Broken River environmental watering plan

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

by

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

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Executive Summary

The Goulburn-Murray Water Connections Project (Connections Project), formerly known as the Northern Victoria Irrigation Renewal Project (NVIRP), aims to modernise the Goulburn-Murray Irrigation District (GMID) system. It is estimated that up to 900GL (Long Term Cap Equivalent) of water in the Goulburn Murray irrigation system is lost through leaks, evaporation and other inefficiencies. In terms of the Broken River system, the works and measures undertaken by the Connections Project are expected to reduce the mean annual discharge of irrigation returns to the Broken River below the East Goulburn Main Channel by approximately 850 ML (approximately 85% of average return flows). This represents a potential average reduction of approximately 5 ML/d in flows entering the Broken River sourced from the East Goulburn Main Channel if apportioned evenly over the summer-autumn irrigation season.

An environmental watering plan (EWP) is required when a waterway or wetland with high environmental values could be adversely affected due to the changed irrigation water contribution by the implementation of the Connections Project in the GMID, or if uncertainty exists as to the materiality of impacts (NVIRP 2010). In the context of the Broken River system, factors such as the recent (2009) decommissioning of Lake Mokoan, and the potential for trade of water out of the valley also represent potential changes to the flow regime of the Broken River since environmental flow issues were examined as part of the Bulk Entitlement process in 2001. This EWP, therefore, focuses on:

- Reconsidering the current and unregulated flow regimes for the Broken River below Lake Nillahcootie, given the decommissioning of Lake Mokoan in 2009;
- Confirming the flow recommendations required to meet flow-related ecological objectives that seek to protect or improve ecological values associated with the river system;
- Assessing the ecological implications of water savings likely to result from the Connections Project (i.e. the volume of water that will no longer enter the Broken river below the East Goulburn Main Channel); and
- Assessing the ecological implications of the potential for increased trade of water out of the Broken River system.

The study area is the Broken River downstream from Lake Nillahcootie to its confluence with the Goulburn River. The environmental watering needs of the river have been considered for three study reaches:

1. Broken River from Lake Nillahcootie to Holland’s Creek (38 km);
2. Broken River from Holland’s Creek to Casey’s Weir (14 km);
3. Broken River from Casey’s Weir to the Goulburn River (69 km).

The assessment (and mitigation) of the ecological implications of increased trade of water out of the Broken River system are outside the direct influence of the Connections Project. However, the Connections Project chose to assess the implications of increased trade as it represented a potential mitigating action that could be taken to offset the reduction in flows resulting from reduced channel outfalls. This assessment of increased trade addresses part of Action 5.6 of the Northern Region Sustainable Water Strategy, which required an assessment of potential environmental impacts associated with water trade out of the Broken River system be undertaken.

This EWP was developed in a manner consistent with the recently revised FLOWS method, which is the standard method for the development of environmental flow recommendations in Victoria. To reflect recent changes to the FLOWS method, this report introduces annually varying flow rules that depend on the antecedent climate conditions. This represents a significant advance over existing flow rules that should lead to a) far lower shortfalls in achieving environmental flow targets during dry years, and b) more ambitious targets for environmental water delivery during wet years.

A series of flow-related threats to ecosystem values were identified (Chapter 5), along with flow-related ecological objectives, and the relevant flow components required to mitigate the threats and achieve the objectives. These provided the basis of the detailed environmental flow recommendations that are presented in Chapter 7, which relate to protecting or improving the biodiversity and ecosystem function of the Broken River through:

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

Existing HECRAS models were used to convert hydrological data for each reach to hydraulic information that supported flow recommendations based on the flow and habitat requirements of river and floodplain/wetland flora and fauna. In summary:

- The environmental flow regime for each reach includes a baseflow component of 30-100 ML/d (or natural) in summer-autumn and 100-200 ML/d (or natural) in winter-spring.
- A series of freshes of varying magnitude and duration, as well as bankfull and overbank flows are also recommended.
- The current flow regime delivers many of the freshes, as well as bankfull and overbank flows, at the same frequency as would occur under the unregulated flow regime. The intention is that the frequency and duration of these events be preserved.
- Large freshes, bankfull and overbank flow events are to be delivered in average and wet years, but not in dry years.

The reduced volume of irrigation return flows expected to occur in Reach 3 below the East Goulburn Main Drain is unlikely to pose an increased risk to ecosystem objectives except in dry years when flows are more likely to fall below 30 ML/d. This is likely to occur infrequently and only very minor volumes of mitigation water will be required. Given that much of the river is unaffected by irrigation return flows, and that meeting minimum flow requirements is possible under existing water management arrangements, it is deemed that mitigation water will not be required (see Section 7.2 for a full explanation). The assumption, that mitigation water is not required to replace the expected reduction in irrigation return flows, is based on the best information available to the scientific panel at the time of writing. It is recommended that the requirement for mitigation water be reviewed if any new information on the volume and timing of irrigation return flows becomes available (i.e. that test the assumptions and the actual volumes of drainage water, including variability under wet and dry conditions).

Increased trade of water out of the Broken River system is likely to result in a number of changes to existing flow regimes (G. Earl, GB CMA, pers. comm.). While generally moderate in terms of increased summer-autumn flows (see Section 7.3), there could be a problem if the predicted maxima of 50-85 ML/d of trade water was delivered continuously on top of the maximum baseflow 100 ML/d recommendation to meet existing (environmental and irrigation) demand. Under this scenario, there would be a large reduction in the slackwater habitat available to invertebrates and native fish. Even so, trade water in excess of 100 ML/d can still be delivered as flow freshes designed to meet ecosystem objectives (e.g. as freshes of 400 ML/d to meet objective G4 in Reach 3; 500 ML/d to meet objective IC4 in Reach 1).

Threats related to the delivery of environmental flows, reduced inflows from irrigation return flows, and increased trade include:

- Environmental flows:
  - Providing conditions favourable to carp populations,
  - Promoting the spread of Cabomba in Lake Benalla and downstream,
  - Loss of terrestrial vegetation on the river bank (e.g. following floods) increasing the threat of bank erosion until replaced by littoral and/or amphibious species.
- Reduced irrigation return flows resulting from Connections Project irrigation modernisation:
  - Loss of in-channel habitat for aquatic organisms, particularly slackwater habitat for fish and invertebrates, as well as slackwater and run habitat for aquatic vegetation. However, as the likelihood of this occurring is low and the potential consequences are also likely to be low (potential reduction in summer-autumn habitat only for 20 kilometres out of 120 river kilometres), the overall risk associated with reduced irrigation return flows is considered low.
- Increased trade:
  - Loss of in-channel habitat for aquatic organisms, particularly slackwater habitat for fish and invertebrates, as well as slackwater and run habitat for aquatic vegetation.
  - Increased rates of bed and bank erosion, particularly if rates of fall are excessive.
  - Increased suspended sediment smothering of marginal bed substrate habitats if bank erosion is exacerbated.

Managing the threats listed above can be achieved by (responsibility in parenthesis):

- Delivering the environmental watering recommendations identified in Chapter 7 (GB CMA, G-MW).
- Monitoring of carp populations and breeding events in each reach of the river (GB CMA).
- Monitoring the extent of Cabomba in Lake Benalla and downstream to Casey's Weir (GB CMA, City of Benalla).

The development of the environmental watering recommendations presented made extensive use of modelling (hydrological, hydraulic, geomorphic). It is important that the physical and ecological responses of the river system (including wetland and floodplain areas) are monitored so that the implicit assumptions in the modelling are reviewed and refined for future decision-making. In this context, there are a number of existing monitoring programs that will provide important information and these should be continued.

The effectiveness of the flow recommendations will also be complemented by actions that maintain or improve the environmental conditions along the Broken River, including:

- Continued efforts to reduce inputs of nutrients, sediment and turbidity entering the river;
- Continued rehabilitation of native vegetation in the riparian zone;
- Limiting livestock access to waterways;
- Continued implementation of pest control strategies (e.g. Cabomba, willows, carp);
- Providing fish passage past barriers such as Gowangardie Weir;
- Ensuring proper maintenance of existing fishways;
- Encouraging responsible recreational fishing for native species.

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1 PURPOSE OF THE PLAN

1.1 Background

1.1.1 Goulburn-Murray Water Connections Project

The Northern Victoria Irrigation Renewal Project (NVIRP) was established by the Victorian Government in 2007 as part of its Our Water, Our Future program. The project is now managed by Goulburn-Murray Water as the Goulburn-Murray Water Connections Project, and aims to modernise the Goulburn-Murray Irrigation District (GMID) system. The Connections Project is Australia's largest irrigation modernisation project and is the most significant upgrade to the region's irrigation infrastructure in its 100-year history (G-MW 2013). The Connections Project will recover water lost through leakage, seepage, evaporation and system inefficiencies through channel automation and remediation, metering upgrades and realigning the historical layout of the irrigation channels. It is estimated that up to 900GL (Long Term Cap Equivalent) of water in the Goulburn Murray irrigation system is lost through leaks, evaporation and other inefficiencies. The Connections Project aims to recover long-term average annual water savings of 425 GL and increase irrigation water use efficiency from approximately 70 % to at least 85 %.

In terms of the Broken River system, the works and measures undertaken by the Connections Project are expected to reduce the mean annual discharge of irrigation returns to the Broken River below the East Goulburn Main Channel by approximately 850 ML (approximately 85%) (C. Solum, G-MW, pers. comm.). This represents a potential average reduction of approximately 5 ML/d in flows entering the Broken River sourced from the East Goulburn Main Channel if apportioned evenly over the summer-autumn irrigation season.

1.1.2 Environmental Effects Decision

In April 2009, the former Minister for Planning decided that an Environment Effects Statement (EES) was not required under the *Environment Effects Act* 1978, subject to a range of conditions. This included provision for the development of Environmental Watering Plans for waterways and wetlands that were deemed to be at risk from the implementation of the Connections Project. Identification of such 'at risk' waterbodies included a desktop assessment to provide a preliminary list of high ecological value waterways and wetlands, connected to the irrigation system, that required further assessment; 17 wetlands and 15 waterways were identified. This list did not include the Broken River but did include Broken Creek. However, the Broken River is referred to in the subsequent (2011) Adjunct Works project, which is additional to the NVIRP previously considered in 2009. The Adjunct Works project involves works to upgrade irrigation delivery infrastructure in the Central Goulburn CG 1-4 channels and the Shepparton Irrigation Area (SIA) within the GMID. A similar list of conditions was set for the Adjunct Works project as for the original EES, of which Conditions 5 and 6 (DPCD 2011) have implications for the management of the Broken River:

5 Before operation of relevant works commences, an approved Environmental Watering Plan is required for the Lower Broken River and other wetlands and waterways nominated by the Secretary DSE, unless he or she is satisfied following advice from the Expert Review Panel that a waterway or wetland would not be at risk such as to warrant an Environmental Watering Plan. Approval of an Environmental Watering Plan is required prior to the operation of modified irrigation infrastructure that could affect the Lower Broken River or nominated wetlands or waterways. The Minister for Water will consider whether or not to approve an Environmental Watering Plan following advice from the Expert Review Panel.

6 Final advice from the Expert Review Panel on the environmental framework for water management (#3 above), the assessment report (#4 above), and individual Environmental Watering Plans (#5 above) is to be made publicly available.

1.1.3 Water Change Management Framework

The Water Change Management Framework (WCMF) (NVIRP 2012) describes the means by which aquatic and riparian ecological values will be protected by management of water allocations and flows that may be impacted by implementation of the Connections Project within the modernised Goulburn-Murray Irrigation District (GMID). In particular, the WCMF addresses the requirements of Condition 3 of the Victorian Minister for Planning's decisions, under which an Environment Effects Statement (EES) is not required for the Connection Project. The relevant principles include:

- Mitigation water will be provided where water to be saved is shown to have a material and beneficial effect on high environmental values;
- Mitigation water, where identified as needed, will be provided to replace incidental irrigation water converted to water savings;
- Regional impacts will be reviewed and, where identified as needed, will be mitigated.

The Bulk Water Entitlement for the Broken River system is currently based on minimum flow requirements of between 22-30 ML/d (or natural) along reaches of the Broken River below Lake Nillahcootie. The minimum flow requirements are based on an environmental flow study conducted by Cottingham et al (2001). The 'or natural' qualification allows minimum flows to fall below the nominated 22-30 ML/d for each reach if lower flows would have occurred naturally (i.e. allow for variability of low flows that would have occurred in absence of current river operations and infrastructure). For example, it is conceivable that in a drought year flow in the river could fall to approximately 10 ML/d; flow in the river would then be permitted to fall below 22-30 ML/d down to 10 ML/d, as this would have occurred 'naturally'. However, under these circumstances the imposition of a 5 ML/d loss of water entering the river due to upgrades associated with the Connections Project could potentially result in a further 50% reduction in river flows below the East Goulburn Main Channel. Where such a reduction threatens the ecological values associated with the river, then mitigation water would be required to offset the threat.

1.1.4 Context of Environmental Watering Plans

The WCMF requires an environmental watering plan (EWP) under two broad circumstances:

(i) when a waterway or wetland with high environmental values could be adversely affected by changes to irrigation water contribution by the implementation of Connections Project in the GMID, or

(ii) (ii) when uncertainty exists as to the materiality of impacts (NVIRP 2012[1]).

The development of an EWP includes an assessment of the current and unregulated flow regimes, and statements on the preferred flow regime required to achieve ecological objectives related to maintaining or improving ecological values. This then provides the basis for considering the potential ecological effects of water savings to be achieved by the Connections Project (i.e. water that would no longer enter the river system) and identifying mitigation water requirements, if any.

[1] WCMF: see Section 15

In the context of the Broken River system, factors such as the recent (2009) decommissioning of Lake Mokoan, and the potential for trade of water out of the valley also represent potential changes to the flow regime of the Broken River since environmental flow issues were examined as part of the Bulk Entitlement process in 2001 (Cottingham et al. 2001). The decommissioning of Lake Mokoan may reinforce the natural pattern of high flows in winter-spring and low flows in summer-autumn, and it has been estimated that up to 5,000 ML of water could be traded out of the Broken River system (G. Earl, GB CMA, pers. comm.) in coming years. This EWP, therefore, focuses on four considerations:

- Reconsidering the current and unregulated flow regimes for the Broken River below Lake Nillahcootie, given the decommissioning of Lake Mokoan in 2009;
- Confirming the flow recommendations required to meet flow-related ecological objectives that seek to protect or improve ecological values associated with the river system, based on an improved understanding of the ecology of the river;
- Assessing the ecological implications of water savings likely to result from the Connections Project (i.e. the volume of water that will no longer enter the Broken River below the East Goulburn Main Channel); and
- Assessing the ecological implications of the potential for increased trade of water out of the Broken River system.

The assessment (and mitigation) of the ecological implications of increased trade of water out of the Broken River system are outside the direct influence of the Connections Project. However, the Connections Project chose to assess the implications of increased trade as it represented a potential mitigating action that could be taken to offset the reduction in flows resulting from reduced channel outfalls. The assessment of increased trade addresses part of Action 5.6 of the Northern Region Sustainable Water Strategy, which required an assessment of potential environmental impacts associated with water trade out of the Broken River system be undertaken.

In addition, the project offered an opportunity to integrate recent changes to the FLOWS method (the standard environmental flows assessment approach in Victoria), which has recently been revised to (among other changes) better reflect inter-annual variability in environmental water needs (SKM 2012).

1.2 Project activities

The main activities of this project were to:

1. Develop a hydrological model of current and unregulated flows in the Broken River between Lake Nillahcootie and the Goulburn River;
2. Review and update the 2001 report on the environmental condition and flows of the Broken River below Lake Nillahcootie (Cottingham et al 2001);
3. Identify and document the Broken River’s current ecological values, and define appropriate seasonal flow regimes required to maintain those values (based on the FLOWS method);
4. Provide information on the relative impacts of changes in flow regimes due to:
   a. Reduction in irrigation outfall to the Broken River between the East Goulburn Main Channel and the Goulburn River; and,
   b. Modified water trading rules proposed to allow trade out of the Broken River system;
2. Where deemed appropriate in Activity 4, provide recommendations on mitigation measures necessary to maintain ecological values, including if necessary, adjustments to outfall reduction and/or water trading limits.

These tasks have been carried out in a manner consistent with the updated FLOWS method, which is the standard method for the development of environmental flow recommendations in Victoria (SKM 2012). There are three important documents that report on the application of the FLOWS method:

- A site paper that outlines the process for assigning representative reaches and identifying sites at which cross-section surveys will be undertaken. Cross-section surveys are a crucial input to hydraulic models that will be developed to support decision-making later in the project.
- An issues paper that considers:
    - The condition of assets and values associated with the reaches of river(s) that are the focus of the study;
    - System hydrology including comparison of current and unregulated (i.e. by water resource development) [2] streamflow regimes and potential future water demands;
    - Key degrading factors, focussing on flow-related and non-flow related issues;
    - Current threats to the environmental assets and values resulting from consumptive water use;
    - The implications of current water resource management; and
    - Flow-related ecosystem objectives consistent with the Regional River Health Strategy.
- A final report that summarises the above and provides environmental flow recommendations required to meet flow-related ecosystem objectives. The threats posed to ecosystem values and assets of not delivering the recommended environmental flows will also be identified.

The site paper (Cottingham et al. 2012) and the issues paper (Cottingham et al. 2013a) have been completed. This EWP should be read in conjuction with the issues paper, and represents the final stage of the FLOWS method, and discusses (i) environmental flow recommendations, (ii) implications in terms of any requirements for mitigation should lower irrigation system return flow prove to increase the risk to environmental values and objectives, and (iii) how to manage the delivery of trade water.

[2] 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. But it does not take into account changes in vegetation and land-use in the catchment, so is ‘natural’ in only a limited sense.

2 CATCHMENT SETTING: BROKEN RIVER BELOW LAKE NILLAHCOOTIE

2.1 Overview

The Broken River rises in the Wellington-Tolmie highlands of central Victoria and flows in a westerly direction to Lake Nillahcootie. The river then flows north to Benalla and then west again, before it discharges to the Goulburn River near Shepparton. The study area is the Broken River downstream from Lake Nillahcootie to its confluence with the Goulburn River. The environmental watering needs of the river have been considered for three study reaches (Cottingham et al. 2012) (Figure 1):

1. Broken River from Lake Nillahcootie to Holland's Creek (38 river km);
2. Broken River from Holland's Creek to Casey's Weir (14 river km);
3. Broken River from Casey's Weir to the Goulburn River (69 river km).

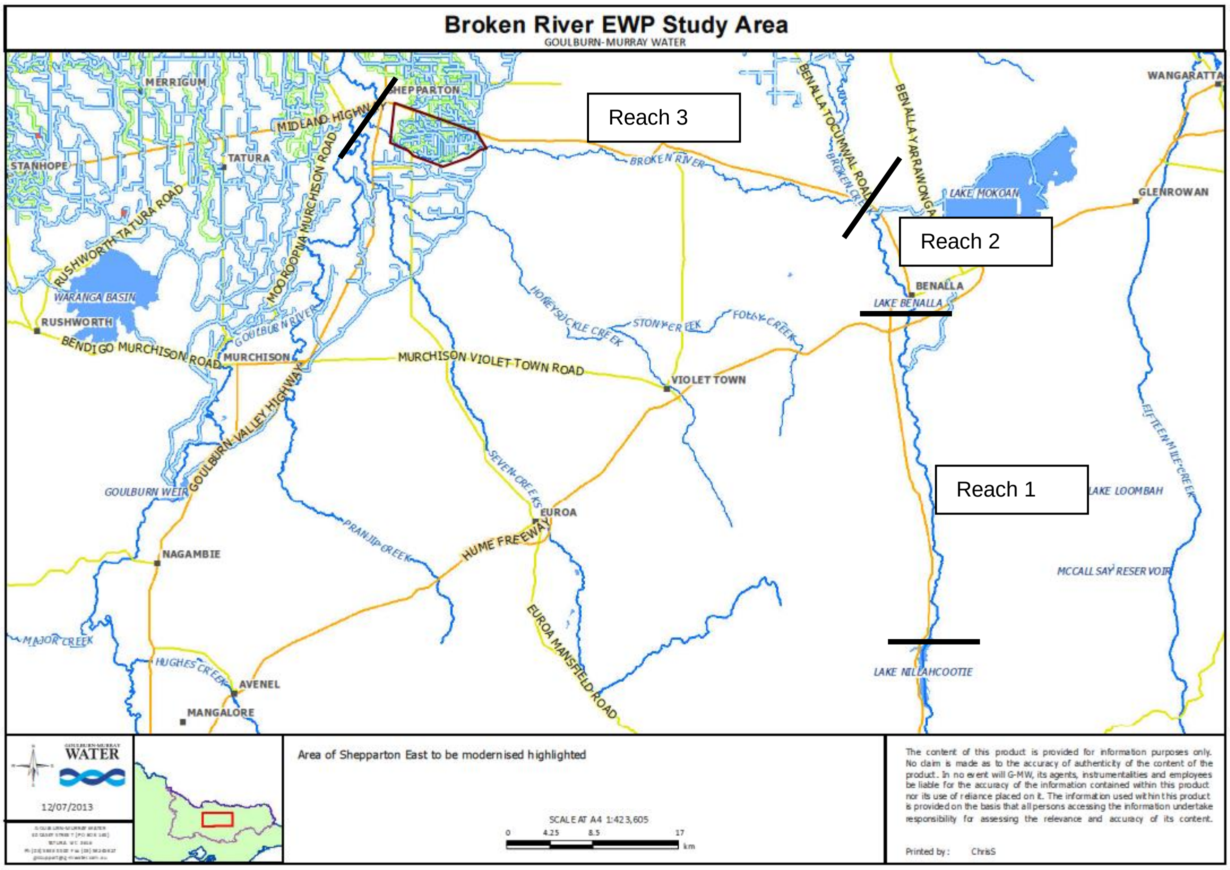


Figure 1: The study area of the Broken River (Courtesy Goulburn-Murray Water).

The Broken River has the characteristics of a foothills stream with relatively steep, confined sections immediately below Lake Nillahcootie. The river then takes on the characteristics of a lowland river with a more extensive floodplain downstream of Swanpool until its confluence with the Goulburn River. The main tributaries of the Broken River include Holland's Creek, Ryan's Creek, and Lima East Creek (formerly Moonee's Creek). Much of the study area has been cleared for agriculture, including dryland (livestock grazing and cereal cropping) and irrigated agriculture (dairy, fruit, livestock). Major urban areas in the study area include Benalla, Dookie and Shepparton. Land tenure is mostly a narrow crown land reserve associated with the main river channel, although some riparian land was alienated in the 1800's and in these areas freehold extends to the riverbank.

The river retains an almost continuous riparian canopy although the width of the riparian zone is generally narrow (e.g. one to a few trees wide). Riparian vegetation is dominated by the Ecological Vegetation Class (EVC) 56: Floodplain Riparian Woodland (see issues paper, Cottingham et al. 2013a, for more information). This EVC occurs along each reach and is characterised by a canopy layer dominated by two species of eucalypt: *Eucalyptus camaldulensis* (River Red Gum) and *Eucalyptus melliodora* (Yellow Box). The EVC describes an open woodland or forest to ~20 m tall, with ~20% tree canopy cover and a ground-layer of amphibious and aquatic herbs and sedges (including various species of *Carex*, *Eleocharis*, *Persicaria* and *Phragmites*). The EVC is listed as 'Endangered' in two relevant bioregions (Central Victorian uplands, Victoria riverine) as vegetation clearing for agriculture has reduced the pre-European cover of EVC 56 (Floodplain Riparian Woodlands) along the river to approximately 40%, and it is often narrower and much less continuous than in pre-European times.

Overall, the Broken River is listed as a wetland of national significance, and is recognised for the presence of threatened fish species (Murray cod, Macquarie perch and Silver perch), which are high value assets whose protection is addressed in management planning (GB CMA 2005). The ecological values associated with the river are described in more detail in Chapter 3 of this report.

2.2 River operations

Mean annual streamflow for the Broken Basin is approximately 308 GL (DSE 2009). Streamflow is variable, both across years and across seasons, and is modified by the following processes:

- The presence and operation of Lake Nillahcootie;
- The construction of irrigation supply and drainage schemes;
- The presence and operation of numerous weirs, progressive extraction of water from the Broken River for irrigation and stock and domestic water supply;
- Changes to the form of the channel due to channelisation and historical snag removal; and
- Changes to floodplain drainage through the construction of levees and drains.

The operation of Lake Nillahcootie and water management along the Broken River is governed by the Bulk Entitlement for the Broken System (DSE 2010). The features of Lake Nillahcootie are summarized in Table 1. Lake Nillahcootie fills in most years, as the storage capacity is approximately half of the mean annual flow of that section of the Broken River. It is regularly drawn down to less than 30% capacity by the end of the annual irrigation season. Water is released to meet downstream demand of up to 300 ML/d and to ensure a minimum 'riparian flow' of 30 ML/d at Moorngag, as well as to meet minimum flow requirements specified under the Bulk Entitlement for the Broken River system. Releases from the dam may be less than 30 ML/d as tributary inflows immediately below the dam (e.g. Back Creek) can supply much of the flow required to meet the prescribed/current minimum flow requirements.

Table 1: Summary features of Lake Nillahcootie

Location	Capacity at FSL (ML)	Outlet Capacity (ML/d)	Spillway Capacity (ML/d)
36 km south of Benalla. Constructed in 1967	40,000	800	110,000

2.2.1 Current environmental (minimum flow) requirements

Cottingham et al. (2001) developed minimum flow recommendations for the three study reaches that were included in the Bulk Entitlement (DSE 2010) for the river system:

Reach 1:

- Maintain minimum winter flow of 30 ML/d or natural at Moorngag while Lake Nillahcootie fills or water is transferred to Lake Mokoan (Note: provision for filling Lake Mokoan is no longer relevant). This flow is to pass along the remainder of the reach and over Broken Weir;
- Apply a flow reduction target of $Q_2 > 0.65Q_1$ [3] when reducing regulated releases (e.g. when reducing flows from Lake Nillahcootie when filling the dam);
- Apply a rule of $Q_2 < 2.1Q_1$ when increasing regulated releases from Lake Nillahcootie.

Reach 2:

- Maintain summer flow above a minimum of 22 ML/d or natural. This was designed to provide sufficient slow water habitat for biota such as juvenile fish (20 ML/d). Compliance is to be measured at Broken Weir and include the 22 ML/d (or natural) and additional flow to meet diversion needs along the reach;
- Apply flow reduction target of $Q_2 > 0.7Q_1$ when adjusting flows (e.g. when diverting to Lake Mokoan; when reducing flows during the irrigation season).
- Apply a rule of $Q_2 < 1.5Q_1$ when increasing regulated releases.

Reach 3:

- Maintain flow above a minimum of 25 ML/d or natural downstream of Casey's Weir. This was designed to be sufficient to maintain slow water habitat (20 ML/d). Compliance is to be measured at Gowangardie Weir and include the 25 ML/d (or natural) plus flows to meet diversion demands downstream of Gowangardie Weir;
- Apply flow reduction target of $Q_2 > 0.55Q_1$ when adjusting flows (e.g. when diverting to Lake Mokoan; when reducing flows at the end of the irrigation season).
- Apply a rule of $Q_2 < 1.8Q_1$ when increasing regulated releases.

2.2.2 Other relevant management plans

Other relevant management plans that influence the management or condition of the Broken River include:

- Goulburn Broken Regional Catchment Strategy (GBCMA 2003);
- Goulburn Broken Regional River Health Strategy (GBCMA 2005);
- Goulburn Broken Biodiversity Strategy (Miles 2010).

[3] Q_2 = flow on day 2, Q_1 = flow on day 1; based on 95th percentile and 5th percentile value for rates of rise and rates of fall, respectively (Cottingham et al. 2001).

3 ENVIRONMENTAL VALUES

The assets and values associated with the Broken River were described in the issues paper (Cottingham et al. 2013) and are restated in the following sections, along with overarching vision and objectives used as the basis for environmental flow recommendations.

3.1 Riverine ecosystem assets and values

Environmental values associated with the Broken River have been outlined in a number of earlier reports (e.g. Cottingham et al. 2001, GBCMA 2005, Carr et al. 2007). Important values include:

- Its listing by the Commonwealth of Australia as containing wetlands of national importance (Environment Australia 2001);
- The largely natural pattern of the flow regime in the lower reaches (Reaches 2 and 3) of the Broken River (including both high and low flows) which maintains geomorphological, biological and ecological processes;
- Habitat diversity, including in-stream features such as large wood accumulations (snags), riffles, pools, bars, anabranches, the littoral fringe, flood runners and floodplain and wetland/billabong features in the nearby landscape (Cottingham et al. 2013a, 2001);
- Threatened species, including a number of species of water birds and of birds associated with riparian vegetation, and up to ten native fish species of State and national conservation significance (e.g. Murray cod, Macquarie perch, Silver perch; see Appendix 1 and also Cottingham et al. 2013);
- Remnant riparian and floodplain vegetation that provides important habitat for threatened species (fish, birds, amphibians) whose natural habitat in the region has been greatly reduced since European settlement (DSE 2004);
- Connectivity between the river channel and its floodplain that maintains floodplain function, except in the case of Broken River/Broken Creek interactions (e.g. Cottingham et al. 2001);
- Links with the Goulburn River and ultimately the Murray River, with the Broken River being important for water yield and potentially for fish movement.
- The presence of Floodplain Riparian Woodland (EVC 56) (DSE 2004), which is listed as an endangered Ecological Vegetation Class (EVC) in the two relevant bioregions;
- The presence of a number of wetlands of high ecological value and which contain plant species of regional and State conservation significance, consisting of at least six local components of the Floodplain Wetland Aggregate EVC (Carr et al. 2007).

The main channel of the Broken River also supports beds of submerged and emergent aquatic vegetation, such as Eelgrass (*Vallisneria australis)*, Common reed (*Phragmites australis)* and Water ribbons (*Triglochin procera*). This sets the Broken River apart from other major rivers in the region, such as the Goulburn River, where such stands of aquatic vegetation are relatively scarce (Cottingham et al. 2013a).

3.2 Guiding vision and objectives

The vision and objectives that guide this study are those stated in the Goulburn Broken Regional River Health Strategy (RRHS, GBCMA 2005). The vision developed by the catchment community is:

'Healthy rivers, streams, wetlands, floodplains and adjacent land that support a vibrant range and abundance of natural environments, provides water for human use, sustains our native flora & fauna and provides for our social, economic and cultural values.'

To attain this vision, the RRHS focusses on achieving four main objectives:

1. Enhance and protect the rivers that are of highest community value from any decline in condition;
2. Maintaining the condition of ecologically healthy rivers (as defined in the Victorian River Health Strategy);
3. Achieving an 'overall improvement' in the environmental condition of the remainder of rivers; and
4. Preventing damage from inappropriate development and activities.

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

The Goulburn Broken Biodiversity Strategy (Miles et al. 2010) is consistent with the requirements of the Commonwealth Environment Protection and Biodiversity Conservation (EPBC) Act, and contains biodiversity targets[4] 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.

The register of social, economic and environmental values held by the GB CMA on its RIVERS data base (W. Tennant, GB CMA, pers. comm.) rates migratory fish, waterbirds, mammals (in the riparian zone) and aquatic invertebrates as high-value assets within and along the Broken River.

EPA Victoria has established biological objectives for freshwaters based on macroinvertebrate communities across five Victorian aquatic bioregions (Metzeling et al. 2004). The Broken River below Lake Nillahcootie falls within two of these bioregions: (i) Reach 1 falls within Bioregion B4 - Cleared Hills and Coastal Plains, while Reach 2 and 3 fall within Bioregion B5 - Murray and Western Plains Region. 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).

In preparing an environmental watering plan for the Broken River, the project team was guided by the desire of the catchment community for maintaining or improving healthy and diverse aquatic ecosystems expressed in the Goulburn Broken RRHS, NRSWS and Biodiversity Strategy, as well as by the EPA Victoria biological and water quality objectives.

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

3.2.1 Recreation and cultural values

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

- Amenity and recreation values (e.g. camping, walking, sight-seeing, picnicking);
- Cultural values (including pre-European, indigenous);
- Economic values (e.g. water storage and delivery, town water supply; includes the river and infrastructure such as Lake Nillahcootie, Lake Benalla, Casey's Weir, Gowangardie Weir).

4 CONSULTATION

Consultations undertaken during the development of this EWP included progress and final presentations to the following groups and individuals:

- Broken River EWP project steering committee, made up of representatives from:
  - Goulburn Broken Catchment Management Authority
  - Goulburn-Murray Water
  - Department of Environment and Primary Industries (previously the Department of Sustainability and Environment)
  - Victorian Environmental Water Holder.
- Connections Project expert review panel:
  - Dr Terry Hillman
  - Dr Jane Roberts
- Broken Environmental Water Advisory Group;
- G-MW Connections Project Environmental Technical Advisory Committee, made up of representatives from:
  - Goulburn-Murray Water
  - Connections Project
  - Department of Environment and Primary Industries
  - Goulburn-Broken Catchment Management Authority
  - North Central Catchment Management Authority
  - Parks Victoria

5 MANAGEMENT OBJECTIVES

The issues paper (Cottingham et al. 2013a) identified a series of flow-related threats to ecosystem values and flow-related ecological objectives. This information is presented in Table 2. This provides the basis of the detailed environmental flow recommendations that are presented in Chapter 7, which relate to protecting or improving the biodiversity and ecosystem function of the Broken River through:

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

Ecological objectives related to hyporheic processes (e.g. nutrient cycling as water flows through river-bed gravels and sands) and in terms of macroinvertebrate diversity and abundance on fallen timber (snags) were also considered for inclusion in Table 2, but were omitted due to a lack of information from which to specify flow objectives. How best to set flow recommendations for these process-related objectives requires further research.

Table 2: `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	Mechanism	Season
Geomorphology	Geomorphic processes contribute to the availability and quality of in-channel and riparian habitat	• Reduced frequency of flow events capable of scouring sediments from pools • Reduced magnitude of spring and summer baseflow that allows encroachment by terrestrial vegetation • Longer than natural duration of low flow events, resulting in excessive deposition of fine materials. • Reduced frequency of flow events that maintain connectivity with riparian and floodplain habitats.	**G1**: Provide baseflow adequate to allow the persistence of aquatic macrophytes at the bank toe.	All	Base flow	Maintain wetted area to allow aquatic macrophytes to persist at the toe of the bank.	All
			G2: Provide baseflow to prevent terrestrial vegetation colonizing the stream bed.	All	Base flow	Maintain wetted area to halt the encroachment of terrestrial vegetation into the stream bed.	All
			G3: Maintain the rates of bed material movement to maintain bed diversity (sand and gravel bed).	All	Winter-spring freshes	Flows of sufficient magnitude to provide critical shear stress to periodically mobilize sand. Flows of sufficient magnitude to scour fine-grained (silt/clay) sediments from surficial coarse-grained sediments.	Win, Spr
			G4: Flows to turn over bed sediments in runs and scour around large wood.	All	Summer-autumn and winter-spring freshes	Flows of sufficient magnitude to provide critical shear stress to turnover bed sediments and scour around large wood.	All
			G5: Provide bench inundation to maintain bench form (and wet vegetation and promote the deposition/retention of organic matter).	All	Winter- spring freshes	Inundation of mid-level benches to a depth of >0.5 m above bench surface.	Win, Spr
			G6: Maintain connectivity between the channel, anabranches and wetlands.	All	Winter-spring bankfull and overbank flows	Flows of sufficient magnitude to inundate anabranches, wetlands and floodplain areas.	Win, Spr
	Intrinsic value of native vegetation	• Decreased	**R1**: Improve the longitudinal and lateral extent and condition of	All	Winter-spring freshes (Reach	Riparian vegetation (canopy layer as	Win, Spr

Ecosystem Attribute	Environmental or Ecological Values	Potential flow related threats	Flow-related ecological objectives	Reach	Flow Component	Mechanism	Season
Vegetation	Preservation of endangered EVCs Protection against bank/channel erosion and sediment suspension Interception of catchment-derived nutrients and sediments Provision of faunal habitat Moderation of in-stream temperatures	incidence of winter-spring flows, with impacts on freshes (especially in Reach 1) • Decreased incidence of bankfull and overbank flows (all Reaches) • Decrease in variability in flows (especially in Reach 3)	remnant native vegetation at the top of the bank and on the floodplain, with a focus on EVC 56: Floodplain Riparian Woodland.		1) (synonymous with bankfull flows in reaches 2 and 3) Winter-spring bankfull flows (Reaches 2 ad 3) Winter-spring overbank flows (Reaches 2 ad 3)	well as understorey) generally requires periodic inundation to maintain good condition of adults and to permit sexual recruitment of juveniles into the population.	
			W1: Maintain a mosaic of wetlands features, including maintenance of individual wetland/vegetation components within Floodplain Wetland Aggregate EVC.	All	Winter-spring freshes (based on wetland commence to fill data that only exists for Reach 3) Winter-spring bankfull flows	Wetland vegetation (generally requires alternating wet and dry cycles (involving periodic inundation and desiccation) to maintain a diversity of habitats and plant species, good condition of adults and to permit sexual recruitment of juveniles into the population.	Win, Spr
			W2: Maintain lateral linkages (hydrological and biological) between floodplain wetlands and main-stream channel of river.	All	Winter-spring overbank flows (to inundate floodplain more generally)	Floodplain rivers and their floodplains require lateral continuity to permit movement of adults and propagules among in-channel habitats, riparian habitats and floodplain wetlands for full ecological functioning.	Win, Spr

Ecosystem Attribute	Environmental or Ecological Values	Potential flow related threats	Flow-related ecological objectives	Reach	Flow Component	Mechanism	Season
			IC1: Maintain the ruderal–temporary character of cobble and gravel riffles	1	Summer-autumn baseflow Winter-spring baseflow Winter-spring freshes	Summer and winter baseflow to result in drowning of terrestrial vegetation that could colonised riffles. Winter freshes scour excessive terrestrial vegetation that has established.	All
			IC2: Minimise the opportunities for woody species to establish and persist on in-channel cobble and gravel bars. .	1	Winter-spring baseflow Winter-spring freshes (synonymous with bankfull flows in Reaches 2 and 3)	Winter baseflow is to prevent colonisation by woody species. Winter-spring freshes approaching bankfull scour excessive woody vegetation that has established.	Win, Spr
			IC3: Minimise the opportunities for woody species to establish and persist on in-channel sand bars.	All	Winter-spring freshes Winter high flows (e.g. bankfull)	Winter-spring freshes result in scour or drowning of terrestrial vegetation that colonise sand bars. Winter high flows may drown terrestrial vegetation that has established.	Win, Spr
			IC4: Slough filamentous algae and refresh biofilms on hard surfaces.	All	Summer-autumn and winter-spring freshes (Reach 1) Winter-spring freshes (Reach 2 and 3)	Flows of sufficient shear stress to slough filamentous algae from hard surfaces.	All

Ecosystem Attribute	Environmental or Ecological Values	Potential flow related threats	Flow-related ecological objectives	Reach	Flow Component	Mechanism	Season
					Winter-spring bankfull flows (all reaches)		
			IC5: Maintain in-channel native submerged and emergent vegetation.	2 and 3	Base flow (all year) Summer-autumn and winter-spring freshes	All-year base flows create conditions of permanent inundation that allow obligate submerged native plant taxa to establish and preclude invasion by flood-intolerant taxa. Freshes required to scour attached periphyton from plant surfaces. Freshes also provide a mosaic of habitats suitable for colonisation by different types of emergent water-dependent vegetation.	All
			IC6: Inundate benches, bars and low levels of the river bank to entrain organic matter and drive ecological processes such as carbon and nutrient cycling	All	Winter-spring freshes	Freshes required to entrain organic matter and from benches.	Win, Spr
Invertebrates	Invertebrates contribute to aquatic biodiversity, are important measures of river health and are integral components of food webs	• Reduced frequency of flow events capable of scouring sediments from pools • Reduced magnitude of	**MI1**: Maintain areas of riffles and runs.	1	Base flow (all year)	Flows of sufficient magnitude to inundate riffles and maintain runs.	All
			MI2: Maintain hydraulic habitat diversity to ensure that there is sufficient water to provide flowing and slackwater habitats within the channel	All	Spring-autumn baseflow	Flows of sufficient magnitude to maintain hydraulic habitat diversity, including slackwater.	Spr, Sum, Aut

Ecosystem Attribute	Environmental or Ecological Values	Potential flow related threats	Flow-related ecological objectives	Reach	Flow Component	Mechanism	Season
		spring and summer base flows that allows encroachment by terrestrial vegetation • Longer than natural duration of low flow events, resulting in excessive deposition of fine materials. • Reduced frequency of flow events that maintain connectivity with riparian and floodplain habitats.	**MI3**: Maintain habitat for macrophytes that provide crucial habitat for macroinvertebrates	All	Baseflow (all year) Summer-autumn and winter-spring freshes	As for IC4 and IC5.	Spr, Sum, Aut
			MI4: Scour fine sediment from the surface of the substrate to promote biofilm productivity	All	Winter-spring baseflow Winter-spring freshes	As for IC1 and IC4.	Win, Spr
			MI5: Provide floodplain connection for exchange of organic matter and fine sediment.	All	Winter-spring bankfull (connects to low level wetlands and other features) Winter-spring overbank flows (widespread floodplain connection)	As for R1	Win, Spr,
			MI6: Retain natural seasonality to ensure synchronicity of life cycle stages with appropriate flows.	All	Spring-autumn baseflow Winter-spring freshes Winter-spring bankfull flows Winter-spring overbank flows	Covered by all previous objectives.	All
Native fish	Native fish contribute to aquatic biodiversity, are key predator in aquatic food webs, valued for recreational fishing. In particular, Murray cod, Macquarie perch and	• Reduced magnitude of base flows that limit the area of habitat available for native	**NF1**: Provide low flows that maintain adequate habitat for native fish populations, particularly slack-water habitats and deep pools	All	Baseflow	Flow of sufficient magnitude to maintain low-flow (e.g. slackwater) habitat and pools.	Sum, Aut
			NF2: Provide flows sufficient to allow fish passage	All	Baseflow	Flow of sufficient depth across the	All

Ecosystem Attribute	Environmental or Ecological Values	Potential flow related threats	Flow-related ecological objectives	Reach	Flow Component	Mechanism	Season
	Silver perch are listed as vulnerable or threatened and are the focus of management objectives in the Goulburn-Broken Regional River Health Strategy.	fish. • Reduced magnitude of base flows that limits fish passage along river reaches. • Reduced frequency of spring flow pulses that serve as migration cues for some native fish. • Reduced frequency and magnitude of floodplain/wetland inundation events that provide habitat for some fish species, enhance riverine production and deliver food material back to the river.			Summer-autumn freshes	channel to allow fish passage.	
			NF3: Provide to water access to billabongs and flood-runners to provide additional habitat diversity and food sources that contribute to production.	All	Winter-spring bankfull flows	Flow of sufficient magnitude to inundate flood runners and floodplain wetlands.	Win, Spr
			NF4: Provide flow cues to stimulate movements	All	Variability	Flow events of sufficient magnitude to serve as breeding and migration cues.	All

6 RIVER HYDROLOGY AND HYDRAULICS

This chapter provides an overview of the modelled flow regime for current conditions, which includes levels of irrigation demand delivered with existing infrastructure (omitting the previous influence of Lake Mokoan), and the unregulated flow regime where the influence of current irrigation demands and infrastructure have been removed (both the current and unregulated regime assume the current catchment setting). Opportunities to deliver environmental flows and address potential changes to the flow regime resulting from increased irrigation efficiency and increased water trade are described in Chapter 7.

6.1 Hydrological modelling

Hydrological modelling has been undertaken for the period of July 1895 to June 2012 (see SKM report in the appendices of Cottingham et al. 2013a) to provide flow time series that represent the current operation of the river system (i.e. without Lake Mokoan) as well as a flow series that represents an unregulated flow regime; i.e. without the influence of Lake Nillahcootie and changes resulting from irrigation and stock & domestic demand.

6.2 Summary of the current flow regime

The decommissioning of Lake Mokoan in 2009 has resulted in changed operation of the Broken River system and, therefore, changes to the flow regime below Lake Nillahcootie. For example, cessation of diversion to Lake Mokoan in winter will reinforce the natural pattern of high winter-spring flows in the Broken River below Benalla.

Hydrological data were presented for the following scenarios:

- Dry years (driest 30% of years),
- Average years (middle 40% of years),
- Wet Years (wettest 30% of years).

Flow duration curves show a general pattern reflecting the influence of Lake Nillahcootie (Figure 2), whereby high flows expected in winter-spring are lower than would normally flow down the river, and low flows expected in summer-autumn are higher than would otherwise be the case (Cottingham et al. 2013). For example in Reach 1, the current 5-25% exceedance flows are less than would occur if the river was unregulated by the presence and operation of Lake Nillahcootie. Conversely, current flows are higher than the unregulated flows for flow exceedance of 30-95%.

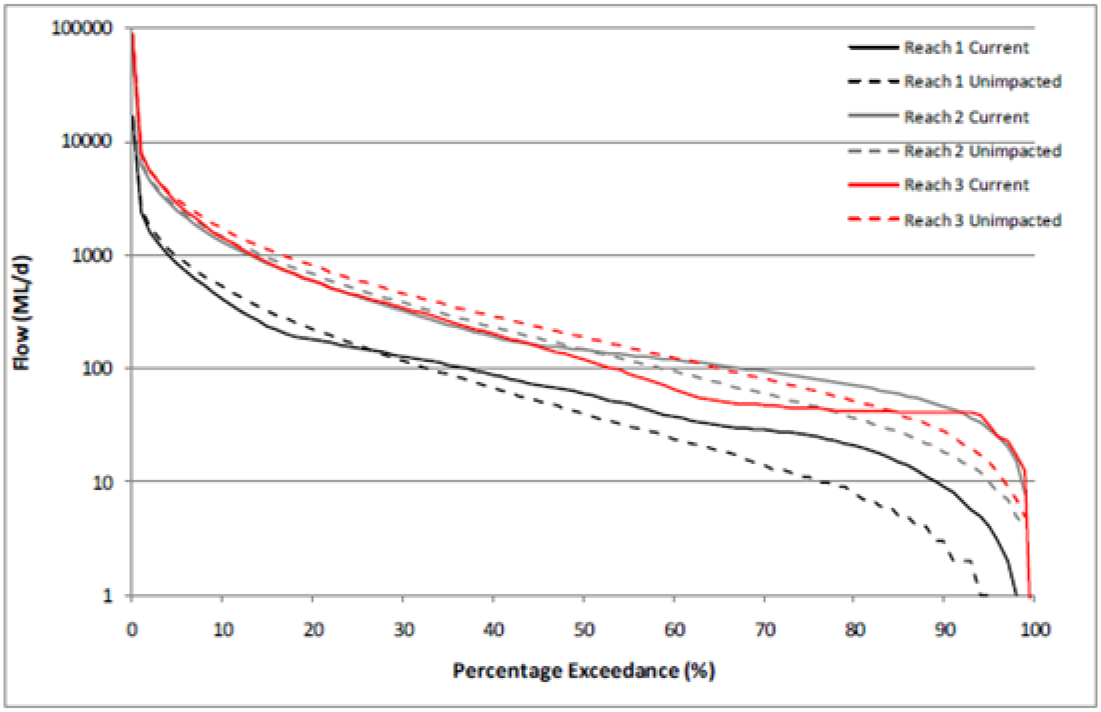
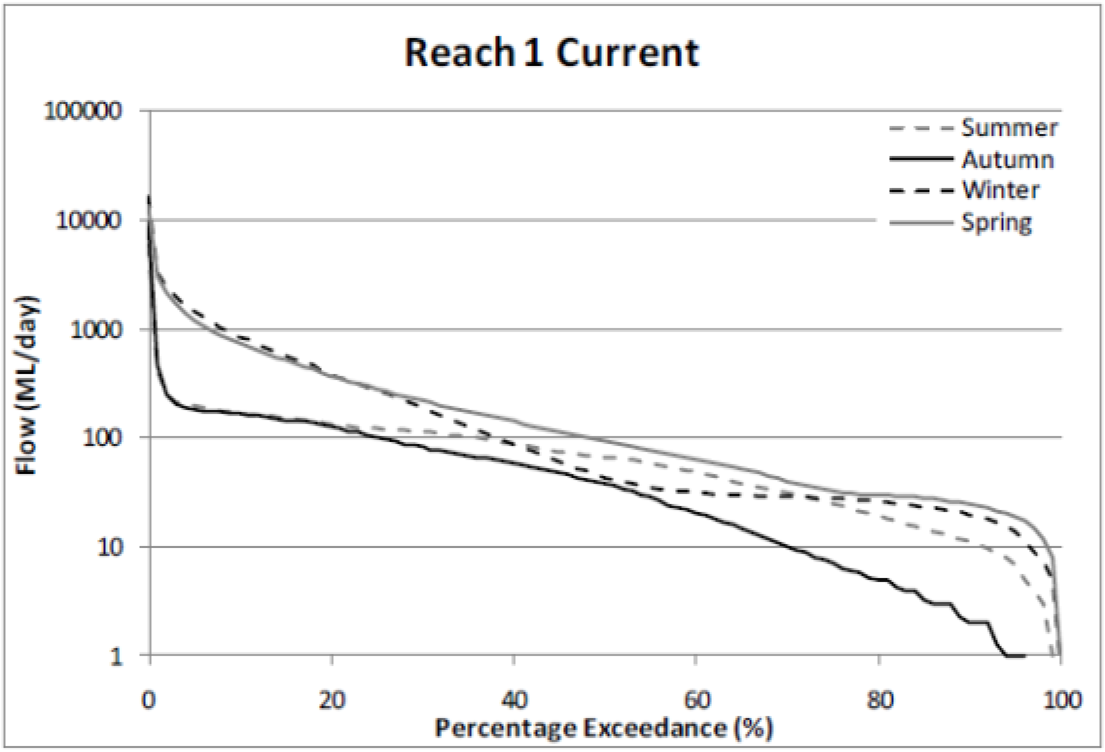


Figure 2: Flow duration curves for the modelled current and unregulated flow series in Reaches 1-3.

Seasonally, the pattern of similar winter-spring and summer-autumn flows was evident for both the current and unregulated flow series, except for the current series for Reach 1 (Figure 3 to Figure 5), although the summer 80-100% flow exceedance for the current series approached that of winter (again reflecting that water retained in Lake Nillahcootie in winter is released to meet irrigation and stock & domestic demand in summer). This effect is most pronounced in dry years in Reach 1 and 2, but is also evident to a lesser degree in average years (Figure 6 to Figure 8).



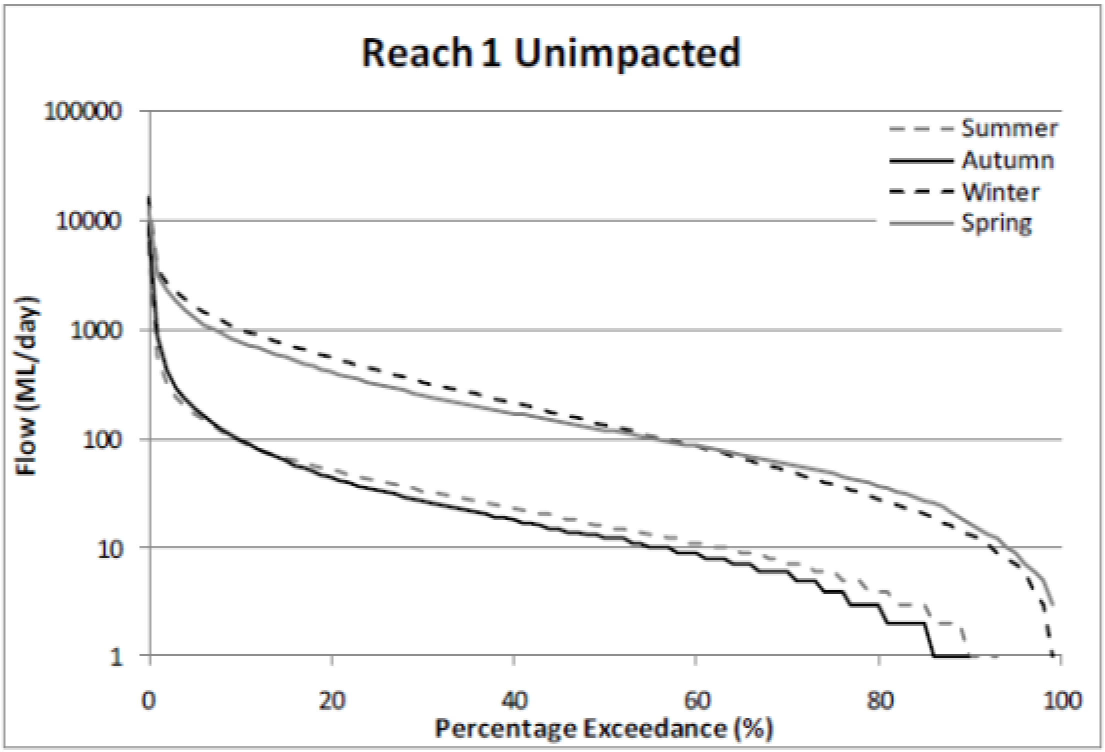


Figure 3: Flow duration curves showing seasonal patterns for modelled current and unregulated conditions.

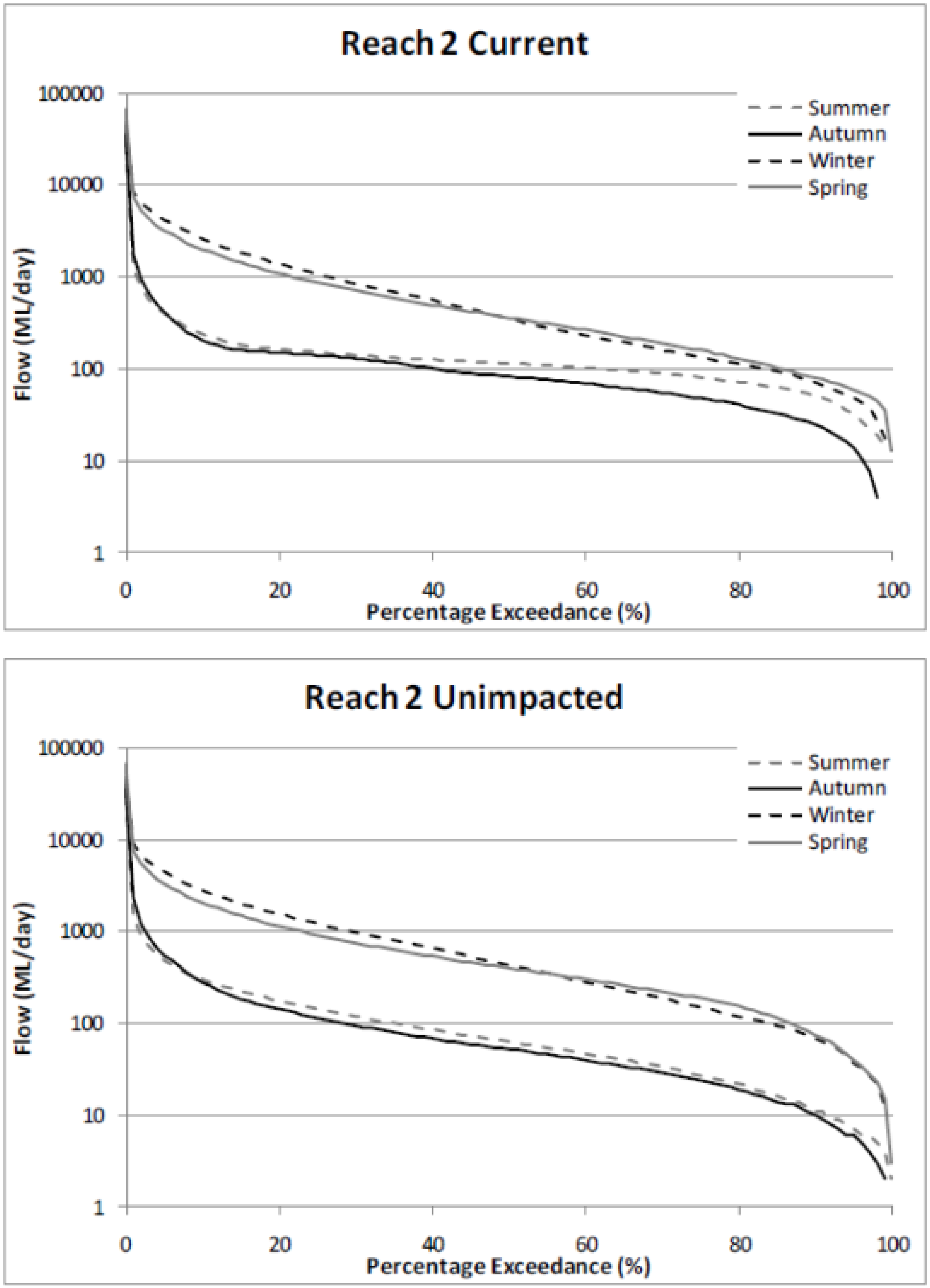


Figure 4: Flow duration curves showing seasonal patterns for modelled current and unregulated conditions.

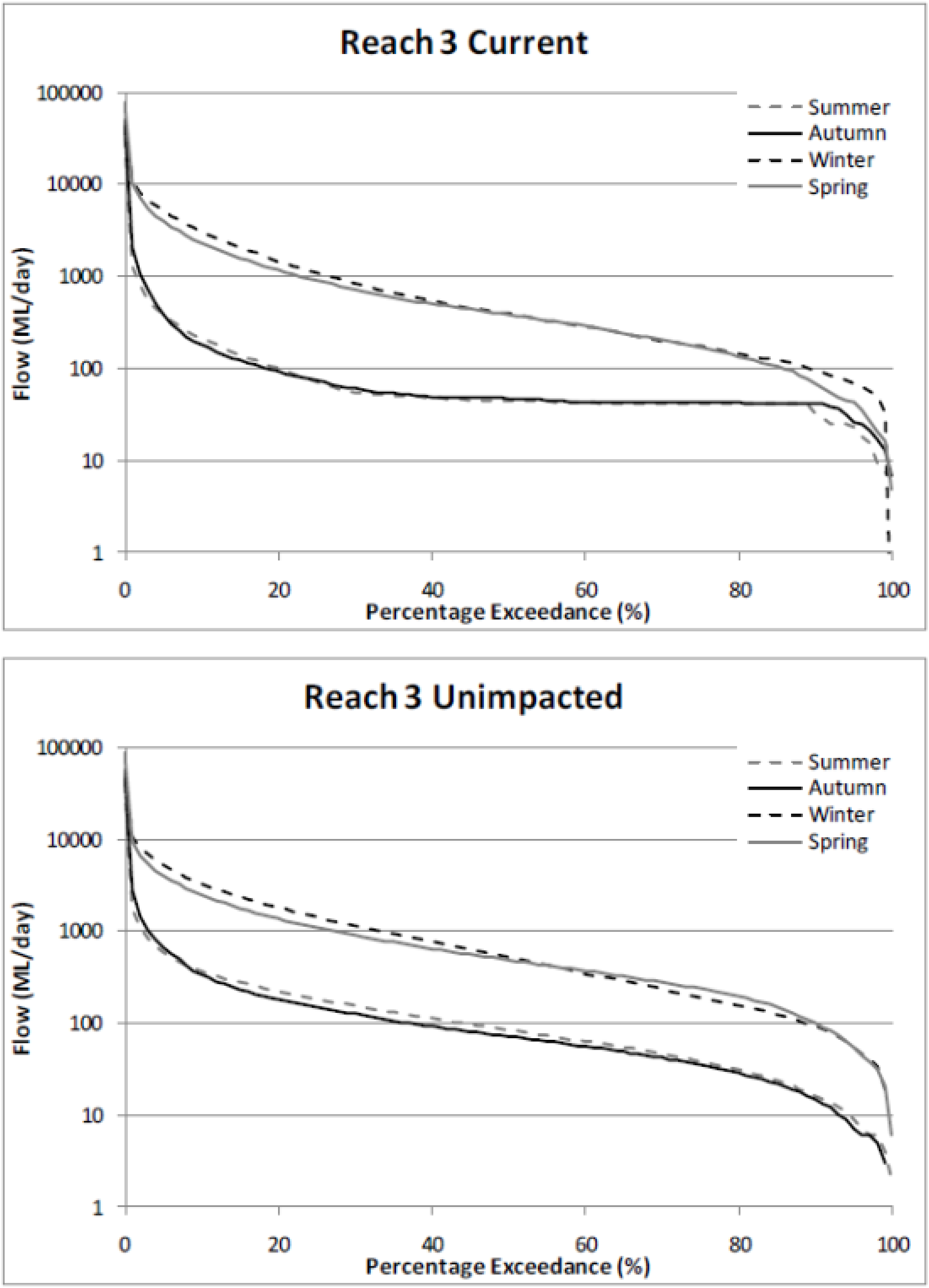


Figure 5: Flow duration curves showing seasonal patterns for modelled current and unregulated conditions.

Reach 1 – split into dry, average and wet years

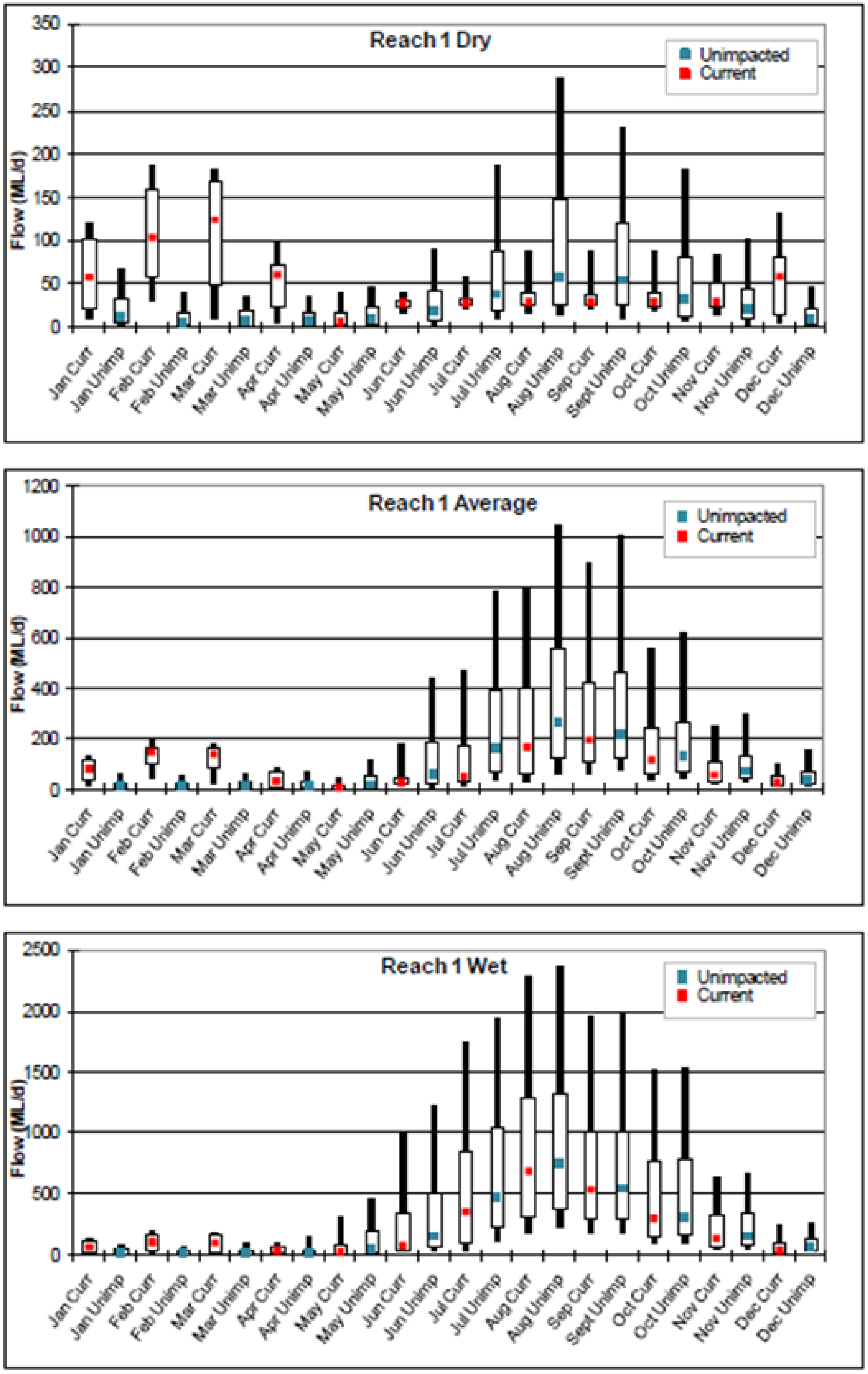


Figure 6: Plots of mean daily flow for each month in dry, average and wet years in Reach 1. Dots in centre of boxes are median values, boxes span the 25th to 75th percentiles, while whiskers span the 5th to 95th percentiles.

Reach 2 – split into dry, average and wet years

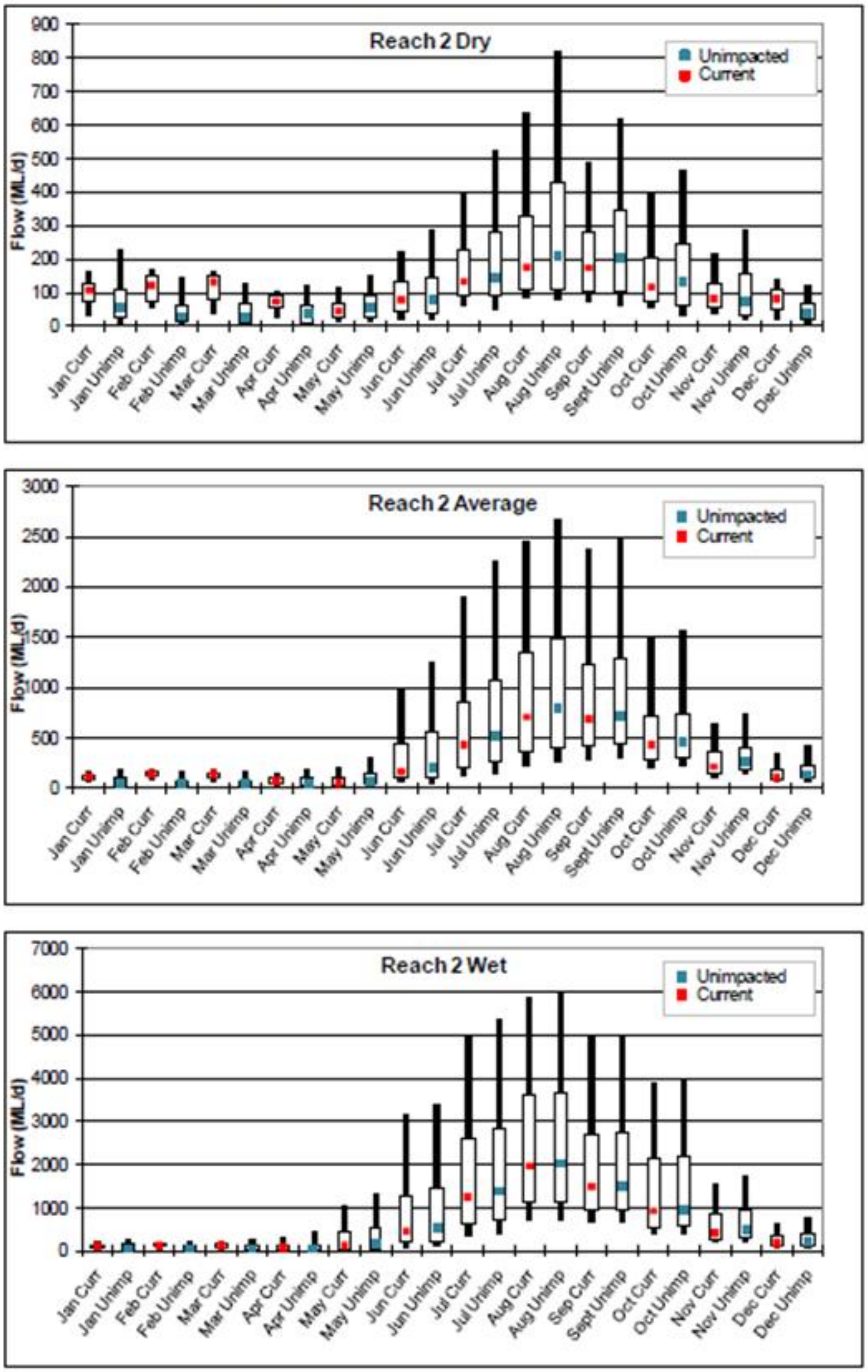


Figure 7: Plots of mean daily flow for each month in dry, average and wet years in Reach 2. Dots in centre of boxes are median values, boxes span the 25th to 75th percentiles, while whiskers span the 5th to 95th percentiles.

Reach 3 - split into dry, average and wet years

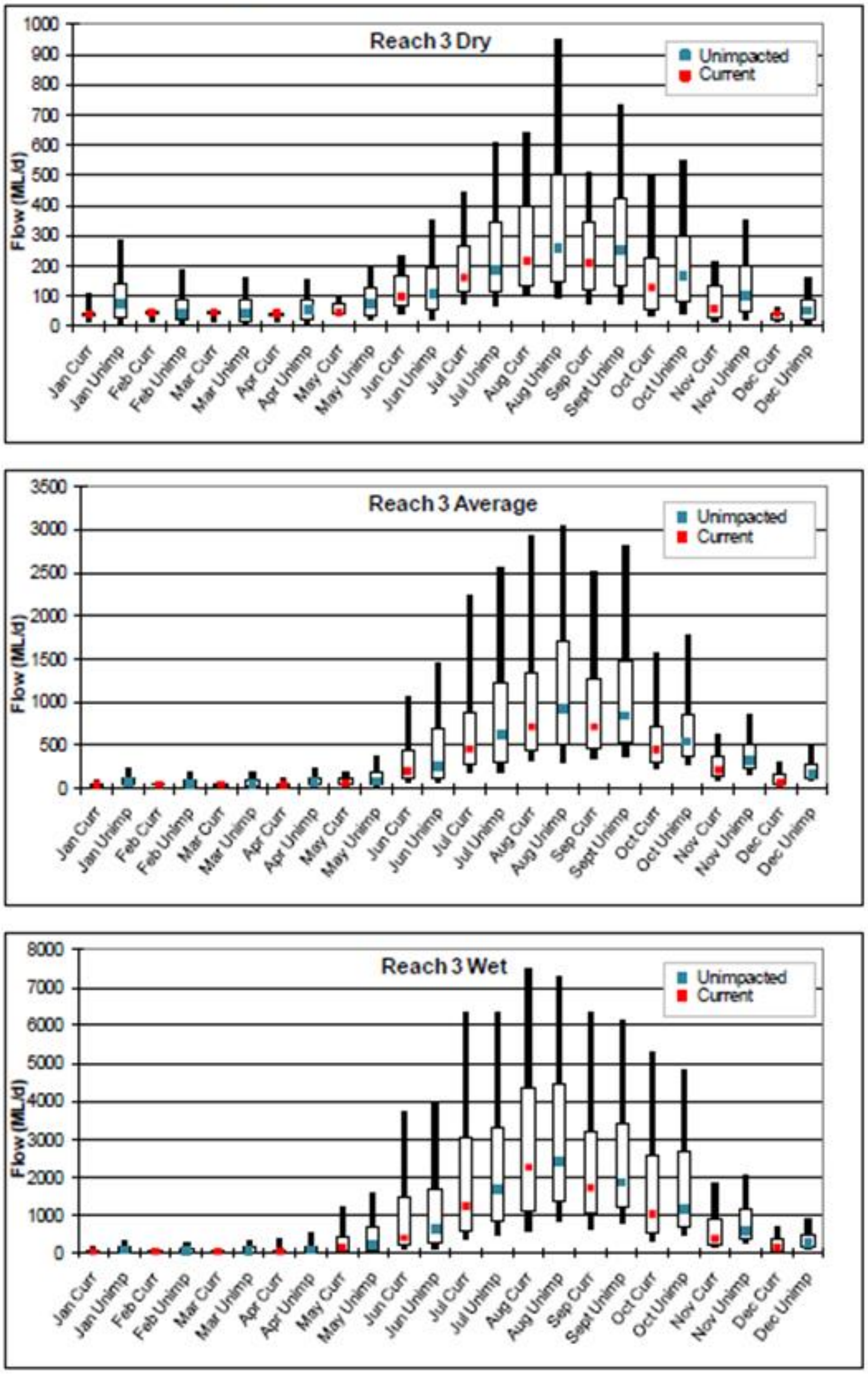


Figure 8: Plots of mean daily flow for each month in dry, average and wet years in Reach 3. Dots in centre of boxes are median values, boxes span the 25th to 75th percentiles, while whiskers span the 5th to 95th percentiles.

6.3 Inflows from irrigation system returns

Irrigation return water enters the Broken River below the East Goulburn Main Drain (EGM) via nine irrigation drains (Figure 9). It has been estimated that an average of approximately 1,100 ML enters the Broken River each water year from these sources (C. Solum, G-MW, pers. comm.). If averaged over the main irrigation months of November-May (inclusive), these inputs are relatively small, equating to approximately 5 ML/d. While seemingly not a large volume of water when compared with minimum flows specified by the Bulk Water Entitlement (e.g. 30 ML/d, or natural), the 'or natural' component means that flows can fall below 30 ML/d if this would have occurred naturally (i.e. if dams and weirs were not present). It is conceivable that a reduction of approximately 5 ML/d when flows in the Broken River below the EGM are in the order of, for example, 10-20 ML/d could greatly reduce the instream habitat available for aquatic biota. This issue is explored in more detail in Chapter 7.

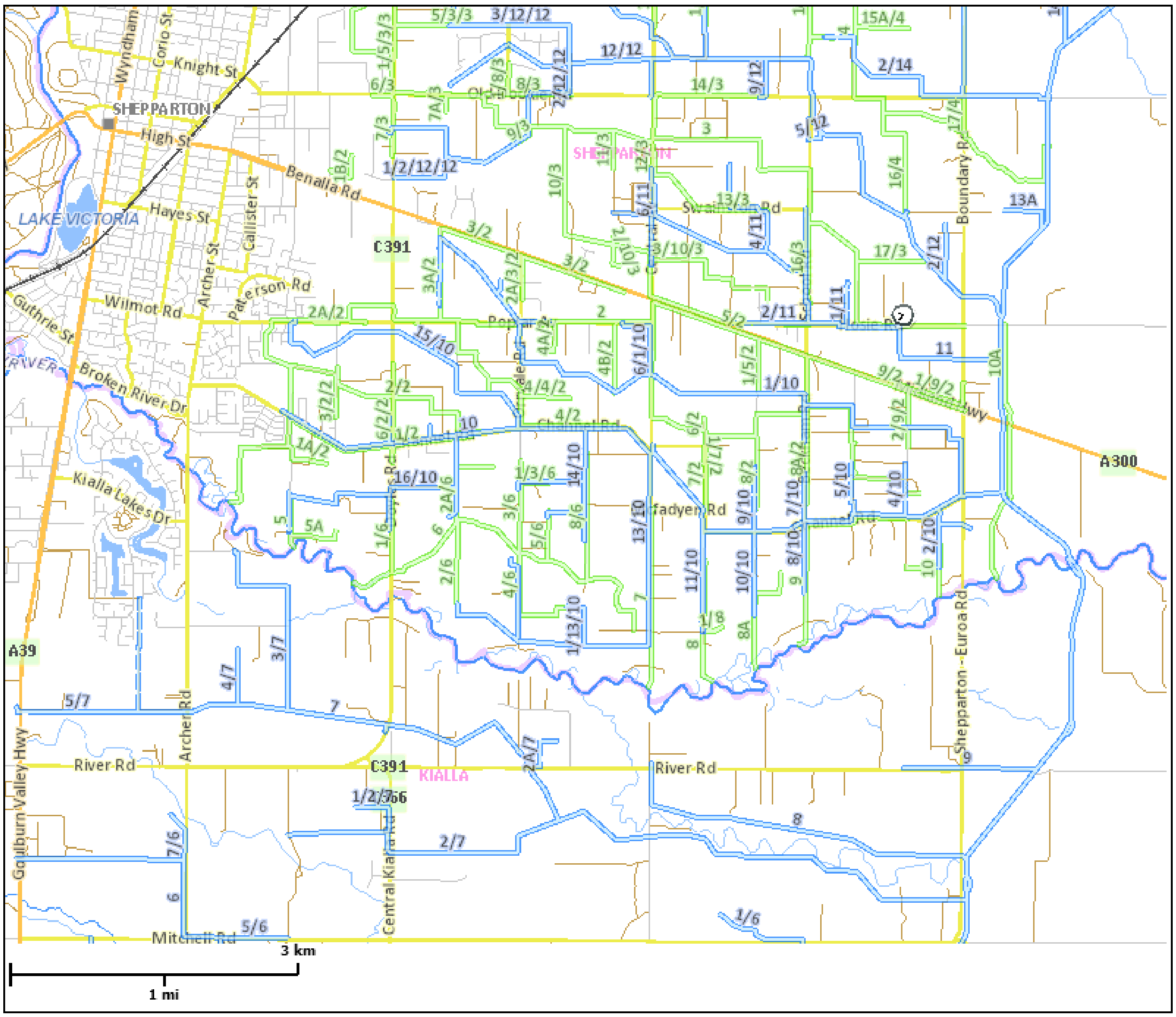


Figure 9: Location of channels (blue lines) and drains (green lines) entering the Broken River below the EGMC (C. Solum, G-MW, pers. comm.)

6.4 Hydraulic modelling

Flow and hydraulic attributes of channels were determined using one-dimensional models (velocity averaged with depth) developed using HECRAS. Models were derived from different sources:

- Reach 1: Swanpool – developed for 2001 environmental flow study (Cottingham et al. 2001);
- Reach 2: Scholes Road – developed for VEFMAP (Water Tech 2009);
- Reach 3: Cosgrove Road – developed for Farms Rivers Markets (Vietz et al., in press).

Whilst pre-existing hydraulic models reduce the requirement for survey and model development, it also means a reliance on the model quality as supplied (Table 3). These models rely on (i) survey data to define the channel topography, (ii) boundary conditions e.g. downstream slope, and (iii) roughness specification for surfaces of the channel. Minor changes were made to downstream boundary conditions (Reach 2 only) and channel roughness (associated with woody debris or vegetation).

Table 3: Positive and negative attributes of hydraulic models used at the three reaches on the Broken River

Model	Positives	Negatives
Reach 1 - Swanpool	Designed for environmental flow assessment and as such appropriate density of points for bed and banks enabled important features to be ascertained.	Survey undertaken in 2001 and some channel change might be expected (aerial imagery indicates increases in vegetation but no major morphologic changes evident)
Reach 2 – Scholes Rd	Outcomes of VEFMAP can be directly compared against EWP recommendations.	VEFMAP surveys had poor spatial resolution. Fewer points than desired across channel and lower density within low flow channel (up to 10 m gaps without points) leading to many features (e.g. bars) not able to be identified. The original model was calibrated without a specific application in mind (for this project Manning's roughness was increased based on the modellers experience – within the constraints of the single calibration flow available).
Reach 3 – Cosgrove Road	Topography developed from recent LiDAR and feature survey (underwater bathymetry) resulting in high resolution topography enabling key features to be identified Modelling for slackwater vs discharge curves included this site so relationships are highly applicable.	None.

In addition to minor adjustments in assumed roughness, the hydrologic input was altered to increase the number of flow points modelled to enable a greater range for comparison. Models were run in steady state (one flow level) to provide outputs such as water surface elevation, velocity and shear stress. The basis for environmental flow recommendations using the HECRAS models is shown in the series of longitudinal and cross section plots in Appendix 3.

7 ENVIRONMENTAL WATER REGIME

This chapter describes the environmental flow regime required to protect or improve the environmental values described in Chapter 3 by meeting the ecological objectives presented in Chapter 5. It provides the basis from which to consider whether mitigation water is required to replace the reduction of irrigation channel and drain outfall expected under the Connections Project (Chapter 8), and the implications of potential water trade out of the Shepparton Irrigation Region (SIR) (Chapter 9).

7.1 Climatic scenarios

Environmental flow recommendations establish the magnitude, frequency, duration and seasonality of flow releases to meet specific ecological objectives. An advance of this project over previous environmental flow studies has been consideration of different climatic conditions. The revised FLOWS method (SKM 2012) includes consideration of the following four climatic scenarios:

- Very dry years (drought);
- Dry years;
- Average years;
- Wet years.

Given that the existing minimum flow recommendations included in the Bulk Water Entitlement were in place for much of the millennium drought that persisted until 2009, and that biological indicators suggested that the river supported invertebrate and fish communities until impacted by the floods of 2010/11 (Cottingham et al. 2013a), it is recommended that the Bulk Water Entitlement minimum flow recommendations be retained in future droughts, but with an absolute minimum flow of 15 ML/d (see sections 7.1.3 to 7.1.5). In doing so, the following general principles developed by Cottingham et al. (2009) should be applied when considering threats (and associated risks) and priorities for action along the Broken River:

- Avoid critical loss of imperiled species (e.g. critically endangered species, at-risk remnant populations at a catchment or regional scale);
- Maintain viable populations of threatened species within the river system;
- Avoid irretrievable ecosystem damage or catastrophic events (e.g. large fish kills due to blackwater events);
- Provide refuges to allow recolonisation following drought or other disturbance;
- Maintain long-term perspective to maintain resilience and ecosystem functioning into the future.

Based on these five principles, Cottingham et al. (2009) determined that the Broken River below Casey's Weir was the highest priority reach for delivery of available environmental water during prolonged and extreme drought periods.

Given the above, the environmental flow recommendations described in the following sections focus on dry, average and wet years (e.g. a flow of a particular magnitude required to meet an ecological objective may have different frequency of occurrence or duration in dry, wet and average years). To allow for these climate scenarios, the annual volume for the 117 year flow record (ranked lowest to highest) was apportioned on a ratio of 30:40:30 to dry, average and wet years, respectively (i.e. driest 30% of years = dry years, wettest 30% of years = wet years; middle 40% of years = average years). Note: on this basis drought years are incorporated into the assessment of hydrology during dry years even though alternative arrangements may apply during drought years (as per the BWE).

7.2 Flow components

The FLOWS method identifies the following flow components:

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

The modelled current and unregulated flow series indicate that cease to flow periods are very rare in Reaches 2 and 3 (a total of 45 days summed for the entire 117 years of the hydrological record). The modelled unregulated data suggested that cease to flow periods occurred in Reach 1 for approximately 4% of the time. Notwithstanding this latter finding, this study does not recommend cease to flow events be implemented even in Reach 1. The reasons for this recommendation are varied. The incidence of cease to flow periods overall (i.e. along the entire length of the river) is low, and threats such as poor water quality could adversely affect ecosystem values and condition while the river is recovering from floods (e.g. based on invertebrate measures of river health; see Issues Paper, Cottingham et al. 2013) following a period of extended drought. The environmental flow recommendations contained in the following sections focus, therefore, on the delivery of baseflow, freshes, bankfull and overbank flows in order to meet the listed ecological objectives. Flow recommendations are defined in terms of magnitude, frequency and duration. Appropriate rates of rise and fall for freshes, bankfull and overbank events are listed in Appendix 2.

The frequency and duration of many freshes, especially in average and wet years, is largely unchanged even under current operating conditions in the river (i.e. the frequency of freshes for the current and unregulated conditions is very similar) (Table 4). This means that the current flow regime largely delivers the medium to large flow events at a similar frequency as the unregulated flow regime (i.e. little active management will be required to deliver the freshes recommended in the following sections). In addition, many of the larger freshes, as well as bankfull and overbank flow events, need only be delivered or allowed to occur in average and wet years, as they would not be expected to occur in dry years. Active management will, however, often be required in terms of delivering baseflow recommendations, particularly in light of the potential effects of reduced irrigation drain inputs below the EGM channel and increased trade of water from the Broken system. The ‘or natural’ qualification is often used with baseflow recommendations (e.g. ‘minimum flow of 30 ML/d, or natural’). The intention of the ‘or natural’ is to preserve variability in the delivery of flow recommendations and prevent over- or under-watering that might result from a strict interpretation of a recommendation (e.g. ‘minimum flow 30 ML/d’ – which could see a constant flow of 30 ML/d delivered without variation; desirable natural variability in flow would be lost).

Table 4: Recurrence interval of selected flow thresholds in Reach 3, presented as 1 event per X years. Note: 16,000 ML/d approaches bankfull.

Flow threshold (ML/d)	Current			Unimpacted		
	Dry	Ave	Wet	Dry	Ave	Wet
2,600	8.3	0.6	0.5	4.3	0.6	0.5
6,900	-	2.0	0.8	37.0	2.1	0.8
12,000	-	6.0	1.5	-	6.0	1.5
16,000	-	8.0	2.0	-	8.0	2.0

7.3 Reach 1: Lake Nillahcootie to Holland's Creek

Environmental flow recommendations for Reach 1 are summarised below and in Table 5. The most salient features of the recommendations are:

- Summer-autumn baseflow in the range of 30-100 ML/d, or natural;
- Winter-spring baseflow of 200 ML/d, or natural (whichever is lowest);
- Winter-spring freshes varying in magnitude between 270-4,400 ML/d, and of varying frequency and duration;
- Winter-spring freshes of up to 9,000 ML/d synchronised with bankfull flows for Reaches 2 and 3.

Baseflow

The baseflow component has both a minimum and a maximum (upper limit) component. Baseflow (minimum flow) recommendations seek primarily to maintain wetted riffle habitat and protect cobble bars from colonisation by terrestrial vegetation. The recommendations are based on habitat area required to achieve macroinvertebrate, in-channel vegetation and native fish objectives and the discharge at which winter-spring water levels are 10cm over gravel and cobble bars (see HECRAS plots Appendix 3).

The upper limit on summer-autumn baseflow is based on the slackwater-discharge relationship. The operating range that optimises this relationship (30-100 ML/d for Reach 3) is discussed in Section 7.1.5 (Figure 11). While the lower limit of 30 ML/d is consistent with the 30 ML/d recommendation for maintaining riffle habitat, the upper limit of 100 ML/d would rarely occur (Figure 10), particularly in dry years. The intention of the 'or natural' qualification is that summer-autumn baseflow would be less than 100 ML/d for the majority of the time but could exceed 100 ML/d for short periods, for example as freshes that have specific ecological objectives. Water can also fall below 30 ML/d in summer-autumn if this was to occur naturally, but should always be above 15 ML/d to reduce the risk of adverse water quality outcomes and to ensure that slackwater habitat is maintained at sufficient extent (see Section 7.1.5).

Freshes

Winter-spring freshes of various magnitudes are specified to achieve objectives related to maintaining habitat quality and the life cycle of biota such as native fish and aquatic macrophytes. Although the magnitude of the freshes defined in Table 5 may vary, this does not mean that each fresh must be delivered in isolation; a larger fresh (e.g. 4,000 ML/d) may also achieve the same outcome as a smaller fresh (e.g. 500 ML/d), addressing multiple ecological objectives. The advantage of this approach is that river managers have some flexibility in the delivery of freshes, both across seasons and inter-annually. In reality, freshes (particularly those of larger magnitude) will be delivered without active management in average and wet years, as Lake Nillahcootie is likely to fill and spill in these times. However, the intention of the recommendations is that the natural frequency and duration of freshes should be maintained in the future.

Bankfull and overbank flows

The channel of Reach 1 is confined by the valley margins and what appears to be a floodplain within the cross section is actually a terrace: a flat surface formed by a former hydrologic regime and not necessarily related to the current one. This means that floodplain inundation is not likely for the majority of Reach 1. The larger freshes of 4,400-9,000 ML/d identified in are intended to be synonymous with events that would result in bankfull flows in Reaches 2 and 3. As is the case for the other larger freshes in Reach 1, the 'bankfull and overbank' events are only required in average and wet years.

Note: it is recognised that the proposition to *actively* manage the overbank flows required for this recommendation is unlikely to be accepted due to the Victorian government policy of not inundating private land. However, it is stated here to provide completeness in terms of recommendations to achieve ecological objectives related to maintaining or improving the conditions of ecosystem assets and values associated with the Broken River. As the current flow regime has had little effect on the natural frequency of events of this magnitude, it is expected that this recommendation will be met without active management.

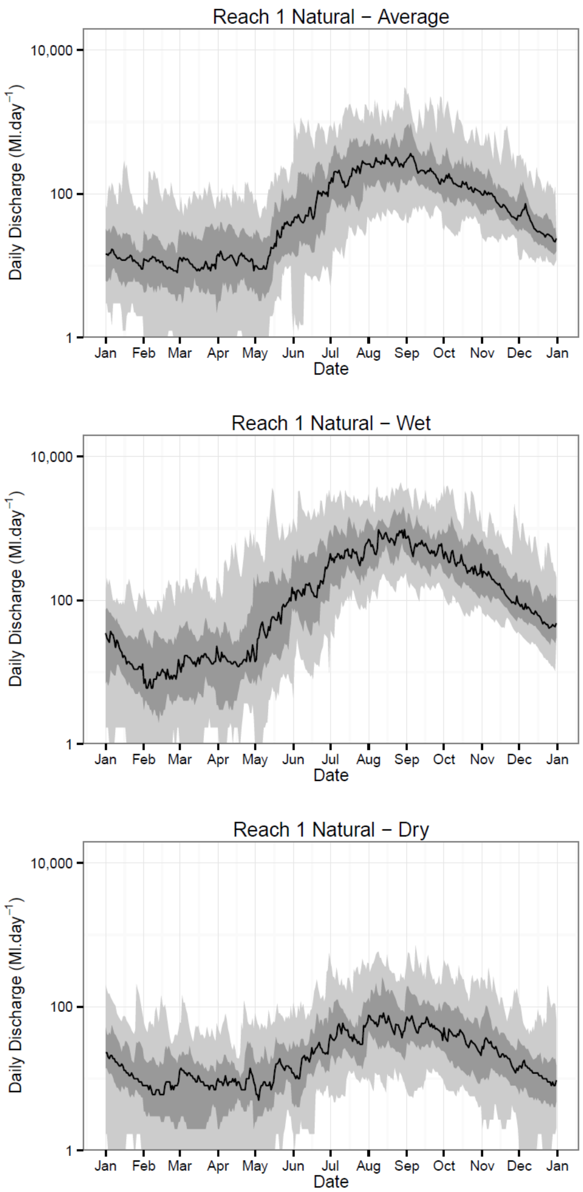


Figure 10: Reach 1 natural flow for average, wet and dry scenarios. Black line = median; dark grey = 20th – 80th percentile flows; light grey = 5th – 95th percentile flows.

Table 5: Environmental flow recommendations for Reach 1: Lake Nillahcootie to Holland's Creek

Objectives (habitat feature in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
Recommendations for Baseflow			
MI1, IC1 (riffles)	• Summer-autumn baseflow	Minimum flow of 30 ML/d, or natural	• From HECRAS: water to cover riffles require >30 ML/d.
MI2 (slackwater)	• Spring-autumn baseflow	Minimum flow of 30-100 ML/d, or natural (see accompanying rationale for expanded explanation) Absolute minimum of 15 ML/d (the desire is for this flow to persist along the length of the river)	• Meeting the needs of Reach 3 is assumed to meet the needs of Reach 1. See baseflow objective MI2 for Reach 3 for full rationale.
IC2 (cobble and gravel bars)	• Winter-spring baseflow	200 ML/d or natural	• Maintain minimum water level in stream at 10 cm over cobble and gravel bars. From HECRAS: ○ Winter-spring baseflow requires >200 ML/d or natural.
NF1 (slackwater and pools)	• Summer-autumn baseflow	As for MI2	• As for MI2.
MI3, MI6 (vegetation habitat and synchronicity)	• Baseflow (all year)	As for MI1 and MI2.	• As for MI1 and MI2.
IC5 (vegetation habitat)	• Baseflow (all year) • Summer and	NA	• Reach 1 – minimal submerged vegetation – no specific recommendation for Reach 1. • Vegetation needs covered by recommendations for

Objectives (habitat feature in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
	winter freshes		Reaches 2 and 3.
Recommendations for Freshes			
IC3 (vegetation encroachment on sand bars)	• Winter-spring freshes	270 ML/d. Frequency is 2 per year in dry years and 4 per year in average and wet years. Duration is 3 days in dry years, 6 days in average years and 9 days in wet years.	• Winter freshes to inundate low-lying sand bars and prevent encroachment of terrestrial vegetation. Based on HECRAS: ○ Reach 1 requires >270 ML/d,
G4 (scour around large wood)	• Summer-autumn and winter-spring freshes	400 ML/d. Frequency is 3 per year (all years), 2 in winter-spring and 1 in summer-autumn. Duration is 2 days in dry years, 5 days in average years and 8 days in wet years.	• As for G4 recommendations for Reach 3.
IC4 (biofilms)	• Summer-autumn and winter-spring freshes	500 ML/d. Frequency is 1 per year in dry years and 2 per year (1 in winter-spring and 1 in summer-autumn) in average and wet years. Duration is 2 days in dry	• >0.6 m/s velocity for sloughing filamentous algae (based on Ryder et al. 2006). From HECRAS: ○ Reach 1 requires than 500 ML/d. Frequency is 1 per year in dry years and 2 per year (1 in winter-spring and 1 in summer-autumn) in average and wet years.

Objectives (habitat feature in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
		years, 5 days in average years and 8 days in wet years.	
G3 (sand and gravel bed diversity)	• Winter-spring freshes	4,400 ML/d. Frequency is 1 in 3 years for average years and annually in wet years. Duration is 1 day in average years and 2 days in wet years.	• Removal of fine-grained sediments (silts/clays) from substrates in pools. Based on shear stress (30 N/m²) required to overturn gravel substrate (particle size median) within majority of pools. From HECRAS: ○ Reach 1 requires 4,400 ML/d; mobilises sediments in 2 out of 3 pools.
IC1 (riffles)	• Winter-spring baseflow	As for IC3	• Increasing the depth of baseflow in winter by 0.2 m to stop excessive encroachment by terrestrial vegetation (see also objective G2). Based on HECRAS: ○ Reach 1 requires >175 ML/d.
G1, G2 (aquatic macrophytes, terrestrial encroachment)	• Baseflow (all year)	As for IC3, IC4 and G3	• As for IC1 and IC2. Water level fluctuations of up to 0.2 m favours emergent aquatic macrophytes such as *Phragmites australis* (Deegan et al. 2007, Rogers and Ralph 2011) that can help to stabilise river banks.
G5 (bench inundation)	• Winter-spring freshes	As for G3.	• From HECRAS: ○ Reach 1 requires 4,000 ML/d (wets highest bench in the model and provide > 0.5 m depth over many benches to maintain bench form).
MI3, MI6, NF2 (invertebrate habitat, fish passage)	• Summer-autumn and winter-spring	As for IC4.	• As for IC4.

Objectives (habitat feature in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
	freshes		
NF4 (fish movement)	• Winter-spring freshes	As for G4, IC4, G3.	• Intention is for a rise in river levels of at least 0.2 m above antecedent winter baseflow levels. • Magnitude covered by other objectives (e.g. G4, IC4, G3).
MI4 (biofilms)	• Winter-spring freshes	As for IC2 and IC3.	• As for IC2 and IC3.
IC6 (benches and bars)	• Winter-spring freshes	As for IC4	• As for G3 and G5.
Recommendations for Bankfull and Overbank flows			
W1 (wetlands)	• Winter-spring freshes (based on wetland commence to fill data for Reach 3)	4,000-9,000 ML/d# Frequency for events above 6,000 ML/d is 1 in 10 years for average years and 1 in 2 years for wet years. Duration is 1 day in average years and wet years.	• Governed by the W1 recommendation for Reach 3. • Connection occurs in average and wet years, as flows of these magnitudes do not occur in dry years. Frequency of events from 4,000-6,000 ML/d is as for objectives G3 and G5. Frequency for events of 6,000-9,000 ML/d is 1 in 10 years for average years and 1 in 2 years for wet years. • #Flows for Reach 1 are described as freshes due to bankfull flows being unrealistic in the confined morphology.
R1 (riparian zone)	• Winter-spring freshes	As for W1.	• River Red Gum used as a surrogate for EVC 56. Both bankfull and overbank flows are recommended to

Objectives (habitat feature in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
	(approaching bankfull flows)		ensure the needs of the understorey are met in addition to RRG. • From HECRAS: ○ Reach 1: freshes of 4,000 – 7,000 ML/d; • Flows of this magnitude would not be expected in dry years. Frequency is 1 in 10 years for average years and 1 in 2 years in wet years. Timing: spring if possible.
G6, W2, IC1, IC2, IC3, MI5, MI6, NF3	• Winter-spring freshes (approaching bankfull)	As for W1 and R1.	• Freshes approaching bankfull as for W1 and R1.

7.4 Reach 2: Holland's Creek to Casey's Weir

Environmental flow recommendations for Reach 2 are summarised below and in Table 6. The most salient features of the recommendations are:

- Summer-autumn baseflow in the range of 30-100 ML/d, or natural;
- Winter-spring baseflow of 100 ML/d, or natural (whichever is lowest);
- Winter-spring freshes varying in magnitude between 400-4,500 ML/d, and of varying frequency and duration;
- Winter-spring bankfull flows of 16,000 ML/d and (naturally occurring) overbank flows exceeding 16,000 ML/d.

Baseflow

As for Reach 1, the baseflow recommendation have a minimum component based largely on provision of water for fish movement and the maintenance of aquatic in-channel habitat, and a maximum component that seeks to maintain adequate areas of slackwaters. Baseflow recommendations thus seek to protect slackwater habitat for invertebrates and native fish, maintain river run habitat, and provide sufficient depth for native fish to move along the reach. HECRAS plots identifying the level at which depth of river runs is maintained are presented in Appendix 3.

An upper limit on summer-autumn baseflow has been based on the slackwater-discharge relationship and the operating range of 30-100 ML/d for Reach 3 that is discussed in Section 7.1.5 (Figure 11). The lower limit of 30 ML/d is consistent with minimum flows in Reach 1 (based on riffle habitat) and with low flow recommendations for Reach 3 (see Section 7.1.5). The intention of the 'or natural' qualification is that summer-autumn baseflow would be less than 100 ML/d for the majority of the time but could exceed 100 ML/d for short periods, for example as freshes that have specific ecological objectives. Water can also fall below 30 ML/d in summer-autumn if this was to occur naturally, but should always be above 15 ML/d to reduce the risk of adverse water quality outcomes and to ensure that slackwater habitat is maintained along the river.

A winter-spring baseflow of 100 ML/d or natural (whichever is less) is also recommended based on the preferred depth (0.5 m) requirements of submerged and emergent aquatic macrophytes (e.g. *Vallisnaria, Phragmites*) (Bowen 2006, Roberts and Marston 2011).

Freshes

Winter-spring freshes of various magnitudes are specified to achieve a suite of objectives related to maintaining habitat quality and the life cycle of biota such as native fish and aquatic macrophytes. As noted mentioned in Section 7.1.3, although while the magnitude of the defined freshes may vary, this does not mean that each fresh must be delivered in isolation and single freshes may be used to address multiple objectives, thus providing river managers with some flexibility in the delivery of freshes both annually and inter-annually. As for Reach 1, freshes of larger magnitude are likely to occur without active management in average and wet years, as Lake Nillahcootie is likely to fill and spill. However, the intention is that the natural frequency and duration of freshes be maintained in the future.

Bankfull and overbank flows

Bankfull flows occur at approximately 16,000 ML/d. Flows of this magnitude are only expected in average and wet years, and are likely to occur without active management. As noted in Section 7.1.3, active management to achieve flows of this magnitude and greater will not occur due to government policy to avoid inundation of private land. However, the intent of the recommendations is that events of this magnitude be preserved in the future.

Table 6: Environmental flow recommendations for Reach 2: Holland's Creek to Casey's Weir

Objectives (habitat feature in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
Recommendations for Baseflow			
MI1 (riffles)	• Summer-autumn baseflow	Minimum flow of 40 ML/d, or natural	• From HECRAS: water to maintain runs: ○ Reach 2 requires 40 ML/d or natural
MI2 (slackwater)	• Spring-autumn baseflow	Minimum flow of 30-100 ML/d, or natural (see accompanying rationale for expanded explanation) Absolute minimum of 15 ML/d (flow to persist along the length of the river)	• Meeting the needs of Reach 3 is assumed to meet the needs of Reach 2. See baseflow objective MI2 in Reach 3 for full rationale.
IC5 (vegetation habitat)	• Baseflow (all year)	Minimum flow of 100 ML/d, or natural	• Baseflow with 0.5 m depth are based on the watering needs of *Vallisneria* (Bowen 2006, Roberts and Marston 2011, Rogers and Ralph 2011). The watering needs of emergent vegetation (e.g. Phragmites) are expected to be catered for by the baseflow for *Vallisneria* and freshes as defined for other objectives. • Maintain 0.5 m depth in runs. From HECRAS: ○ Reach 2 requires 100 ML/d, or natural
IC3 (vegetation encroachment on sand bars)	• Baseflow (all year)	As for MI1 and MI2	• As for MI1, MI2.

Objectives (habitat feature in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
NF1 (slackwater and pools)	• Summer-autumn baseflow	As for MI2	• As for MI2.
NF2 (fish passage)	• Baseflow (all year)	As for MI1	• Intent is 0.4 m over the shallowest point in the longitudinal profile. From HECRAS: ○ Reach 2 requires 40 ML/d.
MI3, MI6 (invertebrate habitat)	• Baseflow (all year)	As for MI1 and MI2.	• As for MI1 and MI2.
G1, G2 (aquatic macrophytes, terrestrial encroachment)	• Baseflow (all year)	As for MI1, MI2 and IC5	• As for MI1, MI2 and IC5.
Recommendations for Freshes			
G4 (scour around large wood)	• Summer-autumn and winter-spring freshes	400 ML/d. Frequency is 3 per year (all years), 2 in winter-spring and 1 in summer-autumn. Duration is 3 days in dry years, and 5 days in average and wet years.	• Shear stress for removing fines from sediments in runs equal to 2 N/m² (based on shear stress required to mobilise sandy bed sediments in runs). From HECRAS: ○ Reach 2 requires 400 ML/d.

Objectives (habitat feature in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
IC3 (vegetation encroachment on sand bars)	• Winter-spring freshes	430 ML/d. Frequency is 3 per year (all years). Duration is 3 days in dry years, and 5 days in average and wet years.	• Winter freshes. Based on HECRAS: ○ Reach 2 - features are indistinct from HECRAS, so adopt Reach 3 requirements. ○ Reach 3 requires 430 ML/d.
G3 (sand and gravel bed diversity)	• Winter-spring freshes	2,600 ML/d. Frequency is 1 in 2 years for dry years, 3 per year in average years and 5 per year in wet years. Duration is 1 day in dry years, and 2 days in average years and 4 days in wet years.	• Removal of fine-grained sediments (silts/clays) from substrates in pools. Based on shear stress (30 N/m²) required to overturn gravel substrate (particle size median) within majority of pools. From HECRAS: ○Reach 2 requires 2,600 ML/d.
IC4 (biofilms)	• Winter-spring freshes	4,300 ML/d. Frequency is 1 in 10 years for dry years, 2 per year for average years and 4 per year in wet years.	• This will require a combination of (i) sloughing algae (freshes) and (ii) turning over cobbles (bankfull, addressed by R1, W1). • >0.6 m/s velocity for sloughing (based on Ryder et al. 2006). Based on HECRAS: ○ Reach 2 requires 4,300 ML/d. Frequency is as for objective G5.

Objectives (habitat feature in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
G5 (bench inundation)	• Winter-spring freshes	4,500 ML/d. Frequency is 1 in 10 years for dry years, 2 per year for average years and 4 per year in wet years. Duration is 1 day in dry years, and 2 days in average years and 3 days in wet years.	• From HECRAS: o Reach 2 requires 4,500 ML/d. Frequency is 1 in 10 years for dry years, 2 per year for average years and 4 per year in wet years. o Duration 1-2 days, with appropriate rates of rise and fall.
IC6 (benches and bars)	• Winter-spring freshes	As for IC4	• As for G3 and G5.
NF4 (fish movement)	• Winter-spring freshes	As for G4, IC4, G3.	• Intention is for a rise in river levels of at least 20 cm above antecedent winter baseflow levels. • Magnitude as for G3, IC4.
MI4 (biofilms)	• Winter-spring freshes	As for IC3.	• As for IC3.
MI3, MI6, NF2 (invertebrate habitat, fish passage)	• Summer and winter freshes	As for IC2, IC3 and IC4.	• As for IC2, IC3 and IC4.
Recommendations for Bankfull and Overbank flows			
R1 (riparian zone)	• Winter-spring freshes (approaching bankfull	16,000 ML/d. Frequency is 1 in 5	• River Red Gum used as a surrogate for EVC 56. Both bankfull and overbank flows are recommended to ensure the needs of the understorey are met in

Objectives (habitat feature in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
	flows)	years for average years and 8 in 10 years for wet years. Duration is 1 day for average and wet years.	addition to RRG. • From HECRAS: ○ Reach 2: bankfull of 16,000 ML/d; • Bankfull and overbank flows would not be expected in dry years. • Note: it is recognised that the proposition to actively manage the flows required for this recommendation will not been accepted due to Victorian policy of not inundating private land. However, it is stated here to provide completeness in terms of recommendations for maintaining or improving the conditions of ecosystem assets and values associated with the Broken River. As the current flow regime has had little effect on the natural frequency of events of this magnitude, it is expected that this recommendation will be met without active management.
W1 (wetlands)	• Winter-spring freshes (based on wetland commence to fill data for Reach 3)	As for R1	• As for R1
G6, W2, IC1, IC2, IC3, MI5, MI6,NF3	• Winter-spring freshes (approaching bankfull)	As for W1 and R1.	• Freshes approaching bankfull as for W1 and R1.

7.5 Reach 3: Casey's Weir to the Goulburn River

Environmental flow recommendations for Reach 3 are summarised below and in Table 7. In summary, they include:

- Summer-autumn baseflow in the range of 30-100 ML/d, or natural;
- Winter-spring baseflow of 80 ML/d, or natural (whichever is lowest);
- Winter-spring freshes varying in magnitude between 400-4,500 ML/d, and of varying frequency and duration;
- Winter-spring bankfull flows of 20,000 ML/d and (naturally occurring) overbank flows exceeding 20,000 ML/d.

Baseflow

As with the two upstream reaches, baseflow recommendations seek to protect slackwater habitat for invertebrates and native fish, river run habitat and provide sufficient depth for native fish to move along the reach. HECRAS plots identifying the level at which depth of river runs is maintained are presented in Appendix 3.

The lower limit on summer-autumn baseflow has been based on the slackwater-discharge relationship (Figure 11) and is the same as the minimum flow recommendations for Reach 1. Flows can be allowed to fall below 30 ML/d in summer-autumn if this was to occur naturally, but should always be above 15 ML/d in order to reduce the risk of poor water quality and to ensure that slackwater habitat is maintained along the river. The flow-area relationship shown in Figure 11 indicates that slackwater habitat is reduced by 33% from its maxima (30-40 ML/d) once discharge falls to 10 ML/d. A minimum flow of 15 ML/d allows for a further reduction of 5 ML/d below the EGM channel associated with the Connections project (see section 7.2).

An upper limit of 100 ML/d for baseflow in summer-autumn has also been set to protect slackwater habitat; the nature of the discharge-slackwater area is such that slackwater habitat is reduced by 33% from its maxima at approximately 100 ML/d. A baseflow of 100 ML/d is also close to the 80^{th} percentile flow of the unregulated flow regime in Reach 3 (Figure 12). The intention of the 'or natural' qualification is that summer-autumn baseflow would be less than 100 ML/d for the majority of the time.

A winter-spring baseflow of 80 ML/d or natural (whichever is less) is recommended based on the preferred depth (0.5 m) requirements of submerged and emergent aquatic macrophytes (e.g. *Vallisneria, Phragmites*) (Bowen 2006, Roberts and Marston 2011).

Freshes

Winter-spring freshes of various magnitudes are specified to achieve a suite of objectives related to maintaining habitat quality and the life cycle of biota such as native fish and aquatic macrophytes. As mentioned in Section 7.1.3, although the magnitude of the defined freshes may vary, this does not mean that each fresh must be delivered in isolation and single freshes may be used to address multiple objectives, thus providing river managers with some flexibility in the delivery of freshes both annually and inter-annually. As for Reach 1 and Reach 2, larger freshes of larger magnitude are likely to occur without active management in average and wet years, as Lake Nillahcootie is likely to fill and spill. However, the intention is that the natural frequency and duration of freshes be maintained in the future.

Bankfull and overbank flows

Bankfull and overbank flows occur at >20,000 ML/d. Flows of this magnitude are only expected in average and wet years, and are likely to occur without active management. As noted in previous sections for Reach 1 and 2, active management to achieve flows of this magnitude and greater will not occur due to government policy to avoid inundation of private land. However, the intent of the recommendations is that events of this magnitude be preserved in the future.

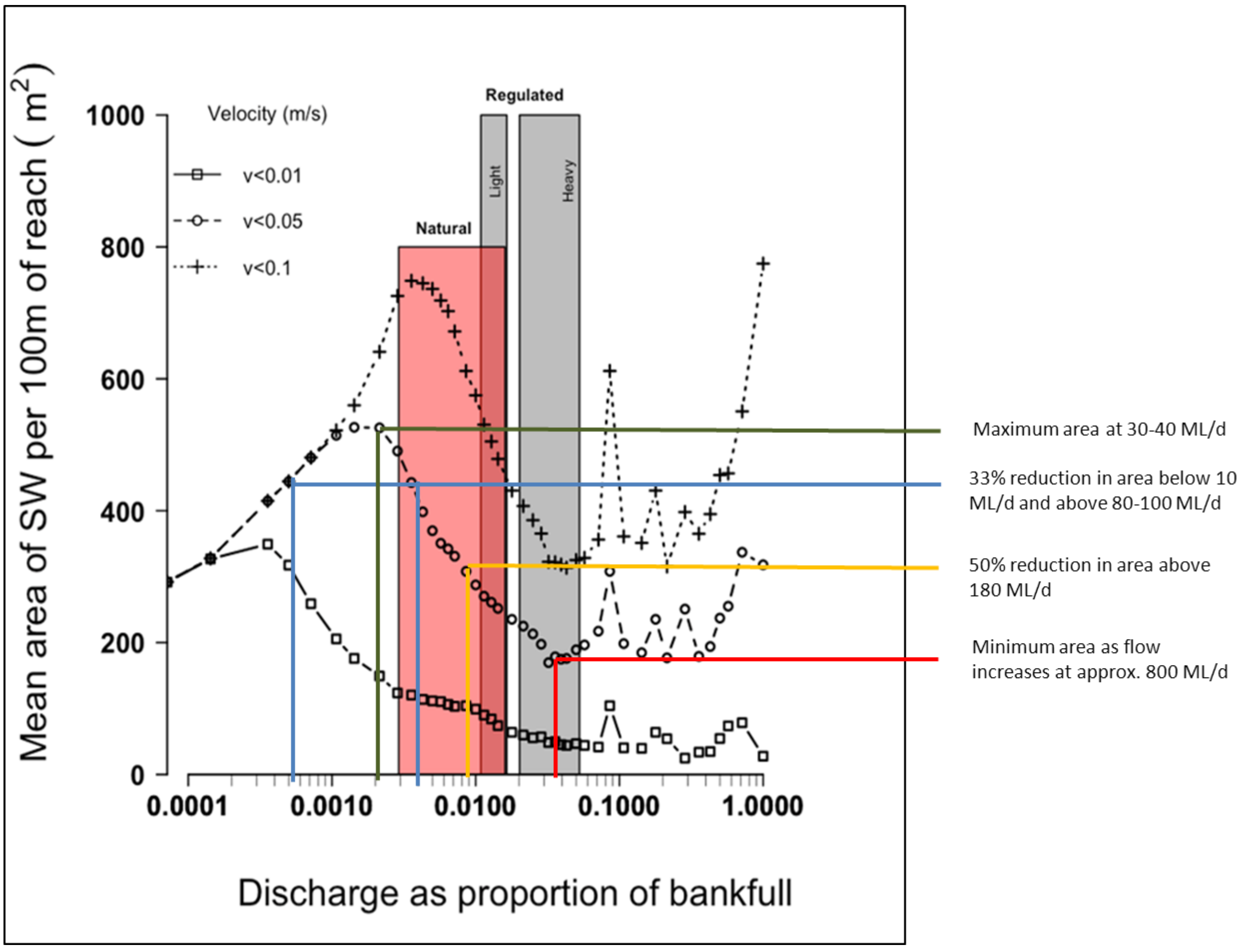


Figure 11: Plot of slackwater area versus discharge (proportion of bankfull: 20,000 ML/d for Reach 3). Modified from Vietz et al. (2013). Note: slackwater for this project is based on velocity >0.05 m/s. Maximum slackwater occurs at approximately 0.002*bankfull discharge (i.e. 0.002*20,000 ML/d = 40 ML/d). Slackwater area declines from the maxima both as discharge falls and increases from 40 ML/d. The light and heavy levels of regulation refer to scenarios of water storage and irrigation diversions: see Vietz et al. 2013 for further details.

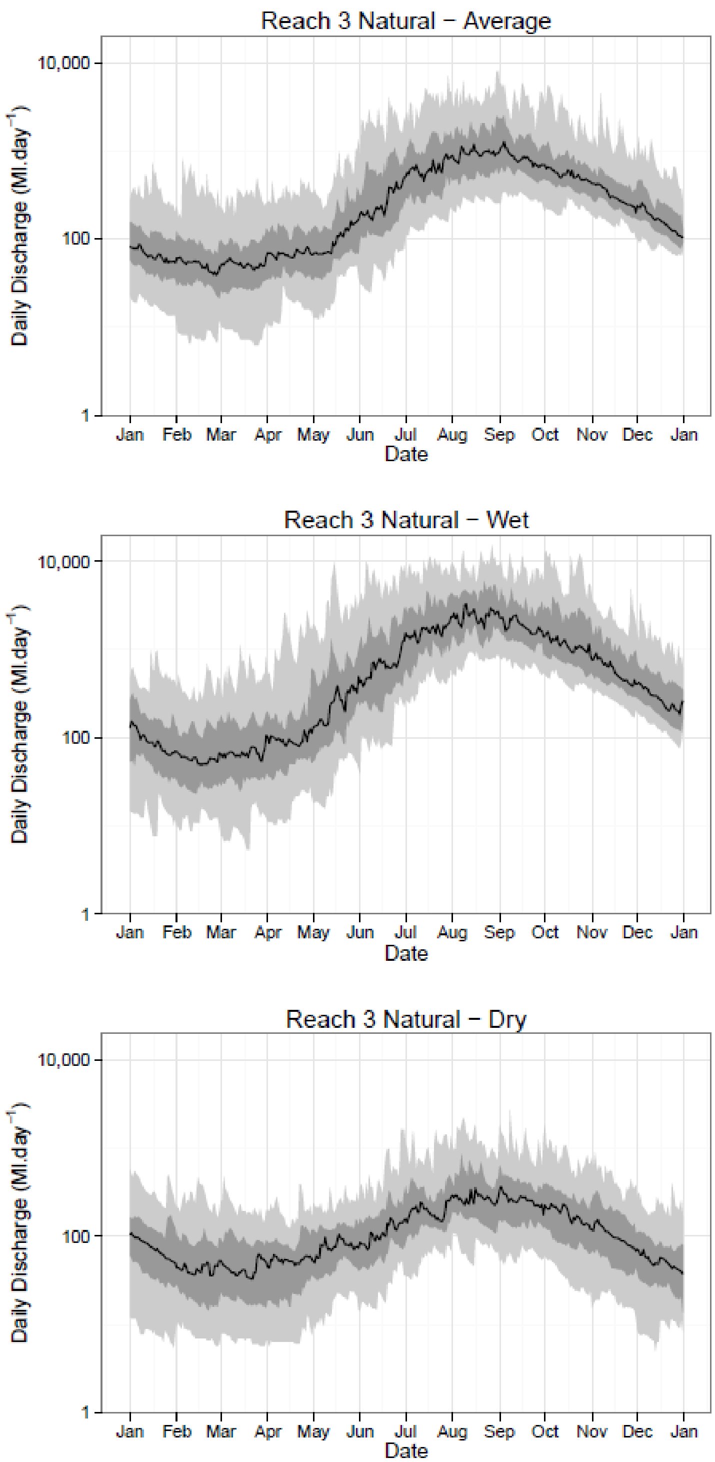


Figure 12: Reach 3 natural flows for average, wet and dry scenarios. Black line = median; dark grey = 20th – 80th percentile flows; light grey = 5th – 95th percentile flows.

Table 7: Environmental flow recommendations for Reach 3: Casey's Weir to the Goulburn River

Objectives (habitat feature in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
Recommendations for Baseflow			
MI1 (riffles)	• Summer-autumn baseflow	40 ML/d, or natural.	• From HECRAS: water to maintain runs: ○ Reach 2 requires 40 ML/d or natural
MI2 (slackwater)	• Spring-autumn baseflow	30-100 ML/d, or natural. Absolute minimum of 15 ML/d.	• Slackwater habitat is best defined here as depth <0.5 m and velocity <0.05 m/s (Vietz et al. 2013). Vietz et al. (2013) show the area of slackwater available in Reach 3 at different discharges (as a proportion of bankfull – approx. 20,000 ML/d). Slackwater habitat area is at its minimum at approximately 800 ML/d and at its maximum at 30-40 ML/d. • Dec-Apr daily flows are very similar for dry and average years (the difference between the 2 scenarios is more pronounced in winter-spring). The Dec-Apr p20 value (i.e. flows are above 100ML/day for <20% of the time) for dry and average years is approximately 100 ML/d (± approximately 20 ML/d). • The nature of discharge-slackwater habitat area is such that as discharge increases or decreases, a 33% reduction in slackwater habitat occurs outside the range of 10-120ML/day (a discharge of 8-10 ML/d represents a 33% reduction; 15 ML/d represents a

Objectives (habitat feature in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
			20% reduction). • Operate within range of 30-100 ML/d, or natural with an absolute minimum of 15 ML/d. • Flows outside of this range are restricted to short periods (e.g. as freshes), with appropriate rates of rise and fall).
IC5 (vegetation habitat)	• Baseflow (all year)	80 ML/d, or natural.	• Baseflow with 0.5 m depth are based on the watering needs of *Vallisneria* (Bowen 2006, Roberts and Marston 2011). The watering needs of emergent vegetation (e.g. Phragmites) are expected to be catered for by the baseflow for *Vallisneria* and freshes as defined for other objectives. • Maintain 0.5 m depth in runs. From HECRAS: ○ Reach 3 requires 80 ML/d, or natural
IC3: (vegetation encroachment on sand bars)	• Baseflow (all year)	As for MI1 and MI2	• As for MI1, MI2.
NF1 (slackwater and pools)	• Summer-autumn baseflow	As for MI2	• As for MI2.
NF2 (fish passage)	• Baseflow (all year)	As for MI1	• Intent is 0.4 m over the shallowest point in the longitudinal profile. From HECRAS: ○ Reach 2 requires 40 ML/d.

Objectives (habitat feature in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
MI3, MI6 (invertebrate habitat)	• Baseflow (all year)	As for MI1 and MI2.	• As for MI1 and MI2.
G1, G2 (aquatic macrophytes, terrestrial encroachment)	• Baseflow (all year)	As for MI1, MI2 and IC5	• As for MI1, MI2 and IC5.
Recommendations for Freshes			
G4 (scour around large wood)	• Summer and winter freshes	400 ML/d. Frequency is 3-4 per year (dry, wet and average years).	• Shear stress for removing fines from sediments in runs equal to 2 N/m^2 (based on shear stress required to mobilise sandy bed sediments in runs). From HECRAS: ○ Reach 3 requires 400 ML/d. Frequency is 3-4 per year (dry, wet and average years).
IC3 (vegetation encroachment on sand bars)	• Winter-spring freshes	430 ML/d. Frequency is 3 per year (dry, wet and average years). Duration is 3 days in dry years, 5 days in average years and 6 days in wet years.	• Winter freshes. Based on HECRAS: ○ Reach 3 requires 430 ML/d.
G3 (sand and gravel bed	• Winter-spring	1,000 ML/d.	• Removal of fine-grained sediments (silts/clays) from substrates in pools. Based on shear stress (30

Objectives (habitat feature in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
diversity)	freshes	Frequency is 2 per year for dry years, 4 per year in average and wet years. Duration is 2 days in dry years, 4 days in average years and 6 days in wet years.	N/m²) required to overturn gravel substrate (particle size median) within majority of pools. From HECRAS: ○ Reach 3 requires 1,000 ML/d.
IC4 (biofilms)	• Winter-spring freshes	4,300 ML/d. Frequency is 1 in 10 years for dry years, 2 per year for average years and 4 per year in wet years. Duration is 1 days in dry years, 2 days in average years and 3 days in wet years.	• This will require a combination of (i) sloughing algae (freshes) and (ii) turning over cobbles (bankfull, addressed by R1, W1). • >0.6 m/s velocity for sloughing (based on Ryder et al. 2006). Based on HECRAS: ○ Reach 2 requires 4,300 ML/d. Frequency is as for objective G5.
G5 (bench inundation)	• Winter-spring freshes	4,500 ML/d Frequency and duration as for IC4.	• From HECRAS: ○ Reach 2 requires 4,500 ML/d.
IC6 (benches and bars)	• Winter-spring freshes	As for IC4.	• As for G3 and IC4.

Objectives (habitat feature in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
NF4 (fish movement)	• Winter-spring freshes	As for G4, IC4, G3.	• Intention is for a rise in river levels of at least 20 cm above antecedent winter baseflow levels. • Magnitude as for G3, IC4.
MI4 (biofilms)	• Winter-spring freshes	As for IC3.	• As for IC3.
MI3, MI6, NF2 (invertebrate habitat, fish passage)	• Summer and winter freshes	As for IC2, IC3 and IC4.	• As for IC2, IC3 and IC4.
Recommendations for Bankfull and Overbank flows			
R1 (riparian)	• Winter-spring freshes (approaching bankfull flows)	20,000 ML/d Frequency is 1 in 10 years in average years and 7 out of 10 years in wet years. Duration is 1 day for both average and wet years.	• River Red Gum used as a surrogate for EVC 56. Both bankfull and overbank flows are recommended to ensure the needs of the understorey are met in addition to RRG. • From HECRAS: ○ Reach 3: bankfull of 20,000 ML/d; • Bankfull and overbank flows would not be expected in dry years. • Note: it is recognised that the proposition to actively manage the flows required for this recommendation will not been accepted due to Victorian policy of not inundating private land. However, it is stated here to provide completeness in terms of recommendations for maintaining or improving the conditions of

Objectives (habitat feature in parenthesis)	Main Flow Components	Flow Recommendation	Rationale
			ecosystem assets and values associated with the Broken River. As the current flow regime has had little effect on the natural frequency of events of this magnitude, it is expected that this recommendation will be met without active management.
W1 (wetlands)	• Winter-spring freshes (based on wetland commence to fill data for Reach 3)	As for R1	• As for R1
G6, W2, IC1, IC2, IC3, MI5, MI6,NF3	• Winter-spring freshes (approaching bankfull)	As for W1 and R1.	• Freshes approaching bankfull as for W1 and R1.

8 POTENTIAL IMPACT OF REDUCED IRRIGATION OUTFALLS TO THE LOWER BROKEN RIVER (CONNECTIONS PROJECT)

The Water Change Management Framework requires assessment of the need for mitigation water against a number of criteria (Table 8). Assessment of each criterion identified some circumstances where a requirement for mitigation water was conceivable, given that the Goulburn-Murray Water Connections Project is expected to result in water savings (i.e. reduced irrigation channel and drain outfall flows to the Broken River) of approximately 85% from average volumes[5] (approximately 850 ML, Table 9). It should be noted that the water source for current irrigation channel and drain outfalls is the East Goulburn Main Channel, and not from the Broken River.

Table 8: Mitigation water assessment criteria

Criteria by which mitigation water may be assessed as not required	Link between incidental water (losses) and environmental values
1. Mitigation water may be assessed as not required where:	
1.1. There is no hydraulic connection (direct or indirect) between the irrigation system and the wetland or waterway.	The irrigation system is directly linked to the Broken River with 16 outfall structures currently discharging directly to the river.
1.2. The water does not reach the wetland or waterway with environmental values (e.g. the outfall is distant from the site and water is lost through seepage and evaporation before reaching the area with environmental values).	Gauging to estimate the volumes were made close to the actual outfall, so the volumes given Table 8 are considered to be representative of that reaching the river. The relative volume compared with river flows does not pose a risk in average and wet years but could pose a risk in dry years without attention to flow management along the river (Table 10). **Mitigation may be required in dry years.**
2. Mitigation water may be assessed as not required where the wetland or waterway receives water from the irrigation system:	
2.1. That is surplus to the water required to support the environmental values (e.g. changing from a permanently wet to an intermittently wet or ephemeral regime is beneficial or has no impact).	Irrigation outfalls contribute to the summer-autumn flows in the Broken River below the EGM channel. It is surplus to requirements in average and wet years. **Mitigation water not required in average and wet years.**
2.2. That occurs at a time that is detrimental to the environmental values.	Irrigation outfalls contribute to the summer-autumn flows that maintain slackwater habitat for invertebrates and fish in the Broken River below the EGM channel. **Mitigation water may be required in dry years.**
2.3. That is of poor quality (or results in water of poor quality entering a site e.g. seepage resulting in saline groundwater intrusions to wetlands) and the removal of	The quality of the irrigation outfalls is unknown but is presumed to contain higher concentrations of nutrients and salt than the Broken River. While the removal of irrigation outfalls may improve water quality to some (unknown) degree, it is unlikely to have such an impact

[5] Volumes are likely to vary depending on weather and allocations: wet years are likely to result in higher outfall volumes, while dry years are likely to result in lower outfall volumes.

Criteria by which mitigation water may be assessed as not required	Link between incidental water (losses) and environmental values
which would lead to an improvement in the environmental values.	that EPA water quality (nutrient) objectives are achieved in the Broken River. **Mitigation water may not be required.**
3. Mitigation water may be assessed as not required where the environmental values:	
3.1. Do not directly benefit from the contribution from the irrigation system (e.g. river red gums around a lake may not directly benefit from an outfall and may be more dependent on rainfall or flooding)	The environmental values include in-channel values associated with summer-autumn slackwater habitat provided by the regulated flow regime, to which the outfalls contribute below the EGM channel. **Mitigation water may be required in dry years.**
4. Mitigation water may be assessed as not required where the removal of the contribution from the irrigation system does not:	
4.1. Increase the risk of reducing the environmental values (e.g. outfalls form a very small portion of the water required to support the environmental values and their removal will not increase the level of risk).	Irrigation outfalls only enter the river below the EGM channel, which is the last 20 km of river before the confluence with the Goulburn River. Thus irrigation outfalls flows will not influence the environmental values associated with 85% of the Broken River between Lake Nillahcootie and the Goulburn River, and is only a minor risk to values below the EGM channel in dry years assuming other elements of the flow regime are maintained. **Mitigation water is not required.**
4.2. Diminish the benefits of deploying any environmental water allocations (over and above the contribution from the irrigation system).	Although the outfalls form a very small portion of the water required to support the environmental values, more environmental water may be required in dry years if the outfalls were removed and this was not accounted for in managing the minimum flow requirements under the Bulk Entitlement for the Broken River. **Mitigation water may be required.**
5. Further investigation should be undertaken where:	
5.1. The margin of error in the estimate of mitigation water is greater than the savings available from the relevant operating component (e.g. the specific outfall).	The magnitude of errors is not knowable, and cannot be resolved easily. Further work is highly unlikely to improve estimates and would be a major undertaking.

When averaged across the November-May irrigation season, the 85% reduction in outfall volume equates to a reduced inflow to the Broken River below the EGM channel (approximately 20 km of 120 river km between Lake Nillahcootie and the Goulburn River) of approximately 5 ML/d. It is anticipated that this reduction is likely to have little effect on ecological objectives when the river is being operated within the range of 30-100 ML/d during summer-autumn. Mitigation water of up to 5 ML/d could be required if flows in Reach 3 (measured at Gowangardie Weir) were to fall below 15 ML/d for extended periods. A 5 ML/d reduction in flow to 10 ML/d in these circumstances means that slackwater habitat between the EGM channel and the Goulburn River would be reduced by one-third from its maximum, which occurs at flows of 30-40 ML/d (Figure 11).

Table 9: Estimate of saved water reaching the Broken River in the baseline year of 2004/05 (from C. Solum, G-MW, pers. comm.).

Channel outfalls to the Broken River 2004/05	Volume (ML)
10 Channel Rd-McPhee Rd corner to Dr 2	278
20/10 Sun City Fence Channel Rd to Dr 2	0
16/10 McPhee Rd to Dr 5A	19
15/10 Downstream Feiglin Rd to Dr 2/2	37
1/14/10 Orrvale Rd to Dr 3/6	10
13/10 Rai's orchard to Dr 2/6	124
2/13/10 Orrvale Rd to Dr 4/6	0
1/13/10 Prentice Rd to Dr 4/6	0
11/10 Jamieson Rd to Dr 8	0
10/10 Hanlon Rd to Dr 8A	1
8/10 Beckham Rd to Dr 9	0
END 1/10 Downstream of Zurcas Lane to 2A/2	29
1/10 Pipeline/Outfall Radevski's Driveway 3A/2	0
Mid 1/10 "The Church"OrrvaleRd/PoplarAve Dr 2	354
7/1/10 Tracey's spur Poplar Ave to Dr 2	2
6/1/10 Central Ave & Poplar Ave to Dr 2	0
Total Volume	**855**

However, examination of flow series suggests that the requirement for mitigation water is low. This is because the modelled flow regimes indicate that summer-autumn flows below 15 ML/d would only occur 4% of the time under the current regime in dry years and less than 1% of the time in average and wet years (Table 10). It is interesting to note that the frequency of flows <15 ML/d under the current flow regime is less than that for the unregulated flow regime (presumably due to releases to meet irrigation water demand). Applying an average reduction of 5 ML/d due to reduced irrigation outflows during the irrigation season increases the frequency of flows <15 ML/d under the current flow regime from 4% to 7% of the time during the irrigation season in dry years. The amount of water required to reduce this 7% to 4% is about 30 ML.

Overall, while there are criteria that leave open the need for mitigation water in dry years, this is not deemed necessary as:

- The current flow regime has a lower frequency of very low flows (<15 ML/d) than would occur under an unregulated flow regime.
- The loss of irrigation return flows would only be a potential threat to ecological objectives in dry years, and then only for relatively short periods of time (6 days on average across the entire irrigation season, although it is conceivable that longer low-flow periods could occur during drought) and assumes that no additional management action would be taken to maintain flows above 15 ML/d.
- Implementation of the existing minimum flow requirements under the Bulk Entitlement could adopt an absolute minimum of 15 ML/d in Reach 3 in dry years.

- As only the river below the EGM channel is involved (lowest 20 river kilometres), and assuming that the largely natural pattern of the flow regime (i.e. seasonality, baseflow, freshes, bankfull flows) is maintained, then the overall risk to ecological values along the 120 kilometres of the Broken River between Lake Nillahcootie and the Goulburn River is low.

The finding that mitigation water is not required is based on the estimates provided by the Connections Project on irrigation return flows and reductions possible with implementation of the Connections Project for the baseline year of 2004/05.

Table 10: Comparison of number of days with flow <15 ML/d during the irrigation season (November-May): current level of irrigation return flows and reduced irrigation inflows. Based on the 117 year modelled flow record and average of 5 ML/d reduction in stream flow due to lower irrigation return flows during the irrigation season.

	Current flow regime		Unregulated flow regime	
	Current irrigation return flows	Reduced irrigation return flows	Current irrigation return flows	Reduced irrigation return flows
Dry years				
Total number of days	12415	12415	12415	12415
Number of days below 15 ML/d	493	835	1109	1455
Percentage of days below 15 ML/d	4%	7%	9%	12%
Average years				
Total number of days	16799	16799	16799	16799
Number of days below 15 ML/d	0%	0%	560	760
Percentage of days below 15 ML/d	0%	0%	3%	5%
Wet years				
Total number of days	12786	12786	12786	12786
Number of days below 15 ML/d	31	62	424	572
Percentage of days below 15 ML/d	0%	0%	3%	4%

9 INCREASED WATER TRADE

Although the Connections Project does not have any mitigation water requirements, the impact of water trade is reported in order to fulfil the Northern Region Sustainable Water Strategy objective, and is therefore considered here even though outside the Connections Project obligations.

Approximately 19 GL of high reliability and 3 GL of low reliability water entitlements are held in the Broken River system (Table 11). The amount of water that could trade, and the location it comes from, is uncertain but for this assessment it is assumed that 5,000 ML of HRWS entitlement will trade out of the Broken River system and it will come proportionally from the existing distribution of holdings; i.e. 1,380 ML reduction between Nillahcootie and Casey's Weir, 870 ML reduction from Broken Creek and Mokoan, and 2,750 ML reduction from Casey's Weir to Shepparton (mainly upstream of Caniambo).

Table 11: Summary of water entitlements in the Broken River supply system (G. Earl, GB CMA, pers. comm. in consultation with GM-W)

Zone	High Reliability Water Supply	Low Reliability Water Supply	Proportion
Zone 2A (Nillahcootie to Casey's Weir)	4,982.7 HRWS	599.2 LRWS	(26.5%)
Casey's Weir (Broken Creek and Mokoan)	3,141.4 HRWS	604.8 LRWS	(17.7%)
Zone 2B (Casey's Weir to Shepparton)	9,906.7 HRWS	1,828.1 LRWS	(55.6%)
Other	34.0 HRWS	6.3 LRWS	(0.2%)
Total	**18,064.8 HRWS**	**3,038.4 LRWS**	

The impact on river flows is also determined by the pattern of use through the year. While there is a mix of industries using water from the Broken River system, an indicative pattern of use in an average year has been assumed as follows: November 10%, December 15%, January 25%, February 25%, March 20%, April 5%. It is also assumed that 100% allocation is available in most years and that the entitlement is fully utilised. In an average year, catchment runoff would meet all flows in August, September and October. In November, Lake Nillahcootie releases would be required to meet some of the irrigation demand, and in December most of the demand would be met by Lake Nillahcootie releases. Reductions in demand in November and December due to trade would reduce Lake Nillahcootie releases. To meet downstream water supply needs, flow to meet supply commitments from water trading is likely to be delivered between December and March (at the latest), with some delivery held back to allow water to temporary trade back into the Broken River system if required up to the end of February.

In summary, increased trade of water out of the Broken River system is likely to result in a number of changes to existing flow regimes (G. Earl, GB CMA, pers. comm.). The most important/relevant of the foreseeable changes are:

- Reduced releases from Lake Nillahcootie between November and March due to reduced irrigation demand within the Broken system (Table 12); combined with
- Increased releases from Lake Nillahcootie between December and March to meet trade commitments outside of the Broken system (Table 13); resulting in
- Moderate fluctuations (increases or decreases in flow up to approximately 30 ML/d) between November and February (inclusive), but a large increase in mean daily flow in March (Table 14).

While generally moderate in terms of increased summer-autumn flows (see Section 7.3), there could be a problem if the predicted maxima of 50-85 ML/d of trade water was delivered continuously on top of the maximum baseflow 100 ML/d recommendation to meet existing (environmental and irrigation) demand. Under this scenario, there would be a large reduction in the slackwater habitat require by invertebrates and native fish. Even so, trade water in excess of 100 ML/d can still be delivered as flow freshes designed to meet ecosystem objectives (e.g. as freshes of 400 ML/d to meet objective G4 in Reach 3; 500 ML/d to meet objective IC4 in Reach 1). In order to minimise the risk of excessive flows causing the baseflow ecological objectives to be exceeded, the delivery of trade water as freshes should be avoided in summer and postponed as far in to autumn as is possible, unless they are used for the dual purpose of achieving ecological objectives (i.e. freshes) identified in the previous sections. Dual purpose flow freshes able to achieve both environmental and end-of-system trade objectives should be encouraged.

Table 12: Estimated mean daily (ML/d) reduction in irrigation within the Broken River system resulting from increased water trade (G. Earl, GB CMA, pers. comm. in consultation with GM-W)

Month	Below Nillahcootie	Below Benalla	Below Casey's Wei	Below EGM
July	0	0	0	0
August	0	0	0	0
September	0	0	0	0
October	0	0	0	0
November	-17	-12	-9	0
December	-25	-18	-14	0
January	-42	-31	-23	0
February	-42	-31	-23	0
March	-33	-25	-18	0
April	-8	-6	-4	0
May	0	0	0	0
June	0	0	0	0

Table 13: Estimated increase mean daily flow (ML/d) required to meet trade from the Broken system (G. Earl, GB CMA, pers. comm. in consultation with GM-W)

Month	Below Nillahcootie	Below Benalla	Below Casey's Wei	Below EGM
July	0	0	0	0
August	0	0	0	0
September	0	0	0	0
October	0	0	0	0
November	0	0	0	0
December	28	28	28	28
January	28	28	28	28
February	28	28	28	28
March	83	83	83	83
April	0	0	0	0
May	0	0	0	0
June	0	0	0	0

Table 14: Estimated increase or decrease in mean daily flow (ML/d) expected to result from the delivery of trade water (G. Earl, GB CMA, pers. comm. in consultation with GM-W)

Month	Below Nillahcootie	Below Benalla	Below Casey's Weir	Below EGM
July	0	0	0	0
August	0	0	0	0
September	0	0	0	0
October	0	0	0	0
November	-17	-12	-9	0
December	3	10	14	28
January	-14	-3	5	28
February	-14	-3	5	28
March	50	58	65	83
April	-8	-6	-4	0
May	0	0	0	0
June	0	0	0	0

10 POTENTIAL RISKS OR ADVERSE IMPACTS

Threats related to provision of environmental water include:

- Providing conditions favourable to carp populations;
- Promoting the spread of Cabomba in Lake Benalla and downstream;
- Loss of terrestrial vegetation on the river bank increasing the threat of bank erosion until replaced by littoral and/or amphibious species.

Threats related to decreased inflows from the irrigation system below the EGM channel include:

- Loss of in-channel habitat for aquatic organisms, particularly slackwater habitat for fish and invertebrates, as well as slackwater and run habitat for aquatic vegetation. However, as the likelihood of this occurring is low and the potential consequences are also likely to be low (potential reduction in summer-autumn habitat only for 20 kilometres out of 120 river kilometres), the overall risk associated with reduced irrigation return flows is considered low.

Threats related to the delivery of trade water include:

- Loss of in-channel habitat for aquatic organisms, particularly slackwater habitat for fish and invertebrates, as well as slackwater and run habitat for aquatic vegetation;
- Increased suspended sediment smothering of marginal bed substrate habitats if bank erosion is exacerbated (bank erosion is the source of 48% of suspended sediment in the Goulburn-Broken system, Wilkinson et al. 2005).

Management actions to address the threats listed above include (responsibility in parenthesis):

- Delivering the environmental watering recommendations identified in Chapter 7 (GB CMA, G-MW). In doing so, attention should be given to avoiding prolonged stable flows, as this can increase the risk of bank-notching, destabilised banks, and a reduction in the abundance and condition of riparian vegetation[6]. Rapid rates of water level fall have been linked to bank slumping (Green 1999) and these should also be considered carefully.
- Monitoring of carp populations and breeding events in each reach of the river (GB CMA). The potential to ‘strand’ carp eggs by manipulating high water levels via rapid drawdown immediately post-spawning in floodplain habitats has been considered in other lowland rivers (e.g. Stuart 2006), but may be difficult in the Broken River due to the difficulties of manipulating high flow events.
- Monitoring the extent of Cabomba in Lake Benalla and downstream to Casey’s Weir (GB CMA, City of Benalla). Mitigation can include manipulation of water levels in Lake Benalla (e.g. partitioning of the lake to allow sections to dry, accompanied by weed control such as physical removal and disposal).

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[6] A noticeable amount of bank slumping has been observed along the lower Goulburn River following the floods of 2010/11. Notching of the river banks occurred following the delivery of a spring fresh in November 2012 (sustained at 5,800 ML/d for 2 weeks). It has been recommended that constant flows be avoided to reduce the risk that notching will contribute to excessive rates of bank slumping in the future (Cottingham et al. 2013b). Ensuring appropriate rates of fall is also very important to avoid slumping of surcharged banks.

11 ON-GOING MANAGEMENT AND GOVERNANCE ARRANGEMENTS

11.1 Water planning and management governance arrangements

Water planning and delivery is governed by the Bulk Water Entitlement for the Broken system (DSE 2010). Goulburn-Murray Water (G-MW) has responsibility under the Bulk Water Entitlement for the planning and delivery of water to the Broken River (DSE 2009). In doing so, G-MW collaborates with:

- The GB CMA and the Victorian Environmental Water Holder, in the delivery of environmental entitlements held by the State Government;
- The GB CMA and the MDBA to manage inter-valley transfers to the River Murray[7];
- The GB CMA and the Commonwealth Environmental Water Office in the delivery of environmental water held by the Commonwealth.

11.2 Maintenance of assets

The maintenance and management of physical assets along the Broken River is the responsibility of:

- G-MW: Lake Nillahcootie, Broken Weir, Casey's Weir (including the fishway) and Gowangardie Weir;
- City of Benalla: Lake Benalla;
- GB CMA: management of crown frontages along the river;
- Landholders: management of frontages on private land.

The channel capacity and Infrastructure to deliver the preferred environmental flow regime (and any mitigation water) already exists, so no additional investment in infrastructure is required.

[7] Note that while G-MW can make recommendations regarding the delivery of inter-valley transfers to support GB CMA objectives, the actual delivery of inter-valley transfers is governed by the MDBA who are working towards the management of the larger Murray-Darling Basin and are not compelled to follow G-MW's recommendations.

12 ADAPTIVE MANAGEMENT

The Connections Project is committed to an adaptive management approach to ensure an appropriate response to changing conditions (NVIRP 2012). In its simplest form, adaptive management is a cycle of planning to address management issues, implementation of management actions, monitoring and evaluation of the management actions and the predicted ecological response to them, followed by review and application of new insights into subsequent adaptive management cycles (e.g. Commonwealth of Australia 2009, Richter et al. 2006). In this way, adaptive management provides one means of improving understanding and reducing uncertainty when dealing with the management of complex systems. Other approaches include resilience building and scenario planning (e.g. Peterson 2005).

When considered as part of a river rehabilitation project, adaptive management provides an opportunity to learn how river ecosystems respond to changes in flow regime and apply this knowledge to the management of the river, and potentially elsewhere. For this project, the adaptive management process refers to outcomes of the implementation of the stipulated/proposed environmental flow regime for the Broken River, as well as the potential ecological impact of reduced irrigation return flows and increased water trade. The insights gained will be used in the future to maintain or improve the condition of the river and its associated floodplain and wetland areas.

Table 15 shows how the adaptive management approach will be applied in the context of this EWP.

Table 15: Adaptive management approach applied to the Broken River EWP

Adaptive management phase	Application to this EWP (Responsible agency)	When
Assessment and design	Assessment identifies environmental values, their water dependencies, and the potential role of incidental water. Design determines the desired water regime to support environmental values and determines any mitigation water commitment. Details of both these phases are documented in this EWP. (Connections Project)	2013
Implementation	Implementation is the active management of environmental water, consistent with this EWP. (Agencies as appropriate)	Continuous
Monitoring (and reporting)	Monitoring is gathering relevant information to facilitate review and enable any reporting obligations to be met. Two types of monitoring are required. Compliance monitoring is checking that the intended water regime is applied. Performance monitoring is used to inform the review of the effectiveness of the environmental watering regime. (GB CMA – performance monitoring to inform assessment of achievement of environmental objectives via VEFMAP program).	Annual
Review	Review is evaluating actual results against objectives and	2015, 2020,

Adaptive management phase	Application to this EWP (Responsible agency)	When
	identifying any improvement opportunities which may be needed. (Connections Project and other Agencies)	2025, etc
Adjustment	Adjustment is determining whether changes are required following review or after considering any new information or scientific knowledge and making any design changes in an updated version of the EWP. (Connections Project and other Agencies)	2015, 2020, 2025, etc

12.1 Refining the knowledge base

12.1.1 Testing assumptions used to developed environmental flow recommendations and underpinning the irrigation return flow estimates

The development of the environmental watering recommendations presented in Chapter 7 made extensive use of modelling (hydrological, hydraulic, geomorphic) which, necessarily, is based on assumptions about the physical conditions of the river and biological and ecological responses to changes in the flow regime. It is, therefore, important that the physical and ecological responses of the river system (including wetland and floodplain areas) are monitored so that the implicit assumptions in the modelling are reviewed and refined for future decision-making. This includes:

- Confirming that the current cross sections in Reach 1 are sufficiently similar to those of 2001, which were used to formulate the current flow recommendations
- Undertaking an additional cross-section survey (appropriately located) and use of a HECRAS model to compare hydraulics in the lower areas of Reach 1 with the results from the HECRAS model at Swanpool. This should include reviewing the bankfull and overbank flows for lower section in Reach 1. Cross-sections and a HECRAS model are available for the lower section of Reach1, but were not used for this study because of the potential influence of an anabranch immediately upstream.
- Adding more detail to existing cross-sections to improve the confidence in the HECRAS model, particularly in terms of assessing cross-section velocity.
- Confirming that the discharge-slackwater area relationships in Reach 1 and 2 are consistent with that in Reach 3.
- Confirming the actual magnitude and timing of irrigation return flow and trade water delivery with the assumptions presented in sections 7.2 and 7.3.

- Continuing to contribute to work of the Victorian Environmental Flows Monitoring & Assessment (VEFMAP) program to evaluate species and community response and geomorphic response to altered flow regimes. VEFMAP is currently investigating geomorphic, vegetation, invertebrate and native fish responses across Victoria, including in the Broken River. These ongoing studies should be complemented by projects that examine processes such as; (i) nutrient and carbon transformations and cycling, (ii) the role of fallen timber (snags) as sites of primary production and macroinvertebrate biodiversity to confirm whether or not the inundation of snags should be considered in future environmental flow studies, (iii) changes in bed topography and substrate habitat condition under altered flow regimes, and (iv) the role of water level variations and high flows in supporting fish movement, recruitment and production.
- Monitoring geomorphic response following a decade of drought and the recent and substantial alterations to hydrology (i.e. altered trade, enhanced environmental flows). This may include more detailed survey and fixed cameras to monitor channel change, specifically slumping that has significant impacts on the morphology of the banks and bed of the channel.

The actions listed above are mostly part of the normal catchment management activities and are not the responsibility of the Connections project. However, the assumption that mitigation water is not required to replace the expected reduction in irrigation return flows is based on the best information available to the scientific panel at the time of writing.

12.1.2 Monitoring and reporting

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

- VEFMAP;
- The Victorian Water Quality Monitoring Network;
- The Major Storages Operational Monitoring Program;
- Flow monitoring undertake by Goulburn-Murray Water.

It is recommended that these programs are continued to confirm that environmental flows are delivered as planned and to test that the predicted ecological responses occur. Where sampling is deemed insufficient to assess the targeted hypotheses identified above (section 10.1.1), more focussed research may be required. Reporting should be undertaken annually to support annual water plans and every 5 years to evaluate ecosystem response.

12.2 Complementary management actions

The effectiveness of the flow recommendations provided in Chapter 7 will be complemented by actions that maintain or improve the environmental conditions along the Broken River, including:

- Continued to reduce inputs of nutrients, sediment and turbidity entering the river;
- Continued rehabilitation of native vegetation in the riparian zone;
- Limiting livestock access to waterways;
- Continued implementation of pest control strategies (e.g. Cabomba, willows, carp);
- Providing fish passage past barriers such as Gowangardie Weir;
- Ensuring proper maintenance of existing fishways;
- Encouraging responsible recreational fishing for native species.

These actions are not the responsibility of the Connections Project.

13 CONCLUSIONS

This EWP has been prepared on behalf of the Connections Project, as required by the WCMF. It has been based on the environmental watering requirements determined for the three river reaches between Lake Nillahcootie and the Goulburn River. The environmental watering requirements then provided the basis from which to consider the implications of:

- Reduced irrigation returns flows (850 ML per year reduction; approximately 5 ML/d on average if spread across the irrigation season) associated with implementation of the Connections Project, and
- Increased flows to meet demand associated with up to 5000 ML water trade out of the SIR, estimated to be up to 85 ML/d in some months.

Overall, the estimated reduction in irrigation return flow volume was considered to be a low risk to environmental values and ecological objectives for the Broken River between Lake Nillahcootie and the Goulburn River. The irrigation drainage system only affects the Broken River downstream of the EGM channel, would only pose a threat to some ecological objectives in dry years (not average or wet years) and then only if discharge from Lake Nillahcootie and tributaries along the river were at very low levels. The situation whereby reduced irrigation inflows could be detrimental is unlikely given the current operation of the river, and even less likely should the proposed the volume of trade water from the Broken River system increase as discussed in Section 7.3. As a result, there is no additional requirement for mitigation water so long as the recommended environmental flow regime is implemented. However, it is recommended that the Connections Project investigate the variability in irrigation return flows and water savings that might result under dry and wet years (current estimates were based on the baseline year of 2004/05). The need for mitigation water should be reviewed if there are large departures from the volumes estimated for the baseline year.

Estimates of the impact of increased water trade out of the SIR of up to 5000 ML suggest changes (increases and decreases of approximately ± 20 ML/d) in mean daily flow that can be managed within the proposed environmental flow range of 30-100 ML/d for most months in the irrigation season. The exceptions are for Reach 3 below the EGM channel and all reaches in March, where increases in the order of 30-85 ML/d are possible. If added to flows at the top of the 30-100 ML/d range, then there could be a substantial loss (e.g. up to 50%, see Figure 11) of slackwater habitat required by invertebrates and native fish along each river reach. The delivery of trade water should be within the upper limit of 100 ML/d set for summer-autumn flows, but can be augmented by using trade water to delivery desired flow freshes (with defined magnitude and duration) for which there are specific ecological objectives.

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

- VEFMAP;
- The Victorian Water Quality Monitoring Network;
- The Major Storages Operational Monitoring Program;
- Flow monitoring undertake by Goulburn-Murray Water.

It is recommended that these programs are continued to confirm that environmental flows are delivered as planned and to test that the predicted ecological responses occur. Reporting should be undertaken annually to support annual water plans and every 5 years to evaluate ecosystem response, as described under the adaptive management arrangements in Chapter 10.

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15 APPENDIX 1: NATIVE FISH AND OTHER THREATENED SPECIES RECORDED ALONG THE BROKEN RIVER

Table 16: Fish species predicted to occur and population numbers recorded in the Broken River (from Davies et al. 2008)

Species	Zone		Total
	Lowland	Slopes	
Native Species			
Australian smelt	59	8	67
Bony herring	0	0	0
Carp gudgeons	39	1	40
Dwarf flat-headed	0	0	0
Flat-headed gudgeon	0	0	0
Freshwater catfish	0	0	0
Riffle galaxias	0	18	18
Golden perch	5	0	5
Macquarie perch	0	0	0
Mountain galaxias	0	273	273
Murray cod	12	0	12
Murray hardyhead	0	0	0
Flat-headed galaxias	0	0	0
Murray–Darling rainbowfish	23	0	23
Obscure galaxias	9	21	30
River blackfish	18	125	143
Short-headed lamprey	0	0	0
Silver perch	0	0	0
Southern purple-spotted gudgeon	0	0	0
Southern pygmy perch	442	297	739
Trout cod	0	0	0
Two–spined blackfish	0	1	1
Un-specked hardyhead	0	0	0
Alien Species			
Brown trout	3	10	13
Carp	87	17	40
Eastern gambusia	13	0	13
Goldfish	38	0	38
Rainbow trout	0	14	14
Redfin perch	10	273	283

Table 17: Threatened fauna for the Broken River below Lake Nillahcootie (from Cottingham et al. 2001). FFG = Flora and Fauna Guarantee, AROTS = Australian Rare or Threatened Species, VROTS = Victorian Rare or Threatened Species, TWV = Threatened Wildlife in Victoria, ESP = Commonwealth Endangered Species Program

Common Name	Species	FFG	AROTS	VROTS	TWV	ESP
Reach 1 Lake Nillahcootie to Holland's Creek						
Murray cod	*Maccullochella peelii peelii*	L			Vul	
Macquarie perch	*Macquaria australasica*	L			End	
River blackfish	*Gadopsis marmoratus*				DD	
Mountain galaxias	*Galaxias olidus*	L			DD	
Crimson spotted rainbow fish	*Melanotaenia fluviatilis*	L			DD	
Golden perch	*Macquaria ambigua*				Vul	
Squirrel glider	*Petaurus norfolcensis*	L			End	
Powerful owl	*Ninox strenua*	L			End	
Reach 2 Holland's Creek to Casey's Weir						
Murray cod	*Maccullochella peelii peelii*				Vul	
Macquarie perch	*Macquaria australasica*	L			End	
River blackfish	*Gadopsis marmoratus*	L			DD	
Mountain galaxias	*Galaxias olidus*				DD	
Crimson spotted rainbow fish	*Melanotaenia fluviatilis*	L			DD	
Golden perch	*Macquaria ambigua*	L			Vul	
Trout cod	*Maccullochella maquariensis*				CEn	
Nankeen night heron	*Nicticorax caledonicus*	L			Vul	
Great egret	*Ardea alba*				End	
Royal spoonbill	*Platalea regia*	L			Vul	
Regent honey eater	*Xanthomyza phrygia*				Cen	
Australasion shoveller	*Anas rhynchotis*	L			Vul	
Musk duck	*Biziura lobata*				Vul	
Hardhead	*Aythya australis*				Vul	End
Carpet python	*Morelia spilota variegata*				End	
Woodland blind snake	*Pamphotyphlops proximus*	L			Vul	
Southern Myotis	*Myotis macropus*				LR	
Grey headed flying fox	*Pteropus poliocephalus*				Vul	
Downy swainson pea	*Swainsonia swainsonoides*	N		e		
Red swainson pea	*Swainsonia plagiotrapis*	L	V	e		V
Reach 3 Casey's Weir to the Goulburn River						
Murray cod	*Maccullochella peelii peelii*	L			Vul	
Golden perch	*Macquaria ambigua*				Vul	
River blackfish	*Gadopsis marmoratus*				DD	
Crimson spotted rainbow fish	*Melanotaenia fluviatilis*	L			DD	
Mountain galaxias	*Galaxias olidus*	L			DD	
Great Egret	*Ardea alba*	L			End	
Royal spoonbill	*Platalea regia*				Vul	
Australasian shoveller	*Anas rhynchotis*					
Bush stone curlew	*Burhinus grallarius*	L			End	
Striped legless lizard	*Delma impar*	L			End	Vul

Table 18: Additional threatened fauna (within the local bioregion) listed within 1 km of the Broken River below Lake Nillahcootie (T. Barlow, GB CMA, pers. comm.).

Species	Common name	Listing
Eucalyptus aff. rubida (Moroka)	Moroka Candlebark	Rare
Eucalyptus alligatrix subsp. limaensis	Lima Stringybark	Endangered
Litoria raniformis	Growling Grass Frog	Endangered
Pseudophryne bibronii	Brown Toadlet	Endangered
Chlidonias hybridus javanicus	Whiskered Tern	Near threatened
Tringa stagnatilis	Marsh Sandpiper	Vulnerable
Dasyurus maculatus maculatus	Spot-tailed Quoll	Endangered
Petauroides volans	Greater Glider	Vulnerable
Petaurus norfolcensis	Squirrel Glider	Endangered

16 APPENDIX 2: RATES OF RISE AND FALL

As described in the Bulk Entitlement, the following operational arrangements apply for meeting the environmental minimum flows:

a) In the reach of Broken River between Lake Nillahcootie and Broken Weir during the months of June to November inclusive, the reduction in mean daily flow measured at Moorngag should be no greater than 35% of the previous day's average flow and the increase should be no greater than 210% of the previous day's average flow.
b) In the reach of Broken River between Broken Weir and Casey's Weir during the months of December to May inclusive, the reduction in mean daily flow measured upstream of Casey's Weir should be no greater than 30% of the previous day's average flow and the increase should be no greater than 150% of the previous day's average flow.
c) In the reach of Broken River downstream of Casey's Weir and upstream of its confluence with the Goulburn River during the months of December to May inclusive, the reduction in mean daily flow measured at Gowangardie Weir should be no greater than 45% of the previous day's average flow and the increase should be no greater than 180% of the previous day's average flow.

Recent experience along the Goulburn River (Cottingham et al. 2013b) has highlighted that increased risk of bank slumping following flooding and the loss of bankside vegetation. Should future flood events along the Broken River result in widespread loss of vegetation, then river operators and mangers may give consideration to more conservative rates of rise and fall while the river recovers.

Additional information on rates of rise and fall for the current and unimpacted flow series are provided in Table 19 and Table 20 to assist in this process. These tables include the 5th percentile, median and 95th percentile rates of rise and fall in each reach. They also include information on rates of rise and fall as they might vary at different flow magnitudes.

For example, consider a flow event of 6,000 ML/d in Reach 1. If there was concern that a rate of rise of approximately 200% (Q_2/Q_1) could have an adverse impact, then a more conservative approach could be to adopt the median value of a 115% rise (Q_2/Q_1) or even the very conservative 103% of the 5th percentile (Table 19). Similarly, if there was concern that a rate of fall of 65% (Q_2/Q_1) could have some adverse effect, then the more conservative approach (e.g. based on the median values) could be considered where the rate fall should be above 70% (Q_2/Q_1) while flow remained above 5,000 ML/d, then be above 77% when flow is between 1,000-5,000 ML, and above 91% when flow is less than 1,000 ML/d (Table 20).

Note that this information is provided as a guide only and specific investigations are required to confirm the rates of rise and fall that may be needed to address risks to geomorphic and ecological values should circumstances such as described by Cottingham et al. (2013b) arise in the Broken River.

Table 19: Rates of Rise (current day's flow as % of previous day's flow). The ranges (0-1000 ML/d, 1000-5000 ML/d and >5000 ML/d) reflect that different rates of rise occur at different flow magnitudes.

		Percentile		
Reach	Flow	5th	Median	95th
	0-1000ML/d	102%	145%	990%
	1000-5000ML/d	101%	124%	260%
R1 current	5000+ ML/d	103%	115%	244%
	0-1000ML/d	105%	178%	1500%
	1000-5000ML/d	101%	123%	258%
R1 unimpacted	5000+ ML/d	103%	115%	244%
	0-1000ML/d	101%	115%	440%
	1000-5000ML/d	102%	131%	277%
R2 current	5000+ ML/d	102%	122%	318%
	0-1000ML/d	102%	124%	644%
	1000-5000ML/d	102%	132%	271%
R2 unimpacted	5000+ ML/d	102%	122%	289%
	0-1000ML/d	100%	111%	251%
	1000-5000ML/d	102%	129%	264%
R3 current	5000+ ML/d	103%	124%	296%
	0-1000ML/d	101%	119%	482%
	1000-5000ML/d	102%	131%	277%
R3unimpacted	5000+ ML/d	102%	127%	354%

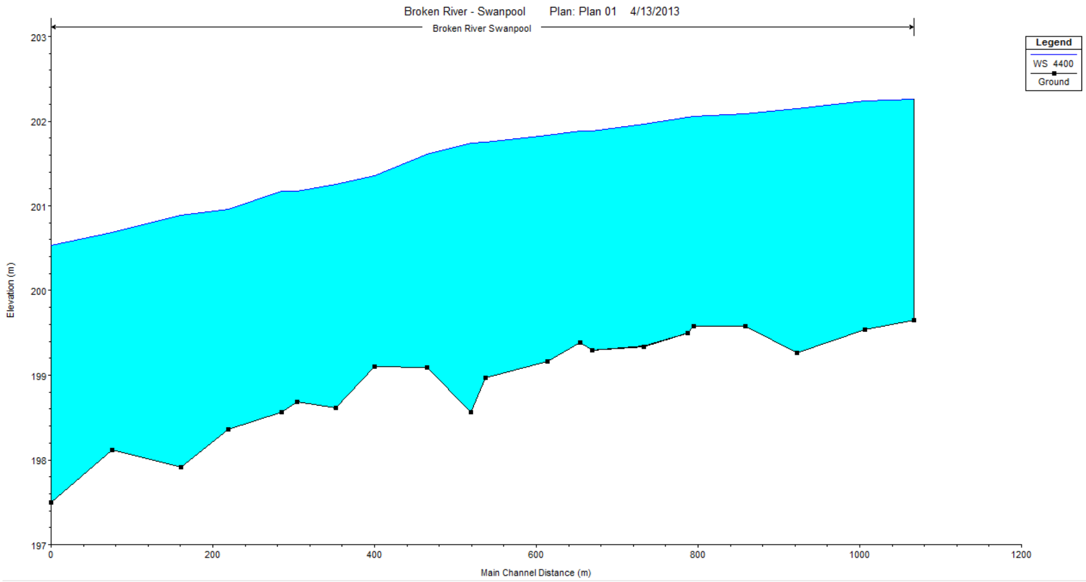
Table 20: Rates of Fall (current day's flow as % of previous day's flow). The ranges (0-1000 ML/d, 1000-5000 ML/d and >5000 ML/d) reflect that different rates of fall occur at different flow magnitudes.

		Percentile		
Reach	Flow	5th	Median	95th
R1 current	0-1000ML/d	68%	91%	98%
	1000-5000ML/d	68%	77%	94%
	5000+ ML/d	66%	70%	80%
R1 unimpacted	0-1000ML/d	72%	88%	96%
	1000-5000ML/d	68%	77%	94%
	5000+ ML/d	66%	71%	80%
R2 current	0-1000ML/d	67%	95%	99%
	1000-5000ML/d	57%	82%	96%
	5000+ ML/d	50%	72%	96%
R2 unimpacted	0-1000ML/d	69%	93%	98%
	1000-5000ML/d	59%	82%	96%
	5000+ ML/d	50%	71%	96%
R3 current	0-1000ML/d	68%	95%	99%
	1000-5000ML/d	51%	83%	96%
	5000+ ML/d	47%	71%	94%
R3unimpacted	0-1000ML/d	72%	94%	98%
	1000-5000ML/d	59%	84%	96%
	5000+ ML/d	50%	72%	95%

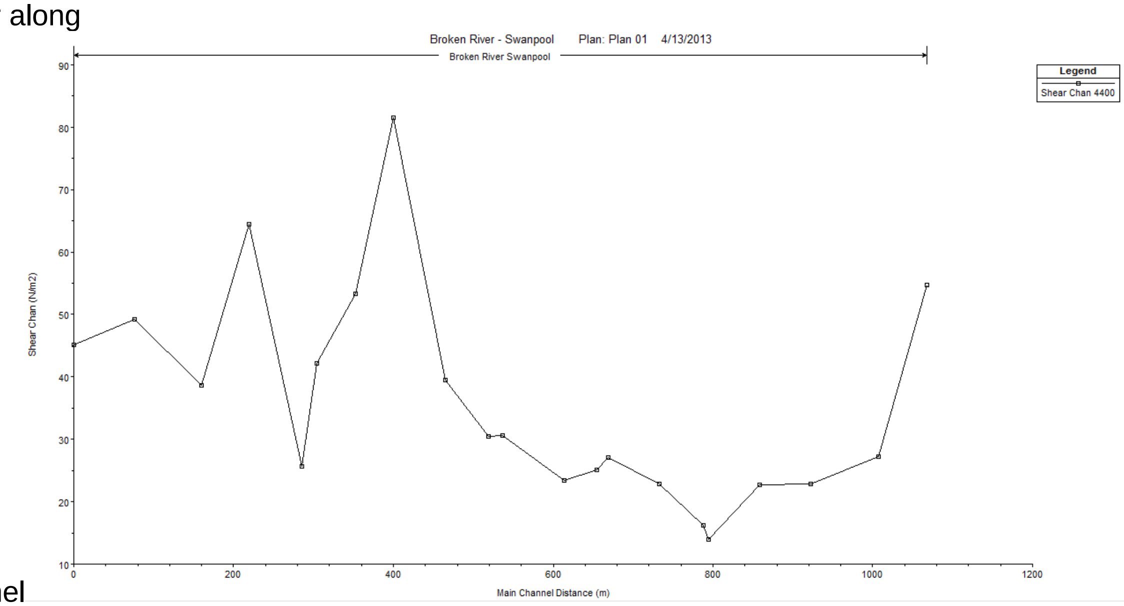
17 APPENDIX 3: HECRAS JUSTIFICATIONS FOR FLOW RECOMMENDATIONS

Meeting objectives G3 and R1 (4400 ML/d)

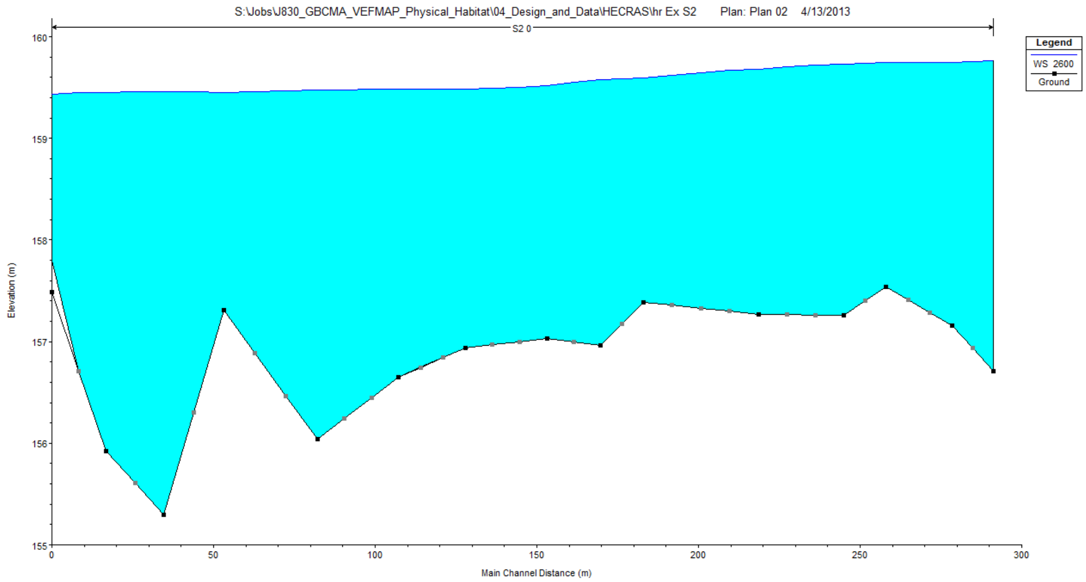
Pools

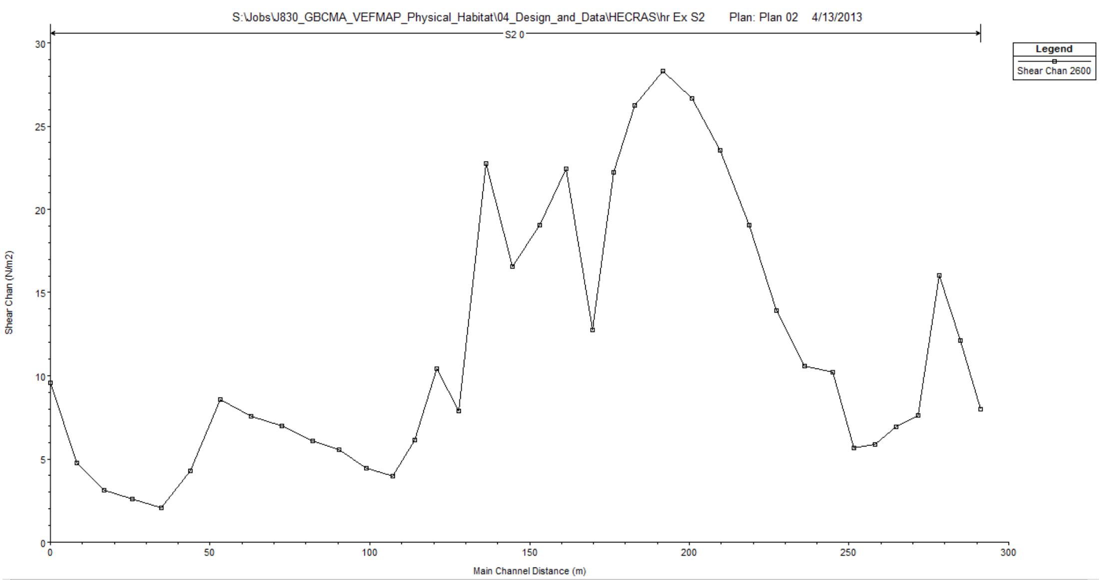


Shear along channel

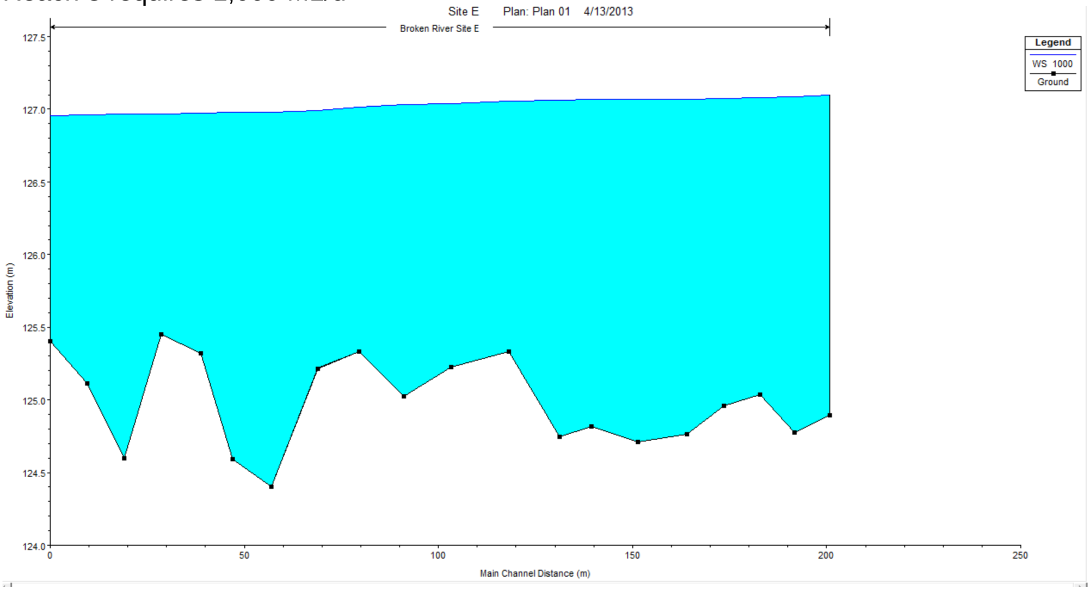


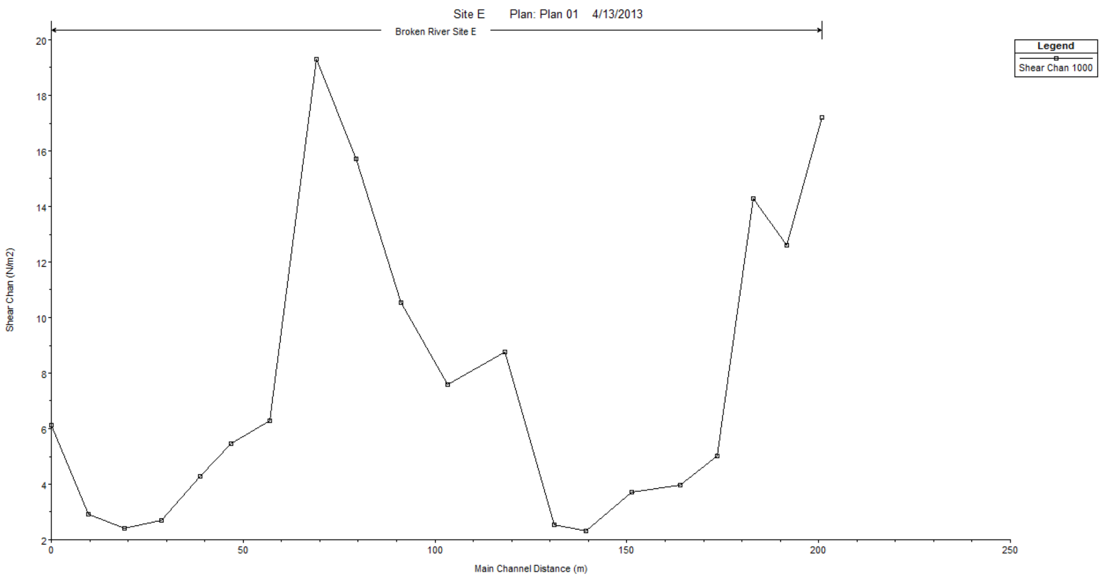
Reach 2 requires 2,600 ML/d





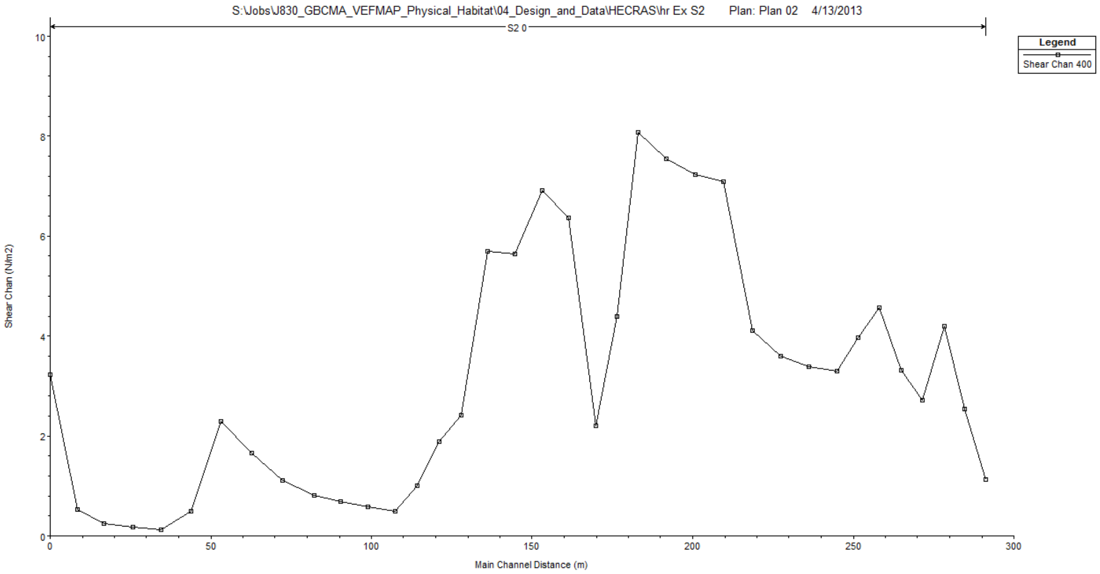
Reach 3 requires 1,000 ML/d



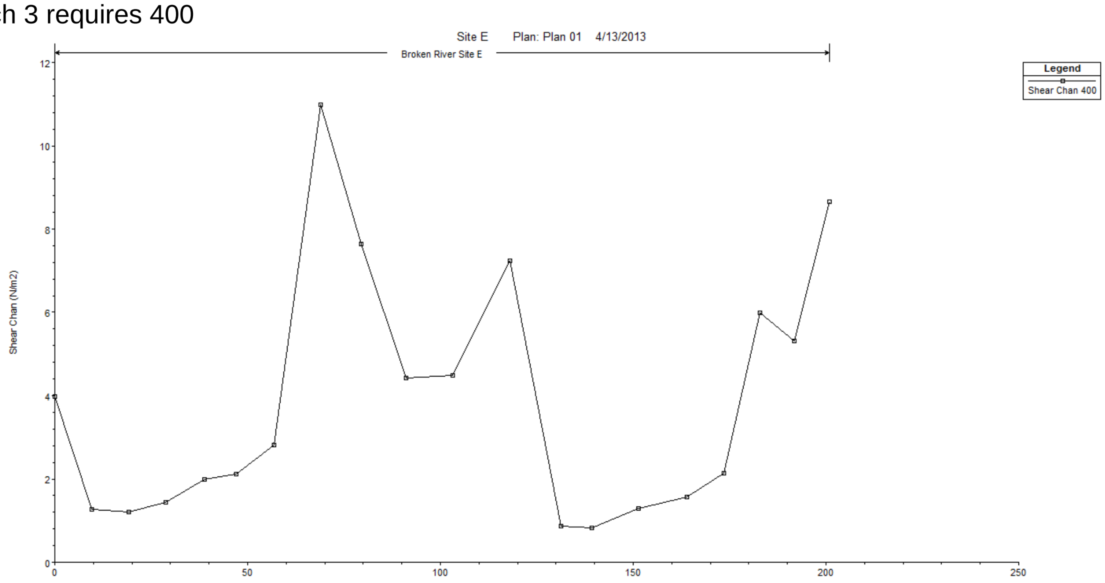


Meeting Objective G4

Reach 2 requires 400 ML/d



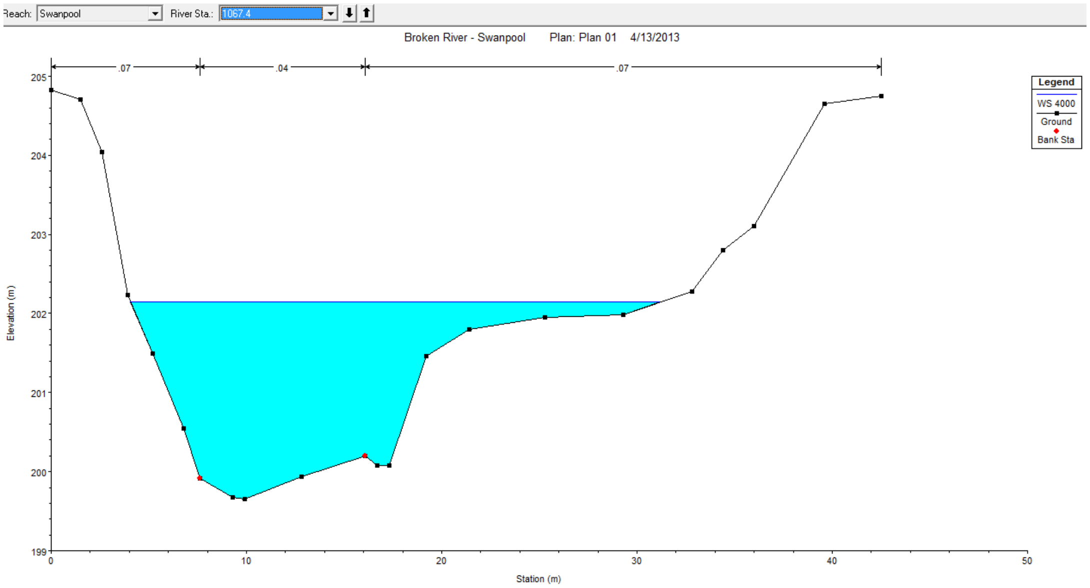
Reach 3 requires 400

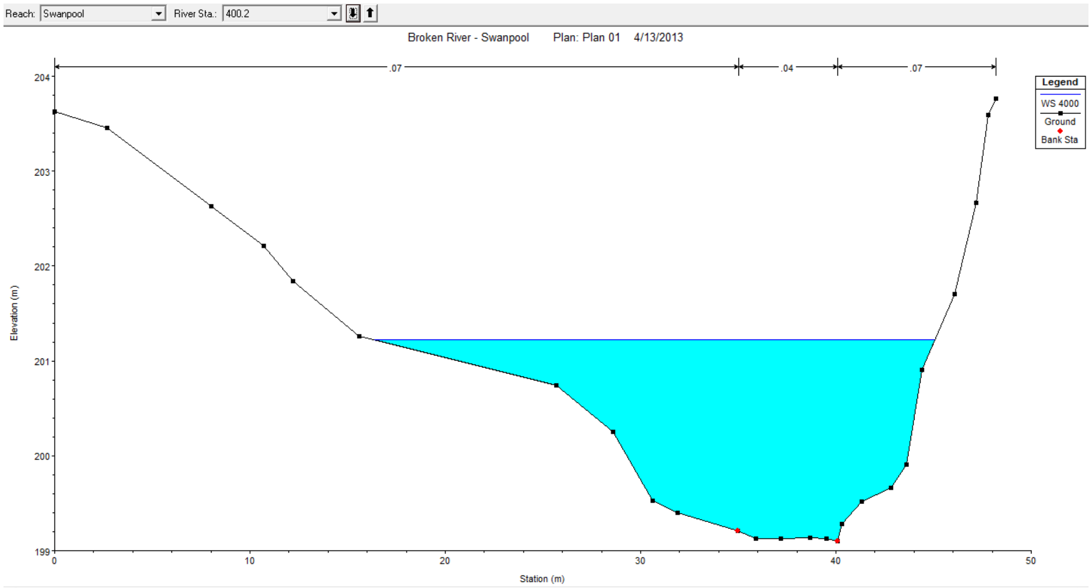


ML/d.

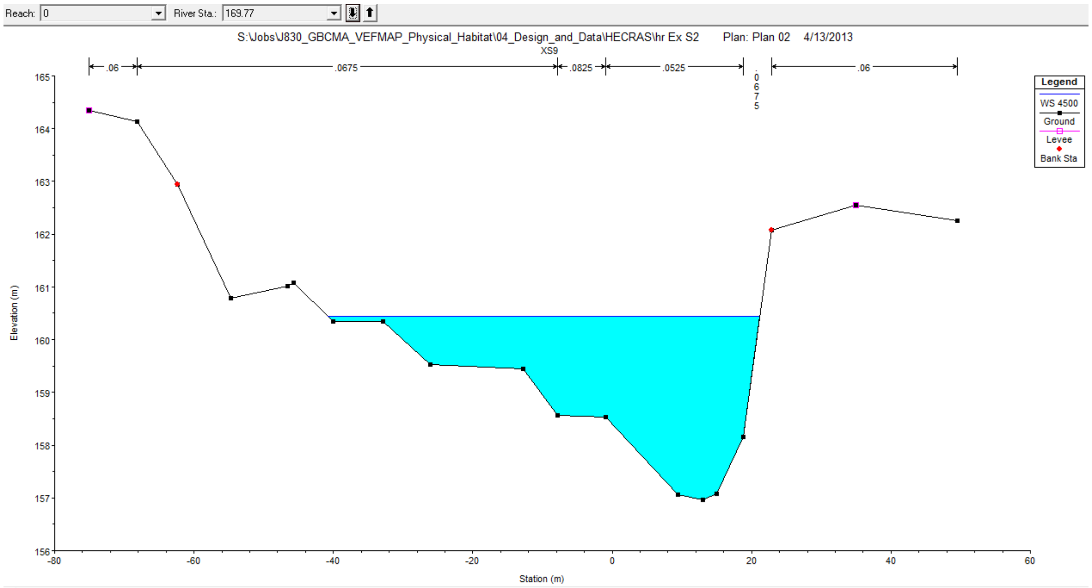
Meeting Objective G5

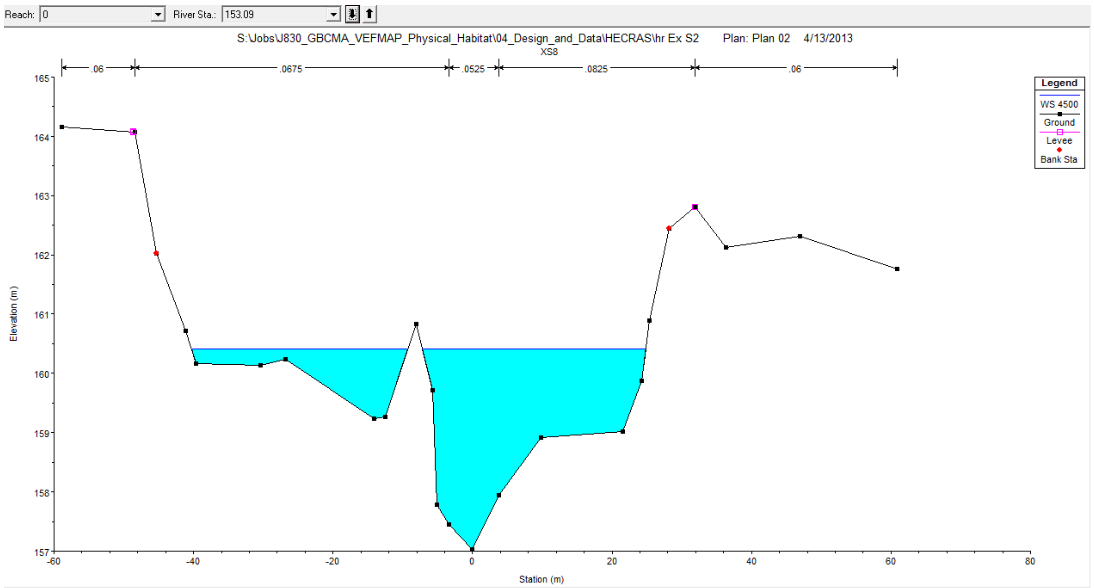
Reach 1 requires 4,000 ML/d (wets highest bench in the model and provide > 0.5 m depth over many benches to maintain bench form)

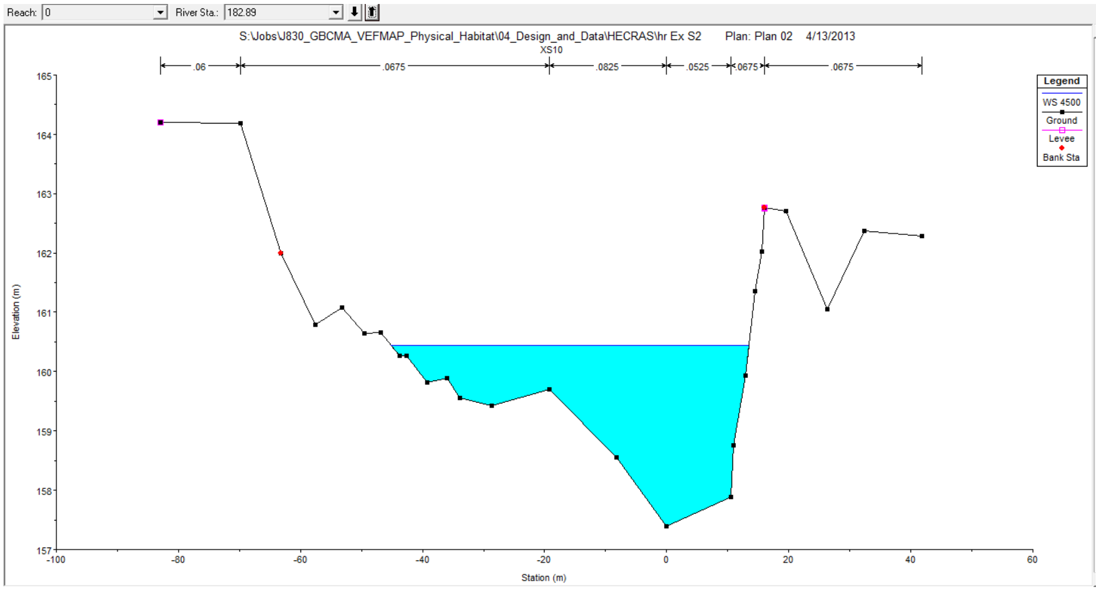


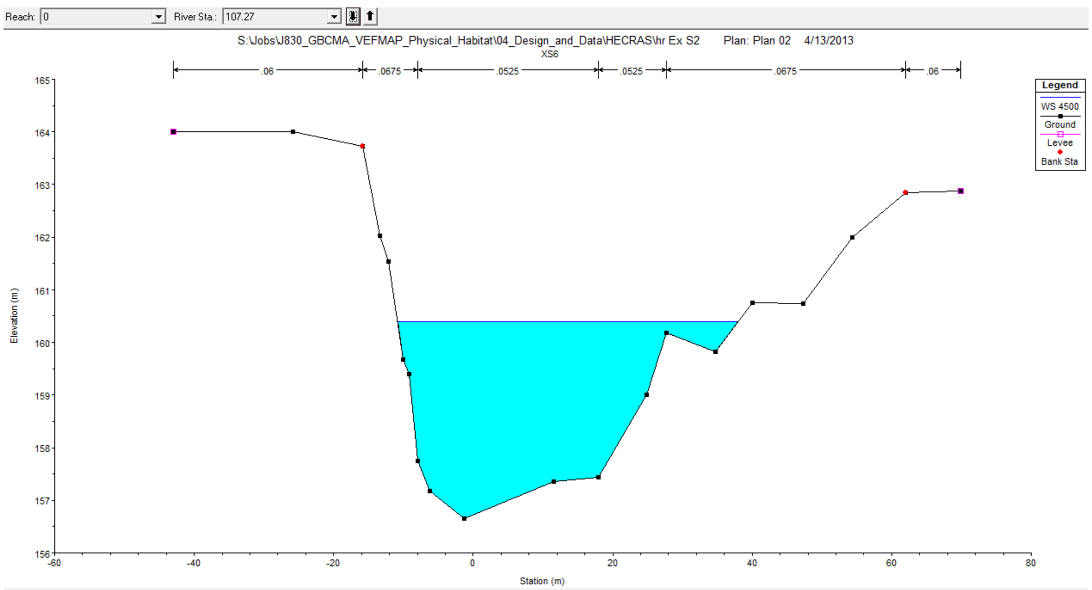


Reach 2 requires 4,500 Ml/d





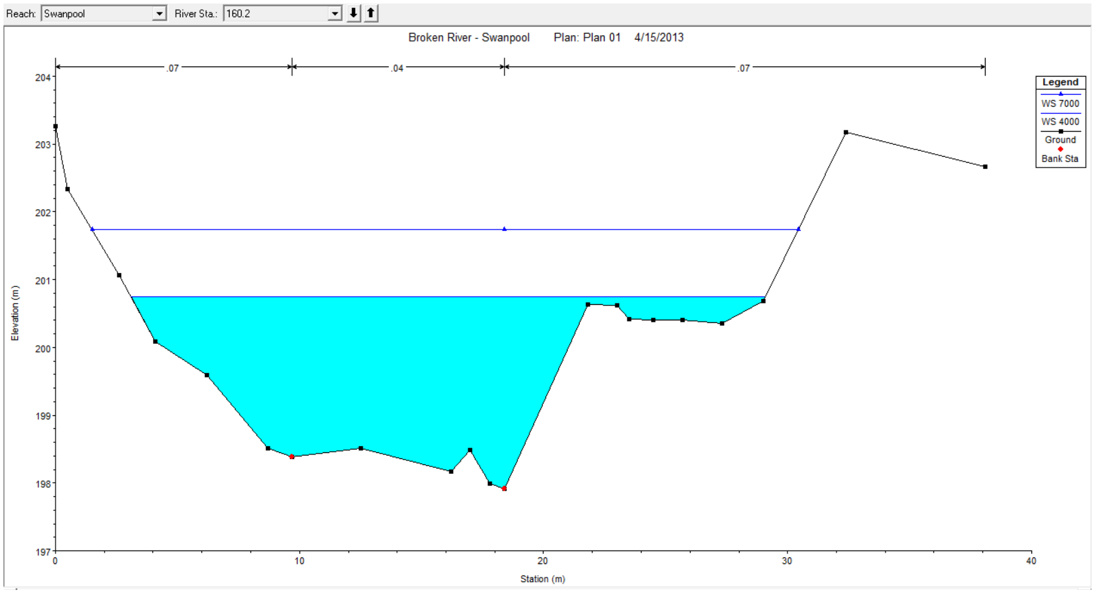


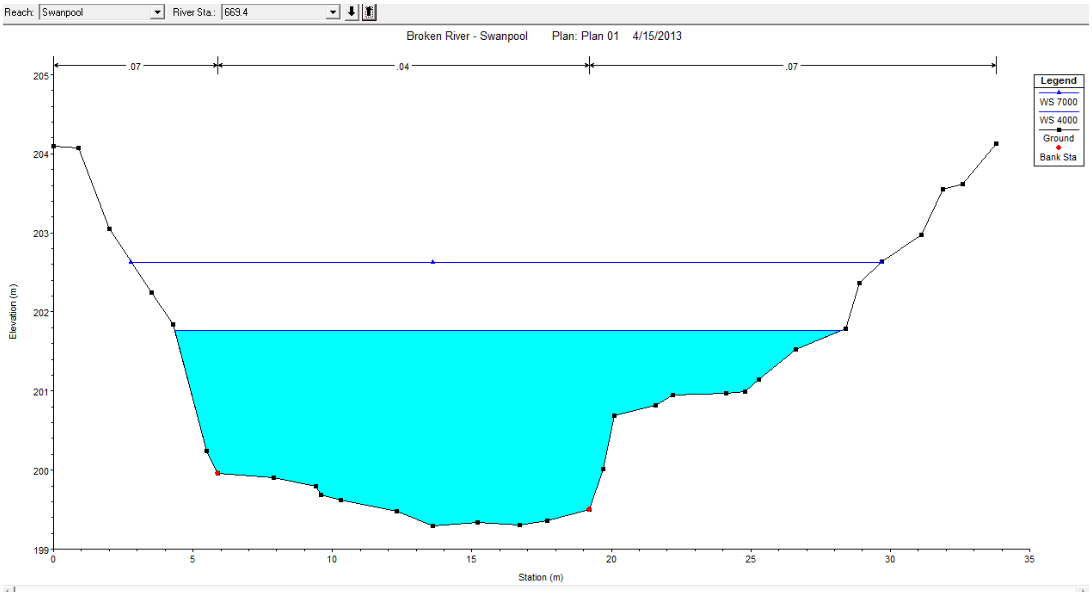


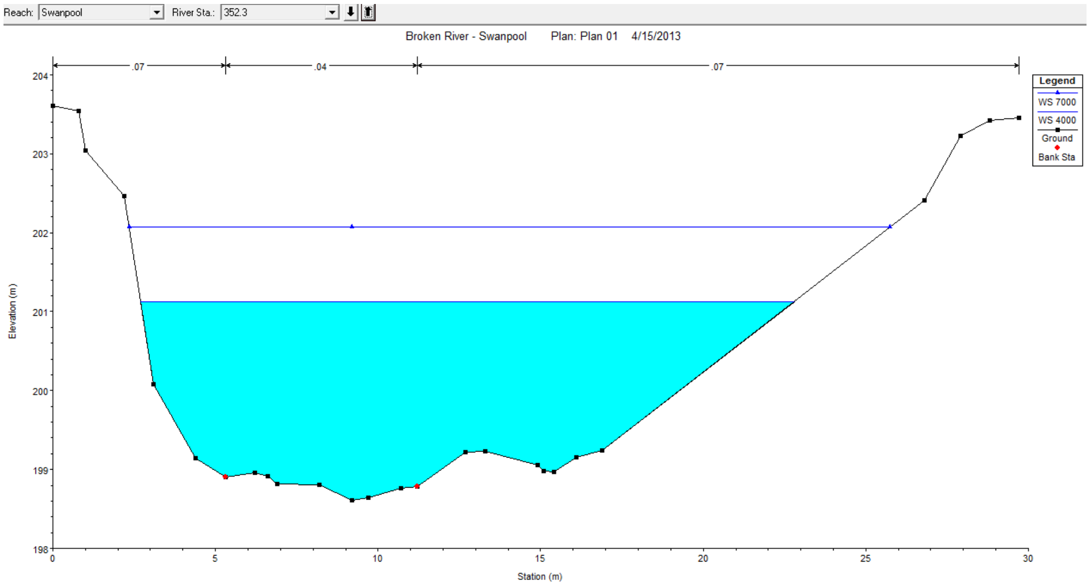
Reach 3 there are few pronounced benches. – preservation of flows from Reach 2

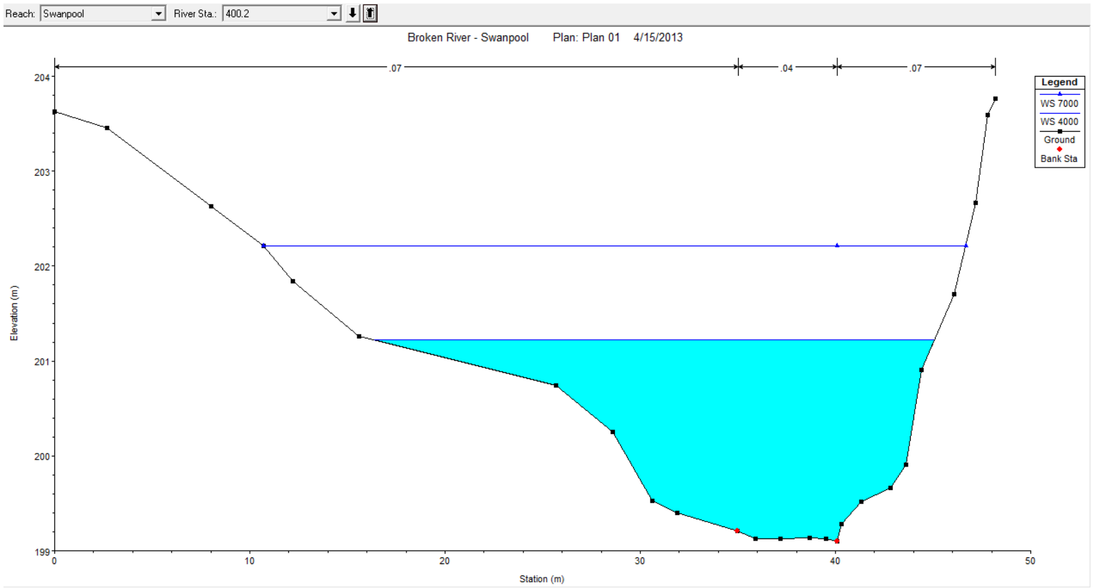
Meeting Objective R1

Reach 1: freshes# of 4,000 – 7,000 ML/d

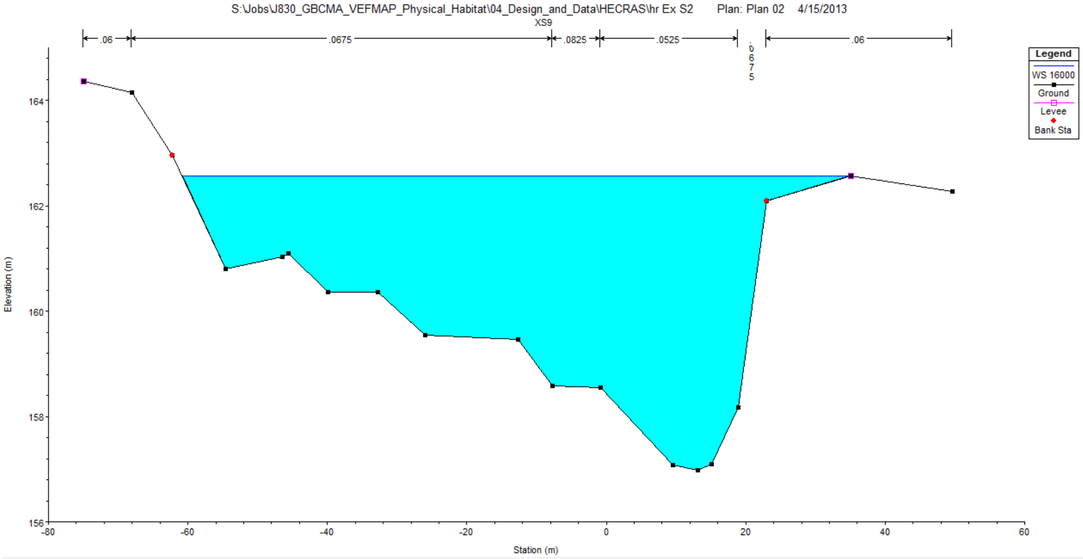


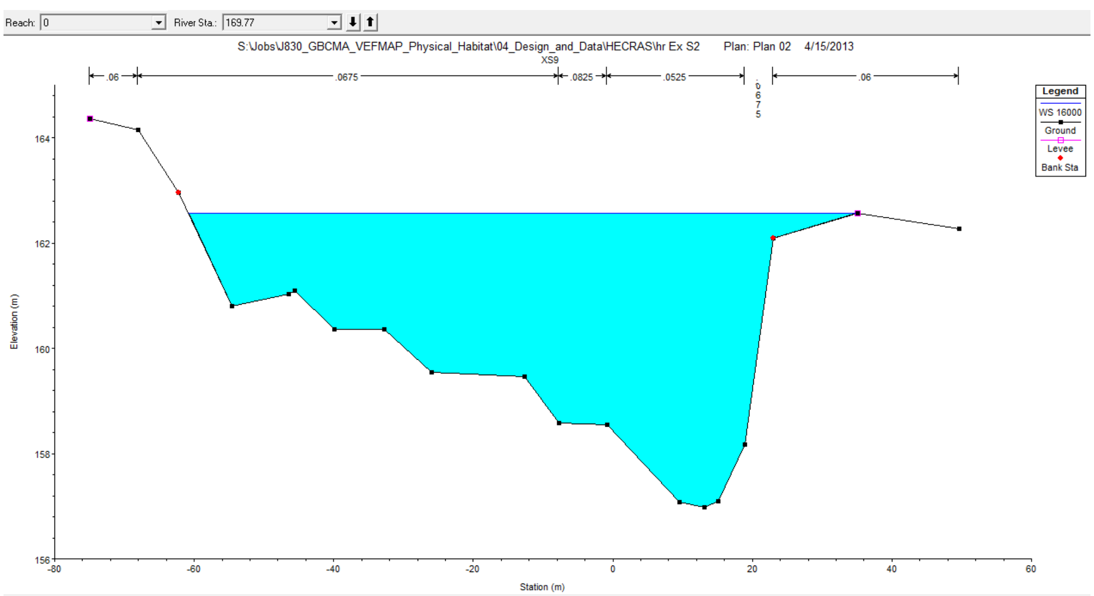


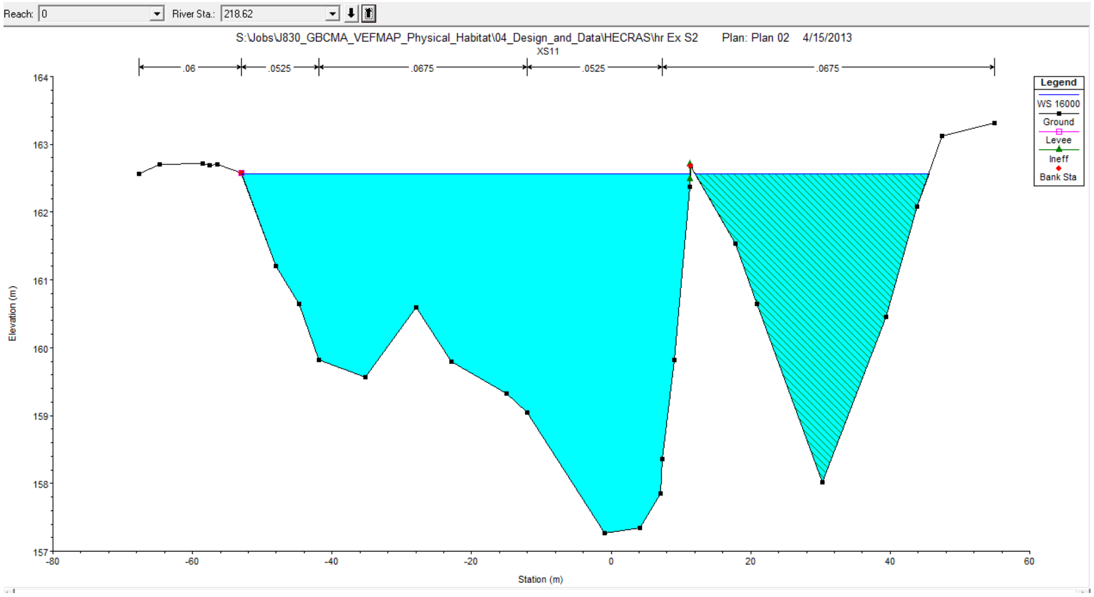

Reach: Swanpool
River Sta.: 352.3
Broken River - Swanpool Plan: Plan 01 4/15/2013
.07
.04
.07
Legend
WS 7000
WS 4000
Ground
Bank Sta
Elevation (m)
Station (m)

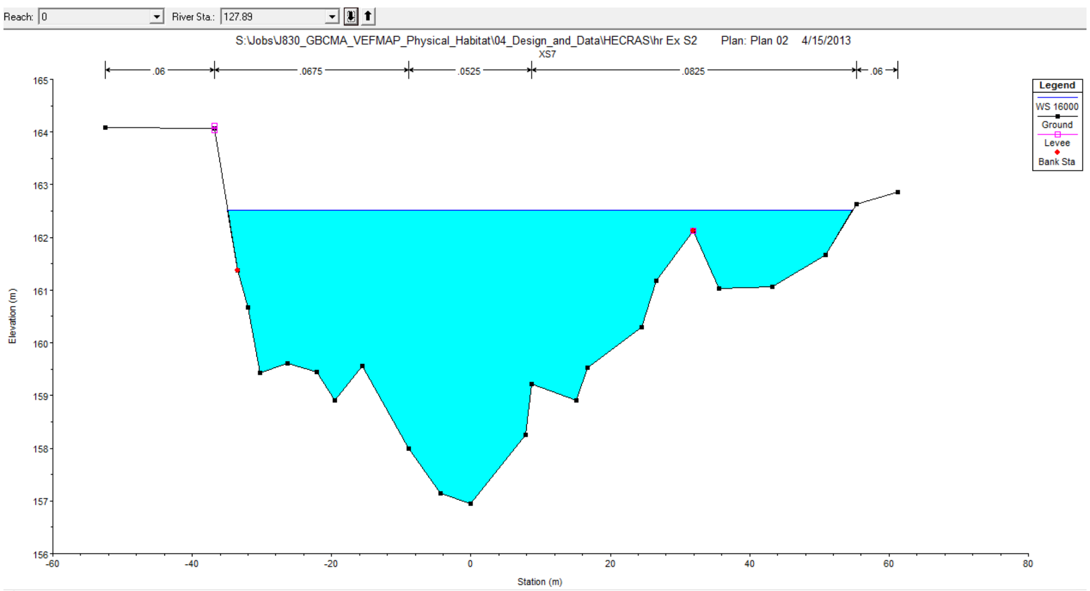

Reach: Swanpool
River Sta.: 400.2
Broken River - Swanpool Plan: Plan 01 4/15/2013
.07
.04
.07
Legend
WS 7000
WS 4000
Ground
Bank Sta
Elevation (m)
Station (m)

Reach 2: bankfull of 16,000 ML/d

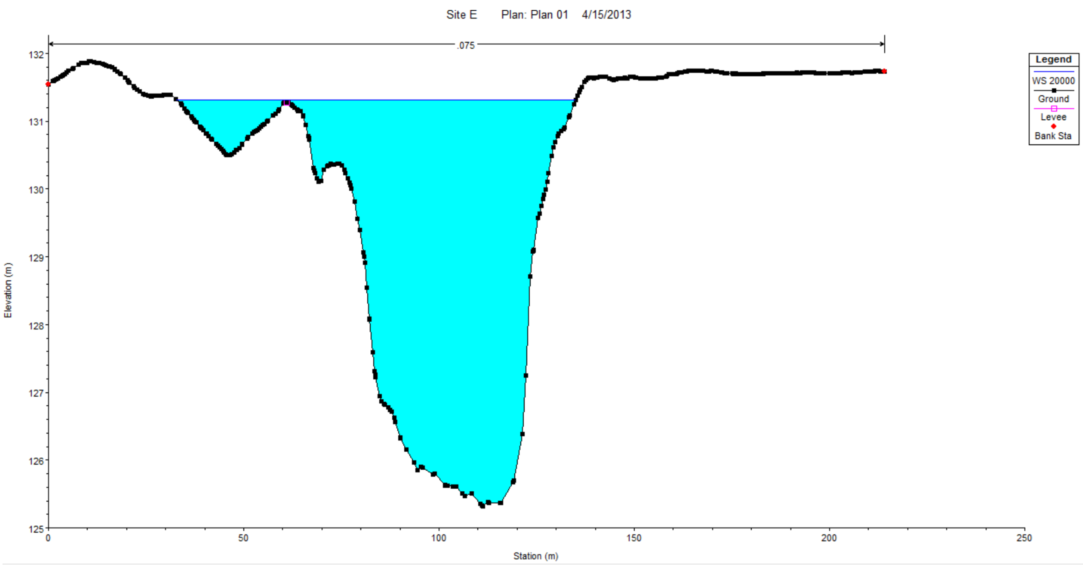


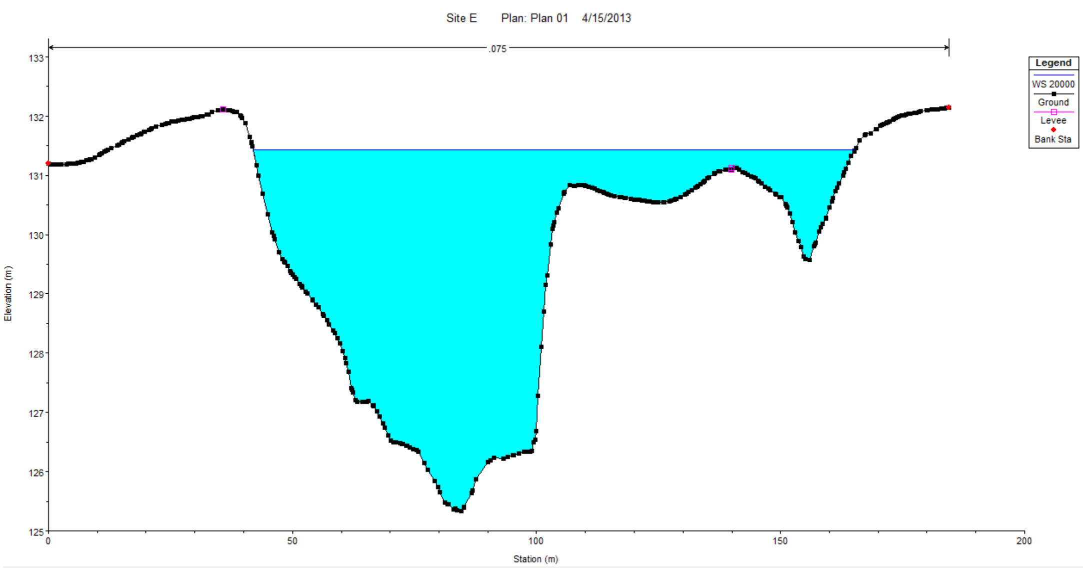


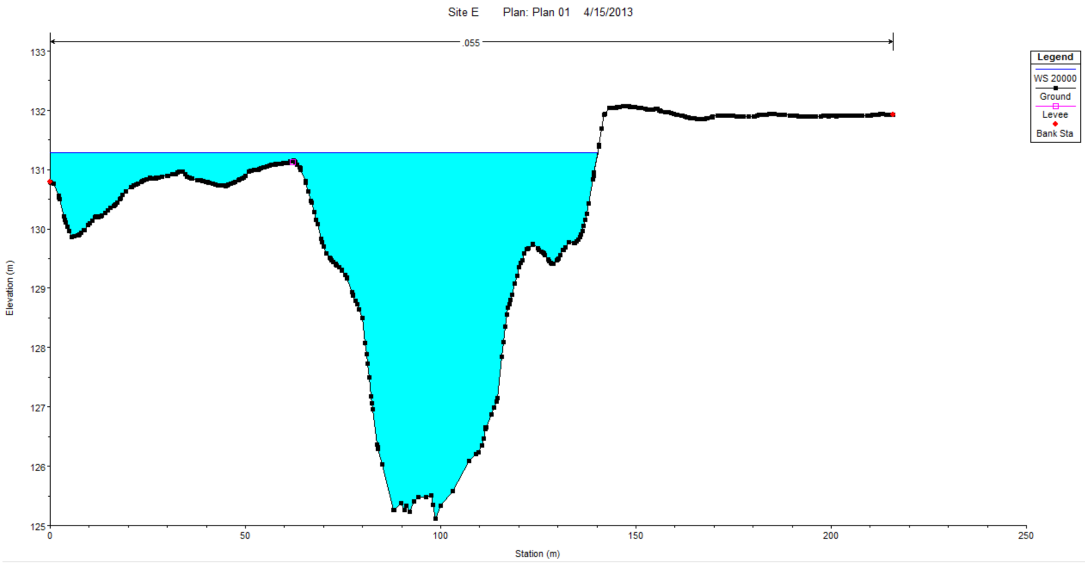

Reach: 0
River Sta.: 218.62
S:\Jobs\J830_GBCMA_VEFMAP_Physical_Habitat\04_Design_and_Data\HECRAS\hr Ex S2 Plan: Plan 02 4/15/2013
XS11
.06
.0525
.0675
.0525
.0675
Legend
WS 16000
Ground
Levee
Ineff
Bank Sta
Elevation (m)
Station (m)


Reach: 0
River Sta.: 127.89
S:\Jobs\J830_GBCMA_VEFMAP_Physical_Habitat\04_Design_and_Data\HECRAS\hr Ex S2 Plan: Plan 02 4/15/2013
XS7
.06
.0675
.0525
.0825
.06
Legend
WS 16000
Ground
Levee
Bank Sta
Elevation (m)
Station (m)

Reach 3: bankfull of 20,000 ML/d





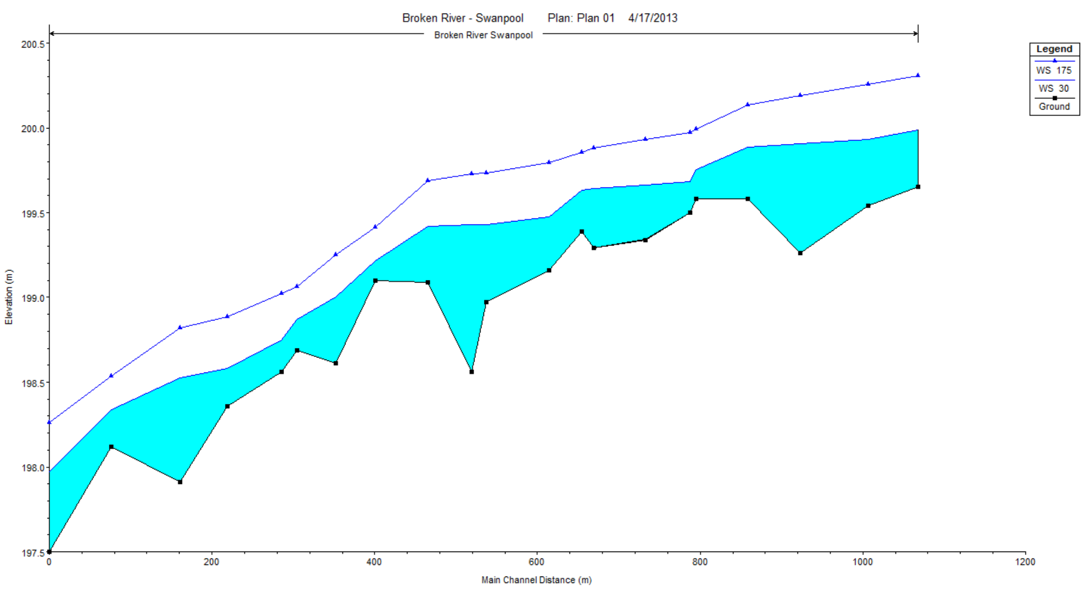


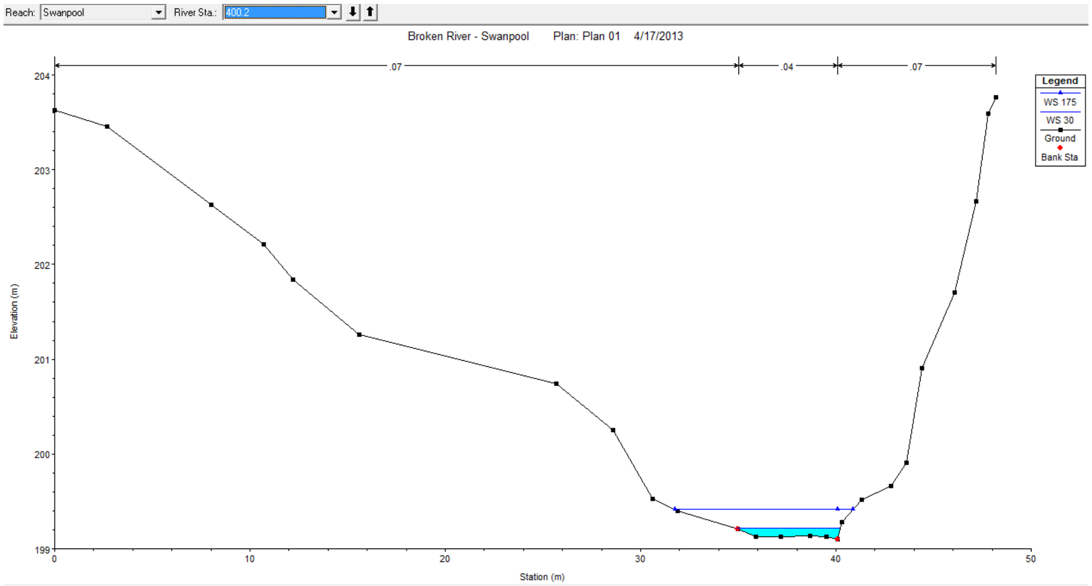
Meeting Objective W1

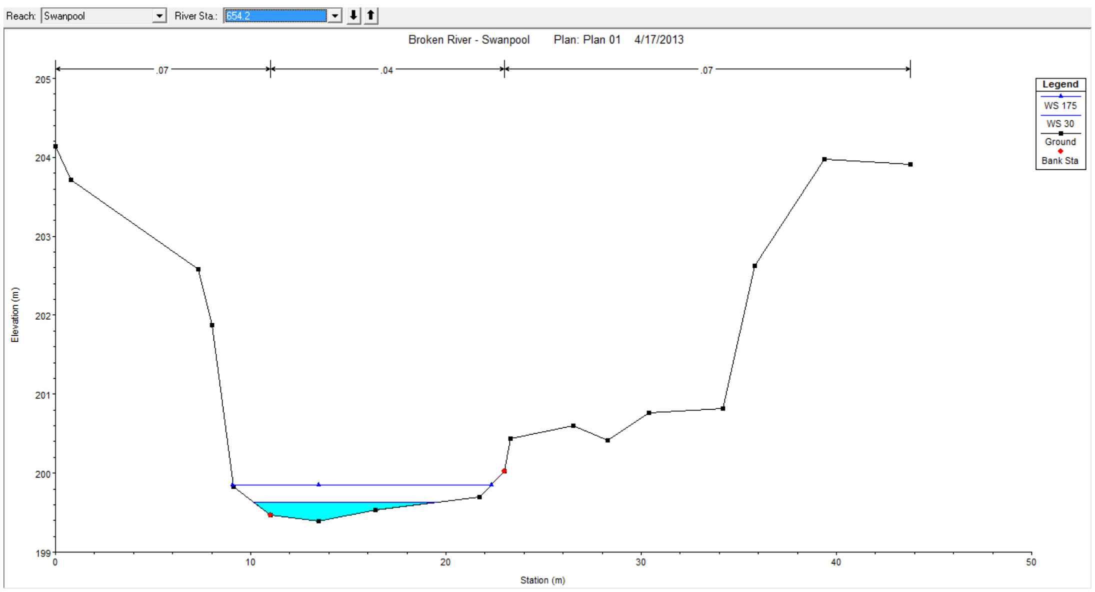
Based on Sammonds et al. (in press)

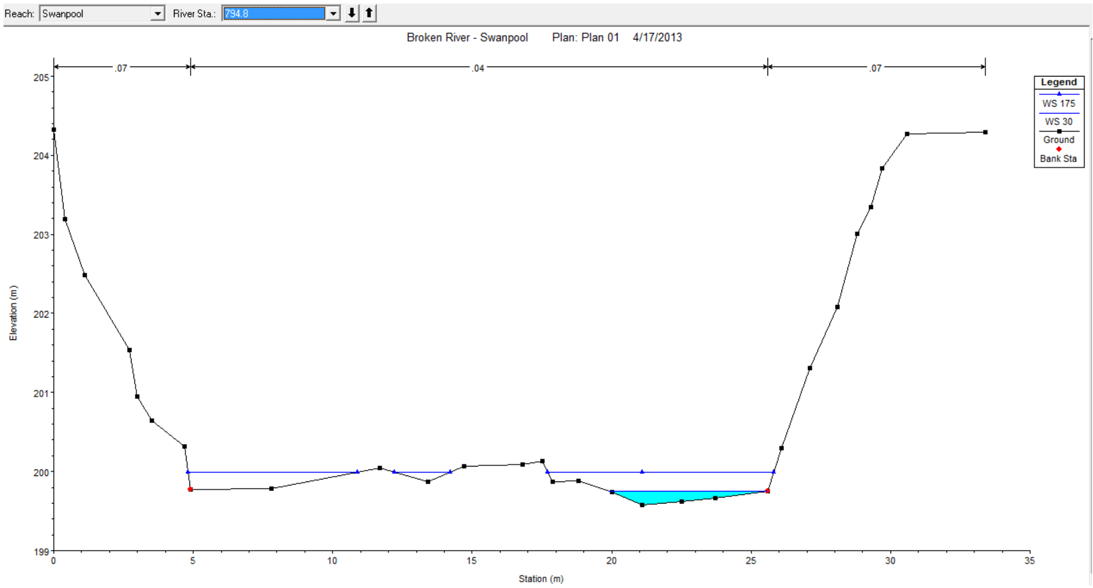
W2 – As for R1

IC1 – 30 to 175 ML/d in R1




Reach: Swanpool
River Sta.: 400.2
Broken River - Swanpool Plan: Plan 01 4/17/2013
.07
.04
.07
Legend
WS 175
WS 30
Ground
Bank Sta
Elevation (m)
Station (m)


Reach: Swanpool
River Sta.: 654.2
Broken River - Swanpool Plan: Plan 01 4/17/2013
.07
.04
.07
Legend
WS 175
WS 30
Ground
Bank Sta
Elevation (m)
Station (m)

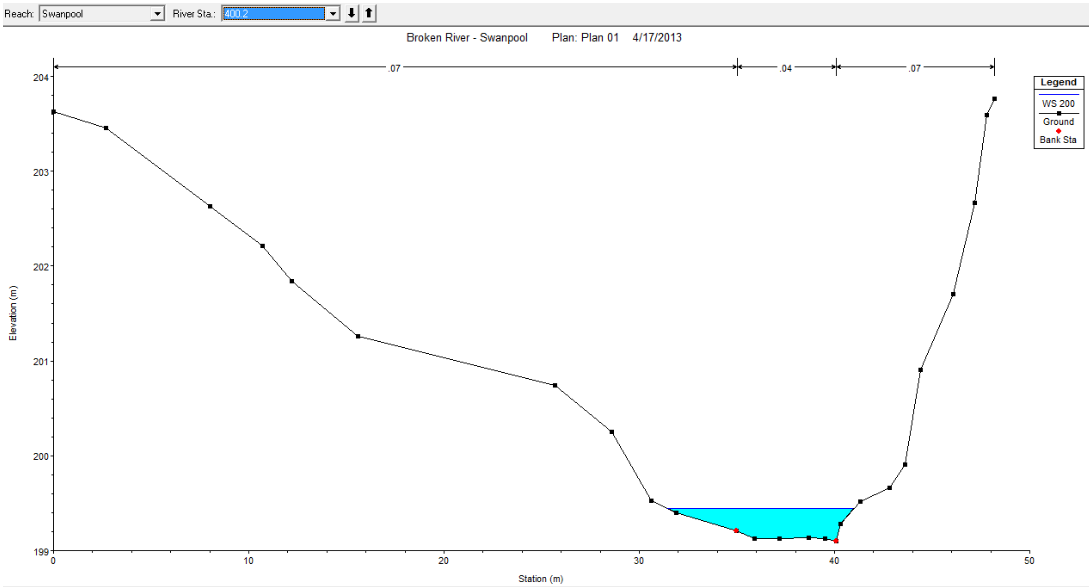


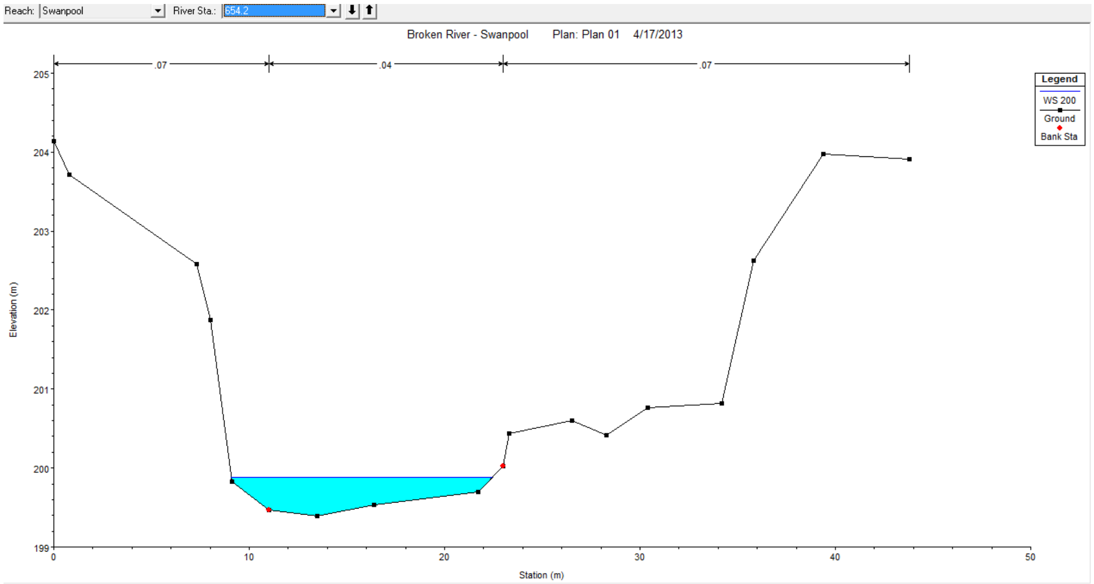
Meeting Objective IC2

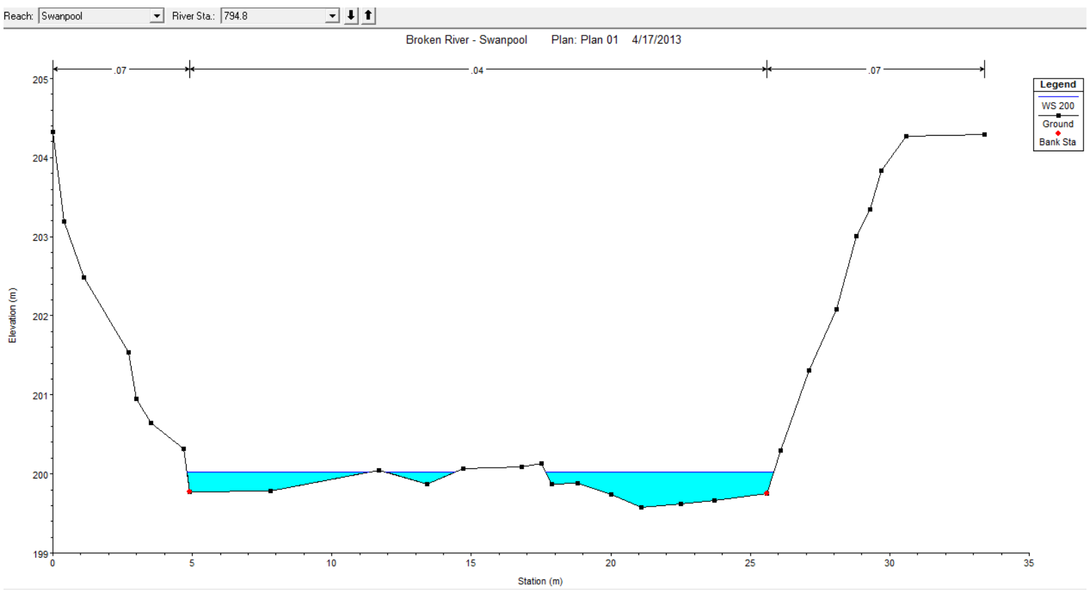
Maintain minimum water level in stream at 10 cm over cobble and gravel bars. From HECRAS:

- Winter-spring baseflow requires >200 ML/d or natural.

Reach 1

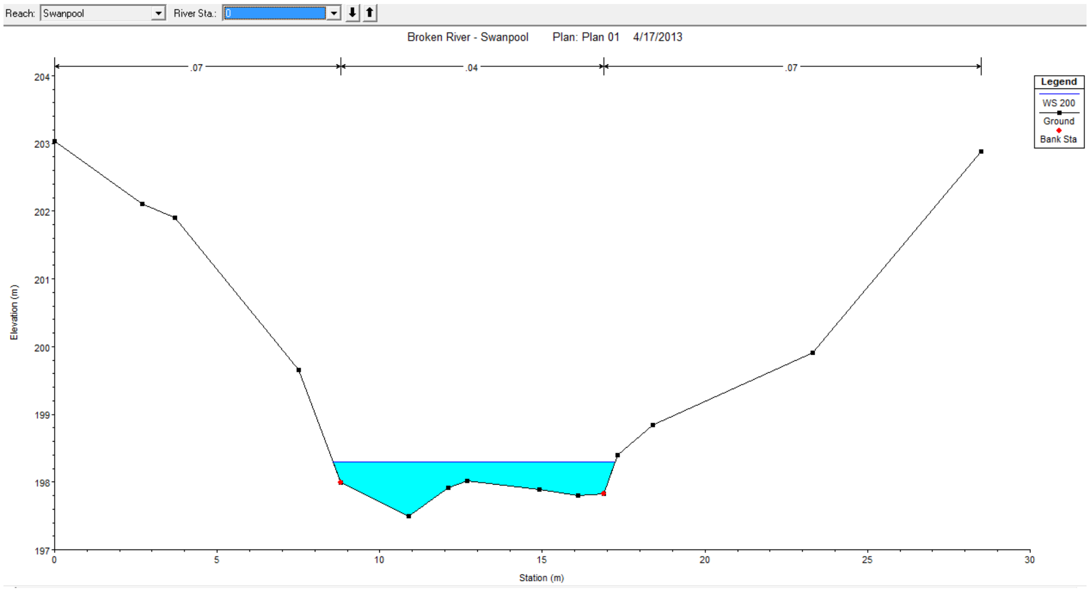


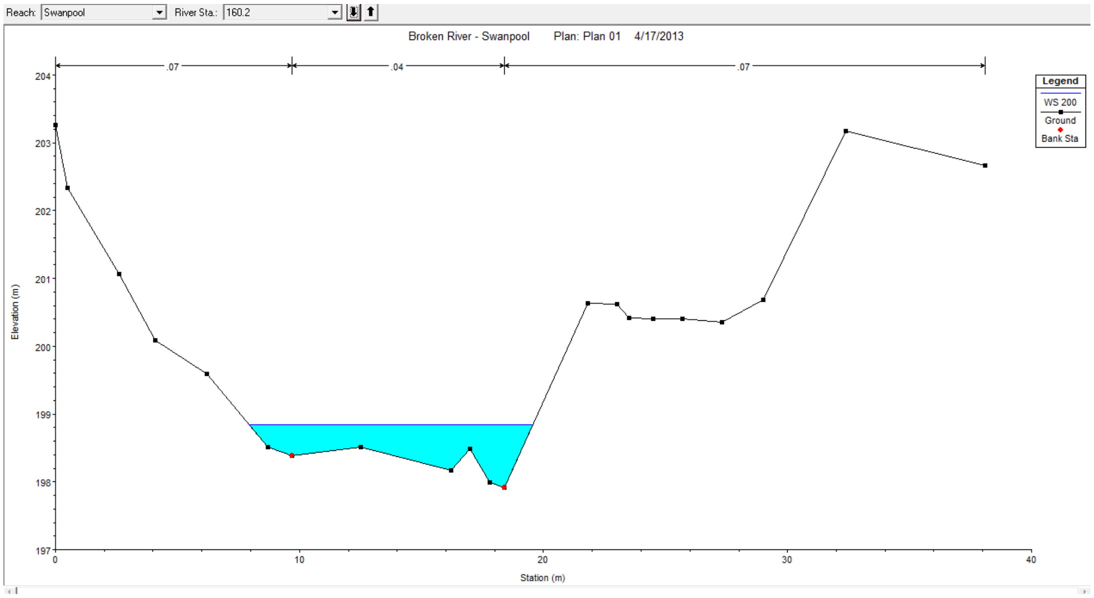

Reach: Swanpool
River Sta.: 654.2
Broken River - Swanpool Plan: Plan 01 4/17/2013
.07
.04
.07
Legend
WS 200
Ground
Bank Sta
Elevation (m)
205
204
203
202
201
200
199
0
10
20
30
40
50
Station (m)

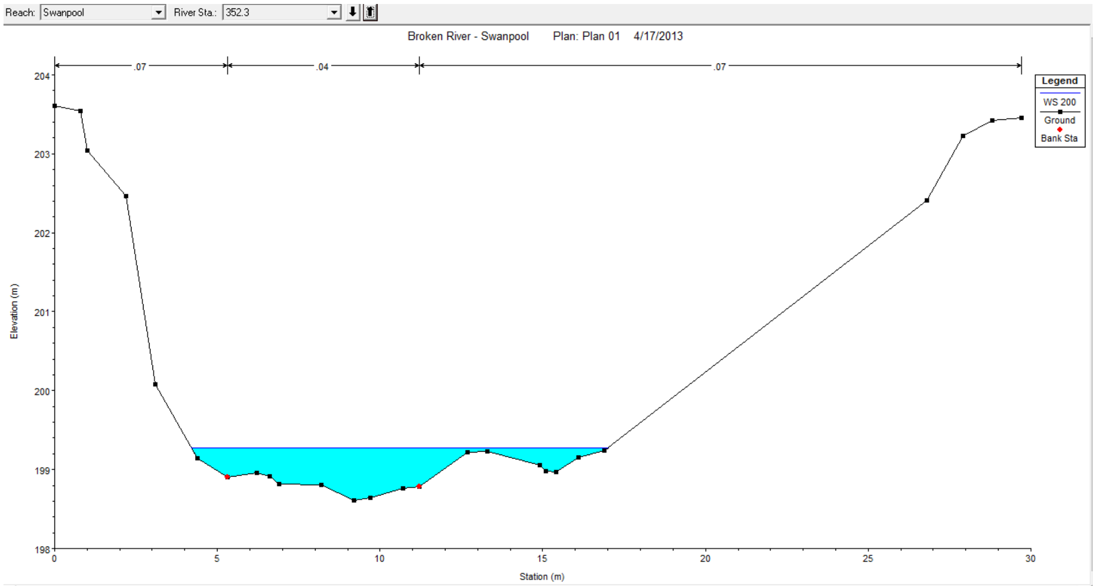

Reach: Swanpool
River Sta.: 794.8
Broken River - Swanpool Plan: Plan 01 4/17/2013
.07
.04
.07
Legend
WS 200
Ground
Bank Sta
Elevation (m)
205
204
203
202
201
200
199
0
5
10
15
20
25
30
35
Station (m)

Meeting Objective IC3 (sand bars)

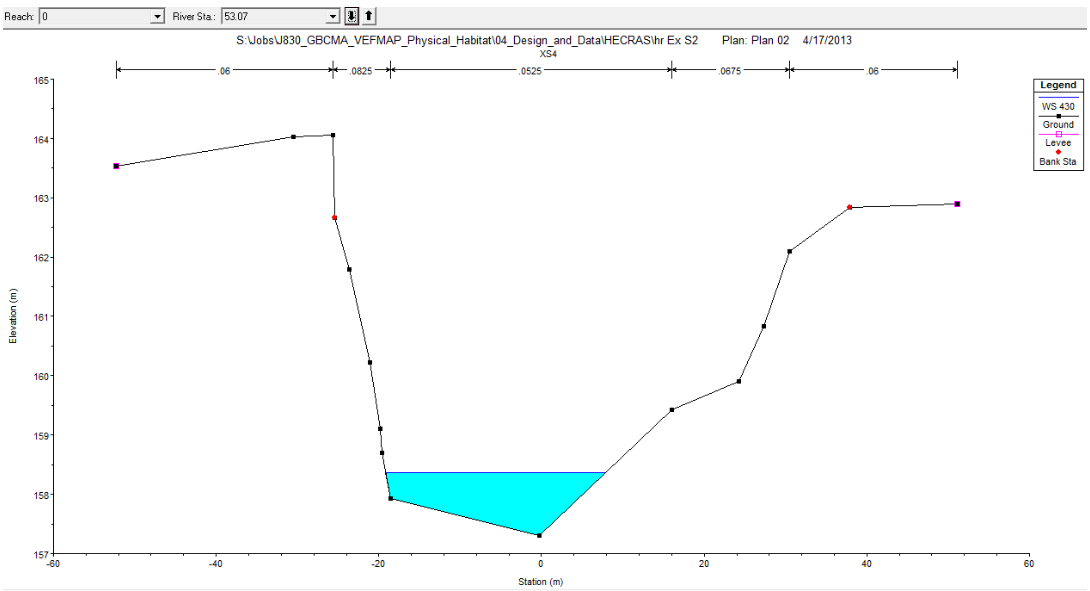
Reach 1 requires 270 ML/d

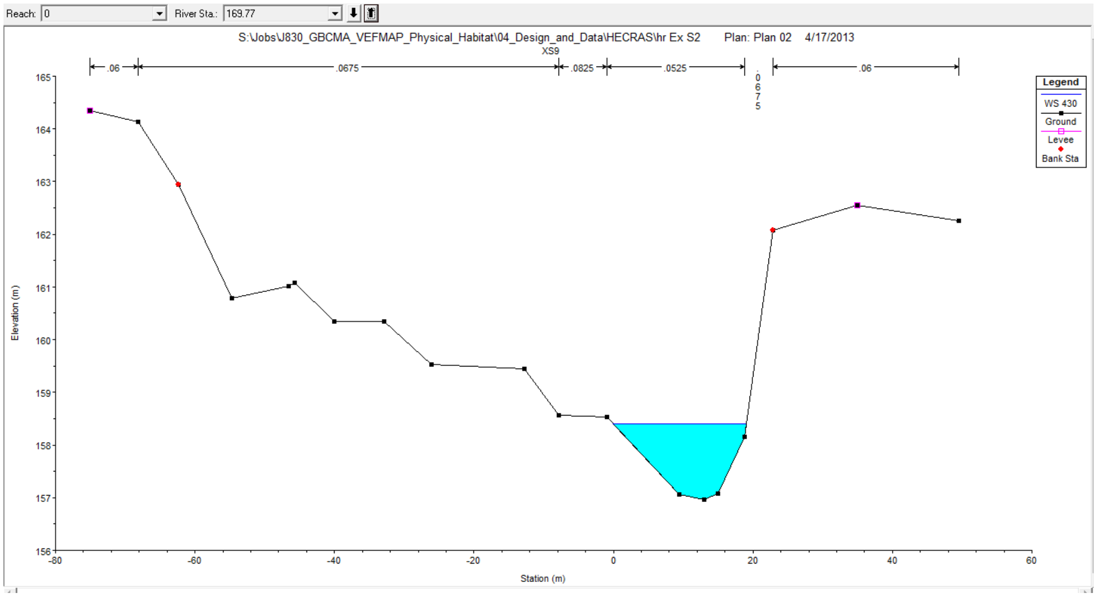




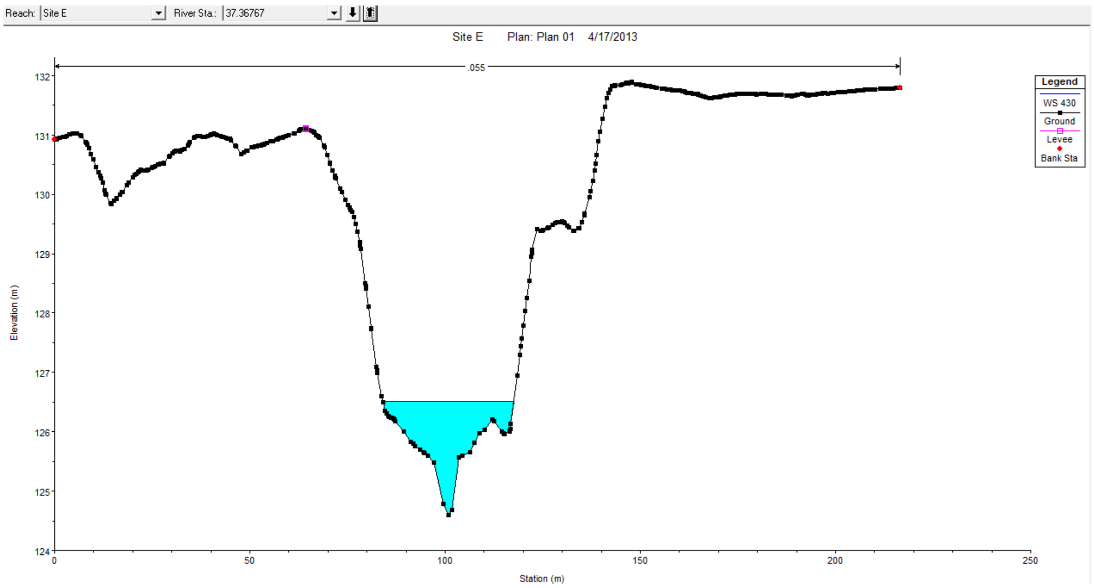


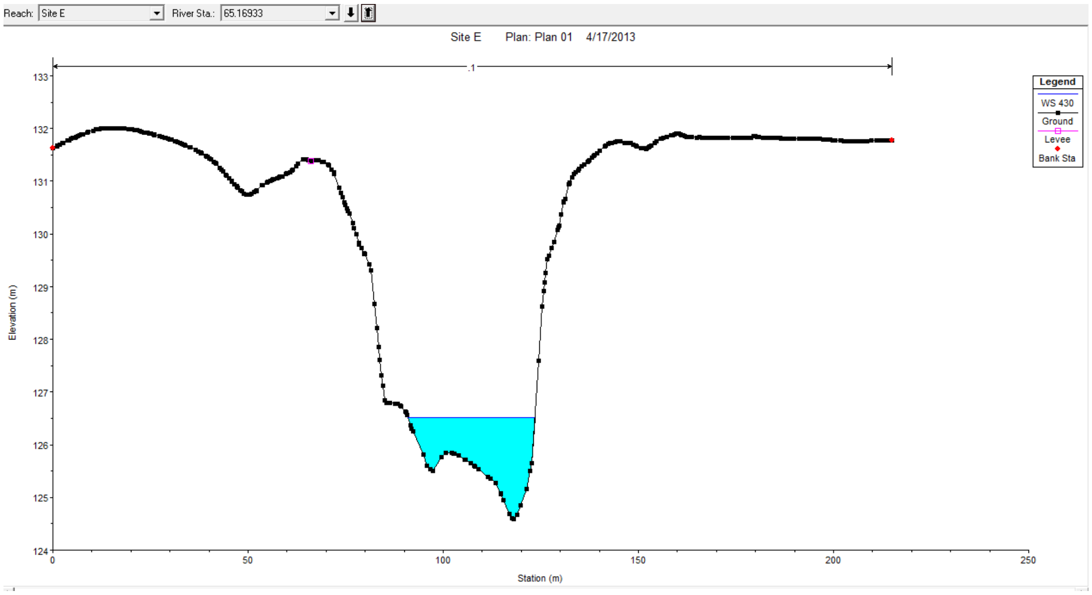
Reach 2 - features are indistinct from HECRAS, so adopt Reach 3 requirements

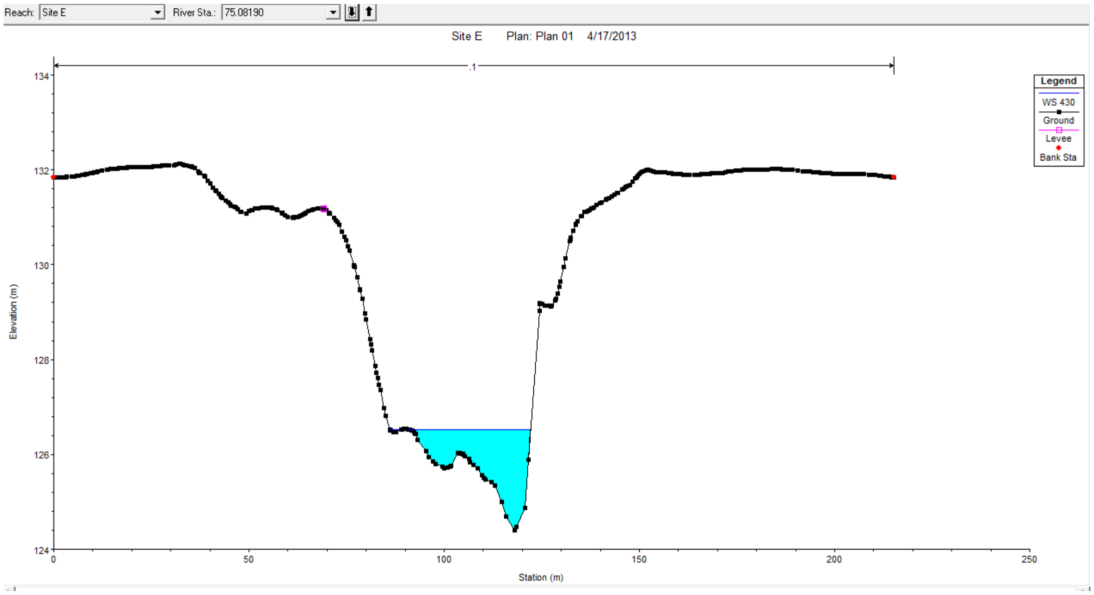




Reach 3 require 430 ML/d





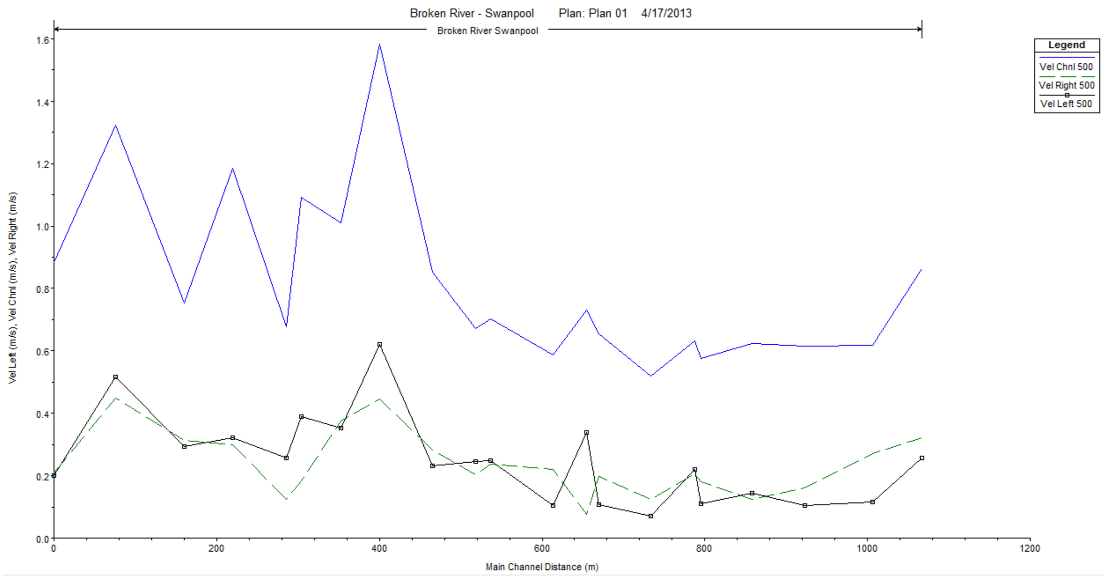


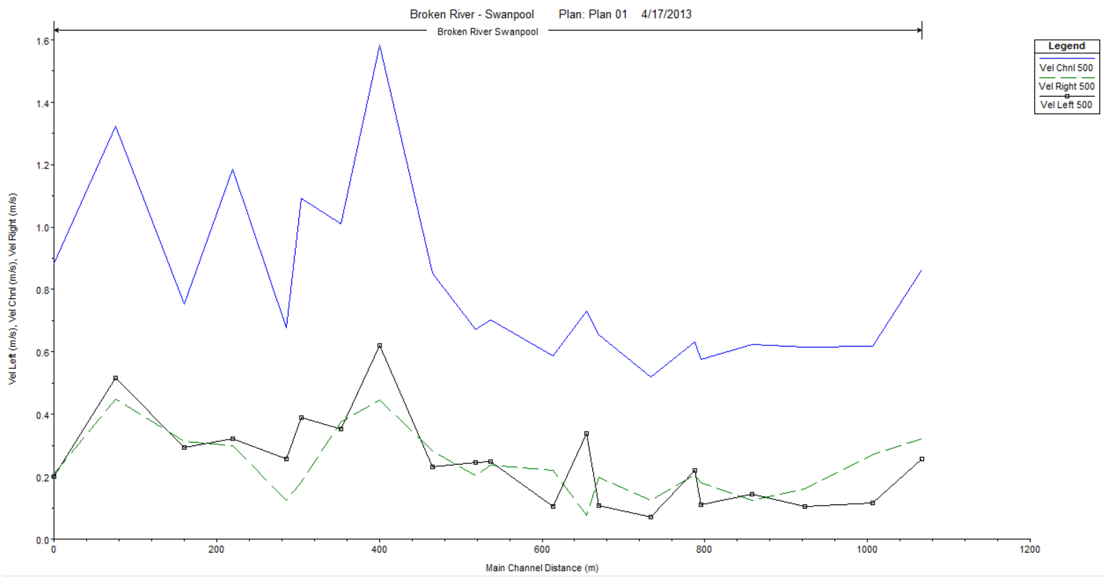
Meeting IC4

>0.6 m/s velocity for sloughing (based on Ryder et al. 2006). Based on HECRAS:

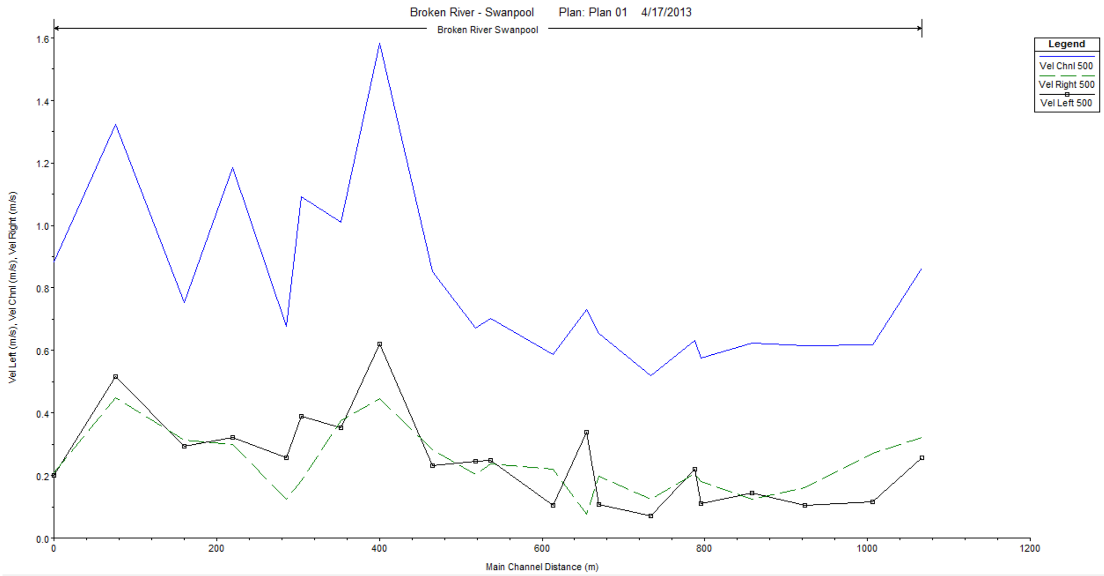
Reach 1 requires greater than 500 ML/d.

VELOCITY > 0.6 IN MAIN CHANNEL (SHOWN AS LONGITUDINAL PROFILE), CHANNEL EDGES < 0.6M





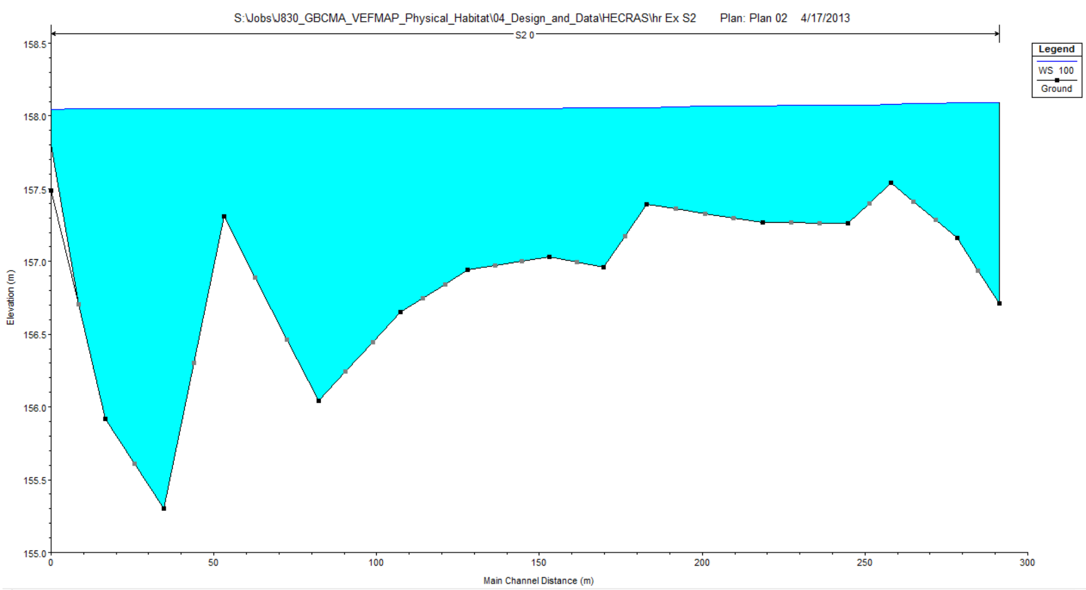
Reach 3 requires 4,300 ML/d (4,000 ML/d could also achieve the objective)



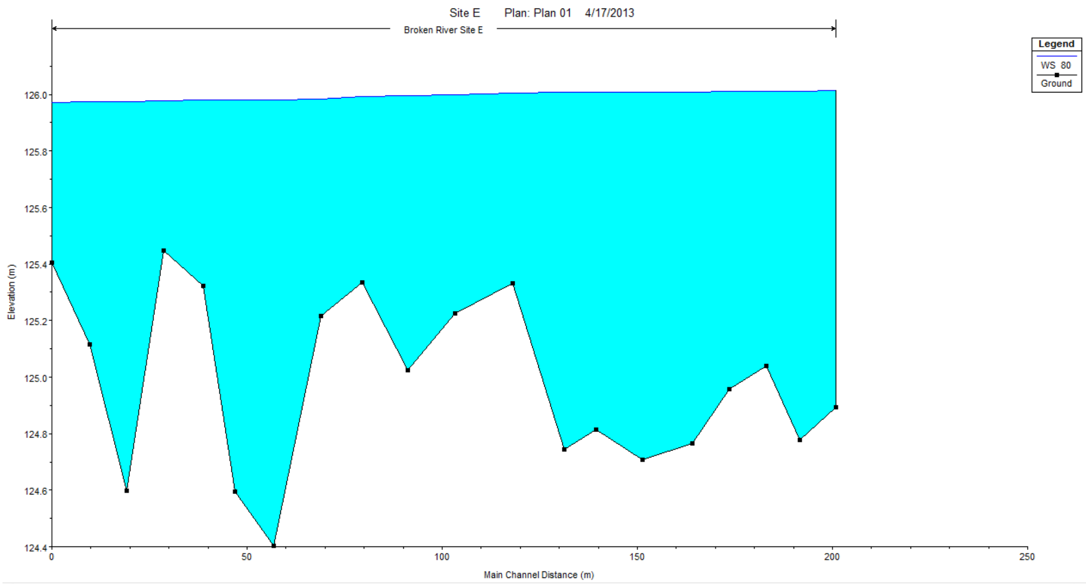
Meeting Objective IC5

Maintain 0.5 m depth in runs (Reaches 2 and 3).

From HECRAS:
Reach 2 requires 100 ML/d, or natural



Reach 3 requires 80 ML/d, or natural

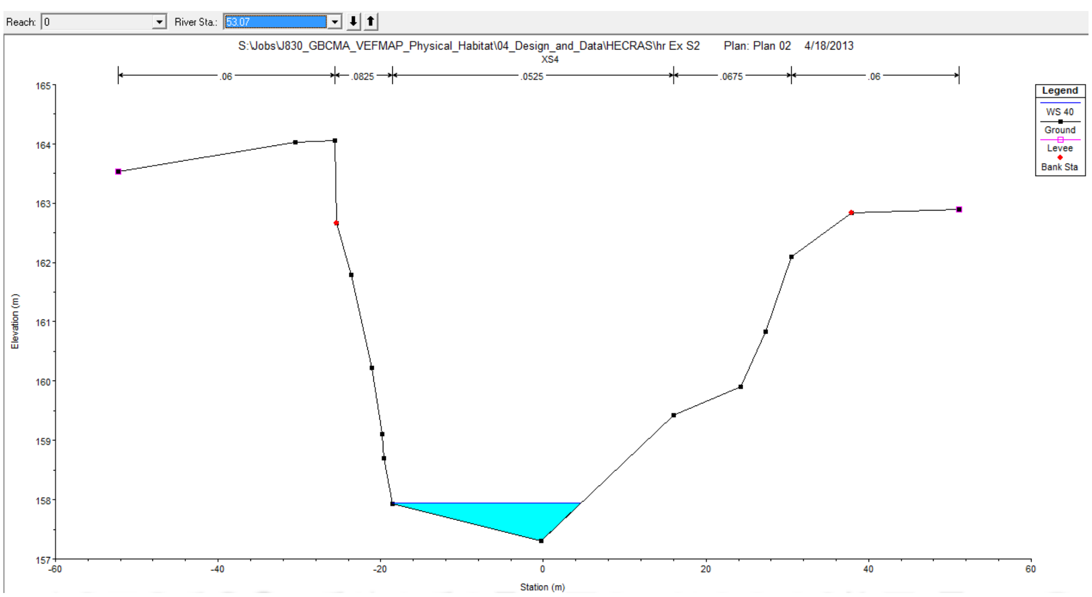


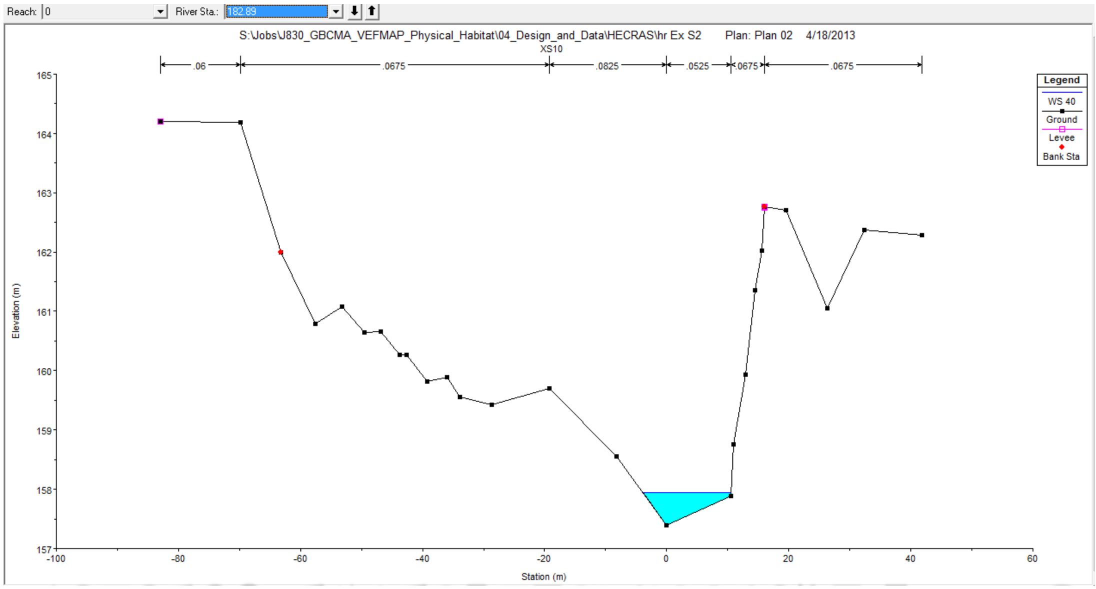
Meeting objective MI 1 - Riffles for Reach 1 and runs for Reaches 2 and 3.

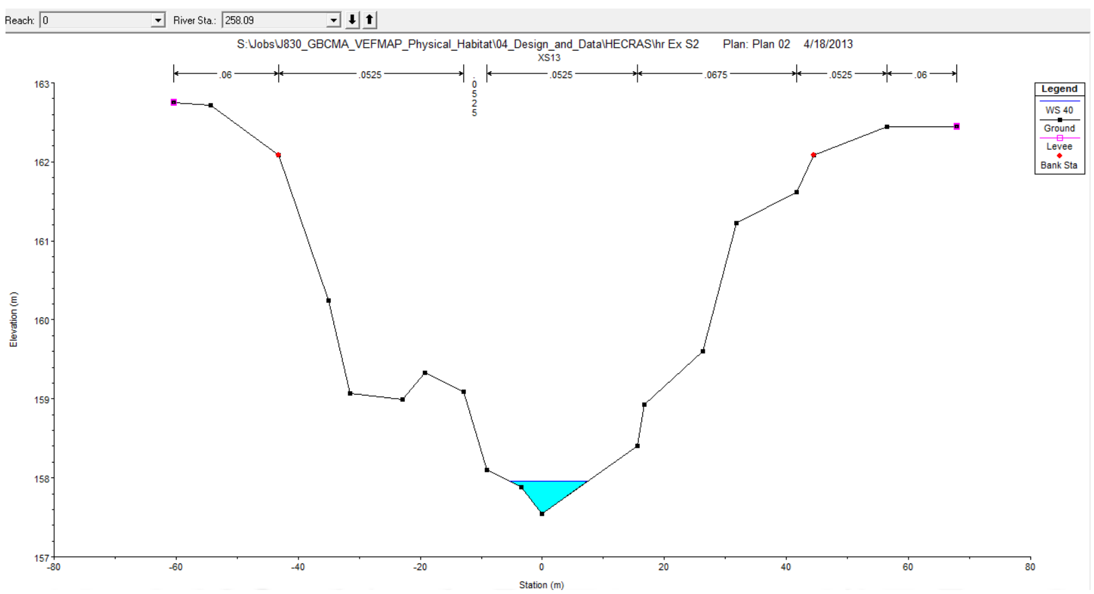
From HECRAS:

Reach 1 requires 30 ML/d, or natural
SAME AS IC1

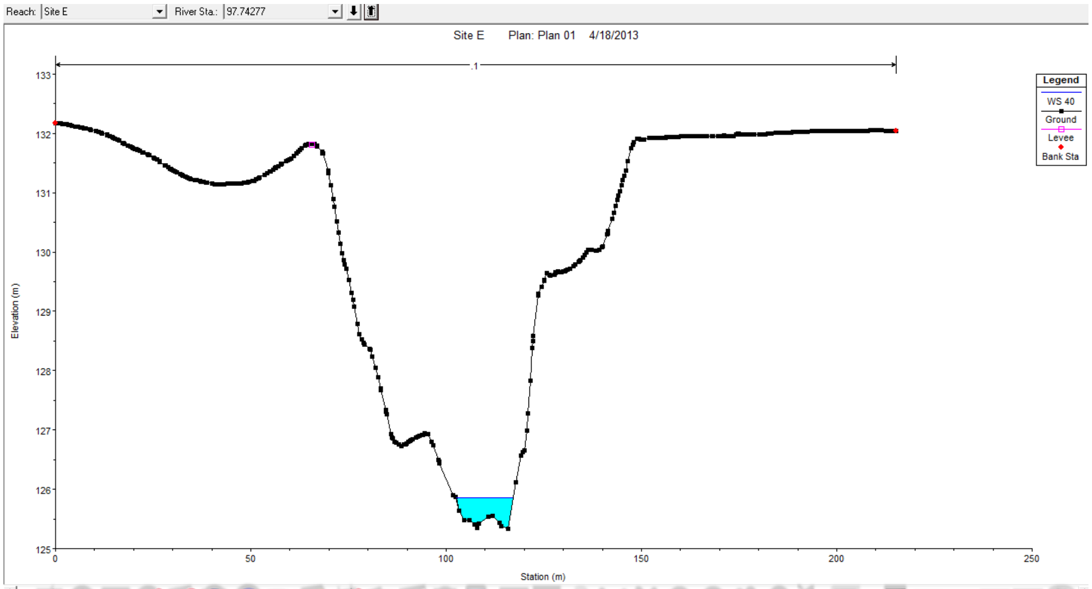
Reach 2 requires 40 ML/d or natural

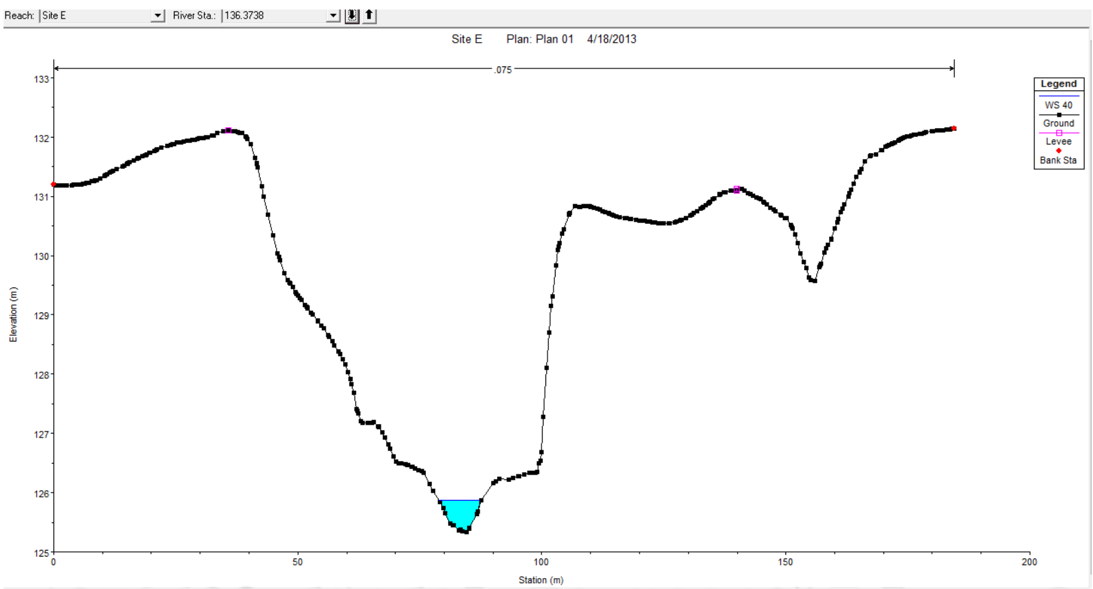


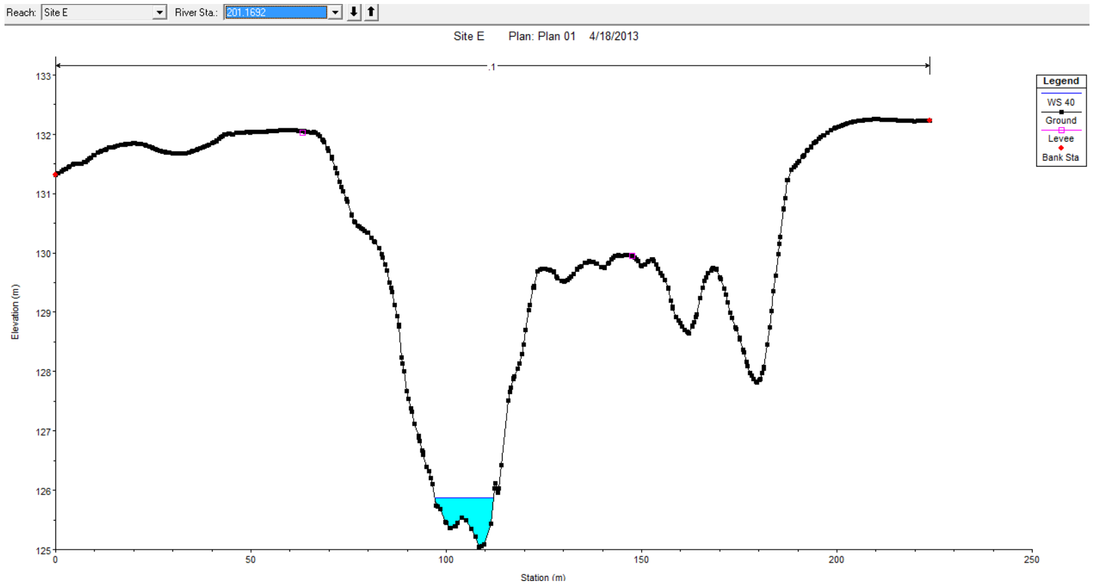

Reach: 0
River Sta.: 182.89
S:\Jobs\J830_GBCMA_VEFMAP_Physical_Habitat\04_Design_and_Data\HECRAS\hr Ex S2 Plan: Plan 02 4/18/2013
XS10
.06
.0675
.0825
.0525
.0675
.0675
Legend
WS 40
Ground
Levee
Bank Sta
Elevation (m)
Station (m)


Reach: 0
River Sta.: 258.09
S:\Jobs\J830_GBCMA_VEFMAP_Physical_Habitat\04_Design_and_Data\HECRAS\hr Ex S2 Plan: Plan 02 4/18/2013
XS13
.06
.0525
.0525
.0525
.0675
.0525
.06
Legend
WS 40
Ground
Levee
Bank Sta
Elevation (m)
Station (m)

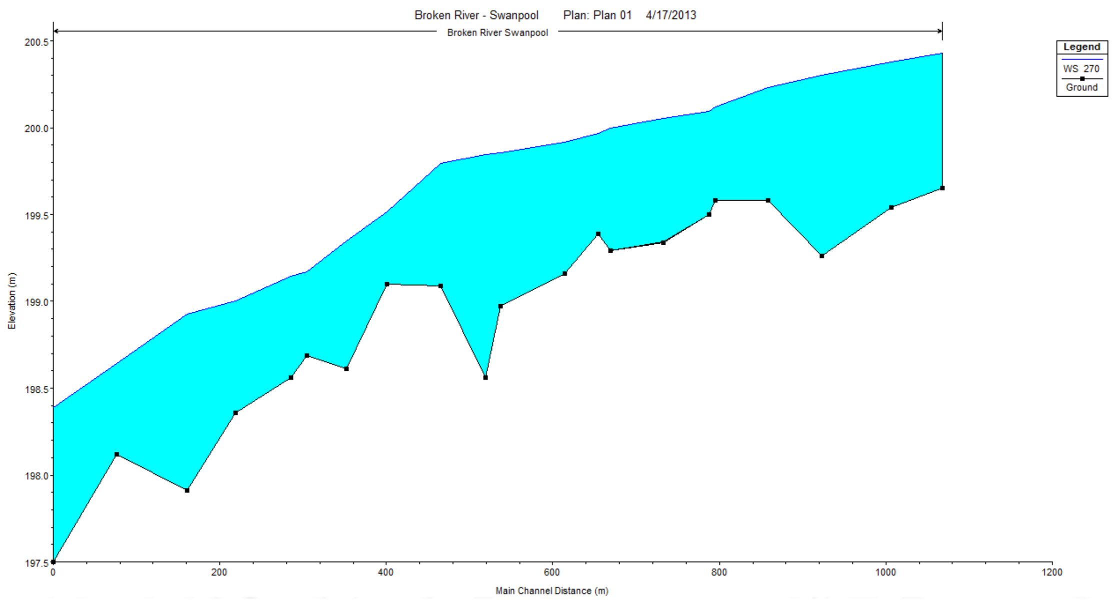
Reach 3 requires 40 ML/d or natural

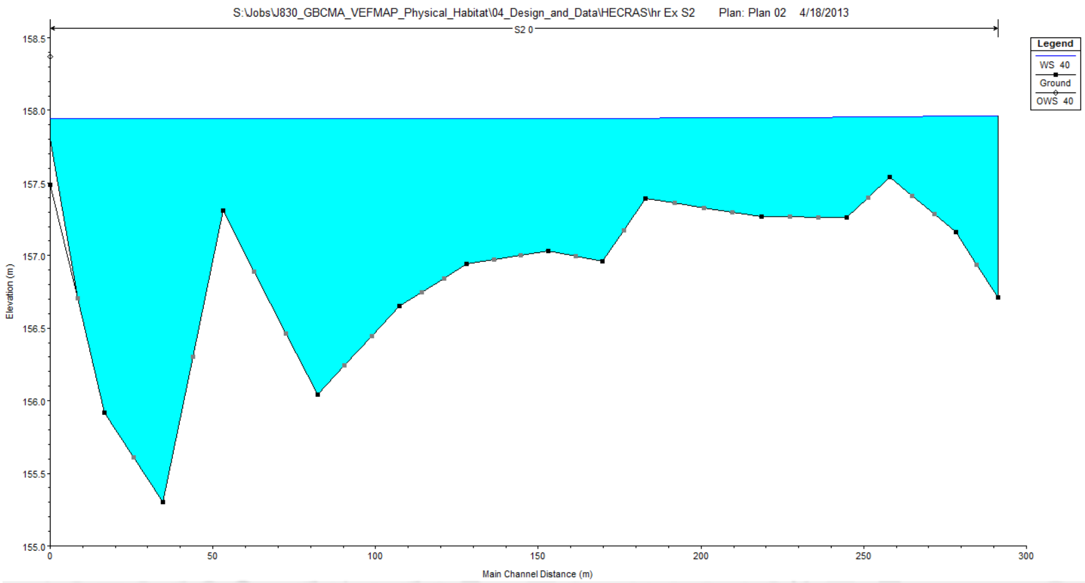


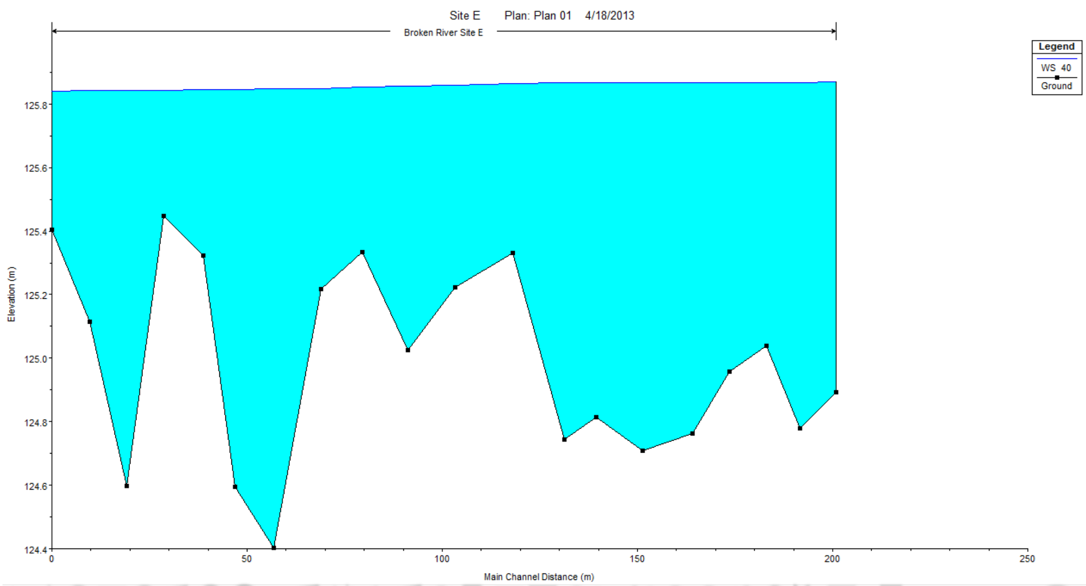




MI 2 – based on slackwater curve
MI – others covered by previous recs
NF1 – based on slackwater curve
NF2 – covered by G4, IC5, MI1 and MI2 (or could use long profile below)




S:\Jobs\J830_GBCMA_VEFMAP_Physical_Habitat\04_Design_and_Data\HECRAS\hr Ex S2 Plan: Plan 02 4/18/2013
S2 0
Legend
WS 40
Ground
OWS 40
Elevation (m)
Main Channel Distance (m)


Site E Plan: Plan 01 4/18/2013
Broken River Site E
Legend
WS 40
Ground
Elevation (m)
Main Channel Distance (m)