



Australian Government



Assessment of environmental water requirements for the proposed Basin Plan: **Lower Border Rivers (in-channel flows)**

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Border Rivers region

Assessment of Lower Border Rivers (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 Border Rivers. 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 (fresches, 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 Border Rivers is one of the key

environmental assets where a detailed assessment of environmental water requirements was undertaken.

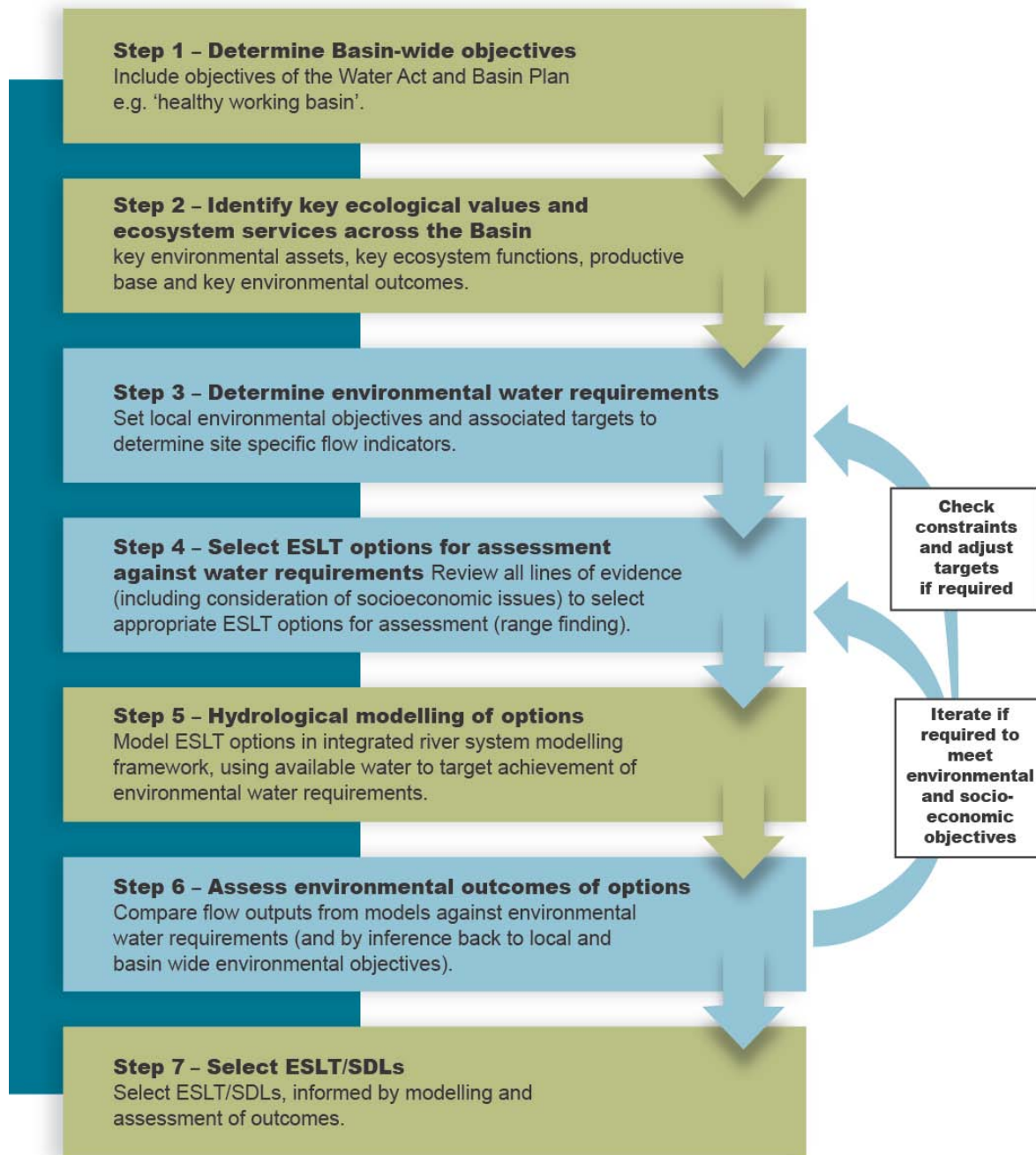


Figure 1 Outline of method used to determine an Environmentally Sustainable Level of Take (Source: MDBA 2011)

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 Border Rivers including information supporting the development of site-specific flow indicators for the site (with reference to flows gauged at Mungindi on the Barwon River). 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 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. Site location and extent

The Border Rivers rise on the western slopes of the Great Dividing Range in the areas straddling the NSW-Queensland border (Figure 2; Spatial data used in Figure 2 are listed in Appendix A). The region’s principal streams are the Macintyre River and Severn River (NSW) in the south-east, the Dumaresq River and Severn River (QLD) in the east, Macintyre Brook in the north and the Weir River in the north-west. The Macintyre River becomes the Barwon River at its junction with the Weir River. This report considers the environmental water needs of the system of rivers and streams which make up the Border Rivers region.

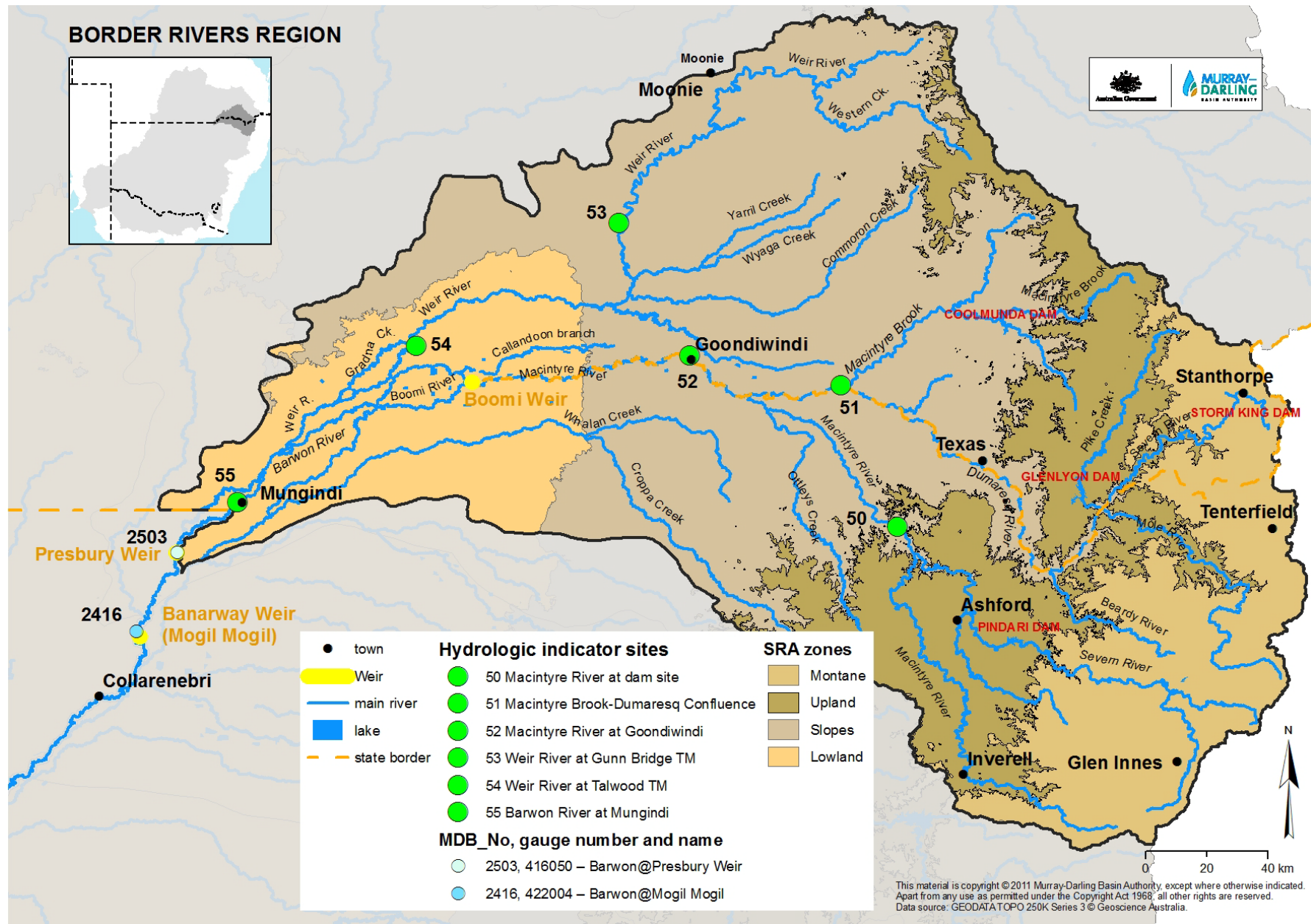


Figure 2 Location of hydrologic indicator sites in the Border Rivers region. In-channel flow indicators are specified at Mungindi on the Barwon River.

3. Ecological Values

The Border Rivers region has been included as part of the endangered aquatic ecological community in the natural drainage system of the lowland catchment of the Darling River, under the NSW Fisheries Management Act (NSW Scientific Committee 2004). The community is known to occur in lowland riverine environments with meandering channels and a variety of aquatic habitats including deep channels and pools, wetlands, gravel beds and floodplains.

The floodplain between Goondiwindi and Mungindi contains a large number of anabranches and billabongs (CSIRO 2007). Downstream from Goondiwindi small effluent creeks such as Boomi, Callandoon, Dingo and Whalan Creeks break off from the main channel and meander across the region forming a complex floodplain of billabongs and wetlands that rely on overbank flows (Kingsford 1999). When flooded, these areas are known to provide large amounts of dissolved organic carbon to the riverine ecosystem which is essential to aquatic ecosystem functioning (CSIRO 2007). The anabranches and billabongs of the Macintyre River floodplain are important geomorphological assets and these wetlands are important breeding habitat for protected waterbirds including brolgas (*Grus rubicunda*), black-necked storks (*Ephippiorhynchus asiaticus*) and magpie geese (*Anseranas semipalmata*) (CSIRO 2007; Appendix B).

The Morella Watercourse/Boobera Lagoon/Pungbougul Lagoon complex is a wetland of national importance and is located on the floodplain between Goondiwindi and Mungindi. This wetland complex is considered one of the most important Aboriginal places in eastern Australia (CSIRO 2007).

The Border Rivers system provides a wide range of aquatic habitats and supports river red gum (*Eucalyptus camaldulensis*), coolibah (*E. coolabah*) and river oak (*Casuarina cunninghamiana*), with weeping bottlebrush (*Callistemon viminalis*) a common understorey plant along the network of rivers (McCosker 1999). The region also provides habitat for 16 species of native fish which includes the EPBC-listed Murray cod (*Maccullochella peelii peelii*), silver perch (*Bidyanus bidyanus*), endangered populations of olive perchlet (*Ambassis agassizii*) and purple spotted gudgeon (*Mogurnda adspersa*) (Appendix B).

At a regional scale, the ecosystem health of the Border Rivers 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 lowland zone of the Border Rivers was degraded with a fish condition index of “poor” (Davies et al. 2008). The slopes zone was given a fish condition index of “moderate”.

At an individual species level, the SRA found that the conservationally significant silver perch were absent from catches in zones where they were expected to be common (Davies et al. 2008). Other species missing in catches from one or more zones where they were expected under without-development conditions included the Darling River hardyhead, flathead gudgeon, olive perchlet, river blackfish, mountain galaxias, southern purple-spotted gudgeon and un-specked hardyhead.

The ecological values of the Lower Border Rivers 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 network of rivers of the Lower Border Rivers, the system meets three of the five key environmental asset criteria (Table 1).

Table 1 Assessment of the Lower Border Rivers against MDBA key environmental assets criteria

Criterion	Ecological values that support the criterion
3. The water-dependent ecosystem provides vital habitat	<p>Healthy vegetation within riverine systems provides a variety of ecological functions including habitat and feeding opportunities for terrestrial and in-stream species, corridors for movement and migration of fauna species and streambank stability. The anabranches and billabongs of the Macintyre River floodplain provide habitat for a number of threatened fauna species (Appendix B) as well as providing a source of organic matter and nutrients for down-stream needs. In-channel structures such as benches accumulate debris or detrital material and when inundated, these areas become an important source of carbon for downstream reaches (Foster 1999).</p> <p>The Border Rivers, in particular the Macintyre River and all major tributaries in NSW, have been identified as supporting important populations of Murray cod, which is listed as vulnerable under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) (National Murray Cod Recovery Team 2010).</p> <p>Silver perch is listed as vulnerable under the NSW Fisheries Management Act 1994 (NSW Department of Primary Industries (2006). The NSW Silver Perch Recovery Plan reports that self-sustaining populations of silver perch have been recorded in the Macintyre River indicating that this section of the Border Rivers provides important habitat for this species.</p>
4. Water-dependent ecosystems that support Commonwealth, State or Territory listed threatened species or communities	Species and communities listed as threatened under both Commonwealth and state legislation that have been recorded at the site are in Appendix B.
5. The water-dependent ecosystem supports, or with environmental watering is capable of supporting, significant biodiversity	The NSW Fisheries Scientific Committee, established to review the status of aquatic ecological communities in the lowland catchments of the Darling River system, found that the community has a diverse assemblage of native species, including 21 native fish species and a large number of native invertebrate species (NSW Department of Primary Industries 2011).

4. Hydrology

Major water storages are located in the headwaters of each of the major rivers and include Pindari Dam on the Severn River, the Glenlyon Dam on the Dumaresq River and Coolmunda Dam on the headwaters of the Macintyre Brook River. System inflows are regulated by Glenlyon and Pindari Dams. Flows from these dams are regulated to Mungindi which is the downstream boundary of the Border Rivers region.

A shift towards using unregulated rivers for irrigation and water harvesting, including harvesting of on-farm overland flow, occurred in the 1990s with on-farm storage increasing. The storage capacity of weirs and private dams in the Queensland Border Rivers region is estimated at 15 GL for weirs, 459 GL for ring tanks and 119 GL for hillside dams (MDBC 2007). A subsequent study in New South Wales estimated the storage capacity of farm dams at 77 GL (Geoscience Australia 2007).

There are also 15 main channel weirs constructed to assist in providing water for irrigation, urban, stock and domestic purposes, as well as numerous small weirs on tributaries and anabranch channels. This includes weirs at Bonshaw, Goondiwindi, Mungindi and Boggabilla. Boggabilla Weir located 20 kilometres upstream of Goondiwindi was constructed in 1991 and is the largest of the main channel weirs. This is the main regulating structure for the lower sections of the Macintyre River, controlling flows during the main irrigation season from October to March.

Water resource development has decreased the average frequency of 20,000 ML/d flows at Goondiwindi that hydrologically connects the anabranches and billabongs of the Macintyre River floodplain to the main river by about 16 percent and has reduced the volume of individual events by about 8 percent on average (CSIRO 2007). Similarly, Thoms et al. (2005) report that current water resource development and river operations have decreased the average frequency of inundation of a number of billabongs on the Macintyre River floodplain by between 12 and 17 percent.

The Sustainable Rivers Audit found that hydrological condition at the Border Rivers sites declines from the upland zone upstream of regulation and diversion, through the slopes zone downstream of the storages, to the lowland zone (Davies et al. 2008). Specifically, by the time most flows enter the upper Barwon-Darling valley downstream of Mungindi, it was found that gross volume of annual flow and high flow events at the lowland zone are generally rated as 'poor' to 'very poor' condition.

As part of an assessment of flood hydrology of the Barwon-Darling River, Gippel (2006) undertook a flood frequency analysis for sites between Mungindi and Menindee. As part of this analysis, bankfull stage/magnitude flow relationships were estimated based on available channel cross sections and rating curves. In addition to estimating bankfull flows, Gippel (2006) also undertook a comparison of flows under current (baseline) arrangements and natural (without-development) conditions (Table 2). The analysis was based on flows predicted by IQQM (Integrated Quantity and Quality Model) for an 80 year period between 1922 and 2002.

This analysis provides the best estimate available of the flow rate for bankfull flows at Mungindi. It also indicates that based on modelled flows at Mungindi, there has been a significant change in bankfull flows in the Lower Border Rivers system as a result of water resource development.

Table 2 Analysis of bankfull flows and average recurrence interval (ARI) events at key locations for Barwon-Darling River under modelled 'natural' and current conditions for the period 1922-2002 (Gippel 2006)

Gauge Location (ID No.)	Magnitude of bankfull flow (ML/d)	ARI of bankfull flow under 'natural conditions'	Magnitude of 1 yr ARI under 'natural conditions'	Magnitude of 1 yr ARI under 'current conditions'
Presbury Weir (416050)	9,576	1.28	8,268	3,590
Mungindi (416001)	9,488	1.56	7,746	4,045
Mogil Mogil -Barnarway Weir (422004)	11,596	0.91	12,953	7,238

In order to further describe changes in flow patterns due to water resource development, the MDBA analysed modelled flow data at Goondiwindi and Mungindi for the period 1895–2009. Figures 3 and 4 show how flows have changed between without-development and baseline (current arrangements) flow regimes at these sites. These figures show that when compared with flow patterns at Goondiwindi, a significant alteration of flows under baseline conditions is apparent for predicted flows at Mungindi. The impact of development on flows at Mungindi has been to reduce average daily flows throughout the year, with a less defined seasonal peak (Figure 4).

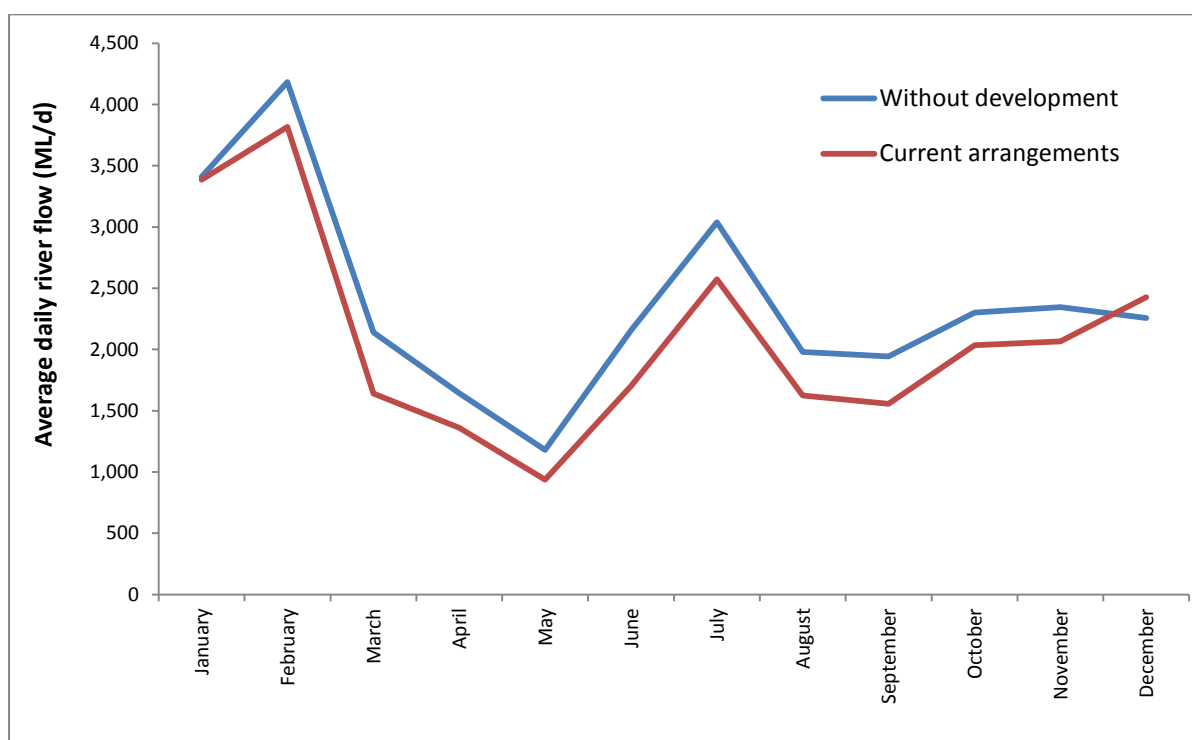


Figure 3 Modelled monthly flow for Macintyre River at Goondiwindi under without-development and baseline (current arrangement) conditions for the period 1895-2009

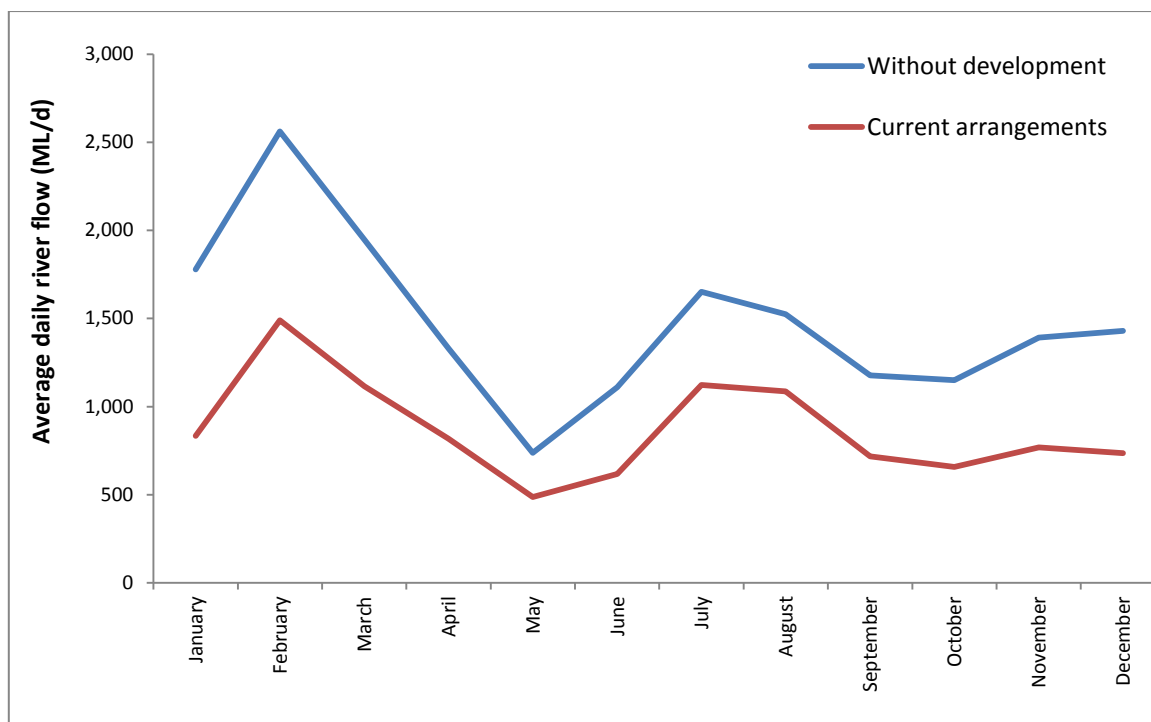


Figure 4 Modelled monthly flows for Barwon River at Mungindi under without-development and baseline (current arrangement) conditions for the period 1895-2009

5. Determining the site-specific flow indicators for the Lower Border Rivers

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 Border Rivers 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 Border Rivers, as described below.

Table 3 Site-specific ecological targets for the Lower Border Rivers

Site-specific ecological targets	Justification of targets
<ul style="list-style-type: none"> • 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 	<p>A joint assessment of the ecological condition of streams in the Border Rivers catchment by NSW and Queensland Government agencies (Queensland DNR and NSW DLWC 1999) reports an abundance of large woody debris and fallen timber on bench platforms and inset floodplain areas located along the Macintyre, Weir, Boomi and Barwon River reaches downstream of Goondiwindi.</p> <p>Snags or large woody debris are important forms of aquatic habitat and periodic access to this type of habitat is an important part of the reproductive cycle for several species (NSW Department of Primary Industries 2011). For example, Murray cod and various species of gudgeons spawn adhesive eggs onto and in submerged logs (NSW Department of Primary Industries 2011).</p> <p>In addition to retaining large amounts of large woody debris and fallen timber, bench platforms and inset floodplain areas act as sediment and nutrient sinks and are an important source of dissolved nutrients (Southwell 2008). The floodplain between Goondiwindi and Mungindi contains a large number of anabranches and billabongs (CSIRO 2007). When flooded, these areas are known to provide large amounts of dissolved organic carbon to the riverine ecosystem which is essential to aquatic ecosystem functioning (CSIRO 2007).</p> <p>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 various species. For example:</p> <ul style="list-style-type: none"> • a number of fish species such as golden perch and silver perch require flow pulses or floods for spawning (Humphries et al. 1999); • monitoring has shown that flows are an important factor in the larval survivorship and subsequent recruitment of Murray cod (Cheshire and Ye 2008); • connectivity between the main river and adjacent wetlands, anabranches and still water habitats provided by increased flows are essential for larvae and juveniles of species such as flathead gudgeons (<i>Philypnodon grandiceps</i>) and Australian smelt (<i>Retropinna semoni</i>), which require high concentrations of small prey to feed on and develop (Humphries et al. 1999).

5.2. Information used to determine site-specific flow indicators

5.2.1. Inundation of key habitat

As outlined in Table 3, the Border Rivers system provides a wide range of aquatic habitats that are ecologically important. The lower section of the Border Rivers system downstream of Goondiwindi is characterised by an extensive floodplain up to 20 km wide and a network of anabranch channels. These ephemeral channels are disconnected from the main channel for most of the year (though many retain pools of water for several months) and commence to flow at a range of discharges. The four main anabranch channels that off-take from the main Macintyre channel, are the Boomi River, Callandoon Creek, Dingo Creek and Whalan Creek. In addition the Macintyre, Weir, Boomi and Barwon River reaches downstream of Goondiwindi contain an abundance of large woody debris and fallen timber on bench platforms and inset floodplain areas.

Anabranches

As part of their investigation, Thoms et al. (2005) identified 69 anabranch channels with a combined length of 236 km, which was 62% of the total channel length of the study area, being the Macintyre River between Goondiwindi and Boomi. Five distinct commence-to-flow phases or flow bands were identified in the study reach (Table 4).

Table 4 Anabranch classification (adapted from Thoms et al. 2005)

Flow group based on commence to flow threshold (ML/d)	No. of anabranch channels	Surface area of anabranch channels (ha)
200 - 7000	40	212.7
8,000 – 13,000	10	302.3
16,000 – 20,000	6	12.8
24,000 – 31,000	9	25.4
>56,000	4	32.8

A follow-up study by Reid (2006) examined the anabranch commence-to-flow relationships for the entire floodplain between Goondiwindi and Mungindi and found that 90% (or 450 km) of the anabranch and billabong systems are hydrologically connected when Macintyre River flows exceed 20,000 ML/day at Goondiwindi (CSIRO 2007). NSW Department of Water and Energy (2007) indicates that the nationally important Morella Watercourse/Boobera Lagoon area is receiving beneficial flooding at higher flow levels. CSIRO (2007) identified that the lagoon floods from the river approximately once in ten years on average, however the flooding threshold is ill-defined (between 25,000 ML/day to 80,000 ML/day at Goondiwindi).

The MDBA has used the flow bands from Thoms et al. (2005) as a basis for further analysis of modelled flow data for the period 1895-2009 at Goondiwindi. This was undertaken to assess the changes in the flow events that are critical to achieve connection between the river and the network of anabranches which dissect the lower floodplain (Table 5).

Table 5 Analysis of key flow bands at Goondiwindi modelled under without-development and baseline conditions for the period 1895-2009

Flow bands		Without-development			Baseline		
Lower Threshold (ML/day)	Upper Threshold (ML/day)	Number of Events	Mean Event Duration (Days)	Mean Event Volume (ML)	Number of Events	Mean Event Duration (Days)	Mean Event Volume (ML)
200	7,000	630	23.1	21,337	964	20.16	21,733
8,000	13,000	110	2.34	22,264	121	1.79	17,360
16,000	20,000	62	1.47	25,743	38	1.39	24,673
24,000	31,000	42	1.6	43,267	35	1.46	39,010
Greater than 56,000		75	2.97	246,329	61	2.59	216,177

The above results show that the characteristics of the two lower flow bands are similar under without-development and baseline (current) conditions. As shown in Table 4, anabranches inundated by flow in these two bands represent a significant proportion (87.8% based on total surface area of surveyed benches). Flows between 16,000 and 20,000 ML/d are the most significantly impacted by water resource development with the number of events reduced by 39%. The broader ecological significance of this change is reduced by the relatively small proportion of anabranches inundated by this flow range (2.2 % based on total surface area of surveyed benches).

This analysis suggests that flows required to inundate anabranches are not significantly modified by water resource development, and consequently the MDBA has not proposed flow indicators for the inundation of anabranches in the lower section of the Border Rivers system.

In-channel

A joint assessment of the ecological condition of streams in the Border Rivers catchment by NSW and Queensland Government agencies (Queensland DNR and NSW DLWC 1999) includes an assessment of the fluvial geomorphology of Macintyre River downstream of Goondiwindi. This report (Queensland DNR and NSW DLWC 1999) notes an abundance of large woody debris and fallen timber on bench platforms and inset floodplain areas located along the Macintyre, Weir, Boomi and Barwon River reaches downstream of Goondiwindi. Snags or large woody debris are important forms of aquatic habitat and periodic access to this type of habitat is an important part of the reproductive cycle for several species (NSW Department of Primary Industries 2011).

Detailed information on the spatial distribution of large woody debris through the lower section of the Border Rivers system is limited. However the prevalence of large woody debris in the lower Border Rivers system is in part supported by surveys undertaken by Boys (2007). Boys (2007) mapped the location of 7,812 large wood pieces across 12 study reaches located between Mungindi and Tilpa and estimated their commence-to-inundate height. In the study reach downstream of Mungindi (between Presbury Weir and Collarenebri), Boys (2007) identified 1,873 large wood pieces and reported that these became progressively inundated at flows up to 20,000 ML/d (gauged at Mogil Mogil).

Figure 5 shows how flows have changed between without-development and baseline (current) conditions at Mungindi. The impact of development on flows at Mungindi is most obvious between flows of 500 and 10,000 ML/d.

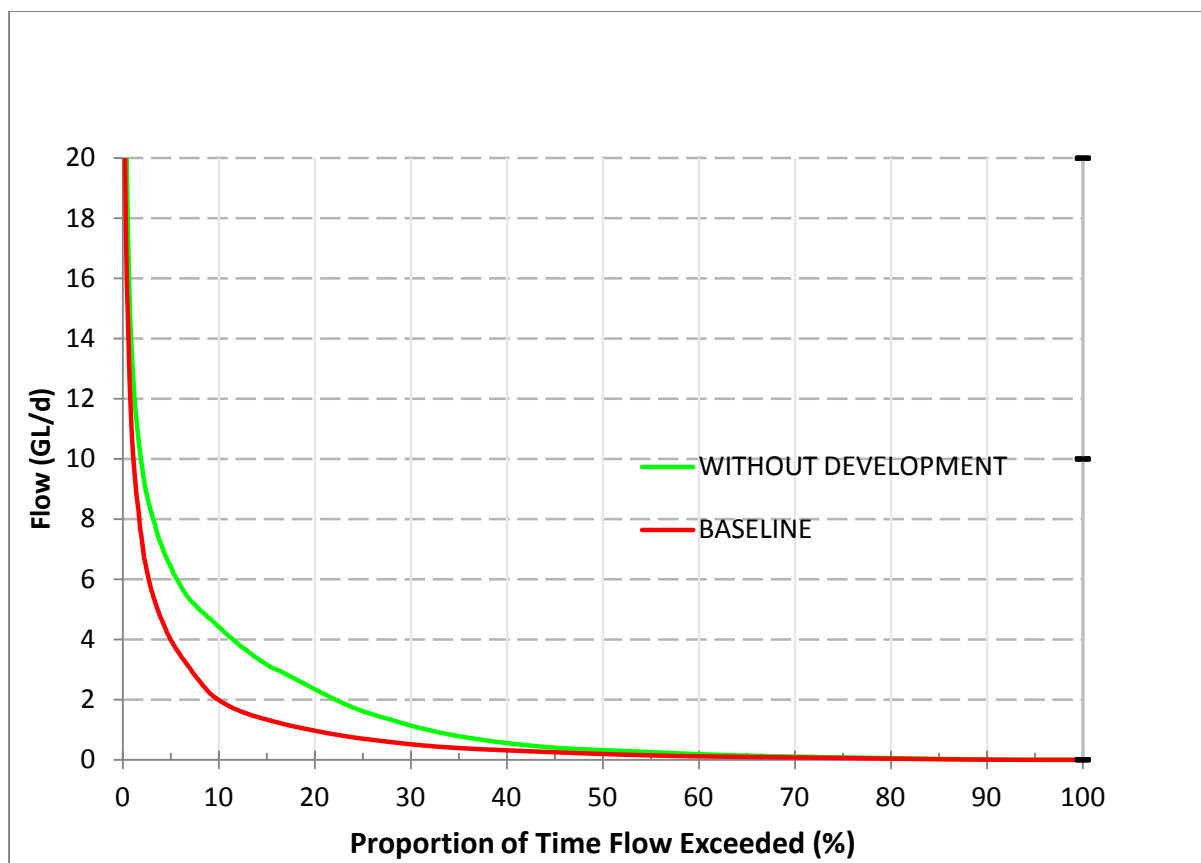


Figure 5 Modelled monthly flows for Barwon River at Mungindi under without-development and baseline (current arrangement) conditions for the period 1895-2009

Assuming that large woody debris becomes progressively inundated up to bankfull flows, the MDBA has analysed modelled flow data for the period 1895–2009 at Mungindi focusing on flows of between 500 and 9,488 ML/d (Table 6). As outlined previously, 9,488 ML/d is the estimated bankfull flow rate at Mungindi (as defined by Gippel 2006).

Table 6 Analysis of key flow bands at Mungindi modelled under without-development and baseline (current) conditions for the period 1895-2009

Flow bands		Without-development			Baseline		
Lower Threshold (ML/day)	Upper Threshold (ML/day)	Number of Events	Mean Event Duration (Days)	Mean Event Volume (ML)	Number of Events	Mean Event Duration (Days)	Mean Event Volume (ML)
500	3,500	435	14.6	20,103	654	11.7	13,312
3501	6,500	162	10.0	44,678	76	8.3	36,634
6501	9,488	66	8.6	64,972	27	6.5	48,888

The above results show that compared to flows predicted under without-development conditions, the number of events with maximum flow thresholds between 3,000 and 10,000 ML/d has significantly decreased under baseline (current) conditions. This indicates that the frequency of

inundation for large woody debris located in the mid and upper section of the channel up-stream and downstream of Mungindi has been significantly reduced.

Native fish species such as the conservationally significant Murray cod spawn adhesive eggs onto and in submerged logs (NSW Department of Primary Industries 2011). Increasing the frequency of events with a minimum threshold of 3,000 – 4,000 ML/d is likely to increase periodic access to large woody debris and in doing so have a positive influence on the reproductive cycle for several species.

The MDBA has drawn on the above information when defining the flow indicators as set out in Table 8. The flow indicators describe a flow event that exceeds a minimum flow rate for a defined duration. The duration has been informed by both hydrologic and ecologic parameters. The average duration of in-channel flows under modelled without-development conditions, as well as the known reproductive requirements of the conservationally significant Murray cod (see Section 5.2.3), support the selection of a duration between 5 and 13 days. The approach used to determine the desired frequency of occurrence for these flows is described in Section 5.3.

5.2.2. Nutrient Cycling

Flow variability facilitates ecosystem processes including nutrient cycling and exchange as previously dry benches and floodplains are alternately inundated and dried. During periods of low flow, leaf litter and other organic material accumulates on in-channel terraces or benches. During periods of high flows, inundation of these areas enables the organic material to become an *in situ* food source for many aquatic organisms (Thoms et al. 1996) and depending on the size of flow, may also be transported from the bench to be recycled within the river/floodplain system (Foster 1999). Due to their location (benches are generally found lower down in the cross-sectional profile of the river channel), benches are more frequently inundated. Both the frequency of inundation and ability to accumulate organic material mean that benches provide an important function in the cycling of carbon and nutrients (Foster 1999).

The work undertaken by Thoms et al. (2005) and McGinness et al. (2002) provides further detail regarding the value of in-channel environments in delivering dissolved carbon to aquatic systems within the Border Rivers. Based on information outlined in Thoms et al. (2005), Table 7 delineates the key elements of the carbon pool in the Macintyre system.

While the surface litter within anabranch channels makes a large contribution of dissolved organic carbon, surface leaf litter is present in higher densities in the main channel. McGinness et al. (2002) states that freshly dropped litter is of much higher quality for consumption by riverine organisms than desiccated degraded leaves. McGinness et al. (2002) also noted that in the Macintyre system the natural flood season coincides with that for leaf-fall of the dominant *Eucalyptus* species. Thus the high leaf litter content of the channel will provide a key role in nutrient cycling. This information indicates that both the broader river channel and, more specifically, bench platforms and inset floodplain areas are important in nutrient cycling and provision of food resources for fish.

Table 7 Carbon pool of the lower Macintyre River (Thoms et al. 2005)

Carbon Pool	Main River Channel	Anabranh Channels	Floodplain surface
Surface Litter – Bark (g/m ²)	98.5	586.5	85.5
Surface Litter – Leaves (g/m ²)	147.3	100.2	100
Surface Litter -Total (g/m ²)	245.8	686.7	185.5
Total Carbon in Surface Sediment (TC%)	2.9	3.3	5.6
Dissolved organic Carbon (DoC) released from surface sediment after 24 hours (ppm)	9.71	16.1	6.54

While it is known that bench platforms and inset floodplain areas are common throughout the network of rivers downstream of Goondiwindi, detailed information outlining the spatial distribution of these features is limited. To gain an insight into the nature, extent and commence-to-inundate heights for bench platforms and inset floodplain areas in the Lower Border Rivers system, the MDBA has analysed surveyed cross-sections. The channel cross-section for the Barwon River up-stream of Presbury Weir (see www.realtimedata.water.nsw.gov.au/water.stm) shows the presence of a range in-channel surfaces and in particular the presence of benches at a stage height of between 3 and 5 metres. Ratings tables for the gauge on the Barwon River up-stream of Presbury Weir (see www.realtimedata.water.nsw.gov.au/water.stm) indicate that flows with a stage height of between 3 and 5 metres equate to a maximum flow of between 4,000 and 10,300 ML/d. It is assumed that this cross-section is representative and is broadly indicative of flows required to inundate mid and high level benches up-stream and downstream Mungindi.

As highlighted in Table 6, the frequency of flow events which inundate the mid to upper sections of the channel (i.e. flows between 4,000 and 9,488 ML/d) have significantly decreased under current (baseline) conditions. Increasing the frequency of events with a minimum threshold of 4,000 ML/d is likely to increase periodic inundation of benches and in doing so have a positive influence on the cycling of carbon and nutrients.

5.2.3. Fish

The lowland sections of the Border Rivers are recognised for their ability to support significant populations of native fish. The importance of this area is elevated because of the widespread decline of fish populations as shown through Sustainable Rivers Audit monitoring (Davies et al. 2008). Environmental water requirements for the lowland sections of the Border Rivers system have been developed to take into account the importance of native fish populations.

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 are 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, which have been recorded in the Border River system, 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 supports the provision of flows to enable access to key habitat features such as large woody debris and anabranch channels, as well as in-channel flow variability, as important to sustaining key ecological features such as native fish populations. The following information on key species spawning and recruitment requirements has been used to inform the timing and duration of flow indicators.

The Border Rivers, in particular the Macintyre River and all major tributaries in NSW, have been identified as supporting important populations of Murray cod, which is listed as vulnerable under the Environment Protection and Biodiversity Conservation Act 1999. Murray cod have been found to spawn adhesive eggs onto and in submerged logs (NSW Department of Primary Industries 2011). Lintermans (2007) reports that Murray cod spawn in spring and early summer when water temperature exceeds about 15°C. Consistent with NSW Department of Primary Industries (2011), Lintermans (2007) reports that eggs are deposited onto hard surfaces such as logs and, rocks or clay banks with hatching occurring 5 to 13 days after spawning. To assist in spawning and incubation of Murray cod flows likely to inundate a significant proportion of large woody debris in the section of river downstream of Goondiwindi for a period of at least 5 days are required.

Golden perch are commonly found throughout the lowland sections of the Border Rivers (Davies 2008). Studies in other sections of the Basin have shown that golden perch prefer deep slow moving pool habitats, are often associated with snags and are thought to rely on flow variability, particularly floods to spawn (Lintermans 2007). The key spawning period is during spring and summer when flow exceeds about 20°C (Lintermans 2007). This period coincides with the peak flows in the Border Rivers system (see Figures 3 and 4). To assist in spawning and incubation of golden perch, variable flows during spring and summer are thought to be necessary.

5.2.4. Other biota

There is little in the way of studies in the Border Rivers examining flow-ecology relationships with regard to other faunal groups. Nevertheless, the MDBA is confident that the specified environmental water requirements for various in-channel and high flow events will have valuable beneficial effects on the life-cycle and habitat requirements of amphibians, and water-dependent reptiles and invertebrates. Key ecosystem functions associated with river and floodplain wetland and lagoon connectivity will also be enhanced.

5.3. Proposed flow indicators

The site-specific flow indicators for in-channel flows in the Lower Border Rivers as set out in Table 8 represent an amalgam of best available information drawn from existing literature, checked against an analysis of modelled without-development and baseline flow data. Site-specific flow indicators are expressed on the Barwon River at Mungindi. This location is used because it is relevant to the information base and being at the end of the system, additional environmental flows will enhance 'longitudinal connectivity' which is important for a range of ecological processes.

Flow indicators as specified for various elements 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.

Generally, the flow indicator component with the greatest level of uncertainty across the Basin is the definition of the desirable frequency of flows, 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, key ecologic and geomorphic features are widely distributed and would have experienced significant variability in their inundation frequency under pre-development conditions 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 or community.

Recognising the degree of confidence in specifying a desirable frequency, ‘low–uncertainty’ and ‘high–uncertainty’ frequency of flow events have been specified (Table 8). 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. The high–uncertainty frequency is considered to indicate a level beyond which the ecological targets may not be achieved.

For the specified flow indicators, the MDBA has relied on general ecological principles to inform the high and low uncertainty frequencies.

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.

As part of the Sustainable Rivers Audit (SRA), Davies et al. (2008) identified five 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 9.

Table 8 Site-specific ecological targets and associated flow indicators for Lower Border Rivers (in-channel flows)

Site-Specific Ecological Targets	Site-Specific Flow Indicators					Without-development and baseline event frequencies	
	Minimum Flow rate required in the Barwon River at Mungindi (ML/d)	Minimum Continuous Duration (days)	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)	4,000	5	October to December	32	24	39	17
	4,000	5	October to March	59	45	74	33
	4,000	11	Minimum of 2 events in a year preferably one summer/autumn and one winter/spring but timing not constrained	36	27	44	13
Provide a flow regime which supports key ecosystem functions, particularly those related to longitudinal connectivity and transport of sediment, nutrients and carbon							

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.

Table 9 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. For major floodplain assets such as those described in other environmental water requirement reports, a larger information base is available to identify site-specific flow indicators.

Based on these principles the high- and low-uncertainty frequencies for the in-stream flows specified here are defined based on an analysis of modelled without-development flow with the high- and low-uncertainty frequencies set at 60% and 80% of the frequency that the specified events occurs under without-development conditions.

It is recognised that periods between inundation events are an important consideration when trying to determine ecosystem resilience or thresholds of irreversible change. When investigating the environmental water requirements for the various sites, consideration was given to specifying a maximum period between events or metrics related to maximum dry. However, the literature regarding the tolerance of various floodplain ecosystems to dry periods is limited. In addition where this information exists, recommended maximum dry intervals often conflicts with the maximum dry experienced under modelled without-development conditions.

Considering these issues, MDBA has not proposed a maximum dry period with the exception of a small number of sites across the Basin, which does not include the Lower Border Rivers system. Even so, the importance of maximum dry periods and their role in maintaining ecosystem resilience is recognised. Maximum dry periods between successful events are reported for hydrological modelling associated with the Lower Border Rivers indicator site (see MDBA 2012) despite reducing the maximum period between events not being the primary objective of the modelling process.

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 Border Rivers system, the 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.

Major storages are located in the headwaters of each of the major rivers and include Pindari Dam on the Severn River, the Glenlyon Dam on the Dumaresq River and Coolmunda Dam on the headwaters of Macintyre Brook. Outlet capacities for Glenlyon and Pindari storages are 3,540 ML/d and 5,000 ML/d respectively, which reduce their capacity to supply environmental flows to sites significantly downstream. Furthermore, the ability to augment unregulated flows to achieve water requirements at Mungindi is reduced by on-farm storage development.

Recognising that the delivery of environmental flows is highly dependent on existing system constraints, the site-specific flow indicators for the Basin have been classified into three broad types. The flow indicators for the Lower Border Rivers system are generally considered achievable when delivered in combination with tributary inflows and/or unregulated flow events (Table 10). 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.

Table 10 Site-specific flow indicators for the Lower Border Rivers 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	4,000 ML/d for 5 consecutive days between October & December for 24% of years
	4,000 ML/d for 5 consecutive days between October & March for 45% of years
	4,000 ML/day for 11 consecutive days between January & December for 27% of years

Key

	Achievable under current operating conditions Flow indicators highlighted in blue are considered deliverable as mostly regulated flows under current operating conditions.
	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.
	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 Border Rivers 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 Border Rivers. 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 Border Rivers 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 Border Rivers.

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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.

Appendix B

Species of significance in the Border Rivers Region

Species	Recognised in international agreement(s) ¹	Fisheries Management Act 2004 (NSW) ²	Threatened species Conservation Act 1995 (NSW) ³
Birds			
Australasian bittern (<i>Botaurus poiciloptilus</i>)			V
Blue-billed duck (<i>Oxyura australis</i>)			V
Common greenshank (<i>Tringa nebularia</i>)	M		
Eastern great egret (<i>Ardea modesta</i>)	M		
Freckled duck (<i>Stictonetta naevosa</i>)			V
Glossy ibis (<i>Plegadis falcinellus</i>)	M		
Latham's snipe (<i>Gallinago hardwickii</i>)	M		
Sharp-tailed sandpiper (<i>Calidris acuminata</i>)	M		
Caspian tern (<i>Hydroprogne caspia</i> or <i>Sterna caspia</i>)	M		
Marsh sandpiper (<i>Tringa stagnatilis</i>)	M		
Black-necked stork (<i>Ephippiorhynchus asiaticus</i>)			E
Black-tailed godwit (<i>Limosa limosa</i>)			V
Brolga (<i>Grus rubicunda</i>)			V
Magpie goose (<i>Anseranas semipalmata</i>)			V
Painted snipe (<i>Rostratula benghalensis</i>)			E
Fish			
Purple spotted gudgeon (<i>Mogurnda adspersa</i>)		E	
Silver perch (<i>Bidyanus bidyanus</i>)		V	
Olive perchlet (<i>Ambassis agassizii</i>)		E	
Freshwater catfish (<i>Tandanus tandanus</i>)		E	
Murray cod (<i>Maccullochella peelii peelii</i>)	V		
Ecological communities			
Aquatic ecological community in the natural drainage system of the lowland catchment of the Darling River ⁴		E	

E = endangered V = vulnerable

1 M = Japan–Australia Migratory Bird Agreement, China–Australia Migratory Bird Agreement, or Republic of Korea – Australia Migratory Bird Agreement. V = vulnerable under EPBC Act

2 dpi.nsw.gov.au/Species/All_Species.aspx

3 http://threatenedspecies.environment.nsw.gov.au/tsprofile/browse_veg.aspx search by habitats: Forested wetlands, freshwater wetlands

4 FSC (undated). Final Recommendation. Aquatic Ecological Community in the natural drainage system of the lowland catchment of the Darling River. Fisheries Scientific Committee. Ref. Nos. FR 22; File No. FSC 01/10. http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0010/208297/FR22-Darling-River-EEC.pdf