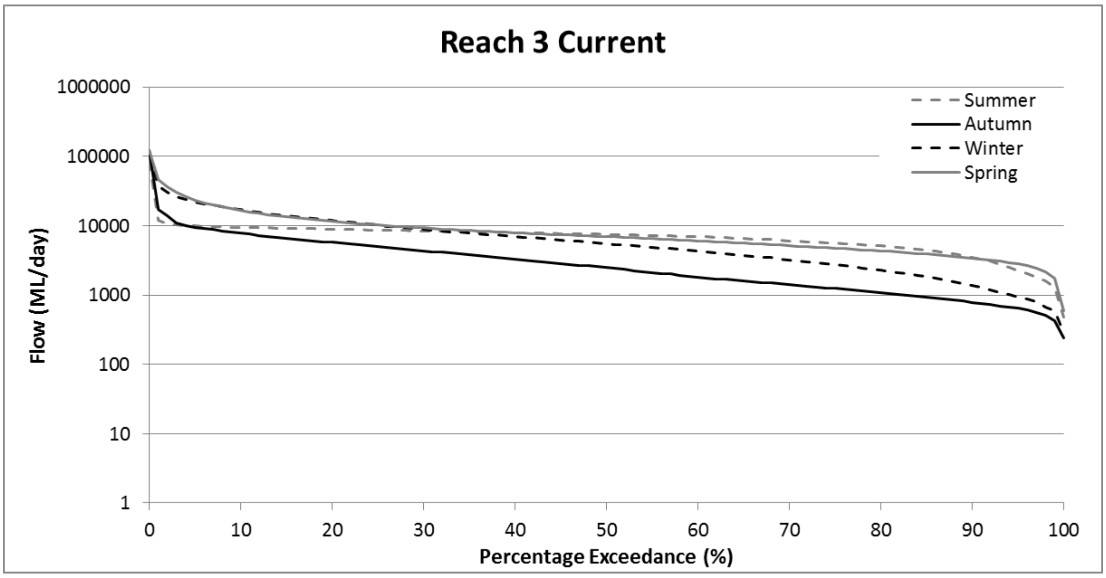



Reach 2 Unimpacted
Summer
Autumn
Winter
Spring
Flow (ML/day)
1000000
100000
10000
1000
100
10
1
0
10
20
30
40
50
60
70
80
90
100
Percentage Exceedance (%)


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


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


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


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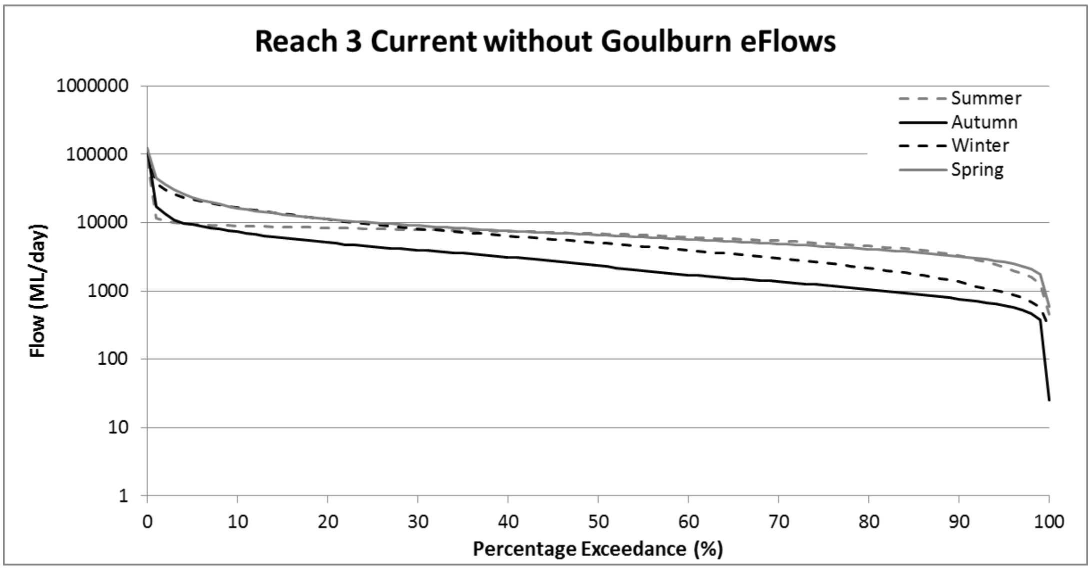
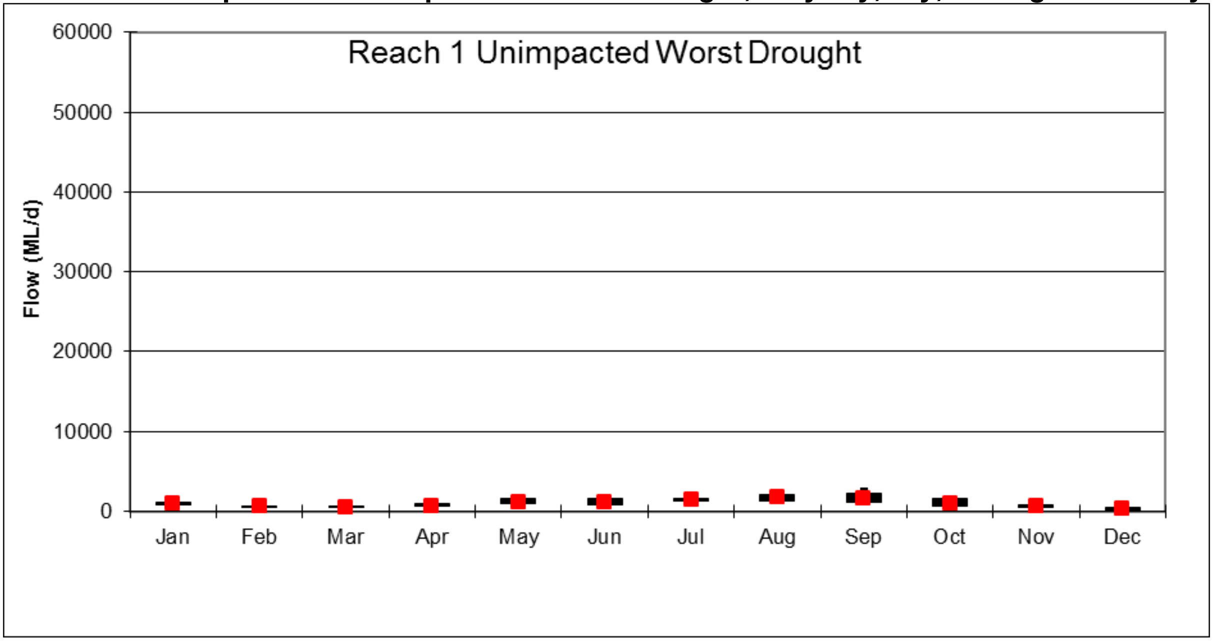
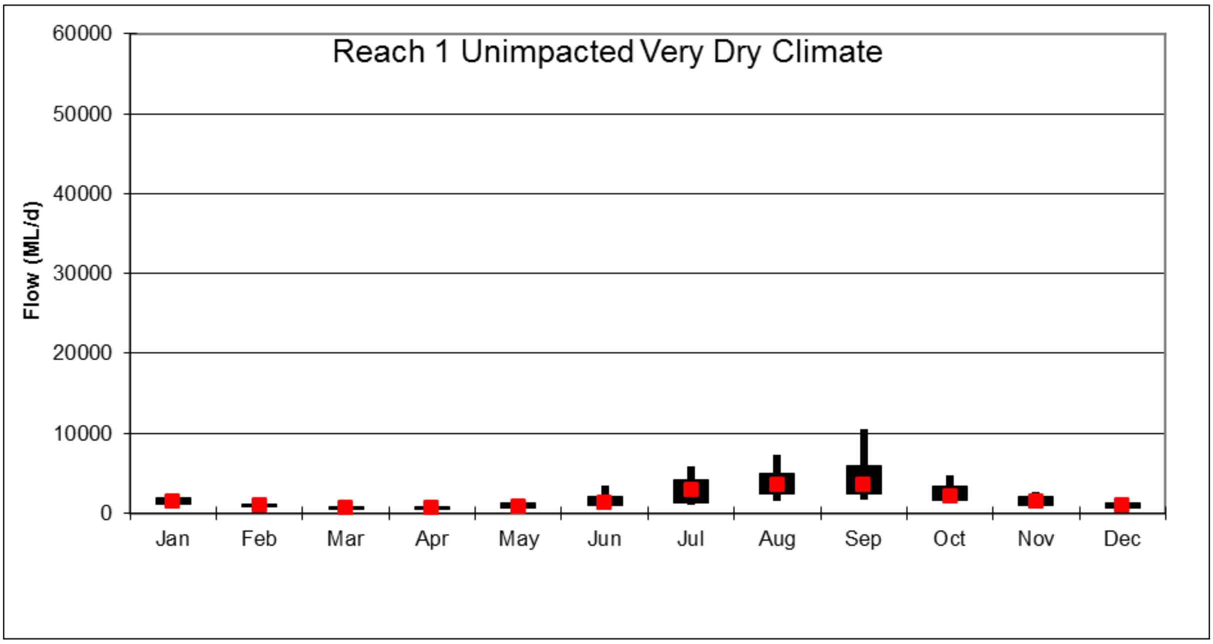
80
90
100
Percentage Exceedance (%)

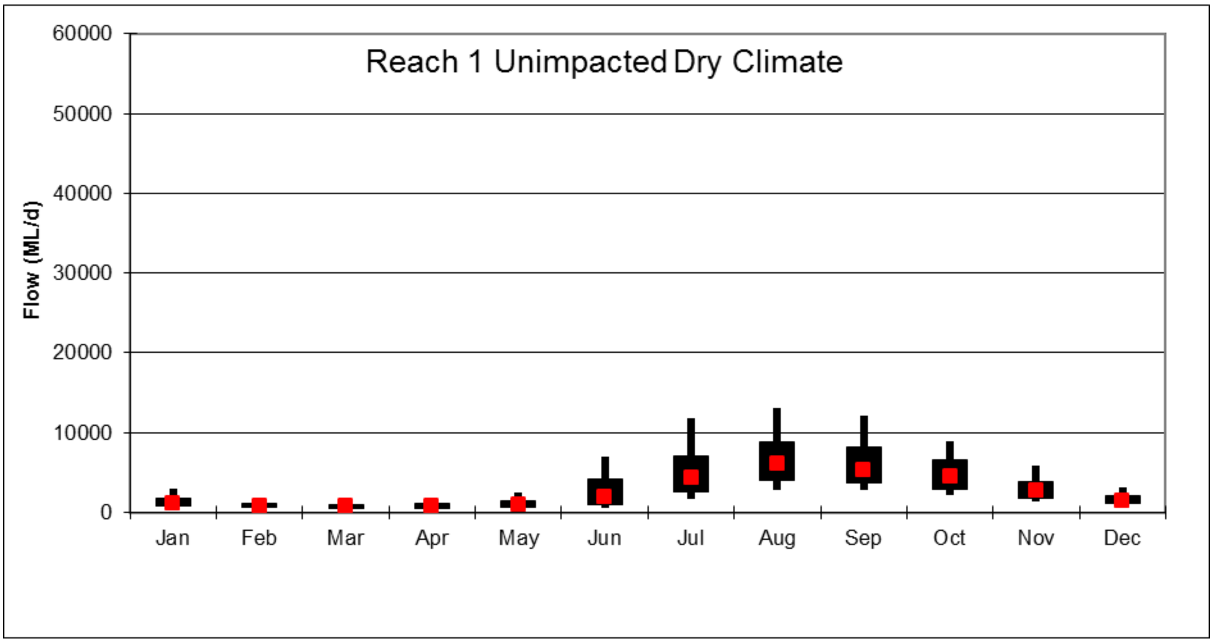

Reach 3 Current without Goulburn eFlows
Summer
Autumn
Winter
Spring
Flow (ML/day)
1000000
100000
10000
1000
100
10
1
0
10
20
30
40
50
60
70
80
90
100
Percentage Exceedance (%)

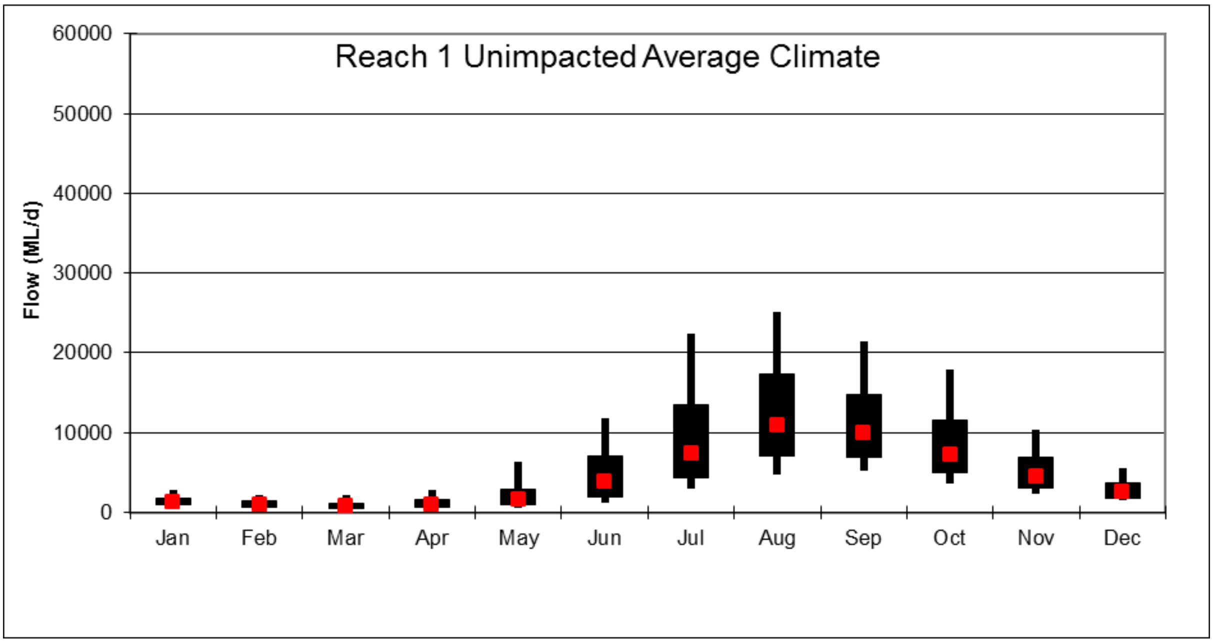
Appendix B – Box Plots

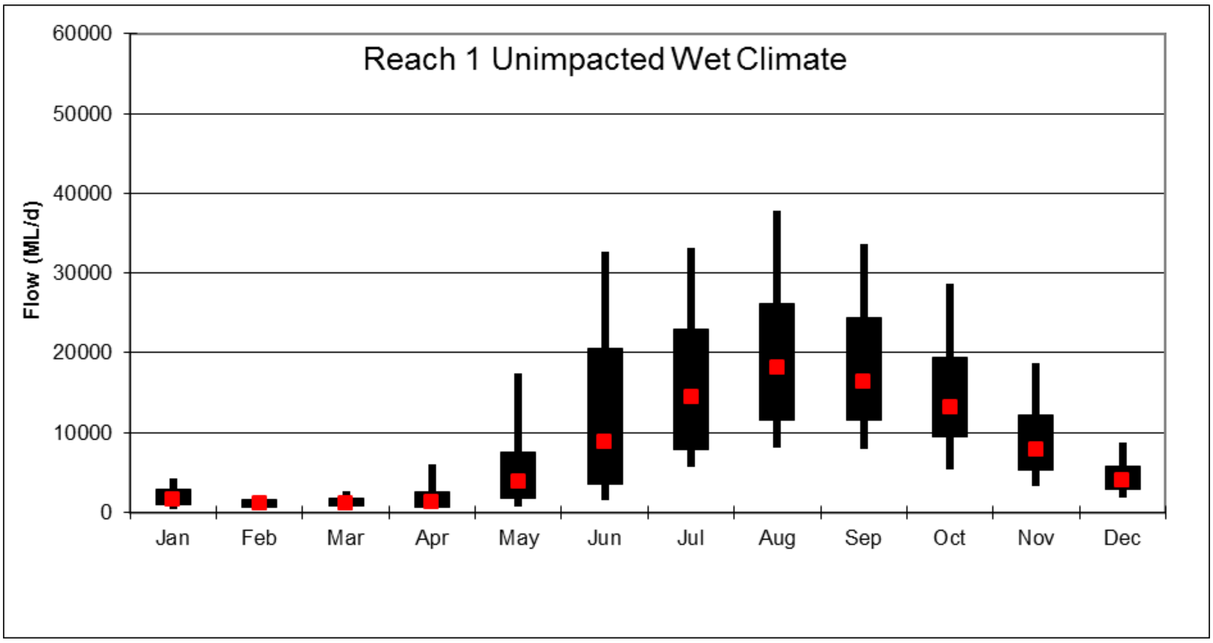
Reach 1 – Unimpacted flows split into Worst Drought, very dry, dry, average and wet years





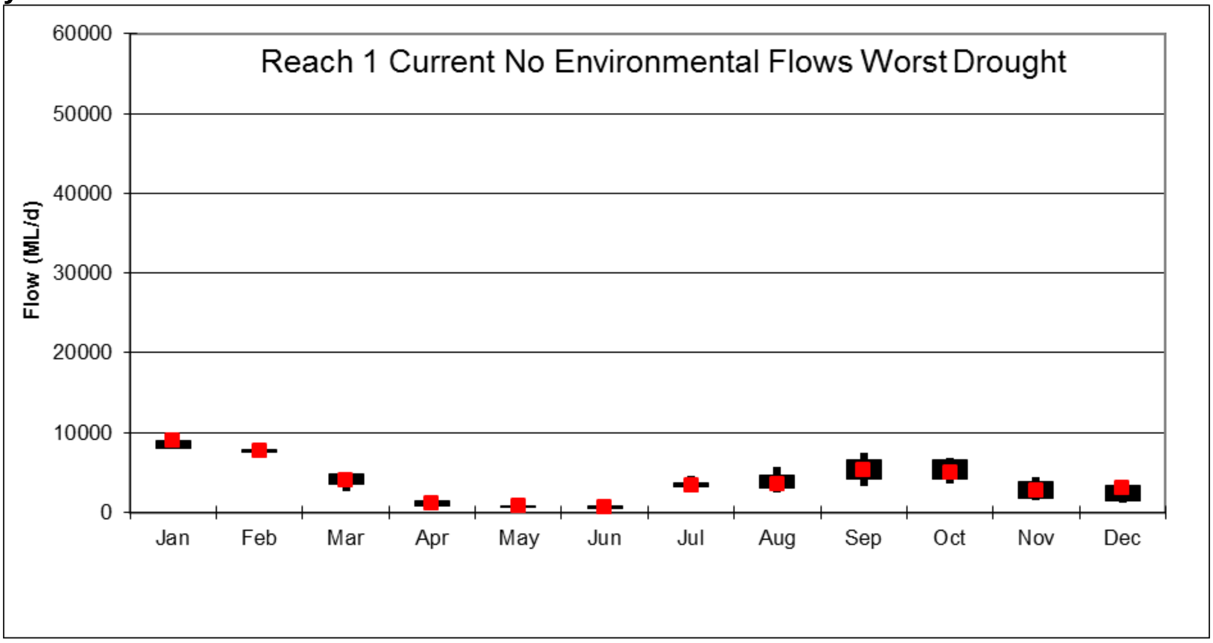

Reach 1 Unimpacted Dry Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

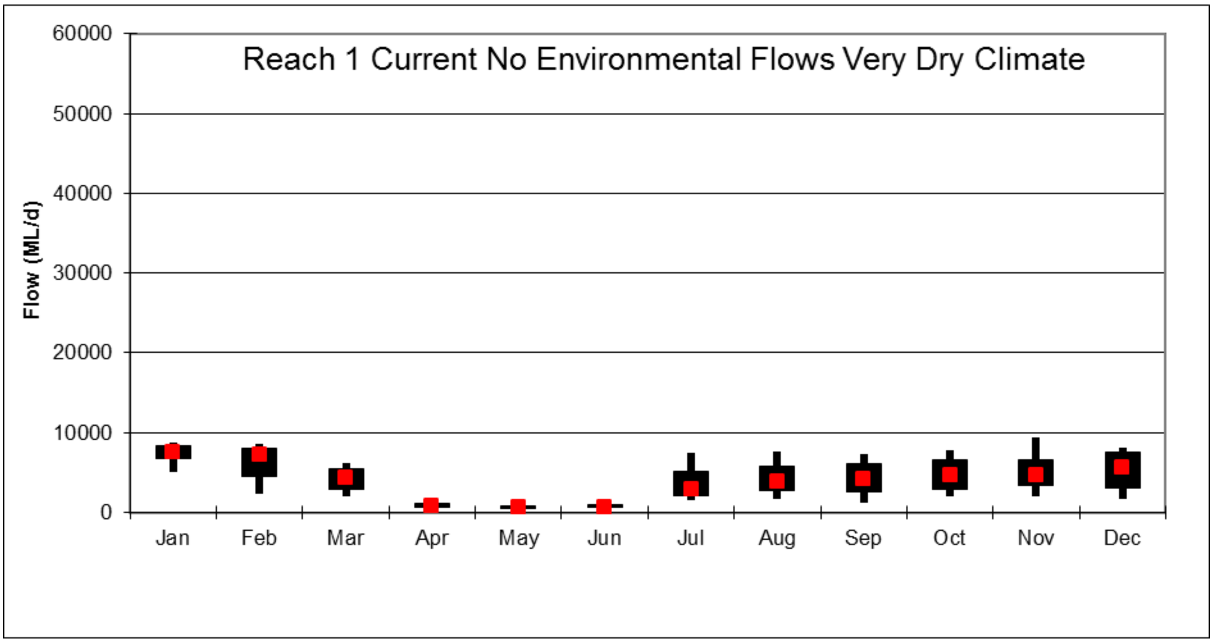

Reach 1 Unimpacted Average Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec



Reach 1 Unimpacted 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 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)
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50000
40000
30000
20000
10000
0
Jan
Feb
Mar
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May
Jun
Jul
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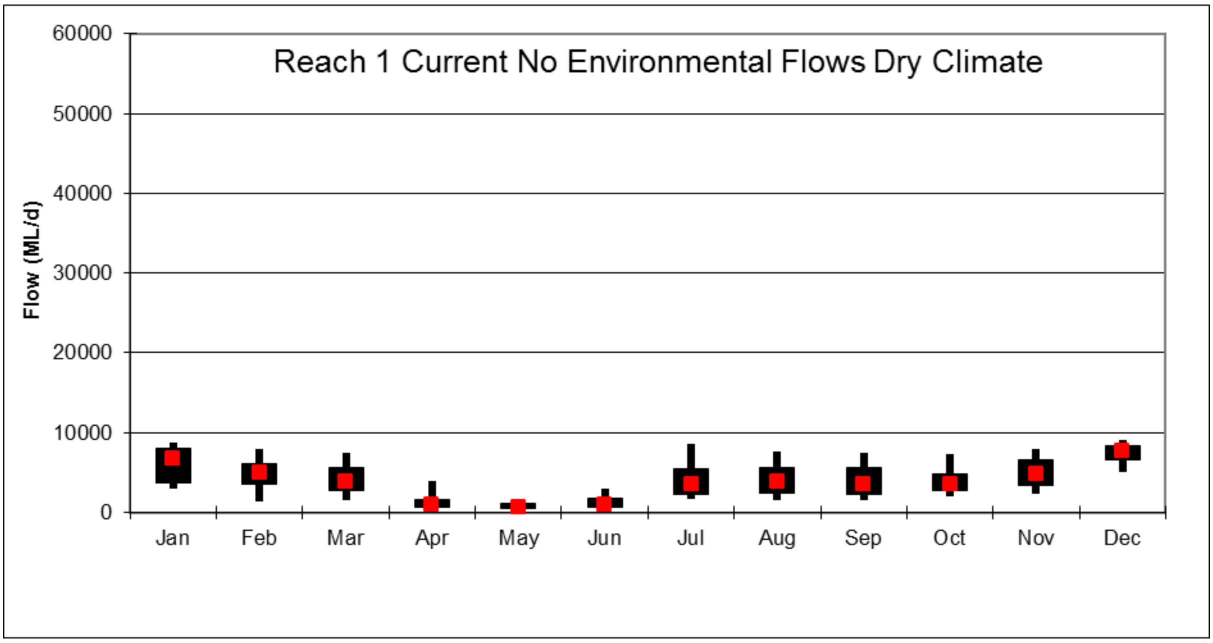
Sep
Oct
Nov
Dec


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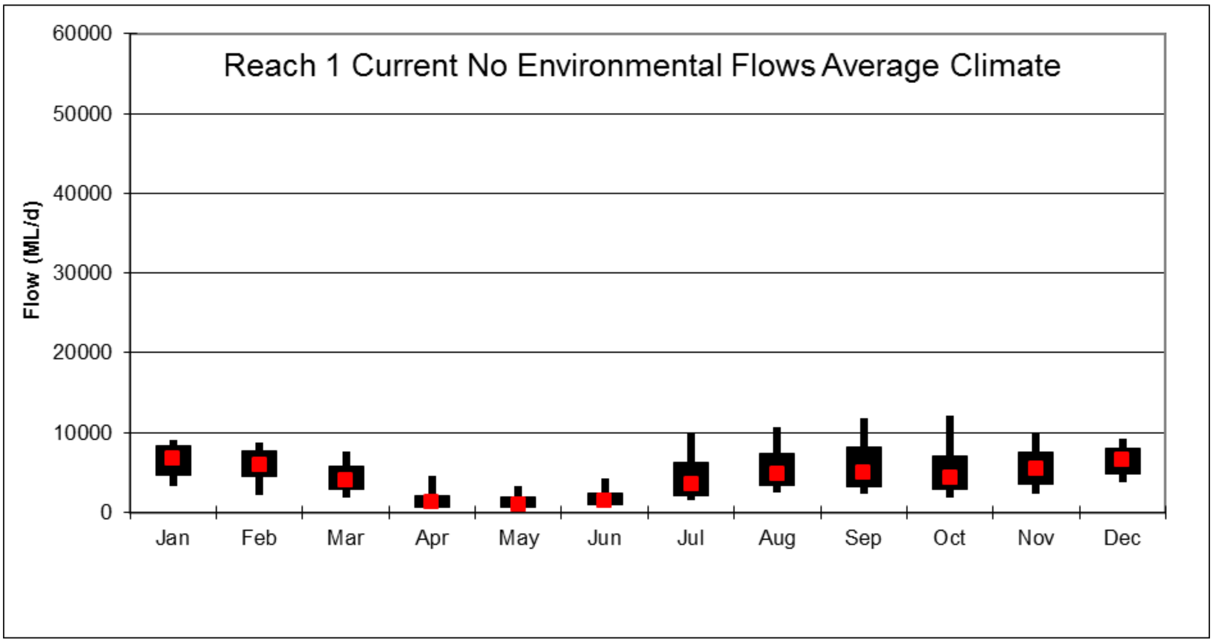
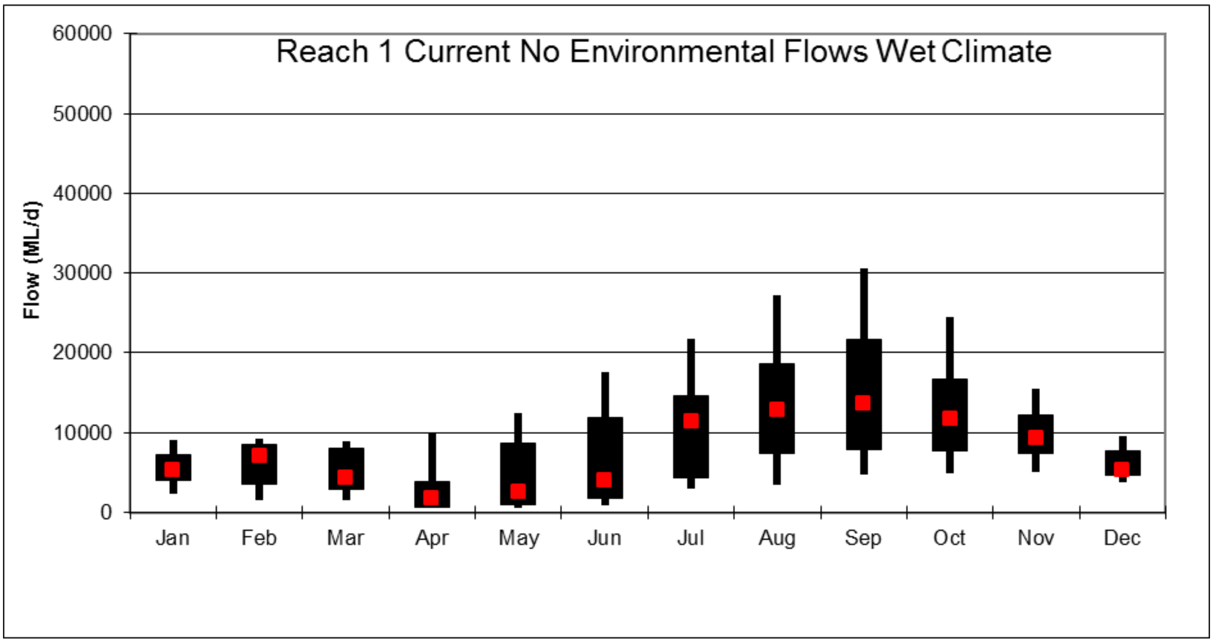
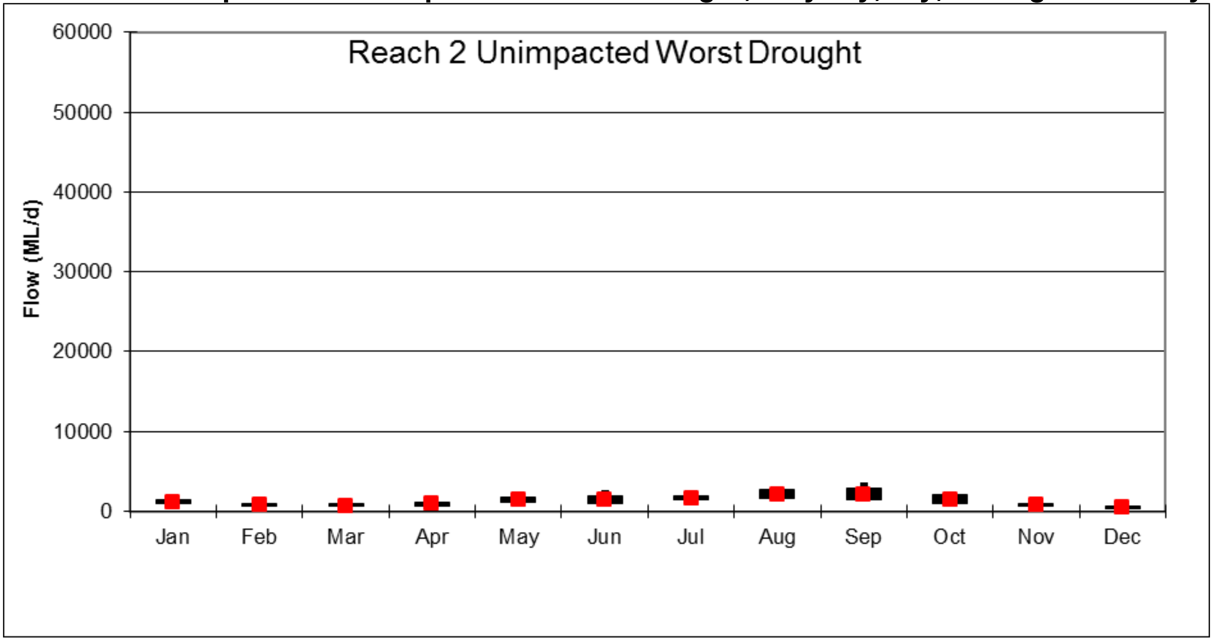
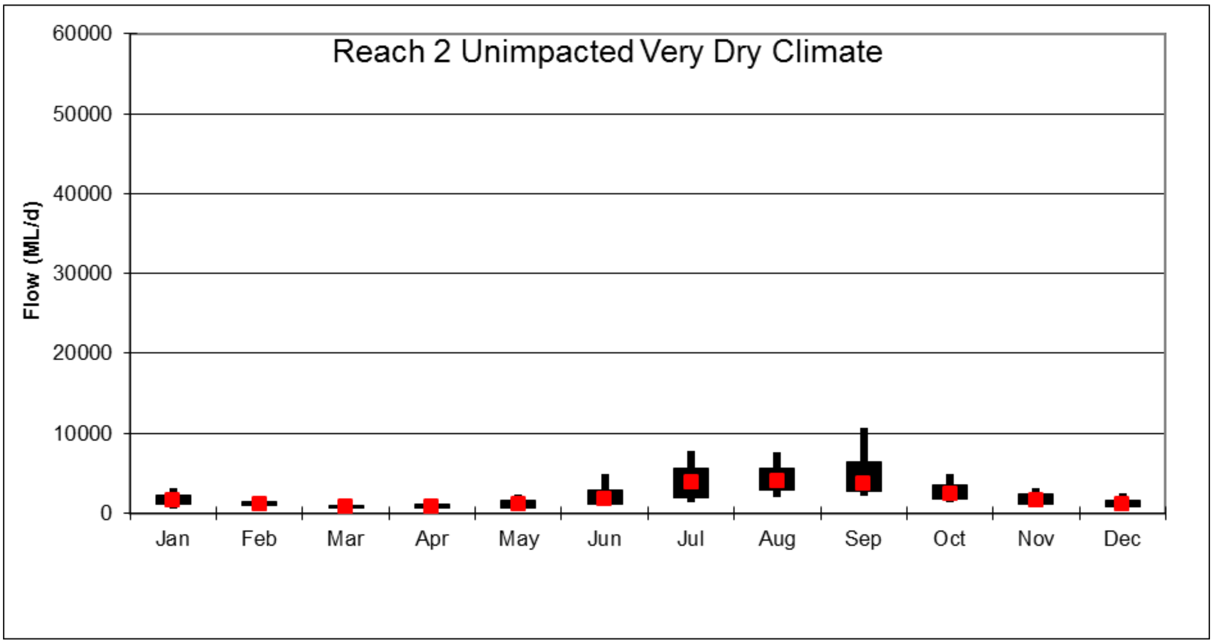
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

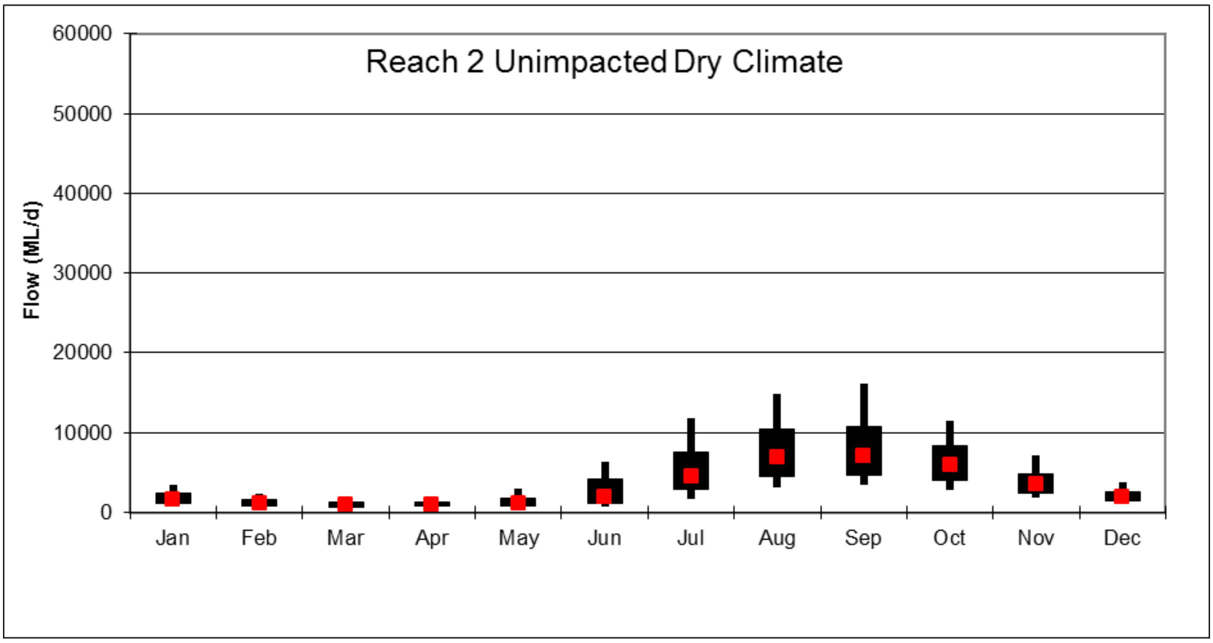

Reach 1 Current No Environmental Flows Average Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

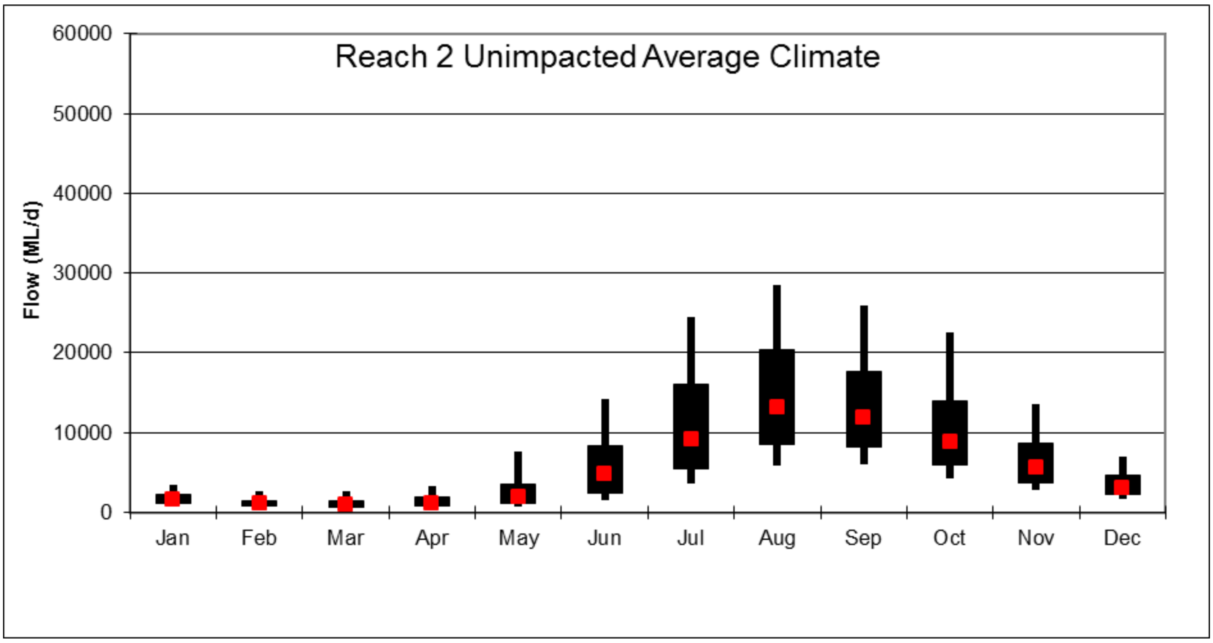

Reach 1 Current No Environmental Flows Wet Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

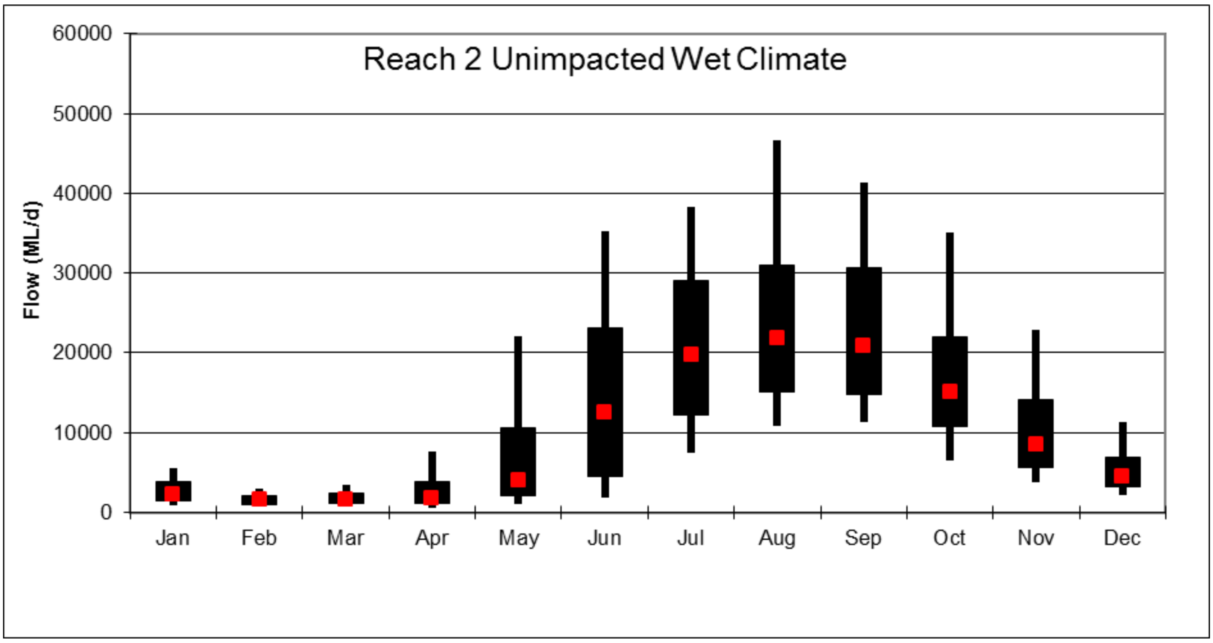
Reach 2 – Unimpacted flows split into Worst Drought, very dry, dry, average and wet years






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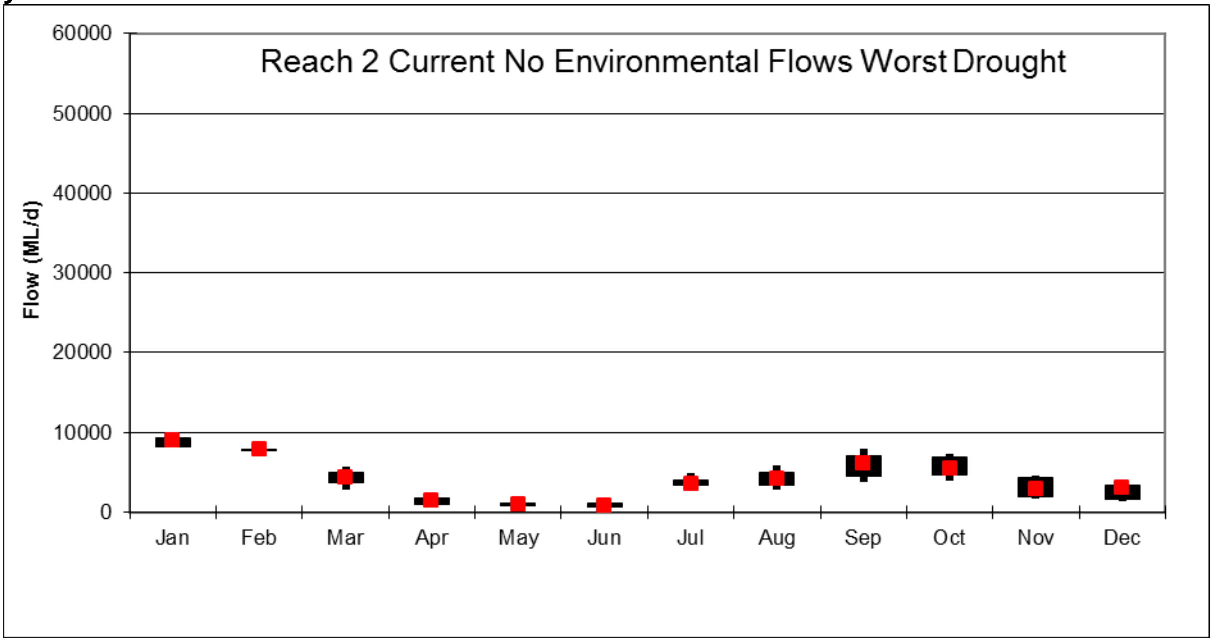
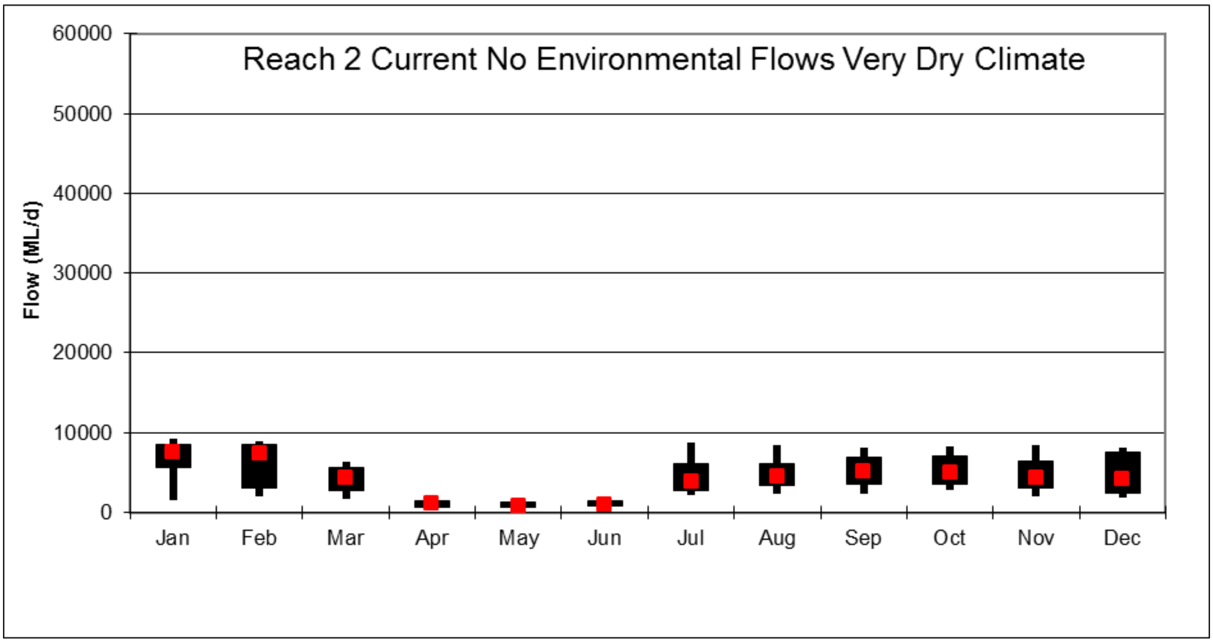
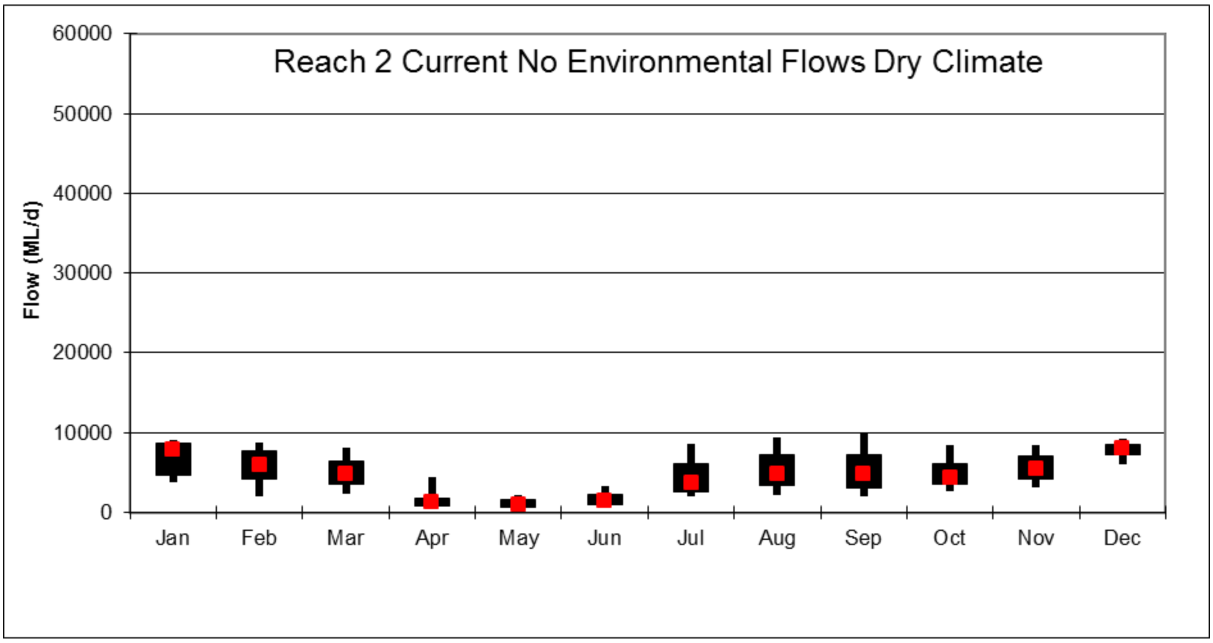
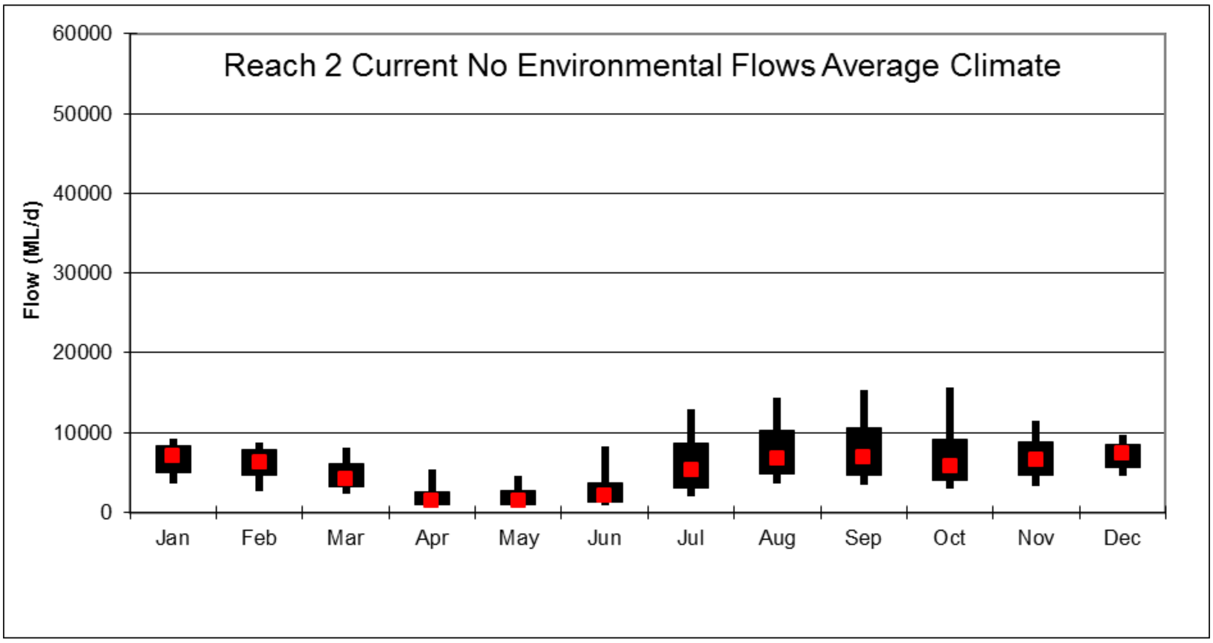
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

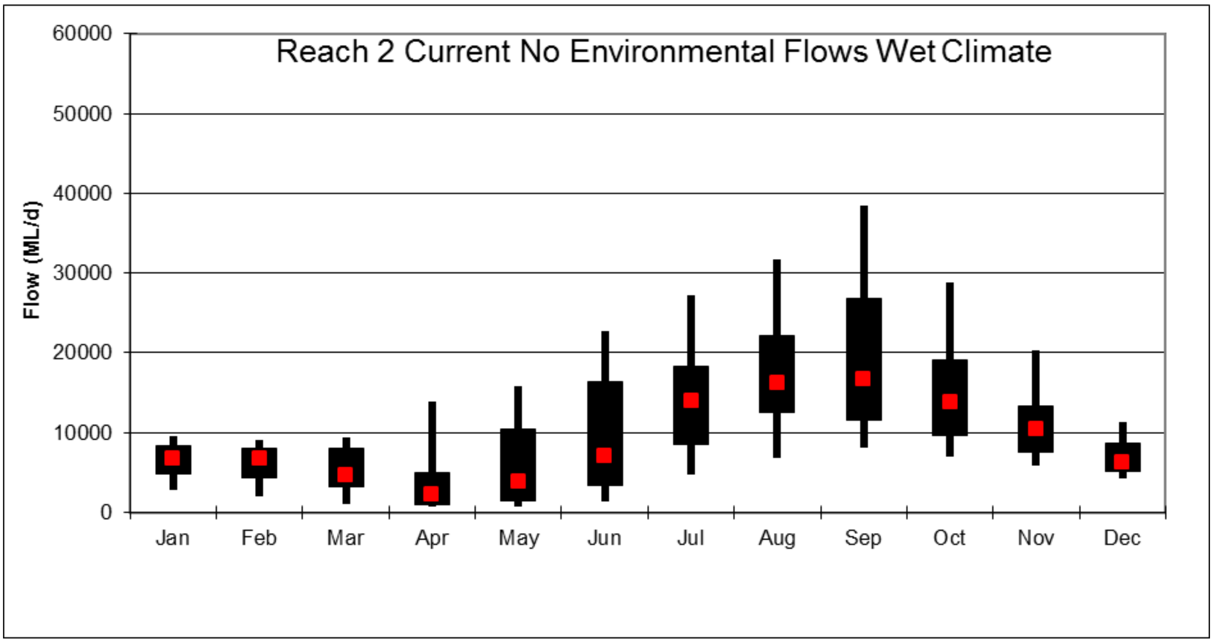
Reach 2 – Current flow regime split into Worst Drought, very dry, dry, average and wet years



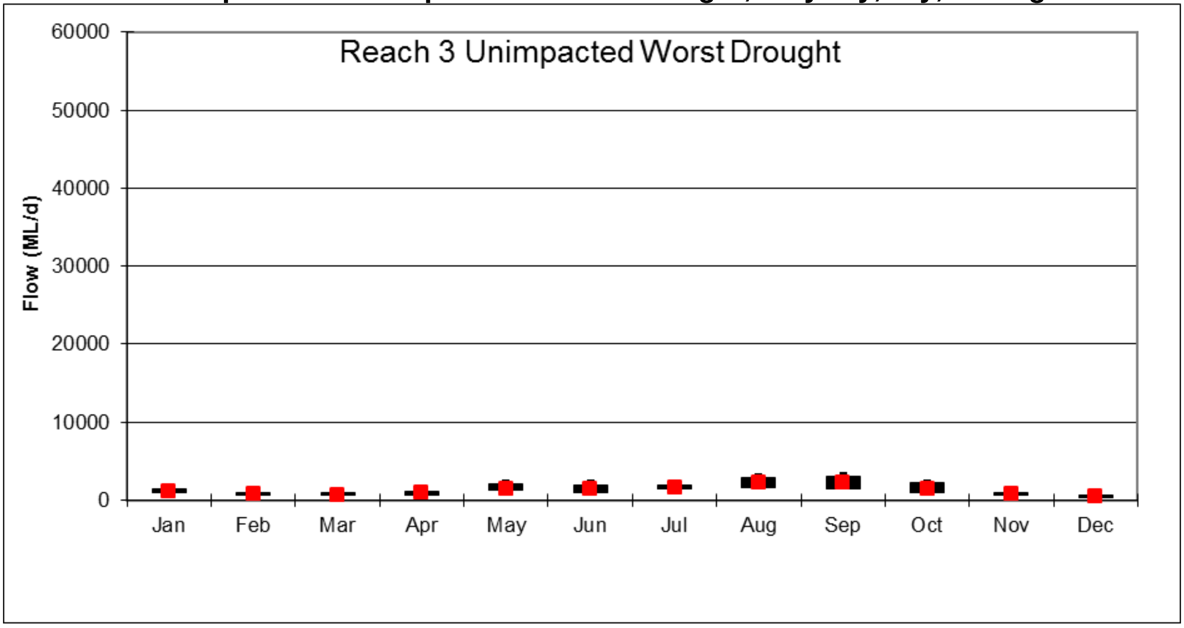

Reach 2 Current No Environmental Flows Very Dry Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

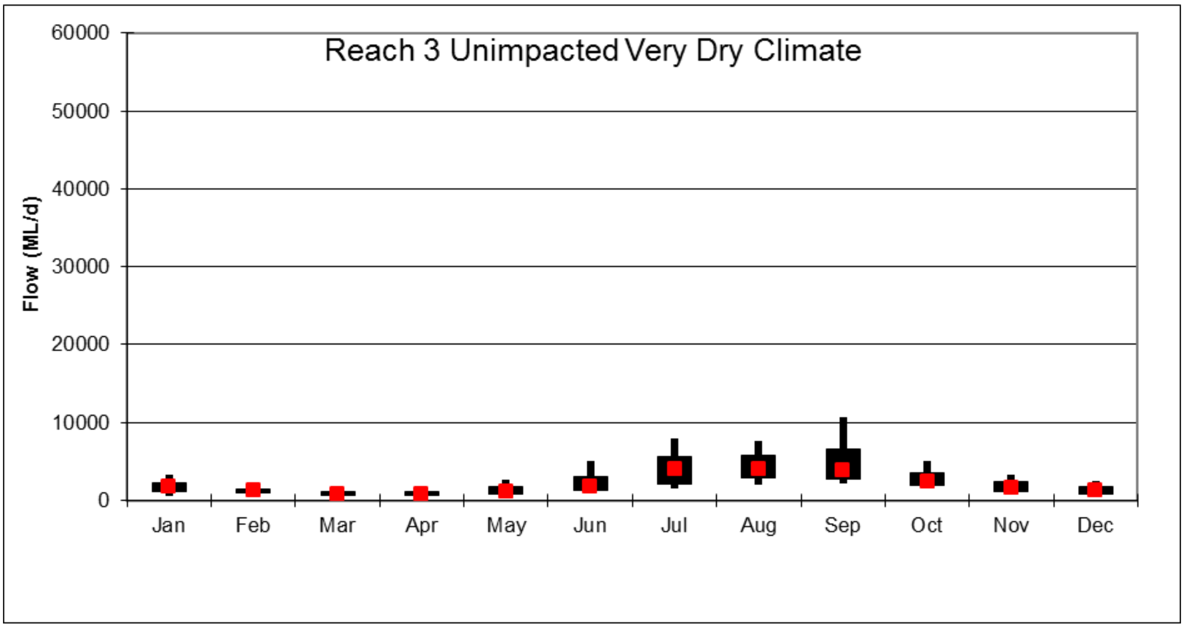

Reach 2 Current No Environmental Flows Dry Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

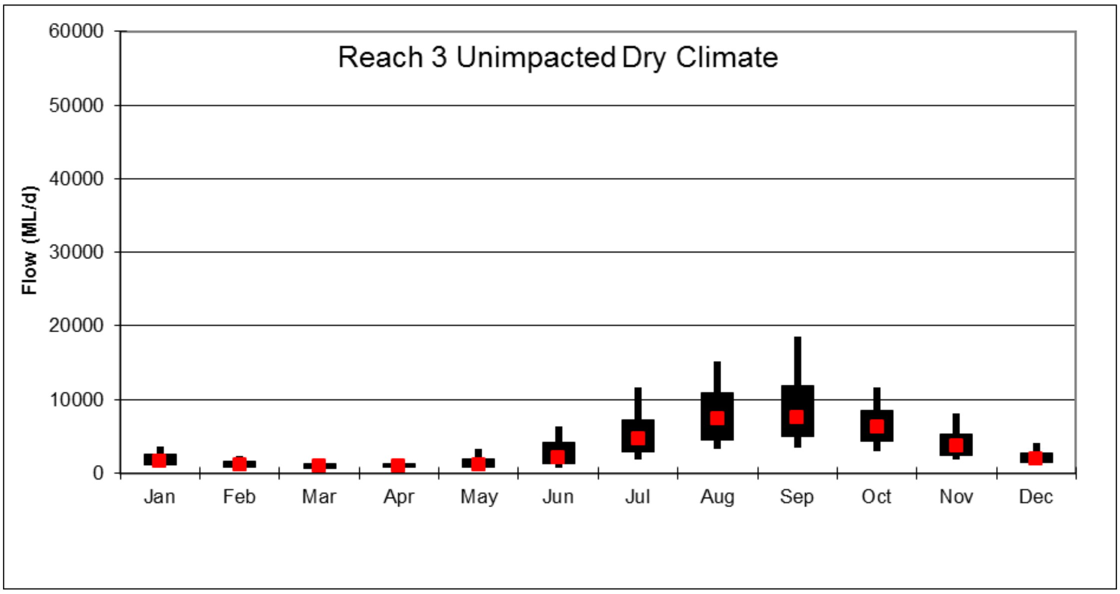

Reach 2 Current No Environmental Flows Average Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

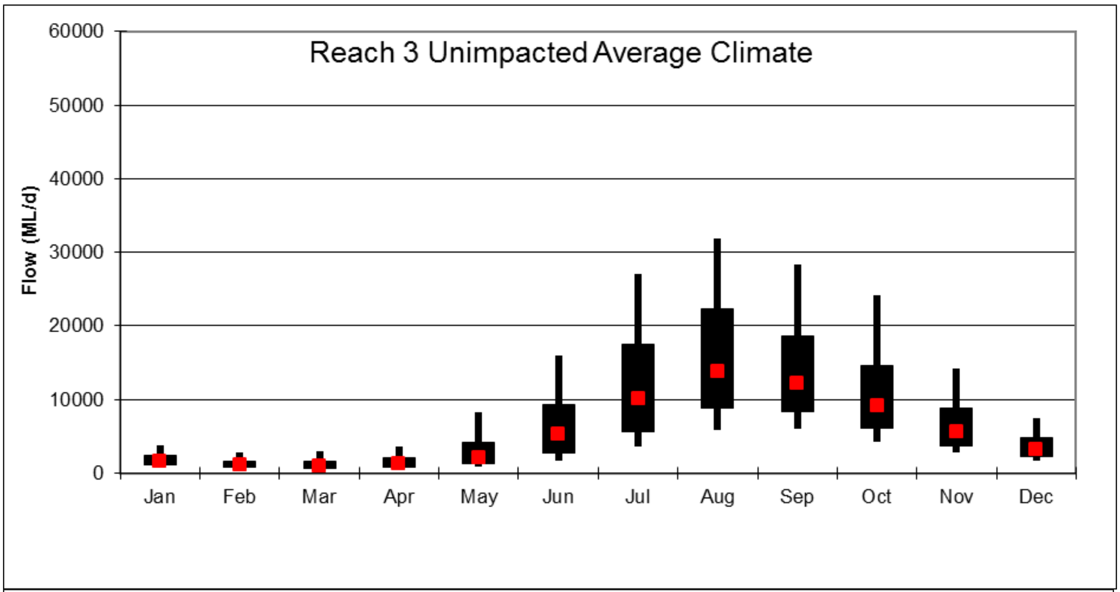

Reach 2 Current No Environmental Flows Wet Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

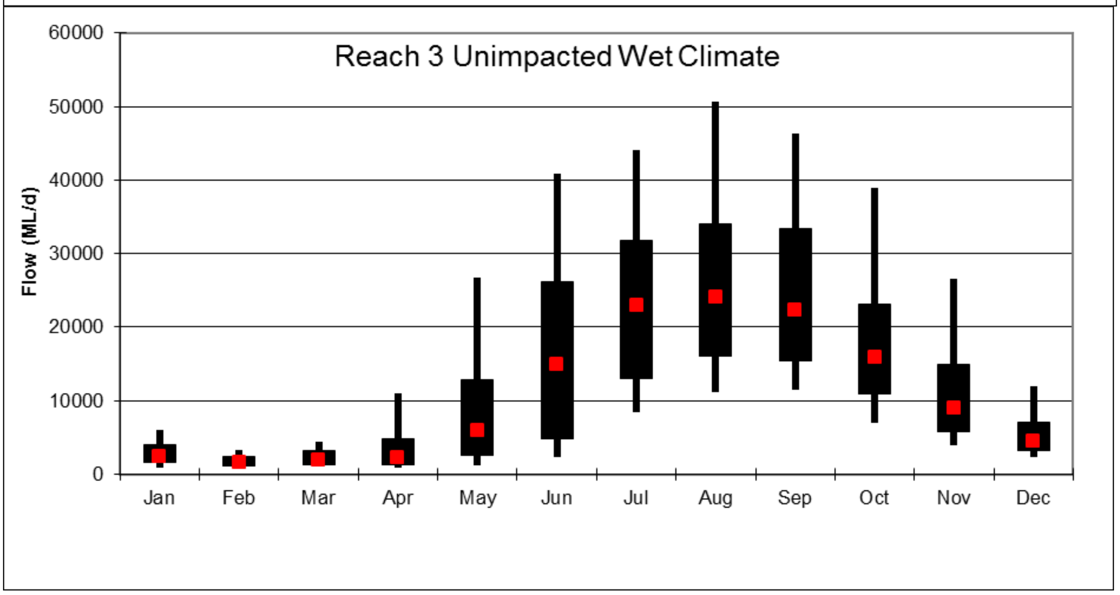
Reach 3 – Unimpacted flows split into Worst Drought, very dry, dry, average and wet years



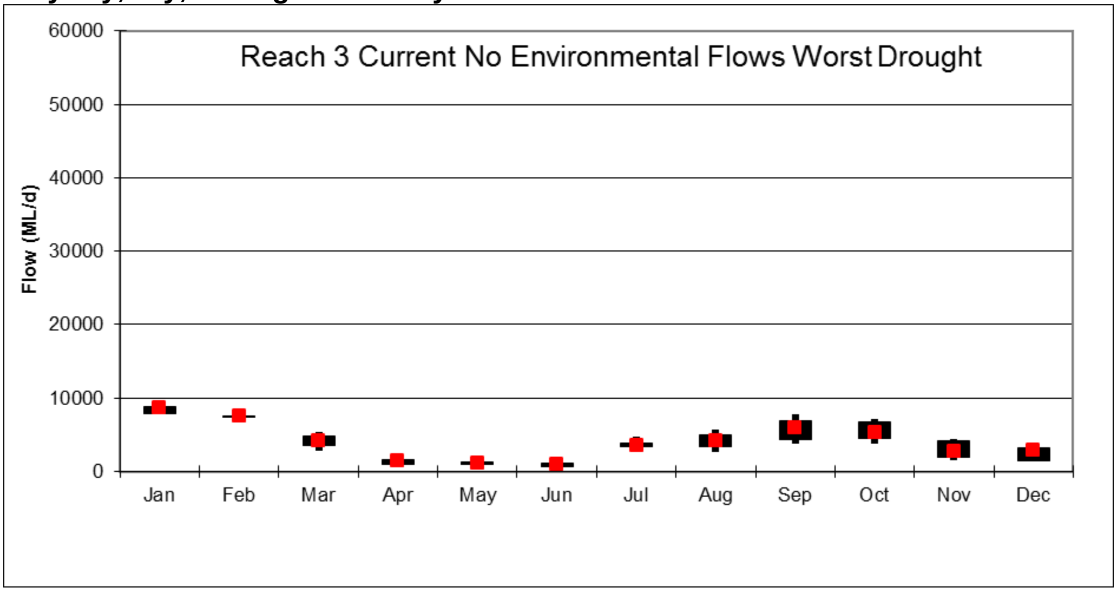


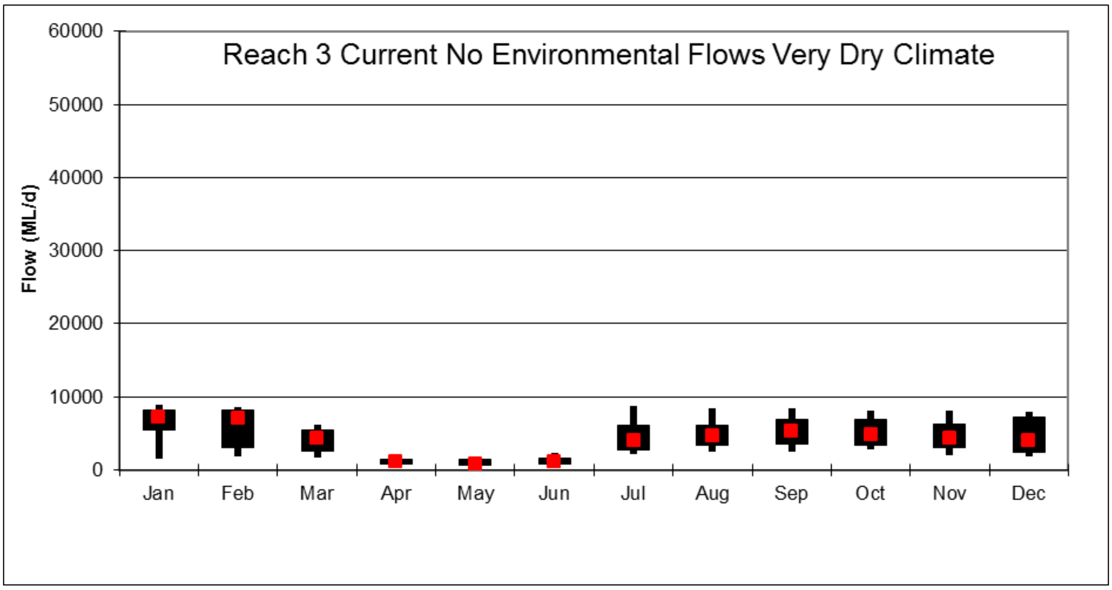

Reach 3 Unimpacted Dry Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

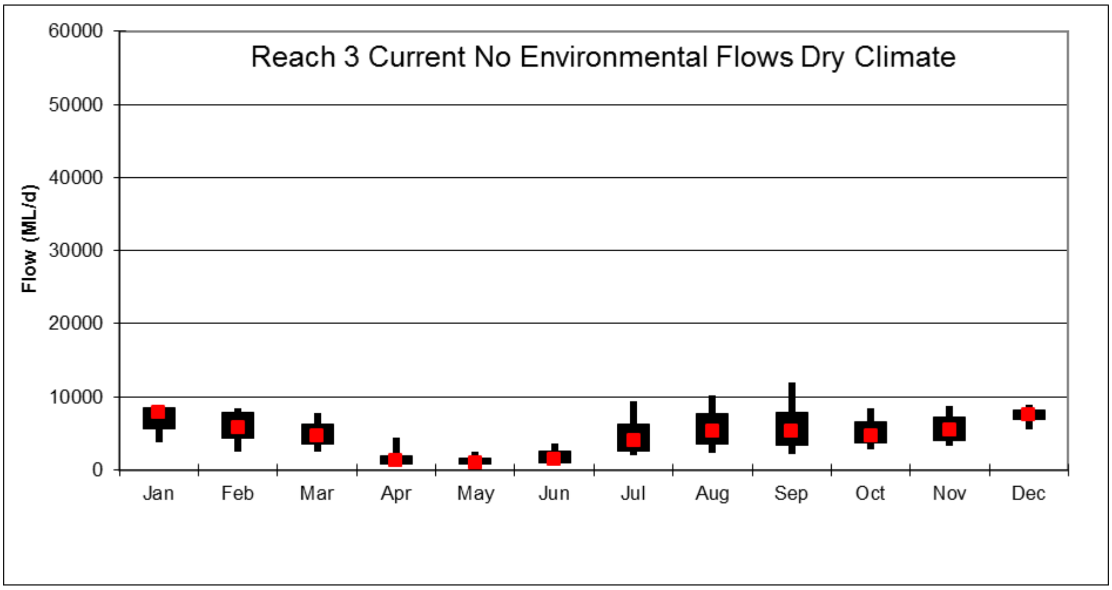

Reach 3 Unimpacted Average Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

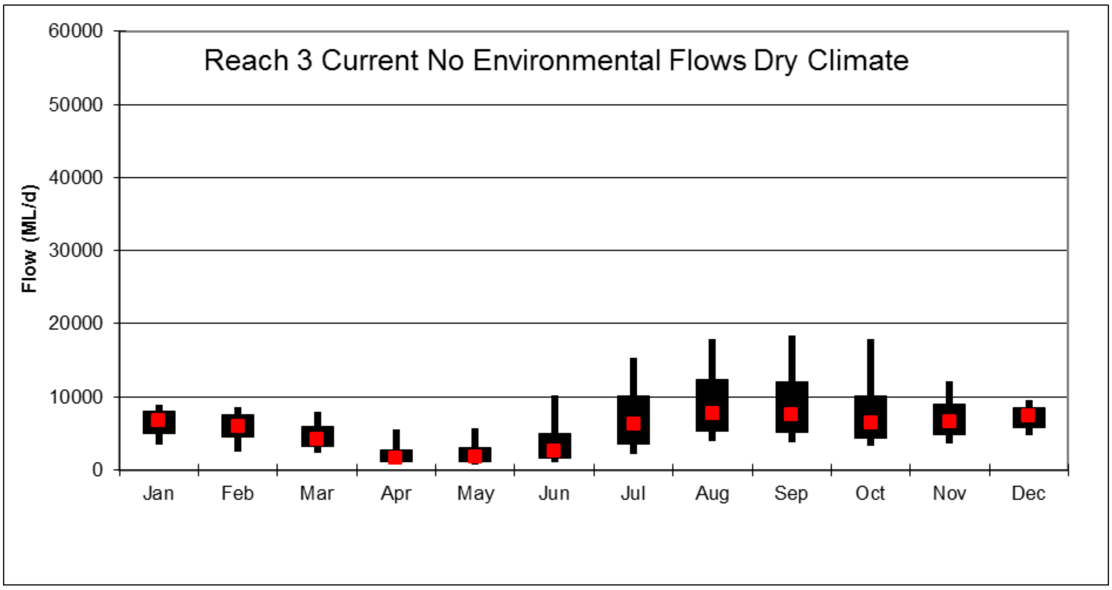

Reach 3 Unimpacted Wet Climate
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

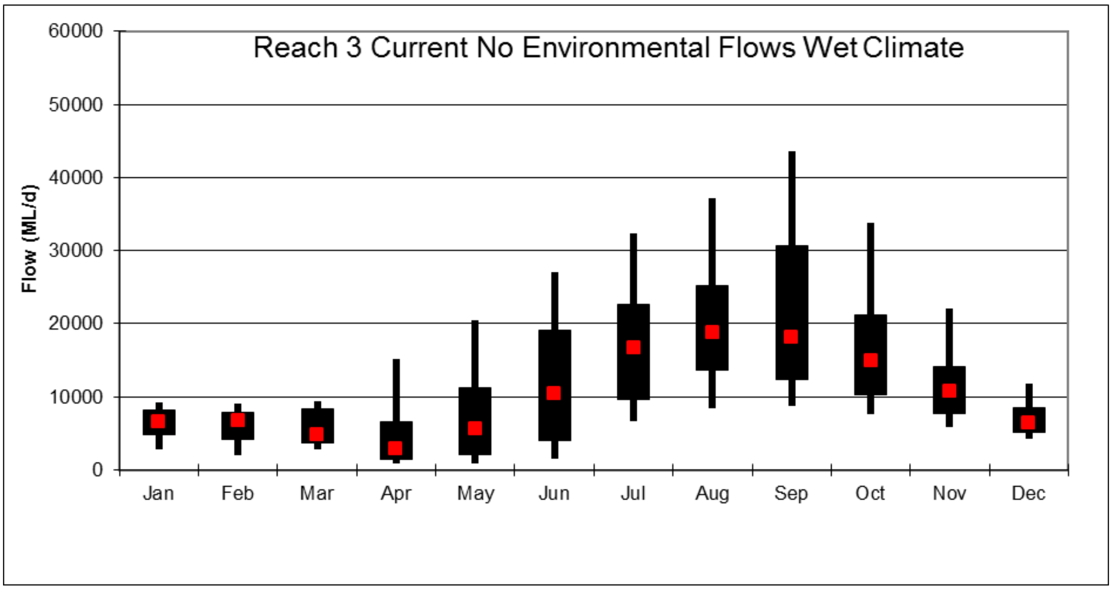
Reach 3 – Current flow regime excluding Environmental Flows split into Worst Drought, very dry, dry, average and wet years




Reach 3 Current No Environmental Flows 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 3 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 3 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 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 C – Rates of Rise and Fall

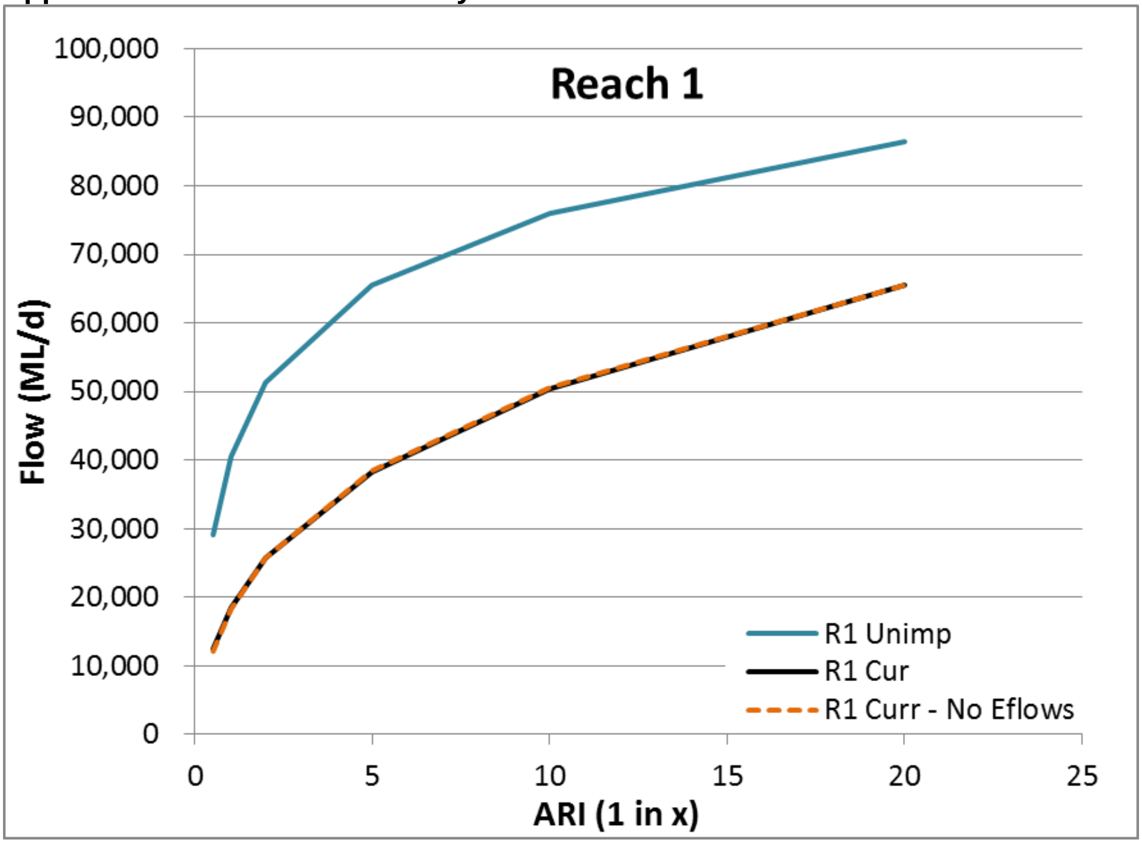
Rates of rise (percentage of previous day's flow)

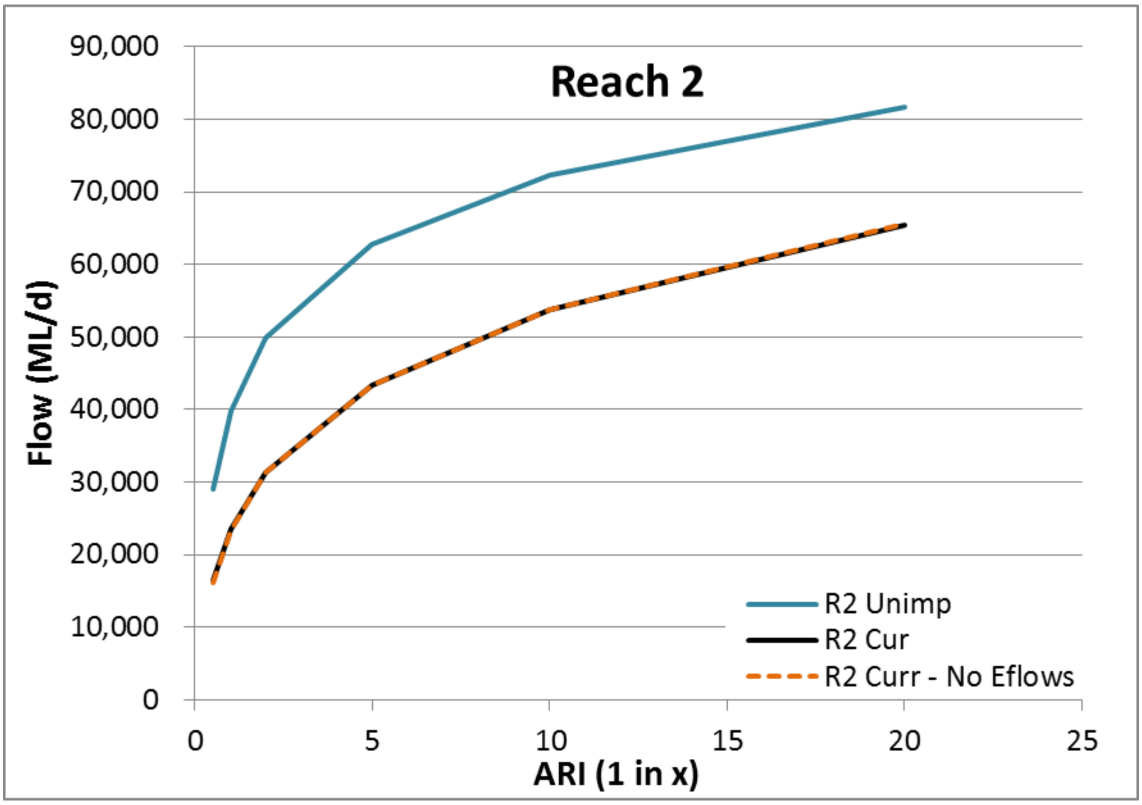
		Percentile		
Reach	**Flow**	**95th**	**Median**	**5th**
R1 unimpacted	0-1000ML/d	100%	106%	165%
	1000-5000ML/d	101%	112%	201%
	5000+ ML/d	101%	120%	271%
R1 current	0-1000ML/d	100%	108%	158%
	1000-5000ML/d	100%	107%	174%
	5000+ ML/d	100%	102%	144%
R1 Current excluding Goulburn Environmental Flows	0-1000ML/d	100%	107%	157%
	1000-5000ML/d	100%	106%	170%
	5000+ ML/d	100%	102%	145%
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%	147%
	1000-5000ML/d	100%	107%	165%
	5000+ ML/d	100%	103%	148%
R3 unimpacted	0-1000ML/d	100%	105%	151%
	1000-5000ML/d	101%	111%	188%
	5000+ ML/d	101%	118%	277%
R3 current	0-1000ML/d	100%	107%	147%
	1000-5000ML/d	100%	108%	185%
	5000+ ML/d	100%	103%	188%
R3 Current excluding Goulburn Environmental Flows	0-1000ML/d	100%	106%	145%
	1000-5000ML/d	100%	107%	180%
	5000+ ML/d	100%	104%	192%

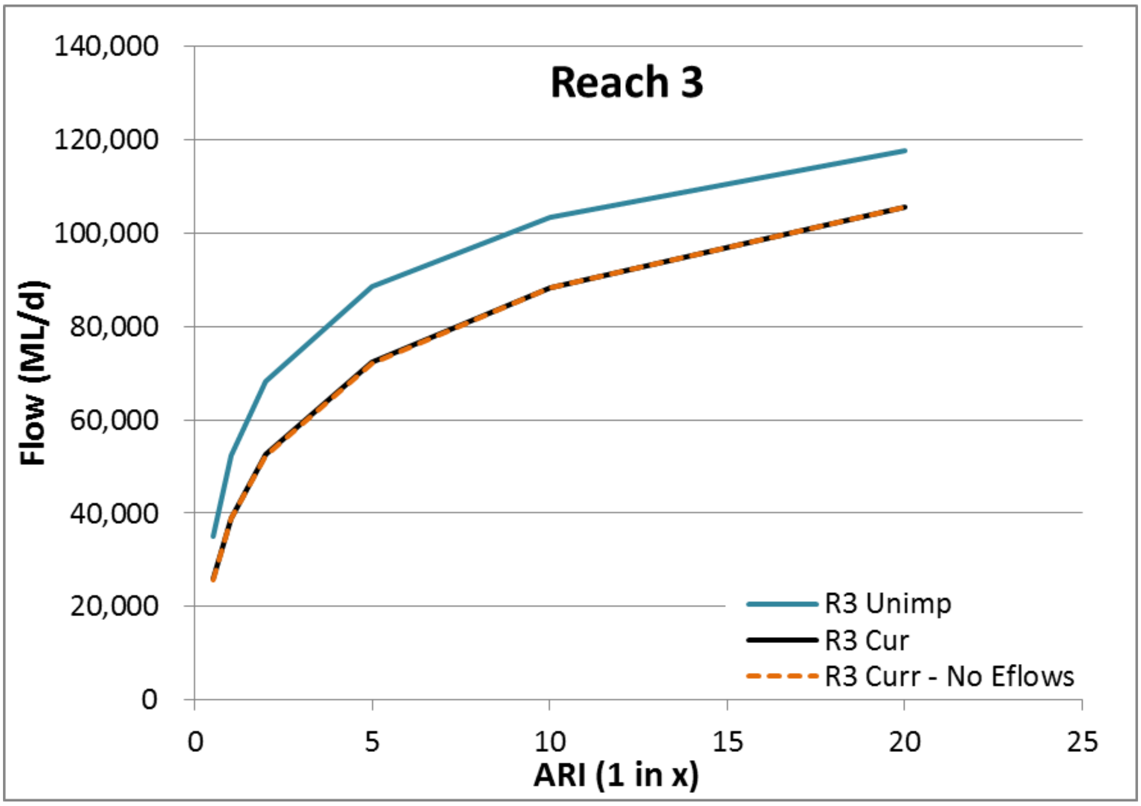
Rates of fall (percentage of previous day's flow)

		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%	100%
	1000-5000ML/d	79%	95%	100%
	5000+ ML/d	81%	97%	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%	99%
	1000-5000ML/d	82%	94%	99%
	5000+ ML/d	84%	96%	100%
R2 Current excluding Goulburn Environmental Flows	0-1000ML/d	86%	96%	99%
	1000-5000ML/d	82%	95%	100%
	5000+ ML/d	83%	96%	100%
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	86%	96%	99%
	1000-5000ML/d	81%	94%	100%
	5000+ ML/d	77%	95%	100%

Appendix D – Partial Series Analysis






Reach 3
Flow (ML/d)
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
0
5
10
15
20
25
ARI (1 in x)
R3 Unimp
R3 Cur
R3 Curr - No Eflows

10 APPENDIX 3: BIOLOGICAL OBJECTIVES RELEVANT TO THE MID GOULBURN RIVER

The relevant objectives for the mid Goulburn River are for the B4 region: cleared hills and coastal plains (Metzeling et al. 2004).

Indicators / Region & Habitat	Number of Families Score	SIGNAL Index Score	EPT Index Score	Key Families Combined Habitat Score	AUSRIVAS O/E score	AUSRIVAS Band
B1 Riffle	22	5.8	10	18	N/A	N/A
B1 Edge	13	6.2	4		N/A	N/A
B2 Riffle	21	6.0	9	22	0.87 – 1.13	A
B2 Edge	22	5.7	7		0.86 – 1.15	A
B3 Riffle	23	6.0	10	26	0.87 – 1.13	A
B3 Edge	24	5.8	9		0.87 – 1.13	A
B4 Riffle	23	5.5	N/A	22	0.82 – 1.18	A
B4 Edge	26	5.5	N/A		0.85 – 1.15	A
B5 Edge	23	5.3	N/A	21	0.87 – 1.13	A