Australian Government

MURRAY–DARLING BASIN AUTHORITY

Preliminary Overview of Constraints to Environmental Water Delivery in the Murray–Darling Basin

Technical Support Document

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Cover image: *Lake Pamamaroo, part of the Menindee Lakes system.* Arthur Mostead

Disclaimer

commitment to undertake or implement a particular course of action, and should not be relied upon in relation to any particular action or decision taken. Users should note that developments in Commonwealth policy, input from consultation and other circumstances may result in changes to the approaches set out in this document.

Acknowledgements

This report was prepared by the Water Resources and Eco-Hydrology teams of the Murray–Darling Basin Authority based on modelling conducted by MDBA. The modelling used MDBA models for the River Murray together with models provided by the Victorian Department of Sustainability and Environment, the New South Wales Office of Water, the Queensland Department of Environment and Resource Management, CSIRO and Snowy Hydro Limited. The modelling was undertaken in the Integrated River System Modelling Framework initially developed by CSIRO in the Murray–Darling Basin Sustainable Yields Project and further developed by CSIRO for MDBA for the Basin Plan modelling.

Executive Summary

Background

In late 2012 the Federal Water Minister adopted the Basin Plan, providing the first integrated framework for water planning in the Murray–Darling Basin. The Basin Plan aims to restore healthy river systems for the benefit of the environment, communities and agriculture.

A central component of the Basin Plan is the establishment of new limits on the volumes of water extracted for consumptive use, known as Sustainable Diversion Limits (SDLs). On a long term average basis, the Basin Plan mandates a Basin-wide SDL of 10,783 GL/y, requiring the recovery of 2,750 GL/y of water for the environment. The Plan also provides for the adjustment of the sustainable diversion limits through supply or efficiency measures that would enable the Sustainable Diversion Limits to be adjusted up, or down, respectively. These SDL Adjustments will be finally determined in 2016. Schedule 5 of the Basin Plan describes the enhanced environmental outcomes to be pursued through the provision of efficiency measures.

The Basin Plan also includes a requirement for the Murray–Darling Basin Authority (MDBA) to develop a Constraints Management Strategy by November 2013. The CMS will provide recommendations to governments on priority constraints to be overcome with implementation of recommendations expected to commence in 2014. The Commonwealth government has notionally allocated $200 million to address priority constraints to environmental water delivery in the Basin.

What are Constraints?

Flow constraints limit how water can be actively delivered through the river system to deliver environmental water requirements.

Flow constraints include:

- **Physical constraints**, such as the rate at which water can be released from a storage (release capacities) or the level to which water can rise before passing over the river bank onto adjacent land (channel capacities).
- **Operational constraints**, relating to the effective management of water resources through a range of operating protocols (for instance, the requirement to maximise reliability of supply for consumptive use, or to protect infrastructure and private property from inundation).
- **Management or Policy constraints**, such as the lack of protection for environmental flows as they travel downstream.

Why do we need to consider constraints?

The regulation of our river systems has resulted in fewer overbank flow events, resulting in a partial disconnect between our rivers and their flood dependent wetlands and floodplains. These ecosystems are under stress because the regulation of the river system predominately constrains flows to remain within the main channel. In the last 30 years, there has been a measurable decline in the number and health of native fish and waterbird populations, and an overall decline in the size and health of wetlands, floodplain forests and woodlands.

As part of the development of the Basin Plan, MDBA (2012y,z) examined the potential environmental benefits of relaxing key flow constraints in the Murray–Darling Basin. It was found that the combination of addressing constraints and recovering an additional (450 GL/y) of water for the environment could increase:

- the area of floodplains and wetlands inundated during a mid-to-high flow event;
- the duration for which these areas are inundated, and;
- the frequency at which these inundation events occur.

An example of these changes is given in Figure 1, showing the River Murray flow at Euston Weir. Modelling conducted by MDBA (2012z) shows that, under water-sharing arrangements prior to the Basin Plan, this flow would have peaked at 65,000 ML/d (red line). Environmental watering under a Basin Plan could increase the flow to 72,000 ML/d (green), and the relaxation of key constraints (with an additional 450 GL/y of environmental water) could further increase this peak flow to 82,000 ML/d. A higher flow will inundate a greater area of water-dependent vegetation and produce improved environmental benefits — Basin Plan watering during this event could increase the inundated area in the river reach by 29% (from 10,500 to 13,500 ha); if key constraints were also addressed this value would increase to 76% (from 10,500 to 18,500 ha). Similar improvements were found along all parts of the southern Murray–Darling Basin.

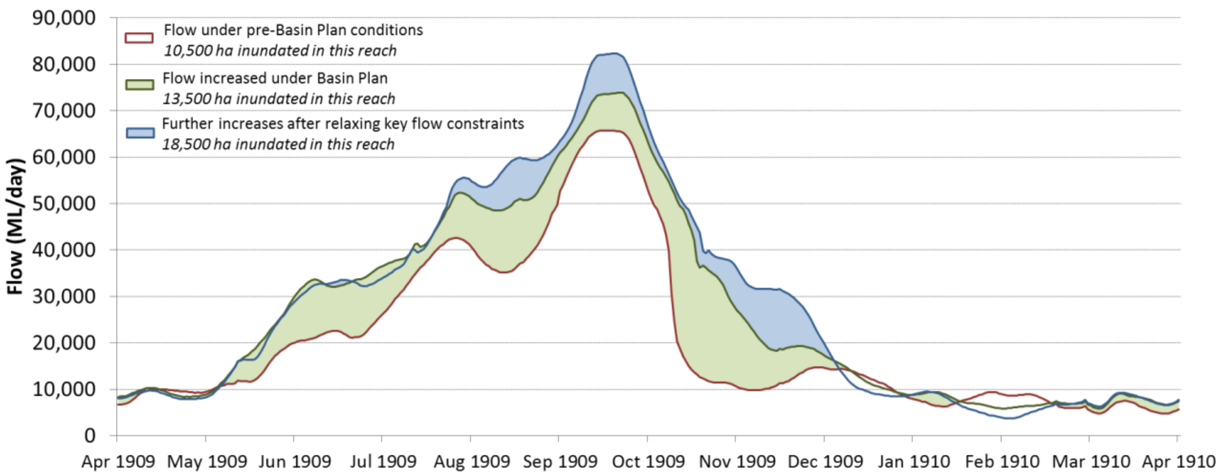

Figure 1 Modelled environmental flow event at Euston Weir under pre-Basin Plan water sharing arrangements (red), post-Basin Plan arrangements with 2,750 GL/y of environmental water (green), and combining an additional 450 GL/y of environmental relaxation of key constraints (blue)

Figure 1: Modelled environmental flow event at Euston Weir under pre-Basin Plan water sharing arrangements (red), post-Basin Plan arrangements with 2,750 GL/y of environmental water (green), and combining an additional 450 GL/y of environmental water with the relaxation of key constraints (blue)

This example illustrates the benefits to the areal extent of floodplain watering which could be achieved if key flow constraints in the Basin rivers were addressed. Addressing constraints also allows managers to have a greater capacity to control the length of time areas (habitats) can be actively watered which is important for many environmental processes. Finally, the capacity to manage the system more actively, and not have to rely solely on unregulated flows, provides greater capacity to actively manage flow events so that watering of important wetlands and floodplains occurs at a frequency that is necessary to ensure resilience.

How will this technical report inform the Constraints Management Strategy?

The MDBA is developing a Constraints Management Strategy consistent with Chapter 7.08 of the Basin Plan by November 2013. The Constraints Management Strategy must:

- identify physical, operational and management constraints that affect environmental water delivery;
- evaluate options, opportunities and risks to water users, communities and the environment associated with relaxing key constraints;
- assess the impact of modifications of constraints, and;
- identify mechanisms by which impacts on third parties can be addressed.

The information contained within this report will form the basis of our initial consultation with the State governments and communities. The MDBA will be seeking feedback on our findings contained within the report, and will be working with others to identify gaps in our knowledge or our understanding of the risks and issues associated with relaxing or modifying constraints.

The MDBA will consider the constraints identified in this technical report when developing the Constraints Management Strategy, as well as the relative merits of addressing them for achieving improved environmental outcomes, including those specified in Schedule 5 of the Basin Plan. This report is just one input into the strategy.

The final strategy will include recommendations for progressing remediation activities for priority constraints by identifying where appropriate action can be taken, and areas where further information is required. It will also identify opportunities for addressing any flow-on effects on third parties, including effects on private land, roads, bridges and other infrastructure.

The purpose of this Technical Report

The first step in the development of the Constraints Management Strategy is to identify the technical information available regarding existing constraints to environmental water delivery in the Basin. This technical report presents the MDBA’s initial assessment and compilation of physical constraints within the Basin. Policy constraints will be examined through a separate study.

It provides a basis for the MDBA to ask for further information on these or other constraints which may have been assessed or explored in regional communities or by river operators, states and environmental water holders.

The purpose of the report is to provide a snap shot and technical overview of the constraints to environmental water delivery in the Basin.

The report includes a technical assessment of each constraint for its impact on delivering specific indicator flow targets identified while developing the Basin Plan (MDBA 2011a, 2012a-x), including the specific objectives for the additional 450 GL identified in Schedule 5 of the Basin Plan.

This technical report does not list all of the flow constraints that may exist in the Basin. The MDBA recognises that as constraints are progressively relaxed, additional constraints may become apparent. Where required, the MDBA will use this technical report and other tools as a basis for consultation with stakeholders, to identify additional such constraints or issues related to addressing the constraints in this report. Importantly, remediating any constraint will require further work and analysis to be done to fully understand the impacts, noting that the knowledge of the impacts of some constraints is further advanced than others.

Method Used to Identify and Classify Constraints

The report draws on available technical information, and issues raised in discussions with water management experts and state governments, as well as the internal knowledge and expertise within the Murray–Darling Basin Authority. It focuses on those constraints that most significantly impede the delivery of environmental flows for the specific outcomes targeted in Schedule 5 of the Basin Plan.

Specifically, this report draws upon:

- hydrologic modelling conducted as part of the Basin Plan development process (MDBA 2012y,z);
- the Basin Plan Environmentally Sustainable Level of Take (ESLT) report (MDBA 2011a), and the 24 ‘Environmental Watering Requirements’ (EWR) reports (MDBA 2012a-x).
- a rapid assessment of constraints (conducted for the Basin Officials Committee, May 2012);
- a workshop held with experienced river operators from each jurisdiction, which focused on increasing the beneficial inundation of the Lower Murray floodplain, and considered the constraints required to be overcome to do so (MDBA Senior River Operators Workshop 2012 MDBA in prep);
- a review conducted by Barma Water Resources (2012) of flow constraints across the Murray–Darling Basin;
- multi-site environmental watering trials in the River Murray System.

Additional information will need to be progressively included in the assessments of constraints as the CMS is developed.

This report also assesses the impact of each constraint by looking at the desirable environmental flow indicators for each reach used in the Basin Plan development process (MDBA 2012a-x) and identifying those that may be impeded by constraints. The potential degree to which each constraint could limit the delivery of these environmentally desirable flows was determined through an examination of:

- an extensive internal literature review and the results of a consultant-based review of Environmental Water Delivery Reports (SEWPaC);
- the results of environmental watering events from recent years; and
- MDBA Basin Plan modelling data; specifically, the results of modelling an environmental watering strategy with existing constraints (MDBA 2012y) and under a relaxed constraints scenario (MDBA 2012z).

The classification of key constraints undertaken in this report includes an initial assessment against the ability to achieve improved environmental outcomes including those listed in Schedule 5 of the Basin Plan, particularly those relating to improved wetland and floodplain outcomes.

Each constraint has been designated as either a 1st, 2nd or 3rd order constraint. Under this system, 1st order constraints are considered to be the primary impediments to environmental flow delivery (noting that policy constraints are not considered in this report). Constraints designated to be 2nd order are those that would further limit environmental flow delivery if the 1st order constraints were overcome. The 3rd order grouping contains relatively minor flow constraints which could be overcome through a change to existing operational practices or a greater level of coordination between environmental and irrigation water delivery.

Primary flow constraints identified in this Report

A summary of the 1st order constraints identified across the Basin is presented. Overall, nine 1st order constraints were identified in the southern Basin, and four were identified in the northern Basin. This summary represents MDBA’s initial assessment of the primary physical and operational constraints to environmental water delivery across the Basin, however it is not an exhaustive list. Policy constraints will be the subject of a separate study, and will also inform the Constraints Management Strategy. Furthermore, MDBA recognises that as constraints are progressively relaxed, additional constraints may become apparent.

Due to differences in the underlying hydrology, infrastructure, and water sharing arrangements, the characteristics of the constraints in the southern Basin are different compared to those in the north. Environmental water delivery in the southern systems will often rely on regulated releases from storage, and the constraints are therefore related to issues such as storage release capacity, channel capacity, and inter-regional coordination of environmental watering strategies. Environmental watering in the northern systems will often be related to unregulated events, and the constraints are therefore related to the ability to protect or enhance these flows.

Next Steps

Importantly, this report is just one input into the Constraints Management Strategy. Discussions with communities and State governments will further inform development of the strategy, as required by the Basin Plan.

Once the MDBA has developed a final list of priority constraints it will undertake additional analysis including inundation modelling. Such modelling can show which areas would be affected at various increased flow heights. The Strategy will include recommendations for progressing constraint remediation by identifying areas where further information is required as well as opportunities for addressing any effects on third parties, including effects on private land, roads, bridges and other infrastructure.

After the strategy is delivered, the Commonwealth and Basin State governments will decide how the recommendations should be implemented over coming years. This is likely to involve further scoping, feasibility and planning phases for each project as required. The Strategy may be updated with further detail after November 2013 as priority projects move into a more comprehensive assessment process.

The timeline below (Figure 2) indicates the position of this report in the overall constraints management process

Figure 2: Constraints management timeline

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1. Introduction

In late 2012, the Federal Water Minister adopted the Basin Plan, providing the first integrated framework for water planning in the Murray–Darling Basin. The Basin Plan aims to restore healthy rivers for the benefit of the environment, communities and agriculture.

A central component of the Basin Plan is the establishment of new limits on the volumes of water extracted for consumptive use, known as Sustainable Diversion Limits (SDLs). On a long term average basis, the Basin Plan mandates a Basin-wide SDL of 10,783 GL/y, requiring the recovery of 2,750 GL/y of water for the environment. The Plan also provides for the adjustment of the sustainable diversion limits through supply or efficiency measures that would enable the Sustainable Diversion Limits to be adjusted up, or down, respectively. These SDL Adjustments would be finally determined in 2016. Schedule 5 of the Basin Plan describes the enhanced environmental outcomes to be pursued through the provision of efficiency measures.

The Basin Plan also includes a requirement for the Murray–Darling Basin Authority to develop a Constraints Management Strategy (CMS) by November 2013. The CMS will provide recommendations to governments on priority constraints to be overcome with implementation of recommendations expected to commence in 2014. The Commonwealth government has notionally allocated $200 million to address priority constraints to environmental water delivery in the Basin

1.1 What are Constraints?

Flow constraints limit the rate at which water can be actively delivered through the river system to deliver environmental water and include:

- **Physical constraints**, such as the rate at which water can be released from a storage (release capacities) or the level to which water can rise before passing over the river bank onto adjacent land (channel capacities).
- **Operational constraints**, relating to the effective management of water resources through a range of operating protocols (for instance, the requirement to maximise reliability of supply for consumptive use, or to protect infrastructure and private property from inundation).
- **Management or policy constraints**, which are generally issues related to licenced water entitlements, access rights, allocations, trade, and carry-over of unused water.

Further background information on flow constraints, and why they are important to environmental delivery is explored in the following sections.

1.2 Why do we need to consider constraints?

Rivers in the Murray–Darling Basin have evolved in response to highly variable inflows. They are characterised as relatively flat, slow meandering rivers where a significant proportion of the flow volume historically moved downstream during flood periods as overbank flows. These overbank flow events provide an important connection with the floodplain and associated flood-dependent vegetation and wetlands. The floodplains are a habitat for various species of flora and fauna, and overbank flow events provide broad environmental benefits for both the floodplain and the river, such as:

- improvements in the health and resilience of inundated flood-dependent vegetation,
- recharging floodplain groundwater systems,
- flushing of salt from the landscape, and
- nutrient and carbon exchange between the floodplain and river supporting fundamental ecosystem functions.

In many ways these floodplains and wetlands represent the lungs of the river system and therefore much of the life within the river depends on this connection.

The regulation of our river systems has resulted in fewer overbank events, resulting in a partial disconnect between our river systems and their associated wetlands and floodplains. These ecosystems are under stress because the regulation of the river system predominately constrains flows to remain within the main channel. In the last 30 years, there has been a measurable decline in the number and health of native fish and waterbird populations, and an overall decline in the size and health of wetlands, floodplain forests and woodlands

1.2.1 Impact of Flow Constraints on Environmental Water Delivery

Some of the important environmental mid-to-high flow events which support the river-floodplain connection are difficult to actively deliver within current system constraints, but would be achievable if key constraints could be addressed. Some of these enhanced regulated flows would be delivered in conjunction with unregulated events.

As part of the process to identify environmental water requirements for the Basin Plan (MDBA 2011b), MDBA used models to assess the level to which desirable environmental flow outcomes could be achieved through this type of 'active management' approach.

The two major conclusions of this modelling (described further below) were:

1. Constraints limit the delivery of specific environmental flows
2. Existing constraints limit the benefits of environmental water beyond the sustainable diversion limits set in the Basin Plan.

Constraints Limit the Delivery of Specific Environmental Flows

The modelling results indicated that flow constraints would impede the delivery of many of the mid-to-high flow environmental events (MDBA 2012y). For example, a flow of 80,000 ML/d (for 30 days) in the River Murray at the South Australian border is important for maintaining the health of black box and red gum woodlands, while connecting important wetlands such as the Riverland-Chowilla floodplain.

Under natural conditions (prior to the river being developed and regulated for flood mitigation and water diversion) these flow events occurred in 34% of years (once every three years). As a result of regulation and the associated constraints, these flows now occur in only 10% of years (once every ten years). Evidence indicates that the continued survival of the flood dependent ecosystems in this river reach requires a flood frequency of approximately 17 – 25% (once every four to six years; MDBA 2012v). Achieving these flows requires existing constraints to be addressed.

Existing Constraints Limit the Benefits of Environmental Water beyond the Sustainable Diversion Limits set in the Basin Plan

The Basin Plan modelling results indicated that recovering a volume of 2,750 GL/y of water for the environment could provide substantial environmental benefits for the river and associated floodplains. However, the modelling results suggested that increasing the volume of water recovered for the environment beyond 2,750 GL/y would not necessarily lead to an additional improvement in environmental outcomes associated with mid-to-high flow events, because existing flow constraints limit the capacity for that water to be used to deliver mid-to- high flow events.

1.2.2 Assessing the potential Environmental Benefits of Overcoming Constraints

At the request of the Murray–Darling Basin Ministerial Council, the MDBA completed a second set of model scenarios to examine the benefits of relaxing key flow constraints and including a scenario with Basin-Wide reduction in diversions of 3200 GL/y. Within these scenarios, eight of the key river operating constraints in the southern Basin were 'relaxed' to increase the peak rate at which environmental flows can be delivered within the model (MDBA 2012z). The specific constraint adjustments are listed in Table 1. These model runs allow the effects of relaxing constraints on provision of flows to adjacent or downstream environments to be assessed by simply modifying them in the model.

It was found that the combination of addressing constraints and recovering an additional (450 GL/y) of water for the environment could increase:

- the area of floodplains and wetlands inundated during a mid-to-high flow event;
- the duration for which these areas are inundated, and;
- the frequency at which these inundation events occur.

Table 1: Existing constraints applied in the models or demands for the proposed Basin Plan scenarios (MDBA, 2012y) and their increased values for the relaxed constraints scenarios (MDBA, 2012z)

Region	Location	Existing constraint (ML/d)	Relaxed constraint in model (ML/d)
Murray	Hume to Yarrawonga	25,000	40,000
	Downstream of Yarrawonga	22,000[1]	40,000
Lower Darling	Weir 32/Increase Menindee outlet capacity	9,300	18,000
	Darling Anabranch	Water flows into the anabranch at flows over 9,300 ML/d (no regulator)	Regulator added and closed above 9,300 ML/d when water is supplied from Menindee to meet environmental needs in the Murray
Murrumbidgee	Gundagai	30,000	50,000
	Balranald	9,000[2]	13,000
Goulburn	Seymour	12,000	15,000
	McCoy's Bridge	20,000[2]	40,000

Notes:

1. Constraint was already relaxed to 40,000 ML/d in previous Basin Plan modelling (MDBA, 2012y); however, the Hume to Yarrawonga constraint of 25,000 ML/d was in place meaning the 40,000 ML/d limit could not be effectively utilised.
2. Constraint is applied to tributary demands designed to contribute to achievement of downstream environmental water events in the River Murray.

MDBA recognises that, if implemented, these changes would lead to a range of real world issues, including potential impacts on third parties. The ongoing constraints management process will identify what these impacts are and options for their remediation and projects would only proceed where they can be acceptably addressed.

MDBA drew two main conclusions from these relaxed constraints scenarios, complementing the conclusions from the original modelling work described above. These were that:

- Addressing constraints can improve the delivery of specific environmental flows; and,
- Addressing constraints can improve the benefits of additional environmental water recovery.

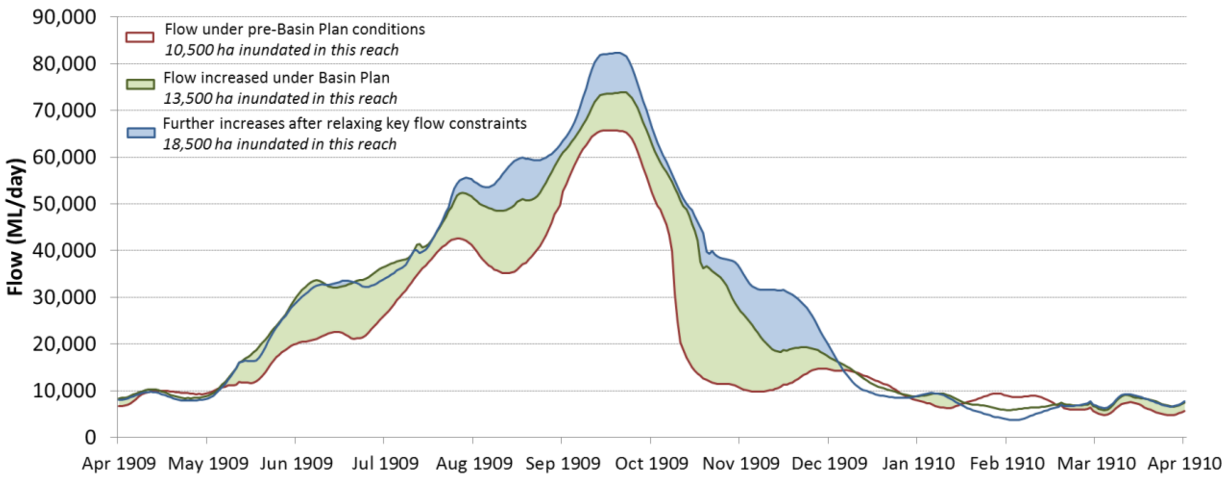
These conclusions are explained further below.

Addressing Constraints Can Improve the Delivery of Specific Environmental Flows

The modelling results indicated that relaxing key constraints would improve the delivery of ecologically important mid-to-high flow events. An example of this type of event is given in Figure 3, showing the modelled River Murray flow at Euston Weir. Modelling conducted by the MDBA (2012z) shows that, under current water-sharing arrangements, this flow would have peaked at 65,000 ML/d (red line). Environmental watering under a Basin Plan could increase the flow to 72,000 ML/d (green), inundating a greater area of flood-dependent vegetation. The relaxation of key constraints (with an additional 450 GL/y of environmental water) could further increase this peak flow to 82,000 ML/d (blue).

A higher flow will inundate a greater area of water-dependent vegetation and produce improved environmental benefits — Basin Plan watering during this event could increase the inundated area in the river reach by 29% (from 10,500 to 13,500 ha); if key constraints were also addressed this value would increase to 76% (from 10,500 to 18,500 ha). Similar improvements were found along all parts of the southern Murray–Darling Basin.

Figure 3: Modelled environmental flow event at Euston Weir under pre-Basin Plan water sharing arrangements (red), post-Basin Plan arrangements with 2,750 GL/y of environmental water (green), and combining an additional 450 GL/y of environmental water with the relaxation of key constraints (blue)

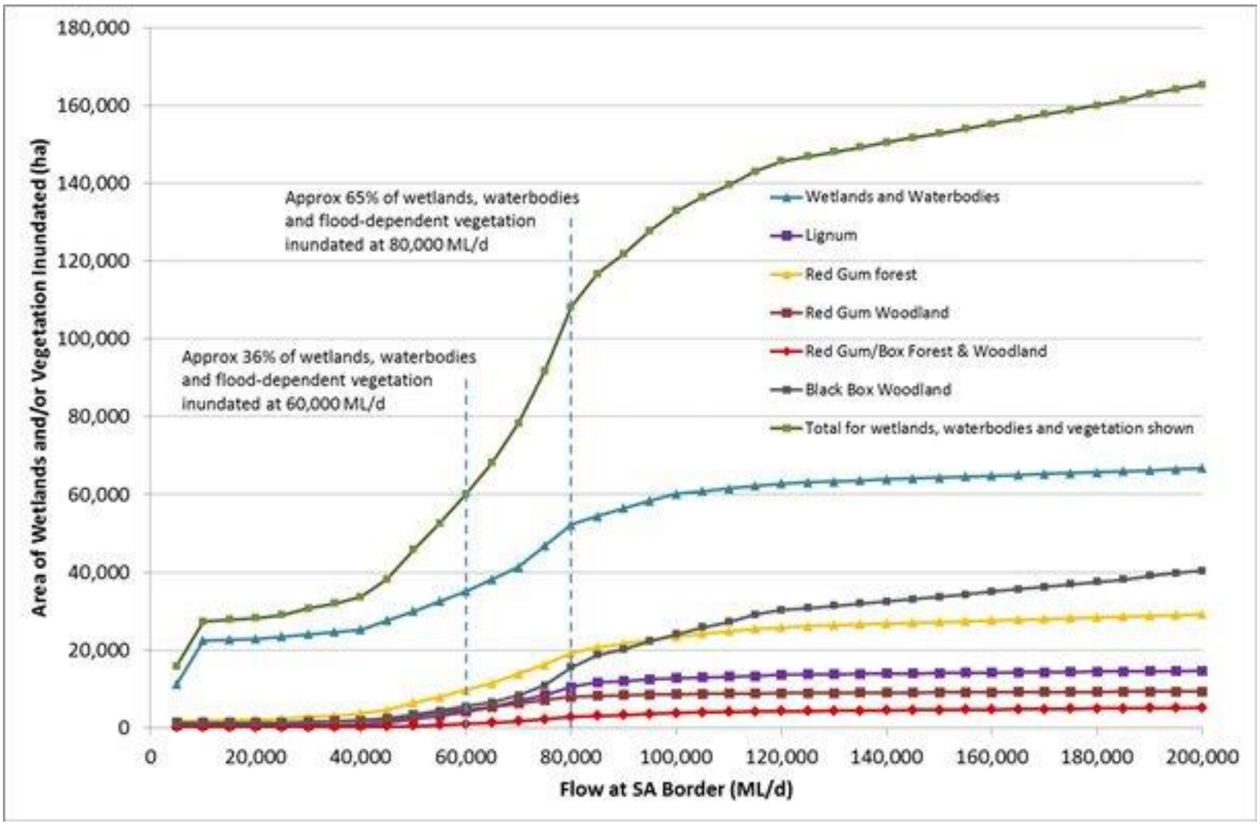


Overall, the modelling results indicated that the relaxation of constraints can increase the upper limit of the active management flow regime downstream of Wakool junction from approximately 60,000 ML/d to 80,000 ML/d. Figure 4 shows the relationship between flow and the proportion of wetlands and native vegetation in this reach that could be actively inundated. As consequence of relaxing constraints, this proportion increased from 36% (at a flow of 60,000 ML/d) to 65% (at a flow of 80,000 ML/d), an improvement of 38,000 ha.

In addition to enabling a larger area to be inundated in a particular event, addressing constraints also allows managers to have a greater capacity to control the length of time areas (habitats) can be actively watered which is important for many environmental processes. Finally, the capacity to manage the system more actively, and not have to rely solely on unregulated flows, provides greater capacity to actively manage flow events so that watering of important wetlands and floodplains occurs at a frequency that is necessary to ensure resilience.

Not all of the environmentally desirable flow regimes are possible to pursue with more active management of the high flow events. Certain high flow events (for example, 125,000 ML/d in the River Murray at the South Australian border) require large unregulated flows from multiple valleys. Such large events cannot be influenced by river operators, and will continue to occur only as natural floods regardless of the operating framework in place. Hence they have not been pursued as part of the Basin Plan and will not be pursued by the Constraints Management Strategy.

Figure 4: Relationship between inundation of wetlands and flood-dependent vegetation and flow in the River Murray between the Wakool River junction and Lock 1



Note: The percentage of wetlands and vegetation communities inundated at 60,000 and 80,000 ML/d is expressed as a percentage of the area inundated at 200,000 ML/d[1].

Addressing Constraints Can Improve the Benefits of Additional Environmental Water Recovery

The modelling results also indicated that relaxing constraints would have the greatest effect if the volume of water recovered for the environment increased to 3,200 GL/y. Specifically, the modelling showed that a 3,200 GL/y long-term average with relaxed constraints enabled 17 of the 18 river channel and floodplain environmental flow indicators for the River Murray to be achieved. This was in contrast to 13/18 indicators achieved for a 3,200 GL/y scenario retaining current constraints (MDBA 2012z).

1.3 The Constraints Management Strategy

The MDBA is developing a Constraints Management Strategy consistent with Chapter 7.08 of the Basin Plan by November 2013. To effectively set out a process for key river system constraints to be addressed the Constraints Management Strategy must:

- identify physical, operational and management constraints that affect environmental water delivery;
- evaluate options, opportunities and risks to water users, communities and the environment associated with relaxing key constraints;
- assess the impact of modifications of constraints, and;
- identify mechanisms by which impacts on third parties can be addressed.

The strategy will make recommendations to governments on how to address constraints in the Basin in order to improve environmental outcomes and make the best use of the environmental water that is available. Any further work to implement the recommendations of the CMS will be dependent on Basin State government decisions.

It is likely that some issues will require further consideration beyond what can be included in the Strategy by November 2013. In these cases the Strategy may identify projects which require further definition, and may recommend that Basin governments undertake further assessment before proceeding with any changed operations or measures to address impacts. In the meantime, the manner in which rivers are operated will not be changed from the current rules and third party impacts will not occur without the issues being worked through and addressed.

The first step in the development of the Constraints Management Strategy is to identify the technical information available regarding existing constraints to environmental water delivery in the Basin. The MDBA will consider the constraints identified in this technical report when developing the Strategy, as well as the relative merits of addressing them for achieving improved environmental outcomes, including those specified in Schedule 5 of the Basin Plan. This report is just one input into the strategy.

1.4 The purpose and scope of this Technical Report

This technical report presents the MDBA's initial assessment and compilation of physical constraints within the Basin. Policy constraints will be examined through a separate study.

The purpose of the report is to provide a snap shot and technical overview of the constraints to environmental water delivery in the Basin. It provides a basis for the MDBA to seek further information on these or other constraints that may have been assessed, or explored in regional communities or by river operators, states and environmental water holders. The MDBA will be seeking feedback on the findings contained within the report, and will be working with others to identify gaps in our knowledge or our understanding of the risks and issues associated with relaxing or modifying constraints.

The report includes a technical assessment of each constraint for its impact on delivering specific indicator flow targets identified while developing the Basin Plan (MDBA 2011a, 2012a-x), including the specific objectives for the additional 450 GL identified in Schedule 5 of the Basin Plan. This report builds on this significant body of previous work to identify and summarise the constraints in the Basin known to the MDBA

This technical report does not list all of the flow constraints that may exist in the Basin. The MDBA recognises that as constraints are progressively relaxed, additional constraints may become apparent.

This report identifies which of the known physical and operational constraints are currently understood to most significantly impede the ability of water managers to deliver environmental water in a manner that will achieve desirable ecological targets and objectives. These constraints will be prioritised for consideration in the Constraints Management Strategy.

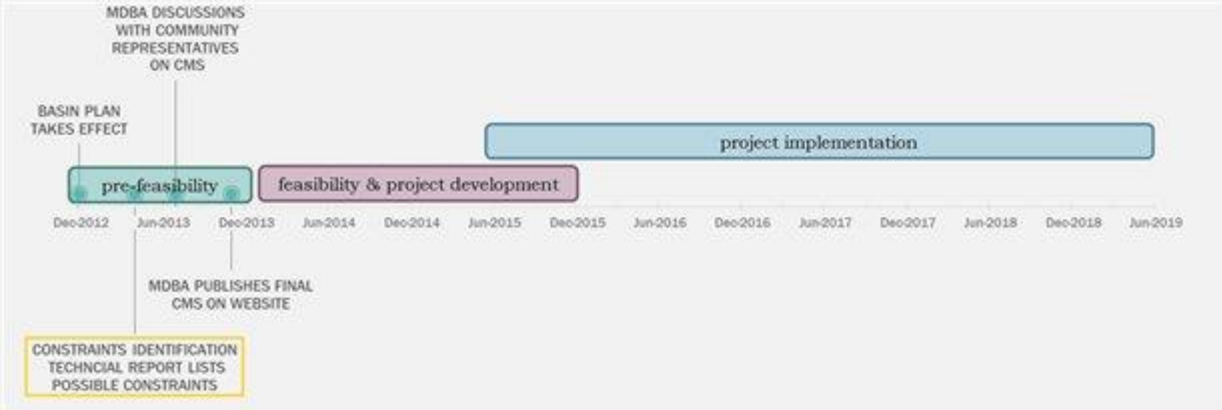
Importantly, this report does not examine options for addressing constraints, or investigate the potential impacts on third parties if the constraints were to be addressed. That work will occur at a preliminary level during the development of the CMS; and in more detail when workable projects go through further feasibility assessment and development.

Next steps

MDBA will consider the constraints identified in this report when developing the Constraints Management Strategy, as well as the relative merits of addressing them for achieving the outcomes specified in Schedule 5 of the Basin Plan and the feasibility, practicality and cost of addressing any of the constraints.

This report is just one input into the Strategy. Discussions with affected communities and stakeholders will further inform the list of constraints and the issues they raise. This report is supporting documentation to the Strategy, and final priorities will only be determined following consultation with State authorities and communities. The timeline in Figure 5 indicates the position of this report in the overall process to address constraints.

Figure 5: Constraints management timeline



Once priority constraints are identified, further work will need to be done to assess the full impact of addressing those constraints. Inundation modelling can show which areas would be flooded at various flow heights. In turn this, along with community consultation, can identify any affected private property and access routes. Part of this assessment will be conducted through the MDBA hydrologic modelling framework (MDBA 2012y,z). For this reason, each regional section in this report includes a description of the constraints as they are represented in the model.

The final Strategy in November 2013 will include broad strategies for addressing any flow-on effects on third parties, including effects on private land, roads, bridges and other infrastructure. The Constraints Management Strategy will begin to outline how and when these further analyses are undertaken for each of the 1st order constraints prior to the commencement of any project to relax those constraints.

After the strategy is delivered, the Commonwealth and Basin State governments will work together to decide how the recommendations should be implemented over coming years. This is likely to involve further scoping, feasibility and planning phases for each project as required. The strategy is likely to identify some priority constraints that are well understood and could be progressed relatively quickly, and others which would require further assessment before informed strategies could be fully developed. The Strategy may be updated with further detail after November 2013 as priority projects move into a more comprehensive assessment process.

2. Method used to identify and classify constraints for this report

2.1. Identification

This report details potential physical and operational constraints to environmental water delivery. Based on initial discussions with communities, water management experts and state governments, MDBA has made a first assessment of those constraints with the greatest potential to impede the delivery of environmental flows for the specific outcomes targeted in Schedule 5 of the Basin Plan. Over recent years, MDBA has been working with communities, water management experts and state governments to begin to understand the problem of constraints. This work has included:

The constraints described in this report were drawn from a number of primary sources, including:

- hydrologic modelling conducted as part of the Basin Plan development process (MDBA 2012y,z);
- the Basin Plan Environmentally Sustainable Level of Take (ESLT) report (MDBA 2011a), and the 24 'Environmental Watering Requirements' (EWR) reports (MDBA 2012a-x).
- a rapid assessment of constraints (conducted for the Basin Officials Committee, May 2012);
- a workshop held with experienced river operators from each jurisdiction, which focused on increasing the beneficial inundation of the Lower Murray floodplain, and considered the constraints required to be overcome to do so (MDBA Senior River Operators Workshop 2012 MDBA in prep);
- a review conducted by Barma Water Resources (2012) of flow constraints across the Murray–Darling Basin.
- multi-site environmental watering trials in the River Murray System.

Physical constraints are inherent to the system, and can be a natural characteristic or related to infrastructure. For example, the Barmah Choke is a natural feature resulting from the narrowing of the River Murray, and flows above a given threshold force water out of the channel and onto the floodplain. The resulting overbank events provide essential water to maintain the ecological health of the Barmah–Millewa Forest, however this process can also introduce complexities when delivering water further downstream or for disrupting access in adjacent flood-runners. Human development has introduced further physical constraints to the system — for example, regulated releases of water are limited by the dam outlet valve release capacity or spillable gates.

Operational and other constraints can be purely human constructs, and relate to the effective management of water resources through a range of operating protocols and practices. In addition to ensuring the effective delivery of water, some of these have evolved in response to physical features which constrain in-channel flow. Thus, there is a degree of commonality between the physical and operational constraints. For instance, the Barmah Choke can be characterised to be a physical constraint, yet this physical constraint has also led to a set of public storage operation constraints which are specifically designed to minimise associated flooding in this reach of the river at times where these flows would have undesirable impacts on the forest. The intent of most other operation rules is twofold: partly to reduce 'losses' on the floodplain during summer regulated periods, and partly to reduce potential flooding of rural communities, infrastructure and private property.

Policy constraints include issues related to water sharing arrangements. These kinds of constraints include complex issues such as the kinds of rights that are granted by an entitlement, or a state's policy on determining water allocations or rules restricting the ability to trade or carry-over unused water allocation. This report does not examine this type of constraint.

2.2 Classification

Constraints typically include any factor that limits the ability for environmental water managers to deliver the flows required to meet environmental flow requirements. A study of environmental flows required to achieve desirable outcomes for the water-dependent ecosystem formed part of the Basin Plan development process, and underlies the determination of the ESLT. These can be found in the Environmental Water Requirements reports (MDBA 2012a-x). The extent to which each constraint could limit the delivery of these flows was determined through an examination of:

- The results of environmental watering events from recent years.
- MDBA Basin Plan modelling data; specifically, the results of modelling an environmental watering strategy with existing constraints (MDBA 2012y) and under a relaxed constraints scenario (MDBA 2012z).
- An extensive internal literature review and the results of a consultant-based review, including the Department of Sustainability, Environment, Water, Population and Communities (SEWPaC) Environmental Water Delivery Reports.

Each of the environmental flow indicators used in the development of the Basin Plan have then been categorised according to the level to which their delivery will be limited by constraints. The three categories are summarised in Table 2, and are consistent with the classification scheme described by MDBA (2012a).

Based on this assessment, a table has been prepared for each region listing the primary constraints to environmental water delivery (see the regional sections in the main body of this report). Flow constraints have been designated as either a 1st, 2nd or 3rd order constraint. Under this system, 1st order constraints are considered to be the primary impediments to environmental flow delivery (noting that policy constraints are not considered in this report), where this assessment was made partly using MDBA modelling data. As a general guideline, environmental flow indicators assigned to the second category ('achievable under some conditions') could be expected to move to the first category ('achievable under current operation conditions') if the 1st order constraints were overcome.

Table 2: Key to the classification of the degree to which identified environmental flow requirements can be achieved within current constraints and operational practice

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.

Constraints designated to be 2nd order are those that would further limit environmental flow delivery if the 1st order constraints were overcome. The 3rd order grouping contains relatively minor flow constraints which could be overcome through a change to existing operational practices or a greater level of coordination between environmental and irrigation water delivery. Where appropriate, the 2nd and 3rd order groupings includes minor, moderate and major flood levels. The full list of site-specific flood levels used throughout this report is given in Appendix B.

The classifications included in this report are based on an initial assessment, and are open to review or comment.

2.3 Structure of this Technical Report

Following on from the introduction material above, Section 3 provides a more detailed discussion of the characteristics of environmental water delivery in regulated and semi- to unregulated systems. Sections 4 – 7 contain detailed constraints information for each river valley, with some systems such as the Murray being further sub divided into reaches.

The section for each river valley contains a description of:

- Key structures and flow constraints
- Representation of constraints in the hydrological model
- Environmental flows effected by constraints
- Summary

The description of environmental flows affected by constraints includes a table listing the primary constraints to environmental water delivery.

3. General Characteristics of Environmental Water Delivery

The characteristics of flow constraints vary between regions. These constraints are largely determined by the practices and policies of environmental water delivery within the valley, which in turn are largely determined by the existing infrastructure and water-sharing arrangements. Each region can be broadly classified as ‘regulated’ or ‘unregulated’.

Regulated regions (mainly those in the southern part of the Basin, and some northern catchments in NSW) are characterised by their infrastructure, such as dams and weirs, which allow a relatively large proportion of the flow to be controlled. These regions have an associated water allocation system that allows entitlement holders to request water from storage for consumptive use purposes. Managed environmental watering in these systems will usually partly rely on storage releases, and the flow constraints in these regions are therefore largely determined by the characteristics of the storages, channel capacities, and water-sharing polices.

Semi-regulated or unregulated regions are characterised by a lower level of flow-controlling infrastructure. A significant proportion of water diverted for consumptive use in these regions is associated with unregulated licences. These allow licence holders to access water during specific flow conditions, such as during times when river levels exceed given heights (pumping thresholds). Environmental watering in these systems will therefore rely heavily on unregulated flow events, and the associated flow constraints (such as the capacity to shepherd environmental water) are distinct from those in regulated regions.

A general summary of environmental watering characteristics within regulated and semi-regulated/unregulated systems is given below. It is important to consider the merits of addressing any of these constraints in the light of these characteristics.

3.1 Regulated Systems

In practice, the achievement of a mid-to-high flow environmental watering event in a regulated system will often seek to combine storage releases with large (possibly unregulated) inflow events from a tributary river system. That is, if a rainfall event is predicted to produce large inflows from a tributary (such as the Ovens River) then environmental releases from an upstream storage (such as Hume Dam) can be coordinated to ensure that the combined flow events can deliver targeted environmental outcomes. This type of opportunistic approach (referred to as enhancement of unregulated flow or piggy backing) has multiple benefits:

- **Larger events can be achieved**
  The mid-to-high flow environmental flow events generally require significant volumes of water, and are impractical to be created by regulated environmental releases alone. The amount of water which can be released from storage is limited by the allocated volume associated with recovered environmental entitlements, by the release capacity of the dam itself, and by downstream channel capacity constraints. However, combining these releases with unregulated inflows allows a greater peak flow and/or event duration (and

hence volume) than would have been possible under a fully regulated scenario, improving the associated environmental outcomes.

- **Natural sequence is maintained**
  Many ecosystem processes respond to ecological cues such as climatic conditions in anticipation of a large flow event. Coordinating environmental releases with a large unregulated inflow ensures that the delivered event occurs at a time when it would have occurred under natural conditions, and therefore makes full use of these ecological cues.

- **Allows some benefits to be achieved within flow constraints**
  If a large tributary stream enters the main river downstream of a major flow constraint, then coordinating releases with an inflow event can reduce the impact of this flow constraint on environmental water delivery. For example, the Goulburn River enters the River Murray downstream of the Barmah Choke, a natural channel capacity constraint which limits releases from Hume Dam and Yarrawonga Weir. A large inflow event from the Goulburn could be supplemented by relatively moderate releases from Hume Dam, which would enhance the environmental event without breaching the flow constraints associated with the Barmah Choke.

Releases from storage will need to be carefully timed to achieve the combined flow event and minimise any risks to third parties. Furthermore, in some cases releases may be made from multiple storages to build a single environmental flow. For example, an environmental flow event in the Lower Murray may rely on the aggregation of a release from Hume Dam with those from Burrinjuck Dam (Murrumbidgee catchment) and Eildon Dam (Goulburn catchment). They may also be timed to coincide with a large unregulated inflow from the Ovens River. Increasing the number of elements associated with the delivery of a specific flow event produces an increasing complexity and requires a greater level of coordination.

As a result, the timing of environmental releases from storage will be an important consideration influencing the delivery of mid-to-high flow environmental events. An initial analysis (Senior River Operators Workshop 2012; MDBA in prep) identified the requirement for well-timed large flows in at least three of the four major southern valleys (Upper Murray, Goulburn, Murrumbidgee, and Lower Darling) to achieve a peak flow of 80,000 ML/d at the South Australian border. This flow is an important threshold for the inundation of large areas of flood-dependent vegetation in the reach encompassing the Riverland–Chowilla Floodplain site. Without the strategy of building events by a combination of unregulated flows and managed releases, the capacity to deliver large flows to South Australia is severely reduced, with probably half (or less) of the peak being the maximum obtainable.

In both the Northern and Southern Basins, flow travel times from tributary storages to the desired location on the main river are generally all greater than one month. Unregulated flow travel times are even longer and can be difficult to predict with an accuracy of better than a few days. As such, the capacity to coordinate the timing of these releases with large tributary inflow events requires further research. An initial investigation indicated that achieving a flow of 80,000 ML/day is possible through the coordination of Hume Dam and Menindee Lakes releases with unregulated inflows from other tributaries (Senior River Operators Workshop 2012; MDBA in prep).

As identified in this report (Section 6.4), the regulated management of environmental flows to the Barwon–Darling River can be particularly difficult, as they will rely almost completely on the accurate timing of releases from multiple storages in tributary catchments. However, delivering combined flows in this region will be more difficult compared to the south due to larger flow travel distances and drier catchments.

If higher regulated releases are to be made to deliver environmental water, the risk of these flows coinciding with a rain event in the following weeks will need consideration. Water managers would consider this risk and obtain the best information possible to lessen the level of risk. Emerging improvements in weather and flood forecasting could improve the predictive capacity.

Regulated environmental releases represented in the Basin Plan modelling scenarios were made under the requirement that reliability of supply for irrigators would not be affected. Similarly, Section 7.15 (1) of the Basin Plan specifies that “adjustments due to supply measures will not have detrimental impacts on reliability of supply of water to the holders of water access rights that are not offset or negated.”

3.2 Semi-Regulated and Unregulated Systems

The largest semi-regulated and unregulated catchments are located in the northern parts of the Murray–Darling Basin. The northern Basin comprises the catchment area of the Barwon–Darling River and its tributaries upstream of Menindee Lakes. It includes more than half of the Murray–Darling Basin and is more arid and flat than the southern Basin. Rainfall and resulting stream flows are more variable compared to the south, and are summer dominant in the northern sections (compared to winter dominant in the southern Basin).

These features of the northern Basin have meant that the surface water resources have been developed and managed differently to the southern Basin. The proportion of flows regulated by dams is much lower and a significant proportion of irrigation production relies on diverting unregulated flows directly into large privately constructed off-stream storages.

As such, many of the water licences in the northern Basin allow access during unregulated flow conditions, known as unsupplemented access in QLD and supplementary access in NSW. Holders of these licences are able to access water during specific flow conditions, often associated with periods of mid-to-high flow.

Due to these differences, environmental watering in the northern Basin will be distinct from that in the south. The Commonwealth and other environmental water holders will generally seek to use the water against their entitlements by leaving it in-stream, however the pumping thresholds of other licence holders may result in that environmental water being extracted for consumptive use. Shepherding arrangements are intended to ensure that environmental water holders are able to use their water for environmental purposes ‘in-stream’, without increasing or diminishing the interests of consumptive users. The type and location of the recovered water licences will also be critical to the achievement of desired environmental outcomes.

4. Murray

The River Murray flows in a westerly direction from its headwaters in the Great Dividing Range south of Khancoban. The major tributaries of the River Murray are the Mitta Mitta, Kiewa, Ovens, Goulburn, Campaspe and Loddon Rivers that flow to the River Murray from Victoria in a northerly direction, and the Murrumbidgee River and Darling River flowing in a south-westerly direction from New South Wales. The Edward and Wakool Rivers are a major anabranch system in New South Wales that re-enter the River Murray upstream of Euston. River Murray flows are also augmented by releases from the Snowy Mountains Hydro-electric Scheme.

The River Murray is regulated by three major storages — Hume Dam, Dartmouth Dam, and Lake Victoria. Hume Dam is located on the upper River Murray near Albury and has a storage capacity of 3,003 GL. It was constructed in 1936 and was enlarged in 1961. Dartmouth Dam constructed in 1979, is located on the Mitta Mitta River and has a storage capacity of 3,856 GL. Lake Victoria, located in far-west New South Wales, was constructed in 1925 around natural wetlands and has a storage capacity of 677 GL. Flows in the River Murray are highly regulated: Dartmouth and Hume Dams both regulate 87% of their total inflow. The major tributary rivers (Murrumbidgee, Goulburn and Darling) for the River Murray are also highly regulated.

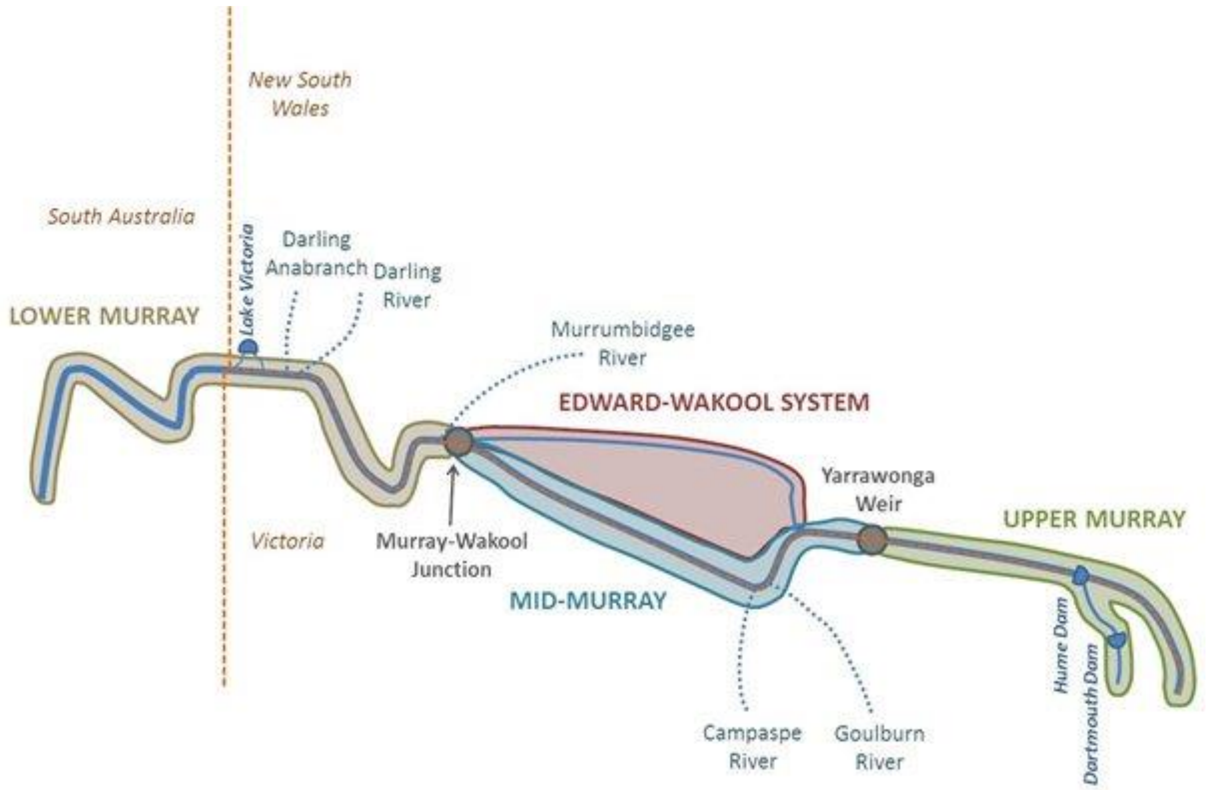
The land adjacent to the River Murray is subject to sporadic inundation caused by high-flow events. These flooding events are beneficial for ecosystems within the associated floodplains and wetlands, however they can be detrimental to public or private holdings located near the river. In general, landholders receive a fair degree of additional flood protection as many potentially large events are captured in storages. The relative proportion of private to public land on the River Murray floodplain changes when moving down the river — land adjacent to some river reaches consists mainly of private holdings, whereas other reaches are predominately bordered by public land.

MDBA has completed an initial assessment of private and public land areas along the River Murray using an in-house framework which relates river flows to inundation areas and GIS land tenure data. While this framework contains some uncertainty regarding the separation of public and private land, it provides an indication of the general pattern of private and public land holdings along the River Murray. These estimates are indicative for the wider floodplain along the River Murray, however the proportions will depend on the extent of each flood event. That is, a relatively small flood event may only affect public land, whereas a larger flood event will also impact privately-owned land.

For the purposes of this report, the River Murray has been split into the four main sections outlined in Figure 6. The Upper Murray comprises the river reaches from the headwaters of the main river, past Dartmouth and Hume Dams, to Yarrawonga Weir. The Mid-Murray encompasses the region from Yarrawonga Weir along the Murray to the junction with the Wakool River. In parallel, the Edward-Wakool region (the third section) includes the complex system of anabranching creeks and rivers located to the north of the River Murray in New South Wales. Finally, the Lower Murray encompasses the region from the Murray-Wakool junction to the Murray Mouth in South Australia.

It should be noted that the River Murray contains multiple environmental assets, described throughout each of the four Murray sections below. Each reach along the river (and each asset) has different hydrological characteristics, due to flow attenuation and the nature of inflows from major tributaries. For example, over the long-term, the Murrumbidgee and Goulburn each contribute similar volumes to the Murray under current water-sharing arrangements, but the character of these flows is substantially different. During wet periods, the Murrumbidgee generally contributes moderate flows steadily over a long period, whereas the Goulburn can contribute higher flows of a shorter duration. These characteristics and the various constraints throughout the Murray system make water delivery to assets a challenging task, as assets in each region of the River Murray are affected by constraints in other regions. Therefore, not only do constraints in the Upper Murray affect the delivery of flows to downstream assets in the Mid- and Lower Murray regions, constraints in the major tributaries such as the Goulburn and the Murrumbidgee also affect flow delivery to assets in the Murray.

Figure 6: Schematic diagram illustrating the four sections of the Murray discussed in this report. The regulated tributaries discussed in other sections of this report are marked with dashed lines



A summary of the flow constraints in the River Murray is presented in Table 3. The MDBA has used the knowledge outlined in Section 1 to make an initial assessment on the relative level to which different constraints limit environmental flow delivery. This will be refined as the Constraints Management Strategy is developed. First order constraints represent the primary impediments to the delivery of mid-to-high flow environmental events. If these constraints were overcome, the 2nd order grouping contains the next set of constraints that would potentially limit environmental water. A full investigation is required to determine the extent and flow at which these take effect. The 3rd order grouping contains relatively minor flow constraints which could be expected to be overcome through a change to existing operational policy, or a practiced coordination between environmental and irrigation water delivery. The various 1st, 2nd and 3rd order constraints are more fully described below.

Table 3: A summary of current understanding of the key constraints limiting environmental flow delivery in the River Murray, where constraints have been initially classified in terms of their capacity to limit flows

Order	Region	Location	Description	Flow Limit (ML/d)
1st	Upper Murray	Doctor's Point	Operating constraint based on channel capacity between Hume Dam and Yarrawonga Weir	25,000
	Mid-Murray	D/S Yarrawonga Weir	Irrigation delivery and downstream inundation control	10,600 (summer) 18,000† (other times)
	All regions		Timing (ability to coincide multiple environmental releases with large unregulated inflow events)	—
2nd	Upper Murray	Corowa	Minor flood level	*19,000
	Mid-Murray Edward-Wakool	D/S Yarrawonga Weir	Private access issues (Bullatale/Tuppal Creeks)	~20,000
	Edward-Wakool	Deniliquin	Channel capacity (minor flood level)	17,100
	Edward-Wakool	Effluent systems (Wakool River, Colligen Creek, Yallakool Creek)	Channel capacity	Various
	Lower Murray	SA Border	Channel capacity (SA shacks between Cadell and Mannum)	≥60,000 (notice required for flows between 60,000 & 90,000)
3rd	Mid-Murray Edward-Wakool	Millewa Forest regulators	Operational practice	—
	Mid-Murray	Gunbower Creek	Channel capacity	<1,600
	Edward-Wakool	Mulwala Canal	Channel capacity	2,100 – 2,400
	Edward-Wakool	Steven's Weir Pool	Operational practice (pool drained in winter)	—

†Impacts on third parties above this flow are taken into consideration by river operators

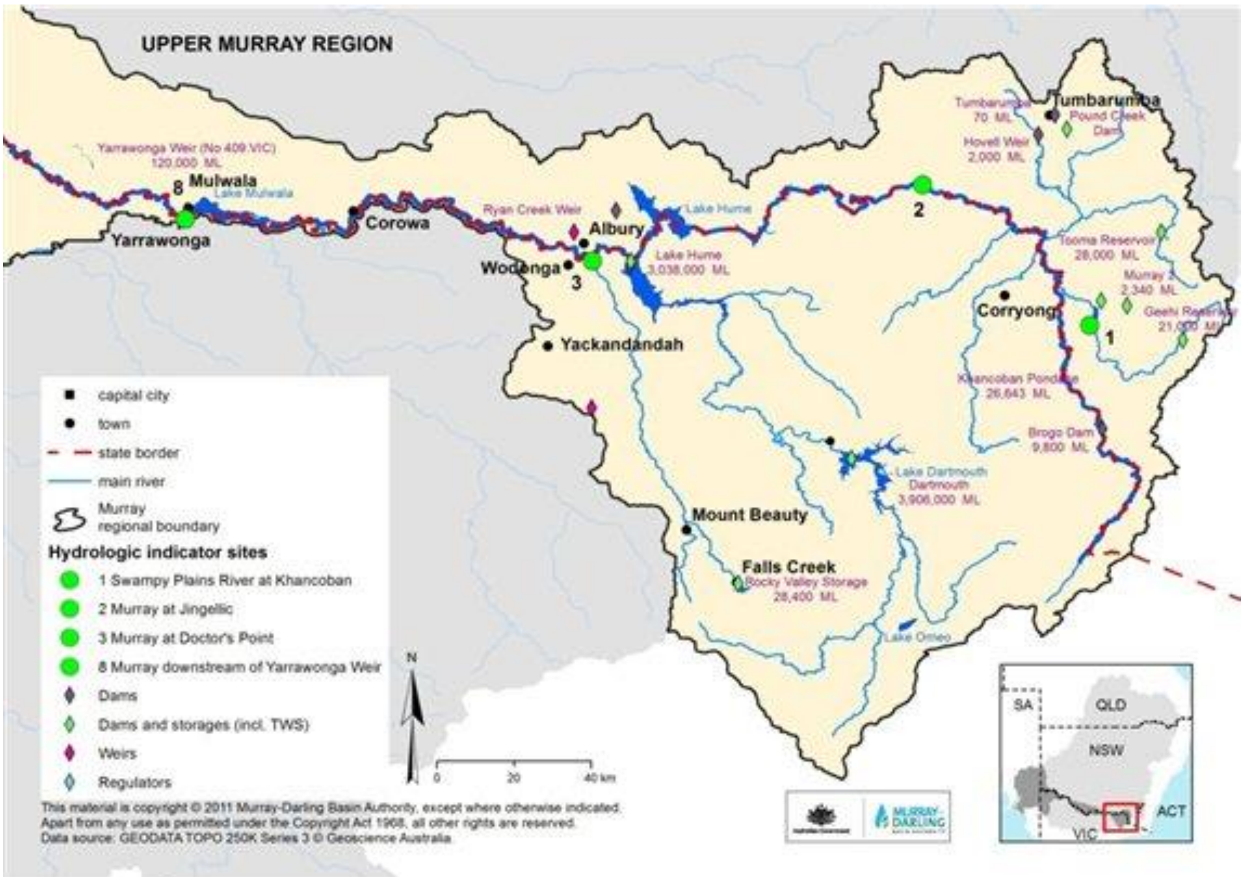
*There is considerable doubt about the minor flood level at Corowa as minor flood level impacts may not be felt until the flow is higher than 19,000. Historically water has already been delivered at flows higher than this.

Removal of constraints is not required to deliver the Basin Plan which was based on achieving environmental outcomes within current management arrangements. However easing or removal of constraints will enable better environmental outcomes to be achieved within the SDLs set by the Basin Plan, and also provides capacity to utilise additional environmental water achieved through Basin Plan efficiency measures.

4.1 Upper Murray

The Upper Murray reach encompasses the river headwaters in the Great Dividing Range, Dartmouth and Hume storages and the reach of the river between Hume Dam and Yarrawonga Weir. Figure 7 shows the extent of the Upper Murray region and key locations. Topography differs widely along this part of the river, from rugged alpine terrain to gently undulating country with low relief floodplains. Initial estimates of the proportion of privately and publicly owned floodplain areas are listed in Table 4. This reach also includes tributary inflows from the Mitta Mitta, Kiewa and Ovens Rivers.

Figure 7: The extent and main features of the Upper Murray region, from the headwaters to Yarrawonga Weir



Flow constraints in this reach are primarily related to channel capacities associated with the operation of Hume Dam to minimise inundation of private agricultural land and minimise losses. They are not associated with the structural release capacity of Dartmouth or Hume Dams. The main constraints in this region are outlined in Figure 6. It should be noted that the minor flood level at Corowa of 19,000 ML/d is known to be an anomaly as historically flows higher than this have been delivered without the impacts expected at minor flood level.

Figure 8: Schematic diagram summarising the key structural features and flow constraints in the Upper Murray region

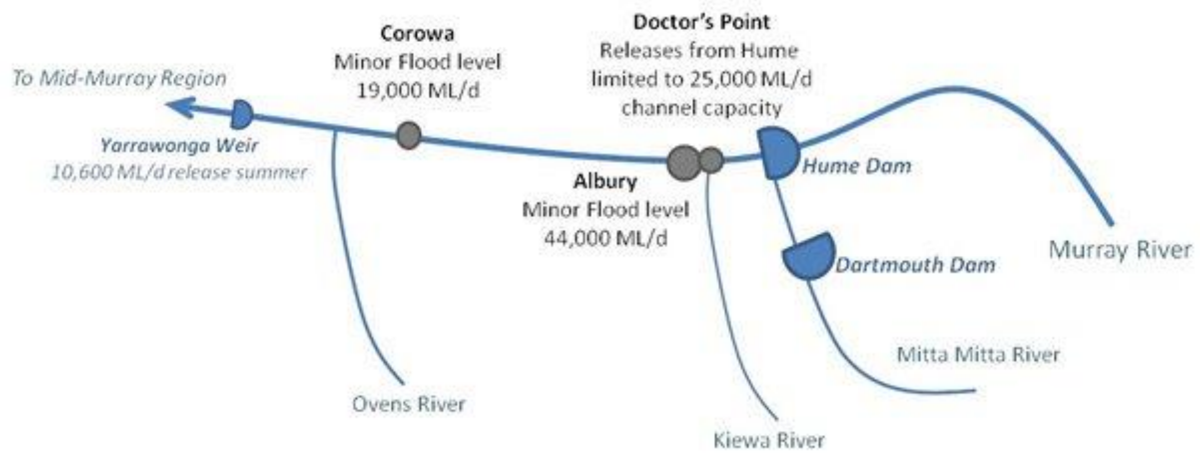


Table 4: Percentage of flood extent that is either privately or publicly owned in the Upper Murray reaches

Reach	% of floodplain privately owned	% of floodplain publicly owned
Hume Dam to Yarrawonga Weir	80%	20%

4.1.1 Key Structures and Flow Constraints

Transfers from Dartmouth Dam to Hume Dam

When required, water is transferred from Dartmouth Dam to Hume Dam to ensure the reliability of irrigation supply. In the Mitta Mitta River downstream of Dartmouth Dam the flow at Tallandoon is constrained to a maximum rate of 9,500 ML/d. Neither TLM nor the Basin Plan EWRs have specified an environmental asset in the Mitta Mitta River dependent on flows greater than this threshold. Given that the amount of flow that can be delivered to the reaches downstream is controlled by Hume Dam and that there are no specific assets currently identified in this reach, this maximum flow rate is currently not believed to represent a constraint to environmental water delivery in this reach or any sites downstream.

Under current water sharing arrangements Hume Dam generally follows an annual cycle of filling (during winter and early spring) and drawdown (during summer and autumn). The Tallandoon flow constraint is not expected to significantly impact transfers between Dartmouth and Hume dams. The current operating practice allows for transfers to be made in a series of pulsed releases to represent a more natural flow regime and enhance the ecological values of the Mitta Mitta River. The ability to both deliver environmental water from Hume Dam and guarantee user supply reliability in some years will depend on the water transfer rate from Dartmouth Dam. In some instances however the rate of release from Dartmouth to Hume can impact on the maximum release available from Hume. This happens in the rare occasions that Dartmouth has a substantial amount of water and Hume Dam is very low. In practice, both the timing and release rates of water from Dartmouth will be selected based on inflow and usage patterns in the River Murray (including environmental usage associated with recovered entitlements) thus this regime of pulsed releases from Dartmouth is not expected to impinge on the ability to deliver mid-to-high flow environmental events downstream of Hume Dam.

Hume Dam Releases

The valve capacity of Hume Dam is greater than 50,000 ML/d, and is therefore not expected to constrain environmental water releases to any great degree. Hume Dam operations are subject to a rule (the ‘six-inch rule’) specifying the rate at which outflow can be reduced. This is related to the risk of bank slumping in the reach immediately downstream of the storage, and is set to a maximum river height reduction of approximately 150 mm/d at Doctor’s Point (corresponding to a flow reduction rate of about 1,500 ML/d) when the flow is within channel capacity (up to 25,000 ML/d). This rule is intended to protect the river and its anabranches downstream of Hume Dam from bank slumping. However, it can sometimes reduce operational flexibility to respond to quickly changing river conditions, and therefore may contribute to environmental impact caused by unseasonal flooding at times of severe rain rejection events (e.g. in Barmah-Millewa forest), if dam releases cannot be quickly scaled back. A package of options is being investigated that would more effectively reduce the risk of unseasonal flooding of the forest.

Downstream of Hume Dam, the Kiewa River joins the River Murray just upstream of Doctor’s Point. The catchment surrounding the Kiewa River (Figure 8) is hilly to mountainous and consists of alpine peaks and plateau along with highly dissected valleys. Due to the nature of this system, the Kiewa River can provide substantial inflow events during wet periods. Under regulated conditions the flow at Doctor’s Point is limited to a maximum of 25,000 ML/d, with Hume releases reduced in parallel with any increase in inflows from the Kiewa River. This operational constraint is based on the nominal channel capacity of the River Murray in this reach, for which easements have been obtained, and is designed to minimise the inundation of privately owned agricultural land associated with the delivery of regulated flows (80% of the floodplain in the reach extending from Hume Dam to Yarrawonga Weir is privately owned). This flow limitation at Doctor’s Point forms a key constraint in the Upper Murray region.

Corowa

The minor flood level at Corowa is exceeded at a river height of 3.8 metres, corresponding to a flow of approximately 19,000 ML/d, while the moderate flood level corresponds to a flow of approximately 44,000 ML/d.

Operationally, the 19,000 ML/d threshold is not a constraint to releases from Hume Dam. Anecdotal evidence provided to MDBA indicates that flows at this rate can lead to some nuisance flooding or affect access within some properties however the effects are not substantial. Furthermore, in practice, environmental watering will combine release from Hume Dam with unregulated inflows from the Ovens River, which joins the River Murray downstream of Corowa. Hence, only a portion of the environmental flow event will pass through Corowa.

The 19,000 ML/d threshold is an important flow level considered as part of river operations, however the Doctor's Point limit of 25,000 ML/d forms the main constraint in this region.

Tributary Flows

The Kiewa River is essentially an unregulated system, although power stations and irrigators are present. The Ovens River contains two storages (Lake Buffalo and Lake William Hovell) which have flow restrictions in place during dry periods to prevent potential water shortage in Wangaratta. These valleys will both contribute to River Murray environmental flows largely through unregulated flow events, not through regulated releases (although Lake Buffalo currently contributes smaller flows during summer periods). Hence neither valley is currently considered to contain a significant constraint to environmental water delivery.

4.1.2 Representation of Constraints in the Hydrological Model

The Murray region in its entirety is modelled using the monthly simulation model (MSM) and an associated daily flow and salinity routing model called BIGMOD. This model has been used extensively for Basin Plan development. A description of the model is provided in MDBA (2012y).

For the Upper Murray region, Hume Dam is modelled with a full capacity of 3,037 GL. Storage release capacity is defined as a table relating release rate with storage level. The operating constraint at Doctor's Point is modelled as a limit on regulated releases from Hume Dam set at a maximum of 25,000 ML/d.

4.1.3 Environmental Flows Affected by Constraints

Environmental flow delivery is not expected to be impacted by the six inch rule described above. Instead, the flow limitation at Doctor's Point (25,000 ML/d) forms a key constraint in the Upper Murray region, and therefore impacts the delivery of mid-to-high environmental flows to all downstream flood-dependent ecosystems. These include those associated with environmental assets such as the Barmah–Millewa Forest, Werai Forest, Gunbower-Koondrook-Perricoota forests, Hattah Lakes and the Riverland–Chowilla Floodplain.

MDBA modelling has demonstrated that relaxing this constraint (in conjunction with a relaxation of the downstream constraint at Yarrawonga Weir; see Section 4.2) can produce tangible environmental benefits at Barmah–Millewa Forest (MDBA 2012z). The results indicated that the delivery of events with a peak flow of 35,000 ML/d downstream of Yarrawonga Weir is directly related to the Doctor's Point constraint. In practice, these events could be delivered by supplementing relatively high unregulated flows from the Ovens and/or Kiewa Rivers with environmental releases from Hume Dam, but only if the Doctor's Point constraint was modified to allow increased flow during the desired period (MDBA 2012z). The MDBA Senior River

Operators Workshop 2012 (in prep) also indicated that relaxing this constraint provides tangible environmental benefits in the mid to lower Murray, by allowing a greater volume of water to be released in the small window of time available to coincide with, and top up, unregulated inflows from other valleys.

In practice, any modification to the Doctor's Point flow constraint would require flood easement or other similar solution to be negotiated with private landholders to allow an increased inundation during environmental flow delivery periods.

4.1.4 Summary

Table 5 below summarises the main constraints present in the Upper Murray and their importance to environmental flow delivery. Overall, the Doctor's Point flow constraint is the only significant impediment to the delivery of higher flow environmental events; the minor flood level at Corowa is a secondary constraint.

Table 5: Summary of Upper Murray constraints, and their importance in downstream environmental flow delivery

Location	Constraint Description	Flow Constraint (ML/d)	Inhibits Environmental Flow Delivery?
Dartmouth Dam	Storage release capacity	10,000	No (possibly in dry years)
Mitta Mitta River	Flow constraint upstream of Hume Dam	9,500	No (possibly in dry years)
River Murray at Hume Dam	Storage release Capacity	53,400 (dependent on lake level)	No (possibly in dry years)
River Murray at Doctor's Point	Operating Constraint	25,000	Yes
River Murray at Corowa	Flood Level	19,000 (minor) 44,000 (moderate)	No

4.2 Mid-Murray

The Mid-Murray region includes the main reaches of the River Murray between Yarrawonga Weir and the split at the Edward River offtake, and the reaches of the River Murray until its confluence with the Wakool River near Kenley upstream of the Murray-Murrumbidgee junction. The region contains significant areas of irrigation and development on the floodplain. It also includes inflows from key tributaries (the Goulburn, Campaspe and Loddon Rivers in Victoria) and return flows from the Edward-Wakool River system. A map of the region is shown in Figure 9, and a schematic diagram showing key constraints, structural features, and environmental assets can be found in Figure 10.

Flow constraints in the Edward-Wakool system are discussed separately (Section 4.3), hence this section describes flow constraints for the River Murray only as it breaks South from the Edward offtake and then north westerly to meet with the Wakool River again past Swan Hill and Tooleybuc. This section of the River Murray can be further divided into three reaches, and initial estimates of the proportion of privately and publicly owned floodplain areas for the reaches are listed in Table 6. Major towns in this region include Cobram, Tocumwal, Echuca, Barham, and Swan Hill.

This section of the Murray contains two hydrological indicator sites with associated environmental water requirements which are affected by constraints:

- The Barmah–Millewa Forest (MDBA 2012a), flows measured downstream of Yarrawonga Weir (HIS 8 in Figure 9).
- Gunbower-Koondrook-Perricoota Forest (MDBA 2012f), flows measured downstream of Torrumbarry Weir (HIS 27 in Figure 9).

The ecosystems comprising these two environmental assets rely on relatively high flows (less than minor flood level) and, at times, long durations to inundate flood-dependent vegetation and provide conditions conducive to colonial waterbird breeding events. The active management of some of these environmental flows are limited by existing system constraints. The Basin Plan was struck in the recognition that not all desirable environmental flows could be delivered so addressing any of these constraints may lead to improvements in environmental outcomes. Flow constraints to environmental water delivery in this reach primarily consist of operational constraints of infrastructure related to the mitigation of urban and rural flooding.

Figure 9: The extent and main features of the Mid-Murray region, from Yarrawonga Weir to the Wakool Junction

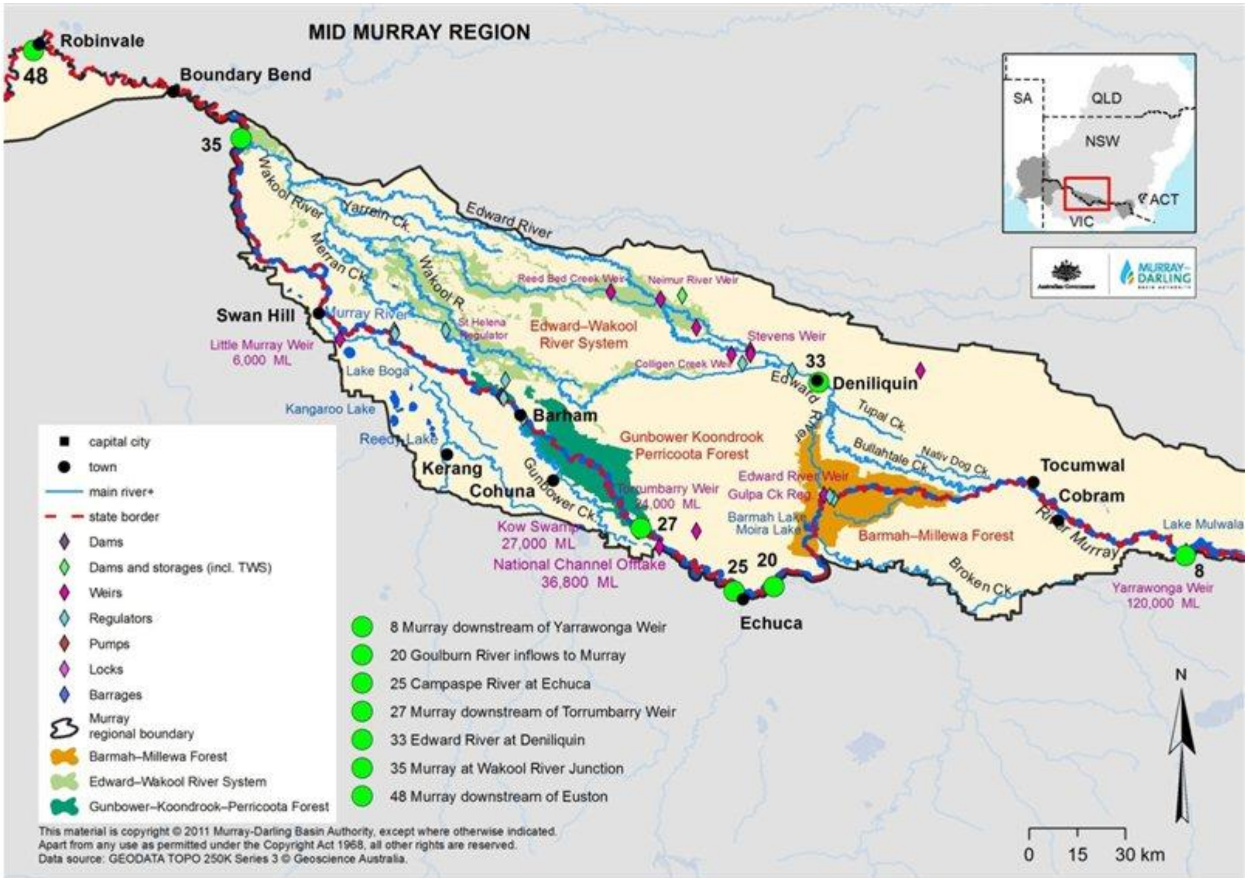


Figure 10: Schematic diagram summarising the key structural features and flow constraints in the Mid-Murray region (including the Edward-Wakool System)

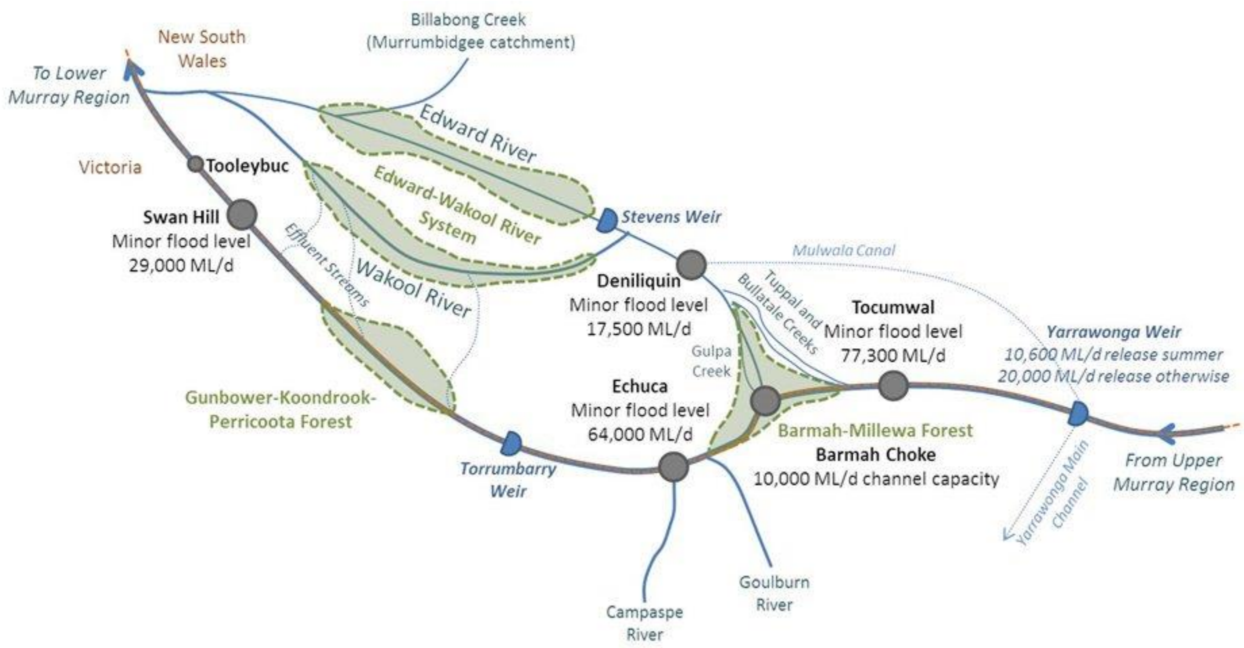


Table 6: Percentage of flood extent that is either privately or publicly owned in the Mid-Murray reaches

Reach	% of floodplain privately owned	% of floodplain publicly owned
Yarrawonga Weir to Barmah	37%	63%
Barmah to Torrumbarry Weir	74%	26%
Torrumbarry Weir to Murray/Wakool Junction	56%	53%

4.2.1 Key Structures and Flow Constraints

Yarrawonga Weir

Yarrawonga Weir is the first major regulating structure on the River Murray downstream of Hume Dam, and is the largest of the 16 weirs operated by the MDBA. The weir artificially raises the water level to create Lake Mulwala, which then supplies irrigation water to licenced entitlement holders through Mulwala Canal (New South Wales) and Yarrawonga Main Channel (Victoria).

Yarrawonga Weir itself does not represent a physical impediment to the delivery of environmental flows. Instead, the practices and policies governing the operation of weir impose flow constraints on regulated water delivery. These operational practices are closely tied to the channel characteristics defining the Barmah Choke. The channel capacity immediately downstream of the weir is 62,000 ML/d, but this decreases substantially when approaching the Barmah Choke.

Barmah Choke

The Barmah Choke constitutes a natural narrowing and reduction of channel capacity of the River Murray upstream of Barmah caused by the Cadell Fault, such that river flows greater than approximately 10,000 ML/d enter the adjacent floodplain. Inundation events caused by back-water flows which occur in this region led to the creation of the Barmah–Millewa Forest. The river splits at this location, with some flow (and most flow during high flow periods) passing north into the Edward River. In very high flow events, the volume of water passing through the Edward-Wakool system (including through several important flood runners to the north of the Murray) can be up to five times greater than that flowing through the main channel of the River Murray downstream of the Barmah Choke. As a result, flows at Barmah on the River Murray downstream of the Choke rarely exceed 60,000 ML/d, irrespective of the flow upstream.

The operation of Yarrawonga Weir is directly related to the flow constraint caused by the Barmah Choke. During summer regulated periods, releases from Yarrawonga Weir are limited to 10,600 ML/d to minimise losses (flows above this threshold will exceed the downstream channel capacity due to the Barmah Choke) and to minimise summer inundation of Barmah–Millewa Forest, which can have a negative impact on the conditions required for the forest to remain healthy.

The Barmah Choke is a natural feature of the river which can impede the delivery of water to downstream sites if it is inappropriate to flood the forest at that time. However the operational considerations associated with Yarrawonga Weir form the main constraint in this region. River operations have not sought to deliberately increase flows above about 18,000 ML/d. Regulated operations aim to keep flows within bank to minimise ‘losses’ and summer flooding of the forest, whilst environmental releases to date have aimed to fill gaps between events, and/or extend the duration of events to allow bird breeding events to be completed. Significant environmental benefits could be obtained by deliberately increasing peak flows and volumes through this part of the river system particularly over the winter/spring period. Whilst high flows may occur as a result of unregulated inflows from the Kiewa and Ovens Rivers upstream, there is no precedent to deliberately create such high flows. Flows greater than 18,000 ML/d downstream of the weir are understood to affect access to private land-holdings and/or inundate private property along the River Murray and Edward-Wakool Systems. This constraint will require resolution before peaks can be deliberately increased.

In summary, Barmah Choke is a natural feature of the River Murray which constrains flow from the Upper Murray to downstream reaches of the river. The Barmah-Millewa forest exists as a result of the flooding that occurred under natural conditions. In the context of this report, which is concerned with identifying constraints to environmental water delivery specifically, Barmah Choke is not considered a priority constraint to environmental water delivery due to its close association with overbank events in the Barmah–Millewa Forest.

Torrumbarry Weir

The pool formed by the Torrumbarry Weir allows water to be diverted for consumptive use; approximately 500 GL of water is supplied to the Torrumbarry Irrigation Area each year via the National Channel. This channel diverts water to Gunbower Creek (see below) and several

Victorian Mid-Murray off-river storages including Kow Swamp, Lake Boga and Kangaroo Lake. Environmental works are also being constructed to divert up to 6,000 ML/d from the Torrumbarry weir north into the Koondrook-Perricoota Forests. When running at capacity, this will be the second largest diversion point on the River Murray. Torrumbarry Weir also provides water for the Kerang Lakes, an internationally-recognised wetland and a significant regional tourism and recreational facility. The original Torrumbarry Weir was completed in 1924, however the detection of a significant leak in 1992 led to the construction of a new weir, completed in 1996.

Flows to the Gunbower-Koondrook-Perricoota Forest are measured downstream of Torrumbarry Weir. The release capacity of the weir itself is not believed to be a constraint to environmental flow delivery, however potential inundation of private land downstream of the weir may limit operational scope to increase peak flows for environmental purposes. There is no precedent for this style of operation. The minor flood level downstream of the weir is approximately 39,000 ML/d, and the moderate flood level is approximately 48,000 ML/d. A detailed study of the private land inundation patterns in this river reach is required to fully determine potential flow constraints.

Gunbower Creek

Gunbower Creek receives water from the National Channel and is predominantly used to deliver water for irrigation purposes. Regulated flows can also be delivered to Gunbower Forest through Gunbower Creek, which is regulated by a series of structures (including, in the future, through the proposed Hipwell Road environmental scheme which is under construction). Flows in this region are limited to the local channel capacity (1,600 ML/d).

Under current arrangements, environmental water does not have guaranteed access to the channel, and hence must rely on spare channel capacity (which is determined by the level of irrigation demand). An analysis of MDBA modelling data (Cooling & SKM 2012) indicates that substantial channel capacity is generally available during winter/spring, when environmental requirements are expected to be highest.

Other Physical and Operational Constraints

Constraints within tributaries of the Mid-Murray, particularly the Goulburn River, also influence the ability to achieve desirable environmental outcomes in this region and further downstream. Release rates from Eildon Dam are constrained by maximum regulated flow levels at Seymour (12,000 ML/d) and Trawool (18,000 ML/d) to avoid inundation of private land. These will act in combination with constraints on the River Murray to limit the delivery potential of environmental flows. Constraints in the Victorian catchments are detailed separately in Section 5.

Flows in the Murray are also restricted by operational rules that regulate the release of salts from (primarily) the Loddon, but also to some extent the Campaspe. It is unclear how much of an impact these rules would have on environmental flow delivery, so further work will be required over the coming months.

4.2.2 Representation of Constraints in the Hydrological Model

Within the Mid-Murray section of the MSM-BIGMOD model, irrigation delivery and inundation control downstream of Yarrawonga Weir are modelled via a series of maximum release rates from the Weir, to represent the summer and autumn-winter-spring operational practice. The 10,000 ML/d flow limit at the Barmah–Millewa Forest is modelled as an additional loss into the forest if flows occur above this level. In summer, the model prevents regulated releases above 10,600 ML/d after the 15th December. The Gunbower Creek channel capacity is modelled at 1,650 ML/d, and is only used to deliver environmental water to the Gunbower Forest when required.

4.2.3 Environmental Flows Affected by Constraints

Environmental water requirements associated with mid to high-flows have been identified in the Mid-Murray Region at two hydrological indicator sites:

- Barmah–Millewa Forest (MDBA 2012a),
- Gunbower-Koondrook-Perricoota Forest (MDBA 2012f).

The delivery of some of the flow requirements at each site is impeded by existing flow constraints described below.

Barmah–Millewa Forest

The Barmah–Millewa Forest is located downstream of Yarrawonga Weir and covers approximately 66,000 ha of floodplain along the River Murray. It is listed as a Ramsar wetland and is recognised as an important environmental site by both The Living Murray (TLM) and Basin Plan programs.

The environmental water requirements at this site are associated with flows between 12,500 ML/d and 60,000 ML/d measured downstream of Yarrawonga Weir. Existing flow constraints (primarily those downstream of Yarrawonga Weir discussed above, and at Doctor's Point in the Upper Murray; Section 4.1) are not expected to impede the delivery of events with a flow less than 20,000 ML/d. At the high end of the flow regime, flows of 50,000 and 60,000 ML/d are classified as beyond regulation capacity based on the constraint at Doctor's Point. Delivering short-term events of this magnitude can be achieved by supplementing a large inflow event from the Kiewa and/or Ovens Rivers, however this cannot be maintained for the desired durations of 21 and 14 days respectively. These events are therefore dependent on large unregulated inflows. To a lesser degree system constraints are expected to affect the delivery of events with a peak flow between 25,000 and 35,000 ML/d (marked yellow in Table 7).

This conclusion is supported by Basin Plan modelling (MDBA 2012y,z), which indicates that a relaxation of the Doctor's Point and Yarrawonga Weir constraints can improve the environmental benefits at this site. As described in the Barmah Choke section above, the effects of relaxing these constraints in practice requires further study, particularly those associated with potential flooding of private land in the Mid-Murray and Edward-Wakool regions. In many cases these impacts are limited to elevated water levels in channel resulting in impeded access rather than inundation of arable land.

Table 7: Ecological targets for the Barmah–Millewa Forest (MDBA 2012a), and the degree to which they can be achieved under current constraints and operational practice

Site-specific ecological targets	Site-specific flow indicators (flow measured downstream Yarrawonga Weir)
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	Achievable under current operating conditions • 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 Achievable under some conditions (constraints limit delivery at some times) • 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 Difficult to influence achievement under most conditions (constraints limit delivery at most times) • 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 Achievable under current operating conditions • 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

Both sections of the Barmah–Millewa Forest include a series of regulators which can control the volume of water passing through forest inlet streams, but only for flows up to 10,600 ML/d downstream of Yarrawonga Weir (i.e. the summer regulated flow limit). For example, the commence-to-flow threshold for Toupna Creek is 3,500 ML/d. Closing the Mary Ada regulator raises this threshold to 10,600 ML/d. These inlet regulators limit the passage of water to the main channels (i.e. River Murray, Edward River, and Gulpa Creek) during summer regulated periods. They therefore have dual benefits:

- Minimise the probability of frequent summer inundation of the forest, which can have a deleterious effect on vegetation health, and
- Improve the efficiency of regulated water delivery through the Barmah Choke and Millewa Forest during summer months by reducing overbank losses.

The seasonality of the environmental watering requirements listed in Table 7 suggests these regulators could be kept open from June to November in some years to maximise environmental outcomes. This would be a change to current river operating practices and the subsequent effects are not clearly understood and would require further analysis.

Gunbower-Koondrook-Perricoota Forest

Downstream of the Barmah Choke and Torrumbarry Weir there are numerous flood runners and limited channel capacity, resulting in significant overbank flows into the Gunbower-Koondrook-Perricoota Forest. This is an important environmental asset recognised by both TLM and Basin Plan, and is a Ramsar Wetland of International Importance. The forest has an area of approximately 51,000 ha. There are various regulators and effluent creeks which allow water to enter the Koondrook-Perricoota Forest (in NSW) when flow exceeds approximately 18,000 ML/d downstream of Torrumbarry Weir, and the Gunbower Forest (in Victoria) when the flow exceeds 15,000 ML/d downstream of Torrumbarry Weir. These are reflected in the requirements listed in Table 8 (see MDBA 2012f for a complete description).

Table 8: Ecological targets for the Gunbower-Koondrook-Perricoota Forest (MDBA 2012f), and the degree to which they can be achieved under current constraints and operational practice

Site-specific ecological targets	Site-specific flow indicators (flow measured downstream Torrumbarry Weir)
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 and invertebrates) Provide a flow regime which supports key ecosystem functions, particularly those related to connectivity between the river and the floodplain	Achievable under current operating conditions • 16,000 ML/d for a total duration of 90 days (with a minimum duration of 7 consecutive days) between June & November for 70% of years • 20,000 ML/d for a total duration of 60 days (with a minimum duration of 7 consecutive days) between June & November for 60% of years • 20,000 ML/d for a total duration of 150 days (with a minimum duration of 7 consecutive days) between June & December for 30% of years Achievable under some conditions (constraints limit delivery at some times) • 30,000 ML/d for a total duration of 60 days (with a minimum duration of 7 consecutive days) between June & May for 33% of years • 40,000 ML/d for a total duration of 60 days (with a minimum duration of 7 consecutive days) between June & May for 25% of years

The Barmah Choke, upstream of Gunbower, limits the flow which can be delivered through the River Murray alone. Under both natural conditions and existing water sharing arrangements many of the desired environmental events are greatly dependent on flows from the Goulburn River tributary, which joins the River Murray downstream of the Barmah Choke. In addition to flow constraints in the River Murray, similar constraints in the Goulburn River also limit environmental water delivery to the Gunbower-Koondrook-Perricoota Forest. Flows of 16,000 and 20,000 ML/d can be delivered within existing Goulburn River constraints when combining both Murray and Goulburn flows together (Section 5.1), and these are therefore marked blue in Table 8.

The delivery of higher flow events (30,000 and 40,000 ML/d for 60 days; marked yellow in Table 8) is limited by flow constraints. The natural narrowing and reduction of channel capacity of the River Murray associated with the Barmah Choke significantly increases floodplain losses and pushes flows north into the Edward-Wakool river system when flows exceed 10,000 ML/d. Existing constraints in the Goulburn River (Section 5.1) limit flows into the River Murray. Due to the combination of these two constraints, 30,000 ML/d events are near the upper limit of event delivery under existing constraints and the maintenance of these flows over a 60 day period is extremely difficult to achieve. The 40,000 ML/d events are beyond the current limits of regulated flow. MDBA modelling suggests that the relaxation of key constraints in the Upper Murray is expected to improve the delivery of events associated with those indicators marked in yellow (MDBA 2012z).

Torrumbarry Weir does not represent an impediment to the delivery of environmental water. In the absence of a high-flow event, the weir can be used to divert water for environmental use. This is important for parts of both Koondrook-Perricoota Forest and Gunbower Forest. Flood enhancement works will use environmental water to inundate parts of Koondrook-Perricoota Forest during periods of regulated flow without raising the water level in the River Murray above the local channel capacity. Gunbower Forest watering utilises the water from the weir distributed through the National Channel, Gunbower Creek, and the Hipwell Road Scheme. This type of environmental watering contributes to environmental outcomes.

The channel capacity of Gunbower Creek may provide a minor constraint to environmental delivery. The rate at which environmental water can be passed through this channel depends on irrigation demand. This demand is generally low during the winter/spring period when environmental demands would be high (Table 8).

If upstream flow constraints were overcome, the success of environmental events would often rely on combining environmental releases from Hume Dam and/or Eildon Dam in the headwaters of the Goulburn system, and higher flow unregulated events from the Ovens River and/or Kiewa River. Environmental outcomes would be maximised when the timing of environmental releases is coordinated to ensure the peak flows from multiple sources coincide. The travel time of high-flow events is subject to a greater uncertainty than low-to-mid flows. The capacity to achieve this level of coordination is not yet known and further work is required to both assess the impacts on private land, and verify if this degree of operational coordination is possible from a governance perspective.

4.2.4 Summary

Table 9 below summarises the key constraints in the Mid-Murray region and their importance in the efficient delivery of environmental water for downstream use.

Table 9: Summary of Mid-Murray constraints, where constraints have been classified in terms of their capacity to limit flows

Location	Constraint Description	Flow Constraint (ML/d)	Inhibits Environmental Flow Delivery?
Below Yarrawonga Weir and Barmah Choke	Irrigation delivery and downstream inundation control	10,000 – 18,000	Yes
Torrumbarry Weir	Supply of National Channel	4,000	No

4.3 Edward-Wakool River System

The Edward-Wakool River System is a major anabranch and floodplain of the River Murray. The system consists of a complex network of inter-connecting rivers, creeks, floodrunners and wetlands, and covers more than 1,000 square kilometres northward of the main River Murray channel. Included in this region is the Ramsar-listed Werai Forest, which comprises the greatest extent of river red gum forest and woodlands in the system, and hosts waterbird breeding events. During regulated periods, the delivery of flow the Werai Forest is controlled using a number of smaller regulators on the forest inlets. The Edward-Wakool River System has been recognised as an important environmental asset within the Basin Plan (MDBA 2012d).

The region includes the townships of Deniliquin, Neimur and Moulamein. The main regulating structures in the system are Stevens Weir, located on the Edward River downstream of Colligen Creek as well as the Edward River offtake, Edward escape and Gulpa offtake. Stevens Weir allows increased flows through Colligen Creek, which then supplies water to users in the Wakool Irrigation District through the Wakool Main Channel (CSIRO 2008j). The Edward-Wakool system also includes Murray Irrigation Limited water users supplied through the Mulwala Canal from the River Murray upstream of Yarrawonga Weir.

The hydrology of this system is complex. During regulated periods, water is supplied to this system from the River Murray through the Edward River and Gulpa Creek (passing through Barmah–Millewa Forest). Water from the Mulwala Canal can re-join the natural river system through a series of ‘escapes’ — during periods when channel capacity is available, MDBA River Operations use the Mulwala Canal to bypass the Barmah Choke to increase the volume and efficiency of water delivery to the Edward-Wakool system and sometimes further downstream. The Edward-Wakool system also receives flows from the River Murray through effluent streams between Barham and Swan Hill, and water is passed from the Murrumbidgee catchment through Billabong Creek.

During periods of higher flow, the Edward-Wakool system receives additional water through overbank flows in the Millewa Forest, and Native Dog, Tuppal and Bullatale Creeks located north-east of the forest. Effluent flows from the River Murray (discussed in the paragraph above) increase during these periods, passing additional water to the Wakool River. The Tuppal and Bullatale Creeks flow from the Murray downstream of Tocumwal, north towards Deniliquin, meeting the Edward River upstream (South) of Deniliquin.

Some levee-banks protecting privately owned arable land are believed to have overtopped, or failed, when natural flood flows in the River Murray have exceeded 100,000 ML/d at Tocumwal. At most times, the Edward-Wakool system carries lower volumes of water than the main River Murray channel to the south, however these roles are reversed during periods of higher flow, when flow rates in the Edward-Wakool system can be up to five times greater than those in the River Murray.

Parts of the Edward-Wakool ecosystem rely on these relatively high flows, and at times long durations, to inundate flood-dependent vegetation and provide conditions conducive to colonial waterbird breeding events. The active management of some of these environmental flows is limited by existing system constraints, as outlined in Figure 10.

The primary constraints inhibiting environmental flow delivery to the Edward-Wakool system are:

- Upstream constraints at Doctor's Point and Yarrawonga Weir (described in Sections 4.1 and 4.2 respectively),
- Channel constraints limiting flow from the main channel of the River Murray to the Edward-Wakool system (during periods when flooding is not occurring in the Barmah–Millewa Forest).
- Access issues, in terms of crossing the Bullatale Creek, at flows greater than approximately 18,000 ML/d at Tocumwal.
- It is understood broader inundation occurs above 80,000 ML/d at Tocumwal. However additional work is required to investigate the effects of flows in the range 18,000 to 80,000 ML/d.
- These issues are recognised but require further investigation and consultation.

The effects of any changes to these constraints, including those in upstream regions, would need to be further investigated through the Constraints Management Strategy before any changes are made.

4.3.1 Key Structures and Flow Constraints

Upstream Constraints

A description of the constraints in the River Murray upstream of this reach can be found in Sections 4.1 and 4.2. In summary, the main constraints limiting environmental flow delivery are located at Doctor's Point in the Upper Murray (maximum flow of 25,000 ML/d) and downstream of Yarrawonga Weir in the Mid-Murray (flow limited to 10,600 ML/d during regulated summer periods). Operators may choose to limit flows from Yarrawonga Weir through Tocumwal to 18,000 ML/d due to access issues in the Bullatale Creek, and potential tourism effects related to the Tocumwal Beaches and other sites.

River Murray to Edward-Wakool — Millewa Forest Channel Constraints

Downstream of Yarrawonga Weir, the River Murray splits into two main sections passing through Barmah–Millewa Forest. The main channel continues southward (through the Barmah Choke), while the northward section defines the Edward-Wakool River system (Figure 10). Northern flows pass through the Millewa Forest, a complex system of creeks and floodrunners, each with a relatively small channel capacity.

During regulated periods, water is carried northward by the Edward River and Gulpa Creek, with a combined maximum offtake capacity of 2,010 ML/d (comprised of 1,660 ML/d for the Edward River, and 350 ML/d for Gulpa Creek). This upper limit represents an operational constraint based on the capacity of the two channels; flows greater than these would inundate sections of the Millewa Forest. The forest is preferentially kept dry during the January– May period when flooding can have a negative impact on vegetation health, hence directing greater flows through the forest in these months is avoided when possible. This, however, is generally not a constraint to delivering environmental water to the Edward-Wakool system, as the environmental water requirements identified for this system are based predominantly on winter/spring events (MDBA 2012d).

During non-summer months, the northward flow can be increased by allowing greater flows through Yarrawonga Weir. Some of this water will then pass northward through multiple channels, with an associated inundation of Barmah–Millewa Forest. These channels are:

- Edward River and Gulpa Creek
- Other Millewa Forest creeks
- 'Bypass creeks' — effluent creeks leaving the River Murray upstream of the Edwards River, bypassing the Millewa forest (such as Native Dog, Bullatale and Tuppal Creeks).

As described above, Edward River and Gulpa Creek are regulated. Opening the regulators allows flows significantly greater than 2,010 ML/d to be passed through these channels. The commence-to-flow thresholds (measured downstream of Yarrawonga Weir) for the remaining creeks passing through Millewa Forest are in the range of 3,500 – 6,000 ML/d (if their regulators are open) or approximately 10,500 ML/d (if their regulators are closed). Additional regulated water can therefore be passed through these Millewa Forest creeks during non-summer months to inundate Millewa Forest and deliver additional water to the Edward-Wakool system. The capacity to pass water through the bypass creeks is limited by existing upstream constraints, including those at Doctor's Point and Yarrawonga Weir.

Mulwala Canal

Under current operating practices MDBA is able to deliver additional water to the Edward-Wakool system through the Mulwala Canal, the property of Murray Irrigation Limited (MIL). Water is currently passed through the canal (under agreement with MIL) if there are capacity constraints elsewhere. The canal has an offtake capacity of 10,000 ML/d, and leaves the River Murray from Lake Mulwala upstream of Yarrawonga Weir to deliver water to MIL licenced entitlement holders. If unused, some of this water enters the Edward-Wakool River system through a series of escapes. The largest of these is the Edward Escape near Deniliquin, which has a capacity of 2,400 ML/d.

The majority of the Mulwala Canal capacity is utilised for irrigation purposes during summer months, but does not operate at capacity at other times of the year. An analysis of MDBA modelling data (Hale & SKM 2011) indicates that the canal will have spare capacity well in excess of the Edward Escape capacity in most years, especially during winter/spring. The environmental water requirements identified for the Edward-Wakool system are based pre-dominantly on winter/spring events (MDBA 2012d) hence the canal is not a significant constraint to environmental water delivery. The use of this canal for environmental watering purposes would be subject to the agreement of MIL, and would be subject to existing canal operating practices. This irrigation system is currently not in operation during winter.

Constraints in the Edward-Wakool System

The main regulating structure within the Edward-Wakool system is Steven's Weir, which also allows flows to be regulated in the Wakool River and Yallakool Creek. The discharge capacity of the weir itself does not represent a constraint to environmental flows downstream of the weir. Flows above 2,700 ML/d will overtop the Werai regulators located further downstream. During higher flow periods, the weir gates can be fully opened to avoid structural damage, and the flows will overflow the downstream regulators and inundate Werai Forest.

Steven's Weir pool is drained annually at the end of the regulated season (late autumn, generally from 1–15 May until 1–15 July) to allow maintenance works and fish migration, and to provide a more natural wetting and drying cycle to maintain riparian health. However, this practice is not expected to be a constraint to environmental water delivery to the Edward-Wakool system — this annual draining cycle can be coordinated with future environmental water delivery.

There are a number of small regulators in the Edward-Wakool system (for example, those located at inlet locations to the Werai Forest). These are designed to minimise inundation events when they would have a negative impact on the conditions required for the vegetation to remain healthy, and to more efficiently pass regulated flows. Structurally, these are not a constraint to environmental water delivery, as they are opened during high flow events.

The flow in some channels may exceed bankfull capacity during a large environmental flow event, causing low-level road crossings to be overtopped (preventing access for local landholders), or private land may be inundated at higher flows (MDBA 2010; Hale & SKM 2011). These issues need further investigation. Specifically, the waterways affected and current understanding of some of the issues include:

- Colligen Creek (regulated summer flow of 170 ML/d. A flow greater than 500 ML/d can cause low-level flooding in low-lying areas in the Niemur River downstream of Moulamein Road, and flows greater than 800 ML/d can inundate surrounding areas).
- Wakool River, supplemented by flows from the Wakool Offtake (regulated capacity of 150 ML/d) from Steven's Weir Pool, and the Wakool escape (capacity 500 ML/d) from Mulwala Canal. Flows in the Wakool River greater than 200 – 300 ML/d can cause third-party impacts.
- Yallakool Creek (capacity of 600 ML/d, but third-party impacts at flows greater than 200 ML/d).

The frequency and duration of these higher flow events would be affected by an alteration to the frequency and duration of high flow events upstream at Yarrawonga Weir. These effects, as a function of flow, are yet to be quantified. The minor flood level at Deniliquin corresponds to a flow of approximately 17,100 ML/d in the Edward River or about 55,000 ML/d in the Murray downstream of Yarrawonga Weir. Flows above this threshold would be anticipated to have progressively greater third-party impacts.

4.3.2 Representation of Constraints in the Hydrological Model

The flows at Deniliquin are dependent on flows from the Edward Escape and offtake as well as the River Murray. The combined capacity of the Edward Escape and other nearby escapes is in the range of 2,720 – 3,020 ML/d, with flows into the offtake dependent on main river flows.

For the Edward River effluent creeks, the Wakool River, Yallakool River and Colligen Creek are all modelled with various maximum flow capacities, one for each month of the year. Mulwala Canal is modelled with a maximum channel capacity of approximately 10,000 ML/d.

The Millewa Forest regulators are modelled to represent operational practise in that regulator settings are changed depending on the flows in the River Murray and whether or not the Barmah–Millewa Forest Environmental Water Allowance (EWA) is in operation. The Steven's Weir Pool (and the operational practise of draining it in the winter) is not simulated in the model.

4.3.3 Environmental Flows Affected by Constraints

Under the ESLT framework, environmental flows for the Edward-Wakool River system are measured on the Edward River at Deniliquin. The environmental water requirements identified as part of the development of the Basin Plan (MDBA 2012d) are summarised in Table 10. All flow events identified in this table are likely to require the associated inundation of Barmah-Millewa Forest to be achieved. The delivery of flow events of 18,000 ML/d at Deniliquin is impeded by existing constraints at some times, and the largest environmental flow events (30,000 ML/d at Deniliquin) are considered to be beyond regulating capacity (marked brown).

Table 10: Ecological targets for the Edward-Wakool System (MDBA 2012d), and the degree to which they can be achieved under current constraints and operational practice

Site-specific ecological targets	Site-specific flow indicators (flow measured at Deniliquin)
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 a range of native aquatic species (e.g. fish, frogs, turtles and invertebrates) Provide a flow regime which supports key ecosystem functions, particularly those related to connectivity between the river and the floodplain	Achievable under current operating conditions • 1,500 ML/d for a total duration of 180 days (with a minimum duration of 1 consecutive day) days between June & March for 99% of years • 5,000 ML/d for a total duration of 60 days (with a minimum duration of 7 consecutive days) days between June & December for 60% of years • 5,000 ML/d for a total of 120 days (with a minimum duration of 7 consecutive days) between June & December for 35% of years Achievable under some conditions (constraints limit delivery at some times) • 18,000 ML/d for a total of 28 days (with a minimum duration of 5 consecutive days) between June & December for 25% of years Difficult to influence achievement under most conditions (constraints limit delivery at most times) • 30,000 ML/d for a total of 21 days (with a minimum duration of 6 consecutive days) between June & December for 17% of years

The Doctor's Point constraint is an important impediment to achieving mid-to-high flow environmental events in the Edward-Wakool system. However, if this constraint was adjusted to allow increased flows during some periods, other flow constraints would become increasingly important. For example:

- Delivering increased flows could lead to water passing through the effluent streams upstream of the Millewa Forest (specifically Native Dog and possibly Bullatale Creeks, amongst others), and water flowing from the River Murray between Barham and Swan Hill. Third party impacts (in terms of property access and flooding of private land) are yet to be determined, and will likely impose other flow constraints that will need to be addressed.
- A portion of the desired flow could be passed through Mulwala Canal, if spare capacity exists. Bypassing the Millewa Forest, the canal can contribute (at most) 3,000 ML/d to

the Edward-Wakool System, mainly through the Edward Escape (capacity 2,400 ML/d) which joins the Edward River just upstream of Deniliquin. This option could be used to reduce third-party impacts along the effluent streams surrounding the Barmah Choke, however coordinating water delivery from the canal to coincide with the peak flow in the main channel introduces a timing constraint.

- The minor flood level at Deniliquin corresponds to a flow of 17,100 ML/d.

Furthermore, delivering 18,000 ML/d environmental events to the Edward-Wakool system would first require the capacity of the Barmah Choke to be exceeded, inundating the surrounding area. Therefore the delivery of a high flow event in the Edward-Wakool system must coincide with the delivery of a similar event to the Barmah–Millewa Forest (requiring the Millewa regulators to be open).

4.3.4 Summary

Table 11 below summarises the key constraints in the Edward-Wakool region and their importance in the efficient delivery of environmental water for downstream use.

Table 11: Summary of Mid-Murray constraints, where constraints have been classified in terms of their capacity to limit flows

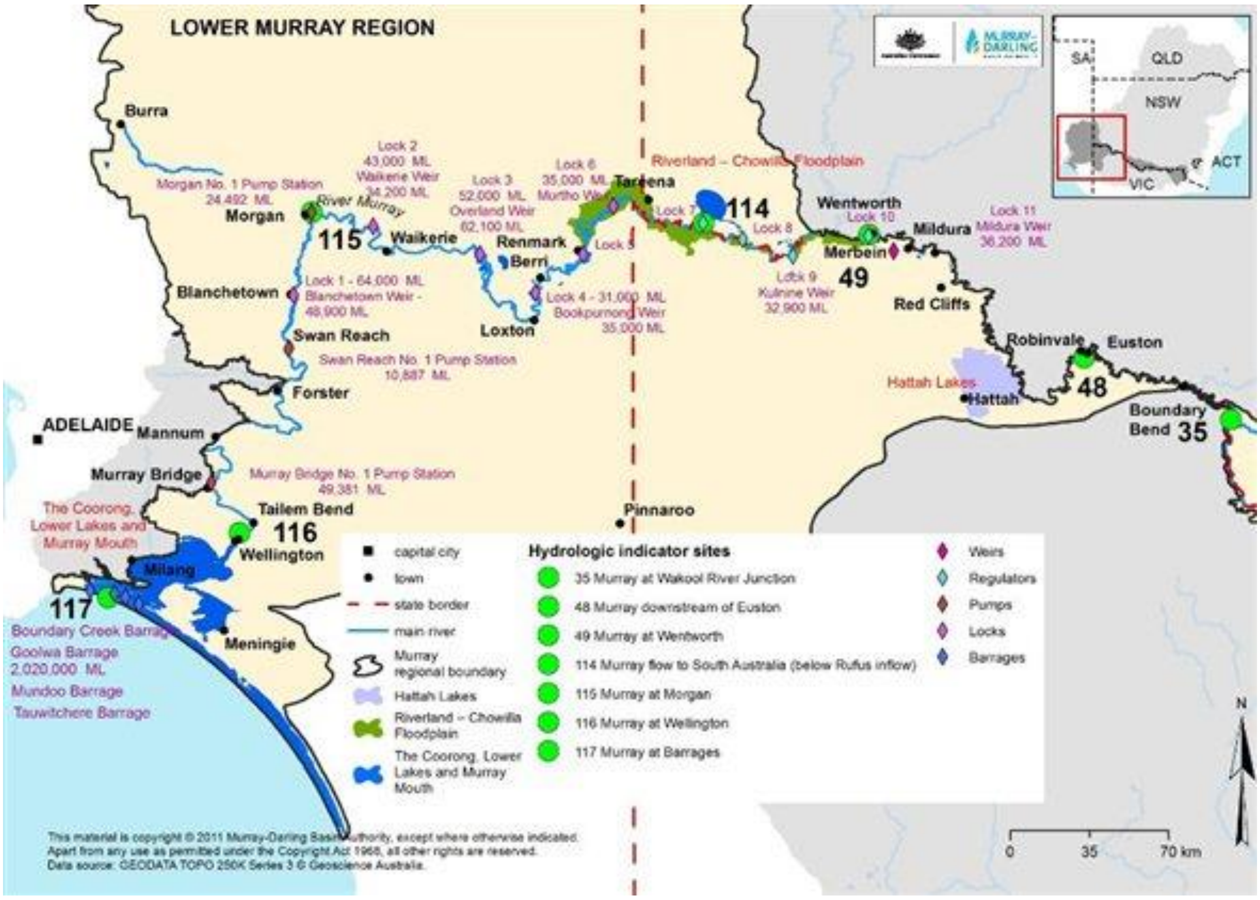
Location	Constraint Description	Flow Constraint (ML/d)	Inhibits Environmental Flow Delivery?
Yarrawonga Weir	Irrigation delivery and downstream inundation control	10,000 – 18,000	Yes
Barmah Choke	River bifurcation and flooding	10,000	Yes
Deniliquin	Minor flood level	17,100	Yes

4.4 Lower Murray

The Lower Murray region extends from the confluence of the Wakool and River Murray and includes inflows from the Murrumbidgee near Boundary Bend and that of the Darling River at Wentworth. The Great Darling Anabranch joins the River Murray downstream of Wentworth. The Lower Murray region contains all sections of the Murray downstream of the South Australian border to its final outflow at the Murray Mouth. Basin Plan modelling indicates that the effect of constraint relaxation at the Coorong, Lower Lakes and Murray Mouth would not be substantial (MDBA 2012z).

A map of the region can be found in Figure 11, and a schematic diagram showing key constraints, structural features, and environmental assets can be found in Figure 12. This section of the River Murray includes Lake Victoria, a small, but important off-river flow re-regulation structure used to guarantee supply for South Australian consumptive and environmental purposes.

Figure 11: The extent and main features of the Lower Murray region, from the confluence of the Murrumbidgee River near Boundary Bend to the Murray Mouth



The region includes two hydrological indicator sites with associated overbank environmental water requirements which are affected by constraints, namely:

- Hattah Lakes (MDBA 2012h), flows measured downstream of Euston Weir (HIS 48 in Figure 11).
- Riverland–Chowilla Floodplain (MDBA 2012v), flows measured at the South Australian border (HIS 114 in Figure 11)

These environmental assets are comprised of ecosystems reliant on relatively high flows to inundate flood-dependent vegetation and provide conditions conducive to colonial waterbird breeding events. The delivery of some of these environmental flows is limited by existing system constraints, both in upstream catchments and in the Lower Murray system. Flow constraints in the upstream catchments are discussed in the following sections:

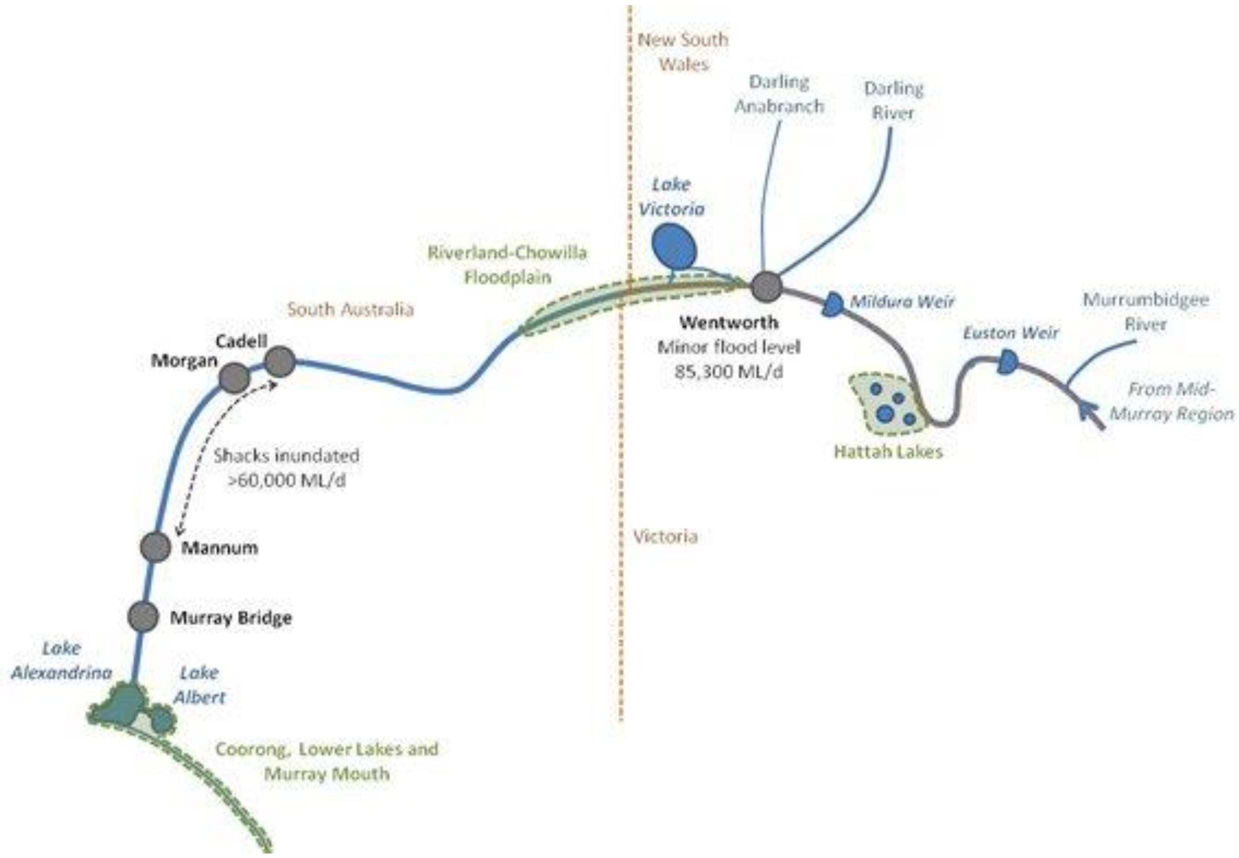
- Upper Murray (Section 4.1)
- Mid-Murray (Section 4.2)
- Edward-Wakool (Section 4.3)
- Goulburn (Section 5.1)
- Lower Darling (Section 6.1)
- Murrumbidgee (Section 6.2)

These sections describe the key physical and operational impediments to environmental flow delivery through the upstream regions, including channel capacities and storage outlet capacities, and constraints relating to the operation of structures such as dams and weirs.

Within the Lower Murray region itself, one of the key issues related to the delivery of mid-to-high flow events is the risk of inundation and reduced access (e.g. shacks) at flows above 60,000 ML/d, particularly along the lower floodplain of the Murray between Cadell and Mannum. South Australia does not expect this to be a constraint to environmental flow delivery, but recognises that the implications of more frequent higher flows need to be further investigated and appropriately managed.

The Lake Victoria Operational Strategy (designed to limit environmental damage to native vegetation and Aboriginal burial sites, and provide water supply security as a major re-regulation storage) is not expected to be a significant constraint. There may be potential to change the operation of Lake Victoria to make releases coincident with flows downstream of Wentworth, in the range of 50,000 ML/d to 70,000 ML/d which would in turn allow enhanced environmental outcomes. Such a use has been trialled previously.

Figure 12: Schematic diagram summarising the key structural features and flow constraints in the Lower Murray region



Major townships in this region include Euston, Mildura, Wentworth, Renmark and Murray Bridge, each of which have specified flood inundation levels based on local river morphology. The Lower Murray also contains 11 locks and weirs located between Blanchetown and Mildura, each of which is operated to maintain a relatively constant water level for water supply purposes, and for recreational and tourism activities. The extent and main features of the Lower Murray region are shown in Figure 11.

Table 12 presents a summary of what proportion of floodplain is occupied by either private or public land in three major reaches of the Lower Murray.

Table 12: Percentage of floodplain that is either privately or publicly owned in various reaches of the Lower Murray

Reach	% of floodplain privately owned	% of floodplain publicly owned
Murray/Wakool Junction to Wentworth	46%	54%
Wentworth to Lock 6 (u/s of Renmark)	27%	73%
Lock 6 (u/s of Renmark) to the Lower Lakes	74%	26%

4.4.1 Key Structures and Flow Constraints

Euston and Mildura Weirs

Euston and Mildura Weirs were built in the 1920s and 1930s to raise the river level at these locations for navigation and water supply purposes. Water drawn from the Euston Weir Pool supports the irrigation regions of Euston (NSW) and Robinvale (VIC), and the urban water requirements of Robinvale and Euston. Similarly, Mildura Weir provides a stable pool for diversions to Lower Murray Water's Mildura and Red Cliffs districts, and numerous private diversion customers. Both weirs include a lock for river navigation purposes (Locks 15 and 11 respectively).

Neither weir provides an impediment to environmental flows. During high flow events (greater than approximately 42,000 ML/d), the weirs are lowered or removed to avoid damage to infrastructure.

Lake Victoria

Lake Victoria is an important off-river storage on the River Murray which re-regulates flows from upstream catchments. Flows into and out of the lake (via Frenchmans Creek and Rufus River) are defined by well-established operational rules. The lake fulfils a crucial role in ensuring reliability of supply for entitlement holders. Overall, the lake is critical to the efficient management of water for South Australia, Victoria and New South Wales. Inflows and discharges are also manipulated to improve the quality of water delivered to South Australia, and large flood peaks can often be mitigated by flow diversion into the lake. As described in Section 6.4, the volumes of water stored in Lake Victoria and Menindee Lakes are managed via a series of ‘harmony’ rules.

Lake Victoria itself constitutes an environmental asset. The south-eastern corner is bordered by large areas of native vegetation, and the Lake Victoria Operating Strategy is designed to minimise the volume of stored water in the lake throughout the autumn to enhance vegetation growth and protect the lake shore (which also contains extensive Aboriginal burial sites) from erosion. During years with wetter-than-average climatic conditions, the filling of Lake Victoria for re-regulation purposes is therefore delayed for this purpose.

The release capacity from Lake Victoria is dependent on the height difference between the storage level and the Rufus River. The maximum release capacity is 8,200 ML/d. During periods of higher flow when water levels in the River Murray are elevated, there is limited capacity for the lake to provide supplementary flows (and thereby contribute to inundation watering of the Riverland–Chowilla environmental asset). There is therefore limited scope for Lake Victoria release to enhance mid-to-high flow environmental watering events.

Lake Victoria is not expected to be a constraint to environmental flow delivery. Environmental flows delivered from upstream can be allowed to bypass Lake Victoria (instead of passing through the lake), and this can be assessed on a case-by-case basis.

Inundation of Private Property in South Australia

Mid-to-high flows in the region provide important environmental outcomes. However there is some risk to inundation of private property and access at flows above 60,000 ML/d e.g. privately owned shacks. The effects of more frequent mid-to-high flow periods will need to be further investigated and adequately managed. This includes assessment of the risks of inundation and potential management options, and continuing communication of information and advice to ensure community and stakeholder awareness prior to mid-to-high flow events.

Locks 1-10

Flows in the lower section of the River Murray are regulated by a series of locks and weirs (numbered one to ten) with the first at Blanchetown and the last at Wentworth. Environmental flows are not constrained by the weirs as they can all be flexibly operated or partially removed. Also, road inundation and overtopping of infrastructure would occur during high flow events at these sites.

A number of these weirs not only create an elevated pool to provide for irrigation and navigation, recreation and tourism, but increasingly the weir pools are being used to divert water to key wetland and floodplain areas via new and proposed environmental works, as follows:

- Lock 9 — Carrs Creek – Moorna State Forrest (NSW)
- Lock 8 — Mulcra wetland and Potterwalkergee Creek
- Lock 7 — Lindsay River and Mullaroo Creek
- Lock 6 — Chowilla Floodplain
- Lock 5 — Pike River
- Lock 4 — Katarapko Creek
- Lock 3 — Banrock wetlands
- Lock 2 — Nigra Creek and Schillers lagoon

4.4.2 Representation of Constraints in the Hydrological Model

The channel capacity of the river between Cadell and Mannum (the location of the shacks) is not included in the model. The Lake Victoria inlet channel is modelled as a maximum channel capacity of 8,000 – 10,000 ML/d, with the outlet channel capacity depending on lake storage levels and the river level.

4.4.3 Environmental Flows Affected by Constraints

Environmental water requirements associated with mid-to-high flows have been identified in the Lower Murray Region at two hydrological indicator sites:

- Hattah Lakes (MDBA 2012h)
- Riverland–Chowilla Floodplain (MDBA 2012v)

The delivery of some of the identified environmental flow requirements at each site is impeded by existing flow constraints, described below.

In addition, the importance of in-channel fresh events has been identified for the Lower Murray (MDBA 2012r), while flow and salinity indicators have been specified for the Coorong, Lower Lakes, and Murray Mouth (CLLMM) wetland area (MDBA 2012w). Achieving these requirements is not expected to be significantly affected by flow constraints, as detailed below.

Hattah Lakes

The Hattah Lakes site lies downstream of Euston and contains 19 well-defined wetland basins that have historically retained water for long periods after River Murray peak flows have passed, together with surrounding vegetation communities that are inundated for shorter periods during flood events. Whilst new environmental works will provide some capacity to water the lakes with environmental water at regulated flow rates, they will not be able to fill all of the lakes, therefore inundation via overbank flow remains important. Flows in excess of 37,000 ML/d downstream of Euston Weir are required for the lakes to start filling through overbank flows (MDBA 2012h).

The desirable environmental water requirements at this site are associated with flows between 40,000 ML/d and 150,000 ML/d. Flow constraints are not expected to impede the delivery of 40,000 ML/d flows, and flow events greater than 85,000 ML/d are classified as beyond regulation capacity and therefore dependent on large unregulated flow events. System constraints are expected to affect the delivery of 50,000 and 70,000 ML/d flow events (marked yellow in Table 13). This conclusion is supported by Basin Plan modelling (MDBA 2012y), which indicates that the event delivery success rate decreases as the flow increases.

Upstream flow constraints in the River Murray (such as Doctor’s Point; Section 4.1) as well as those in the Goulburn and Murrumbidgee Rivers (Sections 5.1 and 6.2) influence the ability to deliver flows greater than 50,000 ML/d to Hattah Lakes. Further Basin Plan modelling has demonstrated that the relaxation of a few key upstream constraints improves the ability to deliver these flows and provide enhanced environmental outcomes at this site (MDBA 2012z).

However, this initial analysis targeted a limited number of flow constraints and did not address the feasibility of their alteration.

Furthermore, as described in Section 3, it is likely that the timing of environmental releases is an important factor— the successful delivery of mid-to-high flow environmental events would often rely on the combination of regulated releases from Hume Dam and substantial tributary inflow events (Senior River Operators Workshop 2012; MDBA in prep). The capacity to coordinate the timing of these releases with large tributary inflow events to maximise the associated environmental outcomes requires further investigation.

Table 13: Ecological targets for the Hattah Lakes (MDBA 2012h), and the degree to which they can be achieved under current constraints and operational practices

Site-specific ecological targets	Site-specific flow indicators (flow measured downstream Euston Weir)
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 and invertebrates) Provide a flow regime which supports key ecosystem functions, particularly those related to connectivity between the river and the floodplain	Achievable under current operating conditions • 40,000 ML/d for a total duration of 60 days (with a minimum duration of 7 consecutive days) between June & December for 40% of years Achievable under some conditions (constraints limit delivery at some times) • 50,000 ML/d for a total duration of 60 days (with a minimum duration of 7 consecutive days) between June & December for 30% of years • 70,000 ML/d for a total duration of 42 days (with a minimum duration of 7 consecutive days) between June & December for 20% of years Difficult to influence achievement under most conditions (constraints limit delivery at most times) • 85,000 ML/d for a total duration of 30 days anytime in the water year (with a minimum duration of 7 consecutive days) for 20% of years • 120,000 ML/d for a total duration of 14 days anytime in the water year (with a minimum duration of 7 consecutive days) for 14% of years • 150,000 ML/d for 7 consecutive days anytime in the water year for 10% of years

Riverland–Chowilla Floodplain

The Riverland–Chowilla Floodplain comprises the Riverland Ramsar site and The Living Murray Chowilla Floodplain and Lindsay-Wallpolla Islands icon site. The floodplain receives flows from both the Murray River including tributary inflows from the Darling River, with the largest flows occurring when both rivers are in flood. Due to flow regulation upstream, a substantial reduction in the frequency, volume and duration of overbank events has occurred, and the floodplain is now drier for periods significantly longer than those that occurred under without development conditions (MDBA 2012v). A flow of 40,000 ML/d is approximately top of bank in the region. The area of floodplain inundated rises rapidly as flows rise above this level. By 80,000 ML/d most of the floodplain covered by flood dependent vegetation is inundated.

Table 14 details the specific ecological targets for the Riverland–Chowilla Floodplain as detailed in MDBA (2012v). New environmental works will provide some capacity to water part of the floodplain at regulated flow rates, but the broader floodplain of the Lower Murray can only be inundated by overbank flows. The desirable environmental water requirements at this site are associated with flows between 40,000 and 125,000 ML/d. Similar to the Hattah Lakes site, flow events of 40,000 ML/d (30 days) are not expected to be impeded by flow constraints (marked blue in Table 14). Flows greater than 80,000 ML/d are classified as beyond regulating capacity and therefore rely on large unregulated inflow events (brown). Flow constraints are known to affect the delivery of 60,000 and 80,000 ML/d events, and long-period (90-day) 40,000 ML/d events (yellow). This conclusion is supported by Basin Plan modelling (MDBA 2012y,z), which indicates that event delivery success rate decreases as the flow increases, particularly under present operating constraints.

Table 14: Ecological targets for the Riverland–Chowilla Floodplain (MDBA 2012v), and the degree to which they can be achieved under current constraints and operational practice

Site-specific ecological targets	Site-specific flow indicators (flow measured at the South Australian Border)
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 and invertebrates) Provide a flow regime which supports key ecosystem functions, particularly those related to connectivity between the river and the floodplain	Achievable under current operating conditions • 40,000 ML/d for a total duration of 30 days (with a minimum duration of 7 consecutive days) between June & December for 50% of years Achievable under some conditions (constraints limit delivery at some times) • 40,000 ML/d for a total duration of 90 days (with a minimum duration of 7 consecutive days) between June & December for 33% of years • 60,000 ML/d for a total duration of 60 days (with a minimum duration of 7 consecutive days) between June & December for 25% of years • 80,000 ML/d for a total duration of 30 days (with a minimum duration of 7 consecutive days) anytime in the water year for 17% of years Difficult to influence achievement under most conditions (constraints limit delivery at most times) • 100,000 ML/d for a total duration of 21 days anytime in the water year for 13% of years • 125,000 ML/d for a total duration of 7 days anytime in the water year for 10% of years

Similar to Hattah Lakes, the capacity to deliver environmental flows to the Riverland–Chowilla Floodplain is influenced by flow constraints in the Upper and Mid-Murray regions, and in the Goulburn and Murrumbidgee systems. Additional flows are also received from the Darling River, which joins the Murray between the Hattah Lakes and Riverland–Chowilla Floodplain sites, hence constraints in this system also affects the delivery of mid-to-high flow events across the South Australian border.

Significant baseflow volumes can be passed from the Murrumbidgee River, however flow from this system has a limited influence on the shape of any resulting peak in the River Murray, mainly due to the natural flow attenuation properties of the Lower Murrumbidgee Floodplain. Flow constraints in the Murrumbidgee system are described in Section 6.2.

Water from the Lower Darling has the potential to substantially increase the peak and duration of a mid-to-high flow environmental event in the Riverland–Chowilla Floodplain. Environmental releases from the Menindee Lakes system could be used to supplement an existing event in the River Murray, thereby providing improved environmental outcomes as identified through a recent analysis (Senior River Operators Workshop 2012; MDBA in prep). However, these releases are subject to operational constraints based on efficiency of delivery in the Lower Darling system and commence-to-flow thresholds for the Great Darling Anabranch; releases through Weir 32 are currently limited to 9,000 ML/d (Section 6.1).

Similar to Hattah Lakes, mid-to-high flow environmental events delivered to the Riverland-Chowilla Floodplain would have the potential to exceed the 60,000 ML/d flow threshold, beyond which a number of shacks in South Australia have access and sewerage impacts. The implications of managed flows above this threshold need to be further investigated and appropriately managed.

The Coorong, Lower Lakes and Murray Mouth

The Coorong, Lower Lakes and Murray Mouth (CLLMM) are located at the end of the River Murray system, and constitute one of Australia's most important wetland areas. They support a diverse range of freshwater, estuarine and marine habitats which sustain unique ecosystems. The River Murray terminates at the Southern Ocean, having passed through Lake Alexandrina (linked to the terminal Lake Albert by a narrow channel, and collectively known as the Lower Lakes), the Coorong and the Murray Mouth. The head difference between the barrages and the Lower Lakes, influenced by both lake and tide levels, leads to highly variable flow rates into the ocean.

Whilst high flow events provide benefits to the CLLMM, the salinity, flow and water level indicators set out in the EWR report (MDBA 2012w) can mostly be achieved through the delivery of regulated or in-channel flows. Basin Plan modelling indicates that the effect of constraint relaxation on these indicators would not be substantial (MDBA 2012z). Consequently flow delivery constraints are not considered to be a significant issue in the achievement of ecological targets for this site. Lake levels (and associated salinity levels) are controlled using the barrages, and these operating strategies may need to account for future increases in mid-to-high flow environmental water delivery, although higher flows could be expected to result in more flexible operation.

Lower Murray Freshes

In addition to the environmental objectives described for the various assets in the Lower Murray, specific requirements have been set for the in-channel flows in the region, and are summarised in Table 15. Full details of the Lower Murray in-channel environmental requirements can be found in MDBA (2012r). Given the relatively low thresholds of the site-specific flow indicators, meeting these indicators and associated site-specific ecological targets is considered to be possible through mostly regulated flows.

Table 15: Ecological targets for Lower Murray in-channel flows (MDBA 2012r), and the degree to which they can be achieved under current constraints and operational practice

Site-specific ecological targets	Site-specific flow indicators (flow measured at the South Australian border)
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.	Achievable under current operating conditions • 20,000 ML/d for 60 consecutive days between August & December for 71% of years

4.4.4 Summary

Table 16 below summarises the key constraints in the Lower Murray region and their importance in achieving the delivery of environmental water.

Table 16: Summary of Lower Murray constraints, where constraints have been classified in terms of their capacity to limit flows

Location	Constraint Description	Flow Constraint	Inhibits Environmental Flow Delivery?
Euston and Mildura Weirs	Inundation controls	—	No
Locks 1-10	Local inundation controls	—	No
Floodplain structures	Inundation of private property and access (e.g. shacks and caravan parks)	60,000 ML/d	No†
Lower Lakes	Foreshore erosion and barrage head difference	—	No

†Not expected to be a constraint, but the risks of inundation for flows above this threshold need to be further investigated and appropriately managed.

5. Victoria

5.1 Goulburn-Broken

The Goulburn–Broken region forms the southern boundary of the Murray–Darling Basin, and is skirted to the north by the River Murray, the east by the Ovens region, and the west by the Campaspe region. It covers an area of 22,378 km^2 and has a population of 144,000. Major centres include Shepparton, Nagambie, Benalla, Kyabram and Tatura. The dominant land use in the region is dryland cropping and grazing, with significant irrigated dairy pasture and other horticultural crops occurring in the Shepparton–Kyabram area (CSIRO, 2008d).

The Goulburn River is a highly regulated system, located in north-central Victoria, rising in the Great Dividing Range and flowing into the River Murray upstream of Echuca. It is a major tributary of the River Murray system. A number of small tributaries (Big River, Jamieson River and Howqua River) flow into Eildon Dam the major storage in the system which has a capacity of 3,334GL. Goulburn Weir is an important mid-river regulating structure and storage on main channel. It has a storage capacity of 25.5 GL is used to divert water into the off-stream storage Waranga Basin (capacity 432 GL) and the surrounding irrigation region. Other tributaries include the Broken and Yea Rivers and Seven, Hughes and Sugarloaf Creeks.

The Broken River, the second main river in the region, forms about 25 km east of Mansfield and flows to the north through Benalla and then west to enter the Goulburn River near Shepparton. Broken Creek is a distributor of the Broken River, leaving the Broken River downstream of Benalla and joining the River Murray just upstream of Barmah.

The region includes the Lower Goulburn Floodplain, a nationally important wetland covering an area of approximately 13,000 ha. It contains a range of flood-tolerant vegetation communities such as black box, grey box, yellow box, white box and flood dependent river red gum communities (MDBA 2012n). The wetlands support important species and habitats, including a large number of colonial nesting waterbirds and a diverse native fish population.

As a result of the recent decommissioning (2009–2010) of Lake Mokoan, additional water is likely to enter the Goulburn River from the Broken River during the winter-to-spring period (Department of Sustainability and Environment 2006-2012). This is expected to partly re-instate the natural pattern of higher winter-to-spring flows and lower summer-to-autumn flows in the lower Goulburn River.

The effect of relaxing constraints in the Goulburn system would be twofold. First, there would be in-valley benefits to the lower Goulburn River Floodplain, which begins downstream of Goulburn Weir and is important at a regional scale. Second, increased environmental watering capacity in the Goulburn Valley would contribute to the watering of important Murray River sites located downstream of the Goulburn–Murray confluence, such as Hattah Lakes, the Ramsar-listed Gunbower Forest, and other environmental assets.

Figure 13: The extent and main features of the Goulburn-Broken region

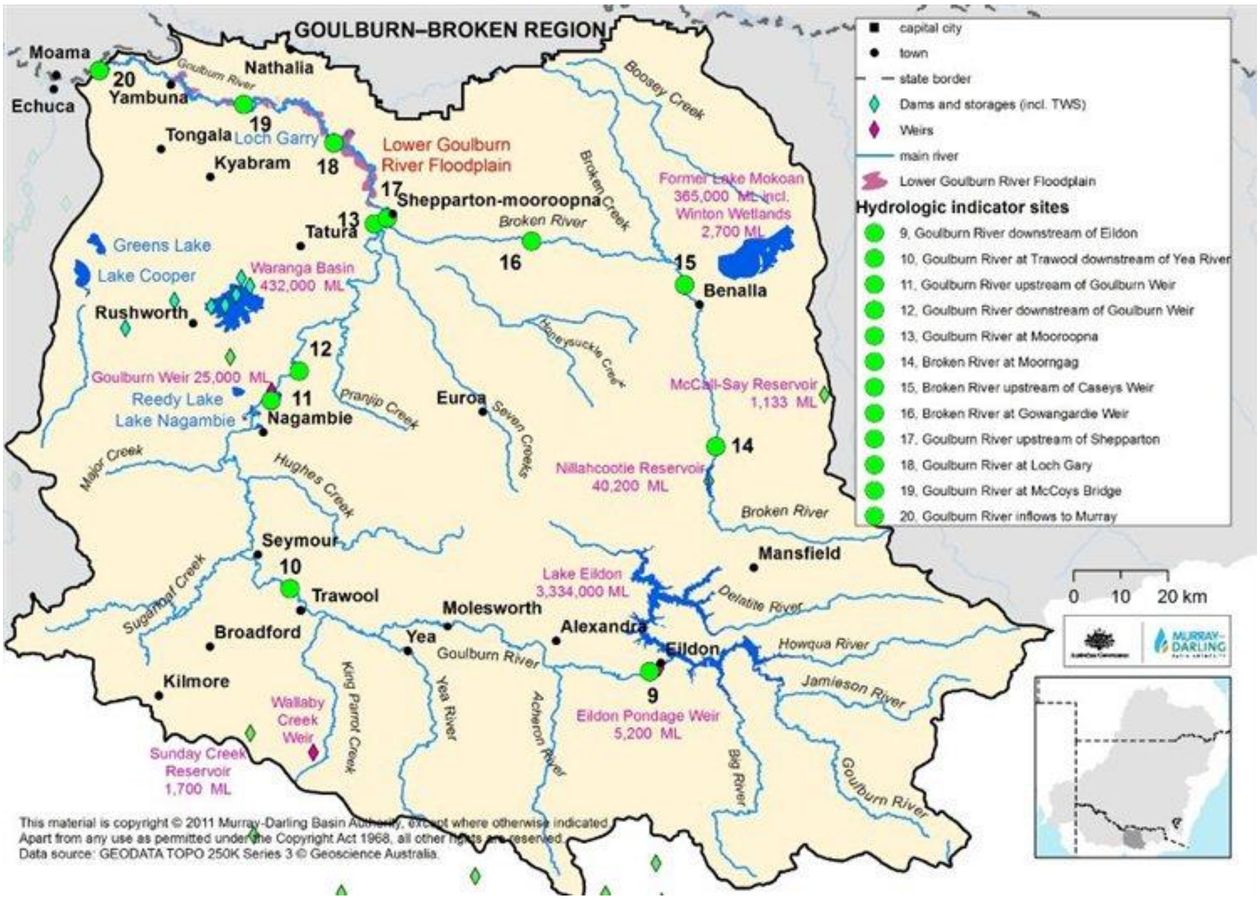
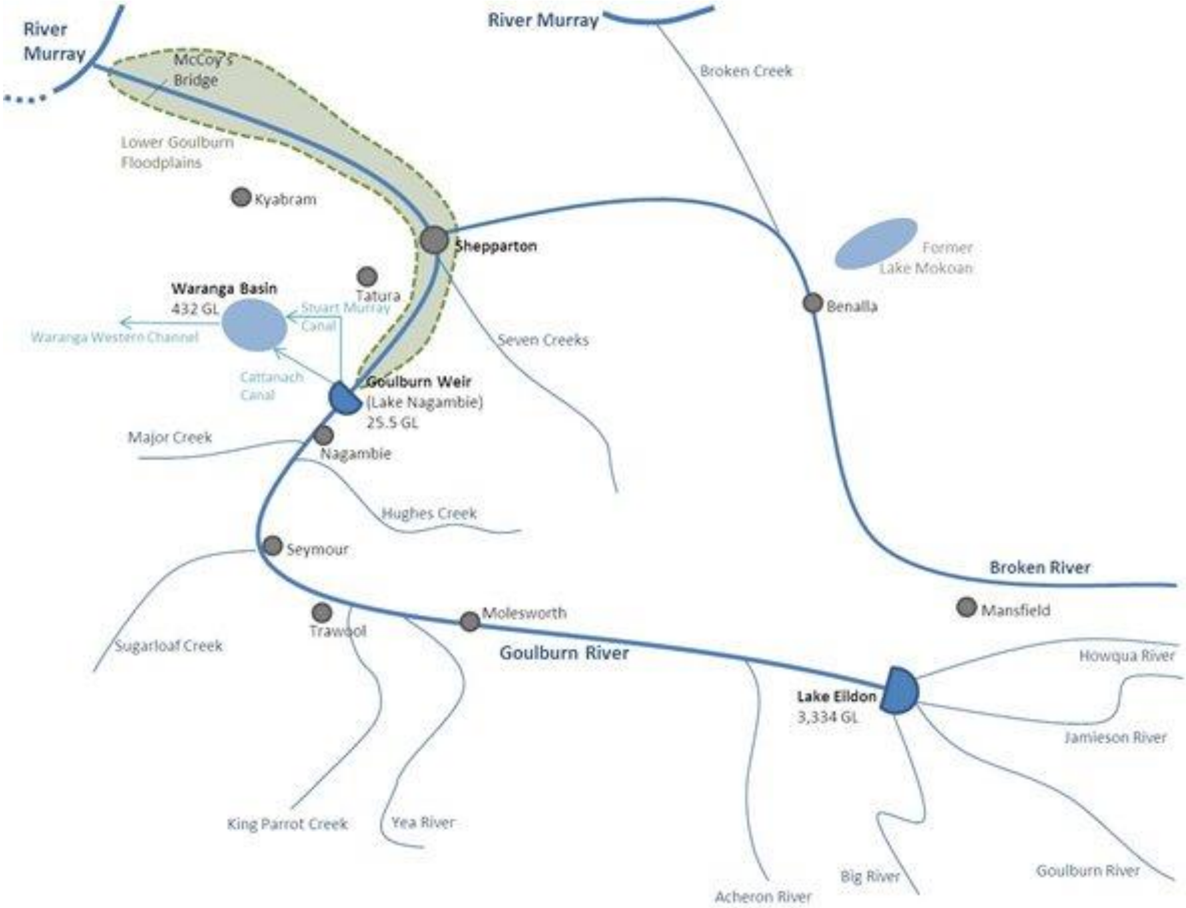


Figure 14: Schematic diagram summarising the key features and flow constraints of the Goulburn River



A summary list of the flow constraints in the Goulburn River is presented in Table 17. First order constraints represent the primary impediments to the delivery of mid-to-high flow environmental events. If these constraints were overcome, the 2nd order grouping contains the next set of constraints that would potentially limit environmental water. A full investigation is required to determine the extent and flow at which these take effect. The 3rd order grouping contains relatively minor flow constraints which could be overcome through a change to existing operational policy, or a practiced coordination between environmental and irrigation water delivery. These constraints are more fully described in the subsections below. No 2nd or 3rd order constraints have been identified for the Goulburn River by this study.

Table 17: A list of key constraints limiting environmental flow delivery in the Goulburn River, where constraints have been classified in terms of their capacity to limit flows

Order	Location	Description	Flow Limit (ML/d)
1st	Eildon Dam	Release rate based on inundation of private property and access at Molesworth	9,500
	Shepparton	Release rate based on inundation of property and access, and minor flood level at Shepparton	26,000
	Eildon Dam and Goulburn Weir	Timing (ability to coincide environmental releases from storage with large unregulated inflow events)	—
2nd	To be identified		
3rd	To be identified		

5.1.1 Key Structures and Flow Constraints

Eildon Dam

Eildon Dam was built between 1915 and 1929, expanded in 1935, and expanded again between 1951 and 1955. The dam contains the second largest water storage in Victoria, with a capacity of 3,334GL. Water stored in Eildon Dam is sent to Goulburn Weir where it is diverted for irrigation and stock and domestic purposes. On average, 91% of water released from Eildon Dam is diverted for irrigation purposes in the Goulburn, Loddon and Campaspe Valleys and the lake supplies about 60% of water used in the Goulburn Murray Irrigation District. The North-South Pipeline (formerly the Sugarloaf Pipeline), can pump up to 360 ML/d from downstream of Eildon Dam to Sugarloaf Reservoir for urban use in Melbourne.

Under regulated conditions, releases for consumptive use from Eildon Dam are typically limited to ensure flows do not affect private land. Releases need to take into account the possibility of additional unregulated inflows from the tributaries downstream of Eildon Dam but upstream of towns like Seymour and Trawool. Releases from Eildon Dam therefore are generally limited to below 9,500 ML/d to minimise flooding risks. Properties near Molesworth (downstream of the Acheron River confluence) are understood to be inundated if releases are made at a greater rate, however there is no flow gauge at Molesworth thus the exact level of flow that results in inundation is uncertain. Further downstream, the minor flood level at Trawool is equivalent to a flow of approximately 21,700 ML/d and at Seymour it is approximately 22,800 ML/d.

Historically, the constraint downstream of Eildon Dam has been relaxed for flood mitigation purposes, allowing pre-releases to minimise the volume of storage spills during a high inflow event into Lake Eildon. However, these releases have not been made in the past specifically for environmental watering. Critically, relaxing flow delivery constraints from Eildon Dam for environmental watering will only improve environmental benefits to the Lower Goulburn Floodplain if constraints downstream of Goulburn Weir are also relaxed.

Goulburn Weir

Water is diverted from the Goulburn Weir pool via the Stuart Murray Canal, Cattanagh Canal and the East Goulburn Main Channel. The Stuart Murray and Cattanagh Canals deliver water to the Waranga Basin, which in turn supplies irrigation water for the Loddon, Campaspe and Goulburn Valleys. The Goulburn Weir forms Lake Nagambie which is used for recreation, and also supplies local farming and residential needs.

The maximum capacity of the weir is 25,500 ML. The minor flood level at Shepparton (located approximately 65 km downstream) corresponds to a flow of 26,062 ML/d (pers. comm. Mark Bailey (GMW), 1 June 2012) which includes inflows from the Broken River. In practice, regulated releases from Goulburn Weir are generally well below this threshold. Similar to the constraints downstream of Eildon Dam, weir operators must take into account inflows from the Broken and Goulburn Rivers when making releases, as well as irrigation diversions to Waranga Basin. The exact release limit from Goulburn Weir depends on these conditions and is often limited to 6,500 ML/day or less during the irrigation season (note that most environmental releases are required at other times in the year).

Broken River

For the purposes of this report, the Broken River has no significant constraints to environmental flows. Apart from Nillahcootie Reservoir, it is largely an unregulated system.

5.1.2 Representation of Constraints in the Hydrologic Model

The following constraints are represented in the monthly Goulburn Simulation Model (GSM):

- Storage release capacity of Eildon Dam
- channel capacity between Eildon Dam and Goulburn Weir

Storage release Capacity of Eildon Dam

The storage release capacity of Eildon Dam has been included in the model as a relationship between storage volume and maximum rate at which releases can be made. The discharge capacity at low storage volumes is set such that the release cannot draw down the reservoir below dead storage. While the actual physical dead storage of the reservoir is 100 GL, an agreement between Goulburn–Murray Water and the relevant power company means that the storage volume in Eildon Dam does not fall below 250 GL, which is represented in the model.

Channel capacity constraints between Eildon Dam and Goulburn Weir

The model includes constraints on the releases from Eildon Dam in order to avoid flooding of areas around Trawool and Seymour, specifically:

- The sum of the release and inflows between Eildon Dam and Seymour cannot exceed 365 GL/month (based on 12,000 ML/d).

- If there are releases for power generation or pre-releases, then the sum of the release and inflows between Eildon Dam and Trawool cannot exceed 547 GL/month (18,000 ML/d).

The flood constraints were implemented in the model as a *monthly* flow volume and thus may be less constraining than in reality—as flooding may occur only for few days in a month, while the model does not reach the constraint unless average flow in the month was greater than the capacity constraint.

Channel capacity constraints downstream of Goulburn Weir

The model does not include any channel capacity constraint in the Lower Goulburn, as the channel capacity constraint in the reach from Eildon Dam to Goulburn Weir (as described above) reduces the likelihood that releases from Eildon Dam would result in flows at Shepparton above the minor flood level of 26,062 ML/d.

5.1.3 Environmental Flows Affected by Flow Constraints

The 195 km stretch of the Goulburn River from Goulburn Weir to the confluence with the River Murray near Echuca is rated highly for its environmental assets and values (GBCMA 2005).

Further, the Goulburn River is listed as a Heritage River downstream from the Eildon Dam to the confluence with the Murray River in recognition of a number of different environmental and social values such as river red gum open forest/woodland, and yellow box and grey box woodland/open forest communities, significant habitat for vulnerable or threatened wildlife and native fish diversity and Murray cod habitat (GBCMA 2005).

The environmental water requirements in the Goulburn system identified through the development of the Basin Plan is described in two separate reports:

- In-channel/baseflow requirements (MDBA 2012m)
- Inundation requirements for the Lower Goulburn Floodplain (MDBA 2012n)

In addition, some of the water recovered in the Goulburn system is expected to contribute towards environmental outcomes in the River Murray system. The delivery of some of the flow requirements is impeded by existing flow constraints, as described below.

Lower Goulburn River – In Channel Flows

The in-channel environmental water requirements detailed in MDBA (2012m) aim to support a healthy flow regime for native aquatic species and support key ecosystem functions. These events will inundate benches and woody debris throughout the Lower Goulburn River, supporting biochemical process such as carbon and nutrient cycling. Furthermore, this type of flow pulse is required for fish spawning and migration patterns.

As set out in Table 18, site-specific flow indicators for in-channel flows in the Lower Goulburn can be readily met under current operating conditions. This means that relaxing constraints solely for the purpose of in channel flows in the Lower Goulburn would not be necessary to achieve the local ecological targets.

Table 18: Site-specific flow indicators for in-channel flows in the lower section of the Goulburn River (MDBA 2012m), and the degree to which they can be achieved under current constraints and operational practice

Site-specific ecological targets	Site-specific flow indicators (flow measured at Shepparton)
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.	Achievable under current operating conditions • 5,000 ML/d for 14 consecutive days between October & November for 49% of years. • Two events annually of 2,500 ML/d for 4 consecutive days between December & April for 36% of years.

The Lower Goulburn River Floodplain

The Lower Goulburn River Floodplain supports a range of flood-dependent vegetation communities including river red gum open forest woodland. Smaller areas of grey box open forest woodland with associated yellow box, white box and black box occur on higher parts of the floodplain (Department of the Environment, Water, Heritage and the Arts 2009).

The environmental water requirements identified for this site through the development of the Basin Plan are summarised in Table 19. An analysis of MDBA Basin Plan modelling data indicates that channel capacity constraints upstream are likely to prevent operators from achieving the desired flows of 25,000 and 40,000 ML/d for the Lower Goulburn Floodplain. In practice, these events would be achieved by synchronising regulated releases of environmental water with an unregulated tributary inflow event downstream. The existing constraints are likely to prevent, or at least significantly limit such releases, and any risks of this manner of river operation still need further assessment.

It is likely that the 40,000 ML/day flow target cannot be met without a resultant minor flood in Shepparton. Enabling this flow would potentially involve constructing levees to protect assets in and around the town of Shepparton during higher regulated flow events, and acquiring interests in affected land to ensure the right to deliver overbank flows as well as dealing with any issues further upstream including backwater effects. Further modelling, including inundation modelling, is required to determine the extent of the potential impacts and the required remediation activities as well as identification of major social and economic issues during the development of the Constraints Management Strategy.

Furthermore, the volume of regulated release that can be used to augment high flow events remains restricted by flood constraints downstream of Eildon Dam. It may be necessary to also address constraints in upstream parts of the Goulburn River in order to release water from Eildon Dam to help meet these flow indicators.

Remediating constraints downstream of Goulburn Weir (Shepparton) as well as downstream of Eildon Dam will make the flow targets set out in Table 19 more achievable.

Table 19: Site-specific flow indicators for the Lower Goulburn Floodplain (MDBA 2012n), and the degree to which they can be achieved under current constraints and operational practice

Site-specific ecological targets	Site-specific flow indicators (flow measured at Shepparton)
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 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	Achievable under some conditions (constraints limit delivery at some times) • 25,000 ML/d for a median duration of 5 days between June & November for 70% of years • 40,000 ML/d for a median duration of 4 days between June & November for 40% of years

5.1.4 Summary

Further modelling, including inundation modelling, is required to determine the extent of potential impacts and required remediation activities in the Goulburn River. A daily, rather than monthly, model may be necessary to fully assess these flows.

The ability to contribute to higher flows with regulated releases would provide environmental benefits for the Lower Goulburn floodplain as well as increase the likelihood of achieving medium to high flow targets in the mid and lower River Murray floodplain (Senior River Operators Workshop 2012; MDBA in prep). For these reasons, relaxing constraints in the Goulburn system is likely to be a priority for the Constraints Management Strategy. Specific constraints are set out in Table 20.

The constraints downstream of both Eildon Dam and Goulburn Weir are interconnected —and the greatest benefits to site-specific ecological targets both in the Goulburn River Floodplain and downstream in the Murray will be achieved if both are addressed. Relaxing constraints downstream of Eildon Dam alone will not enable site-specific ecological targets in the Lower Goulburn Floodplain to be met, as any increased flows from Eildon Dam would then be constrained at Goulburn Weir.

With the contribution of a high flow event from the Broken River, flows up to 25,000 ML/day in the lower Goulburn could potentially be delivered from Goulburn Weir under existing constraints. However these flows may be easier to achieve if there are also higher flow contributions from Eildon Dam.

Table 20: Summary of Goulburn River constraints (from upstream to downstream), where constraints have been classified in terms of their capacity to limit flows

Location	Constraint Description	Flow Constraint	Inhibits Environmental Flow Delivery?
Eildon Dam	Inundation of private property and access at Molesworth	9,500 ML/d	Yes
Shepparton	Inundation of property and access, and minor flood level at Shepparton	Minor flood level of 26,062 ML/d at Shepparton.	Yes

5.2 Campaspe

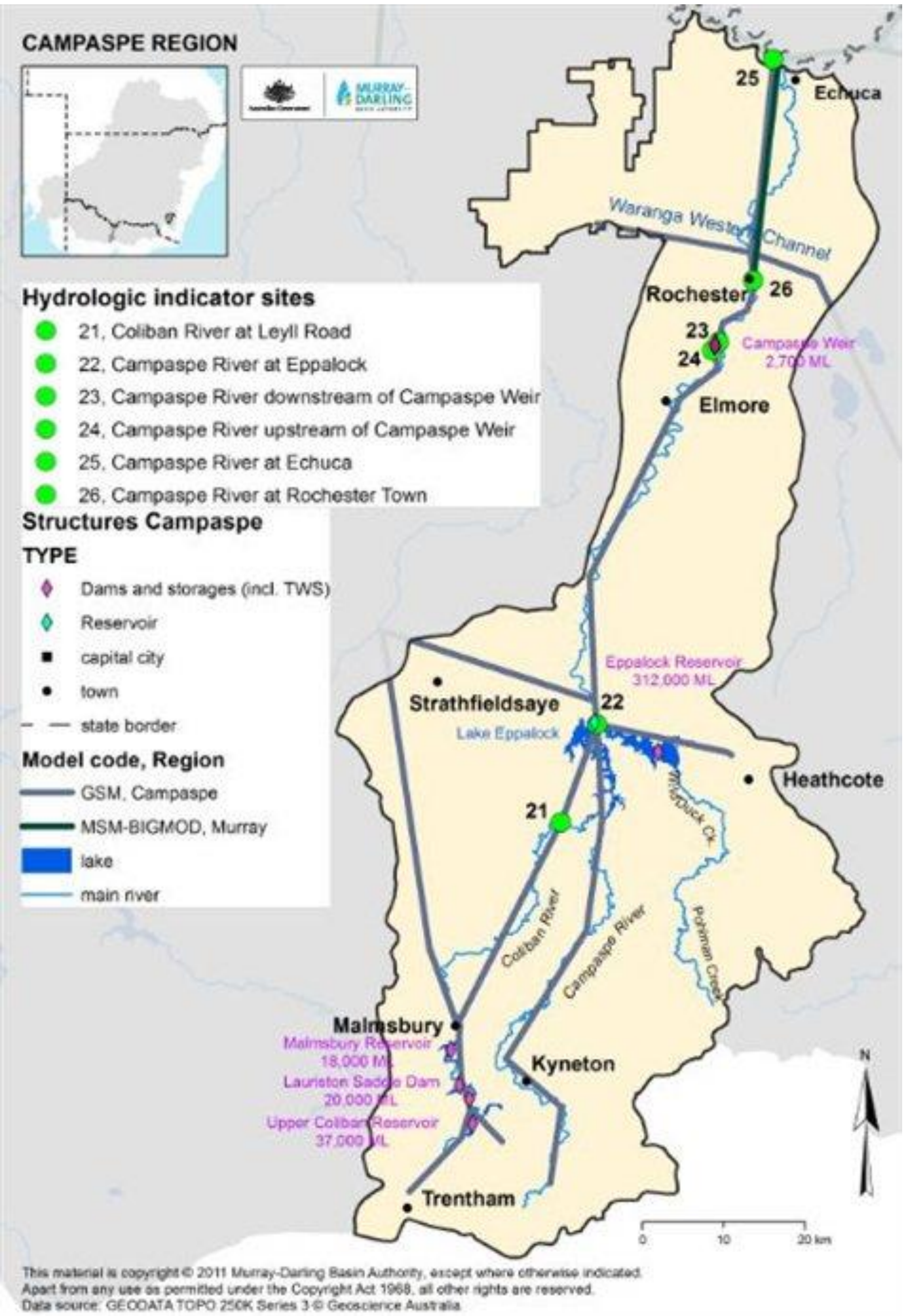
The Campaspe River flows through north central Victoria and constitutes a significant tributary of the River Murray. This highly regulated river rises in the Great Dividing Range and flows north to its confluence with the Murray at Echuca. The Campaspe is bounded by the Loddon valley to the west, the Goulburn River valley to the east and forms part of the southern edge of the Murray–Darling Basin.

The Campaspe River region contains almost 260 indigenous flora and fauna species with rare or threatened species status under the Environmental Protection and Biodiversity Conservation Act 1999 (EPBC Act), including the Murray cod, Macquarie perch, Trout cod, Silver perch and the Murray spiny crayfish (MDBA 2011a). The Sustainable Rivers Audit found the overall ecological health of the Campaspe valley to be in very poor condition (Davies et al 2012).

The dominant land use in the Campaspe region is dryland beef and sheep grazing. Extensive irrigated agriculture occupies the northern riverine plains between Rochester and Echuca, and consists mainly of dairy production along with pasture, hay and cereal crops (CSIRO 2008c). There were around 32,500 ha of irrigated cropping in 2000, predominantly pasture and hay production used in the dairy industry. Most of the water for these irrigation areas originates from the Waranga Western Channel and hence from the Goulburn River. There are small areas of irrigated winter cereal crops grown in the north west of the region and small areas of horticulture in the southern areas (CSIRO 2008c). An increasing amount of land is being developed as rural living/hobby farming and horticulture.

The Campaspe catchment has a population of approximately 47,000, and covers an area of 3,961 km^2. The main population centres are Kyneton, Elmore, Rochester and the largest, Echuca, has a population of over 12,000. The average annual rainfall is 594 mm varying from nearly 900 mm in the more mountainous south to 400 mm in the north. Rainfall varies considerably between years and winter is typically the wettest season (CSIRO 2008c). The extent and main features of the Campaspe River region are shown in Figure 15.

Figure 15: The extent and main features of the Campaspe River region



The upper reaches of the catchment are drained by the Campaspe and Coliban Rivers, which join in the pondage area of Lake Eppalock, the main flow regulating structure in the region. The source of the Campaspe River is located in Wombat State Forest and the river flows west of the township of Woodend and then through the town of Kyneton.

The Coliban River flows from its forested headwaters on the slopes of the Great Dividing Range near Trentham to Lake Eppalock. This river includes three regulating storages, the Upper Coliban Reservoir, the Malmsbury Reservoir and Lauriston Reservoir. These were constructed particularly to supply water to Bendigo and Castlemaine, and are managed by the Coliban Region Water Corporation, as part of the Eppalock Proclaimed Water Supply Catchment. Major tributaries of the Coliban River include the Little Coliban River that drains into the Upper Coliban Reservoir, Kangaroo Creek which flows into Malmsbury Reservoir, and Myrtle Creek that joins the Coliban River just upstream of Lake Eppalock (CSIRO 2008b). The Coliban water resource system includes urban supply agreement with Ballarat as well. Some water transfer is also taking place from Waranga Western Channel to this system. These do not affect environmental watering needs.

Lake Eppalock (304 GL capacity) constitutes the main storage in the Campaspe Region. A major water source for Bendigo and Heathcote, the Lake is a popular location for tourism. It is managed by Goulburn Murray Water and can transfer water for downstream requirements at a maximum rate of 1,850 ML/d (or if power generating turbines are not in use 1,000 ML/d).

Downstream of Lake Eppalock, the Campaspe receives unregulated inflows from several tributaries, including Axe, McIvor, Mt Pleasant, and Forrest Creek Wild Duck Creeks.

The Waranga Western Main Channel, which carries water from the Goulburn River to supply irrigation districts to the west, is partly located in the Campaspe region, although it does not directly intersect the Campaspe River. Water passes underneath the river via a siphon located downstream of Campaspe Weir. The Campaspe River can, however, interact with the Channel by providing supplementary flows to the Goulburn region via the Campaspe pumps. This channel interaction is not thought to be an important constraint for environmental flow delivery.

Campaspe Weir is a small regulating structure controlling flows into the Campaspe Irrigation District. This district is due to be decommissioned as a part of the Northern Victoria Irrigation Renewal Project (NVIRP). Downstream of Rochester the Campaspe flows into the River Murray at Echuca. This weir is also not thought to constitute an important constraint in the Campaspe —higher flows will pass over the fixed weir crest, which is extremely wide (20 – 30 m) and can allow large flows without substantially impacting the weir pool level.

There are no explicit key environmental assets in the Campaspe region, however the Basin Plan has specified a local irrigation diversion reduction of 18 GL/y (compared to water sharing arrangements as of June 2009) for the Campaspe region to preserve its ecological values and contribute to increased environmental flows in the downstream Murray System (see further details below). Figure 16 summarises the key structural features and flow constraints in the Campaspe River.

A summary list of flow constraints in the Campaspe region is presented in Table 21. First order constraints represent the primary impediments to the delivery of environmental events. If these constraints were overcome, the 2nd order grouping contains the next set of constraints that would potentially limit environmental water. A full investigation is required to determine the extent and flow at which these take effect.

Figure 16: Schematic diagram summarising the key structural features and flow constraints in the Campaspe River

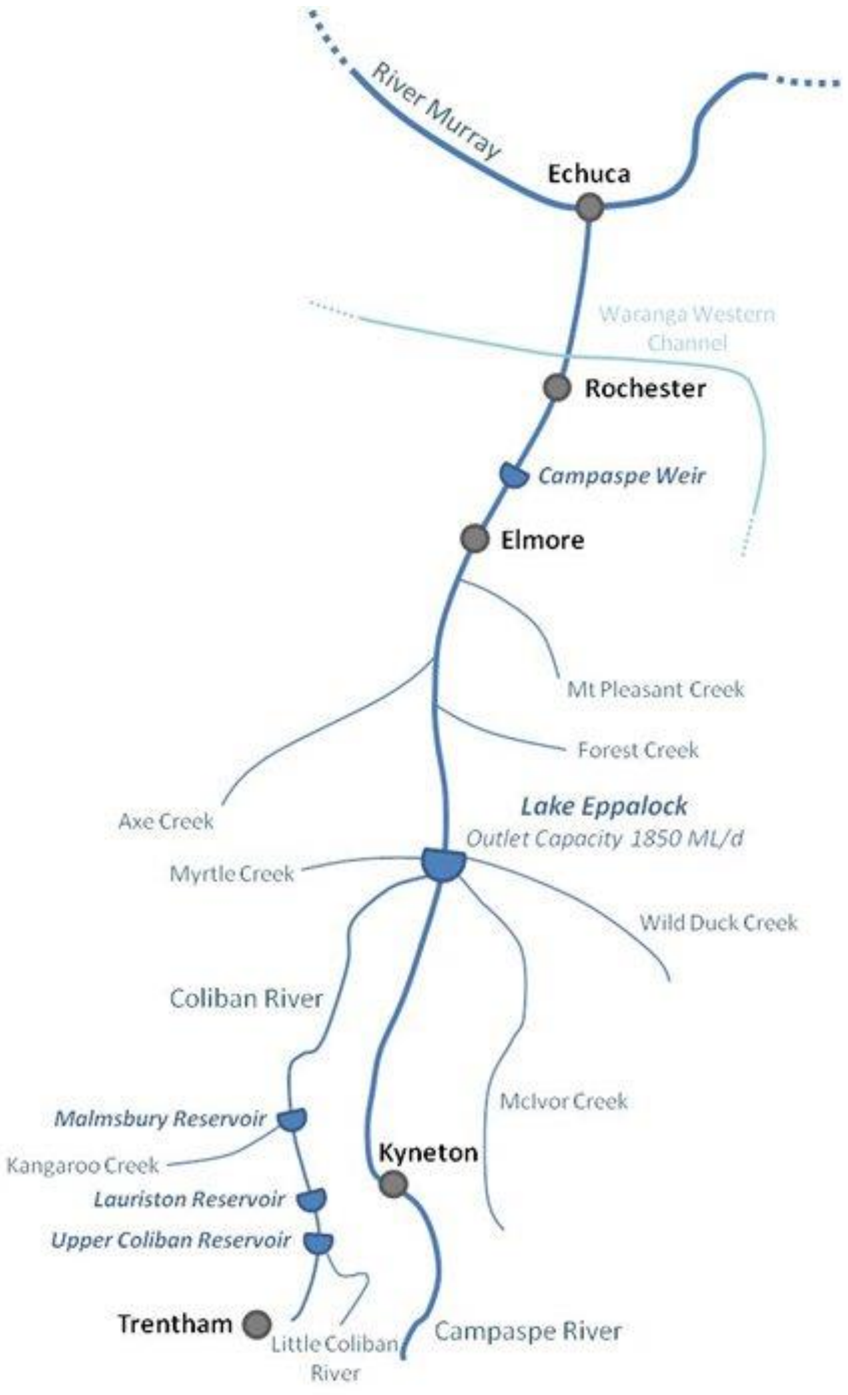


Table 21: A list of key constraints thought to limit environmental flow delivery in the Campaspe region. Constraints have been classified in terms of their capacity to limit flows.

Order	Location	Description	Flow Limit (ML/d)
1st	To be identified		
2nd	Lake Eppalock	Storage release capacity	1,850, or 1,000 when turbines unused
	Lake Eppalock	Timing of water release	—
3rd	To be identified		

5.2.1 Key Structures and Flow Constraints

Public Water Storages

The Campaspe River is regulated below Lake Eppalock, and its main tributary, the Coliban River, is regulated below the Malmsbury Reservoir. The main structures in the Campaspe system, from upstream to downstream, are:

- Upper Coliban Reservoir (37.5 GL, storage release capacity 380 ML/d)
- Lauriston Reservoir (19.8 GL, storage release capacity 900 ML/d)
- Malmsbury Reservoir (17.8 GL, storage release capacity approximately30 ML/d)
- Lake Eppalock (304 GL, storage release capacity 1,850 ML/d)
- Campaspe Weir (3 GL, storage release capacity 107 ML/d)

Other small dams used for irrigation and stock and domestic water are estimated to hold 40 GL (VicMap, 2007 quoted from CSIRO 2008c).

In practice, any held environmental water in the Campaspe system will largely be requested from Lake Eppalock, rather than the other storages. Therefore, the storage release capacity of Lake Eppalock is considered an important potential constraint (2nd order in Table 21 above) when attempting to deliver environmental water.

Basin-wide environmental objectives have been developed in the context of being deliverable under the existing conditions and operating rules of the catchment. MDBA (2011a) recognises that Basin Plan objectives are not adversely affected by existing constraints in the Campaspe catchment, with identified flows and long-term average targets able to be met for all requirements within existing constraints. However, improved environmental outcomes could be achieved for downstream River Murray requirements if key operational constraints in the Campaspe were relaxed.

Releases from Lake Eppalock are classified as the most important constraint in the Campaspe region for delivery of water for use in downstream Murray requirements. Outflows would also need to be critically timed to coincide with flows released from upstream Murray storages and tributaries. A release of 500-1,000 ML/d will require 5 days on average to reach Echuca, with a reduction in release leading to an increase in travel time. This timing issue is important for many valleys across the Murray–Darling Basin and constitutes a 2nd order constraint for the Campaspe. More information on timing issues in the Campaspe region can be found in Cottingham et al. (2011). Although a good option *per se*, actually relaxing the storage release capacity of Lake Eppalock may not deliver flows of much greater than 1,500 ML/d, due to transmission losses and attenuation of flood peaks downstream of Eppalock itself, along with issues associated with reducing the storage release capacity when the Coliban Water turbines are in use and the storage release capacity reducing with reduced storage level.

Although significant flooding has historically occurred in the Campaspe catchment, flood levels around townships are not considered to be a flow constraint for regulated releases in the Campaspe region. The minor flood level downstream of Lake Eppalock is 21,200 ML/d (Bureau of Meteorology 2011), which is well in excess of the peak flows recommended for delivery of environmental water. The Rochester Caravan Park, which is adjacent to the Campaspe River, is evacuated at a flow of 19,000 ML/d at Rochester (SKM 2006b). The flood which occurred near Rochester in 2010-11 was caused by an unregulated high flow event, and would not be reproduced by environmental releases.

5.2.2 Representation of Constraints in the Hydrological Model

The Goulburn-Broken, Campaspe and Loddon River systems are modelled together in the (monthly time step) 'Goulburn Simulation Model' (GSM). The model was provided by the Victorian Department of Sustainability and Environment (DSE), and was used by the MDBA to help develop Victorian environmental flow rules and targets. There is no separate documentation of this version of the model, but the general configuration of the model and its calibration and validation is described in the Cap report (DSE 2005).

Lake Eppalock has a modelled storage capacity of 304,800 ML, and storage release capacities are defined via a table relating storage level to storage release capacity. At full supply level, the modelled storage release capacity is 79,000 ML/month. No rules related to the turbines nor are flood constraints modelled.

5.2.3 Environmental Flows Affected by Constraints

The environmental water requirements for the Campaspe region identified during Basin Plan development can be divided into two main components:

- Baseflow requirements, and
- Contribution to downstream requirements.

There are no overbank requirements for the Campaspe region. Baseflow requirements are based on nutrient cycling, fish passage and riparian health requirements, and are limited to in-channel flows that can be satisfied through relatively low release rates from public storage. All Campaspe baseflow requirements (specified for four sites throughout the region) are achievable within existing constraints (MDBA 2011a). However, a change to these constraints, particularly the storage release capacity of Lake Eppalock, could increase the flexibility with which these requirements could be satisfied into the future.

The primary objective of MDBA modelling for the Campaspe was to represent the proposed level of reduction to inform the contribution of water for downstream River Murray requirements. The levels of diversion reduction and expected environmental outcomes for the Campaspe region are taken from descriptions contained within the Northern Region SWS (DSE 2009). The ecological targets derived from the SWS focus on providing a flow regime in the Campaspe which enables:

- improved emergency management capability (e.g. black water event);
- improved water quality conditions ;
- improved vegetation condition (e.g. including some river red gum communities);
- increased populations for large bodied fish (e.g. Murray cod, Golden perch) with an increased available habitat and opportunity to migrate;
- maintenance of pools and scouring silt from the channel bed;
- significantly improved resilience to manage short term drought events;
- improved water quality and access for domestic and stock users;
- enhanced fishing opportunities; and
- aesthetic flows through the river for towns such as Rochester and Axedale.

The Basin Plan has adopted the water recovery target for the Campaspe identified by the Northern Region SWS. In deriving this target, SKM determined the environmental flow regime and associated targets (SKM 2006a) that are classified as achievable within existing system constraints.

Lake Eppalock

The most important constraint that could impede environmental flow delivery in the Campaspe is the storage release capacity of Lake Eppalock. At full supply level, the storage release capacity is limited to 1,850 ML/d, and this is reduced to 1,000 ML/d during periods when the Coliban Water turbines are in operation. In practice, the supply level of the Lake is often below full, and the 1,850 ML/d rate is therefore rarely achievable.

Releases from Lake Eppalock will be made based on consumptive use requirements (town water or agricultural) and environmental requirements. In general, high-rate environmental releases will be made during the winter-spring period, which would not coincide with the peak season for consumptive use requirements (summer). However, there may be some years in which the timing of releases for both purposes may overlap. In these years, the storage release capacity of Lake Eppalock may limit the ability to meet environmental flows.

Environmental releases will also be made for downstream purposes. The inclusion of a shared component in the diversion reduction volume in the Basin Plan recognises that, under natural flow conditions, some of the water associated with mid-to-high flow events in the River Murray would have originated in the Campaspe region. The Campaspe can contribute to Murray watering by ensuring the timing of releases matches the releases made for Murray purposes in other valleys, including the Murray, Murrumbidgee and Goulburn. Under special circumstances, the storage release capacity of Lake Eppalock may limit the ability to satisfy water requirements for both downstream environmental and consumptive use purposes.

Further analysis is required however to fully quantify this effect, however it is expected that the release capacity will limit environmental water delivery only during years with specific conditions (for instance, during years with both a reduced Lake Eppalock level and high environmental and consumptive use requirements). In most years the storage release capacity will not limit environmental water delivery, and the major limitation will be the volume of available environmental water. The release capacity of Lake Eppalock is therefore categorised to be a 2nd order flow constraint.

Table 22 outlines the various flow indicators and environmental flow targets for the Campaspe region, as detailed by DSE (2009). All targets are considered deliverable under existing system constraints.

Table 22: The degree to which various components of Campaspe ecological outcomes are impacted by existing constraints (extracted from DSE 2009)

Regions/sub regions (based on changes in expected outcomes)	increasing flow magnitude and decreasing frequency of inundation >					
	In-stream habitats	Wetlands - permanent and semi-permanent	Near channel vegetation e.g. Red gum	Lower level floodplain communities e.g. Red gum forest	Mid-level floodplain communities e.g. Red gum/Yellow box/Grey box woodlands	High level floodplain communities e.g. Grassy Black box and White box woodlands
Largely un-regulated tributaries upstream of Lake Eppalock	The tributaries up-stream of Lake Eppalock are generally free flowing with only minor diversions.					
Mid and Lower Campaspe (Downstream of Malmsbury/Eppalock Storages to River Murray junction)	Improved environmental outcomes. Ability to achieve flow indicators	Improved environmental outcomes. Operational constraints limit flow delivery in some conditions			Operational constraints prevent delivery of these flows as managed events. Flows that support these outcomes will continue to occur when flows exceed the regulating capacity of existing infrastructure	

Other Considerations

Tributary inflows (sometimes of a significant volume) occur downstream of Lake Eppalock, therefore in the Campaspe region releases from the Lake may be required to supplement unregulated tributary inflows, depending on the properties of the specific event to be delivered. As a general guide, releases would on average take up to 5 days to reach the confluence with the River Murray at Echuca. The timing of these releases would be an important consideration for successful environmental flow delivery.

The actual volumes required to be released from Lake Eppalock are difficult to determine, as they would need to compensate for highly variable factors including delivery losses *en-route* to the Murray. However, MDBA modelling has shown that flows can be delivered with a high degree of success within the limits imposed by existing system constraints.

Campaspe-sourced water to help supplement environmental flow requirements for the River Murray are very unlikely to ever exceed the minor flood levels downstream of Lake Eppalock or at Rochester, hence they are not considered to be flow constraints.

5.2.4 Summary

Environmental flow requirements were previously determined for the lower Campaspe, set out in DSE (2009), as well as MDBA-based work on a component of downstream environmental requirements on the Murray system which may be sourced from the Campaspe region. Previous modelling (MDBA 2012y) has shown that adopted Campaspe environmental requirements can be achieved within existing system constraints by combining regulated releases with downstream tributary flows (Cottingham et al 2011). Addressing some of the constraints in the catchment may, however, afford future water managers increased flexibility in meeting individual events desired for the downstream River Murray.

There are therefore two main flow constraints identified in the Campaspe region, summarised in Table 23 below. The predominant constraint to the delivery of environmental flows is the storage release capacity and associated operational practice of Lake Eppalock. Timing of environmental water releases to meet unregulated inflows constitutes a secondary level of constraint in the Campaspe region, when considering environmental delivery on an event-by-event basis. Minor flood levels downstream of Lake Eppalock correspond to a flow of 20,000 ML/d. These are far in excess of any required environmental flow and hence do not constitute a potential flow constraint.

Table 23: Summary of Campaspe constraints (from upstream to downstream), where constraints have been classified in terms of their capacity to limit flows

Location	Constraint Description	Flow Constraint	Inhibits Environmental Flow Delivery?
Lake Eppalock	Storage release capacity and operational practices	1,850 or 1,000 when turbines are not in use	Yes
Lake Eppalock	Timing of water release	—	Yes

5.3 Loddon

The Loddon River is a significant tributary of the River Murray that flows through north central Victoria. It is a highly regulated river rising in the Great Dividing Range and flowing north. The catchment covers 15,320 km^2 and is bounded by the Avoca valley to the west, the Campaspe river valley to the east and forms part of the southern edge of the Murray Darling Basin.

The Loddon catchment has a population of nearly 147,000, with some 77,000 residents in Bendigo. Other major towns in the region include Maryborough, Castlemaine, and Inglewood. Smaller centres in the Loddon Valley include Castlemaine, Boort, Pyramid Hill and Kerang. Figure 13 shows the main features of the region.

The dominant land use in the Loddon region is dryland agriculture, characterised by broad acre land uses, primarily cropping and grazing. Extensive irrigated agriculture on the riverine plain near Pyramid-Boort is mainly dairying, mixed cereal and livestock farming. Water supply is primarily from Waranga Western Channel and hence from the Goulburn River. Land close to the major centres is increasingly being developed for horticulture, new and emerging agricultural commodities and as 'rural living' zones (CSIRO 2008f).

The Loddon catchment (downstream of the boundary shown in Figure 17) includes major salt interception schemes along Pyramid Creek and Barr Creek that have extensive policies concerning the release of the salts intercepted. Generally salt is exported during high flow periods, and these schemes prevent large volumes of salt from passing into the Little Murray River.

There are three main watercourses in the Loddon catchment; the Loddon River, Bet Bet Creek and Tullaroop Creek which meet at Laanecoorie Reservoir. In the northern part of the system, Gunbower, Reedy, Pyramid and Barr Creeks occupy the area. Bullock Creek drains the north-central zone and Bendigo Creek carries runoff to Kow Swamp in the east (see Figure 14 in MDBA 2011a). The region contains the Ramsar listed Kerang Wetlands.

The regulated Loddon River is almost 400 km long. It has its headwaters near Daylesford and flows generally northward through Newstead, 40 km west of Bendigo through the Cairn Curran Reservoir and Laanecoorie Reservoir and continues north through the town of Bridgewater and on to Kerang. Finally it turns northwest and flows into the Murray River between Barham and Swan Hill. Tributaries of the Loddon River include Bet Bet, Tullaroop, Serpentine and Pyramid Creeks. Birches Creek is a tributary of Tullaroop Creek. The major storages are Cairn Curran, Tullaroop and Laanecoorie Reservoirs. There are also weirs at Bridgewater and Kerang, and two storages (Newlyns reservoir and Hepburn lagoon) on Birches Creek.

The Loddon region supports a wide variety of flora and fauna habitat, Gunbower Forest and the Kerang Wetlands, which are of international significance and are listed under the Ramsar Convention. The Kerang Wetlands include lakes and swamps controlled by and are part of the Torrumbarry Irrigation System. Torrumbarry Irrigation is supplied via the National Channel and Kow Swamp. Gunbower Forest is located on the River Murray floodplain in northern Victoria and its water supply is also regulated via the National Channel. This forest when combined with the adjoining Koondrook-Perricoota Forests in NSW is the second largest river redgum forest in Australia. The Kerang Lakes are located in northern Victoria on the floodplains associated with the Murray, Avoca and Loddon Rivers. Over 150 species of native plants have been recorded from the Kerang Wetlands Ramsar site, including the threatened Chariot Wheels, River Swamp Wallaby-grass, and the Slender Darling-pea (MDBA 2011a). The Sustainable Rivers Audit found the overall ecological health of the Loddon valley to be in very poor condition (Davies et al 2012).

Figure 17: The extent and main features of the Loddon River region

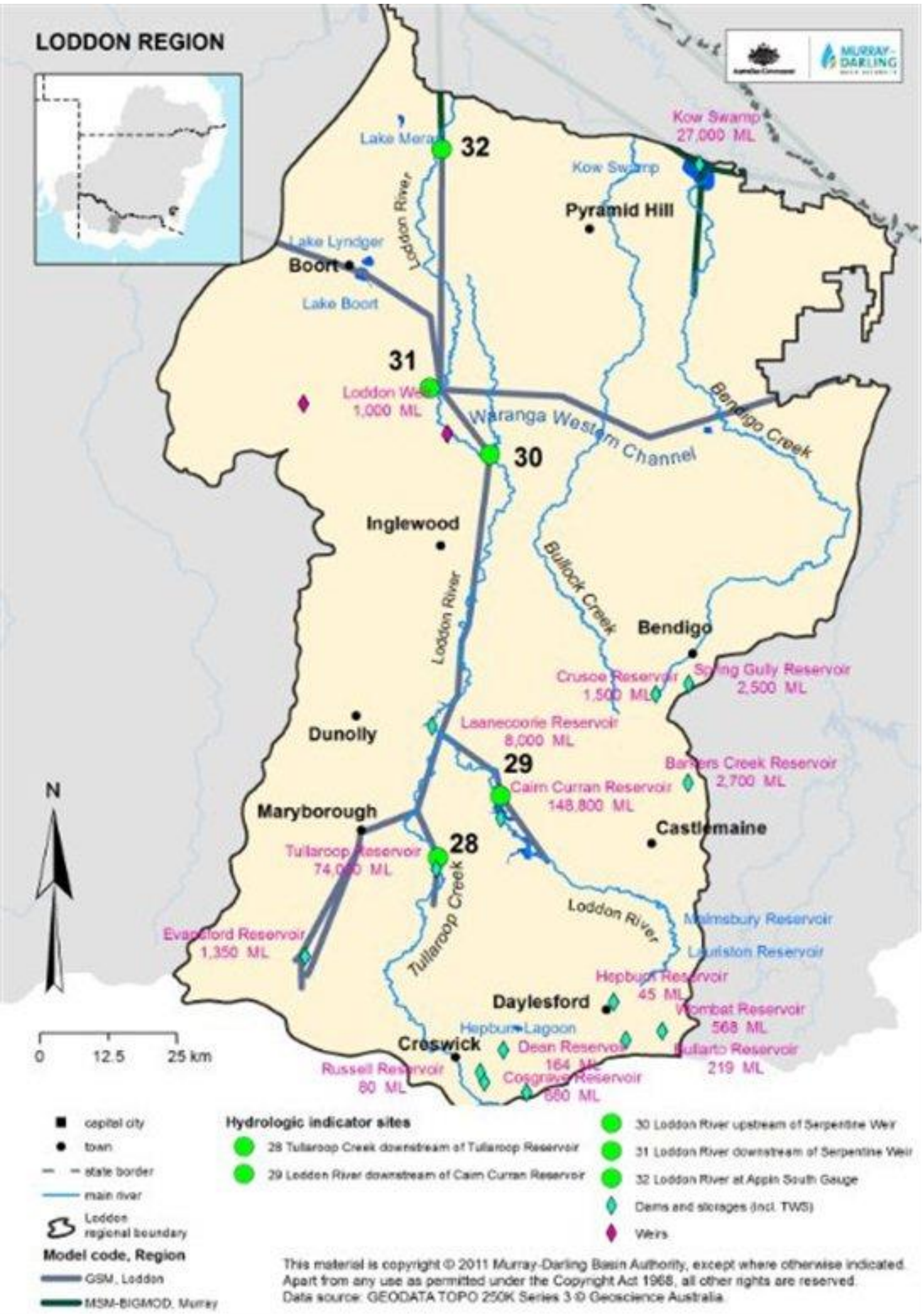


Figure 18: Schematic diagram summarising the key structural features and flow constraints in the Loddon River

A summary list of the flow constraints in the Loddon are presented in Table 24. First order constraints represent the primary impediments to the delivery of mid-to-high flow environmental events. If these constraints were overcome, the 2nd order grouping contains the next set of constraints that would potentially limit environmental water. A full investigation is required to determine the extent and flow at which these take effect.

Table 24: A list of key constraints thought to limit environmental flow delivery in the Loddon region. Constraints have been classified in terms of their capacity to limit flows

Order	Location	Description	Flow Limit (ML/d)
1st	To be identified		
2nd	Cairn Curran Reservoir	Storage release capacity	1,600
	Tullaroop Reservoir	Storage release capacity	730
	Laanecoorie Reservoir	Storage release capacity	1,300
	All reservoirs	Timing of water release	—
3rd	Appin South	Minor flood level	1,720

Key Structures and Flow Constraints

The Loddon River has three major storages in its headlands as well as two small storages on Birch Creek (a tributary to Tullaroop Creek) and four weirs in the northern stretches of the river. The Waranga Western Channel is another structure intersecting the Loddon River. These are listed below from upstream to downstream.

- Newlyn Reservoir (3 GL, discharge capacity 35 ML/d)
- Hepburn Lagoon (2.5 GL, discharge capacity 25 ML/d)
- Cairn Curran Reservoir (148 GL, storage release capacity 1,600 ML/d)
- Tullaroop Reservoir (73 GL, storage release capacity 730 ML/d)
- Laanecoorie Reservoir (8 GL, storage release capacity 1,300 ML/d)
- Bridgewater Weir
- Serpentine Weir
- Loddon Weir
- Appin South Weir
- Kerang Weir

The two small storages on Birch Creek (Newlyn Reservoir and Hepburn Lagoon) are for urban use, irrigation and stock and domestic supplies. Birch Creek then joins Tullaroop upstream of Tullaroop Reservoir, which has a holding capacity of 73 GL. The storage release capacity is 730 ML/d at full supply level. If the storage level is below this, the storage release capacity is reduced to 450 ML/d. A spillway can allow flows of approximately 71,000 ML/d through (SKM, 2006).

Cairn Curran Reservoir on the upper reaches of the Loddon River has a regulated storage release capacity of approximately 1,600 ML/d at supply full level. The irrigation outlet allows releases of approximately 750 ML/d, and when the hydropower station turbines are in use the storage release capacity increases by approximately 810 ML/d. These releases can be combined to increase the regulated flow up to 1,600 ML/d. The reservoir also has three spillway gates that can be opened to allow a flow of up to 189,000 ML/d (SKM 2006c).

The three main upstream tributaries to the Loddon River, the upper Loddon River, Tullaroop Creek and Bet Bet Creek, meet at Laanecoorie Reservoir, which has a capacity of 8 GL. Four irrigation valves can supply around 1,300 ML/d of regulated discharge downstream of the storage (SKM, 2006c).

Bridgewater Weir supplies a local flour mill. The water diverted to the mill returns to the Loddon River downstream of Bridgewater Weir. Serpentine Weir allows water to be diverted to Serpentine Creek during normal regulated flows. Loddon Weir regulates flows from and through the Waranga Western Channel which transfers water between the Goulbourn, Campaspe and Loddon Rivers. Supplementary water can also be supplied into the Boort Irrigation District from the Loddon Weir. Kerang Weir allows up to 850 ML/d to be regulated to the Kerang Lakes system (SKM, 2006).

There are a number of breakout flood runners which distribute flows to both the east and west of the Loddon River downstream of Loddon Weir (Cottingham & SKM 2011), commencing when flows exceed 1,600 ML/d. Although these flows could lead to inundation of private land, they are not a threat to towns in the region. Flooding can occur at Appin South, with minor flooding at 1,720 ML/d, moderate flooding at 7,300 ML/d and flows of 18,620 ML/d resulting in major flooding.

5.3.2 Representation of Constraints in the Hydrological Model

The Goulburn-Broken, Campaspe and Loddon River systems are modelled together in the (monthly time step) 'Goulburn Simulation Model' (GSM). The model was provided by the Victorian Department of Sustainability and Environment (DSE), and was used by the MDBA to help develop Victorian environmental flow rules and targets. There is no separate documentation of this version of the model, but the general configuration of the model and its calibration and validation is described in the Cap report (DSE 2005).

Cairn Curran Reservoir has a modelled storage capacity of 148 GL. Storage release capacities are defined via a table relating storage level to storage release capacity. At maximum storage, the modelled storage release capacity is infinite, as a spillway can allow all inflows to continue through.

Tullaroop Reservoir has a modelled storage capacity of 73 GL. At maximum storage, the modelled storage release capacity is 88,000 ML/m, which corresponds to 2,900 ML/d. This is only constrained by the capacity table. No operational rules or storage release capacity constraints are modelled.

Laanecoorie Reservoir does not have a capacity table in the model.

5.3.3 Environmental Flows Affected by Constraints

During the development of the Basin Plan, baseflow requirements were identified for the Loddon region. Baseflows are an important component of the flow regime which maintains aquatic habitats for fish, plants and invertebrates. They provide drought refuge during dry periods, and contribute to nutrient dilution during wet periods or after a flood event (MDBA 2012y). The Loddon baseflow requirements (specified for five sites throughout the region) are largely achievable within existing constraints (MDBA 2011a). However, a change to these constraints, particularly the regulated storage release capacity of Cairn Curran, Tullaroop and Laanecoorie Reservoirs could increase the flexibility with which these requirements could be satisfied into the future.

The primary objective of MDBA modelling for the Loddon, as with the Campaspe, was to represent the proposed Basin Plan SDLs for these systems to inform the contribution of water to downstream River Murray requirements.

The expected environmental outcomes for the Loddon region are taken from descriptions contained within the Northern Region Sustainable Water Strategy (NRSWS; DSE 2008). Further details of these environmental flow requirements can be found in the Environmental Flow Determination of the Loddon River Catchment, Final Report (Loddon River Environmental Flows Scientific Panel, 2002). The Loddon River reaches 1 – 3 are categorised to be category 3, with a water recovery target of 12GL/yr. These reaches are located between Cairn Curran Reservoir and Loddon Weir, including Tullaroop Creek. The flow component for category 3 does not include overbank or bankfull flows. The ecological targets derived from the NRSWS focus on providing a flow regime in the Loddon which enables:

- improved emergency management capability (e.g. black water);
- riparian vegetation condition stable with some recruitment;
- basic Murray cod habitat is maintained at a moderate risk and there will be some opportunities for movement;
- improved water quality conditions through summer with further improvement over winter.

This water recovery target will also enable the following downstream outcomes:

- improved emergency management capability (e.g. Black water events, salinity spikes);
- increased populations for large bodied fish (e.g. Murray cod, golden perch) with an increase in available habitat and ability to migrate;
- improved water quality conditions through summer with further improvement over winter;
- significantly improved resilience to manage short-term drought events;
- partially functioning anabranch channels (e.g. 12 Mile Creek);
- maintenance of pools and scouring silt from the channel bed environmental values (e.g. Murray cod);
- basic habitat and water quality management
- Limited opportunities for fish movement and limited vegetation recruitment
- Improved water quality and access for domestic and stock users
- Enhanced fishing opportunities
- Aesthetic flows through the river for towns.

The Loddon baseflow requirements (specified for five sites throughout the region) are achievable within existing constraints (MDBA 2011a). However, a change to these constraints, particularly the storage release capacities of the three main storages Cairn Curran, Tullaroop and Laanecoorie Reservoirs, could increase the flexibility with which these requirements could be satisfied into the future.

The inclusion of a shared component in the Basin Plan recognises that, under natural conditions, some of the water associated with mid-to-high flow events in the River Murray would have originated in the Loddon region. However, in practice, water would not be ordered from the Loddon to supplement regulated flows in the Murray, due to the high losses in the Loddon River between Loddon Weir and Kerang Weir (MDBA, 2012y).

The flood levels at Appin South are characterised as 3rd order constraints, as they could become increasingly important if the regulated storage release capacities of the reservoirs are increased, and releases are coordinated. Minor flood levels at Appin South occur from 1,720 ML/d. At locations further upstream (but below Loddon Weir) high flows enter anabranches and distributaries streams at 1,600 ML/d. Therefore a significantly larger flow would be required for flows at Appin South to reach 1,720 ML/d. Given the poor connectivity between the Loddon and the Murray, it is improbable that Loddon water will be sourced to help supplement environmental flow requirements for the River Murray. Therefore it is unlikely that an environmental flow demand will exceed these minor flood levels, however they are mentioned here as a point of issue to be considered if the storage release capacity of upstream storages is increased.

Table 25: The degree to which various components of Loddon ecological outcomes are impacted by existing constraints

Regions/sub regions (based on changes in expected outcomes)	increasing flow magnitude and decreasing frequency of inundation >					
	In-stream habitats	Wetlands - permanent and semi-permanent	Near channel vegetation e.g. Red gum	Lower level floodplain communities e.g. Red gum forest	Mid-level floodplain communities e.g. Red gum/Yellow box/Grey box woodlands	High level floodplain communities e.g. Grassy Black box and White box woodlands
Largely un-regulated tributaries upstream of major storages based	The tributaries up-stream of major storages are generally free flowing with only minor diversions.					
(Downstream of Cairn Curran/Tullaroop Storages to Kerang Weir)	Improved environmental outcomes. Ability to achieve flow indicators	Improved environmental outcomes. Operational constraints limit flow delivery in some conditions		Operational constraints prevent delivery of these flows as managed events. Flows that support these outcomes will continue to occur when flows exceed the regulating capacity of existing infrastructure		
Lower Loddon(Kerang Weir to River Murray junction)	Hydrology is largely influenced by regulated flows from irrigation system. Operational constraints and water shepherding issues limit ability to deliver flows from Loddon system, therefore potential to achieve flow indicators will be dependent on river management in Murray region			Water recovery not targeted for this outcome. Lower Loddon floodplain disconnected from river by levees		

Table 25 outlines the various flow indicators and environmental flow targets for the Loddon region, as detailed in MDBA (2011a). All targets are considered deliverable under existing system constraints, however this assessment is based on long-term average results and the identification and further analysis of Loddon constraints could increase the delivery efficiency of environmental flows.

5.3.4 Summary

Environmental flow requirements have been determined for the upper Loddon and are set out in the Environmental Flow Determination of the Loddon River Catchment Final Report (Loddon River Environmental Flows Scientific Panel, 2002). In addition, a component of the water required for the downstream environmental requirements on the Murray system may be sourced from the Loddon. Delivering these flows would be difficult due to the relatively low level of connectivity between the two systems, and would also need to consider salinity control policies in the region.

Addressing the constraints in the catchment (outlined in Table 3, below) may increase delivery efficiency of environmental water. The dominant constraints to the delivery of environmental flows are the storage release capacities of Cairn Curran, Tullaroop and Laanecoorie Reservoirs.

The secondary constraint in the Loddon region is the timing of environmental water releases, when considering environmental delivery on an event-by-event basis. Potential additional flooding at Appin South is unlikely to occur given the anabranches and distributary channels that divert water from the main channel upstream of Appin South.

Table 26: Summary of Loddon constraints, and their importance in downstream environmental flow delivery

Location	Constraint Description	Flow Constraint	Inhibits Environmental Flow Delivery?
Cairn Curran Reservoir	Storage release capacity (regulated conditions)	1,600 ML/d	No
Tullaroop Reservoir	Storage release capacity (regulated conditions)	730 ML/d	No
Laanecoorie Reservoir	Storage release capacity (regulated conditions)	1,300 ML/d	No
All reservoirs	Timing of water release	—	No
Appin South	Minor flood level Moderate flood level Major flood level	1,720 ML/d 7,300 ML/d 18,620 ML/d	No

5.4 Wimmera-Avoca

The Wimmera River system (Figure 19) originates in the Grampians and the Mt Cole/Pyrenees Ranges, flowing west and then north across the Wimmera Plains before terminating at Lake Hindmarsh, Victoria's largest freshwater lake, and the Ramsar listed site, Lake Albacutya. Regulation has significantly reduced flooding in the Lakes, which require a wet sequence of years to be filled.

The Wimmera covers 30,640 km^2 with a population of 50,000. The major centres are Horsham and Stawell in the southern area. In the northern and central areas of the Wimmera region broad acre cropping of grains, pulses, oilseeds and pasture seed is the dominant land use, while dryland grazing is most common in the south (CSIRO, 2007g).

Under Victorian legislation, the Wimmera River is a declared Heritage River between Polkemmet Bridge and Wyperfeld National Park. The main tributaries of this highly developed river include the MacKenzie River and Mt William, Burnt and Norton Creeks. Yarriambiack Creek carries water away from the river into Lake Coorong and the southern Mallee.

The Basin Plan establishes a reduction (from baseline) of 23 GL in the Wimmera System. The Wimmera System is a disconnected catchment, hence no water recovery has been included to contribute to water requirements in the River Murray.

The Avoca River runs through Charlton and terminates at the Kerang Wetlands, which are listed as Wetlands of International Importance under the Ramsar Convention (DEWHA 2008). The Avoca River provides flows to some of the wetlands, which provide habitat for a range of native and migratory species. The bulk of the Kerang Wetlands is part of the Torrumbarry Irrigation System. Many of these species are listed and protected under the Environment Protection and Biodiversity and Conservation Act 1999 (EPBC Act). The Kerang Wetlands support communities of river red gum, black box and tangled lignum species that provide critical habitat for protected bird species.

The Avoca River is unregulated, and supports very little irrigation. The Basin Plan did not set a water recovery volume or environmental flow requirements for the Avoca River, hence constraints to environmental flows in the Avoca River have not been considered for this report.

Figure 19: Main Features of the Wimmera-Avoca region

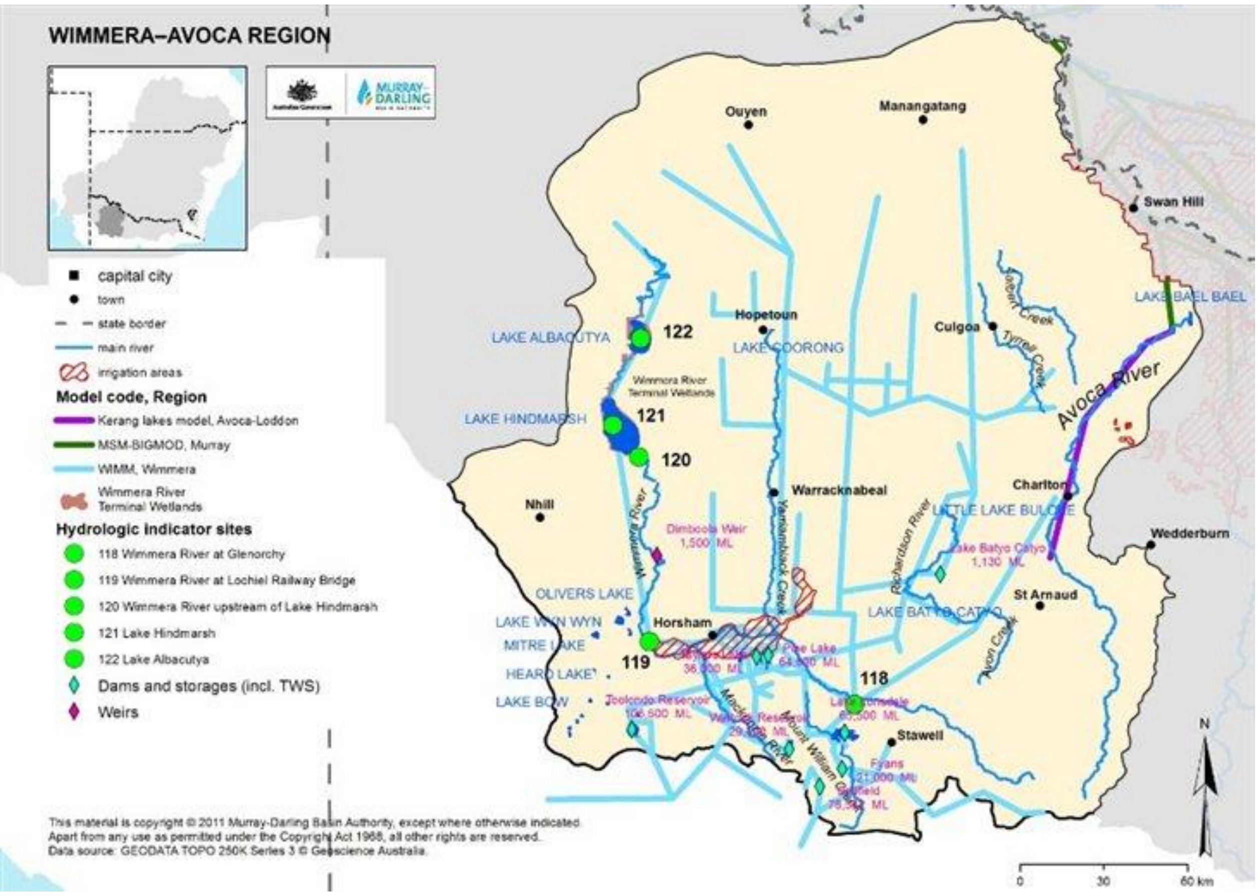
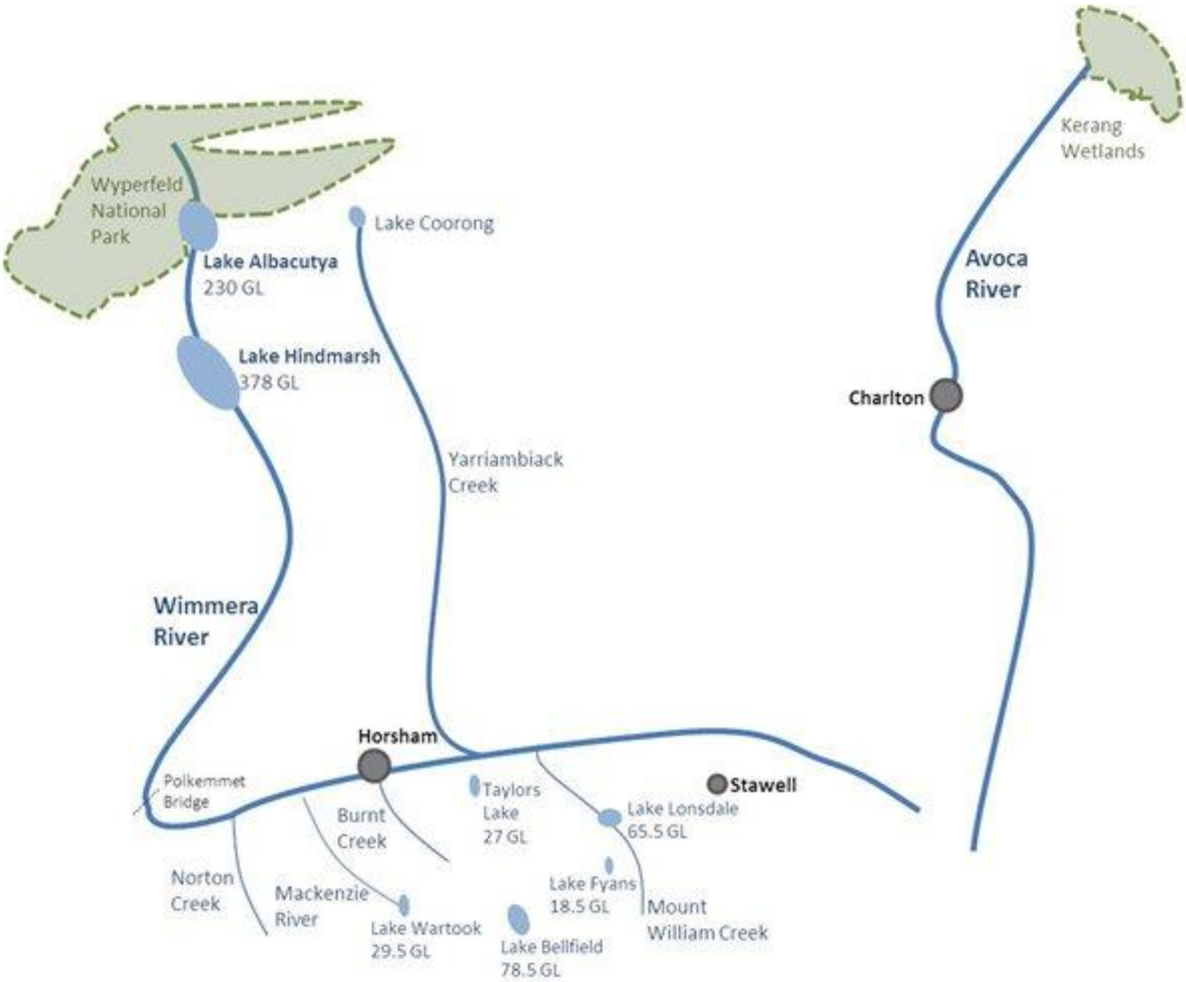


Figure 20: Schematic diagram of the Wimmera-Avoca region



5.4.1 Key Structures and Flow Constraints

Significant changes have occurred to the hydrology of the Wimmera River Terminal Wetlands due to development and water extractions upstream in the Wimmera catchment.

Wimmera-Mallee Pipeline

The Wimmera–Mallee Pipeline Project (WMPP) was a large-scale project that replaced about 17,700 km of the highly inefficient Wimmera–Mallee stock and domestic open channel system with 9,159 km of a piped water distribution system. The WMPP began in 2001, was completed in early 2010, and supplies water to 36 towns and stock and domestic users in the Wimmera-Mallee region. The WMPP resulted in water savings of about 103 GL per year, with 83 GL of this allocated to the environment.

Wimmera Irrigation

The Wimmera Irrigation District services around 250 irrigators and covers an area of about 3,200 ha. The Wimmera Irrigation District is not part of the Wimmera Mallee Pipeline and instead receives water through the existing open channel system. In December 2012 an agreement was reached with Wimmera irrigators for the Commonwealth purchase of entitlements and decommissioning of the irrigation district. Accordingly, irrigation in the Wimmera region has ceased, with the 23 GL/year of entitlements that were historically available making up the entire SDL reduction amount for the Wimmera-Mallee (surface water) water resource plan area under the Basin Plan. Accordingly, irrigation in the Wimmera region has ceased, with the 23 GL/year of entitlements that were historically available making up the entire SDL reduction amount for the Wimmera-Mallee (surface water) water resource plan area under the Basin Plan.

Main Storages

There are five storage lakes with a capacity greater than 15 GL located on tributaries of the Wimmera River (Figure 20). The total storage capacity in the Wimmera catchment is 210 GL, which equates to about 85% of annual inflows (MDBA 2012y).

Prior to the construction of the Wimmera-Mallee Pipeline, approximately 120 GL/y(long-term average) was diverted from these storages annually for consumptive needs; approximately two-thirds of this volume was lost to evaporation and seepage during delivery (CSIRO 2007g).

System Constraints

The environmental water requirements identified for the Wimmera System are set as an end of system volume target at Lake Hindmarsh and Albacutya. These terminal lakes are naturally ephemeral, relying on large, infrequent flows from the Wimmera River to fill. Given the episodic natural hydrology of Lake Hindmarsh and Lake Albacutya achievement of flow indicators set by the Basin Plan will be heavily reliant on large, unregulated inflow events from the Wimmera system. It is anticipated that post Basin Plan the additional water recovery may be used to augment unregulated high flows, however achievement of flow indicators are beyond the scope of being delivered as an entirely managed environmental watering event.

To effectively and efficiently augment unregulated flows to achieve filling of Lake Hindmarsh and Lake Albacutya, it is expected that additional flows will be delivered as in-channel flows. This approach has multiple benefits in that it would contribute to achievement of water requirements of the Wimmera River (as briefly described further below) while also avoiding evaporation and seepage losses and possible private land inundation issues associated with overbank flows.

It is possible that under certain circumstances channel capacity issues may arise due to the large volumes of available water corresponding with wet seasonal conditions when it is likely to be desirable to augment large, unregulated flows. Further analysis would be required to quantify the significance of this issue, however given that the Lake Hindmarsh and Lake Albacutya water requirements do not have a specific timing it is considered this risk is relatively low as it can be mitigated by environmental water delivery being scheduled to augment unregulated flows at a time when channel capacity issues aren’t prevalent. As such, there are unlikely to be flow delivery constraints that would affect the ability to meet environmental targets set by the Basin Plan.

The environmental water requirements for the Wimmera River and its key tributaries have also been described although this work is not part of the Basin Plan environmental water requirements. These water requirements are focussed on in-channel flows. Earthtech (2005) and SKM (2008) have investigated constraints to the delivery of these flow recommendations for the Wimmera River and its tributaries.

Earthtech (2005) identified several physical and operational constraints in the Wimmera System including flow thresholds above which water was diverted from weirs. The report concluded that the most significant constraints to the provision of environmental flow delivery would be the Wimmera Mallee Water Supply System (WMSS) assets and operations. The WMSS was the open-channel predecessor to the WMPP, and has been decommissioned since the study conducted by Earthtech.

SKM (2008) did not identify any physical constraint not addressed by Earthtech (2005). SKM did, however, identify 12 channel constrictions, or permeable features in the Wimmera River such as debris blockages and vegetated sections that were likely to attenuate flow initially, but did not result in a volume loss.

None of these constraints would affect the ability to augment the required end of system volume to Lakes Hindmarsh and Albacutya.

5.4.2 Representation of Constraints in the Hydrological Model

Basin Plan modelling for the Wimmera River System did not include any flow delivery constraints such as minor flood levels that cannot be exceeded. The main reason for this is the nature of the site-specific indicators for the Wimmera terminal wetlands. Unlike many other river valleys in the Basin, which identify discrete flow events with specific flow thresholds, duration and timing, the Wimmera terminal wetlands water requirements are specified as lake volumes to be met for specific periods of time i.e. duration of lake full events.

Achieving the target volumes in the wetlands for the duration specified (Table 27) will not primarily depend on how quickly water flows to them, but will instead rely on the volume of water available being able to be used to augment large, infrequent flow events in the Wimmera system.

5.4.3 Environmental Flows Affected by Constraints

Relatively high storage volume, combined with high evaporation losses, may be contributing to the difficulty in achieving the Wimmera environmental flow requirements identified in the development of the Basin Plan (MDBA 2012x). Decommissioning some storages no longer required for water supply purposes post the WMPP may help restore more natural flow regimes, however further analysis would be required to fully assess the impacts of doing this on social, cultural and recreational values, private land, access routes and entitlement reliability for the remaining entitlements.

Environmental flow requirements for Lake Hindmarsh and Lake Albacutya are described as volumetric targets to be maintained for relatively long periods of time, from six months to three years. These targets do not require a particular flow rate to be achieved. Table 27 sets out the site specific ecological targets for the Wimmera River terminal wetlands. The table shows that reaching the targets is ‘achievable under some conditions’. In this case, the limiting factor is likely to be the volume of water available on a year by year basis, rather than the ability to deliver flows by releasing water at a particular flow rate.

Table 27: Ecological targets for the Wimmera River Terminal wetlands (MDBA 2012x), and the degree to which they can be achieved under current constraints and operational practice

Site-specific ecological targets	Site-specific flow indicators
Provide a flow regime which ensures the current extent of native vegetation of the fringing 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	Achievable under current operating conditions • Fill and maintain Lake Hindmarsh (378 GL) for 6 months duration to achieve an average recurrence interval of 5 years • Fill and maintain Lake Hindmarsh (378 GL) for 2 years duration to achieve an average recurrence interval of 12 years Achievable under some conditions (constraints limit delivery at some times) • Fill and maintain Lake Hindmarsh (378 GL) for 3 years duration to achieve an average recurrence interval of 20 years • Fill and maintain Lake Albacutya (230 GL) for 6 months to achieve an average recurrence interval of 12 years Difficult to influence achievement under most conditions (constraints limit delivery at most times) • Fill and maintain Lake Albacutya (230 GL) for 2 years to achieve an average recurrence interval of 20 years

5.4.4 Summary

The ecological targets for the Wimmera River Terminal Wetlands are set as volumes to be met for specific periods of time, rather than target flow rates. As such there are no substantial constraints to the delivery of environmental flows in the Wimmera Avoca system. There are however two potential constraints identified (Table 28). Firstly, channel capacity issues may arise under certain circumstances where unregulated flow events within the Wimmera system limit the ability to deliver regulated flows to augment flows without exceeding channel capacities and creating an undesirable overbank flow event. The second constraint refers to the study by SKM (2008), which found that debris blockages and vegetated sections may attenuate flow initially but would not affect the volume of delivery required by the Wimmera River Terminal Wetlands (MDBA 2012x).

The Wimmera-Avoca region is one of two disconnected tributaries in the Basin, meaning that additional flow capacity or volume here would have benefits locally, but would have no impact in the River Murray System. For these reasons, remediating constraints in the Wimmera-Avoca region is not proposed as a priority for the MDBA at this time.

Table 28: Summary of Wimmera constraints where constraints have been classified in terms of their capacity to limit flows

Location	Constraint Description	Flow Constraint	Inhibits Environmental Flow Delivery?
Wimmera River and tributaries downstream of storages	Channel capacity constraints limit the ability to augment unregulated flow events	Variable channel capacities – to be confirmed	No
Wimmera River	Channel constrictions, or permeable features such as debris blockages and vegetation	May attenuate flow	No

6. New South Wales

6.1 Lower Darling

The Lower Darling River System is located in south-western New South Wales at the lower end of the Darling River, upstream of its junction with the River Murray at Wentworth. The main towns in the area are Broken Hill, Menindee, Coombah, Pooncarie, Burtundy and Wentworth. The extent and main features of the Lower Darling region are outlined in Figure 21.

A schematic diagram of the region is shown in Figure 22. All catchments in the northern Murray–Darling Basin drain into the Barwon–Darling River, which is separated from the Lower Darling by Menindee Lakes. Under natural conditions, Menindee Lakes are inundated only during large flood events, however they were modified in the 1960s to act as a water resource storage to supply users in the Lower Darling and Lower Murray regions. The Menindee Lakes system is operated by MDBA and the NSW Office of Water in accordance with the Murray–Darling Basin Agreement as set out in Schedule 1 to the Water Act 2007 (Cwlth).

Under regulated conditions, water passes through the main channel of the Darling River, converging with the Murray River at Wentworth. Some water can pass into the Great Darling Anabranch during larger flow events, joining with the River Murray approximately 15 km west of Wentworth.

The region contains a number of important environmental assets as described by MDBA (2012l), and outlined in Figure 22. These include:

- **Menindee Lakes**— a system of lakes covering an area of 45,000 ha, located on the Darling River adjacent to Menindee in the northern reaches of the catchment.
- **Lower Darling River** — the main channel, and adjacent billabongs and wetlands.
- **Great Darling Anabranch**— the ancestral channel of the Darling River, including a series of lakes and floodplains adjacent to the anabranch channel.

The Lower Darling region includes the townships of Menindee, Broken Hill and Pooncarie, all of which are supplied with water from the Lower Darling system. There are also a number of private irrigators located south of Menindee Lakes who extract water directly from the river.

Figure 21: The extent and main features of the Lower Darling region from the Menindee Lakes inflow to the Murray confluence at Wentworth

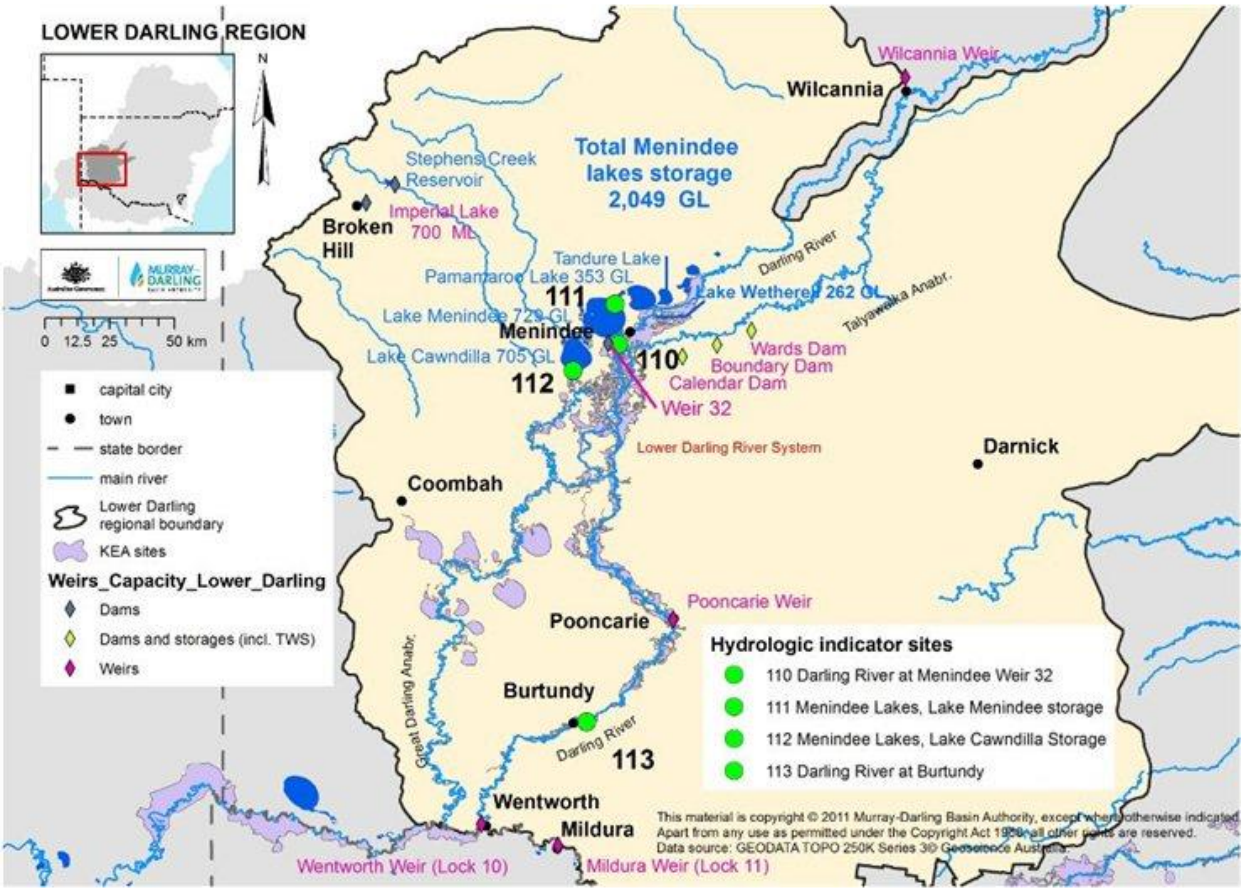
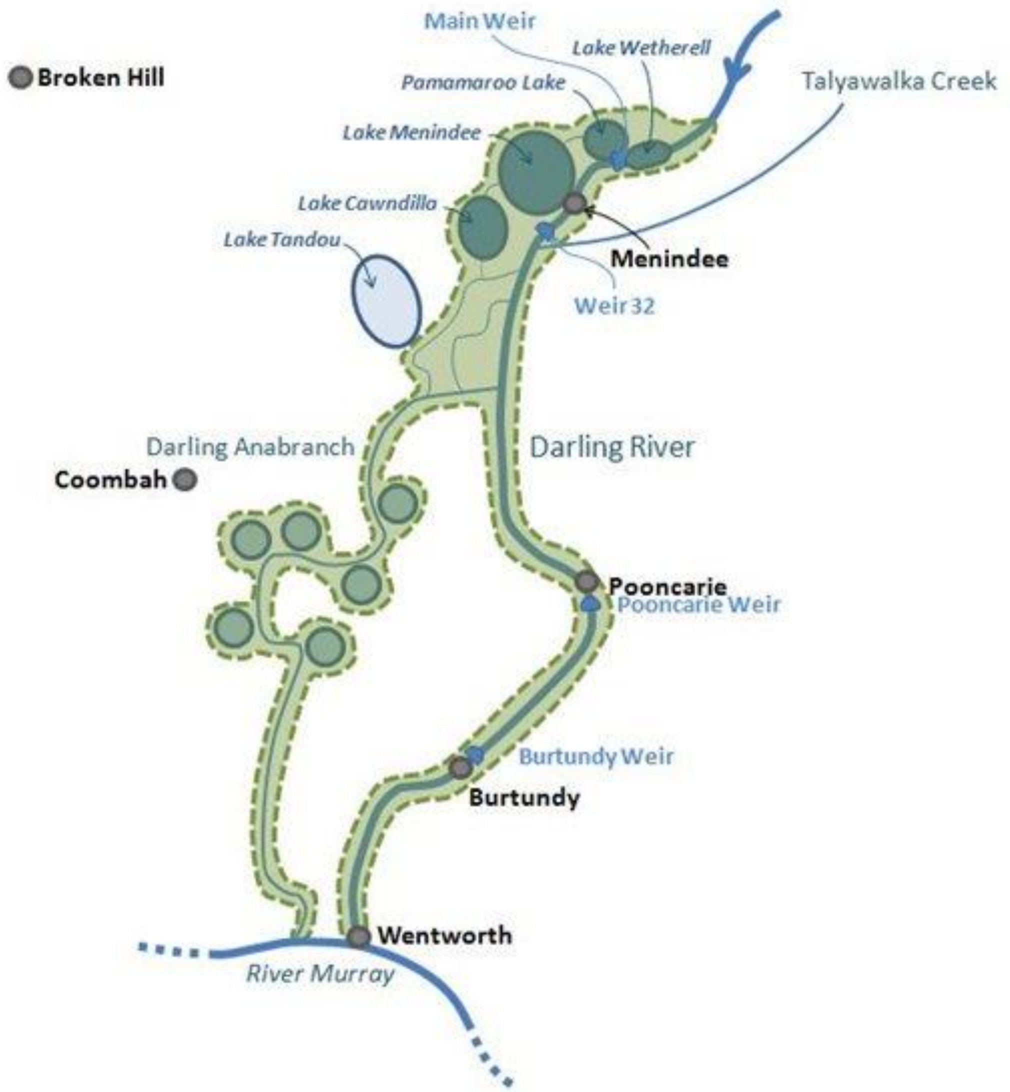


Figure 22: Schematic diagram summarising the key structural features and flow constraints in the Lower Darling region



A summary of the flow constraints in the Lower Darling River is presented in Table 29. First order constraints represent the primary impediments to the delivery of mid-to-high flow environmental events. If these constraints were overcome, the 2nd order grouping contains the next set of constraints that would potentially limit environmental water. A full investigation is required to determine the extent and flow at which these take effect.

Table 29: A list of key constraints limiting environmental flow delivery in the Lower Darling River, where constraints have been classified in terms of their capacity to limit flows

Order	Location	Description	Flow Limit (ML/d)
1st	Weir 32	Commence-to-flow threshold for Great Darling Anabranch	9,000
	Menindee Lakes	Critical human water requirements of Broken Hill and Menindee	—
	Menindee Lakes	Timing (ability to coincide multiple environmental releases from storages with large unregulated inflow events)	—
	Menindee Lakes	Storage release capacity (Lakes Wetherell, Pamamaroo and Menindee regulators)	14,000† (combined capacity at full supply level)
2nd	Menindee Township	Private land access and inundation	20,000
3rd	To be identified		

†Does not include the storage release capacity of Main Weir

6.1.1 Key Structures and Flow Constraints

Menindee Lakes and Weir 32

The Menindee Lakes system originally consisted of a series of natural depressions that filled only during flood events. After a flood event, water would drain from the lakes back into the main river channel, while some would be retained in the lowest parts of the depressions and would eventually evaporate. Due to this natural wetting and drying cycle, the ephemeral lakes in their undeveloped state supported large areas of flood-dependent vegetation. Lakes Menindee and Cawndilla supported large expanses of natural vegetation including lignum, black box and river red gum (MDBA 2012l).

In the 1960s the Menindee Lakes were modified by adding a series of small dams, weirs, regulators, channels, and levees to store large upstream flow events (NSW Department of Land and Water Conservation 1998; MDBA 2012l). The regulated system consists of four main interconnected lakes. Of these, three are modified natural depressions (Lakes Pamamaroo, Menindee and Cawndilla), while the fourth (Lake Wetherell) is an artificial lake along the main river channel formed by the construction of Main Weir. A channel was built to connect Lakes Pamamaroo and Menindee (via Copi Hollow), while the other interconnections are modified natural channels. In total there are seven main regulating structures, as shown in Figure 23 and listed with their capacities in Table 30.

Figure 23: Schematic diagram showing the regulating structures associated with the Menindee Lakes system

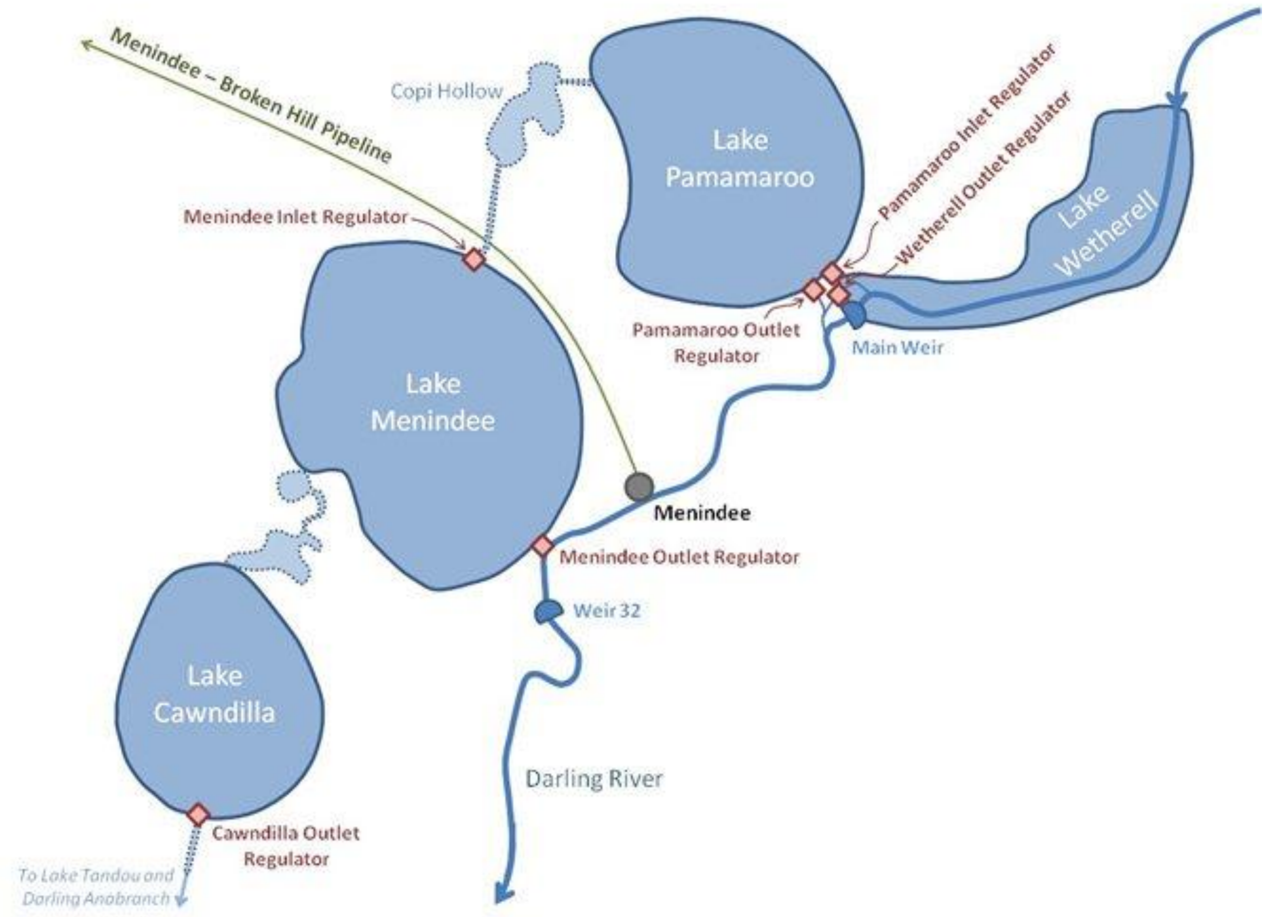


Table 30: The seven main regulating structures in the Menindee Lakes system

Regulator	Capacity (ML/d)
Main Weir (and associated levees)	70,000 (Main Weir gates) 110,000 (Main Weir spillway)
Lake Wetherell outlet	5,000
Lake Pamamaroo inlet	33,000
Lake Pamamaroo outlet	5,000
Lake Menindee inlet	25,000
Lake Menindee outlet	4,000
Lake Cawndilla outlet	2,000

These structures allow water to be transferred both between the lakes and to the main Darling River channel. Releases to the river can be made independently from Lakes Wetherell, Pamamaroo and Menindee — water cannot be released directly from Lake Cawndilla to the Darling River, instead it must first pass through Lake Menindee. The release rates listed in Table 30 for Lakes Wetherell, Pamamaroo and Menindee are available when storage levels are high and the Darling River level is low. At other times, the available release rates will be lower than those quoted in the table.

Total releases from Menindee Lakes to the Darling River are measured at Weir 32, located downstream of all lake outlet locations (Figure 23). Weir 32 was constructed in 1958 to provide additional security for the Broken Hill and Menindee town water supplies, and has a capacity of approximately 4 GL.

At full supply level the lakes can store 1731 GL of water, however during wet periods this can be raised to 2050 GL (subject to MDBA storage operation rules). If the stored volume drops below 480 GL control of the Menindee Lakes system is ceded to the New South Wales Government to maintain the town water supply in the Lower Darling (including Broken Hill and Menindee) and for stock and domestic users located along the river channel. Control of the Lakes reverts to MDBA when the stored volume increases above 640 GL.

Compared with other public storages throughout the Murray–Darling Basin, Menindee Lakes experiences a hotter, drier and windier climate, and each of the four main lakes is relatively shallow. Evaporative loss is therefore a significant issue, comprising an average volume of 420 GL every year.

The operating strategy for Menindee Lakes seeks to satisfy several criteria:

- Ensure supply for users in the Lower Darling, Lower Murray, and town water supplies
- Coordinate the relative levels of each lake
- Coordinate releases in harmony with Lake Victoria
- Act as a flood mitigation structure

Ensuring User Supply

Menindee Lakes supply water for agricultural purposes in the Lower Darling system, and provide additional flow to the Lower Murray when required. However, as a first priority Menindee Lakes provides water supply for the nearby towns of Broken Hill and Menindee, and for stock and domestic users located along the river channel. Of particular importance is the requirement to supply water for Broken Hill (population approximately 19,000), which partially relies on water piped 110 km from the Darling River (via a water treatment plant at Menindee; Figure 23). Although only a maximum of 10 GL per year is delivered from Menindee Lakes to Broken Hill, a significantly larger volume (300 GL; Lawrie et al. 2001) must be stored in the Lakes to protect the town water supply, (due to unpredictable inflows from the Northern Basin, very high evaporative losses, and the volume of inaccessible water — 'dead storage' — in each lake). Allocations for irrigators in the Lower Darling downstream of Weir 32 are maintained at zero if the water level in Menindee Lakes cannot supply Broken Hill for at least 21 months.

Lake Level Coordination

The relative levels of each lake in the Menindee system are coordinated to minimise evaporative and seepage losses, to minimise negative environmental impacts along the lake edges, and to reduce the risk of shoreline erosion, particularly of Aboriginal burial and cultural sites.

In general, water is preferentially stored in Lakes Wetherell and Pamamaroo to minimise evaporative and seepage losses, as these are deeper than Lakes Menindee and Cawndilla. During periods of substantial inflow, the lakes are filled sequentially — Lake Wetherell is filled first (to within the Darling channel), followed by Lakes Pamamaroo, Menindee and Cawndilla, with the option to store further water on the floodplain surrounding Lake Wetherell. If the Menindee Lakes system is relatively full, the lakes are drawn down in the following order:

1. Water is initially released from Lake Wetherell (through the outlet regulator, not Main Weir) to remove water from the inundated floodplain to maintain vegetative health.
2. Releases are then made from Lakes Menindee and Cawndilla (to minimise evaporative losses).
3. If the downstream requirements cannot be met through the Lake Menindee outlet regulator, additional releases are made from Lake Pamamaroo.
4. Finally if required, additional water can be released from the within-channel component of Lake Wetherell.

To minimise bank erosion, the operating strategy includes a set of rules regarding the rate at which releases can be increased or decreased; generally rates of rise are limited to 500 – 2,000 ML/d[2], and rates of fall to 250 – 500 ML/d[2].

'Harmony Operation' with Lake Victoria

Under a process known as 'Harmony Operation' water can be transferred from Menindee Lakes to Lake Victoria (located in the Lower Murray; Section 4.4) if flows in the River Murray are insufficient to maintain a suitable storage level. This process requires Menindee Lakes to be under MDBA control and balances the advantages of reduced evaporation (evaporation rates at Menindee Lakes are higher than at Lake Victoria) against the increased risk of loss of water as a result of spill from Lake Victoria. These transfers are typically made in late spring or summer.

Flood Mitigation

Menindee Lakes can act as a flood mitigation structure during high flow events from upstream catchments, reducing damage to downstream private holdings, notably those in the township of Menindee, located immediately downstream of Lake Wetherell. The first trigger for private flood damage is a flow of 20,000 ML/d at Weir 32.

Some upstream flood events can be completely absorbed by the lakes, depending on the space available in storage and the capacity for large volumes to be passed from Lake Wetherell to the other lakes in the system (water can be passed to Lake Pamamaroo at a rate of 33,000 ML/d, and from there to Lake Menindee at a rate of 25,000 ML/d; Table 30).

Larger magnitude flood events can trigger pre-releases from Lake Wetherell to mitigate the effects of the predicted event on downstream landholders. During normal operations, Main Weir remains closed to maintain Lake Wetherell (Figure 23) and water is released instead through the Wetherell outlet regulator (capacity 5,000 ML/d). However, pre-releases often require a greater release rate, which can be achieved by lifting the Main Weir gates. When possible, releases are maintained at a rate less than 20,000 ML/d to ensure there is no private property inundation, however larger flood events may require greater pre-release rates. To minimise structural damage to the weir the gates are lifted clear of the flow when the release rate exceeds 70,000 ML/d.

Channel Capacity Downstream of Weir 32

One of the main factors determining the operation of Menindee Lakes is the channel capacity downstream of Weir 32. Under normal conditions releases are limited to ensure the flow does not exceed 9,000 ML/d downstream of Weir 32. This operating practice is designed to minimise losses, as flows above this threshold can lead to water entering the Great Darling Anabranch. The anabranch system is itself an important environmental asset, and the requirement for environmental flows to this system (MDBA 2012l) has been recognised as part of the development of the Basin Plan. However, this system does not require environmental flows every year — the natural hydrology of the Great Darling Anabranch is characterised by periodic wetting and drying events. In some years the operational priority is to ensure the efficient delivery of water to downstream users by minimising flows into the anabranch.

Table 31: Flow constraints in the Lower Darling, where the flow and river height are measured at Weir 32 and the Bureau of Meteorology flood levels are marked in grey

Lower Darling Constraint	Flow at Weir 32 (ML/d)	Height at Weir 32 (metres)
Downstream channel capacity (regulated flows)	9,000	3.30
Substantial flows enter Great Darling Anabranch	12,000	4.30
Flow enters Tandou Creek	16,000	5.45
Access difficulties to land/property	17,000	5.70
Inundation of crops	17,700	5.90
BOM Minor Flood Level	18,200	6.00
Access to 5 properties affected	20,000	6.25
Access to 8 properties affected	23,000	6.40
Access to 10 properties affected	25,000	6.55
Tandou Road non-accessible	25,000	6.55
BOM Moderate Flood Level	25,900	6.60
Pooncarie Road non-accessible	29,500	6.78
Approximately 5 dwellings uninhabitable	30,000	6.80
Inundation of floors	31,300	6.86
Approximately 15 dwellings uninhabitable	36,000	7.05
BOM Major Flood Level	42,300	7.30
Approximately 25 dwellings uninhabitable	45,000	7.40
Potentially 100 dwellings evacuated	60,000	>7.50
Main roads and railway affected	>80,000	>7.50

A list of the channel capacity constraints to environmental flow delivery in the Lower Darling is given in Table 31. Flows in the range 9,000 – 20,000 ML/d can cause inconvenience for river-adjacent landholders, such as access issues or the requirement to remove water pumps. Measurements during previous unregulated high flow events indicate that water enters Tandou Creek when the flow exceeds 16,000 ML/d, while access to private land is affected at a flow of

17,000 ML/d. The first trigger for flood damage is a flow of 20,000 ML/d at Weir 32 — where possible, pre-releases from Lake Wetherell are kept below this level.

At higher flows, Tandou Road is no longer traversable when the flow reaches approximately 25,000 ML/d, and a flow of 29,500 ML/d removes access to the Menindee Township via the Pooncarie Road. A flow of approximately 40,000 ML/d exceeds the highest bankfull capacity in the Darling River downstream of Menindee, resulting in significant inundation of private property.

Pooncarie and Burtundy Weirs

Two further regulating structures are situated on the Darling River downstream of Weir 32. Pooncarie Weir was built in 1968 to artificially raise the river level and provide a water supply for the nearby town of Pooncarie. Regulated flows from Weir 32 require 5 – 6 days to reach Pooncarie Weir. Burtundy Weir (another 2 – 4 days of flow travel time further downstream) is a privately-owned structure built in 1942 (and raised in 1956) which provides water for domestic and irrigation purposes.

Neither structure represents an impediment to environmental water delivery as both are designed to allow overtop flows.

6.1.2 Representation of Constraints in the Hydrological Model

The Lower Darling region is included as a part of the MSM-BIGMOD model as used to represent the whole of the Murray region for Basin Plan development. To represent the 9,000 ML/d channel capacity at Weir 32, the model uses an operating rule which limits the flow to a maximum of 279 GL/month. This also represents minimised losses into the Great Darling Anabranch.

Regulated releases from the Menindee Lakes are currently constrained in the model to this same upper flow of 279 GL/month, which limits the ability of the model to deliver high flows to lower parts of the system.

Flooding levels at Menindee itself are not explicitly included in the model. Losses (including overbank losses caused by floods) in various modelled river reaches are represented as losses corresponding to a particular river flow, determined during model calibration.

6.1.3 Environmental Flows Affected by Constraints

As part of Basin Plan modelling development, mid-to-high flow environmental water requirements were identified for the floodplains and wetlands of the Lower Darling region situated along the main river and alongside the Great Darling Anabranch (MDBA 2012l). Additionally, some of the water recovered in the Darling catchment (including that recovered in the tributary catchments) could provide increased flows to Menindee Lakes, which could contribute towards meeting environmental water requirements in the Lower Murray. Existing flow constraints play a role in limiting the delivery of environmental water, as described below.

Lower Darling Floodplain

The Lower Darling region includes a large number of billabongs, wetlands and floodplain adjacent to the two main branches of the river system, the Darling River and Great Darling Anabranch. Unlike the majority of systems in the Murray–Darling Basin, flows in the Lower Darling rely almost entirely on upstream tributary inflows — there is almost no runoff in the region itself. During a large inflow event from an upstream tributary system (such as that from the Condamine–Balonne during 2011), substantial volumes of water are passed into the Lower Darling system. Some flows will pass into the Great Darling Anabranch, inundating the associated lakes and floodplains, while the remainder will pass along the main Lower Darling River channel to inundate nearby billabongs and wetlands.

The modification of the Menindee Lakes system has contributed to changes in the flow regime in the Lower Darling. Combined with the effects of upstream storages and irrigation development, the characteristics of overbank flow events in this region have been greatly altered. Flow seasonality in the Lower Darling has been reversed (higher flows now occur in summer rather than the natural spring/autumn periodicity) and the frequency of high flow events has significantly decreased. Furthermore, the frequency and volume of inundation events in the Great Darling Anabranch have both reduced as a result of upstream regulation and extraction (MDBA 2012l).

Five flow indicators were developed for the Lower Darling as part of the Basin Plan, and the methods and evidence base for these indicators are presented in MDBA (2012l). A summary of these indicators is presented in Table 32. Flow events peaking at 7,000 ML/d (measured downstream of Weir 32) are associated with flushing the Lower Darling channel and providing conditions suitable for fish passage. These events also inundate the riparian wetlands and vegetation communities directly adjacent to the Darling River. The delivery of these events is not impeded by existing physical and operational constraints, which allow flows up to 9,000 ML/d downstream of Weir 32. The delivery of these events requires sufficient water to be stored in Menindee Lakes and the ability to release this water from the lake regulators (an operational decision based on lake levels, river height, and the requirement to maintain reliability of town water supply).

Table 32: Ecological targets for the Lower Darling (MDBA 2012l), and the degree to which they can be achieved under current constraints and operational practice

Site-specific ecological targets	Site-specific flow indicators (flow measured at Weir 32)
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. Provide a flow regime which supports recruitment opportunities for a range of native aquatic species (e.g. fish, frogs, turtles and invertebrates). Provide a flow regime which supports key ecosystem functions, particularly those related to connectivity between the river and the floodplain.	Difficult to influence achievement under most conditions (constraints limit delivery at most times) • 20,000 ML/Day for 30 consecutive days between January & December for 14% of years. • 25,000 ML/Day for 45 consecutive days between January & December for 8% of years. • 45,000 ML/Day for 2 consecutive days between January & December for 8% of years. Achievable under current operating conditions • 7,000 ML/Day for 10 consecutive days between January & December for 70% of years. Achievable under some conditions (constraints limit delivery at some times) • 17,000 ML/Day for 18 consecutive days between January & December for 20% of years.

Events associated with the second indicator (flows of 17,000 ML/d downstream of Weir 32; marked yellow in Table 32) are limited by existing operational constraints, and would also require a change to the current operating practices of Menindee Lakes. Regarding the operational constraints, an examination of Table 31 indicates that these flows would not inundate private land, yet they may present some access difficulties for riverside property owners — these effects would need to be determined before changing operational policy. Furthermore, any changes to the operation of Menindee Lakes would require a change to the Murray–Darling Basin Agreement.

If these operational constraints were overcome, existing physical constraints may present problems delivering these events — releasing water at a rate of 17,000 ML/d from Menindee Lakes is not straightforward. The storage release capacities of the Menindee regulators (at full supply level) are listed in Table 30. The three main outlet regulators used during normal operations (those for Lakes Wetherell, Pamamaroo and Menindee) have a combined capacity of 14,000 ML/d (less if the lakes are not at full supply level or if the river level is relatively high). Hence, achieving a regulated flow of 17,000 ML/d downstream of Weir 32 can only be achieved by lifting the Main Weir gates to make substantial releases from Lake Wetherell.

The delivery of these events could also be constrained by the requirement ensuring critical human water needs in the nearby towns of Broken Hill and Menindee are met. Satisfying the desired hydrological outcomes requires a release of 17,000 ML/d for 18 days, equivalent to a total volume of 306 GL. Under some circumstances, releasing this large volume could result in standing water remaining in Lakes Menindee and Cawndilla (i.e. dead storage level), or significantly draw on the water stored in Lakes Pamamaroo and Wetherell. During years without substantial replenishment flows from upstream catchments, existing lake operation procedures constitute an environmental flow delivery constraint.

This issue could be partially addressed by increasing the release capacity of Lake Menindee, and improving the ability of this regulator to access dead storage (currently 51 GL in Lake Menindee and 48 GL in Lake Cawndilla). However, any adjustment to the current operating practices of the Menindee Lakes system would need to ensure reliability of supply for Broken Hill and Menindee.

The remaining three indicators are associated with flows of 20,000, 25,000 and 45,000 ML/d. These events are classified as beyond regulating capacity (brown in Table 32) due to the combination of storage release capacities, the lake operating strategy, and downstream channel capacities(the trigger for private land inundation near Menindee is a flow of 20,000 ML/d). Furthermore, it is not possible to supplement a large flow through the Menindee township with additional releases from Lake Menindee — during periods of relatively high river flow, the regulator is unable to provide additional volumes of water from Lake Menindee. These events therefore rely on large unregulated inflows from upstream catchments.

Downstream Requirements

The inclusion of a shared component in the diversion reduction volume for all catchments in the Basin Plan recognises that, under natural conditions, some of the water associated with mid-to-high flow events in the River Murray would have originated in the catchments of the Darling River, including those of its tributaries.

The existing practice to limit regulated releases from Menindee Lakes to 9,000 ML/d when possible is based on the commence-to-flow threshold for the Great Darling Anabranch — a flow greater than this rate would result in water passing into the anabranch. Therefore, increasing the release rate would not produce a proportional increase in flows to the River Murray. A significant portion of these extra releases would pass into the anabranch, and only a small fraction of the increased water entering the anabranch would reach the Lower Murray system. Furthermore, due to the meandering nature of the channel, these anabranch flows would have a significantly longer travel time than those through the main channel, and their arrival would therefore not contribute to the peak flow of the downstream inundation event.

In some years, flows entering the anabranch system will be a desired result. The Great Darling Anabranch is itself an important environmental asset and the environmental water requirements for this site (MDBA 2012l) have been recognised through the development of the Basin Plan. However, in other years the preference will be to maximise the volume of water passing downstream to support environmental water requirements in the Lower Murray.

This issue could be addressed by including a regulator to manage flows leaving the Lower Darling river to the Great Darling Anabranch. During periods when water is released to meet environmental requirements in the Lower Murray the regulator could be closed to stop water entering the anabranch and allow increased flows to pass along the main river channel to enhance environmental outcomes in the Lower Murray. The regulator could be open at other times to allow water into the anabranch and provide environmental benefits for the Lower Darling Floodplain.

Modelling conducted as part of the development of the Basin Plan included a scenario whereby increased environmental releases from Weir 32(up to 18,000 ML/d) were combined with an environmental flow regulator at the bifurcation site. The results indicated an increase in the duration and peak flow of overbank events at the Riverland–Chowilla Floodplain site, thereby increasing the inundation area and providing improved environmental benefits at this site (MDBA 2012z). Further work is required to determine the impact of this strategy on the hydrology of the Great Darling Anabranch (particularly in relation to the environmental water requirements of this system) and any potential third party impacts throughout the Lower Darling region. Any additional breakout points along the main channel would need to be addressed to provide efficient flow delivery to the River Murray.

Compared to releases from other major storages in the Southern connected Basin, regulated releases from Menindee Lakes have a considerably shorter travel time to Murray–Darling junction (about 10 days). The flow at Euston can be used to trigger such a release, as large flows from Euston have a similar travel time to Lake Victoria. Furthermore, Euston is located downstream of the Barmah-Millewa and Gunbower-Koondrook-Perricoota Forests, hence the uncertainty in conveyance losses and travel times associated with these systems will not affect the timing and volume of releases from Menindee Lakes. Compared to other storages, there is less risk in making such regulated releases to achieve environmental benefits (Senior River Operators Workshop 2012; MDBA in prep).

6.1.4 Summary

Table 33 below summarises the key constraints in the Lower Darling region and their importance in achieving the delivery of environmental water. The main constraints to downstream environmental flow delivery are the existing operational rules based on the channel capacity downstream of Weir 32, and the operational strategy and storage release capacity of the Menindee Lakes system.

Menindee Lakes are operated in such a way to provide a secure water supply for Broken Hill and Menindee, as well as provide added security for downstream water supply in this very arid region. Under regulated conditions, the maximum combined storage release capacity of the lakes is 14,000 ML/d at full supply level. Additional aims of the operational strategy are to mitigate flooding at the nearby township of Menindee. These rules can potentially adversely affect the ability to deliver environmental water at times that it is required for downstream use.

The third constraint listed in Table 33 is the flooding level of Menindee township, for which private land starts to become inundated at 20,000 ML/d. This constraint, however, is not thought to be a major constraint to downstream environmental flow delivery.

Table 33: Summary of Lower Darling constraints where constraints have been classified in terms of their capacity to limit flows

Table 33: Summary of Lower Darling constraints where constraints have been classified in terms of their capacity to limit flows

Location	Constraint Description	Flow Constraint	Inhibits Environmental Flow Delivery?
Weir 32	Operational rules based on commence-to-flow threshold for Great Darling Anabranch	9,000 ML/d	Yes
Menindee Lakes	Storage release Capacity and Operational Strategy	14,000 ML/d (combined)	Yes
Menindee	Flooding Level	20,000 ML/d	No

6.2 Murrumbidgee

The Murrumbidgee River spans almost 1,600 km rising in the Monaro Plains near Cooma and running northward through the ACT before moving westward to its junction with the River Murray downstream of Balranald. The Murrumbidgee constitutes a major tributary of the River Murray and is one of Australia's most developed and regulated river systems.

The upper section of the Murrumbidgee contains the river source, regulated through Tantangara dam, and runs through upland areas, the ACT, and Burrinjuck storage. Burrinjuck is a comparatively small storage, relative to the size of its catchment, and spills frequently (in 67% of years under Baseline conditions).

The lowland section of the Murrumbidgee runs between Gundagai and Balranald, and has a well-defined meandering channel with steep banks. Bank full channel widths vary between 80 m at Gundagai (minor flood level 48,500 ML/d) and Wagga Wagga, and 50 m or less at Balranald (minor flood level 26,000 ML/d).

The channels and wide floodplains of the Murrumbidgee (the Mid-Murrumbidgee Wetlands and Lower Murrumbidgee Floodplain) provide extensive lignum and aquatic habitat resulting in high ecological diversity. Regulation and development over the past century have significantly degraded these habitats and associated ecosystems throughout the valley.

Environmental water requirements for the Mid-Murrumbidgee Wetlands (MDBA 2012t) and the Lower Murrumbidgee Floodplain (MDBA 2012p), which include mid-to-high flow events to inundate areas of natural floodplain have been specified as part of the development of the Basin

Plan. The extent and features of the Upper and Mid-to-Lower Murrumbidgee regions are both presented in Figure 24 and Figure 25.

In-channel flow requirements have also been identified in the Lower Murrumbidgee River (MDBA 2012o) however the delivery of these events to the region is not expected to be influenced by upstream flow constraints.

A schematic diagram outlining the key structural features and flow constraints in the Murrumbidgee region is shown in Figure 26. The general trend in the Murrumbidgee River is for the carrying capacity of the river channel to gradually decrease when moving downstream of Gundagai, and this is a major driver of operational policy in the valley.

Flood levels are specified in terms of river height at a specific site. Note that the rating tables used to convert river height to flow rate used in this report are currently being updated for several gauges in the Murrumbidgee. Hence the specific flow numbers presented in this section may be subsequently revised slightly. The values presented here correspond to those used in the Murrumbidgee Water Sharing Plan and other sources as used to collate the information.

Figure 24: The extent and main features of the Upper Murrumbidgee region, from the river headwaters to Narrandera

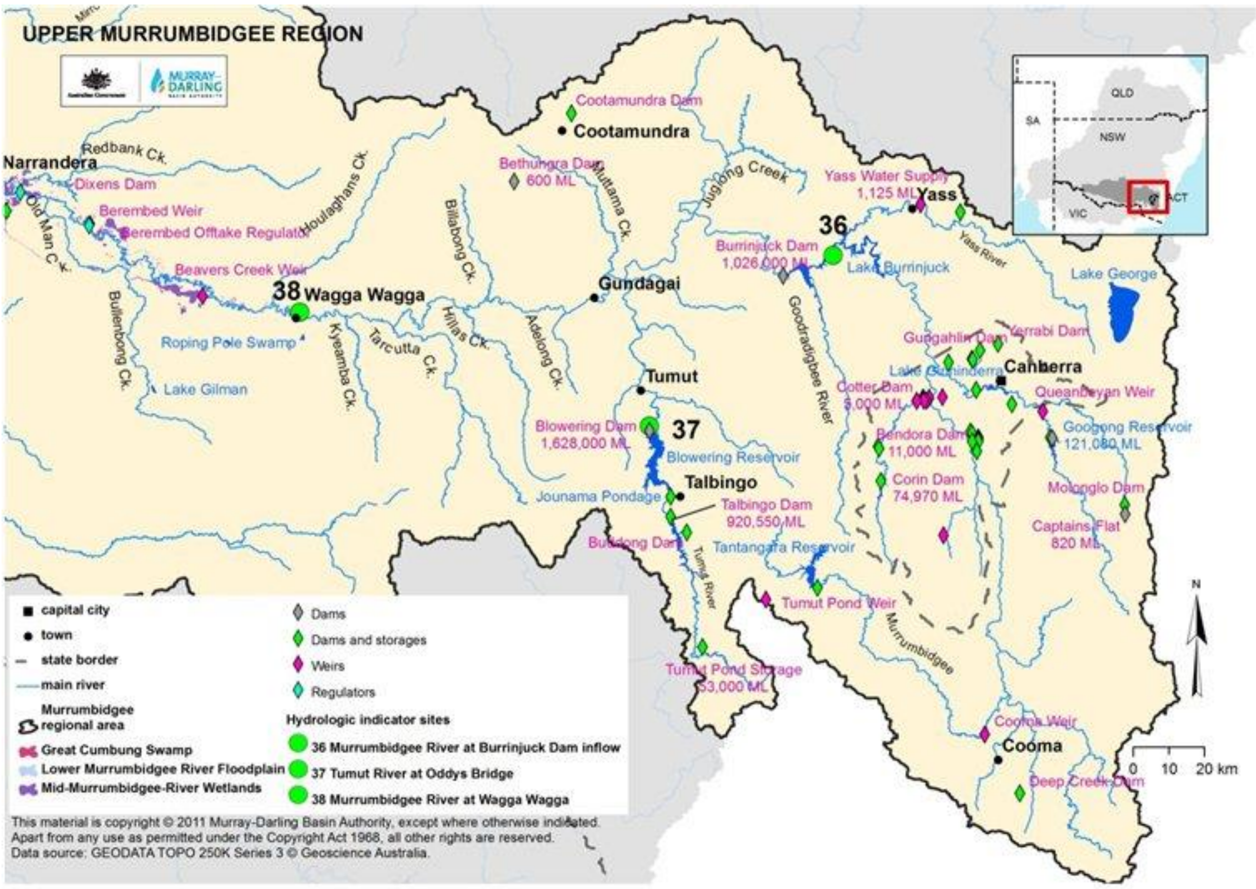


Figure 25: The extent and main features of the Mid-to-Lower Murrumbidgee regions, from Narrandera to the Murray

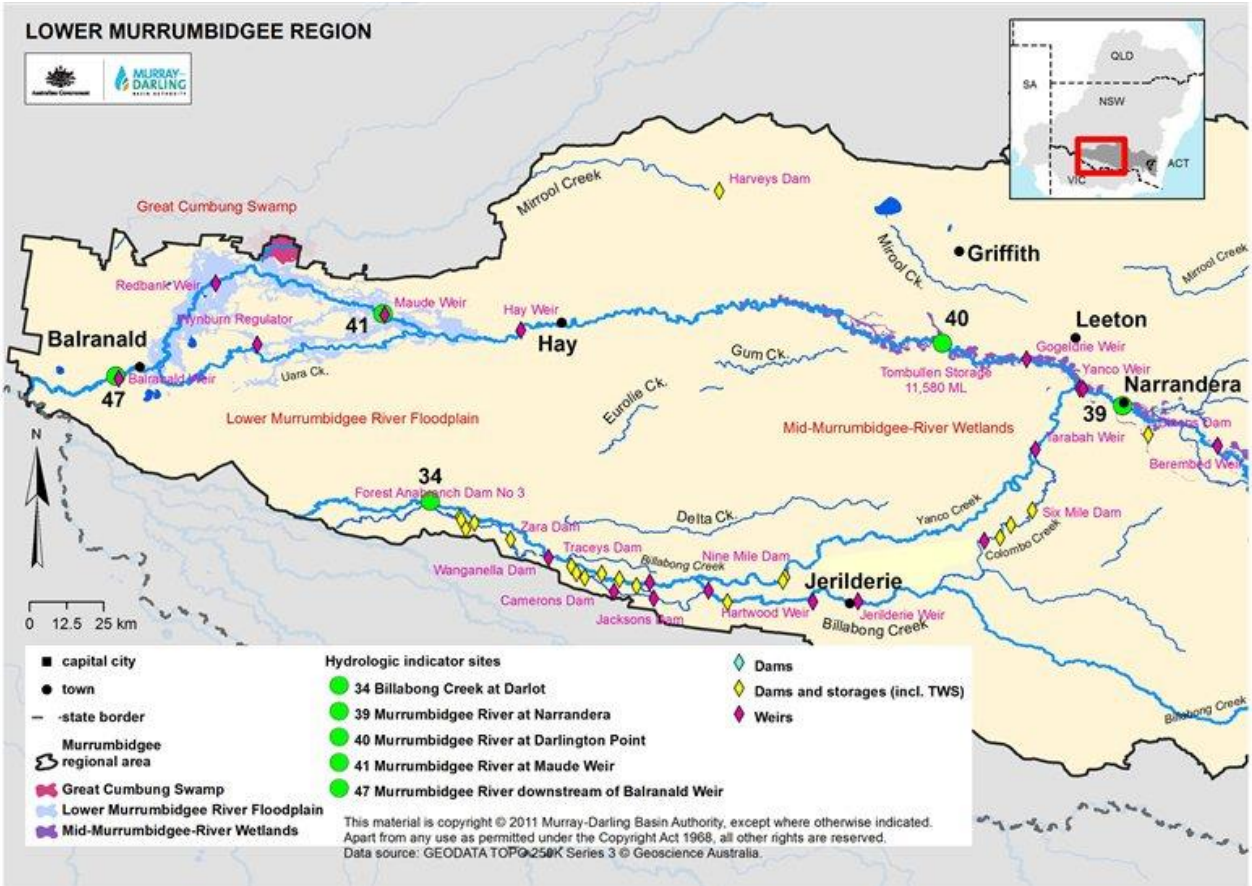
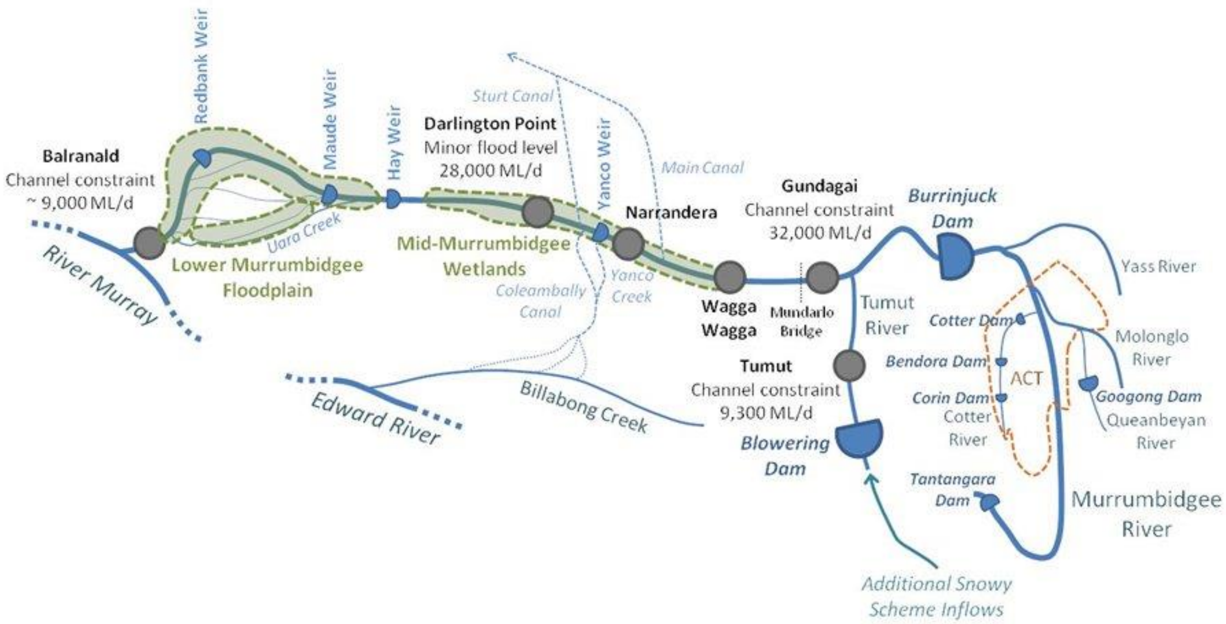


Figure 26: Schematic diagram summarising the key structural features and flow constraints in the Murrumbidgee region



A summary list of the flow constraints in the Murrumbidgee River is presented in Table 34. First order constraints represent the primary impediments to the delivery of mid-to-high flow environmental events. If these constraints were overcome, the 2nd order grouping contains the next set of constraints that would potentially limit environmental water. A full investigation is required to determine the extent and flow at which these take effect. The 3rd order grouping contains relatively minor flow constraints which could be overcome through a change to existing operational policy, or a practiced coordination between environmental and irrigation water delivery. These constraints are more fully described in the subsections below.

Table 34: A list of key constraints limiting environmental flow delivery in the Murrumbidgee River, where constraints have been classified in terms of their capacity to limit flows

Order	Location	Description	Flow Limit (ML/d)
1st	Gundagai	Private land access and inundation (Mundarlo Bridge)	32,000
	Tumut River at Tumut	Channel constraint and erosion control	9,000
	Tumut River at Oddy's Bridge	Channel constraint and erosion control	9,300
	Yanco Creek	Private land access and inundation	1,400 at offtake (~20,000 at Narrandera)
	Blowering and Burrinjuck Dams	Timing (ability to coincide multiple environmental releases from both storages with large unregulated inflow events)	—
2nd	Darlington Point	Channel capacity (minor flood level)	27,700
	Balranald	Channel capacity and delivery of flows to downstream locations on River Murray	~9,000
3rd	Lower Murrumbidgee Floodplain	Management of regulators	—

6.2.1 Key Structures and Flow Constraints

Upper Murrumbidgee

The Upper Murrumbidgee region includes several storages to ensure reliability of water supply for ACT/Queanbeyan residents, and to allow the mitigation of natural flood events. These storages include the Corin, Bendora and Cotter Dams (all located on the Cotter River in the ACT) and Googong Reservoir, located in the upper reaches of the Queanbeyan River in NSW. The Queanbeyan River joins the Molonglo River downstream of the ACT border (Figure 26); both the Molonglo and Cotter Rivers are major tributaries of the Upper Murrumbidgee River.

There are a number of privately and publicly-owned sites adjacent to the Queanbeyan, Molonglo and Upper Murrumbidgee Rivers that could be subject to flooding during unregulated mid-to-high flow events. However, no overbank environmental watering requirements have been identified in those river reaches upstream of Burrinjuck Dam, hence potential flooding effects are not a constraint to environmental water delivery in the Upper Murrumbidgee region.

Furthermore, the capacity to manage flood events in the Upper Murrumbidgee River is limited. The majority of flow between Tantangara and Burrinjuck storage hence originates from local catchment inflows, which (excluding the Molonglo and Cotter Rivers) are unregulated.

The upper reaches of the Murrumbidgee are partially regulated through Tantangara Dam, with a maximum release rate of 2,445 ML/d. Riparian releases are made mostly in summer and autumn, at discharge rates that are generally lower than 50 ML/d. Environmental releases have been previously made in the spring and have had maximum flows exceeding 100 ML/d in the spring of 2007, 2008 and 2009 (Snowy Scientific Committee 2010, DIPNR 2004a).

Burrinjuck and Blowering Dams

At full supply level, the maximum release rates for Burrinjuck and Blowering Dams are 29,100 and 21,300 ML/d respectively. At Burrinjuck in particular, lower storage level will impact on storage release capacity. In practice these values do not represent a limit to the delivery of environmental water. Instead, releases are limited by operational practices which aim to minimise bed and bank erosion and mitigate flooding of private land downstream of the dams on the Murrumbidgee and Tumut Rivers. These constraints are discussed below.

Tumut River

Flows in the Tumut River downstream of Blowering Dam are limited to ensure flows do not exceed 9,000 ML/d at Oddy's Bridge and 9,300 ML/d at Tumut, with the aim of minimising bank erosion. Release rates from Blowering Dam are hence limited to this range (9,250 ML/d). This is therefore an operational constraint based on physical limitations.

If this constraint was overcome, the next impediment to environmental releases from Blowering Dam would be potential inundation of private land. A full inundation map of this river reach is not yet available, however the minor flood level for Tumut is associated with a flow of 16,104 ML/d, around which private land can be flooded and access routes affected.

Mundarlo Bridge — Murrumbidgee Channel Constraint at Gundagai

The regulated flow at Gundagai cannot exceed 32,000 ML/d as listed in the Murrumbidgee Water Sharing Plan (DIPNR 2004a). Flows above this limit affect private land access, notably via Mundarlo Bridge downstream of Gundagai. This limit also reduces the potential for larger overbank events further downstream (i.e. at Darlington Point). This limit can impede the delivery of environmental water from Blowering and Burrinjuck Dams to downstream sites, particularly the Mid-Murrumbidgee Wetlands, for which target environmental flows of 44,000 and 63,250 ML/d have been identified (flow measured at Narrandera; MDBA 2012t).

The inundation of private land along the Mid-Murrumbidgee is emerging (from ongoing public consultation) as an important consideration and is to be subsequently investigated in greater detail, including further research to map the geographical inundation patterns. As a guide, the minor flood level at Gundagai corresponds with a flow of approximately 48,500 ML/d. Private land inundation along the length of the Mid-Murrumbidgee may emerge as an immediate constraint to be considered in parallel with any policy changes to Gundagai flow rates.

However, the ability to exceed 32,000 ML/d at Gundagai could improve the achievement of higher flows downstream of the main irrigation off-takes at Berembed and Gogelderie Weirs. Under current arrangements large volumes are extracted during unregulated events at these locations to feed supplementary access entitlements, particularly in late summer and early spring, impacting wetlands between Darlington Point and Hay. Hence high flows required for the Mid-Murrumbidgee wetlands can currently only be met through high-flow unregulated events in the upstream catchment or by releasing water from Blowering and/or Burrinjuck Dams. This would supplement high-flow unregulated events originating in smaller tributaries downstream of Mundarlo Bridge (such as Hillas, Tarcutta and Houlaghans Creeks).

Yanco Creek

Yanco Creek is an important regulated effluent stream on the Murrumbidgee River downstream of Narrandera (Figure 26). Under natural conditions (prior to 1856), water would have passed into the creek only when flow in the Murrumbidgee River exceeded approximately 40,000 ML/d (White et al. 1985). In the late 1880s, an eight-mile cutting was made to improve connectivity between Yanco Creek and the main river channel, and Yanco Weir was built in the 1920s to regulate flows at the offtake site through the weir pool. Yanco Creek is now used to deliver water to irrigation and agricultural users in the Yanco Creek System (including Yanco, Colombo and Billabong Creeks), and to residents in the towns and villages of Morundah, Urana, Oaklands, Jerilderie, Conargo and Wanganella. Some of the water passing into this system can eventually reach the Edward River (a major anabranch of the River Murray) through Billabong Creek (the minimum flow target at Darlot is 50 ML/d; DIPNR 2004a).

Under regulated conditions, the flow in Yanco Creek is maintained between a minimum of 500 ML/d (100 ML/d during drought, normal winter minimum is around 300 ML/d) to ensure supply for stock and domestic purposes and a maximum of 1,400 ML/d (DIPNR 2004a). Flows above this upper threshold will start to inundate private land adjacent to the creek at approximately 2,000 ML/d and lead to additional losses. An analysis of MDBA (2011b) modelling data indicates that a flow of approximately 18,000 ML/d at Narrandera triggers an increase in flow into Yanco Creek above the 1,400 ML/d threshold. The environmental water requirements identified for the Mid-Murrumbidgee Wetlands are associated with flows of at least 26,850 ML/d at Narrandera. The existing operational capacity of Yanco Creek will therefore divert a portion of this flow from the Murrumbidgee under current practice.

Darlington Point

Downstream of Narrandera the channel capacity of the Murrumbidgee River decreases, causing a greater proportion of flows to overtop the river bank and inundate the surrounding floodplain, creating a region known collectively (from Wagga Wagga to Hay) as the Mid-Murrumbidgee Wetlands. Some parts of the wetlands are inundated at flows below the nominal 'bankfull flow'. The reduction in channel capacity also increases the inundation rate of private land adjacent to the river channel, particularly near Darlington Point, compared with upstream reaches of the river.

The minor flood level at this location is associated with a flow of approximately 27,700 ML/d. This generally corresponds to the flow constraint at Gundagai (32,000 ML/d) after accounting for losses between the two sites, hence the upstream constraint on regulated flows also minimises the potential for flood events at Darlington Point. As a result, if the upstream Gundagai constraint was overcome, there would be a risk of potential flooding of private land near (and downstream of) Darlington Point during periods of environmental water release, as well as potential increases to bank erosion caused by higher flows. A quantification of potential third-party impacts in this region is necessary.

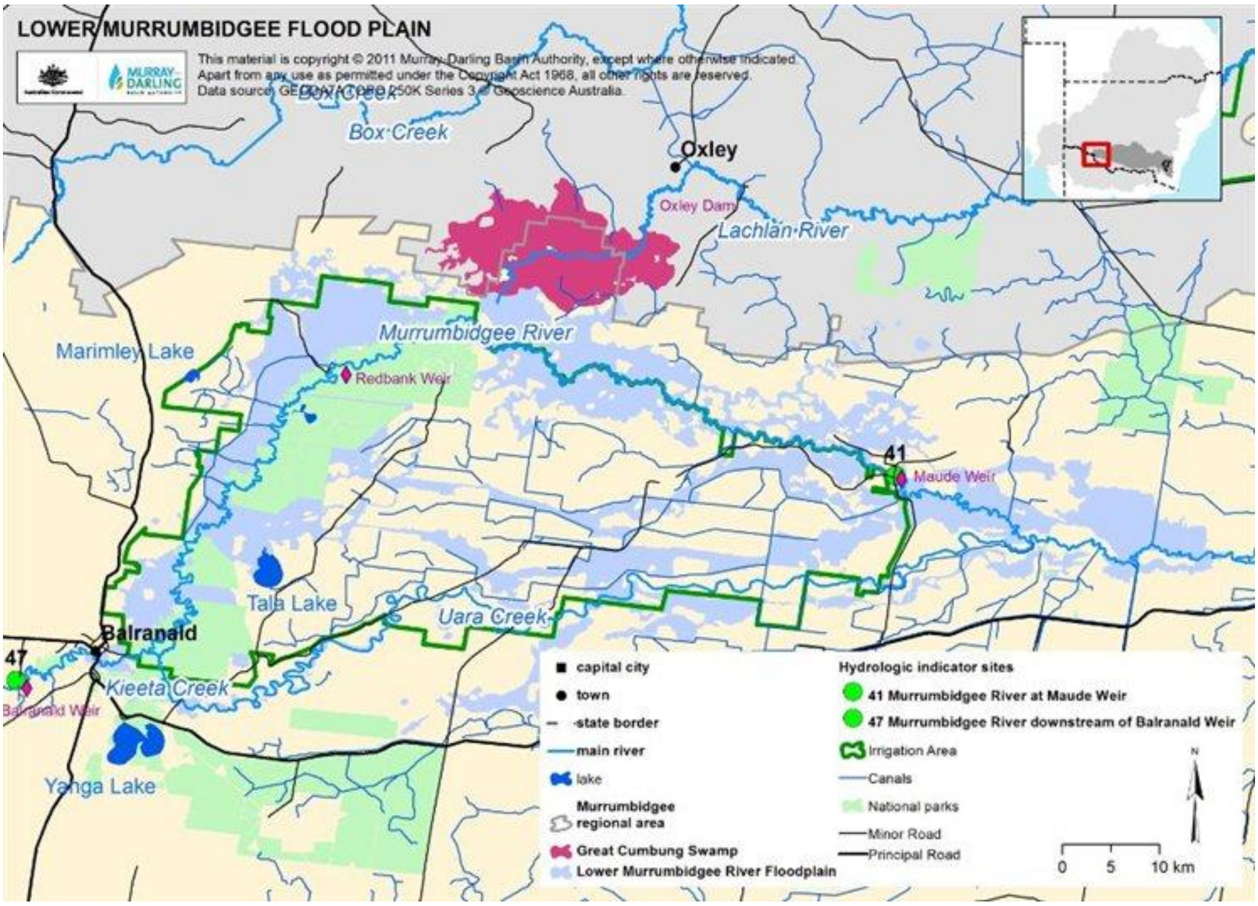
Flow Delivery to the Lower Murrumbidgee Floodplain

The Lower Murrumbidgee Floodplain (Figure 27) is a major environmental asset of the southern Murray–Darling Basin. It is also the site of a significant irrigation centre, the Lowbidgee Flood Control and Irrigation District. Water consumption in this region is shared between the environment and irrigators, with the vast majority of regulated diversion used in controlled flooding in the Nimmie–Caira region. Maude and Redbank Weirs (Figure 26) are government-owned structures which allow supplementary access water to be diverted from the main channel onto the Lower Murrumbidgee Floodplain, and historically a series of privately-owned structures allow a portion of this water to be diverted towards agricultural production. More recently, new regulating structures have partially restored the natural hydrological function in parts of the floodplain (DEH 2012).

Flows downstream of Redbank Weir at Chaston's Cutting are significantly attenuated due to rapidly narrowing channel capacity. This part of the system is known as the Murrumbidgee Choke and constitutes a natural constraint to downstream water delivery (channel capacity approximately 8,000 ML/day), which may affect the delivery of high flow environmental requirements for the River Murray. The channel then widens again until it reaches a capacity of 9,000 ML/d at Balranald with some variation in the published values. Further work is required to determine the channel capacity to a greater degree of certainty.

The environmental water requirements specified for the Lower Murrumbidgee Floodplain are based on a total volume of water during a specific season at Maude Weir (MDBA 2012p). The desired volumes can generally be delivered to Maude Weir as in-channel flows (i.e. 20,000 ML/d at this location) within current operational constraints (subject to timing, upstream channel capacity constraints and irrigation demands); the floodplain inundation could then be achieved using existing structures such as Maude and Redbank Weirs, and regulators on the floodplain inlet channels. Subsequent shepherding of flows through the various properties in the Nimmie–Caira region would require considerable involvement of landholders in the area. Such flows would eventually lead to Lake Tala where they could subsequently return to the Murrumbidgee during periods of high flow. Major unregulated events also pass down Uara Creek upstream of Maude Weir and re-enter the Murrumbidgee upstream of Balranald. The flow indicators are based on a minimum flow of 5,000 ML/d at Maude Weir, which enables diversions onto the floodplain while maintaining in-channel flows downstream of Redbank Weir.

Figure 27: The extent and main features of the Lower Murrumbidgee Floodplain environmental asset



End of System Channel Constraint at Balranald

Through the development of the Basin Plan, environmental water requirements were identified for Balranald, located downstream of the Lower Murrumbidgee Floodplain and near the junction with the River Murray (Figure 26). This water has a dual purpose:

- To satisfy in-channel fresh requirements identified in the Lower Murrumbidgee River (measured at Balranald; MDBA 2012o)

- To assist with the achievement of environmental outcomes downstream on the River Murray, notably those associated with overbank flows at Hattah Lakes (MDBA 2012h) and the Riverland–Chowilla Floodplain (MDBA 2012v)

The minor flood level at Balranald is associated with flows of approximately 26,000 ML/d, well above the maximum flow that could be achieved through regulated environmental flows, and is therefore not expected to impede environmental releases from upstream storages.

Upstream of Balranald, the delivery of water to this location is subject to a physical flow constraint. Due to the natural morphology of the river channel and adjacent land, the Lower Murrumbidgee Floodplain acts as a re-regulating feature which significantly attenuates high flow events. That is, the characteristics of a relatively short duration and high peak flow event in the Murrumbidgee River are altered by its passage through the Lower Murrumbidgee such that the flow event reaching the River Murray has an increased duration and reduced peak flow. Furthermore, much of the volume is lost in the Lower Murrumbidgee Floodplain due to uptake by vegetation, evaporation and seepage to groundwater systems. Under current operating practices and arrangements, environmental releases in the Murrumbidgee River will generally not be able to produce flows greater than 9,000 ML/d at Balranald (as this typically corresponds to a flow of 30,000 – 35,000 ML/d at Gundagai), although additional work is required to determine the bankfull flow rates at Balranald with greater certainty. Environmental release could be used to extend the duration of a 9,000 ML/d flow event at Balranald.

There is potential to overcome this natural constraint through a number of actions, such as pre-filling the Lower Murrumbidgee system to ensure it is ‘primed’ for upcoming environmental flows passing to the Murray. The water required for this pre-filling could be provided by upstream watering actions, such as those for the Mid-Murrumbidgee Wetlands and/or the Lower Murrumbidgee Floodplain.

The presence of regulators in the Lower Murrumbidgee offers two further scenarios to pass additional flows downstream. Firstly, it may be possible to bypass the Nimmie–Caira region by closing existing regulators once internal watering requirements have been satisfied, allowing water to pass through the main channel. In this scenario, flows would still be affected by the Murrumbidgee Choke at Chaston’s cutting. A second option is to bypass the Choke by allowing additional flows to pass through the Nimmie–Caira region (or, to a lesser extent, the Redbank System). Most of the Nimmie–Caira region is currently privately owned, and significant involvement of private landholders would need to occur to implement this option.

6.2.2 Representation of Constraints in the Hydrological Model

In general, the constraints described above are reproduced in the hydrological model, with the following notable changes:

- **Tumut River:** water orders in the model are truncated to 9,100 ML/d at Tumut, and releases from Blowering are limited to 9,250 ML/d
- **Gundagai:** the model includes this constraint as 30,000 ML/d (rather than the 32,000 ML/d value described above). Under baseline conditions this limit is never exceeded, however the increased water orders for environmental purposes in the Basin Plan

scenario modelling does lead to water orders being truncated to 30,000 ML/d a fraction of the time.

- **Yanco Creek:** The model includes a maximum flow rate of 1,300 to 1,400 ML/d at the Yanco Creek offtake, however this is exceeded at times of increased river flows.
- **Maude Weir:** Flows into the Nimmie–Caira region include a maximum flow rate of 3,500 ML/d to represent regulator operation.

6.2.3 Environmental Flows Affected by Constraints

As described, the main flow constraints in the Murrumbidgee system are:

- 9,000 ML/d in the Tumut River at Oddy's Bridge (limiting Blowering releases)
- 9,300 ML/d in the Tumut River at Tumut (limiting Blowering releases)
- 32,000 ML/d at Gundagai (limiting combined Blowering and Burrinjuck releases)
- 1,400 ML/d in Yanco Creek at the offtake
- 9,000 ML/d at Balranald (with uncertainty)

Environmental water requirements associated with mid-to-high flows have been identified in the Murrumbidgee region at two hydrological indicator sites:

- Mid-Murrumbidgee Wetlands (MDBA 2012t)
- Lower Murrumbidgee Floodplain (MDBA 2012p)

In addition, the importance of in-channel fresh events has been identified for the Lower Murrumbidgee (MDBA 2012o), and some of the water recovered in the Murrumbidgee system is expected to contribute towards environmental outcomes in the River Murray system. The delivery of some of the flow requirements is impeded by existing flow constraints, as described below.

Mid-Murrumbidgee Wetlands

Compared with other reaches of the Murrumbidgee River, the natural reduction in channel capacity in the central reaches results in a higher frequency and duration of overbank inundation events. This provides conditions conducive to the establishment of flood-dependent vegetation and the Mid-Murrumbidgee Wetlands. This asset comprises a large number of lagoons and billabongs formed by a combination of floodplain geography and old river channels. The flood-dependent vegetation includes large areas of river red gums and black box woodlands, and aquatic vegetation in lagoons and swamps adjacent to the river channel. The wetlands are also an important site for waterbirds, frogs and native fish. The environmental flows associated with this site are measured at Narrandera (MDBA 2012o).

The main ecologically-significant flows at this site that are affected by constraints are the high flow events with peak flows of 34,650, 44,000 and 63,250 ML/d. These events inundate large areas of the wider floodplain downstream of Narrandera, and are important to maintain the health and resilience of the river red gum and black box population. Flows below these levels are also ecologically important and are also affected by upstream system constraints. Any alleviation of constraints will play an important role in enhancing both low and high flow regimes throughout the Murrumbidgee system.

Preliminary hydrological modelling conducted for the MDBA Senior River Operators Workshop 2012 (unpublished) shows that the Tumut River constraint limits the extent to which Blowering Dam can help deliver the highest flow requirements at this site (44,000 ML/d and 63,250 ML/d, both for three consecutive days). That is, a relaxation of the constraint would be beneficial for high flow delivery. However, this constraint is based on channel erosion minimisation and the practicality of its relaxation is yet to be fully investigated. If this constraint was relaxed, the potential inundation of private land and potential increase in bank erosion would impose a new flow constraint, which would need to be assessed.

Further modelling indicates that a relaxation of the Gundagai constraint (from 32,000 to 50,000 ML/d) would improve the ability to deliver 34,650 and 44,000 ML/d events to the Mid-Murrumbidgee Wetlands (MDBA 2012z). Additional modelling (Senior River Operators Workshop 2012; MDBA in prep) indicates that pre-filling the channel before delivering 44,000 ML/d events can significantly increase their success rate. The success rate of 63,250 ML/d events was not influenced by constraint relaxation or channel pre-filling, being driven by unregulated main river and tributary inflow events.

Flows greater than approximately 18,000 ML/d, at Narrandera will result in additional water passing from the weir pool into Yanco Creek and exceeding the 1,400 ML/d threshold, inundating private land. Furthermore, a significant portion of the water delivered for the Mid-Murrumbidgee Wetlands would be lost down this effluent stream. NSW is assessing environmental flow needs to the Yanco Creek System (Barma Water Resources 2012). The effects of installing a regulator on the Yanco Creek offtake, to provide greater control over the flows entering the creek, require further investigation.

Table 35 summarises the specific ecological targets for the Mid-Murrumbidgee Wetlands (MDBA 2012t). Consistent with the modelling results described above, the colour scheme denotes whether or not the indicator can be met within current constraints and operational practices (blue), or if a relaxation of constraints could improve the successful delivery of these events (yellow). The highest flows (63,250 ML/d; marked brown) are categorised as beyond regulating capacity.

Table 35: Ecological targets for the Mid-Murrumbidgee wetlands (MDBA 2012tand the degree to which they can be achieved under current constraints and operational practice

Site-specific ecological targets	Site-specific flow indicators (flow measured at Narrandera)
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 and invertebrates). Provide a flow regime which supports key ecosystem functions, particularly those related to connectivity between the river and the floodplain.	Achievable under current operating conditions • 26,850 ML/d for a total duration of 45 days between July and November between 20 to 25% of years • 26,850 ML/d for 5 consecutive days between June and November between 50 to 60% of years Achievable under some conditions (constraints limit delivery at some times) • 34,650 ML/d for 5 consecutive days between June and November between 35 to 40% of years • 44,000 ML/d for 3 consecutive days between June and November between 30 to 35% of years Difficult to influence achievement under most conditions (constraints limit delivery at most times) • 63,250 ML/d for 3 consecutive days between June and November between 12 to 15% of years

If upstream flow constraints were overcome the success of these events would often rely on a combination of environmental releases from Burrinjuck and/or Blowering Dams and unregulated inflow events from tributaries downstream of these storages (such as Adelong, Tarcutta and Muttama Creeks). Therefore these events are also constrained by timing. Environmental outcomes are maximised when the timing of environmental releases is coordinated to ensure the peak flows from separate events coincide. The travel time of high flow events is subject to greater uncertainty than in-channel flows, and varies depending on antecedent conditions and whether the flow is regulated or unregulated. There are therefore significant operational challenges related to the timing of environmental releases, and the capacity to achieve this level of coordination between the two major storages is not yet known. To date, coordination has been successful in delivering flows up to 32,000 ML/d at Gundagai.

Lower Murrumbidgee Floodplain

The Lower Murrumbidgee Floodplain contains the largest complex of wetlands in the Murrumbidgee system, including one of the largest lignum wetlands in New South Wales and extensive River Red Gum and Black Box communities. The floodplain receives water from the Murrumbidgee River from either overbank events or via controlled diversions from Maude and Redbank Weirs. It can be divided into four management units based on distinct ecological and hydrological characteristics, covering 155,000 ha. Namely:

- Nimmie–Caira system
- Redbank management unit
- Murrumbidgee management unit
- Fiddlers–Uara Creeks system

The hydrology of the district has been significantly altered by human development and flow regulation. In addition to the inflow regulation provided by Maude and Redbank Weirs, the floodplain now includes a large number of block, channel and levee banks designed to control flooding within the district. These changes, combined with agricultural land development, are estimated to have resulted in a loss of 58% of the original wetland area (Kingsford & Thomas 2004). MDBA (2012p) provides a full description of the system.

As described above, flow constraints are not expected to prevent the delivery of water to this site, as floodplain inundation here can be achieved using regulators (including Maude and Redbank Weirs) under existing arrangements. This is reflected in Table 36, in which all flow indicators are marked blue. However, passing significant flows through the Nimmie–Caira region from Maude Weir to Lake Tala for potential downstream use would require considerable involvement and agreement of landholders in the region. The Lower Murrumbidgee Floodplain consists mostly of privately held land, and the proposed watering actions would require landholder permission.

Table 36: Ecological targets for the Lower Murrumbidgee Floodplain(MDBA 2012p), and the degree to which they can be achieved under current constraints and operational practice

Site-specific ecological targets	Site-specific flow indicators (flow measured at Maude Weir)
Provide a flow regime which ensures the current extent of native vegetation of 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.	Achievable under current operating conditions • A total in-flow volume of 175 GL above a minimum flow threshold of 5000 ML/d during July & September for 70% of years • A total in-flow volume of 270 GL above a minimum flow threshold of 5000 ML/d during July & September for 60% of years • A total in-flow volume of 400 GL above a minimum flow threshold of 5000 ML/d during July & October for 55% of years • A total in-flow volume of 800 GL above a minimum flow threshold of 5000 ML/d during July & October for 40% of years • A total in-flow volume of 1700 GL above a minimum flow threshold of 5000 ML/d during July & November for 20% of years • A total in-flow volume of 2700 GL above a minimum flow threshold of 5000 ML/d during May & February for 10% of years

Lower Murrumbidgee River (in-channel flows)

The in-channel environmental water requirements specified at Balranald have two general aims:

- To provide healthy flow conditions for a range of native aquatic species (e.g. fish, frogs, turtles and invertebrates)
- To support key ecosystem functions such as longitudinal connectivity and transport of sediment, nutrients and carbon

An examination of MDBA modelling results indicates that, under current arrangements, the maximum regulated flow which can be delivered to Balranald is 9,000 ML/d. The in-channel requirements for the Lower Murrumbidgee River do not exceed 4,500 ML/d (MDBA 2012o, summarised in Table 37), hence these are classified as “achievable under current operating conditions” (blue).

Table 37: Ecological targets for the Lower Murrumbidgee in-channel flows (MDBA 2012o), and the degree to which they can be achieved under current constraints and operational practice

Site-specific ecological targets	Site-specific flow indicators (flow measured at Balranald)
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	Achievable under current operating conditions • 1100 ML/d for 25 consecutive days between December & May for 58% of years • 4500 ML/d for 20 consecutive days between October & December for 54% of years • 3100 ML/d for 30 consecutive days between October & March for 55% of years

Downstream Requirements

The inclusion in the Basin Plan of a shared component in the diversion reduction volume recognises that under natural conditions, some of the water associated with mid-to-high flow events in the River Murray would have originated from the Murrumbidgee River.

Due to losses and extraction en route, a regulated flow of approximately 9,000 ML/d at Balranald corresponds to a flow of approximately 30,000–35,000 ML/d at Gundagai, and can therefore be achieved under current water management arrangements. This was reflected in the environmental watering regime represented in the Basin Plan modelling scenarios (MDBA 2012y), which limited the downstream contribution to a flow of 9,000 ML/d. A set of companion 'relaxed constraints' scenarios (MDBA 2012z) raised the target flow to 13,000 ML/d to further assist the successful delivery of periodic overbank flow events at the downstream sites on the River Murray, specifically those at Hattah Lakes and the Riverland–Chowilla Floodplain sites. From these companion scenarios the following key conclusions can be drawn:

- Achieving a flow of 13,000 ML/d at Balranald requires a significantly greater release rate from upstream storages, and much of this water can be lost to overbank flows.
- Under current arrangements, it may be possible to achieve a flow of 13,000 ML/d at Balranald, however a pre-filling of the Lower Murrumbidgee Floodplain would significantly increase the number of days at which the target flow is deliverable. In practice this would be very difficult to accomplish as much of the Lowbidgee Flood Control and Irrigation District is privately-owned, and the required volumes may be prohibitively large.
- Alternatively, a changed water management process for the Lower Murrumbidgee Flood Control and Irrigation District (that is, changes to the operation of Maude and Redbank Weirs) during downstream delivery periods could maximise the volume of water passing through the main channel or bypassing the Murrumbidgee Choke.

In addition, managing the timing of environmental releases from upstream storages to ensure water from the Murrumbidgee is coincident with high flows in the Murray and Goulburn systems will be challenging, but is expected to improve with experience and as forecasting abilities improve. As a general guide, the travel times from the Murrumbidgee storages to the SA border are the longest in the southern-connected Basin, therefore it is most likely that releases from Hume and Eildon will be triggered on the basis of high flows in the Murrumbidgee. The options for releases from the Murrumbidgee storages are limited to the following (Senior River Operators Workshop 2012; MDBA in prep):

- Regulated release from Burrinjuck to increase Balranald flow and augment high flows arising from Upper Murray and Goulburn, triggered by high, unregulated flows at Yarrawonga and/or McCoy's Bridge; or,
- release from Burrinjuck to extend duration of existing unregulated event in Murrumbidgee; or,
- proactive release from Burrinjuck to meet in-valley environmental requirements and pre-wet Lower Murrumbidgee floodplain so that subsequent events are passed with reduced losses and possibly a higher peak.

The ability to combine environmental releases from multiple valleys is yet to be fully investigated but has been shown to be theoretically possible (Senior River Operators Workshop 2012; MDBA in prep).

6.2.4 Summary

Table 38 below summarises the key constraints in the Murrumbidgee region and their importance in environmental flow delivery. The main constraints relate to the operation of both Burrinjuck and Blowering Dams, as well as channel capacities and the operation of regulators within the Lower Murrumbidgee Floodplain.

Burrinjuck and Blowering Dams are operated in a manner to provide increased security for irrigation and town water supply in downstream reaches, and to provide existing environmental flows as stated in the Murrumbidgee Water Sharing Plan (DIPNR 2004a). The storage release capacities of the two storages are not considered an important constraint for environmental flow delivery however the operational policies in place to limit release based on channel erosion and inundation are potentially important.

Additionally, as for other valleys in the Murray–Darling Basin, the timing of releases to coincide with downstream tributary inflow events is of prime importance in the successful delivery of higher flow environmental requirements for the Mid-Murrumbidgee Wetlands. Travel times between the storages and their flow confluence at Gundagai is of the order of one day, however, tributaries downstream of the confluence add significantly more time when trying to synchronise regulated releases with unregulated inflows. Hence the timing of releases is considered a constraint in the Murrumbidgee region.

Flooding levels have been identified for Gundagai (confluence of the Tumut River and Murrumbidgee River, downstream of Burrinjuck) and Tumut (downstream of Blowering). The Gundagai constraint is specified to keep regulated releases below 32,000 ML/d at Gundagai, to limit inundation directly caused by those regulated releases. The Tumut constraint is related to bank erosion in the Tumut River as well as limiting inundation of Tumut township. Both are considered important constraints to the successful delivery of environmental water.

The offtake capacity of Yanco Creek is also listed as a constraint. This could potentially affect the peaks of high flow environmental flows although additional analysis is needed to full explore this possible effect.

The final two constraints involve the operational management policies of the Lower Murrumbidgee Floodplain and the channel capacity at Balranald. These are particularly important for the delivery of Murrumbidgee water for downstream River Murray requirements, considering the significant attenuation of peak flows in the Lower Murrumbidgee and the limited capacity of the main river channel to deliver flows downstream. A potential change to the management policy of the Lower Murrumbidgee could allow downstream-directed flows to bypass the Murrumbidgee Choke at Chaston's Cutting and the small channel capacity at Balranald.

Table 38: Summary of Murrumbidgee, where constraints have been classified in terms of their capacity to limit flows

Location	Constraint Description	Flow Constraint	Inhibits Environmental Flow Delivery?
Burrinjuck and Blowering Dams	Timing (ability to coincide multiple environmental releases from both storages with large unregulated inflow events)	—	Yes
Gundagai	Flooding Level	32,000 ML/d	Yes
Tumut	Flooding Level and Bank Erosion	9,000 ML/d	Yes
Yanco Creek	Offtake Channel Capacity	1,400 ML/d	Possibly
Darlington Point	Channel Capacity	27,700 ML/d	Possibly
Lower Murrumbidgee Floodplain	Management of Regulators	—	Yes
Balranald	Channel Capacity	9,000 ML/d	Yes

6.3 Lachlan

The Lachlan region is a major component of the Murray–Darling Basin to the north of the Murrumbidgee region and to the south of the Macquarie–Castlereagh region, covering an area of 84,700 km^2, lying in central western New South Wales. A map of the region, showing its extent and main features, is shown in Figure 28. The regulated Lachlan River flows in a well-defined channel for 1,450km in a westerly direction from its headwaters in the foothills of the Great Dividing Range near Gunning, and terminates in the Great Cumbung Swamp to the north of the Lower Murrumbidgee Floodplain (a site of major ecological significance covering an area of approximately 16,000 ha). Major towns in the Lachlan region include Cowra, Forbes and Condobolin, with the region having a total population of around 100,000.

The topography of the Lachlan region varies significantly from tablelands in the east, through sloping country in the central regions to plains in the west, with varying rainfall across the differing terrain. The Lachlan catchment is primarily a terminal system, ending at its western extremity in the Great Cumbung Swamp near Oxley. Flows can, however, during periods of high unregulated inflow discharge southwards and connect with the Lower Murrumbidgee Floodplain between Hay and Balranald. Flows in the regulated Lachlan River are highly variable with periods of zero flow possible during times of drought. Due to the location of the region and unlike the Murrumbidgee or Murray regions, headwater inflows are not driven by reliable spring flows due to melting snow. Irrigation occurs in the middle reaches of the region, with 14% of total NSW agricultural production being generated in the region (CSIRO 2007f).

A major tributary of the Lachlan River is the regulated Belubula River, which flows through Canowindra to its confluence with the Lachlan downstream of Wyangala Dam. Other tributaries include the Boorowa, Crookwell and Abercrombie Rivers, which join the Lachlan upstream of Cowra.

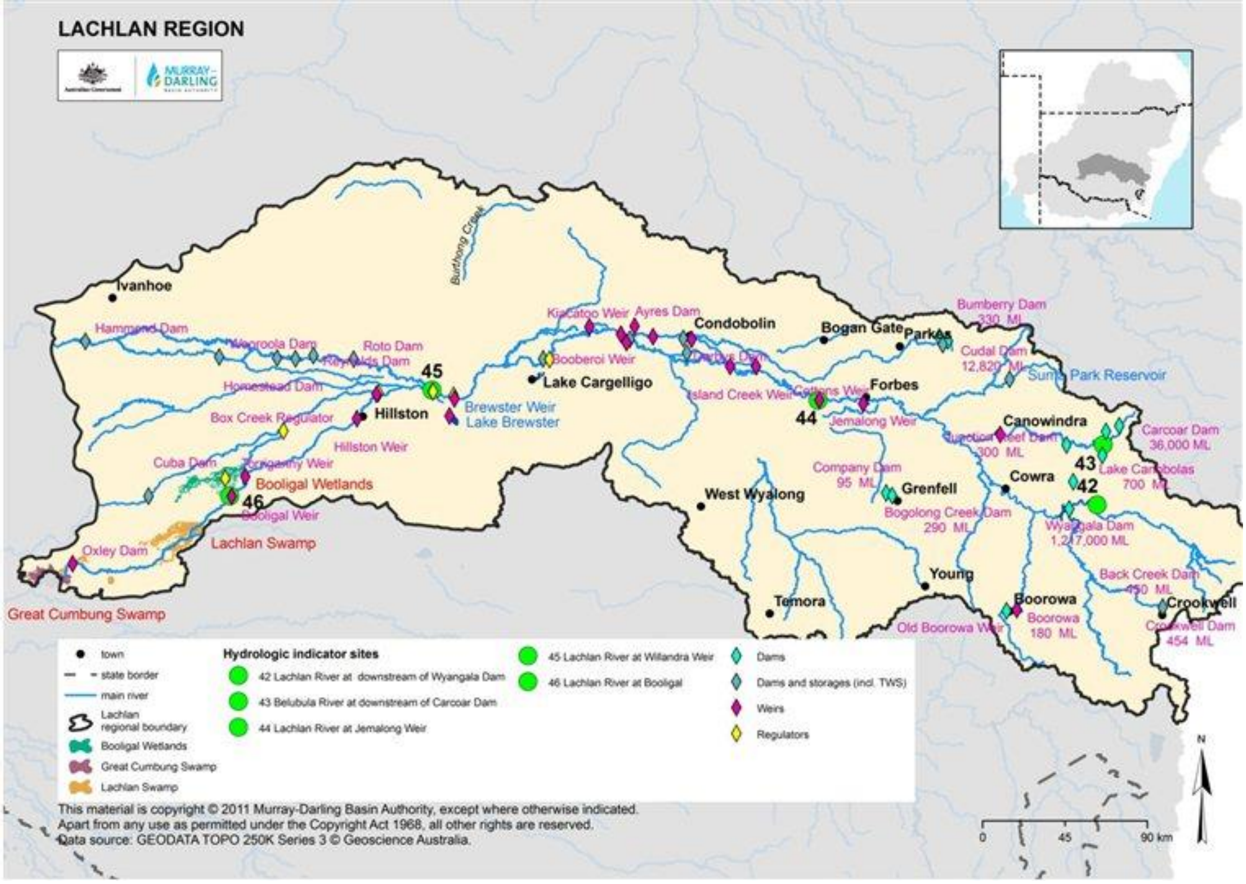
The flow regime of the Lachlan region has been significantly affected by human development and extraction, with extensive banks, cuttings and regulators (including the major storages) reducing the frequency and duration of small to medium-level flood events. Periods of zero flows have been extended and period of high flow have shifted later in the season to satisfy irrigation demand. A schematic diagram of the Lachlan region, showing structural features and a summary of flow constraints, is presented in Figure 29.

The Lachlan catchment is regulated by two major headwater storages:

- Wyangala Dam (1,220 GL capacity) and
- Carcoar Dam (36 GL capacity).

Flows into Wyangala are highly variable and greatly unreliable. For example, in 2009 the combined effect of the Millennium Drought and the cumulative effect of releases for consumptive use was to reduce the storage level to only 4.5% of full capacity. Water from Carcoar Dam is released directly into the Belubula River which is used by downstream irrigators.

Figure 28: The extent and main features of the Lachlan region

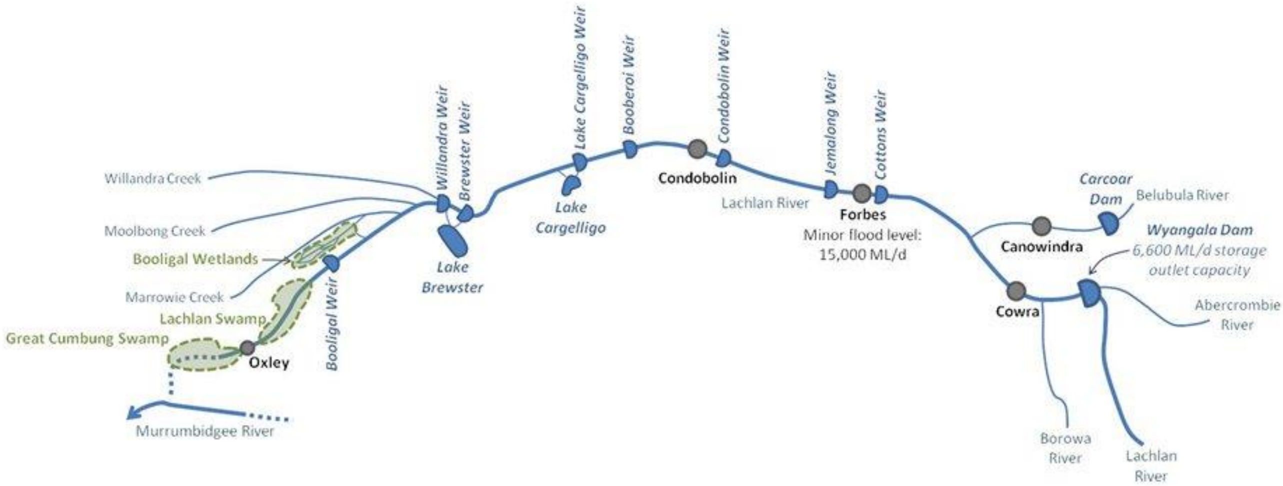


Downstream mid-river regulating storages include Lake Cargelligo (36 GL capacity) and Lake Brewster (154 GL capacity). Minor re-regulating structures include Brewster Weir, Jemalong Weir and Willandra Weir. Part 3 of the Water Sharing Plan for the Lachlan Regulated River Water Source 2003 (DIPNR 2004f) specifies a series of translucency releases for specific Environmental Water Provisions.

The Lachlan River undergoes a significant reduction in channel capacity downstream of Lake Brewster, with the river breaking in various anabranches and flood runners. This part of the region supports a number of significant water dependent ecosystems including the Great Cumbung Swamp, the Booligal Wetlands and the Lachlan Swamp. Environmental flow requirements have been specified for this significant set of assets as part of Basin Plan development. These requirements are associated with flows between 300 and 2,700 ML/d at Booligal Weir; full details are provided in MDBA (2012e).

The swamps and wetlands in this region are of major national significance, supporting extensive river red gum, lignum, reed and black box communities and provide conditions conducive for waterbird (and other wetland fauna) breeding events. These wetlands also provide a refuge for a very large variety of wildlife during drier years. Higher flows in the Lachlan River are subject to re-regulation at Lake Brewster and to a lesser extent at Lake Cargelligo 40 km upstream of Brewster. This may affect the size, timing and duration of flooding in the Lower Lachlan. Regulation has significantly altered the flow regime for these assets, including a decrease in high flow inundation and an increase in cease-to-flow events throughout the Lachlan region. Full details of the environmental properties and background to the work defining requirements for these significant assets can be found in MDBA (2012e). Basin Plan modelling (MDBA 2012y) indicates that these environmental flows can be delivered within existing flow constraints.

Figure 29: Schematic diagram summarising the key structural features and flow constraints in the Lachlan



A summary list of potential constraints in the Lachlan region is presented in Table 39. Flow constraints defined as 1st order constitute primary constraints to successful delivery of environmental flows for the catchment. Constraints which become sequentially important once 1st order constraints are considered are defined as 2nd and 3rd order constraints. For the Lachlan, the identified constraints to efficient flow delivery are the storage release capacity of Wyangala Dam (2nd order) and the reregulating capacity of Lakes Cargelligo and Lake Brewster (3rd order). There are no 1st order constraints specified for the Lachlan region. Policy constraints (such as those related to water sharing plan rules) will be investigated in a separate document.

No flooding levels have been included as constraints for the Lachlan, as the minor flood levels (e.g. at Forbes corresponding to a flow of 15,000 ML/d) are far in excess of any environmental requirement for the region. However further investigation into the effects of removing the identified constraints could potentially lead to flooding risks being added to those listed.

Table 39: A list of key constraints limiting environmental flow delivery in the Lachlan region, where constraints have been classified in terms of their capacity to limit flows

Order	Location	Description	Flow Limit (ML/d)
1st	To be identified		
2nd	Wyangala Dam	Storage release capacity	6,600
3rd	Lake Cargelligo	Re-regulation	—
	Lake Brewster	Re-regulation	—

6.3.1 Key Structures and Flow Constraints

The main storages in the Lachlan region comprise:

- Wyangala Dam (1,220 GL capacity)
- Carcoar Dam (36 GL capacity)
- Lake Cargelligo (36 GL capacity)
- Lake Brewster (153 GL capacity)

Wyangala Dam has a maximum storage release capacity of 6,600 ML/d. Lakes Brewster and Cargelligo act as re-regulating lakes in the middle reaches of the Lachlan River.

The region also includes a number of weirs along the main river stem (Figure 29) which artificially raise the water level to provide reliability of supply for nearby towns and irrigation systems. Additionally, a number of potential constraints related to local channel capacities are described in the Lachlan Water Sharing Plan (DIPNR 2004f).

6.3.2 Representation of Constraints in the Hydrological Model

The MDBA has used the IQQM Lachlan Model as developed by the NSW Office of Water to represent the Water Sharing Plan to help develop Basin Plan environmental flow rules and targets.

Wyangala Dam is modelled as a headwater storage with a maximum capacity of 1,217 GL. Storage release capacity rates are defined via a storage level/release capacity table with an storage release capacity of 6,800 ML/d when full, which decreases with decreasing storage level. Carcoar Dam is modelled with a full capacity of 36 GL which spills when the storage level rises to greater than this level.

Lake Cargelligo is modelled as an off river storage with a maximum storage volume of 60 GL. Storage inlet flow rate is defined by a constant 1200 ML/d, and outlet flow rates are defined by a table relating release rate to month of the year. Lake Brewster is modelled as an extraction point defined by a series of flow conditions which define inlet and outlet flow rates. The results of the conditions are determined on a daily basis within the model. Constraints as defined in the Lachlan Water Sharing Plan (DIPNR 2004f) are not included in the model.

Flood levels at various locations are not explicitly modelled. However losses (including overbank losses) in those reaches are represented as losses corresponding to a particular river flow, determined during model calibration.

6.3.3 Environmental Flows affected by Constraints

The environmental water requirements in the Lachlan region identified during Basin Plan development can be characterised as volumetric requirements for three main sites:

- Great Cumbung Swamp,
- Booligal Wetlands, and
- Lachlan Swamp.

Full details of these requirements can be found in MDBA (2012e), which aim to provide a minimum volume of water to be delivered to these sites in a specified frequency and in a specified season. The flow indicators, along with the degree to which existing system constraint affect their delivery, are summarised in Table 40, Table 41 and Table 42respectively. The indicators are associated with flows between 300 and 2700 ML/d measured at Booligal Weir in the lower reaches of the Lachlan River (Figure 29).

Modelling conducted as part of Basin Plan development suggests that these flow indicators can largely be satisfied under existing constraints (MDBA 2012y). However, the modelling also indicates that constraints may limit the delivery of these flows during specific conditions, such as dry years with relatively high irrigation demands. Addressing constraints could allow for increased flexibility in delivering some environmental flows.

Wyangala Dam

The main 2nd order constraint identified in Table 39is the storage release capacity of Wyangala Dam. At full supply level, the storage release capacity is 6,600 ML/d however this decreases as the volume of stored water decreases. Wyangala Dam is required to provide a more secure water supply for downstream irrigators and town water. Hence some environmental releases to meet the desired flows would be made in addition to existing irrigation releases.

The identified environmental flows range from 300 to 2,700 ML/d, far less than the maximum release capacity of Wyangala Dam. Hence in general the release capacity will not be a constraint to environmental water delivery. However, in order to compensate for delivery losses downstream of the storage, a larger volume of water may sometimes be required to be released. Larger flows can overtop some weirs and off-takes along the river, spilling water into distributary systems.

There is a resulting attenuation in the system which may affect the ability to deliver larger flows. It can be difficult to predict the exact volumes required, as they depend on the antecedent catchment conditions at that particular time, and on the properties of the individual event required. Further analysis, based on practical environmental watering events and additional modelling, can further clarify the extent to which this could impede environmental water delivery.

Furthermore, the delivery of some larger environmental flows may be impeded under specific water conditions. For example, a relatively low storage level (and consequently a reduced release capacity) combined with high irrigator demand could impede environmental releases.

This type of occurrence would be rare, and would not affect the ability to achieve the desired environmental outcomes over the long-term.

A potential increase of the storage release capacity of Wyangala Dam may afford future water managers added flexibility in delivering individual events. Further modelling could determine more accurately the need of any increased storage release capacity at Wyangala Dam. If an increased storage release capacity was considered, potential third-party impacts would need to be quantified.

Additional Flow Constraints

Additional constraints identified in Table 39constitute the operational re-regulation properties of Lakes Brewster and Cargelligo. The operation of these lakes provides a secure water supply for nearby townships, as well as for regional tourism. Part 3 of the Lachlan Water Sharing Plan (DIPNR 2004f) identifies flows to be delivered through Brewster Weir for the lakes region, as well as rules defining outflow rates for downstream use. An alteration of these rules may be required to allow environmental water to pass by these locations for use in downstream environmental assets. Further analysis is required to scope out potential options to change the management of these lakes to maximise efficiency of water delivery and minimise third party impacts, particularly during years when the lakes are low.

Flows into Willandra Creek via the inlet regulator commence to flow at 2,400 ML/d, which is significantly lower than the threshold for without-development conditions (8,000 ML/d). This lower threshold leads to increased flows into Willandra Creek and hence greatly increased losses for flows that may have been targeted for environmental outcomes further downstream on the Lachlan River. A proposal has been prepared by the Lachlan Riverine Working Group (LRWG) to raise the inlet regulator to allow increased ability to pass flows without the extra losses into the creek.

Flood levels throughout the Lachlan region are not thought to constitute a constraint to environmental flow delivery. Inundation rates for major towns (i.e. Forbes) are far in excess of any required environmental volumes, however further analysis is required to fully quantify any additional flood risk to small scale landholders.

Assessment of Environmental Flow Indicators

Table 40, Table 41 and Table 42 summarise the specific flow indicators for the environmental assets in the Lachlan region as detailed in MDBA (2012e). All indicators are considered to be deliverable within existing system constraints, however this assessment is based on long-term average results and the identification and further analysis of the constraints could potentially increase delivery efficiency of environmental flows in the region.

Table 40: Site-specific flow indicators for Great Cumbung Swamp (MDBA 2012e) and the degree to which they can be achieved under current constraints and operational practice

Site specific ecological targets	Site specific flow indicators (flow measured at Booligal Weir)
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.	Achievable under current operating conditions • 700 ML/Day for 25 consecutive days between June & November for 50% of years • 1500 ML/Day for a total of 35 days between June & November for 40% of years • 2700 ML/Day for 30 consecutive days between June & November for 20% of years

Table 41: Site-specific flow indicators for Booligal Wetlands (MDBA 2012e) and the degree to which they can be achieved under current constraints and operational practice

Site specific ecological targets	Site specific flow indicators (flow measured at Booligal Weir)
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	Achievable under current operating conditions • 300 ML/day for 25 consecutive days between June & November for 70% of years • 850 ML/day for a total duration of 70 days between June & November for 33% of years • 2500 ML/day for 50 consecutive days between June & November for 20% of years

Table 42: Site-specific flow indicators for Lachlan Swamp (MDBA 2012e) and the degree to which they can be achieved under current constraints and operational practice

Site specific ecological targets	Site specific flow indicators (flow measured at Booligal Weir)
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.	Achievable under current operating conditions • 850 ML/Day for 20 consecutive days between June & November for 50% of years • 850 ML/Day for a total duration of 70 days between June & November for 33% of years • 1,000 ML/Day for 60 consecutive days between June & November for 20% of years • 2,500 ML/Day for 50 consecutive days between June & November for 20% of years

Downstream Requirements

The Lachlan region is characterised as a terminal system. Hence no downstream requirements have been identified during the development of environmental requirements for the Basin Plan.

6.3.4 Summary

Environmental flow requirements have been specified for volumetric requirements in the Great Cumbung Swamp, Booligal Wetlands and Lachlan Swamp, with full details presented in MDBA (2012e). Previous Basin Plan modelling has shown that by recovering the required volume of water to specifically target these requirements through a combination of regulated releases and tributary inflows, all can be met within existing system constraints when results are considered as a long-term average (MDBA 2012y). Hence there are no 1st order constraints in the Lachlan region.

Table 43includes 2nd and 3rd order constraints which may limit the delivery of specific environmental flow events under special circumstances. These include the storage release capacity of Wyangala Dam, and the operation strategy of Lakes Brewster and Cargelligo.

Table 43: Summary of Lachlan constraints (from upstream to downstream), where constraints have been classified in terms of their capacity to limit flows

Table 43: Summary of Lachlan constraints (from upstream to downstream), where constraints have been classified in terms of their capacity to limit flows

Location	Constraint Description	Flow Constraint	Inhibits Environmental Flow Delivery?
Wyangala Dam	Storage release capacity	6,600 ML/d	Yes (rarely)
Lake Cargelligo	Operational Practise	—	Yes (rarely)
Lake Brewster	Operational Practise	—	Yes (rarely)

6.4 Barwon–Darling

The Barwon–Darling is a large semi-arid river system draining the northern section of the Murray–Darling Basin (Figure 30). The flow regime of the river is one of the most variable in the world, with low flows punctuated by episodic flooding events that inundate the extensive areas of floodplain (Boys 2007). The upper component (Barwon River) is a continuation of the Macintyre River channel located in the Border Rivers region, and receives inflows from the following rivers:

- Moonie
- Macintyre, Boomi and Weir (Border Rivers)
- Gwydir and Mehi
- Namoi
- Castlereagh, Macquarie and Bogan
- Culgoa, Bokhara and (intermittently) Narran, all draining the Condamine–Balonne system

The lower component (Darling River)is a continuation of the same river channel, and commences downstream of the Culgoa junction near Bourke. During wet periods, the Darling receives further inflows from the Warrego and Paroo Rivers, though the latter system has contributed downstream flow on only four occasions (most recently in 2011) since European settlement (CSIRO 2008b).

The Darling River continues southward to join with the Murray River near Wentworth, however the Menindee Lakes system near Broken Hill provides a significant flow regulation structure which, for the purposes of water management, divides the Darling into the upstream (Barwon–Darling) and downstream (Lower Darling) segments. This section describes flow constraints in the Barwon–Darling system, while those for the Lower Darling are described separately in Section 6.1. A schematic of the Barwon–Darling region is shown in Figure 31.

The region covers an area of approximately 45,000 km^2 and has a population of 50,000 (CSIRO 2008b). Towns in the region include Collarenebri, Walgett, Brewarrina, Bourke, Cobar and Wilcannia, and water from the Barwon–Darling system is used for associated town water supplies, and stock and domestic purposes. In addition to dryland pasture used for beef and sheep grazing, the region contains large areas of irrigated agriculture, supporting cotton and horticultural crops. Annual rainfall is relatively low and exhibits substantial inter-annual variability. As a result, the region experiences very little in-valley runoff, and river flows are almost entirely reliant on upstream catchment inflows.

Figure 30: Location and extent of Barwon–Darling system upstream of Menindee Lakes

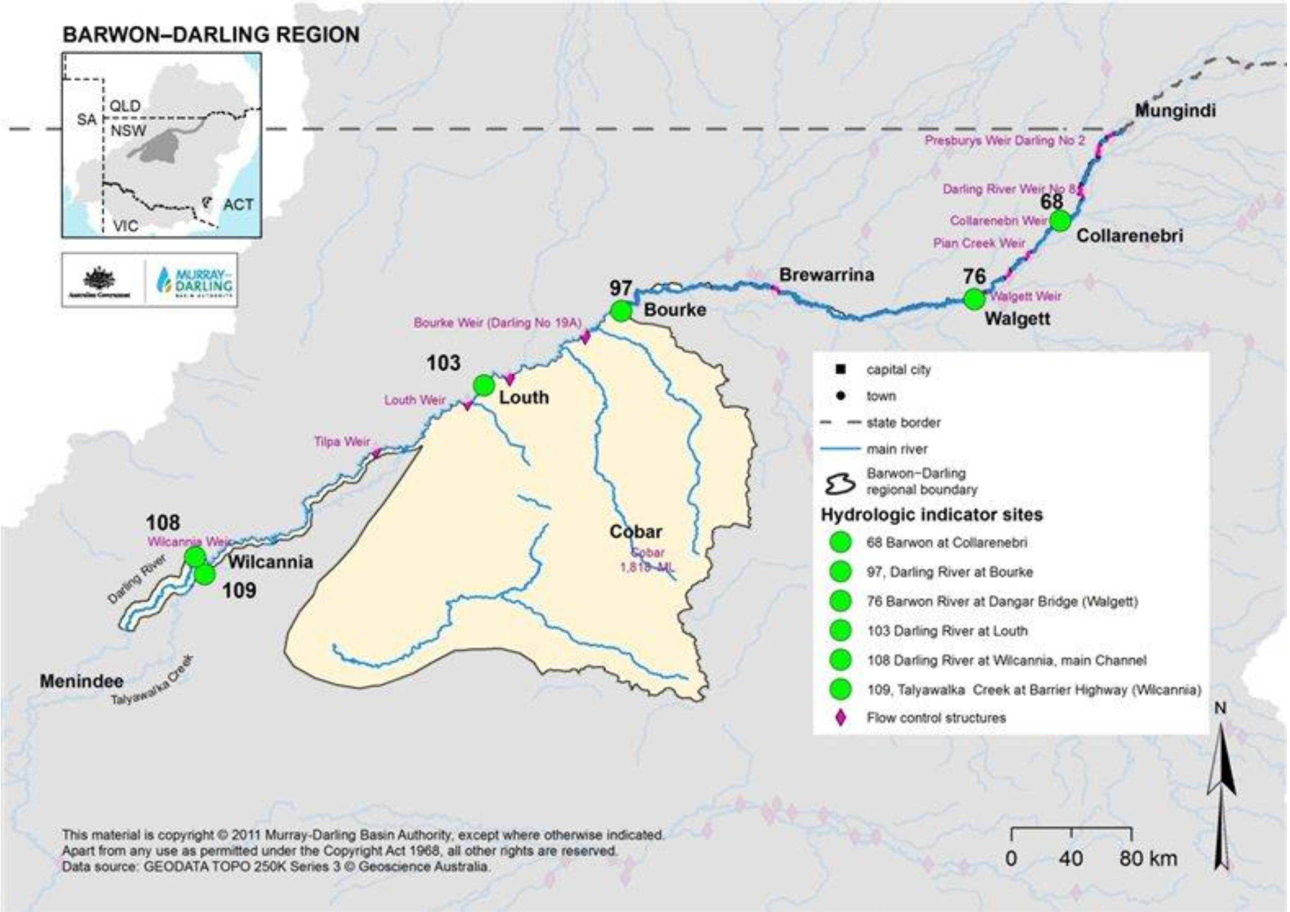
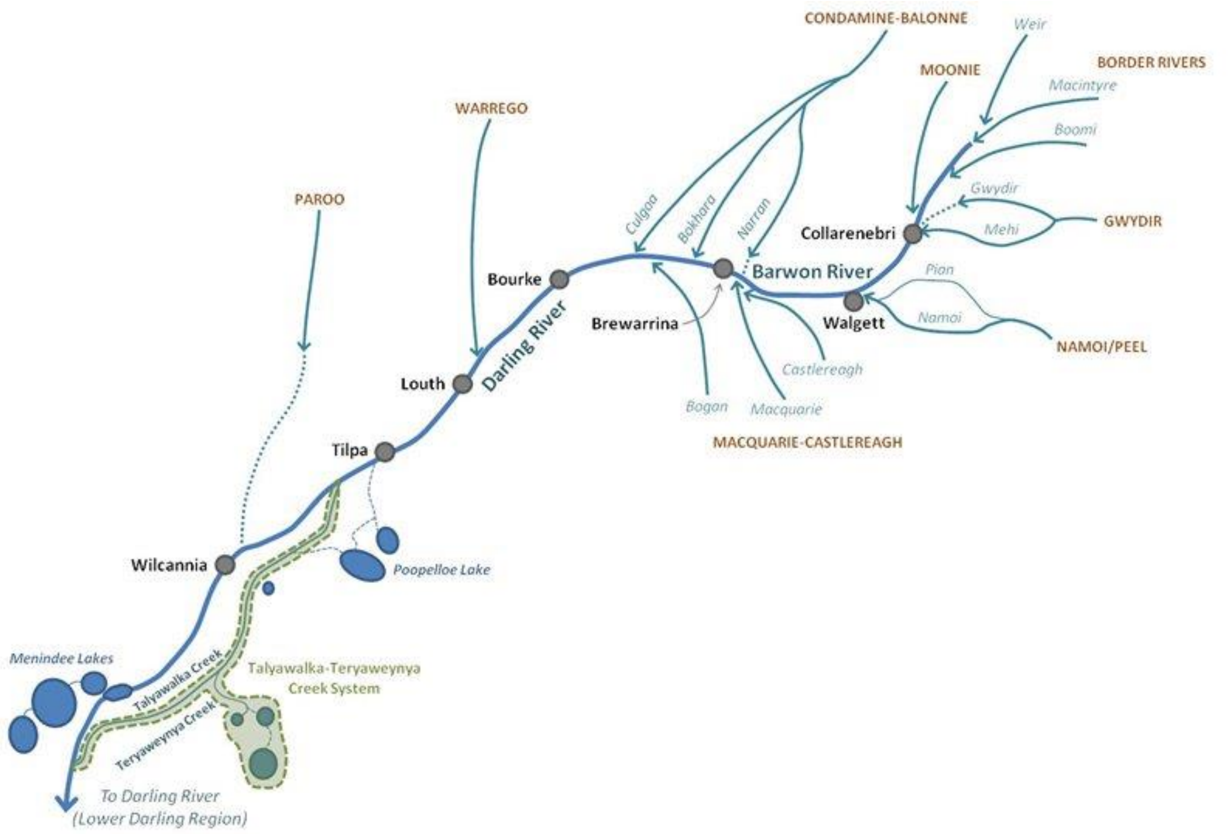


Figure 31: Schematic diagram summarising the key structural features and flow constraints in the Barwon–Darling region



The river supports a variety of water-dependent ecosystems, including fish, invertebrates and native birds, and vegetation in the riparian, wetland and floodplain areas. The natural flow regime in the Barwon–Darling system has been altered as a result of river regulation and extraction in upstream catchments, and the environmental water requirements identified as part of the Basin Plan development process are related to in-channel flows (associated with nutrient cycling, fish passage, and the inundation of river benches and riparian vegetation) and mid-to-high flow overbank/floodplain events (to support native vegetation and nesting waterbirds). A full description of these requirements and the supporting data may be found in MDBA (2012b).

A summary list of the flow constraints affecting environmental flow delivery in the Barwon–Darling system is presented in Table 44. First order constraints represent the primary impediments to the delivery of mid-to-high flow environmental events. If these constraints were overcome, the 2nd order grouping contains the next set of constraints that would potentially limit environmental water. A full investigation is required to determine the extent and flow at which these take effect. These constraints are more fully described in the subsections below.

Table 44: A list of key constraints limiting environmental flow delivery in the Barwon–Darling system, where constraints have been classified in terms of their capacity to limit flows

Order	Location	Description	Flow Limit (ML/d)
1st	Tributary catchments	Storage release capacity	Various (see Table 45)
	Tributary catchments	Channel capacity	Various (see Table 45)
	Tributary catchments	Capacity to shepherd environmental flows	—
	Barwon–Darling	Capacity to shepherd environmental flows	—
	Tributary catchments	Timing (ability to coincide environmental releases from multiple storages, sometimes with large unregulated inflow events)	—
2nd	Barwon–Darling	Private land access and inundation	~25,000 – 30,000 (location-dependent)
3rd	To be identified		

6.4.1 Key Structures and Flow Constraints

The delivery of environmental flows in the Barwon–Darling region will be unique compared with all other catchments in the Murray–Darling Basin. This is as a result of two broad characteristics associated with this system:

- Near-complete reliance on upstream water delivery
- Near-unregulated nature of the Barwon–Darling system

Consequently, all of the constraints to environmental flows are confined to upstream catchments — the Barwon–Darling system contains a number of weirs built largely for town-water supply purposes, yet none of these limit (or have the capacity to re-regulate) mid-to-high environmental flows.

Upstream Catchments

The Barwon–Darling system receives very little in-catchment runoff due to the hot and dry climate and the largely flat geomorphology of the landscape. Flows in the river are therefore almost entirely reliant on inflows from upstream catchments. A portion of the water to be recovered in each upstream region through the Basin Plan is assigned towards downstream environmental purposes (specifically, those in the Barwon–Darling) and the ability to deliver these flows is limited by the constraints in each tributary.

Under an active water management regime, a successful environmental flow event in the Barwon–Darling will correspond to one of the following three categories:

1. **Fully regulated** — occurs primarily due to a planned set of releases from upstream storages.

2. **Semi-regulated** — triggered by an unregulated flow event (either in a single or multiple catchments), this type of event may combine unregulated environmental 'use' (e.g. in the Condamine–Balonne) with regulated releases from storages in other regions (e.g. the Border Rivers and Namoi).
3. **Fully unregulated** — occurs due to large unregulated inflows from one or more tributaries.

Events occupying the third category are due to high rainfall events resulting in large unregulated flows that exceed the capacity of flow regulation infrastructure. These are unaffected by flow constraints, and are beyond the scope of this document. Events of Type I or II can be actively managed, however the successful achievement of the desired environmental flow will be limited by constraints (operational and physical) in the tributary catchments.

Type I Events

For the purposes of constraints management in the Barwon–Darling, physical constraints can be considered to be those that affect the level of connectivity with each tributary. That is, the capacity to deliver a desired flow is affected by factors such as flow limitation (channel and storage releases capacities) and in-river losses (evaporation and river-aquifer exchange). These factors partly determine the maximum flow which can be achieved through a Type I process, which theoretically could combine storage releases from the following five catchments:

- Condamine–Balonne
- Border Rivers
- Gwydir
- Namoi
- Macquarie

A more detailed examination of these issues is presented in Appendix A. In summary, existing physical constraints allow a Type I process to deliver a theoretical maximum tributary inflow of 10,000 ML/d to the Barwon–Darling from the five main tributaries. For comparison, the peak flow at Bourke during the 2010 unregulated flood event exceeded 200,000 ML/d. The estimated maximum possible regulated contribution of each valley (considering physical constraints only) is summarised in Table 45. The Paroo, Warrego and Moonie catchments are not listed here as they have a very limited flow regulating capacity.

Table 45: Estimate of maximum achievable flow for a Type I event at end-of-system location in the major tributaries of the Barwon–Darling, based on physical constraints (channel and storage release capacities). Further details can be found in Appendix A.

Region	Estimated Maximum Achievable Regulated Flow at End-of-System (ML/d)	Flow Constraint
Condamine–Balonne	550	Storage release capacity (Beardmore)
Border Rivers	4,700	Storage release capacity (Glenlyon and Pindari)
Gwydir	300	Channel capacity
Namoi	4,000	Channel capacity and storage release capacity (Keepit Dam)
Macquarie	900	Channel capacity and storage release capacity (Burrendong Dam)
Total Inflow to Barwon–Darling U/S Bourke	**10,000**	**Tributary Channel and Storage Release Capacities**

However, in practice, it is highly difficult for the Condamine–Balonne and Gwydir catchments to make substantial regulated contributions towards a Type I event in the Barwon–Darling. The water recovery program in the Condamine–Balonne region has thus far consisted entirely of unregulated entitlements, which do not allow access to water from storage to contribute towards a Type I event. Furthermore, regulated downstream contributions from the Gwydir system are extremely difficult to manage, due to the relatively low level of connectivity between this tributary and the Barwon–Darling. Also, flow travel times can be difficult to estimate as a result of the complex hydraulic characteristics of the Lower Gwydir channel system.

Therefore, the estimate listed in Table 45 represents a theoretical upper limit based on physical constraints only and would likely be further constrained by operational difficulties, and by the location and licence characteristics of the recovered entitlements in each region. Regulated releases from the Border Rivers, Namoi and Macquarie catchments specifically targeting environmental outcomes in the Barwon–Darling are achievable. If the flows are adequately synchronised and subject to flexible flow shepherding arrangements, these three catchments can provide a cumulative flow of approximately 9,000 ML/d at Bourke — deliberately managing higher flows would necessitate a Type II ‘semi-regulated’ process.

The ability to achieve this flow is further constrained by timing capacities. Operationally, the capacity to synchronise storage releases across the Border Rivers, Namoi and Macquarie catchments represents a substantial constraint. This type of environmental watering would require an accurate prediction of the flow travel time between all tributary storages and the Barwon–Darling — these travel times are generally a few weeks, however they often depend on antecedent river conditions and can be difficult to predict. Furthermore, this type of collaborative cross-jurisdictional storage release strategy may require further development to overcome policy constraints. The capacity to which multi-storage releases can be managed to ensure flows arrive concurrently is yet to be determined.

Type II Events

The Warrego, Condamine–Balonne, Moonie and Gwydir catchments will likely contribute to environmental flows in the Barwon–Darling through a Type II process (i.e. through unregulated flows).

A Type II event would be triggered by an unregulated event in one or more of these regions. In addition to reduced extraction in the source catchment(s), regulated release from the Border Rivers, Namoi and/or Macquarie regions could provide an additional flow of up to 9,000 ML/d. This would enhance the environmental outcomes for the Barwon–Darling floodplain.

The constraints to this sort of environmental watering strategy are similar to those described for Type I events above. The contribution from the regulated valleys would be limited by physical constraints (channel and storage release capacities), and by operational constraints (the capacity to which flows could be adequately synchronised and shepherded).

Barwon–Darling Structures and Flow Constraints

Fifteen fixed-crested weirs are located between Mungindi and Wilcannia (Thoms et al. 1996), many to supply water to nearby towns. The most notable of these weirs are located near the towns of Brewarrina, Bourke and Louth (Boys 2007). These structures are not impediments to environmental water delivery, as they are designed to allow overtop flows during high flow events.

The towns along the Barwon–Darling system can be subjected to flooding during high flows. The flows associated with minor flood levels for these towns are listed in Table 46. These could be a constraint to environmental water delivery, as flows greater than these thresholds can have third-party impacts on private landholders.

Table 46: Flows associated with minor flood levels for towns along the Barwon–Darling system

Site	Flow at Minor Flood Level (ML/d)
Barwon at Collarenebri	23,841
Barwon at Dangar Bridge (Walgett)	33,000
Darling at Bourke	27,275
Darling at Louth	28,590
Darling at Tilpa	27,761
Darling at Wilcannia (main canal)	25,600

If environmental flows were delivered from upstream regions, water sharing rules in the Barwon–Darling would need to include flexible flow shepherding arrangements. These arrangements would be required to allow water to pass through the channel without consumptive extraction at specific times.

6.4.2 Representation of Constraints in the Hydrological Model

The MDBA has used the IQQM Barwon–Darling model as developed by the NSW Office of Water. The model setup, validation and calibration are described in detail in DNR (2006). The model receives Gwydir, Namoi and Border Rivers tributary inflows from the respective IQQM models for those catchments, as well as from the Warrego, Condamine–Balonne and Macquarie–Castlereagh models.

Table 44 lists the main constraints identified for the Barwon–Darling region, and their representation in the model is described here. For the shepherding of stock, domestic and town water supplies, the system has been divided into sections and commence to pump thresholds are set for each section in turn. The shepherding of environmental flows is currently not represented in the baseline model.

Flood levels at various locations are not explicitly modelled. However losses (including overbank losses) are defined in various reaches, determined during model calibration. In some cases the floodplain loses and particularly the breakouts to Lake Talyawalka are defined for overbank flows.

The various storages in the Warrego River are represented as a lumped storage having a storage release capacity of 1 ML/d and spilling at 30,000 ML/d. Though the storage is located in the intersecting stream region, for mass balance purposes losses from Warrego storages are presented in the Barwon Darling valley.

6.4.3 Environmental Flows Affected by Constraints

The environmental water requirements identified for the Barwon–Darling system (MDBA 2012b) as part of Basin Plan development cover a large range of flows. They include:

- Baseflows (based on nutrient cycling and fish passage requirements)
- In-channel freshes (for riparian health, maintenance of river-floodplain connectivity, and to submerge logs and branches to provide refugia and spawning habitats for fish)
- High flows for the Talyawalka–Teryaweynya Creek system (which maintain the current extent of native floodplain vegetation and provide flow conditions conducive to waterbird breeding events)

Baseflow (or low flow) requirements are not greatly impeded by existing flow constraints. However, as discussed below, the active management of in-channel freshes and high flows will be difficult under existing flow constraints.

In-channel Freshes

The flow regime in the Barwon–Darling system is characterised by variable patterns of high and low flows. These have resulted in complex channel cross-sections featuring in-channel benches occurring at multiple levels (Southwell 2008). These benches are an important source of dissolved nutrients, which can re-enter the nutrient cycle during inundation events. Furthermore, these events submerge logs and branches, an important aquatic habitat for several species (Boys 2007).

Based on these ecosystem needs, a number of environmental water requirements (summarised in Table 47) were identified as part of the development of the Basin Plan. The evidence-base and analysis underlying these indicators has been described in full by MDBA (2012b).

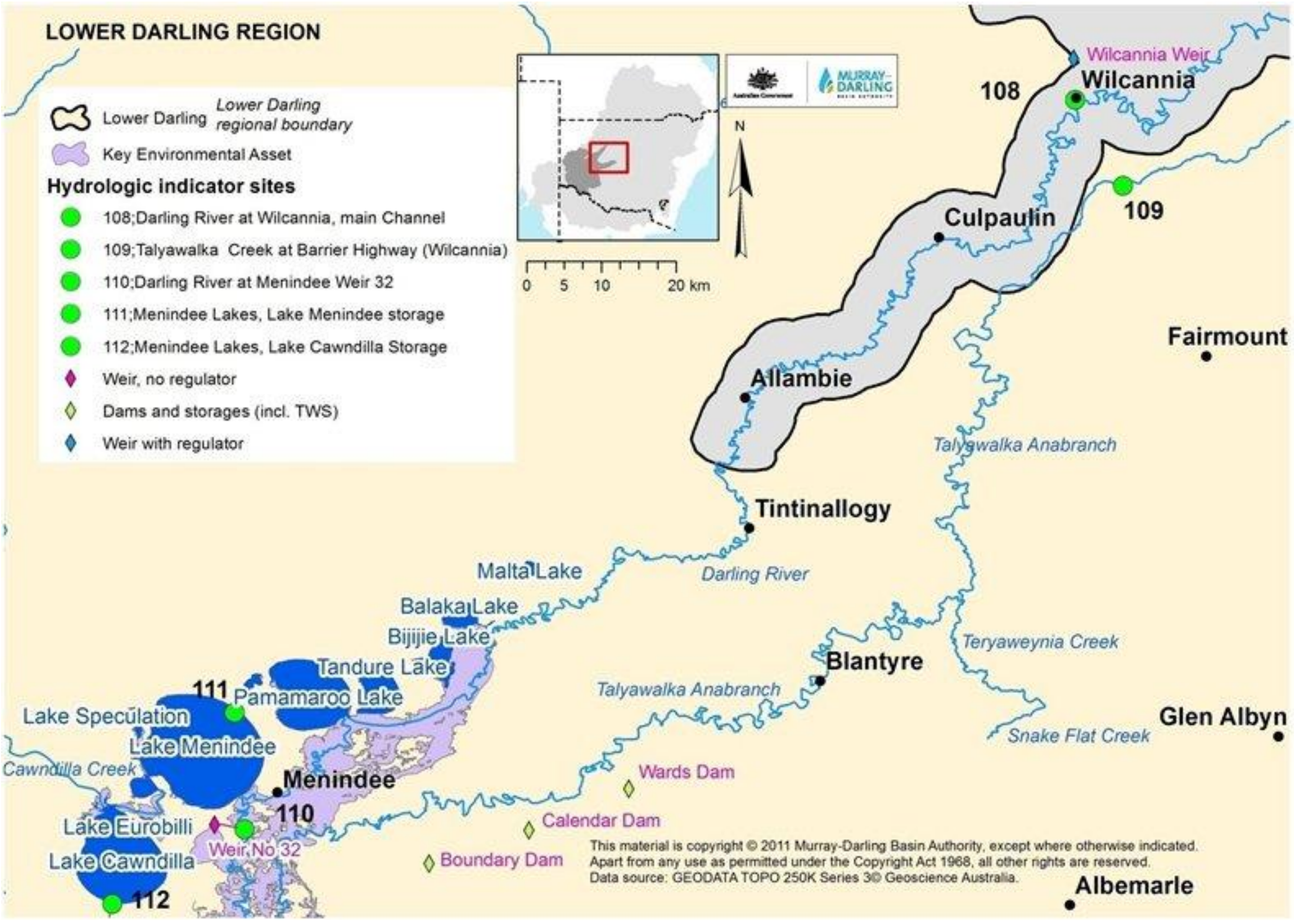
Table 47: Ecological targets for the Barwon–Darling in-channel flows (MDBA 2012b), and the degree to which they can be achieved under current constraints and operational practice

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	Achievable under some conditions (constraints limit delivery at some times) *In-channel flows specified at Bourke* • Two events annually of 10,000 ML/d for 5 consecutive days between January & December for 45% of years • Two events annually of 10,000 ML/d for 17 consecutive days between January & December for 29% of years • Two events annually of 20,000 ML/d for 5 consecutive days between January & December for 29% of years *In-channel flows specified at Louth* • Two events annually of 5,000 ML/d for 10 consecutive days between January & December for 50% of years • Two events annually of 10,000 ML/d for 10 consecutive days between January & December for 38% of years • Two events annually of 14,000 ML/d for 10 consecutive days between January & December for 28% of years

As described above, due to physical and operational constraints, the maximum fully regulated (i.e. Type I) flow event that can achieved at Bourke would peak at approximately 9,000 ML/d. However, the delivery of this flow is subject to additional operational constraints, such as the coordination of releases from storages in multiple catchments, and flow shepherding. For this reason, the delivery of flows of 5,000 and 10,000 ML/d has been classified as 'limited by constraints at some times' (marked yellow in Table 47).

Flows greater than 10,000 ML/d can be achieved through a combination of an unregulated flow event and regulated releases in one or more valleys (i.e. a semi-regulated Type II event), or through a purely unregulated event (Type III). Regulated releases contributing to type II events are subject to constraints similar to those contributing to Type I events, therefore the delivery of flow events of 20,000 ML/d (Bourke) and 14,000 ML/d (Louth) are also categorised as limited by constraints at some times (marked yellow in Table 47).

Figure 32: Location and extent of Talyawalka–Teryaweynya Creek System (MDBA 2012b)



Talyawalka–Teryaweynya Creek System

During higher flow periods, water from the Darling River can enter the Talyawalka–Teryaweynya Creek system, an anabranching structure which includes a number of lakes, creeks and billabongs. Talyawalka Creek leaves the Darling River upstream of Wilcannia and travels approximately 350 km south-west before re-joining the Darling below Menindee (Figure 31).

A set of lakes (including Poopelloe Lake) is located near the northern end of this system. These lakes fill directly from the Darling River during high flows and can contribute additional water to Talyawalka Creek when overflowing. Further south, Teryaweynya Creek carries flows from the main anabranch channel to fill a complex lake system (including Teryaweynya, Eucalyptus, Victoria and Brummeys Lakes; Figure 32). The Talyawalka–Teryaweynya Creek system supports a large number of waterbirds as well as large areas of black-box, river red gum and a variety of other flood-dependent and tolerant vegetation including lignum. This vegetation is predominantly located alongside creeks and lake edges.

Based on a number of scientific studies, MDBA (2012b) has identified a flow of 30,000 ML/d (measured at Wilcannia) as the commence-to-flow threshold for the Talyawalka–Teryaweynya Creek system. The associated environmental flow indicators represent the water requirements of the identified environmental assets (summarised in Table 48).

As described above, a fully regulated environmental watering event in the Barwon–Darling cannot exceed a flow of approximately 9,000 ML/d due to flow constraints in the tributary catchments. As a result, the active management of a 30,000 ML/d flow to satisfy the Talyawalka–Teryaweynya flow requirements can only be achieved through a semi-regulated (Type II) event. This type of event is subject to flow constraints. Furthermore, the required flow could exceed the minor flood level at several locations on the Darling River (Table 46). For these reasons, the Talyawalka–Teryaweynya flow requirements are classified as 'difficult to achieve under most conditions'.

Table 48: Ecological targets for the Talyawalka–Teryaweynya Creek system in the Barwon–Darling (MDBA 2012b), and the degree to which they can be achieved under current constraints and operational practice

Site-specific ecological targets	Site-specific flow indicators (flow measured at Wilcannia)
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.	Difficult to influence achievement under most conditions (constraints limit delivery at most times) • 30,000 ML/d for a total of 21 days between January & December for 20% of years. • 30,000 ML/d for a total of 30 days between January & December for 15% of years. • A total in-flow volume of 2350 GL (based on a minimum flow rate of 30,000 ML/d) during January & December for 8% of years.

6.4.4 Summary

Table 49 summarises the constraints to environmental flow delivery identified in the Barwon–Darling region. The active management of environmental water in this catchment is difficult, due to the relatively unregulated nature of many of the upstream catchments, and the natural hydrological features of the system (substantial evaporation, long flow travel times, and poor connectivity from some upstream catchments).

Regulated releases from upstream catchments can provide flows to the Barwon-Darling. The environmental benefits associated with these releases will be constrained by timing difficulties. Flooding levels have been specified for various locations throughout the region (Table 46). Third party impacts are likely if flows proceed above these identified thresholds. This is, however, very unlikely to occur from regulated tributary releases.

Policy constraints (such as issues associated with flow shepherding) are important, and will be explored through a separate process.

Table 49: Summary of Barwon Darling constraints (from upstream to downstream), where constraints have been classified in terms of their capacity to limit flows

Location	Constraint Description	Flow Constraint	Inhibits Environmental Flow Delivery?
Throughout	Capacity to shepherd environmental flows	—	Yes
Tributary catchments	Timing (ability to coincide environmental releases from multiple storages, sometimes with large unregulated inflow events)	—	Yes
Various towns	Private land inundation (minor flood levels)	25,000 to 30,000 ML/d	Yes

6.5 Macquarie–Castlereagh

The Macquarie–Castlereagh region is located in central western NSW, and includes the regulated Macquarie River, and the unregulated Castlereagh and Bogan Rivers. It encompasses an area of approximately 90,000 km^2. Towns in the region include Bathurst, Mudgee, Wellington, Dubbo, Narromine, Warren, Nyngan and Coonabarabran. A map of the extent and main features of the region is shown in Figure 33. The Macquarie River rises near Bathurst and originates as a combination of the Fish River, Campbell's River and Davy's Creek. The river runs northwest from the western side of the Blue Mountains to its termination point on the Barwon River upstream of Brewarrina. The long-term average annual flow in the regulated sections of the Macquarie River is approximately 1,500 GL/y measured downstream of Dubbo. Of this, approximately 26% is extracted for town water, industry and irrigation supplies and the remainder constitute outflows and losses (CSIRO 2008h).

The unregulated Castlereagh River originates in the Warrumbungle Mountains and initially flows east through Coonabarabran before following a looping course and passing the towns of Binnaway, Mendooran, Gilgandra and Coonamble. It then joins the Macquarie River just downstream of Carinda near the junction with the Barwon River. As it does not rise in the Great Dividing Range, flows in the Castlereagh are on average quite low and variable. Extraction rates for the 50 irrigation licences in the region are low, and included in the Water Sharing Plan for the Castlereagh River above Binnaway (DIPNR 2004b).

The unregulated Bogan River flows in a general north-north-westerly direction from its origin near Parkes to a point approximately 600km downstream where it joins with the Little Bogan River and the Darling River. It does not join with the Macquarie River during average flow conditions, but some water is passed from the Macquarie to the Bogan River through a system of small effluent streams during periods of higher flows. Despite its lack of regular connection, the Bogan River forms a substantial water source in the catchment. Unlike many of the other rivers of the Basin the source of the Bogan River is not located in a highland area, hence the flow is generally erratic and there is very little extraction. No major storages regulate the flow in the river, and the largest of the associated towns is Nyngan.

The flow regimes in the Bogan and Castlereagh Rivers have not been significantly modified by human development or extraction, and no mid-to-high flow environmental flow requirements have been identified in these rivers, hence the remainder of this section discusses constraints to environmental flow delivery in the Macquarie River only. A schematic diagram of the region, including structural features and summary of flow constraints, is shown in Figure 34.

The Macquarie River catchment is a regulated Water Management Area that includes several regions of private irrigation as well as several public irrigation schemes in the regulated sections of the valley. Irrigated agriculture covers approximately 1% of the total area of the catchment. The region has a history of overbank events, the most recent of which was in November/December 2010 with substantial inundation in the Lower Macquarie region following heavy rainfall. Floodwaters flow through and beyond the catchment and join the Barwon River upstream of Brewarrina.

Burrendong Dam (1,118 GL capacity) is the largest flow regulating structure in the region, and is located on the Macquarie River upstream of Wellington. Burrendong is the largest dam on the Macquarie and regulates flows from the river itself, along with the Cudgegong and Turon Rivers, for flood control and downstream irrigation use. Many tributaries enter the river upstream of Narromine and most are located upstream of Burrendong Dam. Additional regulating capacity is provided by Windamere Dam (with a capacity of 368 GL, located on the Cudgegong River upstream of Guntawang) and Ben Chifley Dam (with a capacity of 30.8 GL, located on the Campbell River to provide water for Bathurst).

Part 3 of the Water Sharing Plan for the Macquarie and Cudgegong Regulated Rivers Water Source (DIPNR 2004c) describes an ‘Environmental Water Allowance’ (EWA) account, constituting up to 160 GL per water year. This consists of 64 GL/y and an additional 96 GL/y which is subject to fluctuating allocations. This EWA is released from Burrendong Dam to provide:

- A more natural flow regime downstream of Burrendong Dam from June to November and March to May each year,
- To attain flows at Marebone Weir between 500 ML/d and 4,000 ML/d, and
- To provide opportunities for native fish recruitment and waterbird breeding events in the Macquarie Marshes.

From Burrendong Dam the main Macquarie River channel continues north. A natural reduction in channel capacity towards the bottom of the system allows some water to periodically enter the surrounding floodplain, forming the Macquarie Marshes. This is a nationally and internationally important environmental asset, parts of which have been identified in the Ramsar Convention (DEWHA 2008). The Marshes begin downstream of Warren and extend approximately 120 km along the river to just upstream of Carinda (Figure 33). They cover about 200,000 ha and include areas inundated by flows from the Macquarie River and its streams and anabranches, including the Macquarie River, Bulgeraga Creek (MDBA 2012s) and effluent creeks such as Gunningbar and Marra Creeks (MDBA 2012b).

The Marshes support a complex system of native flood-dependent vegetation and, when inundated for an extended period provide conditions conducive for waterbird (and other wetland fauna) breeding events. Additionally, species and communities that do not depend on overbank flows thrive on the edge of the inundated areas and within isolated pockets. Extensive communities of river red gum and weeping myall, belah, and poplar box woodlands are a distinctive feature of the Marshes. Significant changes to the flow regime in the Marshes have been identified from studies of observed and modelled flows, due to river regulation and extraction. Further details of the environmental features of the Marshes are reported in MDBA (2012s), as well as details of the environmental water requirements that were used to develop the Basin Plan.

Most of the Marshes are privately owned, except for a region of approximately 22,300 ha managed by the NSW Office of Environment and Heritage. This includes the Macquarie Marshes Nature Reserve (approximately 19,000 ha). This nature reserve and nearby Mole Marsh were listed as Ramsar Sites in 1986, with the Wilgara Wetland being listed in 2000.

Figure 33: The extent and main features of the Macquarie–Castlereagh region

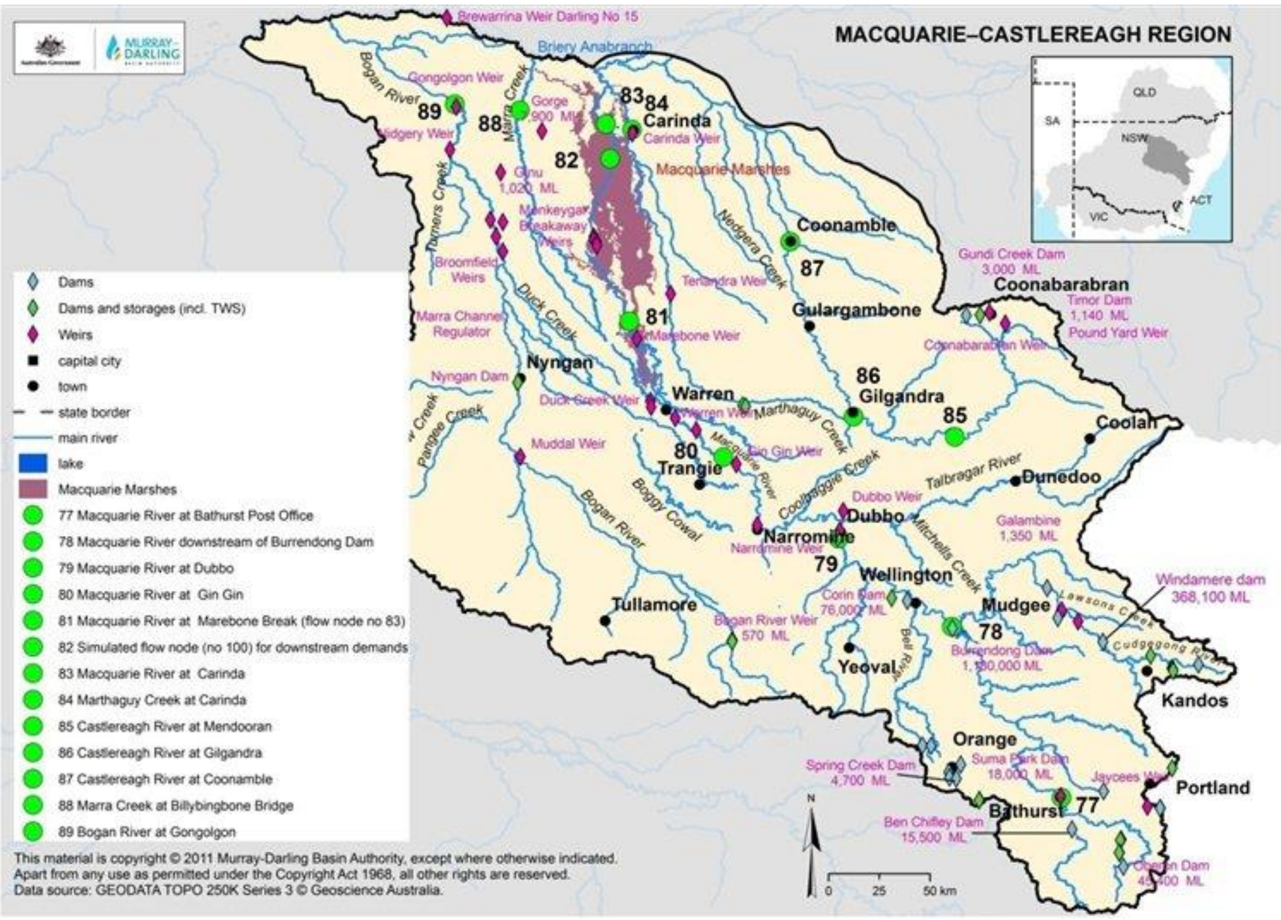
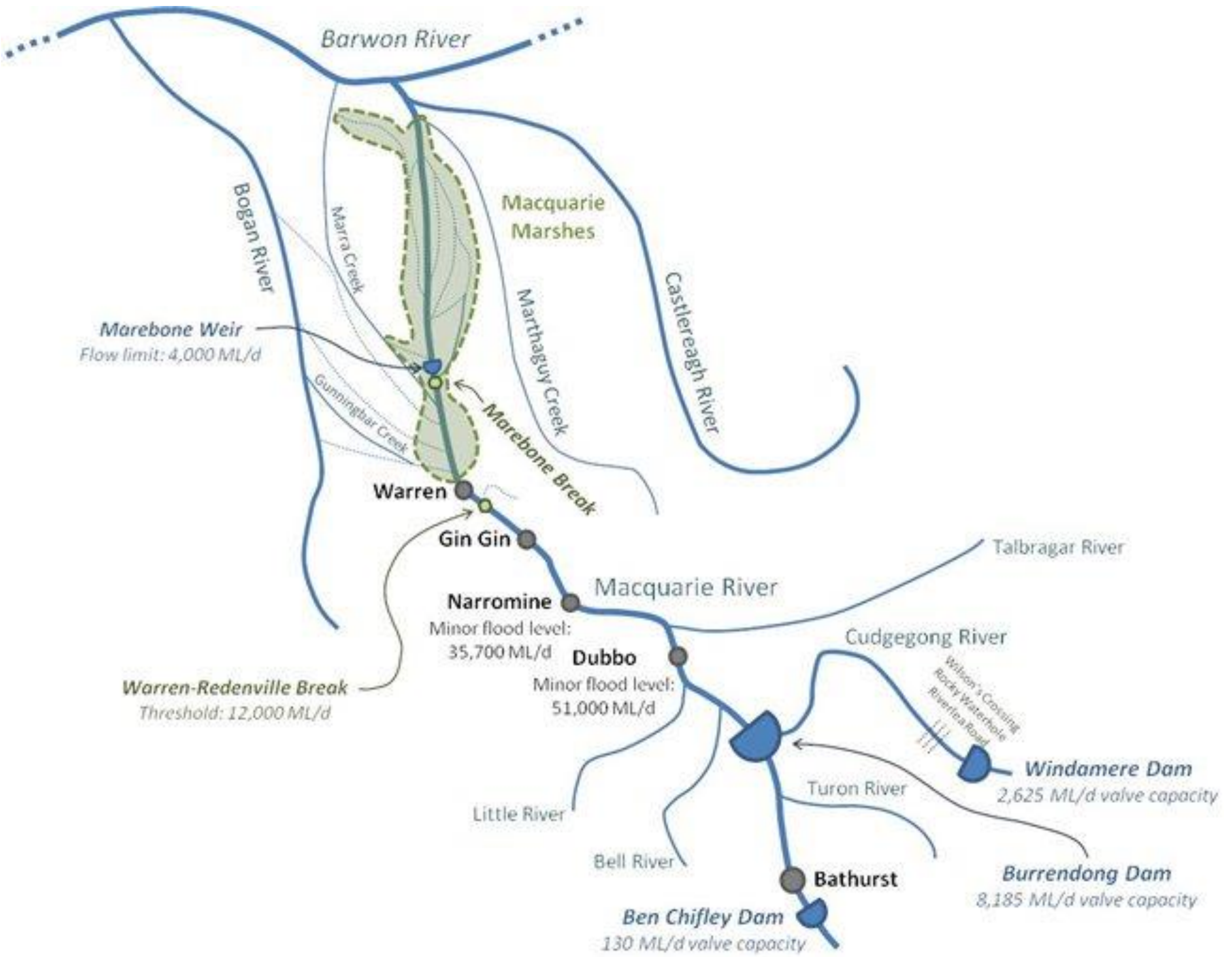


Figure 34: Schematic diagram summarising the key structural features and flow constraints in the Macquarie–Castlereagh region



A summary of flow constraints in the Macquarie–Castlereagh catchment is presented in Table 50. Flow constraints defined as 1st order constitute primary constraints to successful delivery of identified environmental flows for the catchment. Constraints which become sequentially important once 1st order constraints are considered are defined as 2nd and 3rd order constraints.

No 1st order constraints have been identified in the Macquarie–Castlereagh region. Under specific circumstances, the storage release capacity of Burrendong Dam could limit environmental flow delivery, and this has been identified as a 2nd order constraint. The remaining 2nd and 3rd order constraints consist of flooding levels for various locations along the main river channel, however further investigation into the effects of removing constraints could potentially identify flooding risks in addition to those listed.

Table 50: A list of key constraints limiting environmental flow delivery in the Macquarie–Castlereagh region, where constraints have been classified in terms of their capacity to limit flows

Order	Location	Description	Flow Limit (ML/d)
1st	To be identified		
2nd	Burrendong Dam	Storage release capacity	8,185
	Warren	Breakout flow	12,000
	Marebone Weir	Operational policy	4,000
3rd	Dubbo	Flood levels	51,000 (Minor) 72,900 (Moderate) 244,000 (Major)
	Narromine	Flood levels	35,700 (Minor) 74,000 (Moderate) 195,000 (Major)

6.5.1 Key Structures and Flow Constraints

Public Water Storages

The main public storages in the Macquarie–Castlereagh region are:

- Burrendong Dam (1,118 GL capacity)
- Ben Chifley Dam (30.8 GL capacity)
- Windamere Dam (368 GL capacity)

Potential constraints to environmental flow delivery in the Macquarie–Castlereagh consist mainly of storage release capacity limits and downstream channel capacities designed to mitigate flooding of towns and private land, particularly in the Dubbo, Narromine and Gin Gin regions.

As full supply level, Burrendong Dam has a storage release capacity of 8,185 ML/d, however this decreases as the volume of stored water is lowered. When the storage level is 40% of full supply level, the storage release capacity is approximately 1,700 ML/d. Storage releases are also limited to mitigate downstream flooding, for example the minor flood level at Dubbo corresponds to a flow of 51,000 ML/d (2nd order). Both Ben Chifley and Windamere Dams lie upstream of Burrendong Dam, and are therefore not considered to present significant constraints to environmental flow delivery to the Macquarie Marshes. However, they each (particularly Windamere) operate within release limits designed to mitigate flooding in their respective downstream reaches.

The Warren–Reddenville Breakout threshold (12,000 ML/d) and the downstream Marebone Weir maximum flow limit (4,000 ML/d) are both operational policy settings to reduce conveyance losses and thereby increase the efficiency of downstream consumptive water delivery when such flows are required. Breakout flows are minimised by keeping flows below these levels. However, by definition, this limit also reduces the incidence of breakout flow into the environmental assets at these locations and at the Macquarie Marshes. Neither limit is significantly affecting the delivery of environmental flows into the surrounding area.

6.5.2 Representation of Constraints in the Hydrological Model

The MDBA has used the IQQM Macquarie–Castlereagh model as developed for the Water Sharing Plan to help develop environmental flow rules and targets. Both Windamere and Ben Chifley Dams are modelled as headwater storages with full storage capacities of 368.12 GL and 15.5 GL respectively. Outlet flow rates are modelled via a function of storage release capacity against storage volume. The modelled maximum storage release capacities (when full) are 2,625 ML/d and 130 ML/d respectively.

Burrendong Dam, the major storage in the valley, has a modelled storage capacity of 1,188 GL. Extra airspace is provided to the storage for flood mitigation purposes up to a limit of 1,650 GL. Release rates pertaining to this flood mitigation zone are explained in Clause 64 of the Macquarie–Castlereagh Water Sharing Plan (DIPNR 2004c). Modelled storage release capacities correspond to values listed in a volume/storage release capacity table. Valve capacities operate up to 11,220 ML/d for storage levels up to 1,188 GL. Operational practice is to limit outlet rates to 8,185 ML/d. The 160 GL/y (64 GL/y as a fixed annual pattern and 96 GL/y as general security dependent on annual allocation values) Environmental Water Allowance previously described is included in both the baseline and Basin Plan versions of the Macquarie IQQM.

Flood levels at various locations as specified in Table 50are not explicitly modelled, as flows are below the identified flow thresholds for 99% of the days under existing water sharing arrangements. However losses (including overbank losses) in those reaches are represented as losses corresponding to a particular river flow, determined during model calibration.

The Warren–Reddenville Break and the Marebone Break are both modelled as specified effluent rates corresponding to river flows, with 4,000 ML/d at the Marebone Break marking the point at which flows are no longer regulated. Marebone Weir itself is not represented in the model.

6.5.3 Environmental Flows Affected by Constraints

The environmental water requirements in the Macquarie–Castlereagh system identified through the development of the Basin Plan can be divided into three main categories:

- Baseflow requirements
- Macquarie Marshes volumetric requirements
- Contribution to downstream requirements

Achievement of the first two of these categories is not greatly impeded by existing system constraints. Baseflow targets are based on nutrient cycling, fish passage, and riparian health requirements, and are limited to in-channel flows that can be satisfied through relatively low release rates from public storages. The requirements for the Macquarie Marshes necessitate larger flows, and these are achievable within existing constraints (MDBA 2012s). However, as described below, a change to these constraints could increase the flexibility with which these requirements could be satisfied.

The rate at which water can be delivered from the Macquarie–Castlereagh system to the Barwon River is limited by physical constraints, specifically the natural capacity of the river channel near the junction.

Burrendong Dam and the Macquarie Marshes

The main potential constraint impeding the delivery of water to the Macquarie Marshes is the storage release capacity of Burrendong Dam during years of reduced storage level. Burrendong Dam is required to provide reliability of supply for downstream users, hence some environmental releases (for example through the Environmental Water Allowance) will be made in addition to existing irrigation releases. The capacity of the dam to satisfy both requirements through releases could impede environmental water delivery, especially during years when the volume of water in storage is relatively low.

However, the results of environmental watering actions in recent years suggest that the environmental water requirements for the Macquarie Marshes can be met within existing constraints over the long-term period (for example, the watering program of 2012–13). This conclusion is supported by hydrologic modelling conducted by MDBA (2012y) as part of the development of the Basin Plan.

Several significant tributary inflows occur downstream of Burrendong Dam, including the Bell, Talbragar and Little Rivers (Figure 34). Under typical conditions Burrendong environmental flow releases will be planned to combine with downstream tributary inflows — only a fraction of the environmental water required for specific downstream flow targets would be released from storage. An examination of hydrologic modelling data indicates that an additional flow of 500 ML/d (on average) is needed at the Marebone Break to satisfy the identified environmental water requirements for the Macquarie Marshes (MDBA 2012s,y).

The need to compensate for delivery losses *en-route* to the Macquarie Marshes (consisting of evaporation, losses within anabranches and distributary channels) would likely require a larger volume to be released from Burrendong Dam. However, the efficiency of environmental water delivery is not constant — the required release volume will be influenced by factors including:

- Period since the last flow of a similar magnitude
- Changes to riparian vegetation type or health
- Sediment deposition from previous large flows
- Volume and timing of downstream tributary inflows

As a result, the exact release volume would be difficult to predict for each specific event. Despite these difficulties, Basin Plan modelling (MDBA 2012y) has indicated that these flow rules can be delivered with a high rate of success within the limits imposed by existing system constraints.

In summary, the storage release capacity of Burrendong Dam will only be constraint under specific circumstances (for example, during years of relatively low supply level in which the storage release capacity cannot accommodate both irrigation and environmental water requirements). This is categorised to be a 2nd order constraint.

Additional Flow Constraints

Additional water could be called from Windamere Dam to assist in overcoming insufficient water volume in storage or any operational constraints at Burrendong Dam, however such releases could lead to overbank flows in the lower Windamere catchment depending on the rate at which they are released. The channel capacity of 1,800 ML/d at Wilson's Crossing, 1,200 ML/d at Rocky Waterhole and 2,000 ML/d at Riverlea Road put these areas at risk. Although unlikely to occur due to current operational practices, these settings may need to be altered in the future, if conditions change with potentially increased water transfer rates to Burrendong Dam for environmental use.

Flood levels at Dubbo and Narromine are characterised as 2nd order constraints, as they could become important if the release capacity of Burrendong Dam is increased. For example, low level bridges across the river in Dubbo are inundated at 30,000 ML/d, and the minor flood level is associated with a flow of 51,000 ML/d. In Narromine minor flooding occurs at a flow of 35,700 ML/d. The specified environmental flow targets can be satisfied under existing constraints in the Macquarie, and it is unlikely that flows of 30,000 ML/d(or higher) would result from the delivery of the environmental water under the targets specified by MDBA (2012s).

The Warren–Reddenville breakout upstream of Marebone Weir has a commence-to-flow threshold of 12,000 ML/d. This constitutes a river operational delivery constraint, as this flow rate is the point at which water released for consumptive use encounters increased conveyance losses from the main channel into the Warren–Reddenville anabranch. This breakout flow has environmental benefits, and is not considered to constrain environmental watering. The breakout flows at Marebone Weir (for flows over 4,000 ML/d) are also classified as non-constraining for the same reason.

Assessment of Environmental Flow Indicators

Table 51summarises the specific flow indicators for the Macquarie Marshes as detailed in MDBA (2012s). Based on long-term average results all indicators are considered to be deliverable within existing system constraints, however the identification and further analysis of constraints could potentially increase delivery efficiency of environmental flows in the region.

Table 51: Site-specific flow indicators for the Macquarie Marshes (MDBA 2012s) and the degree to which they can be achieved under current constraints and operational practice

Site-specific ecological targets	Site-specific flow indicators (flow measured at Marebone Weir)
Provide a flow regime which ensures the current extent of native vegetation of 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 and invertebrates) Provide a flow regime which supports key ecosystem functions, particularly those related to connectivity between the river and the floodplain	Achievable under current operating conditions • Achieve a total inflow volume of 100 GL (over 5 successive months) during June to April for 80% of years • Achieve a total inflow volume of 250 GL (over 5 successive months) during June to April for 40% of years • Achieve a total inflow volume of 400 GL (over 7 successive months) during June to April for 30% of years • Achieve a total inflow volume of 700 GL (over 8 successive months) during June to May for 17% of years

Downstream Requirements

Environmental flow events in the Barwon–Darling system are almost purely reliant on water delivered from upstream tributaries. The delivery of downstream water from the Macquarie–Castlereagh region is subject to in-valley constraints such as storage release and channel capacities, and flow shepherding, and these are discussed in detail in Section 6.4on the Barwon–Darling.

6.5.4 Summary

Environmental water requirements have been specified for in-channel flows and the Macquarie Marshes, as well as for the downstream Barwon–Darling system. Full details of this work are presented in MDBA (2012s). Previous MDBA modelling has shown that the volume of water identified for recovery in the Macquarie system is sufficient to satisfy all the flow indicators under existing system constraints when determined as a long-term average.

Table 55 outlines the constraints in the Macquarie–Castlereagh region. The storage release capacity of Burrendong Dam is the constraint most limiting the flexibility for delivering water for Macquarie Marshes use, however this has been categorised as a 2nd order constraint only. Minor flood levels have been identified for Dubbo and Narromine, although these are far in excess of any required environmental flows. It is highly unlikely that flooding risks would be increased as a result of increased environmental flows, however further analysis could reveal additional smaller-scale flooding risks in addition to those listed here. Marebone Weir operational policy is not thought to be a constraint as it has environmental benefit in its own right.

Table 52: Summary of Macquarie–Castlereagh constraints (from upstream to downstream), where constraints have been classified in terms of their capacity to limit flows

Location	Constraint Description	Flow Constraint	Inhibits Environmental Flow Delivery?
Burrendong Dam	Storage release capacity	8,185 ML/d	Possibly
Dubbo	Minor flood level Moderate flood level Major flood level	51,000ML/d 72,900ML/d 244,000 ML/d	No
Narromine	Minor flood level Moderate flood level Major flood level	35,700 ML/d 74,000 ML/d 195,000 ML/d	No
Marebone Weir	Operational Policy	4,000 ML/d	No

6.6 Namoi

The Namoi region is located in central eastern NSW, and constitutes a major tributary of the Barwon River. It includes the regulated Namoi, Peel and Manilla Rivers, and unregulated inflows from Cox's Creek, the Mooki and Macdonald Rivers and further downstream tributaries such as the Bohena, Baradine, Etoo and Coghill Creeks. Irrigation is concentrated in the regulated portions of the region. Irrigated agriculture is the largest employer (mostly cotton, pastures for stock feeds and cereals), and covers only 1.5% of the catchment but contributes 32.3% of total production. Average annual extractions in the regulated Namoi River are 180 GL, approximately 22.8% of average annual flow. Major towns in the region include Tamworth, Quirindi, Gunnedah, Boggabri, Narrabri, Walgett and Wee Waa. A map of the region showing its extent and main features is shown in Figure 35.

The Namoi River originates as the Macdonald River on the western slopes of the Great Dividing Range east of Niangala, flowing in a north-westerly direction until its name changes to the Namoi River in Warrabah National Park. The Namoi then continues to flow north-westerly, ending on the alluvial floodplain at the junction with the Barwon River near Walgett. Keepit Dam is the largest storage in the Namoi catchment (capacity 425 GL, providing water supply for Walgett, irrigation releases and hydro-electric power generation) and is on the Namoi River just upstream of its confluence with the Peel. There is also a number of smaller regulating weirs downstream of Keepit Dam. In total, the Namoi River covers 845 km in length. Major tributaries include Cox's Creek and the Mooki, Peel and Manilla Rivers. These join the Namoi River upstream of the township of Boggabri while Pian (itself a returning offtake of the Namoi River), Baradine and Bohena Creeks contribute flows downstream of Boggabri.

The Peel River constitutes the first of two major regulated tributaries of the Namoi, rising near Nundle and flowing through Tamworth. It flows into the Namoi River just downstream of Keepit Dam. The Peel River in turn has a number of significant tributaries including the Cockburn River and Dungowan and Goonoo Goonoo Creeks. Peel River waters are regulated via Chaffey Dam, with a capacity of 62 GL providing town water supply and flood mitigation controls for Tamworth, and some irrigation supply. A planned enlargement to Chaffey Dam will increase the maximum storage to 100 GL. Dungowan Dam (6.2 GL capacity, located on Dungowan Creek) is owned by the Tamworth Regional Council and provides town water supply for Tamworth.

The Manilla River is a second regulated tributary which flows generally south and contributes to the Namoi River at the town of Manilla. The Manilla River includes Split Rock Dam upstream of Manilla (with a capacity of 397 GL), which is one of the main water storages for town water supply, flood control and irrigation supply in the Namoi region. Keepit Dam and Split Rock Dam are operated as a joint water supply scheme, in much the same way that Hume and Dartmouth Dams are operated on the Murray.

The unregulated Mooki River flows northwards from the Coolah Tops and flows into the Namoi River just upstream of Gunnedah. Cox's Creek joins the Namoi River just upstream of Boggabri. Both the Mooki River and Cox's Creek contain some of the best agricultural soils in the Namoi region, with activity including irrigation, dryland cropping and grazing little native vegetation remains on the surrounding plains.

The floodplain regions of the Namoi are characterised by a primary channel (about 50 m wide and 6 m deep) with a network of several converging and diverging anabranches and flood channels separated by floodplain segments. The complex morphology, particularly of the lower floodplains, provides a number of ecologically-significant components, and it is for this reason that the MDBA has specified a number of in-channel environmental water requirements to allow for improved connectivity along the full length of the river (full details can be found in MDBA 2012q).

Environmental flow requirements for the Lower Namoi specify in-channel flow thresholds for a particular length of time to address a specified environmental outcome. The Namoi region includes three such requirements (Table 54). This table also highlights whether or not these requirements are likely to be impacted by constraints as modelled under baseline conditions within the region. A schematic diagram outlining the key structural features and flow constraints in the Namoi region is shown in Figure 36.

Figure 35: The extent and main features of the Namoi region

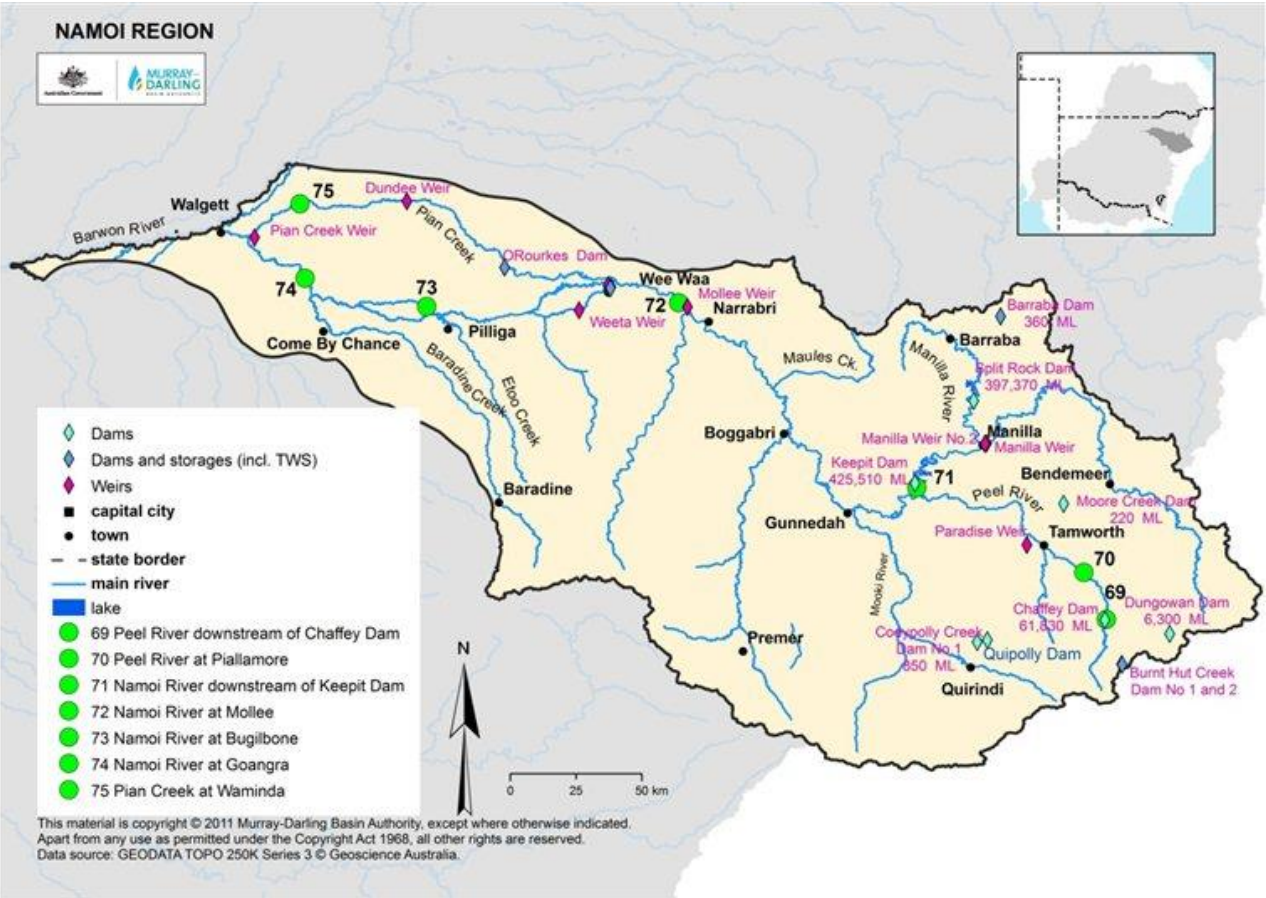
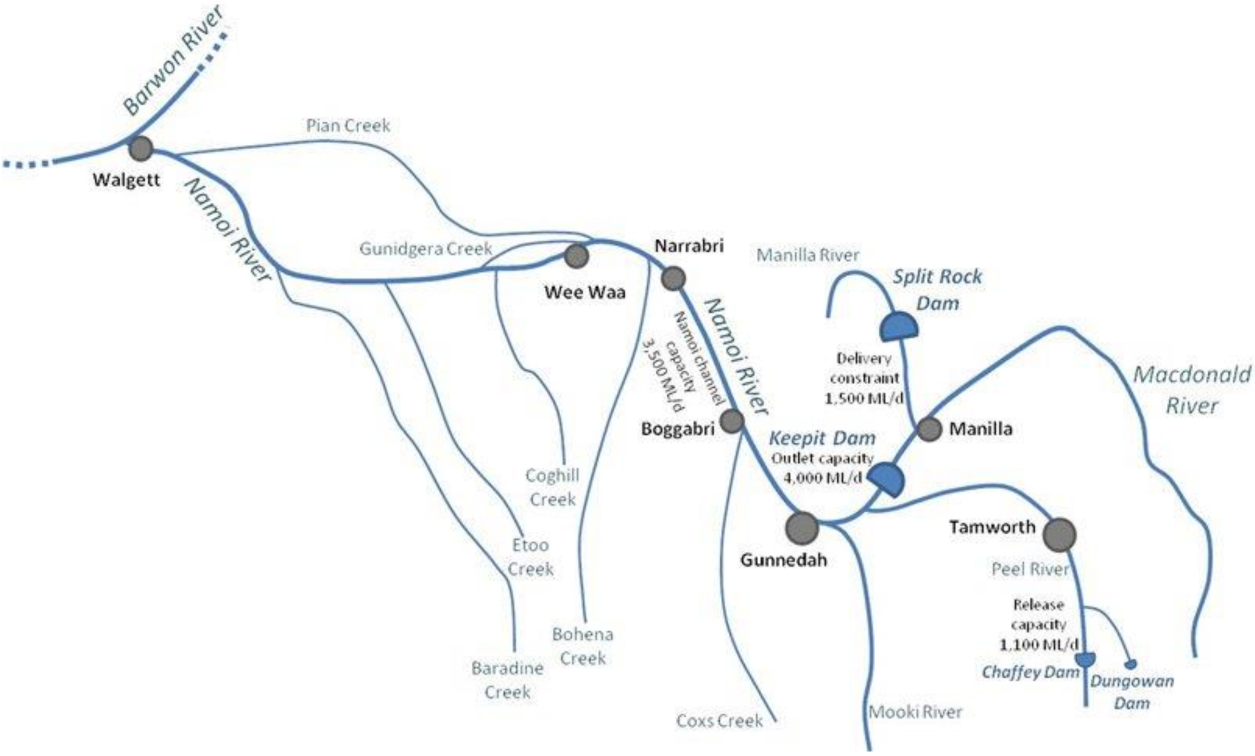


Figure 36: Schematic diagram summarising the key structural features and flow constraints in the Namoi region



A summary of flow constraints in the Namoi catchment is presented in Table 53. No 1st order constraints have been identified in this region. Described below are the 2nd order constraints, which could impede the delivery of environmental flows during specific years. These include the Bulk Water Transfer protocols between Split Rock and Keepit Dam, the release rate of Keepit Dam (which decreases as the supply level decreases), and the ability to time releases with unregulated inflows from downstream tributary streams. No 3rd order constraints have been identified.

Environmental releases are highly unlikely to present any increased flooding risk for major towns in the Namoi.

Table 53: A list of key constraints limiting environmental flow delivery in the Namoi region, where constraints have been classified in terms of their capacity to limit flows

Order	Location	Description	Flow Limit (ML/d)
1st	To be identified		
2nd	Keepit Dam	Storage release capacity	4,000
	Split Rock to Keepit reach	Bulk transfer rate	1,500
	Keepit Dam	Timing (ability to coincide environmental releases with large unregulated inflow events)	—
3rd	To be identified		

6.6.1 Key Structures and Flow Constraints

Public Water Storages

The main public storages in the Namoi region are:

- Chaffey Dam (62 GL capacity)
- Split Rock Dam (397 GL capacity)
- Keepit Dam (425 GL capacity)

Chaffey Dam lies on the Peel River upstream of Tamworth and is not considered to be a constraint to environmental flow delivery as, in practice, the water required for environmental flows will largely be sourced from Split Rock and Keepit Dams.

Split Rock Dam is located on the Manilla River, and regulates flow from a relatively small catchment area. Water from this storage is used for irrigation, stock/domestic, and town water supply purposes in the Manilla River. Furthermore, water is sometimes transferred from Split Rock Dam to Keepit Dam (the main flow regulating structure in the Namoi River) to ensure reliability of supply for downstream licenced water entitlement holders. These ‘Bulk Water Transfers’ are subject to NSW Ministerial approval, and associated protocols determine the pattern of releases from Split Rock Dam. At full supply level, the dam has an outlet capacity of 6,000 ML/d, however the discharge is limited to 4,500 ML/d to minimise:

- possible drowning of platypus colonies,
- damage to the river channel,
- native fish kills due to large releases, and
- access issues for private landholders.

In practice, Bulk Water Transfers between the two storages are generally achieved at a flow significantly less than 4,500 ML/d — State Water Corporation advises of potential property access issues for flows downstream of Split Rock Dam greater than several hundred megalitres per day. The travel time of regulated flows between the two storages is 4 – 5 days.

The majority of regulated environmental flows in the Namoi region will be achieved through releases from Keepit Dam (the remainder will largely be regulated low flow requirements in upstream reaches). Hence the structural and operational characteristics of Split Rock and Keepit Dams have the greatest potential to impede environmental flow delivery. The storage release capacity from Keepit Dam is 4,000 ML/d at full supply level, however the release capacity decreases as the level of stored water decreases. Furthermore, the Namoi channel can accommodate a maximum release of 3,500 ML/d from Keepit Dam. When required for flood mitigation purposes, significantly greater flows can achieved through the flood mitigation gates.

Environmental watering events will often combine storage releases with unregulated inflows from downstream tributaries. Regulated releases from Keepit Dam must therefore be carefully timed to coincide with unregulated inflows from the Mooki River and Cox’s Creek in order to use these for Lower Namoi and downstream Barwon–Darling environmental requirements. This timing is crucial to successful watering of peak flow events required in the Namoi and hence is listed as a constraint to environmental flow delivery.

There are two actively used weirs situated on the Namoi River downstream of Narrabri. Mollee Weir has a storage capacity of 3,300 ML and is designed to re-regulate flows to improve the delivery of water to the lower valley. Gunidgera Weir is located further downstream near Wee Waa and has a storage capacity of 1,900 ML. Its main function is for the control of regulated flows into Gunidgera and Pian Creeks. Neither of these weirs is considered to present a constraint to environmental water delivery.

There are a number of additional small weirs on Pian Creek (Hazeldean, Greylands and Dundee Weirs) and Gunidgera Creek (Knights Weir) that assist in the provision of water for local users. These are not thought to constrain environmental flow delivery.

6.6.2 Representation of Constraints in the Hydrological Model

The MDBA has used the IQQM Namoi and Peel models as developed for the Water Sharing Plan (DIPNR 2004) to help develop environmental flow rules and targets for Basin Plan development. The two models are linked and run sequentially together.

Keepit Dam is represented as an on-river storage with a full capacity of 425.5 GL. The volume of water released from the dam depends upon a tabulated function relating storage volume to the outlet valve capacity. Split Rock Dam, upstream, contributes water if the order to Keepit Dam is outside the limits of this table. The vast majority of modelled orders (98%) to Keepit Dam are, however, below this limit. The bulk transfer rate from Split Rock Dam to Keepit Dam is modelled at a fixed 1,500 ML/d, an important constraint in the catchment as previously described.

Split Rock Dam is modelled with a full capacity of 397.37 GL. Dam release rates and storage volume are again modelled as a tabulated relationship, with water orders always below 2,000 ML/d.

The flood level at Gunnedah is not explicitly modelled as flows are below the flow threshold for the vast majority of the time under baseline conditions. However losses (including overbank losses) in those reaches are represented as losses corresponding to a particular river flow, determined during model calibration.

6.6.3 Environmental Flows Affected by Constraints

Environmental water requirements in the Namoi identified during Basin Plan development can be divided into the following categories:

- Baseflow requirements
- Lower Namoi in-channel fresh requirements
- Contribution to downstream requirements

Baseflow targets are based on nutrient cycling, fish passage, and riparian health requirements, and are limited to in-channel flows which can be satisfied through relatively low release rates from public storages. These requirements are not impeded by existing flow constraints.

The in-channel fresh requirements identified for Bugilbone in the Lower Namoi are related to flows of 500, 1,800 and 4,000 ML/d (Table 54). The delivery of these events aims to improve nutrient cycling, facilitate the migration and recruitment of native fish species, and enhance anabranch connection and riverine woodlands.

Modelling conducted as part of the development of the Basin Plan allowed MDBA to investigate the capacity to which these environmental water requirements could be satisfied through the recovery of additional water and an active environmental water management regime. An analysis of the modelling results (MDBA 2012y) indicated that in-channel fresh requirements could be satisfied over a long-term period, however existing constraints could limit the delivery of specific flow events during years experiencing special conditions.

Keepit Dam Release Capacity

At full supply level, the release capacity of Keepit Dam is 4,000 ML/d (the Namoi channel can accommodate a release of 3,500 ML/d). When combined with unregulated inflows from downstream tributary streams, releases from Keepit Dam at this rate are able to deliver the environmental flow events listed in Table 54.

However, the release capacity decreases as supply level decreases. In some years, a reduced supply level will affect the ability to deliver some environmental events, specifically those related to flows of 4,000 ML/d at Bugilbone.

Furthermore, the achievement of these flows will rely on supplementing unregulated tributary inflows. The capacity to which these releases can be adequately timed will be a potential constraint. If supply levels are relatively low, the dependence on unregulated tributary inflows will be greater, and the timing of releases will have a greater importance. Both the release capacity and ability to adequately schedule the timing of environmental releases are categorised to be 2nd order constraints.

Table 54: Site-specific flow indicators for Namoi in-channel flows (MDBA 2012q) and the degree to which they can be achieved under current constraints and operational practice

Site-specific ecological targets	Site-specific flow indicators (flow measure at Bugilbone)
Provide a flow regime which ensures the current extent of native vegetation of the anabranch communities is sustained in a healthy, dynamic and resilient condition 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	Achievable under current operating conditions • 500 ML/d for a total duration of 75 days (with a minimum duration of 25 consecutive days) between July & June for 44% of years • 1,800 ML/d for a total duration of 60 days (with a minimum duration of 6 consecutive days) between July & June for 32% of years • 4,000 ML/d for a total duration of 45 days (with a minimum duration of 7 consecutive days) between July & June for 22% of years

Split Rock to Keepit Transfer Rates

The transfer rate of water between Split Rock Dam and Keepit Dam could affect the ability of Keepit Dam to provide water to downstream environmental assets. The release pattern from Split Rock Dam on any particular occasion is subject to NSW Ministerial approval, but can be no more than 4,500 ML/day (expect during flood mitigation periods). These transfers are typically made at much lower flows.

As identified above, the timing of environmental releases from Keepit Dam will be important to make full use of downstream unregulated tributary inflows. In some years, the Bulk Water Transfer protocols could limit or delay releases from Split Rock Dam, which in turn could limit or further delay releases from Keepit Dam. The flow travel time between the two storages is 4 – 5 days, however the effective delivery of environmental water could rely on opportunistic releases for Keepit Dam supplementing downstream unregulated inflows at relatively short notice. Overall, the Bulk Water Transfer protocols will be a constraint to environmental water delivery only during years with specific conditions, hence this is categorised to be a 2nd order constraint. Further modelling could quantify the potential environmental benefit of any changes to these protocols.

Downstream Requirements

Environmental flow events in the Barwon–Darling system are almost purely reliant on water delivered from upstream tributaries. The delivery of downstream water from the Namoi region is subject to in-valley constraints such as storage release and channel capacities, and flow shepherding, and these are discussed in detail in Section 6.4 on the Barwon–Darling.

6.6.4 Summary

Environmental water requirements have been specified for in-channel flows in the Lower Namoi, as well as for the downstream Barwon–Darling system. These requirements are presented in MDBA (2012q). Previous MDBA modelling has shown that the environmental water requirements (Table 54) identified through the development of the Basin Plan can be satisfied within existing system constraints over long term periods. However, the identification and further analysis of constraints in the catchment could lead to potential improvements in delivery efficiency of environmental water, and the success of individual events on a year-by-year basis.

Table 55 outlines the constraints in the Namoi region. The storage release capacity of Keepit Dam and the maximum transfer rate between Split Rock and Keepit Dams are the most important constraints in the Namoi. If the maximum transfer rate could be increased significantly then the storage release capacity of Split Rock Dam would also become important. The ability to accurately time releases from Keepit Dam to coincide with unregulated inflows from the Mooki River and Cox's Creek is also of prime importance.

Channel capacities throughout the region (including those of Pian Creek) are not thought to represent a significant impediment to environmental flow delivery.

Table 55: Summary of Namoi constraints (from upstream to downstream), where constraints have been classified in terms of their capacity to limit flows

Location	Constraint Description	Flow Constraint	Inhibits Environmental Flow Delivery?
Keepit Dam	Storage release capacity	4,000 ML/d	Possibly
Split Rock Dam to Keepit Dam reach	Bulk transfer rate	4,500 ML/d	Possibly
Keepit Dam	Timing (ability to coincide environmental releases with unregulated inflow events)	—	Yes
Split Rock Dam	Storage release capacity	6,000 ML/d	No
Pian Creek	Channel capacity	2,000 ML/d	No
Gunidgera offtake (regulates flows into Pian Creek)	Offtake capacity	1,250 ML/d	No

6.7 Gwydir

The Gwydir region is located in the north-west of NSW, lying to the south of the Border Rivers region (separated by the Mastermans Range) and to the north of the Namoi region (separated by the Nandewar Range), with the Barwon–Darling region located to the west. The region covers an area of approximately 26,600 km^2, with the Gwydir catchment extending 670 km from the Great Dividing Range to the Barwon River near Collarenebri. A map of the region is shown in Figure 37, and a schematic diagram detailing the major structures and constraints in the region is shown in Figure 38.

Moree is the only major town in the region, with smaller townships on the main river including Bundarra, Bingara, Gravesend and Pallamallawa. Land use in the Gwydir is dominated by extensive agriculture with approximately 70% of the catchment being used for grazing. Other water users include irrigated and dryland agriculture, and local councils and water utilities. Cotton is grown near Moree, which relies heavily on irrigation, consuming approximately 87% of agricultural water extracted from the Gwydir River.

Figure 37: The extent and main features of the Gwydir region

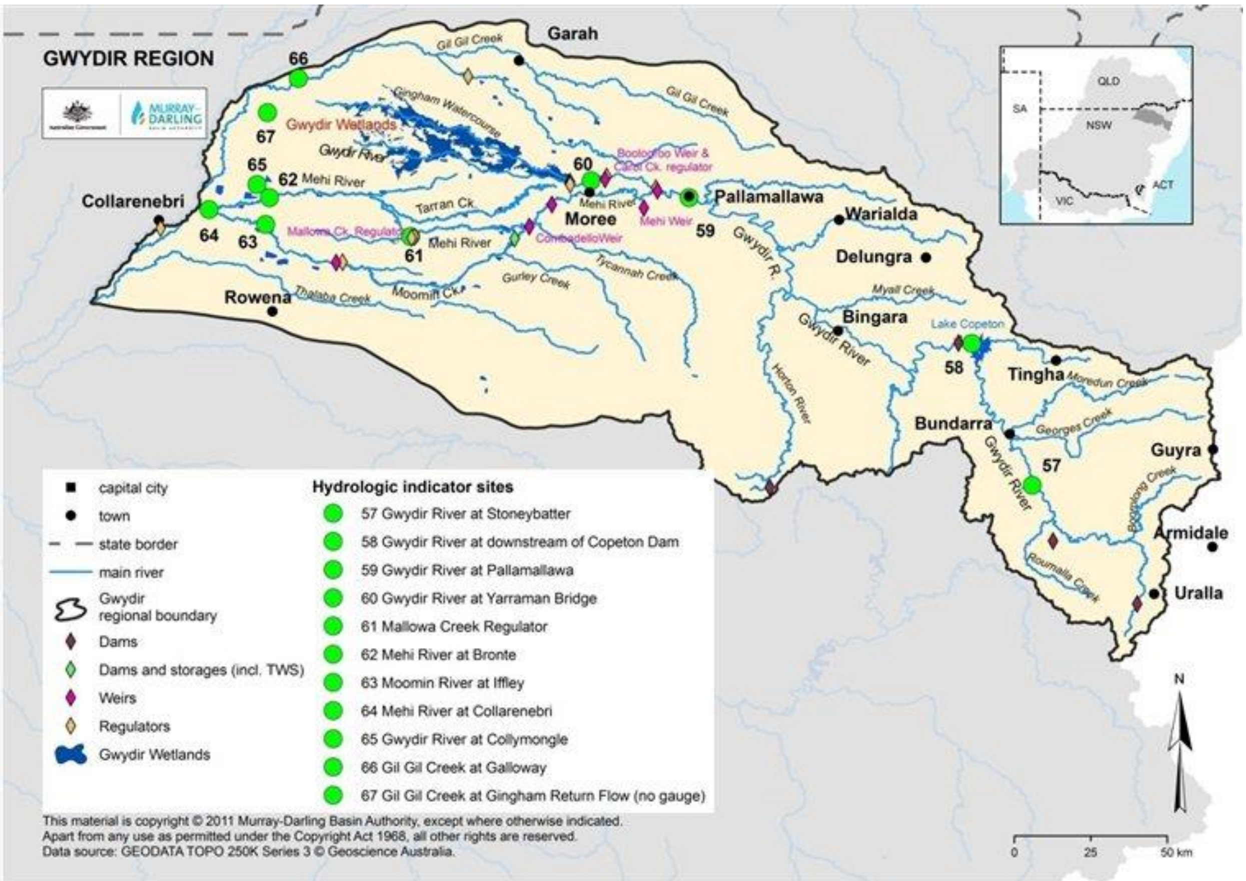
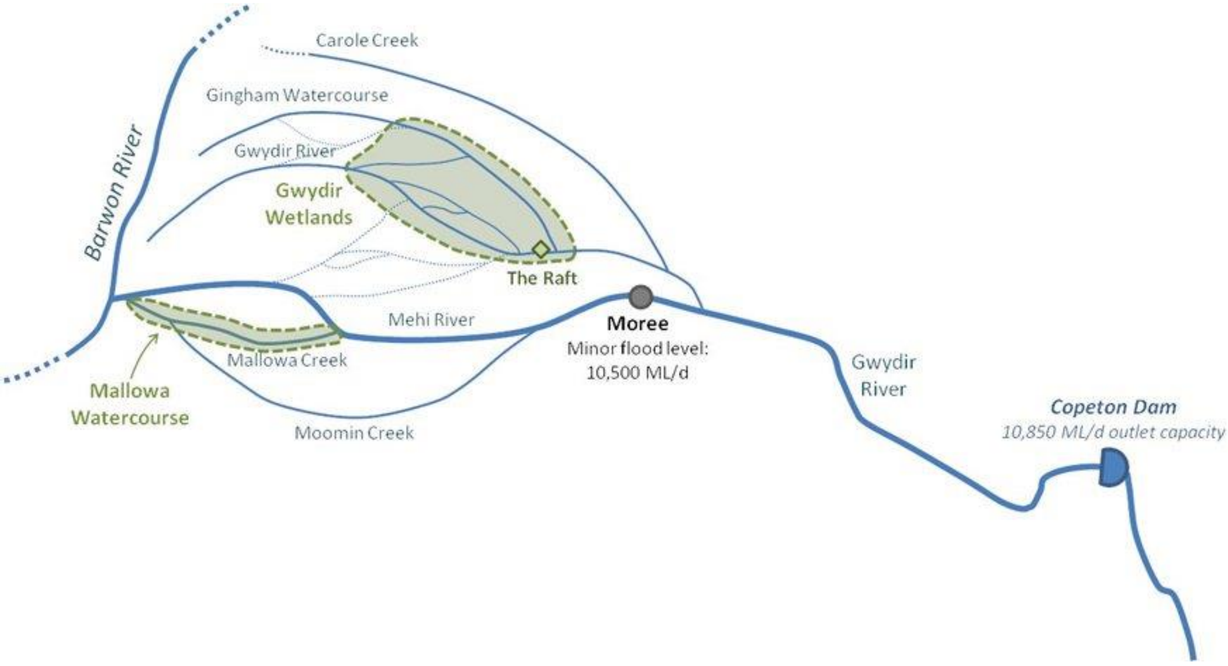


Figure 38: Schematic diagram summarising the key structural and flow constraints in the Gwydir region



The regulated Gwydir River rises near the town of Uralla and flows westward towards Lake Copeton, receiving tributary inflows from the Moredun and George's Creeks. Downstream of Copeton Dam, the Gwydir River flows westwards onto the plains passing the towns of Bingara and Pallamallawa, with further unregulated flows contributing from the Horton River and several other minor tributaries.

Near Moree, the river splits into a series of smaller distributary channels — the lower section of the Gwydir region is characterised by a series of creeks and anabranches with limited channel capacities. The channel first splits into the Gwydir and Mehi Rivers upstream of Moree. Further downstream, a large build-up of silt and large woody debris, known as 'The Raft' has created a partial blockage of the Gwydir River approximately 20 km to the west of Moree, further splitting the river into several smaller components. Similarly, the Mehi River, the dominant channel in the Lower Gwydir region, splits into a number of smaller streams (Figure 37).

Flows from the Mehi River and Moomin Creek continue westward and join the Barwon River near Collarenebri during times of high flow. In comparison flows from the Gwydir River and Gingham Watercourse are typically terminate in the wetlands. In general very little water is contributed from the Gwydir system as a whole to the Barwon–Darling. Significant volumes are passed downstream only during relatively high flow events.

The geography of the Lower Gwydir region, combined with the reduction in channel capacity, has produced the Gwydir and Mallowa Wetlands, a series of irregular inundated wetlands covering more than 1000 km^2 (when fully flooded) comprising an inland terminal delta. The area has great importance as one of Australia's most significant bird breeding sites, providing habitat for hundreds of species of birds and animals. Four sites totalling 823 ha within the Lower Gwydir and Gingham Management Unit have been listed as Ramsar wetlands of significant international importance (DEWHA 2008), which includes three parcels of privately owned land and includes one property of 600 ha acquired by the NSW Government in 2010.

Irrigation has led to significant reduction in environmental flows, particularly for the Gwydir Wetlands and associated creeks and anabranches in the lower parts of the region. The Water Sharing Plan for the Gwydir Regulated River Water Source which came into effect on July 1 2004 (DIPNR 2004d). Rocky Creek, Cobbadah, Upper Horton and Lower Horton water resources are managed under a separate Water Sharing Plan (DIPNR 2004e).

Part 3 of the Gwydir Water Sharing Plan (DIPNR 2004d) describes an Environmental Contingency Allowance (ECA) which constitutes up to 90 GL/y of planned environmental water held in Copeton Dam. The ECA is operated under the rules similar to those related to general security entitlements. This ECA is specifically required to:

- Support a colonially nesting native bird breeding event that has been initiated in the Gwydir Wetlands following natural flood inundation,
- Provide additional inundation in the Gingham and Lower Gwydir Wetlands during or following periods of extended dry climatic conditions,
- Provide inundation of higher level benches in the river reaches between Copeton Dam and the Gwydir River at Gravesend,
- Provide short-term inundation of the wetlands to promote germination of hyacinth as part of a weed management strategy involving a wetting and drying cycle,
- Provide flows for environmental purposes in effluent streams,
- Support native fish populations and habitat,
- Support invertebrates and other aquatic species,
- Support threatened species, and
- Maintain aquatic ecosystem health.

In a separate process, environmental water requirements have been defined for the hydrologic indicator sites within the Gwydir region (MDBA 2012g) as part of Basin Plan development. These requirements are related to a range of ecological processes important for the floodplain and wetland vegetation in the lower Gwydir, such as nutrient cycling, bird breeding, the migration and recruitment of native fish species, and the maintenance of key riparian features such as benches and banks. Releases related to the ECA have made progress towards achieving these aims, but the Basin Plan recognises that additional water is required to achieve the desired environmental outcomes.

A summary list of flow constraints which may impede environmental water delivery in the Gwydir catchment is presented in Table 56. Flow constraints defined as 1st order constitute primary constraints to successful delivery of identified environmental flows for the catchment. The primary constraint to environmental watering in the region consists of private landholdings adjacent to the Gingham Watercourse in the Lower Gwydir. Determining the impacts of environmental watering on private landholders in the lower reaches of the Gwydir requires further investigation.

Second order constraints are thought to impede environmental water delivery only under specific conditions. The outlet capacity of Copeton Dam may limit environmental watering under special circumstances.

Increases in the frequency or duration of flooding events near Moree due to environmental releases is thought to be unlikely, and these flood levels are therefore categorised to be 3rd order constraints.

Table 56: A list of key constraints limiting environmental flow delivery in the Gwydir region, where constraints have been classified in terms of their capacity to limit flows

Order	Location	Description	Flow Limit (ML/d)
1st	Gingham Watercourse	Private landholdings	—
2nd	The Raft	Channel Capacity	5,000 – 10,000†
	Copeton Dam	Storage release capacity	10,850
	Copeton Dam	Timing	—
3rd	Moree (Mehi River)	Flood Levels	10,500 (Minor) 21,000 (Moderate) 33,000 (Major)
	Yarraman Bridge (Gwydir River)	Flood Levels	9,700 (Minor) 35,700 (Moderate) 51,000 (Major)

†The gauge at Yarraman Bridge measures inflow to the wetlands of the Gingham and Lower Gwydir watercourses. Flooding in these wetlands starts to occur when river flows at Yarraman are between 5,000 and 10,000 ML/ day

6.7.1 Key Structures and Flow Constraints

The only major regulating storage in the Gwydir region is Copeton Dam (1,364 GL capacity), on the Gwydir River near Inverell. Together with a series of minor weirs located further downstream, Copeton Dam provides a reliable water supply to the irrigators in the region under the Gwydir Water Sharing Plan (DIPNR 2004d). Water is also provided for environmental, stock/domestic and town water supplies. The storage release capacity of Copeton Dam is 10,850 ML/d.

Parts of the wetlands in the Lower Gwydir system comprise privately owned landholdings. Near Moree, the level to which these are inundated during higher flow events can be measured by the flood levels at Yarraman Bridge (Table 56). However, the geomorphology of the lower reaches of the Gwydir River are characterised by a decreasing channel capacity when moving downstream, hence the potential for inundation increases (Pietsch 2006; NSW Department of Environment, Climate Change and Water 2011).

The characteristics of floods in this part of the catchment has changed in recent years due to extraction by upstream users and the reduced flows experienced under drought conditions. However, these properties would historically have been subject to periodic inundation events. The potential effects of environmental watering on these properties are not fully understood and require further analysis.

Potential constraints to environmental flow delivery in the Gwydir therefore consist mainly of the storage release capacity and possible third-party flooding impacts in the lower reaches of the river system.

6.7.2 Representation of Constraints in the Hydrological Model

MDBA has used the Gwydir IQQM as developed to represent the Water Sharing Plan (DIPNR (2004d) to help develop environmental flow rules and targets. Copeton Dam is modelled as a storage with full supply capacity of 1,364 GL. Storage release capacity flow rates are determined via a function of storage release capacity against storage volume. The modelled maximum storage release capacity (when full) is 10,700 ML/d. The Environmental Contingency Allowance is included in both the baseline and Basin Plan versions of the model.

The flood level at Moree is not explicitly modelled as flows are below the flow threshold for the vast majority of the time under baseline conditions. However losses (including overbank losses) in those reaches are represented as losses corresponding to a particular river flow, determined during model calibration. Further details of how the Gwydir model was used for Basin Plan development (and how the ECA was incorporated) are described in MDBA (2012y).

6.7.3 Environmental Flows Affected by Constraints

The environmental water requirements for the Gwydir region identified during Basin Plan development can be divided into four main groups:

- Baseflow requirements,
- Gwydir and Mallowa Wetland volumetric requirements,
- Gwydir Wetland threshold requirements, and
- Contribution to downstream requirements.

Baseflow targets are based on nutrient cycling, fish passage and riparian health requirements, and are limited to in-channel flows that can be satisfied through relatively low release rates from public storage.

The environmental water requirements for the Gwydir and Mallowa Wetlands can largely be satisfied, however delivering events associated with the largest of these flow indicators can sometimes be limited by constraints.

The rate at which water can be delivered from the Gwydir system to the Barwon River is strongly limited by physical constraints, namely the natural reduced channel capacity of the various creeks and anabranches towards the end of the system.

Copeton Dam and the Gwydir Wetlands

Modelling completed by the MDBA as part of the Basin Plan development process investigated the capacity to which environmental watering events in the Gwydir can be delivered within existing constraints (MDBA 2012y). The results indicated that only one of the nine Gwydir indicators is associated with events which may be difficult to actively manage. The 250 GL indicator has therefore been categorised to be beyond active management (marked brown in Table 44), consistent with the assessment given by MDBA (2012g).

Recent environmental watering actions have indicated that the delivery of even small volumes to the Gwydir Wetlands has been significantly constrained by the lack of flow delivery rights for inundation of private land (pers. comm. Commonwealth Environmental Water Office). This has therefore been classified as a 1st order constraint.

The storage release capacity of Copeton Dam is an important constraint when trying to satisfy the environmental flow targets. At full capacity, the outlet can achieve its maximum flow capability of 10,850 ML/d. However, this decreases as storage level decreases. Copeton Dam is required to provide reliability of supply for downstream users, hence some environmental releases (for example through the ECA) will be made in addition to existing irrigation releases. The capacity of the dam to satisfy both requirements could impede environmental flow delivery on an event-by-event basis (as irrigation reliability must be maintained), particularly during years when the storage levels are low and the catchment is relatively dry. An increase in storage release capacity for Copeton Dam could afford water managers increased flexibility to deliver environmental events.

Downstream of Copeton Dam, the Gwydir River receives inflows from a number of unregulated tributaries. In practice, mid-to-high flow environmental watering will be achieved by combining releases from Copeton Dam with relatively large unregulated inflows from these tributaries. Careful timing of these releases would be required to maximise the environmental benefits of these releases, and would therefore be an important consideration of environmental watering.

Additional Flow Constraints

Flooding levels at Moree and the channel capacity caused by The Raft are both characterised as 2nd order constraints in the Gwydir region, as they could potentially become more important if the storage release capacity if Copeton Dam was increased. For example, minor flooding at Moree commences at 10,500 ML/d, with moderate flooding occurring at 21,000 ML/d. All but one of the environmental targets can be met under existing system constraints, with the remaining one depending on better timing of existing releases with unregulated tributaries. Understanding the full effects requires further research.

Table 57 and Table 58summarise the specific flow indicators for the Gwydir and Mallowa Wetlands as detailed in MDBA (2012g). All but one of the Gwydir Wetland indicators and all of the Mallowa Wetland indicators are considered deliverable under existing system constraints. This analysis is based on long-term average results.

Table 57: Site-specific flow indicators for the Gwydir Wetlands (flows gauged at Yarraman Bridge on the Gwydir River; MDBA 2012g) and the degree to which they can be achieved under current constraints and operational practice

Site-specific ecological targets	Site-specific flow indicators (flow measured at Yarraman Bridge)
Provide a flow regime which supports recruitment opportunities for a range of native aquatic species (e.g. fish, frogs, turtles and invertebrates) 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 and invertebrates) Provide a flow regime which supports key ecosystem functions, particularly those related to connectivity between the river and the floodplain	Achievable under current operating conditions • A total inflow of 150 ML/d for 45 days during October to January for 85% of years • A total inflow of 1000 ML/d for 2 days during October to January for 85% of years • A total in-flow volume of 45 GL during October & March for 80% of years • A total in-flow volume of 60 GL during October & March for 60% of years • A total in-flow volume of 80 GL during October & March for 40% of years • A total in-flow volume of 150 GL during October & March for 20% of years Difficult to influence achievement under most conditions (constraints limit delivery at most times) • A total in-flow volume of 250 GL during October & March for 12% of years

Table 58: Site-specific flow indicators for the Mallowa Wetlands (MDBA 2012g)and the degree to which they can be achieved under current constraints and operational practice

Site-specific ecological targets	Site-specific flow indicators (flow measure at Mallowa Creek offtake)
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 key ecosystem functions, particularly those related to connectivity between the river and the floodplain	Achievable under current operating conditions • A total in-flow volume of 5.4 GL during February to March and August to September for 91% of years • A total in-flow volume of 4.5 GL during November & January for 40% of years

Downstream Requirements

Under the Basin Plan, a portion of the water recovered in each region is allocated towards downstream requirements. This recognises that environmental flow events in the Barwon–Darling are almost purely reliant on water delivered from upstream tributaries, including the Gwydir. Although the majority of water from the Gwydir is used within the Gwydir Wetlands, and very little makes it downstream, at times of high flow some of this water continues into the Barwon–Darling. Consideration of Gwydir constraints can help, if required, in delivering environmental water during those high flow events. The capacity of the Gwydir region to contribute to environmental water requirements in the Barwon–Darling region is detailed in Section 6.4.

6.7.4 Summary

Environmental flows have been specified for the Gwydir and Mallowa Wetlands (MDBA 2012g). Modelling conducted as part of the development of the Basin Plan indicates that all but one of the Gwydir environmental water requirements can be met within existing system constraints (Table 57 and Table 58). The one remaining target can be met with improved timing of environmental releases with downstream tributary inflows. In practice, environmental watering will be constrained by the inability to inundate private landholdings along the Gingham Watercourse.

Table 59summarises the constraints in the Gwydir region. The impacts of environmental water delivery on three private properties in the Lower Gwydir (on the Gingham Watercourse) are not fully understood and require further analysis. The ability to accurately time releases from Copeton Dam to coincide with unregulated inflows from tributaries is of prime importance in the Gwydir, as per other regulated valleys in the Murray–Darling Basin. The storage release capacity of Copeton Dam is not considered of prime importance, but it can constrain the flexibility of water managers to meet individual events.

The minor flood level at Moree is also listed. This, as well as the channel capacity at The Raft, is an important operational constraint but is not thought to represent a significant impediment to environmental flow delivery.

Table 59: Summary of Gwydir constraints (from upstream to downstream), where constraints have been classified in terms of their capacity to limit flows

Location	Constraint Description	Flow Constraint	Inhibits Environmental Flow Delivery?
Gingham Watercourse	Private landholdings	—	Possibly
Copeton Dam	Maximum storage release capacity	10,850 ML/d	No
Copeton Dam	Timing (ability to coincide environmental releases with unregulated inflow events)	—	Possibly
The Raft	Channel Capacity	5,000 – 10,000 ML/d	No
Yarraman Bridge	Flood Level	9,700 ML/d	No
Moree	Flood Level	10,500 ML/d	No

7. Queensland

7.1 Border Rivers

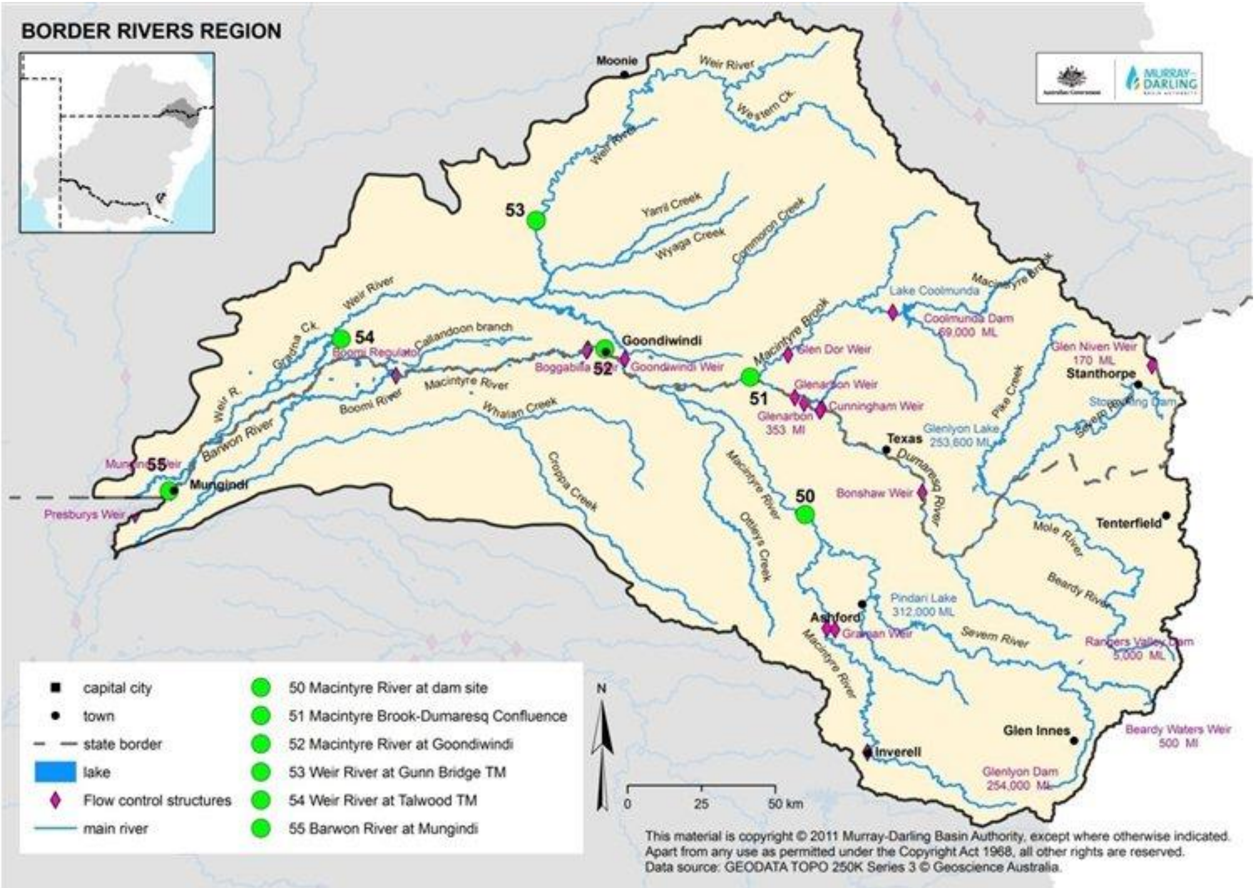
The Border Rivers rise on the western slopes of the Great Dividing Range in the areas straddling the NSW–Queensland border. The principle streams are the Macintyre River (NSW), Severn River (NSW), Dumaresq River (QLD), Macintyre Brook (QLD) and the Weir River (QLD). The region covers an area of approximately 44,600 km^2 and a map of the region is shown Figure 39.

It is bounded to the east by the Great Dividing Range, to the north by the Condamine–Balonne and Moonie regions, to the south by the Gwydir region and to the west by the Barwon–Darling region (CSIRO 2007a). Flow leaves the region at three locations; the Barwon River at Mungindi, the Boomi River at Neeworra and Gil Gil Creek at Weemelah. A schematic diagram of the region, including key structures and flow constraints, is shown in Figure 40.

Broad acre livestock grazing is the dominant land use in the region. In the year 2000, there were approximately 75,300 ha of irrigated cropping, with cotton accounting for over 75%of this area. Irrigation is mostly from surface water diversions although groundwater is used predominantly in the Dumaresq River valley to irrigate fodder crops. Small-scale crops such as grapes, stone fruit, vegetables and apples are grown on the upland areas. There is a small amount of commercial plantation forestry and large numbers of farm dams and ring tanks in the region (CSIRO 2007a). The extent and main features of the Border Rivers region is presented in Figure 39, while a schematic of the river and its main regulating structures are shown in Figure 40

The headwaters of the regulated Macintyre River are in the Northern Tablelands of NSW, rising to the south of Glen Innes. The river drains to the northwest, passing through the town of Inverell. The principle tributary to the Macintyre River in NSW is the Severn River, which joins the Macintyre River northwest of Ashford. It rises in the elevated region north of Glen Innes and flows to the Pindari Dam, through Kwaimbal National Park and then into the Macintyre River. Major tributaries of the Severn River (NSW) include Beardy Waters and Wellingrove Creek.

Figure 39: The extent and main features of the Border Rivers region



The regulated Macintyre River continues flowing to the northwest, where it converges with the Dumaresq River a few kilometres east of Boggabilla. At this confluence point the Macintyre River forms the border between New South Wales and Queensland.

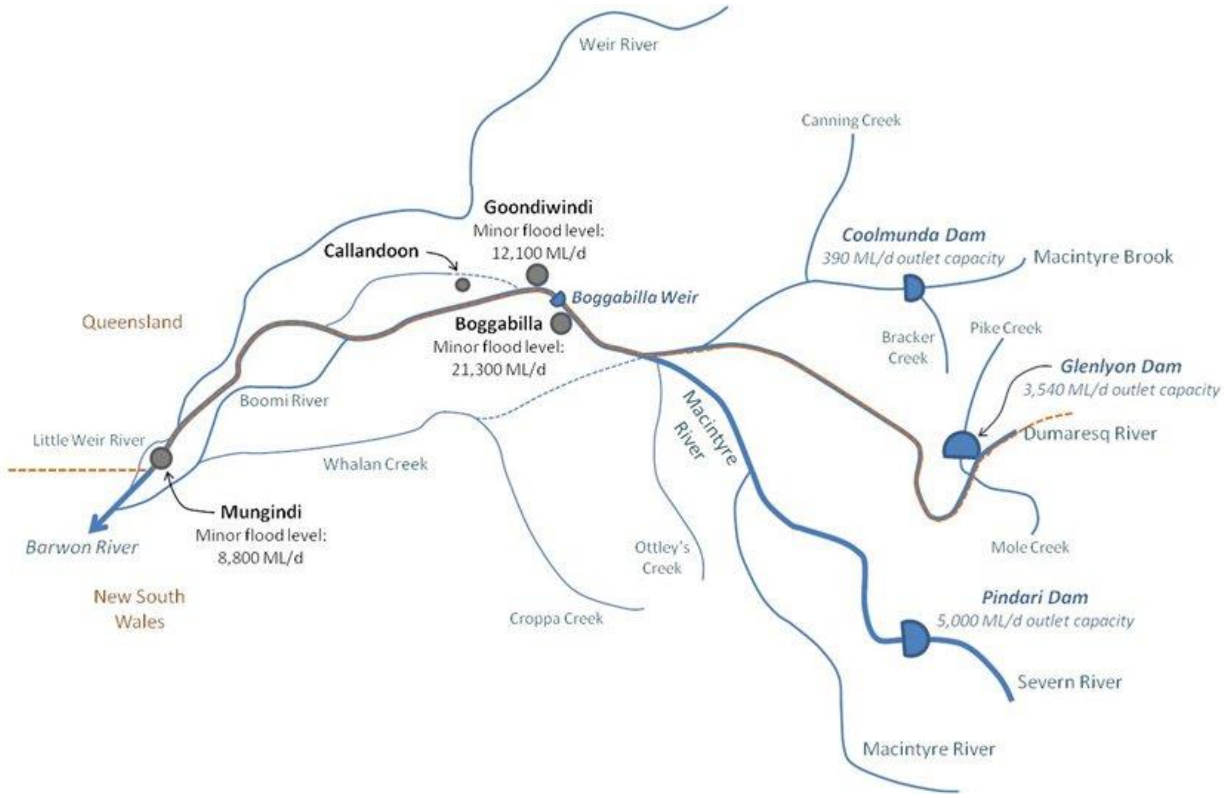
The Dumaresq River in QLD begins about 50 km west of Tenterfield at the junction of Queensland's Severn River, the Mole River and Pike Creek. Glenlyon Dam is situated on Pike Creek and is one of the major storages in the system. About halfway between Texas and Boggabilla the Dumaresq is joined by the regulated Macintyre Brook, which has its headwaters below Mount Burrabaranga at an elevation of 674 m above sea level. Major tributaries include the Canning and Bracker Creeks. Coolmunda Dam is the major storage for the Macintyre Brook Water Supply Scheme which supplies water for irrigation and town water for Inglewood (CSIRO 2007a).

The Macintyre River passes through the Boggabilla Weir, nine kilometres upstream of Goondiwindi. The River then swings southwest through Goondiwindi and eventually becomes the Barwon River at its junction with the Weir River.

The Weir River is a major unregulated stream in the Border Rivers region, joining the Macintyre River 23 km upstream of Mungindi. During high flow events, water can be passed from the Weir to the Macintyre River at a location further upstream, where the distance between the two channels narrows to approximately one kilometre (CSIRO 2007a). Downstream of Mungindi, the

Macintyre River becomes the Barwon River, however this is a continuation of the same river channel with a different name.

Figure 40: Schematic diagram summarising the key structural features and flow constraints in the Border Rivers



The major water storages in the system are located in the headwaters of each of the major rivers and include Pindari Dam (312 GL capacity) on the Severn River, Glenlyon Dam (254 GL capacity) on Pike Creek near the junction with the Dumaresq River, and Coolmunda Dam (69 GL capacity) on the Macintyre Brook. These storages are primarily used to supply agricultural water (largely cotton and grain and fodder crops) and water to nearby towns. A significant volume of unregulated inflow occurs downstream of these storages throughout the region, from sources such as southern section of the Macintyre River, Canning Creek, Ottley's Creek, and the Weir River (Figure 40)

Major NSW towns include Glen Innes, Tenterfield, Inverell, Ashford, Boggabilla and Mungindi. Major QLD towns include Inglewood, Texas, Stanthorpe and Goondiwindi. The region has a population of around 50,000 people (CSIRO 2007a).

The floodplain between Goondiwindi and Mungindi contains a large number of anabranches and billabongs (CSIRO 2007a). Downstream from Goondiwindi small effluent creeks such as Boomi River, Callandoon Creek and Whalan Creek break off from the main channel and meander westward across the region forming a complex floodplain of billabongs and wetlands that rely on overbank flows to receive water (Kingsford 1999). These anabranches and billabongs are important geo-morphological assets and the wetlands are important breeding habitat for protected waterbird species (MDBA 2012k). Floodplain harvesting is common along this stretch of the system.

The nationally significant wetland Morella Watercourse/Boobera Lagoon/Pungbougal Lagoon 6 km south-west of Goondiwindi in New South Wales is considered to be one of the most important Aboriginal places in eastern Australia. It is located on the Macintyre River floodplain (CSIRO 2007a).

Management arrangements for both surface and groundwater resources are set out in state legislation in both New South Wales and Queensland. Both States have a New South Wales – Queensland Border Rivers Act to ratify the New South Wales – Queensland Border Rivers Agreement. The regulated component of the system supplying water to New South Wales is sourced from Pindari Dam, a share of Glenlyon Dam, and tributary inflows.

In Queensland, the Queensland Border Rivers Water Supply Scheme regulated system is supplied by a share of Glenlyon Dam and tributary inflows, and the Queensland Macintyre Brook Water Supply Scheme regulated system is supplied by Coolmunda Dam. In 2000/01 Border Rivers surface water diversions for irrigation were 535 GL (or 4.4%) of the total surface water diversions within the Murray–Darling Basin (CSIRO 2007a). Details of the Border Rivers Water Resource Plan, Border Rivers Resource Operations Plan and NSW Border Rivers Water Sharing Plan can be found in DNRM (2003b, 2006a) and DWE (2007) respectively.

Environmental water requirements have been defined for the Border Rivers region (MDBA 2011k) as part of the development of the Basin Plan. These requirements are related to in-channel fresh events which aim to enhance longitudinal connectivity throughout the river system. This connectivity is important for a range of ecological process, such as nutrient cycling, the migration and recruitment of native fish species, and the maintenance of key riparian features such as benches and banks. The required flow events have been specified at Mungindi.

A summary list of flow constraints considered important for the Border Rivers catchment is presented in Table 60. Flow constraints defined as ‘1st order’ constitute primary constraints to successful delivery of environmental flows for the catchment.

Constraints which become sequentially important once 1st order constraints are considered are classified as 2nd and 3rdorder constraints. For the Border Rivers, the primary identified constraint to environmental flow delivery of the specified frequency is the access conditions for unregulated licence holders which are characterised as a1st order constraint. Second order constraints to the efficient delivery of environmental flows are the storage release capacities of Pindari and Glenlyon Dams, which are expected to constrain environmental water delivery only during specific flow and climatic conditions.

Third order constraints may become important once 1st and 2nd order constraints are addressed, and consist of flooding levels for various locations along the river. These levels are far in excess of the environmental water requirement flow rates for the Border Rivers region, hence townships are not thought to have any significant risk of increased flooding as a result of environmental watering. A schematic diagram of the region, including structural features and summarising key flow constraints, is shown in Figure 40.

Table 60: A list of key constraints thought to limit environmental flow delivery in the Border Rivers region, where constraints have been classified in terms of their capacity to limit flows

Order	Location	Description	Flow Limit (ML/d)
1st	Irrigation region between Goondiwindi and Mungindi and along the Weir river	Capacity to shepherd environmental flows (unsupplemented water access conditions)	—
2nd	Pindari Dam	Storage release capacity	5,000
	Glenlyon Dam	Storage release capacity	3,540
	Coolmunda Dam	Storage release capacity	390
3rd	Boggabilla	Minor flood level Moderate flood level Major flood level	21,300 117,300 149,500
	Goondiwindi	Minor flood level Moderate flood level Major flood level	12,100 26,900 71,000
	Mungindi	Minor flood level Moderate flood level Major flood level	8,800 12,100 16,300

7.1.1 Key Structures and Flow Constraints

The Federal Government has initiated a Basin-wide buyback process to recover water licences from willing sellers for environmental flow purposes. Once complete, some of these licences will be associated with regulated flow conditions in which water can be ordered from an upstream storage (termed ‘supplemented access’ in Queensland, and high or general security access in New South Wales), whereas others will be associated with unregulated conditions (termed ‘unsupplemented flows’ in Queensland, and ‘supplementary flows’ in New South Wales). The most prominent constraint limiting environmental water delivery depends on the type of licence with which the water is associated.

Public Water Storages

For those licences associated with regulated flow conditions, the primary limiting factor is the physical constraints associated with the public water storages. The main public storages in the Border Rivers region are:

- Pindari Dam (312 GL capacity)
- Glenlyon Dam (254 GL capacity)
- Coolmunda Dam (69 GL capacity)

Pindari, Glenlyon and Coolmunda Dams are operated within a release rate limit of 5,000, 3,540 and 390 ML/d respectively. These storage release capacities are applicable when the storages are at full supply level; the storage release capacities decrease as the volume of stored water decreases. In practice, little (if any) of the recovered water licences will be associated with

Coolmunda Dam, hence the Pindari and Glenlyon Dam storage release capacities have the greatest potential to limit regulated environmental water delivery.

As described in Section 3, the delivery of an environmental event will often be accomplished by combining regulated releases from a public storage with an unregulated inflow event from a downstream tributary, such as the Macintyre, Mole, Severn and Weir Rivers. Combining these flows allows the benefits of environmental water to be enhanced, hence the timing of these releases is an important constraint to environmental water delivery. Furthermore, the opportunity to augment unregulated flows to achieve water requirements at Mungindi is also reduced by on-farm storage development (MDBA 2012k).

Shepherding of Environmental Flows

During unregulated flow conditions, unsupplemented access (QLD) and supplementary access (NSW) licence holders are able to pump water directly from the river. Subject to certain provisions, the access rights are associated with specific flow conditions, generally during periods of mid-to-high flow. River conditions during an environmental flow event will often coincide with the active access rights, and subsequent pumping will reduce the effectiveness of this event for native vegetation, waterbirds and other aquatic species on the downstream floodplain.

Therefore, in addition to the ongoing water recovery program, a water sharing strategy to allow environmental flows to pass unimpeded at specific times (shepherding) is likely to provide improved environmental outcomes. Shepherding arrangements are intended to ensure that environmental water holders are able to use their water for environmental purposes, without increasing or diminishing the interests of consumptive users. These arrangements would need to be managed with licence holders, and a full quantification of the benefits is yet to be determined.

Channel Capacities

Periods of high flow can exceed the channel capacity at specific locations along the river, sometimes inundating private property. Existing operational practices of the public storages include provisions to mitigate potential flooding of downstream private land. The flows associated with minor, moderate and major flood levels for Boggabilla, Goondiwindi and Mungindi are listed in Table 60.

7.1.2 Representation of Constraints in the Hydrological Model

The MDBA has used two models, the Macintyre Brook IQQM and the Border Rivers IQQM, to represent the region for Basin Plan modelling purposes (MDBA 2012y). The baseline models, as used by MDBA, are the models corresponding to the Inter-Government Agreement (IGA) between New South Wales and Queensland.

Macintyre Brook Model

This model simulates the Macintyre Brook system from Coolmunda Dam to its confluence with the Dumaresq River. Coolmunda Dam is the only regulated storage in the model and is modelled as a headwater storage with a maximum capacity of 69 GL. Inflow rates to Coolmunda Dam are less than 390 ML/d (the operational maximum storage release capacity) for more than 99% of days. Maximum storage release capacities are set to reflect the capacity to pass any of this inflow that may be required downstream on a daily basis.

Modelled water extractions include Queensland high and medium priority water allocations and town water supplies. No changes have been made to the Macintyre Brook model from that received from QLD to that used in the Basin Plan.

Border Rivers Model

This model simulates the Border Rivers region from the headwater inflows of Pike Creek into Glenlyon Dam and the Severn River (NSW) into Pindari Dam. The model covers the main rivers, urban centres and tributary inflows downstream to the confluence with the Barwon River at Mungindi. These include:

- The Dumaresq River (which defines the border) and associated tributaries
- The Severn River (QLD) and tributaries
- The Severn River (NSW) and tributaries
- The Weir River (QLD), Little Weir River and tributaries
- Callandoon Creek (QLD)
- Boomi Creek (NSW), and
- Whalan Creek (NSW).

Natural weir pools and floodplains across the length of the Border Rivers are modelled as individual storages.

Pindari Dam is modelled with a full capacity of 312 GL, and a maximum storage release capacity of up to approximately 9,000 ML/d when at full storage level. The storage release capacity depending on storage level is defined by the capacity table. The operational practice represented in the model is to limit outlet rates to 5,000 ML/d when at full storage level.

Similarly, Glenlyon Dam is modelled with a full storage capacity of 253.6 GL. Maximum storage release capacity is defined via an equation relating storage volume to storage release capacity using a constant exponent factor. For a full supply level, this storage release capacity equals 3,840 ML/d.

Water is shared between QLD and NSW in these two storages (and for surplus flows) under the rules and definitions described in the Inter-Governmental Agreement between the two States. Water extractions are modelled in detail. The water use in Queensland is modelled for high and medium priority water allocations, unsupplemented water allocations and town water supplies and in NSW for general security, supplementary access and high security town water supplies in various regions and reaches throughout the model (MDBA 2012y). Specific unsupplemented/supplementary access diverters are modelled as having specific pumping thresholds and flow conditions within which they are permitted to extract water.

Flood levels at various locations are not explicitly modelled as flows are below the thresholds for a large fraction of the time under baseline conditions. However losses (including overbank losses) in those reaches are represented as a loss corresponding to a particular river flow, determined during model calibration.

7.1.3 Environmental Flows affected by Constraints

The environmental water requirements in the Border Rivers system identified through Basin Plan development can be divided into three main categories:

- Baseflow requirements
- In-channel fresh requirements
- Contribution to downstream requirements

Ensuring the achievement of the first of these is not greatly impeded by existing system constraints; baseflow targets are limited to in-channel flows which can be satisfied through relatively low release rates from public storages.

In contrast, satisfying the second and third targets would be limited by existing flow constraints. Achieving the associated environmental outcomes requires relatively high in-channel flows at Mungindi (4,000 ML/d; MDBA 2012k), and Basin Plan modelling (MDBA 2012y) indicates that the achievement of these flows may require flow shepherding arrangements.

Flow Shepherding and Storage Release Capacities

In developing the Basin Plan, environmental water requirements have been specified at Mungindi (MDBA 2012k). These requirements (Table 61) are rarely achieved under existing water sharing arrangements, with the frequency of individual flow events considerably less than the target.

The primary (1st order) constraints impeding the delivery of water to Mungindi are the access conditions which may limit water shepherding of environmental flows through the system. Unsupplemented/supplementary (QLD/NSW respectively) water licence holders in the Border Rivers region are able to access water during specific flow conditions. Many of these licence holders are located between Goondiwindi and Mungindi, and subsequent pumping will reduce the effectiveness of an environmental flow event to support recruitment opportunities for native aquatic species and key ecosystem functions relating to longitudinal connectivity and sediment, nutrient and carbon transport.

There are also a high number of unsupplemented licence holders on the unregulated Weir River. Significant inflows from the Weir River and other smaller tributaries occur downstream of Goondiwindi, however take from the watercourse under unsupplemented water licences can reduce these inflows.

The storage release capacities of Pindari, Glenlyon and Coolmunda Dams may impede environmental flow delivery under certain conditions. At full supply level, the storage release capacities are 5,000, 3,540 and 390 ML/d respectively (noting that these values decrease as the volume of stored water is lowered). The environmental water requirements for the lower Border Rivers are related to flow rates of 4,000 ML/d for durations of 5 days and 11 days respectively (MDBA 2012k). It is likely that this flow could be achieved in most years, especially if storage releases are combined with unregulated inflow event from a downstream tributary stream.

However the capacity of the dams to satisfy both environmental and irrigation requirements through releases could impede environmental water delivery during years when the volume of water in storage is relatively low. Furthermore, the exact release volume would be difficult to predict for each specific event, as conveyance losses between the storages and Mungindi vary on an event-by-event basis. As described above, any environmental release would require a shepherding arrangement to ensure the desired flow is achieved. Quantification of these effects would require additional analysis, however it is expected that the storage release capacities will not impede the achievement of desired environmental flows over the long term.

Channel Capacities

Flood levels at Boggabilla, Goondiwindi and Mungindi are characterised as3rd order constraints. In Mungindi minor flooding occurs at 8,800 ML/d, while 12,100 ML/d results in more moderate flooding. The minor flood levels for Goondiwindi and Boggabilla correspond to flows of 12,100 and 21,300 ML/d respectively (Table 60). The environmental flow targets specified at Mungindi are associated with flows of 4,000 ML/d. The flooding levels are therefore significantly greater than the specified environmental flows, hence it is unlikely that the release of environmental water would produce flows exceeding 8,800 ML/d at Mungindi.

Assessment of Environmental Flow Indicators

Table 61summarises the specific flow indicators for the lower Border Rivers as detailed in MDBA (2012k). Basin Plan modelling (MDBA 2012y) has demonstrated that a combination of regulated releases and flow shepherding arrangements can meet the desired environmental flows. However, increasing the storage release capacities of these storages would enable increased flexibility of water managers to deliver environmental water.

Table 61: Site-specific flow indicators for Lower Border Rivers (in-channel flows) (MDBA 2012k) and the degree to which they can be achieved under current constraints and operational practice

Site-specific ecological targets	Site-specific flow indicators (flow measured at Mungindi)
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	Achievable under current operating conditions • 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

Downstream Requirements

Environmental flow events in the Barwon–Darling are almost purely reliant on water delivered from upstream tributaries. The delivery of downstream water from the Border Rivers region is subject to in-valley constraints such as storage release and channel capacities, and flow shepherding, and these are discussed in detail in Section 6.4on the Barwon–Darling.

7.1.4 Summary

There are a number of constraints throughout the Border Rivers system, summarised in Table 62below. The predominant constraint to the delivery of environmental flows to the lower Border Rivers is the existing access arrangements for unsupplemented/supplementary (QLD/NSW) water licences. The maximum storage release capacity of the Pindari and Glenlyon Dams constitute the secondary level of constraints in the Border Rivers region, when considering environmental delivery on an event-by-event basis.

Potential additional flooding of Boggabilla, Goondiwindi and Mungindi is highly unlikely to occur if larger environmental releases are made, as flooding levels are far in excess of any required environmental volume. However, further analysis is required to fully quantify the effect of these constraints on environmental flow delivery and flooding issues at other locations. Table 62 summarises the key constraints in the Border Rivers region.

Table 62: Summary of Border River constraints, and their importance in downstream environmental flow delivery where constraints have been classified in terms of their capacity to limit flows

Location	Constraint Description	Flow Constraint	Inhibits Environmental Flow Delivery?
Irrigation region between Goondiwindi and Mungindi and along the Weir river	Shepherding of environmental flows (unsupplemented water access conditions and)	—	Yes
Pindari Dam	Storage release capacity	5,000 ML/day	Yes
Glenlyon Dam	Storage release capacity	3,540 ML/day	Yes
Coolmunda Dam	Storage release capacity	390 ML/day	No
Boggabilla	Minor flood levels	21,300 ML/day	—
	Moderate flood levels	117,300 ML/day	
	Major flood level	149,500 ML/day	
Goondiwindi	Minor flood level	12,100 ML/day	—
	Moderate flood level	26,900 ML/day	
	Major flood level	71,000v ML/day	
Mungindi	Minor flood level	8,800 ML/day	—
	Moderate flood level	12,100 ML/day	
	Major flood level	16,300 ML/day	

7.2 Condamine–Balonne

The Condamine-Balonne region lies mainly in southern Queensland and extends about 100 km south-west into New South Wales (Figure 41). The major waterways in the region are the Condamine, Balonne and Maranoa rivers. The Condamine River flows through southern Queensland and is only regulated in its upper reaches (by Leslie Dam near Warwick) and for a small section near Chinchilla. West of Surat, it becomes the Balonne River. The river passes through Beardmore Dam which, in conjunction with Jack Taylor Weir, provides water for the St George Irrigation Area and the township of St George. The Maranoa River joins the Balonne within the pondage area of Beardmore Dam.

Compared with most catchments located further south, the Condamine-Balonne system has experienced a lower level of river regulation. As a proportion of the volume of available water, the combined capacity of public storages in this region is relatively limited. The total storage volume capacity in this region is estimated to be 1,582 GL (Webb et al. 2007), and this is dominated by numerous private off-stream water storages located primarily downstream of

Beardmore Dam (CSIRO 2008d). Only a small proportion of the total capacity (208 GL; 13%) can be found in the four major public storages:

- Leslie Dam (106 GL, Upper Condamine)
- Chinchilla Weir (10 GL, Mid-Condamine)
- Beardmore Dam (82 GL, St George)
- Jack Taylor Weir (10 GL, St George)

Leslie Dam, the main flow-regulating structure in the Upper Condamine catchment, is located on Sandy Creek, a major tributary of the Condamine River. This storage provides water to the towns of Warwick and Cecil Plains, and irrigation water through the Upper Condamine Water Supply Scheme. Flow in the Mid-Condamine catchment is re-regulated by Chinchilla Weir. This structure artificially raises the river level to create a weir pool, which is accessed to supply water to the nearby town of Chinchilla and allows irrigation water to be delivered throughout the Condamine alluvial flat country via the Chinchilla Weir Water Supply Scheme.

Flow into the Lower Balonne (from both the Condamine and Maranoa Rivers) is controlled through the combined operation of Beardmore Dam and Jack Taylor Weir, both located near the major township of St George. Beardmore Dam provides regulated supplies to the off-river St George Water Supply Scheme, mainly through the Thuraggi Watercourse (via Moolabah Weir), but also from Jack Taylor Weir (located approximately 22 km downstream of the dam). Only minor regulated supplies are delivered along the river downstream of the Dam. The release capacity of Beardmore Dam depends on the water level in the Dam. When the water level is above the fixed crest level of the outlet works the release capacity depends on the water level and the number of gates opened. Below the fixed crest level, the low level outlet has a capacity of approximately 1,000 ML/d.

Downstream of Jack Taylor Weir the system breaks into a number of distributary channels with hydraulic characteristics similar to those displayed by a river delta. Some of the water passes through the easternmost channel, the Narran River, which terminates in the Narran Lakes. The remaining water flows through the complex distributary channels which form the Lower Balonne Floodplain, passing water to the Barwon-Darling River.

Regulated supplies from dams and weirs only supply a small proportion of irrigation water in the region. The majority of irrigation production relies on diverting unregulated flows into large privately owned off-stream storages, particularly downstream of St George.

Nebine Creek is an unregulated system which irregularly contributes water to the Culgoa from the relatively flat Nebine catchment (Figure 41). A schematic map of the region, including structural features and flow constraints, is given in Figure 42.

The Condamine Balonne region includes two hydrologic indicator sites assessed through the development of the Basin Plan, both located in the Lower Balonne:

- Lower Balonne Floodplain (MDBA 2012n)
- Narran Lakes (MDBA 2012u)

The Lower Balonne Floodplain comprises a complex channel system, which includes the channels, waterholes and floodplains of the Culgoa, Ballandool, Birrie, Bokhara and Narran Rivers. In-channel and overbank flows support a variety of fish and macro-invertebrate species, and vegetation such as river redgum, black box, lignum and coolibah. Environmental water requirements have been determined for the floodplain using a combination of scientific studies and hydrological model data, as outlined in MDBA (2012n).

The Narran Lakes system is a large terminal wetland on the lower reaches of the Narran River between Brewarrina and Walgett in New South Wales. The system is a floodplain–wetland complex consisting of four lakes: Clear Lake, Back Lake and Long Arm (which form the northern lakes) and Narran Lake; and a complex network of river channels that dissect the floodplain. Narran Lakes includes a Ramsar wetland that has areas of extensive, frequently-available breeding and feeding habitat for numerous waterbird species. The main land use in the region is grazing, with Narran Lake used for dryland cropping (MDBA 2012u). When full, Narran Lake is about 2 m deep and Clear Lake approximately 1.5 m deep. The Narran Lakes system is about 278 km2 in area and holds some 146 GL of water when full (MDBA 2012u). About half its area comprises the lakes while the rest (136 km2) is associated floodplain (Thoms et al. 2007). A description of the environmental water requirements for this site, and the underlying evidence base, is given in MDBA (2012u).

Figure 41: The extent and main features of the Condamine–Balonne region

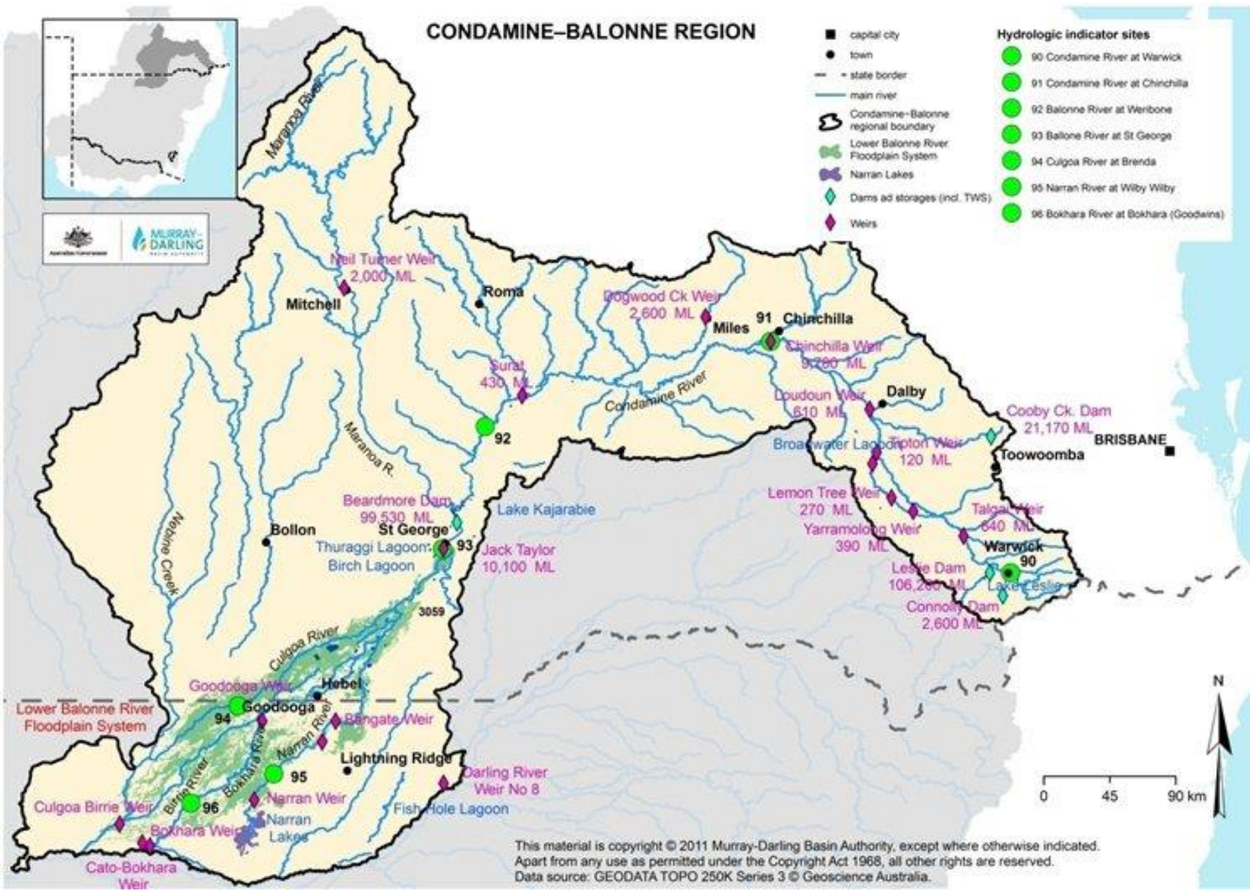
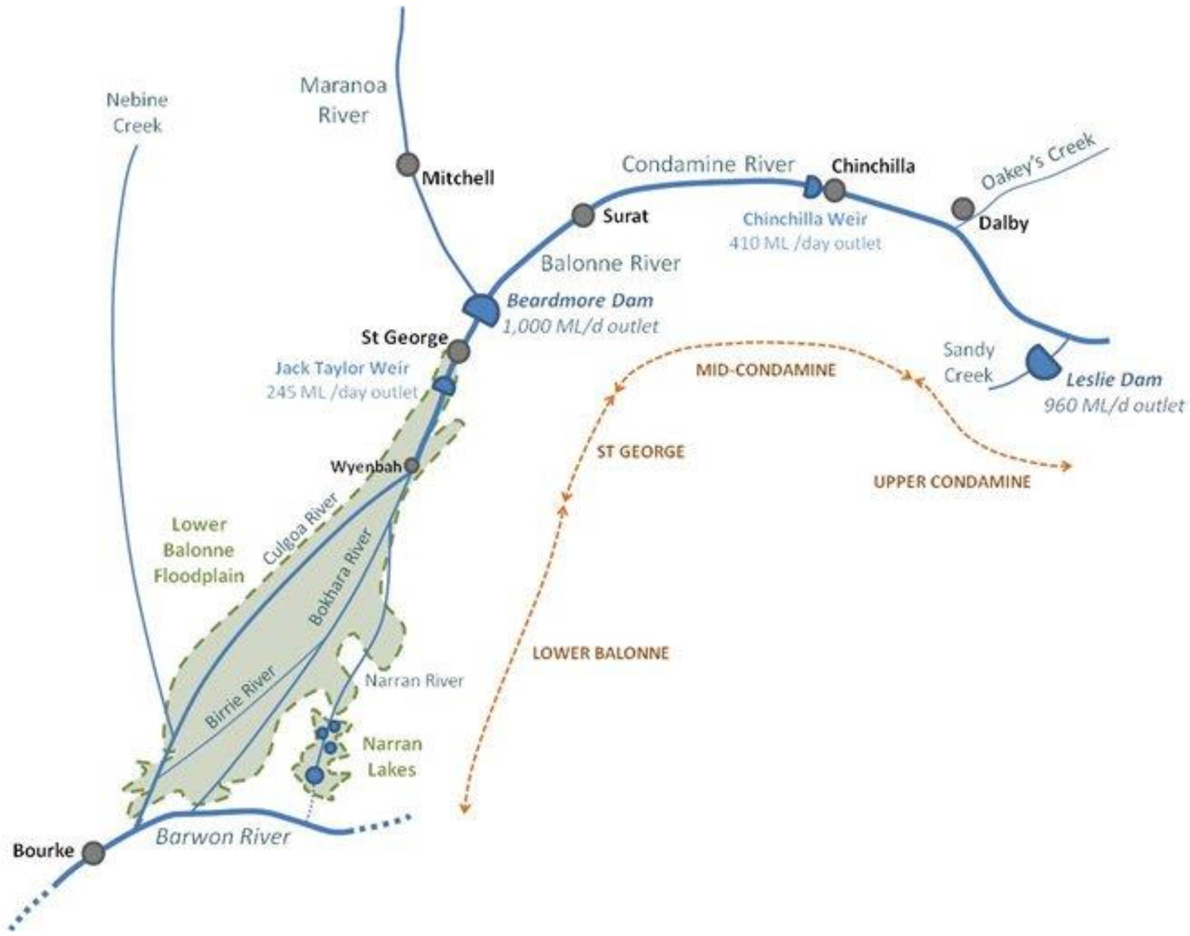


Figure 42: Schematic diagram summarising the key structural features and flow constraints in the Condamine–Balonne



A summary list of the flow constraints in the Condamine–Balonne catchment is presented in Table 63. To date, the water recovery process undertaken in this region has been limited to unregulated entitlements. These do not allow the entitlement holder to request water from an upstream storage, but instead are associated with access conditions during unregulated flow events. Modelling conducted by MDBA indicates that environmental outcomes are closely associated with the geographic location of the recovered entitlements, and the large number of available recovery options represents the first order constraint. No 2nd order constraints have been identified in the Condamine-Balonne region.

Under current arrangements, regulated flows from Beardmore Dam are limited to 1,000 ML/d, and this is listed as a 3rd order constraint which would take effect if future recovery included a regulated licence component. Existing bifurcation weirs in the Lower Balonne could help regulate low flows for environmental purposes. This may require an adaptation of existing weir operating practices and is also listed as a 3rd order constraint.

Table 63: A list of key constraints limiting environmental flow delivery in the Condamine–Balonne region, where constraints have been classified in terms of their capacity to limit flows

Order	Location	Description	Flow Limit (ML/d)
1st	St George and Lower Balonne regions	Options available for water recovery limited mainly to unregulated entitlements	—
2nd	To be identified		
3rd	Lower Balonne bifurcation weirs	Operational practices during low flows	—
	Beardmore Dam	Storage release capacity (regulated conditions)	1,000
	St George	Flood levels	14,700 (minor) 19,600 (moderate) 33,000 (major)
	St George and Lower Balonne regions	Shepherding of environmental flows (unsupplemented water access conditions)	—

7.2.1 Key Structures and Flow Constraints

Public water storages in the Condamine-Balonne region have a relatively limited capacity. As a result, a large proportion of mid-to-high flow environmental watering in this region will rely on unregulated events and water recovery which reduces extraction from these events. Due to the nature of these licences, the impact that their recovery will have on the flow regime in the Lower Balonne region is highly dependent on their location. The large number of options available for this recovery program is a primary potential constraint.

The management of low-flow environmental events in the Lower Balonne can be achieved through the use of existing bifurcation weirs. This type of regulation may require an adaptation of existing operational guidelines.

Unregulated Entitlements and Environmental Flows

The Commonwealth Government is conducting a Basin-wide buyback process to recover licensed water entitlements from willing sellers for environmental purposes. To date, this process has not included entitlements associated with regulated releases in the Condamine Balonne, but rather from unregulated (referred to as 'unsupplemented') entitlements.

Subject to certain provisions, unregulated entitlements are active when river levels exceed a given height (the pumping threshold), and are therefore often associated with periods of mid-to-high flow. These licences allow a limited volume to be pumped from the river (often directly to on-farm storages) for agricultural purposes. River conditions during an environmental flow event will often coincide with the active access rights of unsupplemented water users in the Lower Balonne, and subsequent pumping will reduce the effectiveness of this event for native vegetation, waterbirds and other aquatic species on the downstream floodplain.

Recovering these entitlements reduces consumptive extraction during unregulated events, hence the water can remain in-stream and contribute to downstream environmental water requirements. The spatial location where these entitlements are recovered will influence how much of this water reaches the targeted assets. The recovery process is still underway, and the location of the recovered entitlements in the future is the primary potential constraint to environmental outcomes in this region (Table 63).

On an event-by-event basis, the environmental outcomes of Commonwealth water may be enhanced through ‘shepherding’ or protection as it moves through the system. Shepherding arrangements are intended to ensure that environmental water holders are able to use their water for environmental purposes, without increasing or diminishing the interests of consumptive users. Water shepherding will rely on a combination of existing water resource management systems including the Murray–Darling Basin Cap on diversions (“the Cap”), existing/proposed water resource plans, and new arrangements where necessary (CEWH 2012). The capacity and management of shepherded environmental flows represents a 3rd order constraint (Table 63).

Bifurcation Weirs and Low Flows

The Lower Balonne system commences as a single channel passing through Beardmore Dam and Jack Taylor Weir near St George. Near Whyenbah, the river splits into the Balonne Minor and Culgoa Rivers, and the proportion of flow passing into each channel is controlled through the B1 Bifurcation weir. Further downstream, each channel experiences further bifurcations, producing the distributary delta-like hydrology of the Lower Balonne. Flows through many of the major bifurcations are also controlled by weirs, designed to control flows for consumptive use purposes.

These weirs are not able to control flows during higher flow events identified to be ecologically significant for the Lower Balonne Floodplain and Narran Lakes system. However, during the development of the Basin Plan, MDBA also identified baseflow (or low flow) requirements throughout the Basin, including in the Lower Balonne. The existing weirs could be used to regulate baseflows to provide environmental outcomes associated with the lower component of the flow regime, such as maintaining aquatic habitats for fish, plants and invertebrates. This type of environmental flow management may require an adaptation of existing weir operational practices. Furthermore, the management of low flows could be further enhanced through the recovery of regulated entitlements, allowing these flows to be requested from an upstream storage.

7.2.2 Representation of Constraints in the Hydrological Model

The Upper and Mid-Condamine models have included the constraints at Leslie Dam, Talgia, Yarramalong, and Lemon Tree weirs, but these are unlikely to affect the delivery of environmental flows as no mid-to-high environmental water requirements have been identified in these reaches of the river. The St George and Lower Balonne model has included constraints at Beardmore Dam, Jack Taylor, Moolabah and Buckinbah Weirs.

7.2.3 Environmental Flows Affected by Constraints

In the preparation of the Basin Plan, environmental water requirements have been specified in the Culgoa River at Brenda (Lower Balonne Floodplain; MDBA 2012j) and in the Narran River at Wilby Wilby (Narran Lakes; MDBA 2012u). These requirements are summarised in Table 64and Table 65 respectively.

Table 64: Site-specific flow indicators for Lower Balonne Floodplain (MDBA 2012j) and the degree to which they can be achieved under current constraints and operational practice

Site specific ecological targets	Site specific flow indicators (flow measured at Brenda)
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. Provide a flow regime which supports 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.	Difficult to influence achievement under most conditions (constraints limit delivery at most times) • 1,200 ML/Day for 7 consecutive days anytime in the water year • 12,000 ML/Day for 11 consecutive days anytime in the water year • 18,500 ML/Day for 9 consecutive days anytime in the water year • 26,500 ML/Day for 7 consecutive days anytime in the water year • 38,500 ML/Day for 6 consecutive days anytime in the water year

An internal analysis has demonstrated that meeting the lowest magnitude flow indicator at each site would require a flow of approximately 3,000 ML/d downstream of Jack Taylor Weir, well beyond the structurally-limited release rate of the Beardmore Dam (1,000 ML/d under regulated conditions). The flow indicators are therefore classified to be beyond regulating capacity (brown in Table 64 and Table 65).

Modelling conducted by MDBA as part of the Basin Plan development process indicates that the geographic location of the recovered entitlements can have a substantial impact on the achievement of the desired environmental flows.

Table 65: Site-specific flow indicators for the Narran Lakes (MDBA 2012u)and the degree to which they can be achieved under current constraints and operational practice

Site specific ecological targets	Site specific flow indicators (flow measured at Wilby Wilby)
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 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.	Difficult to influence achievement under most conditions (constraints limit delivery at most times) • Total inflow volumes of 25,000 ML over 2 months • Total inflow volumes of 50,000 ML over 3 months • Total inflow volumes of 250,000 ML over 6 months • Total inflow volumes of 100,000 ML over 12 months • 2 events annually each with a total inflow volume of 50,000 ML over 3 months

Downstream Requirements

Under the Basin Plan, a portion of the water recovered in each region is allocated towards downstream requirements. This recognises that environmental flow events in the Barwon–Darling are almost purely reliant on water delivered from upstream tributaries. The delivery of downstream water from the Condamine–Balonne region is subject to in-valley constraints such as flow shepherding, and these are discussed in detail in Section6.4.

7.2.4 Summary

There are a number of structures throughout the Condamine–Balonne system, summarised in Table 66 below. In-stream storages such as Leslie Dam and Chinchilla Weir have limited capacity to regulate flows within the Condamine-Balonne system, yet no mid-to-high flow requirements have been identified in the Upper and Mid-Condamine regions.

Beardmore Dam and Jack Taylor Weir have limited release capacities (1,000 and 245 ML/d respectively) however these are not expected to limit environmental flow delivery as the recovered entitlements are not associated with regulated flow conditions.

Instead, the primary impediment to environmental flow delivery is the location of recovered unregulated access entitlements. The capacity to shepherd environmental flows in the Lower Balonne region is a secondary constraint.

Table 66: Summary of Condamine–Balonne constraints, where constraints have been classified in terms of their capacity to limit flows

Location	Constraint Description	Flow Constraint	Inhibits Environmental Flow Delivery?
Leslie Dam	Storage release capacity (full storage conditions)	960 ML/d	No
Talgai Weir	Storage release capacity	740 ML/d	No
Yarramalong Weir	Storage release capacity	560 ML/d	No
Lemon Tree Weir	Storage release capacity	830 ML/d	No
Chinchilla Weir	Storage release capacity	410 ML/d	No
Neil Turner Weir	Storage release capacity	230 ML/d	No
Beardmore Dam	Storage release capacity (regulated conditions)	1,000 ML/d	No
St. George	Minor flood level	14,700 ML/d	No
	Moderate flood level	19,600 ML/d	
	Major flood level	33,000 ML/d	
Jack Taylor Weir	Storage release capacity	245 ML/d	No
Moolabah Weir	Estimated maximum discharge capacity	1,400 ML/d	No
Buckinbah Weir	Storage release capacity	Un specified	No
Lower Balonne	Options available for water recovery limited mainly to unregulated entitlements	—	Yes
Lower Balonne	Shepherding of environmental flows (unsupplemented water access conditions)	—	Yes

7.3 Moonie

The Moonie region lies in south-western Queensland, with less than 10 per cent of the region extending into northern New South Wales. Bounded to the east by the Border Rivers region, to the north and west by the Condamine–Balonne region and to the south by the Barwon–Darling region, the catchment is east of St George and encompasses 1.4 per cent of the total area of the Murray–Darling Basin.

The Moonie River is an unregulated river flowing in a westerly direction from its headwaters south of Dalby. The upper reaches of the Moonie River system include a number of tributary creeks, of which the largest is Teelba Creek, which joins with Bidgel Creek, flowing into the Moonie River upstream of Nindigully. This tributary, along with other small tributaries upstream, contributes to major flooding following local heavy rainfall. The main extent and features of the region are presented in Figure 43.

The region is very flat and has a number of small settlements including Thallon and Nindigully, but no major towns. The dominant land use is dryland pasture for livestock grazing. Annual surface water use is strongly influenced by the seasonal rainfall patterns that determine access by irrigators to supplementary water during periods of high river flow. Surface water diversions are small but make up almost all of the water used for irrigation. Approximately 6,200 ha were irrigated in 2000 and cotton comprised more that 50% of the irrigated area (CSIRO 2008i).

While the wetlands in the region are not considered to be of national importance, the waterholes in the river are important aquatic habitats especially during periods of cease-to-flow conditions. The Thallon waterholes have been identified as significant for waterbirds in the Murray–Darling Basin (Kingsford et al. 1997).

In January 2010, the Queensland Government gave 1.1 GL of unallocated water within the Moonie to the Commonwealth Environmental Water Holder. Preservation of this unallocated water for the environment increased end of system flows to approximately 77% of without development levels.

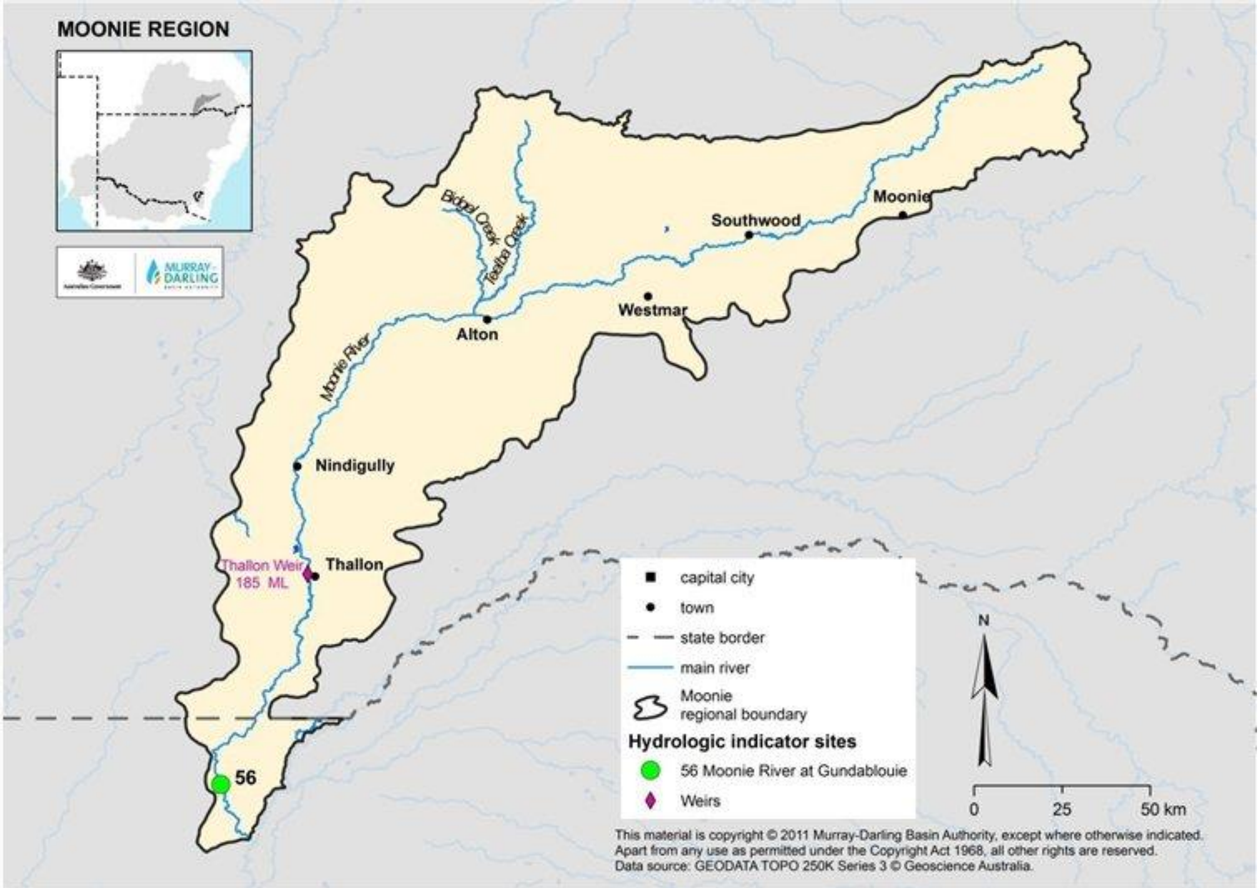
Environmental requirements for the Moonie consist of a single baseflow requirement at Gundablouie, however this is largely met under current water sharing arrangements (MDBA 2012y). MDBA therefore considers that the Moonie contains a relatively intact flow regime.

A summary of flow constraints present in the Moonie catchment is presented in Table 67. There are few constraints in the Moonie region as it is a largely unregulated catchment. Access conditions for floodplain harvesters with unsupplemented water licences are the main consideration for the shepherding of environmental water, and thus its delivery to downstream sites. This is labelled as a 2nd order constraint as it will have an affect only during periods of specific flow conditions. The Moonie region has therefore only one 2nd order no constraint and no 1st order constrains identified (Table 67).

Table 67: A list of key constraints limiting environmental flow delivery in the Moonie region, where constraints have been classified in terms of their capacity to limit flows

Order	Location	Description	Flow Limit (ML/d)
1st	To be identified		
2nd	Throughout	Shepherding of environmental flows (access conditions for unsupplemented water licence pumping thresholds)	—
3rd	To be identified		

Figure 43: The extent and main features of the Moonie region



7.3.1 Key Structures and Flow Constraints

As previously stated, the Moonie River is largely unregulated and contains a small public storage, Thallon Weir, which supplies water to the township of Thallon and has a capacity of 185 ML. Itis not considered to be a constraint to the delivery of environmental water as mid-to-low flow events can pass over the weir. There are also a number of smaller private off-river storages throughout the region.

Potential constraints to environmental flow delivery in the Moonie region consist mainly of access conditions for floodplain harvesters. These access rights are active when river levels exceed a given height (the pumping threshold). While such diversions constitute the primary potential constraint for the Moonie region, MDBA considers the overall impact to be relatively minor.

7.3.2 Representation of Constraints in the Hydrological Model

The Moonie River system is modelled using a small IQQM developed by the Queensland Department of Environment and Resource Management (DERM, 2006). The Without Development and Baseline versions of the models were provided to the MDBA by DERM for Basin Plan modelling purposes. Full details of the modelling methodology used for the Basin Plan are presented in MDBA (2012y).

The Moonie model represents the region from Nindigully to Gundablouie, representing the Resource Operations Plan for the region (DNRMW 2006). No regulated storages are represented, but natural water bodies and pools are included.

Water extractions in the Moonie model include unsupplemented water allocations, overland flow diversions and urban water allocations. The 1.1 GL/y of unallocated water gifted to the Commonwealth is included in the model as an additional diversion. In general, flow access conditions for irrigation regions are defined as rules for a specified fraction of river flow which can be extracted at that particular location in the model, on that particular day of the simulation period.

7.3.3 Environmental Flows Affected by Constraints

Due to the relatively intact flow regime in the Moonie region, the MDBA did not specify any mid-to-high flow environmental water requirements during the Basin Plan development process. A single baseflow requirement was specified for Gundablouie, for which shortfalls are negligible under existing water sharing arrangements. However, due to licence access holder rules, extractions in the region impede flows from contributing to downstream requirements. The shepherding of environmental flows in the region and can largely be achieved under existing water sharing arrangements.

7.3.4 Summary

The Moonie River is relatively unregulated and un-impacted, with low levels of consumptive use. As such, constraints do not greatly affect the environmental outcomes for the region.

However, the existing access arrangements for unsupplemented water licences could be considered a constraint to the delivery of water to the downstream Barwon–Darling system, particularly in times of high flow and greater connectivity (Table 68). Further modelling would quantify the environmental benefits of shepherding arrangements to overcome the constraint.

Table 68: Summary of Moonie constraints, where constraints have been classified in terms of their capacity to limit flows

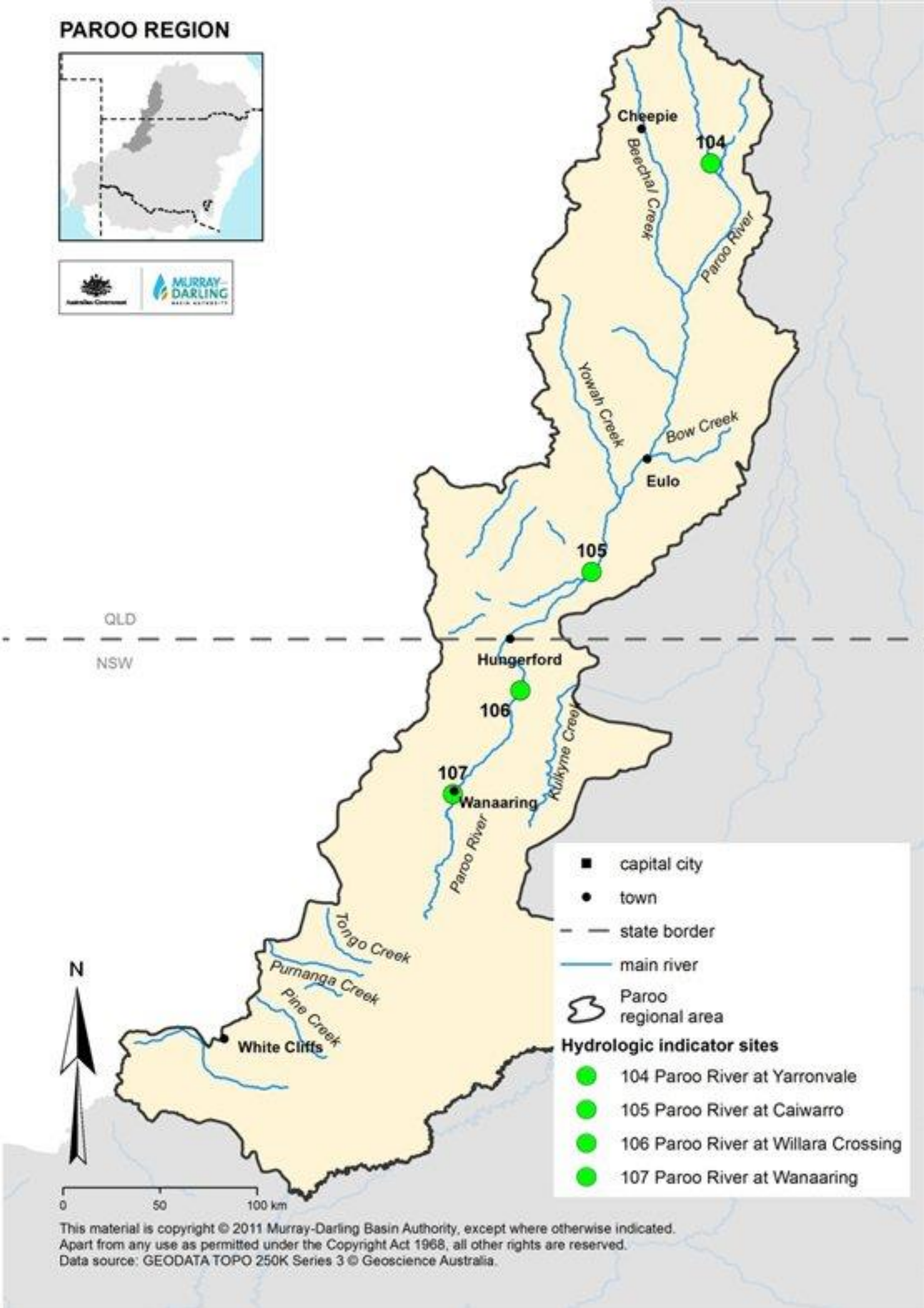
Location	Constraint Description	Flow Constraint (ML/d)	Inhibits Environmental Flow Delivery?
Throughout	Shepherding of environmental flows (unsupplemented water access conditions)	—	Yes

7.4 Paroo and Warrego

The Paroo region is situated in approximately equal proportions in southern Queensland and northern NSW (Figure 44). It is predominantly flat and covers an area of approximately 59,000 km^2, with a population of less than 700. The dominant land use is broad acre livestock grazing for beef and wool production, with some small scale stock feed cropping (CSIRO 2007d).

The main waterway is the ephemeral Paroo River, which originates in the Warrego Ranges in Queensland and flows southward, terminating in complex distributary channels and the Paroo Overflow Lakes south of Wanaaring. The largest tributary is Beechal Creek, which joins the Paroo River south of Yalamurra. Other tributaries include Bow Creek, which joins the main stream north of Eulo, and Yowah Creek, which meets downstream of Eulo.

Figure 44: The extent and main features of the Paroo region



In very wet years, flows continue past the Overflow Lakes to reach the Darling, however this only occurred three times in the Twentieth Century (Power et al 2007; CSIRO 2007d). Flows into the lower Paroo are also occasionally supplied from the Warrego Catchment via high flows in Cuttaburra Creek. A schematic of the Paroo and Warrego catchments is shown in Figure 45.

The Paroo is considered to be an unregulated river with a flow regime largely un-impacted by diversions. This is reflected by flows at Hungerford; under natural conditions (i.e. without development) the mean annual flow is modelled to have been 500 GL/y, while development has reduced this to 499 GL/y (Webb et.al. 2007)

The floodplain vegetation of the Paroo region is largely undisturbed by development and contains some of the largest wetlands in the Murray–Darling Basin. The Currawinya Lakes north of Hungerford and the Paroo Overflow Lakes south of Wanaaring can support large breeding populations of waterbirds and both sites are listed as wetlands of international importance under the Ramsar Convention.

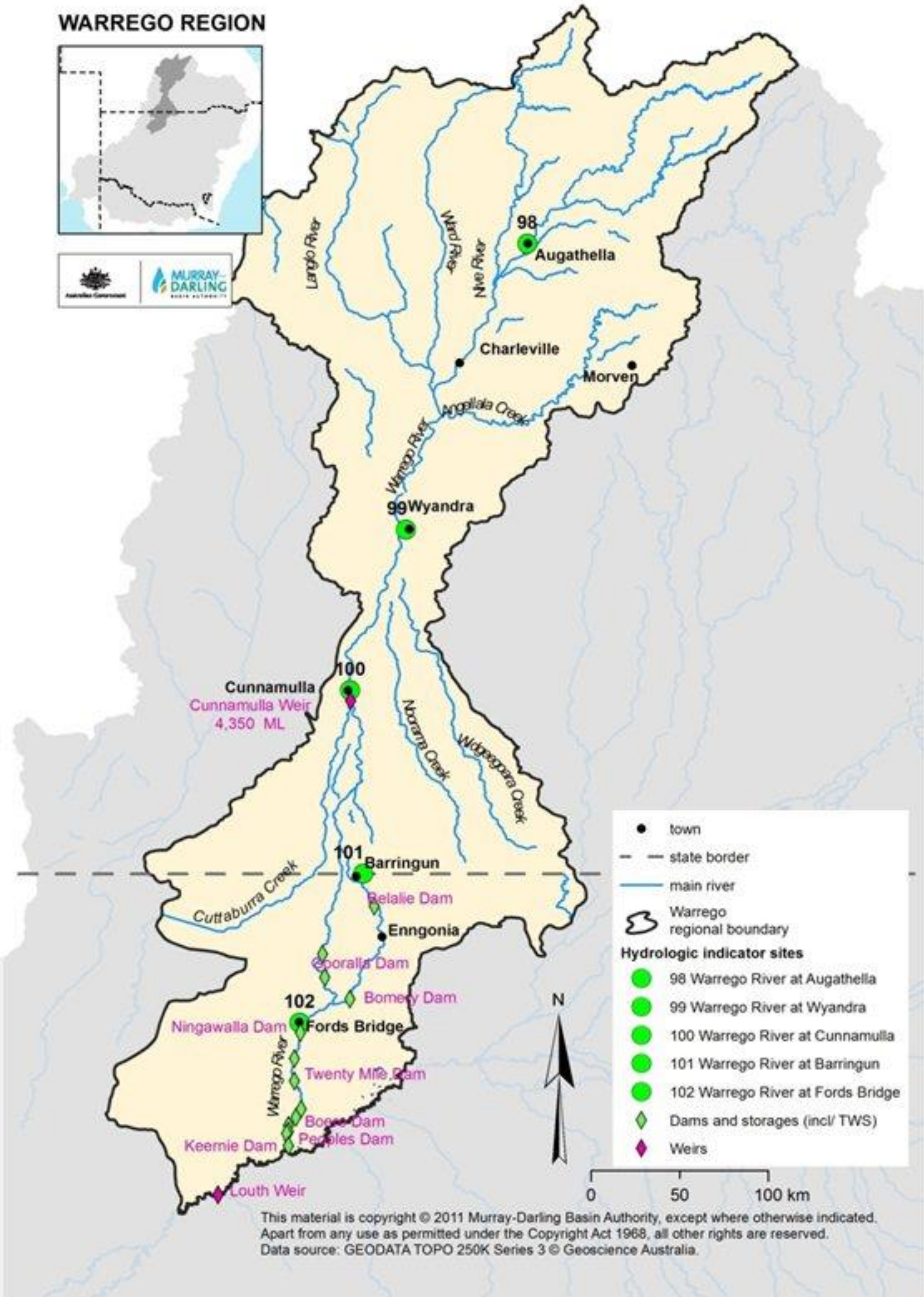
The Warrego catchment is located immediately east of the Paroo catchment, with the majority of its 86,000 km^2area located in Queensland (Figure 46). The region has a population of 7,100. The dominant land use is dryland stock grazing (sheep and cattle), with approximately 300 ha of irrigated cotton and horticulture (CSIRO 2007e).

The headwaters of the Warrego River and some of its tributaries are located in the Warrego and Chesterton Ranges and the main river flows in a generally southward direction for about 770 km before draining into the Darling River downstream from Bourke. The Warrego is an ephemeral river and water only reaches the Darling in times of flood. The primary tributaries join the Warrego either side of Charleville; the Nive River joins upstream and the Ward and Langlo Rivers meet downstream of the town (see schematic diagram of the region in Figure 45).

Similar to the Paroo, the floodplain vegetation of the Warrego is relatively undisturbed by development, there being only about 300 ha of irrigated cropping. While there are no internationally recognised wetlands, there are many wetlands of national importance, including the 500 ha Warrego River Waterholes between Charleville and Wyandra. The Warrego breaks into distributaries (including the Cuttaburra and Kulkyne Creeks, and the anabranch Irrara Creek among many others) below Cunnamulla. These distributaries form the Warrego Distributary Wetlands (12,000 ha), the Cuttaburra Basin and Yantabulla Swamp, with water eventually flowing through to the Paroo River under high flows.

Figure 45: Schematic diagram summarising the key structural features and flow constraints in the Paroo and Warrego regions

Figure 46: The extent and main features of the Warrego region



There is about 43,000 ML of allocated entitlement for consumptive use in the Queensland portion of the Warrego system, including 2,612 ML of supplemented water in the Cunnamulla Water Supply Scheme and 40,003 ML of unsupplemented water from unregulated flows and floodplain harvesting. MDBA modelling indicates that the average annual diversion for this part of the system is 45,000 ML/y, while the modelled diversion for the NSW portion of the Warrego averages 7,000 ML/y (MDBA 2012y).

The Warrego River has a relatively intact flow regime, however hydrological modelling data indicates that some impact from diversions is evident on mid to lower flows (particularly those between 500 – 2,500 ML/d).

No constraints to environmental water delivery are evident in the Paroo River. A summary list of the flow constraints in the Warrego River is presented in Table 69. First order constraints represent the primary impediments to the delivery of mid-to-high flow environmental events. If these constraints were overcome, the 2nd and 3rd order groupings contain the next set of constraints that would potentially limit environmental water. Further investigation is required to determine the extent and flow at which these take effect.

Table 69: A list of key constraints limiting environmental flow delivery in the Warrego region, where constraints have been classified in terms of their capacity to limit flows

Order	Location	Description	Flow Limit (ML/d)
1st	General	Shepherding of environmental flows (unsupplemented water access conditions)	—
2nd	To be identified		
3rd	Allan Tannock Weir	Storage release capacity	300
	Ford's Bridge	Flood levels	350 (Minor) 820 (Moderate) 5,400 (Major)
	Toorale Station	Toorale infrastructure operating rules	—

7.4.1 Key Structures and Flow Constraints

There are no significant regulating structures or flow constraints in the Paroo system. The majority of storages are farm dams which store bore water from the Great Artesian Basin (CSIRO 2007e). The discussion below is therefore limited to the Warrego system.

Shepherding of Environmental Flows

Unsupplemented water licence holders in the Warrego region are able to access water during specific flow conditions. These access rights are active when river levels exceed given heights (pumping thresholds), and are therefore often associated with periods of mid-to-high flow. The Commonwealth and other environmental water holders may take water against their entitlements by leaving flows in-stream, however the pumping thresholds of other licence holders may result in environmental water being extracted for consumptive use. Shepherding arrangements are intended to ensure that environmental water holders are able to use their water for environmental purposes, without increasing or diminishing the interests of consumptive users.

Allan Tannock Weir

The main regulating structure in the Warrego system is Allan Tannock Weir (also known as Cunnamulla Weir) located about 5 km downstream of Cunnamulla. It provides town and irrigation water for the Cunnamulla Water Supply Scheme and water for downstream stock and domestic use. The storage capacity is 4,770 ML, with dead storage of 500 ML. The estimated maximum discharge capacity of the outlet pipe at full supply level is 300 ML/d, although the flow rate drops as the weir level falls. The flow is controlled by a sluice gate. The weir and associated breakout structure (saddle dam) sit below bank height and are overtopped relatively easily during higher flows.

The Queensland Warrego, Paroo, Bulloo and Nebine Resource Operations Plan (QDNRM 2006) includes operating requirements for Allan Tannock Weir that control releases to minimise environmental damage (such as bank slumping and fish stranding). It also includes requirements for downstream stock and domestic water delivery, specifying that inflows of up to 300 ML/d into the weir are credited to a stock and domestic account when storage levels are above 500 ML (i.e. above the cease-to-flow level of the valve outlet), and that equivalent flows are passed downstream within one month of the inflow.

Ford’s Bridge

Ford’s Bridge is a low-lying bridge over the lower Warrego River on the Bourke to Hungerford Road. The minor flood level for this location is 1.7 m (BOM 2012), which equates to a flow of about 350 ML/d; the moderate flood level is 2.3 m, equating to a flow of about 820 ML/d; and the major flood level is 3.2 m, equating to a flow of about 5,400 ML/d. Under baseline conditions, flows of more than 350 ML day (i.e. the minor flood level) occur about 11 per cent of the time at Ford’s Bridge.

Infrastructure works on Toorale Station

Toorale Station has a number of storages and regulating structures that control flows and therefore potentially affect the delivery of environmental water within the lower Warrego system to either the Western Floodplain or into the Barwon/Darling system. Infrastructure management options are being negotiated (as at December 2012) between the Australian and NSW governments.

7.4.2 Representation of Constraints in the Hydrological Model

The Warrego and Paroo systems are modelled using an IQQM. Allan Tannock Weir on the Warrego is the only regulated storage in the model. The model assumes that inflows up to 300 ML/d to Allan Tannock Weir will bypass the weir. This represents the rules in the Resource Operations Plan which require that when water is credited against the stock and domestic water account (up to 300 ML/d), an equivalent volume must be released or the weir will spill within one month of the inflow.

The Warrego model provides input to the Barwon–Darling system as flows at Fords Bridge; diversions downstream of Fords Bridge and inflows into the Darling are represented within the

Barwon–Darling model. Entitlements associated with Toorale Station are included in the Barwon–Darling model.

7.4.3 Environmental Flows Affected by Constraints

Because of the relatively intact flow regimes in the Paroo and Warrego systems, MDBA did not identify any mid-to-high flow environmental water requirements through the Basin Plan development. Baseflow requirements were however specified at four sites on the Paroo and five sites on the Warrego (MDBA 2012y).

MDBA modelling indicated that there were no significant shortfalls in mean annual baseflow requirements in either the Paroo or Warrego systems under existing water sharing arrangements, indicating that constraints do not limit the delivery of this component of the flow regime (MDBA 2012y).

Similar to the other catchments in the Northern Basin, environmental water use in the Warrego will generally consist of leaving entitlement water in the channel. Unless suitable shepherding arrangements are in place, there is a risk that the water could legitimately be taken by other holders of unregulated water entitlements.

Under specific flow conditions the relatively low flood level at Ford's Bridge could be a constraint to environmental flow delivery depending on the final shepherding arrangements to deliver environmental water held in the Warrego system to environmental assets downstream on the Barwon/Darling River, Lower Darling River, or River Murray. This flood level is therefore characterised as a 3rd order constraint. Because of the relatively flat landscape near Ford's Bridge, there would be benefit in undertaking further analysis of the relationship between river level and flow to confirm the flows at which flooding occurs.

There are no significant constraints in the Paroo, and water recovery has not been undertaken in this region.

7.4.4 Summary

Both the Paroo and Warrego are largely unregulated rivers, with limited regulating structures and relatively low levels of consumptive use. As such constraints do not play a large role in achieving environmental outcomes in these two regions.

Nevertheless, the Warrego has some physical and operational constraints that, if overcome, would optimise the benefits of environmental watering. Chief among these is the need to finalise suitable shepherding arrangements so that environmental water can be effectively delivered to priority environmental assets within the catchment and the Basin.

8. Summary and Conclusion

This technical report is a first step in the development of the Constraints Management Strategy. It contains MDBA's initial assessment and compilation of physical constraints within the Basin.

Not all constraints within the Basin are listed in this report; policy constraints will be examined through a separate study. Furthermore, MDBA recognises that as constraints are progressively relaxed, additional constraints may become apparent. The report provides a basis for the MDBA to ask for further information on these or other constraints which may have been assessed or explored in regional communities or by river operators, states and environmental water holders.

The most prominent flow constraints for the southern and northern Basin identified in this report are listed in Table 70 and Table 71 respectively. These tables comprise all 1st order constraints identified in each region. In the left column of each table, the constraints are labelled FCS ('Flow Constraint South'; Table 70) or FCN ('Flow Constraint North'; Table 71), with a numeric identifier. The schematic map of the Murray–Darling Basin shown in Figure 47 displays the location of these constraints.

Both tables include 'timing' as a constraint to environmental flow delivery (labelled FCS1 and FCN1 respectively). In practice, the active management of most mid-to-high flow environmental events in regulated regions will be achieved by combining storage releases with a large (possibly unregulated) inflow event from a tributary river. That is, by combining either:

- releases from a *single storage* with *unregulated inflows*; or,
- releases from *multiple storages* with *unregulated inflows.*

The first of these scenarios would require careful timing to ensure both flow events are synchronised (for example, releases from Hume Dam could be combined with an inflow event from the Ovens River to achieve a desired outcome at the Riverland–Chowilla Floodplain). The second type of scenario would require an even greater level of coordination; for example, including additional releases from Burrinjuck Dam (Murrumbidgee) and Lake Eildon (Goulburn) to enhance the peak flow of the Hume/Ovens event with the aim of inundating a greater area of floodplain. The capacity to which this level of cross-jurisdictional timing can be achieved is not yet known, but a meeting of Senior River Operators did conclude it may be possible.

Table 70: A summary list of key constraints limiting environmental flow delivery throughout the southern Murray–Darling Basin

Label	River	Location	Description	Flow Limit (ML/d)
FCS1	All regions		Timing (ability to coincide environmental releases from multiple storages with large unregulated inflow events)	—
FCS2	Upper Murray	Doctor's Point	Operating constraint based on channel capacity between Hume Dam and Yarrawonga Weir	25,000 (summer)
FCS3	Mid-Murray	D/S Yarrawonga Weir	Irrigation delivery and downstream inundation control	10,600 (summer) 20,000† (other times)
FCS4	Lower Darling	Weir 32	Commence-to-flow threshold for Darling Anabranch and downstream inundation control	9,000
FCS5	Lower Darling	Menindee Lakes	Critical human water requirements of Broken Hill and Menindee, and storage release capacities	—
FCS6	Murrumbidgee	Gundagai	Private land access and inundation (Mundarlo Bridge)	32,000
FCS7	Murrumbidgee	Tumut/Oddy's Bridge	Channel constraint and erosion control	9,000/9,300
FCS8	Goulburn	Lake Eildon	Private land access and inundation	9,500
FCS9	Goulburn	Shepparton	Private land access and inundation	26,000

'FCS' refers to Flow Constraint South

†Not an operational constraint, but impacts on third parties above this flow are taken into consideration by river operators.

In addition to the requirement for accurate timing of storage releases, a total of nine 1st order flow constraints have been identified in the southern Murray Darling Basin (Table 70). The majority of these constraints relate to river channel capacities, such as downstream of Yarrawonga Weir. Additionally, the requirement to ensure reliability of supply for critical human water needs in the towns of Broken Hill and Menindee may constrain environmental water delivery from Menindee Lakes during relatively dry periods (FCS6).

Due to differences in the underlying hydrology, water sharing arrangements, and the level of flow regulation, environmental watering in the northern Basin will be distinct from that in the south. These differences are emphasised by the four 1st order flow constraints identified in the northern Basin (Table 71). Some of the environmental flow requirements can be achieved through regulated releases from storage, hence the timing and impact of these releases are potential flow constraints (FCN1 and FCN3). However, a large proportion of the environmental flows will be achieved through unregulated events, hence the ability to protect or enhance these flows are also potential constraints (FCN2 and FCN4).

Table 71: A summary list of key constraints limiting environmental flow delivery throughout the northern Murray–Darling Basin

Label	River	Location	Description	Flow Limit (ML/d)
FCN1	All regions		Timing (ability to coincide environmental releases from multiple storages with large unregulated inflow events)	—
FCN2	Barwon–Darling	Barwon–Darling and tributaries	Capacity to shepherd environmental flows	—
FCN3	Gwydir	Gingham Watercourse	Possible inundation of private landholdings in Gwydir Wetlands	—
FCN4	Condamine-Balonne	Whole-of-system	Options available for water recovery limited mainly to unregulated entitlements	—

'FCN' refers to Flow Constraint North

MDBA will consider the constraints identified in this report when developing the Constraints Management Strategy, as well as the relative merits of addressing them for achieving the outcomes specified in Schedule 5 of the Basin Plan and the feasibility, practicality and cost of addressing any of the constraints.

Some regions do not contain 1st order constraints as defined in this report. These regions are:

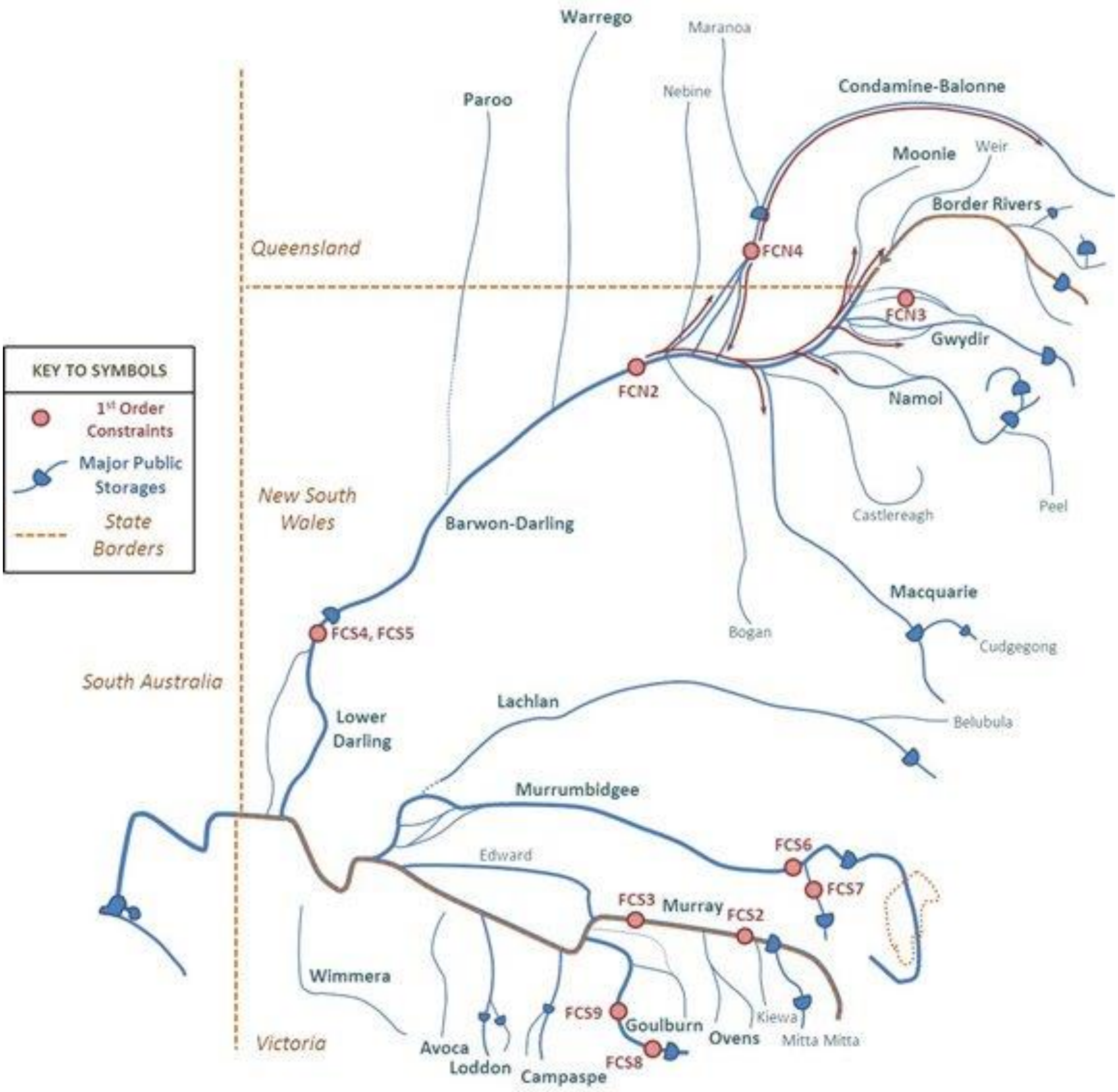
- Campaspe
- Loddon
- Wimmera
- Lachlan
- Macquarie-Castlereagh
- Namoi
- Moonie
- Paroo
- Warrego

Of these, the Campaspe, Loddon, Lachlan, Macquarie-Castlereagh, and Namoi contain 2nd order constraints which, if addressed, could improve the achievement and effectiveness of environmental watering in some years. Furthermore, there may be other constraints (such as those associated with existing policy arrangements) which could also impede environmental watering. This will be the subject of future investigations conducted through the Constraints Management Strategy.

This report is just one input into the Strategy. Discussions with affected communities and stakeholders will further inform the list of constraints and the issues they raise. This report is supporting documentation to the strategy, and final priorities will only be determined following consultation with State authorities and communities. The final strategy in November 2013 will include broad strategies for addressing any flow-on effects on third parties, including effects on private land, roads, bridges and other infrastructure.

After the strategy is delivered, the Commonwealth and Basin State governments will decide how the recommendations should be implemented over coming years. This is likely to involve further scoping, feasibility and planning phases for each project as required. The strategy is likely to identify some priority constraints that are well understood and could be progressed relatively quickly, and others which would require further assessment before informed strategies could be fully developed. The Strategy may be updated with further detail after November 2013 as priority projects move into a more comprehensive assessment process.

Figure 47: Schematic diagram displaying the location of the key constraints identified in this document, using the notation listed in Table 70 and Table 71.



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Appendix A. Regulated Environmental Flow Delivery to the Barwon-Darling

The Barwon–Darling system receives very little in-catchment runoff due to the hot and dry climate and the largely flat geomorphology of the landscape. Flows in the river are therefore almost entirely reliant on inflows from upstream catchments. A portion of the water to be recovered in each upstream region through the Basin Plan is assigned towards downstream environmental purposes (specifically, those in the Barwon–Darling) and the ability to deliver these flows is limited by the constraints in each tributary.

In practice, environmental water delivery to the Barwon–Darling, particularly mid-to-high flows, will largely be accomplished through unregulated events. A large proportion of the entitlements recovered in the northern Basin tributaries are related to unregulated licences, and environmental water holders may take water against their entitlements by leaving flows in-stream. This strategy, combined with a shepherding management arrangement, can deliver water to the Barwon–Darling. However, regulated releases from tributary storages will provide some benefit to the Barwon–Darling, and the analysis described here quantifies the potential regulated contribution of each tributary system.

Options for Environmental Flow Delivery

Under an active water management regime, a successful environmental flow event in the Barwon–Darling will correspond to one of the following three categories:

i. **Fully regulated** — occurs primarily due to a planned set of releases from upstream storages.
ii. **Semi-regulated** — the result of combining releases in one region (e.g. from Keepit Dam in the Namoi region) with an unregulated event in another region (e.g. from the Condamine–Balonne).
iii. **Fully unregulated** — occurs due to large unregulated inflows from one or more tributaries.

Events occupying the third category are due to high rainfall events resulting in large unregulated flows that exceed the capacity of flow regulation infrastructure. These are unaffected by flow constraints, and are beyond the scope of this document.

Delivering events of Type I or II will be limited by tributary flow constraints, including the requirement to coordinate storage releases to deliver the greatest environmental outcomes. The discussion below examines the main constraints in each tributary valley that limit the delivery of environmental water downstream, and includes an estimate of the maximum flow that can be achieved at Bourke under a Type I scenario; delivering a larger flow event will therefore be dependent on a Type II process.

Each upstream catchment in the northern Basin displays unique hydrology — they have different levels of flow, extraction, flow regulation and connectivity with the Barwon–Darling system. For instance, the Condamine–Balonne carries relatively large volumes of water, however it has a limited capacity to regulate mid-to-high flows and (during normal flow conditions) only a small proportion of the water passing through St George reaches the Barwon–Darling due to natural (e.g. evaporation) and human-induced (extraction) losses. In contrast, the Namoi system carries less water, but displays a higher degree of flow regulation and connectivity with the Barwon River.

These characteristics determine the capability of these upstream catchments to contribute water towards environmental flow events in the Barwon–Darling. Similar to constraints in other valleys, the tributary constraints affecting Barwon–Darling environmental flows can be broadly divided into operational and physical constraints; these are summarised in Table A.1.

The *operational* constraints have been described separately in each of the regional sections (for example, Section 7.2 for the Condamine–Balonne), and their general properties are summarised below. For the purposes of constraints management in the Barwon–Darling, *physical* constraints are considered to be those that affect the level of connectivity with each tributary. The physical constraints impeding flow delivery to the Barwon–Darling are not included in the regional sections, and are therefore detailed below.

Table A.1: Operational and physical constraints in upstream catchments related to environmental flow delivery to the Barwon–Darling

Categorisation	Description
Operational Constraints (i.e. level of regulation)	Inter-valley timing of releases Shepherding
Physical Constraints (i.e. level of connectivity)	Storage release capacity Efficiency of delivery from storage Channel capacity at junction with Barwon–Darling

Operational Constraints — Level of Regulation

As described below, none of the mid-to-high environmental flow requirements identified for the Barwon–Darling can be actively managed by a single tributary valley — they will therefore rely on the combined releases from storages in multiple catchments (Type I) or combining releases with unregulated events in another catchment (Type II). The capacity to achieve this level of flow coordination across the Barwon–Darling tributary catchments is not yet known.

Assuming that these inter- and intra-valley releases can be appropriately timed, a policy is yet to be developed to ensure that these flows are protected from extraction by irrigators (i.e. ‘shepherded’, both within the tributary catchment and within the Barwon–Darling itself) during periods of environmental demand.

Physical Constraints — Level of Connectivity

Assuming that altered operating practices allow environmental flows for the Barwon–Darling to be adequately coordinated across multiple catchments and shepherded through each tributary, the capacity to deliver the desired flow can then be affected by factors such as flow limitation (channel and storage releases capacities) and in-river losses (evaporation and river-aquifer exchange). In order to determine the feasibility of actively managing mid-to-high flow events in the Barwon–Darling system, the physical limitations governing water delivery rates from the tributary valleys should be examined.

The level of hydrologic connectivity between the tributary valleys and the Barwon–Darling system is determined by the physical constraints, as listed in Table A.1. Firstly, water released from upstream storages will be subject to an inherent storage release capacity. Secondly, due to variations in channel morphology, rates of river-aquifer exchange, and climate, each river has a natural 'delivery efficiency' governing flow transfers between the upstream storage and the junction with the Barwon–Darling. That is, some rivers will lose a greater proportion of water in transit (and will lose more if the flows are not adequately shepherded). Thirdly, each tributary has a well-defined channel capacity near its junction with the Barwon–Darling. Flows above this level can result in additional losses on the surrounding floodplain and inundation of private land in the tributary catchment, hence it is assumed that the regulated delivery of environmental water to the Barwon–Darling will be achieved (where possible) within bankfull capacity.

That is, each tributary can deliver environmental water at a rate subject to both channel capacity and storage release capacity. As a general rule, in relatively high-loss valleys, the storage release capacity will determine the tributary flow; in low-loss valleys, the end-of-system channel capacity will be the determining factor. These three issues are discussed separately, with a final summary of the capability of the tributaries to the deliver the desired flows.

Issue 1 — End-of-system Channel Capacity

Channel capacities for the regulated Northern systems were determined through an examination of the river cross-sectional data provided online by the NSW Department of Primary Industries (2011). These capacities are listed in Table A.2. Except for the Gwydir system, the bankfull flows listed here were measured at or near the end-of-system. The Gwydir is an unusual system in which the main channel in the lower reaches (Mehi River) exhibits a sharp decrease in channel capacity near the Mallowa Creek offtake site (approximately 300 ML/d; Pietsch 2006) and then substantially increases before the junction with the Barwon River. The Mallowa offtake site has therefore determined bankfull capacity for this tributary.

Table A.2: Flow delivery efficiencies to end-of-system locations under without-development conditions, assuming each Barwon–Darling tributary delivers a fully regulated bankfull flow to the end of system location

Region	Main Regulating Storage	Release Capacity of Storage (ML/d)	Storage Outflow Representative Location	End of System Location	Bankfull Flow at End-of-System (ML/d)	Estimated Delivery Efficiency	Required Flow at Storage Representative Location to Achieve Bankfull EOS Flow (ML/d)
Condamine–Balonne	Beardmore	1,000	St George	D/S Collerina	2,500 – 3,000	0.55	4,500 – 5,500
Border Rivers	Glenlyon (QLD) Pindari (NSW)	3,450 (Glenlyon) 5,000 (Pindari)	Goondiwindi	Mungindi	7,000 – 7,500	0.56	12,500 – 13,500
Gwydir	Copeton	10,850	Pinegrove	Collarenebri	250 – 300	0.53	450 – 600
Namoi	Keepit	4,000	Gunnedah	Goangra	3,500 – 4,000	0.99	3,500 – 4,000
Macquarie	Burrendong	8,185	Dubbo	Carinda	800 – 1,000	0.11	7,000 – 9,000
Maximum Total regulated flow at end-of-system	—	~10,000†	Inflow upstream of Bourke		~14,000*	—	—

†Estimate of the total achieved flow at Bourke if all tributary storages release water at maximum storage release capacity (assuming full flow coordination and shepherding is achieved; see Table A.3).

*Estimate of the total achieved flow at Bourke if all tributaries provide bankfull flow at their end-of-system locations (assuming full flow coordination and shepherding is achieved)

Issue 2 — Delivery Efficiency

The Murray–Darling Basin Sustainable Yields project (MDBSY; CSIRO 2008a) estimated the long-term average efficiency at which water would have passed through each tributary to the end of system (and then through to Bourke) under natural conditions using without-development modelled flows. The process has been repeated here, but limited to events at or near bankfull flow (i.e. the flow ranges listed in Table A.2. The without-development models have again been used here as they provide a more accurate representation of shepherded environmental flows compared to other existing model scenarios.

The resulting delivery efficiencies are listed in Table A.2. These are estimates of the proportion of water which will pass from the storage representative location (at or near the upstream storage) to the end-of-system location during bankfull events. Based on these delivery efficiencies, Table A.2 includes an estimate of the flow required at the storage representative location to achieve a bankfull flow event at the end-of-system site.

Each storage representative location was chosen to be the site immediately downstream of the storage(s) for which well-calibrated model flows exist. The above analysis assumes little to no loss between the storage(s) and the representative location. For most valleys the location is only a few kilometres downstream of the storage, hence this assumption is valid. The only exception is the Border Rivers. Due to its location on the Queensland–NSW border, this region includes two storages (one located in each jurisdiction) with similar storage and release capacities. The site immediately downstream of the Dumaresq–Macintyre junction was chosen as the representative location. This site is located at least 200 km (river distance) downstream of both Pindari and Glenlyon Dams, therefore the estimated delivery efficiency for this region represents an upper limit of the water transfer rate (and the required flow downstream of the storages is likely to be a lower limit).

Issue 3 — Storage Release Capacity

Release capacities for the main regulating storages are listed in Table A.2. It is apparent from comparing the third and eighth columns in this table, that the Gwydir and Namoi regions can deliver a bankfull flow to the end-of-system purely from storage releases. Burrendong Dam can likely deliver near-bankfull flows to the Macquarie end-of-system under most conditions, however the Condamine–Balonne and Border Rivers storages cannot achieve this target through storage releases alone.

Delivering bankfull flows from the Border Rivers could be achieved by combining storage releases from Pindari and Glenlyon Dams with unregulated tributary inflows within the region. The Border Rivers zone includes a number of substantial tributary streams (such as Macintyre Brook and Weir River) that join the main channel downstream of the dams and storage releases could be coordinated with these inflows to ensure bankfull flows at Mungindi, thereby maximising the regulated contribution of this catchment to the Barwon–Darling environmental flows. Supplementing unregulated events to this flow level would not lead to flooding in the Border Rivers region.

An additional option in the Border Rivers would be to include environmental releases from Coolmunda Dam, located at the headwaters of the Macintyre Brook (a tributary of the Dumaresq River). However, the channel capacity of the brook allows a bankfull flow of approximately 700 ML/d (measured at Booba Sands; QLD Department of Environment and Resource Management 2012), which would address only a small part of the required additional water to achieve bankfull flows at Mungindi.

Similarly in the Condamine–Balonne, it may be possible to align releases from Beardmore Dam and Jack Taylor Weir to coincide with inflows from the near-unregulated Nebine system (which flows into the Culgoa River just downstream of the QLD–NSW border). However, this task would be significantly more difficult. Regulated releases from St George are limited to 1,000 ML/d, which translates to approximately 700 ML/d at the end-of-system site (assuming adequate shepherding of flows), so reaching the desired 3,000 ML/d rate would rely predominately on Nebine inflows. Furthermore, the flow travel times are significantly longer (and subject to greater uncertainty) compared to those in the Border Rivers.

Summary of Physical Constraints

By aggregating bankfull flows at end-of-system locations, the maximum total flow which can be delivered to the Barwon–Darling within tributary channel capacity is approximately 14,000 ML/d. However, as described above, for some catchments (Condamine–Balonne and Border Rivers) this would rely on combining releases with unregulated inflows from in-catchment tributaries. Instead, by aggregating storage release rates alone (and applying the delivery ratios listed inA.3), the maximum fully regulated (i.e. Type I) event that can be delivered to the Barwon–Darling is approximately 10,000 ML/d. Both maximum flow values cited here assume that storage releases in each catchment (and flow shepherding arrangements) can be coordinated to ensure that tributary flows coincide.

Table A.3: Estimate of maximum achievable flow for a Type I event at end-of-system location in the tributaries of the Barwon–Darling, based on physical constraints (channel and storage release capacities)

Region	Estimated Maximum Achievable Regulated Flow at End-of-System (ML/d)	Flow Constraint
Condamine–Balonne	550	Storage release capacity (Beardmore)
Border Rivers	4,700	Storage release capacity (Glenlyon and Pindari)
Gwydir	300	Channel capacity
Namoi	4,000	Channel capacity and storage release capacity (Keepit Dam)
Macquarie	900	Channel capacity and storage release capacity (Burrendong Dam)
Total Inflow to Barwon–Darling U/S Bourke	~**10,000**	**Tributary Channel and Storage Release Capacities**

Regulating higher flows in the Barwon–Darling can therefore only be achieved by combining storage releases (possibly in multiple catchments) with large unregulated flow events (again, possibly in multiple catchments). That is, under ideal conditions, a 10,000 ML/d event at Bourke could be achieved through a Type I 'fully regulated' process (assuming fully successful flow coordination and shepherding), but deliberately managing higher flows would necessitate a Type II 'semi-regulated' process.

Appendix B. Flood levels at specific sites used in this report

This report includes references to the minor, moderate and major flood levels. These are drawn from the Bureau of Meteorology (BOM 2012) data available online, and are consistent with the BOM flood levels:

- **Minor flooding:** Causes inconvenience. Low-lying areas next to watercourses are inundated which may require the removal of stock and equipment. Minor roads may be closed and low-level bridges submerged.
- **Moderate flooding:** In addition to the above, the evacuation of some houses may be required. Main traffic routes may be covered. The area of inundation is substantial in rural areas requiring the removal of stock.
- **Major flooding:** In addition to the above, extensive rural areas and/or urban areas are inundated. Properties and towns are likely to be isolated and major traffic routes likely to be closed. Evacuation of people from flood-affected areas may be required.

A full listing of the flooding levels at specific sites used in this report is given in Table C.1. Flood levels have been used throughout this report as initial indicators of river levels leading to third-party impacts. As the Constraints Management Strategy is further developed and applied, a more detailed assessment will be undertaken to identify specific third-party impacts at river levels above and below the flood levels listed in Table B.1.

Table B.1: Minor, moderate and major flood levels at specific sites used throughout this report

Region	Location	Minor (ML/d)	Moderate (ML/d)	Major (ML/d)
Upper Murray	Doctor's Point	50,000 (5.5m)	114,000 (6.5m)	187,000 (7m)
	Albury	44,500 (4.3m)	71,600 (4.9m)	139,000 (5.5m)
	Corowa	19,000 (3.8m)	44,400 (5.9m)	203,000 (8.6m)
Mid-Murray	Tocumwal	77,300 (6.4m)	98,000 (6.7m)	190,000 (7.3m)
	Echuca	64,400 (93.5m AHD)	71,700 (93.9m AHD)	82,200 (94.4m AHD)
	Swan Hill	29,000 (4.5m)	30,000 (4.6m)	32,700 (4.7m)
Edward-Wakool	Deniliquin	17,100 (4m)	49,600 (7.2m)	140,500 (9.4m)
Lower Murray	Wentworth	85,300 (32m AHD)	110,000 (33m AHD)	193,000 (34m AHD)
Goulburn-Broken	Shepparton	27,500 (9.5m)	67,500 (10.7m)	87,000 (11m)
	Seymour/Trawool	22,800 (4m)	41,400 (5.7m)	83,000 (7.5m)
Campaspe	D/S of Lake Eppalock	21,200 (158.4m AHD)	47,300 (160.4m AHD)	80,200 (162.4m AHD)
	Rochester	19,000 (8.0m)	19,300 (8.8m)	39,200 (9.1m)
Loddon	Appin South	1,720 (2.8m)	7,300 (3.1m)	18,600 (3.3m)
Lower Darling	Menindee	20,000 (6.3m)	29,500 (6.7m)	40,000 (7.3m)
Murrumbidgee	Gundagai	48,500 (6.1m)	78,500 (7.6m)	112,000 (8.5m)
	Tumut	16,100 (2m)	23,000 (2.6m)	71,500 (3.7m)
	Darlington Point	27,700 (5.5m)	64,500 (7m)	83,600 (7.3m)
	Balranald	26,000 (6.7m)	36,800 (6.9m)	52,300 (7.1m)
Lachlan	Forbes	15,000 (3.5m)	22,300 (5.3m)	33,000 (6.6m)
Barwon–Darling	Collarenebri	24,000 (5.8m)	105,000 (7.9m)	181,400 (8.5m)
	Walgett	33,000 (10.5m)	82,000 (12m)	125,000 (12.5m)
	Bourke	27,300 (9m)	43,900 (10.7m)	73,500 (12.2m)
	Louth	28,600 (8.6m)	32,200 (9.2m)	38,500 (10m)
	Tilpa	27,800 (9m)	31,200 (9.7m)	34,700 (10.3m)
	Wilcannia	25,600 (9.7m)	30,000 (9.7m)	37,200 (10.4m)
Macquarie–Castlereagh	Dubbo	51,000 (5.5m)	72,900 (7.9m)	244,000 (11.0)
	Narromine	35,700 (5.5m)	74,000 (9.1m)	195,000 (13.7m)
Namoi	Gunnedah	43,000 (7.3m)	58,000 (7.6m)	78,300 (7.9m)
Gwydir	Moree	10,500 (5.5m)	21,000 (7.6m)	33,000 (8.8m)
	Yarraman Bridge	9,700 (4.0m)	35,700 (6.5m)	51,000 (7.0m)
Border Rivers	Boggabilla	21,300 (5m)	117,300 (11.5m)	149,500 (12m)
	Goondiwindi	12,100 (4m)	27,000 (6.0m)	71,000 (8.5m)
	Mungindi	8,800 (6.1m)	12,100 (6.7m)	16,400 (7.2m)
Condamine–Balonne	St. George	14,700 (4.0m)	19,600 (5.0m)	33,000 (5.9m)
Warrego	Ford's Bridge	350 (1.7m)	820 (2.3m)	5,400 (3.2m)