Australian Government

MURRAY–DARLING BASIN AUTHORITY

Assessment of environmental water requirements for the proposed Basin Plan:

Lower River Murray (in-channel flows)

Published by Murray-Darling Basin Authority
Postal Address GPO Box 1801, Canberra ACT 2601
Office location Level 4, 51 Allara Street, Canberra City
Australian Capital Territory
For further information contact the Murray-Darling Basin Authority office
Telephone (02) 6279 0100 international + 61 2 6279 0100
Facsimile (02) 6248 8053 international + 61 2 6248 8053
E-Mail info@mdba.gov.au
Internet http://www.mdba.gov.au

MDBA Publication No: 46/12

ISBN: 978-1-922068-55-2 (online)

Murray Region

Assessment of Lower River Murray (in-channel flows) environmental water requirements

1. Introduction

The Water Act 2007 (Cwlth) established the Murray–Darling Basin Authority (MDBA) and tasked it with the preparation of a Basin Plan to provide for the integrated management of the Basin's water resources. One of the key requirements of the Basin Plan is to establish environmentally sustainable limits on the quantities of surface water that may be taken for consumptive use, termed Sustainable Diversion Limits (SDLs). SDLs are the maximum long-term annual average volumes of water that can be taken from the Basin and they must represent an Environmentally Sustainable Level of Take (ESLT).

The method used to determine the ESLT is described in detail within *'The proposed "environmentally sustainable level of take" for surface water of the Murray-Darling Basin: Method and Outcomes,'* (MDBA 2011). A summary of the main steps undertaken to determine the ESLT is presented in Figure 1. The assessment of environmental water requirements including specification of site-specific flow indicators at a subset of hydrologic indicator sites (Step 3 of the overall ESLT method) is the focus of this document.

The work described herein is the MDBA's current understanding of the environmental water requirements of the in-channel environments of the Lower River Murray. It is not expected that the environmental water requirements assessments will remain static, rather it is intended that they will evolve over time in response to new knowledge or implementation of environmental watering actions. Within this context, feedback is sought on the material presented within this document whether that be as part of the formal draft Basin Plan consultation phase or during the environmental watering implementation phase within the framework of the Environmental Watering Plan.

1.1. Method to determine site-specific flow indicators

Assessment of environmental water requirements for different elements of the flow regime using the hydrologic indicator site approach is one of the key lines of evidence that has informed the proposed SDLs. Effort focussed on regions and parts of the flow regime with greatest sensitivity to the scale of reduction in diversions necessary to achieve environmental objectives, an ESLT and a healthy working Basin.

Within the overall framework of the ESLT method (Figure 1) the MDBA used an iterative process to assess environmental water requirements and develop site-specific flow indicators.

The hydrologic indicator site approach uses detailed eco-hydrological assessment of environmental water requirements for a subset of the key environmental assets and key ecosystem functions across the Basin. Effort focused on high flow (freshes, bankfull flows and overbank flows) requirements reflecting the prioritisation of effort on parts of the flow regime that are most sensitive to the determination of the ESLT and SDLs. The Lower River Murray is one of the key environmental assets where a detailed assessment of environmental water requirements was undertaken.

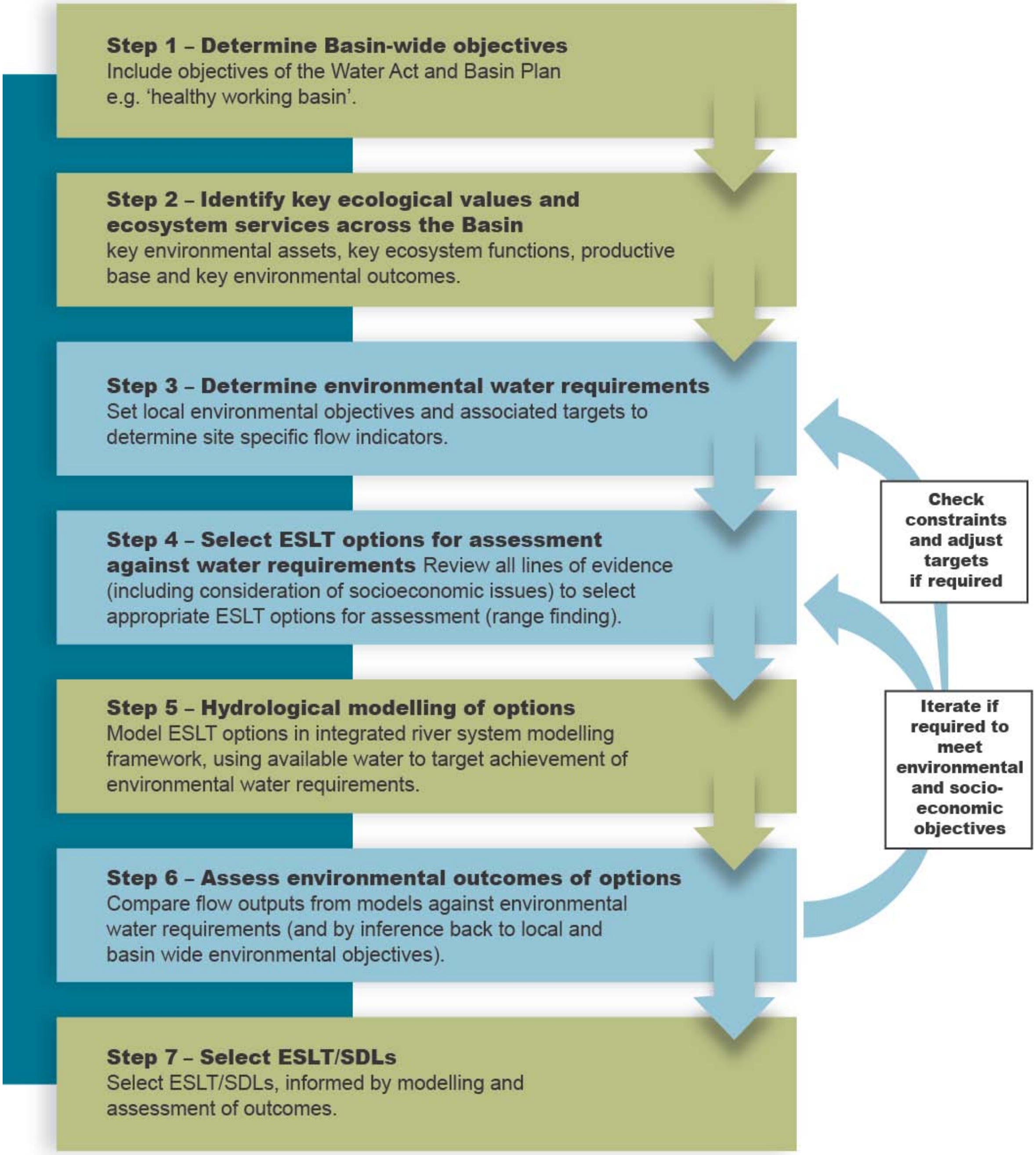

Figure 1 Outline of method used to determine an Environmentally Sustainable Level of Take (Source: MDBA 2011).

Detailed environmental water requirement assessments lead to the specification of site-specific flow indicators to achieve site-specific ecological targets. Flow indicators were expressed at a hydrologic indicator site or sites. Environmental water requirements specified at hydrologic indicator sites are intended to represent the broader environmental flow needs of river valleys or reaches and thus the needs of a broader suite of ecological assets and functions.

This report provides a description of the detailed eco-hydrological assessment of environmental water requirements for the in-channel environments of the Lower River Murray including information supporting the development of site-specific flow indicators for the site (with reference to flows measured on the River Murray at the South Australian border). More information on how the site-specific flow indicators for the site were used within the Basin-wide modelling process to inform the ESLT (i.e. Step 5 and 6 in Figure 1) can be found in the report *'Hydrologic modelling to inform the proposed Basin Plan: Methods and results'* (MDBA 2012).

A description of the detailed eco-hydrological assessments of environmental water requirements for other indicator sites, including overbank flow requirements of the Lower River Murray as represented by the Riverland-Chowilla Floodplain, are described in other documents in the series *'Assessment of environmental water requirements for the proposed Basin Plan'*.

1.2. Scope and purpose for setting site-specific flow indicators

The MDBA's assessment of environmental water requirements and associated site-specific flow indicators at hydrologic indicator sites has been used to inform the development of SDLs. This enables the MDBA to estimate the amount of water that will be required by the environment over the long-term to achieve a healthy working Basin through the use of hydrological models. Accordingly, site-specific flow indicators are not intended to stipulate future use of environmental water. MDBA expects that the body of work undertaken to establish these site-specific flow indicators will provide valuable input to environmental watering but this watering will be a flexible and adaptive process guided by the framework of the Environmental Watering Plan and natural eco-hydrological cues. It will be up to the managers of environmental water, such as the Commonwealth Environmental Water Holder, State Government agencies, and local communities to decide how best to use the available environmental water during any one year to achieve environmental outcomes.

2. Location and extent

The River Murray holds iconic status and is arguably the nation's most important river. It supports a diverse range of water dependent ecosystems from sub-alpine swampy meadows to estuarine lakes and over 2000 km of river channel. For most of its length the River Murray is a large, low gradient, anabranching river system that is characterised by low water and sediment yields, and, low flow energies and highly cohesive bed and bank materials (MDBC 2006b).

For the purposes of this report, the Lower River Murray extends from the junction of the River Murray with the Darling River, downstream to the Lower Lakes - Alexandrina and Albert (Figure 2; Spatial data used in Figure 2 are listed in Appendix A). This broadly corresponds to reaches 4 and 5 of *The River Murray Channel Icon Site Environmental Management Plan* (MDBC 2006b). The section of the Lower River Murray between the Darling River junction and upstream of Overland Corner flows in a wide valley up to 10 km wide and is flanked by a broad floodplain and riparian swamplands (many reclaimed) (MDBC 2006b; Ecological Associates 2010). It is geomorphically diverse compared to the reach downstream of Overland Corner where the river is confined to a deep, narrow limestone gorge and the floodplain is narrower (MDBC 2006b; Ecological Associates 2010).

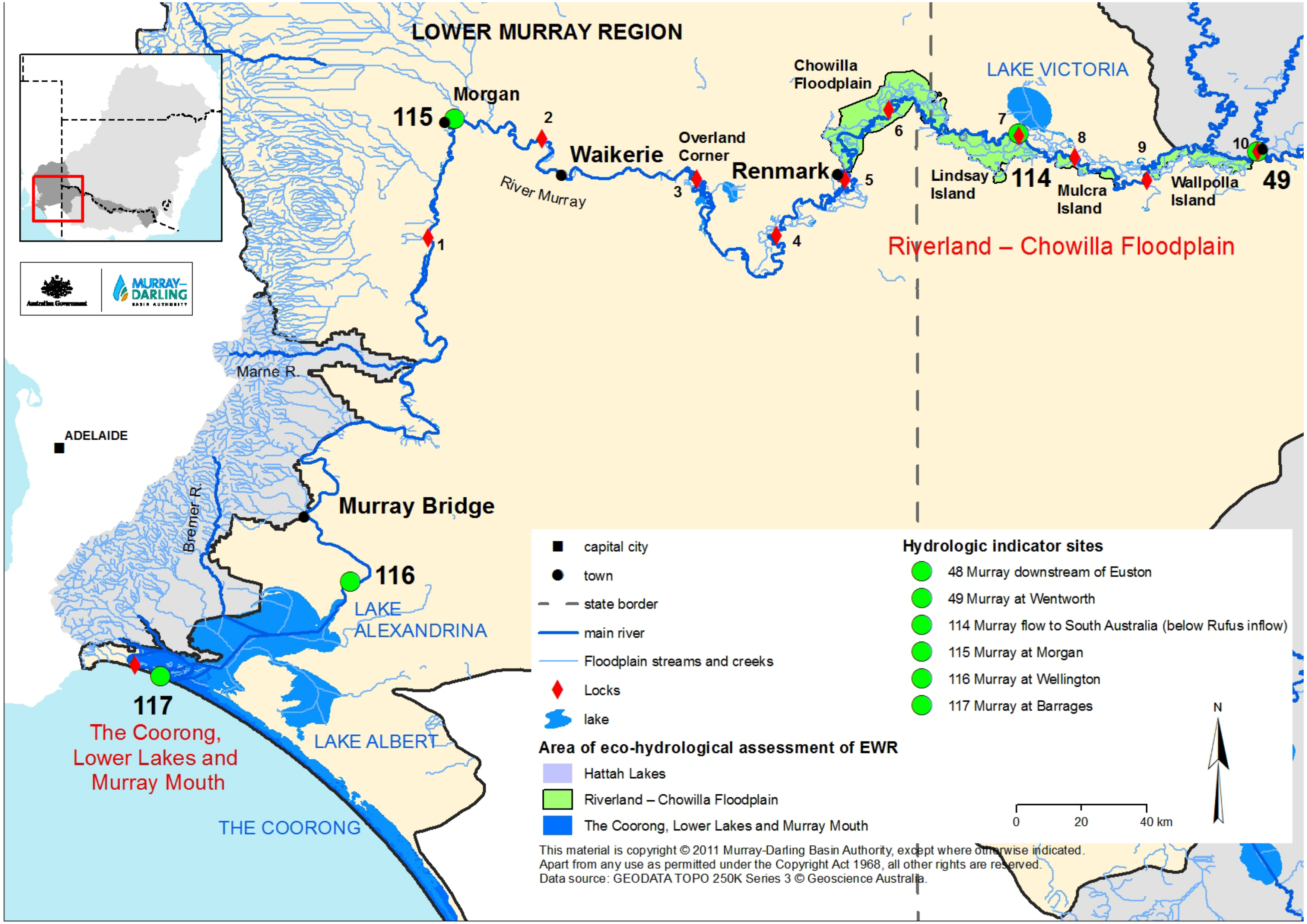

Figure 2 Location and extent of Lower River Murray key environmental asset. In-channel flow indicators are specified at the South Australian Border.

The focus of environmental water requirements specified herein for in-channel environments of the Lower River Murray are particularly centred on the section of the River Murray and associated anabranch systems at Riverland-Chowilla and Lindsay-Mulcra-Wallpolla Islands where high value native fish populations have been identified and specific information on environmental water requirements is available. Consistent with the indicator site approach, flow indicators developed are intended to be representative of a broader reach of the Lower River Murray and improve ecological outcomes at a broader scale.

3. Ecological values

The River Murray channel is recognised as an icon site under The Living Murray program, extending over 2,150 km (river distance) from Hume Dam near Albury to Wellington in South Australia (MDBC 2006b). The River Murray channel is the 'main artery' of the system that links riverine environments along its course, including floodplain forests, wetlands and the estuary at the river's mouth and is valued for the range of environments and the cultural, social and economic values it supports (MDBA 2006b).

The River Murray supports aquatic, riparian, floodplain and estuarine habitats along its course, including Ramsar-listed wetlands and a diversity of species including native fish, vegetation, vertebrates (e.g. birds, frogs), invertebrates and crustaceans (e.g. Murray Crayfish, yabbies) (MDBC 2006b). The Lower River Murray supports eleven native fish species with conservation status under Federal and/or State legislation (Table 1).

At a regional scale, the ecosystem health of the Lower River Murray (including the Mount Lofty Zone) was assessed as part of the Sustainable Rivers Audit (SRA) for the period 2004-2007. The SRA health assessment is comprised of three individual condition indices for fish, macro-invertebrates and hydrology which are combined to provide an overall indicator of river health (Davies et al. 2008). This assessment indicated that the condition of native fish populations across the Lower River Murray Valley was degraded with a fish condition index of "poor" recorded across the 4 zones of the valley (Davies et al. 2008). Across the weir pool environments 95% of individuals were native. However only 36% of native species predicted under reference conditions were caught during sampling. Conservationally significant Murray cod, silver perch, Macquarie perch, trout cod, Murray hardyhead and southern pygmy perch were absent from catches in zones where they were expected (Davies et al. 2008).

At a local scale, a detailed assessment of the fish communities of the Chowilla anabranch system between 2005 and 2008 collected a total of 38,942 individuals including 11 native fish species and four introduced species (Zampatti et al. 2008). The most abundant species caught each year being small to medium-bodied species including bony herring, unspecked hardyhead and Australian smelt (Zampatti et al. 2008). Low numbers of the large bodied, conservationally significant Murray cod, silver perch and freshwater catfish were observed with evidence that Murray cod successfully bred during the sampling period. The area also supports a large, breeding population of the recreationally important golden perch.

The ecological values of the Lower River Murray are reflected in the MDBA's assessment against the criteria used to identify key environmental assets within the Basin. The MDBA established five criteria to identify assets based on international agreements and broad alignment with the National

Framework and Guidance for Describing the Ecological Character of Australian Ramsar Wetlands (Department of the Environment, Water, Heritage and the Arts 2008) and the draft criteria for identifying High Conservation Value Aquatic Ecosystems (SKM 2007).

Based on the ecological values identified for the Lower River Murray, the system meets four of the five key environmental asset criteria (Table 1).

4. Hydrology

The Lower River Murray downstream of the Darling River junction is controlled by 10 weirs, plus river mouth barrages, floodplain levees and many small regulating structures on riparian wetlands which collectively compound the effects of upstream reservoirs (Ecological Associates 2010). The progressive regulation of the River Murray has changed it from a variable and somewhat unpredictable system to a reliable source of water that has enabled development of inland towns. Collectively, the regulating infrastructure (dams, weirs, etc) on the River Murray have changed its hydrological and ecological character (MDBC 2006b).

The dominant feature of the River Murray downstream of the Murray–Darling confluence is that it is operated as a series of stepped weir pools (MDBC 20006b). The locks and weirs were built originally (1922-37) to aid year-round riverboat transport but are currently operated mainly to provide stable pool levels for irrigation diversions and navigable passage for recreational and tourist boats (Walker 2001). Weirs elevate the water level above them, creating a 'weir pool' that extends for tens of kilometres upstream. The weirs are operated to hold the river level above them stable, even when the rate of flow changes. Weir pools have been held 'steady' (nominally +/- 50mm) during regulated flow periods since their construction approximately 60-70 years ago. Immediately below each weir, however, there are daily rises and falls in river level (typically +/- 200mm daily), diminishing downstream towards the next weir (Walker et al. 1994).

The construction of weirs has resulted in a shift of inundation regime for many wetlands of the Lower River Murray from periodically dry to permanently inundated (MDBC 2006b). Pressey (1986) estimated that approximately 70% of the area of Lower Murray wetlands (backwaters, side-arms, anabranches, lakes, billabongs) downstream of the Darling River junction are permanently inundated at Lock/Weir Full Supply Level.

Another example of the impact of weirs is that flows in the Chowilla anabranch creek system would have varied in response to those in the Murray-Darling system however since weir construction, the River and the main anabranch systems flow continuously due to the river level having risen up to 3 m in the pools impounded by weirs at Locks 5 – 6. As a consequence water levels in anabranch systems, such as Chowilla, tend to be more stable than prior to river regulation. Prior to the construction of the weirs, flowing water habitat was available in both the river and the anabranches, but now only occurs in some anabranch sections (Newall et al. 2009). The loss of flow variability, in particular, constant river heights within weir pools, and prolonged periods of low flow are identified as key threatening processes to the Lower River Murray (MDBC 2006b).

Table 1 Assessment of the Lower River Murray against MDBA key environmental assets criteria

Criterion	Ecological values that support the criterion
2. The water-dependent ecosystem is natural or near-natural, rare or unique	The Chowilla anabranch system is the largest remaining area of undeveloped floodplain habitat in the Lower River Murray and the diversity of habitats available within Chowilla is now rare within the Lower River Murray and support significant native fish populations (MDBC 2006a, Zampatti et al. 2008). Flowing environments within Mullaroo Creek on the Lindsay Island floodplain and Chowilla Creek on the Chowilla Floodplain provide key Murray cod recruitment habitat on the Lower River Murray (Ecological Associates 2010).
3. The water-dependent ecosystem provides vital habitat	Relatively constant and stable water level conditions within weir pools of the Lower River Murray provide drought refuge habitat. Under the current regulated regime, permanence of aquatic habitat has increased, nonetheless, permanent aquatic habitat has an important role in maintaining the ecological health of the Lower River Murray (Ecological Associates 2010). The riverine system between the Murray-Darling confluence and Lake Alexandrina contains two distinct elements, both of which are considered important for maintaining the long-term survival and recovery of the nationally listed Murray cod (National Murray Cod Recovery Team 2010). The two key elements are the main trunk and connected wetlands of the River Murray and the floodplains and anabranches of the Chowilla and Lindsay/Wallpolla systems. Zampatti et al. (2011) suggest that the Chowilla anabranch system acts as important drought refuge conferring resilience on the regional Murray cod population by maintaining population structure and providing a source of colonists after disturbance. Anabranch creeks within the Chowilla floodplain are important breeding areas for native fish species and refugia for declining aquatic species (Newall et al. 2009). Anabranches also provide passage for fish between river reaches and are particularly important for the migratory species silver perch, golden perch and, to some extent, Murray cod (Ecological Associates 2007, Newall et al. 2009). The Chowilla anabranch is important as a pathway for these fish to migrate around Lock 6.
4. Water-dependent ecosystems that support Commonwealth, State or Territory listed threatened species or communities	The fish community of the Lower River Murray is significant in terms of its conservation value. Eleven native fish species have been recorded which have conservation status under state or federal legislation (Davies et al. 2008; Ecological Associates 2010): • Trout cod which are listed as endangered nationally under the Environment Protection and Biodiversity Conservation (EPBC) Act 1999, critically endangered under the Victorian Flora and Fauna Guarantee (FFG) Act 1988 and protected under the South Australian Fisheries Management (SAFM) Act 2007; • Murray cod and Murray hardyhead which are listed as vulnerable nationally under the EPBC Act 1999 and endangered under the Victorian FFG Act 1988; • Freshwater catfish which are listed as vulnerable under the Victorian FFG Act 1988 and protected under the SAFM Act 2007; • Silver perch which are listed as critically endangered under the Victorian FFG Act 1988 and protected under the SAFM Act 2007; • Yarra pygmy perch which are listed as vulnerable nationally under the EPBC Act 1999, listed under the Victorian FFG Act 1988 and protected under the SAFM Act 2007; • Southern pygmy perch and river blackfish which are listed as protected under the SAFM Act 2007; • Unspecked hardyhead and Murray-Darling rainbow fish which are listed under the Victorian FFG Act 1988; and • Olive perchlet and purple spotted gudgeon which are listed as extinct in the wild under the Victorian FFG Act 1988 and protected under the SAFM Act 2007.
5. The water-dependent ecosystem supports, or with environmental watering is capable of supporting, significant biodiversity	The Lower River Murray has a diverse native fish population with a total of 18 native fish species recorded, which includes several species of conservation significance (Zampatti et al. 2008; Ecological Associates 2010). Lower River Murray anabranches including Mullaroo Creek and Chowilla Creek support significant populations of Murray cod, golden perch and silver perch (Zampatti et al. 2008; Ecological Associates 2010).

As well as changes in flow regime, river regulation has led to the construction of barriers that prevent longitudinal or lateral movement of fish, and altered the way particulate matter and biota are transported downstream. Removal of these barriers or installation of fishways is an important step towards improving habitat access for native fish. The "Sea to Hume" fishway program currently in progress aims to provide fish passage on all River Murray locks/weir from the sea to Hume Dam and is integral to improving fish passage along the Lower River Murray.

The impacts of river regulation have not all been negative for native fish populations with the maintenance of river levels in the Lower Murray in a series of pools behind locks meaning that regulation tends to mitigate the severity of low flows.

In order to describe the change in flows in the Lower River Murray due to water resource development, the MDBA analysed modelled flow data at the South Australian border for the period 1895 – 2009. Figure 3 illustrates how average monthly flows have changed between without-development and baseline (current arrangement) flow regimes with the impact of development being to reduce average daily flows throughout the year, with a more pronounced effect during the high flow period from approximately August to December resulting in a less defined seasonal peak.

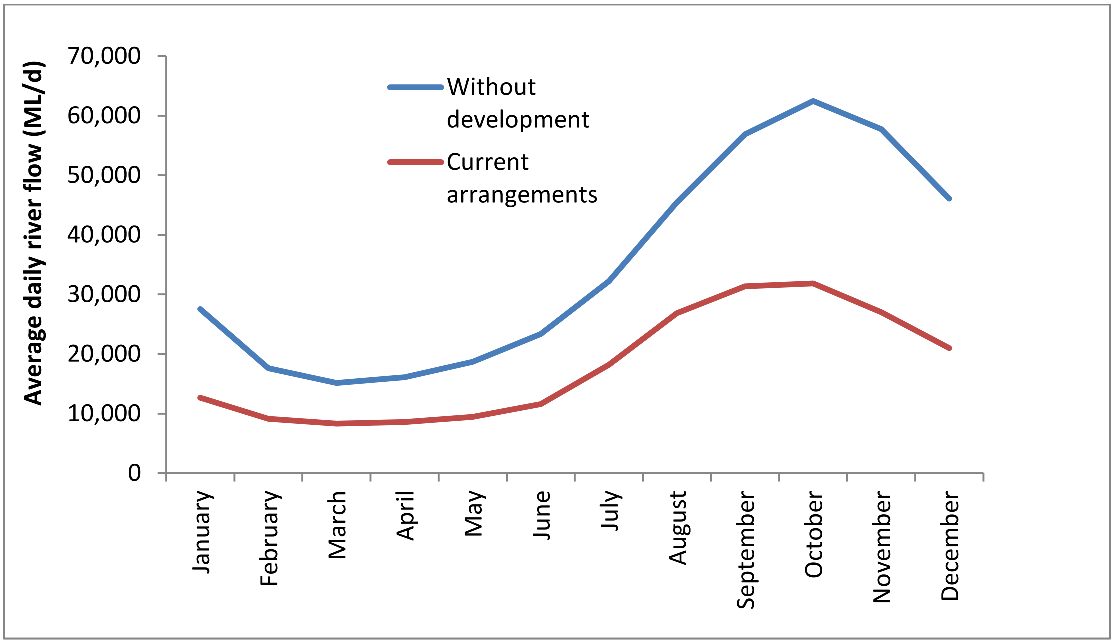

Figure 3 Modelled monthly flows in the River Murray at the South Australian border under without-development and baseline (current arrangement) conditions, 1895-2009

Further analysis of modelled flow data for the period 1895 – 2009 was undertaken to describe changes to hydrology for in-stream events, specifically 'freshes'. Fresh events are flow pulses exceeding the underlying base flow and, depending on the river system, last anywhere between a few days and a few weeks. Fresh events are contained within the confines of the channel – they are not large enough to provide overbank flows.

For the analysis conducted, freshes were defined as flow events between baseflows (lower threshold) and bankfull flows (upper threshold). The lower (baseflow) threshold is highly seasonal and for the purposes of MDBA fresh event analysis was defined using a hydrologic analysis based on high and low flow seasons (see MDBA 2012 for a description of the method used to define baseflows). The upper, bankfull threshold was defined as the 1 year Average Recurrence Interval (ARI) flow which correlates well with known bankfull discharges of the Lower River Murray (MDBA 2012a).

Table 2 present the results of analysis of low season and high season freshes under without-development and baseline conditions for flow to South Australia. In essence the tables present the characteristics of flows that exceed the baseflow and are less than the bankfull flow (this being the definition of a fresh). Flows that exceed the upper, bankfull threshold are not included in this assessment.

This analysis indicates that in-channel freshes within the Lower River Murray have been impacted to varying degrees by water resource development (Table 2). While the 'number of freshes' has not been significantly impacted and is higher than without-development conditions for the high flow season from July to November, both the 'mean fresh duration' and 'mean fresh volume' have declined with the impact more pronounced for the low flow season from January to May.

Table 2 shows the specific characteristics of in-channel freshes and the changes that have occurred through river regulation and water extraction. As highlighted above, the data analysis does not include flows that exceed channel capacity – i.e. overbank flows – which can also contribute to eco-hydrological outcomes associated with freshes. If overbank flows were included in the analysis the number of years containing an event would be considerably greater, and the changes due to river regulation would be more significant. It is also worth noting that some events that would have been overbank flows under without-development conditions are reduced to freshes under baseline conditions, reflecting modifications to the flow regime. Similarly events that would have been freshes under without-development conditions no longer exist under baseline conditions.

Table 2 Analysis of in-channel 'freshes' for low season and high season at flow to South Australia modelled under without-development and baseline conditions for the period 1895-2009

Scenario	Baseflow (ML/day) – lower threshold	Bankfull (ML/day) – upper threshold	Number of events	Mean Fresh Duration (Days)	Mean Fresh Volume (ML)
High season: July – November					
Without-development	27,879	43,756	30	36	1,207,521
Baseline	27,879	43,756	39	27	907,440
Low season: January – May					
Without-development	13,878	43,756	66	43	923,289
Baseline	13,878	43,756	66	21	391,077

Note: * freshes are defined as a flow event that exceeds the baseflow and is less than the bankfull flow. This table shows the number of these events (freshes) that occurred in the model time period (114 years), as well as the mean duration and mean volume of these events.

The flow duration curve for the Lower River Murray at South Australian Border further illustrates that in-channel freshes, as illustrated by the range within the green box, is one of the most significantly modified parts of the flow regime from without-development conditions (Figure 4). This analysis is supported by Zampatti et al. (2011) who state that small to medium sized flow events are the component of the flow regime that has been most significantly altered by river regulation in the Lower River Murray, nevertheless it is these events (e.g. 15-25,000 ML/day) that could be practically restored within the constraints of current system operation. Further analysis of ecologically relevant in-channel flows is described below.

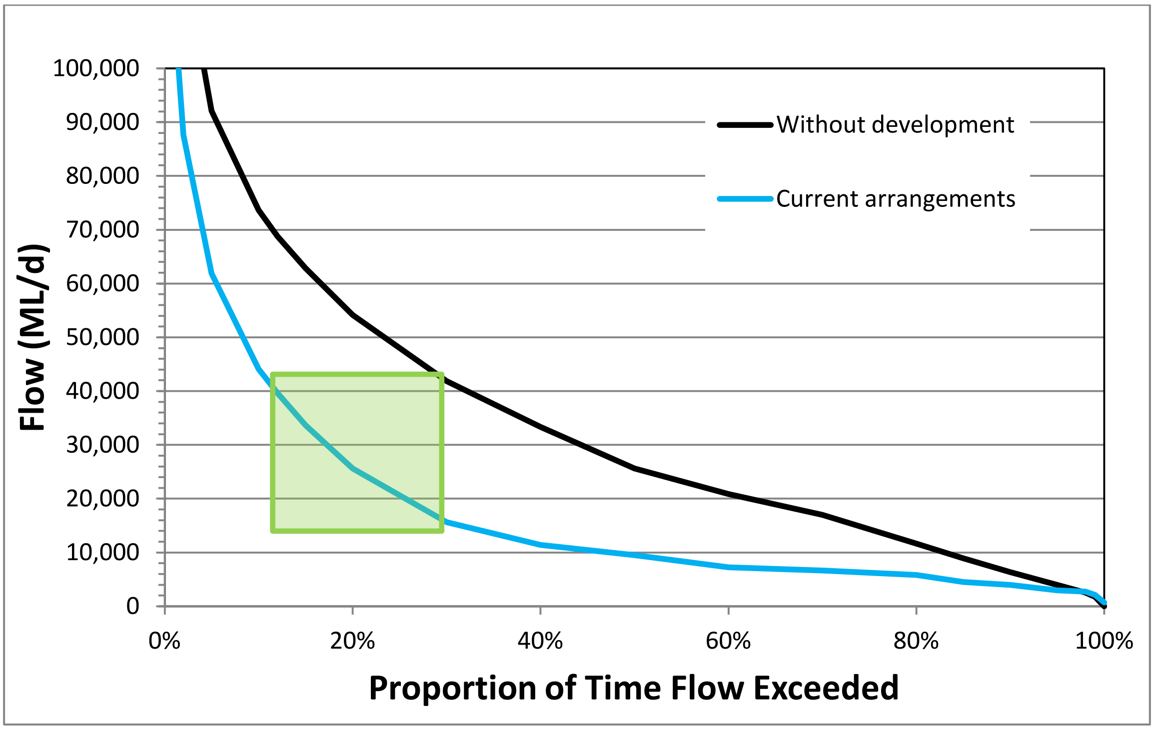

Figure 4 Flow duration curve for flow to South Australia based on modelled data for the period 1895-2009 under without-development and baseline (current arrangement) conditions. The green box is used to highlight flows categorised as in-channel freshes using lower and upper thresholds adopted for analysis of modelled flow data.

5. Determining the site-specific flow indicators for the Lower River Murray

5.1. Setting site-specific ecological targets

The objective setting framework used to determine the ESLT is outlined in the report '*The proposed "environmentally sustainable level of take" for surface water of the Murray-Darling Basin: Method and Outcomes*' (MDBA 2011). In summary, the MDBA developed a set of Basin-wide environmental objectives and ecological targets, which were then applied at a finer scale to develop site-specific objectives for individual key environmental assets. Using these site-specific objectives, ecological targets that relate specifically to in-channel environments of the Lower River Murray were developed (Table 3). Information underpinning site-specific ecological targets is shown in Table 3.

Site-specific ecological targets formed the basis of an assessment of environmental water requirements and the subsequent determination of site-specific flow indicators for the Lower River Murray, as described below.

Table 3 Site-specific ecological targets for the Lower River Murray (in-channel flows)

Site-specific ecological targets	Justification of targets
• Provide a flow regime which supports recruitment opportunities for a range of native aquatic species (e.g. fish, frogs, turtles, invertebrates) • Provide a flow regime which supports key ecosystem functions, particularly those related to longitudinal connectivity and transport of sediment, nutrients and carbon	The Lower River Murray contain vital habitat for native fish and supports diverse native fish populations. The importance of native fish populations within the Lower River Murray is highlighted by this area supporting breeding populations of the nationally vulnerable Murray cod (Maccullochella peelii peelii) (Zampatti et al. 2008; Ecological Associates 2010). Populations of Murray cod in the Lower River Murray downstream from the NSW border are considered as "under serious threat" with river regulation and low and stable summer and winter flows being identified as key threats (National Murray Cod Recovery Team 2010). Similarly, Cheshire and Ye (2010) report that protracted low flow conditions pose a significant risk to spawning success and larval survivorship of Murray cod, golden perch and silver perch. Similarly, populations of Murray cod in the floodplains and anabranches of the Mullaroo/Lindsay/Wallpolla are considered as "under serious threat" with potential change in flows due to expansion of irrigation industry and/or introduction of new regulators identified as key threats (National Murray Cod Recovery Team 2010). Key ecosystem functions support fish, birds and invertebrates by: • maintaining connectivity within and between water-dependent ecosystems; • protecting and restoring carbon and nutrient dynamics; and • protecting refuges to support long-term survival and resilience of the populations dependent on them during drought and allow for their subsequent recolonisation.

5.2. Information used to determine site-specific flow indicators

In-channel flow pulses, or freshes, have important ecological functions including stimulating fish breeding and migration to fulfil requirements of life-history stages, increase wetted area including inundation of important in-channel habitat features such as benches, organic and inorganic sediment delivery to downstream reaches, mobilisation of fine particulate material that can smother submerged macrophytes and invertebrate habitat, dispersal of aquatic communities including drift and recolonisation of aquatic fauna and flora communities (Humphries et al. 1999; Cottingham et al. 2003; Cottingham et al. 2010). Freshes serve to increase the diversity of flows, and hence habitat availability after a prolonged period of (stable) low flow or drought periods and can also assist in improving water quality through reducing stratification and increase dissolved oxygen concentrations (Cottingham et al. 2003; Cottingham et al. 2010).

The development of site-specific indicators for in-channel environments of the Lower River Murray as described below has focussed on the in-channel fresh element of the flow regime to inundate key in-channel habitat and maintain native fish populations. Separate reports have been prepared specifying environmental water requirements and associated site-specific flow indicators for Riverland-Chowilla Floodplain and the Coorong, Lower Lakes and Murray Mouth. Flow indicators specified for in-channel freshes as described below are intended to complement flow indicators for bankfull and overbank elements of the flow regime which will also contribute to enhanced outcomes for native fish.

5.2.1. Flows for key in-channel habitat provision and diversity

Anabranch connection

Aquatic habitats across the floodplain (i.e. fast flowing anabranches, slow flowing anabranches, backwaters/billabongs) provide fish species with a variety of macrohabitats that differ from the main river channel and such habitats are used for shelter, feeding, spawning and recruitment (Humphries et al. 1999, Zampatti et al. 2008).

Anabranch systems at Riverland-Chowilla and Lindsay-Wallpolla have been identified as critical habitat for native fish populations of the Lower River Murray. River regulation has had a variable impact on the flow regime of anabranches with weirs increasing the connectivity of some anabranches e.g. Chowilla Creek but reducing inundation of others e.g. Lindsay-Wallpolla Creeks. In-channel fresh environmental water requirements aim to increase connectivity of some anabranches such as within the Lindsay-Wallpolla systems and also maintain suitable habitat such as the fast-flowing anabranches within the Chowilla floodplain that provides valuable habitat for the Murray cod, rather than increase connectivity.

There is no single volume of flows that will maintain and connect anabranches as different anabranches will connect at different flow thresholds, however anabranch connection information is available for both the Riverland-Chowilla and Lindsay-Wallpolla systems. At Riverland-Chowilla an approximate 50 cm rise in in-channel water levels in most of the outer anabranch system was observed in September 2005 after an environmental flow was delivered peaking at approximately 15,000 ML/day (Newall et al. 2009; Zampatti et al. 2011). Flows between 10,000 ML/day and 60,000 ML/day roughly approximate in-channel flows for much of Lindsay, Mulcra and Wallpolla islands upstream of Riverland-Chowilla and start to affect higher backwaters, anabranches and wetlands off the main river channel (MDBC 2006a). More specifically at Lindsay Island and Wallpolla Island, Ecological Associates (2007) report that at flows between 20,000 ML/day to 35,000 ML/day major creeks and anabranches in the Lindsay and Wallpolla systems begin to flow as inactive anabranches become connected to the River Murray resulting in a change from ponded to flowing conditions.

Habitat diversity including flowing water habitat

Changes to depositional processes following weir construction has resulted in the infilling of deeper pools and scour holes, and combined with extensive removal of snags and erosion, have led to simplification of habitat diversity in the river channel of the Lower River Murray (MDBC 2006b).

The aquatic habitat diversity of the Chowilla system, including fast and slow-flowing anabranches, backwaters and temporary billabongs, is unmatched in the Lower River Murray downstream of the Darling River junction (Zampatti et al. 2011). The complex of physical and hydraulic habitats within the Chowilla system is a fragmented relict of the unregulated River Murray (Zampatti et al. 2011).

The diverse aquatic habitats in the Chowilla anabranch system support a range of life history phases of native and non-native fish species (Zampatti et al. 2008; Zampatti et al. 2011). Murray cod populations seem to benefit in particular from the diversity of aquatic habitats within the anabranch systems, allowing different sized Murray cod to exploit different habitats (Newall et al. 2009) with Murray cod and silver perch almost exclusively being caught in fast-flowing mesohabitats and in the River Murray (Zampatti et al. 2008). In the Chowilla anabranch system it is suggested that fast-flowing creeks create a structurally diverse mesohabitat in terms of woody debris, aquatic vegetation and hydraulic environments (Zampatti et al. 2008). This is supported by information within the Riverland Ramsar Site Ecological Character Description that suggests Murray cod are highly dependent on woody debris for habitat, using it to shelter from fast-flowing water and for spawning in lowland rivers. Accordingly, the large network of flowing anabranches within the Chowilla floodplain provides valuable habitat for the Murray cod, particularly as several of the anabranches are susceptible to flooding, connecting the channel to the floodplain (Newall et al. 2009). Similarly, Ecological Associates (2010) report that there are strong positive associations between the presence of aquatic macrophytes / large woody debris and native fish populations.

Zampatti et al. (2011) suggest that the conservation of the diverse aquatic mesohabitats in the Chowilla system, along with restoration of a more variable flow regime and promotion of physical and hydrological connectivity at the river scale will aid in maintaining and potentially restoring native fish populations in the Lower River Murray.

Flowing water habitat is an important habitat component for a number of native fish (Ecological Associates 2010). Flowing water provides an attractant flow for fish, encouraging upstream migration and is associated with the successful recruitment of juvenile Murray cod, golden perch and silver perch and provides important breeding habitat for Australian smelt (Ecological Associates 2010). Murray crayfish, river snails and river mussels also require permanent, fast-flowing aquatic habitat (Ecological Associates 2010).

Prior to regulation, fast flowing habitat was present in the main channel of the river, floodplain anabranches and meander loop cutoffs. Due to river regulation, and in particular weir operation, flowing environments are limited to a small number of anabranches: Mullaroo Creek, Chowilla Creek and Eckerts/Katarapko Creeks. Reductions in fast-flowing habitat by the operation of weirs represents the loss of an aspect of the original ecological character of the river and has contributed to the extinction of River Murray crayfish and river snail within the South Australian portion of the Lower River Murray (Ecological Associates 2010). Ecological Associates (2010) identify the restoration of flowing water habitat as an important component of restoring biodiversity and health to the South Australian River Murray although no specific recommendations were made as the flows required to provide these conditions will vary in every watercourse depending on hydraulic conditions.

Flow variability

As highlighted previously, populations of Murray cod in the Lower River Murray downstream from the NSW border are considered as “under serious threat” with river regulation and low and stable summer and winter flows being identified as key threats (National Murray Cod Recovery Team 2010). Similarly, protracted low flow conditions have been reported to pose a significant risk to spawning success and larval survivorship of Murray cod, golden perch and silver perch (Cheshire and Ye 2010).

Variation in flow (and therefore water level) is an important component of fast-flowing habitat. Flow influences the composition and abundance of plant communities and the maintenance of bacteria rich biofilms on which invertebrates depend (Ecological Associates 2010). In-channel flow requirements aim to introduce greater flow variability, particularly for the main channel of the River Murray, where stable and low flows have a negative impact on native fish populations, particularly the conservationally significant Murray cod.

Preliminary mapping of hydraulic diversity within the main channel of the River Murray (Mallen-Cooper pers. comm. 27th May 2010) indicates that 20,000 ML/day flows are associated with increased hydraulic diversity within the main channel of the River Murray in the section of river near Chowilla.

5.2.2. Native fish spawning and recruitment

Native fish species are a well-recognised asset of the Chowilla-Riverland area and the broader Lower River Murray region, including a number of species listed as threatened or vulnerable under Federal or State legislation. River regulation in the Murray-Darling Basin has resulted in marked changes in the flow regime and these changes are thought to have led to a decline in the range, abundance and diversity of native fish species within the system (Rowland 1989, Cadwallader and Lawrence 1990, Walker and Thoms 1993, Gehrke et al. 1995, Humphries et al. 2008).

By restoring aspects of the natural flow regime, particularly flows necessary for fish migration, spawning and recruitment, and habitat protection and connectivity, the MDBA aims to maintain healthy populations of key resident native fish species.

Investigations undertaken at various locations in the Murray-Darling Basin indicate that flow patterns and variability are important for native fish and flows are linked to parts of the life cycle of native fish. For example:

- A number of fish species, such as golden perch and silver perch, require flow pulses or floods for spawning i.e. flood recruitment hypothesis (Humphries et al. 1999). Within channel rises in water level during spring and summer appear to play an important role as cues for fish migration and spawning (Mallen Cooper and Stuart 2003; Cottingham et al. 2007). Mallen Cooper and Stuart (2003) found that strong golden perch recruitment occurred in years where there were flow pulses of 1-2m in stage height within the main channel of the River Murray;
- Monitoring has shown that flows are an important factor in the larval survivorship and subsequent recruitment of Murray cod (Cheshire and Ye 2008; Cheshire and Ye 2010);
- A number of small-medium bodied native fish species breed opportunistically every year regardless of flow i.e. low flow recruitment hypothesis (Humphries et al. 1999). However, connectivity between the main river and adjacent wetlands, anabranches and still water habitats provided by increased flows improve recruitment of species such as flathead gudgeons and Australian smelt as larvae and juveniles require high concentrations of small prey to feed on and develop (Humphries et al. 1999).

There is still debate in the scientific literature as to the relative role of various types of flows to fish community dynamics, and an understanding of the nature of 'fish ecology'-'river flow' interactions is by no means clear (Humphries et al. 1999, Mallen-Cooper and Stuart 2003, Graham and Harris 2004, King et al. 2009). For example, it has been suggested that some fish species, such as the conservationally significant silver perch require flow pulses or floods for spawning i.e. flood recruitment hypothesis (Humphries et al. 1999). Other factors such water temperature and day lengths, or the interaction of a range of environmental variables including flow, are suggested to also be important for native fish recruitment (King et al. 2009).

Despite the ongoing debate regarding the link between hydrology and fish ecology, available evidence (e.g. Beesley et al. 2011) suggests that provision of flows that connect the river channel to the floodplain, as well as in-channel flow variability, as important to sustaining key ecological features such as native fish populations. The fish species present in the River Murray exhibit a variety of life history strategies and, as a result, a number of different ecological requirements need to be considered. Flow indicators described elsewhere for the Riverland-Chowilla floodplain primarily based on the water requirements of flood dependent vegetation communities are expected to be sufficient to support lifecycle and habitat requirements of native fish associated with connectivity between the river and floodplain (MDBA 2012a).

A number of documents have been assessed to determine a range of in-channel flows required to support the life-cycle and habitat requirements of native fish including provision of cues for spawning and migration and access to food sources. However, it was found that no single existing plan or document sets out these requirements completely.

Flow threshold

There is some evidence that rises in flow contained within the river channel may lead to fish recruitment, particularly where there are appropriate conditions for spawning and a suitable availability of food for larvae. In the middle reaches of the River Murray, strong year-classes of golden perch were associated with spring within-channel flows, and poor year-classes were associated with high spring flows that inundated the floodplain (Mallen-Cooper and Stuart 2003). The authors hypothesised that golden perch had spawned and recruited (i) predominantly during within-channel flows, or (ii) during both within-channel flows and floods. Similarly, King et al. (2009) in a review of existing knowledge of the requirements for successful breeding of native fish in the River Murray reported that for the Barmah-Millewa forest there was a strong relationship between golden perch spawning strength and occurrence with water temperatures and increased flow. Inferences that can be made from a single study are generally only limited to the population or area where the study was conducted, however this is consistent with previous studies and literature which also suggest that golden perch spawning and recruitment is linked with an increase in flows, particularly within channel flows (King et al. 2009). Zampatti et al. (2011) present data to support the view that strong golden perch recruitment is not reliant on flood flows (i.e. overbank) and that even relatively small in-channel flow events may support significant recruitment. Cheshire and Ye (2010) also report that a within channel flow pulse is sufficient to induce breeding and promote larval survivorship for both golden and silver perch.

King et al. (2009) also reported that spawning of Murray cod at Barmah-Millewa Forest was observed with positive change in flow and temperature, however the relationship was relatively weak and a range of factors appear to influence spawning of Murray cod. As such a high level of uncertainty regarding the effects of increased flow and temperature on Murray cod spawning remains (King et al. 2009). Zampatti et al. (2008) suggest that Murray cod spawn annually regardless of flow and it is the environmental conditions present during the larval stage that is likely to influence successful recruitment of larvae to the adult population. Furthermore, it is suggested that flow, particularly small-scale hydraulics, maybe important for the survival of Murray cod larvae and the diversity of flow and physical habitats within the Chowilla anabranch system facilitate the successful recruitment of Murray cod (Zampatti et al. 2008).

Even in the absence of flow triggers, large fish species such as trout cod, Murray cod, golden perch and silver perch are known to spawn to a relatively small degree on an annual basis (Ecological Associates 2010). However, usually flow events are required for golden and silver perch to spawn in large numbers (Cheshire and Ye 2008a; Ecological Associates 2010).

Timing

Fish generally spawn during the warmer months (spring/summer) when conditions are ideal for maximum growth and there is maximum production of food for larvae and juveniles (Ecological Associates 2010). Currently in the Lower Murray River high flows overlap with warmer temperatures further suggesting fish are most likely to breed during spring/summer (Cale 2009). While King et al. (2009) reported that most fish species appear to be flexible in their spawning period, their review of previous studies suggests the probable spawning period for Murray cod is October to December, silver perch is November to February and golden perch is October to March. A range of small to medium bodied native fish species including carp gudgeon, flatheaded gudgeon, bony herring, unspecked hardyhead, Murray-Darling rainbowfish and Australian smelt are also likely to spawn during the spring/summer period, however many of these species are more flexible in their spawning timing compared to the large bodied native fish species (King et al. 2009). This is consistent with larvae surveying in Zampatti et al. (2011) who reported Murray cod larvae from mid October to late November, golden perch larvae from late November to early January, gudgeons and smelt from September to February and bony herring, unspecked hardyhead and Murray-Darling rainbowfish from mid October to February.

Duration

The estimated time from spawning to full juvenile development for some native fishes ranges from 2 to 4 months (Cale 2009), and King et al. (2003) suggested an optimum period of floodplain inundation would be several weeks to several months to cater for all fish species.

Frequency

In-channel freshes are categorised as events that typically would occur in most years and it is assumed that restoring this element of the flow regime has an important ecological role in the maintenance of native fish populations. Some fish species are short-lived, for example, Australian smelt live 1-2 years (Zampatti et al. 2008) therefore it is important that regular breeding opportunities are provided to maintain sustainable populations. Similarly, Ecological Associates (2010) suggest that small bodied native fish require breeding events on an annual basis.

Ecological Associates (2007) recommend freshes occur in 80% of years which is consistent with in-channel freshes being categorised as events that typically would occur in most years and it being important that regular breeding opportunities are provided to maintain sustainable native fish populations. MDBA analysis of modelled without-development flow data for the period 1895 to 2009 shows that the combination of flows of 20,000 ML/day for 2 months during the ecologically relevant timing of August through to December occurs in almost 90% of years.

Previous in-channel fresh environmental water requirement assessments

Consistent with many of the native fish requirements identified above, Ecological Associates (2007) recommend 3-4 freshes (15,000 ML/day for 14 days) between August and December in 80% of years for breeding and recruitment by Australian smelt and Murray cod in anabranches within the Victorian portion of the Living Murray Chowilla Floodplain and Lindsay-Wallpolla Islands Icon site.

MDBA replicated analysis of the number of 15,000 ML/day events at Lock 7 and 9 similar to that presented within Ecological Associates (2007) using modelled data for the period 1895-2009. This revealed that under without-development conditions flow events of 15,000 ML/day for at least 14 days occurred 114 times during the 114 year model period with only 3 years with multiple (2) fresh events. There were no years under without-development conditions with 3-4 freshes. The average duration of events was 140 days. Therefore, the recommendations of Ecological Associates (2007) have been respecified as a total duration which is more consistent with the natural hydrology of the Lower River Murray in this region that is characterised by long duration events and not flashy, short duration events as recommended. This is illustrated in Figure 5 which is a typical hydrograph for the flow to South Australia.

5.2.3. Riparian vegetation

Previous monitoring indicates that riparian vegetation may also benefit from the delivery of in-channel freshes. Following the delivery of a 15,000 ML/day flow in September 2005 river red gums at Chowilla showed a positive response (indicated by tree health scores) in both low velocity outer anabranches (Punkah and Monoman Creeks) and in high velocity creeks flowing out of the main channel (Boat and Pipeclay Creeks) (Cale 2009). A tree condition response was seen in healthy, stressed and extremely stressed (i.e. 'near dead') trees. The response lasted for about nine months and was still detectable at 18 months post-inundation (Cale 2009). These results suggest river red gums adjacent to creeks in the Chowilla anabranch system may benefit from pulse flows (Cale 2009). Tree condition responses suggest that pulse flows need to occur every 9-18 months to ensure the improved condition of the trees is maintained (Cale 2009; Newall et al. 2009). In addition, recruitment of some riparian native species was observed after the high river in spring 2005 (Zampatti et al. 2011).

5.2.4. Other Biota

The understanding of flow-ecology relationships for faunal groups other than native fish populations generally has more uncertainty owing to the reduced number of studies undertaken for these species. The MDBA is confident that the site-specific flow indicators determined for native fish species will also have valuable beneficial effects on the life-cycle and habitat requirements of amphibians, and water-dependent reptiles and invertebrates. Aquatic macro-invertebrates are important as a food source for small fish species, juveniles of large fish and waterbirds, and the decline in the abundance of fish and in the magnitude of waterbird breeding events can be attributed in part to a decline in riverine macro-invertebrate production (Ecological Associates 2010).

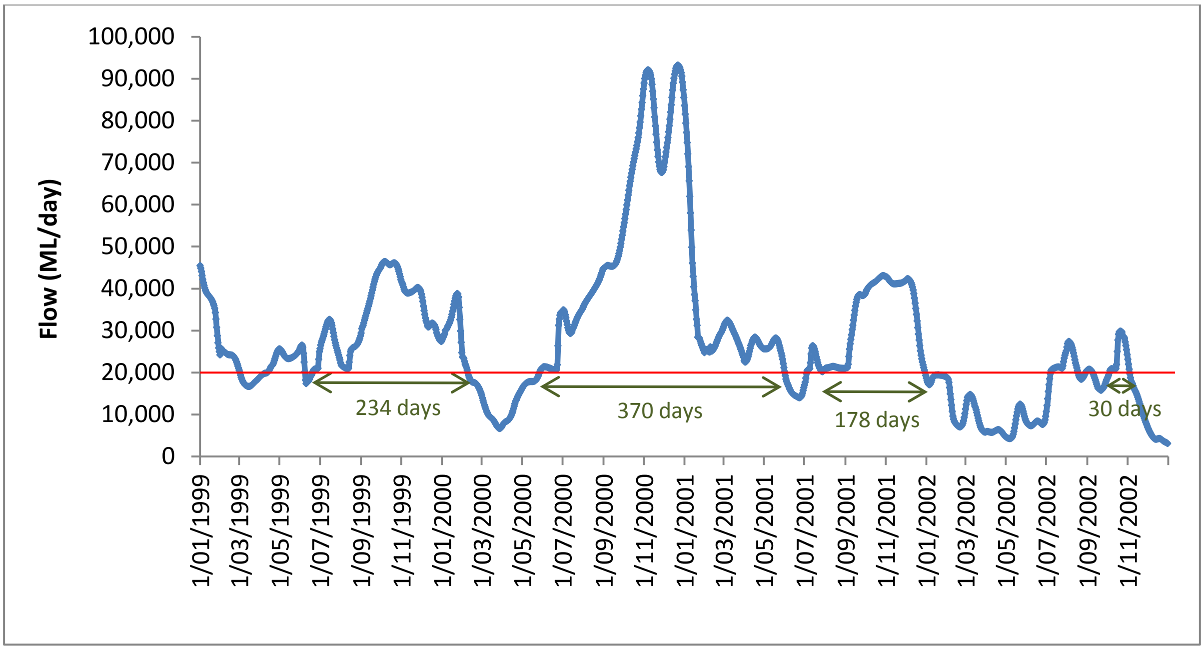

Figure 5 Modelled flow to South Australia under without-development conditions for the period 1999-2003 illustrating the typical hydrology of the Lower River Murray. Number of days exceeding the threshold of 20,000 ML/day are shown as an example of the characteristic long, duration events.

Key ecosystem functions associated with river connectivity and sediment and nutrient transport will also be enhanced. For example, Ecological Associates (2010) identify that permanent, fast flowing watercourses and the river channel and connecting wetlands are important for ecosystem functions including organic matter processing and supply, biofilm productivity and diversity, and sediment supply, mobilisation and transport.

5.3. Proposed flow indicators

Based on information presented in Section 5.2, there is support within the scientific literature for specification of in-channel freshes to enhance fish spawning and recruitment particularly for Murray cod and golden perch, increase connectivity of high value diverse habitats in the anabranch systems and introduce greater flow variability to support native fish populations in the Lower River Murray. The site-specific flow indicators for in-channel flows in the Lower River Murray as set out in Table 4 represent an amalgam of best available information from existing literature, checked against an analysis of modelled without-development and baseline flow data. Site-specific flow indicators are expressed on the River Murray as flow to South Australia. Although water requirements are specified as flow to South Australia to primarily maintain high value fish populations present within the Riverland-Chowilla and Lindsay-Wallpolla anabranch systems and the River Murray near Riverland-Chowilla, it is intended that these flows are indicative of water requirements for native fish populations within a broader reach of the Lower River Murray and will improve outcomes for native fish at a broader scale.

Hydrological analysis presented in Section 4 classified freshes within the Lower River Murray as being within the range of 13,878 ML/day to 43,756 ML/day for the low season (January-May) and 27,879 ML/day to 43,756 ML/day for the high season (July-November) (Table 2). Therefore in-channel events of 15,000-20,000 ML/day, which can be related to ecological functions and increasing flow and hydraulic habitat variability as described in Section 5.2, correspond to the lower end of hydrological events categorised as freshes.

Flow indicators as specified for the fresh element of the flow regime attempt to strike a balance between desirable flow threshold, duration and timing with desirable frequency and represent a variable flow regime that is consistent with the "without-development" hydrology of the site. Where a discrepancy exists between the literature and hydrology modelling, an analysis of modelled without-development flows has been used to guide the determination of site-specific flow indicators, particularly to ensure the recommended flows are achievable and not greater than without-development flows.

Generally, the flow indicator metric with the greatest level of uncertainty across the Basin is the definition of the desirable frequency of specified flow events, expressed as the proportion of years an event is required. This uncertainty is due to a number of reasons. Firstly, it is likely that there are thresholds for many plants and animals beyond which their survival or ability to reproduce is lost, but the precise details of those thresholds are mostly unknown or where there is information our knowledge is evolving. Secondly, in-channel flows even under pre-development conditions are extremely variable which subsequently makes specification of a single frequency metric deceptively certain. For many species and ecological communities the relationship between water provisions and environmental outcomes may not be threshold based, rather there could be a linear relationship between flow and the extent of environmental outcomes or the condition of a particular ecological species/community.

Recognising the degree of confidence in specifying a desirable frequency, 'low–uncertainty' and 'high–uncertainty' frequency of flow events have been specified (Table 4). For the low uncertainty frequency, there is a high likelihood that the environmental objectives and targets will be achieved. The lower boundary of the desired range is referred to here as the high uncertainty frequency. This is effectively the best estimate of the threshold, based on current scientific understanding, which, if not met, may lead to the loss of health or resilience of ecological communities, or the inability of species to reproduce frequently enough to sustain populations. The high uncertainty frequencies attempt to define critical ecological thresholds.

For in-channel flows in the Lower River Murray the MDBA has adopted Ecological Associates (2007) recommended 80% of years for freshes in the Victorian portion of the Living Murray Chowilla Floodplain and Lindsay-Wallpolla Islands Icon site as the low uncertainty frequency. MDBA has relied on general ecological principles and hydrological analysis to inform the high uncertainty frequencies in the absence of more specific information on desired frequency.

As advocated by Poff et al. (2010), the degree to which the hydrology of a system is altered from natural indicates a decline in the integrity of the aquatic ecosystem. In working rivers such as many of those in the Basin it is not possible nor desirable to reinstate "natural" flows, however in general scientific methods use the degree of change from natural flows as a measure of assessment.

Table 4 Site-specific ecological targets and associated flow indicators for In-channel flows: Lower River Murray

Site-Specific Ecological Targets	Site-Specific Flow Indicators					Without-development and baseline event frequencies	
	Flow required (measured as flow to South Australia; ML/d)	Duration	Timing	Frequency - proportion of years event required		Proportion of years event occurred under modelled without-development conditions (%)	Proportion of years event occurred under modelled baseline conditions (%)
				Low uncertainty (%)	High uncertainty (%)		
Provide a flow regime which supports recruitment opportunities for a range of native aquatic species (e.g. fish, frogs, turtles, invertebrates) Provide a flow regime which supports key ecosystem functions, particularly those related to longitudinal connectivity and transport of sediment, nutrients and carbon	20,000	60 days (continuous)	August to December	80	71	89	43

Note: Multiplication of the flow rate by the duration and frequency (proportion of years event required) does not translate into the additional volume of water the site needs to be environmentally sustainable. This is because part of the required flow is already provided under baseline conditions. Additional environmental water required is the amount over and above the baseline flows.

As part of the Sustainable Rivers Audit (SRA), Davies et al. (2008) identified 5 categories to assess river condition and ecosystem health. In the SRA, reference condition is a reconstruction of the hydrology of the system without significant human intervention (e.g. dams, irrigation development) and is equivalent to the concept of 'without-development' as applied in the modelling framework used by the MDBA. The classes identified in the SRA are in Table 5.

Table 5 SRA ecosystem health classes

Condition of ecosystem health	Difference from reference condition	Metric
Good	Near Reference Condition	Greater than 80% of reference
Moderate	Moderate Difference	Greater than 60% of reference
Poor	Large Difference	Greater than 40% of reference
Very Poor	Vary large Difference	Greater than 20% of reference
Extremely Poor	Extreme Difference	Less than 20% of reference

It is likely that the level to which flow alteration is important will be different for different fish species, different life stages of fish species and for other biota and ecosystem functions. However there is a reasonably limited science base to draw on to set informed high and low uncertainty frequencies. As such, as a first step to including flow indicators for in-stream needs, the MDBA has drawn on the SRA classification and is proposing that 60% protection of key aspects of the in-stream flows as a reasonable start to identify in-stream needs and 80% would represent greater certainty of achieving desired ecological outcomes. For major floodplain assets such as those described in environmental water requirement reports, a larger information base is available to identify site specific flow indicators.

Based on these principles the high uncertainty frequencies for the in-stream flows specified here are defined based on an analysis of modelled without-development flow with the high uncertainty frequencies set at 80% of the frequency that the specified events occurs under without-development conditions.

It is also worth noting that the in-channel fresh water requirements specified for the Lower River Murray in Table 4 have been developed as flow indicators for input/assessment of modelling scenarios to inform estimates of the volume of water required to reinstate this flow component. As per Ecological Associates (2010) it is acknowledged that environmental water requirements of the Lower River Murray are potentially more appropriately described as weir level given that weirs can be adjusted to raise or lower water levels while discharge remains constant. That is, there is scope for weir pool manipulation to address in-channel environmental water requirements by simulating the environmental effects of variation in river flow (MDBC 2006b; Ecological Associates 2010).

Consistent with the scope and purpose for setting site-specific flow indicators as described in Section 1.2, on-ground delivery of in-channel fresh water requirements is expected to enhance flow variability and take into account more specific environmental flow recommendations, operational delivery issues, antecedent conditions and previous monitoring as part of an adaptive management approach to environmental water delivery. From an operational delivery perspective, the ability to manipulate weir pools to achieve ecological outcomes for in-channel environments of the Lower

River Murray could potentially reduce or eliminate the need to provide specific in-channel fresh flows however this issue requires further consideration and assessment. MDBA analysis indicates that delivery of flows for other key environmental assets and key ecosystem functions upstream are likely to achieve the Lower River Murray in-channel fresh indicators as flow primarily targeted to achieve overbank outcomes at upstream sites attenuates as it flows downstream. Given the overlap between Lower River Murray in-channel fresh indicators and other flow indicators within the Basin, any modifications to flow indicators specified in Table 4 are unlikely to have a significant impact on informing SDLs at the Basin scale.

6. Flow Delivery Constraints

Basin wide environmental objectives have been developed within the context of being deliverable in a working river system that contains public and private storages and developed floodplains. To understand and assess the implications of key constraints on the ability to achieve flow indicators specified for in-channel flows in the lower sections of the River Murray, MDBA has drawn upon a combination of existing information (e.g. Water Sharing Plans, operating rules of water agencies, flood warning levels) and practical knowledge of river operators supported by testing using hydrological modelling.

Given the relatively low thresholds of the site-specific flow indicators, the achievement of these indicators and associated site-specific ecological targets are considered deliverable as mostly regulated flows (Table 6).

Table 6 Site-specific flow indicators for in-channel flows in the Lower River Murray and the effect of system constraints

Site-specific ecological targets	Site-specific flow indicators
Provide a flow regime which supports recruitment opportunities for a range of native aquatic species (e.g. fish, frogs, turtles, invertebrates) Provide a flow regime which supports key ecosystem functions, particularly those related to longitudinal connectivity and transport of sediment, nutrients and carbon.	20,000 ML/d for 60 consecutive days between August & December for 71% of years

Key

(blue)	Achievable under current operating conditions Flow indicators highlighted in blue are considered deliverable as mostly regulated flows under current operating conditions.
(yellow)	Achievable under some conditions (constraints limit delivery at some times) Flow indicators highlighted in yellow are considered achievable when delivered in combination with tributary inflows and/or unregulated flow events. They may not be achievable in every year or in some circumstances, and the duration of flows may be limited to the duration of tributary inflows.
(brown)	Difficult to influence achievement under most conditions (constraints limit delivery at most times) Flow indicators highlighted in brown require large flows that cannot be regulated by dams and it is not expected that these flows can currently be influenced by river operators due to the river operating constraints outlined above.

7. Summary and conclusion

The Lower River Murray is a key environmental asset within the Basin and is an important site for the determination of the environmental water requirements of the Basin. MDBA has undertaken a detailed eco-hydrological assessment of in-channel flows for the Lower River Murray. Specified flow indicators are indicative of a long-term flow regime required to enable the achievement of site-specific ecological targets for in-channel environments along the Lower River Murray and for the broader river valley and reach. Along with other site-specific flow indicators developed across the Basin at other hydrologic indicator sites, these environmental flow requirements were integrated within hydrological models to inform the ESLT. This process including consideration of a range of constraints such as those outlined in Section 6 is described in further detail within the companion report on the modelling process '*Hydrologic modelling to inform the proposed Basin Plan: Methods and results*' (MDBA 2012).

The flow indicators in this report are used to assess potential Basin Plan scenarios. MDBA (2012) summarises how the proposed draft Basin Plan released in November 2011 performs against flow indicators for in-channel flows in the Lower River Murray.

References

Beesley, L, Price, A, King, A, Gawne, B, Nielsen, D, Koehn, J, Meredith, S, Vilizzi, L & Hladyz, S 2011, *Watering floodplain wetlands in the Murray–Darling Basin for native fish*, Waterlines report, National Water Commission, Canberra.

Cadwallader, PL & Lawrence, B 1990, Fish. In *The Murray* (Eds. N Mackay and D Eastburn) p. 317-363. Murray Darling Basin Commission, Canberra.

Cale, B 2009, *Literature review of the current and historic flooding regime and required hydrological regime of ecological assets on the Chowilla Floodplain*, report for South Australian Murray–Darling Basin Natural Resources Management Board, Murray Bridge, South Australia.

Cheshire, KJ & Ye, Q 2008, *Larval fish assemblage structure below Locks 5 and 6, in the River Murray, South Australia from 2005 to 2007: with reference to the water manipulation trials.* SARDI Publication Number F2007/000705-1. SARDI Research Report Series No.175. South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

Cheshire, K & Ye, Q 2008a*, Spatial and temporal variations in larval fish assemblages between Locks 1 and 6 in the River Murray, South Australia: with reference to drought intervention monitoring 2007.* SARDI Aquatic Sciences Publication No F2008/000685-1. SARDI Research Report Series No 304. South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

Cheshire, KJ & Ye, Q 2010, Chapter 5. The influence of hydrology and water quality in structuring the inter-annual and spatial dynamics of larval fish assemblages in the Lower River Murray, South Australia. In *Influences of salinity, water quality and hydrology on early life stages of fishes in the Lower River Murray, South Australia*. (Eds Q Ye, KJ Cheshire and DG McNeil) pp. 128-159. SARDI Publication Number F2009/000470-5. SARDI Research Report Series No.446. South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

Cottingham, P, Stewardson, M, Crook, D, Hillman, T, Roberts, J & Rutherfurd, I 2003, *Environmental flow recommendations for the Goulburn River below Lake Eildon*, technical report 01/2003, Cooperative Research Centre for Freshwater Ecology, Canberra.

Cottingham, P, Stewardson, M, Crook, D, Hillman, T, Oliver, R, Roberts, J & Rutherfurd, I 2007, *Evaluation of summer inter-valley water transfers from the Goulburn River*, report to Goulburn-Broken Catchment Management Authority, Shepparton, Victoria.

Cottingham, P, Crook, D, Hillman, T, Oliver, R, Roberts, J & Stewardson, M 2010, *Objectives for flow freshes in the lower Goulburn River 2010/11*, report to the Goulburn-Broken CMA and Goulburn Murray Water.

Davies, PE, Harris, JH, Hillman, TJ & Walker, KF 2008, *Sustainable Rivers Audit Report 1: a report on the ecological health of rivers in the Murray–Darling Basin, 2004–2007*, Report prepared by the Independent Sustainable Rivers Audit Group for the Murray–Darling Basin Ministerial Council, Murray–Darling Basin Commission, Canberra.

Department of the Environment, Water, Heritage and the Arts 2008, National framework and guidance for describing the ecological character of Australian Ramsar wetlands, module 2 of the

national guidelines for Ramsar wetlands — implementing the Ramsar Convention in Australia, viewed 5 January 2010,
<www.environment.gov.au/water/publications/environmental/wetlands/module-2-framework.html>

Ecological Associates 2007, *Floodplain option investigation: Lindsay, Wallpolla and Mulcra islands*, Mallee Catchment Management Authority, Mildura, Victoria.

Ecological Associates 2010, *The environmental water requirements of the South Australian River Murray*, report prepared for South Australian Murray-Darling Basin Natural Resources Management Board, Adelaide.

Gehrke, PC, Brown, P, Schiller, CB, Moffatt, DB & Bruce, AM 1995, 'River regulation and fish communities in the Murray–Darling River system, Australia'. *Regulated Rivers: Research and Management* 11, 363-375.

Graham, R & Harris, JH 2004, *Floodplain inundation and fish dynamics in the Murray-Darling Basin. Current concepts and future research: a scoping study*. CRC for Freshwater Ecology, Canberra.

Humphries, P, King, AJ and Koehn, JD 1999, 'Fish, flows and flood plains: links between freshwater fishes and their environment in the Murray-Darling River system, Australia'. *Environmental Biology of Fishes* 56, 129-151.

Humphries, P, Brown, P, Douglas, J, Pickworth, A, Strongman, R, Hall, K & Serafini, L 2008, 'Flow-related patterns in abundance and composition of the fish fauna of a degraded Australian lowland river'. *Freshwater Biology* 53, 789-813.

King, AJ, Humphries, P & Lake, PS 2003, 'Fish recruitment on floodplains: the roles of patterns of flooding and life history characteristics'. Canadian Journal of Fisheries and Aquatic Sciences 60, 773-786.

King, AJ, Ramsey, D, Baumgartner, L, Humphries, P, Jones, M, Koehn, J, Lyon, J, Mallen-Cooper, M, Meredith, S, Vilizzi, L, Ye, Q & Zampatti, B 2009, *Environmental requirements for managing successful fish recruitment in the Murray River Valley – Review of existing knowledge*, Arthur Rylah Institute for Environmental Research Technical Report Series No. 197, Department of Sustainability and Environment, Heidelberg.

Mallen-Cooper, M 1993, Habitat changes and declines of freshwater fish in Australia: what is the evidence and do we need more*?* In *Sustainable Fisheries through Sustaining Fish Habitat* (Ed. DA Hancock) pp. 49-56. Proceedings of the Australian Society for Fish Biology Workshop, August 1992. Bureau of Rural Resources, Canberra.

Mallen-Cooper, M & Stuart, IG 2003, 'Age, growth and non-flood recruitment of two potamodromous fishes in a large semi-arid/temperate river system'. *River research and applications* 19: 697-719.

MDBA (Murray-Darling Basin Authority) 2011*, The proposed "environmentally sustainable level of take" for surface water of the Murray-Darling Basin: Method and Outcomes.* Murray-Darling Basin Authority, Canberra.

MDBA (Murray-Darling Basin Authority) 2012*, Hydrologic modelling to inform the proposed Basin Plan: Methods and results.* Murray-Darling Basin Authority, Canberra.

MDBA (Murray-Darling Basin Authority) 2012a*, Assessment of environmental water requirements for the proposed Basin Plan: Riverland-Chowilla Floodplain.* Murray-Darling Basin Authority, Canberra.

MDBC (Murray–Darling Basin Commission) 2006a, *The Chowilla Floodplain and Lindsay–Wallpolla Islands icon site environmental management plan*, MDBC, Canberra.

MDBC (Murray–Darling Basin Commission) 2006b, *The River Murray channel icon site environmental management plan*, MDBC, Canberra.

National Murray Cod Recovery Team 2010, 'National Recovery Plan for the Murray Cod *Maccullochella peelii peelii*'. Department of Sustainability and Environment, Melbourne.

Newall, P, Lloyd, L, Gell, P & Walker, K 2009, *Riverland Ramsar Site ecological character description,* South Australia Department of Environment and Heritage, Adelaide.

Poff, NL, Richter, BD, Arthington, AH, Bunn, SE, Naiman, RJ, Kendy, E, Acreman, M, Apse, C, Bledsoe, BP, Freeman, MC, Henriksen, J, Jacobson, RB, Kennen, JG, Merritt, DM, O'Keefe, JH, Olden, JD, Rogers, K, Tharme, RE & Warner, A 2010, 'The Ecological Limits of Hydrologic Alteration (ELOHA): A new framework for developing regional environmental flow standards.' *Freshwater Biology* 55:147-170.

Pressey, RL 1986, *Wetlands of the River Murray below Lake Hume*. Prepared for the River Murray Commission. RMC Environmental Report 86/1.

Rowland, SJ 1989, 'Aspects of the history and fishery of the Murray cod, *Maccullochella peeli* (Mitchell) (Percichthyidae)'. *Proceedings of the Linnean Society of New South Wales* 111, 201-213.

Schiller, C & Harris, JH 2001, Native and alien fish. In *Rivers as Ecological Systems – the Murray-Darling Basin* (Ed. W Young) pp. 229-258. Murray-Darling Basin Commission, Canberra.

SKM (Sinclair Knight Merz) 2007, *High Conservation Value Aquatic Ecosystems project - identifying, categorising and managing HCVAE*, Final report, Department of the Environment and Water Resources, 16 March 2007, <www.environment.gov.au/water/publications/environmental/ecosystems/hcvae.html>

Walker, KF 2001, *A river transformed: the effect of weirs on the River Murray*. In *The Proceedings of The Way Forward on Weirs*. Inland Rivers Network. Blanch, S (ed.). pp. 7-22.

Walker, KF & Thoms, MC 1993, 'Environmental effects of flow regulation on the lower River Murray, Australia'. *Regulated Rivers: Research and Management* 8, 103-119.

Walker, KF, Boulton, AJ, Thoms, MC & Sheldon, F 1994, 'Effects of water-level changes induced by weirs on the distribution of littoral plants along the River Murray, South Australia'. *Australian Journal of Marine & Freshwater Research* 45, 1421-1438.

Zampatti, BP, Leigh, SJ & Nicol, JM 2008, *Chowilla Icon Site – Fish Assemblage Condition Monitoring 2005-2008*. SARDI Publication Number F2008/000907-1. SARDI Research Report Series No. 319. South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

Zampatti, BP, Leigh, SJ & Nicol, JM 2011, *Fish and Aquatic Macrophyte Communities in the Chowilla Anabranch System, South Australia. A report on investigations from 2004-2007*. SARDI Publication Number F2010/000719-1. SARDI Research Report Series No. 525 180pp. South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

Appendix A

Data used in producing hydrologic indicator site maps

Data	Dataset name	Source[a]
Basin Plan regions	Draft Basin Plan Areas 25 May 2010	Murray–Darling Basin Authority (2010)
Dam walls/barrages	GEODATA TOPO 250K Series 3 Topographic Data	Geoscience Australia 2006
Gauges	100120 Master AWRC Gauges	
Icon sites	Living Murray Indicative Icon Site Boundaries	Murray–Darling Basin Commission (2007)
Irrigation areas	Combined Irrigation Areas of Australia Dataset	Bureau of Rural Sciences (2008)
Lakes	GEODATA TOPO 250K Series 3 Topographic Data	Geoscience Australia (2006)
Maximum wetland extents	Wetlands GIS of the Murray–Darling Basin Series 2.0 (Kingsford)	Murray–Darling Basin Commission (1993)
National parks/nature reserves	Digital Cadastral Database	New South Wales Department of Lands (2007)
National parks/nature reserves	Collaborative Australian Protected Areas Database — CAPAD 2004	Department of the Environment, Water, Heritage and the Arts (2004)
Nationally important wetlands	Directory of Important Wetlands in Australia Spatial Database	Department of the Environment, Water, Heritage and the Arts (2001)
Ocean and landmass	GEODATA TOPO 250K Series 3 Topographic Data	Geoscience Australia (2006)
Ramsar sites	Ramsar wetlands in Australia	Department of the Environment, Water, Heritage and the Arts (2009)
Rivers	Surface Hydrology (AUSHYDRO version 1-6)	Geoscience Australia (2010)
Roads	GEODATA TOPO 250K Series 3 Topographic Data	Geoscience Australia (2006)
SRA Zones	Sustainable Rivers Audit Zones	MDBA 2008
State border	GEODATA TOPO 250K Series 3 Topographic Data	Geoscience Australia (2006)
State forests	Digital Cadastral Database	New South Wales Department of Lands (2007)
Towns	GEODATA TOPO 250K Series 3 Topographic Data	Geoscience Australia (2006)
Weirs	Murray–Darling Basin Weir Information System	Murray–Darling Basin Commission (2001)
Weirs 2	River Murray Water Main Structures	Murray–Darling Basin Authority (2008)

[a] Agency listed is custodian of relevant dataset; year reflects currency of the data layer.