Assessment of the hydraulics of the Little Murray River Weir Pool under alternative operating scenarios

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For

Goulburn-Murray Water

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1 Introduction

1.1 Background to this study

The Little Murray Weir (LMW) (Figure 1) and Fish Point Weir (FPW) (Figure 2) are situated on the Little Murray River, an anabranch of the River Murray (Figure 3). LMW forms the Little Murray Weir Pool (LMWP), which extends approximately 37 km upstream. The LMW was constructed in 1900 to raise the water level of the Little Murray River to allow gravity feed into the No.9 Channel which at that time serviced Swan Hill, Tyntynder Flats and Woorinen Irrigation Areas (NVIRP, 2010). The LMW has required major repairs at various times throughout its history. The height of the water in the weir pool can be controlled by manipulation of a combination of drop bars and motorised regulators with doors. Operation of the doors will drop the weir pool to a certain level, and then a few bars may be taken out manually to drop the pool to the sill level.

Figure 1. Little Murray Weir.

The LMWP supplies various diverters and irrigators in the Torrumbarry Irrigation Area, on the weir pool itself, and along the No. 9 channel heading north to Swan Hill. The FPW was constructed across the Little Murray River at the upstream end of the weir pool, at the mouth of the Loddon River (Figure 2, Figure 3). FPW controls inflows from the River Murray and diverts flow from the Loddon River to the River Murray via the upper part of the Little Murray River anabranch. At times of high flow in the Loddon River or River Murray, water can be passed to the Little Murray River via FPW. Under normal flow conditions, flow is supplied to the LMW pool via Pental Island Pumps on the River Murray or No. 6/7 Channel. Water is diverted from the Murray River into No. 6/7 Channel via Kow Swamp and the Kerang Lakes.

Figure 2. Fish Point Weir. State Library of Victoria, May 1964.

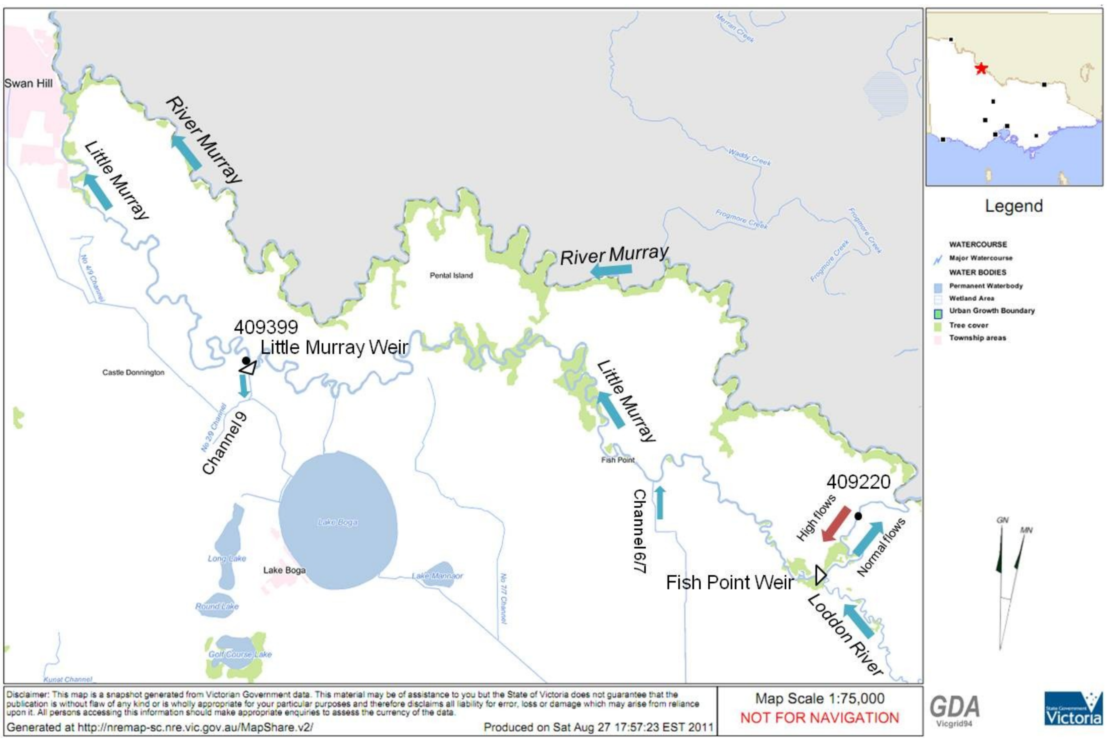


Figure 3. Location of Little Murray Weir Pool, formed by Little Murray Weir, showing flow paths, control structures, and gauges.

As part of a program to investigate possible water savings and improved ecological outcomes, alternative operating scenarios for Little Murray Weir and Fish Point Weir are currently under investigation. Consideration is being given to lowering the operational level of the LMW to increase the life of the structure, and reconfiguring the way water is supplied to customers, taking account of the Mid-Murray Storage Project and the desirability of removing the No.9 open channel flowing through Swan Hill. Lowering the LMW would also achieve water savings by reducing the evaporative area of the LMW pool and reducing groundwater levels in the immediate vicinity, which have historically been problematic. Under the existing arrangement, Goulburn-Murray Water does not incur losses from the LMWP when FPW is open. The FPW is opened when combined flow in the Murray and Loddon Rivers exceeds 12,200 ML/d to avoid damage to the structure, although there have been instances when it has been opened when combined Murray and Loddon flows are lower than this (Gippel, 2011). With FPW open, the Little Murray River functions as a flowing anabranch of the River Murray. Thus, there could be environmental benefits to having FPW permanently open, perhaps with an altered sill level.

A previous report by Gippel (2011) assessed the potential for achieving savings under a range of LMW and FPW operating scenarios using a water balance model called SWET. The main purpose of the modelling was to explore the range of potential savings rather than to recommend any particular option. While the viability of any operating scenario depends to a large extent on savings potential, it also depends on a number of other important factors. Two of those factors are addressed in this report:

- Risks to meeting irrigation demands at lower weir pool levels, and
- Hydraulic character of the weir pool (depth distribution, and flow rate) under alternative operating scenarios.

The water balance models developed by Gippel (2011) used best knowledge and data available at the time. The lack of hydraulic information concerning the weir pool meant that a horizontal water surface had to be assumed. Also, the bathymetric relationships (water level versus volume and surface area) used in the models were preliminary.

In this report, the Little Murray River weir pool SWET models were upgraded on the basis of the revised and new information, and revised estimates of water saving were made for those future scenarios identified in the first phase (Gippel et al., 2011) as offering the most potential. While the future scenarios involve Fish Point Weir being open most of the time, the savings were calculated on the basis that the number of days per year that Goulburn-Murray Water would not incur losses would be the same as for the existing arrangement (i.e. when combined Murray and Loddon inflows exceed 12,200 ML/d).

1.2 Objectives of this report

The main objectives of this report are:

1. *Determine the volume of water held in the Little Murray River weir pool under the current operating conditions*.

   While bathymetric survey data have been available for some time, there is a need to revise the data and calculate a relationship between water surface elevation and volume. The relationship between elevation and water surface area also requires updating, for inclusion in revised water balance models.

2. *Determine the volume and timing of water that will pass through Fish Point Weir from the River Murray and into Little Murray River, if Fish Point Weir is kept open whenever possible*.

   There may be times when Fish Point Weir has to be closed due to high salinity levels in the Loddon River, or inflows cease because levels in the River Murray are not high enough to create a head.

3. *Determine the volume and depth of water that will be held in the Little Murray River at three potential lowered LMW level options of:*

   - *67.0 mAHD, 67.25 mAHD and 67.5 mAHD,* *and three potential FPW level options of:*

- *67.22 mAHD, 67.81 mAHD and 68.41 m AHD,*

for a range of flows in Little Murray River.

4. *Assess the likelihood of not being able to meet peak irrigation demands.*
5. *Assess the hydraulic habitat conditions in Little Murray River under the potential alternative operating scenarios*.

   In this context, hydraulic habitat refers to depth conditions that maintain connectivity of pools, and depth and velocity conditions that discourage invasion of macrophytes (principally *Typha* spp., also known as cumbungi).
6. *Model the salinity time series of Little Murray River under the potential alternative operating scenarios with respect to ecological and irrigation requirements.*

   In this context, median and maximum salinity thresholds have been defined for the aquatic biota, and maximum thresholds have been identified for irrigation water supply.
7. *Refine the estimates of the long-term water savings achieved under selected alternative operating scenarios*.

For time series data, results for river management criteria should be reported for:

- the entire modelled series, and
- over the Millennium Drought period

2 Method

2.1 Time series analysed

The models developed here used MSM_Bigmod data, which is in the form of daily time series of flow from 1/07/1895 to 30/06/2009 and salinity from 1/01/1975 to 30/06/2009. The analysis was undertaken for these full time series, and also for the drought period that occurred towards the end of the series, known as the Millennium Drought.

The Millennium Drought has been variously defined as extending over the period 1996 – 2009 (MDBA, 2011), 1997 – 2009 (Chiew and Prosser, 2011, p. 31; SEACI, 2011; MDBA, 2012), 2000 – 2010 (Australian State of the Environment Committee, 2011; Kirby et al., 2012), 2002 – 2010 (Pittock, 2011), with Kendall (2010) suggesting both 2002 – 2009 and 1997 – 2009. None of these references indicated the method used to define the period of drought. If defined statistically, the result would depend on whether flow or rainfall data were analysed, and where the hydrological gauges were located.

For this project, the time series of MSM_Bigmod modelled annual River Murray flow at locations close to Little Murray River (Barham and Pental Island) were analysed for trend using TREND V1.0.2 (CRC for Catchment Hydrology). The analysis used regulated flow data (assuming existing level of development) as the flow conditions in Little Murray River are strongly conditioned by regulation of the River Murray. For both locations, the Mann-Kendall, Spearman's rho and linear regression tests indicated no statistical trend in the data from 1896 to 2008. A step-change was indicated in 1996 by the CUSUM, Cumulative deviation and Worsely likelihood tests, with only the latter showing statistical significance at $\alpha < 0.1$. The Rank sum and Student's t tests indicated statistically lower medians and means, respectively, over the period 1896 – 1996 compared with 1997 – 2008. On this basis, for the data analysed here, the Millennium Drought period was defined as 1997 – 2009.

2.2 SWET model structure

A description of the SWET water balance model was provided in a previous report (Gippel, 2011) and is not repeated here. The main model refinement undertaken here was improvement of the bathymetry relationships for Little Murray River. The more detailed bathymetry relationships (together with a hydraulic model of the river) allowed removal of the assumption of a horizontal water surface at times when significant volumes of water were flowing through the weir pool.

Under future scenarios with a lowered Fish Point Weir level and lowered Little Murray Weir level, it would be usual for flow to enter Little Murray River through Fish Point Weir (under the existing conditions this is an irregular and short duration event). This would lead to a sloping water surface on the weir pool. This effect was modelled using the HEC-RAS one-dimensional backwater model (see description below). Irrigation water is supplied to the weir pool through Channel 6/7, which enters at a distance of about 8.3 km downstream of Fish Point Weir. Thus, the modified SWET model comprised two cells, one upstream of Channel 6/7 and one downstream.

The SWET model was configured such that, at times when Fish Point Weir was open, and flowing, weir pool water surface area and volume were determined entirely by the inflow rate. At times of no inflow from Fish Point Weir, control over surface area and volume reverted to the water balance components of rainfall, evapotranspiration, and sill levels.

2.3 HEC-RAS model

A hydraulic model of the Little Murray Weir pool was developed and run by Geordie McKinlay (Goulburn-Murray Water). The model utilized 240 cross-sections between LMW and FPW that were extracted from previous survey data, plus a further seven cross-sections located between the River Murray and Fish Point Weir that were surveyed by Price Merrett Consulting specifically for this report. The model incorporated the floodway and weir at Fish Point Weir. The Floodway at FPW has a crest level of 69.71 m. A Mannings n roughness value of 0.034 was assumed for the river channel. The model predicted the water surface profile of the Little Murray River for discharges over the range 100 to 10,000 ML/d.

The HEC-RAS model was run for the existing scenarios of Little Murray Weir at 66.79 m (sill level) and 69.21 m (existing irrigation season operating level), and for three potential future scenarios of Little Murray Weir at 67.0 m, 67.25 m and 67.5 m.

For the existing scenarios, Fish Point Weir was assumed to be closed unless flow in the River Murray reached a threshold. The Fish Point Weir operation manual indicates that the weir is opened when flow at Torrumbarry exceeds 12,000 ML/d (which also requires an allowance for travel time). However, in this report we used MSM_Bigmod modelled flow data, so we abided by the assumptions of that model. The supplied MSM_Bigmod model runs included the assumption that Fish Point Weir was opened when the combined flow of the Loddon and Murray rivers (at the junction of Little Murray River/Loddon and the River Murray) exceeded 12,200 ML/d. Under the existing scenarios, when open, the Fish Point Weir was at its existing sill level of 68.41 m. The potential future scenarios included Fish Point Weir at three possible levels: the existing floor level of 67.22 m, an intermediate level of 67.81 m, and at the existing sill level of 68.41 m.

2.4 Scenarios

The scenarios included existing conditions, here called benchmark scenario (BM) and potential future scenarios (Table 1). Under existing conditions, most of the time FPW and LMW were closed at levels of 69.71 m and 69.21 m respectively. Thus, most of the time, FPW disconnects Little Murray River for the River Murray. When combined flows in the Loddon and Murray rivers exceeded 12,200 ML/d, both FPW and LMW are opened to their sill levels of 68.41 m and 66.79 m respectively. In this situation, a proportion of River Murray water flows into Little Murray River.

The potential future scenarios assumed that Fish Point Weir would be at its current sill level of 68.41 m, or lowered to 67.81 m or 67.22 m. Under future scenarios, the weir level would be fixed. In addition, Little Murray Weir would be lowered from its current operating level of 69.21 m (irrigation season) to a permanent level of 67.0 m, 67.25 m or 67.5 m. This gave nine potential future scenarios (Table 1).

Table 1.
Levels of Little Murray Weir (LMW) and Fish Point Weir (FPW) associated with the scenarios modelled in this report.

Scenario	LMW level (m)	FPW level (m)
BM	69.21 (closed) 66.79 (open)	69.71 (closed/floodway level) 68.41 (open)
F1	67.00	67.22
F2	67.00	67.81
F3	67.00	68.41
F4	67.25	67.22
F5	67.25	67.81
F6	67.25	68.41
F7	67.50	67.22
F8	67.50	67.81
F9	67.50	68.41

2.5 Time series model of flow distribution between Murray and Little Murray rivers

The HEC-RAS hydraulic model for Little Murray River does not predict how much flow will enter the river at any particular time. Rather, it is a static model that describes the water surface profile for a given discharge in the channel. Flow into the Little Murray River is governed by the water level of the River Murray at the Little Murray River/Loddon River junction.

The HEC-RAS model predicts the water surface elevation at the junction of the Little Murray River and the River Murray for a given flow in Little Murray River, so the flow potentially entering Little Murray River could be estimated on the basis of an independent estimate of the water level in the River Murray at the junction. One problem with this is that if it is assumed that a portion of the flow in the River Murray then flows down Little Murray River, the elevation of the water in the River Murray will fall, and in turn, less water can potentially flow down Little Murray River. Modelling of this feedback ideally requires a combined hydraulic model of the Murray and Little

Murray rivers. However, such a model was not available, so a simpler approach was taken.

First, rating curves from Barham and Pental Island were used together with MSM_Bigmod pre-TLM (The Living Murray) flow series' from 1895 to 2009 to create a daily time series of water level in the River Murray at the junction of Little Murray River. In adopting pre-TLM assumptions, the model predictions do not take into account the impacts that future environmental flow allocations (such as The Living Murray or Commonwealth Water Holder) might have on flows in the River Murray. Similarly, the model predictions do not take into account any additional flows that may enter the Little Murray River in the future as a result of releases from the Victorian Mid-Murray Storages.

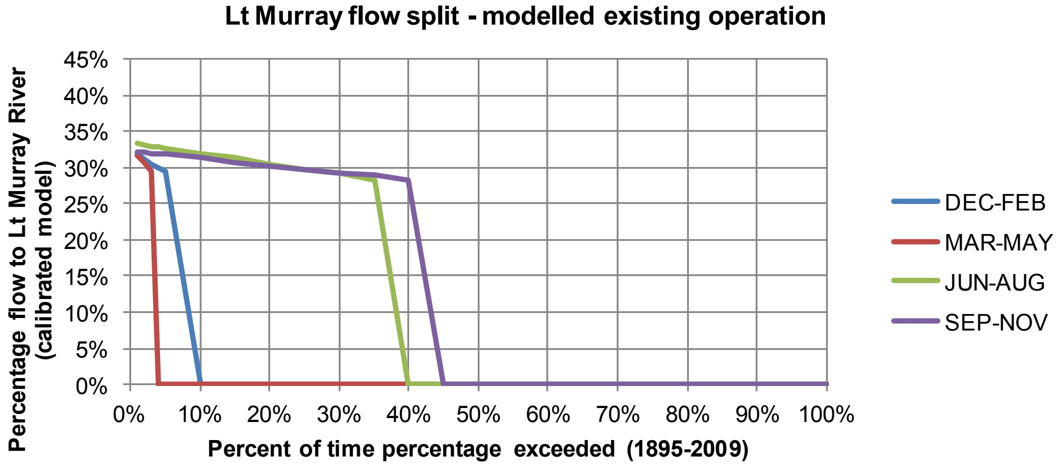
This model assumed the standard travel times in MSM_Bigmod. Initially, the estimate of elevation was based on the assumption that none of the flow entered Little Murray River, although flow from the Loddon River to the River Murray was accounted for. The maximum flow that could enter Little Murray River was then estimated for each day of the time series on the basis of the HEC-RAS profiles. That is, for each configuration of LMW and FPW levels, a rating curve was developed between discharge in Little Murray River (x) and water elevation at the junction between the river Murray and Little Murray River. The ratio (z) of this flow into Little Murray River (x) to the sum of River Murray flow (y) and x, i.e. $z = x/(x+y)$, was calculated for each day, to give an assumed daily flow split between the Little Murray River and the River Murray. This flow split (i.e. proportion of flow in each river) was then applied to the total River Murray flow on each day of the time series (i.e. flow in Little Murray River = $z \times y$ and flow in River Murray = $x - (z \times y)$). These estimated flow splits were then compared with the actual flow splits for each day in MSM_Bigmod. This comparison applies only to the situation when combined Loddon and River Murray flows exceed 12,200 ML/d, because Fish Point Weir is normally closed at discharges below this level. The flow split of each day (z) was then calibrated by multiplying z by a single factor (a) to achieve the closest fit between the predicted water level at Pental Island and the level in the MSM_Bigmod series (Figure 4). The factor that achieved the best fit was $a = 0.94$. This calibrated relationship was then used to split the flows between the Little Murray River and the River Murray for scenarios involving altered levels at Little Murray Weir and Fish Point Weir. A condition placed on this relationship was that alternative operation of Fish Point Weir could not increase flows in the River Murray at Pental Island compared to the existing situation. If the flow split incorrectly predicted an increase in Murray flows at Pental Island, then the value for that day in the current MSM_Bigmod scenario was adopted.

The assumptions used to derive the flow split time series (described above) involve a degree of uncertainty. It should be recognised that any (unquantifiable) errors arising in this step are transferred through to the modelling of connectivity, salinity, and water savings.

2.6 Time series model of salinity in Little Murray River

A daily time series model of salinity in Little Murray River was created using MSM_Bigmod pre-TLM scenario salinity and flow time series data from 1975 to 2009.

The main potential source of high salinity water to Little Murray River is Barr Creek. The MSM_Bigmod model uses a salinity input at Capels Crossing sourced from the Victorian REALM model. SKM (2011) indicated that since 1968 the flow in Barr Creek has been selectively diverted to evaporative disposal sites in order to minimise the outfall of salt to the River Murray. A Barr Creek Catchment Strategy (BCCS) was adopted in 1987. In the 1990s, MDBC showed that a greater overall benefit could be obtained for the River if pumping targeted the highest salinities in Barr Creek, regardless of the time of year. This resulted in the "1999 Rules" in which the diversion scheme pumps water from the Creek when flows reach a threshold salinity (SKM, 2011). The MSM_Bigmod time series assumes these “existing” (post-2000) conditions until 2005-06 and then it assumes historical conditions (Matthew Hardy, MDBA, pers. comm., 9 Oct 2012).



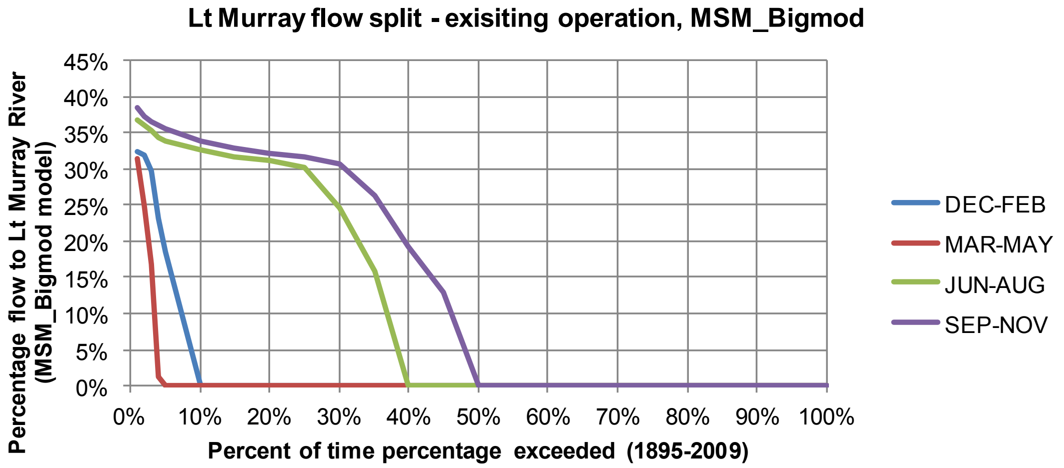


Figure 4. Comparison of seasonal distribution of the split of flows between Little Murray River and the River Murray for the calibrated model created here (top) and MSM_Bigmod (bottom) (which uses a rule that Fish Point Weir is closed unless combined Murray and Loddon flows exceed 12,200 ML/d).

While the salinity modelling undertaken here represents post-2000 operating conditions projected over the 1975 - 2009 time series, it is worth noting that major changes underway in and around the Barr Creek catchment could in the future markedly reduce the effect of salt discharge from Barr Creek on the River Murray (SKM, 2011).

Salinity data were in the EC “concentration” units of µS/cm. Salinity EC load for each day in each river was calculated as the product of EC concentration and discharge. If flows from two sources were mixed, the salinity loads of the two sources were summed. The resultant EC concentration was then calculated as the combined salinity load divided by the combined discharge.

MSM_Bigmod data for Loddon River at Kerang and Barr Creek downstream of Capels Crossing were mixed to predict the salinity in the Loddon River where it meets

Little Murray River. A travel time of 1 day from Kerang and Capels Crossing to Little Murray River junction was assumed. The flow time series model (described in the previous section) predicted the flow that would pass through Little Murray River on the basis of flow in the River Murray. If the flow in the Loddon River was equal to or greater than this flow rate, then all water entering Little Murray River would be sourced from the Loddon River, and the salinity of Little Murray River was the same as that of the Loddon River. Otherwise, sufficient water from the River Murray was added to Loddon River water to provide the required flow in the Little Murray River. The salinity of the River Murray water was based on MSM_Bigmod salinity predictions for Barham (allowing for travel time to Little Murray River junction). MSM_Bigmod takes REALM input for Lake Boga and Lake Kangaroo inflows and produces a flow and salinity at the end of Channel 6/7. The daily EC concentration of Little Murray River water as it enters FPW was then calculated on the basis of the proportions of water sourced from the Loddon and Murray rivers. Downstream of Channel 6/7, the salinity of Little Murray River water was also influenced by the salinity of inflows from Channel 6/7.

2.7 Bathymetry

Digital elevation data of Little Murray River (between LMW and FPW) were supplied by Goulburn-Murray Water. This was a mix of raw data and gridded elevation data. The raw data were used together with the highest resolution gridded data. First, a few obviously erroneous elevations points were edited from the data, then a boundary was drawn around the extent of the ground survey data. A digital elevation model (DEM) was created within this boundary. Using tools in Global Mapper™, surface area and volume were calculated, using a high resolution setting, for 29 elevations over the range 60.0 – 69.3 mAHD.

The above described bathymetric relationships assume a horizontal water surface, but when water is flowing through the Little Murray River, the surface acquires a downstream slope. There are no standard tools available within GIS to perform the calculation of surface area and volume under the assumption of a sloping water surface, unless a digital elevation model of the water surface can be created. This is not a trivial exercise, and was not feasible for this project. An alternative approach was used that relied on outputs of the HEC-RAS hydraulic model of the Little Murray River. Interpolation was applied to the predicted top width at each cross-section, together with the distance between each section, to derive an estimate of surface area. Similarly, interpolation was applied to the predicted area of each cross-section to derive an estimate of volume. Relationships were derived for the total surface area and volume (for two separate weir pool cells: FPW to Channel 6/7 and Channel 6/7 to LMW) as a function of discharge at FPW, under a range of LMW and FPW sill and crest elevations. The intercepts of these relationships represent estimates of the volume and surface area at zero discharge, when the water surface is horizontal. These values were compared with the accurate estimates of volume and surface area made directly from the DEM. The differences were relatively small and consistent, and on that basis a small correction was applied to the relationships derived from the HEC-RAS model output.

A thalweg was drawn on the Little Murray River channel (between LMW and FPW) following the deepest point in the channel at any location. A longitudinal profile of the thalweg was generated at 1 m spacings of elevations. This detailed thalweg was used to evaluate minimum depths through the weir pool.

2.8 Environmental criteria

Preliminary environmental flow objectives and criteria have been developed for Little Murray River between LMW and FPW for connectivity, salinity and macrophytes.

2.8.1 Minimum depth for habitat connectivity

Connectivity criteria were suggested in a preliminary set of guidelines for the environmental requirements of Little Murray River prepared in March 2011 by Environous and Streamline Research (2011). The criteria were at least partly based on habitat preference/tolerance information from the Loddon River, as indicated in LREFSP (2002) and SKM (2010). The main connectivity-related biological objective was listed by Environous and Streamline Research (2011) as "*sustain longitudinal connectivity for movement of macroinvertebrates and some fish*". The low flow criteria were stated as "*maintain 0.3 – 0.5 m minimum depth*" year round and "*at least 0.3 m depth would be a minimal requirement over the shallowest stream reaches to maintain connectivity*".

In June 2012 a final report on the potential impacts of the proposed lowering the LMW on state and national listed fish fauna was prepared by Environous and Streamline Research (2012). The report included a literature review relating to the aquatic community of the river, and outlined potential mitigation options. It was indicated (Environous and Streamline Research, 2012, p. 29) that "*large bodied species including Murray cod, golden perch, silver perch and freshwater catfish…require a minimum of 0.5 m depth*". The environmental flow recommendation suggested that it might be favourable to "*…maintain instream connectivity and a minimum depth of 0.5 m*" (Environous and Streamline Research, 2012, p. 31), although the previously stated range of minimum depth 0.3 – 0.5 m (year round, but a focus on summer) was retained in the recommendations (Environous and Streamline Research, 2012, p. 32). The above reports did not explicitly state whether connectivity meant that the entire 37 km of river between LMW and FPW had to exceed the minimum depth criterion, or whether the objective was adequate local movement over shorter lengths. However, it was stated that connectivity between Little Murray River and the River Murray was important for feeding and spawning purposes, especially the larger bodied species such as Murray cod and silver perch that undertake large-scale migrations (Environous and Streamline Research, 2012, p. 26). It was recommended that this need be met by larger freshes and pulses in winter/spring. Thus, here we assume that the year round connectivity requirement of at least 0.3 – 0.5 m is mainly for local movement. Thus, habitat for local movement would still provided when the pool is split into a number of pools, isolated from each other by sills shallower than 0.3 – 0.5 m depth of water, but the potential range of movement would be greater the fewer sills were present, i.e. the longer were the individual pools making up the river length.

The intent of the connectivity requirements was interpreted here as that least 0.3 m depth would be a minimal requirement over the shallowest stream reaches to maintain connectivity, but 0.5 m depth will provide connectivity at a lower level of risk to large bodied fish species. Thus, the connectivity objective was defined as a year-round minimum depth of 0.3 – 0.5 m, with a criterion of 0.5 m interpreted as lower risk to fish movement than a criterion of 0.3 m. Also, the risk to fish movement was lower the fewer pools the river was split into, and the greater was the percentage of the length of the river that had a minimum cross-sectional depth exceeding 0.3 – 0.5 m.

2.8.2 Salinity

Salinity criteria were suggested in a preliminary set of guidelines for the environmental requirements of Little Murray River prepared in March 2011 by Environous and Streamline Research (2011). The criteria were median and maximum salinity should be < 500 µS/cm and < 3000 µS/cm respectively. The authors of Environous and Streamline Research (2011) (T. Ryan and J. McGuckin) later advised Aquaterra (2011, p. 45) that the EC criterion was daily average EC should not exceed 2,000 µS/cm, although it is not stated in Aquaterra (2011) what ecological values this threshold protects, and at what level of risk. The later final report by Environous and Streamline Research (2012, p. 25) noted that "*…minor peaks in salinity and dissolved oxygen stratification are likely to have minimal impacts*". This final report by Environous and Streamline Research (2012) did not list any salinity criteria, but suggested that specific environmental flows could be required to dilute "*…elevated water conductivity*" (p. 33). They also suggested that monitoring water quality be undertaken for at least 12 months and that the collected data could be used to set criteria (p. 33).

The above suggested criteria are variable, and although the criterion of an average daily salinity not exceeding 2,000 µS/cm (in Aquaterra, 2011) is not linked to any specific ecological objectives, it was adopted for this study on the basis that it is the most recent, quantitatively stated, criterion.

Under the existing operational regime, Fish Point Weir is only open during times of high flow, when salinity is well below the thresholds of concern. Under an alternative operating regime that aims to keep Fish Point Weir open, the risk of high salinity inflow to Little Murray River would be associated with low to intermediate River Murray flows in conjunction with saline flows from the Loddon River and Barr Creek (DG Consulting, 2012). Historically, the Murray and Loddon rivers have not exceeded the salinity criteria, but Barr Creek has. Before water from Barr Creek enters Little Murray River, it is first diluted by Loddon River water, and then by River Murray water.

DG Consulting (2012) expected that in the future, as a result of improved environmental flows in the River Murray, reduced irrigation application in the Barr Creek catchment and improvements to Barr Creek salt interception scheme, the frequency of highly saline water potentially entering Little Murray River will be low.

2.8.3 Macrophytes

In a review of an earlier draft of this report, Hogan and Maher (2012) raised concern about potential for shallow water associated with the alternative operating scenarios allowing excessive growth of macrophytes (in particular cumbungi or *Typha* spp.).

Macrophyte growth is a function of numerous factors, but water flow is known to be a prime factor (Franklin et al., 2008). The effects of flow on macrophytes are usually considered in terms of the hydrological regime (frequency of disturbance and duration of stable flow conditions) and velocity (which is associated with mechanical damage and uprooting). Long periods of stable baseflow may encourage invasion by macrophytes; for example, in Australia, *Typha* spp. are associated with stable water levels typical of regulated rivers (Mackay and Marsh, 2005; Marsh, 2012). Riis and Biggs (2003) found that significant macrophyte development in New Zealand rivers was restricted to streams which experienced an average of less than 13 flood events per year (i.e. events exceeding 7 times the median discharge magnitude). In sandy substrates, the important flood events may be of a lower magnitude than this (Riis et al., 2008). Periods of low flow can also keep macrophytes in check (Franklin et al., 2008). Both the abundance and diversity of macrophytes are stimulated at low to medium velocities, with growth being restricted at higher velocities (Madsen et al., 2001). Roberts and Ludwig (1991) found a relationship between the zonation of emergent species and the strength of current and wave action and a gradual change in the plant community along the velocity gradient. Riis and Biggs (2003) found that macrophyte abundance peaked in the velocity range 0.3 – 0.5 m/s. Chambers et al. (1991) suggested 1 m/s as an upper limit of velocity, above which macrophytes are few or absent. The flexible stems and leaves of *Potamogeton crispus* reduce the frontal area exposed to flow so it has a high tolerance to hydraulic stress and is found in slow to fast-flowing water (Mackay and Marsh, 2005). Based on similarity of growth forms, information in the literature, and field observations, Mackay and Marsh (2005) rated *Scirpus acutus* (tule – a giant species of sedge in the plant family Cyperaceae) and *Schoenoplectus validus* (river club rush – a native plant of Australia) as having moderate resistance to hydraulic disturbance. The linear leaves of *Typha* spp. would be expected to reduce drag, but longer leaves would experience higher drag than shorter leaves, so Mackay and Marsh (2005) rated *Typha* spp, slightly lower in resistance to hydraulic disturbance than *Schoenoplectus validus*. In an area of the Tone River, Japan, with maximum velocities of 0.8 – 0.9 m/s, Asaeda et al. (2005) observed that the depths at which *Typha angustifolia* (0.4 – 0.7 m) and *Zizania latifolia* (0.4 – 0.6 m) grew overlapped, while the velocity in both zones was generally < 0.8 m/s. *Phragmites australis* zones were relatively shallower (mostly < 0.3 m) and had low velocity (< 0.4 m/s). Greening Australia (2007) noted that *Typha* spp. cannot survive in water deeper than 2 m.

Groeneveld and French (1995) found that colonisation of channels by *Scirpus acutus* (tule) could be prevented if flow events of sufficient water velocity and depth were delivered. They showed that sufficient bending stress induced by hydrodynamic drag on the macrophyte stem caused stem rupture – failure involving permanent deformation and loss of plant function. They quantified the depth-velocity envelope required to induce rupture, providing a means to estimate the flow required to provide hydrodynamic protection against encroachment by macrophytes.

In Little Murray River, the discharge required to rupture macrophyte stems was computed by application of Groeneveld and French's (1995) relationship. The diameter of the macrophyte stems was set, as recommended by Groenveld and French (1995), to 11.9 mm. A threshold was then evaluated to give a 95 percent chance of stem rupture (this allowed some macrophytes to remain in the channel for seasonal re-colonisation). The threshold was reported as the discharge required for the product of flow depth (D) and velocity (V) to exceed 0.52. Velocity was assumed to be cross-section mean and depth was maximum channel depth. While the relationship of Groeneveld and French (1995) is specific to *Scirpus acutus*, it would be expected to apply to robust macrophytes with moderate resistance to hydraulic stress such as *Typha* spp. Given that Chambers et al. (1991) reported few if any macrophytes were found in waters with velocities exceeding 1 m/s, and that Greening Australia (2007) noted that *Typha* spp. is not found in water deeper than 2 m, these were included as additional criteria. Thus, the minimum discharge for limiting the potential for macrophyte invasion in the Little Murray River was the lowest of that determined by $V = 1$ m/s, $D = 2$ m and $V \cdot D = 0.52$.

2.9 Irrigation criteria

2.9.1 Water demand

Irrigation demand on any day mainly varies according to: (i) the type of plants under cultivation, (ii) the volume of irrigation water applied in the recent past, (iii) the pattern of rainfall and evaporation over the recent past, and forecast short-term future, and (iv) percentage of allocation available at the time (which reflects the longer term climate pattern). Empirical water use data, and predictions of demand based on crop type and acreage, can give some indication of the likely range in annual demand, but it is not possible to accurately model a daily time series of demand on the Little Murray Weir pool. Historical annual demand data for the years 2002/03 to 2011/12, along with flow data for 6/7 Channel outfalls to the weir pool, and No 9 Channel diversions from the weir pool, were supplied by Goulburn-Murray Water. In addition, Price Merrett Consulting estimated demand on the weir pool on the basis of irrigable area and assumed areal crop demand.

2.9.2 Salinity

DG Consulting (2012) suggested the following operational salinity targets:

- Aim to maintain water salinities below 600 µS/cm.
- When monitoring at the No. 9 pump station indicates that salinities will exceed 800 µS/cm in the Little Murray River, warnings should be placed on WaterLine to alert horticultural and viticultural users of the salinity risks (according to Torrumbarry operating procedures).

3 Results

3.1 Irrigation demand

The historical water demand on the Little Murray weir pool varied significantly between years (Table 2), mainly as a function of the allocation. The Woorinen system was part of the No. 9 Channel until the 2003/04 season which is why there was a big drop in usage after then (Table 2). The peak flows on the 6/7 channel during the irrigation season have exceeded 600 ML/d for 16 days since the 2002/03 irrigation season. The peak recorded flow was 781 ML/d. The outfalls from the 6/7 Channel during the irrigation season has exceeded 500 ML/day for 113 days since the 2002/03 irrigation season.

Table 2.
Historical water demand data for Little Murray Weir Pool.

Year	Historical water usage (ML/year)		
	No. 9 Offtake	Little Murray Weir pool	Total
2011/12	17,626	3,934	21,560
2010/11	7,319	1,330	8,649
2009/10	10,007	1,845	11,852
2008/09	9,250	796	10,046
2007/08	9,261	644	9,905
2006/07	21,108	2,882	23,990
2005/06	24,187	3,679	27,866
2004/05	21,117	4,053	25,170
2003/04	22,199	3,978	26,177
2002/03	34,163		

Under a reconfigured No 9 Channel and LMW pool operation there will be about 110 delivery shares remaining on the No. 9 Channel that need to be supplied. There would also be 60 delivery shares to service on the LMW pool. In a peak allocation year, this equates to 11,000 ML demand on No. 9 Channel and 6,000 – 10,000 ML demand on the LMW pool. Here we assumed the upper figure of 10,000 ML/d for the LMW pool, giving a predicted total demand of 21,000 ML per year in a peak allocation year.

A peak daily demand of 200 ML/d can be assumed for the No. 9 Channel, as that will be the pump capacity. The LMW pool peak daily demand is more difficult to estimate. The estimate of maximum daily use made by Price Merrett suggested a value of 160 ML/d, expressed as the average over a 10-day period (Figure 5). One landholder suggested that it would be possible for a single user to draw 50 ML in one day. The constraint of the annual allocation means that these sorts of peak demands could not be sustained for very long.

On the basis of the above information, it was assumed that the peak daily demand would be 200 ML/d on No. 9 Channel and 300 ML/d from the weir pool. This would represent a single day only. Over a 10 day period, the peak average daily total demand was assumed to be 250 ML/d.

The data of Price Merrett (Figure 5) suggest that there is very little (or unknown) demand on the weir pool upstream of the Channel 6/7 inflow point. This implies that low inflows to Little Murray River through FPW would not represent a risk to irrigators' security of supply, provided their demand could be met by inflows from Channel 6/7.

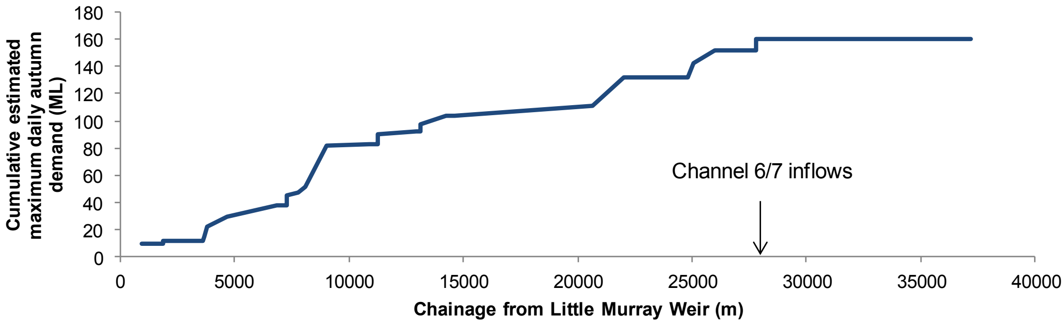


Figure 5. Estimated downstream cumulative maximum daily demand by for irrigation directly from Little Murray River weir pool. The values represent 10-day average demands. Source: Price Merrett (unpublished data).

3.2 Channel 6/7 inflows to Little Murray River

DG Consulting (2012) suggested that in the future, the primary source of water that should be used to meet estimated requirements of water users in the system is the Torrumbarry 6/7 Channel. The sum of the estimated demands for water users on the No. 9 Channel and for users drawing directly from the weir pool, plus the estimated demand for former No. 9 users transferred to the No. 10 Channel system would be the total release that should be ordered from Channel 6/7 into the weir pool. Based on the estimated peak demands (around 500 ML/d, see above), the Channel 6/7 has sufficient capacity (750 ML/d) to meet any demand situation.

The modelling undertaken here assumed that irrigation demand is met by inflows from Channel 6/7 rather than from inflows through Fish Point Weir. The inflows through Fish Point Weir are exclusively for environmental benefit, although Channel 6/7 inflow could also contribute environmental benefit as it passes through Little Murray River. It was important to include inflows from Channel 6/7 into the hydrological model of Little Murray River, as flows were sufficient that they could make a significant impact on water depth and salinity (and thus ecological habitat suitability).

In the absence of a predicted Channel 6/7 inflow time series for future arrangements, it was assumed here that the future seasonal demand pattern would follow the historical pattern, but that the volumes would be less. The seasonal pattern of MSM_Bigmod Channel 6/7 flows for the existing situation was similar to that of the gauged flows (Figure 6). The pattern of gauged flows was adopted as a basis to model future flows, as these are more recent data.

The MSM_Bigmod modelled Channel 6/7 daily flow data were a reasonable match with the gauged data, however, in recent years the modelled data overestimated actual inflows (Figure 7). This is explained by recent system operational changes that were not built into the MSM_Bigmod assumptions.

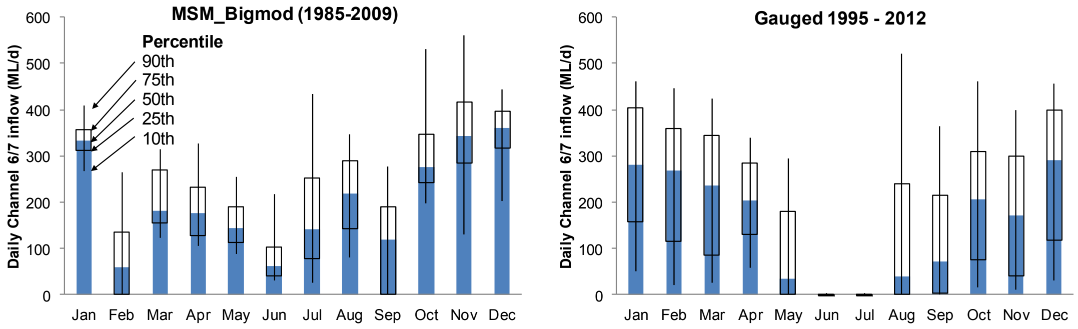


Figure 6. Descriptive statistics by month for Chanel 6/7 inflows: MSM_Bigmod for period 1895 – 2009 for pre-TLM scenario (left), and gauged data for period 1995 – 2012. Source: derived from data provided by MDBA and Goulburn-Murray Water.

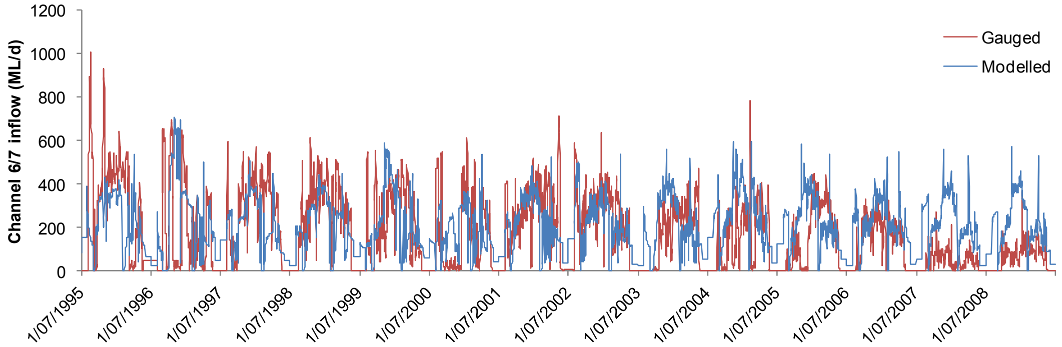


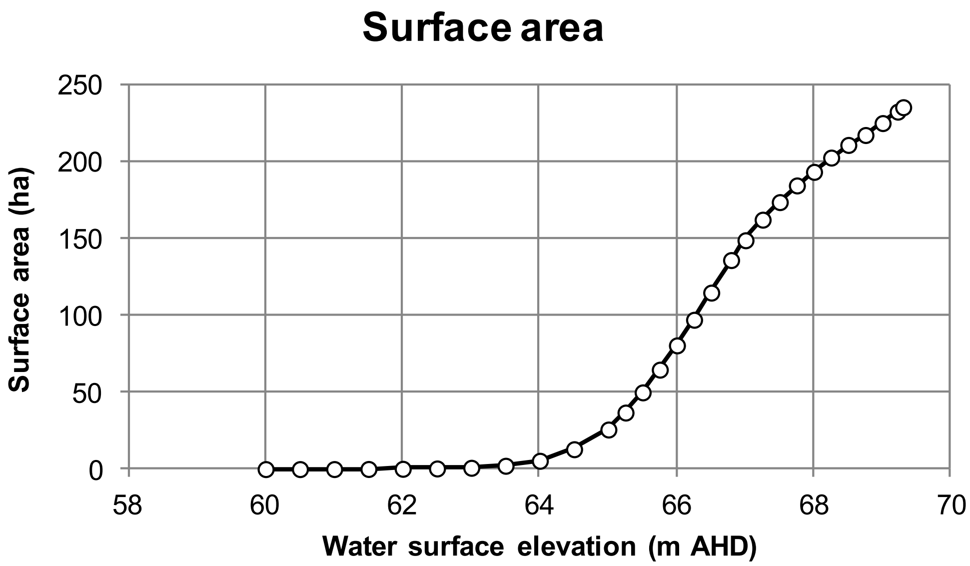
Figure 7. Comparison of time series of daily Channel 6/7 flows, gauged, and modelled by MSM_Bigmod assuming existing conditions (only overlapping time series are shown). Source: derived from data provided by MDBA and Goulburn-Murray Water.

The MSM_Bigmod series of Channel 6/7 inflows overestimates the flows that would occur in the future, with a reconfigured No 9 Channel and LMW pool operation. However, the variation in annual volumes of MSM_Bigmod flows would be a reasonable reflection of the availability of water in the system. On this basis, a synthetic daily time series of Channel 6/7 inflows was generated as follows:

1. The 95th percentile of MSM_Bigmod Channel 6/7 annual flows (1895 – 2009) (assumed to represent a peak annual allocation) was calculated to be 117,695 ML. This was 5.6 times greater than the predicted future annual combined No. 9 Channel and LMW pool demand of 21,000 ML in a peak annual allocation year. All of the MSM_Bigmod Channel 6/7 annual flows (1895 – 2009) were then factored down by dividing by 5.6. This generated a series of Channel 6/7 future annual flows.
2. A monthly pattern of seasonality was derived as the proportion of the mean flow of each month to the mean annual flow, based on gauged Channel 6/7 data from 1995 to 2012. The annual flow series was then disaggregated to a monthly flow series.
3. The monthly series was disaggregated to a daily flow series by assuming that daily flows were distributed evenly through each month.

3.3 Bathymetry relationships

Bathymetric data assuming a horizontal water surface are provided in tabular (Table 3) and graphical form (Figure 8). Bathymetric data for flowing water conditions are provided for five Little Murray Weir levels (Table 4).



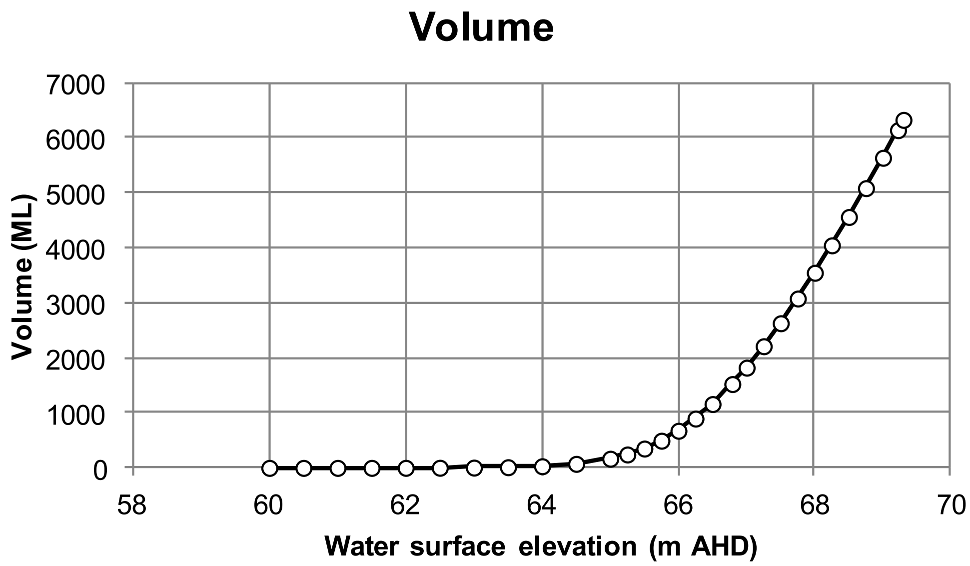


Figure 8. Bathymetry relationships Little Murray River between Little Murray Weir (LMW) and Fish Point Weir (FPW), assuming a horizontal water surface.

Table 3.
Bathymetry data Little Murray River between Little Murray Weir (LMW) and Fish Point Weir (FPW), assuming no discharge and horizontal water surface.

Elevation (m AHD)	Volume (ML)	Surface area (ha)	Elevation (m AHD)	Volume (ML)	Surface area (ha)
60.50	0.000	0.000	66.25	897.0	97.0
61.00	0.025	0.014	66.50	1161.3	114.7
61.50	0.258	0.076	66.79	1524.8	135.8
62.00	0.867	0.179	67.00	1823.4	148.7
62.50	2.25	0.400	67.25	2212.9	162.0
63.00	5.19	0.843	67.50	2631.3	173.5
63.50	12.1	2.16	67.75	3080.7	184.3
64.00	29.8	5.40	68.00	3549.5	193.1
64.50	73.4	12.9	68.25	4048.5	202.4
65.00	166.7	25.7	68.50	4564.8	210.6
65.25	243.8	36.7	68.75	5088.8	217.0
65.50	351.7	49.8	69.00	5641.1	224.8
65.75	494.5	64.6	69.22	6143.6	232.2
66.00	675.3	80.4	69.30	6330.5	235.1

Table 4.
Bathymetry data for Little Murray River between Little Murray Weir (LMW) and Fish Point Weir (FPW), for three potential future LMW levels and existing upper and lower LMW levels, over a range of discharges. Note that the river has a sloping surface under flowing water conditions. The elevation of FPW does not affect these area and volume estimates. The area and volume estimates assume constant flow throughout the length of the river between LMW and FPW.

Little Murray River discharge (ML/d)	Future scenario						Existing conditions			
	LMW = 67.00 m F1, F2 & F3		LMW = 67.25 m F4, F5 & F6		LMW = 67.50 m F7, F8 & F9		LMW = 66.79 m BM (open)		LMW = 69.21 m BM (closed)	
	Area (ha)	Volume (ML)	Area (ha)	Volume (ML)	Area (ha)	Volume (ML)	Area (ha)	Volume (ML)	Area (ha)	Volume (ML)
0	148.7	1823.4	164.8	2366.4	173.5	2631.3	135.8	1524.8	231.9	6120.7
100	150.8	1862.5	166.6	2406.8	174.3	2656.5	141.3	1587.9	231.8	6121.2
500	162.2	2125.2	173.3	2598.3	178.3	2782.2	156.8	1931.0	232.0	6131.0
750	168.1	2319.4	177.4	2757.5	181.3	2902.5	164.2	2168.2	232.3	6148.6
1,000	173.2	2518.8	181.0	2926.3	184.1	3036.9	170.5	2407.6	232.6	6172.6
1,500	181.6	2918.0	187.3	3276.4	189.6	3328.6	180.6	2870.3	233.6	6239.0
2,000	188.9	3306.7	192.9	3625.7	194.7	3631.3	188.6	3291.0	234.8	6326.8
2,500	195.0	3680.9	197.6	3966.2	199.3	3935.0	194.9	3679.1	236.3	6433.2
3,000	200.4	4040.6	202.0	4296.3	203.6	4234.8	200.4	4040.8	239.0	6554.9
5,000	219.2	5316.0	218.0	5516.6	220.1	5377.4	219.2	5316.0	247.0	7145.4
7,500	238.6	6697.9	235.1	6882.7	238.7	6703.5	238.5	6697.6	260.7	8019.3
10,000	258.9	7956.6	252.9	8113.2	258.9	7956.6	258.9	7956.6	272.4	8931.1

3.4 Weir pool hydraulics

3.4.1 Connectivity

3.4.1.1 Bed profile

The weir pool has variable bed topography, with amplitude of about 2 – 3 m over most of its length, although the bed is less variable in depth at the upstream end (Figure 9). The river has a few pools up to about 6 m deep measured from the elevation of the LMW sill. In close proximity to LMW and FPW there were some points on the thalweg profile that slightly exceeded the sill levels of the weirs.

Under an alternative operating regime with lowered weir levels and water flowing through the river most of the time, discharge would exceed 5,000 ML/d in most years. At this flow rate, mean channel velocities would exceed 1.0 m/s, which would be sufficient to scour these high points in the bed (which are composed of settled clay) (Fortier and Scobey, 1926; Chang, 1988; Laycock, 2007, p. 231). Over the long-term, an open Little Murray River would likely experience bed scour, which would lead to improved connectivity over time. Thus, when applying the pool depth criteria, the areas within 200 m of the two weirs were excluded.

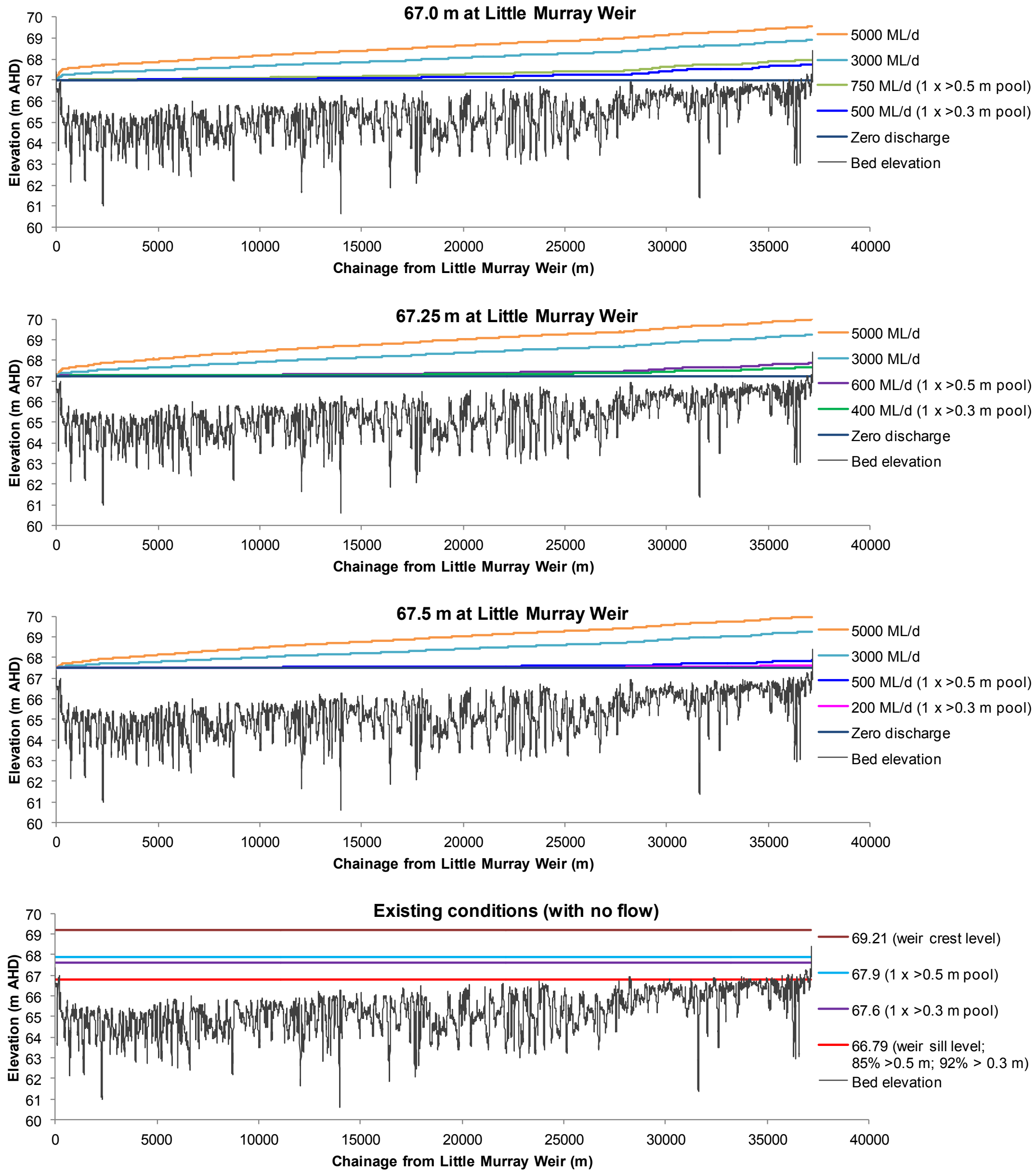
3.4.1.2 Connectivity under existing conditions

Under existing conditions, when the river is not flowing, the habitat connectivity criterion of 0.3 m minimum depth is met at a water level higher than 67.6 m, and the stricter criterion of 0.5 m minimum depth is met at a water level higher than 67.9 m (Figure 9 and Figure 10). As the water surface elevation declines, the weir pool divides into a number of shorter pools separated by water of a depth shallower than these criteria. As the water level falls, the shorter pools start to form at the upstream end of the weir pool, upstream of Channel 6/7 inlet. For example, at 65.5 m water level, 45% of the pool length is deeper than 0.3 m, and 36% is deeper than 0.5 m, but the weir pool has separated into more than 200 pools (Figure 10). When the water level falls below 64 m, less than 5% of the pool length meets the depth criteria (Figure 10). Between water levels 67.6 m and 61.5 m the mean depth of these disconnected pools has a median value of around 0.5 – 0.7 m and the maximum depth of the pools has a median value of around 0.8 – 1.0 m (Figure 10). During the irrigation season the LMW pool is maintained at 69.21 m, when the 0.5 m minimum depth criterion for connectivity is exceeded along the entire river (Figure 9 and Figure 10).

3.4.1.3 Connectivity under alternative operating scenarios

The habitat connectivity was modelled for three alternative operating scenarios: LMW at 67.0 m, 67.25 m and at 67.5 m, with all assuming inflows to Little Murray River through an open Fish Point Weir. For these scenarios the water surface is sloping (Figure 9). The elevation of Fish Point Weir sill is irrelevant to this analysis, as the sill level of FPW does not impact the water levels in the Little Murray River for a given flow rate through FPW.

For the FPW at 67.0 m, the habitat connectivity criterion of 0.3 m minimum depth is met at a flow rate of 460 ML/d or higher, and the stricter criterion of 0.5 m minimum depth is met at a flow rate of 730 ML/d or higher (Figure 9 and Figure 11). For the FPW at 67.25 m, the habitat connectivity criterion of 0.3 m minimum depth is met at a flow rate of 330 ML/d or higher, and the stricter criterion of 0.5 m minimum depth is met at a flow rate of 560 ML/d or higher (Figure 9 and Figure 12). For the FPW at 67.5 m, the habitat connectivity criterion of 0.3 m minimum depth is met at a flow rate of 160 ML/d or higher, and the stricter criterion of 0.5 m minimum depth is met at a flow rate of 420 ML/d or higher (Figure 9 and Figure 13).



Notes:

1. Critical discharge and level thresholds corresponding to the criteria of (i) a continuous reach ≥ 0.3 m deep and (ii) a continuous reach ≥ 0.5 m deep are shown. These correspond to requirements for fish movement, with 0.5 m depth a lower risk criterion.
2. The water surface profiles and the thalweg profile were all adjusted to a standardised length, equivalent to a river centre-line length of 37,172 m.
3. Under existing conditions Little Murray Weir is open at the sill level of 66.79 m during the non-irrigation season (16 May to 14 August) and is closed at the crest level of 69.21 m during the irrigation season (15 August to 15 May). When flow occurs, the water surface profile is above the crest level or sill level for the length of the weir pool.

Figure 9. Thalweg (lowest point of the bed) elevation of Little Murray River between Little Murray Weir and Fish Point Weir. Also shown are water surface profiles for a range of discharges up to 5,000 ML/d. Levels 67.0 m and 67.5 m are two possible options for future operation of Little Murray Weir, with Fish Point Weir open to allow flow from the Murray and Loddon rivers to enter Little Murray River.

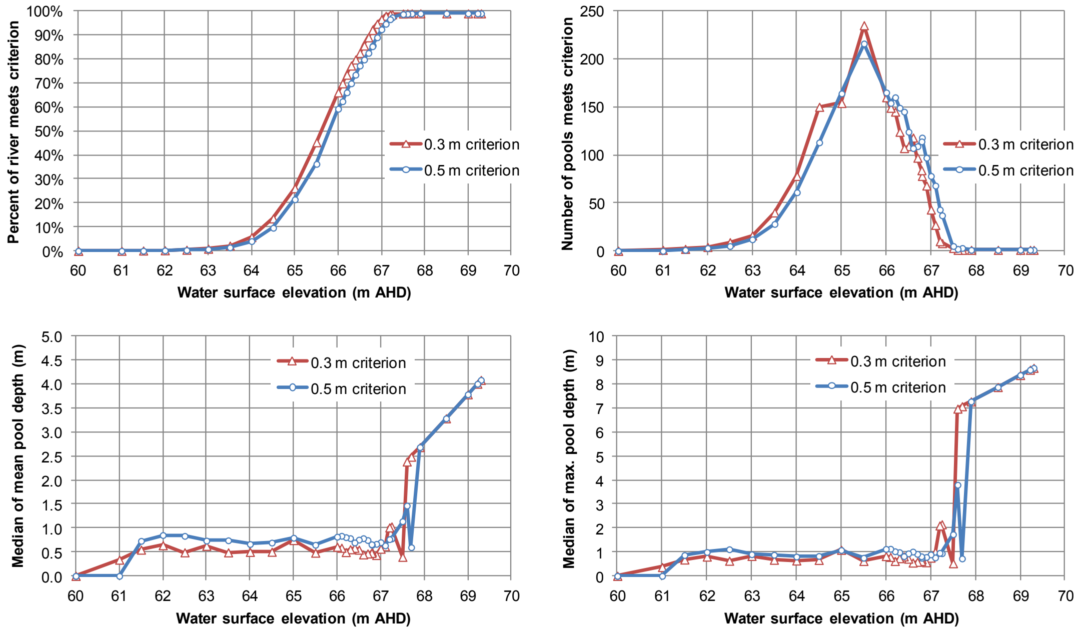


Figure 10. Characteristics of pools with depth ≥ 0.3 m and ≥ 0.5 m within Little Murray Weir pool as a function of water surface elevation, assuming horizontal surface with no flow (i.e. existing conditions during the majority of the year). The water level is at 69.21 m during the irrigation season and is lowered to the sill at 66.79 m (or lower) during the non-irrigation season.

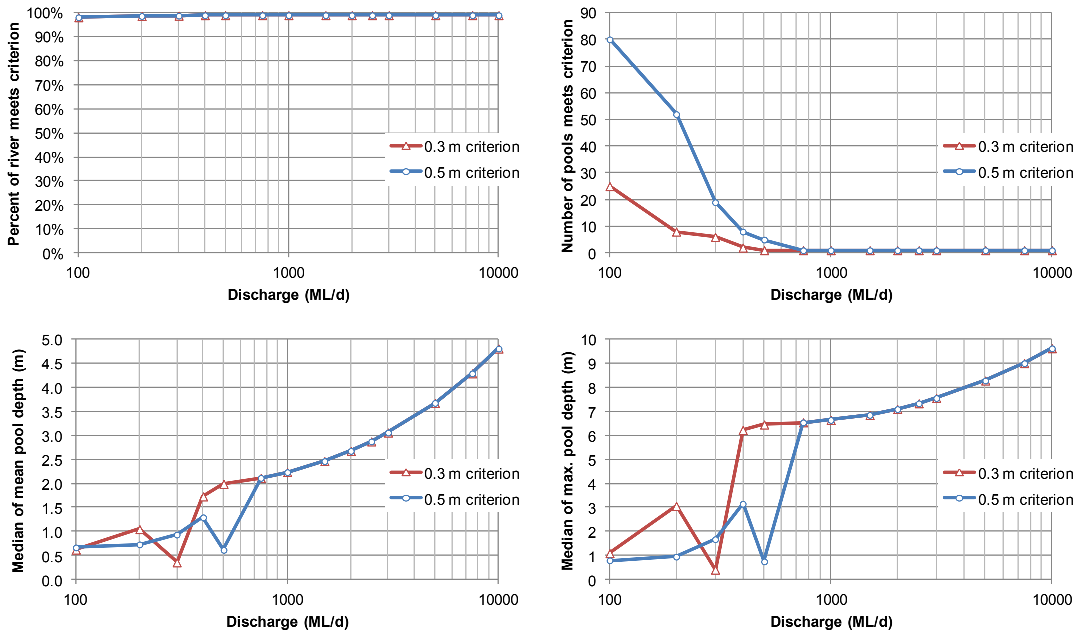


Figure 11. Characteristics of pools with depth ≥ 0.3 m and ≥ 0.5 m within Little Murray Weir pool as a function of discharge, assuming Little Murray Weir is at the alternative level of 67.0 m (F1, F2 and F3). Note that for these conditions the water surface is sloping.

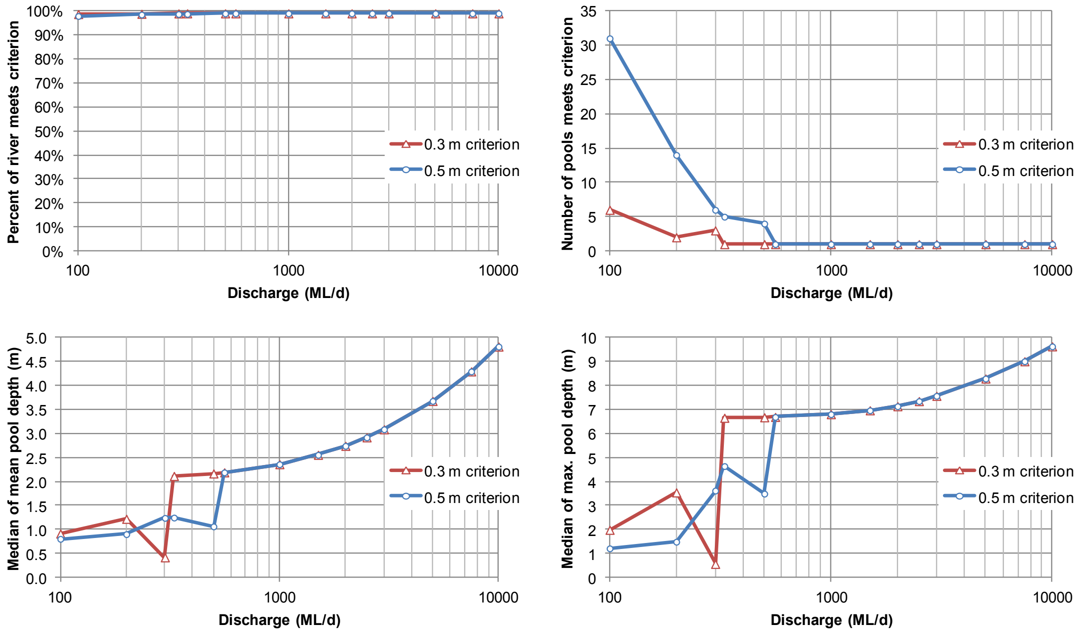


Figure 12. Characteristics of pools with depth ≥ 0.3 m and ≥ 0.5 m within Little Murray Weir pool as a function of discharge, assuming Little Murray Weir is at the alternative level of 67.25 m (F1, F2 and F3). Note that for these conditions the water surface is sloping.

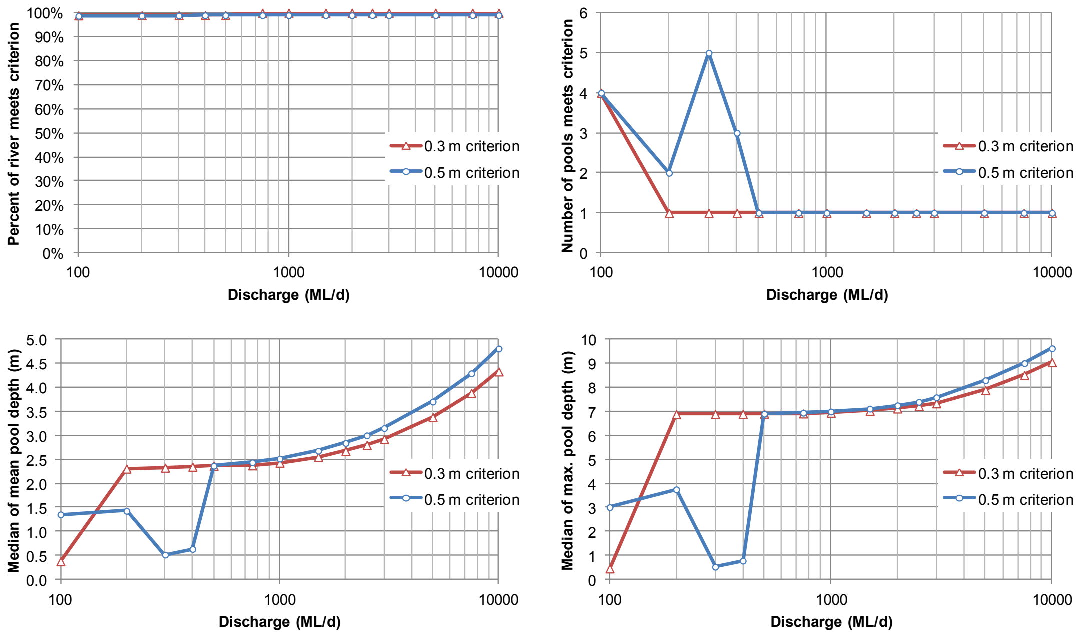


Figure 13. Characteristics of pools with depth ≥ 0.3 m and ≥ 0.5 m within Little Murray Weir pool as a function of discharge, assuming Little Murray Weir is at the alternative level of 67.5 m (F7, F8 and F9). Note that for these conditions the water surface is sloping.

For the FPW at 67.0 m, as the discharge declines below 730 ML/d and 460 ML/d, the weir pool divides into a number of shorter pools separated by water of a depth shallower than the 0.5 m and 0.3 m depth criteria, respectively (Figure 9 and Figure 11). As the discharge (and water level) falls, the shorter pools start to form at the upstream end of the weir pool, upstream of Channel 6/7 inlet. For example, at 200 ML/d, 99% of the weir pool length is deeper than 0.3 m, and 97% is deeper than 0.5 m, but the weir pool has separated into 8 pools deeper than 0.3 m deep and 52 pools deeper than 0.5 m (Figure 11). Overall, with FPW at 67.0 m, the sloping water surface of that prevails when Little Murray River is flowing at 5,000 ML/d produces deeper pools in the upstream (shallower) 6.5 km of the river, compared to the existing situation with LMW at 69.21 m and the river not flowing (Figure 9).

For the FPW at 67.25 m, as the discharge declines below 560 ML/d and 330 ML/d, the weir pool divides into a number of shorter pools separated by water of a depth shallower than the 0.5 m and 0.3 m depth criteria, respectively (Figure 9 and Figure 12). As the discharge (and water level) falls, the shorter pools start to form at the upstream end of the weir pool, upstream of Channel 6/7 inlet. For example, at 100 ML/d, 99% of the weir pool length is deeper than 0.5 m, but the weir pool has separated into 6 pools deeper than 0.5 m (Figure 12). Overall, with FPW at 67.25 m, the sloping water surface that prevails when Little Murray River is flowing at 5,000 ML/d produces deeper pools in the upstream (shallower) 13.5 km of the river, compared to the existing situation with LMW at 69.21 m and the river not flowing (Figure 9).

For the FPW at 67.5 m, as the discharge declines below 420 ML/d and 160 ML/d, the weir pool divides into a number of shorter pools separated by water of a depth shallower than the 0.5 m and 0.3 m depth criteria, respectively (Figure 9 and Figure 13). As the discharge (and water level) falls, the shorter pools start to form at the upstream end of the weir pool, upstream of Channel 6/7 inlet. For example, at 100 ML/d, 99% of the weir pool length is deeper than 0.5 m, but the weir pool has separated into 4 pools deeper than 0.5 m (Figure 13). Overall, with FPW at 67.5 m, the sloping water surface that prevails when Little Murray River is flowing at 5,000 ML/d produces deeper pools in the upstream (shallower) 13.6 km of the river, compared to the existing situation with LMW at 69.21 m and the river not flowing (Figure 9).

3.4.1.4 Conditions to meet connectivity criteria within Little Murray River

The conditions for Little Murray River that met the two connectivity criteria, a continuous pool at least 0.3 m deep along the thalweg, and a continuous pool at least 0.5 m deep along the thalweg, were determined for current and alternative operational scenarios. The threshold conditions associated with these criteria are given in Table 5. These thresholds are conservative because the HEC-RAS model characterised the bed of the river with only 240 cross-sections, so it would have missed some high points; in contrast, the bed profile was based on 1 m-spaced observations that picked up the detail of all the high points. These high points would in reality act as hydraulic controls, raising the water level over them, and drowning out some lesser high points upstream.

Table 5.
Threshold conditions for Little Murray River that meet two connectivity criteria: (i) a continuous pool between LWM and FPW, at least 0.3 m deep along the thalweg, and (ii) a continuous pool between LWM and FPW, at least 0.5 m deep along the thalweg.

Scenario	LMW level (m)	FPW level (m)	Threshold condition to meet connectivity criterion	
			≥ 0.3 m continuous depth	≥ 0.5 m continuous depth
Existing (BM)	69.21/66.79	69.71/68.41	≥ 67.6 m elevation	≥ 67.9 m elevation
F1, F2, F3	67.0	67.22, 67.81, 68.41	≥ 460 ML/d	≥ 730 ML/d
F4, F5, F6	67.25	67.22, 67.81, 68.41	≥ 330 ML/d	≥ 560 ML/d
F7, F8, F9	67.5	67.22, 67.81, 68.41	≥ 160 ML/d	≥ 420 ML/d

The criteria listed in Table 5 require that there be no interruptions to connectivity along the full 37 km of the river from LMW to FPW. Most of the potential for breaks in connectivity occur over the 9 km reach from FPW to near Channel 6/7 inflow. When the river is not flowing, LMW levels of 67.0 – 67.5 will provide a 28.6 km long continuous pool ≥0.3 m deep, stretching from LMW to the Channel 6/7 inflow point (Table 6). This pool is ≥0.5 m deep for weir levels of 67.25 m and 67.5 m, and meets this criterion for a weir level of 67.0 m if the discharge is at least 450 ML/d (Table 6). Under low flow conditions, a long continuous pool from LMW to Channel 6/7 inlet would provide suitable conditions for local movement over the majority of the river, but shallow points upstream of Channel 6/7 inlet would restrict connectivity with the River Murray.

Table 6.
Threshold conditions for Little Murray River that meet two connectivity criteria: (i) a continuous pool at least 28.6 km long, at least 0.3 m deep along the thalweg, and (ii) a continuous pool at least 28.6 km long, at least 0.5 m deep along the thalweg.

Scenario	LMW level (m)	FPW level (m)	Threshold condition to meet connectivity criterion	
			≥ 0.3 m continuous depth	≥ 0.5 m continuous depth
F1, F2, F3	67.0	67.22, 67.81, 68.41	≥ 0 ML/d	≥ 450 ML/d
F4, F5, F6	67.25	67.22, 67.81, 68.41	≥ 0 ML/d	≥ 0 ML/d
F7, F8, F9	67.5	67.22, 67.81, 68.41	≥ 0 ML/d	≥ 0 ML/d

3.4.1.5 Conditions to favour connectivity through Fish Point Weir

Connectivity between Little Murray River and River Murray requires: (i) full connectivity throughout Little Murray River, and (ii) passage through the Fish Point Weir structure. Conditions to meet connectivity criteria within Little Murray River were described above (Table 5). A depth of at least 0.5 m over Fish Point Weir requires a minimum discharge of 340 ML/d, while a depth of at least 0.3 m requires a minimum discharge of 161 ML/d, with both independent of the height of Little Murray Weir (Figure 14). At these discharges and greater, mean velocity at Fish Point Weir varies over the range 0.20 – 0.45 m/s, and is relatively independent of FPW or LMW height at discharges greater than 500 ML/d (Figure 14).

The fall in the water surface elevation through Fish Point Weir is dependent on FPW height, LMW height and discharge (Figure 15). The fall in elevation is small when FPW is at 67.22 m, regardless of the elevation of LMW. When FPW is at 67.81 m and 68.41 m, there is a significant fall in water surface elevation through FPW (over the range of about 0.7 – 1.4 m) until the weir is drowned out at discharges above about 3,000 ML/d (Figure 15). This fall in elevation was measured across two cross-sections in the HEC-RAS model that were 175 m apart. Over this distance, the greatest estimated fall in elevation represents a surface slope of 1 in 120, but the actual fall would likely occur over a distance shorter than 175 m.

The significance for fish passage of the predicted velocities and water surface slopes over Fish Point Weir cannot be assessed here because the relevant criteria are not readily available [e.g. they are not provided in Environous and Streamline Research (2012)]. Overall, connectivity through FPW is likely to be better for FPW at 67.22 m than at higher elevations, while for most conditions, the height of LMW appears to have little impact on connectivity through FPW.

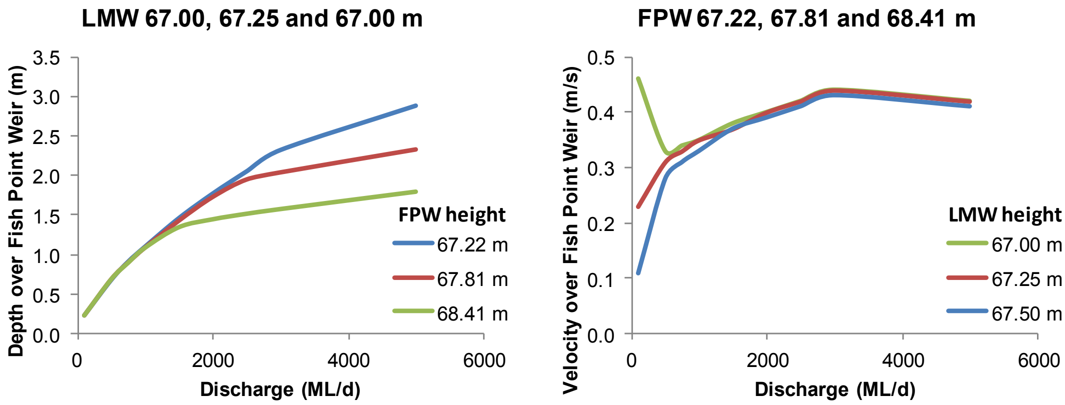


Figure 14. Depth and velocity at Fish Point Weir (FPW) as a function of discharge, for three heights of FPW (left) and three heights of Little Murray Weir (LMW) (right). Depth at FPW is independent of LMW height, and velocity at FPW is independent of FPW height.

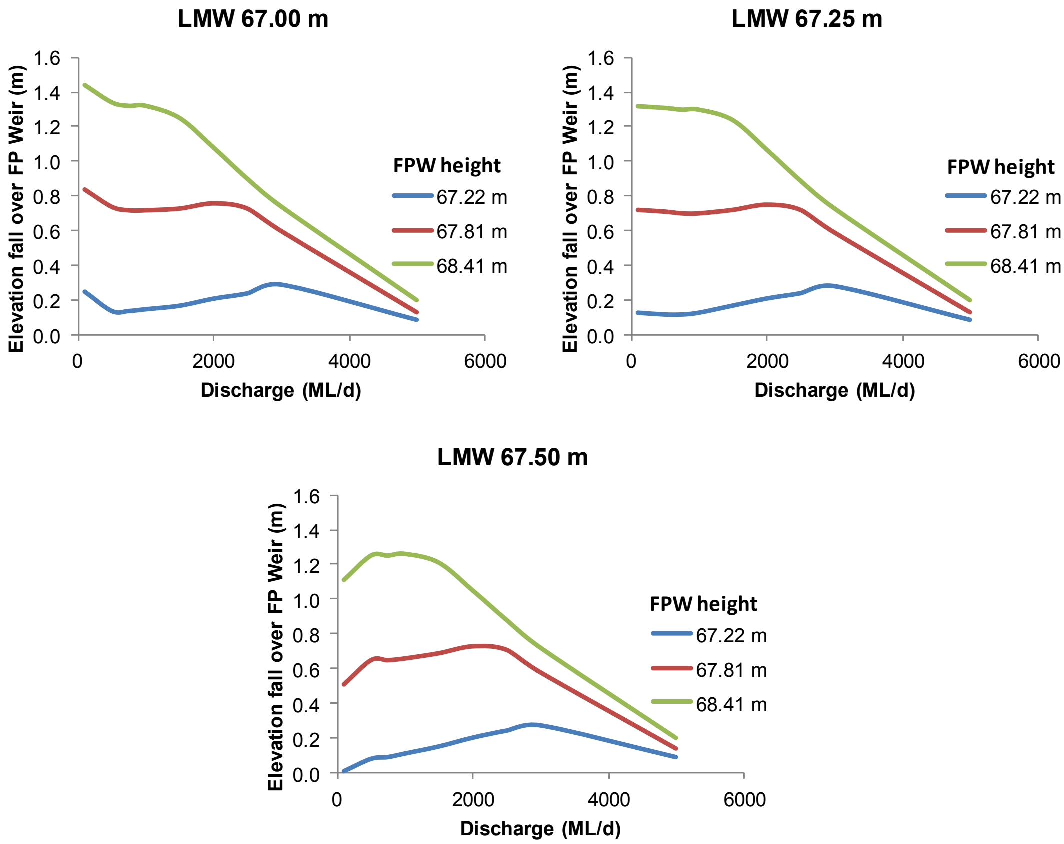


Figure 15. Fall in water surface elevation at Fish Point Weir (FPW) as a function of discharge, for three heights of FPW and three heights of Little Murray Weir (LMW). The fall in elevation was estimated between HEC-RAS cross-sections that were 175 m apart.

3.4.1.6 Conditions to favour connectivity from Fish Point Weir to the River Murray

Seven cross-sections were surveyed by Price Merrett Consulting between the River Murray and Fish Point Weir specifically for this report. These cross-sections were used in the HEC-RAS model to estimate the surface water profile upstream of Fish Point Weir. The cross-sections were then used to define the flow required to satisfy the connectivity thresholds of ≥0.3 m and ≥0.5 m (Table 7).

3.4.1.7 Conditions to favour full connectivity

The discharges to favour full connectivity: (i) throughout the entire Little Murray River, (ii) over Fish Point Weir, and (iii) to the River Murray for each potential alternative operating scenario were based on the highest discharge required to meet each of the three conditions, for both the 0.3 m and 0.5 m depth criteria (Table 8).

Table 7.
Threshold conditions for connectivity from Fish Point Weir to the River Murray that meet two connectivity criteria: (i) at least 0.3 m deep along the thalweg, and (ii) at least 0.5 m deep along the thalweg.

Scenario	LMW level (m)	FPW level (m)	Threshold condition to meet connectivity criterion	
			≥ 0.3 m depth	≥ 0.5 m depth
F1, F4	67.0, 67.25	67.22	≥ 108 ML/d	≥ 262 ML/d
F7	67.5	67.22	≥ 47 ML/d	≥ 224 ML/d
F2, F5, F8	67.0, 67.25, 67.5	67.81	≥ 0 ML/d	≥ 0 ML/d
F3, F6, F9	67.0, 67.25, 67.5	68.41	≥ 0 ML/d	≥ 0 ML/d

Table 8.
Threshold conditions for full connectivity that meet two connectivity criteria: (i) at least 0.3 m deep along the thalweg, and (ii) at least 0.5 m deep along the thalweg.

Scenario	LMW level (m)	FPW level (m)	Threshold condition to meet connectivity criterion	
			≥ 0.3 m depth	≥ 0.5 m depth
F1	67.00	67.22	≥ 460 ML/d	≥ 730 ML/d
F2	67.00	67.81	≥ 460 ML/d	≥ 730 ML/d
F3	67.00	68.41	≥ 460 ML/d	≥ 730 ML/d
F4	67.25	67.22	≥ 330 ML/d	≥ 560 ML/d
F5	67.25	67.81	≥ 330 ML/d	≥ 560 ML/d
F6	67.25	68.41	≥ 330 ML/d	≥ 560 ML/d
F7	67.50	67.22	≥ 161 ML/d	≥ 420 ML/d
F8	67.50	67.81	≥ 161 ML/d	≥ 420 ML/d
F9	67.50	68.41	≥ 161 ML/d	≥ 420 ML/d

3.4.2 Macrophyte (cumbungi) growth

3.4.2.1 Existing conditions

Under current conditions, for most of the year (the irrigation season, from mid-August to mid-May) the thalweg of the weir pool exceeds 2 m depth, which is the maximum depth at which cumbungi will grow. At the existing irrigation season weir pool level of 69.21 m, 31% of the weir pool area has a depth less than 2 m. Thus, while cumbungi could potentially establish in shallower water around the margins of the weir pool, the majority of the pool would be free of macrophytes. This matches the description of the distribution of cumbungi in Little Murray River by Environous and Streamline Research (2012).

3.4.2.2 Alternative operating scenarios

Under potential alternative operating scenarios, Little Murray Weir would be lowered, thereby lowering the water depth, and potentially creating conditions that favour the growth of macrophytes. However, high discharges entering the river through Fish Point Weir could potentially keep macrophytes in check by exceeding their velocity tolerance. Under current conditions, flows of up to about 8,000 ML/d occur when Fish Point Weir is opened (under conditions of high flows in the River Murray), and under the alternative operating scenarios Fish Point Weir would be open all of the time, thereby increasing the frequency of high flows in Little Murray River.

An analysis of the hydraulic conditions created by a range of flows, for a range of LMW heights, suggests that for the potential alternative weir heights of 67.0 – 67.5 m a flow rate of >2,000 ML/d will create conditions that discourage cumbungi along the entire thalweg of the river (Figure 16). As explained in the methods section of this report, the criterion was the minimum discharge associated with V = 1 m/s, D = 2 m and $V \cdot D$ = 0.52 (V = mean cross-section velocity and D = maximum channel depth). Even at 1,500 ML/d, hydraulic conditions along most of the thalweg are not favourable for cumbungi, either because the depth exceeds 2 m or areas of lower depth have sufficiently high velocity to discourage establishment. As with the current conditions of water level at 69.21 m and no flow, with a lowered LMW level and flows exceeding 2,000 ML/d, there will be areas along the channel margins that favour growth of cumbungi. Thus, a threshold flow of 2,000 ML/d will meet the criterion for discouraging excessive growth of cumbungi in the channel. This threshold flow does not need to occur year round in order to discourage excessive growth of cumbungi. Any cumbungi that begins to grow during a period of low flows will be checked when flows of 2,000 ML/d occur, either through damage to the stems or drowning (starving the rhizomes of oxygen). Knowledge is insufficient to allow estimation of the annual duration of flow exceeding 2,000 ML/d that would be required for control of cumbungi (Marcus Cooling, Ecological Associates, pers. comm., 13 November, 2012).

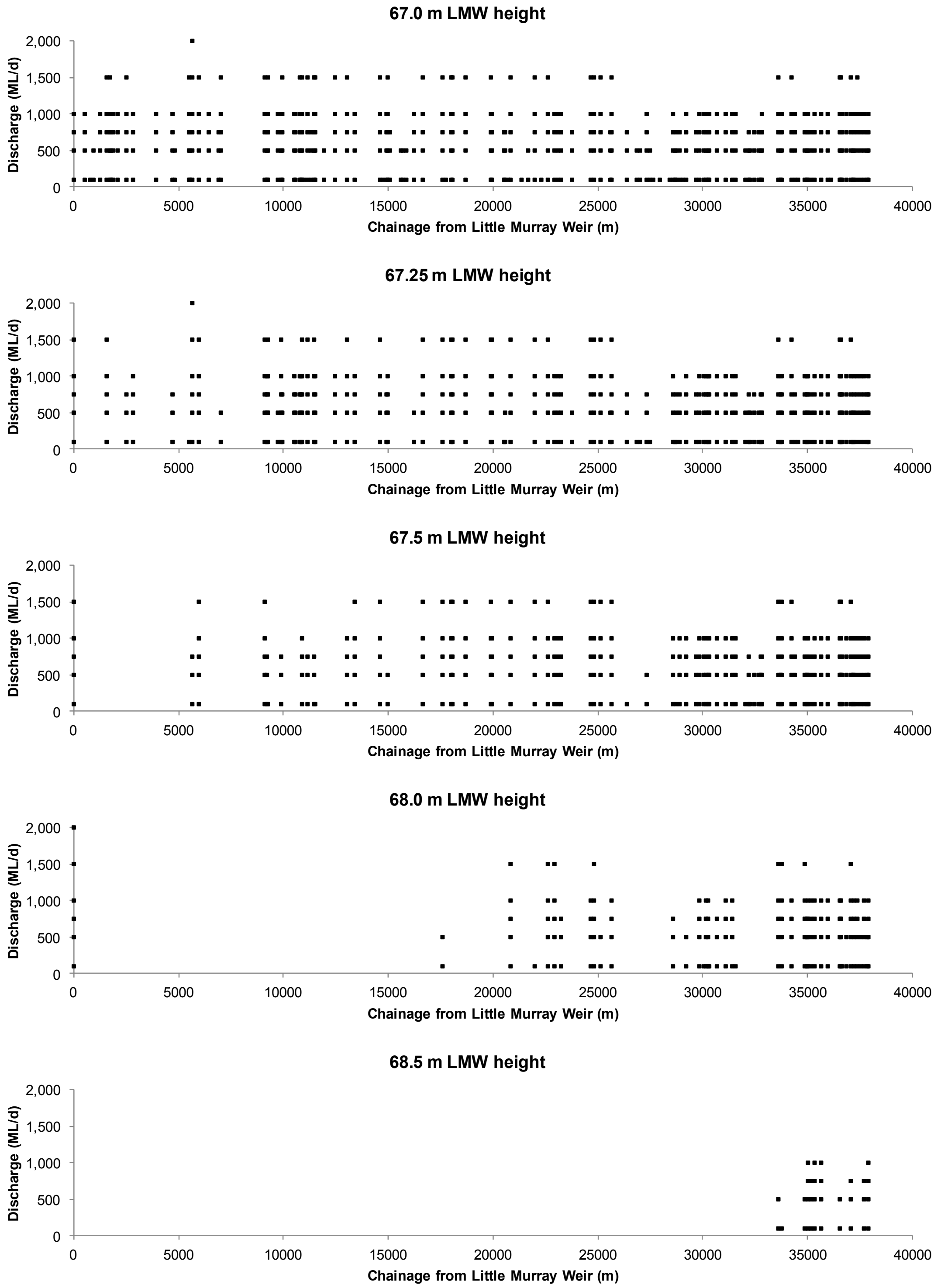


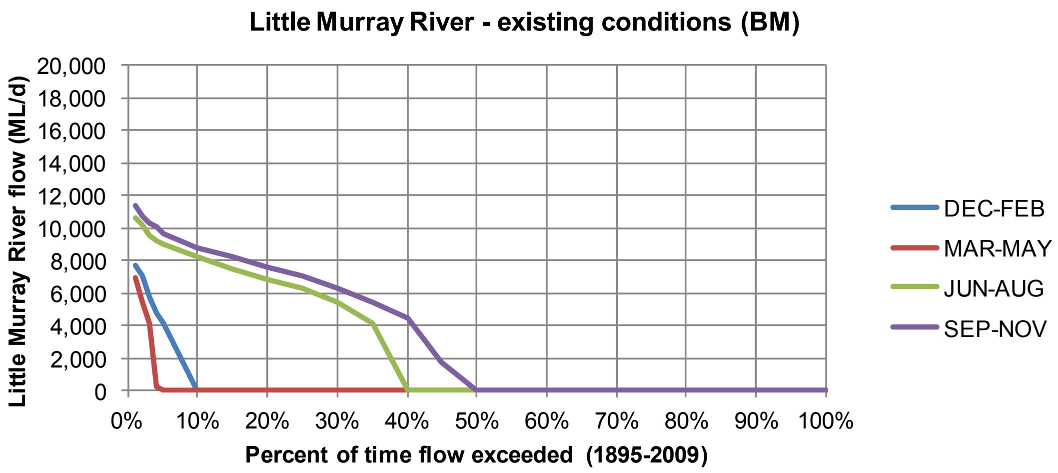
Figure 16. Longitudinal distributions of depth and velocity conditions that do not exclude growth of *Typha* spp. (cumbungi) in the thalweg of Little Murray River between Little Murray Weir and Fish Point Weir. Criterion based on the minimum discharge associated with V = 1 m/s, D = 2 m and $V \cdot D$ = 0.52 (V = mean cross-section velocity and D = maximum channel depth). Plotted points correspond with HEC-RAS cross-sections, which are spaced 50 – 700 m apart (mean distance 152 m).

3.5 *Modelled time series of flows for existing and potential future scenarios, 1895 – 2009*

3.5.1 Flow distributions

3.5.1.1 Existing scenario (BM)

Under existing conditions (BM), flow passes down Little Murray River infrequently in summer and autumn, and for less than half of the time in winter and spring (Figure 17, Figure 18).



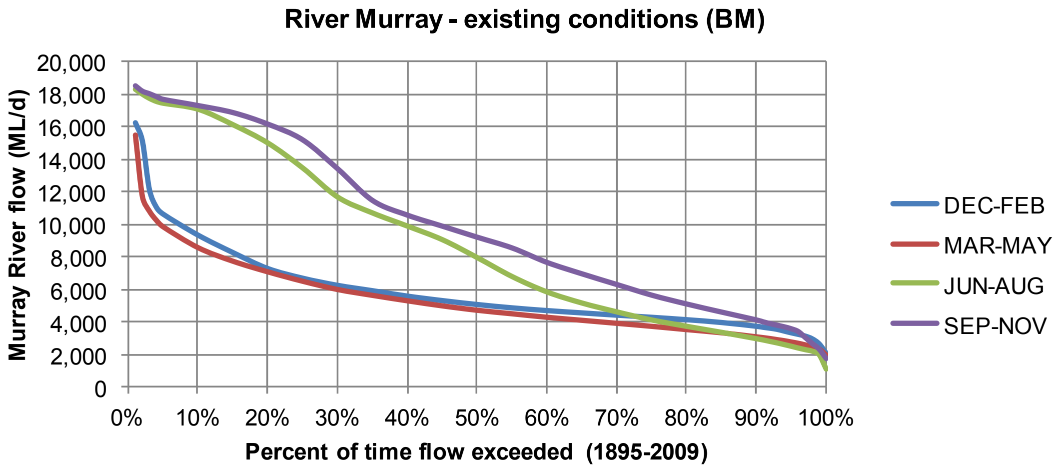


Figure 17. MSM_Bigmod modelled (1895 – 2009) seasonal distribution of flows in the Little Murray River and the River Murray under existing (pre-TLM) conditions (Scenario BM) for full range of flows.

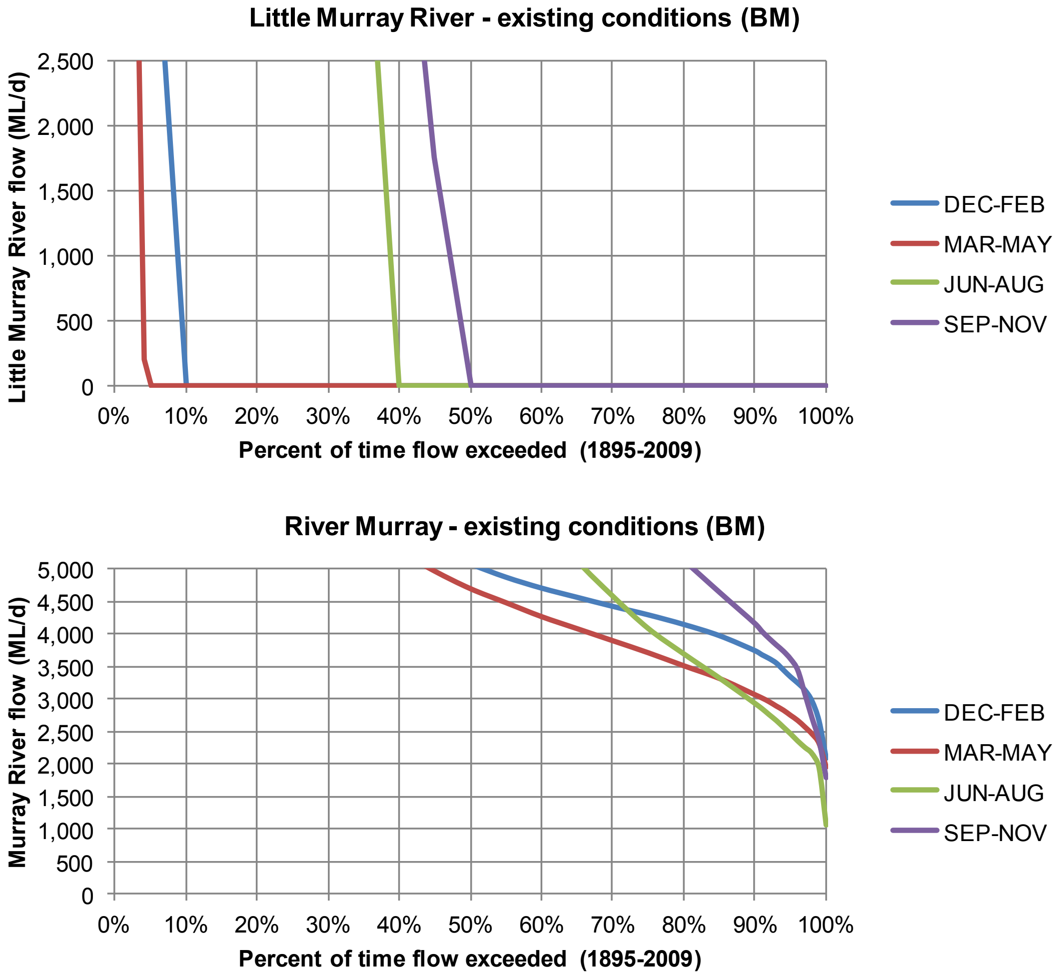
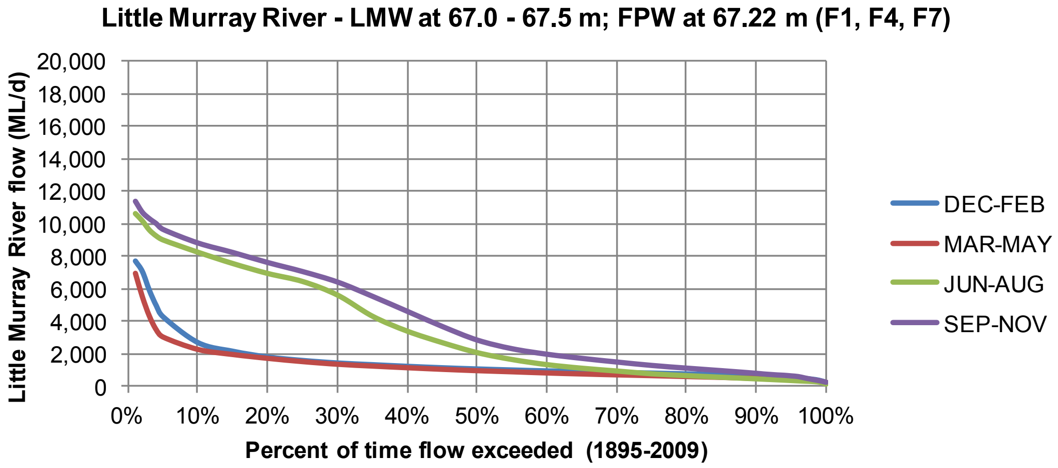


Figure 18. MSM_Bigmod modelled (1895 – 2009) seasonal distribution of flows in the Little Murray River and the River Murray under existing (pre-TLM) conditions (Scenario BM) for low flow range.

3.5.1.2 Future scenarios F1, F4 and F7, Fish Point Weir at 67.22 m

Modelling of the future scenarios F1, F4 and F7, with FPW at 67.22 m, revealed that the distribution of flows in Little Murray River was controlled by the Fish Point Weir crest level, and was insensitive to the 0.5 m difference in LWM crest height for the scenarios (i.e. the three LMW crest heights gave virtually the same flow distributions for any given FPW crest level). Under these potential future scenarios, with the model run from 1895 to 2009, flow never ceased in Little Murray River (Figure 19, Figure 20).

The lowest inflows to Little Murray River occurred in the Jun-Aug period. The predicted lowest flow was 70.2 ML/d in the Jun-Aug period for a LMW level of 67.5 m and 74.4 ML/d in the Jun-Aug period for a LMW level of 67.0 m.



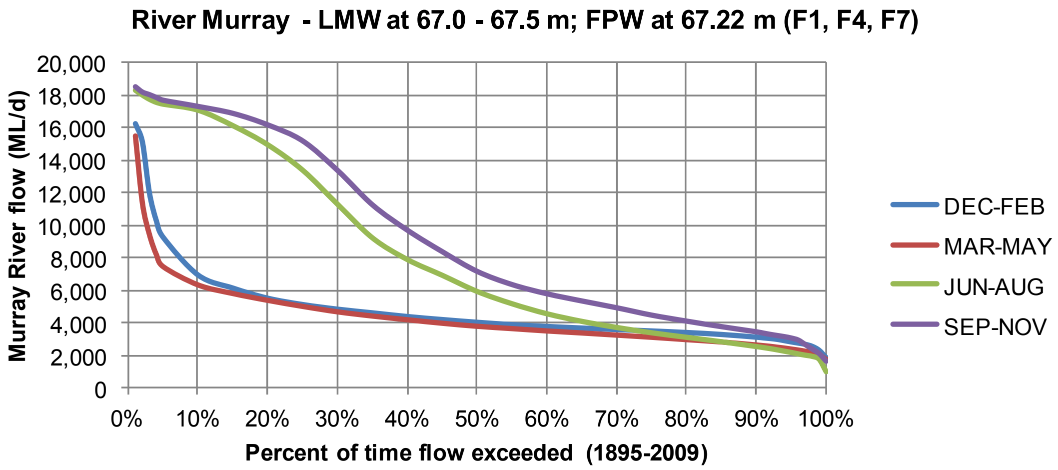
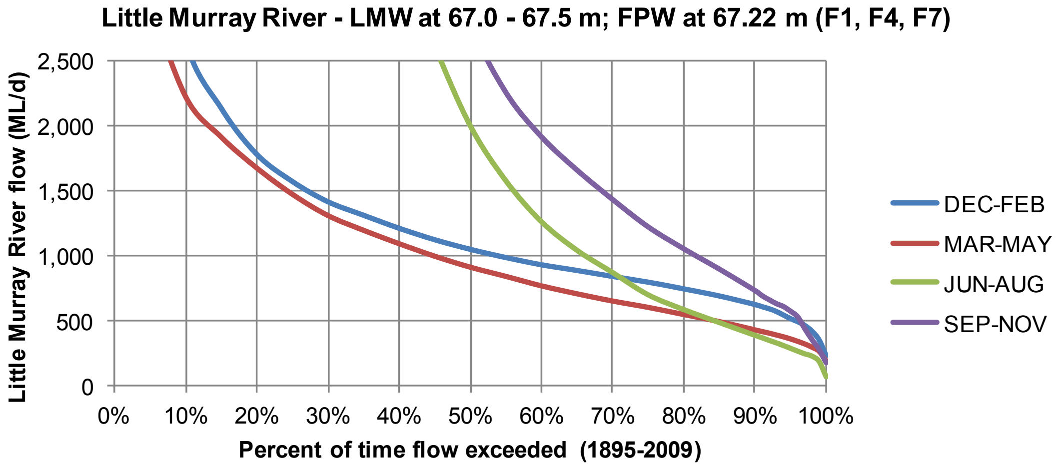


Figure 19. Modelled (1895 - 2009) seasonal distribution of flows in the Little Murray River and the River Murray under simulated conditions of Little Murray Weir crest lowered permanently to 67.0 m and Fish Point Weir sill lowered to 67.22 m and permanently open, for full range of flows.



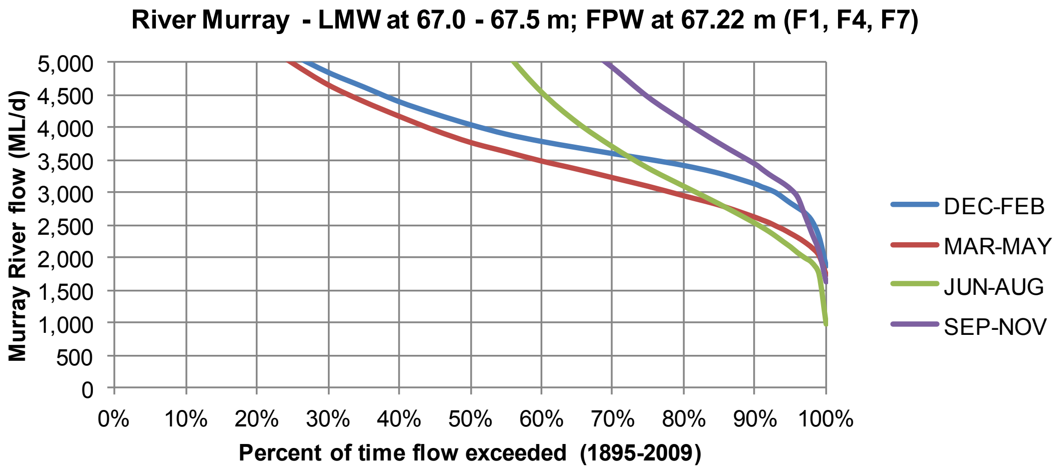


Figure 20. Modelled (1895 – 2009) seasonal distribution of flows in the Little Murray River and the River Murray under simulated conditions of Little Murray Weir crest lowered permanently to 67.0 m and Fish Point Weir sill lowered to 67.22 m and permanently open, for low flow range.

3.5.1.3 Future scenarios F2, F5 and F8, Fish Point Weir at 67.81 m

Modelling of the future scenarios F2, F5 and F8, with FPW at 67.81 m, revealed that the distribution of flows in Little Murray River was controlled by the Fish Point Weir crest level, and was insensitive to the 0.5 m difference in LWM crest height for the scenarios (i.e. the three LMW crest heights gave the same flow distributions for any given FPW crest level) (Figure 21, Figure 22).

The lowest inflows to Little Murray River occurred in the Jun-Aug period. Inflows ceased on one day over the entire 114 year modelled period. Inflows were <101 ML/d for 1 percent of the time in the Jun-Aug period.

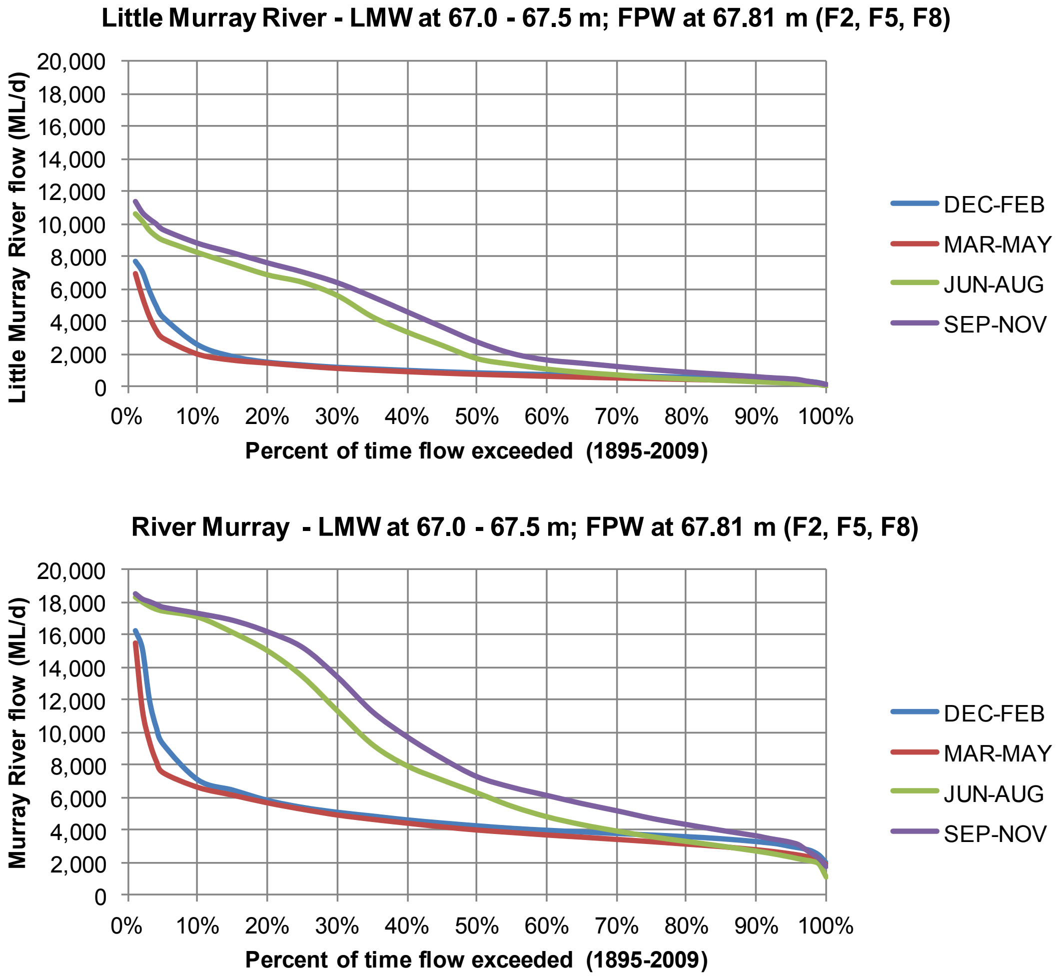
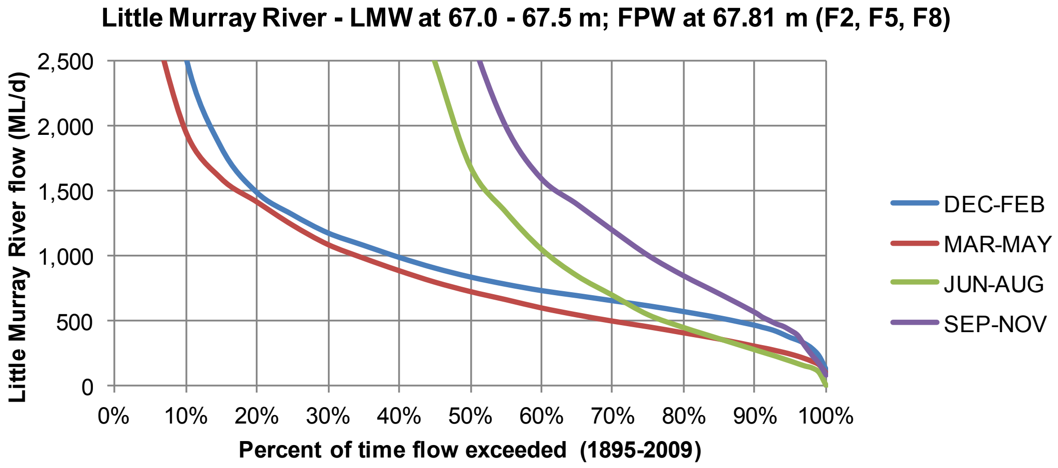


Figure 21. Modelled (1895 - 2009) seasonal distribution of flows in the Little Murray River and the River Murray under simulated conditions of Little Murray Weir crest lowered permanently to 67.0 m and Fish Point Weir sill lowered to 67.81 m and permanently open, for full range of flows.



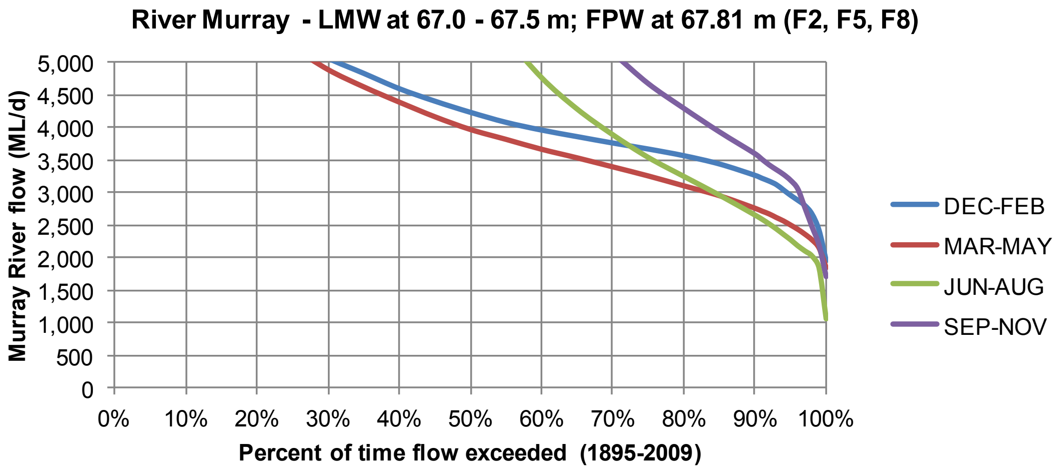
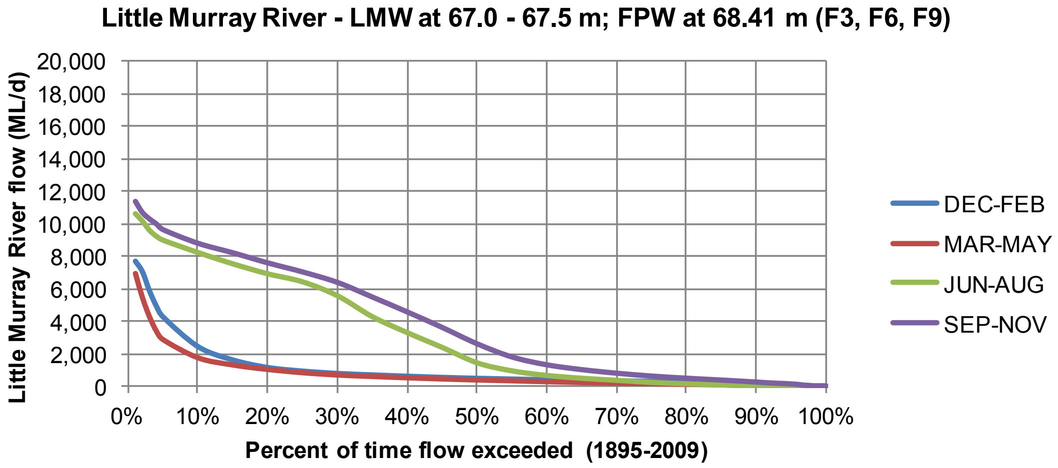


Figure 22. Modelled (1895 – 2009) seasonal distribution of flows in the Little Murray River and the River Murray under simulated conditions of Little Murray Weir crest lowered permanently to 67.0 m and Fish Point Weir sill lowered to 67.81 m and permanently open, for low flow range.

3.5.1.4 Future scenarios F3, F6 and F9, Fish Point Weir at 68.41 m

Modelling of the future scenarios F3, F6 and F9, with FPW at 68.41 m, revealed that the distribution of flows in Little Murray River was controlled by the Fish Point Weir crest level, and was insensitive to the 0.5 m difference in LWM crest height for the scenarios (i.e. the three LMW crest heights gave the same flow distributions for any given FPW crest level) (Figure 23).

The lowest inflows to Little Murray River occurred in the Jun-Aug period. Inflows ceased in each season: 8 per cent of the time in Jun-Aug, 5 percent of the time in Mar-May, 2 percent of the time in Sep-Nov and 1 percent of the time in Dec-Feb,



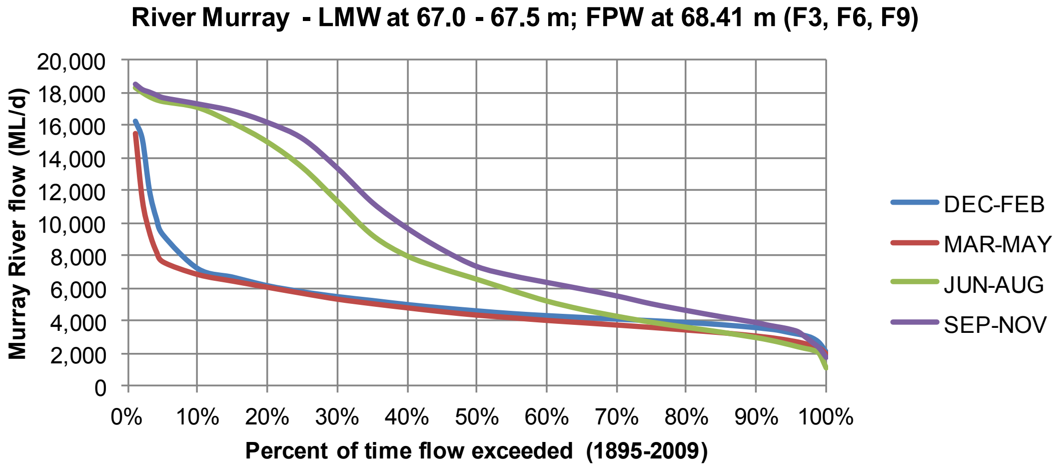


Figure 23. Modelled (1895 - 2009) seasonal distribution of flows in the Little Murray River and the River Murray under simulated conditions of Little Murray Weir crest lowered permanently to 67.0 m and Fish Point Weir sill lowered to 68.41 m and permanently open, for full range of flows.

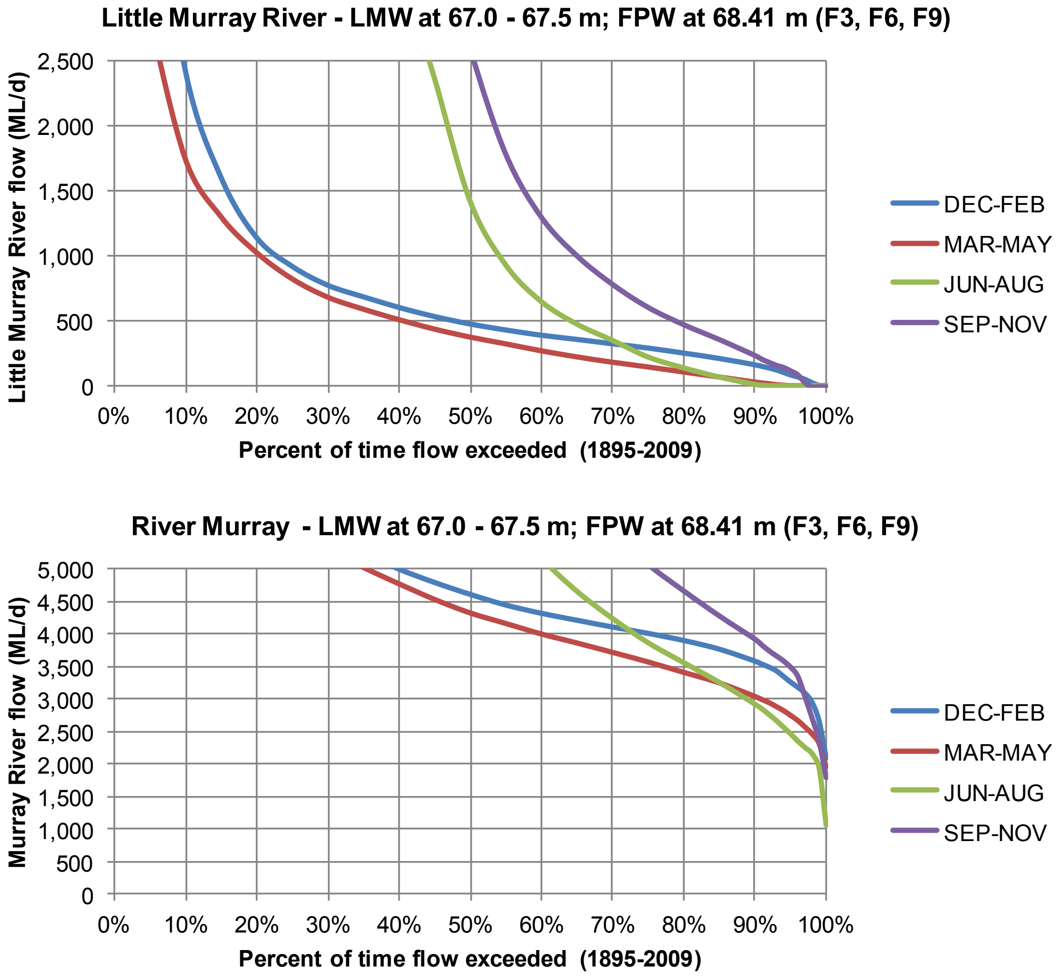
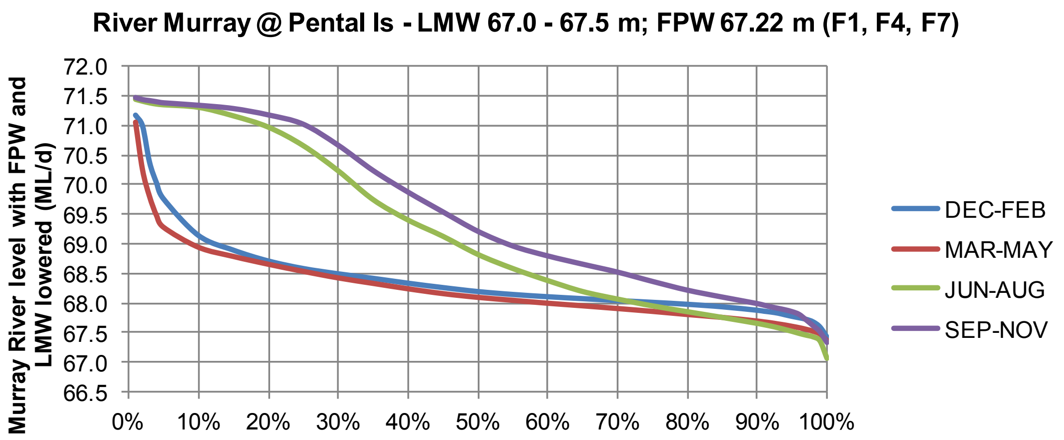


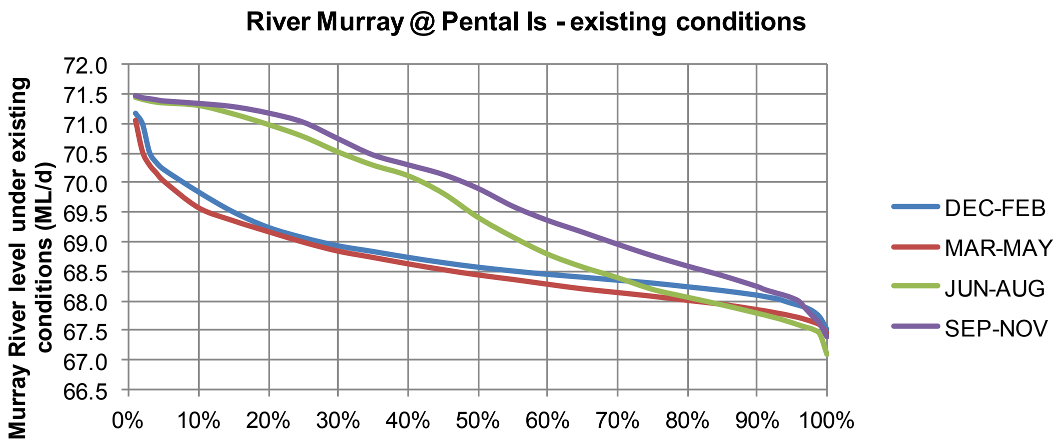
Figure 24. Modelled (1895 – 2009) seasonal distribution of flows in the Little Murray River and the River Murray under simulated conditions of Little Murray Weir crest lowered permanently to 67.0 m and Fish Point Weir sill lowered to 68.41 m and permanently open, for low flow range.

3.5.2 Impact of lowering of FPW and LMW operational levels on River Murray water levels

Under the existing situation, flow only enters Little Murray River when the weir is opened under conditions of high flows in the River Murray. Under the potential alternative operating conditions with Fish Point weir permanently open, flow would enter Little Murray River most of the time. This has the effect of reducing flows to the River Murray between Little Murray River offtake and return point (Pental Island to Swam Hill reach (Figure 3).

Lowering FPW to 67.22 m reduces the levels in the River Murray at Pental Island by a median elevation of 0.21 - 0.36 m, depending on the season (Figure 25). The decrease in level can be up to 0.8 m. For the scenario with FPW at the higher level of 67.81 m, the reduction in River Murray levels is less (median of 0.17 - 0.30 m) (Figure 26), and For the scenario with FPW at the higher level of 68.41 m, the reduction in River Murray levels is even less (median of 0.08 - 0.15 m) (Figure 27),





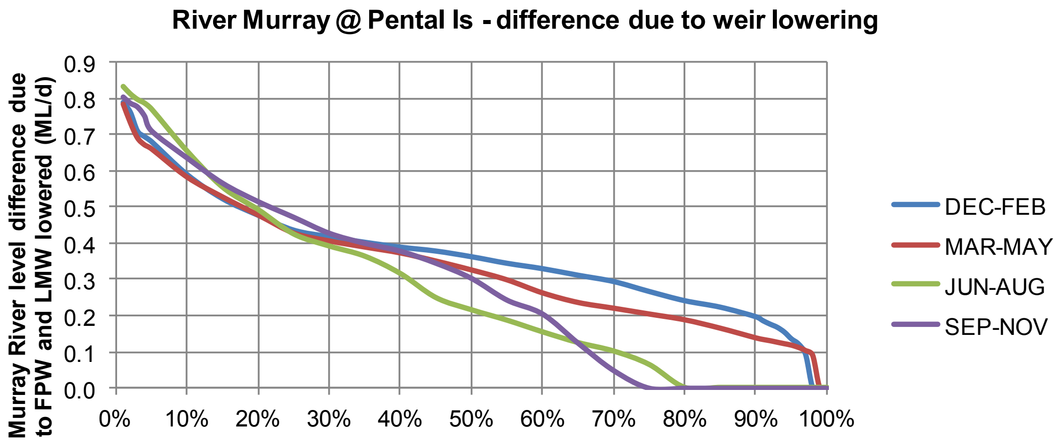
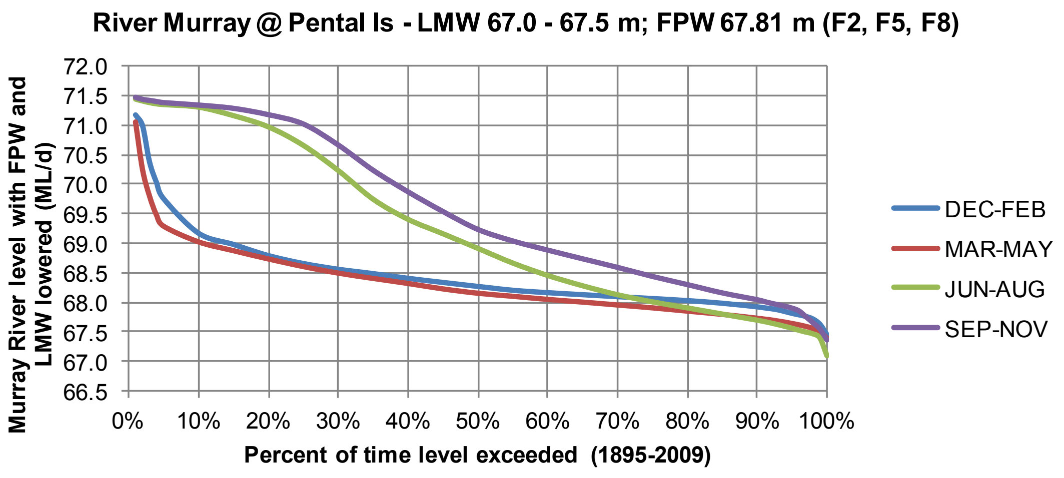
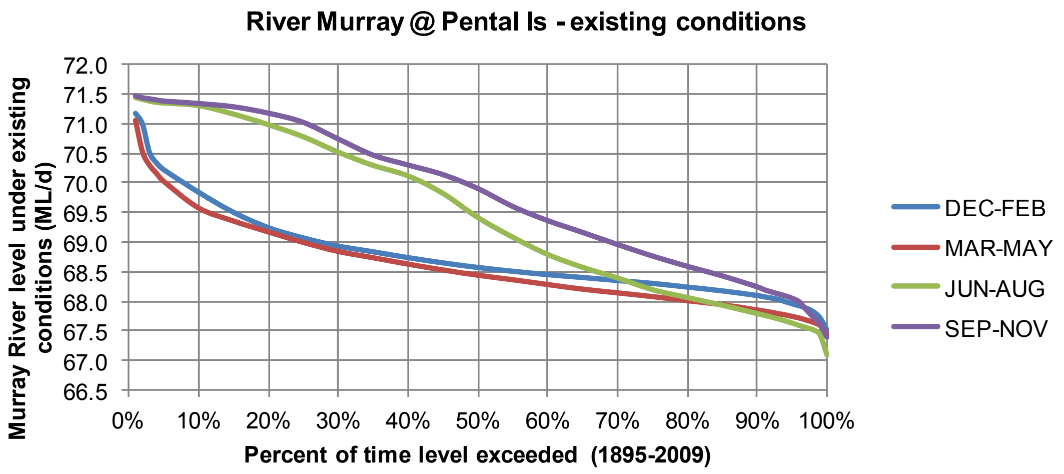


Figure 25. Modelled (1895 – 2009) seasonal distribution of water levels at Pental Island gauge on the River Murray under simulated conditions of Little Murray Weir crest lowered permanently to 67.0 – 67.5 m and Fish Point Weir sill lowered to 67.22 m and permanently open. Also shown is the distribution of water levels under existing conditions, and the difference between these two scenarios. For the difference plot, a positive value indicates a lowering of the River Murray water level.





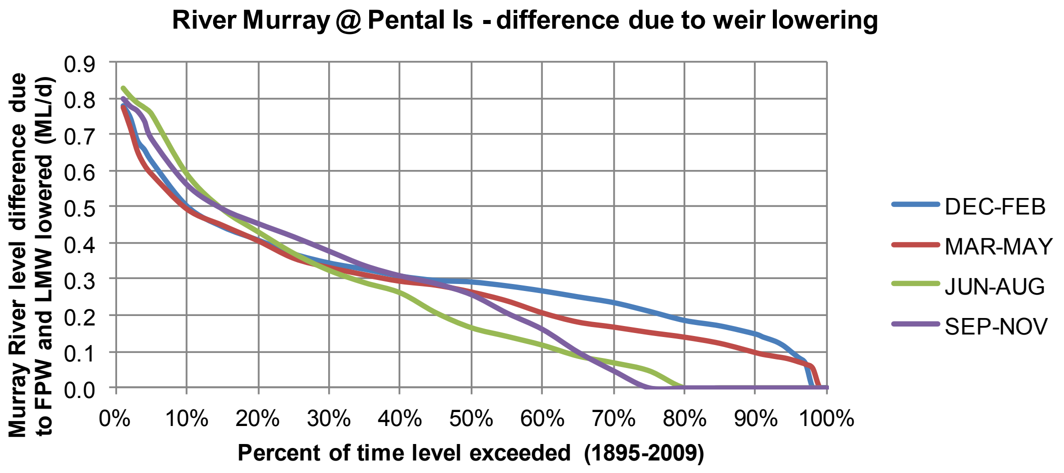
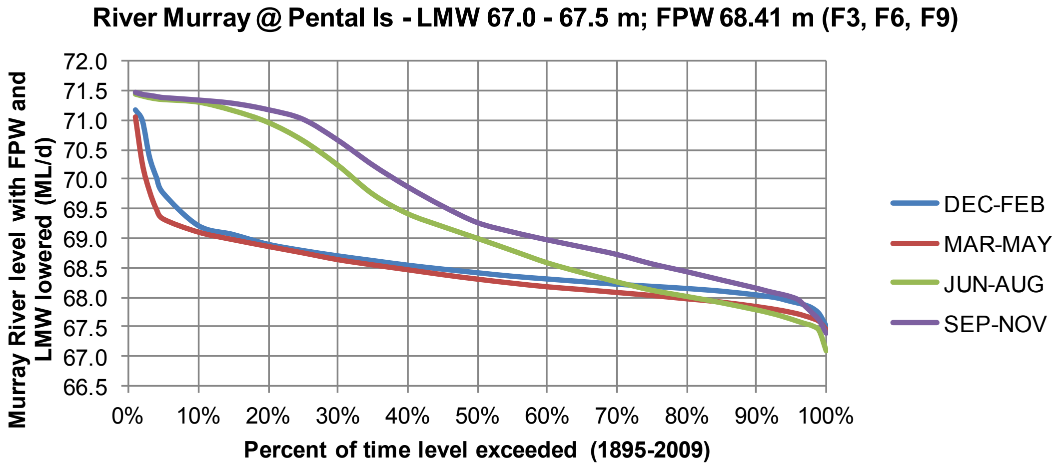
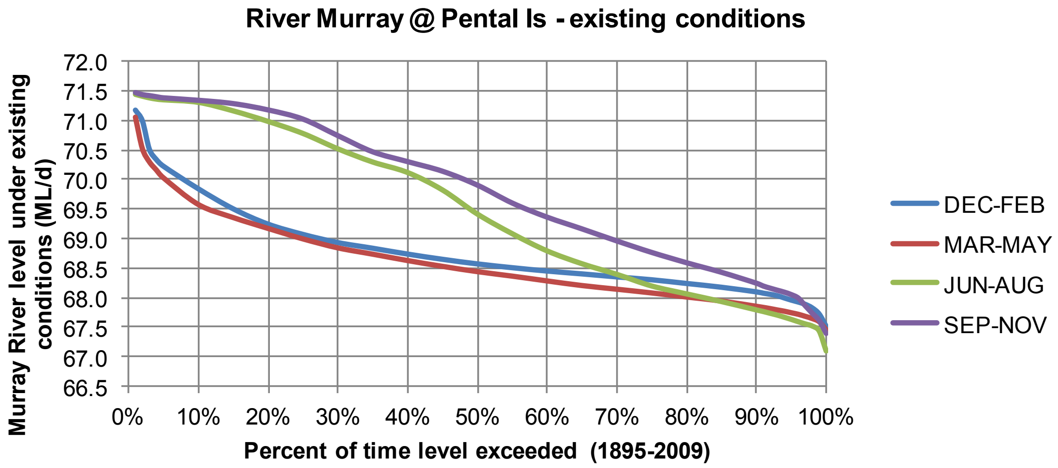


Figure 26. Modelled (1895 – 2009) seasonal distribution of water levels at Pental Island gauge on the River Murray under simulated conditions of Little Murray Weir crest lowered permanently to 67.0 – 67.5 m and Fish Point Weir sill lowered to 67.81 m and permanently open. Also shown is the distribution of water levels under existing conditions, and the difference between these two scenarios. For the difference plot, a positive value indicates a lowering of the River Murray water level.





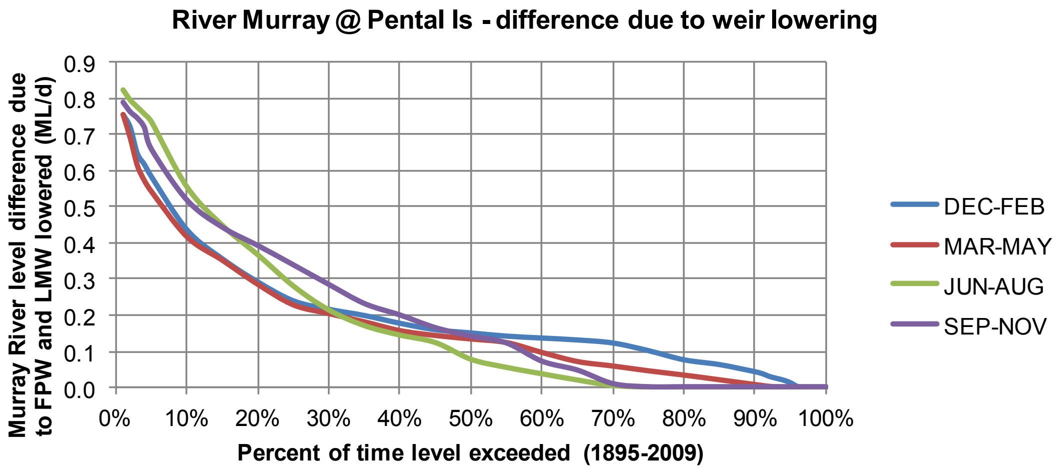


Figure 27. Modelled (1895 – 2009) seasonal distribution of water levels at Pental Island gauge on the River Murray under simulated conditions of Little Murray Weir crest lowered permanently to 67.0 – 67.5 m and Fish Point Weir sill lowered to 68.41 m and permanently open. Also shown is the distribution of water levels under existing conditions, and the difference between these two scenarios. For the difference plot, a positive value indicates a lowering of the River Murray water level.

3.5.3 Habitat connectivity

3.5.3.1 Existing scenario (BM)

Under existing conditions, the weir pool is at the Little Murray Weir crest level or higher from 15 August to 15 May (75% of the year), in which case the 0.3 and 0.5 m minimum depth criteria are met all the time (Figure 9). For the remainder of the year (25% of the time), the water level is lowered to the sill, in which case the 0.3 m and 0.5 m minimum depth criteria are never met (Figure 9).

3.5.3.2 Future scenarios (F1 – F9)

The results of the modelling future scenarios suggest that for the potential alternative operating scenarios, the lower is the level of the Fish Point Weir sill, the more often connectivity is achieved (Table 9 and Table 10). There is a much greater loss of connectivity when the sill is raised from 67.81 m to 68.41 m than when it is raised from 67.22 m to 67.81 m (Table 9 and Table 10). Also, the higher is the level of the Little Murray Weir sill, the more often connectivity is achieved (Table 9 and Table 10).

The stricter 0.5 m minimum depth criterion is met less often than is the 0.3 m criterion. The percent of time that the criteria are met varies seasonally, with connectivity achieved more often in the main spring spawning season (where movement into and out of the Little Murray River is desirable) compared to the other seasons (Table 9 and Table 10).

Connectivity was lower during the Millennium Drought period compared with the entire modelled period (Table 9 and Table 10).

Table 9.
Percent of time 0.3 m connectivity criteria were met for modelled flow series 1895 - 2009, for nine potential alternative scenarios.

Scenario	LMW level (m)	FPW level (m)	Percent of time 0.3 m connectivity criterion met			
			Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
Entire period 1895 - 2009						
F1	67.00	67.22	97%	87%	87%	97%
F2	67.00	67.81	91%	74%	79%	94%
F3	67.00	68.41	51%	43%	66%	81%
F4	67.25	67.22	99%	96%	93%	98%
F5	67.25	67.81	97%	88%	87%	97%
F6	67.25	68.41	69%	54%	71%	86%
F7	67.50	67.22	100%	100%	100%	100%
F8	67.50	67.81	100%	99%	96%	99%
F9	67.50	68.41	90%	73%	78%	93%
Millennium Drought 1997 - 2009						
F1	67.00	67.22	89%	75%	67%	81%
F2	67.00	67.81	75%	57%	57%	75%
F3	67.00	68.41	35%	31%	37%	55%
F4	67.25	67.22	96%	87%	80%	88%
F5	67.25	67.81	89%	75%	68%	81%
F6	67.25	68.41	48%	39%	45%	62%
F7	67.50	67.22	100%	100%	99%	100%
F8	67.50	67.81	99%	95%	87%	95%
F9	67.50	68.41	74%	55%	55%	74%

Table 10.
Percent of time 0.5 m connectivity criteria were met for modelled flow series 1895 - 2009, for nine potential alternative scenarios.

Scenario	LMW level (m)	FPW level (m)	Percent of time 0.5 m connectivity criterion met			
			Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
			Entire period 1895 - 2009			
F1	67.00	67.22	81%	63%	74%	90%
F2	67.00	67.81	61%	50%	69%	84%
F3	67.00	68.41	32%	28%	58%	71%
F4	67.25	67.22	93%	79%	82%	95%
F5	67.25	67.81	82%	63%	74%	90%
F6	67.25	68.41	43%	37%	62%	77%
F7	67.50	67.22	98%	91%	89%	97%
F8	67.50	67.81	93%	79%	82%	95%
F9	67.50	68.41	56%	46%	67%	83%
			Millennium Drought 1997 - 2009			
F1	67.00	67.22	62%	45%	49%	68%
F2	67.00	67.81	41%	36%	42%	60%
F3	67.00	68.41	17%	19%	25%	44%
F4	67.25	67.22	80%	62%	60%	77%
F5	67.25	67.81	63%	46%	50%	68%
F6	67.25	68.41	27%	26%	32%	51%
F7	67.50	67.22	92%	78%	70%	82%
F8	67.50	67.81	80%	62%	60%	77%
F9	67.50	68.41	38%	33%	39%	57%

3.5.4 Macrophyte (cumbungi) growth

3.5.4.1 Existing scenario (BM)

Under the existing conditions, colonisation of the entire weir pool by cumbungi is prevented by the high water depth during the irrigation season. Cumbungi growth is restricted to the shallower areas along the margins.

3.5.4.2 Future scenarios (F1 - F9)

The results of modelling future scenarios suggest that the lower is the level of the Fish Point Weir sill, the more often conditions are unfavourable for growth of cumbungi (Table 11). However, the differences between scenarios in the degree of achievement of this criterion are small. There are large differences between seasons in the duration that conditions are unfavourable for cumbungi. The main spring growing season has the longest duration of unfavourable conditions (exceeding 50 percent of the time) (Table 11), so it appears unlikely that cumbungi would be able to colonise the entire channel under the alternative operating scenarios. Cumbungi would likely continue grow along shallow, low velocity channel margins.

The percent of time that conditions were unfavourable for growth of cumbungi was lower during the Millennium Drought period compared with the entire modelled period (Table 11). However, over this drought period, during the main growing season conditions were unfavourable for approximately 30% of the time (Table 11), which would likely be sufficient to prevent cumbungi colonising the entire channel. Cumbungi would likely continue grow along shallow, low velocity channel margins.

Table 11.
Percent of time criterion to discourage cumbungi was met for modelled flow series 1895 – 2009, for nine potential alternative scenarios.

Scenario	LMW level (m)	FPW level (m)	Percent of time flow exceeds 2,000 ML/d (unfavourable for cumbungi)			
			Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
Entire period 1895 - 2009						
F1, F4, F7	67.0, 67.25, 67.5	67.22	17%	13%	50%	59%
F2, F5, F8	67.0, 67.25, 67.5	67.81	14%	10%	48%	55%
F3, F6, F9	67.0, 67.25, 67.5	68.41	13%	8%	47%	53%
Millennium Drought 1997 - 2009						
F1, F4, F7	67.0, 67.25, 67.5	67.22	8%	7%	16%	31%
F2, F5, F8	67.0, 67.25, 67.5	67.81	7%	3%	13%	29%
F3, F6, F9	67.0, 67.25, 67.5	68.41	6%	3%	12%	28%

3.6 Salinity

3.6.1 Environmental salinity criterion

The Little Murray River inflow salinity criterion to protect ecological values is mean daily EC ≤2,000 µS/cm. In practice, salinity might require active management in order to prevent high salinity water from entering Little Murray River. However, here we simply report the spells of salinity exceeding this threshold.

Daily salinity was modelled at two points on the river: just downstream of Fish Point Weir, and just downstream of Channel 6/7 inflow. Inflows to Little Murray River were mainly controlled by the level of FPW, so for each of the three alternative FPW levels, the three alternative LMW levels had virtually identical salinity regimes. The modelled daily salinity regime showed a step-change in January 2003, after which the daily variability of salinity and the absolute salinity reduced markedly (Figure 28). This relates to the onset of severe drought conditions, when flows in Barr Creek became very low. The data suggest that the salinity criterion of 2,000 µS/cm was not exceeded after January 2003 for the scenarios with FPW at 67.22 m and 67.81 m (Figure 28).

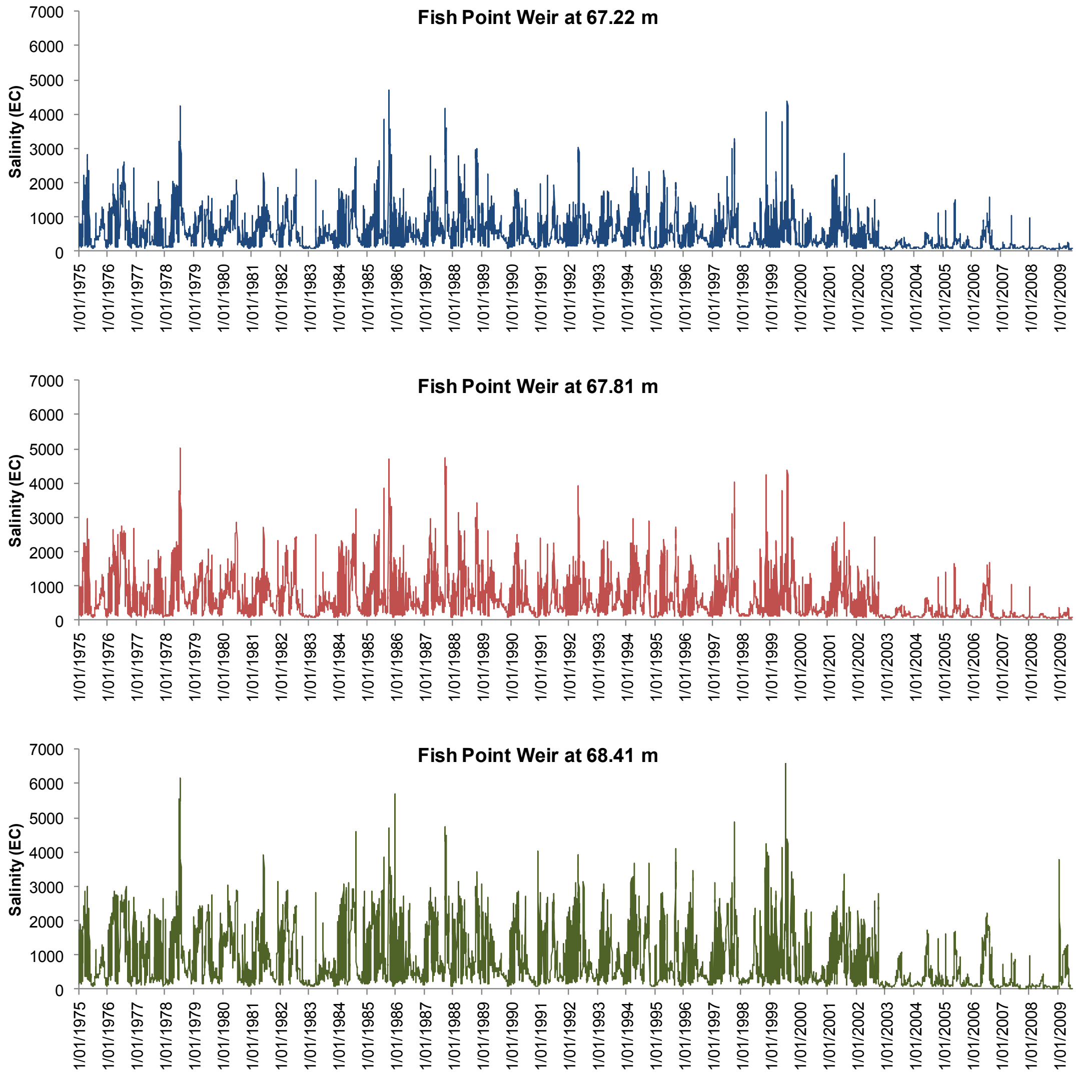
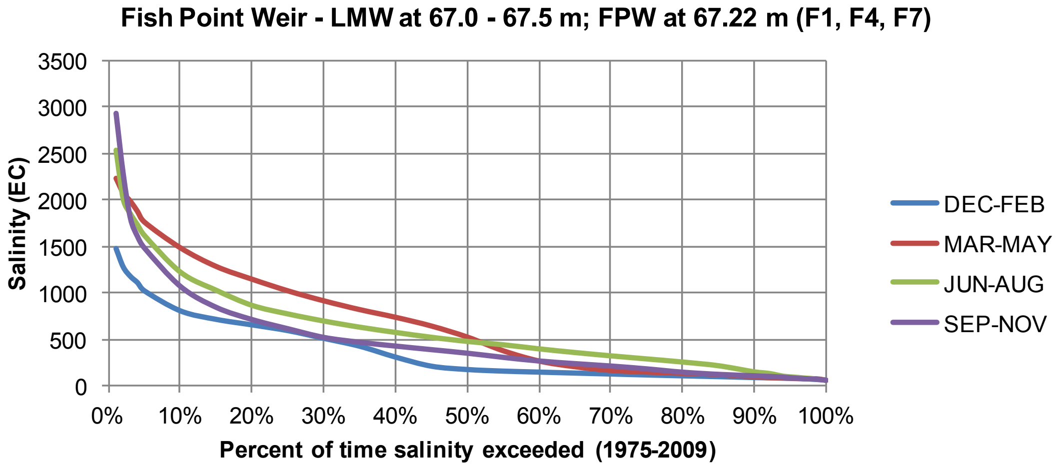


Figure 28. Modelled (1975 – 2009) daily salinity at just downstream of Fish Point Weir for FPW level of 67.22 m, 67.81 m and 68.41 m, in EC units of µS/cm.

In general, there was little difference in the salinity regimes at just downstream of Fish Point Weir, and just downstream of Channel 6/7 inflow, regardless of the level of FPW (Figure 29, Figure 30, Figure 31, Table 12, Table 13). Overall, Channel 6/7 inflows were less saline than flows entering Little Murray River through Fish Point Weir, so salinity was lower downstream of Channel 6/7 than downstream of FPW. Scenarios with FPW at 68.41 m produced the highest salinities and March-August had higher salinity than September-February. Salinity was lower during the Millennium Drought compared to the entire period from 1975 to 2009.



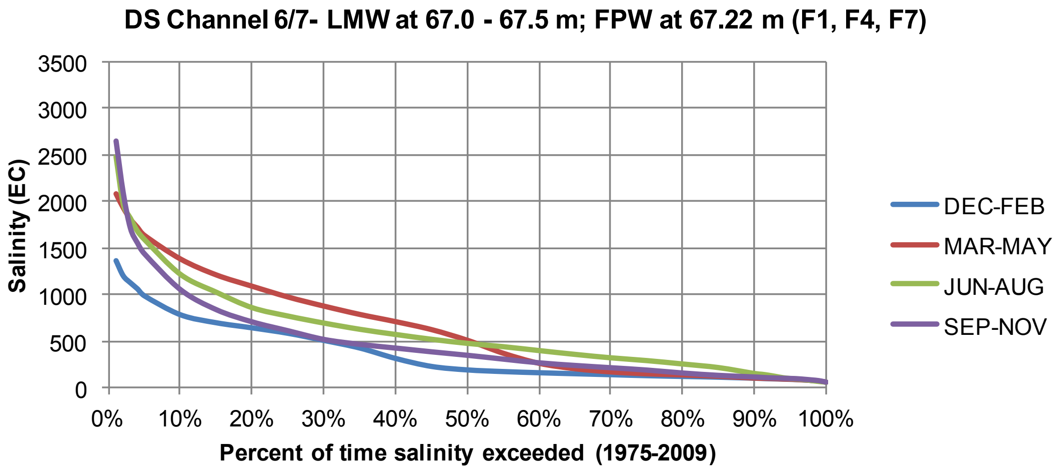
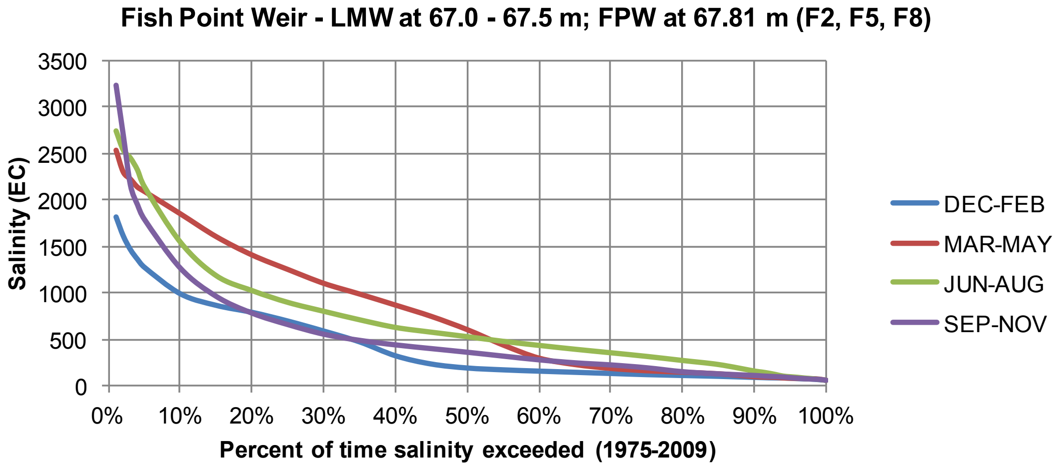


Figure 29. Modelled (1975 - 2009) seasonal distribution of salinity in the Little Murray River at just downstream of Fish Point Weir (top) and just downstream of Channel 6/7 (bottom), for FPW at 67.22 m.



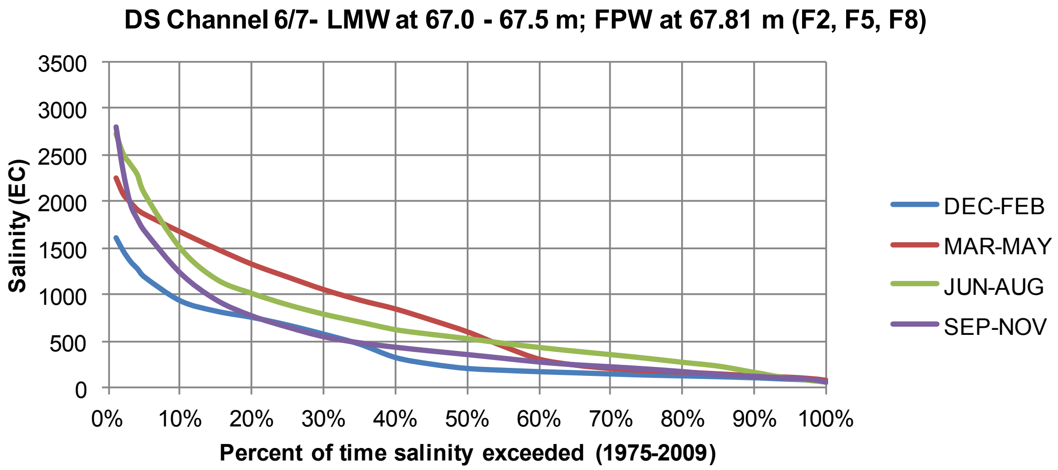
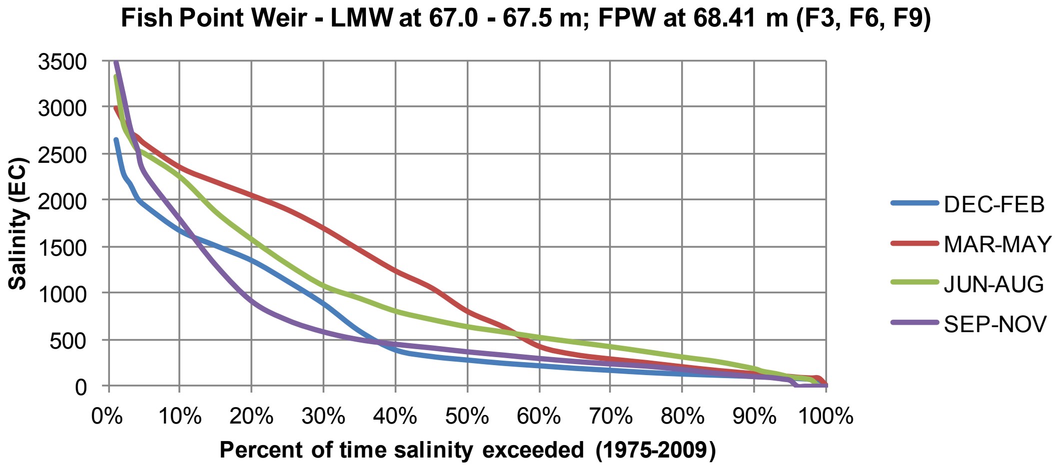


Figure 30. Modelled (1975 - 2009) seasonal distribution of salinity in the Little Murray River at just downstream of Fish Point Weir (top) and just downstream of Channel 6/7 (bottom), for FPW at 67.81 m.



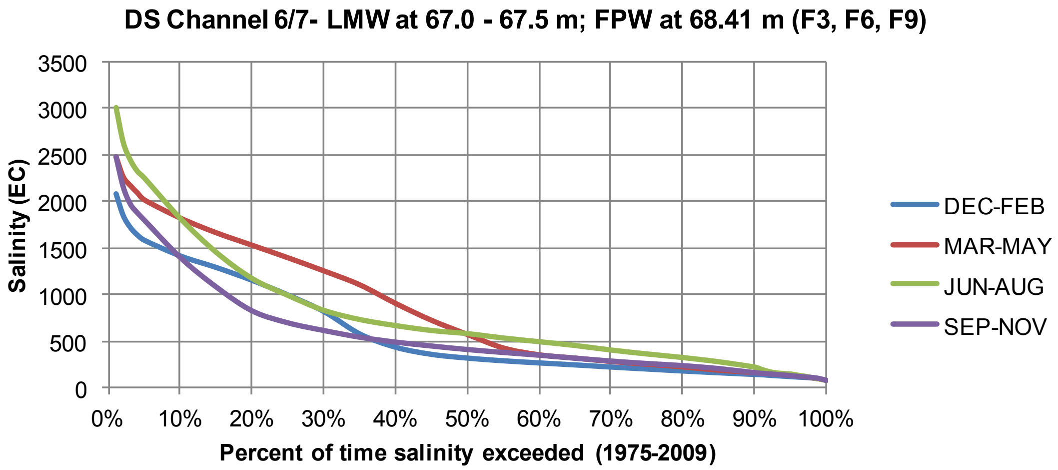


Figure 31. Modelled (1975 - 2009) seasonal distribution of salinity in the Little Murray River at just downstream of Fish Point Weir (top) and just downstream of Channel 6/7 (bottom), for FPW at 68.41 m.

Table 12.
Percent of time that salinity threshold of 2,000 µS/cm is exceeded at just downstream of Fish Point Weir, 1975-2009, and 1997-2009.

Scenario	LMW level (m)	FPW level (m)	Percent of time 2000 µS/cm exceeded			
			Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
Entire period 1975 - 2009						
F1, F4, F7	67.0, 67.25, 67.5	67.22	0%	3%	2%	2%
F2, F5, F8	67.0, 67.25, 67.5	67.81	1%	7%	6%	4%
F3, F6, F9	67.0, 67.25, 67.5	68.41	4%	21%	13%	7%
Millennium Drought 1997 - 2009						
F1, F4, F7	67.0, 67.25, 67.5	67.22	0%	1%	1%	1%
F2, F5, F8	67.0, 67.25, 67.5	67.81	0%	2%	3%	3%
F3, F6, F9	67.0, 67.25, 67.5	68.41	3%	6%	9%	9%

Table 13.
Percent of time that salinity threshold of 2,000 µS/cm is exceeded at just downstream of Channel 6/7 inflow, 1975-2009, and 1997-2009.

Scenario	LMW level (m)	FPW level (m)	Percent of time 600 µS/cm exceeded			
			Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
Entire period 1975 - 2009						
F1, F4, F7	67.0, 67.25, 67.5	67.22	0%	1%	2%	2%
F2, F5, F8	67.0, 67.25, 67.5	67.81	0%	3%	5%	3%
F3, F6, F9	67.0, 67.25, 67.5	68.41	1%	5%	8%	3%
Millennium Drought 1997 - 2009						
F1, F4, F7	67.0, 67.25, 67.5	67.22	0%	0%	1%	1%
F2, F5, F8	67.0, 67.25, 67.5	67.81	0%	0%	3%	2%
F3, F6, F9	67.0, 67.25, 67.5	68.41	1%	1%	5%	3%

3.6.2 Irrigation salinity criteria

Two EC criteria were used for irrigation water. A value of 600 µS/cm is the desirable upper limit, and 800 µS/cm is a warning threshold for horticultural and viticultural users. The modelled daily time series of inflow salinity suggest that these thresholds were often exceeded (Table 14 and Table 15). The lower the level of FPW, the less frequently the EC exceeded the salinity thresholds. March-August had higher salinity than September-February, and salinity was lower during the Millennium Drought compared to the entire period from 1975 to 2009. The lower salinity of the Millennium Drought is a better guide to the future than the entire period from 1975 to 2009, because the salinity load from Barr Creek (which was reduced during the drought) is predicted to reduce further over time (SKM, 2011).

Table 14.
Percent of time that salinity threshold of 600 µS/cm is exceeded at just downstream of Channel 6/7 inflow, 1975-2009, and 1997-2009.

Scenario	LMW level (m)	FPW level (m)	Percent of time 600 µS/cm exceeded			
			Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
Entire period 1975 - 2009						
F1, F4, F7	67.0, 67.25, 67.5	67.22	24%	47%	38%	26%
F2, F5, F8	67.0, 67.25, 67.5	67.81	29%	50%	43%	27%
F3, F6, F9	67.0, 67.25, 67.5	68.41	34%	49%	47%	30%
Millennium Drought 1997 - 2009						
F1, F4, F7	67.0, 67.25, 67.5	67.22	7%	20%	21%	20%
F2, F5, F8	67.0, 67.25, 67.5	67.81	8%	22%	29%	21%
F3, F6, F9	67.0, 67.25, 67.5	68.41	12%	22%	40%	27%

Table 15.
Percent of time that salinity threshold of 800 µS/cm is exceeded at just downstream of Channel 6/7 inflow, 1975-2009, and 1997-2009.

Scenario	LMW level (m)	FPW level (m)	Percent of time 600 µS/cm exceeded			
			Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
Entire period 1975 - 2009						
F1, F4, F7	67.0, 67.25, 67.5	67.22	9%	35%	23%	16%
F2, F5, F8	67.0, 67.25, 67.5	67.81	17%	42%	30%	19%
F3, F6, F9	67.0, 67.25, 67.5	68.41	30%	43%	31%	20%
Millennium Drought 1997 - 2009						
F1, F4, F7	67.0, 67.25, 67.5	67.22	4%	13%	12%	14%
F2, F5, F8	67.0, 67.25, 67.5	67.81	7%	17%	21%	16%
F3, F6, F9	67.0, 67.25, 67.5	68.41	10%	18%	28%	18%

3.7 Security of supply of water for irrigation

The alternative operation of Fish Point Weir and Little Murray Weir will not, in itself, impact the security of supply of irrigation water to customers that are supplied from Channel 9 or Little Murray River. The reason is that, regardless of the level of FPW or LMW, the supply of irrigation water into Little Murray River is principally from Channel 6/7. The changed inflows through Fish Point Weir will impact the water level of the river, but this will not affect how much water is supplied to the river via Channel 6/7. Investigation of the reliability of the supply of water from Channel 6/7, and the responsiveness of the supply, was not within the scope of this report.

In the hypothetical situation that demand exceeded supply from Channel 6/7 for a few days, because of a time lag in responding to demand, there would be a buffer of water in the river that could be drawn on. Under the existing operation, the buffer is large because LMW maintains the pool at a high level. If LMW was operated at 67.0 m, the pool downstream of Channel 6/7 would hold a volume of 1,732 ML if the river was not flowing. In the highly unlikely event that Channel 6/7 inflows were delayed, and there was no inflow through Fish Point Weir, the pool would sustain 2 – 3 days of extreme demand of 500 ML/d and 5 – 6 days of very high demand of 250 ML/d. The estimated peak 10-day average demand of 160 ML/d could be sustained for 10 days.

3.8 Revised estimate of water savings potential

The revised SWET water balance model was run for the existing (benchmark) scenario. The estimated mean irrigation season net loss was 2,307 ML. The median annual loss was 2,347 ML. The losses exceeded 2,500 ML for 40 percent of years.

The water loss model for the alternative operating scenarios was based on net evapotranspirative losses from the surface of the weir pool, with Goulburn-Murray

Water incurring losses from the weir pool throughout the irrigation season (15 August to 15 May), except on those days when they would previously have been exempt. These days corresponded to when the combined flow of the Loddon and Murray rivers exceeded 12,200 ML/d day (which previously resulted in Fish Point Weir being opened).

In the SWET models, the Little Murray River was represented by two cells, one upstream of Channel 6/7, and one downstream of Channel 6/7. The flows downstream of Channel 6/7 increased due to irrigation water supply inflows. Downstream of Channel 6/7, irrigators withdraw water, with the cumulative withdrawl increasing downstream. By the time flow reaches Little Murray Weir, the water allocated to customers on Little Murray Weir has been withdrawn, but the water destined for Channel 9 remains. For calculating surface area in the SWET model runs, it was assumed that half of Little Murray river withdrawls had taken place.

The volume of savings for each year was calculated as the annual loss under benchmark conditions minus the annual loss under the alternative scenario. This produced a time series of annual savings that was highly variable (Figure 32). The savings varied because of climatic variations, variation in the flow rate in Little Murray River (which affected the water surface area), and the number of days Fish Point Weir would have been opened in the benchmark scenario.

For the nine scenarios tested here, the difference between the greatest average savings and the lowest average savings was 170 ML/yr (Table 16). The Millenium Drought period (1997 – 2009) produced average savings that were higher than the long term average for the entire modelled period (1895 – 2009) (Table 16).

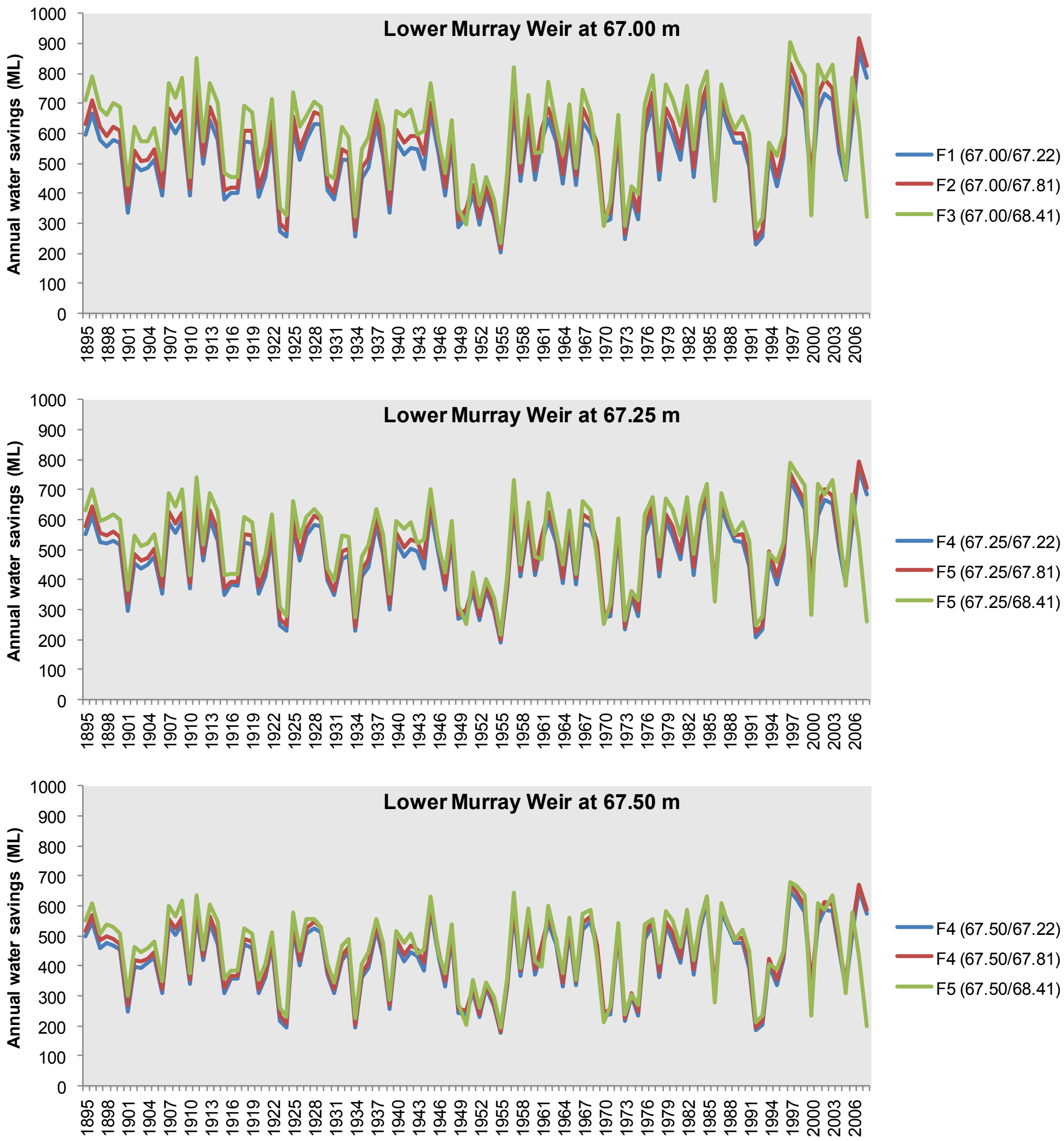


Figure 32. Modelled (1895 - 2009) annual water savings achieved through alternative operation of Little Murray Weir and Fish Point Weir. LMW crest lowered permanently to 67.0 m, 67.25 m or 67.5 m, and FPW sill lowered to 67.22 m, 67.81 m or 68.41 m, and permanently open.

Table 16.
Mean annual water savings achieved by the alternative operating scenarios.

Scenario	LMW level (m)	FPW level (m)	Mean water savings (ML/yr)
Entire period 1895 - 2009			
F1	67.00	67.22	517
F2	67.00	67.81	549
F3	67.00	68.41	592
F4	67.25	67.22	474
F5	67.25	67.81	497
F6	67.25	68.41	524
F7	67.50	67.22	422
F8	67.50	67.81	439
F9	67.50	68.41	453
Millennium Drought 1997 - 2009			
F1	67.00	67.22	669
F2	67.00	67.81	709
F3	67.00	68.41	676
F4	67.25	67.22	606
F5	67.25	67.81	633
F6	67.25	68.41	592
F7	67.50	67.22	532
F8	67.50	67.81	551
F9	67.50	68.41	506

4 Summary

The bathymetry of Little Murray Weir pool was accurately characterised. A model of the hydraulics and hydrology of Little Murray River was created. The models suggested that operating Fish Point Weir at 68.41 m gave higher water savings than at lower levels, but the ecological outcomes were better at the lower Fish Point Weir level of 67.22 m. The models suggested that operating Little Murray Weir at 67.0 m gave higher water savings than at higher levels, but the ecological outcomes were marginally better at the higher Little Murray Weir level of 67.5 m. A qualitative (unweighted) scoring and ranking was applied to the scenarios to assist decision making (Table 17). The rankings should not be interpreted as recommendations. Risk to security of irrigation water supply was not included in the scoring and ranking of scenarios, because the risk should be almost non-existent.

The lowest risk to fish movement is provided by year round connectivity with a minimum depth of 0.5 m all the way from Little Murray Weir upstream to the junction of the River Murray. However, even if inflows to Little Murray River ceased, a pool 28.6 km long and at least 0.5 m deep along its thalweg would provide suitable habitat for local fish movement. In the Sep-Nov period, when full connectivity to the River

Murray is likely to be more critical, all scenarios, except those with FPW at 68.41 m, provided a high degree of connectivity. This was particularly the case with scenarios with FPW at 67.22 m, for which full connectivity was available for more than 90 percent of the time.

Table 17.
Qualitative (unweighted) scoring of the characteristics of the alternative operating scenarios, with a final ranking based on sum of ticks (which ranged from 7 to 11). Ticks correspond to classification of degree of compliance with environmental and irrigation criteria into three classes. This result is with respect to the entire modelled period (1895 – 2009).

Scenario	LMW level (m)	FPW level (m)	Savings	Connectivity	Cumbungi	Env. salinity	Irrig. salinity	Overall rank
F1	67.00	67.22	✓✓	✓✓	✓✓✓	✓✓	✓	3
F2	67.00	67.81	✓✓✓	✓✓	✓✓✓	✓✓	✓	1
F3	67.00	68.41	✓✓✓	✓	✓✓✓	✓	✓	7
F4	67.25	67.22	✓✓	✓✓✓	✓✓✓	✓✓	✓	1
F5	67.25	67.81	✓✓	✓✓	✓✓✓	✓✓	✓	3
F6	67.25	68.41	✓✓✓	✓	✓✓✓	✓	✓	7
F7	67.50	67.22	✓	✓✓✓	✓✓✓	✓✓	✓	3
F8	67.50	67.81	✓	✓✓✓	✓✓✓	✓✓	✓	3
F9	67.50	68.41	✓	✓	✓✓✓	✓	✓	9

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