Environmental Water Management Plan for the Murray River from Lock 6 to Lock 10

mallee
catchment management authority

DOCUMENT CONTROL

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Executive Summary

Environmental Water Management Plans (EWMPs) have been developed for key sites in the Mallee region. The Mallee Waterway Strategy 2014-22 (Mallee CMA, 2014) identified 23 Waterway Management Units (WMU) from 216 targeted waterways in the Mallee. The interconnectedness and commonality of threats impacting on the waterways values were used to group them into planning units.

This EWMP has been prepared for the river channel, wetlands and floodplain between Lock 6 and the upper limit of the Lock 10 weir pool in the Darling and Murray rivers. This region includes areas in Victoria and New South Wales. Although EWMPs are a Victorian water management instrument, this document has been prepared cooperatively with all jurisdictions to provide a reference and guide to environmental water management for the entire reach. The area able to be inundated through environmental water management will be subject to specific negotiations on the operation of the Locks and the installation of infrastructure as proposed.

The study area supports important conservation values that are subject to significant water-related threats. It supports important populations of native fish, birds, reptiles and extensive communities of floodplain vegetation. Many plant and animal species are rare or threatened and several birds are migratory species that are protected under international agreements. These values are threatened by river regulation, including the depletion of flood flows and the stabilisation of river levels by weirs.

The overall objective of water management in the target area is to protect and restore the key species, habitat components and functions of the ecosystem by providing the hydrological environments required by indigenous plant and animal species and communities.

To achieve this, ecological and hydrological objectives were developed to target the ecological values within the target area.

Broad environmental water management measures have been identified that have been and can be used to improve habitat values in the target area. Measures include:

- Weir pool manipulation;
- Regulation of wetlands; and
- Provision of flowing habitat.

1 Acknowledgements

The EWMP was produced by the Mallee Catchment Management Authority, with funding from the Victorian Government. The valuable contributions of Parks Victoria, Jane Roberts, Terry Hillman, other agencies and community members are also acknowledged.

2 Introduction

This Environmental Watering Management Plan has been prepared for the Mallee CMA to establish the long-term management goals of the Murray River channel, wetlands and floodplain from Lock 6 to the Lock 10 weir pool.

Environmental Water Management Plans (EWMP) are prepared by Catchment Management Authorities to present the water management intentions for a site over a five to ten year time-frame. The plans are used by the Department of Environment, Land, Water and Planning (DELWP) and the Victorian Environmental Water Holder (VEWH) for short-term and long-term environmental water planning.

The key components of an EWMP are:

- identify the long-term objectives and water requirements for the wetlands, identified as a high priority by the CMA;
- provide a vehicle for community consultation, including for the long-term objectives and water requirements of the wetland;
- inform the development of seasonal watering proposals and seasonal watering plans;
- inform Long-term Watering Plans that will be developed under Basin Plan requirements.

EWMPs are a Victorian water management instrument, but this document has been prepared cooperatively with all jurisdictions to provide a reference and guide to environmental water management for the entire reach.

Within the study area, EWMPs are also being prepared for specific sites:

- Lake Hawthorn and Lake Ranfurly
- Merbein Common
- Johnstons and Chaffey Bend

The study area supports important conservation values that are subject to significant water-related threats. It supports important populations of native fish, birds, reptiles and extensive communities of floodplain vegetation. Many plant and animal species are rare or threatened and several birds are migratory species that are protected under international agreements. These values are threatened by river regulation, including the depletion of flood flows and the stabilisation of river levels by weirs.

In recent years a range of measures have been implemented to address these threats and to restore natural values. On-ground works have been completed to promote floodplain inundation, to increase fast-flowing fish habitat and to restore seasonally variable water levels. Increased environmental water reserves have provided new opportunities to improve the river flow regime and to reduce threats associated with river operations. A program to vary weir levels to meet ecological objectives has recently been implemented at Locks 8 and 9 by the New South Wales Office of Water (Ecological Associates 2013). This program introduces seasonal variability to wetlands and riparian vegetation throughout the weir pools, both in Victoria and New South Wales. Further works and new water management opportunities are currently being investigated.

The governance and water management of the study area is complex. The Murray River itself and the floodplain to the north, including the Darling River, lie in New South Wales. The floodplain to the south of the river lies in Victoria. The state border cuts across the region below Lock 7 and the remaining area to the west lies in South Australia. The river is a shared resource, managed cooperatively by the states and the Commonwealth Government through the Murray-Darling Basin Authority (MDBA). Environmental water in the reach may be supplied through the Commonwealth Environmental Water

Holder, the New South Wales Office of Environment and Heritage, the South Australian Department of Environment, Water and Natural Resources, the Victorian Environmental Water Holder or private organisations.

Parts of this report have been adapted from Ecological Associates (2013), a report prepared on the operation of Locks 8 and 9 for the New South Wales Office of Water, supported with funding from the Commonwealth Environmental Water Holder.

4 Site Overview

4.1 Site Location

The Mallee CMA region is situated in the north-west of Victoria. The area of responsibility is close to 39,000 km^2 (3.9 million ha), with a regional population estimated to be 65,000. Population centres include Mildura, Birchip, Sea Lake, Ouyen, Robinvale, Red Cliffs and Merbein.

The boundaries of the Mallee CMA region cover almost one fifth of Victoria, making it the largest area managed by a CMA in the state.

Approximately 40% of the land area within the Mallee CMA boundary is public land, consisting mainly of national parks, reserves, wilderness, and large areas of riverine and dryland forests. The other 60% is predominantly dryland crops, but there is also a significant investment in irrigation of grapes, citrus, almonds, olives and vegetables along the Murray River corridor which contributes over 40% of the value of agricultural production for the region.

In 2006, the Mallee CMA engaged consultants (Ecological Associates) to investigate water management options for the Murray River floodplain from Robinvale to Wallpolla Island. One of the major outcomes of these investigations was the development of a system of Floodplain Management Units (FMUs). These divide the floodplain into management units which water regimes can be managed independently of another FMU, but which are relatively consistent in their ecological values and land uses. The Mallee CMA has based its environmental water management plans on these FMUs to achieve more effective management of hydrologically connected systems. In addition to this, the Mallee CMA has also used individual FMUs or groupings of FMUs to form Waterway Management Units (WMUs) for planning within its Mallee Waterway Strategy.

This EWMP has been prepared for the river channel, wetlands and floodplain between Lock 6 and the upper limit of the Lock 10 weir pool in the Darling and Murray rivers shown in Figure 1.

This region includes areas in Victoria, New South Wales and South Australia. Although EWMPs are a Victorian water management instrument, this document has been prepared cooperatively with all jurisdictions to provide a reference and guide to environmental water management for the entire reach.

A regional context document has been prepared to compliment the Mallee CMA EWMPs and should be read in conjunction with this document.

4.2 Catchment Setting

The study area is in the lowland reaches of the Murray River and Darling Rivers. The Murray River flows mainly from east to west through a broad valley up to 10 km wide (Walker and Thoms 1993). The Darling River flows to the southwest, joining the Murray River at Wentworth.

The floodplain features a range of hydrological environments that contribute to the diversity of habitats present and the species they support. The main hydrological environments are permanently inundated wetlands, permanent and temporary watercourses, intermittently flooded wetlands, River Red Gum (*Eucalyptus camaldulensis*) and Black Box (*Eucalyptus largiflorens)* forests and woodlands and alluvial plains supporting chenopod shrublands and grasses. Each of these zones is associated with particular soil types, groundwater conditions and flooding histories.

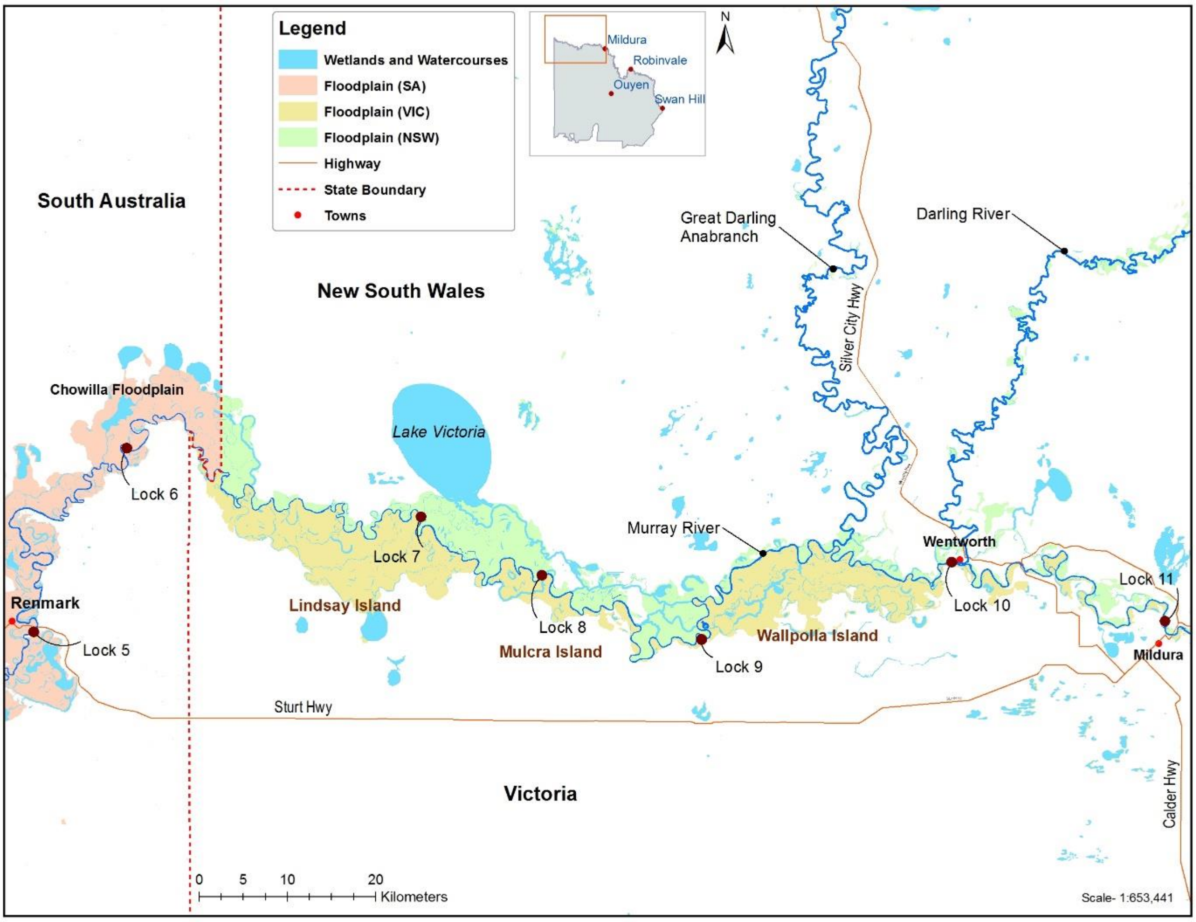


Figure 1. The Murray River and its weirs between Mildura and Renmark

4.3 Land Status and Management

The area involves land in three states. The western part of the study area lies in South Australia whose border crosses the Murray River between Locks 6 and 7. To the east of the border, the river channel and region to the north is part of New South Wales. The area south of the southern bank of the river lies within Victoria.

There is a wide range of land ownership and management arrangements in the region.

The Victorian floodplain between Lock 10 and the South Australian border is mainly public land managed for conservation and recreation. The Murray-Sunset National Park encompasses most of Wallpolla Island, Mulcra Island and Lindsay Island. Between Lock 10 and Lock 11 floodplain land management is more diverse. The river frontage generally lies in the Murray River Reserve. Other floodplain areas include Proposed Murray River Park and leasehold and freehold areas.

The majority of the New South Wales floodplain is privately owned and managed for agricultural production, recreation and, to some extent, for conservation. Significant Crown land areas include Moorna State Forest, Wangumma State Forest and Lake Victoria State Forest. The ownership of some public land is currently in the process of transfer to indigenous owners. Although it lies in New South Wales, Lake Victoria is owned by the South Australian government but operated by the Murray-Darling Basin Authority.

Most of the South Australian floodplain upstream of Lock 6 is public land within the Chowilla Game Reserve, including the floodplain to the north of the river and the Nelwood floodplain system to the south. Some floodplain areas extend into pastoral leases. There are two other small floodplain systems to the south of the river, Queen Bend and Bunyip Reach, both of which are privately owned.

4.4 Wetland Characteristics - Floodplain Morphology and Hydraulics

4.4.1 Murray River Floodplain from Lock 10 to Lock 11

Lock 10 is located on the Murray River at Wentworth just downstream of the confluence with the Darling River (Figure 2). At low river flows the weir pool extends 53 km upstream in the Murray River to Mildura Weir (Lock 11) and 60 km upstream in the Darling River.

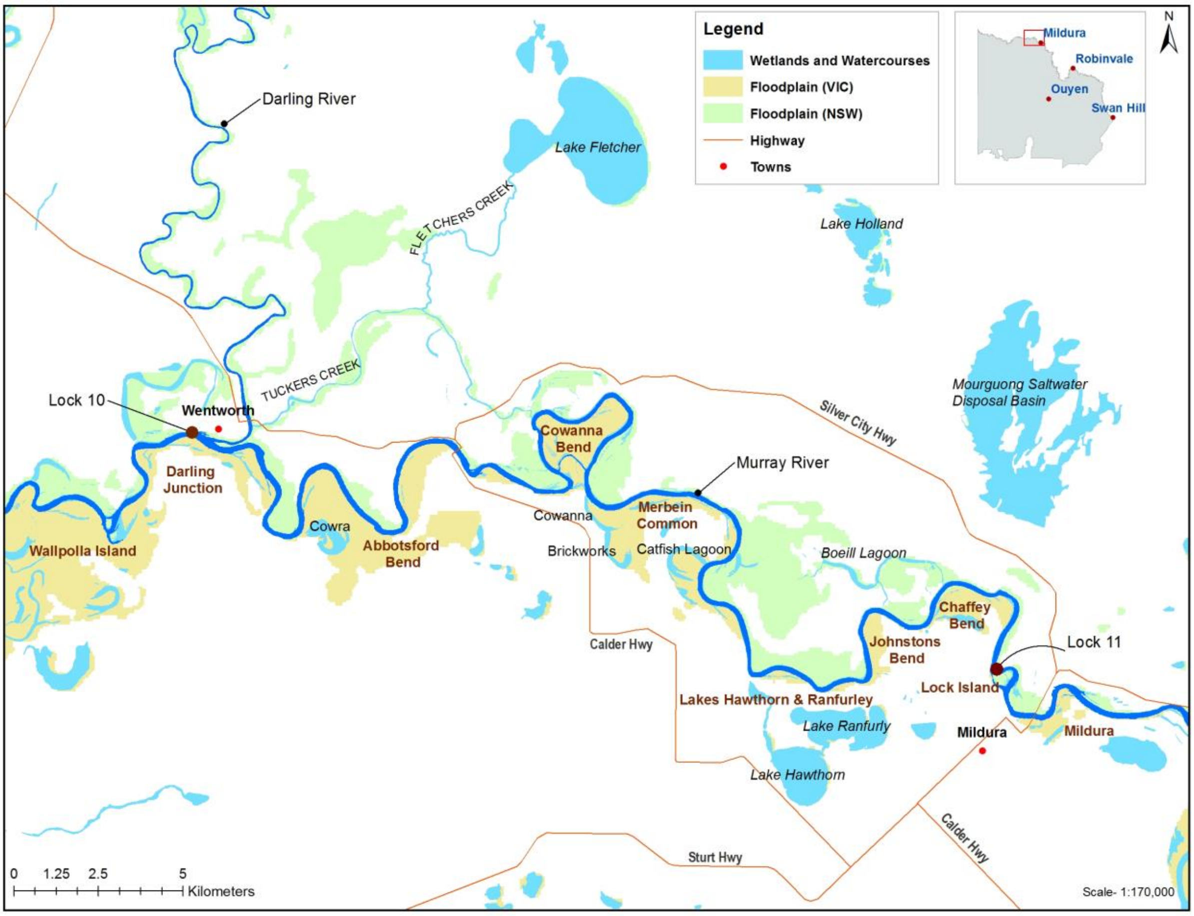


Figure 2. Floodplain systems upstream of Lock 10

From Mildura to Wentworth the Murray River flows through a floodplain that is relatively confined and only 3 to 4 km wide. The floodplain is pinched out where the higher mallee landscape approaches the river, creating a series of detached floodplain areas on each bank. The floodplain areas are comprised mainly of point-bars featuring a shallow, crescent-shaped wetland depression. As river levels rise flooding commences at the downstream end of each system, backing up into the billabongs and wetlands. Upstream effluents are engaged at high river flows and through-flow occurs.

Deeper aquatic habitat is present in stranded river channels at Boeill Lagoon and Merbein Common (Catfish Lagoon and Cowanna Billabong).

Victorian Floodplain

Table 1. Victorian floodplain systems upstream of Lock 10 (Ecological Associates 2007)

River km	Floodplain Management Unit	EWMP Status
880	Chaffey Bend	in preparation
877	Johnston's Bend	in preparation
873	Lake Hawthorn and Lake Ranfurly	in preparation
865	Merbein Common	in preparation
855	Cowanna Bend	
840	Abbotsford Bend	
830	Darling Junction	

An EWMP has been prepared for Chaffey Bend and Johnstons Bend (Australian Water Environments 2014).

Chaffey Bend is a meander scroll is located between 878.5 and 884 river km, 3 km north-west of Mildura. The floodplain is public land; the area closest to the river is proposed Murray River Park while the higher, southern area is operated by the council as the Mildura Wastewater Treatment Plant. The only significant wetland basin detains treated effluent and is isolated from the river by a levee. The lower part of the floodplain features shallow meander scrolls (Ecological Associates 2007).

Johnstons Bend is a meander scroll located between 875 and 878 river km. The lower part of the floodplain, closest to the river is proposed Murray River Park and has shallow scroll features that support Black Box and Lignum (*Muehlenbeckia florulenta*) vegetation. The higher floodplain area near the upstream edge of the floodplain is Crown Land managed for community use including a firing range and motorcycle track (Ecological Associates 2007).

Environmental watering at Chaffey and Johnstons Bends has had limited success in promoting vegetation health, possibly due to the effects of shallow saline groundwater. Groundwater intervention may be required to improve the effectiveness of environmental watering (Australian Water Environments 2014).

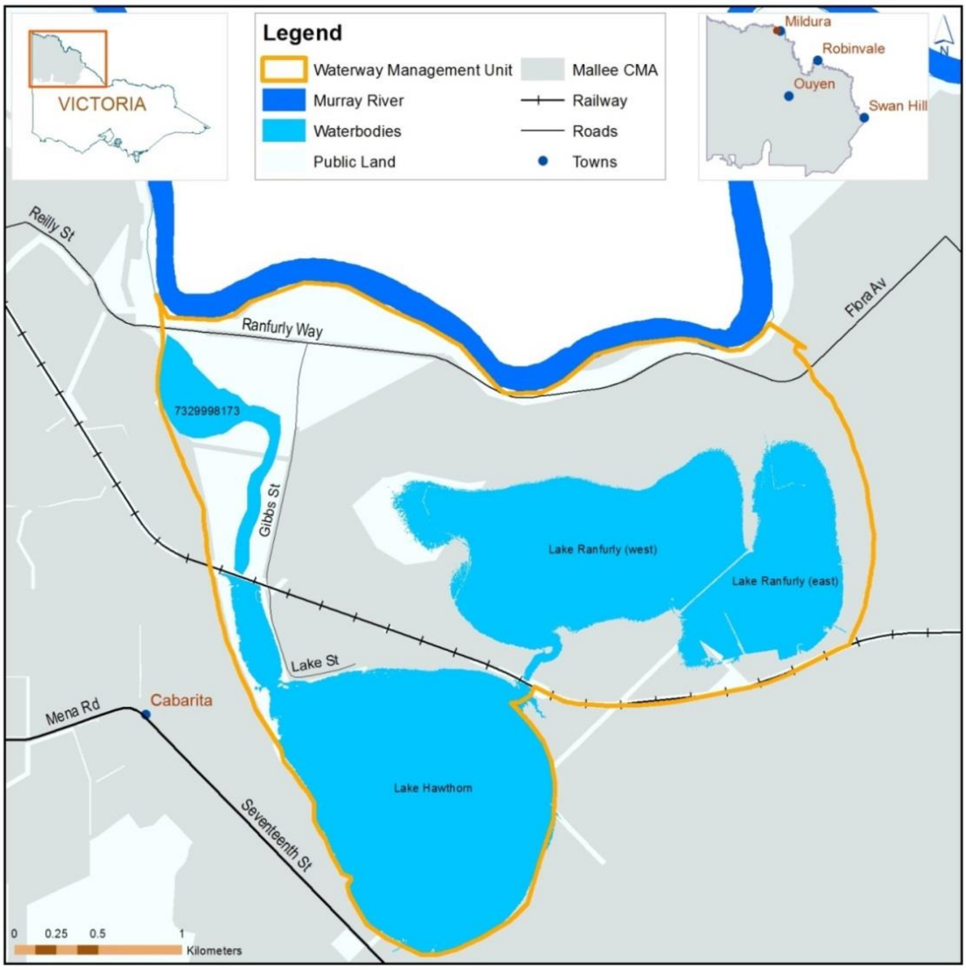


Figure 3. Lakes Hawthorn and Ranfurly

Lakes Hawthorn and Ranfurly are a broad, shallow, floodplain lake located between 871 and 875 river km, approximately 3 km north west of Mildura (Figure 3).

Lake Hawthorn is a natural floodplain wetland. The lake is filled by high flows in the Murray River, although levee banks near the river have raised the connection threshold to approximately 40,000 ML/d (Mallee CMA 2015). Water enters the system near 871 river km where it fills a small wetland, which then overflows to a channel that fills the lake. The lake is approximately 255 ha in area. It was originally a freshwater wetland, but has been salinised by irrigation drainage and urban stormwater inflows since the 1960s. Saline drainage water from Lake Hawthorn may be released to the Murray River when river discharge is high (Ecological Associates 2007). In the past the lake has supported Murray Hardyhead (*Craterocephalus fluviatilis*), a threatened fish species listed under the EPBC and FFG acts, but the population died when the lake dried out during the Millennium Drought of 2002-2007.

Lake Ranfurly is a natural floodplain lake that has also been isolated from Murray River inflows by levee banks. A causeway crosses the lake and, when water levels are low, divides it into east (80 ha) and west (140 ha) basins. Lake Ranfurly was originally a freshwater system but has been salinised by irrigation drainage disposal and groundwater inputs from the Mildura-Merbein Groundwater Interception Scheme (SKM 2001). Water in Lake Ranfurly West is hypersaline and has reached levels exceeding 200,000 EC (Mallee CMA 2015). Corrosive groundwater disposal and stormwater runoff maintains lower salinities in Lake Ranfurly East, but still in excess of 60,000 EC (SKM 2001). Lake

Ranfurly supports salt tolerant herblands of Austral Seablite (*Suaeda australis*) and Ruby Saltbush (*Enchylaena tomentosa*) with areas of Black Box and Eumong (*Acacia stenophylla*) on higher ground (Ecological Associates 2007). The lake provides habitat for wading birds, many of which are protected under international migratory waterbird agreements.

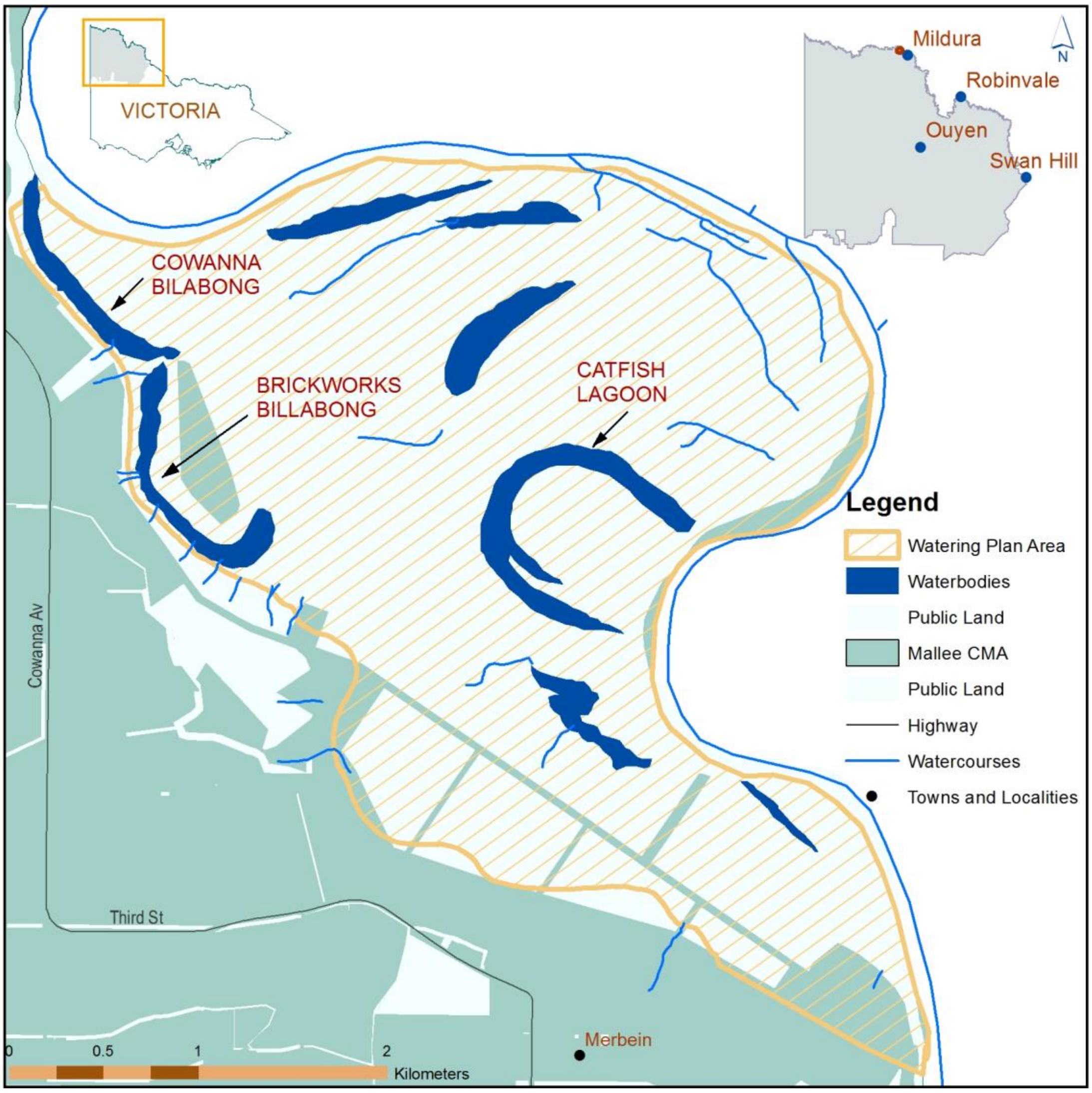


Figure 4. Merbein Common (Mallee CMA 2010)

Merbein Common is the floodplain area between 870.5 and 860 river km (Figure 4). The floodplain has two large lagoon systems and an extensive higher-elevation area of Black Box woodland and chenopod shrubland. The outer part of the floodplain, which is near the river and includes Catfish Billabong, is Murray River Reserve. The inner floodplain area is mainly proposed Murray River Park but also includes part of the Merbein Wastewater Treatment Plant (Ecological Associates 2007). This system has extensive shallow littoral areas that potentially benefit from the manipulation of Lock 10 weir levels.

An EWMP has been prepared for Merbein Common (Mallee CMA 2010).

In the downstream area of Merbein Common, Cowanna Billabong is a shallow wetland permanently inundated by the Lock 10 weir pool. The billabong has a patchy fringe of Cumbungi (*Typha* spp.). Healthy River Red Gum trees occur on the lagoon bank, but tree health deteriorates a short distance back. The woodland understorey comprises Lignum and chenopods. Brickworks Billabong is isolated from Cowanna Billabong by a causeway and has received saline irrigation drainage water in the past. Brickworks Billabong has open water or bare mud in the deeper areas with Samphire (*Halosarcia* spp. and *Sarcocornia* spp.) on the intermittently flooded fringes. An environmental regulator on Cowanna allows water levels in the billabongs to be managed independently of the Lock 10 weir pool. The regulator may be used to allow Cowanna Billabong to dry or may be used to surcharge the system and flood both wetlands. Brickworks Billabong has been identified as a potential reintroduction site for Murray Hardyhead and is known to provide habitat for Intermediate Egret (*Ardea intermedia*), Blue-billed Duck (*Oxyura australis*) and Growling Grass Frog (*Litoria raniformis*) (Mallee CMA 2010).

In the upstream section of Merbein Common, Catfish Billabong is a deep stranded river channel which receives shallow intermittent flooding from the river via a shallow road crossing on the river track. Woodland vegetation near the river is in good health and dense stands of Cumbungi and Common Reed (*Phragmites australis*) are located near the mouth of the wetland. Further from the river saline groundwater impacts result in very poor tree health and the loss of understorey vegetation (Ecological Associates 2007).

Cowanna Bend is the floodplain area enclosed by a meander loop of the Murray River between 851 and 860 river km. The floodplain lies entirely within the Murray River Reserve. The floodplain has no significant wetlands and appears to be inundated at a fairly uniform flow threshold. Two channels cut off the meander loop and have formed partly through excavation and partly from river flow.

Abbotsford Bend comprises two floodplain meander across systems between 837 and 894 river km. The upstream area has a narrow river frontage of Murray River Reserve. The floodplain is privately owned in the east and proposed Murray River Park in the west. The downstream area, is privately owned except for the narrow Murray River Reserve on the river frontage. The general floodplain surface lies well above the river level at normal low flows. River Red Gum woodland is present in the lowest-lying downstream areas of the meander loops but the remainder of the floodplain is occupied by Black Box and Lignum. The vegetation is in poor health due to infrequent flooding, but possibly also due to shallow saline groundwater. The downstream section of Abbotsford Bend is relatively low-lying floodplain with a permanently inundated wetland (Ecological Associates 2007). The shallow littoral areas around the wetland would benefit from variation in the weir level at Lock 10.

The Darling Junction floodplain area lies adjacent to Lock 10 on the left bank between 836.5 and 828.5 river km. The upstream part of the floodplain, within the Lock 10 weir pool, is proposed Murray River Park. The downstream part of the floodplain, below Lock 10 is privately owned except for the river frontage, which is part of the Murray River Reserve. The weir pool permanently inundates one wetland above Lock 10, at 833 river km. This lagoon is approximately 100 m wide and extends 1.2 km into the floodplain. A number of low channels spread towards the river from the eastern edge of the lagoon and represent an extensive shallow littoral area that would benefit from weir manipulation. The lower fringes of the lagoon support River Red Gum forest which grades into Lignum shrubland and Black Box woodland at higher elevations. A watercourse extends from the bank of the lagoon through the floodplain to join the river below Lock 10. Rock embankments prevent water from entering the watercourse from the lagoon or the river. (Ecological Associates 2007).

New South Wales Floodplain

The Mourquong floodplain is a relatively high and somewhat disturbed floodplain area located downstream of Lock 11 in New South Wales.

The Boeill Lagoon wetland complex is in New South Wales opposite to Lakes Hawthorn and Ranfurly. The central part of the floodplain has a relatively high elevation and has been developed for horticulture. Boeill Lagoon is an isolated deep, steep-sided former river channel in the central floodplain area and is permanently inundated by saline groundwater drainage. The lagoon and surrounding areas are severely impacted by salt and at risk of developing acid sulfate soils (Ward, et al. 2011). Low-lying terraces at the floodplain fringe are inundated by low to moderate peaks in river flow.

Downstream of the Boeill Lagoon complex is a small un-named point-bar system comprising a low outer terrace vegetated by River Red Gum and a higher intern terrace supporting Black Box and Lignum.

The hydraulics of the floodplain approaching the Darling River is relatively complex. Tuckers Creek is a permanently inundated anabranch that connects the Darling and Murray rivers upstream of the confluence. The creek encloses former mallee and high-level floodplain, most of which has been developed for horticulture in the Curlwaa irrigation district. Fletchers Creek is a small watercourse that branches off Tuckers Creek to the north and flows to the large Fletchers Lake deflation basin. The area to the north and west of Fletchers Creek is continuous with the Darling River floodplain.

The floodplain in this reach is exposed to shallow saline groundwater and has significant areas of degraded vegetation and wetland habitat. Acid sulfate soil risks have been identified at Merbein Common (Ecological Associates 2007) and at Boeill Creek (Ward, et al. 2011). Lake Ranfurly receives saline groundwater from the Mildura Merbein salt interception scheme.

Table 2. New South Wales floodplain systems upstream of Lock 10 (Ecological Associates 2008)

River km	Bank	Floodplain Management Unit
885	Right	Mourquong (ref. FMU16)
870	Right	Boeill Lagoon (ref. FMU15)
855	Right	No Name (ref. FMU 14)
840	Right	Wentworth (ref. FMU13)

Lower Darling River

The Darling River drains an extensive catchment that comprises areas of southern Queensland and northern and western New South Wales. Flow in the lower Darling is regulated to some extent by the operation of the Menindee Lakes scheme.

The Menindee Lakes scheme uses several large natural lakes adjacent to the Darling River as storages. Water is diverted into the lakes at the Menindee Main Weir and stored water is returned to the Darling by the Menindee Lake Main Regulator. The four main lakes of Menindee, Cawndilla, Pamamaroo and Wetherell can store 1,730 GL. The lakes contribute to water demands in New South Wales, South Australia and Victoria, supply the town of Broken Hill and replenish the Lower Darling environment (Kumar and Alamgir 2013).

Below Menindee the Darling River flows south for 200 km before joining the Murray River at Wentworth. The Darling Anabranch diverges from the Darling River approximately 55 km south of Menindee. The anabranch flows broadly parallel to the Darling and discharges to the Murray River approximately 15 km downstream of the Daring River confluence. The anabranch diverts flow from the Darling when discharge exceeds approximately 9,000 ML/d at Weir 32 (Bogenhuber and Linklater 2012). At river flows greater than 15,000 ML/d approximately half the Darling flow diverts to the anabranch. The anabranch can also be supplied with water directly from the Menindee Lakes at Packers Crossing.

Three low level weirs affect the lower Darling River: Weir 32 at Menindee, Pooncarie Weir and Burtundy Weir. At a discharge of 13,000 ML/d at Weir 32, 50% of the billabongs in the Lower Darling are filled.

The influence of the Lock 10 weir pool extends upstream about 60 km, as far as Elerslie.

Darling River water can be relatively saline, requiring operational responses to manage Murray River water quality.

Table 3. Key inundation thresholds upstream of Lock 10 (pers. comm. Scott Jaensch, NSW Office of Water, (Bogenhuber and Linklater 2012)

Threshold*	Feature
5,000 ML/d	Minor disruption to access roads and pumps commences
10,000 ML/d	Overbank Flow Increasing connection to the Great Darling Anabranch
15,000 ML/d	Significant disruption to floodplain access, pumps and assets commences
26,000 ML/d	Menindee to Pooncarie Road is cut

** Flow at Weir 32*

4.4.2 Murray River Floodplain from Lock 9 to Lock 10

Victoria

The Murray River floodplain upstream of Lock 9 on the Victorian side lies almost entirely within Wallpolla Island (Figure 4. Merbein Common (Mallee CMA 2010)). Wallpolla Island is made up of watercourses, wetland basins and freely-draining floodplain areas. It extends for 29 km from east to west and covers an area of approximately 9,000 ha. Wallpolla Creek is 7 km from the river at the island's widest point.

The watercourses are deeply incised in the floodplain and, in the west of the island, are permanently inundated by the Lock 9 weir pool. The weir pool of Lock 9 extends 25 km upstream through Wallpolla Creek and a number of other channels (Ecological Associates 2007). "The Bong" is a permanent wetland within the island located 2 km upstream of the weir.

The upstream connections of watercourses in the east of the island start to become active at Murray River flows exceeding 3,000 ML/d, but significant anabranch flow requires higher levels. Finnigans Creek becomes active at flows exceeding 8,000 ML/d and Sandy Creek flows when river discharge exceeds 33,000 ML/d. The upstream connection of Wallpolla Creek becomes active when river discharge exceeds 70,000 ML/d.

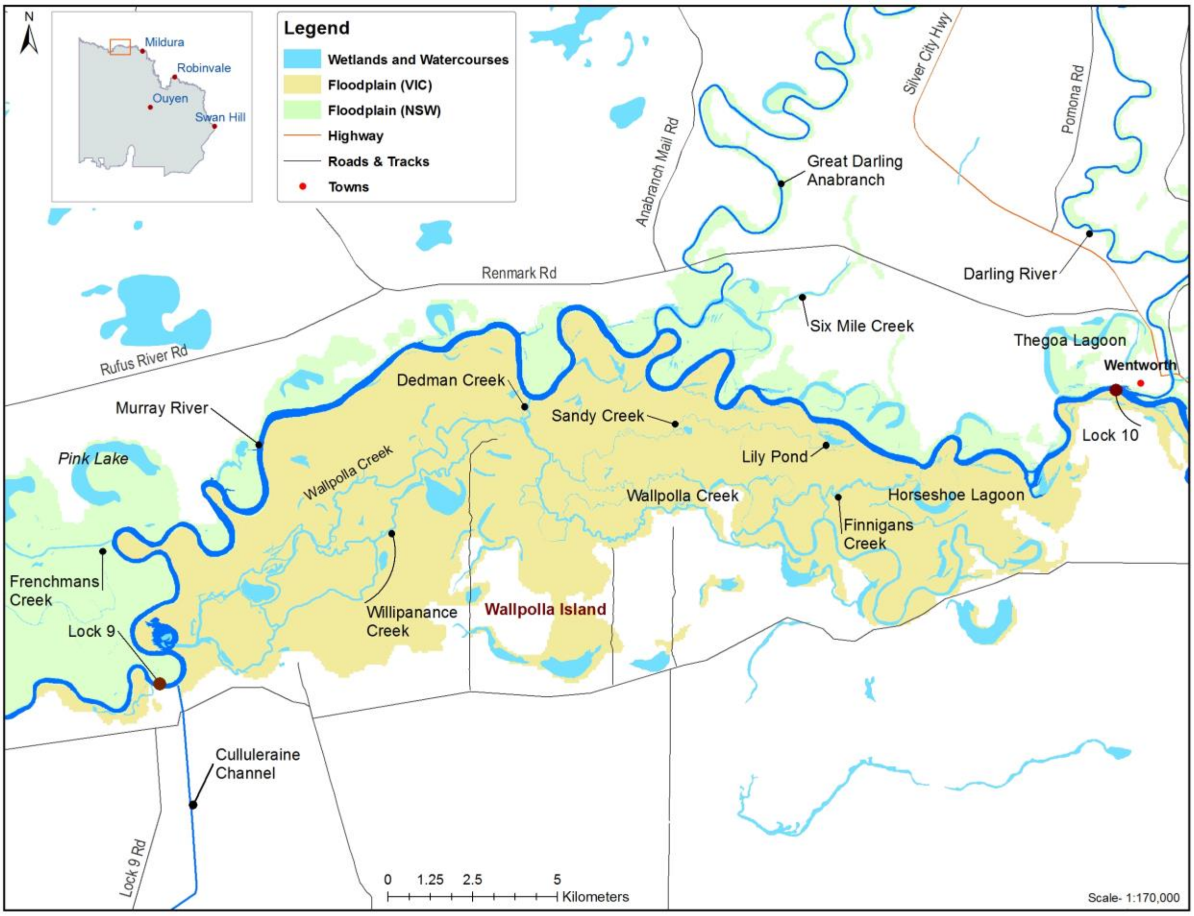


Figure 5. Murray River Floodplain from Lock 9 to Lock 10

There are few low-lying wetland areas at Wallpolla Island. Water backs into several scroll bar wetlands along the river bank at flows exceeding 30,000 ML/d, including the Lilyponds. As river levels continue to rise water spills into the surrounding River Red Gum forest and woodland.

Several low-lying wetlands lie adjacent to the anabranches and are filled as river levels increase. Most wetlands are filled at flows between 30,000 and 60,000 ML/d.

Flood water is largely confined within the wetlands and deeply incised channels until river flows exceed 70,000 ML/d at which point water spills to Black Box woodlands and Lignum shrublands. Widespread floodplain inundation, including to alluvial plain vegetation, occurs at flows exceeding 90,000 ML/d.

Horseshoe Lagoon is a managed wetland on Wallpolla Island and is connected to river flows via Finnigans Creek in the east of the island. The wetland receives relatively frequent inflows at river discharges exceeding 30,000 ML/d. A regulator was constructed on the wetland in 1996 to exclude unseasonal flows and to control managed inundation events.

Table 4. Key inundation for the Wallpolla Island

Threshold*	Feature
3,000 ML/d	Minor anabranch inflows
8,000 ML/d	Finnigans Creek inflow commences
30,000 ML/d	Inundation commences at Horseshoe Lagoon, the Lilyponds, other point-bar billabongs and surrounding floodplain
33,000 ML/d	Sandy Creek inflow commences
70,000 ML/d	Inflows to upstream connection of Wallpolla Creek Significant floodplain inundation commences
90,000 ML/d	Widespread floodplain inundation

** Lock 10*

New South Wales

On the northern bank of the river, the floodplain between the Darling River and Frenchmans Creek is generally less than 2 km wide (Figure 3). The floodplain features a series of billabongs with low-level sills at the downstream end through which water backs up when river levels first start to rise. At higher flows, water enters the upstream end of the billabong and through-flow commences.

When the Murray River is in flood, the floodplain corridor along the river is inundated, including the areas surrounding the billabongs. When the Darling is in flood, water enters this reach via the Great Darling Anabranch and by overland flow from the Darling which inundates the area between Six Mile Creek, the Darling River and the Murray River (MDBA 2010).

Thegoa Lagoon is a wetland located downstream of the Darling Junction, west to the town of Wentworth with an area of 80 ha. The wetland is regulated and has been managed according to a wetland management plan since 1996. It can be filled from the Lock 10 weir pool and may be drained to the Lock 9 weir pool (Thegoa Lagoon Management Steering Group 2003).

Nelda is a low-lying ephemeral wetland that is inundated by small increases in the river level upstream of Lock 9. Wambalano (351) is an oxbow wetland permanently inundated by the Lock 9 weir pool.

Purda Billabong is connected to Frenchmans Creek on the northern (upstream) side. The wetland is permanently inundated by Lock 9. A second upstream connection diverts water to the wetland from the Murray River at high flows (Jensen 2004).

The Darling Anabranch is an ancestral channel of the Darling River. The anabranch is approximately 480 km long and diverges from the Darling River about 55 km south of Menindee. It joins the Murray River between Locks 9 and 10 at 807 river km. The anabranch receives water from the Darling River when flows upstream of the anabranch offtake exceed 9,000 ML/d at Weir 32 (Bogenhuber and Linklater 2012) or via Tandou or Redbank Creeks when flow passing Menindee exceeds 20,000 ML/d

(GHD 2008). Under low Murray flows, the Lock 9 weir pool backs up approximately 30 km in the anabranch (MDBA 2010). The weir pool has promoted the growth of Cumbungi in the anabranch channel and maintains the health of River Red Gum, Black Box and Lignum on the banks (Bogenhuber, Linklater and Campbell 2011).

Considerably upstream of the Lock 9 weir pool the anabranch features 11 large lakes and several lesser lakes and wetlands that are connected at various levels. Under natural conditions the anabranch flowed about every two years out of three in the upper reaches. Only in major floods did a significant volume of water reach the Murray River via the anabranch, with water flowing the full length only nine times in the period from 1890 to 1961. Flows in February to April generally correspond to summer rainfall in southern Queensland while flows in July and August result from winter rainfall in central and southern New South Wales(GHD 2008).

The hydraulics of the anabranch have been modified, including the excavation of a channel from the Darling River to increase flows into the anabranch. However the effect of the lower flow threshold has been counteracted somewhat by reduced flows in the Darling associated with the Menindee Lake Scheme and irrigation diversions (GHD 2008).

Environmental flows may be used to support ecological outcomes in the anabranch channel. There is potential to piggy back environmental flows on flood events (Bogenhuber, Linklater and Campbell 2011).

4.4.3 Murray River Floodplain from Lock 8 to Lock 9

The floodplain upstream of Lock 8 on the left bank comprises Mulcra Island and Big Paddock.

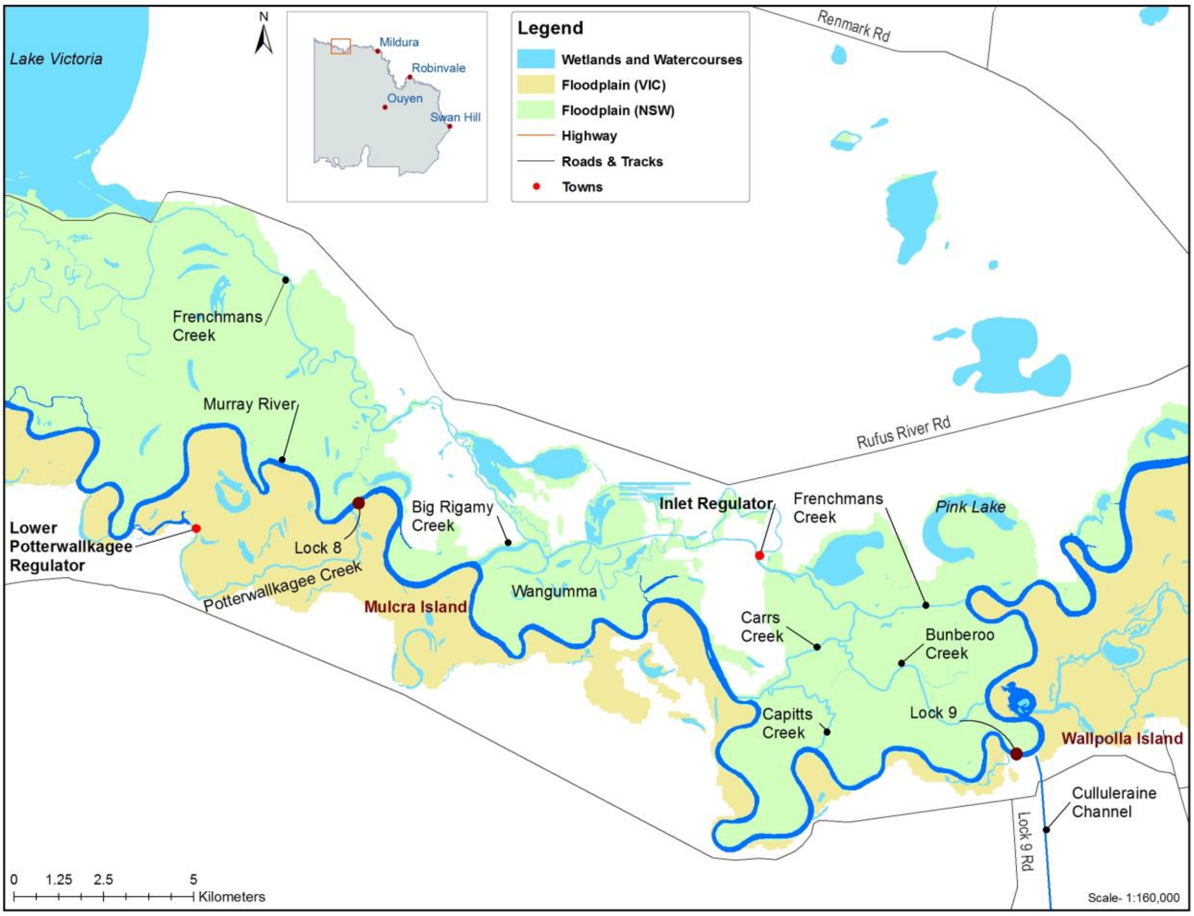


Figure 6. Floodplain systems upstream of Lock 8

The Mulcra Island floodplain system comprises Mulcra Island and the adjacent floodplain areas, covering an area of 3,199 ha (Figure 6). The island is enclosed between the river and the Potterwalkagee Creek anabranch. The system is located on the left (Victorian) bank of the Murray River between 758 and 720 river km. Lock 8 is located on the Murray River at the mid-point of the island at 732 river km.

Potterwalkagee Creek diverges from the river at 746 river km. The first section of the creek flows intermittently and passes through the shallow wetland of Snake Lagoon. Near the central part of the island the creek receives inflows from the Stoney Crossing effluent which diverts water from the Lock 8 weir pool. The lower part of the creek, near the confluence with the Murray River, is permanently inundated by the Lock 7 weir pool.

The Mulcra Horseshoe is a deep billabong located between Potterwalkagee Creek and the Murray River below Lock 8. The billabong and its flood runners occupy 78 ha. The wetland starts to receive inflows from the river when discharge exceeds 26,000 ML/d and is filled when flow exceeds 40,000 ML/d.

Floodplain inundation commences with water spilling into low meander scrolls on the river bank and backing up into shallow woodland and Lignum areas in the lower Potterwalkagee Creek area. Widespread inundation of woodland areas occurs at flows exceeding 60,000 ML/d with flooding of higher level Black Box woodland complete at flows over 120,000 ML/d.

Under TLM Mulcra Island flood enhancement project, works were completed to promote flowing water habitat and more frequent floodplain inundation. The works involve:

- The Mulcra Weir on lower Potterwalkagee Creek. This may be raised in conjunction with the Lock 9 weir pool to inundate a combined area of 822 ha in Victoria and NSW.
- A lower sill and regulator at Stoney Crossing and a regulator on Upper Potterwalkagee Creek. These works permit greater and more variable flow into Potterwalkagee Creek from Lock 8 and may be operated in conjunction with raising Lock 8.
- Regulators and stop banks on the Mulcra Horseshoe to detain flood water. Flood water may be introduced when the Mulcra Weir is raised, by natural flood events or by pumping.

Big Paddock is part of the Kulnine grazing lease (Ecological Associates 2007).

Table 5. Key inundation for the Murray River floodplain at Mulcra Island

Threshold*	Feature
Pool Level	Stoney Crossing inflows to Lower Potterwalkagee Creek
40,000 ML/d	Mulcra Horseshoe filled
60,000 ML/d	Red gum woodlands largely inundated
120,000 ML/d	Black box woodlands largely inundated

** Flow at Lock 9*

4.4.4 Lake Victoria Floodplain

The Lake Victoria Floodplain comprises the area on the right bank of the Murray River between Frenchmans Creek (near Lock 9) in the east and the Chowilla Floodplain in the west. Lock 8 is located near the mid-point of the system (Figure 7). The downstream extent of the floodplain is defined by Rufus River which joins the Murray River just below Lock 7. The outer boundary of the floodplain is broadly defined by the regulated channels that deliver water to and from Lake Victoria.

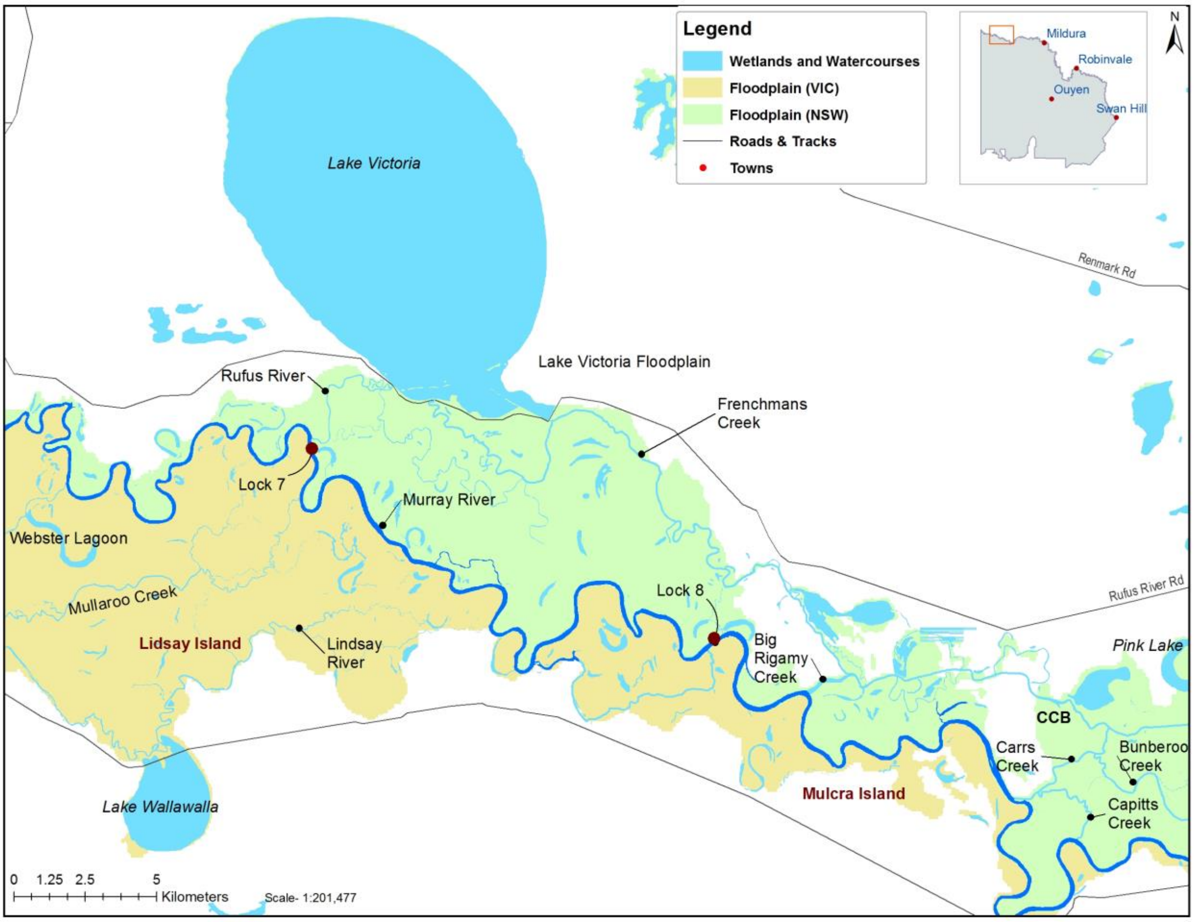


Figure 7. Lake Victoria floodplain and upper Lindsay Island

Lake Victoria is a naturally occurring shallow freshwater lake that is managed as a water storage. The lake has an area of 12,200 ha and a maximum depth of about 5.5 m. River water is diverted to the lake from the Lock 9 weir pool and returned via Rufus River below Lock 7 (Figure 8).

Frenchmans Creek diverges from the Murray River at 779 river km, approximately 14 km upstream of Lock 9. Lock 9 raises the river level to provide gravity feed to Lake Victoria, with inflow controlled at the Inlet Regulator 7 km from the Murray. The creek flows approximately parallel to the river at a distance of 2 to 5 km in a channel that has been straightened and enclosed by levees to deliver water more efficiently. The Control Regulator is located at the entrance to Lake Victoria to control flow from Frenchmans Creek into the lake but is no longer in operation.

Substantial cut-off channels along Frenchmans Creek include Carrs Billabong to the north and Little Rigamy Creek to the south. Levees on the south side of Frenchmans Creek limit the spread of water to the floodplain, but a number of wetlands receive controlled flows, including Latinas Flat and Purda Billabong to the north. Big Rigamy Creek is a broad backwater, approximately 100 m wide that extends from the Murray River at 737 river km to the Frenchmans Creek levee bank.

Flow into Lake Victoria can often exceed the passing flow in the Murray River below Lock 9. Similarly, releases from the lake, which can reach 9,000 ML/d, result in a higher flows below Lock 7 than above.

The floodplain in the vicinity of Rufus River is salinised by groundwater discharge induced by the hydraulic head of Lake Victoria (see section 4.5 Hydrogeology below).

The Carrs, Cappitts and Bunberoo Creeks (CCB) system is a network of floodplain anabranches to the north of Lock 9. Banks prevent water spilling to the creeks from the Lock 9 weir pool in Frenchmans Creek: fixed crest weirs are located at the two major inlets at Carrs No. 1 and Carrs No. 2, while a block bank B is located on a higher level floodrunner that flows into Bunberoo Creek.

The Lock 8 weir pool permanently inundates the lower reaches of the CCB system.

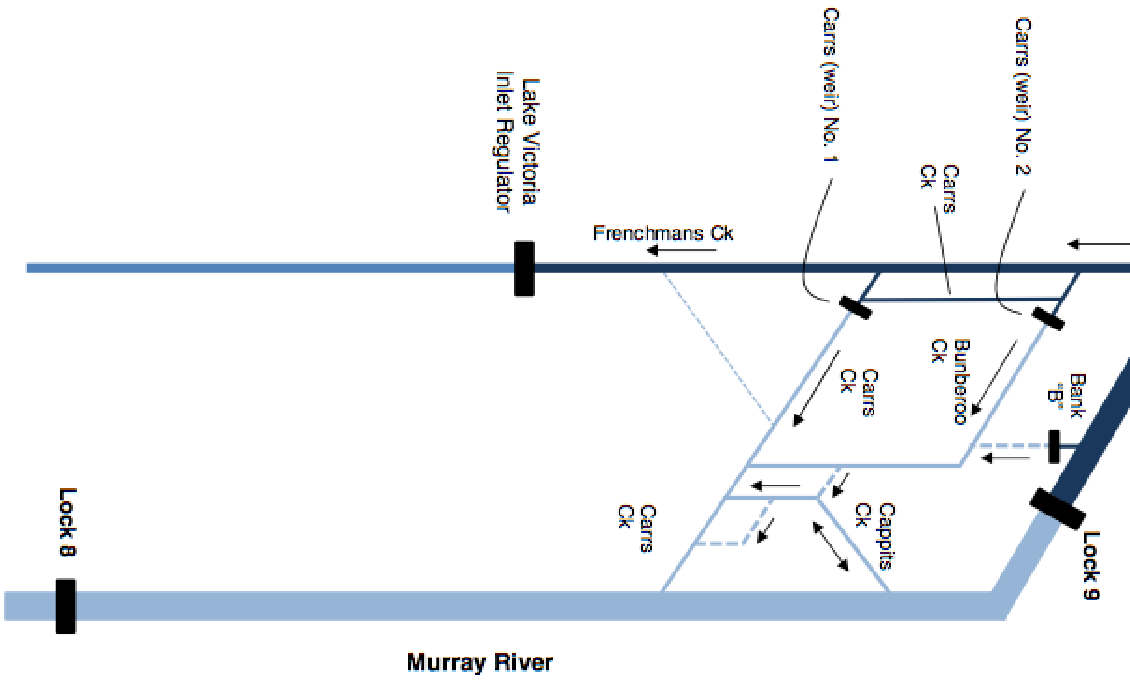


Figure 8. Schematic diagram of the Carrs Cappitts Bunberoo system. The Lock 9 weir pool is shown in dark blue and the Lock 8 weir pool is shown in light blue. Lake Victoria levels are shown in mid-blue (Robinson and Mallen-Cooper 2013)

Lock 8 Wetland is located adjacent to Lock 8. The entrance to the wetland is crossed by the access road to the lock where a regulator has been installed to allow water to be stored in or excluded from the wetland independently of Lock 8 levels.

With the exception of the Lake Victoria and Carrs-Cappitts-Bunberoo systems, the structure and hydraulics of the floodplain are poorly understood. Further work is required to develop a comprehensive picture of flow paths and floodplain habitats.

4.4.5 Lindsay Island

The Lindsay Island floodplain system comprises Lindsay Island and the adjacent floodplain areas. The system is located on the left bank (Victorian side) between 720 and 659 river km (Figure 9).

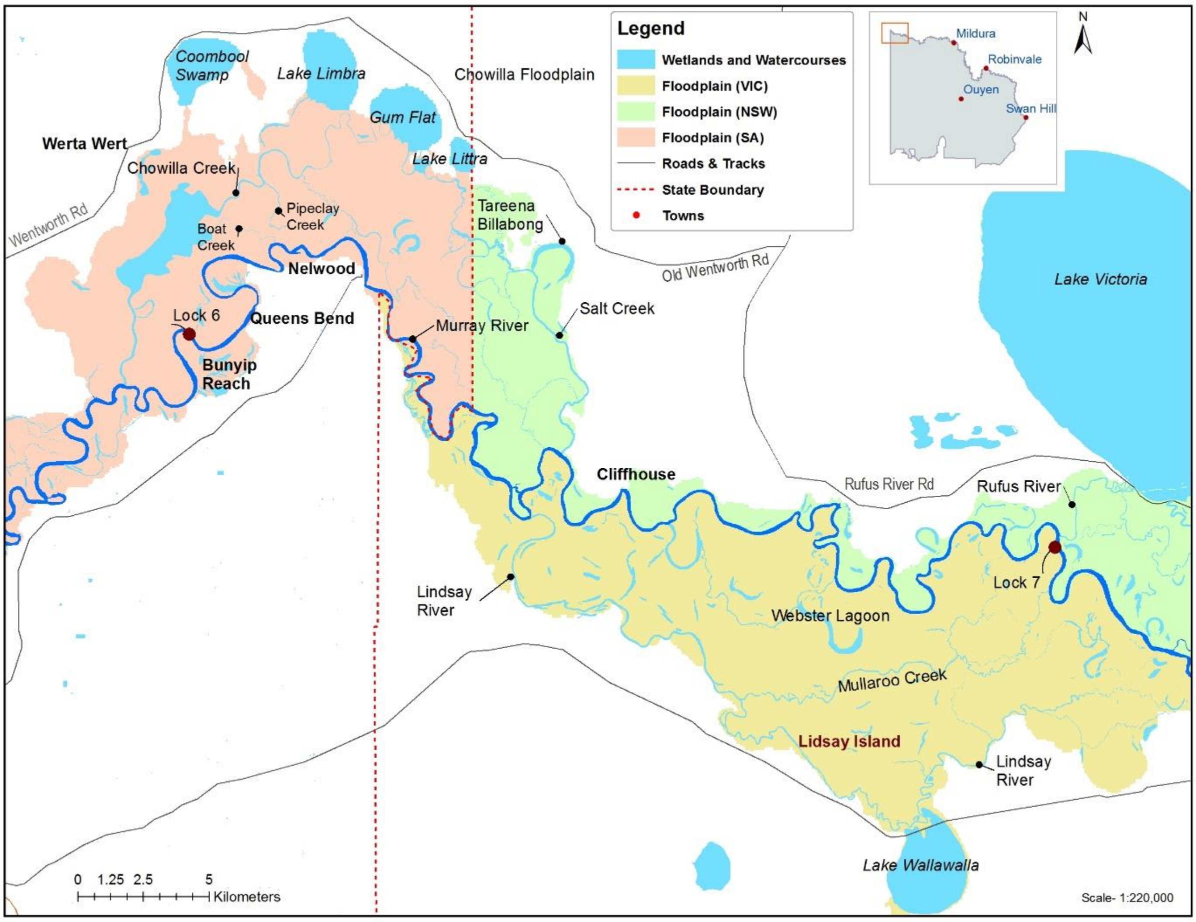


Figure 9. Floodplain systems upstream of Lock 6

Lock 6 is located downstream of Lindsay Island in South Australia at 620 river km. The weir ponds water in the channels in the west of the island, including Lindsay River, Toupnein Creek and lower Mullaroo Creek. Lock 7 is located alongside Lindsay Island at 703 river km. Water from the weir pool flows into the Mullaroo Creek anabranch, creating a continuous fast-flowing environment in the first 4 km of the channel. A smaller inflow also enters Lindsay River from the Lock 7 weir pool.

At elevated river levels, flow into Mullaroo Creek increases and a second Lindsay River effluent becomes active. Regulators at the entrances to these channels control inflows at a range of weir and river levels. Lindsay River and Mullaroo Creek are deeply incised and flow generally remains in well-defined channels until river discharge exceeds 35,000 ML/d. Above this threshold water spills to the benches alongside the channels.

Websters Lagoon is a wetland adjacent to Toupnein Creek below Lock 7. The wetland lies close to the tailwater of the weir and is readily inundated by minor increases in river flow. An environmental regulator is used to prolong flooding or exclude water inflows associated with the Lock 7 tailwater and Lock 6 weir pool.

Small peaks in river flow, between 25,000 and 35,000 ML/d inundate minor point bar wetlands along the Murray River and the floodplain surrounding Toupnein Creek. More widespread wetland flooding occurs at flows between 35,000 and 60,000 ML/d including Lake Wallawalla, Pollards Lagoon, The Crankhandle, the Mullaroo Wetland Complex and the Upper Lindsay Complex. The largest of these is Lake Wallawalla which is an 828 ha deflation basin to the south of Lindsay River. The lake receives inflows at river flows of 40,000 ML/d, flows and is filled by flows exceeding 90,000 ML/d. An environmental regulator on Lake Wallawalla is operated to prolong flooding by controlling the return of water from the lake to Lindsay River.

Extensive floodplain inundation occurs at flows exceeding 60,000 and 120,000 ML/d. Initially Red Gum woodland is inundated then Black Box woodland. Lignum tends to occur in shallow floodplain depressions that are inundated by floods and seasonally waterlogged by local rainfall. High flows, exceeding 120,000 ML/d, mainly introduce water to floodplain grasslands and chenopod shrublands.

Under TLM Lindsay Island flood enhancement project, works were completed to promote flowing water habitat and more frequent floodplain inundation. The works involve:

- A regulator at the entrance to Mullaroo Creek. This structure allows flow to Mullaroo Creek to be controlled at a range of river flows and Lock 7 weir pool levels.
- Regulators on the two effluents that introduce water to Lindsay River. The Lindsay North regulator allows water to enter Lindsay River at pool level. The Lindsay South regulator lowers the inflow threshold. Both regulators control inflows over a range of river flows and weir pool levels.
- A regulator on Websters Lagoon to exclude unseasonal flooding or to prolong targeted floods by capturing flood peaks or storing pumped water.
- A regulator at Lake Wallawalla to detain water provided by floods or pumping.

Table 6. Key inundation thresholds at Lindsay Island

Threshold ML/d*	Feature
3,000	Mullaroo Creek and Lindsay River North divert water from Lock 7 weir pool Websters Lagoon potentially inundated by Lock 6 weir pool, depending on Lock 6 levels and Lake Victoria outflows
15,000	Lindsay River South diverts water from Lock 7 weir pool
35,000-60,000	Water spills to benches along channels and floodplain near Toupnein Creek. Water enters low-lying billabongs in point-bars along Murray River Floodplain wetlands inundated including Lake Wallawalla, Pollards Lagoon, The Crankhandle, Mullaroo Wetland Complex, Upper Lindsay Complex
60,000	Significant floodplain inundation commences
80,000	Red gum forest and woodland largely inundated Lignum shrubland and woodland largely inundated
115,000	Black box woodland largely inundated Significant inundation of chenopod shrublands and grasslands commences

** Flow at Lock 8*

4.4.6 Murray River Floodplain from Rufus River to Salt Creek

The floodplain between Rufus River and Salt Creek comprises a series of six detached floodplain areas isolated by contact between the river and the higher mallee landscape.

Table 7. Floodplain systems upstream of Lock 10 (Ecological Associates 2013) (Ecological Associates 2008)

River km	Floodplain Management Unit
698	FMU 6
690	FMU 5
683	FMU 4 Nampoo. One pool level wetland. Three high level wetlands.
675	FMU 3
670	FMU 2
665	FMU1 Cliffhouse. Two moderate level wetlands

The floodplain units are generally point bar systems that feature wetlands inundated by flows between 30,000 and 60,000 ML/d. Widespread inundation of higher terraces occurs at flows over 60,000 ML/d. Nampoo Wetland is permanently inundated by the Lock 6 weir pool.

Cliffhouse Wetland is notable for a population of Growling Grass Frog (NSW Office of Heritage and Environment 2013). Cliffhouse and Nampoo wetlands have both received environmental watering in the past.

Table 8. Murray River floodplain from Rufus River to Salt Creek (Water Technology 2014)

Threshold ML/d*	Feature
3,000	Nampoo Wetland inundated by Lock 6 weir pool
30,000-60,000	Point-bar billabongs and low lying floodplain inundated
80,000	Floodplain largely inundated
110,000	Outer floodplain areas inundated

* Flow at SA Border

4.4.7 Chowilla Floodplain

The Chowilla floodplain is located on the right bank (north) of the Murray River between 658 and 612 river km and lies partly in New South Wales but mainly in South Australia. The system extends over 17,700 ha and contains a diversity of habitats including lakes, flowing creeks, islands, billabongs, floodouts, levees and lunettes (Sharley and Huggan 1995).

The floodplain starts where the Salt Creek anabranch diverges from the Murray. Salt Creek joins Chowilla Creek to enclose most of the floodplain area. Woolshed Flat is the lowest tributary of Chowilla Creek and marks the downstream extent of the floodplain.

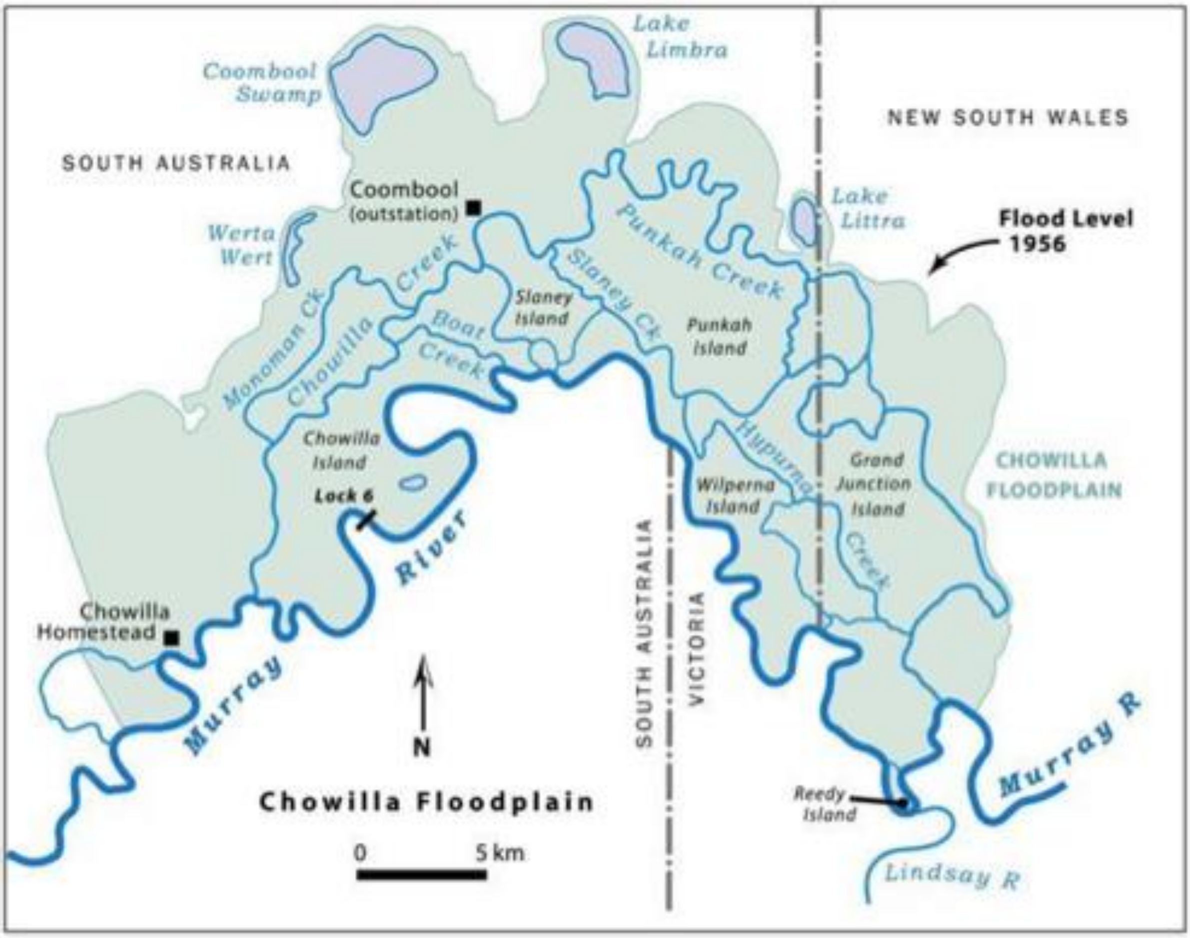


Figure 10. Chowilla floodplain watercourses and wetlands

Lock 6 is located adjacent to the floodplain at 620 river km and directs flow from the river channel into a number of floodplain effluents. The two major flows at Slaney Creek and Pipeclay Creek are controlled by weir structures. A smaller inflow occurs at Swifty's Creek further upstream. At elevated river levels Salt Creek and Hypurnah Creek are also active. Stop banks at several locations limit further effluent inflows. The effluent inflows contribute to the Chowilla Creek anabranch which discharges back to the river below Lock 6. The lower reach of Chowilla Creek is ponded by the Lock 5 weir pool.

The total length of the creek system carrying water under normal pool conditions is 110 km (Sharley and Huggan 1995). At flows less than 10,000 ML/d between 20% and 90% of total river flow passes through Chowilla. At higher flows up to 25,000 ML/d less than 10% of flow passes through floodplain watercourses. At river discharges exceeding 55,000 ML/d, when Lock 6 is removed, approximately one-third of river flow passes through the floodplain (Mallen-Cooper, et al. 2011).

A series of deflation basins fringe the outer floodplain channels including Lake Littra, Gum Flat, Lake Limbra, Coombool Swamp and Werta Wert. These wetlands are among the first significant areas of inundation when river levels rise. Lake Limbra, Lake Littra and Werta Wert start to fill at river flows exceeding 35,000 ML/d. At this flow water also spreads into river benches and low wetlands within the floodplain. Flows exceeding 42,000 ML/d introduce water to Gum Flat (Mallen-Cooper, et al. 2008). Coombool Swamp requires high flows of 75,000 ML/d to fill (Sharley and Huggan 1995).

Flows exceeding 56,000 ML/d initiates more widespread inundation of the floodplain. Flows exceeding 100,000 ML/d inundate 90% of red gum forest and woodland, 85% of Lignum and 70% of Black Box vegetation (Sharley and Huggan 1995).

Table 9. Key inundation thresholds for the Chowilla floodplain

Threshold*	Feature
<7,000 ML/d	16% of inflows received by Outer Creeks (Salt Creek at Bank K and L) 33% of inflows received by Inner Creeks (Hypurna Creek at Bank K and J, Slaney Creek) 51% of inflows received by Lower Creeks (Pipeclay Creek, Boat Creek)
30,000	Minor flooding of low point bar systems along the Murray River Low-lying floodplain wetlands inundated including Tarena Billabong and Horseshoe Lagoon
40,000	Filling of Lake Limbra
50,000	Filling of Werta Wert Lagoon, Gum Flat and Lake Littra
65,000	Significant floodplain inundation commences 50% of red gum forest and woodland inundated
75,000	Filling of Coombool Swamp 50% of lignum shrubland inundated
90,000	50% of black box woodland inundated
100,000	75% of black box woodland inundated

** Flow at South Australian border*

4.4.8 Murray River Floodplain from Lindsay Point to Lock 6

The Lindsay Point Wetland Complex comprises a system of low-lying wetland areas and waterways in Victoria, located 1 km upstream of the South Australian border and 26 km upstream of Lock 6 (GHD 2012). The main feature of the complex is a chain of wetlands running parallel to the River over 4 km, approximately 100 to 200 m distant from the river bank. The complex is connected to the river at the upstream and downstream ends and at one effluent towards the downstream end. The complex is permanently inundated by the Lock 6 weir pool and a landowner extracts water at two locations (GHD 2012). Due to the low-lying nature of the floodplain and complex edges, the system would benefit from a program of seasonal water level variation in the weir pool. Proposals have been developed to inundate the floodplain with local structures that control flow at the Murray River effluents (GHD 2012).

The floodplain between Lindsay Point and Lock 6 comprises a series of three units, each isolated by contact between the Murray River and the higher Mallee landscape (Woodward-Clyde 2000).

Nelwood is located near the border at 633 river km and is part of the Chowilla Game Reserve. It comprises two adjacent point bar systems both of which are inundated by the Lock 6 weir pool from the downstream end. Water flows through part of the Nelwood system at normal weir pool levels, although the upstream connection is becoming blocked with reeds (Smith, et al. 2007).

Queen Bend is a privately owned floodplain area located at 627 river km. The floodplain is a point-bar system where raised river levels associated with Lock 6 permanently inundate wetland areas on the downstream side.

Bunyip Reach is the most-downstream unit and is located adjacent to Lock 6. A relatively low terrace adjacent to the river features shallow wetlands, red gum woodlands and lignum swamps. A higher terrace lies at the base of the highland cliff.

Table 10. Key inundation for the Murray River floodplain between Lindsay Point and Lock 6 (Mallen-Cooper, Koehn, et al. 2008), (Sharley and Huggan 1995)

Threshold*	Feature
3,000 ML/d	Downstream inundation of Nelwood and Queen Bend by the Lock 6 weir pool
35,000 ML/d	Inundation of low-lying river red gum and wetland margins at Nelwood and Queen Bend
40,000	Inundation of Bunyip Reach point bar downstream of Lock 6
55.000	Complete inundation of Queen Bend and Nelwood low-lying red gum forest
70,000	Bunyip Reach effluents from upstream of Lock 6 are activated, some wetlands are inundated Nelwood and Queen Bend completely inundated except for river levee.
80,000	All lignum wetlands and woodland areas of Bunyip Reach are inundated
100,000	Complete floodplain inundation

** Flow at SA Border*

4.5 Management Scale

This EWMP has been prepared for the river channel, wetlands and floodplain between Lock 6 and the upper limit of the Lock 10 weir pool in the Darling and Murray rivers. The area able to be inundated through environmental water management will be subject to specific negotiations on the operation of the Locks and the installation of infrastructure as proposed.

4.6 Environmental Water Sources (Victorian Sites)

The Environmental Water Reserve (EWR) in Victoria is the legally recognised amount of water set aside to meet environmental needs. The EWR includes water provided through:

- minimum river flows, usually called 'passing flows' that must be released from storages are provided at a particular point of a river;
- unregulated flows; and
- specific environmental entitlements which set aside a volume of water in storage that can be called out of storage when needed and delivered to wetlands or streams to protect their environmental values and health.

Environmental water for the target area may be sourced from the water entitlements and their agencies listed in the table below.

Table 11 - Summary of environmental water sources available to the Locks 6 - 10 target area (Victorian assets).

Water Entitlement*	Responsible Agency
Murray River Unregulated Flows (RMUF)	Murray Darling Basin Authority
Murray River Surplus Flows	
Victorian environmental water holdings	Victorian Environmental Water Holder
Commonwealth environmental water holdings	Commonwealth Environmental Water Holder
Donated Water	Victorian Environmental Water Holder

**Other sources of water may become available through water trading or changes in water entitlements.*

Mallee Regional Waterway Strategy

The Mallee Regional Waterway Strategy (Mallee CMA, 2014) prioritises the development of EWMPs for key sites within the Locks 6 - 10 target area.

Scoping Study: Environmental Water Management Plans

In July 2014, Sunraysia Environmental completed a report for Mallee CMA to identify priorities for the development of environmental water management plans. The scoping study identified a number of sites within the Lock 15 target area for EWMP preparation.

Investigation of water management options for the Murray River – Merbein to SA

In 2006, the Mallee CMA engaged consultants Ecological Associates to investigate water management options for the floodplain of the Murray River from Merbein to SA (Ecological Associates, 2006). This investigation prioritised options to increase the frequency and duration of floodplain inundation for each FMU. The investigation also looked at the scope of manipulating river levels to benefit ecosystems through operation of the Locks.

The Living Murray Program

Chowilla Floodplain and Lindsay-Wallpolla-Mulcra Islands are icon sites under the Living Murray Program, and fall within the influence of Locks 6 – 10.

Mallee CMA Frontage Action Plan for Merbein to SA

The Lock 15 target area is within the area covered by the Mallee CMA Frontage Action Plan (FAP) for Merbein to SA (Mallee CMA, 2003) and has the potential to attract future funding and works through that project.

Environmental Water Management Plans for Lake Hawthorn and Lake Ranfurly, Merbein Common and Johnstons and Chaffey Bend

Environmental water management plans for Lake Hawthorn and Lake Ranfurly, Merbein Common and Johnstons and Chaffey Bend have been developed and should be considered in conjunction with this EWMP.

Lock 8 - 9 Weir Manipulation Trials

A program to vary weir levels to meet ecological objectives has recently been implemented at Locks 8 and 9 by the New South Wales Office of Water.

Other

The EWMP covers sections of the Victorian floodplain of the Murray River which is the subject of investigation in many guises. These include salinity management plans, flow studies and Land Conservation Council reviews.

6 Hydrology and System Operations

6.1 Hydrology of the Murray River

Murray River flows originate in the largely temperate southern Murray-Darling basin, which includes the Murray, Murrumbidgee and Goulburn tributaries. These produce largely seasonal flows that are highest from late winter to early summer. The Darling River, which drains the northern basin, is often influenced by sub-tropical weather systems that generate large flows in summer. The largest flow events downstream of Lock 10 occur when both Darling and Murray systems are in flood.

River hydrology has been altered significantly by regulation and diversion upstream. Storages in Victoria and New South Wales are managed to capture water in winter and spring and to deliver this water at manageable flow rates to consumers (primarily irrigators) during the summer. The impact on river hydrology has been a reduction in large winter and spring flow peaks and enhancement of low summer flows. Locks and weirs have further altered floodplain water regimes by stabilising river levels.

The ecologically significant effects of these hydrological and hydraulic changes have been to:

- largely eliminate flowing water habitat under normal regulated flows;
- permanently inundate wetlands, the river channel and low-lying floodplain areas in the vicinity of the weir pools; and
- reduce the frequency and duration of floods that reach higher-level wetlands and floodplain areas.

The hydrology of the river upstream of Lock 9 has been characterised by analysing the MSM_Bigmod daily flow series for Natural and Current (Benchmark) scenarios, using data from 1891 to 2009 (Figure 11).

The river now spends more time fluctuating at very low flows, less than 10,000 ML/d, than under natural conditions as indicated by higher than natural spell frequency but much shorter spell duration. Events that inundate low-lying wetlands, between 30,000 and 60,000 ML/d, now occur at less than half the frequency of natural conditions. The duration of these events, when they do occur, has also been reduced by approximately 50%. The impact on floodplain inundation is also significant. While the duration of spells exceeding 70,000 ML/d under current conditions is similar to natural, the frequency of these events has declined to as much as 25% of natural. This has resulted in a major increase in the interval between spells for very high flows.

The spell timing (represented by start day) was shifted forward by around one month for spells with threshold lower than 80,000 ML/d.

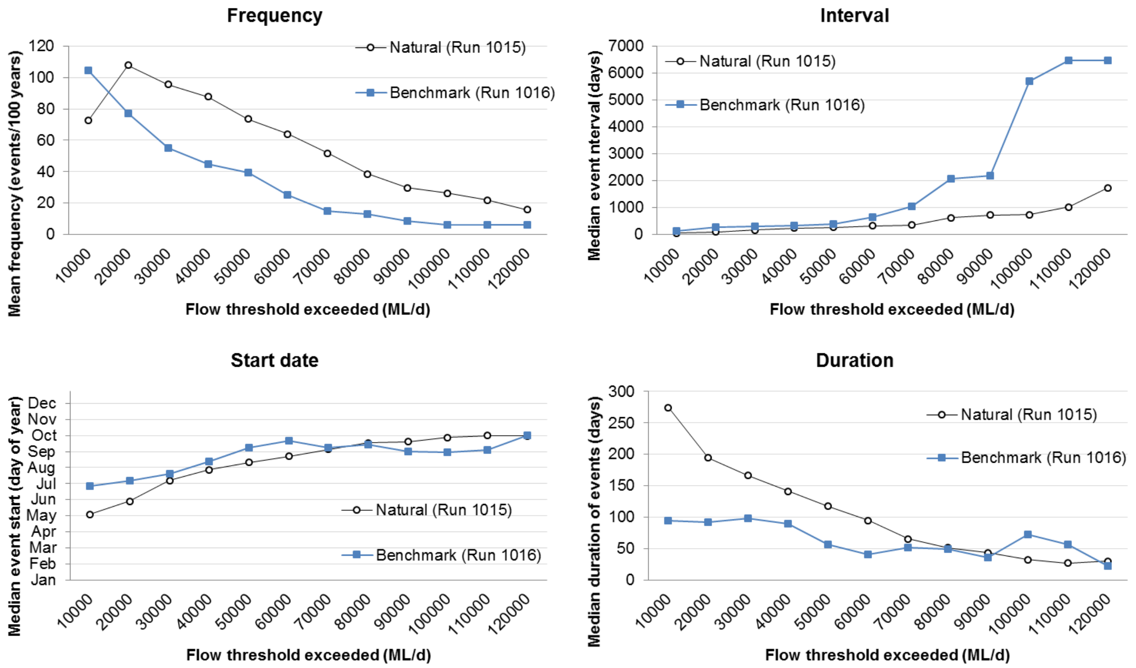


Figure 11. Spells analysis for Murray River flows upstream of Lock 9 for natural and Benchmark scenarios over a 114 year modelled period (Fluvial Systems 2014)

6.2 Hydrogeology

The study area lies at the centre of the Murray Geological Basin, which is a shallow sedimentary basin with a sequence of sediments of Tertiary to Recent age. The three main sedimentary sequences underlying the project area are the Renmark Group, the Murray Group Limestone and the Parilla Sands. Geological units outcropping in the surrounding landscape include:

- the Parilla Sands which broad parallel dunes underlying the more recent landscape
- the Blanchetown Clay and
- aeolian dune deposits of the Woorinen Sands formation.

The hydrogeology of the study area is largely related to the regional Parilla Sand Aquifer. The aquifer is a closed system where regional groundwater flows to the central-west of the basin (Figure 12). Groundwater in sediment profiles can only be released through seepage into the river system or evaporation where water tables reach the ground surface (Evans 2012). Discharge to the river contributes to river salinity while evaporation from the water table contributes to soil salinisation.

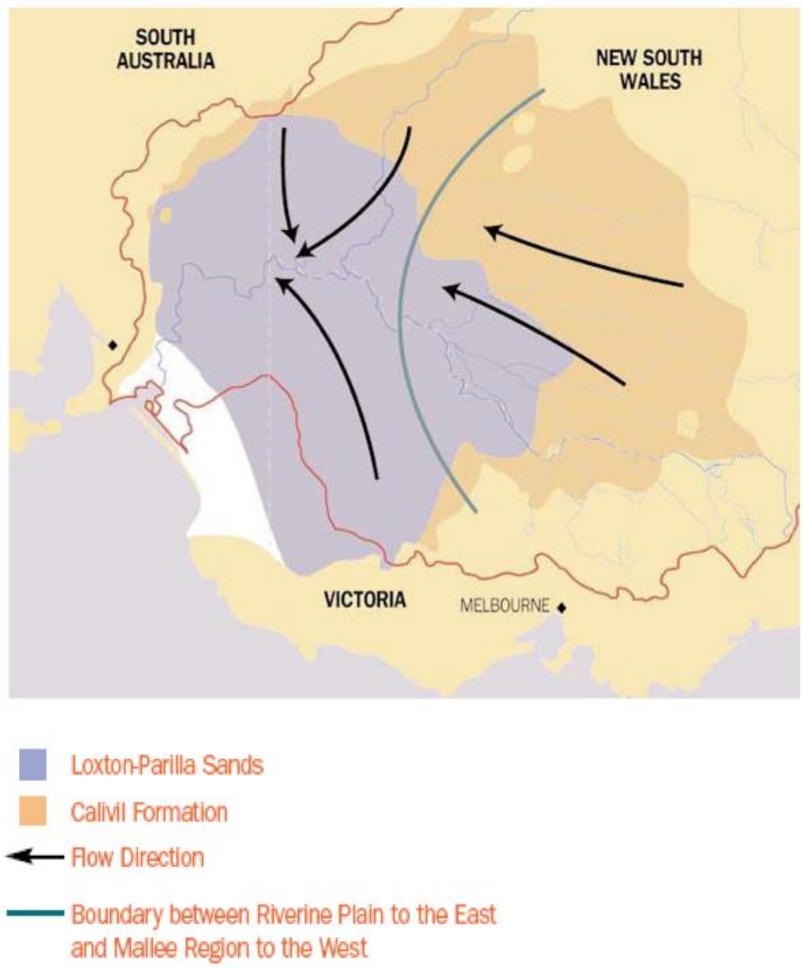


Figure 12. Flow directions in the Parilla Sand aquifer (MDBC 1999 Murray Darling Basin Groundwater - a resource for the future).

Naturally high groundwater salinities have resulted in saline floodplain soils and areas of shallow saline groundwater on the floodplain. In the natural system, salt that accumulated in floodplain soils in dry periods was leached or flushed by flooding, creating a long- term, quasi-stable equilibrium that supported a productive floodplain ecosystem. This equilibrium has been disrupted by four factors.

- There has been a decline in the floodplain inundation events that replenish fresh soil water reserves and export salt from wetlands and backwaters.
- The weirs have raised floodplain groundwater levels, promoting the accumulation of salt in the soil through evaporative concentration and reducing the potential for groundwater to discharge to the river channel.
- Augmented recharge in irrigation developments and at Lake Victoria have created local groundwater mounds that accelerate the flow of saline groundwater toward the river.
- The storage of saline irrigation drainage water in floodplain disposal basins has resulted in severe local salinisation. However improvements in irrigation practices over the past 20 years have reduced irrigation drainage and the impacts of its disposal.

Consequently floodplain areas are subject to more severe salinisation than under natural conditions.

In the study area floodplain salinisation is most severe where land management in the adjacent landscape has raised groundwater levels. Irrigation developments upstream of Lock 10, in New South Wales and Victoria have created groundwater mounds that promote the flow of groundwater to the floodplain (Figure 13). A groundwater mound associated with Lake Victoria promotes shallow groundwater and salinisation between the lake and Murray River. Elsewhere floodplain salinisation is a threat, but it is not so severe.

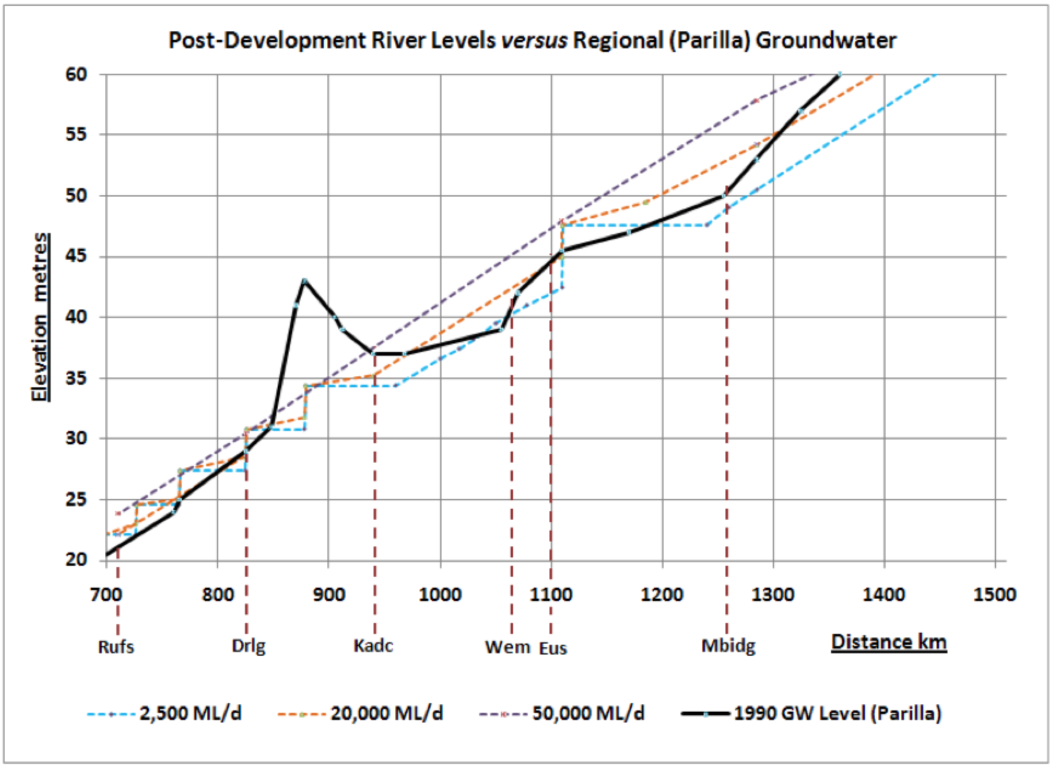


Figure 13. Murray River level at three river flows compared with the 1990 regional groundwater level in the Parilla Sand. Distance is from the river mouth (river km). Locations are Rufus River, Darling River, Karadoc, Wemen, Euston, Murrumbidgee River (From Evans 2012).

Figure 14. Salt affected land near Frenchmans Creek (photo credit Ben Dyer 2011)

Salt interception schemes (SIS) have been developed to reduce the discharge of saline groundwater to the Murray River. However the schemes do not necessarily reduce the level or salinity of groundwater in the floodplain. Three salt interception schemes are relevant to the study area (Telfer, Burnell and Charles 2012).

The Rufus River SIS is located near Lake Victoria and is operated by SA Water. The hydraulic loading from water stored in Lake Victoria forces saline groundwater within the Parilla Sands to flow into floodplain sediments before discharging into Rufus River. This scheme consists of 178 groundwater interception wellpoints located along both sides of Rufus River, extending from the Lake Victoria outlet to the Murray River. Groundwater from these wellpoints is pumped into Brilka Creek and Meander Loop. A pumping station at Meander Loop then diverts saline groundwater into an evaporation basin located approximately four km northeast of the wellfield (Kumar and Alamgir 2013).

The Curlwaa SIS is located in the Curlwaa Irrigation District to the west of Wentworth between the Murray River and Tuckers Creek. Long term irrigation in the Curlwaa irrigation area has led to the establishment of a groundwater mound causing saline discharge to the river through the shallow alluvial aquifer. The pumped water is discharged into open drains and then into an evaporative basin.

The Mildura-Merbein SIS consists of eighteen production bores on the southern side of the Murray River, mostly alongside the upper Lock 10 weir pool (Telfer et al. 2012). The SIS intercepts groundwater discharge to the Murray River driven by local groundwater mounds associated with irrigation drainage. Groundwater is disposed to Lake Ranfurly East and West basins and the Wargan Disposal Basin.

6.3 Hydraulic Effects of the Weirs

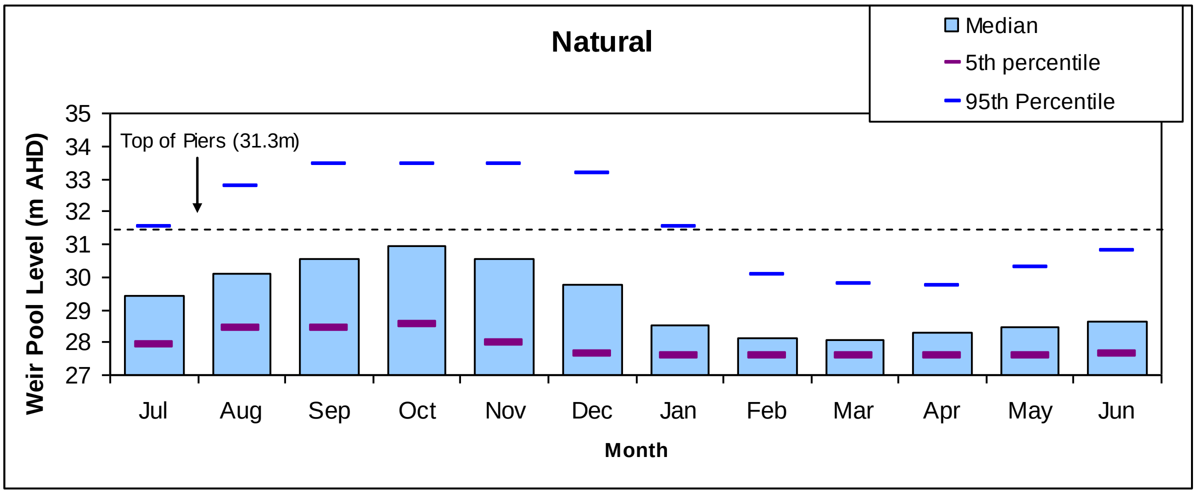
6.3.1 Water Level Variability

The weirs are currently managed to create a stable level upstream, close to the capacity of the river channel. The weirs are opened and closed as flow varies, so a stable river level can be maintained. The weirs are effective until discharge at the weir exceeds the capacity of the structure. At this point the river levels below and above the weir equalise. If the weir cannot be opened any further, it is removed and rising discharge results in rising river levels.

The influence of the weirs is strongest in the river immediately upstream. Water spilling over the next weir upstream creates a tailwater zone, where variation in river discharge results in variable river levels. The tailwater zone becomes longer as discharge increases, which corresponds to a shrinking of the weir pool.

Variation in river levels has been greatly reduced by the operation of the weirs and the depletion of flows through storage and diversion. An analysis of natural and current weir levels at Lock 10 is provided in Figure 15 with results for the remaining weirs provided in Appendix A.

Under natural conditions the river levels exhibited a strong seasonal cycle in water levels with the median autumn level two to three metres lower than the median level in spring. The river levels showed high interannual variability with range between the 5th and 95th percentile in spring ranging over 1.5 to 5 m, depending on the site. A smaller variability in flows is exhibited at sites where floodplains convey a substantial proportion of high flows (Lock 6, Lock 7 and Lock 8). Variability is greater at Lock 9 and 10 where the floodplain is relatively narrow and high flows are conveyed in the main river channel.



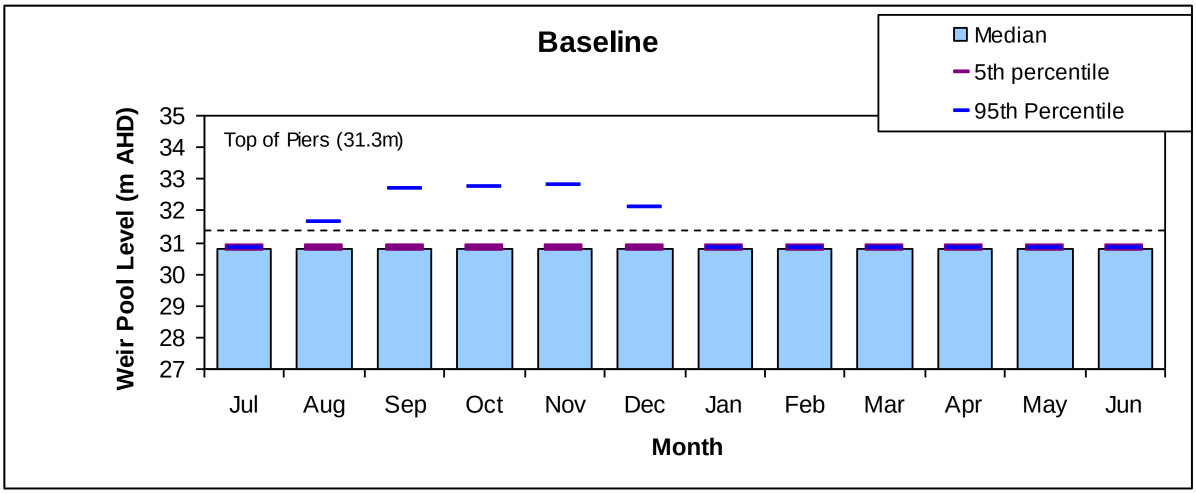


Figure 15. Distribution of monthly water levels downstream of Lock 10 under Natural and Baseline scenarios. Natural (Pre-weir and pre-regulation) water levels have been modelled using data that relates river level and discharge. Analyses for the other weirs is presented in Appendix A.

Under current development and operating practices the weirs have raised the river to a level similar to the median annual peak, i.e. the spring seasonal level. Variation in river levels has been largely eliminated from the low-flow seasons of summer and autumn. In winter and spring median river levels are maintained close to the target pool level, but rare, high flows continue to provide elevated water levels.

In contrast to the other sites, the Lock 6 high levels in spring do not occur for the 95th percentile. Reasons for the differing Lock 6 monthly natural water level pattern are unclear, however it may due to the influence of Lake Victoria and the be assumed operation of the lake under natural conditions in the river system modelling used to support the analysis.

6.3.2 Velocity

Prior to the construction of the weirs, fast- and slow-flowing habitat was present throughout the lower Murray River. Water velocity was elevated in areas where the channel bed was shallow or confined. Velocity was lower where the channel was deep and broad.

The weirs have largely eliminated fast-flowing habitat and converted the lower Murray River into a series of lakes. Weirs confine head loss to the short step in river level immediately below the weir and create a relatively flat river surface elsewhere. Weirs increase the cross-sectional area of the channel and reduced water velocities to ecologically insignificant levels. Anabranches provide moderately elevated velocities by spreading the weir head loss over a longer channel length; these conditions are provided around Lock 6 in the Chowilla floodplain, around Lock 7 in the Lindsay floodplain and around Lock 8 in the Mulcra floodplain. Significant velocities now only occur in the river channel at high river discharges.

Fast-flowing water is an important habitat requirement for native fish and is associated with the diversity, abundance and recruitment success of native fish populations in Chowilla Creek and Mullaroo Creek.

An analysis of the river channel between Lock 6 and 7 illustrates the effect of weir construction on velocity in the study reach (Mallen-Cooper, Zampatti, et al. 2011). This study classified channel velocities according to their ecological significance (Table 12) and modelled natural river hydraulics at a range of flows (Figure 16).

Table 12. Fish habitat velocity classification (Mallen-Cooper, Zampatti, et al. 2011)

Water Velocity m/s	Fish habitat
0-0.03	Backwaters
0.04-0.1	Weir pools in the main river channel
0.11-0.17	Slow-flowing
0.08-0.30	Moderate-flowing
0.31-0.50	Fast-flowing
>0.50	Very fast

A velocity greater than 0.17 m/s is the minimum required for species dependent on flowing habitat. Watercourses with velocities greater than 0.3 m/s provide the habitat for large-bodies fish but particularly for spawning Murray Cod (*Maccullochella peelii*) in spring. Murray Cod and other large-bodies fish select these fast-flowing habitats.

Prior to the construction of the weirs, a discharge of more than 5,000 ML/d provided fast water velocities (greater than 0.3 m/s) in 70% of the reach. With the weirs in place a discharge of 5,000 ML/d generates fast flowing habitat in only 5% of the reach. The extent of fast flowing habitat increases as river discharge rises, but only becomes similar to natural conditions at a discharge exceeding 40,000 ML/d.

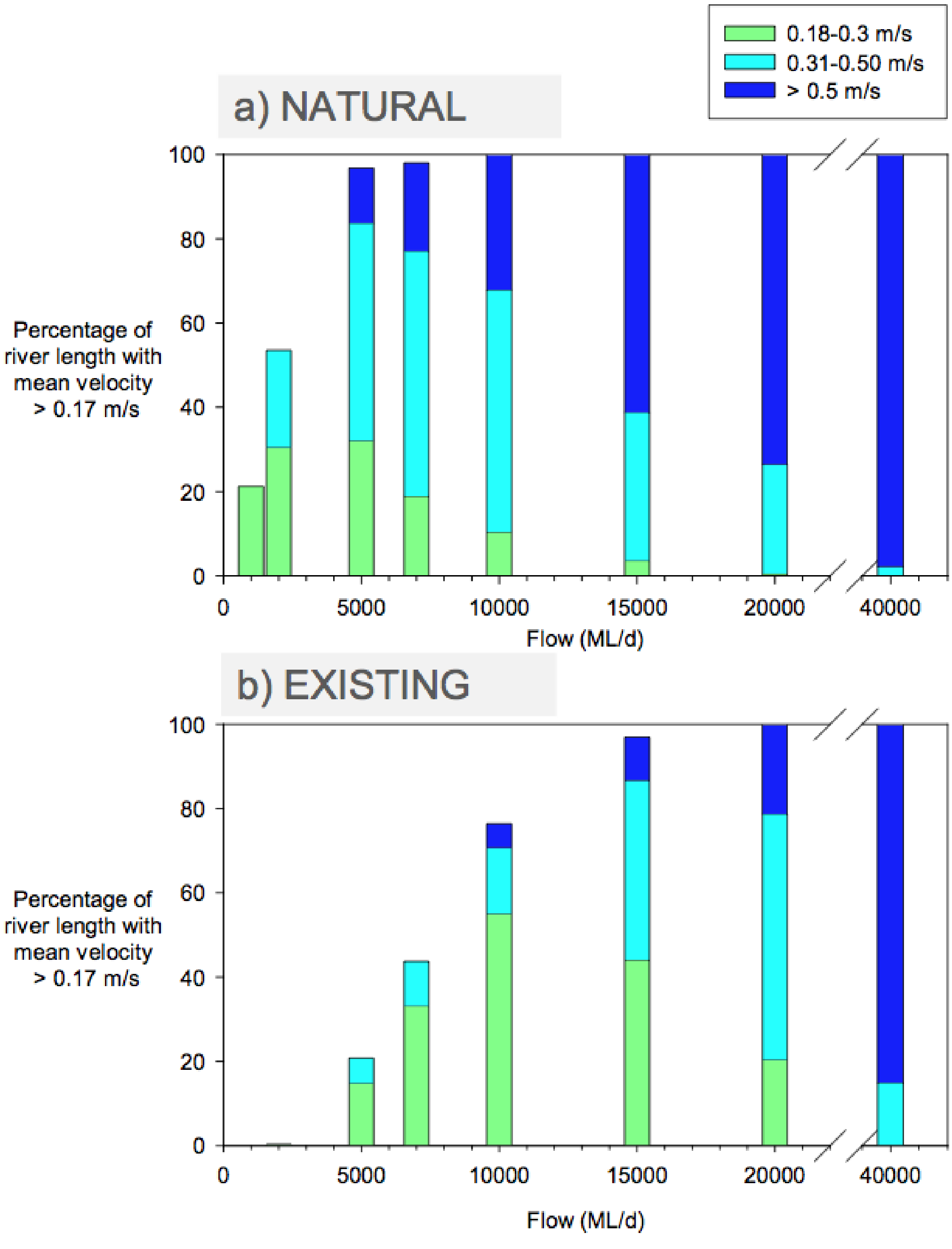


Figure 16. Length of the Murray River (Lock 5 to Lock 7) with moderate (0.17 to 0.3 m/s), fast (0.31-0.5 m/s) and very fast (>0.5 m/s) mean water velocity under natural conditions (a) and with the weirs in place (b)

6.3.3 Weir Re-instatement

Weir structures are removed during high flows then re-instated when river levels fall.

Weir re-instatement is timed to restore the weir pool while flood water is present in the river and levels are still above normal operating level. This ensures that the weir pools can be restored quickly and with unregulated flood water. If weirs were re-instated after the river fell below the normal operating level, the weir pools could not be restored until water flowing down the river re-filled the weir storage. This could involve the use of relatively costly regulated water and would involve an undesirable period of low water levels. Capturing water in the weir pool would also reduce flow downstream of the weir which would reduce the supply of water downstream and delay the re-filling of other weirs.

To prevent downstream weirs being starved of water by the re-instatement of upstream weirs, the re-instatement of all weirs is synchronised. This results in a widespread, accelerated reduction in river level, effectively curtailing the natural tail of the flood peak.

The effect of weir reinstatement on downstream water levels is illustrated by Figure 17.

Figure 17 shows upstream and downstream water levels and rates of change at Lock 8 at the tail of a flood peak in September 1995. Initially, the upstream and downstream water levels are similar and about 1.4 m above the normal pool level of 24.6 m AHD. The weir is reinstated when the river level is about 0.4 above the normal pool level. This reduces the supply of water downstream which, in combination with declining river discharge, results in tailwater levels falling by 3 m over the following six days. In contrast the upstream level fell by only 0.4 m.

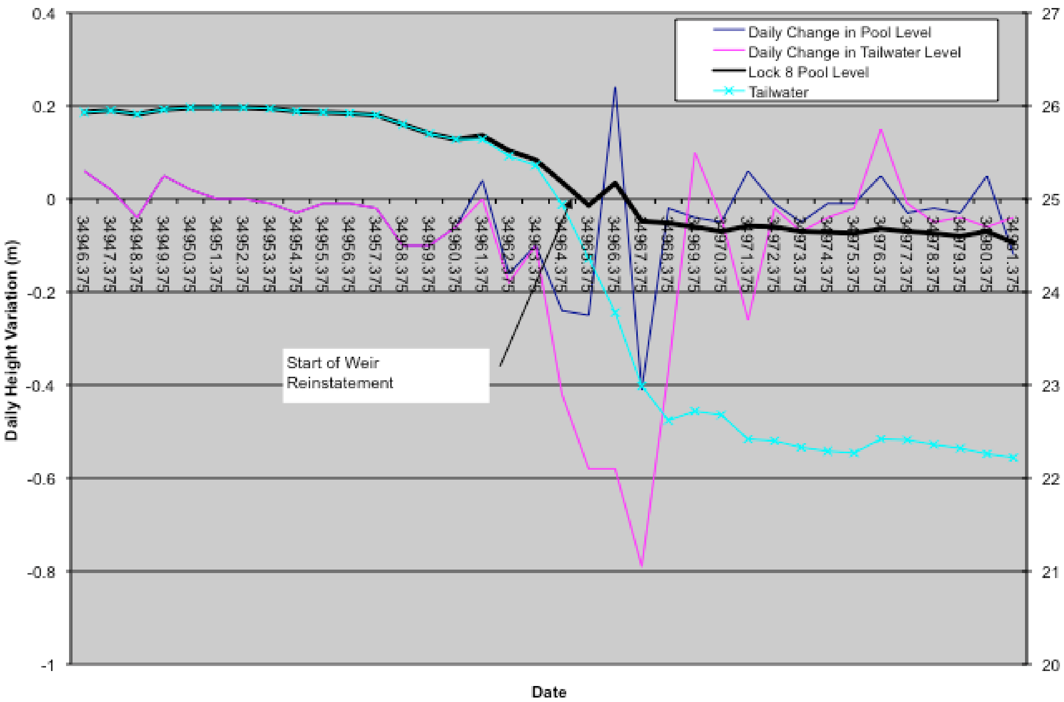


Figure 17. Lock 8 water level dynamics during weir reinstatement at the tail of a flood peak in September 1995 showing upstream and downstream water levels and rates of water level change.

Rapid rates of fall in tailwater levels was identified as a threat to bank stability (Thoms and Walker 1992). Rapidly falling water levels also have the potential to strand fish in isolated floodplain water bodies, with potentially significant impacts to fish recruitment success and adult survival. There is no data and little anecdotal evidence to verify the significance of this threat. However, the importance of exit cues for fish and carefully managed drawdown rates are recognised in managed floodplain inundation projects such as Koondrook Perricoota, Mulcra and Chowilla. Further investigation of this issue is required.

The time required to reinstate weirs, and therefore the impacts on downstream water levels, has decreased considerably in recent years due to advancements in the navigable pass configuration. Reinstalment times have been reduced from four days to times now in the order of half a day. The decrease in reinstatement time reduces the likelihood that pool levels will fall below normal levels during reinstatement and allows a more flexible re-instatement approach.

The reinstatement of Lock 8 under current arrangements is illustrated for a 2011 flood event in May 2011. The tailwater level initially tracks closely to the upstream level after reinstatement commences and only diverges after the normal pool level has been restored. The rate of change in the downstream level increases only slightly after weir reinstatement, falling by 1 m over 7 days.

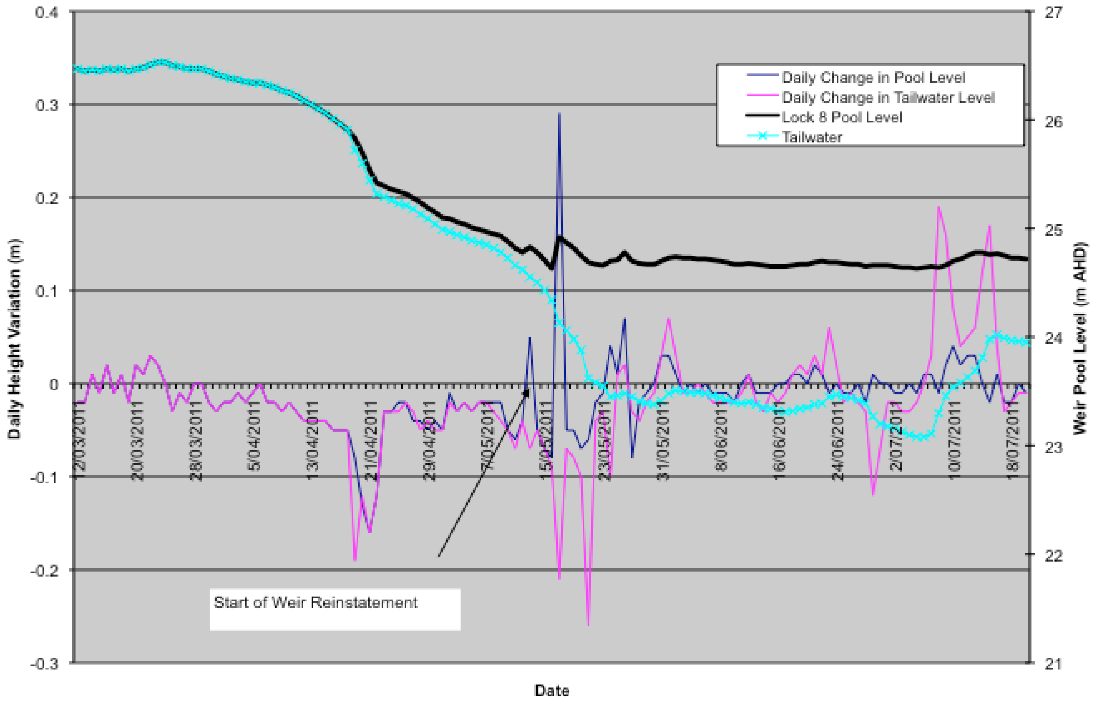


Figure 18. Lock 8 water level dynamics during weir reinstatement at the tail of a flood peak in May 1995 showing upstream and downstream water levels and rates of water level change.

This comparison is not a conclusive analysis of the operation of the weirs under current arrangements because the results are influenced by the shape of the underlying floods that the weir operators were managing. However the data support advice from the weir operators that the new arrangements allow weirs to be reinstated with less impact on the rate of change in downstream water levels.

Nevertheless, the potential ecological impacts of weir reinstatement should be recognised. Rates of fall in tailwater levels should be a consideration in weir operating guidelines.

6.4 Environmental Watering

6.4.1 Regulated wetlands

Regulators have been constructed at the entrance of several wetlands in the study area. The main purpose of the regulators is to increase wetland flooding frequency and duration. Water may be introduced to the wetlands by natural floods, by raising weirs or by pumping. The regulator at Websters Lagoon on Lindsay Island is also operated to exclude water. This wetland is located downstream of Lock 7 and the combined effects of the Lock 6 weir pool and the Lock 7 tail water frequently result in excessive, unseasonal flooding.

Table 13. Wetlands regulated to achieve environmental objectives

Wetland	Location	Operation				
		Pumping	Weir Pool Connection	Weir Raising	Capture Flood Peak	Managed Floodplain Inundation
Cowanna Billabong and The Brickworks	Lock 10 weir pool, left bank	Y	Y	N*	Y	N
Thegoa Lagoon	Adjacent to Lock 10, right bank	Y	Y	N*	Y	N
Horseshoe Lagoon	Wallpolla Island, connected to Finnigans Creek	Y	N	N	Y	Y**
Lock 8 Wetland	Upstream of Lock 8, right bank	Y	Y	Y	Y	Y
Mulcra Horseshoe	Mulcra Island, below Lock 8	Y	N	N	Y	Y
Websters Lagoon	Lindsay Island below Lock 7	Y	Y	N	Y	Y**
Lake Wallawalla	Wallpolla Island, connected to Lindsay River	Y	N	N	Y	Y**
Werta Wert	Chowilla, connected to Monoman Creek	Y	N	N	Y	Y
Lake Limbra	Chowilla, connected to Hancock Creek	Y	N	N	Y	Y
Lake Littra	Chowilla, connected to Punkah Creek	Y	N	N	Y	Y
Pilby Wetland System	Chowilla, connected to Lock 6 weir pool	Y	Y	Y	Y	Y
Slaney Billabong	Chowilla, connected to Slaney Creek	Y	Y	Y	Y	Y

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Wetland	Location	Operation				
		Pumping	Weir Pool Connection	Weir Raising	Capture Flood Peak	Managed Floodplain Inundation
Pipeclay Billabong	Chowilla, connected to Pipeclay Creek	Y	Y	Y	Y	Y
Chowilla Island Loop Channel and Regulator	Chowilla, connected to Chowilla Creek	Y	N	N	Y	Y
Woolshed Creek	Chowilla, connected to Chowilla Creek	Y	N	N	Y	Y

** Lock 10 weir pool may not be raised significantly under current constraints.*

*** Under proposed Sustainable Diversion Limit Supply Measure project*

6.4.2 Mulcra Island

The Mulcra Island Environmental Flows Project is a TLM project developed to enhance the ecological health of Mulcra Island (MDBA 2011). The project involves diverting water from the Lock 8 weir pool through watercourses on the island and inundating the floodplain through manipulation of Lock 8 levels.

Lock 8 is located near the mid-point of the Mulcra Island and allows water to be diverted through the island to provide flow in watercourses and to inundate the floodplain.

The key environments affected by the Mulcra Island project are

- Potterwalkagee Creek and Upper Potterwalkagee Creek
- Lock 8 Wetland
- Mulcra Island Horseshoe Wetland
- the Mulcra Island Floodplain

The project is operated under four main water management scenarios.

The Base Flow Scenario maintains a flowing environment in Potterwalkagee Creek, which diverges from the Murray River at Stoney Crossing above Lock 8 and rejoins the river below the weir. Flow can be varied in the creek by means of a regulator or by raising the weir pool.

The Spring Fresh Scenario provides faster flow in Potterwalkagee Creek and activates flow in an upstream floodplain effluent, Upper Potterwalkagee Creek. Lock 8 is raised to between +0.2 to +0.6 m above normal operating level to generate flows of up to 280 ML/d at Stoney Crossing into Potterwalkagee Creek and 150 ML/d into Upper Potterwalkagee Creek. The Spring Fresh Scenario is ideally operated on an annual basis in the winter and spring period. The weir is typically raised over 10 days, held at the higher level for 21 to 28 days and lowered over 10 days. The Spring Fresh Scenario affects water levels throughout the Lock 8 weir pool and contributes to the watering requirements of the Lock 8 Wetland (Wangumma) in NSW.

The Partial Drying Scenario is designed to temporarily prevent flow into Potterwalkagee Creek to control environmental threats such as carp or the growth of cumbungi. It is implemented by closing regulators at Stoney Crossing and on Upper Potterwalkagee Creek while the Lock 8 weir pool is operated at normal levels. This scenario is expected to be implemented less than 1 year in 10.

The Floodplain Inundation Scenario uses water diverted from the Lock 8 weir pool to create widespread inundation on Mulcra Island. Floodplain inundation is achieved by blocking flow in Potterwalkagee Creek while raising the Lock 8 weir pool. The Lower Potterwalkagee Regulator is raised to a level matching the Lock 8 weir pool up to a maximum of 25.6 m AHD, which is 1.0 m above the normal weir operating level. At this level floodplain inundation increases throughout the Lock 8 weir pool resulting in flooding of 532 ha in Victoria (including Mulcra Island) and 290 ha in New South Wales. Water levels are raised over a period of approximately 40 days. The structures are operated at the maximum level for at least 7 days but ideally 28 days and then lowered again. The total duration of events is approximately four months.

6.4.3 Lindsay River and Mullaroo Creek Regulators

Inflows to the Lindsay River and Mullaroo Creek anabranches are controlled by regulators recently constructed under TLM.

Mullaroo Creek diverts water from the Lock 7 weir pool to create fast-flowing habitat over approximately 4 km through the Lindsay Island floodplain. The regulator provides safe downstream passage with a vertical slot fishway for safe upstream fish passage. The regulator can be operated to maintain fast-flowing habitat at a range of Lock 7 levels or river flows.

Flow in Lindsay River is supplied by two effluents from the Lock 7 weir pool. The lower, Lindsay River North provides to Lindsay River at normal weir levels. The higher Lindsay River South effluent is active at elevated river levels. The regulators control flow rates in conjunction with Lock 7 operations.

6.4.4 Chowilla Floodplain Inundation Project

The TLM Chowilla environmental watering project has the goal of promoting floodplain inundation while preserving the fast-flowing anabranch habitat (DEWNR 2014). The project enables water levels to be raised across the floodplain and anabranch flows to be regulated.

The primary water level and flow control structures are Lock 6 and the Chowilla Regulator. Located on Chowilla Creek near the confluence with the Murray River, the Chowilla Regulator can be operated in conjunction with the Lock 6 weir to raise water levels upstream. The purpose of these events can be to raise water levels within anabranch channels or to produce an overbank flow. The maximum level of the Chowilla Regulator is 19.8 m AHD and the maximum level of the Lock 6 weir is 19.87 m AHD (DEWNR 2014).

Raising the Lock 6 weir to a higher level at the same time as raising the Chowilla Regulator maintains a head difference between the river channel and floodplain anabranches and preserves fast-flowing habitat (DEWNR 2014).

The two major flow paths into the Chowilla anabranch system are Pipeclay and Slaney Creeks. The flow into these creeks is controlled by weirs at the upstream end of each creek. The weirs are used to vary flow in the creeks on a seasonal basis. In addition, these structures are used to support major inundation events. By controlling flow from the Lock 6 weir pool to the anabranch system, the structures maintain target water velocities in fast-flowing floodplain habitat when the Chowilla Weir and Lock 7 weir are raised.

Additional in-stream structures are used in operations:

- Woolshed Creek is an ephemeral creek connecting Chowilla Creek upstream of the Chowilla Regulator and the Murray River downstream of Lock 7. The creek is regulated to maintain the Chowilla weir pool and to control inundation of the creek. Regulators at each end - Woolshed Creek South and Woolshed Creek East - control flow into the wetland and can detain water introduced by pumping, natural events or the Chowilla Regulator when water levels exceed 18.7 m AHD.
- Chowilla Island Loop is a wetland to the east of Chowilla Creek upstream of the Chowilla Regulator. The Chowilla Island Loop Channel and Regulator regulates flooding of the wetland, which commences when Chowilla Regulator levels exceed 18.0 m AHD. The regulator can also detain water introduced by pumping or natural events.

Regulators have been constructed at additional locations to control the inundation of individual wetland systems.

- Werta Wert wetland is a 37 ha terminal wetland that begins to fill via a small flood runner from Monoman Creek at flows greater than 52,000 ML/d. A regulating structure near Yarraman Yards allows inflow and outflow to be managed at levels over 18.08 m AHD.
- Lake Limbra is a 168 ha terminal wetland on the outer floodplain that begins to fill at flows exceeding 45,000 ML/d. A bank and box culvert on Hancock Creek regulates inflows at levels above 17.6 m AHD.
- Lake Littra is a 60 ha terminal lake on the outer floodplain. The lake begins to fill at levels exceeding 19.01 mm AHD or flows of about 47,000 ML/d.
- Thy Pilby Wetland System consists of three wetlands, Pilby Lagoon, Pilby Creek and Lock 6 Depression. Water management in the system is complex and guided by the Pilby Lagoon Wetland Management Plan (Suitor and Scott 2012). The structures allow the complex to be managed in conjunction with, or independently of, regulator and / or Lock 6 operations. Four inlet structures allow the filling of the three wetlands at normal Lock 6 pool level. The Pilby Creek outlet structure retains water in Pilby Creek and allows Pilby Creek and Pilby Lagoon to be drained into Chowilla Creek. Water can be retained in only Pilby Lagoon by closing the Pilby Lagoon outlet / Pilby Creek inlet structure allowing independent management of the two wetlands. If Lock 6 is raised during a regulator operation then a greater area of inundation will be achieved and lead to greater hydrological variation at these wetland sites. The Lock 6 Depression wetland structure allows Lock 6 Depression to be filled at Lock 6 pool level, hence hydrological management of this site is possible without operating the Chowilla environmental regulator. However filling during a regulator operation or when Lock 6 is raised will contribute to hydraulic diversity at this site by allowing inundation at different levels.
- A regulator on Slaney Billabong controls flows to the wetland at Lock 6 pool level and independently of the Chowilla Regulator.
- Pipeclay Billabong is filled via a number of flow paths at river levels exceeding 50,000 ML/d. A regulator allows the wetland to be filled at Lock 6 pool level and independently of the Chowilla Regulator.

The Chowilla project can be operated under a wide range of scenarios to meet different ecological objectives under a range of hydrological conditions. The principal management actions are:

- delivery of water to individual wetlands by pumping or gravity
- weir pool manipulation
- pulse flows via Pipeclay and Slaney weirs
- in-channel rise
- managed inundations
- manage hydrograph recession.

8 Water Dependent Values

This section identifies important conservation values of the area based on a search of database records and recent surveys of Lindsay and Wallpolla Islands. This summary is representative of the entire region, but does not comprehensively review flora and fauna records and their conservation status in all three states.

8.1 Listed Flora

The study area has a diverse flora and supports numerous plant species of conservation significance. A recent vegetation survey (Australian Ecosystems 2013) reported 228 indigenous plant species of which 44 are floodplain species that are rare or threatened under the Victorian Advisory List of Threatened Plants. One species, Striate Spike-sedge (*Eleocharis abicis)*, is vulnerable in Victoria and listed vulnerable under the *Commonwealth EPBC Act 1999*.

The survey confirmed the presence of most species that had been reported from databases and previous surveys (Table 14).

Table 14. Plant species of conservation significance reported from Lindsay Island (Australian Ecosystems 2013)

Scientific Name	Common Name	Conservation Status			2013 Survey	Databases
		EPBC	FFG	VROTS		
Asperula gemella	Twin-leaf Bedstraw			R	x	x
Atriplex holocarpa	Pop Saltbush		L	V	x	x
Atriplex limbata	Spreading Saltbush		L	V	x	x
Atriplex lindleyi subsp. conduplicata	Baldoo			R	x	x
Atriplex nummularia subsp. omissa	Dwarf Old-man Saltbush			R	x	x
Atriplex pseudocampanulata	Mealy Saltbush			R	x	x
Atriplex rhagodioides	Silver Saltbush		L	V	x	x
Bergia trimera	Small Water-fire			V	x	x
Calotis cuneifolia	Blue Burr-daisy			R	x	x
Centipeda crateriformis subsp. compacta	Compact Sneezeweed			R	x	x

Scientific Name	Common Name	Conservation Status			2013 Survey	Databases
		EPBC	FFG	VROTS		
Centipeda thespidioides s.l.	Desert Sneezeweed			R	x	x
Craspedia haplorrhiza	Plains Billy-buttons			K	x	x
Crinum flaccidum	Darling Lily		L	V	x	x
Cynodon dactylon var. pulchellus	Native Couch			K	x	x
Eleocharis obicis	Striate Spike-sedge	V		V	x	x
Eragrostis lacunaria	Purple Love-grass			V	x	x
Eremophila bignoniiflora	Bignonia Emu-bush		L	V	x	x
Eremophila divaricata subsp. divaricata	Spreading Emu-bush			R	x	x
Frankenia serpyllifolia	Bristly Sea-heath			R	x	x
Glossostigma drummondii	Desert Mud-mat			K	x	x
Haloragis glauca f. glauca	Bluish Raspwort			K	x	x
Lawrencia spicata	Salt Lawrencia			R	x	x
Lepidium fasciculatum	Bundled Peppercress			K	x	x
Lepidium papillosum	Warty Peppercress			K	x	x
Lepidium pseudohyssopifolium	Native Peppercress			K	x	x
Malacocera tricornis	Goat Head			R	x	x
Mimulus prostratus	Small Monkey-flower			R	x	x
Picris squarrosa	Squat Picris			R	x	x
Rumex crystallinus s.s.	Glistening Dock			V	x	x
Sclerolaena decurrens	Green Copperburr			V	x	x

Scientific Name	Common Name	Conservation Status			2013 Survey	Databases
		EPBC	FFG	VROTS		
Sclerolaena divaricata	Tangled Copperburr			K	x	x
Sclerolaena muricata var. muricata	Black Roly-poly			K	x	x
Senecio cunninghamii var. cunninghamii	Branching Groundsel			R	x	x
Solanum lacunarium	Lagoon Nightshade			V	x	x
Stellaria sp. 2	Rangeland Starwort			K	x	x
Swainsona greyana	Hairy Darling-pea		L	E	x	x
Swainsona microphylla	Small-leaf Swainson-pea			R	x	
Swainsona phacoides	Dwarf Swainson-pea		L	E	x	x
Tecticornia triandra	Desert Glasswort			R	x	x
Tetragonia moorei	Annual Spinach			K	x	
Wahlenbergia tumidifructa	Mallee Annual-bluebell			R	x	
Tecticornia tenuis	Slender Glasswort			R		x
Tetragonia eremaea s.l.	Desert Spinach			K		x
Zygophyllum ammophilum	Sand Twin-leaf			R		x

8.3 Fauna

8.3.1 Fish

Twelve native fish species are encountered regularly in the study area (Table 15).

Small fish species that inhabit localised riparian and wetland habitats include Flat-headed Galaxias (*Galaxias rostratus*), Southern Pygmy Perch (*Nannoperca australis*) and Hardyhead species. Large-bodied fish that specialise in deeper channel habitat include Murray Cod, Golden Perch (*Macquaria ambigua*) and Silver Perch (*Biyanus bidyanus*). Freshwater Catfish (*Tandanus tandanus*) spend time in deep channel habitat but use wetlands to breed.

Fast-flowing habitat in Mullaroo Creek and Chowilla Creek support the only two self-sustaining populations of Murray Cod in the lower Murray River (Mallen-Cooper, Koehn, et al. 2008; Saddlier, O'Mahony and Ramsey 2008). The high quality of fish habitat in these creeks also contributes to healthy populations of Golden Perch, Australian Smelt (*Retropinna semoni*) and Freshwater Catfish.

Table 15. Native fish fauna of the study area (Lloyd 2012)

Scientific Name	Common Name	Conservation Status		
		EPBC	FFG	VROTS
Retropinna semoni	Australian Smelt			
Galaxias rostratus	Flat-headed Galaxias			DD
Nannoperca australis	Southern Pygmy Perch			
Craterocephalus stercusmuscarum fulvus	Unspecked Hardyhead			DD
Melanotaenia fluviatilis	Murray-darling Rainbowfish		L	
Philypnodon grandiceps	Flat-headed Gudgeon			
Hypseleotris spp.	Carp Gudgeon			
Nematalosa erebi	Bony Herring			
Tandanus tandanus	Freshwater Catfish			V
Macquaria ambigua	Golden Perch			V
Biyanus bidyanus	Silver Perch			CE
Maccullochella peelii	Murray Cod	V		V

8.3.2 Birds

The study area has a highly diverse bird fauna with 196 bird species reported from the site, of which 35 have conservation significance at the state and national level and four are protected under international migratory bird agreements (Table 16). A recent bird survey in 2013 observed 93 species (GHD 2014).

Wetlands provide habitat for dabbling, diving and filter feeding ducks while small fish will provide prey for piscivorous waterbirds such as White-bellied Sea-eagle (*Haliaeetus leucogaster*). Large wading birds such as Egrets (*Ardea* spp.), Herons and Spoonbills will prey on macroinvertebrates, frogs and small fish and will make use of large woody debris and emergent macrophytes for cover.

Flooded woodland and Lignum shrubland provide nesting sites for waterbirds including waterfowl and colonial nesting species. Broad areas of shallow flooding in alluvial plains and wetlands provide feeding areas for waterbirds, including migratory species which visit Lindsay Island in summer and early autumn.

Flooding promotes plant productivity and will increase the food resources for bush birds that depend on fruit, seeds, nectar and insects. Understorey complexity will increase the availability of vertebrate prey species such as lizards and will provide sheltering and nesting sites for bush birds.

Table 16. Rare or endangered birds of conservation significance expected to occur in the study area (GHD 2014)

Scientific Name	Common Name	Conservation Status			Migratory Bird Agreements	
		EPBC	FFG	VROTS	Bonn	CAMBA JAMBA ROKAMBA
Anas rhynchotis	Australasian Shoveler			V		
Ardea intermedia	Intermediate Egret		L	E		
Ardea modesta	Eastern Great Egret		L	V		C J
Aythya australis	Hardhead			V		
Biziura lobata	Musk Duck			V		
Burhinus grallarius	Bush Stone-curlew		L	E		
Charadrius australis	Inland Dotterel			V		
Egretta garzetta nigripes	Little Egret		L	E		

Scientific Name	Common Name	Conservation Status			Migratory Bird Agreements	
		EPBC	FFG	VROTS	Bonn	CAMBA JAMBA ROKAMBA
Falco subniger	Black Falcon			V		
Gelochelidon nilotica macrotarsa	Gull-billed Tern		L	E		
Geopelia cuneata	Diamond Dove		L	NT		
Haliaeetus leucogaster	White-bellied Sea-Eagle		L	V		C
Hydroprogne caspia	Caspian Tern		L	NT		C J
Lophocroa leadbeateri	Major Mitchell's Cockatoo		L	V		
Lophoictinia isura	Square-tailed Kite		L	V		
Melanodryas cucullata cucullata	Hooded Robin		L	NT		
Ninox connivens connivens	Barking Owl		L	E		
Oreoica gutturalis gutturalis	Crested Bellbird		L	NT		
Oxyura australis	Blue-billed Duck		L	E		
Polytelis anthopeplus monarchoides	Regent Parrot	V	L	V		
Pomatostomus temporalis temporalis	Grey-crowned Babbler		L	E		
Ptilonorhynchus maculatus	Spotted Bowerbird		L	CE		
Pyrrholaemus brunneus	Redthroat		L	E		
Stictonetta naevosa	Freckled Duck		L	E		

Scientific Name	Common Name	Conservation Status			Migratory Bird Agreements	
		EPBC	FFG	VROTS	Bonn	CAMBA JAMBA ROKAMBA
Struthidea cinerea	Apostlebird		L			
Tringa nebularia	Common Greenshank			V	A2H	C J R
Turnix pyrrhothorax	Red-chested Button-quail		L	V		

8.3.3 Native mammals

The bat fauna of Lindsay Island is diverse with nine species observed at the site (Table 17). The bats are almost entirely insectivorous. Flooding maintains the high levels of canopy and understorey productivity required to provide insect prey while trees provide roosting habitat in bark, crevices and hollows.

Table 17. Native mammal species reported from Lindsay Island (GHD 2014)

Species	Scientific Name	Conservation Status			2013 Survey	Data-bases
		EPBC	FFG	VROTS		
Chalinolobus gouldii	Gould's Wattled Bat				x	x
Chalinolobus morio	Chocolate Wattled Bat				x	
Hydromys chrysogaster	Water Rat				x	x
Macropus fuliginosus	Western Grey Kangaroo				x	x
Macropus giganteus	Eastern Grey Kangaroo				x	x
Macropus rufus	Red Kangaroo				x	x
Mormopterus sp. 3	Inland Freetail Bat					x
Mormopterus sp. 4	Southern Freetail Bat					x
Nyctophilus geoffroyi	Lesser Long-eared Bat					x

Species	Scientific Name	Conservation Status			2013 Survey	Data-bases
		EPBC	FFG	VROTS		
Ornithorhynchus anatinus	Platypus					x
Planigale gilesi	Giles' Planigale		L	NT	x	x
Scotorepens balstoni	Inland Broad-nosed Bat				x	
Sminthopsis crassicaudata	Fat-tailed Dunnart			NT	x	x
Tachyglossus aculeatus	Short-beaked Echidna				x	x
Tadarida australis	White-striped Freetail Bat					x
Vespadelus regulus	Southern Forest Bat					x
Vespadelus vulturnus	Little Forest Bat					x

The open plains and grassland provide habitat for kangaroo species while watercourses and wetlands provide habitat for water rat and platypus. Understorey vegetation, including Lignum shrublands, is an important habitat component for Gile's Planigale (*Planigale gilesi*).

8.3.4 Reptiles and amphibians

Wetland, forest and woodlands provide habitat for a range of reptiles and frogs. Twenty eight reptiles have been reported from Lindsay Island including five species of conservation significance (Table 18). Six frog species occur at Lindsay Island, of which one, the Growling Grass Frog is vulnerable nationally and endangered in Victoria (GHD 2014).

Table 18. Reptiles and amphibians of conservation significance reported from Lindsay Island (GHD 2014)

Species	Scientific Name	Conservation Status			2013 Survey	Data-bases
		EPBC	FFG	VROTS		
Reptiles						
Furina diadema	Red-naped Snake		L	V		x
Chelodina expansa	Broad-shelled Turtle		L	E		x
Morelia spilota metcalfei	Carpet Python		L	E		x
Pseudonaja aspidorhyncha	Patch-nosed Brown Snake			NT		x
Varanus varius	Lace Monitor			E	x	x
Amphibians						
Litoria raniformis	Growling Grass Frog	V	L	E		x

10 Environmental Objectives and Hydrological Requirements

10.1 Management Goal

The overall objective of water management in the target area is:

"to protect and restore the key species, habitat components and functions of the ecosystem by providing the hydrological environments required by indigenous plant and animal species and communities".

10.2 Environmental Objectives

Environmental objectives represent the desired environmental outcomes of the site based on the management goal, above, as well as the key values outlined in the Water Dependent Values section. It is intended that EWMP objectives will be described in terms of the primary environmental outcomes, in most cases ecological attributes. The focus of the objectives should be on the final ecological outcomes and not the drivers *per se*.

During 2020, the environmental objectives (formally ecological objectives) undertook a refinement process with the intent of improving the specificity and measurability of the objectives through the development of targets, and to improve line of sight to the Basin Plan. While the process attempted to maintain the intent and integrity of the original objectives, it provided an opportunity to reassess the suitability of these objectives for the asset. The rationalisation, assessment of SMARTness, mapping to Basin Plan and update of each objective for Murray River from Lock 6-10 can be found in Section 5.15.1 of Butcher et al. (2020).

10.2.1 Alignment to Murray-Darling Basin Plan

The primary environmental outcome of the Basin Plan is the protection and restoration of water-dependent ecosystems and ecosystem functions in the Murray-Darling Basin, with strengthened resilience to a changing climate. The MDBA is required to measure progress towards achieving the objectives of the Environmental Watering Plan (EWP) (Chapter 8 of the Basin Plan) by using the targets in Schedule 7 and having regard to the long-term average sustainable diversion limits, ecological objectives and ecological targets. These are set out in Long-Term Watering Plan's (LTWP), the Basin-wide Environmental Watering Strategy (BWS) and annual Basin environmental watering priorities.

10.2.2 Mapping of Environmental objectives to high level planning documents

As well as alignment with Basin Plan, the objectives have alignment with Basin-wide environmental Watering Strategy objectives and State level Long-term Watering Plan objectives. Table 19 maps the current EWMP objectives against these objectives to provide a line of sight

Table 19 Mapping updated Murray River from Lock 6-10 EWMP objectives to Basin Plan Environmental Watering Plan (EWP) objectives, Basin Plan Schedule 7 targets, Basin wide Environmental Watering strategy (BWS) quantified environmental expected outcomes (QEEO) (MDBA 2019), and Long-term Watering Plan (LTWP) Victorian Murray objective (DELWP 2015).

EWMP objectives	Basin Plan EWP objective	Relevant Schedule 7 target	Relevant BWS QEEO	LTWP objective
MRB2a	8.05,3(b)	Condition of priority asset - prevention of decline in native biota	None specified	LTWPVM19 LTWPVM20

	8.05,3(a)	Condition of priority asset - Vital habitat - feeding, breeding, nursery		
MRB2b:	8.05,3(b)	Condition of priority asset - prevention of decline in native biota	4.5	LTWPMV15
MRB3	8.06,6(b)	Recruitment and populations of native water-dependent birds	B3.3	LTWPVM10 LTWPVM11
MRB4	8.05,3(b)	Condition of priority asset - Vital habitat - feeding, breeding, nursery	B3.1	LTWPVM12 LTWPVM13

10.2.3 Environmental objectives and targets

While every attempt has been made to make the following objectives and targets as complete as possible, there still remains gaps as critical information is not currently available. As such, baselines are not able to be set at this time. In the interests of moving forward, the objectives and targets have been written in a way (i.e. red highlighted text) that allows this information to be included at a later stage as this information becomes available.

Table 20 Updated ecological objectives for Murray River from Lock 6-10

Environmental objective	Target
MRB2a: By 2030, protect and restore biodiversity by maintaining representative populations of frogs at the Murray River Lock 6-10 asset.	By 2030, maintain self-sustaining populations of frogs at the Murray River Lock 6-10 asset including: • Eastern Sign-bearing Froglet (*Crinia parinsignifera*), Barking Marsh Frog (*Limnodynastes fletcheri*), Spotted Marsh Frog (*Limnodynastes tasmaniensis*), Eastern Banjo Frog (*Limnodynastes dumerilii*) and Perons Tree Frog (*Litoria peronii*) in 80% of years. • By 2030 maintain abundance of Growling Grass Frog (*Litoria raniformis*) as measured by being recorded at 60% of wetlands surveyed in any three year period on Lindsay Island.
MRB2b: By 2030, protect and restore biodiversity by maintaining representative populations of small-bodied fish at the Murray River Locks 6-10 asset, including Australian Smelt (*Retropinna semoni*); Unspecked Hardyhead (*Craterocephalus stercusmuscarum fulvus*); Murray-Darling Rainbowfish (*Melanotaenia fluviatilis*); Flat-headed Gudgeon (*Philypnodon grandiceps*); Carp Gudgeon (*Hypseleotris* spp).	By 2030, maintain self-sustaining populations of Australian Smelt (*Retropinna semoni*); Unspecked Hardyhead (*Craterocephalus stercusmuscarum fulvus*); Murray-Darling Rainbowfish (*Melanotaenia fluviatilis*); Flat-headed Gudgeon (*Philypnodon grandiceps*); Carp Gudgeon (*Hypseleotris* spp) at the Murray River Locks 6-10 asset. Measured as: • Adults or YoY for each species recorded in 8 out of 10 years
MRB3: By 2030, maintain nesting and recruitment of colonial (N7, after Jaensch 2002) and non-colonial waterbirds (N1-3, after Jaensch 2002) at the Murray River Lock 6-10 asset, by maintaining a mixture of tree, low vegetation/shrubs, and ground/islet nesting habitat.	There is a lack of data on species that breed at the site. The expectation is that the list of species commonly nesting at Murray River Lock 6-10 will be confirmed over time. By 2030, at least two of the following species to be recorded as nesting and/or breeding at the Murray River Lock 6-10 asset in 50% years in which nesting/breeding conditions are suitable over the 10 year period:

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	• Representative N7 colonial breeding species include: Great Egret (*Ardea modesta*), Intermediate Egret (*Ardea intermedia*), Little Egret (*Egretta garzetta nigripes),* Caspian Tern (*Hydroprogne caspia*) By 2030, at least two of the following non-colonial nesting species, (N1-3, after Jaensch 2002) to be recorded as nesting and/or breeding at the Murray River Lock 6-10 asset in 70% of years in which nesting/breeding conditions are suitable over the 10 year period: • Representative (N1-3) non-colonial breeding species include: Not able to be set at this point
MRB4: By 2030, maintain representative populations of shallow-water and deep-water feeding guilds of waterbird (F2 and F3, respectively, after Jaensch 2002) at the Murray River Lock 6-10 asset, by maintaining a mixture of shallow and deep-water habitats.	By 2030, 80% of representative F2 and F3 species recorded at the Murray River Lock 6-10 asset in 8 years out of any 10-year period where conditions are suitable: • Representative F2 species include: Caspian Tern (*Hydroprogne caspia*), Common Greenshank (*Tringa nebularia*), Great Egret (*Ardea modesta*), Gull-billed Tern (*Sterna nilotica*), Intermediate Egret (*Ardea intermedia*), Little Egret (*Egretta garzetta nigripes*), Pacific Black Duck (*Anas superciliosa*) • Representative F3 species include: Australasian Shoveler (*Anas rhynchotis*), Blue-billed Duck (*Oxyura australis*), Freckled Duck (*Stictonetta naevosa*), Hardhead (*Aythya australis*), Musk Duck (*Biziura lobata*), White-bellied Sea-Eagle (*Haliaeetus leucogaster*), • Feeding habitat defined as a mixture of deep feeding areas (water >1 m) and shallow feeding areas (<0.5 m depth and or drying mud) with intermittent inundation of densely vegetated shrublands. By 2030, total waterbird numbers at the Murray River Lock 6-10 asset maintained at >5000 in 4 years over any 10 year period

10.3 Watercourses

10.3.1 Ecology

Watercourses are the principal aquatic environments in the study area, providing a network of permanent and intermittent habitat in the river channels and through the floodplain.

Watercourses provide mainly open water habitat where moderate levels of primary productivity are provided by planktonic algae. Macrophyte vegetation occurs in riparian zones, backwaters and in low connected wetlands. Shallow water, where there is some protection from turbulence, supports semi-emergent macrophytes including *Vallisneria* spp. and Swamp Lily (*Ottelia ovalifolia)* (Water Technology 2009). Persistently flooded river banks can support dense riparian vegetation of Common Reed, River Club-sedge (*Schoenoplectus validus*) and Cumbungi. Intermittently-inundated channel fringes will support seasonal aquatic macrophytes such as Salt Club-sedge (*Bolboschoenus caldwellii)* or drought tolerant species such as Spiny Flat Sedge (*Cyperus gymnocaulos*).

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Stable water levels associated with weir operation and river regulation have reduced the productivity and diversity of riparian habitat and the restoration of seasonally variable water levels is an important objective.

The river channels and other permanent watercourses are the principal habitat and refuge for large-bodied native fish species. Murray Cod, Golden Perch and Silver Perch are largely predators, consuming small fish, various larvae and macro-invertebrates. Bony Herring (*Nematalosa erebi*) eat algae and micro-crustaceans and are a significant prey for the large Murray Cod and Golden Perch. Habitat complexity is provided by access to deep open water, snaggy banks and riparian vegetation. Fast-flowing water is an important habitat requirement, particularly for Murray Cod. Freshwater Catfish use lentic habitats in the main stem and lotic habitats in small and large creeks. Vegetated riparian zones are important habitat components for small fish such as Murray-Darling Rainbowfish (*Melanotaenia fluviatilis*) and Gudgeon while backwaters, slow flowing creeks are important habitat for Freshwater Catfish. In the study area watercourses support tortoises and a variety of macroinvertebrates. Larger species such as Freshwater Prawns or Shrimps (*Macrobrachium* spp. and *Paratya* spp.) are an important food source for fish and waterbirds while zooplankton contribute to the food requirements of larval fish.

Watercourses are largely heterotrophic environments. Some primary productivity is provided by phytoplankton and algal biofilms, but most organic carbon and mineral nutrients originate from catchment runoff and the inundation of wetlands and floodplain.

Biofilms are communities of bacteria, algae and fungi that grow on submerged surfaces such as wood, rocks, plants and sediments. They are an important food source for a number of grazing invertebrates including snails (Sheldon and Walker 1997) and decapods (Burns and Walker 2000) which in turn are important food sources for fish and waterbirds. The composition of biofilms and their nutritional value has been related to water regimes. Bacteria are the primary colonisers when degradable substrates are first flooded and will dominate the biofilm community, consuming the nutrients made available by the preceding dry conditions. Over time autotrophic algae increase in abundance and become dominant. Permanent inundation of wetlands, backwaters and benches by weirs has promoted algae in biofilms while bacterial biofilms have declined (Sheldon and Walker 1993). Disturbance such as exposure and drying for periods exceeding 40 days (Burns and Walker 2000) and scouring flows (Burns and Ryder 2001) can re-establish bacteria as the dominant component of biofilms.

The composition of biofilms is important to aquatic fauna because the carbon to nitrogen ratio in bacterial biofilms is much lower than in algae, making them more nutritious to grazers. It has been suggested that macroinvertebrate productivity of the Murray River has decreased as a result and been specifically linked with the decline of the River Snail (*Notopala sublineata hanleyi*) (Sheldon and Walker 1997).

Fast-flowing water is an important habitat component for a number of fish. Water flowing from watercourses provides attractant flows, encouraging their upstream migration (Leigh and Zampatti 2005). Stream complexes that include fast and slow-flowing water are associated with large, viable populations of Murray Cod (Saddlier, O'Mahony and Ramsey 2008) and is associated with increased survival rates of young fish in their first year. Mullaroo Creek and Chowilla Creek provides Murray Cod recruitment habitat and support significant populations of Golden Perch and Silver Perch (Conallin and Meredith 2006). Flowing water provides breeding habitat for Australian Smelt (Sheldon and Lloyd 1990).

Variation in flow (and therefore water level) is an important component of fast-flowing habitat. Increasing discharge in spring is associated with spawning in Golden Perch and Silver Perch (King, Tonkin and Mahoney 2007; Humphries et al. 1999; as it is believed to act as a reliable indicator of the imminent availability of productive floodplain habitat to support juvenile fish recruitment. Freshes in the Darling can trigger upstream spawning migrations in these species after which eggs and larvae drift downstream to grow in the productive conditions that follow floods (Mallen-Cooper, et al. 1995). (Zampatti, et al. in prep.)

For many native species movements over long distances are an important part of their life cycle. Golden and Silver Perch travel over thousands of kilometres, often swimming upstream in response to spawning cues. Other species including Bony Herring and Murray Cod, move long distances to access food or to colonise new areas. Even small native fish species, such as Carp Gudgeon, Murray-darling Rainbowfish and Unspecked Hardyhead (*Craterocephalus stercusmuscarum fulvus*) are understood to make upstream migrations (Barret 2008). Adult Murray Cod generally move in a small home range (5 km) in summer, autumn and winter. In spring adult fish may remain in their home range or move actively up to 25 km between main-stem and anabranch habitats. Movement of sub-adult fish is limited.

Barriers to fish passage also fragment habitat. Isolated habitats may not be recolonised after disturbance, so that overall populations decline. Barriers also isolate breeding populations. Inbreeding occurs, reducing the genetic diversity of fish populations and reducing their long-term viability (Schiller and Harris 2001).

10.3.2 Water Requirements

Watercourses provide a variety of hydraulic environments that are important to the diversity of aquatic fauna and the viability of local populations.

Slow-flowing, open water bodies are provided by the weir pool and provide migration routes and drought refuges for aquatic fauna. Fast-flowing habitats have been significantly depleted in the study area and are a priority for restoration. Floodplain anabranches represent the only opportunity to promote flow-dependent fauna. Experience from Mullaroo Creek and Chowilla provide the basis for Murray Cod and Golden Perch are favoured by habitat where water velocity ranges between 0.2 and 0.4 m/s, ideally in the upper part of this range (Mallen-Cooper, Koehn, et al. 2008). These environments should be provided in a mosaic with slower-flowing backwaters and wetlands. Periods of high flow in spring are associated with spawning in Golden Perch and spawning migrations in both Golden Perch and Silver Perch.

The diversity of wetland water regimes and connection regimes is important to the diversity of aquatic fauna communities. Predation by large fish can reduce the abundance of small fish, macroinvertebrates and frogs and can thereby impact on the food available to waterbirds. Diversity is promoted when wetlands are connected to permanent aquatic habitat at different times and the access of large predators is varied.

Table 21. Water management objectives for watercourses

Ecological Objectives	Maintain aquatic habitat and provide refuge for a range of aquatic fauna species Promote aquatic fauna associated with fast flowing habitat Support migration and spawning of aquatic fauna dependent on spring freshes Promote productivity of riparian habitat

Hydrological Objectives	Maintain permanent aquatic habitat in weir pools Increase the productivity of permanent aquatic habitat by varying water levels on a seasonal basis Promote a mosaic of fast and slow-flowing habitat in floodplain watercourses Provide elevated flows in spring

10.4 Semi-permanent Wetlands

10.4.1 Ecology

Semi-permanent wetlands occur close to the river channels and at the fringes of the principal anabranches. Under natural conditions water was almost always present in these wetlands due to low flow thresholds, frequent peaks in river flow, and the capacity of wetlands to retain water for long periods. Many wetlands would only dry out during rare, prolonged periods of low flow. Within the wetlands water levels would vary seasonally with deep flooding in winter and spring and receding water over summer and autumn. In some respects the fringes of the weir pools fills the role of semi-permanent wetland habitat.

Wetland vegetation is made up of species with a range of flooding tolerances (Table 14). These are ordered along the banks of wetlands from the deepest, most persistently flooded areas to the higher, intermittently flooded areas (Blanch et al. 1999). Stable water levels promote communities dominated by species at the lower and upper range of this continuum, i.e. species that are adapted to permanent inundation or prolonged exposure. The habitat for species that exist between these extremes, and depend on intermittent wetting and drying, is greatly reduced.

Persistent, deep flooding excludes emergent macrophytes from the central wetland bed, which instead either provides open water or supports semi-emergent plant species such as Water-milfoil (*Myriophyllum* spp.), Eel Grass (*Vallisneria Americana*) and Pondweed (*Potamogeton* spp). Seasonal inundation of the wetland fringe provides habitat for emergent macrophytes such as Common Reed, Marsh Club-sedge (*Bolboschoenus medianus*) and Spiny Flat Sedge. Vegetation at the perimeter grades into the grass and sedge-rich understorey of the surrounding red gum forest and woodland (Reid et al. 2009, Ecological Associates 2007).

The productivity of open water habitat can be low, with an accumulation of unavailable organic matter in anoxic sediments. Productivity is maintained by the growth of macrophytes at the wetland fringe and mineralisation of plant debris through annual water level variation. Overhanging vegetation can also provide significant organic matter inputs.

The recession of water levels from a peak in the winter / spring period exposes a broad zone of shallow water or damp soils during the spring / summer period. This environment is the habitat for a range of emergent aquatic plants including Mud Grass (*Pseudoraphis spinescens*), Common Spikerush (*Eleocharis acuta*), Common Reed and Salt Club-sedge, as well as River Red Gum. The deepest areas are the last to be exposed and form open mudflats before they are opportunistically colonised by herbland plants such as Common Sneezeweed (*Centipeda cunninghamii*) and Bushy Groundsel (*Senecio cunninghamii*). A flooding regime dominated by spring, rather than summer, flooding promotes higher macrophyte diversity and abundance (Robertson et al. 2001).

The extent of these communities is severely impacted by stable water levels. Prior to the construction of the weirs, water levels varied in the order of 3 m over the course of most years. The distinction between macrophyte beds and red gum woodlands would have been less clear than at present as river red gum trees would have formed a sparse canopy over the lower macrophyte beds and macrophytes would have extended into the understorey of the more frequently inundated River Red Gum woodland.

Table 22. Plant species adapted to habitats provided by different water regimes. Adapted from Blanch et al. (1999, 2000)

Habitat Inundation Characteristics	Species
Infrequently flooded	*Cyperus gymnocaulos, Brachyscome basaltica, Muehlenbeckia florulenta, Sporobolus mitchellii*
Flooded moderately frequently	*Pseudoraphis spinescens, Eleocharis acuta*
Tolerant of flooding and exposure	*Phragmites australis, Centipeda cunninghamii, Bolboschoenus caldwellii, Cynodon dactylon, Paspalidium jubiflorum, Persicaria lapathifolia*
Permanently flooded, stable water levels	*Schoenoplectus validus, Vallisneria americana, Typha domingensis*

Extensive and complex riparian vegetation benefits a range of fauna species including turtles, avian herbivores, cryptic waterbirds such as crake and bittern, frogs that lay eggs on flooded vegetation and shelter from predators in reeds, and small fish such as Murray-darling Rainbowfish and gudgeon which occur predominantly in aquatic vegetation. Reed beds provide nesting materials for swan and grebes and nesting sites for a wide range of bird species. Inundated littoral vegetation is an important source of organic matter in the aquatic food web.

Semi-permanent wetlands are the principal habitat several important of species. Growling Grass Frog depend on permanent water and dense swampy vegetation as a refuge habitat. When surrounding areas are flooded frog populations can increase and frogs may disperse to other sites. Crake and bittern also depend on the dense reedy vegetation that permanent flooding provides. A number of insectivorous birds and bats obtain food and nesting habitat in and near wetlands, which can be important for maintaining local populations between flood events.

Dabbling ducks such as Freckled Duck (*Stictonetta naevosa*), Australasian Shoveler (*Anas rhynchotis*) and Pink-eared Duck (*Malacorhynchus membranaceus*) feed on soft-leaved aquatic plants and aquatic macro-invertebrates. Semi-permanent wetlands provide reliable breeding habitat for bird species which build nests using reeds on scrapes in and around fringing vegetation and require water to be present for at least three months in winter and spring. Reeds provide frogs with a source of food, a substrate for eggs and shelter from predators. Grazing waterfowl including Black Swan (*Cygnus atratus*), Australian Shelduck (*Tadorna tadornoides*) and Wood Duck (*Chenonetta jubata*) will also be favoured by semi-emergent vegetation and will regularly breed.

Frequent connection and isolation to riverine aquatic habitats is important to the ecological role of these wetlands. Isolated wetlands can support local aquatic fauna populations that would otherwise be vulnerable to large predators including Murray Cod. A mosaic of semi-permanent wetlands across the landscape provides some protection from local disturbance and contributes significantly to overall plant and animal diversity. Reconnection permits aquatic fauna to disperse and interbreed, maintaining genetic diversity. A large number of wetlands with a semi-permanent water regime is required to maintain viable populations across the region.

The microbial decay of plant material is an important route for energy and nutrients to enter the riverine food chain (Young et al. 2001). During dry periods, organic matter such as leaf litter and grasses is slowly decomposed by bacteria, releasing carbon and nutrients which accumulate in the soil. On re-wetting, decomposition accelerates and becomes more efficient. Carbon and nutrients are released from the soil and enter the water where they become available for aquatic plants and animals. The release of energy and nutrients results in a very rapid increase in productivity with a proliferation of bacteria and invertebrates. These organisms are food for larger animals and support an increase in their abundance and diversity.

10.4.2 Water Requirements

In order to maintain resident populations of aquatic fauna, semi-permanent wetlands may only dry out on rare occasions, in 5 to 10% of years. The wetland depth should exceed 0.5 m 80% of the time and 1 m 30% of the time. Inflows are required in more than 80% of years to provide seasonal inundation of the littoral zone, which will mineralise organic matter and maintain emergent macrophyte beds.

Table 23. Water management objectives for semi-permanent wetlands

Ecological Objectives	Maintain a vegetation structure with open water, emergent macrophytes and fringing woodland vegetation Provide habitat for wetland specialist species including small-bodied native fish and growling grass frog Provide annual breeding opportunities for waterbirds
Hydrological Objectives	Inundation of more than 50% of the wetland bed in 90% of years Seasonal fluctuation in water level in the upper 50% of the wetland bed in 90% of years Intermittent connection and isolation of wetlands from other aquatic habitat

10.5 Temporary Wetlands

10.5.1 Ecology

Temporary wetlands are distributed throughout the floodplain. They represent a variety of flooding frequencies, durations and depths but are characterised by an intermittent, broadly seasonal flooding regime.

Temporary wetlands alternate between flooded and dry states. They tend to be filled by freshes in river flow in winter and spring after which they gradually dry out. Flooding may persist over several years if the wetlands receive summer inflows, but will dry out to some degree between inflow events. The wetlands may remain dry over several years if river levels fail to reach the wetland sill.

When flooded, beds of soft-leaved semi-emergent plants will develop in the deeper parts of the lake bed including Water Milfoil and Pondweed. Open water may be present in the central part of the wetlands where water is too deep to support these species. Emergent macrophytes such as Spiny Flat Sedge and Common Spikerush will occupy the narrow seasonally inundated zone at the fringe of the wetland. Tangled Lignum and Southern Cane-Grass (*Eragrostis infecunda*) may also extend into the bed of less-frequently flooded wetlands.

Flooded wetlands will be colonised by the larvae of flying insects and by invertebrates released from resting stages on the lake bed. Over several weeks the wetlands will provide productive food sources for small fish, waterbirds, frogs and turtles.

Many of the temporary wetlands in the study area are extensive and have the potential to support thousands of waterbirds. After years of persistent flooding substantial populations of fish can develop, including large-bodied native species such as Golden Perch.

The drying wetland bed will support a range of wetland herbs such as Common Sneezeweed*,* Pale Knotweed (*Persicaria lapathifolia), Alternanthera* spp. *Glossostigma elatinoides* and *Heliotropum* spp. Between flood events the wetland bed will develop a community of lake bed herbs and grasses such as Native Liquorice (*Glycyrrhiza acanthocarpa*) and Pale Knotweed. These plants, together with colonising River Red Gum, will die during subsequent sustained flood events.

In sustained dry periods the wetland water levels will fall below the reed zone to expose a muddy herbland on the lake bed. Small wading birds such as ruddy turnstone and red-necked stint will feed on macro-invertebrates in shallow water and mud. Fish-eating birds and carrion feeders, including white-bellied sea-eagle, will feed on stranded fish.

10.5.2 Water Requirements

Temporary wetlands should be intermittently inundated and exposed on a broadly seasonal cycle. This water regime will create productive aquatic habitats with diverse aquatic plant and animal communities.

Temporary wetlands should be completely filled between 25% and 90% of years. The peak in wetland level is required some time between September and December to match the growth requirements of emergent macrophytes and the breeding requirements of waterbirds, small native fish and frogs. Drying of 80% of the wetland bed is required in more than 50% of years to promote the growth of wetland macrophytes and herbs on the wetland bed and to mineralise organic matter.

Table 24. Water management objectives for temporary wetlands

Ecological Objectives	Frequently provide feeding and nesting habitat for waterbirds Contribute to the carbon requirements of the Murray River channel ecosystem
Hydrological Objectives	Completely fill wetlands between 25% and 90% of years Peak water level between September and December Dry 80% of the wetland bed in more than 50% of years

10.6 River Red Gum Forest and Woodland

10.6.1 Ecology

Woodlands of River Red Gum are a substantial component of the vegetation and occurs mainly on low river terraces along watercourses and around wetlands. Forest vegetation is less widespread and mainly occurs on meander scroll bars with low flooding thresholds adjacent to the Murray River.

Inundation occurs mostly in spring so that the ground is generally dry over summer and autumn. The plant community comprises species that benefit from seasonal flooding but tolerate dry conditions over summer and occasional years without any flooding. During floods aquatic plants develop from propagules including Nardoo (*Marsilea drummondii),* Common Spikerush and *Triglochin multifructum*. The drier areas are dominated by grasses and sedges including *Spiny Flat Sedge* and Rat-tail Couch (*Sporobolus mitchellii*) and may include Tangled Lignum. Species that colonise the drying forest floor include Common Blown Grass (*Lachnagrostis filiformis*), Native Liquorice and Common Sneezeweed.

Inundation of red gum woodland provides temporary habitat for aquatic fauna, particularly vegetation-dependent fish such as Gudgeon complex, Murray-darling Rainbowfish and hardyhead. The habitat for terrestrial frogs, which is normally limited to the reeds fringing wetlands, will expand to the River Red Gum understorey. Burrowing frogs, which aestivate in the floodplain soil, will become active. Other wetland species that will extend into the flooded woodland will include yabby, tortoises and water rat.

During longer flooding events red gum woodland will support waterbird breeding. The trees provide nesting sites for waterbirds that breed over water such as Nankeen Night-heron (*Nycticorax caledonicus*), Cormorant and Australasian Darter (*Anhinga novaehollandiae*). A range of other waterbird guilds will breed including waterfowl, large waders and small waders.

River Red Gum trees and their understorey have an important role in providing structural habitat for floodplain fauna, particularly hollows for Carpet Python, bats and Brush-tailed Possum (*Trichosurus vulpecula*). River Red Gums growing close to water provide nesting habitat for some birds which feed in adjacent mallee including Regent Parrot (*Polytelis anthopeplus*) and Major Mitchell Cockatoo (*Lophochroa leadbeateri*). The tree growth triggered by flooding will provide much of the leafy and woody material on which the floodplain ecosystem depends and will also increase flowering which supports nectar-eating insects and birds and insectivorous birds.

10.6.2 Water Requirements

Flows of 70,000 to 90,000 ML/d downstream of Lock 10 inundate red gum woodland below Lock 10. Under natural conditions these events occurred almost annually and lasted for two to three months.

River Red Gum woodland has been severely degraded. Mean flood duration has declined to less than 6 weeks while flood frequency has declined to approximately one event every two years. Tangled Lignum has invaded the understorey and the density of River Red Gum has increased. The diversity of understorey vegetation has declined. Waterbird breeding events are smaller and less frequent.

Flooding in spring and early summer for two to three months will meet the seasonal requirements of understorey plants and maintain vegetation structure and diversity. Flooding at this time of year will also address the seasonal breeding requirements of native fish, frogs and waterbirds.

Long flooding events, lasting over six months, are required to support breeding by colonial nesting waterbirds. These events will influence the structure of the vegetation, limiting reducing the cover of Tangled Lignum and River Red Gum and promoting wetland understorey species.

Flooding frequencies of 6 years in 10 are recommended for lower-lying areas and 5 years in 10 for high floodplain areas.

Table 25. Water management objectives for red gum forest and woodland

Ecological Objectives	Provide reliable breeding habitat for waterbirds, including colonial nesting species Protect and restore floodplain productivity to maintain resident populations of vertebrate fauna including Carpet Python, insectivorous bats and Giles' Planigale Contribute to the carbon requirements of the Murray River channel ecosystem
Hydrological Objectives	Inundation events should commence between September and December For areas above an inundation threshold equivalent to 70,000 ML/d downstream of Lock 10 • provide flooding 6 years in 10 • three of these events to be 4 weeks long • three of these events to be 10 weeks long For areas above an inundation threshold equivalent to 85,000 ML/d downstream of Lock 10 • provide flooding 5 years in 10 • two of these events to be 3 weeks long • two of these events to be 6 weeks long

10.7 Lignum Shrubland and Woodland

10.7.1 Ecology

Lignum shrubland and woodland occurs on intermediate floodplain terraces and shallow floodplain depressions that are intermittently waterlogged or flooded by rainfall or high river levels. Lignum is the dominant species and, when flooded frequently, can form extensive, dense thickets. Other large shrubby species Nitre Goosefoot (*Chenopodium nitrariaceum*) and Swamp Canegrass (*Eragrostis australasica*) can co-occur with Lignum. The trees River Red Gum, Black Box and Eumong can form a sparse overstorey.

Lignum shrublands experience intermittent flooding separated by potentially long dry periods. When flooded frequently the shrubs grow quickly and form dense, continuous thickets. The ground layer supports a range of wetland herbs including Nardoo, Common Spikerush, Spiny Flat Sedge and Dock (*Rumex* spp). When flooding is less frequent the shrubs are smaller and more widely spaced allowing the groundlayer vegetation to become denser and more diverse, supporting shrubs, grasses and herbs including Round-leaved Pigface (*Dysphyma crassifolium*), Slender-Fruited Saltbush (*Atriplex leptocarpa*), Lindley's Saltbush (*A. lindleyi*), Streaked Copperburr (*Sclerolaena tricuspis*) and Wallaby Grass (*Austrodanthonia* sp).

Inundation of Lignum shrubland represents an extension of the habitat for aquatic floodplain fauna such as fish, reptiles and frogs. Their bushy structure and debris provides a productive substrate for epiphytes that supports high macroinvertebrate productivity and also provides shelter from predators. Flooded lignum is also used as a platform by nesting waterbirds including ibis and spoonbill.

Floodwater draining from lignum will carry dissolved and particulate carbon as well as algae and invertebrates which will contribute to the food web of the river channel.

Between flood events, lignum is an important habitat for terrestrial vertebrate fauna including lizards and Giles' Planigale.

10.7.2 Water Requirements

Lignum shrubland and woodlands are generally in poor condition. In the higher, less frequently flooded parts of the floodplain lignum shrublands have been replaced by low chenopod shrubs. The size and density of shrubs in remaining stands has declined and formerly frequently flooded areas have developed a more terrestrial vegetation.

A range of flooding frequencies is required to achieve the ecological objectives. Lower-lying shrublands (equivalent to 70,000 ML/d downstream of Lock 10) should be flooded 8 years in 10. Brief events, of two months duration will maintain ecosystem structure and productivity and will provide seasonal habitat for aquatic fauna. Longer floods, of four to six months duration, should be provided in four of these years to support waterbird breeding.

Higher areas (equivalent to 85,000 ML/d flow threshold) should be flooded 4 years in 10. Half of these events should be one month long to maintain ecosystem structure. Half of the events should be of two to three months duration to promote breeding by fish, frogs and waterbirds.

Table 26. Water management objectives for Lignum shrubland and woodland

Ecological Objectives	Provide reliable breeding habitat for waterbirds, including colonial nesting species Frequently provide habitat for thousands of waterbirds Protect and restore floodplain productivity to maintain resident populations of vertebrate fauna including Carpet Python, insectivorous bats and Giles' Planigale Contribute to the carbon requirements of the Murray River channel ecosystem
Hydrological Objectives	For areas above an inundation threshold equivalent to 70,000 ML/d downstream of Lock 10 • provide flooding 6 years in 10 • three of these events to be 4 weeks long • three of these events to be 10 weeks long For areas above an inundation threshold equivalent to 85,000 ML/d downstream of Lock 10 • provide flooding 5 years in 10 • two of these events to be 3 weeks long • two of these events to be 6 weeks long

10.8 Black Box Woodland

10.8.1 Ecology

Black box woodland occurs mostly on high, infrequently flooded floodplain terraces. The canopy is open and the community has a diverse, shrubby understorey that includes Tangled Lignum, Nitre Goosefoot, Spiny Saltbush (*Rhagodia spinescens*), Ruby Saltbush and Eumong. The ground layer comprises low shrubs, herbs and a range of terrestrial grasses. Aquatic plants that appear during or shortly after flooding would include Nardoo, Common Spikerush and Rat-tail Couch.

Tree recruitment and the productivity of the vegetation is strongly linked to flooding (Roberts and Marston 2011). Flooding maintains a diverse age structure and a complex understorey plant community that is required by Carpet Python and other vertebrate fauna. The diversity of birds is particularly high because Black Box woodland contributes to the habitat requirements of both riverine and dryland species (Carpenter 1990). Black Box woodland supports a high proportion of ground foragers and hollow-nesting species. Black box woodlands are important for canopy feeding bush birds such as Superb Fairy-wren (*Malurus cyaneus*), Little Friarbird (*Philemon citreogularis*) and Blue-faced Honeyeater (*Entomyzon cyanotis*). Black Box woodland also supports seasonal migrants normally associated with higher rainfall areas such as Grey Fantail (*Rhipidura albiscapa*) and White-bellied Cuckoo-shrike (*Coracina papuensis*). Black box is an important habitat component for insectivorous bats.

Flood events that inundate Black Box woodland contribute to the carbon requirements of permanent watercourses. Receding flood water conveys organic debris to the river channel where it promotes macro-invertebrate productivity and maintains the riverine food web.

10.8.2 Water Requirements

Flows of 80,000 to 115,000 ML/d downstream of Lock 10 inundate Black Box woodland at Lindsay Island. Under natural conditions these flows occurred in approximately 3 years in 10 and lasted approximately 1 month. While the duration of flood events is similar under the current flow regime, the frequency of events has declined to 1 year in 10 of years.

The overall structure of Black Box woodland has been maintained, but tree recruitment and productivity has declined, threatening the long-term viability of vertebrate fauna populations. Resilience to prolonged drought events, where understorey vegetation becomes sparse and food resources diminish, is poor.

Black box woodland productivity can be restored by increasing the frequency of floods equivalent to 100,000 ML/d to 3 years in 10 and reducing the maximum dry spell between events to seven years.

Table 27. Water management objectives for black box woodland

Objectives Addressed	Protect and restore floodplain productivity to maintain resident populations of vertebrate fauna including Carpet Python, insectivorous bats and Giles' Planigale Contribute to the carbon requirements of the Murray River channel ecosystem
Strategy	Restore flooding to Black Box woodland
Hydrological Targets	Provide flooding 3 years in 10 for 2 to 6 weeks duration The maximum period between events is to be 7 years

10.8.3 Alluvial Plain

10.8.4 Ecology

Alluvial plains occupy the high floodplain terraces and the extensive plains at the perimeter of the floodplain.

The alluvial plain vegetation comprises terrestrial vegetation of salt and waterlogging tolerant species. The dominant species include chenopods such as Bladder Saltbush (*Atriplex vesicaria*), Kidney Saltbush (*A. stipitata*) and Hairy Bluebush (*Maireana pentagona*) as well as the larger shrubs Thorny Fan-leaf (*Lawrencia squamata*) and Nitre Bush (*Nitraria billardieri*). Round-leaved Pigface (*Dysphyma crassifolium* ssp. *Clavellatum*) forms an extensive groundcover in saline areas. Trees are largely absent, but Umbrella Wattle (*Acacia oswaldii*) or Boonaree (*Alectyron oleifolius*) may be present on local rises.

Alluvial plains are rarely flooded and do not normally support wetland plant species. However flooding creates a productive feeding resource for waterbirds, including those that may be nesting in wetland, Lignum and woodland habitats. Widespread, shallow flood water is an important feeding habitat for migratory wading birds which visit Lindsay Island in late summer and early autumn.

10.8.5 Water Requirements

Alluvial plains represent a terrestrial vegetation community and flooding is not required to maintain its structure or productivity.

Flooding does provide opportunistic habitat for floodplain fauna, including feeding habitat for wading birds. Flooding of the alluvial plain will contribute to the success of waterbird breeding events by increasing the availability of food. Extensive flooding may also attract birds to the site and trigger breeding behaviour.

Alluvial plains should be flooded to complement waterbird breeding objectives in wetland, Lignum and woodland habitats. When flooding events of four to six months are provided to promote breeding in these areas, floods of one to two months duration should also be provided to alluvial plains.

To maintain the terrestrial character of the alluvial plains, flooding should not be provided more than 3 times in 10 years.

Table 28. Water management objectives for alluvial plains

Ecological Objectives	Provide reliable breeding habitat for waterbirds, including colonial nesting species Frequently provide habitat for thousands of waterbirds
Hydrological Objectives	Provide flooding 1 years in 10 for 3 weeks in summer. Highest priority years are during major waterbird breeding events. Inundate the alluvial plains no more than 3 times in 10 years.

11 Hydrological Objectives

11.1 Summary of hydrological objectives

As discussed in the ecological objectives section, hydrological objectives have been identified for each of the water areas within the target area. The hydrological objectives are summarised below in Table 29.

Table 29 - Summary of hydrological objectives

Water Area	Hydrological Objective
Watercourses	Maintain permanent aquatic habitat in weir pools Increase the productivity of permanent aquatic habitat by varying water levels on a seasonal basis Promote a mosaic of fast and slow-flowing habitat in floodplain watercourses Provide elevated flows in spring
Semi-permanent wetlands	Inundation of more than 50% of the wetland bed in 90% of years Seasonal fluctuation in water level in the upper 50% of the wetland bed in 90% of years Intermittent connection and isolation of wetlands from other aquatic habitat
Temporary wetlands	Completely fill wetlands between 25% and 90% of years Peak water level between September and December Dry 80% of the wetland bed in more than 50% of years
River Red Gum forest and woodland	Inundation events should commence between September and December For areas above an inundation threshold equivalent to 70,000 ML/d downstream of Lock 10 • provide flooding 6 years in 10 • three of these events to be 4 weeks long • three of these events to be 10 weeks long For areas above an inundation threshold equivalent to 85,000 ML/d downstream of Lock 10 • provide flooding 5 years in 10 • two of these events to be 3 weeks long two of these events to be 6 weeks long

<table>
<tr><th>Water Area</th><th>Hydrological Objective</th></tr>
<tr><td>Lignum Shrubland and woodland</td><td>For areas above an inundation threshold equivalent to 70,000 ML/d downstream of Lock 10
provide flooding 6 years in 10
three of these events to be 4 weeks long
three of these events to be 10 weeks long
For areas above an inundation threshold equivalent to 85,000 ML/d downstream of Lock 10
provide flooding 5 years in 10
two of these events to be 3 weeks long
two of these events to be 6 weeks long</td></tr>
<tr><td>Black Box woodland</td><td>Provide flooding 3 years in 10 for 2 to 6 weeks duration
The maximum period between events is to be 7 years</td></tr>
<tr><td>Alluvial plains</td><td>Provide flooding 1 years in 10 for 3 weeks in summer.
Highest priority years are during major waterbird breeding events.
Inundate the alluvial plains no more than 3 times in 10 years.</td></tr>
</table>

11.2 Environmental Water Management Measures

The following sections describe the water management measures that have been and can be used to improve habitat values in the target area. Measures have been developed to:

- improve the movement of fish
- increase riparian and wetland connectivity, productivity and habitat value
- restore fast-flowing habitat
- increase floodplain habitat integrity and productivity

11.3 Fish Passage

Obstructions that limit the movement of fish are a significant factor in the decline of native fish populations in the Murray River. Barriers impact on fish by restricting access to spawning grounds and preferred habitat and by preventing dispersal and recolonisation. Barriers also interrupt the movements of migratory fish species.

For many native species movements over long distances are an important part of their life cycle. Golden and Silver Perch travel over thousands of kilometres, often swimming upstream in response to spawning cues. Other species including bony herring and Murray Cod, move long distances to access food or to colonise new areas. Even small native fish species, such as Carp Gudgeon, Murray-darling Rainbowfish and Unspecked Hardyhead are understood to make upstream migrations (Barret 2008).

Barriers to fish passage also fragment habitat. Isolated habitats may not be recolonised after disturbance, so that overall populations decline. Barriers also isolate breeding populations. Inbreeding occurs, reducing the genetic diversity of fish populations and reducing their long-term viability (Schiller and Harris 2001).

Beginning in 2001, the Sea to Hume Dam program was developed as a component of the Native Fish Strategy to provide continuous upstream passage for native fish in all the principal channels of the river system. In the study area this has involved installing fishways at each of the Murray River weirs. The fishways have a vertical slot design where fish swimming upstream enter a series of chambers through which water is flowing. The chambers distribute the head difference across the weir over a long distance with an alternating series of small fast-flowing steps and slow-flowing resting areas (Figure 19).

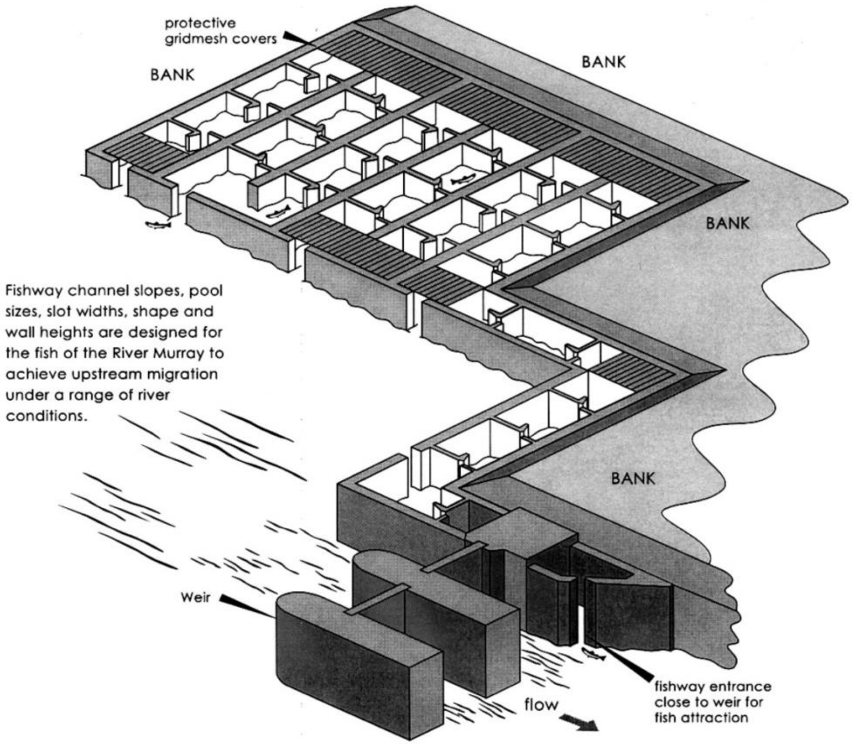


Figure 19. Schematic representation of the Lock 8 fishway

The fishways have proved very successful. The fishways successfully pass a large number, high diversity and wide size range of fish, ranging from 40 mm to 1,000 mm (Barret and Mallen-Cooper 2009).

In some respects, Lake Victoria is operated as a part of the Murray River channel and presents similar fish movement risks to the weirs. A significant proportion of the water that reaches South Australia passes through Lake Victoria and inflows to the lake are frequently greater than passing flows below Lock 9. Inflows to the lake have the potential to divert fish moving downstream as well as drifting material such as fish eggs and larvae, invertebrates and organic matter. Approximately 50% of the drifting material in influent water remain in the lake (Adridge and Brookes 2014). With a potential discharge of more than 7,000 ML/d the outflows can also represent a significant proportion of the river flow below Lock 7 and the lake may represent a more attractive migration route than the main river channel. Lake Victoria provides habitat for native fish including Murray Cod and breeding populations of Golden Perch (Mallen-Cooper, Zampatti, et al. 2011) and it is reasonable to consider the lake as an important component of the river ecosystem.

Fish passage structures at the Lake Victoria outlet and inlet regulators would help integrate the lake with the river ecosystem by facilitating fish movement into and out of the lake, allowing them to utilise the aquatic habitat and nutrients in the lake while also contributing to the riverine fish populations.

Fish passage is now a consideration in the design of all obstructions on watercourses including regulators and weirs. Fishways have been incorporated in the construction of the Chowilla Weir and Potterwalkagee Weir at Mulcra Island and in the design of the proposed Berribee Weir at Lindsay Island.

11.4 Weir Pool Variation

The rise and fall of river levels is an important factor in the health of the Murray River and its floodplain. Intermittent flooding and exposure is associated with the growth, productivity and recruitment of floodplain vegetation, with the extent and complexity of riparian plant communities, with the formation of bacterial biofilms, with the mineralisation of organic matter and with the quality of habitat for birds, fish and other fauna (Ecological Associates 2013).

Water level variation has been reduced in the study area through a combination of river regulation and weir operation. Weirs raise and stabilise the river levels upstream while flow regulation has reduced the frequency and duration of peaks that inundate the floodplain.

There is scope to operate the weirs at Locks 6, 7, 8, 9 and 10 to restore some water level variation to the river bank and the nearby floodplain.

The primary targets are the water requirements of a small but important component of the ecosystem: the littoral and riparian zone of wetlands and watercourses, and flowing water habitat. The objectives are to promote a broader zone of macrophytes, to increase productivity and habitat quality, to promote habitat use by aquatic fauna and waterbirds and to promote fish growth and reproduction.

These objectives are met most effectively by a regime of inundation in late winter or spring and gradual drawdown over late spring and summer. Inundation provides aquatic fauna with access to flooded vegetation when it is most important to growth and reproduction. A gradual drawdown over spring will promote macrophyte growth over a broad zone, with shallow water and mudflats provided in summer.

Interannual variability is an important component of natural water regimes. Variability would be imposed on this cycle by high river discharge or the operation of weirs to support floodplain inundation.

11.5 Regulation of Wetlands

Regulated wetlands are an important component of environmental water management in this reach. They provide close control of wetland water regimes and can be used to maintain specific conservation values at localised sites. They can be operated to provide drought refuge for aquatic fauna.

However, regulated wetlands are relatively labour-intensive to manage. They generally require individual operating and management plans and seasonal watering proposals. During the course of a watering event operational decisions must be made on how water levels and regulators should be managed.

Several of the wetlands can be operated as a component of larger, reach-scale watering events. Water can be introduced through weir pool raising or the operation of floodplain inundation regulators. In these circumstances local regulators may be used to prolong localised flooding as part of a larger integrated watering event.

11.6 Flowing Habitat

Prior to the construction of the weirs, fast-flowing water was a normal characteristic of the Murray River channel, even at low discharges. Fast-flowing habitat provides a diversity of hydraulic environments that support a wide range of macro-invertebrates, small fish and larvae that provide prey for large predatory fish like Murray Cod and Golden Perch. It has been suggested that slower flowing habitats, adjacent to or downstream of these reaches, are the destination of eggs and spawn of these species, where food resources would be concentrated and aid in their survival (Mallen-Cooper, Koehn, et al. 2008).

The decline of fast-flowing habitat has contributed to the decline of native fish populations in the Murray River below Lock 10. The only two reaches of perennial fast-flowing habitat in the Murray River below Lock 10 are found in Mullaroo Creek and at Chowilla, where anabranches divert water around weirs. These sites support the only self-sustaining populations of Murray Cod in the lower Murray (Mallen-Cooper, Koehn, et al. 2008; Saddlier, O'Mahony and Ramsey 2008). These sites also contribute to healthy populations of Golden Perch, Australian Smelt and Freshwater Catfish.

The hydraulics of natural channels is complex and involves spatial and temporal variation associated with channel form, debris, vegetation and variable discharge. As a general guide to managing flow for native fish mean cross sectional velocities between 0.3 and 0.5 m/s are targeted as fast-flowing habitat, as shown earlier in Table 12.

11.6.1 Lindsay Island

Mullaroo Creek receives inflows from the Lock 7 weir pool. The creek flows through the Lindsay Island floodplain to join Lindsay River and then rejoin the Murray River above Lock 6 near Lindsay Point. Inflows exceed 400 ML/d and generate fast-flowing habitat over the first 4 km. Beyond this point the creek reaches the upstream limit of the Lock 6 weir pool and velocity is significantly reduced.

Lindsay River also diverts water from the Lock 7 weir pool and contributes to fast-flowing habitat. This watercourse receives inflows from two effluents. The northern effluent flows at normal weir pool levels while the southern effluent becomes active at elevated river levels.

The Murray Cod population at Lindsay Island includes fish of ages from young of year to adult, indicating that the population is breeding and self-sustaining. The watercourses also support significant populations of Golden Perch, Australian Smelt and Freshwater Catfish.

11.6.2 Chowilla

Chowilla Creek is an anabranch system with several outlets upstream of Lock 6 and a single outlet downstream of Lock 6. The major inlets are near Lock 6 comprising Pipeclay Creek, Slaney Creek and Swifty's Creek.

Habitat complexity and value is contributed by the combination of slow- and fast- flowing reaches, riparian vegetation, large woody debris and connection to adjacent wetland habitats.

Chowilla supports a self-sustaining population of Murray Cod and significant populations of Golden Perch. Bony Herring are abundant, as are the small-bodied species Unspecked Hardyhead, Carp

Gudgeons, Australian Smelt, Murray-darling Rainbowfish and Flathead Gudgeon (Mallen-Cooper, Koehn, et al. 2008).

11.6.3 Mulcra Island

Potterwalkagee Creek receives inflows from the Lock 8 weir pool and flows through the Mulcra Island floodplain to rejoin the Murray River above Lock 7. At the normal operating level Lock 8 creates a flow of 35 ML/d at the Stoney Crossing regulator. Raising Lock 8 by 0.2 m generates a flow of 80 ML/d at Stoney Crossing and activates the Upper Potterwalkagee effluent which contributes an additional 50 ML/d. A spring fresh can be provided by raising Lock 8 to 25.3 m AHD which generates a flow of up to 400 ML/d through the system (Greenfield 2013).

Potterwalkagee Creek has a diverse range of aquatic habitats including deep and shallow sections with both steep and sloping banks. The creek supports dense stands of aquatic macrophytes and contains significant amounts of instream woody debris. The creek has significant potential to support a range of small-bodied fish species as well as Golden Perch and freshwater catfish (Greenfield 2013).

11.6.4 Darling River

The Darling River has a more confined channel than the Murray River and has potential to provide fast-flowing habitat at discharges as low as 200 ML/d (Mallen-Cooper, Zampatti, et al. 2011). Analysis of Darling River flows from 1988 to 2010 show that there is significant potential to provide fast-flowing habitat through the transmission of water for consumptive use or through an environmental flow (Figure 20).

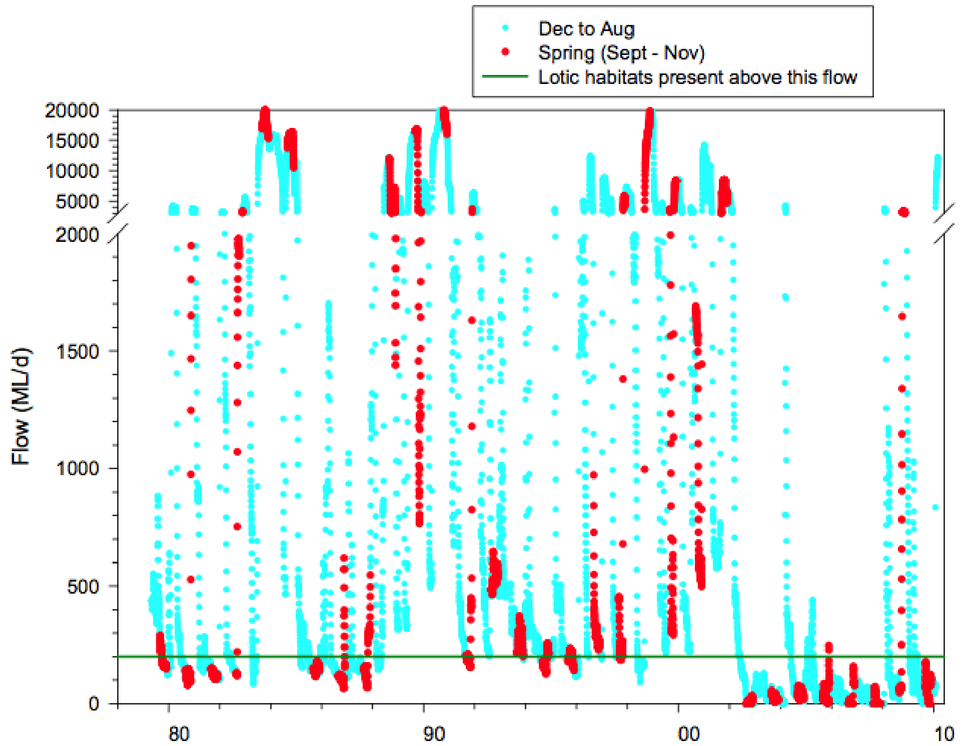


Figure 20. Flow in the lower Darling River from 1988 to 2010 showing the occurrence of flowing habitat in the spawning period of Murray Cod in spring (Mallen-Cooper, Zampatti, et al. 2011)

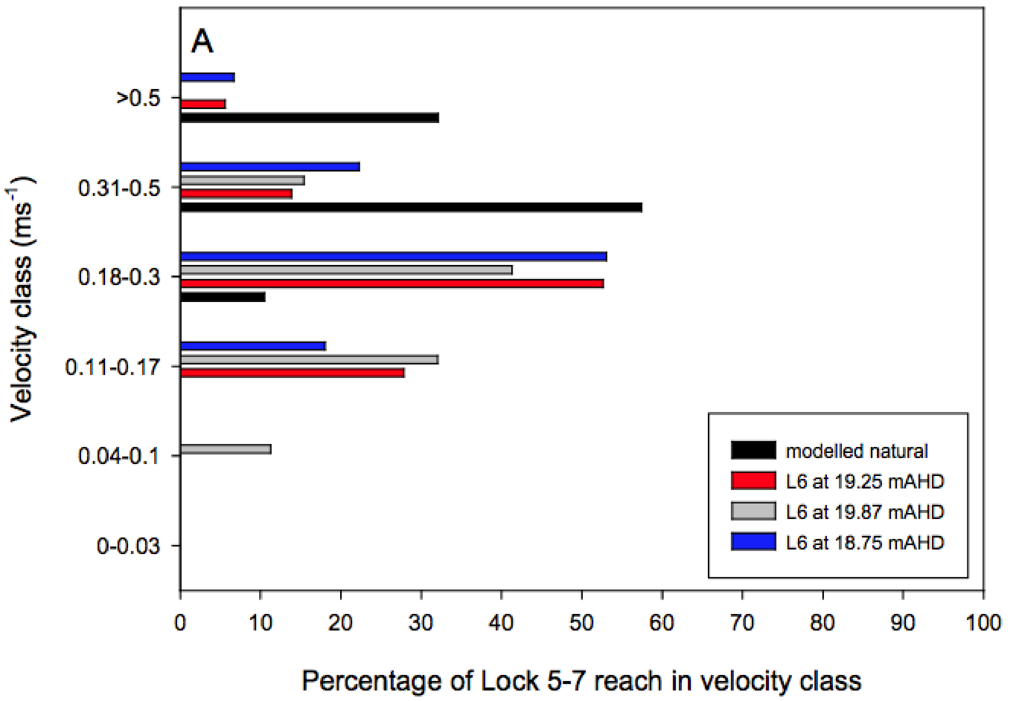
11.6.5 The Murray River Channel

There is scope to provide fast-flowing habitat in the river channel by lowering weir levels when river discharge is high. At normal weir levels the pool of each weir in the study area can extend to the base of the upstream weir. If weirs are removed, the gradient in river level is restored and fast-flowing habitat is created throughout the reach.

Hydraulic modelling of the reach between Locks 5 and 7 has explored the potential to increase channel velocities by the Lock 6 weir.

Under natural hydraulic conditions (in the absence of weirs), a discharge of 10,000 ML/d would have created velocities of more than 0.3 m/s over approximately 90% of the reach velocity (Figure 21A). With the Lock 6 weir in place at 19.25 m AHD, less than 25% of the reach has a velocity of more than 0.3 m/s. At this low discharge raising or lowering the weir has little effect on velocity.

At a discharge of 20,000 ML/d, velocity can be increased by lowering the weir (Figure 21B). The length of channel flowing faster than 0.3 m/s remains about 25% when the weir is operated at the normal level. If the weir is lowered by 0.5 m the length of channel flowing faster than 0.3 m/s increases to more than 85% of the channel.



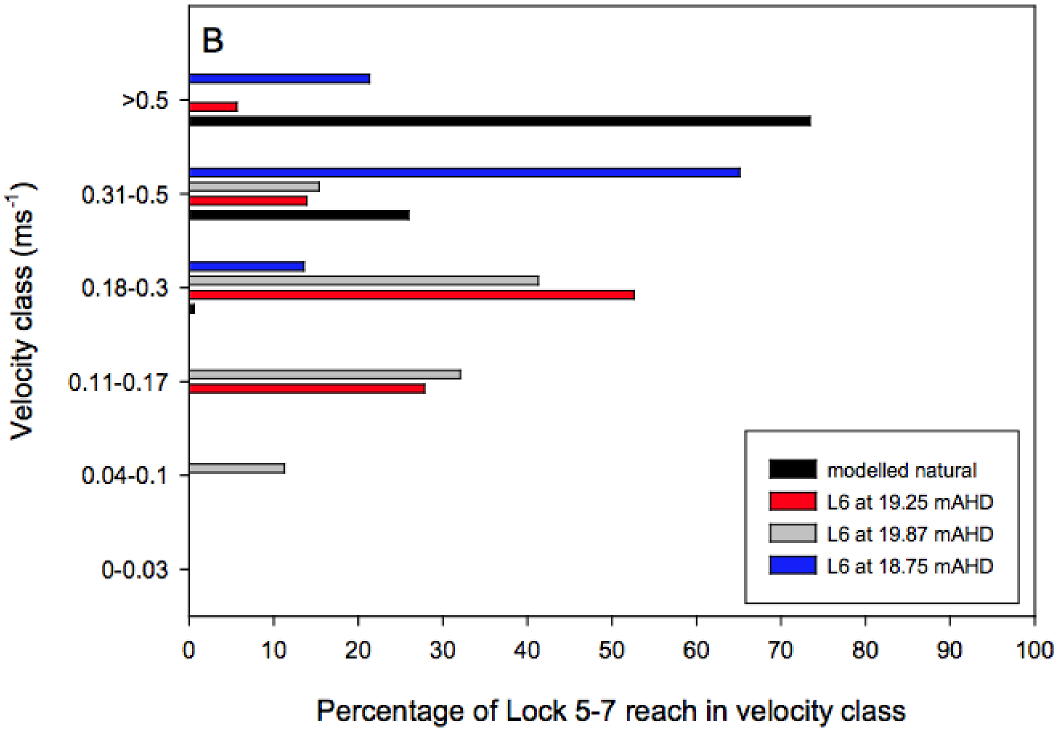


Figure 21. Effect of Lock 6 on the percentage of the Lock 5 to 7 reach with velocity in the respective classes for 10,000 ML/d and 20,000 ML/d (Mallen-Cooper et. al. 2011)

While fast-flowing habitat is generally considered an important habitat component of several native fish species, further work is required to determine how weir lowering would contribute to fish outcomes or interact with other ecosystem requirements. Weir lowering may be beneficial in early spring if it promotes fish breeding or migration. However high water levels are required in late spring to inundate wetland and riparian habitat.

A possible management regime would involve low river levels with fast-flowing conditions in winter and early spring transitioning to high river levels with low velocities in late spring and early summer.

12 Environmental Water Delivery Infrastructure

12.1 River System Management - Storages

The water resources of the Murray River system are managed under the Murray-Darling Basin Agreement by the Murray-Darling Basin Authority in coordination with the New South Wales, Victorian and South Australian governments. The agreement aims to promote and co-ordinate effective planning and management for the equitable, efficient and sustainable use of the water and other natural resources of the Murray-Darling Basin.

The principle sources of water for the study area are from:

- Regulated releases from Hume Dam and Dartmouth Dams (3,005 GL and 3,856 GL) and Lake Victoria (6,77G L) on the Murray River.
- the Menindee Lakes Scheme (2,050 GL) on the Lower Darling River.
- NSW and Victorian tributary unregulated inflows to the Murray River.

Under the Murray-Darling Basin Agreement New South Wales and Victoria each receive 50% of the inflows to Hume, Dartmouth and from the Kiewa unregulated tributary, and 50 % of inflows to Menindee Lakes. South Australia owns all of the water in the Murray River within South Australia.

Other inflows to the Murray River are credited to the state from which they originate (e.g. flow in the Goulburn River at McCoys Bridge is credited to Victoria and the Murrumbidgee River at Balranald is credited to New South Wales).

12.1.1 Hume Dam

Hume Reservoir is the main operating storage of the Murray River System. The storage regulates the Murray River and re-regulates water discharged from the Snowy Mountains Hydro-electric Scheme. Lake Hume is located near Albury-Wodonga, 1,583 river km upstream of the South Australian border. Releases from the reservoir, in conjunction with downstream tributary flows, supply water along the Murray River to New South Wales, Victoria and South Australia for irrigation, stock and domestic, urban as well as environmental purposes.

Releases from Hume Reservoir also supplements water supplies to South Australia from Lake Victoria and Menindee Lakes. In many years, when storage in Lake Victoria and Menindee Lakes is low, additional releases are made specifically for South Australian requirements, although deliveries are subject to the constraints of the Barmah Choke.

12.1.2 Menindee Lakes

Menindee Lakes is a group of large natural lakes adjacent to the Lower Darling River that have been modified to operate as storages under the Menindee Lakes Scheme (Figure 22). The lakes divert water from the Darling River at Main Weir (Lake Wetherell) and return it to the river at Weir 32. The storage has a capacity of 1,731 GL and may be surcharged to 2,050 GL. The storage is owned by New South Wales and is leased to the MDBC.

The Menindee Lakes Scheme was completed in 1960 to provide a secure water supply for Broken Hill and to provide water for stock, domestic and irrigation use along the Lower Darling and Great Darling Anabranch. Water from the scheme is also used to meet water requirements along the Murray River in South Australia. Prior to the scheme the lakes filled only under flood conditions.

Under the terms of the Murray-Darling Basin Agreement the water held in Menindee Lakes is to be shared equally between New South Wales, Victoria and South Australia. The scheme delivers water to South Australia to meet part of its annual entitlement (around 39% on average) as well as up to 9,000 ML/d (limited by channel capacity) to meet monthly storage targets in Lake Victoria (MDBA 2010).

When the total volume of the scheme falls below 480,000 ML (28% capacity) management of the system reverts to New South Wales to meet the needs of far-west New South Wales including Broken Hill and the irrigation in the Lower Darling. This may also include providing water to meet the needs of water users and the environment in the New South Wales Murray Valley. When Menindee Lakes is under New South Wales control the Darling River is treated as a New South Wales tributary with inflows to the Murray River system being measured at Burtundy.

When the total volume of the scheme exceeds 640,000 ML (37% capacity) management of the system reverts to MDBA for the provision of the water requirement needs of New South Wales, Victoria and South Australia. When the scheme total volume is between 480,000 and 640,000 ML the current management regime remains until a trigger volume is met. This is known as the 640/480 rule which effectively provides an additional 160,000 ML for drought security.

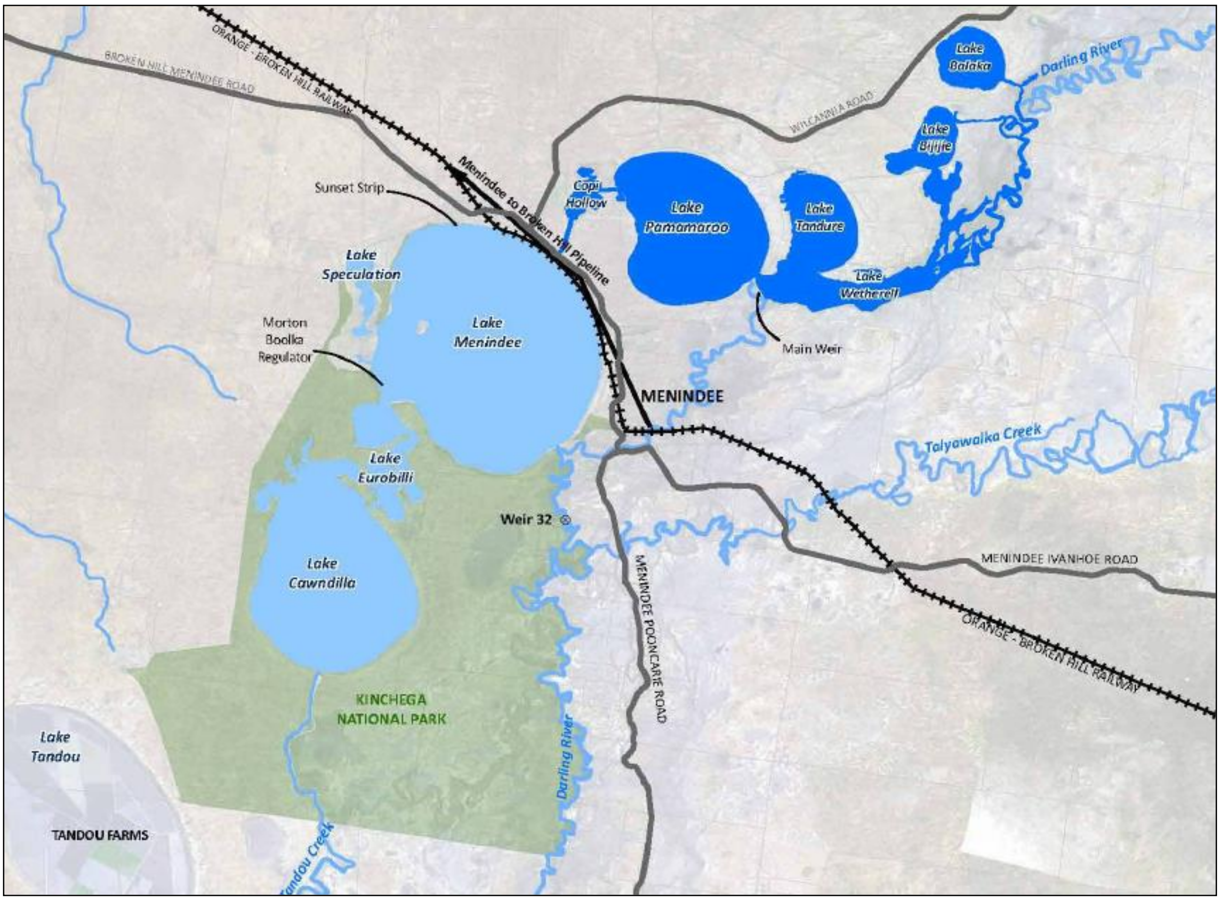


Figure 22. Menindee Lakes Scheme

12.1.3 Lake Victoria

Lake Victoria is a naturally occurring shallow freshwater lake on the Murray River floodplain, approximately 60 km downstream of the Murray-Darling confluence in south-western New South Wales (Figure 23).

Lake Victoria has been modified to act as a water storage and plays a key role in managing flows in the Murray River system. The lake receives inflows from the Murray River via Frenchmans Creek, an anabranch of the Murray River above Lock 9, and returns flows to the river via Rufus River below Lock 7. The capacity of the storage is 677 GL of which about 100 GL is dead storage (MDBA 2010).

Lake Victoria assists with the supply of water in the lower Murray River. The delivery of water from upstream storages, particularly Lake Hume, can be constrained by high upstream irrigation demand and by the limited channel capacity at the Barmah Choke. Located downstream of the major New South Wales and Victorian irrigation areas and downstream of the Choke, Lake Victoria supplements supply to South Australia and provides flexibility in the delivery and management of water throughout the southern connected basin.

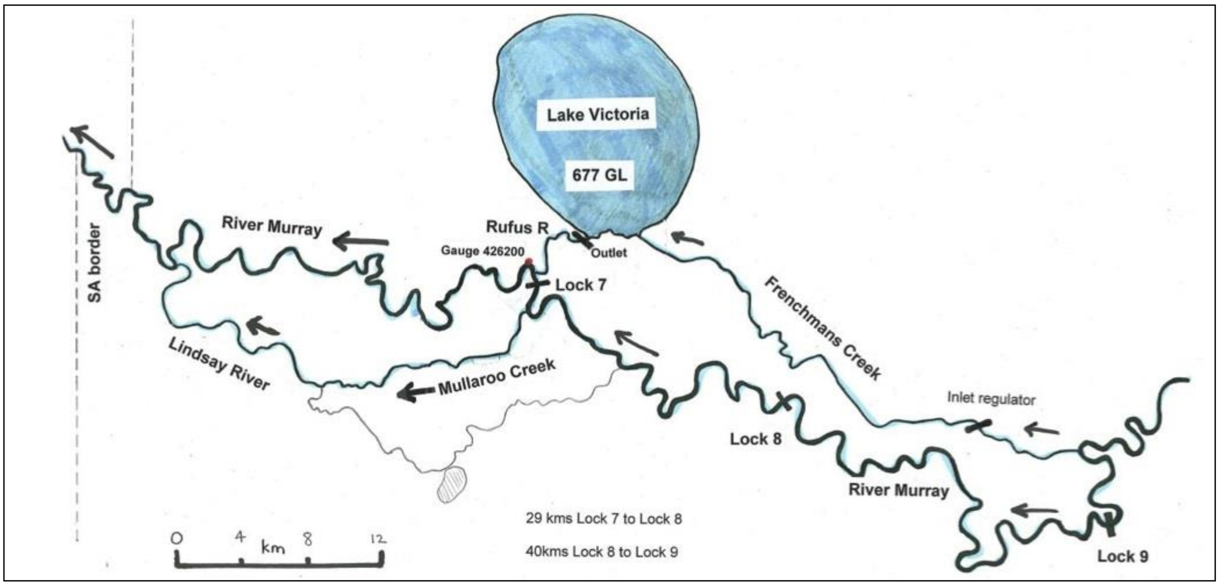


Figure 23. Lake Victoria in relation to the Murray River

Water is diverted to the lake from the Murray River using the weir pool of Lock 9 and a series of embankments and regulators along Frenchmans Creek and at Lake Victoria itself (MDBA 2010). When Lake Victoria is full the head difference between normal operating level of Lock 9 and the lake is 0.4 m. Flow in Frenchmans Creek is controlled by the Inlet Regulator which has three manually operated gates. The capacity of Frenchmans Creek is approximately 9,000 to 10,000 ML/d. There is no formal rule for a minimum flow in Frenchmans Creek. However, a flow of at least 100 to 200 ML/d is normally provided to maintain water quality for stock that access the creek and to minimise the risk of saline groundwater inflows.

Inflows to Lake Victoria area highest between July and December but can occur at any time of year (Figure 24).

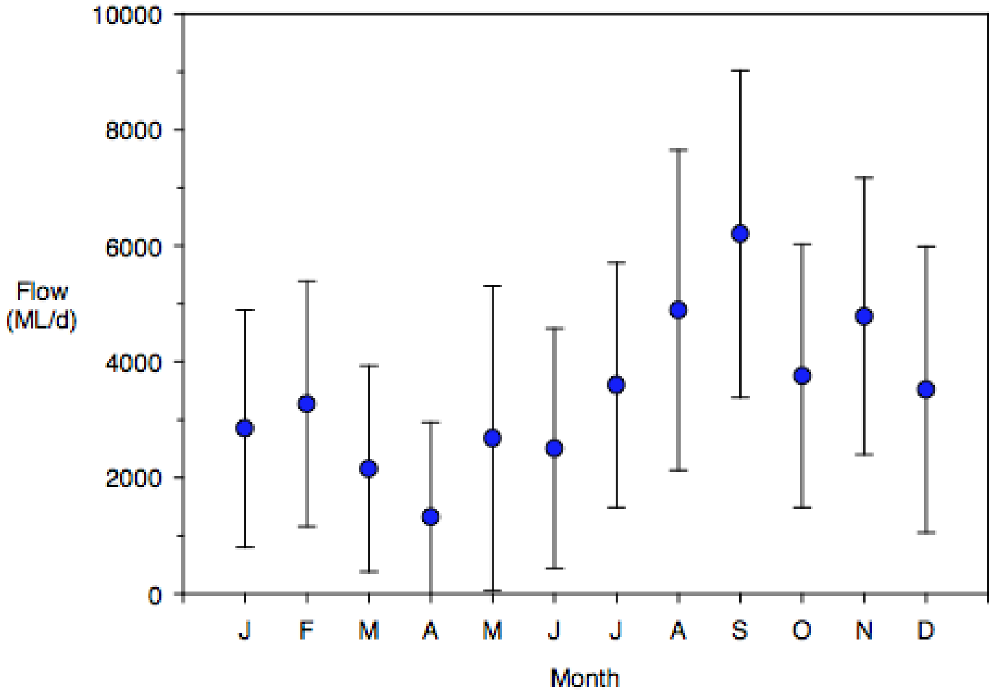


Figure 24. Mean daily flow by month (+/- std dev) in Frenchmans Creek 1994-2007 (Robinson and Mallen-Cooper 2013)

Water is mainly released during late summer and early autumn. Depending on the storage level in Lake Victoria at the start of the irrigation season, water might need to be transferred from Hume Reservoir to Lake Victoria during spring and early summer when there is spare capacity along the Murray.

In general, the lake is filled as late as possible in the winter/spring period. If water resources in the catchment are low, the lake is filled earlier to ensure that the target lake storage can be achieved.

Lake Victoria can also be used to re-regulate tributary inflows downstream of Hume Reservoir (rain rejections) that are in excess of South Australia's entitlement. If the forecast flows cannot be captured in Lake Victoria (because it is in excess of the inlet capacity, or the lake will fill and spill), and the flow to South Australia will exceed the entitlement flow, the MDBA may declare a period of Murray River Unregulated Flows.

Water can be transferred from Menindee Lakes to Lake Victoria under harmony operation of the two storages. Water is transferred if flow in the Murray River is insufficient to maintain suitable storage volumes in Lake Victoria, provided that Menindee Lakes is under MDBA control. Harmony operation balances the advantages of reduced evaporation (annual evaporation rates at Menindee Lakes are higher than at Lake Victoria) against the increased risk of spill from Lake Victoria.

Lake Victoria can be operated to reduce the salinity of water entering South Australia. During periods when flow in the Murray River is regulated and the salinity at Lock 9 exceeds the salinity in Lake Victoria, flow passing Lock 9 is minimised and the flow diverted to Lake Victoria is maximised, where it mixes with water of a lower salinity. The target flow to South Australia is maintained by releases from Lake Victoria.

During periods of drought, when water resources are low, a system-wide strategy is implemented whereby the volume of water in Lake Victoria at the end of May is minimised and the volume of water stored in Hume and Dartmouth Reservoirs is maximised. This reduces evaporative losses and also reduces the chance of spilling in Lake Victoria.

A critical constraint on Lake Victoria is that it must be operated to minimise damage to Aboriginal relics that may be exposed by erosion on the foreshore. The Lake Victoria Operating Strategy (MDBC 2002) details the rules and procedures that govern lake operation.

The manipulation of the Lock 9 weir pool for environmental purposes generally assists with filling of the lake. The lake is usually filled in the winter/spring period when the weir pool is more likely to be raised which will assist with inflows. A lower weir pool would reduce inflows, but the weir would only be lowered in summer and autumn when lake inflows are not usually required. Weir levels would have to be restored if a flow peak in summer/autumn were to be re-regulated using Lake Victoria.

The approximate travel times for water to reach the Lake Victoria are shown in Table 30.

Table 30. Travel times from upstream storages to Lake Victoria at low flows

Source	Approximate Travel Time
Hume Reservoir	25 days
Yarrawonga Weir	21 days
Euston Weir	7 days
Menindee Lakes	10-14 days

12.2 River system management - South Australian entitlement flow

New South Wales and Victoria must provide, in equal proportions, South Australia's entitlement flow. The South Australian entitlement flows are defined as monthly totals but are provided as a steady flow throughout the month (Table 31). The volumes associated with South Australia Entitlement Flows are supplied from the Menindee Lakes Scheme and Lake Victoria.

Table 31. South Australia's entitlement flow distribution

Month	Dilution component (GL)	Non dilution component (GL)	Total entitlement (GL)	Entitlement flow (ML per day)
Jan	58	159	217	7000
Feb	58	136	194	6929
Mar	58	128	186	6000
Apr	58	77	135	4500
May	58	35	93	3000
Jun	58	32	90	3000
Jul	58	50.5	108.5	3500
Aug	58	66	124	4000
Sep	58	77	135	4500
Oct	58	112.5	170.5	5500
Nov	58	122	180	6000
Dec	58	159	217	7000

12.2.1 Surplus flow to South Australia

If the flow in the Murray River is in excess of the South Australian entitlement flow and the flow that can be regulated by storing it in Lake Victoria, the excess is defined as surplus flow. Any period of surplus flow does not result in a subsequent reduction in the South Australian entitlement flow.

12.2.2 Additional Dilution Flow

In 1987, as part of the MDBC Salinity and Drainage Strategy, it was agreed that South Australia would be entitled to additional water to mitigate the impacts of surface water salinity. This volume, known as additional dilution flow, is only provided when the storage volumes in the Menindee Lakes exceed nominated trigger points and at the same time the combined storage volume of Hume and Dartmouth Reservoirs also exceed nominated triggers. The trigger volumes within the Menindee Lakes vary between months (Table 32). When these trigger volumes are exceeded, South Australia is entitled to an additional flow of 3,000 ML/d.

Table 32. Additional dilution flow and triggers

Month	Entitlement flow (ML/d)	Additional Dilution flow (ML/d)	Total Flow (ML/d)	Menindee Trigger (GL)	Hume & Dartmouth Trigger (GL)
Jan	7000	3000	10000	1300	2000
Feb	6928	3000	9928	1300	2000
Mar	6000	3000	9000	1300	2000
Apr	4500	3000	7500	1300	2000
May	3000	3000	6000	1300	2000
Jun	3000	3000	6000	1650	2000
Jul	3500	3000	6500	1650	2000
Aug	4000	3000	7000	1500	2000
Sep	4500	3000	7500	1300	2000
Oct	5500	3000	8500	1300	2000
Nov	6000	3000	9000	1300	2000
Dec	7000	3000	10000	1300	2000

12.3 Flowing Habitat

12.3.1 Carrs-Cappitts-Bunberoo (Proposed)

A proposal has been developed to rehabilitate the Carrs-Cappitts-Bunberoo (CCB) system to provide perennial, fast-flowing habitat over a total channel length of 12 km (Robinson and Mallen-Cooper 2013). The proposal replicates elements of the perennial and hydraulically diverse environment of the river channel under natural conditions.

The concept is to use the head difference between the Lock 9 and Lock 8 weir pools to generate perennial flow through the network of narrow creek channels. The physical habitat in the creek includes deep holes, snags and backwaters that would contribute to significant hydraulic and habitat diversity for aquatic fauna. The system has potential to support significant populations of Murray Cod and Golden Perch and to support lesser populations of Silver Perch and Freshwater Catfish. Small-bodied fish would also benefit. Fish which live and reproduce in the CCB system are likely to contribute to regional populations as they disperse to other sites via the Murray River.

Hydraulic modelling indicates that suitable habitat is provided by discharges of 1,500 ML/d in Carrs Creek (via Carrs No. 1) and 500 ML/d in Bunberoo Creek (via Carrs No. 2). These flows generate significant hydrodynamic diversity including slow-flowing edge habitats, pools up to 2.5 m deep and fast-flowing reaches with channel velocities exceeding 0.3 m/s.

Further modelling is required to refine these flows and develop a program of seasonal flow variation.

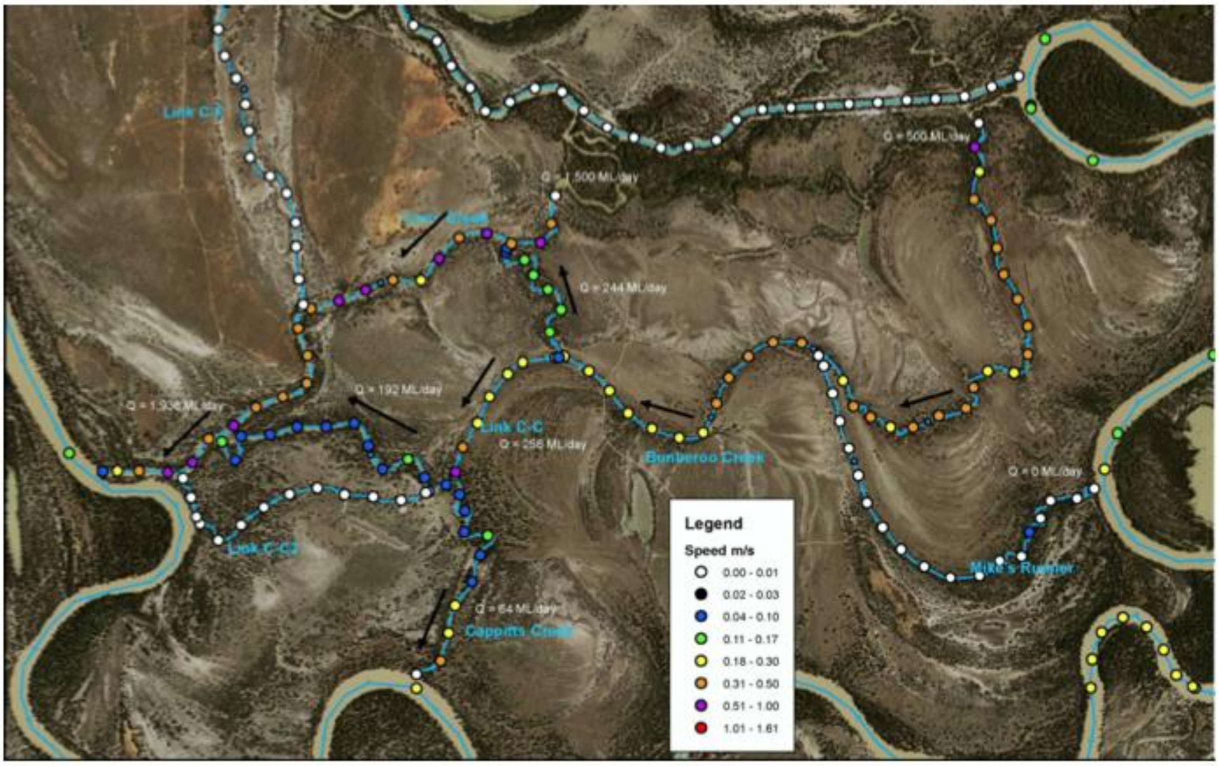


Figure 25. Hydrodynamic modelling of CCB system showing mean velocity within the channel with inflows of 1,500 ML/d at Carrs No. 1 and 500 ML/d at Carrs 2 (Robinson and Mallen-Cooper 2013).

The proposed works involve structures to control flow from Frenchmans Creek to Carrs Creek and Bunberoo Creek, two block banks and five road crossing structures. The works are designed to provide provide upstream fish passage with attractant flows and safe downstream passage for fish. They would be designed to provide variable flows and would allow for the operation of Lock 9 at a raised level of +0.3 m. Existing block banks and road crossings would be upgraded.

12.4 Floodplain Inundation Projects

12.4.1 Wallpolla Island (Proposed)

The Wallpolla Island Floodplain Management Project has been proposed to provide a three-tiered inundation system. Inundation will be managed by gravity and pumping infrastructure to water 2,870 ha of floodplain.

The aim of the project is to restore and protect watercourse, wetland and floodplain habitat integrity and productivity thereby:

- increasing the population size, health and age structure of native fish populations in floodplain watercourses
- restoring and protect semi-permanent wetland habitat, increasing the range and resilience of aquatic fauna such as Growling Grass Frog
- providing seasonal waterbird breeding opportunities
- restoring frequent breeding opportunities for colonial nesting waterbirds
- restoring the productivity and structure of floodplain woodland and shrubland communities, increasing the viability of vertebrate fauna populations including Carpet Python, Giles' Planigale, Fat-tailed Dunnart and bat species
- supplying organic matter to the Murray River channel ecosystem.

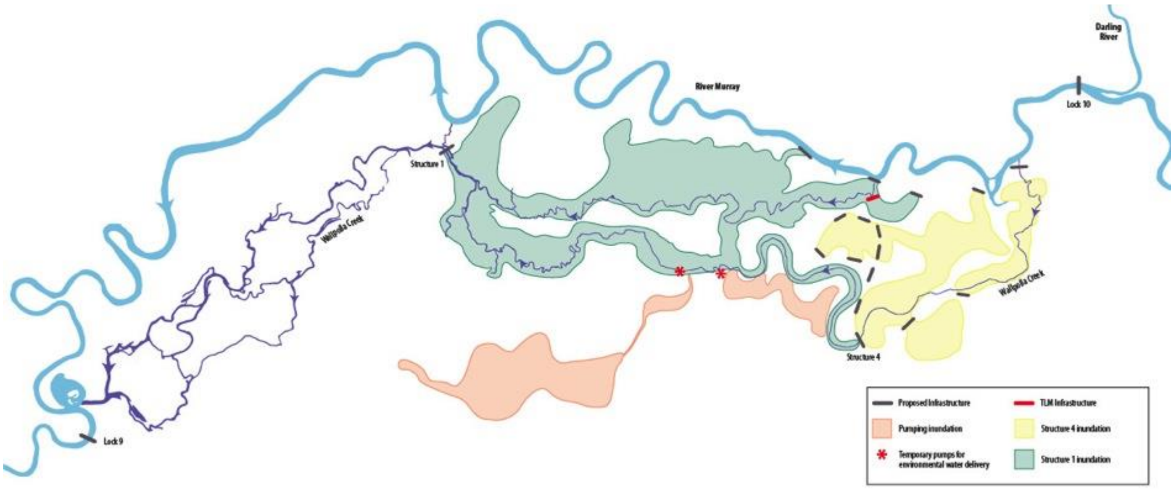


Figure 26. Planned SDL works and inundation at Wallpolla Island

The management areas represent three tiers of flooding. Water is detained in each area by stop banks constructed across the floodplain. Flow through the stop banks is controlled by regulators. Water is held at the highest level in Upper Wallpolla at 32.0 m AHD. Water can be released from this area to Mid Wallpolla where structures will detain water up to 30 m AHD. South Wallpolla will hold water at levels up to 30.6 m AHD and can be partially filled with water released from Mid Wallpolla. It can also be filled by pumping or by detaining peaks in river flow.

These works would be complemented by seasonal cycle of weir levels at Lock 9. The velocity of flow through Wallpolla Creek can be increased by reducing the Lock 9 level. This creates a greater water level gradient across the system and potentially increases both the velocity and discharge through Wallpolla Creek. For a weir pool level at Lock 9 of 27.4 m AHD, and based on a Murray River flow of 10,000ML/d, which allows inflows through Finnigan's Creek, Dedman's Creek, and Moorna Creek, 777 ML/d can be expected to flow through Wallpolla Creek. Modelling suggests that if the weir pool were dropped by a half metre to 26.9 m AHD, the average velocity in the reach downstream of Dedman's Creek could be increased from about 0.1 m/s to 0.15 m/s (50% increase) (Alluvium, 2013).

Raising the pool level at Lock 9 by 0.5 metre would provide riparian inundation and some wetland inundation in the western part of the island.

12.4.2 Lindsay Island Floodplain Management Project (Proposed)

The proposed Lindsay Island Floodplain Management Project uses a system of flow detention and regulating structures to promote floodplain inundation. The system would create two tiers of inundation and would utilise peaks in river flow, pumped water or a combination of the two. Supplementary works would promote inundation in three adjacent floodplain areas.

The aim of the project is to restore and protect watercourse, wetland and floodplain habitat integrity and productivity thereby:

- increasing population size, health and age structure of native fish populations in floodplain watercourses, including Murray Cod in Mullaroo Creek
- protecting and restore semi-permanent wetland habitat, increasing the range and resilience of aquatic fauna such as Growling Grass Frog
- providing seasonal waterbird breeding opportunities
- protecting and restoring frequent breeding opportunities for colonial nesting waterbirds
- protecting and restoring the productivity and structure of floodplain woodland and shrubland communities, increasing the viability of vertebrate fauna populations
- supplying organic matter to the Murray River channel ecosystem.

Figure 27. Conceptualisation of proposed Berribee Regulator on Lindsay River

The primary component of the works is a new regulator and levee system in the western part of Lindsay River near Berribee Homestead (Figure 27). The regulator will allow the level in Lindsay River to be raised as high as 23.2 m AHD. This would inundate up to 3,782 ha including floodplain areas adjacent to the river, Lake Wallawalla and the river benches and wetlands associated with the Mullaroo Creek and upper Lindsay River. Lock 7 would be raised at the same time by up to 1.1 m to provide the driving head required to achieve floodplain inundation.

A second tier of flooding would be created in the floodplain north of the Berribee Regulator. Water could be released from the Berribee weir pool to flood Billgoes Billabong and the Crankhandle Wetland Complex. A number of stop banks and regulators would contain water over an area of 335 ha.

Outflows from the Crankhandle Complex would create a third tier of flooding in Crankhandle West over an area of 147 ha. When flooding targets are met, water would be returned to the Murray River.

Supplementary works will promote floodplain inundation in three high-level floodplain areas; Lake Wallawalla East and West and Lindsay River South. Regulators will be constructed on these shallow floodplain basins to detain flood water or to store water pumped from the Berribee Weir pool.

Analysis of flood flow equivalence (GHD 2013) shows that:

- the proposed works achieve an inundation extent in the Berribee Weir Pool, Crankhandle Complex and Crankhandle West equivalent to flows between 50,000 and 90,000 ML/d
- the inundation of Lake Wallawalla West, Lake Wallawalla East and Lindsay South is equivalent to flows exceeding 120,000 ML/d

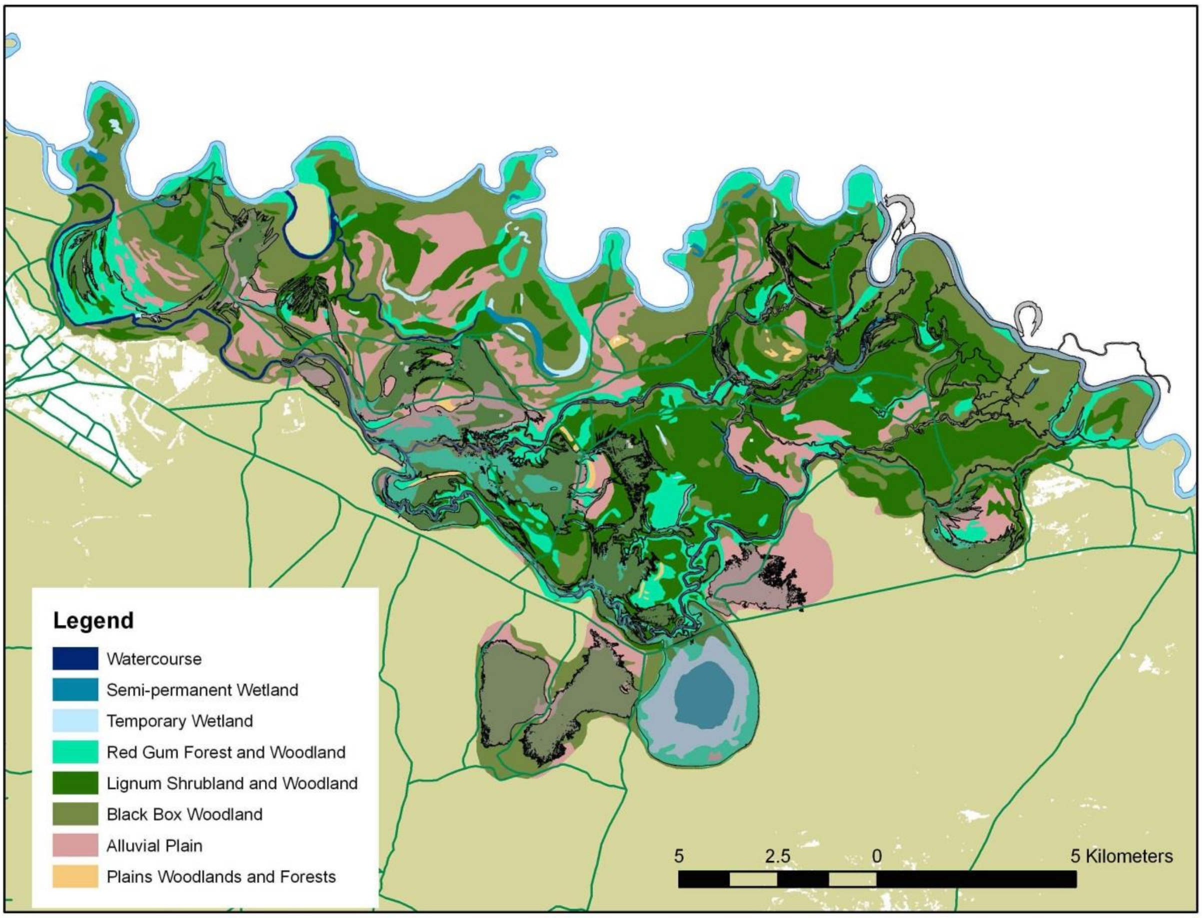


Figure 28. Extent of inundation from the proposed floodplain inundation project for Lindsay Island.

14 Managing Risks to Achieving Objectives

14.1 River System - Environmental Water Delivery Constraints

There are a number of constraints to water deliver to the study area (Table 33) which affect the development of environmental watering options. Relatively low, sustained flow deliveries will rarely be constrained and will be sufficient for most environmental water uses such as wetland watering, weir manipulation and floodplain inundation. Delivery constraints are likely to be significant for options involving large, sustained discharges, particularly at short notice. These may be sought to increase river discharge during unregulated flow events, to promote fast-flowing habitat in the river channel or to mitigate water quality risks during floodplain inundation events.

Table 33. Constraints on environmental water delivery to the study area

Valley	Component	Constraint Type	Reason for Constraint
Murray	**Hume to Yarrawonga**		
	Flow downstream of Hume Dam (Doctors Point) are typically limited to 25,000 ML/d under regulated flow conditions	Channel	River operational delivery constraint
	River channel has a capacity of 62,000 ML/d downstream of Yarrawonga Weir.	Channel	River operational delivery constraint
	Barmah-Millewa		
	The Barmah Choke channel capacity of approximately 8,000 - 10,000 ML/d during autumn, winter, summer	Channel	River operational delivery constraint
	The Barmah Choke channel capacity of approximately 22,000 ML/d during Spring	Channel	River operational delivery constraint
	Lake Victoria maximum inlet capacity = 10,000 ML/d	Channel	River operational delivery constraint
	Lake Victoria maximum outlet capacity at lake full supply level 9,000 ML/d (when tailwater level at Rufus River Junction is low)	Structure	Physical delivery limitation
Lower Darling	**Menindee Scheme**		
	Lake Wetherell Regulator Outlet Capacity at full supply level 5,000 ML/d (For low tailwater level at Weir 32)	Structure	Physical delivery limitation
	Lake Pamamaroo Regulator Outlet Capacity at full supply level 4,500 ML/d (For low tailwater levels at Weir 32)	Structure	Physical delivery limitation
	Lake Menindee Regulator Outlet Capacity at full supply level 4,300 ML/d (For low tailwater levels)	Structure	Physical delivery limitation
	Lake Cawndilla Regulator Outlet Capacity at full supply level 1,800 ML/d (For low tailwater levels)	Structure	Physical delivery limitation

Valley	Component	Constraint Type	Reason for Constraint
	Lower Darling River Main Weir outlet capacity (18,100 ML/d)	Main Weir	Physical delivery limitation
	9,300 ML/d at Weir 32 in-channel flow, without landholder impacts	Channel	River operational delivery constraint
	20,000 ML/d channel capacity at Weir 32	Channel	River operational delivery constraint

14.1.1 Lake Victoria

Lake Victoria can be operated to increase river flow below Lock 7 up to 8,000 ML/d for environmental purposes (DWLBC 2002). Releases could be made to augment flow peaks at short notice, but could only be sustained for a short period.

Releases from Lake Victoria are constrained by:

- the valve outlet capacity
- the volume in storage
- the downstream tailwater levels at the Rufus River junction and
- the erosion caused by sustained outflows over 8,000 ML/d.

The outlet capacity falls below 7,000 ML/d when lake levels are less than 23.5 m AHD. Water levels are managed under the Lake Victoria Operating Strategy to stabilise the foreshore and protect cultural heritage sites. The strategy can affect the times and rates at which water may be discharged from the lake.

14.2 Locks and Weirs

14.2.1 Locks and Weir 10 (Wentworth Weir)

Weir Description

Lock and Weir 10 (Figure 29) at Wentworth is an asset of the MDBA, for which NSW State Water Corporation has responsibility for operation and maintenance (Table 34). The structure is situated at 825 river km about 500 m downstream of the junction of the Murray and Darling Rivers. At the normal operating level of 30.8 m AHD, the influence of the weir extends upstream to Mildura Weir on the Murray River (a distance of 53 km), and about 60 km up the Darling River. The weir pool is maintained within a range of +/- 0.1 m of the normal operating level to provide access for irrigation pumps, to assist with navigation and to avoid inundation of assets (MDBA 2010).

The primary purpose of the weir is to maintain a high level of water for irrigation. The lock provides for navigation past the weir. A fishway has been built at the abutment of the lock to fish to pass upstream. The fishway was constructed in 2006 and is operable for flows up to 35,000 ML/d. Above this flow fish are able to pass directly through the weir structure.

Figure 29. Lock 10 showing the lock on the North (Right) bank. The fishway is on the South (left) bank. (Source: Google Maps)

Table 34. Lock 10 specifications (MDBA 2010)

Year of Completion	1929
Construction	Fixed weir and navigable pass consisting of concrete piers and stop logs. Lock Chamber Fishway
Distance from mouth	825 km
Length of weir pool	53 km on the Murray 60 km on the Darling
Weir pool storage at normal operating level	approx. 47 GL
Normal operating level	30.8 m AHD
Level of top of piers	31.3 m AHD
Flow at which upstream and downstream pools equalise	66,000 ML/d*

** Estimated from rating curve.*

During times of high flow components of the weir are removed to protect the structure and minimise impacts on flow (MDBA 2010). This involves the complete removal of the weir structure except for the concrete columns. The current operating rules require that the movable components are reinstated as soon as flows allow to minimise the risk that the weir pool will fall below the normal operating level and to minimise the rate of drawdown on the river downstream. The approximate flows of weir removal and reinstatement are shown in Table 35.

Table 35. Lock 10 Weir Removal and Reinstatement Flows (MDBC 2010)

Weir Status	Flow (ML/d)
Removal	55,000
Reinstatement	55,000

Operating Limitations

The following limits need to be considered when operating Lock and Weir 10 (MDBA 2010):

1. The maximum operational head differential between weir pool and tailwater level is 3.30 m, and with this head difference, upper pool level is not to exceed 30.80 m AHD.
2. The maximum operational head differential can be increased up to 3.60 m subject to specified increased surveillance including:

- Daily reading of the four vibrating wire piezometers and the two standpipe piezometers, with the results provided to Dam Surveillance Unit of State Water and Hume Dam Asset Manager.
- Comparison of these readings to previous readings by weir staff, with immediate advice of significant changes to the Dam Surveillance Unit of State Water and Murray Lower-Darling Asset Manager. Reading of the four vibrating wire piezometers and the two standpipe piezometers will only be carried out when two staff members are available.
- Daily visual surveillance looking for movements including differential movements of the structure or signs of structural distress. Changes to be immediately notified to Dam Surveillance Unit of State Water and Hume Dam Asset Manager.

The weir pool is normally maintained close to normal operating level (30.80 m AHD) within a range of +/- 0.1 m. A weir pool level that exceeds this range for more than a few days would require special approval from senior managers of Murray River Water, liaison with Goulburn Murray Water and public notification (MDBA 2010).

14.2.2 Lock and Weir 9 (Kulnine Weir)

Weir Description

Lock and Weir 9 (Figure 30), also known as the Kulnine Weir, is located at 765 river km (Table 36).

The weir was constructed in 1926 primarily to aid navigation. At the normal operating level of 27.4 m AHD the weir pool extends 63 km upstream to Wentworth Weir (Lock 10) and 30 km upstream in the Great Darling Anabranch (MDBA 2010).

The lock and weir is an MDBA asset operated by the South Australian Water Corporation (SA Water).

The weir diverts water to Lake Victoria, an important storage in the Murray-Darling Basin that contributes significantly to the management of water supply to South Australia. The weir raises the water level high enough to allow gravity diversion to Lake Victoria via the Frenchmans Creek Offtake, which is about 14 km upstream of the weir at 779 river km.

There is one major irrigation diversion from the Lock 9 weir pool, which supplies water to Lake Cullulleraine. The pump is located 500 m upstream of the weir on the left bank.

Figure 30. Lock 9 showing the lock on the south (left) bank. The fishway is on the north (right) bank. (Source: Google Maps)

The lock and weir has three main sections. The lock chamber allows boats to pass from one weir pool to the next while the weir is in place. The fixed weir comprises concrete piers with concrete stoplogs which are used for flow regulation. The navigable pass allows navigation through the structure when the lock and weir are removed. It consists of concrete piers, removable deck units and concrete stop logs.

Lock 9 has a fishway installed at the abutment on the northern (New South Wales) side of the river to allow native fish to migrate upstream.

Table 36. Lock 9 specifications (MDBA 2010)

Year of Completion	1926
Construction	Fixed weir and navigable pass consisting of concrete piers and stop logs. Lock Chamber Fishway
Distance from mouth	765 km
Length of weir pool	63 km
Weir pool storage at normal operating level	approx. 32 GL
Normal operating level	27.4 m AHD
Level of top of piers	28.03 m AHD
Flow at which upstream and downstream pools equalise	49,000 ML/d

During times of high flow or flooding, components of the weir are removed to protect the structure and minimise impacts on flow (MDBA 2010). This involves the complete removal of the weir structure except for the concrete columns. The current operating rules require that the movable components are reinstated as soon as flows allow to minimise the risk that the weir pool will fall below the normal operating level and to minimise the rate of drawdown on the river downstream. The approximate flows of weir removal and reinstatement are shown in Table 37.

Table 37. Lock 9 Weir Removal and Reinstatement Flows (MDBA 2010)

Weir Status	Lowest Flow (ML/d)	Highest Flow (ML/d)
Removal	48,000	58,000
Reinstatement	55,000	65,000

Under the current operating rules weirs can be raised or lowered to facilitate river operations, allow maintenance of the weir or lock, or to assist with environmental watering of wetlands connected to the weir pool (MDBA 2010).

Under normal operations the weir may be raised +0.1 m or lowered -0.2 from the normal operating level without for special approval (MDBA 2010). There should be close liaison between MDBA river operators and SA Water operators. To adjust the weir outside this range requires special approval from the Executive Director River Management Division MDBA and the operating authority (SA Water).

Operating Limitations

The design limit to raising the weir at Lock 9 is 27.7 m AHD or +0.3 m (MDBA 2010). This allows for 0.33 m freeboard to the top of the piers. Freeboard of as little as 0.1 m is permitted at other weirs. The weir structure is subject to ongoing review and it is possible that the freeboard requirement at Lock 9 may be altered in the future (pers. comm. Hugh Christie MDBA June 2012).

The top of the fishway walls is 28.10 m AHD. The fishway becomes less effective as the weir level rises and is ineffective when flooded. There is some scope to adjust the settings of the fishway to accommodate higher weir levels, but this is yet to be fully tested.

The access road to Lock 9 from NSW is cut when the weir is raised by more than 0.2 m (pers. comm. David Sly SA Water June 2012).

Stop banks are constructed on Carrs Creek at Carrs 1, Carrs 2, James 1 and James 2, all of which hold the Lock 9 weir pool in Carrs Creek. The banks are constructed to 27.67 m AHD (MDBA 2010). If overtopped, there is a high potential for scour and erosion at the toe of the banks and around the banks. A similar scour risk exists if access roads were overtopped (pers. comm. Nigel Rutherford, SA Water, 14 Dec 2012).

Other flood runners, some of which are blocked by stop banks, may also divert water at elevated pool levels.

There is no design limit specified for lowering Lock 9.

14.2.3 Lock and Weir 8 (Wangumma Weir)

Weir Description

Lock and Weir 8 (Figure 31), also known as the Wangumma Weir, is located 726 river km and 39 km downstream of Lock 9. At the normal operating level of 24.6 m AHD the weir pool extends up to Lock 9. Specifications for the Lock and Weir are presented in Table 38. .

The lock and weir is an MDBA asset and operated by SA Water. The weir has no major water management function and is operated primarily to aid navigation. It assists with the delivery of environmental water in the Mulcra Island Environmental Flows Project.

Figure 31. Lock 8 showing the lock on the north (right) bank. The fishway is on the south (left) bank (Source: Google Maps)

The lock and weir has three main sections. The lock chamber allows boats to pass from one weir pool to the next when the weir is in place. The fixed weir comprises concrete piers with concrete stoplogs which are used for flow regulation. The navigable pass allow navigation through the structure when the lock and weir are removed. It consists of concrete piers, removable deck units and concrete stop logs.

Lock 8 has a fishway installed at the abutment on the southern (Victorian) side of the river.

Table 38. Lock 8 specifications (MDBA 2010 and MDBC 2006)

Year of Completion	1935
Construction	Fixed weir and navigable pass consisting of concrete piers and stop logs. Lock Chamber Fishway
Distance from mouth	726 km
Length of weir pool	39 km
Weir pool storage at normal operating level	approx 24 GL
Normal operating level	24.6 m AHD
Level of top of piers	25.70 m AHD
Flow at which upstream and downstream pools equalise	37,000 ML/d

During times of high flow or flooding, components of the weir are removed to protect the structure and minimise impacts on flow (MDBA 2010). The weir removal and reinstatement flows are shown in Table 39.

Table 39. Lock 8 Weir Removal and Reinstatement Flows (MDBC 2010)

Weir Status	Lowest Flow (ML/d)	Highest Flow (ML/d)
Removal	40,000	50,000
Reinstatement	47,000	57,000

Under normal operations the weir may be raised +0.3 m or lowered -0.3 m from the normal operating level without special approval (MDBA 2010) as long as close liaison between MDBA river operators and SA Water operators is maintained. To adjust the weir outside this range requires special approval from the Executive Director River Management Division MDBA and the operating authority (SA Water).

Operating Limitations

The design limit to raising the weir at Lock 8 is 25.6 m AHD or +1.0 m, which allows 0.11 m of freeboard to the top of the piers (MDBA 2010). However, the weir may not be raised to more than 25.15 m AHD, or +0.55 m, unless special conditions are satisfied because (Operation limits.xls 6/9/2007 MDBA):

- the performance of the fishway is reduced when the weir is raised by more than +0.5 m
- the fishway walls may overtop when the weir is raised by more than +0.7 m
- above +0.6 m there is potential for water to pond against the left end of the abutment, potentially endangering the structural integrity of the weir (Mason and Kattou 2006)
- The weir may be raised higher if the following conditions are met:
- the structural integrity of the weir is not compromised or put at risk
- if necessary, sandbags or other techniques are applied to ensure there is no potential for water to pond against the left abutment of the weir
- water will not bypass the weir along nearby flood runners
- approval has been granted by the Executive Director, River Management Division MDBA.

Work has been completed to raise the fishway level to match the top of piers and to prevent water pooling against the left end of the abutment (pers. comm. Nigel Rutherford SA Water July 2014).

There is no design limit specified for lowering Lock 8 however flow to Potterwalkagee Creek at Stoney Crossing ceases if the weir is lowered to more than -0.6 m.

14.2.4 Lock and Weir 7 (Rufus River Weir)

Weir Description

Lock and Weir 7 also known as the Rufus River Weir is located 697 river km and 29 km downstream of Lock 6 (Table 40, Figure 32). At the normal operating level of 22.1 m AHD the weir pool extends up to Lock 8.

The offtake to the Mullaroo Creek anabranch is immediately upstream of the weir. The flow into Mullaroo Creek is determined by a regulator at the creek entrance and the water level in the weir pool. Under regulated conditions a flow of 200 to 800 ML/day usually maintained. The water passing down Mullaroo Creek flows into the Lindsay River which rejoins the Murray near the South Australian border, upstream of Lock 6 (MDBA 2010).

Figure 32. Lock 7 showing the lock on the South (left) bank. The fishway is on the north (right) bank (Source: Google Maps)

Table 40. Lock 7 specifications (MDBA 2010)

Year of Completion	1934
Construction	Fixed weir and navigable pass consisting of concrete piers and stop logs. Lock Chamber Fishway
Distance from mouth	697 km
Length of weir pool	29 km
Weir pool storage at normal operating level	13 GL
Normal operating level	22.1 m AHD
Level of top of piers	23.34 m AHD
Flow at which upstream and downstream pools equalise	25,000 ML/d

During times of high flow or flooding, components of the weir are removed to protect the structure and minimise impacts on flow (MDBA 2010). The weir removal and reinstatement flows are shown in Table 41. The weir at Lock 7 has a relatively low removal flow and provides little scope to adjust river levels when river discharge is elevated.

Table 41. Lock 7 Weir Removal and Reinstatement Flows (MDBC 2010)

Weir Status	Lowest Flow (ML/d)	Highest Flow (ML/d)
Removal	24,000	34,000
Reinstatement	30,500	40,500

Operating Limitations

The range for normal operations of Lock and Weir 7 where special approval is not required is between 21.9 m and 22.2 m AHD (normal operation is at 22.1m) (MDBA 2010). The lower limit results in a minimum flow down Mullaroo Creek of about 250 to 300 ML/day. Operational levels below 21.9m AHD and above 22.2m AHD require special approval from the Murray River Executive Director at MDBA and/or relevant State operating authority.

Pool levels below 21.9 m AHD may result in Mullaroo Creek ceasing to flow. Regulators on Mullaroo Creek and the two Lindsay River effluents have been designed to accommodate raised water levels and moderate flows into these watercourses.

The maximum practical level of Lock 7 is believed to be +0.5 m AHD. Higher levels inundate the adjacent floodplain in New South Wales where water may enter a watercourse and by-pass the weir. High water levels may also cut landholder access in the area (Scott Jaensch pers. comm. NSW Office of Water April 2015).

14.2.5 Lock and Weir 6 (Murtho Weir)

Weir Description

Lock and Weir 6 (Figure 33), also known as the Murtho Weir, is located at 620 river km and 77 km downstream of Lock 6. The normal operating level of the weir is 19.25 m AHD which can extend up to Lock 7 if river discharge is low. The lock and weir is difficult to drawdown due to:

- the potential to increase saline groundwater discharge to the river near Rufus River
- the potential to reduce inflows to the Chowilla anabranches where flowing habitat is important to native fish
- the potential to isolate irrigation pumps.

Specifications for the lock and weir are presented in Table 42.

Figure 33. Lock 6 showing the lock on the north (right) bank. The fishway is on the south (left) bank (Source: Google Earth)

Table 42. Lock 6 specifications (MDBA 2010)

Year of Completion	1930
Construction	Fixed weir and navigable pass consisting of concrete piers and stop logs. Lock Chamber Fishway
Distance from mouth	620 km
Length of weir pool	77 km*
Weir pool storage at normal operating level	34 GL
Normal operating level	19.25 m AHD
Level of top of piers	19.87 m AHD
Flow at which upstream and downstream pools equalise	81,000 ML/d**

* *Depending on river flows, at Full Supply Level the weir pool above L&W 6 does not necessarily extend the full distance upstream to the base of Weir 7.*

*** Estimated from rating curve.*

During times of high flow components of the weir are removed to protect the structure and minimise impacts on flow (MDBA 2010). The weir removal and reinstatement flows are shown in Table 43.

Table 43. Lock 6 Weir Removal and Reinstatement Flows (MDBC 2010)

Weir Status	Lowest Flow (ML/d)	Highest Flow (ML/d)
Removal	55,000	65,000
Reinstatement	67,500	77,500

Operating Limitations

The range for normal operations of Lock and Weir 6 where special approval is not required is between 19.15 m and 19.4 m AHD). When raising Lock 6 it is important to check the impacts on regulators and block banks on side creeks and anabranches (MDBA 2010). Levels above 19.39 m result in flows entering the Chowilla floodplain and creeks.

Since 2000 the pool has been below 19.33 m AHD 90 % of the time and below 19.40 m AHD for 98%. It has not gone below 19.00 m AHD, with only 6 days below 19.10 m AHD.

The scope for weir pool manipulation differs at each weir according to river hydraulics, structure design and local water uses. Ongoing investigations, monitoring and review is required to refine the limits of weir manipulation including the following questions:

- effects of higher or lower pool levels on fishway function
- the tailwater levels required to maintain upstream passage to fishways
- the location, level and stability of banks, roads and other structures that are overtopped by weir raising
- the level of pumps that may be isolated by weir lowering
- effects of raising weirs on upstream fast-flowing habitat
- the potential to inundate private infrastructure.

14.3 Considerations in Weir Manipulation

14.3.1 Weir Stability

In the past, the risk of weir instability has constrained the manipulation of water levels for environmental purposes. However recent investigations by URS (2014) have found that the risk of weir sliding or overturning failure does not increase to unacceptable levels as a result of environmental water level manipulation.

The weirs present an obstacle to the movement of water and are therefore subject to a downstream sliding force. Sliding instability increases as the head difference across the weirs increases.

The mass, and therefore the weight, of the weirs contributes to their stability. Submersion of the weirs by raising the upper weir pool while the tailwater level is high increases the buoyancy of the structures and reduces the downward force of their weight. The weirs are at an increased risk of overturning when the upper and lower weir pool levels are both elevated and the head difference across the weirs provides a turning moment. An analysis of the instability risk at water level settings and flows relevant to environmental manipulation of weirs is provided in Appendix B based on URS (2014) data. The analysis shows that for the range of weir levels and flows relevant to environmental water management the risk of sliding or overturning failure remains at acceptable levels.

14.3.2 Water Supply

Lowering weir pool levels may isolate pumps from water and interrupt water supply to irrigators and stock and domestic water users.

Neither the governments of South Australia nor New South Wales guarantee water supply. They are under no obligation to provide river level heights for diversion, water quality nor water quantity. The supply of water is maintained with the best reasonable efforts of the water resource managers. The governments cannot be held liable for water supply quantity, river level height nor water quantity.

However community expectations for weirs supply water is a significant consideration when planning environmental weir level adjustments.

The extent of irrigation development upstream of Lock 10 is significant. There are numerous pumps that are potentially isolated if the weir were lowered. A weir pool adjustment of -0.06 m will isolate diverters on the Darling River if Darling flows are low. At times of low Darling flow (less than 1,500 ML/d at Burtundy) the Lock 10 weir pool may be raised to maintain water levels to diverters at Ellerslie. A weir pool adjustment of -0.10 m will isolate diverters on the Murray River (Danny Bourke NSW State Water 10 Sep 2014).

The Lock 9 weir pool is accessed by water supply pumps to Lake Cullulleraine. The pumps operate at levels as low as -0.3 m (27.1 m AHD) from the normal operating level (Peter Ebner Lower Murray Water August 2013).

There are no significant diversions from the Lock 8 or 7 weir pools.

Lowering the Lock 6 weir pool has the potential to isolate pumps at Murtho and Lindsay Point. A survey of pumps upstream of Lock 6 in 2007 reported 35 irrigation pumps, 1 recreation pump and 18 domestic pumps. A weir level adjustment of -0.3 m would isolate nine of these while an adjustment of -0.5 would isolate 14 irrigation pumps (Table 44) (Rural Solutions SA 2007). Only 10 of the 35 irrigation pumps would be operable if the weir were lowered by 1 m.

Table 44. The number of irrigation and recreation pumps in Lock 6 - 7 that can operate at various levels below pool

Operation	-0.3 m	-0.5 m	-1.0 m
Can Operate	26	21	10
Extension Required	4	6	12
Relocate	5	8	13
Backwater	0	0	0
Unavailable	1	1	1

14.3.3 Navigation and River Access

Lowering weir pool levels for environmental purposes may exposure river traffic to reefs and other navigation hazards.

There is no obligation for the South Australian or New South Wales governments or the MDBA to maintain river levels to enable navigation in the river channel.

However community expectations for weirs supply water is a significant consideration when planning environmental weir level adjustments. The Merbein Houseboat trolleys are stranded by Lock 10 weir pool adjustments of more than -0.1 m (Danny Bourke NSW State Water 10 Sep 2014). No other similar constraints are known.

14.3.4 Navigation at the Locks

The Murray-Darling Basin Agreement is a schedule of the *Water Act 2007* (Cwth). Clause 68 of the agreement requires that locks must be operated so that the depth of water immediately downstream of the lock is

- sufficient for navigation of vessels drawing 1.4 m of water or
- any such depth determined by the MDBA under clause 124 except when the lock is closed for maintenance or when there is an emergency.

Clause 124 allows the MDBA to vary the depth of water immediately downstream of a lock during any period of special accounting (i.e. very low water reserves).

The reference points to evaluate depth are the upstream sill and downstream apron levels at each lock (Table 45).

Table 45. Downstream apron level (m AHD) of Locks 6, 7, 8, 9 and 10 (pers. comm. Nigel Rutherford, SA Water 31 Jan 2013) (URS 2004)

Structure	Downstream Apron (m AHD)	Minimum Level of Downstream Weir (m AHD)	Difference to Normal Operating Level of the Downstream Weir (m)
Lock 6	outside study area	-	-
Lock 7	16.83	18.23	0.62
Lock 8	19.19	20.59	1.51
Lock 9	21.52	22.92	1.68
Lock 10	25.8 (approx.)	27.2	0.2

The minimum depth downstream of Lock 10 lies close to the normal operating level of Lock 9. Lock 9 could not be adjusted by than -0.2 m at flows less than 5,000 ML/d. Flows above 5,000 ML/d provide sufficient tailwater to allow further lowering. Lock 10 tailwater levels at flows of 5,000 ML/d have been modelled for adjustments of -0.2 m and -0.4 m at Lock 9 (MDBA 2012) (Table 46). The modelled data indicate that Lock 9 may be lowered by -0.4 m at flows of 5,000 ML/d while meeting the navigation requirement. However, close monitoring of these levels would be required to verify the modelled estimate.

Table 46. MDBA modelled Lock 10 tailwater levels at 5,000 ML/d in relation to lowered Lock 9 weir pool levels (MDBA 2012)

Lock 9 Adjustment (m)	Lock 9 Level (m AHD)	Lock 10 Tailwater Level (m AHD)
-0.4	27.0	27.2
-0.2	27.2	27.4
0	27.4	27.6

Adjustments below -0.4 m are not contemplated at Lock 9 due to the limitations of the Cullulleraine pump offtake. The navigation requirement at Lock 10 does not present a constraint on weir adjustments at Lock 9 for flows above 5,000 ML/d.

14.3.5 Effects on Upstream Fast-flowing Habitat

Fast-flowing habitat occurs where floodplain watercourses divert water around weirs, distributing the head loss over a long reach of confined channel. Anabranches provide fast-flowing habitat around Lock 6 at Chowilla, Lock 7 at Lindsay Island and around Lock 8 at Potterwalkagee Creek. The Carrs-Cappitts-Bunberoo system provides a future opportunity for fast-flowing habitat around Lock 8.

Raising weirs potentially degrades fast-flowing habitat by extending the weir pool upstream. The hydraulic effects of weir raising on fast flowing habitat were explored upstream of Lock 6 by Mallen-Cooper et al. (2011). Under current conditions water entering Mullaroo Creek from the Murray River above Lock 7 flows over a distance of approximately 7.5 km before reaching the Lock 6 weir pool. Over this distance mean cross sectional velocities generally exceed 0.2 m/s (Figure 34). If Lock 6 is raised by 0.63 m to 19.88 m AHD there is a 50% reduction in fast flowing habitat (i.e. 0.31 to 0.5 m/s) in Mullaroo Creek.

This impact can be mitigated by raising Lock 7 to restore the head difference between the weirs. If the weir at Lock 7 is raised by 0.15 m similar velocities to current can be achieved. If the weir is raised by 0.65 m produces much higher velocities than existing conditions. Such high velocities may be detrimental to fish habitat.

Similar mitigation strategies would be required to maintain fast-flowing habitat in Chowilla Creek if Lock 5 were raised, in Potterwalkagee Creek if Lock 7 were raised and in Carrs-Cappitts-Bunberoo if Lock 8 were raised.

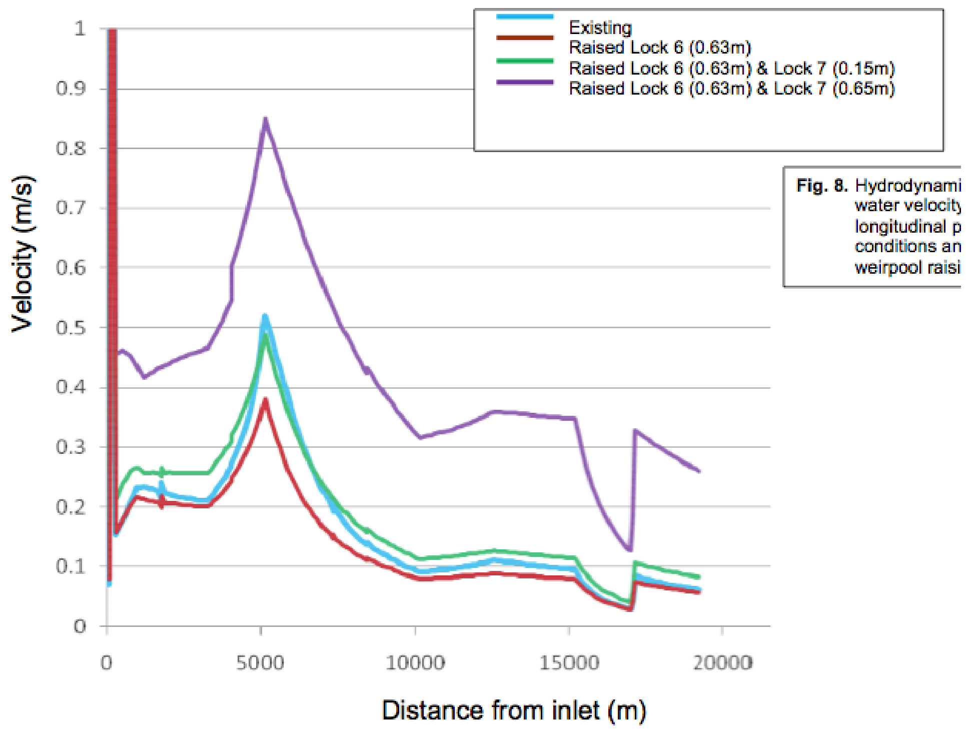


Figure 34. Hydrodynamic 1D model of mean water velocity in Mullaroo Creek then Lindsay River showing interpolated longitudinal profile under existing conditions and three scenarios of weir pool raising (Mallen-Cooper, Zampatti, et al. 2011).

14.3.6 Summary of key constraints on weir manipulation

Table 47. Key constraints on weir manipulation

Weir	Raising	Lowering
Lock 6	+0.4 m Lock 7 would have to be raised at the same time to maintain fast flowing habitat in Mullaroo Creek The Chowilla Floodplain Inundation Project has been designed for a maximum level of +0.62 m but so far a raising of only 0.4 m has been trialled successfully.	0 m Lowering is limited by risks to irrigator water supply.
Lock 7	0.5 m The weir is removed when flow exceeds approximately 20,000 ML/d so opportunities to raise the weir are constrained.	-0.2 m Lowering is limited the requirement to maintain fast-flowing habitat in Mullaroo Creek and to maintain water quality for Lindsay Point irrigators
Lock 8	+0.85 m Recent trials have confirmed this as the maximum level. The fishway walls overtop at higher levels.	-0.6 m There is no design limit to lowering Lock 8 but flow to Potterwalkagee Creek at Stoney Crossing ceases below this level.
Lock 9	+0.2 m Lock 9 access road is cut at higher levels. Improvements to roads and stop banks would allow the level to be raised to the design maximum of +0.35 m for short periods	-0.1 m Supply to the Lake Cullulleraine pumps is cut at lower levels. Modifications to the pump would be required to allow the weir to be lowered any further Lowering reduces the head which provides flow into Lake Victoria. However the times when weirs would be raised coincide with peak inflow time to the lake.
Lock 10	+0.1 m Greater raising is limited by inundation of private infrastructure.	-0.1 m Greater lowering is limited by risks to irrigator water supply.

At present, weir manipulations represent a change from normal operations. For each event, planning and coordination is required between weir operators, environmental managers and the MDBA. In addition, significant consultation is required with the community. It is hoped that seasonal water level cycles will become a routine part of weir operations at Locks 7 to 10.

The first step to making seasonal weir variation routine is to establish management arrangements and to adjust community expectations. This began at Locks 8 and 9 in 2013 where there are low levels of development and there are few impacts on river users. Initially the objectives are not ecological, but administrative: to establish processes for administration and community consultation. Once these arrangements are in place, ecological objectives will become the primary focus.

16 Knowledge Gaps and Recommendations

Recommendations covering three key areas have been made to assist with environmental water management for the Murray River Locks 6 – 10. These areas are:

- ecological objectives and risks;
- integrated regional objectives; and
- river hydraulics and operation.

16.1 Ecological Objectives and Risks

- Organic matter generated on floodplains and wetlands is generally seen as critical to the food web and productivity of riverine habitats. However there is little information available to describe how floodplain and wetlands in the lower Murray River should be managed to optimise this process.
- The hydraulics and habitats of the floodplain between Lake Victoria and the Murray River is poorly understood. An investigation is required to document flow paths, flow thresholds as well as wetland, watercourse and floodplain habitats is required. These investigations should identify environmental water management opportunities.
- An objective of floodplain inundation is to promote feeding and breeding by large numbers of water birds. The occasional failure of water birds to visit flooded areas in large numbers is has been attributed to a failure of regional environmental cues, such as high rainfall or regional inundation. It has been suggested that coordinated flooding over extensive areas within a region may be more effective than flooding individual sites. The coordination of floodplain watering events should be considered to better achieve this objective.
- The potential value and risks of promoting fast-flowing habitat in the Murray River channel should be investigated. It has been proposed that weirs could be lowered to increase fast-flowing habitat in the river when river discharge is elevated. The times and opportunities when this practice is feasible should be determined. The nature and significance of the ecological benefit should be evaluated. Potential impacts on other ecological objectives should be identified, such as the disconnection or drying of wetlands during winter and spring.
- Investigate the potential role of Lake Victoria as an important habitat component of the Murray River ecosystem. Investigations should consider the relative benefits of passing flows through the lake to the main river channel and the value of fish passage through the lake.
- The Darling River potentially has high environmental value as a fast flowing environment and spawning habitat for migrating golden and Silver Perch. The delivery of water at times that optimise migration and spawning opportunities for these species should be investigated.
- The cumulative effect of local risk practices to manage water quality risks in floodplain inundation projects should be considered on a regional basis. Management of black water, salinity and algal blooms can involve curtailing watering events, releasing water from floodplain storages or sourcing additional environmental water for dilution. These actions can affect the flow and water quality of the river which may impact on water quality at downstream sites. Management of water quality risks between sites should be addressed during watering events.

16.2 Integrated Regional Objectives

Throughout the study area, significant progress has been made to improve conservation outcomes through environmental water management. Initiatives have included works to improve fish passage, wetland regulation, floodplain inundation, water level variation and fast flowing habitat. Most of these initiatives have been developed independently by each jurisdiction with regard to local opportunities. The exception has been the Sea to Hume fish passage program, which has been implemented throughout the southern connected basin to address habitat requirements over a broad region in an integrated way.

Local actions have been effective in promoting conservation outcomes at each site. However, as these works are completed it is now become possible to take a more regional perspective to environmental watering priorities and opportunities. There are environmental threats and conservation priorities that are difficult to address on a site-by-site basis, and environmental outcomes that can only be achieved by managing the region in an integrated way.

This discussion presents a number of issues that will be important to the coordinated and integrated management of the reach.

Regional environmental water management is required where conservation outcomes depend on habitat components that are distributed across a region. To achieve conservation outcomes, they must be managed together in a coordinated way. Three regional objectives are proposed to guide future discussions on coordination and integration.

16.2.1 Golden Perch

The development of a healthy regional population of Golden Perch is an important conservation outcome. Golden Perch are widespread in the Murray-Darling basin but have declined in some areas and are given a Vulnerable conservation rating in Victoria. Golden Perch are highly mobile and use a variety of habitats throughout the region.

- Chowilla and Lindsay Island, which feature fast flowing habitat support healthy populations with high abundances and a wide range of size and age classes. Larvae and young-of-year have been collected indicating that these sites may be important recruitment zones. Connectivity between these zones and food sources and dispersal routes is required to maintain regional populations.
- Golden Perch spawn in response to rising river levels in spring and early summer. Regional coordination may be important in providing high flows and river levels in this period.
- Golden Perch have the potential to migrate over thousands of kilometres. The removal of barriers to fish passage along migration routes is important to the fish completing their life cycle.
- Spring freshes can provide a cue for spawning migration. Golden Perch will swim upstream and then release eggs which drift downstream towards productive nursery habitats. It has been suggested that spring freshes in the Darling River may attract Golden Perch in the Chowilla and Lindsay Island systems, and that eggs will drift downstream to floodplain watercourse and wetland habitats. Successful recruitment in this scenario involves the coordination of flows in the Darling with the availability of flooded habitat in the study area.

Golden Perch are a useful indicator of effective regional management. By targeting the requirements of this species, the requirements of other species can be met. These will include the maintenance of core fast-flowing habitat for Murray Cod, support for local migration by Murray Cod, the integration of wetland and watercourse habitat for freshwater catfish and the maintenance of productive riparian zones and seasonally connected wetlands.

16.2.2 Growling Grass Frog

A number of species of high conservation significance in the region depend on semi-permanent wetland habitats, which is one of the most depleted habitat components. Many low-lying wetlands are permanently inundated by weir pools, and are now less productive and have less complex, less diverse plant communities and structural habitat. Intermediate-level wetlands, inundated by flows between 30,000 and 60,000 ML/d downstream of Lock 10, are now flooded more briefly and intermittently and few remain flooded throughout the year.

Growling grass frog is a nationally vulnerable species that specifically depends on semi-permanent wetland water regimes. Persistent annual flooding is required to maintain dense communities of emergent macrophytes and to provide a refuge for adult frogs between flood events. A regional approach is important to this objective due to the fragmented nature of the habitat.

- Populations in isolated wetlands are vulnerable to local disturbances such as drought, predation or fire. A large number of wetlands, widely dispersed across the region provides security for the population at the regional scale.
- Dispersal opportunities are provided by high flow events during which growling grass frogs can colonise new wetland sites. Regionally coordinated flooding events will promote the wide dispersal of the species.
- Isolated populations are vulnerable to in-breeding. Intermittent connection during flood events are required to maintain genetic diversity.

Several other species that depend on semi-permanent habitats are also in decline, including Southern Purple-spotted Gudgeon, Southern Pygmy Perch, Flat-headed Galaxias and Murray Hardyhead. Their decline most likely reflects the loss of this habitat (Mallen-Cooper, Zampatti, et al. 2011).

16.3 River Hydraulics and Operations

- A hydraulic model of all the weir pools would be a useful tool to plan weir manipulations and calculate water use under a range of flow conditions.
- Investigate the constraints on raising and lowering the Lock 10 weir, particularly undesirable flooding of private infrastructure and isolation of pumps. Develop a program, if possible, for the gradual removal of constraints and initiation of a seasonal cycle in water levels.
- When weir pools are manipulated, monitoring is undertaken to check the function and levels of block banks, pumps, roads, fishways and weir infrastructure. This information should be documented centrally to ensure that future manipulation events are based on the best possible information and that constraints on weir manipulation can be identified and modified, if necessary.
- Aspects of the River Operations Manual have become out of date as new infrastructure is completed and investigations refine our understanding of existing structures. The operations manual should be updated using recent investigations such as the URS weir review (URS 2014).

- When planning environmental watering events, review all proposed actions across the region to coordinate ecological outcomes, risk management and water delivery.
- Investigate the performance of fishways under a range of weir levels to better understand the limits of weir operation and how objectives for variable water levels should be balanced with objectives for fish passage.
- Many river operation decisions, such as the transfer of water between storages or the operations to manage water quality, can have ecological impacts. It should be a step in that ecological impacts and opportunities are a consideration in all river operation decisions.
- Coordination of watering events should be addressed at the commencement of the annual water planning cycle, in January. Representatives from each state, the MDBA and Commonwealth Environmental Water Holder should review the environmental watering actions proposed at each site to identify potential interactions, synergies, conflicts, re-use opportunities and constraints on timing of events.

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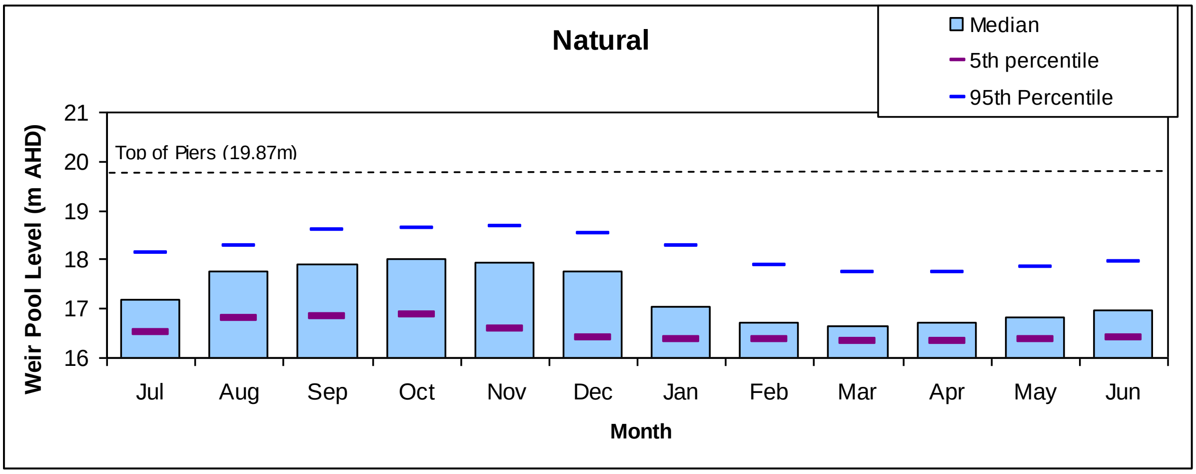
Appendix 1. Weir Stability

The variation in Lock and Weir Sliding and Overturning Safety Levels for normal weir pool levels are presented below. Safety levels have been colour coded, with the value in the colour coded cells equalling the lock and weir tailwater level. Purple corresponds to safety levels that are approximately equal to those experienced for normal weir pool and tail water levels. The green colour code corresponds to improved safety levels beyond that experienced under normal lock and weir operation. The blue colour code corresponds to reduced safety levels below that experienced with normal weir operation. Importantly the levels are still judged to be acceptable. Orange colour coding indicates unacceptable safety levels, and black cells indicate flows and levels outside the range of weir regulation.

The data indicate that none of the weirs have unacceptable sliding or overturing safety issues for normal weir pool levels up to river discharges approaching weir removal.

Lock 6



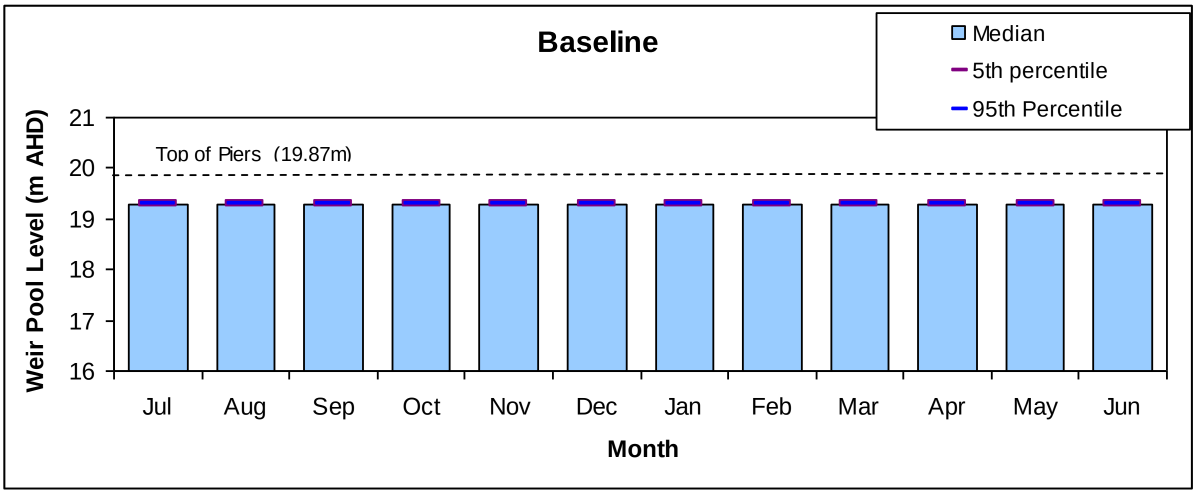
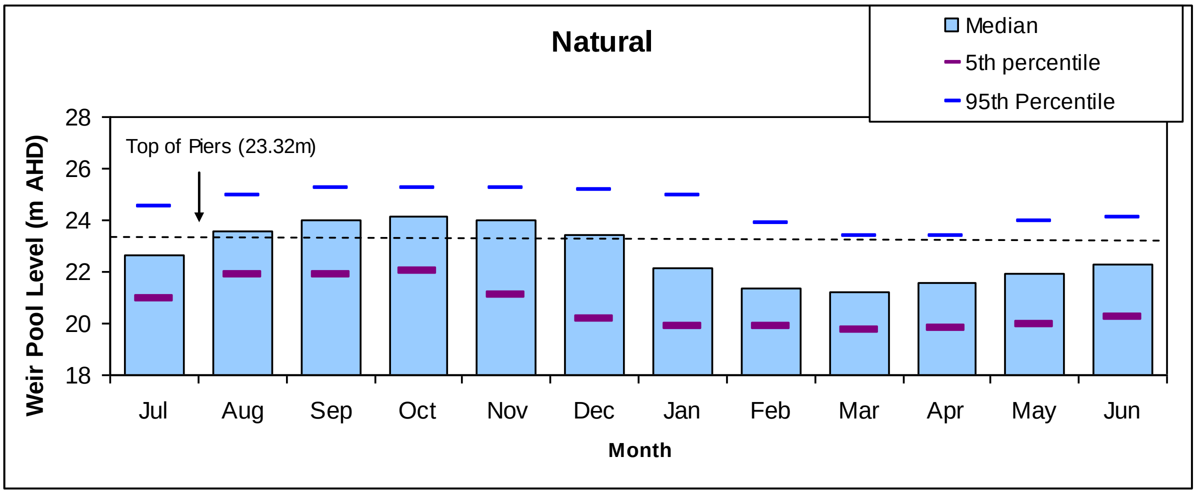


Figure 35. Distribution of monthly water levels at weir locations downstream of weirs for Natural and Baseline (2009 Development Conditions) flow series

Lock 7



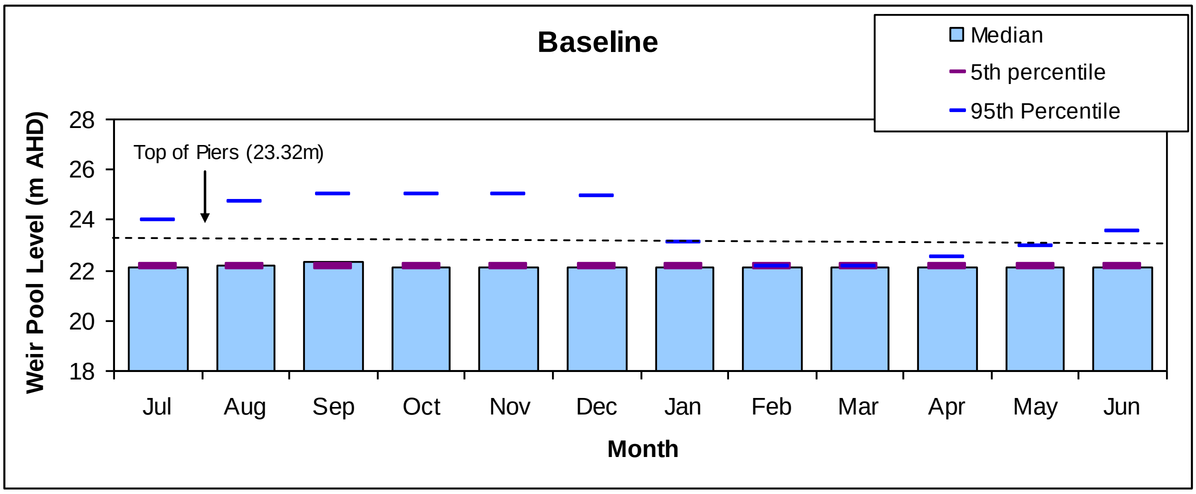


Figure 36. Distribution of monthly water levels at weir locations downstream of weirs for Natural and Baseline (2009 Development Conditions) flow series

Lock 8

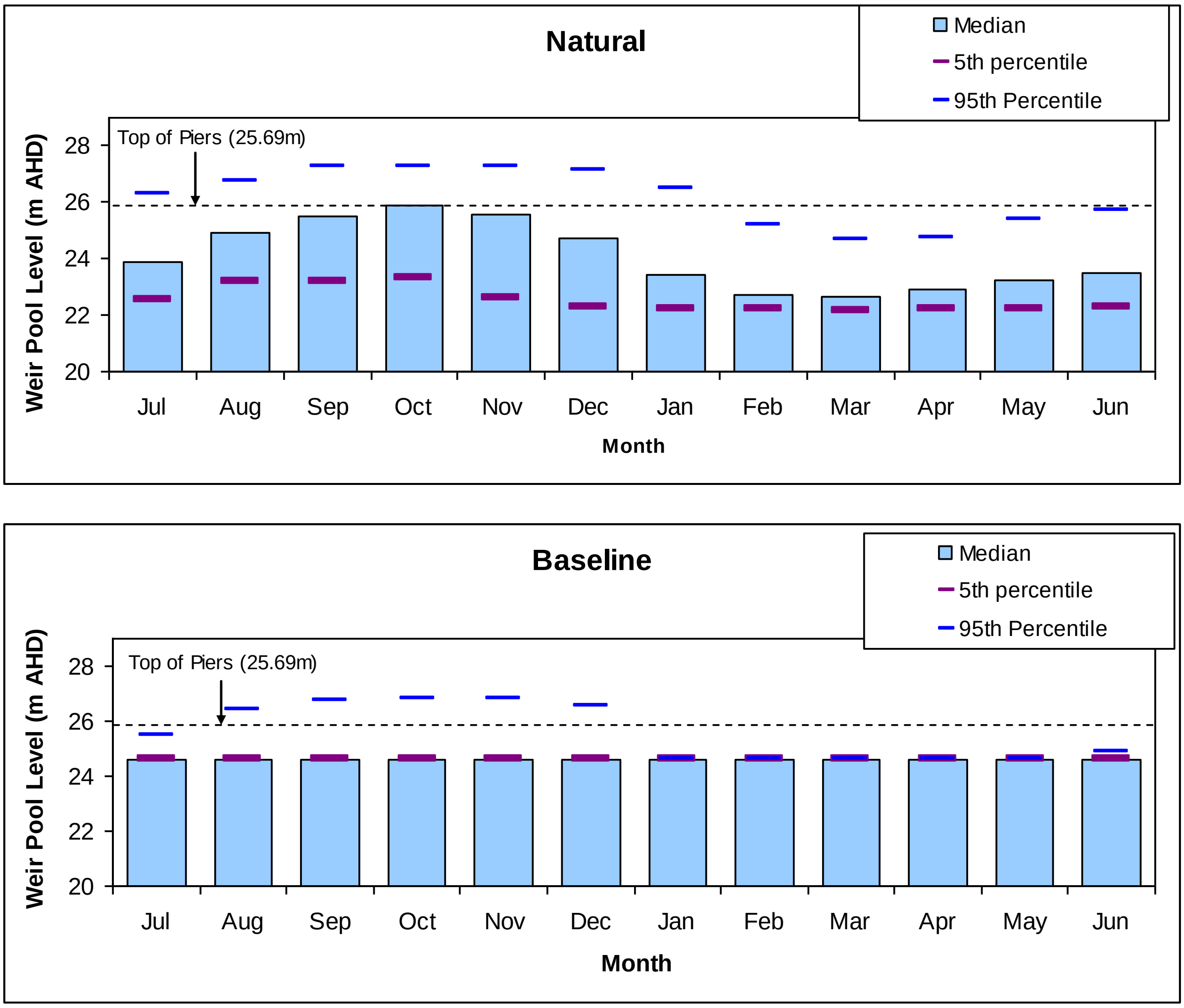
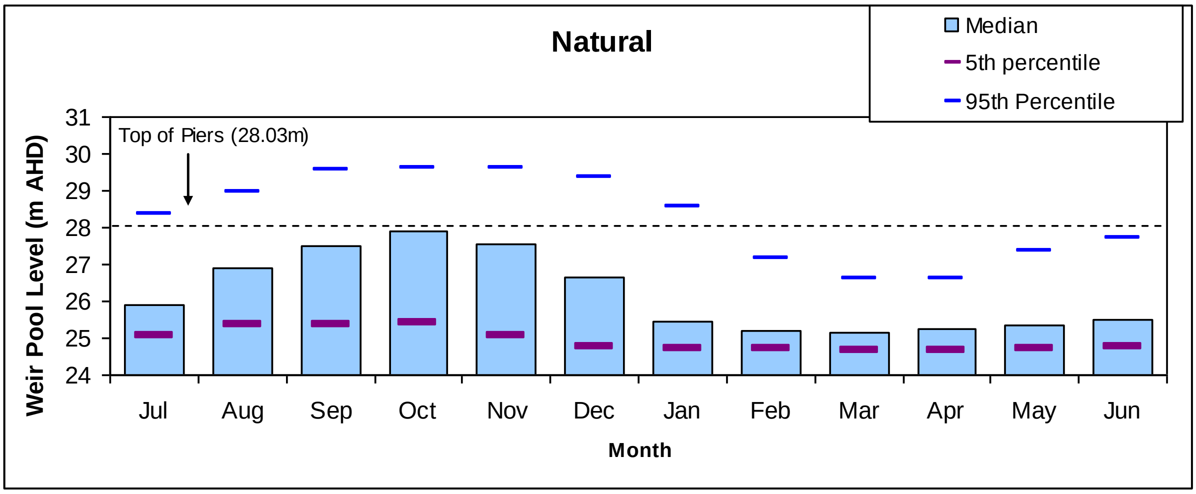


Figure 37. Distribution of monthly water levels at weir locations downstream of weirs for Natural and Baseline (2009 Development Conditions) flow series

Lock 9



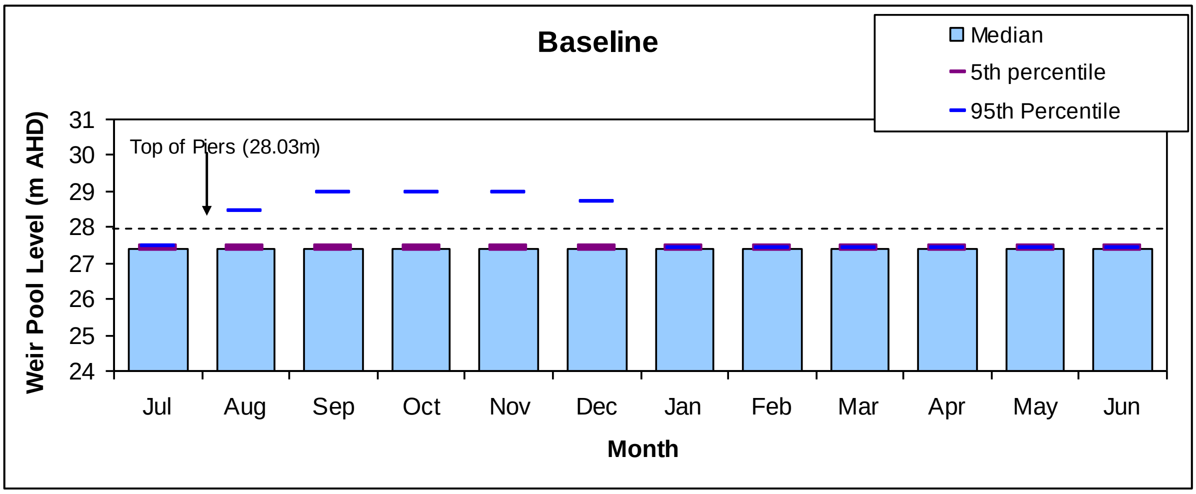
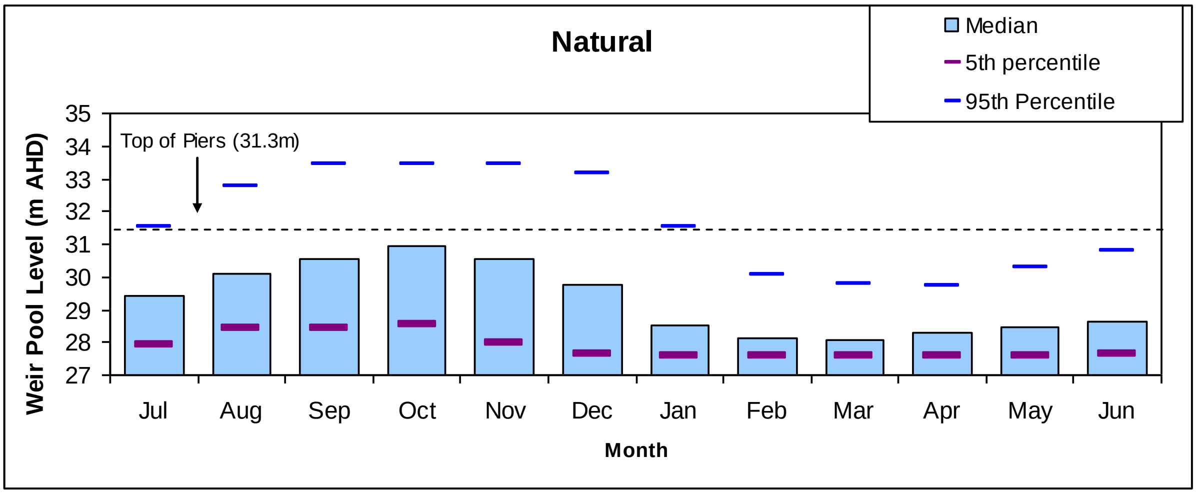


Figure 38. Distribution of monthly water levels at weir locations downstream of weirs for Natural and Baseline (2009 Development Conditions) flow series.

Lock 10



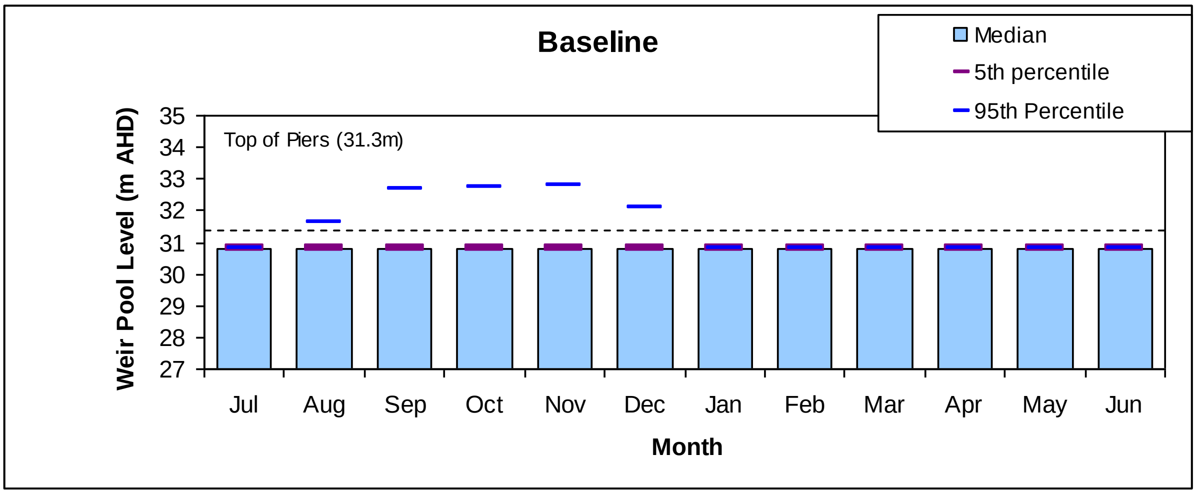


Figure 39. Distribution of monthly water levels at weir locations downstream of weirs for Natural and Baseline (2009 Development Conditions) flow series

16.3.1 Lock 10

		Flow Over Lock 10 Weir							
Lock 9 Weir Pool Level	0	10000	15000	20000	30000	40000	50000	55000	60000
28.03	28.0	28.6	29.0	29.3	30.0	30.6			
27.9	27.9	28.5	28.8	29.1	29.8	30.4			
27.8	27.8	28.4	28.7	29.0	29.7	30.3			
27.7	27.7	28.3	28.6	28.9	29.6	30.2			
27.6	27.6	28.2	28.5	28.8	29.5	30.1	30.7		
27.5	27.5	28.1	28.4	28.7	29.4	30.0	30.6		
27.4	27.4	28.0	28.3	28.6	29.3	29.9	30.5		
27.3	27.3	27.9	28.2	28.5	29.2	29.8	30.4		
27.2	27.2	27.8	28.1	28.4	29.1	29.7	30.3		
27.1	27.1	27.7	28.0	28.3	29.0	29.6	30.2		
27	27.0	27.6	27.9	28.2	28.9	29.5	30.1		
26.9	26.9	27.5	27.8	28.1	28.8	29.4	30.0		
26.8	26.8	27.4	27.7	28.0	28.7	29.3	29.9		
26.7	26.7	27.3	27.6	27.9	28.6	29.2	29.8		
26.6	26.6	27.2	27.5	27.8	28.5	29.1	29.7		
26.5	26.5	27.1	27.4	27.7	28.4	29.0	29.6		
26.4	26.4	27.0	27.3	27.6	28.3	28.9	29.5		
26.3	26.3	26.9	27.2	27.5	28.2	28.8	29.4		
26.2	26.2	26.8	27.1	27.4	28.1	28.7	29.3		
26.1	26.1	26.7	27.0	27.3	28.0	28.6	29.2		

Sliding Safety Level at Normal Lock 10 Weir Pool Level (30.86m)

Improved Safety Above that for Normal

Approximately Equal to Safety Level for Normal Pool (30.86m) and Normal Tailwater Levels (27.7m)

Acceptable Reduced Safety Level Below Normal

Unacceptable Safety Level

Table 48. Lock & Weir 10 Sliding Safety Levels with Varying Lock and Weir 9 Pool Level for Normal Weir 10 Pool Level (30.86 m AHD)

		Flow Over Lock 10 Weir							
Lock 9 Weir Pool Level	0	10000	15000	20000	30000	40000	50000	55000	60000
28.03	28.0	28.6	29.0	29.3	30.0	30.6			
27.9	27.9	28.5	28.8	29.1	29.8	30.4			
27.8	27.8	28.4	28.7	29.0	29.7	30.3			
27.7	27.7	28.3	28.6	28.9	29.6	30.2			
27.6	27.6	28.2	28.5	28.8	29.5	30.1	30.7		
27.5	27.5	28.1	28.4	28.7	29.4	30.0	30.6		
27.4	27.4	28.0	28.3	28.6	29.3	29.9	30.5		
27.3	27.3	27.9	28.2	28.5	29.2	29.8	30.4		
27.2	27.2	27.8	28.1	28.4	29.1	29.7	30.3		
27.1	27.1	27.7	28.0	28.3	29.0	29.6	30.2		
27	27.0	27.6	27.9	28.2	28.9	29.5	30.1		
26.9	26.9	27.5	27.8	28.1	28.8	29.4	30.0		
26.8	26.8	27.4	27.7	28.0	28.7	29.3	29.9		
26.7	26.7	27.3	27.6	27.9	28.6	29.2	29.8		
26.6	26.6	27.2	27.5	27.8	28.5	29.1	29.7		
26.5	26.5	27.1	27.4	27.7	28.4	29.0	29.6		
26.4	26.4	27.0	27.3	27.6	28.3	28.9	29.5		
26.3	26.3	26.9	27.2	27.5	28.2	28.8	29.4		
26.2	26.2	26.8	27.1	27.4	28.1	28.7	29.3		
26.1	26.1	26.7	27.0	27.3	28.0	28.6	29.2		

Overturning Safety Level at Normal Lock 10 Weir Pool Level (30.86m)

- Improved Safety Above that for Normal
- Approximately Equal to Safety Level for Normal Pool (30.86m) and Normal Tailwater Levels (27.7m)
- Acceptable Reduced Safety Level Below Normal
- Unacceptable Safety Level

Table 49. Lock & Weir 10 Overturning Safety Levels with Varying Lock and Weir 9 Pool Level for Normal Weir 10 Pool Level (30.86 m AHD

		Flow Over Lock 10 Weir							
Lock 9 Weir Pool Level	0	10000	15000	20000	30000	40000	50000	55000	60000
28.03	28.0	28.6	29.0	29.3	30.0	30.6			
27.9	27.9	28.5	28.8	29.1	29.8	30.4	31.0		
27.8	27.8	28.4	28.7	29.0	29.7	30.3	30.9	31.0	
27.7	27.7	28.3	28.6	28.9	29.6	30.2	30.8	30.9	
27.6	27.6	28.2	28.5	28.8	29.5	30.1	30.7	30.8	
27.5	27.5	28.1	28.4	28.7	29.4	30.0	30.6		
27.4	27.4	28.0	28.3	28.6	29.3	29.9	30.5		
27.3	27.3	27.9	28.2	28.5	29.2	29.8	30.4		
27.2	27.2	27.8	28.1	28.4	29.1	29.7	30.3		
27.1	27.1	27.7	28.0	28.3	29.0	29.6	30.2		
27	27.0	27.6	27.9	28.2	28.9	29.5	30.1		
26.9	26.9	27.5	27.8	28.1	28.8	29.4	30.0		
26.8	26.8	27.4	27.7	28.0	28.7	29.3	29.9		
26.7	26.7	27.3	27.6	27.9	28.6	29.2	29.8		
26.6	26.6	27.2	27.5	27.8	28.5	29.1	29.7		
26.5	26.5	27.1	27.4	27.7	28.4	29.0	29.6		
26.4	26.4	27.0	27.3	27.6	28.3	28.9	29.5		
26.3	26.3	26.9	27.2	27.5	28.2	28.8	29.4		
26.2	26.2	26.8	27.1	27.4	28.1	28.7	29.3		
26.1	26.1	26.7	27.0	27.3	28.0	28.6	29.2		

Sliding Safety Level at Top of Pier Lock 10 Weir Pool Level (30.86m)

- Improved Safety Above that for Normal
- Approximately Equal to Safety Level for Normal Pool (30.86m) and Normal Tailwater Levels (27.7m)
- Acceptable Reduced Safety Level Below Normal
- Unacceptable Safety Level

Table 50. Lock & Weir 10 Sliding Safety Levels with Varying Lock and Weir 9 Pool Level for Top of Piers Weir 10 Pool Level (31.30 m AHD

		Flow Over Lock 10 Weir							
Lock 9 Weir Pool Level	0	10000	15000	20000	30000	40000	50000	55000	60000
28.03	28.0	28.6	29.0	29.3	30.0	30.6			
27.9	27.9	28.5	28.8	29.1	29.8	30.4	31.0		
27.8	27.8	28.4	28.7	29.0	29.7	30.3	30.9	31.0	
27.7	27.7	28.3	28.6	28.9	29.6	30.2	30.8	30.9	
27.6	27.6	28.2	28.5	28.8	29.5	30.1	30.7	30.8	
27.5	27.5	28.1	28.4	28.7	29.4	30.0	30.6		
27.4	27.4	28.0	28.3	28.6	29.3	29.9	30.5		
27.3	27.3	27.9	28.2	28.5	29.2	29.8	30.4		
27.2	27.2	27.8	28.1	28.4	29.1	29.7	30.3		
27.1	27.1	27.7	28.0	28.3	29.0	29.6	30.2		
27	27.0	27.6	27.9	28.2	28.9	29.5	30.1		
26.9	26.9	27.5	27.8	28.1	28.8	29.4	30.0		
26.8	26.8	27.4	27.7	28.0	28.7	29.3	29.9		
26.7	26.7	27.3	27.6	27.9	28.6	29.2	29.8		
26.6	26.6	27.2	27.5	27.8	28.5	29.1	29.7		
26.5	26.5	27.1	27.4	27.7	28.4	29.0	29.6		
26.4	26.4	27.0	27.3	27.6	28.3	28.9	29.5		
26.3	26.3	26.9	27.2	27.5	28.2	28.8	29.4		
26.2	26.2	26.8	27.1	27.4	28.1	28.7	29.3		
26.1	26.1	26.7	27.0	27.3	28.0	28.6	29.2		

Overturning Safety Level at Top of Pier Lock 10 Weir Pool Level (31.30m)

- Improved Safety Above that for Normal
- Approximately Equal to Safety Level for Normal Pool (30.86m) and Normal Tailwater Levels (27.7m)
- Acceptable Reduced Safety Level Below Normal
- Unacceptable Safety Level

Table 51. Lock & Weir 10 Overturning Safety Levels with Varying Lock and Weir 9 Pool Level for Top of Piers Weir 10 Pool Level (31.3 m AHD)

16.3.2 Lock 9

		Flow Over Lock 9 Weir						
Lock 8 Weir Pool Level	0	10000	13000	18000	20000	30000	35000	40000
27.1								
27	27.0							
26.9	26.9							
26.8	26.8	27.0						
26.7	26.7	26.9						
25.4	25.4	25.6	25.8	26.1	26.2	26.9		
25.3	25.3	25.5	25.7	26.0	26.1	26.8	27.0	
25.2	25.2	25.4	25.6	25.9	26.0	26.7	26.9	
25.1	25.1	25.3	25.5	25.8	25.9	26.6	26.8	27.0
25	25.0	25.2	25.4	25.7	25.8	26.5	26.7	26.9
24.8	24.8	25.0	25.2	25.5	25.6	26.3	26.5	26.7
24.7	24.7	24.9	25.1	25.4	25.5	26.2	26.4	
24.6	24.6	24.8	25.0	25.3	25.4	26.1		
24.5	24.5	24.7	24.9	25.2	25.3	26.0		
24.4	24.4	24.6	24.8	25.1	25.2	25.9		
24.3	24.3	24.5	24.7	25.0	25.1	25.8		
24.2	24.2	24.4	24.6	24.9	25.0	25.7		
24.1	24.1	24.3	24.5	24.8	24.9	25.6		
24	24.0	24.2	24.4	24.7	24.8	25.5		
23.8	23.8	24.0	24.2	24.5	24.6	25.3		

Sliding Safety Level at Normal Lock 9 Weir Pool Level (27.4m)

- Improved Safety of Safety Above that for Normal
- Approximately Equal to Safety Level for Normal Pool (27.4m) and Normal Tailwater Levels (24.75m)
- Acceptable Reduced Safety Level Below Normal
- Unacceptable Safety Level

Table 52. Lock & Weir 9 Sliding Safety Levels with Varying Lock and Weir 8 Pool Levels for Normal Weir 9 Pool Level (27.4 m AHD)

		Flow Over Lock 9 Weir						
Lock 8 Weir Pool Level	0	10000	13000	18000	20000	30000	35000	40000
27.1								
27	27.0							
26.9	26.9	27.1						
26.8	26.8	27.0						
26.7	26.7	26.9	27.1	27.4	27.5			
25.4	25.4	25.6	25.8	26.1	26.2	26.9	27.1	
25.3	25.3	25.5	25.7	26.0	26.1	26.8	27.0	
25.2	25.2	25.4	25.6	25.9	26.0	26.7	26.9	27.1
25.1	25.1	25.3	25.5	25.8	25.9	26.6	26.8	27.0
25	25.0	25.2	25.4	25.7	25.8	26.5	26.7	26.9
24.8	24.8	25.0	25.2	25.5	25.6	26.3	26.5	
24.7	24.7	24.9	25.1	25.4	25.5	26.2		
24.6	24.6	24.8	25.0	25.3	25.4	26.1		
24.5	24.5	24.7	24.9	25.2	25.3			
24.4	24.4	24.6	24.8	25.1	25.2			
24.3	24.3	24.5	24.7	25.0	25.1			
24.2	24.2	24.4	24.6	24.9	25.0			
24.1	24.1	24.3	24.5	24.8	24.9			
24	24.0	24.2	24.4	24.7	24.8			
23.8	23.8	24.0	24.2	24.5	24.6			

Overturning Safety Level at Normal Lock 9 Weir Pool Level (27.4m)

Improved Safety of Safety Above that for Normal

Approximately Equal to Safety Level for Normal Pool (27.4m) and Normal Tailwater Levels (24.75m)

Acceptable Reduced Safety Level Below Normal

Unacceptable Safety Level

Table 53. Lock & Weir 9 Overturning Safety Levels with Varying Lock and Weir 8 Pool Levels for Normal Weir 9 Pool Level (27.4 m AHD)

		Flow Over Lock 9 Weir						
Lock 8 Weir Pool Level	0	10000	13000	18000	20000	30000	35000	40000
27.1	27.1	27.3	27.5					
27	27.0	27.2	27.4					
26.9	26.9	27.1	27.3					
26.8	26.8	27.0	27.2	27.5				
26.7	26.7	26.9	27.1	27.4	27.5			
25.4	25.4	25.6	25.8	26.1	26.2	26.9	27.1	27.3
25.3	25.3	25.5	25.7	26.0	26.1	26.8	27.0	27.2
25.2	25.2	25.4	25.6	25.9	26.0	26.7	26.9	27.1
25.1	25.1	25.3	25.5	25.8	25.9	26.6	26.8	27.0
25	25.0	25.2	25.4	25.7	25.8	26.5	26.7	26.9
24.8	24.8	25.0	25.2	25.5	25.6	26.3	26.5	26.7
24.7	24.7	24.9	25.1	25.4	25.5	26.2	26.4	
24.6	24.6	24.8	25.0	25.3	25.4	26.1		
24.5	24.5	24.7	24.9	25.2	25.3	26.0		
24.4	24.4	24.6	24.8	25.1	25.2	25.9		
24.3	24.3	24.5	24.7	25.0	25.1	25.8		
24.2	24.2	24.4	24.6	24.9	25.0	25.7		
24.1	24.1	24.3	24.5	24.8	24.9	25.6		
24	24.0	24.2	24.4	24.7	24.8	25.5		
23.8	23.8	24.0	24.2	24.5	24.6	25.3		

Sliding Safety Level at Top of Pier Lock 9 Weir Pool Level (28.03m)

Improved Safety of Safety Above that for Normal

Approximately Equal to Safety Level for Normal Pool (27.4m) and Normal Tailwater Levels (24.75m)

Acceptable Reduced Safety Level Below Normal

Unacceptable Safety Level

Table 54. Lock & Weir 9 Sliding Safety Levels with Varying Lock and Weir 8 Pool Levels for Top of Pier Weir 9 Pool Level (28.03 m AHD)

		Flow Over Lock 9 Weir						
Lock 8 Weir Pool Level	0	10000	13000	18000	20000	30000	35000	40000
27.1	27.1	27.3	27.5					
27	27.0	27.2	27.4					
26.9	26.9	27.1	27.3					
26.8	26.8	27.0	27.2	27.5				
26.7	26.7	26.9	27.1	27.4	27.5			
25.4	25.4	25.6	25.8	26.1	26.2	26.9	27.1	27.3
25.3	25.3	25.5	25.7	26.0	26.1	26.8	27.0	27.2
25.2	25.2	25.4	25.6	25.9	26.0	26.7	26.9	27.1
25.1	25.1	25.3	25.5	25.8	25.9	26.6	26.8	27.0
25	25.0	25.2	25.4	25.7	25.8	26.5	26.7	26.9
24.8	24.8	25.0	25.2	25.5	25.6	26.3	26.5	26.7
24.7	24.7	24.9	25.1	25.4	25.5	26.2	26.4	
24.6	24.6	24.8	25.0	25.3	25.4	26.1		
24.5	24.5	24.7	24.9	25.2	25.3			
24.4	24.4	24.6	24.8	25.1	25.2			
24.3	24.3	24.5	24.7	25.0	25.1			
24.2	24.2	24.4	24.6	24.9	25.0			
24.1	24.1	24.3	24.5	24.8	24.9			
24	24.0	24.2	24.4	24.7	24.8			
23.8	23.8	24.0	24.2	24.5	24.6			

Overturning Safety Level at Top of Pier Lock 9 Weir Pool Level (28.03m)

- Improved Safety of Safety Above that for Normal
- Approximately Equal to Safety Level for Normal Pool (27.4m) and Normal Tailwater Levels (24.75m)
- Acceptable Reduced Safety Level Below Normal
- Unacceptable Safety Level

Table 55. Lock & Weir 9 Overturning Safety Levels with Varying Lock and Weir 8 Pool Levels for Top of Pier Weir 9 Pool Level (28.03 m AHD).

16.3.3 Lock 8

	Flow Over Lock 8 Weir							
Lock 7 Weir Pool Level	0	5000	10000	15000	20000	30000	35000	40000
23.3	23.3	23.4	23.7	24.1	24.5			
23.2	23.2	23.3	23.6	24.0	24.4			
23.1	23.1	23.2	23.5	23.9	24.3			
23	23.0	23.1	23.4	23.8	24.2			
22.9	22.9	23.0	23.3	23.7	24.1	24.4	24.5	
22.8	22.8	22.9	23.2	23.6	24.0	24.3	24.4	
22.7	22.7	22.8	23.1	23.5	23.9	24.2		
22.6	22.6	22.7	23.0	23.4	23.8	24.1		
22.5	22.5	22.6	22.9	23.3	23.7	24.0		
22.4	22.4	22.5	22.8	23.2	23.6			
22.3	22.3	22.4	22.7	23.1	23.5			
22.2	22.2	22.3	22.6	23.0	23.4			
22.1	22.1	22.2	22.5	22.9	23.3			
22	22.0	22.1	22.4	22.8				
21.9	21.9	22.0	22.3	22.7				

Sliding Safety Level at Normal Lock 8 Weir Pool Level (24.6m)

Improved Safety of Safety Above that for Normal

Approximately Equal to Safety Level for Normal Pool (24.6m) and Normal Tailwater Levels (22.1m)

Acceptable Reduced Safety Level Below Normal

Unacceptable Safety Level

Table 56. Lock & Weir 8 Sliding Safety Levels with Varying Lock and Weir 7 Pool Levels for Normal Weir 8 Pool Level (24.6m

Lock 7 Weir Pool Level	Flow Over Lock 8 Weir							
	0	5000	10000	15000	20000	30000	35000	40000
23.3	23.3	23.4	23.7	24.1	24.5			
23.2	23.2	23.3	23.6	24.0	24.4			
23.1	23.1	23.2	23.5	23.9	24.3			
23	23.0	23.1	23.4	23.8	24.2			
22.9	22.9	23.0	23.3	23.7	24.1	24.4	24.5	
22.8	22.8	22.9	23.2	23.6	24.0	24.3	24.4	
22.7	22.7	22.8	23.1	23.5	23.9	24.2		
22.6	22.6	22.7	23.0	23.4	23.8	24.1		
22.5	22.5	22.6	22.9	23.3	23.7	24.0		
22.4	22.4	22.5	22.8	23.2	23.6			
22.3	22.3	22.4	22.7	23.1	23.5			
22.2	22.2	22.3	22.6	23.0	23.4			
22.1	22.1	22.2	22.5	22.9	23.3			
22	22.0	22.1	22.4	22.8	23.2			
21.9	21.9	22.0	22.3	22.7	23.1			

Overturning Safety Level at Normal Lock 8 Weir Pool Level (24.6m)

Improved Safety Above that for Normal

Approximately Equal to Safety Level for Normal Pool (24.6m) and Normal Tailwater Levels (22.1m)

Acceptable Reduced Safety Level Below Normal

Unacceptable Safety Level

Table 57. Lock & Weir 8 Overturning Safety Levels with Varying Lock and Weir 7 Pool Levels for Normal Weir 8 Pool Level (24.6m)

	Flow Over Lock 8 Weir							
Lock 7 Weir Pool Level	0	5000	10000	15000	20000	30000	35000	40000
23.3	23	23.4	23.7	24.1	24.45	24.8	24.9	24.9
23.2	23	23.3	23.6	24	24.35	24.7	24.8	24.8
23.1	23	23.2	23.5	23.9	24.25	24.6	24.7	
23	23	23.1	23.4	23.8	24.15	24.5	24.6	
22.9	23	23	23.3	23.7	24.05	24.4	24.5	
22.8	23	22.9	23.2	23.6	23.95	24.3	24.4	
22.7	23	22.8	23.1	23.5	23.85	24.2		
22.6	23	22.7	23	23.4	23.75	24.1		
22.5	23	22.6	22.9	23.3	23.65	24		
22.4	22	22.5	22.8	23.2	23.55			
22.3	22	22.4	22.7	23.1	23.45			
22.2	22	22.3	22.6	23	23.35			
22.1	22	22.2	22.5	22.9	23.25			
22	22	22.1	22.4	22.8				
21.9	22	22	22.3	22.7				

Sliding Safety Level at Top of Piers Lock 8 Weir Pool Level (25.69m)

- Improved Safety of Safety Above that for Normal
- Approximately Equal to Safety Level for Normal Pool (24.6m) and Normal Tailwater Levels (22.1m)
- Acceptable Reduced Safety Level Below Normal
- Unacceptable Safety Level

Table 58. Lock & Weir 8 Sliding Safety Levels with Varying Lock and Weir 7 Pool Levels for Top of Piers Weir 8 Pool Level (25.69 m AHD)

Lock 7 Weir Pool Level	Flow Over Lock 8 Weir							
	0	5000	10000	15000	20000	30000	35000	40000
23.3	23.3	23.4	23.7	24.1	24.45	24.8	24.9	24.9
23.2	23.2	23.3	23.6	24	24.35	24.7	24.8	24.8
23.1	23.1	23.2	23.5	23.9	24.25	24.6	24.7	
23	23	23.1	23.4	23.8	24.15	24.5	24.6	
22.9	22.9	23	23.3	23.7	24.05	24.4	24.5	
22.8	22.8	22.9	23.2	23.6	23.95	24.3	24.4	
22.7	22.7	22.8	23.1	23.5	23.85	24.2		
22.6	22.6	22.7	23	23.4	23.75	24.1		
22.5	22.5	22.6	22.9	23.3	23.65	24		
22.4	22.4	22.5	22.8	23.2	23.55			
22.3	22.3	22.4	22.7	23.1	23.45			
22.2	22.2	22.3	22.6	23	23.35			
22.1	22.1	22.2	22.5	22.9	23.25			
22	22	22.1	22.4	22.8				
21.9	21.9	22	22.3	22.7				

Overturning Safety Level at Top of Piers Lock 8 Weir Pool Level (25.69m)

- Improved Safety Above that for Normal
- Approximately Equal to Safety Level for Normal Pool (24.6m) and Normal Tailwater Levels (22.1m)
- Acceptable Reduced Safety Level Below Normal
- Unacceptable Safety Level

Table 59. Lock & Weir 8 Overturning Safety Levels with Varying Lock and Weir 7 Pool Levels for Top of Piers Weir 8 Pool Level (25.69 m AHD)

16.3.4 Lock 7

Lock 6 Weir Pool Level	Flow Over Lock 7 Weir								
	0	5000	10000	15000	20000	30000	40000	50000	60000
19.87	19.9	20.6	21.3	21.8					
19.75	19.8	20.5	21.2	21.7					
19.65	19.7	20.4	21.1	21.6					
19.55	19.6	20.3	21.0	21.5					
19.45	19.5	20.2	20.9	21.4	21.9				
19.35	19.4	20.1	20.8	21.3	21.8				
19.25	19.3	20.0	20.7	21.2	21.7				
19.15	19.2	19.9	20.6	21.1	21.6				
19.05	19.1	19.8	20.5	21.0	21.5				
18.95	19.0	19.7	20.4	20.9	21.4				
18.85	18.9	19.6	20.3	20.8	21.3				
18.75	18.8	19.5	20.2	20.7	21.2	22.0			
18.65	18.7	19.4	20.1	20.6	21.1	21.9			
18.55	18.6	19.3	20.0	20.5	21.0	21.8			
18.45	18.5	19.2	19.9	20.4	20.9	21.7			
18.35	18.4	19.1	19.8	20.3	20.8	21.6			
18.25	18.3	19.0	19.7	20.2	20.7	21.5			
18.15	18.2	18.9	19.6	20.1	20.6	21.4			
18.05	18.1	18.8	19.5	20.0	20.5	21.3	22.0		
17.95	18.0	18.7	19.4	19.9	20.4	21.2	21.9		
17.85	17.9	18.6	19.3	19.8	20.3	21.1	21.8		
17.75	17.8	18.5	19.2	19.7	20.2	21.0	21.7		

Sliding Safety Level at Normal Lock 7 Weir Pool Level (22.1m)

Improved Safety of Safety Above that for Normal

Approximately Equal to Safety Level for Normal Pool (22.1m) and Normal Tailwater Levels (19.7m)

Acceptable Reduced Safety Level Below Normal

Unacceptable Safety Level

Table 60. Lock & Weir 7 Sliding Safety Levels with Varying Lock and Weir 6 Pool Levels for Normal Weir 7 Pool Level (22.1 m AHD)

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Lock 6 Weir Pool Level	Flow Over Lock 7 Weir								
	0	5000	10000	15000	20000	30000	40000	50000	60000
19.87	19.9	20.6	21.3	21.8					
19.75	19.8	20.5	21.2	21.7					
19.65	19.7	20.4	21.1	21.6					
19.55	19.6	20.3	21.0	21.5					
19.45	19.5	20.2	20.9	21.4	21.9				
19.35	19.4	20.1	20.8	21.3	21.8				
19.25	19.3	20.0	20.7	21.2	21.7				
19.15	19.2	19.9	20.6	21.1	21.6				
19.05	19.1	19.8	20.5	21.0	21.5				
18.95	19.0	19.7	20.4	20.9	21.4				
18.85	18.9	19.6	20.3	20.8	21.3				
18.75	18.8	19.5	20.2	20.7	21.2	22.0			
18.65	18.7	19.4	20.1	20.6	21.1	21.9			
18.55	18.6	19.3	20.0	20.5	21.0	21.8			
18.45	18.5	19.2	19.9	20.4	20.9	21.7			
18.35	18.4	19.1	19.8	20.3	20.8	21.6			
18.25	18.3	19.0	19.7	20.2	20.7	21.5			
18.15	18.2	18.9	19.6	20.1	20.6	21.4			
18.05	18.1	18.8	19.5	20.0	20.5	21.3	22.0		
17.95	18.0	18.7	19.4	19.9	20.4	21.2	21.9		
17.85	17.9	18.6	19.3	19.8	20.3	21.1	21.8		
17.75	17.8	18.5	19.2	19.7	20.2	21.0	21.7		

Overturning Safety Level at Normal Lock 7 Weir Pool Level (22.1m)

Improved Safety of Above that for Normal

Approximately Equal to Safety Level for Normal Pool (22.1m) and Normal Tailwater Levels (19.7m)

Acceptable Reduced Safety Level Below Normal

Unacceptable Safety Level

Table 61. Lock & Weir 7 Overturning Safety Levels with Varying Lock and Weir 6 Pool Levels for Normal Weir 7 Pool Level (22.1 m AHD).

Lock 6 Weir Pool Level	Flow Over Lock 7 Weir								
	0	5000	10000	15000	20000	30000	40000	50000	60000
19.87	20	20.6	21.27	21.82	22.32				
19.75	20	20.5	21.15	21.7	22.2				
19.65	20	20.4	21.05	21.6	22.1	22.9			
19.55	20	20.3	20.95	21.5	22	22.8			
19.45	19	20.2	20.85	21.4	21.9	22.7			
19.35	19	20.1	20.75	21.3	21.8	22.6			
19.25	19	20	20.65	21.2	21.7	22.5			
19.15	19	19.9	20.55	21.1	21.6	22.4			
19.05	19	19.8	20.45	21	21.5	22.3	23		
18.95	19	19.7	20.35	20.9	21.4	22.2	22.9		
18.85	19	19.6	20.25	20.8	21.3	22.1	22.8		
18.75	19	19.5	20.15	20.7	21.2	22	22.7		
18.65	19	19.4	20.05	20.6	21.1	21.9	22.6		
18.55	19	19.3	19.95	20.5	21	21.8	22.5		
18.45	18	19.2	19.85	20.4	20.9	21.7	22.4		
18.35	18	19.1	19.75	20.3	20.8	21.6	22.3		
18.25	18	19	19.65	20.2	20.7	21.5	22.2		
18.15	18	18.9	19.55	20.1	20.6	21.4	22.1		
18.05	18	18.8	19.45	20	20.5	21.3	22		
17.95	18	18.7	19.35	19.9	20.4	21.2	21.9		
17.85	18	18.6	19.25	19.8	20.3	21.1	21.8		
17.75	18	18.5	19.15	19.7	20.2	21	21.7		

Sliding Safety Level at Top of Piers Lock 7 Weir Pool Level (23.32m)

- Improved Safety of Safety Above that for Normal
- Approximately Equal to Safety Level for Normal Pool (22.1m) and Normal Tailwater Levels (19.7m)
- Acceptable Reduced Safety Level Below Normal
- Unacceptable Safety Level

Table 62. Lock & Weir 7 Sliding Safety Levels with Varying Lock and Weir 6 Pool Levels for Top of Piers Weir 7 Pool Level (23.32 m AHD

Lock 6 Weir Pool Level	Flow Over Lock 7 Weir								
	0	5000	10000	15000	20000	30000	40000	50000	60000
19.87	20	20.6	21.27	21.82	22.32				
19.75	20	20.5	21.15	21.7	22.2				
19.65	20	20.4	21.05	21.6	22.1	22.9			
19.55	20	20.3	20.95	21.5	22	22.8			
19.45	19	20.2	20.85	21.4	21.9	22.7			
19.35	19	20.1	20.75	21.3	21.8	22.6			
19.25	19	20	20.65	21.2	21.7	22.5			
19.15	19	19.9	20.55	21.1	21.6	22.4			
19.05	19	19.8	20.45	21	21.5	22.3	23		
18.95	19	19.7	20.35	20.9	21.4	22.2	22.9		
18.85	19	19.6	20.25	20.8	21.3	22.1	22.8		
18.75	19	19.5	20.15	20.7	21.2	22	22.7		
18.65	19	19.4	20.05	20.6	21.1	21.9	22.6		
18.55	19	19.3	19.95	20.5	21	21.8	22.5		
18.45	18	19.2	19.85	20.4	20.9	21.7	22.4		
18.35	18	19.1	19.75	20.3	20.8	21.6	22.3		
18.25	18	19	19.65	20.2	20.7	21.5	22.2		
18.15	18	18.9	19.55	20.1	20.6	21.4	22.1		
18.05	18	18.8	19.45	20	20.5	21.3	22		
17.95	18	18.7	19.35	19.9	20.4	21.2	21.9		
17.85	18	18.6	19.25	19.8	20.3	21.1	21.8		
17.75	18	18.5	19.15	19.7	20.2	21	21.7		

Overturning Safety Level at Top of Piers Lock 7 Weir Pool Level (23.32m)

- Improved Safety of Above that for Normal
- Approximately Equal to Safety Level for Normal Pool (22.1m) and Normal Tailwater Levels (19.7m)
- Acceptable Reduced Safety Level Below Normal
- Unacceptable Safety Level

Table 63. Lock & Weir 7 Overturning Safety Levels with Varying Lock and Weir 6 Pool Levels for Top of Piers Weir 7 Pool Level (23.32 m AHD)

16.3.5 Lock 6

Lock 5 Weir Pool Level	Flow Over Lock 6 Weir								
	0	5000	10000	15000	20000	30000	40000	50000	60000
16.8	16.8	16.8	17.1	17.4	17.7	18.3	18.9		
16.7	16.7	16.7	17.0	17.3	17.6	18.2	18.8		
16.6	16.6	16.6	16.9	17.2	17.5	18.1	18.7		
16.5	16.5	16.5	16.8	17.1	17.4	18.0	18.6		
16.4	16.4	16.4	16.7	17.0	17.3	17.9	18.5		
16.3	16.3	16.3	16.6	16.9	17.2	17.8	18.4	19.0	
16.2	16.2	16.2	16.5	16.8	17.1	17.7	18.3	18.9	
16.1	16.1	16.1	16.4	16.7	17.0	17.6	18.2	18.8	
16	16.0	16.0	16.3	16.6	16.9	17.5	18.1	18.7	
15.9	15.9	15.9	16.2	16.5	16.8	17.4	18.0	18.6	
15.8	15.8	15.8	16.1	16.4	16.7	17.3	17.9	18.5	
15.7	15.7	15.7	16.0	16.3	16.6	17.2	17.8	18.4	
15.6	15.6	15.6	15.9	16.2	16.5	17.1	17.7	18.3	
15.5	15.5	15.5	15.8	16.1	16.4	17.0	17.6	18.2	
15.4	15.4	15.4	15.7	16.0	16.3	16.9	17.5	18.1	
15.3	15.3	15.3	15.6	15.9	16.2	16.8	17.4	18.0	
15.2	15.2	15.2	15.5	15.8	16.1	16.7	17.3	17.9	
15.1	15.1	15.1	15.4	15.7	16.0	16.6	17.2	17.8	
15	15.0	15.0	15.3	15.6	15.9	16.5	17.1	17.7	
14.9	14.9	14.9	15.2	15.5	15.8	16.4	17.0	17.6	
14.8	14.8	14.8	15.1	15.4	15.7	16.3	16.9	17.5	
14.7	14.7	14.7	15.0	15.3	15.6	16.2	16.8	17.4	

Sliding Safety Level at Normal Lock 6 Weir Pool Level (19.25m)

Improved Safety of Safety Above that for Normal

Approximately Equal to Safety Level for Normal Pool (19.25m) and Normal Tailwater Levels (16.43m)

Acceptable Reduced Safety Level Below Normal

Unacceptable Safety Level

Table 64. Table 60. Lock & Weir 7 Overturning Safety Levels with Varying Lock and Weir 6 Pool Levels for Top of Piers Weir 7 Pool Level (23.32 m AHD)

Lock 5 Weir Pool Level	Flow Over Lock 6 Weir								
	0	5000	10000	15000	20000	30000	40000	50000	60000
16.8	16.8	16.8	17.1	17.4	17.7	18.3	18.9		
16.7	16.7	16.7	17.0	17.3	17.6	18.2	18.8		
16.6	16.6	16.6	16.9	17.2	17.5	18.1	18.7		
16.5	16.5	16.5	16.8	17.1	17.4	18.0	18.6		
16.4	16.4	16.4	16.7	17.0	17.3	17.9	18.5		
16.3	16.3	16.3	16.6	16.9	17.2	17.8	18.4	19.0	
16.2	16.2	16.2	16.5	16.8	17.1	17.7	18.3	18.9	
16.1	16.1	16.1	16.4	16.7	17.0	17.6	18.2	18.8	
16	16.0	16.0	16.3	16.6	16.9	17.5	18.1	18.7	
15.9	15.9	15.9	16.2	16.5	16.8	17.4	18.0	18.6	
15.8	15.8	15.8	16.1	16.4	16.7	17.3	17.9	18.5	
15.7	15.7	15.7	16.0	16.3	16.6	17.2	17.8	18.4	
15.6	15.6	15.6	15.9	16.2	16.5	17.1	17.7	18.3	
15.5	15.5	15.5	15.8	16.1	16.4	17.0	17.6	18.2	
15.4	15.4	15.4	15.7	16.0	16.3	16.9	17.5	18.1	
15.3	15.3	15.3	15.6	15.9	16.2	16.8	17.4	18.0	
15.2	15.2	15.2	15.5	15.8	16.1	16.7	17.3	17.9	
15.1	15.1	15.1	15.4	15.7	16.0	16.6	17.2	17.8	
15	15.0	15.0	15.3	15.6	15.9	16.5	17.1	17.7	
14.9	14.9	14.9	15.2	15.5	15.8	16.4	17.0	17.6	
14.8	14.8	14.8	15.1	15.4	15.7	16.3	16.9	17.5	
14.7	14.7	14.7	15.0	15.3	15.6	16.2	16.8	17.4	

Overturning Safety Level at Normal Lock 6 Weir Pool Level (19.25m)

- Improved Safety Above that for Normal
- Approximately Equal to Safety Level for Normal Pool (19.25m) and Normal Tailwater Levels (16.43m)
- Acceptable Reduced Safety Level Below Normal
- Unacceptable Safety Level

Table 65. Lock & Weir 6 Overturning Safety Levels with Varying Lock and Weir 5 Pool Levels for Normal Weir 6 Pool Level (19.25 m AHD)

Lock 5 Weir Pool Level	Flow Over Lock 6 Weir								
	0	5000	10000	15000	20000	30000	40000	50000	60000
16.8	16.8	16.8	17.1	17.4	17.7	18.3	18.9	19.5	
16.7	16.7	16.7	17.0	17.3	17.6	18.2	18.8	19.4	
16.6	16.6	16.6	16.9	17.2	17.5	18.1	18.7	19.3	
16.5	16.5	16.5	16.8	17.1	17.4	18.0	18.6	19.2	
16.4	16.4	16.4	16.7	17.0	17.3	17.9	18.5	19.1	
16.3	16.3	16.3	16.6	16.9	17.2	17.8	18.4	19.0	
16.2	16.2	16.2	16.5	16.8	17.1	17.7	18.3	18.9	
16.1	16.1	16.1	16.4	16.7	17.0	17.6	18.2	18.8	
16	16.0	16.0	16.3	16.6	16.9	17.5	18.1	18.7	
15.9	15.9	15.9	16.2	16.5	16.8	17.4	18.0	18.6	
15.8	15.8	15.8	16.1	16.4	16.7	17.3	17.9	18.5	
15.7	15.7	15.7	16.0	16.3	16.6	17.2	17.8	18.4	
15.6	15.6	15.6	15.9	16.2	16.5	17.1	17.7	18.3	
15.5	15.5	15.5	15.8	16.1	16.4	17.0	17.6	18.2	
15.4	15.4	15.4	15.7	16.0	16.3	16.9	17.5	18.1	
15.3	15.3	15.3	15.6	15.9	16.2	16.8	17.4	18.0	
15.2	15.2	15.2	15.5	15.8	16.1	16.7	17.3	17.9	
15.1	15.1	15.1	15.4	15.7	16.0	16.6	17.2	17.8	
15	15.0	15.0	15.3	15.6	15.9	16.5	17.1	17.7	
14.9	14.9	14.9	15.2	15.5	15.8	16.4	17.0	17.6	
14.8	14.8	14.8	15.1	15.4	15.7	16.3	16.9	17.5	
14.7	14.7	14.7	15.0	15.3	15.6	16.2	16.8	17.4	

Sliding Safety Level at Top of Piers Lock 6 Weir Pool Level (19.87m)

Improved Safety of Safety Above that for Normal

Approximately Equal to Safety Level for Normal Pool (19.25m) and Normal Tailwater Levels (16.43m)

Acceptable Reduced Safety Level Below Normal

Unacceptable Safety Level

Table 66. Lock & Weir 6 Sliding Safety Levels with Varying Lock and Weir 5 Pool Levels for Top of Piers Weir 6 Pool Level (19.87 m AHD)

Lock 5 Weir Pool Level	Flow Over Lock 6 Weir								
	0	5000	10000	15000	20000	30000	40000	50000	60000
16.8	16.8	16.8	17.1	17.4	17.7	18.3	18.9	19.5	
16.7	16.7	16.7	17.0	17.3	17.6	18.2	18.8	19.4	
16.6	16.6	16.6	16.9	17.2	17.5	18.1	18.7	19.3	
16.5	16.5	16.5	16.8	17.1	17.4	18.0	18.6	19.2	
16.4	16.4	16.4	16.7	17.0	17.3	17.9	18.5	19.1	
16.3	16.3	16.3	16.6	16.9	17.2	17.8	18.4	19.0	
16.2	16.2	16.2	16.5	16.8	17.1	17.7	18.3	18.9	
16.1	16.1	16.1	16.4	16.7	17.0	17.6	18.2	18.8	
16	16.0	16.0	16.3	16.6	16.9	17.5	18.1	18.7	
15.9	15.9	15.9	16.2	16.5	16.8	17.4	18.0	18.6	
15.8	15.8	15.8	16.1	16.4	16.7	17.3	17.9	18.5	
15.7	15.7	15.7	16.0	16.3	16.6	17.2	17.8	18.4	
15.6	15.6	15.6	15.9	16.2	16.5	17.1	17.7	18.3	
15.5	15.5	15.5	15.8	16.1	16.4	17.0	17.6	18.2	
15.4	15.4	15.4	15.7	16.0	16.3	16.9	17.5	18.1	
15.3	15.3	15.3	15.6	15.9	16.2	16.8	17.4	18.0	
15.2	15.2	15.2	15.5	15.8	16.1	16.7	17.3	17.9	
15.1	15.1	15.1	15.4	15.7	16.0	16.6	17.2	17.8	
15	15.0	15.0	15.3	15.6	15.9	16.5	17.1	17.7	
14.9	14.9	14.9	15.2	15.5	15.8	16.4	17.0	17.6	
14.8	14.8	14.8	15.1	15.4	15.7	16.3	16.9	17.5	
14.7	14.7	14.7	15.0	15.3	15.6	16.2	16.8	17.4	

Overturning Safety Level at Top of Piers Lock 6 Weir Pool Level (19.87m)

Improved Safety Above that for Normal

Approximately Equal to Safety Level for Normal Pool (19.25m) and Normal Tailwater Levels (16.43m)

Acceptable Reduced Safety Level Below Normal

Unacceptable Safety Level

Table 67. Lock & Weir 6 Overturning Safety Levels with Varying Lock and Weir 5 Pool Levels for Top of Piers Weir 6 Pool Level (19.87 m AHD)