<u>Research Report 1</u>

Hydrology, Hydraulics and Physical Effects of Weirs in the Mallee Tract

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Report Linkages

This individual Research Report forms a component of the larger report:

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Introduction

The River Murray

The River Murray is an important natural asset and it sustains communities along its path dependent on it for irrigated agriculture. Yet the discharge of the River Murray is low and highly variable in comparison to other rivers of the world (e.g. Crabb, 1997). These factors make irrigated agriculture a challenge and have led to a progressive increase in regulation and extraction from the River Murray. Today, storages at Hume, Dartmouth, Lake Victoria and on other tributaries of the River Murray capture winter and spring flows for controlled release during the summer period. This greater security of water has allowed increased agricultural production along the river but has resulted in significant changes to the natural flow regime (Maheshwari *et al*., 1993; 1995).

A cap on the level of extraction from the Murray-Darling Basin was introduced in the 1990s in recognition of the limited nature of the water resource and the potential for over-allocation of actual river flows. In addition, the River Murray is increasingly being viewed as more than a supply and delivery mechanism for consumptive water use. There is a growing awareness of the ecological assets of the River Murray and the benefits that a healthy, functioning river supplies. The Living Murray initiative has formally recognised the link between reduced river flows and ecological deterioration of the river system, and has focussed on allocating a portion of the rivers flow to enhance specific ecological assets along the River Murray. The Murray-Darling Basin Commission Ministerial Council has designated 500,000 $ML.yr^{-1}$ as a first step toward this aim, with this water being sourced from identified savings within the system.

Regulation by Weirs

The construction of 14 weirs and 5 barrages has provided further regulation of the river but in a different way to the large water storages. The barrages are located near the mouth of the River Murray and together they act to prevent tidal flows entering the Lower Lakes system, thereby allowing it to remain fresh in contrast to its naturally estuarine state. The weirs, in contrast, are positioned along the River Murray system from Blanchetown (River Murray Lock and Weir No.1) to Yarrawonga. Those weirs of the Mallee and Lower Murray Tracts (as defined by Thoms *et al*., 2000) were originally designed to provide deeper water to allow year-round paddleboat navigation for trading purposes, and each of these structures is locked to allow the passing of river traffic.

Each weir acts to create a small storage, or weir pool, upstream of each structure. The role of the lockmaster is to position boards to maintain the water level immediately upstream of each weir within several centimetres of a designated full supply level, despite changing river flows. Water levels may exceed full supply level during periods of flood but are maintained at the designated full supply level at other times. Further to the navigational advantages and increases in recreational boating that weir pools provide, the stable water levels have also provided time-saving advantages to river pumpers because it allows pumps to be maintained at a set position on the bank for efficient water extraction. Pumpers located in areas subject to river level change (i.e. in free-flowing areas) typically need to adjust their pumps with changing water levels to maintain an efficient pumping rate or install pontoon-mounted pumps.

Because the weirs create a weir pool that is typically maintained at a set level, they do not necessarily alter riverine flows (discharge). Hence, flows entering the weir pool from upstream equal those flowing over the weir when balances from extraction, seepage, groundwater flows, rainfall and evaporation are accounted for. Possible exceptions to this are the Yarrawonga and Torrumbarry weirs (which facilitate major diversions into irrigation canals during the irrigation season) and Lock 9 weir (which facilitates diversions into Lake Victoria), which have the potential to decrease riverine flows substantially.

Weirs do, however, increase the water level and are operated to maintain a stable water level above the weir. The greater water depth increases the cross-sectional area of the river, and thereby reduces the flow velocity for a particular discharge. This has the further effect of increasing the retention time of water within the weir pool and river. In addition to these changes to aspects of the flow regime, weirs act as a physical barrier to fish movement (Koehn, 2001), sediment and nutrient transport (Brizga, 2001), and the longitudinal movement of other biota (e.g. Murray crayfish).

Measuring the ecological effects of weirs

Isolating the effects of weirs on riverine ecology is hampered by the lack of ecological data prior to weir construction. Further, potential changes in the weir pools may have arisen from other aspects of river regulation - such as a reduction in flow volumes – making it difficult to isolate the variable responsible for the change. However, several strategies are available for investigating the effects of weirs including (1) historical information, (2) gradient effects along weir pools, and (3) comparing weir pools with free-flowing reaches.

Information prior to weir construction provides insight into changes that have arisen from river regulation in general. For example, photographs of the Lower Murray Tract reveal that bare banks were a dominant feature of the river channel and that littoral macrophytes were relatively sparse in the main river channel prior to regulation. This contrasts strongly with the weir pools today where macrophytes are both abundant and diverse (Research Report 6; Walker *et al*., 1994; Blanch *et al*., 2000).

The examination of *gradients of change* along a weir pool (e.g. Blanch *et al*., 2000) allows features to be quantified to examine the specific effects of weir-induced water level change on biota. The examination of multiple points along a weir pool also increases spatial coverage and provides a detailed picture of the weir pool reach and the preferred conditions of individual species.

Further insights into weir effects can be gleaned by contrasting weir pool reaches with sections of river uninfluenced by weirs (i.e. free-flowing reaches). This method is limited to areas where appropriate free-flowing sites are available (sites are available in the Mallee Tract but not the Lower Murray Tract) and, with appropriate replication, provides strong inference regarding weir-induced changes. Further advantages of this method are that weir effects can be quantified, and that the free-flowing sites provide a Reference condition of what the environment might look like in the absence of weirs. These Reference sites *do not necessarily reflect pre-regulation conditions* because of other changes to the riverine environment (e.g. water extraction, land modification, flow regulation and other anthropogenic influences). However, they do provide an indication of the effects of weirs in the current riverine setting, and provide a window into what the weir pool sections of river may resemble in the absence of weirs.

The weirs influencing the Mallee Tract of the Murray River include Wentworth (No. 10), Mildura (No.11) and Euston (No.15). These weirs elevate the water level 3-5m upstream of the weir and create an impoundment, or weir pool, that influences the hydraulics of flow for approximately 50-60 km upstream before the river becomes free-flowing again (or a further weir is present and the weir pool sequence is reset).

Objectives

The objectives of this Research Report are to:

1. Detail the hydrologic and hydraulic conditions throughout the Mallee Tract over the study period.

2. To characterise some of the physical effects of weirs, partly through a comparison of weir pools and free-flowing reaches in the Mallee Tract.

Methods

Details of the three weir pool (WP) and two free-flowing (FF) reaches along the Mallee Tract of the River Murray are provided in the Project Report. Daily flow and stage data was supplied by the MDBC and Thiess for several of the study sites. Flow velocity was measured in the centre of the river channel at 0.5 m depth intervals to a maximum of 4.5 m with a Marsh-McBirney Inc. Flow Mate Portable Flowmeter. Water depth was also determined and the flow velocity measured at a distance of 0.4 x total depth from the bottom to obtain a single point estimate of the flow velocity across the river.

River widths were measured from River Murray Mapping (MDBC, 2^{nd} Edition) using ArcView GIS 3.2 software. The River Murray Mapping photography was conducted from March-May 1996 when flows at Euston were in the range of 5,060 - 10,100 $ML.d^{-1}$. The river was divided into 10 km reaches that commenced at each weir or tributary (measured in the middle of the river) and extended upstream. The surface water edge of the main river channel along each 10 km river reach was enclosed in a modifiable shape and the surface area of each shape recorded to allow mean river widths to be calculated.

Results

Flow

Drought conditions persisted throughout the Murray-Darling Basin during the study period (August 2001 – June 2003) and this was reflected in river flows. Mean daily flow at Euston (1/7/01-30/6/03) was low compared to the longer-term modelled natural and current flows (data from Maheshwari *et al.*, 1993) (Figure 1). Flows were most similar to modelled natural conditions during the summer period when releases for irrigation occurred. However, the winter-spring flood pulse typical of most years was absent during the study period.

The modelled data of Maheshwari *et al*. (1993) also highlights several important hydrologic changes. Storage and diversion upstream of Euston has resulted in ca. 50% of natural flows being removed. Also, the seasonality of the flow pattern at Euston has been largely preserved in contrast to some sites further upstream (e.g. Albury), due to larger contributions from unregulated tributaries. Highest discharges occur in spring with lowest flows occurring from February-May (Figure 1).

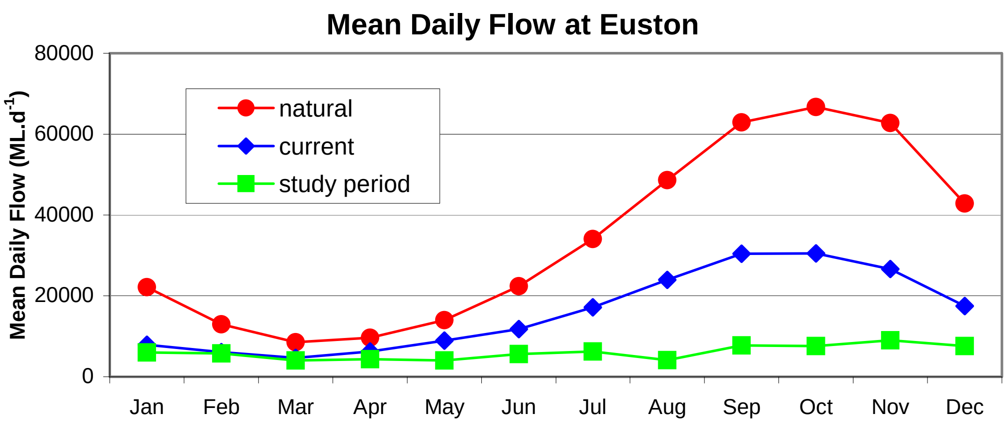

Figure 1. Mean daily flow at Euston during the study period (1/7/01-30/6/03; squares) and under modelled current (diamonds) and natural (circles) conditions (modelled data from Maheshwari *et al.*, 1993).

Flow at Euston has remained low since 1997 with the exception of a single flood pulse in late 2000 (Figure 2A). During the study period, flow at Euston remained below 13,000 $ML.d^{-1}$. Flows differed between sites along the Mallee Tract, with extraction for irrigation most pronounced in the Mildura and Wentworth weir pools (downstream of Hattah) during the warmer months (Figure 2B). Note that the Wentworth daily flows are River Murray contributions only. Contributions from the Darling River, which joins the River Murray immediately upstream of the Wentworth weir, were removed (daily flow at Wentworth minus daily flow at Burtundy on the Darling River from 3 days prior) to describe the flow through the Wentworth weir pool.

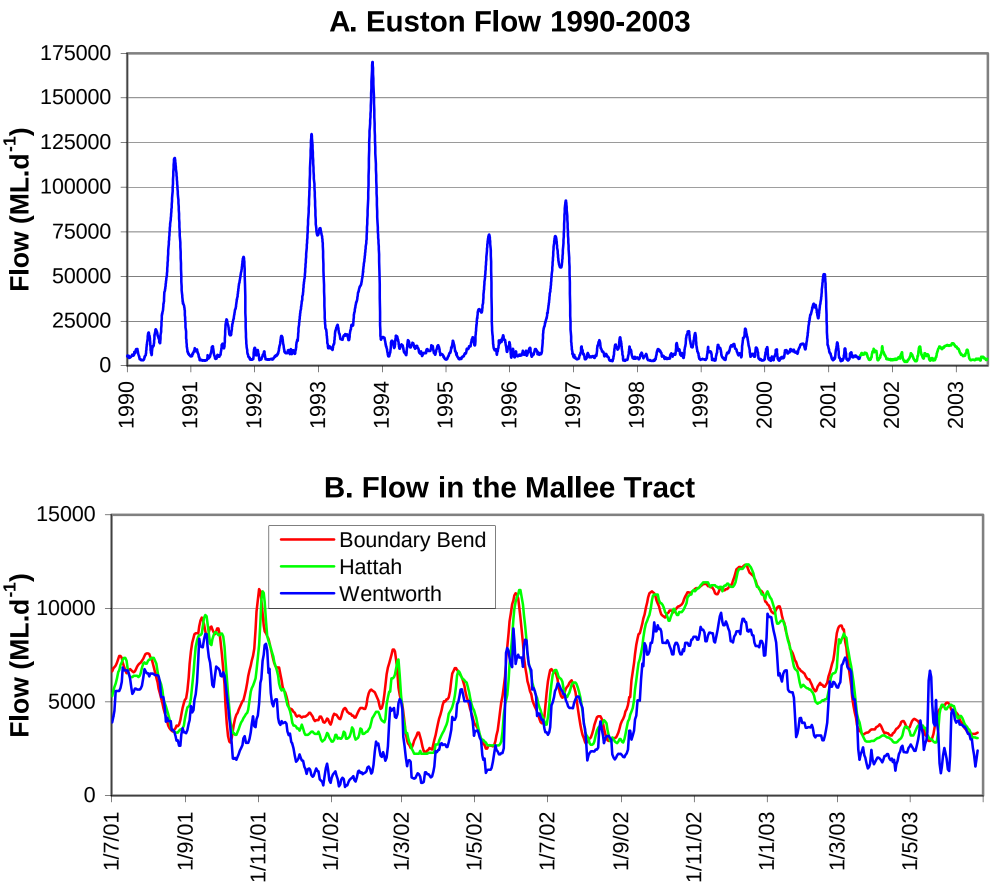

Figure 2. Daily flow at (A) Euston from 1990-2003 (two-year study period highlighted in light green), and (B) at Boundary Bend, Hattah (Colignan gauge) and Wentworth from July 2001 – June 2003.

Stage

The relatively low flows passing along the Mallee Tract meant that weirs remained in place throughout the study period (except for maintenance at the Mildura weir) and lockmasters were able to control water levels within a narrow range. The greatest water level fluctuations occurred at the Mildura weir (ca. 3.5 m) during the complete drawdown of the weir pool in each of 2002 and 2003 (a further drawdown occurred in 2001; McCarthy *et al*., 2004). These drawdown and refilling events were brief (16 d and 18 d), and outside of these periods water levels fluctuated little from the full supply level of 34.40 mAHD. The water levels in the Euston and Wentworth weir pools generally remained within a narrow range throughout the study period, with the exception of a short-term, partial (0.31 m) drawdown of the Euston weir pool in February 2002 to assist in the supply of water for downstream use (Figure 3).

Water levels at the free-flowing sites underwent numerous rises and falls as river flows changed. From August 2001–June 2003 water levels fluctuated within a ca. 2 m and 1.5 m range at Boundary Bend and Hattah, respectively. The highest flows and water levels occurred from October 2002-December 2002 as a result of water being transferred from upstream storages to Lake Victoria to assist in delivering entitlement flows to South Australia over the summer period of 2002-03.

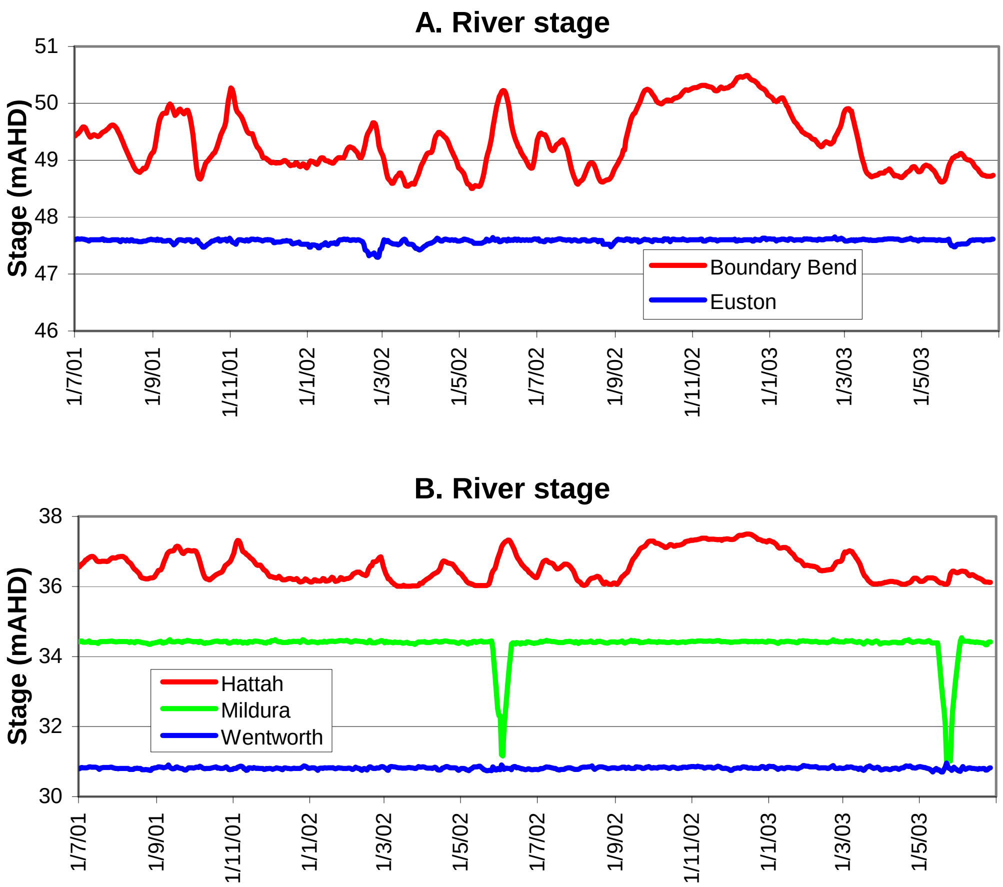

Figure 3. River stage at (A) Boundary Bend and Euston, and (B) Hattah, Mildura and Wentworth from July 2001 – June 2003. For weirs, gauges were located immediately upstream of the structures.

Flow Velocity

Flow velocities were considerably greater at the free-flowing sites compared to the weir pool sites at a given discharge (Figure 4), reflecting the greater cross-sectional area of the river channel in the weir pools. The free-flowing sites exhibited considerable variation in the relationships between flow velocity and discharge, which likely reflects more natural differences in cross-sectional areas between these sites. This heterogeneity between the four free-flowing sites contrasts strongly with the homogenous flow velocity patterns within the weir pools.

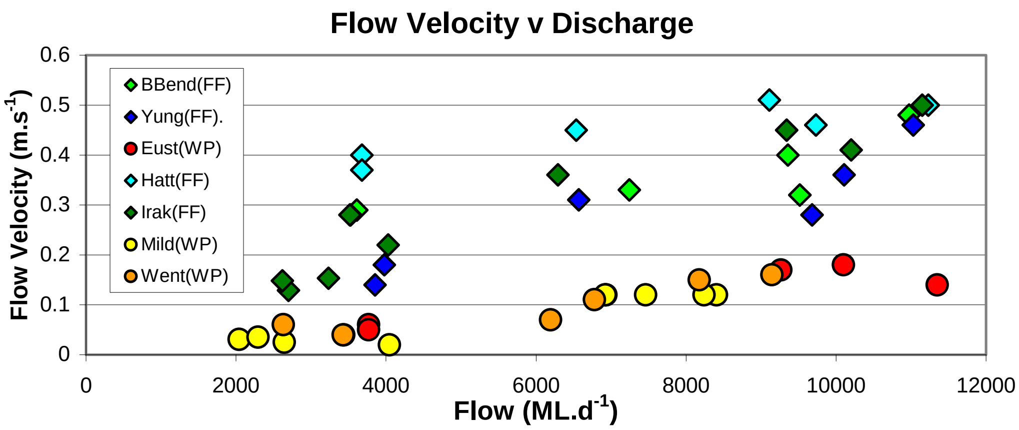

Figure 4. Flow velocity v discharge relationships at seven riverine sites within the study reach. Note the different relationships between the weir pool (circles) and free-flowing (diamonds) sites.

Physical Attributes

Weir effects on stage

The Euston weir elevates the water level upstream of the structure to a greater extent than the Mildura and Wentworth weirs (and other weirs in the Lower Murray Tract). At a designated flow of 4,000 $ML.d^{-1}$, the water level downstream of Euston weir approximates 42.85 mAHD compared to the full supply level of 47.60 mAHD upstream, resulting in an elevation of 4.75 m at this flow. The Mildura and Wentworth weirs elevate the water level 3.55 m and 3.21 m at the 4,000 $ML.d^{-1}$ flow, respectively (Table 1).

Table 1. Weir-induced changes in water level

River Murray Weir	Upstream Water Level (Full Supply Level)	Downstream Water Level @ 4000 $ML.d^{-1}$	Elevation Change
Euston (15)	47.60 mAHD	42.85 mAHD	4.75 m
Mildura (11)	34.40 mAHD	30.85 mAHD	3.55 m
Wentworth (10)	30.80 mAHD	27.59 mAHD	3.21 m

River Width

The weirs pools of the Mallee Tract are considerably wider than for the free-flowing reaches (Figure 5), due to the elevated water levels in these sections. The mean river width in the free-flowing reaches of the River Murray also abruptly increases downstream of each of the Wakool and Murrumbidgee confluences. Note that a 122 km reach of free-flowing river between Hattah and Euston was not examined.

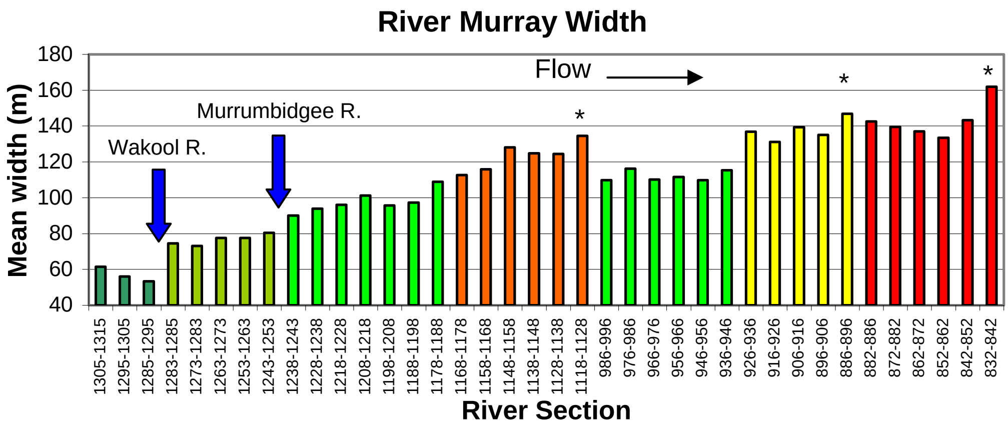

Figure 5. Mean River Murray widths (surface water) over 10 km reaches of the Mallee Tract. Note that the X-axis is categorical and represents river km from the sea (left represents upstream), and the free-flowing river section between river signs 996-1118 has been omitted. The Euston (orange), Mildura (yellow) and Wentworth (red) weir pools and the free-flowing reaches (green) are highlighted along with the tributary inputs from the Wakool and Murrumbidgee Rivers (arrows). Asterisks show the 0-10km reach upstream of each weir.

Discussion

Limited precipitation and an extreme period of drought resulted in low flows in the Mallee Tract throughout the period of study. The flood event late in the year 2000 (peak ca. 50,000 ML.d^{-1}) was the only event to have exceeded 25,000 ML.d^{-1} at Euston for the past seven years. The low flows during the study period allowed the lockmasters to control the water levels upstream of each weir. The most significant deviations from full supply level occurred at Mildura where complete drawdowns of the weir pool occurred for maintenance in 2002 and 2003 to replace the weir trestles. The drawdown and refilling events at Mildura were of large amplitude (3.5 m) and short duration, and the rates of rise and fall significantly exceeded those of rising and falling floods. These events formed the focus of a separate study and are detailed elsewhere (McCarthy *et al*., 2004). In this study, ecological monitoring at Mildura for this study was conducted outside of these drawdown periods as detailed in the Project Report. A smaller deviation in water level from full supply level occurred at Euston in February 2002 when the re-regulatory function of the Euston weir was employed to lower the weir pool 0.31 m to supply water for downstream consumption.

The weir at Euston elevates the water to a much greater extent than for the Mildura and Wentworth weirs. It needs to be considered that the greater elevation at Euston (4.75 m compared to 3.55 m at Mildura) may be partly due to there not being a weir pool immediately downstream of the Euston weir. At Mildura, for example, the Wentworth weir pool backs up to the Mildura weir and thereby maintains water levels immediately downstream of the Mildura weir at a level above pre-regulation levels. It is logical from a navigational perspective that "overlapping" the weir pools would be an important design feature to ensure that the river remained navigable at low flows. (Daily gauge records of past drawdowns of the Wentworth weir pool were not available for flows of 4,000 ML.d^{-1} and therefore could not provide an indication of the amplitude of water level change downstream of Mildura as a result of the Wentworth weir). It is likely that the increase in water level is less than 0.5 m given the relatively shallow water depth below the Mildura weir.

The greater water level elevation upstream of the Euston weir would likely influence a longer section of river than for other River Murray weirs (assuming comparable bed slopes). However, the extent of the Euston weir pool is not clear. Mean river widths (Figure 5) indicate that it may extend 60-70 km upstream of the weir (assuming uniformity in channel morphology). A drawdown of the Euston weir pool would allow water level changes to be documented in the same manner as for the 60 km Mildura weir pool (McCarthy *et al*. 2004).

The increase in channel width of the River Murray downstream of the Wakool and Murrumbidgee River confluences may be expected given the increased flows that these sections of river convey relative to the upstream portions. Hydraulic changes would also be expected in the River Murray at these points. At the Murrumbidgee confluence, for example, the River Murray widens from approximately 75 m upstream of the junction to 90 m below. During low flow periods, this may result in an increase in the cross sectional area of the channel and consequently a decrease in flow velocity and hence turbulent energy. As such, some of the solids suspended in the water column (contributed by the two streams) may settle out of the water column and the section below each confluence could be considered a depositional zone. The consistent decrease in suspended solids between the free-flowing sites Boundary Bend and Yungera Island, and the composition of sediments at these sites, provide supportive evidence of this (Research Report 2).

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