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Assessment of environmental water requirements for the proposed Basin Plan: **Barmah–Millewa Forest**

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Murray region

Assessment of Barmah–Millewa Forest 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 Barmah-Millewa Forest. 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. Barmah-Millewa Forest is one of the key environmental assets where a detailed assessment of environmental water requirements was undertaken.

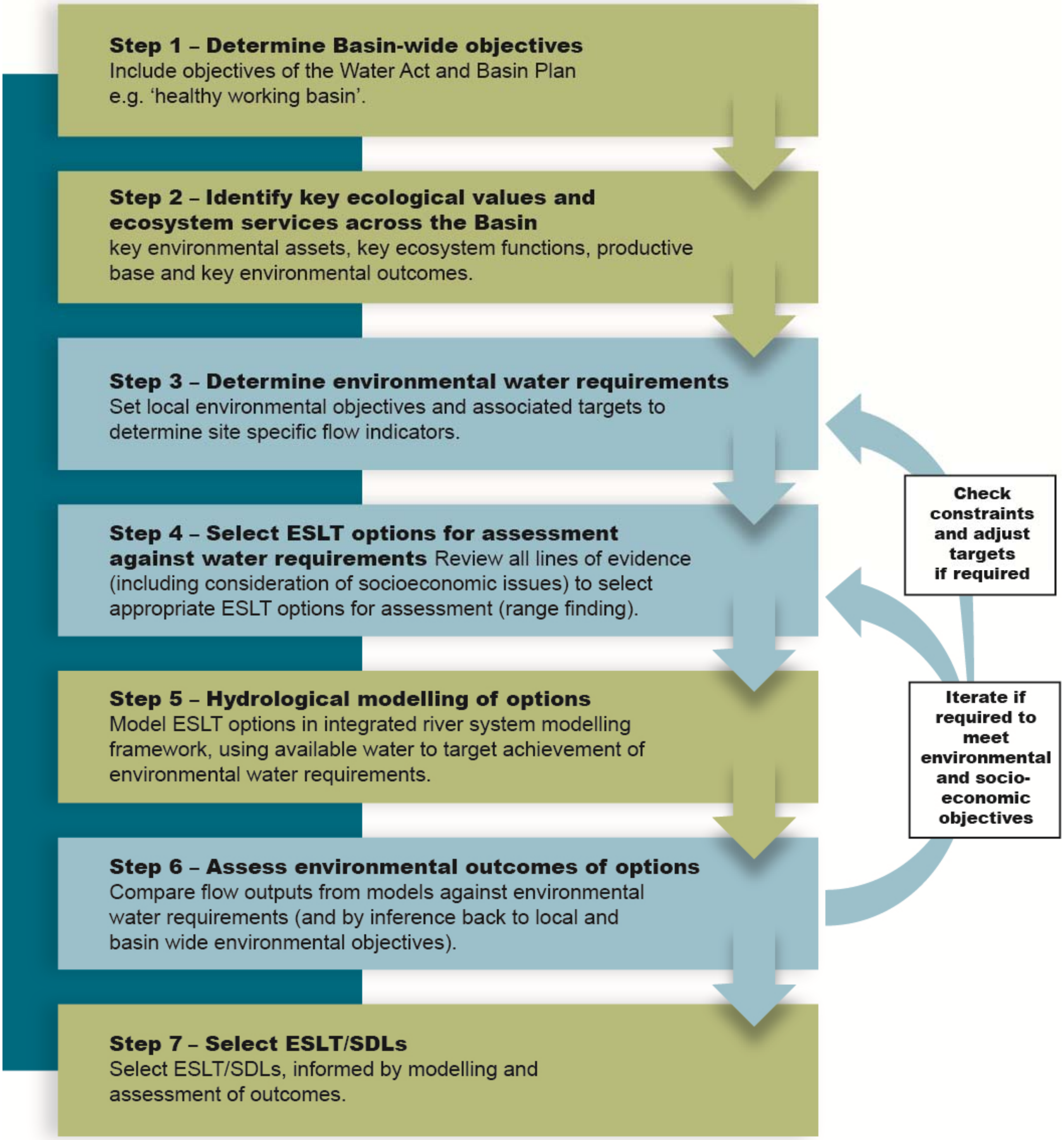

Figure 1: Outline of method used to determine an Environmentally Sustainable Level of Take (Source: MDBA 2011).

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 Barmah-Millewa Forest including information supporting the development of site-specific flow indicators for the site (with reference to flows gauged on the River Murray downstream of Yarrawonga Weir). More information on how the site-specific flow indicators for Barmah-Millewa Forest 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 Barmah–Millewa Forest covers approximately 66,000 ha of floodplain along the River Murray between Tocumwal, Echuca and Deniliquin, downstream of Yarrawonga Weir and upstream of Torrumbarry Weir (Figure 2). Barmah Forest (29,500 ha) is located on the Victorian side of the River Murray and Millewa Forest (36,500 ha) on the New South Wales side.

The Barmah–Millewa Forest is also an icon site under The Living Murray program and the entire asset is listed as a Ramsar wetland. The Barmah Forest was Ramsar listed in 1982; the Millewa Forest was Ramsar listed in 2003 and is a component of the broader NSW Central Murray State Forests Ramsar site.

The Ramsar wetlands of Australia dataset has been used to define the boundary/extent of the indicator asset. Spatial data used to define the extent of this site is listed in Appendix A. Environmental water requirements expressed as site-specific flow indicators for the Barmah-Millewa Forest are specified at the River Murray downstream of Yarrawonga Weir.

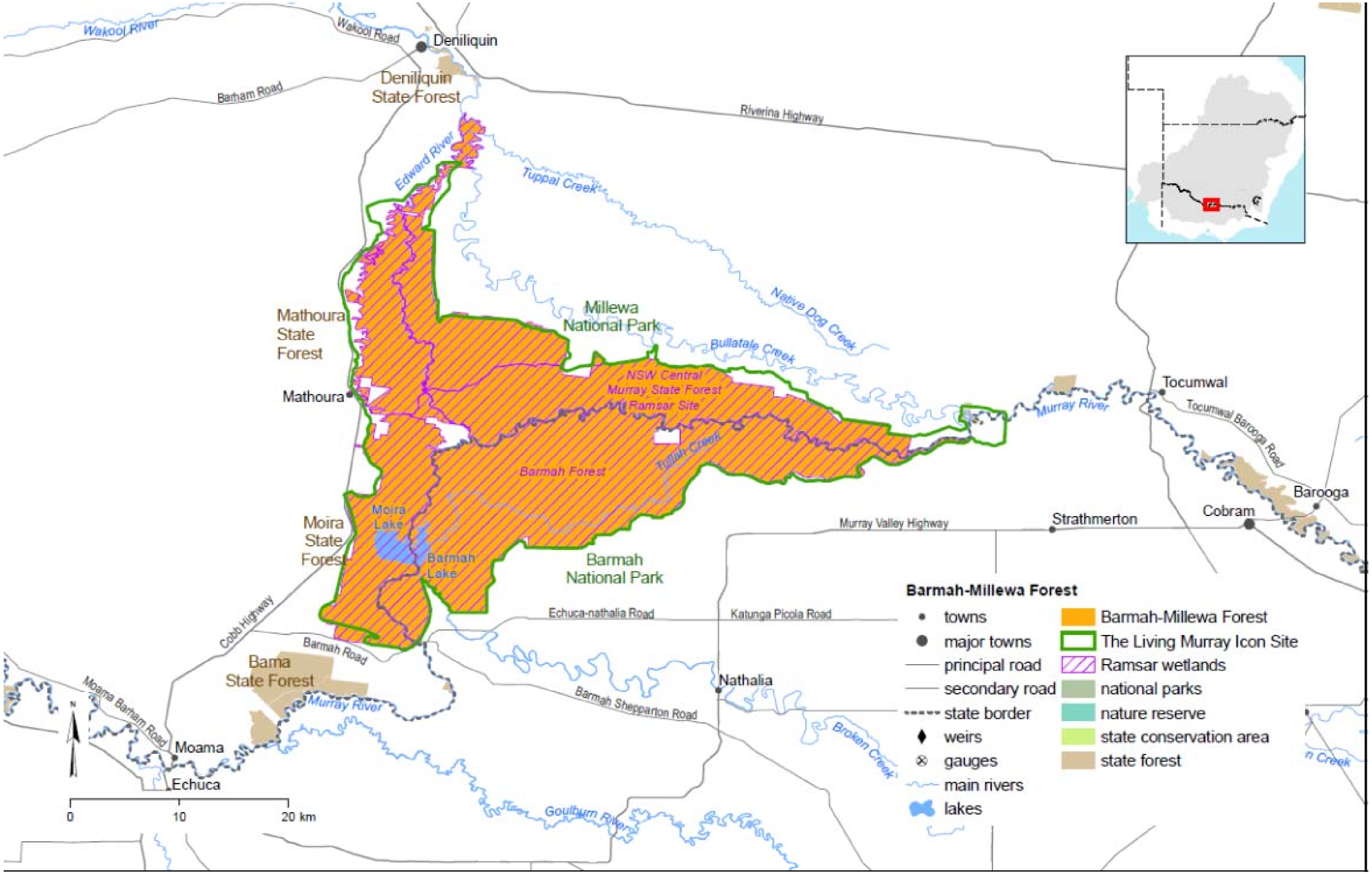

Figure 2 **Location and extent of Barmah–Millewa Forest key environmental asset. Flow indicators are specified at River Murray downstream of Yarrawonga Weir, which is not shown on this map (approximately 40km upstream from the map extent).**

3. Ecological Values

The Barmah–Millewa Forest is a Living Murray Icon Site and is widely recognised as one of the most ecologically valuable sites within the Basin. It has a wide variety of ecosystem types including:

- swamps and marshes in the lower areas that are frequently flooded, where water can pond;
- rushbeds surrounding the swamps and marshes, and generally in wetter areas;
- lakes and billabongs which are generally deeper water environments and are important in providing feeding areas for large colonial nesting waterbird breeding events;
- open grassland plains, including large plains of moira grass, which, when flooded, provide highly significant breeding and feeding habitats for colonial nesting waterbirds such as egrets, herons, spoonbills and marsh terns;
- river red gum (*Eucalyptus camaldulensis*) forest (the largest area remaining in Australia) of various types and health, depending on inundation, with the lower areas supporting larger and denser red gum forest; and
- black box (*Eucalyptus largiflorens*) woodland in the high, drier zones.

The vegetation communities present in the Barmah–Millewa Forest have been grouped into five broad categories, the areas of which are shown in Table 1.

Table 1 Vegetation types by area, based on analysis of data presented in ecological character descriptions for Barmah–Millewa Forest (Source: Victorian Department of Sustainability and Environment 2008; GHD 2009).

Vegetation type	Barmah (ha)	Millewa (ha)	Total area (ha)
Giant rush (*Juncus ingens*)	531	2,667[a]	3,198 (4.8%)
Moira grass (*Pseudoraphis spinescens*)	1,535	774[a]	2,309 (3.5%)
River red gum forest (with a flood-dependent understorey)	16,617	26,181	42,798 (64.8%)
River red gum woodland (with a flood-tolerant understorey)	9,711	4,002	13,713 (20.8%)
River red gum/yellow box/grey box/black box woodland	1,063	2,919	3,982 (6.0%)
Total	29,457	36,543	66,000

a The area of giant rush and moira grass in Millewa Forest is not directly identified in GHD (2009); areas shown are derived from the area of wetland.

The Barmah-Millewa Forest support important species and habitats that are listed in international agreements such as Ramsar, and include vulnerable and endangered species. Appendix B provides a summary of the conservationally significant species recorded at the Forest.

The ecological values of the Forest are reflected in 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 at Barmah-Millewa Forest, the site meets all five key environmental asset criteria (Table 2).

4. Hydrology

The River Murray and the Barmah Choke define the hydrology of the Barmah–Millewa Forest. The Barmah Choke is a narrowing of the river channel and a reduction in channel capacity associated with a geological uplift known as the Cadell Tilt. When river flow downstream of Yarrawonga Weir is greater than 10,400 ML/d, the flow exceeds the capacity of the River Murray through the Barmah–Millewa Forest (GHD 2009). Once this occurs water begins to flow overbank onto the floodplain and into floodrunners upstream. To allow water to enter and be managed within the forest, regulators are progressively opened once the channel capacity has been exceeded (GHD 2009). The smaller channel capacity at the choke increases the frequency of floodplain inundation compared to other parts of the River Murray floodplain. This frequent flooding has led directly to the formation of the forests and associated wetland systems.

The regularity, extent, duration and seasonality of flooding within the forests are governed by flow in the River Murray. Relatively small changes in topography also influence the distribution and depth of flooding. Water passes over the floor of the forests as sheet flow in large floods, and flows through the forests predominantly as creek flow during smaller flood events (MDBC 2006).

Barmah–Millewa Forest is dissected by many 'effluent' streams, the largest of which are the Edward River and Gulpa Creek. Together, these form the beginning of the Edward–Wakool River System that passes through the Werai Forest before returning to the River Murray some 200 km to the west at Wakool Junction. Key effluents start to flow depending on the level of flow in the River Murray. For example, information provided by the Victorian Department of Sustainability and Environment suggests that Gulf Creek begins to flow at 3,500 ML/d, Boals Creek at 6,000 ML/d and Smiths and Tullah Creeks begin to flow once flows exceed 9,500 ML/d.

The forests also contain numerous wetlands, the largest of which are Barmah Lake (Victoria) and Moira Lake (New South Wales). Wetlands are also flooded at different flow levels. Flows up to 15,000 ML/d inundate large areas of open wetlands and moira grass plains (Water Technology 2009). Most red gum forest with flood-dependent understorey is flooded at flows of 25,000–35,000 ML/d, with higher flows up to and in excess of 60,000 ML/d needed to inundate red gum/black box woodland located at higher elevations on the floodplain (Water Technology 2009).

Table 2 Assessment of the Barmah–Millewa Forest against MDBA key environmental asset criteria.

Criterion	Ecological values that support the criterion
1. The water-dependent ecosystem is formally recognised in international agreements or, with environmental watering, is capable of supporting species listed in those agreements	Barmah–Millewa Forest is formally recognised in, or is capable of supporting species listed in, the Japan–Australia Migratory Bird Agreement, the China–Australia Migratory Bird Agreement or the Republic of Korea–Australia Migratory Bird Agreement. The site contains the Barmah Forest Ramsar site and includes part of the NSW Central Murray State Forests Ramsar site. Species listed in international agreements that have been recorded in the Barmah–Millewa Forest are in Appendix B.
2. The water-dependent ecosystem is natural or near-natural, rare or unique	Barmah–Millewa Forest supports the largest area of red gum forest in Australia (Victorian Department of Sustainability and Environment 2008; GHD 2009). As the largest area of floodplain listed as an icon site for The Living Murray program, this asset is perhaps the largest and most intact floodplain system along the River Murray. The forests can be considered 'near natural', as they retain trees older than European settlement and areas that are structurally equivalent to undisturbed forest, despite 150 years of timber harvesting (GHD 2009).The Barmah side of the forest supports the most extensive area of moira grass (*Pseudoraphis spinescens*) plains in Victoria, with the grass dominating 5.2%, or 1,535 ha, of the Barmah Forest Ramsar site in 1979 (Victorian Department of Sustainability and Environment 2008). In addition, King, Tonkin and Mahoney (2007) highlight that Barmah–Millewa Forest is a significant area for native fish conservation, with extensive wetland, creek and river habitats for fish now relatively rare in the region.
3. The water-dependent ecosystem provides vital habitat	Because it floods at relatively low river flows and therefore more frequently than other sites, Barmah–Millewa Forest provides drought refuge for waterbirds (Victorian Department of Sustainability and Environment 2008). About 54 waterbird species have been recorded breeding in the NSW Central Murray State Forests Ramsar site, including 25 colonial nesting species (GHD 2009).
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 Victorian flora information system and the Victorian Wildlife Atlas have recorded 381 indigenous flora species and 221 indigenous vertebrate species for the Barmah Forest site. Barmah Forest meets the Ramsar wetland criteria "A wetland should be considered internationally important if it regularly supports 20,000 or more waterbirds" because it regularly supports 1% of the population of Australian white ibis (*Threskionis molucca*)

Criterion	Ecological values that support the criterion
	and straw-necked ibis (*Threskiornis spinicollis*) (Victorian Department of Sustainability and Environment 2008). Similarly, Millewa Forest also supports significant biodiversity, for example, during a waterbird breeding event in 2000/01, there were 5,508 pairs of 13 species of colonially nesting waterbirds recorded in Millewa Forest (GHD 2009).

More than 50 water management structures are present throughout the Barmah–Millewa Forest. They comprise two broad categories of regulators (MDBC 2006):

- primary regulators (discharge capacity generally >100 ML/d) occur in anabranch streams near their exit point from the River Murray, Edward River and Gulpa Creek. These structures maintain regulated instream flows, and permit river freshes and floods to pass into the forest; and
- Secondary and tertiary regulators (discharge capacity generally <100 ML/d) are mostly situated in drainage features within the interior portions of the forest, and include pipes, culverts and regulators, and earthen banks. These structures manipulate water distribution and depth within localised areas, and provide vehicle access. They are overtopped or outflanked during large floods.

Due to the extent to which they enable flows to be manipulated, these regulators provide flexibility for the use of existing and future environmental water allocations for Barmah–Millewa Forest (Victorian Department of Sustainability and Environment 2008).

The ecological values of the Barmah–Millewa Forest have been threatened by several factors, but the main impact has been through river regulation, particularly through a decrease in medium-sized spring floods (MDBC 2006).

CSIRO (2008) found that as a result of water resource development, the average period between beneficial spring-summer floods has approximately doubled (from 1.8 to 3.5 years). Flood volumes have also been greatly reduced such that the average annual flood volume is now less than a quarter of the volume under without development conditions (from 1217 to 291 GL). Similarly, GHD (2009) report that river regulation has been implicated in the steady decline of ecosystem health of the NSW Central Murray State Forests over the last 75 years — inappropriate flood regimes have been the main adverse impact on the ecological character of the site.

5. Determining the site-specific flow indicators for the Barmah-Millewa Forest

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 the Barmah-Millewa Forest were developed (Table 3). Information underpinning site-specific ecological targets is shown in Table 3.

Table 3 Site-specific ecological targets for Barmah–Millewa Forest.

Site-specific ecological targets	Justification of targets
• Provide a flow regime which ensures the current extent of native vegetation of the riparian, floodplain and wetland communities is sustained in a healthy, dynamic and resilient condition • Provide a flow regime which supports the habitat requirements of waterbirds and is conducive to successful breeding of colonial nesting waterbirds • 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 connectivity between the river and the floodplain.	The site contains the Barmah Forest Ramsar site and includes part of the NSW Central Murray State Forests Ramsar site. The site supports a number of different flood dependent vegetation types which are important habitats for a range of biota. Barmah–Millewa Forest supports the largest red gum forest in Australia (Victorian Department of Sustainability and Environment 2008; GHD 2009). In addition, the NSW Central Murray State Forests are the largest complex of tree-dominated floodplain wetlands in southern Australia (GHD 2009). Recognising these key values, any loss or substantial decline in the current area or health of red gum vegetation communities would signal a change in ecological character (Victorian Department of Sustainability and Environment 2008). The Barmah-Millewa Forests contains extensive areas of freshwater meadows/ shallow freshwater marshes. The Victorian Department of Sustainability and Environment (2008) and GHD (2009) specify that any decrease in the current area of these wetland types would signal a change in ecological character. The Barmah-Millewa Forest supports extensive area of moira grass plains. Victorian Department of Sustainability and Environment (2008) identify that a change in ecological character of Barmah Forest would be signalled by a decrease in the area mapped by Chesterfield, Loyn and Macfarlane (1984) as being dominated by moira grass, and would be accompanied by the encroachment of giant rush and the regeneration of red gum. The Victorian Department of Sustainability and Environment (2008) specifies that any reduction in the recorded frequency and abundance of bird breeding would signal a change in ecological character. GHD (2009) specifies a change in ecological character would be signalled by successful breeding of thousands of colonial waterbirds occurring in less than three out of ten years. Achieving the targets for floodplain wetlands and waterbirds will ensure inundation of breeding and feeding habitats considered key for a range of fish, amphibian and water-dependent reptile and invertebrate species. Key ecosystem functions support fish, birds and invertebrates through habitat maintenance, energy transfer and facilitating connections between rivers and floodplains. Overbank flows supply the floodplains with nutrients and sediments from the river, accelerate the breakdown of organic matter and supply water to disconnected wetlands, billabongs and oxbow lakes. As the floodwaters recede, the floodplains provide the main river channel with organic matter. The hydrological connection between watercourses and their associated floodplain provides for the exchange of carbon and nutrients (Thoms 2003). The connections are considered essential for the functioning and integrity of floodplain-river ecosystems.

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 Barmah-Millewa Forest, as described below.

5.2. Information used to determine site-specific flow indicators

5.2.1. Vegetation

Hydrology is critical to the ecological character of the Barmah–Millewa Forest and a key driver of the system. Variation in flood regimes across the River Murray floodplain has been identified as the primary determinant of vegetation composition and structure (GHD 2009). There is a strong link between the frequency, timing and duration of flood events and maintaining the ecological character of the Barmah–Millewa Forest (Victorian Department of Sustainability and Environment 2008; GHD 2009). The development of site-specific flow indicators to achieve the site specific ecological targets focused on assessment of the bankfull and overbank elements of the flow regime necessary to maintain flood dependent vegetation communities. These flood dependent vegetation communities are a critical component of the sites ecological character and have experienced decline as a result of water resource development alterations to the natural hydrology (GHD 2009).

A number of documents were assessed to determine the flow required to achieve site-specific ecological targets, as described below. However, it was found that no single existing plan or document sets out these requirements completely. The *Barmah–Millewa Forest Icon Site Environmental Management Plan 2006–2007* (MDBC 2006) sets out the flood frequencies and durations of selected vegetation communities that existed before river regulation (Table 4). Complementary to this information, the Victorian Department of Sustainability and Environment (2008) recommend increasing both flooding frequency and duration of flows in the range of 15,000–60,000 ML/d to maintain vegetation communities in Barmah-Millewa Forest and the ecological character of the site.

Table 4 Flood frequency, timing and duration of selected vegetation communities that existed before river regulation for Barmah–Millewa Forest (Source: MDBC 2006).

Vegetation community	Flood frequency (% of years with inundation)	Duration	Season
Giant rush (*Juncus ingens*)	75–100	7–10 months	Winter to mid-summer
Moira grass (*Pseudoraphis spinescens*)	65–100	5–9 months (no more than 10 months at minimum depth of 0.5 m)	Winter to mid-summer; 2–3 months dry in late summer to early autumn
River red gum forest	40–92	5 months	Winter to spring
River red gum woodland	33–46	1–2 months	Spring
River red gum and black box woodland	14–33	1–4 months	Winter to spring

Data presented in the Barmah–Millewa Forest hydrodynamic model report was another key source of information to determine flows required to sustain the current extent of the riparian, floodplain and wetland communities and support key ecosystem functions associated with improved connectivity between the river and its floodplain (Water Technology 2009). The hydrodynamic model has been assessed in parallel with the ecological character descriptions of the forests (Figure 3) and provides information on vegetation type inundation at particular flow magnitudes (Victorian Department of Sustainability and Environment 2008; GHD 2009). Hydrodynamic modelling confirms that flows in the range 10,600-60,000ML/d inundate key vegetation communities present at Barmah-Millewa Forest (Figure 3). Vegetation community inundation modelling has been further supported and validated by local water manager's observations of on-ground inundation during both natural and managed flow events.

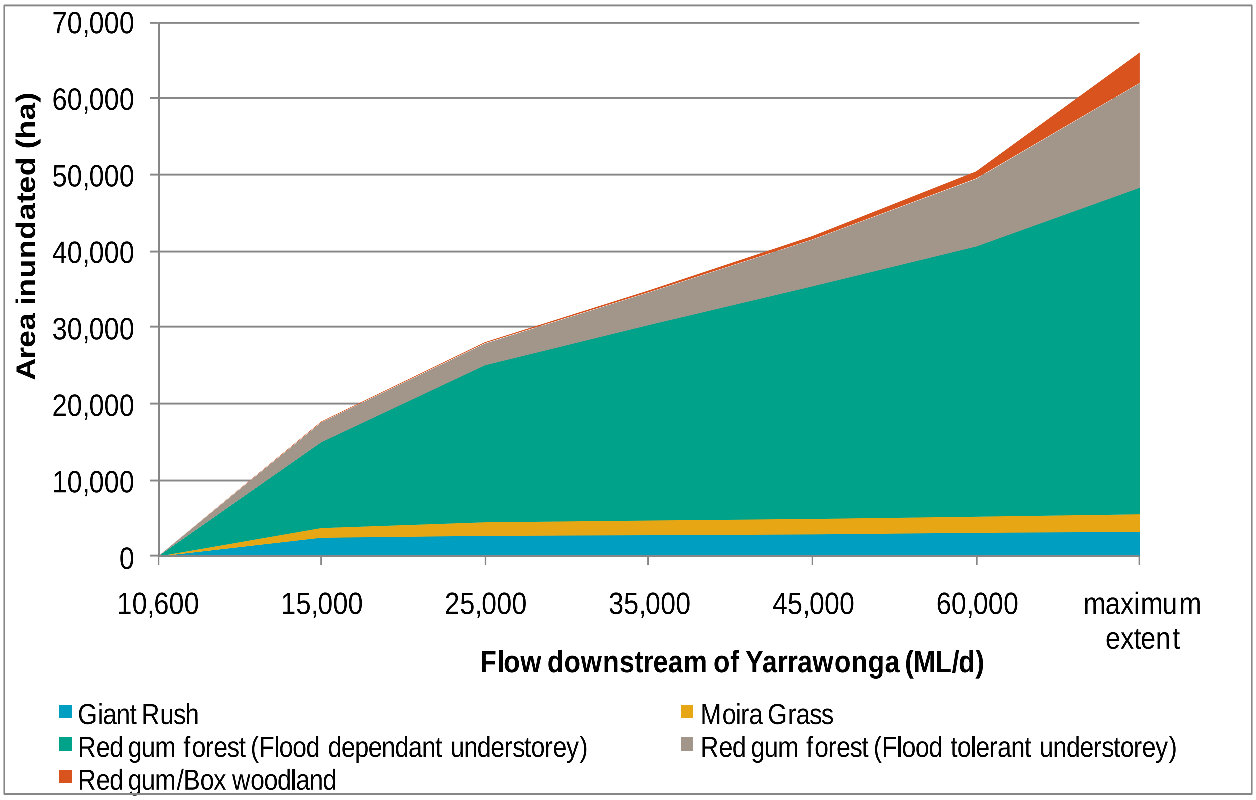

Figure 3 Flows required to inundate selected vegetation communities for Barmah–Millewa Forest (Source: Victorian Department of Sustainability and Environment 2008; GHD 2009; MDBA analysis of data in Water Technology 2009).

5.2.2. Waterbirds

A variety of information sources have been used to inform development of site-specific flow indicators to achieve the ecological target of providing a flow regime which supports the habitat requirements of waterbirds and is conducive to successful breeding of colonial nesting waterbirds (Scott 1997; Leslie 2001; MDBC 2006; Overton et al. 2009).

Overton et al. (2009) analysed the relationship between breeding attempts by colonial nesting waterbirds at Barmah–Millewa and flow thresholds. This study reported a high probability of breeding attempts by ibis, spoonbills, herons and egrets after approximately 50 days of flows greater than 15,000 ML/d. These flow thresholds to induce breeding are broadly consistent with Leslie (2001), which identified 18,330 ML/d and the Victorian Department of Sustainability and Environment (2008), which recommends 20,000 ML/d. It should be noted that the number of days corresponds to a high probability of a breeding attempt. However, for successful fledging, colonial nesting waterbirds require an additional 2.5–3.5 months of flooding (i.e. 4–5 months in total) (Overton et al. 2009). MDBA analysis of modelled without development flow data shows that flows of 15,000 ML/d for five months duration are regularly associated with higher flow peaks (>30,000 ML/d) of shorter duration. These flows peaks are likely to be important for successful waterbird breeding by providing a shifting spatial and temporal mosaic of wetland inundation patterns (Overton et al. 2009) and healthy and productive foraging and nesting habitats.

Two key factors dictate that waterbirds do not need to breed every year on the same river system (Scott 1997). Firstly, Australian waterbirds are highly mobile and their mobility over large spatial scales is a defining characteristic (Scott 1997; Overton et al. 2009). Most of the 80 odd species of (non-vagrant) Murray-Darling Basin waterbirds that use inland wetlands have broad Australia-wide distributions and it is believed that individuals of most species are capable of dispersing at the scale of the continent (Overton et al. 2009). As such, prior to river regulation at least some individuals of the more mobile waterbird species have would have been able to seek suitable conditions for successfully breeding somewhere within the Basin in most years (Scott 1997).

Secondly, it is not essential for waterbirds to breed every year to maintain sustainable populations as they are generally long-lived (Scott 1997). Waterbirds become sexually mature at the age of one to two years and have a life expectancy ranging generally from 3-4 years for ducks, up to 8 years for larger birds such as ibis (Scott 1997).

These two key factors have informed the frequency of events for site-specific flow indicators intended to support the habitat requirements of waterbirds, including provision of conditions conducive to successful breeding of colonial nesting waterbirds. Specifically, it is desirable to provide multiple opportunities for successful waterbird breeding within the range of their life expectancy. The proposed successful breeding of colonial nesting waterbirds at Barmah-Millewa Forest in at least three years out of ten (MDBC 2006) and adopted here is consistent with this rationale.

5.2.3. Other biota

There are numerous studies concerning the water-dependent vegetation communities and needs of colonial nesting waterbirds of the Barmah-Millewa forest. The understanding of flow-ecology relationships of other faunal groups is generally less well understood as there are fewer studies undertaken for these species. The MDBA is confident that the site-specific flow indicators determined to achieve the ecological targets relating to the current extent of native vegetation communities and the habitat requirements for waterbirds will also have valuable beneficial effects on the life-cycle and habitat requirements of native fish, amphibians, and water-dependent reptiles and invertebrates.

There is still debate in the scientific literature as to the relative role of flooding 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 Golden perch (*Macquaria ambigua ambigua*) and the conservationally significant Silver perch (*Bidyanus bidyanus*), which have been recorded at Barmah-Millewa Forest, require flow pulses or floods for spawning i.e. flood recruitment hypothesis (Humphries et al. 1999). This is partly supported by King et al. (2009) which suggest that flow is one environmental variable, although not always the key environmental variable, identified explaining the occurrence and abundance of spawning of Golden Perch, Silver Perch and Murray Cod at Barmah-Millewa Forest. Other factors such water temperature and day length, 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 that provision of flows that connect the river channel to the floodplain as well as in-channel flow variability are important to sustaining key ecological features such as native fish populations. Flow indicators described herein for the bankfull and overbank elements of the flow regime primarily based on the water requirements of flood dependent vegetation communities and waterbirds are expected to be sufficient to support life-cycle and habitat requirements of native fish including provision of cues for spawning and migration and access to food sources.

5.3. Proposed flow indicators

The site-specific flow indicators for Barmah-Millewa Forest set out in Table 5 represent an amalgam of information from existing literature and vegetation inundation hydrodynamic modelling data, checked against an analysis of modelled without development and baseline flow data. Site-specific flow indicators are expressed at River Murray downstream of Yarrawonga Weir which generally represents the flow into the Barmah-Millewa Forest. Flow indicators as specified for the bankfull and overbank elements of the flow regime attempt to strike a balance between desirable flow threshold, duration and timing with desirable frequency (as described in Table 4) 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 inundation / hydrology modelling, an analysis of modelled without development flows has been used to guide the determination of site-specific flow indicators, particularly to ensure that the recommended flows are achievable and not greater than without development flows.

The site-specific flow indicators needed to achieve ecological targets for Barmah–Millewa Forest should be read in their entirety to understand the environmental water requirements as multiple flow indicators will contribute to achieving each ecological target. This approach has been used because it is not possible to define a single flow threshold for each vegetation community. The flood dependent vegetation communities cover a wide range of flows (Figure 3) and a single indicator would be misleading.

Generally, the flow indicator metric with the greatest level of uncertainty across the Basin is the definition of the desirable frequency of inundation, 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 (for instance river red gum communities) our knowledge is evolving. Secondly, vegetation communities are located across the floodplain and would have experienced significant variability in their inundation frequency under predevelopment 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/community.

Recognising the degree of confidence in specifying a desirable frequency, ‘low-uncertainty’ and ‘high-uncertainty’ frequency of flow events have been specified (Table 5). 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 which 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 Barmah-Millewa Forest a number of key sources of information were used to inform the high and low uncertainty frequencies. Site specific information, particularly the *Barmah–Millewa Forest Icon Site Environmental Management Plan 2006–2007* (MDBC 2006) and the *Barmah Forest Ramsar Site Ecological Character Description* (Victorian Department of Sustainability and Environment 2008) as presented in Table 4, was complemented by more generic literature on water requirements of flood dependent vegetation communities, particularly Roberts and Marston (2011). These documents express the desired frequency as a range and the high and low uncertainty frequency flow indicator metrics attempt to encapsulate the broad water requirements represented by this range. Modelled flow data was used to verify if recommended frequencies were achievable and not greater than without development flows.

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 Barmah-Millewa Forest. Even so, the importance of maximum dry periods and their role in maintaining ecosystem resilience is recognised. Maximum dry periods between successful events is reported for hydrological modelling associated with the Barmah-Millewa Forest hydrologic indicator site (see MDBA 2012) despite reducing the maximum period between events not being the primary objective of the modelling process.

Table 5 **Site-specific ecological targets and associated flow indicators for Barmah–Millewa Forest.**

<table>
<tr><th rowspan="3">Site-Specific Ecological Targets</th><th colspan="5">Site-Specific Flow Indicators</th><th colspan="2">Without development and baseline event frequencies</th></tr>
<tr><th colspan="3">Event</th><th colspan="2">Frequency – proportion of years event required</th><th rowspan="2">Proportion of years event occurred under modelled without development conditions (%)</th><th rowspan="2">Proportion of years event occurred under modelled baseline conditions (%)</th></tr>
<tr><th>Flow required (measured at Yarrawonga; ML/d)</th><th>Duration[a]</th><th>Timing</th><th>Low uncertainty (%)</th><th>High uncertainty (%)</th></tr>
<tr><td rowspan="7">Provide a flow regime which ensures the current extent of native vegetation of the riparian, floodplain and wetland communities is sustained in a healthy, dynamic and resilient condition

Provide a flow regime which supports the habitat requirements of waterbirds and is conducive to successful breeding of colonial nesting waterbirds

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 connectivity between the river and the floodplain</td><td>12,500</td><td>10 weeks total (with 7 day min)</td><td rowspan="3">June to November</td><td>80</td><td>70</td><td>87</td><td>50</td></tr>
<tr><td>16,000</td><td>14 weeks total (with 7 day min)</td><td>50</td><td>40</td><td>66</td><td>30</td></tr>
<tr><td>25,000</td><td>6 weeks total (with 7 day min)</td><td>50</td><td>40</td><td>65</td><td>30</td></tr>
<tr><td>35,000</td><td>1 month total (with 7 day min)</td><td rowspan="3">Preferably winter/spring but timing not constrained to reflect that high flows are dependent on occurrence of heavy rainfall and will be largely unregulated events</td><td>40</td><td>33</td><td>54</td><td>25</td></tr>
<tr><td>50,000</td><td>3 weeks total (with 7 day min)</td><td>30</td><td>25</td><td>39</td><td>17</td></tr>
<tr><td>60,000</td><td>2 weeks total (with 7 day min)</td><td>25</td><td>20</td><td>34</td><td>15</td></tr>
<tr><td>15,000</td><td>5 months total (with 7 day min)</td><td>June to December</td><td>30</td><td>30</td><td>44</td><td>11</td></tr>
</table>

a Duration is expressed both as a total and minimum duration, allowing multiple smaller flow events that met the minimum duration criteria to comprise a successful event. Minimum durations are therefore a subset of total duration and should not be read independently. MDBA analysis showed that if a minimum duration is not specified and individual events must meet the total duration criteria, this resulted in a significantly reduced proportion of years.

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.

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 the Barmah-Millewa Forest, 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.

Flows downstream of Hume Dam are typically limited to 25,000 ML/d under regulated flow conditions to minimise overbank flows and the associated inundation of agricultural land. This constraint prevents the release of flows, or adding water to augment natural flows above 25,000 ML/d. However, flow indicators up to 60,000 ML/d have been specified for Barmah-Millewa Forest to meet ecological targets.

Within the hydrological modelling process used by the MDBA to assess the achievement of site-specific flow indicators, orders for environmental flows downstream of Hume Dam have been constrained to 25,000 ML/d at Doctors Point, consistent with the constraints represented by the baseline model. This limits the delivery of regulated flows to the Barmah–Millewa Forest. As such, site-specific flow indicators with thresholds equal to or greater than 25,000 ML/d downstream of Yarrawonga Weir will be difficult to support with only regulated releases from dams. Achieving the higher threshold flows will be reliant on supplementing tributary inflows with regulated release from storage and their duration will be limited to the duration of the tributary inflow.

Without addressing a range of constraints, it is likely that the 50,000 ML/d and 60,000 ML/d flow indicators downstream of Yarrawonga Weir will be not be achievable at the desirable frequency and the duration of flow indicators above 25,000 ML/d will be difficult to achieve. The achievement of site-specific ecological targets and flow indicators limited by constraints will be heavily reliant on unregulated flows that exceed the capacity of existing infrastructure.

Recognising that the delivery of environmental flows is highly dependent on existing system constraints, the site-specific flow indicators have been classified into three broad types (Table 6).

Table 6 Site-specific flow indicators for Barmah–Millewa Forest and the effect of system constraints.

Site-specific ecological targets	Site-specific flow indicators
Provide a flow regime which ensures the current extent of native vegetation of the riparian, floodplain and wetland communities is sustained in a healthy, dynamic and resilient condition Provide a flow regime which supports the habitat requirements of waterbirds and is conducive to successful breeding of colonial nesting waterbirds 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 connectivity between the river and the floodplain	12,500 ML/d for a total duration of 70 days (with a minimum duration of 7 consecutive days) between June and November for 70% of years
	16,000 ML/d for a total duration of 98 days (with a minimum duration of 7 consecutive days) between June and November for 40% of years
	25,000 ML/d for a total duration of 42 days (with a minimum duration of 7 consecutive days) between June and November for 40% of years
	35,000 ML/d for a total duration of 30 days (with a minimum duration of 7 consecutive days) between June and May for 33% of years
	50,000 ML/d for a total duration of 21 days (with a minimum duration of 7 consecutive days) between June and May for 25% of years
	60,000 ML/d for a total duration of 14 days (with a minimum duration of 7 consecutive days) between June and May for 20% of years
	15,000 ML/d for a total duration of 150 days (with a minimum duration of 7 consecutive days) between June and December for 30% 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 Barmah-Millewa Forest 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 Barmah-Millewa Forest environmental water requirements. Specified flow indicators are indicative of a long-term flow regime required to enable the achievement of site-specific ecological targets at the Barmah-Millewa Forest 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 Barmah-Millewa Forest.

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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)
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 relevant to criteria 1 and 4: Barmah–Millewa Forest

Species	Recognised in international agreement(s)[1]	*Environment Protection and Biodiversity Conservation Act 1999* (Cwlth)	*Fisheries Management Act 2004* (NSW)	*Threatened Species Conservation Act 1995* (NSW)	*Flora and Fauna Guarantee Act 1998* (Vic.)
Amphibians and reptiles					
Bibron's or brown toadlet (*Pseudophryne bibronii*)[2, 4]					E
Carpet python (*Morelia spilota metcalfei*)[4]					E
Southern bell or growling grass frog (*Litoria raniformis*)[4]		V		E	E
Birds					
Australasian bittern (*Botaurus poiciloptilus*)[3, 4]				V	E
Barking owl (*Ninox connivens*)[3]				V	E
Black-chinned honeyeater (eastern subspecies) (*Melithreptus gularis gularis*)[3]				V	
Blue-billed duck (*Oxyura australis*)[3]				V	E
Brolga (*Grus rubicunda*)[4]				V	V
Brown treecreeper (*Climacteris picumnus*)[3]				V	
Bush stone-curlew (*Burhinus grallarius*)[3]				E	E
Caspian tern (*Sterna caspia*)[5]	✓				NT
Cattle egret (*Bubulcus ibis*)[5]	✓				
Diamond firetail (*Stagonopleura guttata*)[3, 4]				V	V
Eastern great egret (*Ardea modesta*)[2]	✓				V
Forked-tailed swift (*Apus pacificus*)[5]	✓				
Freckled duck (*Stictonetta naevosa*)[3]				V	E
Gilbert's whistler (*Pachycephala inornata*)[3]				V	
Glossy ibis (*Plegadis falcinellus*)[5]	✓				
Greenshank (*Tringa nebularia*)[5]	✓				
Grey-crowned babbler (eastern subspecies) (*Pomatostomus temporalis temporalis*)[4]				V	E
Hooded robin (*Melanodryas cucullata*)[3]				V	NT
Intermediate egret (*Ardea intermedia*)[4]					CE

Species	Recognised in international agreement(s)[1]	*Environment Protection and Biodiversity Conservation Act 1999* (Cwlth)	*Fisheries Management Act 2004* (NSW)	*Threatened Species Conservation Act 1995* (NSW)	*Flora and Fauna Guarantee Act 1998* (Vic.)
Latham's snipe (*Gallinago hardwickii*)[5]	✓				
Lewin's rail (*Lewinia pectoralis*)[4]					V
Little bittern (*Ixobrychus dubius*)[2, 4, 5]					E
Little egret (*Egretta garzetta*)[2, 4]					E
Marsh sandpiper (*Tringa stagnatilis*)[5]	✓				
Masked owl (*Tyto novaehollandiae*)[3, 4]				V	V
Painted honeyeater (*Grantiella picta*)[2, 3, 4]				V	V
Painted snipe (*Rostratula australis*)[5]	✓	V		E	CE
Red-necked stint (*Calidris ruficollis*)[5]	✓				
Regent honeyeater (*Anthochaera phrygia*)[4]		E		E	CE
Sharp-tailed sandpiper (*Calidris acuminata*)[5]	✓				
Square-tailed kite (*Lophoictinia isura*)[4]				V	V
Superb parrot (*Polytelis swainsonii*)[2, 4, 5]		V		V	E
White-bellied sea-eagle (*Haliaeetus leucogaster*)[2, 4, 5]	✓			V	V
White-throated needletail (*Hirundapus caudacutus*)[5]	✓				
Fish					
Flat-headed galaxias (*Galaxias rostratus*)[2]			CE		
Freshwater catfish (*Tandanus tandanus*)[2]			E		E
Macquarie perch (*Macquaria australasica*)[2]		E	E		E
Murray cod (*Maccullochella peelii peelii*)[2]		V	V		E
Murray–Darling rainbowfish (*Melanotaenia fluviatilis*)[2]					DD
Silver perch (*Bidyanus bidyanus*)[2]			V		CE
Trout cod (*Maccullochella macquariensis*)[2]		E	E		CE
Mammals					
Brush-tailed phascogale (*Phascogale tapoatafa*)[4]				V	V
Koala (*Phascolarctos cinereus*)[3]				V	
Southern myotis (*Myotis macropus*)[3]				V	NT

Species	Recognised in international agreement(s)[1]	*Environment Protection and Biodiversity Conservation Act 1999* (Cwlth)	*Fisheries Management Act 2004* (NSW)	*Threatened Species Conservation Act 1995* (NSW)	*Flora and Fauna Guarantee Act 1998* (Vic.)
Squirrel glider (*Petaurus norfolcensis*)[2]				V	E
Yellow-bellied sheathtail bat (*Saccolaimus flaviventris*)[3]				V	
Plants					
Buloke (*Allocasuarina luehmannii*)[4, 5]					L
Fat spectacles (*Menkea crassa*)[4]					E
Mountain swainson-pea (*Swainsona recta*)[2]		E		E	E
Mueller daisy (*Brachyscome muelleroides*)[2]		V			E
River or floating swamp wallaby-grass (*Amphibromus fluitans*)[5]		V		V	
Small scurf-pea (*Cullen parvum*)[4]		E		E	E
Violet swainson-pea (*Swainsona adenophylla*)[4]				E	E
Yellow-tongue daisy (*Brachyscome chrysoglossa*)[4]					V
Communities					
Lowland Murray River endangered ecological community[6]			E		
Lowland riverine fish community of the southern Murray–Darling Basin[2]					L

E = endangered CE = critically endangered DD = data deficient L = listed NT = near threatened T = threatened V = vulnerable

1 Japan–Australia Migratory Bird Agreement, China–Australia Migratory Bird Agreement, or Republic of Korea – Australia Migratory Bird Agreement

2 Victorian Department of Sustainability and Environment (2008)

3 NSW Department of Environment, Climate Change and Water (2009)

4 Victorian Department of Sustainability and Environment (2009)

5 GHD (2009)

6 NSW Department of Primary Industries (2007)