Priority constraints analysis

Methods and results

Contents

Background

The Constraints Management Strategy is a key part of the implementation of the Murray–Darling Basin Plan and was published in November 2013 following 12 months of technical work and consultation with local communities and industries.

The aim of the Strategy is to improve the environmental outcomes achievable beyond current operating conditions by allowing better use of environmental water while avoiding, managing or mitigating impacts to local communities and industries. The changes being investigated are modest and aim to increase the frequency of some of the small to medium flow events that have been reduced through river regulation.

The Commonwealth Government has allocated $200 million to ease or remove priority constraints in the context of the SDL adjustment mechanism.

The Constraints Management Strategy sets out a timetable for a three phased assessment process for managing constraints in the Basin.

Key components of phase 1 (pre-feasibility phase - 2014) include:

- analysing each key focus area to understand the changes arising from the different flow events such as the area inundated, when and for how long
- analysing impacts and identifying benefits of constraints relaxation
- analysing options to mitigate negative impacts, including preliminary assessment of project costs and any benefits of mitigation options
- analysing and prioritising constraints (the focus of this report).

The purpose of the analysis and prioritisation process is to determine which constraints are the most feasible. It draws together all the information gathered in phase 1 under the key constraint area analysis. This process considers how to identify which constraints are the highest priority to overcome based on comparing benefits against the impacts and the costs of mitigating the impacts.

The outcomes of the analysis formed the basis of MDBA's recommendations to governments about which constraints (or packages of constraints) should be further assessed under phase 2 (feasibility assessment).

Scope of the analysis and prioritisation
The 'constraints measures' in this context are in two categories:

- physical measures which involve proposals to mitigate the potential effects of higher flows, like building bridges, improving access roads and acquiring easements, and
- operational and management constraints measures which are changes to 'river operation practices to allow us to use environmental water as efficiently as possible.

For the purposes of the analysis and prioritisation exercise, only physical constraints measures were considered. These are expected to include (i) land-based mitigation options, e.g. easements, and (ii) infrastructure works.

Operational and management constraints measures are not subject to the prioritisation exercise.

The prioritisation will be applied only in the seven key focus areas as defined in the Constraints Management Strategy: Goulburn, Lower Darling, Hume-Yarrawonga, Murrumbidgee, Yarrawonga-Wakool, South Australian River Murray and Gwydir.

Methodology

MDBA assessed the benefits of relaxing constraints, both in-valley benefits in each key focus area, and the contribution to basin-wide benefits from flows continuing downstream. In order to assess the benefits associated with relaxing constraints and prioritise which ones should be progressed further, the MDBA examined:

- flow rates determined to have environmental benefits
- the area of ecologically important indicator vegetation species and wetlands inundated under the different flow rates
- progress towards achieving Schedule 5 – Enhanced Environmental Outcomes referred to in paragraph 7.09(e) of the Basin Plan
- costs associated with mitigating the impacts of the different flow rates

Following the prioritisation we also considered the acceptability to communities of the flow rates being examined and this will continue to be a factor for consideration in the final decisions about which constraint measures will be implemented.

Flow rates determined to have environmental benefit

In 2012, the 3200 GL without constraints model run established the case for the CMS. The subsequent Preliminary Overview of Constraints to Environmental Water Delivery in the Murray–Darling Basin (2013) further examined the hydrology related to the flows identified in the 2800GL and 3200GL without constraints model run. The constraint limit included in the 3200 GL model run for the Yarrawonga to Wakool constraint area is 40,000 ML/day, but in practice this was heavily confined by the 25,000 ML/day flow limit in the upstream reach. Flows explored for this region as part of phase 1 include this limit and two higher limits of 50,000 ML/day and 77,000 ML/day.

Throughout 2014 MDBA has been investigating and consulting internally and externally on flow bands within these upper and lower boundaries with a view to achieving the highest possible flows within practical limits of being able to mitigate impacts. Flow bands for further investigation have been identified for each constraint area. These are presented with supporting rationale in **Appendix A**.

Analysis of inundated vegetation and wetlands

Analysis was undertaken to determine the environmental benefit of relaxing constraints through examination of inundated vegetation and wetlands in each of the key focus areas, particularly with reference to the inundation resulting from CMS determined flow rates.

Four flood dependent vegetation types were identified - River Red Gum Woodland, River Red Gum Forest, Black Box Forest and Woodland, and Shrublands. In addition to the vegetation inundation, the inundation of wetlands was also determined. For more information about this analysis see **Appendix B**.

Analysis against Schedule 5 – Enhanced Environmental Outcomes referred to in paragraph 7.09(e) of the Basin Plan

As well as the assessment of local benefit through examination of the area of vegetation inundated, a determination of the relative hydrologic contribution of flows at each constraint area toward System scale outcomes was also assessed by examining the constraint areas relative contribution to achieving a successful event at the South Australian border of 80,000 ML/d. A key objective of Schedule 5 – Enhanced Environmental Outcomes referred to in paragraph 7.09(e) of the Basin Plan.

Appendix C provides an outline of the hydrology underlying an 80,000 ML/d event and quantifies the contribution provided by each key focus area under natural (i.e. without development), current (i.e. pre-Basin Plan) and Basin Plan conditions.

Preliminary cost assessments of mitigating the impacts

The MDBA has estimated the costs that might be associated with mitigating the impacts of higher flows. The MDBA investigated in particular the costs associated with two types of activity:

- The possibility of negotiating easements with landholders, or other arrangements, which would provide for the passage of environmental flows over low-lying parts of their land.
- The possibility of infrastructure works to mitigate the impacts of higher flows—for example, works on roads or river crossings.

These were chosen because they are the options that are likely to be most material to the potential costs that may be associated with mitigation.

Appendix D provides a summary of the approaches used to estimate mitigation costs. Further details are in the separate Cost Estimates Report (MDBA 2014), the Easement Costing Methodology by GHD (2014), and the Infrastructure Costing Assumptions report by URS (2014). Comments from Basin States on the method reports were taken into account in finalising the work.

Community views

Throughout 2013 and 2014 CMS project officers worked with key stakeholders in the key focus areas to identify the flow rates examined and their impact. Reach Information Reports have been developed for each of the key focus areas and describe in detail community feedback about the flow rates investigated and hydrology of the area. Ratings identified in this report at Table 1 are qualitative and interpreted from these interactions with the community.

Results

The above analyses were conducted for each of the key focus areas. The results are summarised in Table 1 below.

Table 1: Analysis of Key Focus Areas for Constraints

Key focus area	Flows that appear feasible	Correlation with peak flow events >60,000 ML/d at SA border (as a surrogate for overall system health)	Total area of red gum and black box inundated (ha)[1]	Total area of Australian National Aquatic Ecosystems wetlands inundated (ha)	Preliminary cost estimate (moderate estimate – high estimate)	Community acceptance for continued investigations
Hume to Yarrawonga (flows as measured at Doctor's Point)	Up to 40,000 ML/day	90%	5,000	4,000	$16-22 million	OK, concerns at upper end of flow range
Yarrawonga to Wakool junction (flows as measured at Tocumwal/downstream of Yarrawonga Weir[2])	40,000 ML/day – 77,000 ML/day	50% - 100%	73,000 - 156,000	38,000 - 52,000	$105-218 million	OK at low to mid-range flows, concerns at upper end of flow range
SA River Murray (flows as measured at SA border)	Up to 80,000 ML/day	—	33,000	49,000	$5 million	OK
Lower Darling (flows as measured at Weir 32)	up to 16,000 ML/day	40%	2,500-3,600	400-1,200	$4-6 million	OK
Goulburn (flows as measured at Shepparton)	up to 40,000 ML/day	58%	19,000	3,000	$31-47 million (assuming levee upgrades)	OK, concerns at upper end of flow range
Murrumbidgee (flows as measured at Wagga Wagga) [3]	Up to 48,500 ML/day	45%	69,000	20,000	$66-80 million	OK, concerns at upper end of flow range
Gwydir	Unknown at this stage	—	—	—	Uncertain	OK

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[1] Increase in inundated vegetation is used as a surrogate for in-valley benefits

[2] CMS prefeasibility work in the Yarrawonga-Wakool drew on information which was generated with reference to both the Tocumwal gauge and downstream of Yarrawonga Weir. Inundation maps (i.e. the areas modelled as inundated at specified flow rates, which informed the assessment of effects and/or impacts of higher flows) were generated with reference to the Tocumwal gauge, while hydrological data (i.e. frequency, timing and duration of flows) were generated with reference to downstream of Yarrawonga Weir. Flow rates at the two sites are similar, but not identical—in general, a given flow rate at Yarrawonga Weir equates to a slightly lower flow rate at Tocumwal. For practical purposes the discrepancy is not material to the prefeasibility cost estimates described in this report.

[3] Some of the increased benefits in the Murrumbidgee can also derive from other investments such as the Nimmie Caira project.

Prioritisation of constraints

The results of the analyses were examined in combination with each other to identify the most feasible options for relaxing constraints.

Preliminary estimates of cost indicate that addressing constraints in all seven key focus areas may exceed the $200 million set aside for constraints measures in the Water for the Environment Special Account. However, these estimates are preliminary only and will be refined with further investigation. Because of this limitation, it was not possible to determine a single flow rate that should be pursued for each key focus area. Specific flow rates to relax constraints will need to be decided in the next phase.

A decision support tool was used to help explore the relationships between environmental flows/outcomes, changes in constraints, and the costs of mitigation.

The use of the decision support tool highlighted the inter-dependencies between the three River Murray key focus areas. In order to achieve the flow target of 60,000–80,000 ML/day in SA, it is important to relax all three River Murray constraints together as an integrated package. These three key focus areas were also identified as the highest priority to address because of the high contribution to system scale benefits and high in-valley benefits. However, cost and diminishing benefits mean constraints in these areas might not be relaxed to the highest flow rates investigated.

Both local and system scale benefits and impacts were considered equally as important in the prioritisation process. If system scale benefits were to be considered more important, the Goulburn would be prioritised ahead of the other tributaries because of its greater contribution to meeting higher flows in the Murray floodplain. If in-valley benefits were considered more important the Murrumbidgee would be prioritised ahead of the other tributaries because of the greater area of flood dependent vegetation within that key focus area.

Conclusions

Due to the dependencies between them, the three parts of the Murray — Hume to Yarrawonga, Yarrawonga to Wakool Junction and the lower Murray — should be considered as a single integrated package. Without relaxing constraints along all three reaches, it would not be possible to take advantage of relaxed constraints in just one reach of the Murray. Relaxing constraints along the main stem of the Murray can provide some of the greatest environmental outcomes, particularly if regulated releases can be timed to combine with unregulated flows to build a flow of 60,000 ML/day to 80,000 ML/day at the South Australian border. Without relaxing constraints in the River Murray, relaxed constraints in the Goulburn, Murrumbidgee and Lower Darling will be limited to in-reach benefits only. As such, it makes sense to consider the package of constraints along the main stem of the Murray to be the first priority for constraint measures.

The best Basin-scale outcomes that could be achieved for around $200 million would arise from addressing constraints along the entire main stem of the River Murray, the Lower Darling as part of the Menindee Lakes Water Savings Project, and, if funds are limited, one of either the Goulburn or the Murrumbidgee.

- Further work would need to be done on costing work in the Goulburn and Murrumbidgee to prioritise between them, and this should be done by developing business cases.
- More investigations are needed in the Gwydir to prove feasibility before cost estimates could reasonably be provided. This work should be done through business case

development if jurisdictions wish to align proposals with the timelines in the Inter-Governmental Agreement.

Appendix A: Physical Constraints Flow Rate Selection and Rationale

Table 2: Flow rates selected

Focus Area	Gwydir	Hume-Yarrawonga	Yarrawonga-Wakool	Goulburn		Murrumbidgee		Lower Darling	SA
Location	-	Drs Point	Tocumwal / downstream of Yarrawonga Weir[4]	Mid (d/s Eildon)	Lower (D/S Shepp)	Lower (d/s Hay)	Mid (d/s Wagga)	Weir 32	The border
Minor flood level	Moree 10.5; Yarraman Bridge 9.7	40,000 ML/d < minor flood level at Albury	Tocumwal 77,300 ML/d	Eildon 15;000 ML/d Trawool 21,700 ML/d; Seymour 22,800 ML/d; Murchison 29,200 ML/d	Shepp 26; McCoys 29,200 ML/d	Darlington Point 25,500 ML/d; Balranald 26,000 ML/d	Tumut 16,100 ML/d; Gundagai 43,900 ML/d; Narrandera 40,300 ML/d	Weir 32,000 ML/d 18,000 ML/d	Shacks > 60,000 ML/d
Experienced River Operators Report	N/A	40,000 ML/d	>65,000 ML/d	-	>28,000 ML/d	>10,000 ML/d	-	>8,000 ML/d	80,000 ML/d
2,800 current constraint	250GL	25,000 ML/d	22,000 ML/d	12,000 ML/d	20,000 ML/d	9,000 ML/d	30,000 ML/d	9,000 ML/d	40,000 ML/d
In practice	-	25,000 ML/d	10,000 - 18,000 ML/d	9,000 ML/d	-	-	-	9,000 ML/d	-
3,200 RC	N/A	40,000 ML/d	40,000 ML/d	15,000 ML/d	40,000 ML/d	13,000 ML/d	50,000 ML/d	18,000 ML/d	80,000 ML/d

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[4] CMS prefeasibility work in the Yarrawonga-Wakool drew on information which was generated with reference to both the Tocumwal gauge and downstream of Yarrawonga Weir. Inundation maps (i.e. the areas modelled as inundated at specified flow rates, which informed the assessment of effects and/or impacts of higher flows) were generated with reference to the Tocumwal gauge, while hydrological data (i.e. frequency, timing and duration of flows) were generated with reference to downstream of Yarrawonga Weir. Flow rates at the two sites are similar, but not identical—in general, a given flow rate at Yarrawonga Weir equates to a slightly lower flow rate at Tocumwal. For practical purposes the discrepancy is not material to the prefeasibility cost estimates described in this report.

Flow rates proposed for CMS impact assessment

Focus Area	Gwydir	Hume-Yarrawonga	Yarrawonga-Wakool	Goulburn		Murrumbidgee		Lower Darling	SA
Flow rate 1	GVFMP Zone A	40,000 ML/d	20,000 ML/d	12,000 ML/d	25,000 ML/d	9,000 ML/d	20,000 ML/d	14,000 ML/d	60,000 ML/d
Flow rate 2	GVFMP Zone b	-	35,000 ML/d	15,000 ML/d	30,000 ML/d	13,000 ML/d	30,000 ML/d	17,500 ML/d	80,000 ML/d
Flow rate 3	-	-	50,000 ML/d	20,000 ML/d	40,000 ML/d	-	50,000 ML/d	-	-
Optional extra 1	-	-	77,000 ML/d	-	-	-	35,000 ML/d	-	-
Optional extra 2	-	-	-	-	-	-	40,000 ML/d	-	-
Optional extra 3	-	-	-	-	-	-	45,000 ML/d	-	-

Hume to Yarrawonga

First order constraint (identified through Preliminary Overview of Constraints To Environmental Water Delivery in the MDB, MDBA 2013)

- Doctor's Point – operating constraint based on channel capacity between Hume Dam and Yarrawonga Weir (25,000 ML/day)
- The right to deliver water at flows up to 25,000 ML/day are secured through a network of easements, river access program and a river health program
- Flows above 25,000 ML/day access the floodplain

40,000 ML/day (Doctor's Point)

Rationale - Relaxing this constraint would allow higher end-of system and downstream flow rates that would contribute to a number of key environmental asset and River Murray environmental outcomes.

- Minor Flood Level at Albury is 44,500 ML/day
- Flows at rates approximately >41,000 ML/day provide nuisance flooding for a considerable number of landholders
- There has been a general community acceptance that impacts for flows up to 40,000 ML/day would be examined by MDBA
- The MDBC undertook flow modelling and inundation mapping for flows up to 40,000 ML/day in 2006 and the Murray River Action Group undertook a landholder impact assessment in 2011

Yarrawonga to Wakool junction

First order constraint (identified through Preliminary Overview of Constraints To Environmental Water Delivery in the MDB, MDBA 2013)

- Downstream of Yarrawonga Weir – irrigation delivery and inundation control (10,600 ML/day in summer, 15,000 ML/day at other times)
- Access issues and other impacts are likely in the creek network associated with Barmah at flows above 18,000 ML/day
- There is potential for additional impacts including inundation, isolation
- Minor Flood Level at Tocumwal, downstream of Yarrawonga Weir, is 77,300 ML/day

20,000 ML/day (downstream of Yarrawonga Weir)

Rationale – examining this flow rate would help to determine the range of potential impacts at low flows and help to validate the modelling work supplied by CSIRO.

35,000 ML/day (downstream of Yarrawonga Weir)

Rationale - examining this flow rate would help to determine the range of potential impacts at mid-sized flows that would be likely for delivery of environmental water.

50,000 ML/day (downstream of Yarrawonga Weir)

Rationale - examining this flow rate would help to determine the mid-range of potential impacts at large-sized flows.

77,000 ML/day (downstream of Yarrawonga Weir)

Rationale – 77,300 ML/d is the Minor Flood Level at Tocumwal. Examining this flow rate would help to determine potential impacts at Minor Flood Level.

Note #1: new constraints have the potential to 'emerge' while exploring the types of flow rates discussed above. It is likely that a number of additional flows may need to be assessed (between the rates described above) once an impact threshold becomes apparent.

Note #2: inundation patterns provided by the CSIRO inundation mapping may not adequately reflect the complex nature of the fluvial geomorphology of the western parts of the region, particularly beyond the Barmah Choke. Any inundation modelling/mapping will likely need to be validated by individuals with detailed expertise in the hydrology of the region.

Southern Murray (to Echuca, Swan Hill)

- The Preliminary Overview of Constraints to Environmental Water Delivery in the MDB, (MDBA 2013) did not identify any 1st order constraints in this reach, however, this area will need to be examined as part of the assessment for this Key Focus Area.

Goulburn

Two constraints:

- D/S of Eildon (limited channel capacity near Alexandra/Molesworth, 9,500ML/day) and
- D/S of Shepparton (26,000 ML/d, minor flood level)

Flow rates to be investigated as first priority:

Constraint 1, Reaches A to D, downstream of Eildon, 3 flow rates – 12,000, 15,000 and 20,000ML/day.

Rationale – Relaxing this constraint would allow higher release rates from Lake Eildon (where environmental entitlements are held).

- Lake Eildon water releases are currently restricted, where possible, to prevent inundation and access issues in the mid-Goulburn as the channel capacity downstream of lake Eildon is only 9,000-10,000 ML/day (e.g. Molesworth 9,500 ML/day). When calculating release rates from Lake Eildon, operators must also leave sufficient space/buffer to allow for the flow contributions of several unregulated tributaries downstream.
- From 2013 MDBA consultation, a flow rate of 12,000ML/d would start impacting people around Alexandra, and by 15,000ML/d people near Molesworth and Thornton would be impacted and getting increasingly concerned. Although 20,000 ML/d exceeds/approaches downstream minor flood levels and therefore causing widespread impacts and some alarm, it is a useful upper boundary of potentially higher flow rates to be considered for the mid-Goulburn River.
- (Minor flood flow rates – Eildon 15,000, Trawool 21,700, Seymour 22,800ML/d).

Constraint 2, Reaches G&H, downstream of Shepparton, 3 flow rates – 25,000, 30,000 and 40,000ML/day

Rationale - Relaxing this constraint would allow higher end-of system and downstream flow rates that would contribute to both lower Goulburn floodplain and River Murray environmental outcomes.

- Flow rates in the lower Goulburn downstream of Shepparton are currently kept well below 24,000ML/d to confine flows to the river channel and to stay below the minor flood level at Shepparton (26,000 ML/d).
- Two overbank flow rates for the Lower Goulburn floodplain downstream of Shepparton have been derived from an understanding of the watering requirements of different vegetation communities (DSE 2011) and were adopted by MDBA during development of the Basin Plan for use in determining the ESLT and SDL (MDBA 2012).
    - A 25,000 ML/d flow rate was selected in order to inundate the majority of floodplain wetlands and watercourses as well as vegetation communities that require more frequent flooding in the lower Goulburn floodplain (DSE 2011).
    - A 40,000 ML/day flow rate was selected in order to inundate the majority of flood dependent vegetation on the lower Goulburn floodplain whilst avoiding risks and liabilities of flooding outside of the levee network (Water Technology 2010, DSE 2011).

- From 2013 MDBA consultation, 25,000ML/d (9.4m river height at Shepparton) would be impacting people and assets but unlikely to be causing widespread alarm as water is only just getting out of channel. However at higher flow rates of 40,000ML/d (between minor and moderate flood levels at Shepparton), there would be widespread impacts and people would be very concerned. At 40,000ML/day, (10.31m river height at Shepparton), there is the risk of inadvertently opening the Loch Garry flood protection scheme which is undesirable (removal of bars commences 24hours after the Shepparton gauge level has exceeded 10.36 m). A flow rate of 30,000ML/d offers a step increase between 25,000 and 40,000 ML/day, and impact assessment has already been carried out by Water Technology 2010.

NOTE inundation modelling and impact assessment has been carried out by Water Technology and GBCMA for flow rates of 20,000, 30,000, 40,000, 50,000 and 60,000ML/day. In 2013 MDBA used the Water Technology model to carry out additional inundation modelling runs of 12,000 and 15,000 ML/day for reaches A to D, and 25,000ML/day for reaches F, G & H which haven't undergone any additional model calibration, checking or review

Murrumbidgee

A number of constraints exist along the Murrumbidgee:

- Tumut at Oddy's Bridge: water sharing plan limit 9,000 ML/day
- Tumut at Tumut town: water sharing plan limit 9,300 ML/day. Minor flood level: 16,100 ML/day.
- Gundagai (to avoid inundation of Mundarlo Bridge): 30,000 ML/day. Minor flood level: 43,900 ML/day.
- Wagga: to avoid inundation of private land near Collingullie and need to shut stormwater flood gates at Wagga City a number of flow rates are applicable. From around 20,000 ML/day private land begins to be inundated at Collingullie. At 26,600 ML/day stormwater floodgates begin to be closed at Wagga. An environmental flow was planned for spring 2013 at around 28,000 ML/day with some opposition from farmers.
- Narrandera: Stormwater floodgate closed at 31,500 ML/day; Minor Flood Level (40,300 ML/day).
- Yanco Creek Offtake: Water sharing plan limits flows to 1,400 ML/day in Yanco Creek. [5] This equates to a flow of about 22,000 ML/day in the Murrumbidgee at Wagga Wagga. This meant the environmental flow planned for spring 2013 was unable to go ahead. The actual flow where problematic inundation occurs is believed to be 2,000 ML/day.
- Darlington Point: Minor flood level: 25,500 ML/day.
- Balranald: Channel capacity at Chastons Cutting 9,000 ML/day.

Flow rates to be investigated:

Wagga is a key point for setting flows to be investigated because it is downstream of the major tributaries.

Key flow rates to model:

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[5] This constraint may be relaxed in the next Water sharing plan

20,000 ML/day in Wagga (the point at which flows can currently be delivered without any third party impacts).

30,000 ML/day at Wagga (around the point at which environmental flows have previously been undertaken).

50,000 ML/day at Wagga: Just below minor flood level at Wagga and likely to correspond to levels below minor flood level at Gundagai once tributary flows have been included and the minor flood level at Narrandera (40,300 ML/day).

40,000 ML/day at Wagga: to provide a mid- point for consideration between 30,000 ML/day and 50,000 ML/day to provide a more graduated assessment of the changes in impacts (positive and negative) as flows increase. For the same reason, if modelling capability exists it would be advantageous to also do **35,000 ML/day and 45,000 ML/day at Wagga**.

Flows should be modelled with different limits on other points on the river, including:

- Raising the flow at Gundagai up to 40,000 ML/day and then to minor flood level (43,900 ML/day).
- Raising the flow at Balranald from 9,000 ML (base case) to 12,000 ML or 13,000 ML/day.
- A model run with Tumut river releases (at Tumut) up to 15,000 ML/day (for a max of 3 days with natural recession to below 9,000 ML/day thereafter) would also be valuable.

Three further modelling needs for the Murrumbidgee:

- A variation of the models could be run with the Yanco Creek Offtake flows limited to minimum flows. This assumes a Yanco Creek offtake regulator has been installed. Such a regulator would allow greater flows to remain in the Murrumbidgee main stem providing improved flow heights at Darlington Point.
- Modelling of what flows are required at Gundagai, Wagga and other downstream gauges to achieve a flow of 9,000 ML/day and 13,000 ML/day at Balranald. Do this with and without irrigation demand. Can limit to months of July to November. This will determine if flow demands for the Murray which require delivery of peak flows from the Murrumbidgee will require rates of delivery in the upper parts of the river which could cause impacts.
- Modelling the effect on allocation reliability if higher piggy-back flows are undertaken. It is possible that larger piggy back flows will draw more heavily on Burrinjuck Dam (as opposed to Blowering Dam) than is the case under normal operations.

    NOTE All these flow levels are from the most recent ratings tables (these have changed since the original Basin Plan modelling was done).

Lower-Darling

The key constraints for consideration in the Lower Darling are as follows:

- Flow begins to enter the Great Darling Anabranch between 9-12,000ML per day
- Combined capacity for regulated flows over Weir 32 is only 14,000ML per day when levels are high (possible to let higher flows out via Main weir)
- Flows above 20,000 ML/day are at minor flood level and result in inundation of private property including house blocks in Menindee

In determining what flow rates to model, consideration needs to be given to the above as well as several other factors. The CSIRO LIDAR data to form the basis for the modelling is not currently available for the Lower Darling Reach, but is expected in February/March 2014. However, some maps in the form of Landsat satellite images of specific high flow events projected onto aerial photography might be used to determine inundation extent in the absence of this data. These images exist for the following flow rates taken at Weir 32:

- 14,000ML per day at Weir 32
- 17,500ML/day at Weir 32
- 20,000ML/day at Weir 32
- 32,000ML/day at Weir 32

The above flow rates roughly correspond to the target flows specified in the Basin Plan for the Lower Darling, with 20,000ML/day and 17,000ML day specified for meeting certain ecological targets. Aligning the requests for additional modelling to the flow rates above will therefore:

- make best use of existing information on flows for environmental services; and
- enable consultation with stakeholders to start around these flow targets using the satellite mapping, should the LIDAR data not be available in a timely manner.

This work may also have some relationship to the Mendindee Lakes Water Savings Project. The NSW Government and Australian Government recently agreed to undertake a project to investigate water savings in the Menindee Lakes systems. Components of this project include consideration of enlarging the Menindee regulator, installing a regulator on the Great Darling Anabranch and flood protection in and around Menindee township.

Modelling of 18,000ML flow with installation of a regulator on the anabranch indicated there was an increase in peak flow of overbank events at the Riverland/Chowilla, however there is currently no understanding of the potential impact of a regulator on the flood inundation patterns in the Lower Darling reach. Therefore, modelling flow rates with and without the installation of a regulator on the anabranch will provide a greater understanding of the impacts of higher flows in a system with improved flexibility in water delivery will look like.

In addition, modelling several flow rates will provide understanding of the flows under which unacceptable impacts begin to occur. Based on the above and the long-term goal of increasing flexibility in flow-delivery, the priority flow rates to model are as follows:

- 14,000ML per day (with and without the Anabranch regulator)
- 17,500ML per day (with and without the Anabranch regulator)

In addition MDBA has received a request to provide modelling support for the Menindee Lakes Water Savings Project. While the details of this modelling work have not yet been confirmed, there is a possibility that there may be some overlap in the work that needs to be done.

River Murray (SA)

In South Australia two key flow rates were considered: 60,000 ML/day and 80,000 ML/day. Flows of 40,000 ML/day and below are generally accepted as remaining in-channel. Modelling shows that the greatest change in area of floodplain inundation occurs between 60,000 and 80,000 ML/day – see Table 3.

The SA Government has undertaken an assessment of these flows to provide an indication of impacts on the areas inundated and assets affected. The assessment included hydrological modelling using RiM-FIM version IV and MIKE 21 (only above Mannum for flows >60,000 ML/day) and GIS analysis. The results of the assessment indicated where impacts need to be investigated further and mitigation options may be required. More information and maps of the inundation extent at different flow rates can be found on the SA Government's Waterconnect website: www.waterconnect.sa.gov.au/

Further work is required to test modelling on the ground using the experiences from the high flows of 2011-2012 as a useful reference point.

60,000 ML/day at SA border

A flow of 60,000 ML/day at the SA border represents a level where the risk of third party impacts increases, including impacts on some shack areas downstream of Cadell due to their proximity to the River's edge as well as floodplain roads, access tracks and some council infrastructure. This was shown during the high flow events of 2011 (peak flow of 93,000 ML/day at SA border) and 2012 (peak flow of 60,000 ML/day). Accordingly, the SA Government flood level descriptions for the River Murray adopt a 'minor flood' warning for the shack areas downstream of Cadell when flows at the SA border reach 60,000 ML/day, but at 100,000 ML/day for the rest of the SA River Murray.

A flow of 60,000 ML/day for 60 days is an Environmental Watering Requirement for the SA River Murray in the Basin Plan.

80,000 ML/day at SA border

MDBA modelling indicates that flows of approximately 80,000 ML/day represent an upper threshold of the range of flows that could be practically delivered to South Australia within the limits identified for upstream areas. A flow of 80,000 ML/day for 30 days is an Environmental Watering Requirement for the SA River Murray in the Basin Plan.

Table 3: Area of flood inundation for each flow scenario for the River Murray from the SA border to Wellington (Cetin & Eckert 2012)

Flow rate	Floodplain area inundated (ha)	Difference in area inundated between flow rates (ha)
20,000 ML/day	25130	-
40,000 ML/day,	28820	3690
60,000 ML/day,	40381	11561
80,000 ML/day,	67711	27330
100,000 ML/day,	83085	15374

Gwydir

The key constraints for consideration in the Gwydir are:

- The primary constraint to environmental watering in the region consists of private landholdings adjacent to the Gingham Watercourse in the Lower Gwydir. The potential effects of environmental watering on these properties are not fully understood and require further analysis.

- The storage release capacity of Copeton Dam (10,850 ML/d) may limit environmental watering under special circumstances.
- The Basin Plan has a site specific flow indicator of a total in-flow volume of 250 GL during October and March for 12% of years, but it was determined that it is not possible to actively manage the delivery of this volume of water in the Gwydir. However, 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 that involve inundation of private land (pers. comm. Commonwealth Environmental Water Office).

In determining what flow rates to model, consideration needs to be given to the above as well as several other factors, including current NSW planning processes. The CSIRO LIDAR data to form the basis for the modelling is not currently available for the Gwydir Key Focus area.

Appendix B: Vegetation and Wetland Inundation for the CMS

Introduction

Any plan to relax or remove river system constraints has a direct impact on resulting river flows, which is a unique impact depending on where in the river system the constraint lies. This change in the flow regime can have great benefit for the local environment, but can also have a negative impact on individual landholders and existing infrastructure if flows greater than any given flooding level occur more frequently as a result .

To help prioritise river system constraints, both the environmental benefits and undesired impacts of the constraint relaxation must be determined. This can be broadly carried out via:

- Determining the environmental benefit of relaxing constraints through analysis of inundated vegetation and wetlands, particularly with reference to the inundation resulting from CMS-determined flow rates of interest,
- Determining the incidence of flows above and beyond prescribed flooding levels across the Southern Connected System both with and without constraint relaxation, and
- Determining the cost associated with any resulting inundation of private land.

This report details work undertaken to help answer the first of the points above. In particular, the inundated area of four vegetation types, plus wetlands, was determined for the specified CMS flows. This will subsequently be used to help determine the environmental significance of relaxing constraints in the Southern Connected System.

It would be beneficial to compare the inundated vegetation at the CMS flows-of-interest to the extent of vegetation inundated on the larger floodplain (for example that which is inundated at the various maximum Basin Plan SFIs) to directly gauge the improvement resulting from the relaxation of constraints. This cannot be carried out consistently, quickly or easily as the CMS spatial zones (and sometimes data used) differ from those adopted for use in the SDL Adjustment Mechanism.

Method Applied

To determine the vegetation and wetlands that are inundated at the flow rates specified by the CMS, three pieces of information are required:

1. The spatial extent of the flooding,
2. The spatial distribution of the wetlands, and
3. The spatial distribution of the vegetation to be measured.

Flood Inundation footprints

The first of these data (flooding extent) was provided by the CMS, and consists of spatial information for six regions (Table 4). Also included are the flow rates of interest, the gauge for which the flows are measured and notes on the origin of the data and the spatial resolution of the data.

Table 4: Regions and flow rates specified by the CMS for vegetation inundation to be calculated, along with notes on the origin of the data used for the inundation surface.

Region	CMS Flow Rates	Gauge	Notes
Hume to Yarrawonga	30,000 ML/d	Doctor's Point	Using inundation layers prepared for work on easement purchases and is based on Hydrodynamic modelling by GHD (2010), 10m cells.
	35,000 ML/d		
	40,000 ML/d		
	45,000 ML/d		
	50,000 ML/d		
Yarrawonga to Wakool Junction	20,000 ML/d	Tocumwal[6]	Using same CSIRO RiM-FIM inundation rasters as per SDL Adjustment Mechanism accounting for attenuation along the length of the region, 5m cells.
	35,000 ML/d		
	50,000 ML/d		
	77,000 ML/d		
Lower Darling	9,000 ML/d	Weir 32	Using the CSIRO RiM-FIM data for the Lower Darling, 5m cells. Zones 1 and 2 analysed separately.
	14,000 ML/d		
	17,000 ML/d		
Goulburn	25,000 ML/d	Shepparton	Using State water Hydrodynamic inundation model as SDL Adj Mech accounting for attenuation, 25m cells.
	30,000 ML/d		
	40,000 ML/d		
Upper Murrumbidgee	30,000 ML/d	Wagga Wagga	Provided by NSW State Water, accounting for attenuation, 5m cells.
	40,000 ML/d		
	48,500 ML/d		
Lower Murrumbidgee	20,000 ML/d	Wagga Wagga	Provided by NSW State Water, accounting for attenuation, 5m cells.
	30,000 ML/d		
	40,000 ML/d		
	48,500 ML/d		
South Australian Border to the Lower Lakes	40,000 ML/d	SA Border	Using RiM-FIM inundation rasters as per SDL Adjustment Mechanism work accounting for attenuation, 5m cells.
	60,000 ML/d		
	80,000 ML/d		
	100,000 ML/d		
	125,000 ML/d		

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[6] CMS prefeasibility work in the Yarrawonga-Wakool drew on information which was generated with reference to both the Tocumwal gauge and downstream of Yarrawonga Weir. Inundation maps (i.e. the areas modelled as inundated at specified flow rates, which informed the assessment of effects and/or impacts of higher flows) were generated with reference to the Tocumwal gauge, while hydrological data (i.e. frequency, timing and duration of flows) were generated with reference to downstream of Yarrawonga Weir. Flow rates at the two sites are similar, but not identical—in general, a given flow rate at Yarrawonga Weir equates to a slightly lower flow rate at Tocumwal. For practical purposes the discrepancy is not material to the prefeasibility cost estimates described in this report.

The datasets used represent the best flood inundation available. These models consist of two types; hydrodynamic models such as Mike11-Flood or flood inundation models developed by CSIRO referred to broadly as Rim-FIM.

Vegetation Mapping

The vegetation mapping used to determine inundated areas here is the same as that previously determined for the SDL Adjustment Mechanism. For that work, the Ecological Elements project defined four vegetation 'elements', which consist of:

- River Red Gum Woodland,
- River Red Gum Forest
- Black Box Forest and Woodland, and
- Shrublands

These were determined via a conglomeration of two specific vegetation layers. These are:

- The Monash (Cunningham) vegetation layer (25m resolution)[7], and
- The NVIS 4.1 vegetation layer (100m resolution).[8]

The Monash dataset was produced by classifying Landsat data and utilising field mapping data for training and vegetation classification. The NVIS data is a combination of various state-based vegetation maps and constitutes the best available at this time across the whole basin.

Wetland Mapping

In addition to the vegetation inundation, the inundation of wetlands was also determined. This was carried out using the Australian National Aquatic Ecosystem (ANAE) wetlands database, which originated with the Interim Australian National Aquatic Ecosystem Classification Framework, which was undertaken with participation of the MDBA, the Commonwealth Environmental Water Office and representation from each of the Basin State authorities.

Some cross-border ANAE Classification Framework discrepancies were noted, particularly across the NSW/VIC border due to different base mapping incorporated in its construction. However the overall dataset is the best available, providing an excellent source for wetlands mapping with good accuracy, and has been endorsed for use by the states.

Determining Inundation Extent

The output inundation extents were calculated via specific GIS operations and code that overlay the vegetation, wetland and inundation footprint data to calculate the area wherever the two intersect.

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[7] Cunningham SC, White M, Griffioen P, Newell G and Mac Nally R, (2013) Mapping Floodplain Vegetation Types across the Murray–Darling Basin Using Remote Sensing. Murray–Darling Basin Authority, Canberra.
[8] Australian Government Department of the Environment (2012). National Vegetation Information System (NVIS) 4.1.

Results

Hume to Yarrawonga

For the Hume to Yarrawonga reach the CMS is examining a range of flows from 30,000 to 50,000 ML/d (particularly 40,000 ML/d), measured at Doctor's Point. Figure 1 presents the spatial extent of the maximum flow (50,000 ML/d).

Figure 1: Extent of inundation for the maximum flow provided (50,000 ML/d) in the Hume to Yarrawonga reach

Table Table 5: Flow rates of interest, total area inundated and area inundated for the sampled vegetation types and wetlands for the Hume to Yarrawonga reach. details the flow rates of interest, the total area inundated within the footprint, and total area inundated for the various vegetation types sampled (plus wetlands) for Hume to Yarrawonga.

Table 5: Flow rates of interest, total area inundated and area inundated for the sampled vegetation types and wetlands for the Hume to Yarrawonga reach.

Flow Rate (Doctor's Pt, ML/d)	Total Area Inundated (Ha)	Total Inundated Vegetation				
		Red Gum Woodlands (Ha)	Red Gum Forests (Ha)	Black Box (Ha)	Shrubs (Ha)	Wetlands (Ha)
30000	9761	874	3022	15	0	3521
35000	10504	986	3425	16	0	3692
40000	11199	1090	3814	17	0	3795
45000	11922	1198	4200	18	0	3874
50000	12641	1306	4562	19	0	3937

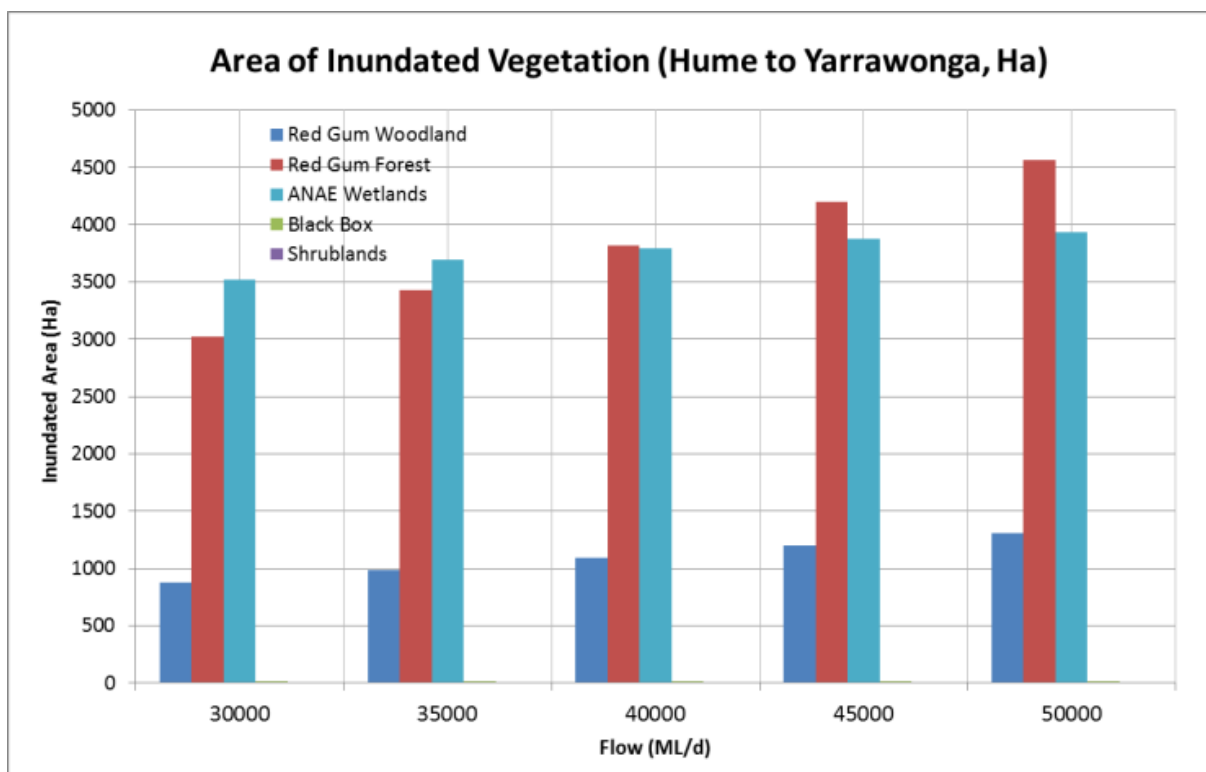Figure 2 presents a bar chart of the information presented in Table 5 above.

Figure 2: Bar chart of inundated vegetation types and wetlands at the flow rates of interest for the Hume to Yarrawonga reach.

Yarrawonga to Wakool Junction

For Yarrawonga to Wakool Junction the CMS is examining a range of flows (20,000, 35,000, 50,000, 77,000 ML/d), measured at Tocumwal. Figure 3 presents the maximum flow extent (77,000 ML/d).
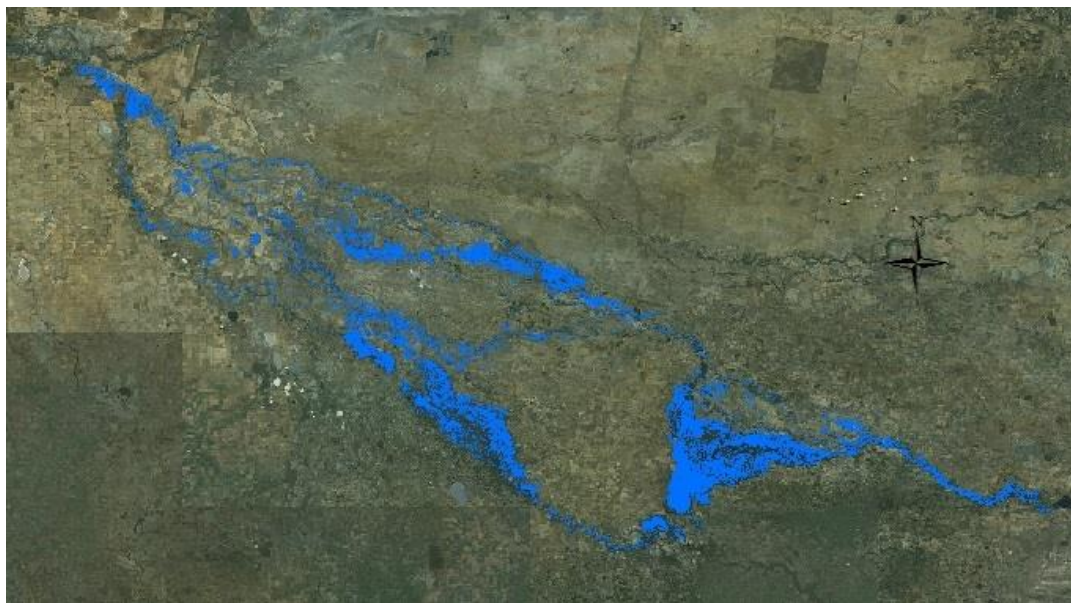

Figure 3: Extent of inundation for the maximum flow provided (77,000 ML/d) in the Yarrawonga to Wakool Junction reach

Table 6 details the flow rates of interest (measured at Tocumwal), the total area inundated within the flow footprint and the total area inundated for the various vegetation types sampled and wetlands for the Yarrawonga to Wakool Junction reach.

Table 6: Flow rates of interest, total area inundated and area inundated for the sampled vegetation types and wetlands for the Yarrawonga to Wakool Junction reach.

| Flow Rate (Tocumwal, ML/d) | Total Area Inundated (Ha) | Total Inundated Vegetation | | | | |
		Red Gum Woodlands (Ha)	Red Gum Forests (Ha)	Black Box (Ha)	Shrubs (Ha)	Wetlands (Ha)
20000	**45344**	14128	13176	6628	384	24096
35000	**89642**	33194	26211	13747	1559	37920
50000	**116642**	46116	32093	18605	2023	43753
77000	**191179**	70826	41871	43472	6012	51827

Figure 4 presents a bar chart of the information presented in Table 6 above.
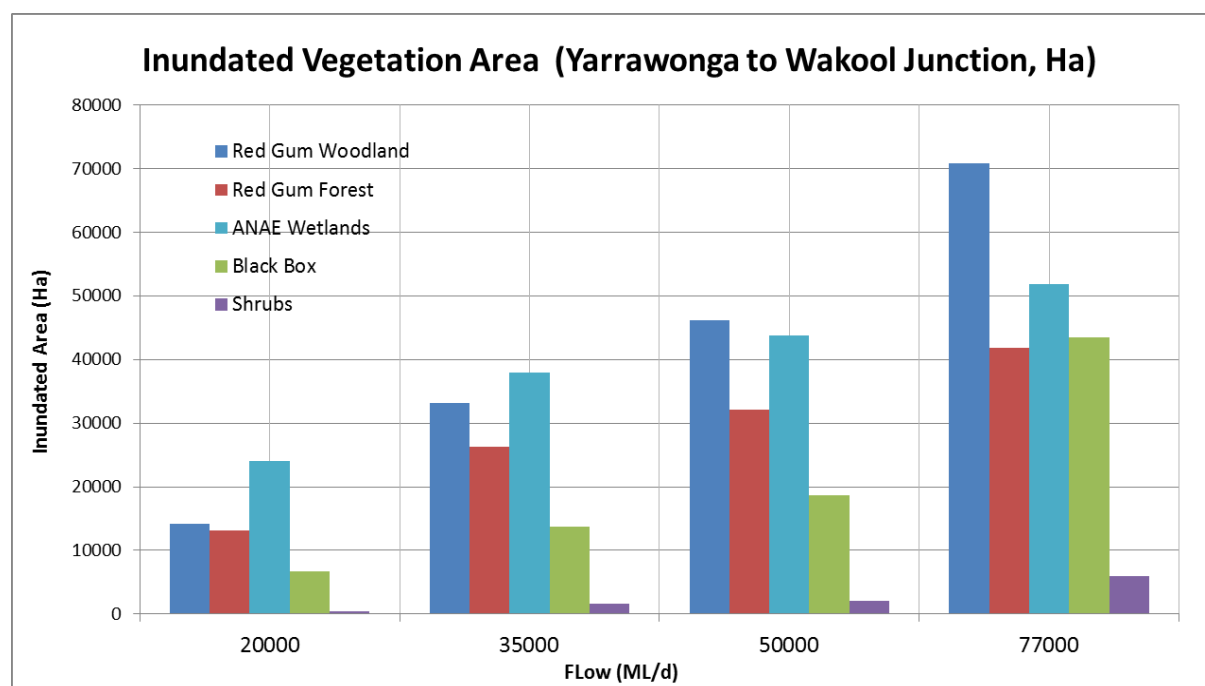

Figure 4: Bar chart of inundated vegetation types and wetlands at the flow rates of interest for the Yarrawonga to Wakool Junction reach.

Goulburn

For the Goulburn the CMS is examining three flows (25,000, 30,000 and 40,000 ML/d), measured at Shepparton. Figure 5 presents the spatial extent of the maximum flow (40,000 ML/d).
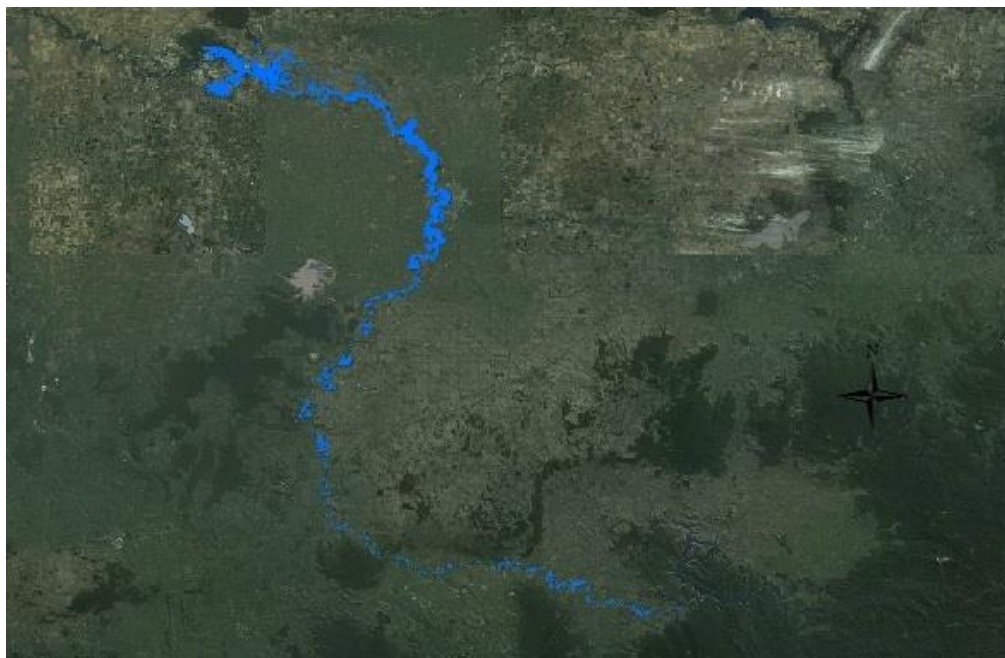

Figure 5: Extent of inundation for the maximum flow provided (40,000 ML/d) in the Goulburn reach

Table 7 details the flow rates of interest (measured at Shepparton), the total area inundated within the flow footprint and the total area inundated for the various vegetation types sampled and wetlands for the Goulburn.

Table 7: Flow rates of interest, total area inundated and area inundated for the sampled vegetation types and wetlands for the Goulburn.

| Flow Rate (Shepparton, ML/d) | Total Area Inundated (Ha) | Total Inundated Vegetation | | | | |
		Red Gum Woodlands (Ha)	Red Gum Forests (Ha)	Black Box (Ha)	Shrubs (Ha)	Wetlands (Ha)
25000	14609	6656	4119	351	0	1880
30000	20336	9011	5489	669	0	2442
40000	26226	11557	6598	1008	0	3276

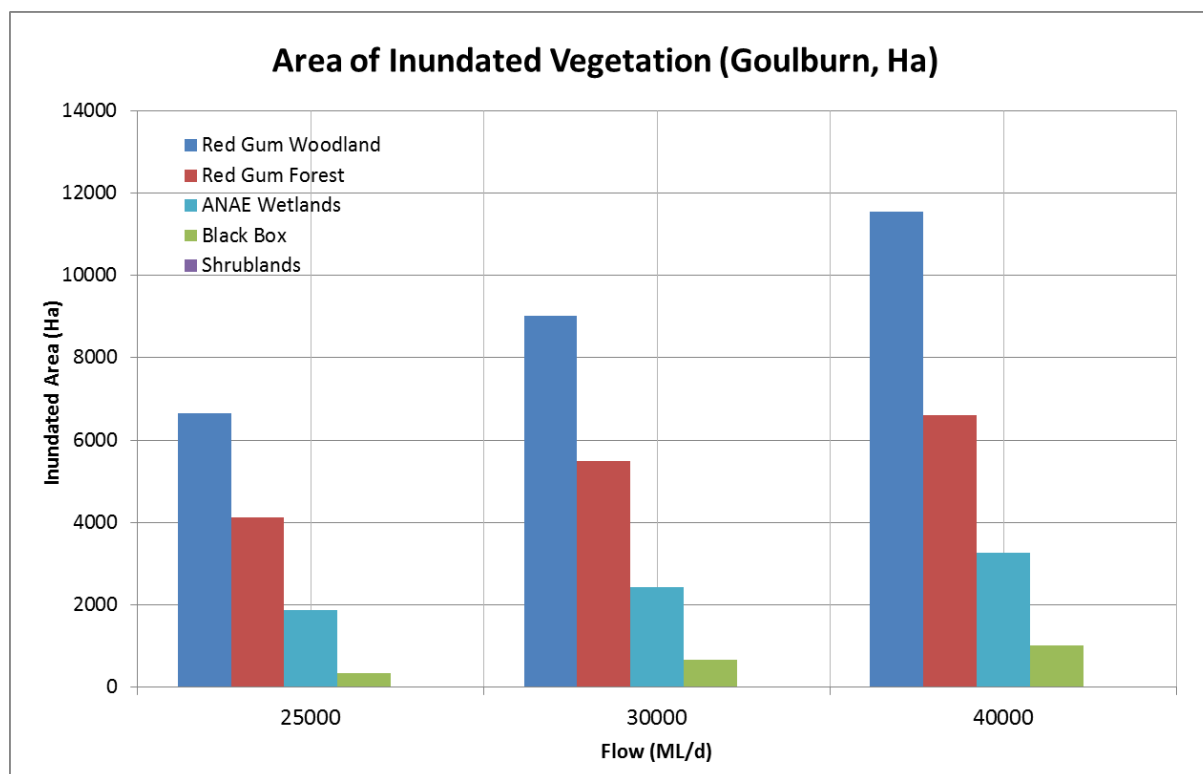Figure 6 presents a bar chart of the information presented in Table 7 above.

Figure 6: Bar chart of inundated vegetation types and wetlands at the flow rates of interest for the Goulburn

Lower Darling

For the Lower Darling region the CMS is examining a range of flows (9,000, 14,000 and 17,000ML/d), measured at Weir 32. The Lower Darling region inundation model is split into two zones, one which covers the main river and upper part of the Anabranch, and one which covers the lower part of the Anabranch.

Both zones shall be presented separately in this report. Figure 7 presents the maximum flow extent (17,000 ML/d) for zone 1 of the Lower Darling.

Zone 1

Figure 7: Extent of inundation for the maximum flow provided (17,000 ML/d) in the Lower Darling Zone 1
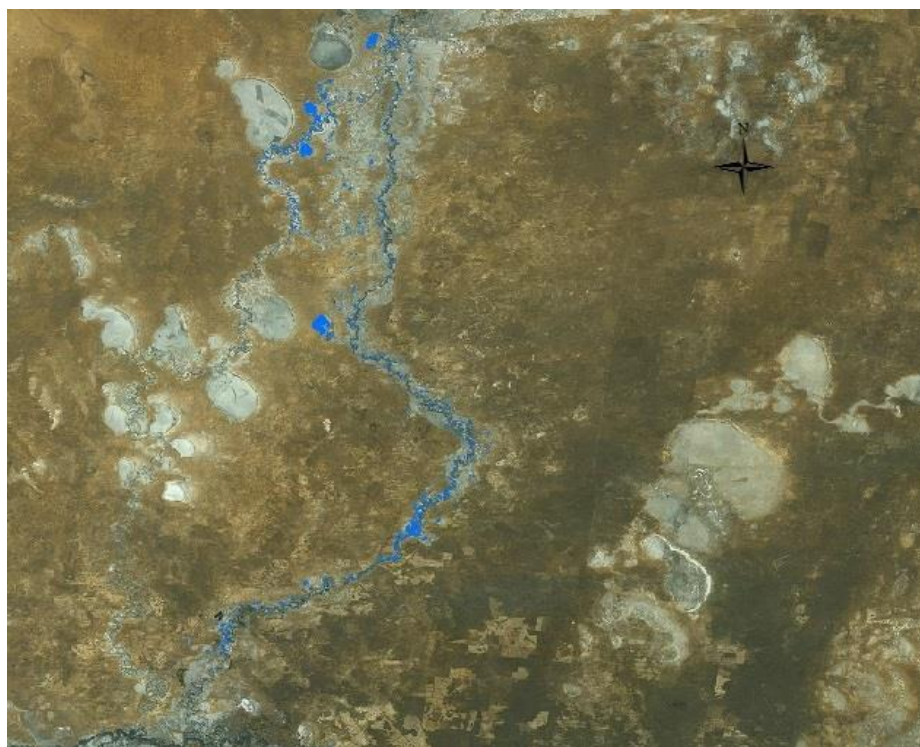
Figure 7: Extent of inundation for the maximum flow provided (17,000 ML/d) in the Lower Darling Zone 1

Table 9 details the flow rates of interest (measured at Weir 32), the total area inundated within the flow footprint and the total area inundated for the various vegetation types sampled and wetlands for Lower Darling zone 1.

Table 8: Flow rates of interest, total area inundated and area inundated for the sampled vegetation types and wetlands for Lower Darling Zone 1.

		Total Inundated Vegetation				
Flow Rate (Weir 32, ML/d)	Total Area Inundated (Ha)	Red Gum Woodlands (Ha)	Red Gum Forests (Ha)	Black Box (Ha)	Shrubs (Ha)	Wetlands (Ha)
9000	8234	188	521	2702	572	3338
14000	12561	217	660	4597	1188	5030
17000	16362	255	818	6463	1603	5848

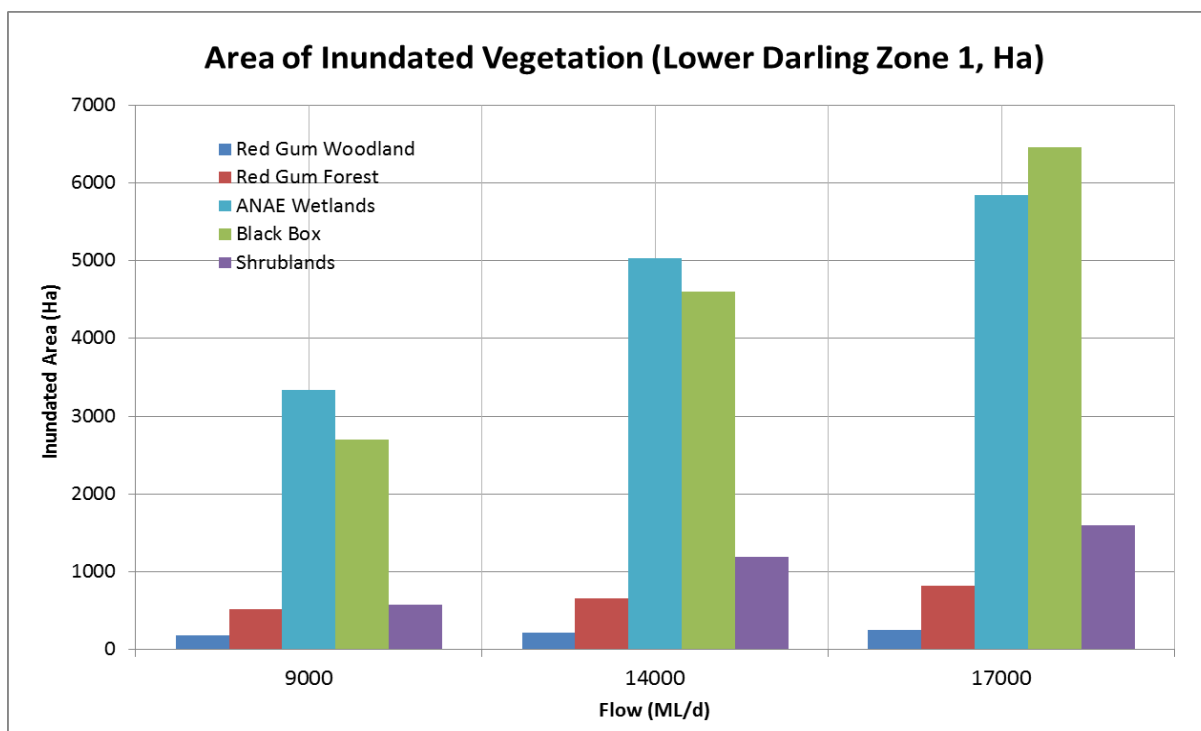Figure 8 presents a bar chart of the information presented in Table 9 above.

Figure 8: Bar chart of inundated vegetation types and wetlands at the flow rates of interest for Lower Darling Zone 1.

Zone 2

Zone 2 of the Lower Darling encompasses the same flows as per zone 1. Figure 9 presents the maximum flow extent (17,000 ML/d at Weir 32) for zone 2 of the Lower Darling.

Figure 9: Extent of inundation for the maximum flow provided (17,000 ML/d at Weir 32) in the Lower Darling Zone 2

Table 10 details the flow rates of interest (measured at Weir 32), the total area inundated within the flow footprint and the total area inundated for the various vegetation types sampled and wetlands for the Lower Darling zone 2.

Table 9: Flow rates of interest, total area inundated and area inundated for the sampled vegetation types and wetlands for the Lower Darling Zone 2.

Flow Rate (Weir 32, ML/d)	Total Area Inundated (Ha)	Total Inundated Vegetation				
		Red Gum Woodlands (Ha)	Red Gum Forests (Ha)	Black Box (Ha)	Shrubs (Ha)	Wetlands (Ha)
9000	12912	3	65	3535	739	11600
14000	16866	3	75	4419	843	14813
17000	23361	3	84	5505	1013	20254

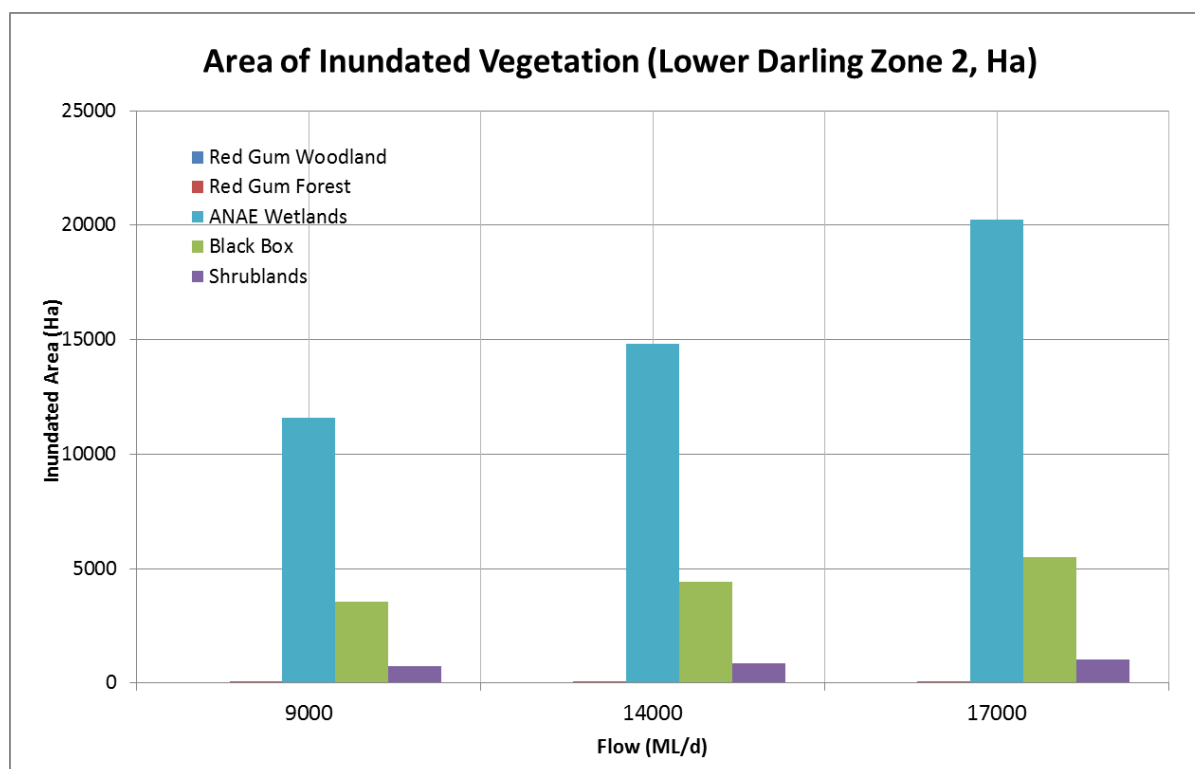Figure 10 presents a bar chart of the information presented in Table 10 above.

Figure 10: Bar chart of inundated vegetation types and wetlands at the flow rates of interest for Lower Darling Zone 2.

Upper Murrumbidgee

For the Upper Murrumbidgee the CMS is examining a range of flows (30,000, 40,000 and 48,500 ML/d), measured at Wagga Wagga. Figure 10 presents the maximum flow extent (48,500 ML/d) for the Upper Murrumbidgee.
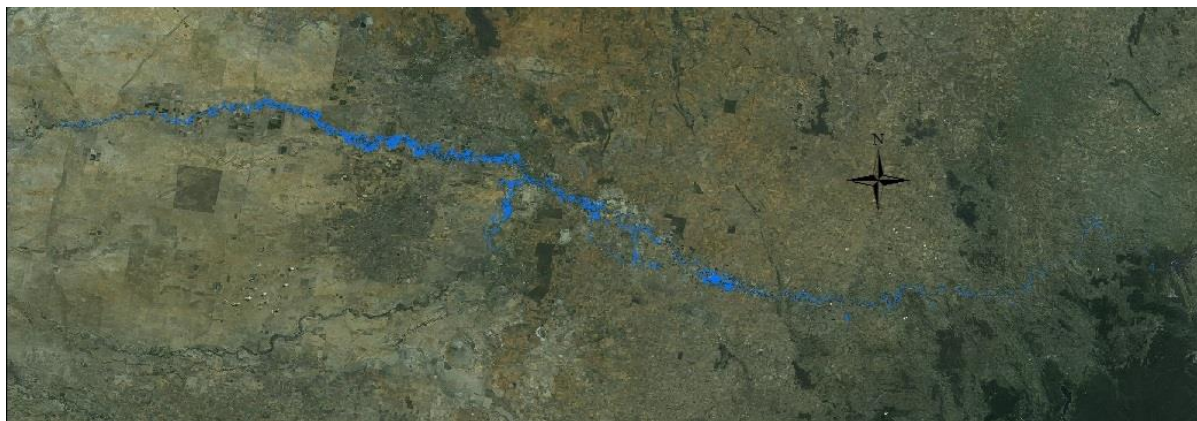

Figure 11: Extent of inundation for the maximum flow provided (48,500 ML/d at Wagga) in theUpper Murrumbidgee reach

Table 11 details the flow rates of interest (measured at Wagga Wagga), the total area inundated within the flow footprint and the total area inundated for the various vegetation types sampled and wetlands for the Upper Murrumbidgee.

Table 10: Flow rates of interest, total area inundated and area inundated for the sampled vegetation types and wetlands for the Upper Murrumbidgee.

| Flow Rate (Wagga Wagga, ML/d) | Total Area Inundated (Ha) | Total Inundated Vegetation | | | | |
		Red Gum Woodlands (Ha)	Red Gum Forests (Ha)	Black Box (Ha)	Shrubs (Ha)	Wetlands (Ha)
30000	15441	249	9760	717	167	6013
40000	28484	504	18163	1615	290	7705
48500	36560	612	22226	2120	427	8088

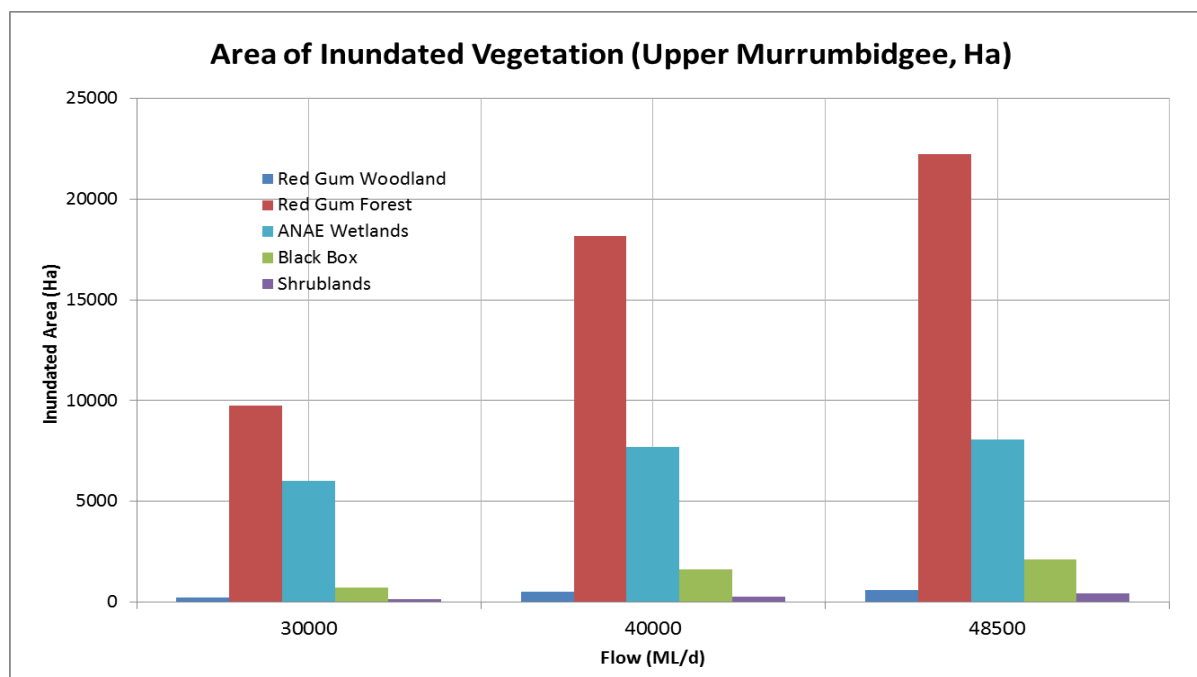Figure 12 presents a bar chart of the information presented in Table 11 above.

Figure 12: Bar chart of inundated vegetation types and wetlands at the flow rates of interest for the Upper Murrumbidgee.

Lower Murrumbidgee

For the Lower Murrumbidgee the CMS is examining a range of flows (20,000, 30,000, 40,000 and 48,500 ML/d), measured at Wagga Wagga. Figure 13 presents the maximum flow extent (48,500 ML/d) for the Lower Murrumbidgee.
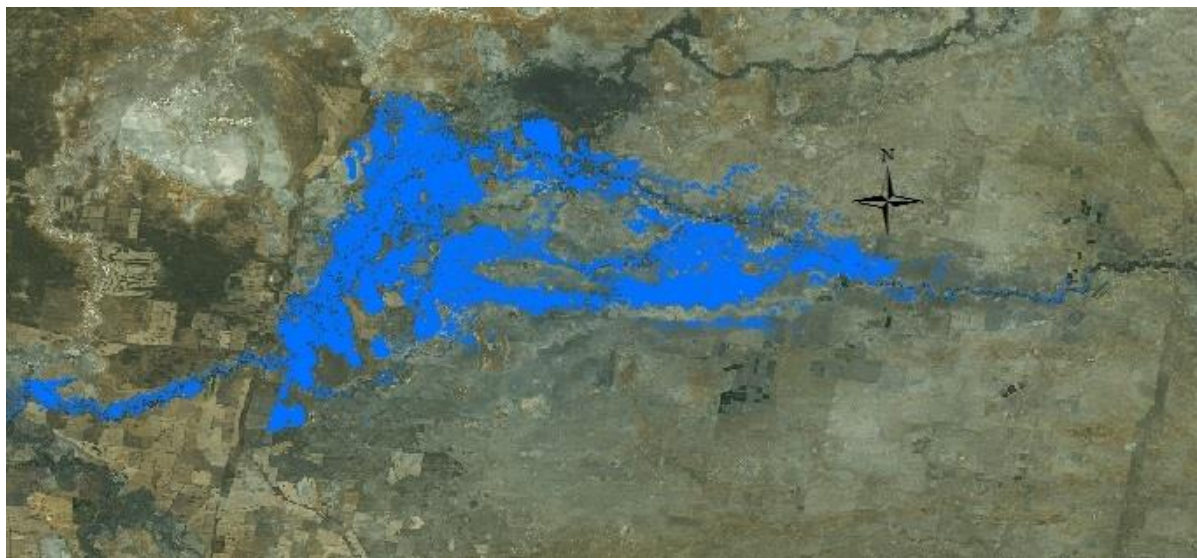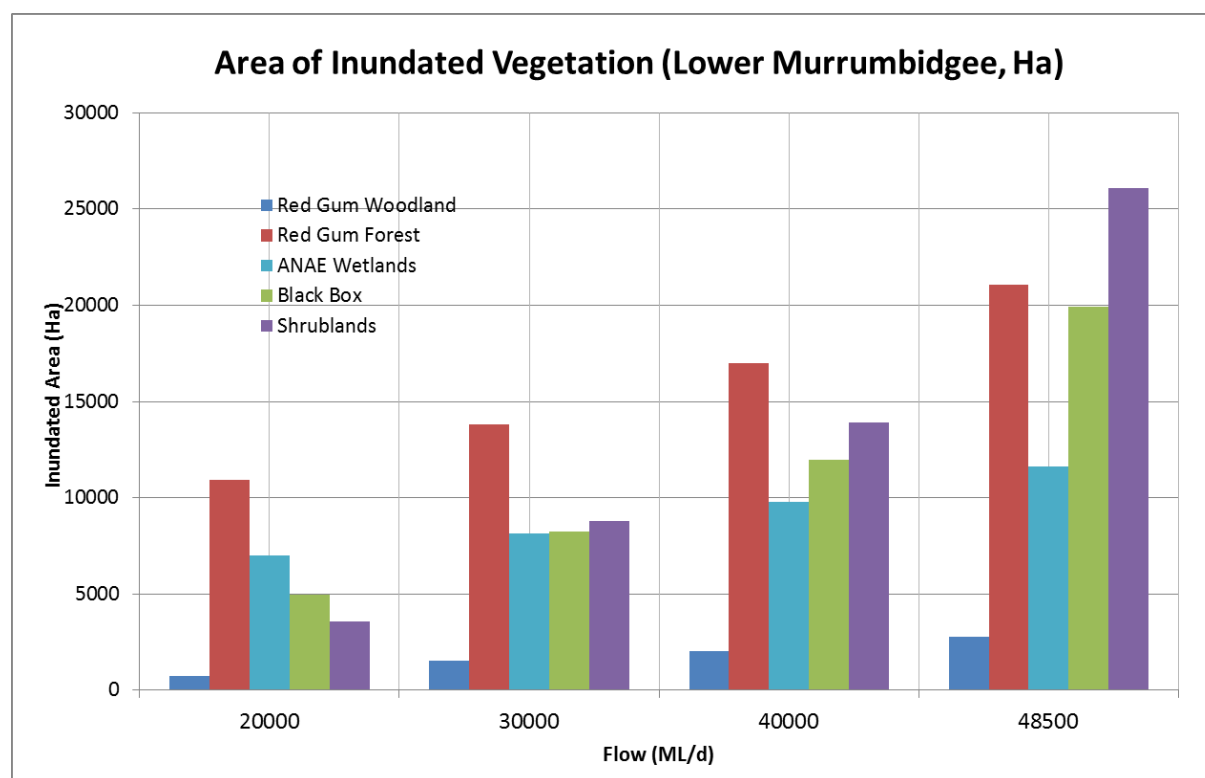

Figure 13: Extent of inundation for the maximum flow provided (48,500 ML/d at Wagga) in the Lower Murrumbidgee reach

Table 12 details the flow rates of interest (measured at Wagga Wagga), the total area inundated within the flow footprint and the total area inundated for the various vegetation types sampled and wetlands for the Lower Murrumbidgee.

Table 11: Flow rates of interest, total area inundated and area inundated for the sampled vegetation types and wetlands for the Lower Murrumbidgee.

| Flow Rate (Wagga Wagga, ML/d) | Total Area Inundated (Ha) | Total Inundated Vegetation | | | | |
		Red Gum Woodlands (Ha)	Red Gum Forests (Ha)	Black Box (Ha)	Shrubs (Ha)	Wetlands (Ha)
20000	**30059**	745	10916	4952	3569	7009
30000	**47455**	1511	13834	8239	8772	8148
40000	**66639**	2005	17009	11995	13916	9794
48500	**103205**	2756	21076	19944	26100	11641

Figure 14 presents a bar chart of the information presented in Table 12 above.

Figure 14: Bar chart of inundated vegetation types and wetlands at the flow rates of interest for the Lower Murrumbidgee.

South Australia

For South Australia the same inundation footprint and the same flows have been provided as analysed for the SDL Adjustment Mechanism. Figure 15 presents the maximum flow extent (125,000 ML/d, measured at the SA Border) for South Australia.

Figure 15: Extent of inundation for the maximum flow provided (125,000 ML/d) in the South Australia reach

Table 13 details the flow rates of interest (measured at the SA Border), the total area inundated within the flow footprint, and the total area inundated for the various vegetation types sampled and wetlands for South Australia from the border to the Lower Lakes.

Table 12: Flow rates of interest, total area inundated and area inundated for the sampled vegetation types and wetlands for South Australia from the border to the Lower Lakes.

		Total Inundated Vegetation				
Flow Rate (SA Border, ML/d)	Total Area Inundated (Ha)	Red Gum Woodlands (Ha)	Red Gum Forests (Ha)	Black Box (Ha)	Shrubs (Ha)	Wetlands (Ha)
40000	**45138**	271	1250	2769	2772	38333
60000	**64258**	964	2426	8244	9254	42652
80000	**116117**	1995	4009	26896	29159	48801
100000	**143854**	2299	4452	40812	38256	50750
125000	**151116**	2370	4565	45157	40095	51029

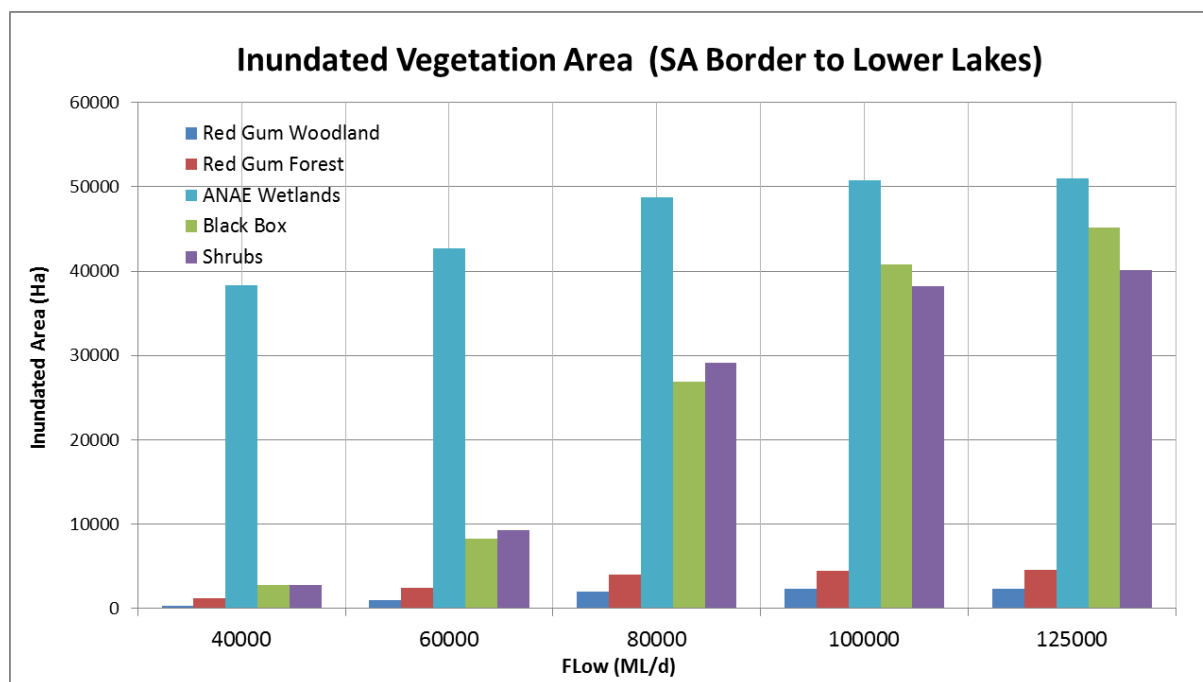Figure 16 presents a bar chart of the information presented in Table 13 above.

Figure 16: Bar chart of inundated vegetation types and wetlands at the flow rates of interest for South Australia from the border to the Lower Lakes.

Summary and Data Overview

This report presents the results of analysis to determine the areas of inundated vegetation for six of the seven key focus areas of the Constraints Management Strategy, using flood inundation extents, and intersecting with the vegetation and wetland layers originating in the Ecological Elements project, developed for use in the SDL Adjustment Mechanism.

This work helps explore the environmental benefit of relaxing constraints in the Murray, Lower Darling, Goulburn and Murrumbidgee catchments, using CMS flows of interest and existing MDBA relaxed constraints model scenarios, and will aid in future work to prioritise constraints in the Southern Connected System.

Appendix C: Building an 80,000 ML/d Event: High Flow Hydrology in the Southern Connected System

Introduction

Flow events exceeding 80,000 ML/d at the South Australian border provide important environmental outcomes. These events inundate the mid-to-high level floodplain in the lower reaches of the River Murray, providing water for vegetation such as river red gum and black box. Flow regulation has reduced the frequency of such high flow events significantly. As a result, large sections of the floodplain habitat are transitioning from flood-dependent vegetation (e.g. black box woodland) to flood-tolerant communities (samphire and chenopod shrublands).

The Basin Plan seeks to re-instate the ecologically significant components of the flow regime. However, flow events peaking at 80,000 ML/d are beyond current regulating capacity. Constraints in the river system (e.g. operating rules related to channel capacities) limit the rate at which water can be released from headwater storage.

Flow events of 80,000 ML/d at the SA border are relatively rare and almost always require the combination of flows from multiple valleys. This document outlines the hydrology underlying 80,000 ML/d flow events and quantifies the contribution provided by each of various regions, under natural (i.e. without development), current (i.e. pre-Basin Plan) and Basin Plan conditions. The regions studied were:

- Upper Murray (DS Yarrawonga Weir),
- Goulburn (McCoy's Bridge),
- Murrumbidgee (Balranald), and
- Lower Darling (Weir32).

The analysis concentrates on the flow conditions required for an 80,000 ML/d event to be successful, and an investigation into how each region contributes to such an event, through analysis of both flow threshold and flow duration. A discussion then follows on the way in which an 80,000 ML/d event could be built operationally and the effect of relaxing constraints on successful flow delivery with subsequent prioritisation.

River Operators Workshop

A similar study was the centrepiece of the Experienced River Operators Workshop held in April 2012. This workshop discussed the delivery of flow events in the range of 50,000 – 80,000 ML/d to the Lower Murray. The associated report (MDBA 2013) provides a detailed description of the hydrology of the Southern Basin, and provides some examples of historical flow events which could have been supplemented through additional releases to achieve the desired flow at the SA Border. The workshop provided some key findings, the first three of which are:

- Significant inflows are required from *at least* 3 of the 4 major valleys (the Upper Murray, Goulburn, Murrumbidgee, and Lower Darling) for the target events to occur downstream of Euston.
- The target events tended to be the culmination of multiple events (or peaks) across multiple valleys, as opposed to a single event originating in one valley. The initial events

pre-wet, or "prime" the upstream wetlands, forests and floodplains, so that subsequent events pass through more quickly and with less "loss".

- Accordingly, the volume of inflow over multiple events is as important as the peak flows in generating the target event.

The workshop also identified strong correlations between flow rates and volumes of the regions and the target event. The work described here further investigates these correlations.

Average Region Contribution: Peak Flows

Custom-built software (FreshFind) was used to detect distinct flow events in each of the four regions, and to match these with subsequent events in the Lower Murray. Figure 16 shows the relationship between total peak flow from all four regions and the subsequent flow at the SA border, for 137 matched events which led to a flow of at least 40,000 ML/d at the SA border.

Figure 16 shows that to achieve a specific flow at the SA Border, on average the tributaries would need to have combined peak flows of twice that amount. Hence a typical combined peak flow from all four regions of approximately 160,000 ML/d would be necessary to result in a flow of 80,000 ML/d at the SA border. This is due to significant flow attenuation and the natural misalignment of contributory peak flows from the four regions. The analysis shows that an 80,000 ML/d event at the SA Border requires a *minimum* combined tributary peak flow of 110,000 ML/d — this represents the near-perfect alignment of events from the four tributaries.

The results from all three analysed model scenarios are shown in the figure, and all display the same trend. For each event, unregulated flows have provided a significant component of the SA Border flow. Higher flow events (i.e. those in the range 60,000 – 80,000 ML/d) display a significant reliance on unregulated flows, and hence cannot be formed through regulated releases only.
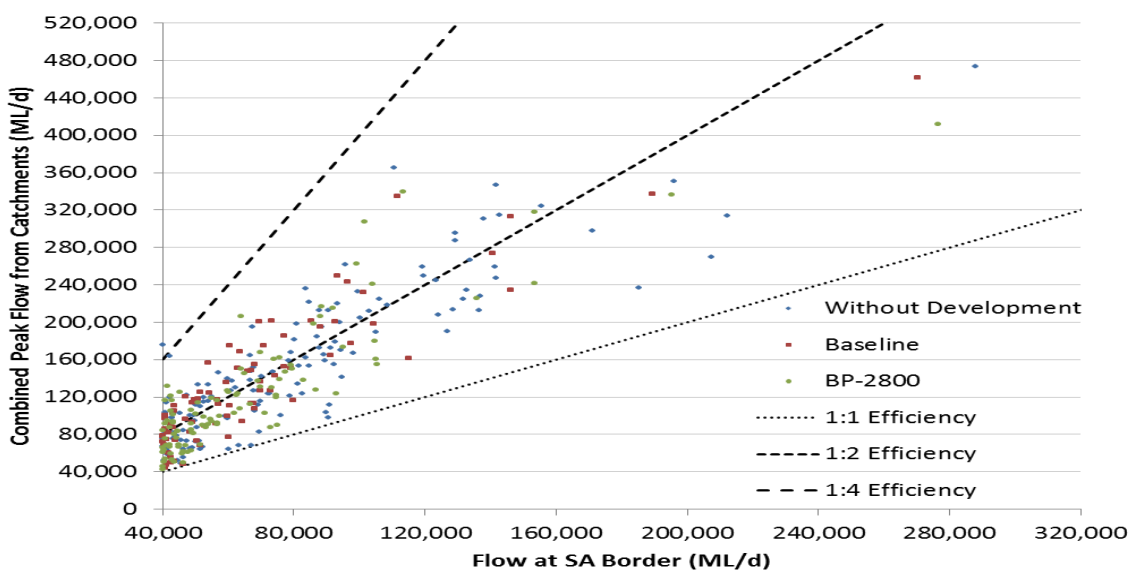

Figure 17: The relationship between combined peak flow from all four regions and the resulting flow at the SA border. A "1:2 efficiency" describes the data well, that is the required combined peak flow is twice that required at the SA border.

Figure 17 shows, for the same flow events presented above, the average contribution each of the four regions makes to peak flow (left panel) and duration (right panel) at the SA border. It can be seen that the Goulburn and Upper Murray contribute the bulk of the peak flows whereas the Murrumbidgee and Lower Darling play a much larger role in delivering the required volume of flow. This is true for all model scenarios analysed.
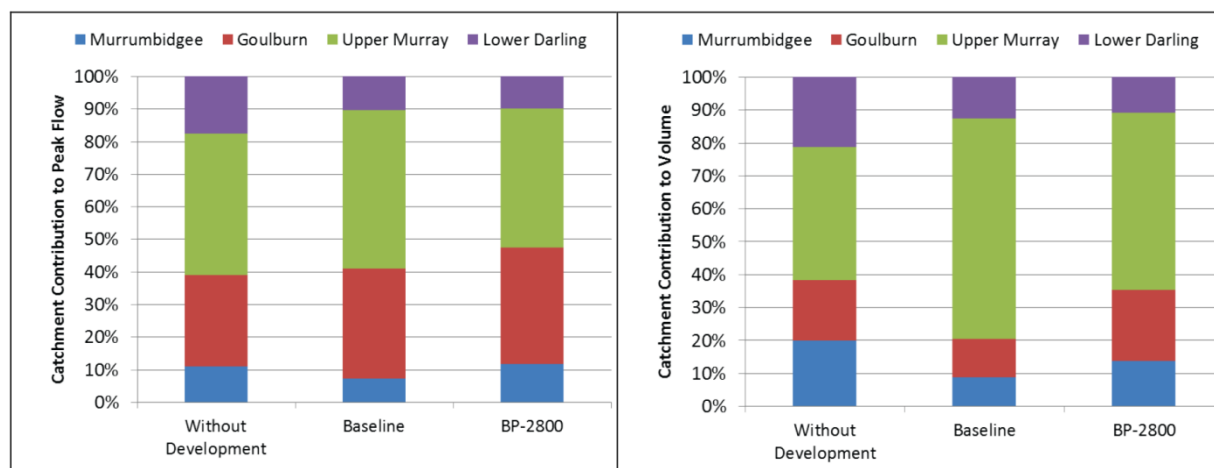

Figure 18: Average contribution of each region to peak flow (left panel) and volume (right panel) for all flow events plotted above.

Relaxing Constraints: The Effect on 80,000 ML/d Flow Delivery

Each of the four regions analysed have a distinct hydrological character, which results in a specific overall contribution to a downstream flow event. This is revealed in their average contributions to both peak flow and duration as presented in Figure 17.

To investigate this interdependency further, for each region in turn, the relationship between peak flow for that region and resulting flow at the SA border was determined. In other words, what is the probability that a particular peak flow from a particular region will lead to an event of ≥60,000 ML/d at the SA border? Similarly, the distribution of event durations from each region was determined.

This peak flow and duration analysis reveals specific parts of the flow regime for each region which has a large bearing on the successful delivery of a high flow event at the SA border. The current operational constraint for that region can hence be discussed in this context, along with advice on how relaxation of that constraint can affect high flow delivery at the SA border. The following subsections deal with the peak flow correlations for each region in turn. Durations are discussed in the following section.

Upper Murray

Figure 18 shows the probability relationship between peak flow measured downstream of Yarrawonga Weir with flow events of ≥60,000 ML/d at the SA border. The way in which increased peak flow at Yarrawonga results in a higher probability of achieving the flow target is clear, with the relationship being linear for all three model scenarios analysed.

Also plotted (shaded areas) are the current operational constraints for this region of the Murray (25,000 ML/d and the more recent 15,000 ML/d) as well as the range of constraint levels under

consideration by the Constraints Management Strategy (CMS). A flow limited to 15,000 ML/d in the Upper Murray results in only a ~18% chance of contributing to a successful event at the SA border — the target Lower Murray flow would only then be achieved if large flows are provided from the other three regions. In contrast, a flow of 40,000 ML/d provides a ~55% chance of achieving the desired Lower Murray flow, and a flow of 77,000 ML/d, when combined with unregulated flows from downstream tributaries, is almost certain to achieve the target flow.

The dotted line defines the point where improvements become more marginal with any additional flow. For the Upper Murray, this point is at 65,000 ML/d.
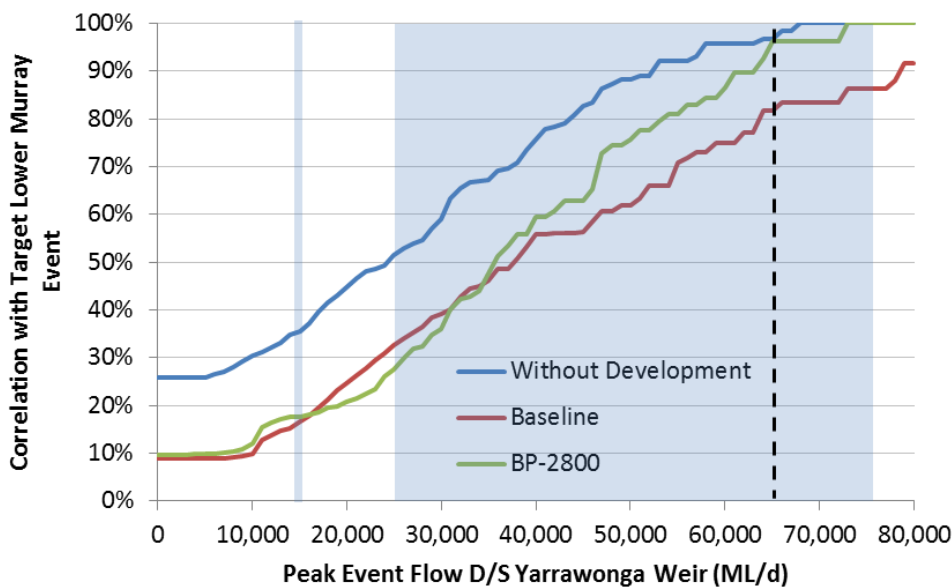

Figure 19: The correlation between peak flow (measured D/S Yarrawonga Weir) to ≥60,000 ML/d SA border events. Current constraints (25,000 ML/d and the recent 15,000 ML/d) and the CMS constraint range are shaded.

Murrumbidgee

Figure 19 shows the probability relationship between peak flow measured at Balranald with flow events of ≥60,000 ML/d at the SA border. It can be seen that an increase in Balranald flow from 9,000 ML/d to 10,000 ML/d leads to a significant increase in probability of the Murrumbidgee to contribute to a successful high flow event at the SA border. This increase continues at a lower rate to a flow of 18,000 ML/d (marked by the dotted line), beyond which additional benefit becomes marginal.

Basin Plan modelling attempts to deliver water for several environmental requirements, including internal tributary and downstream requirements, increasing the frequency of all flows in the tributaries, and not only flows that deliver high flow events at the SA border. As such the timing of flow peaks are very difficult to perfectly align. The net result of this is to lower the overall probability for BP-2800 when compared to models that do not include active environmental watering. Hence for the Murrumbidgee (and Goulburn), the BP-2800 probability numbers for low to mid flow regimes appear lower than under without development and baseline conditions.

Generally, under current conditions, the Murrumbidgee region cannot provide significant peak flows to the Murray, and it plays a much larger role in total volume delivery than flow threshold, as seen in the following section. The restoration of natural hydraulic behaviour in the Nimmie-Caira region

has the ability to increase the peak flow contribution from the Murrumbidgee. However, the Nimmie-Caira buyback is only expected to change the flow contribution from the Murrumbidgee during large unregulated flow events, beyond the range under consideration of the CMS.
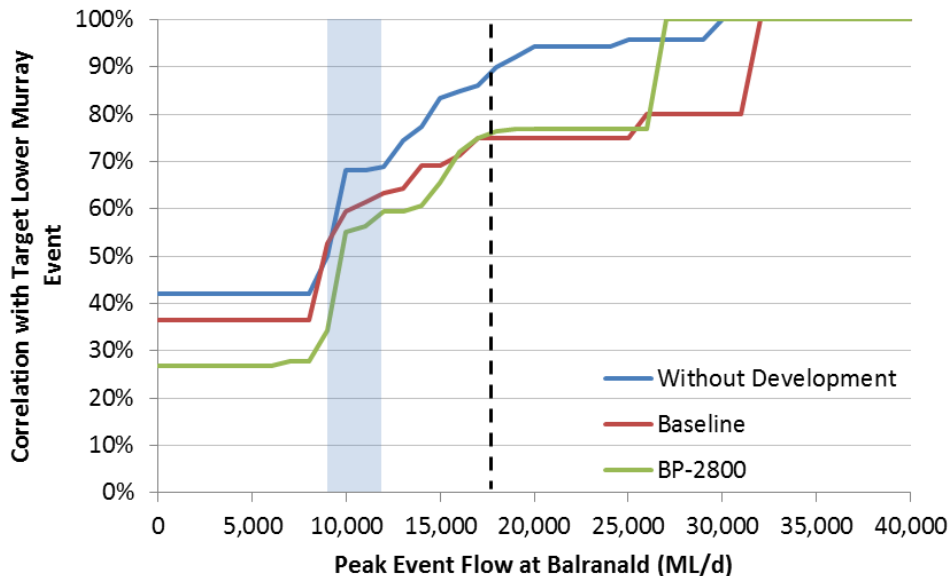

Figure 20: The correlation between peak flow (measured at Balranald) to SA border events of ≥60,000 ML/d. Current constraints (9,000 ML/d) and the range of constraint considered by the CMS are marked as a shaded area.

Goulburn

Figure 20 shows the probability relationship between peak flow measured at McCoy's Bridge with flow events of ≥60,000 ML/d at the SA border. An increase in McCoy's Bridge flow leads to an approximately linear increase in probability of the flow contributing to a successful high flow event at the SA border. Typical numbers are an increase in probability of ~45% to ~60% (for BP-2800) within the range of constraints the CMS are considering. The point at which additional benefit becomes more marginal is defined by the dotted line (60,000 ML/d).

Goulburn flow correlation behaviour is very similar to that seen in the Upper Murray.
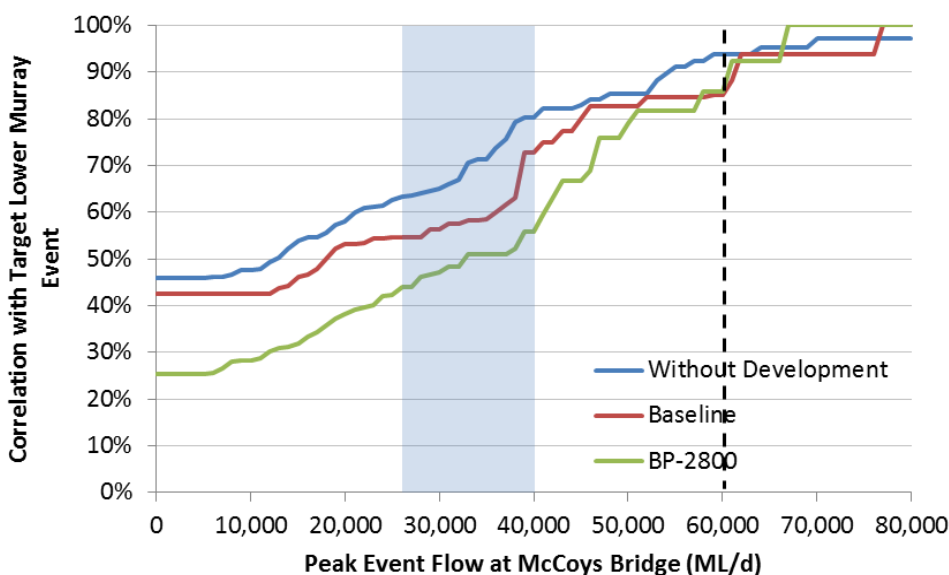

Figure 21: The correlation between peak flow (measured at McCoy's Bridge) to SA border events of ≥60,000 ML/d. The range of constraints considered by the CMS is marked as a shaded area.

Lower Darling

Figure 21 shows the probability relationship between peak flow measured at Weir 32 with flow events of ≥60,000 ML/d at the SA border. The Lower Darling displays behaviour similar to that seen in the Murrumbidgee, where a 9,000 ML/d flow defines the point where the correlation with a high flow at the SA border starts to increase.

The correlation increases further to 30,000 ML/d, from that point only marginal improvement are seen for any further increased flow (marked by the dotted line). Flows become exceedingly large in the Lower Darling under regulated flow conditions.

These higher flows originate in unregulated flows from the Northern basin. Those few events in the modelled record (including a flow of 113,000 ML/d in 1951) always lead to a high correlation with the required flow at the SA border.
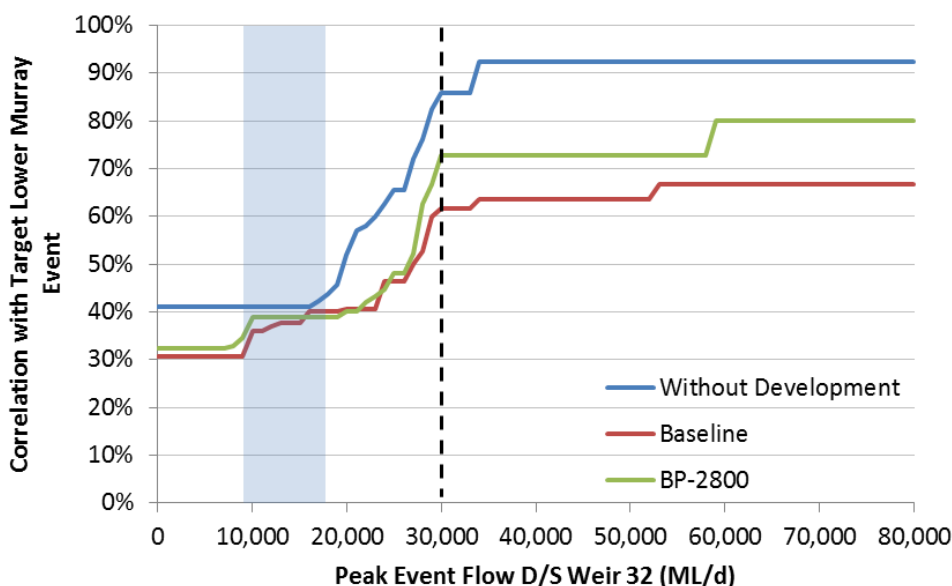

Figure 22: The correlation between peak flow (measured at Weir 32) to SA border events of ≥60,000 ML/d. The range of constraints considered by the CMS is marked as a shaded area.

Duration

Duration information is a by-product of the method applied to match flow events, and is the second piece of information to the differing hydrological character of the four regions analysed. Due to way in which the Freshfind algorithm operates, durations presented are those which apply to the entire flow event which was matched, hence includes the rise and fall of the hydrograph.

Figure 22 presents the duration distribution of all flow events for all four analysed regions which lead to events of ≥60,000 ML/d at the SA border. Two types of hydrology are clear.

- Short-to-medium duration:
  Both the Upper Murray and Goulburn regions provide shorter duration contributions to flow events at the SA border. The Goulburn is known to be a region which typically contributes short, high peak flow events. For the Upper Murray, the greatest number of

flow events which contribute to a high flow event at the SA border have durations of 40 – 60 days. For the Goulburn this occurs for flow events of duration 20 – 40 days. (These durations include the rise and fall periods of the flow event.)

Flow events of longer duration in these two regions are the result of large unregulated events, and are not part of the actively-managed flow regime considered.

- Long duration:
Both the Murrumbidgee and Lower Darling regions have a duration distribution which is indicative of long duration events playing a significant role in delivering high flow events to the SA border. That is, they both provide a significant channel filling role and hence for these two regions, the total volume of flow delivery is more important than flow threshold when attempting to deliver a high flow event.

For the Murrumbidgee, the greatest number of flow events which contribute to high flow events at the SA border have durations typically in the ~50 – 100 day range, with some events lasting up to ~250 days. Again, events of extreme long duration result from large unregulated flows (seen strongly for without development).

For the Lower Darling, the duration distribution peaks at relatively long flows (of the order ~20 to ~100 days). Single outlier events are seen at very long durations (~200 days), which reflect the ability of the Lower Darling to deliver significant flow resulting from high rainfall events in the Northern Basin. Such events are considered beyond the range of deliverability through any managed process. The Lower Darling plays a large role in helping deliver the volumes required for flow delivery to the SA border rather than peak, a similar result to that seen in the Murrumbidgee.
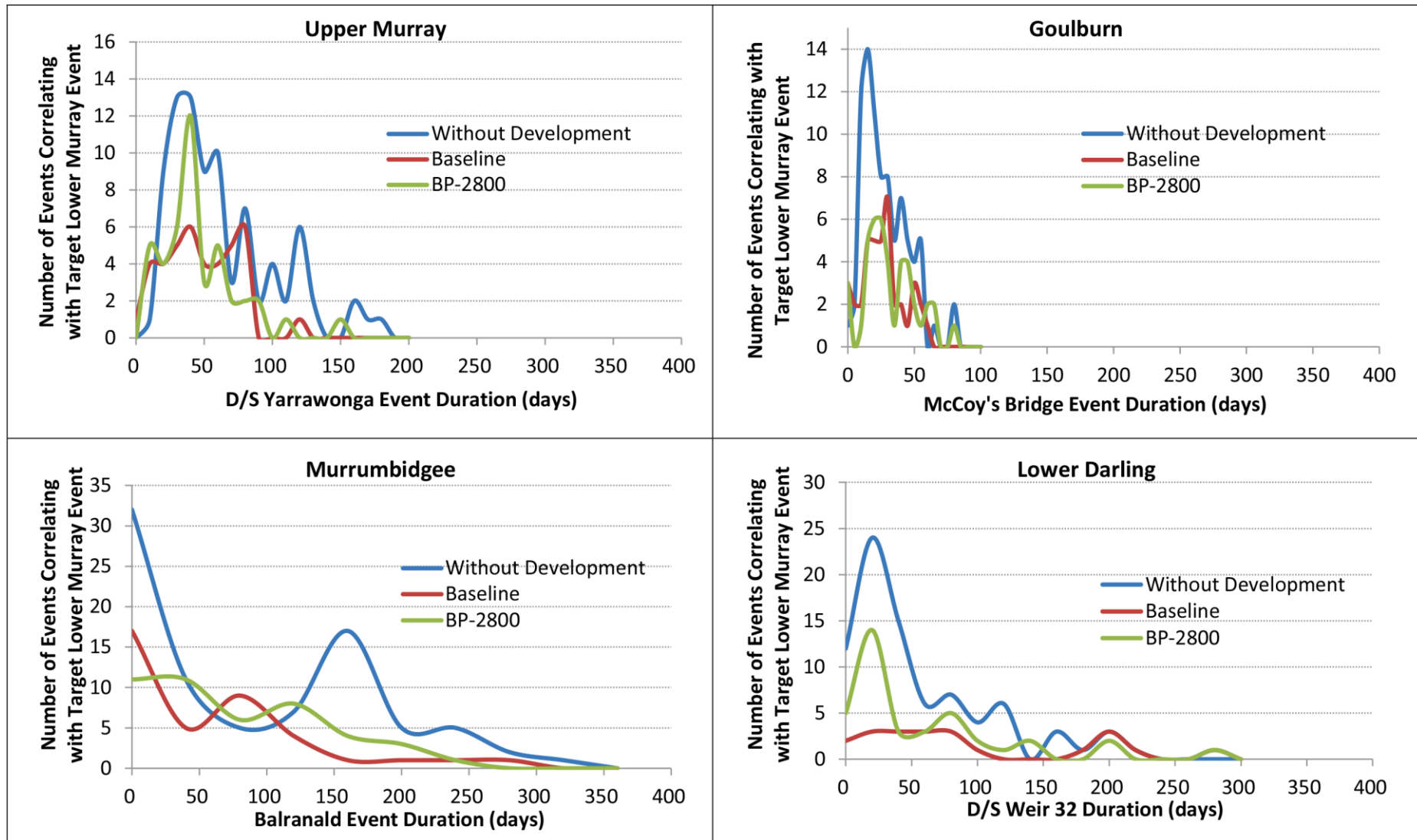
Figure 23: The duration distribution of all events in all four analysed regions leading to flows of ≥60,000 ML/d at the SA border.

Operationally Building an 80,000 ML/d Event

Deliberately managing the river system to provide a flow of 80,000 ML/d at the South Australian border is a significant challenge. A simple summation of current flow limits indicates that the desired flow in the Lower Murray requires an unregulated component. Therefore at least one of the four main regions must be experiencing unregulated flows to produce the desired event.

This was demonstrated in Section 1, showing that flows from all four regions in the range 150,000-160,000 ML/d are required to produce very good prospects of successful delivery.

Additionally, releases must be made from storage to supplement the unregulated flow, requiring a strategy to ensure cross-region cooperation. This could be undertaken with an agreed 'trigger' at which storage releases would be made.

The analysis presented here has shown the general contributions each region makes when a high flow event occurs at the SA border. It also allows advice to be given, from the hydrological character of the contribution, about how each region can be actively used to maximise the chance of delivering such an event, assuming significant unregulated flow conditions are occurring.

The regions occupy two categories:

- **Category 1 — Limited Benefit – Murrumbidgee and Lower Darling**
  The Murrumbidgee and Lower Darling both show very similar behaviour when contributing to a target event. Both show limited improvement in the probability if the constraints are raised to the levels considered by the CMS; the greatest contribution is made through volume rather than flow peak.

  These two regions perform a channel-filling role that can largely be met by in-channel flows over a period of months — the correlation for these systems is strongest when measured against *volume* rather than flow. For these regions, flows have the greatest chance of success when occurring over 50 – 100d and 20 – 100d durations for the Murrumbidgee and Lower Darling respectively.

  Peak Murrumbidgee flows display a significant increase near 9,000 ML/d. This represents bank-full at Balranald, and is achieved during wet conditions when the LowBidgee Floodplain has been saturated (which may occur more frequently as a result of the Nimmie-Caira purchase). The analysis indicates that the channel-filling role can be achieved with flows of 9,000 ML/d, and there is increased benefit if the peak flow is increased to 12,000 ML/d, with additional incremental benefit occurring to a flow rate of 18,000 ML/d. Flows beyond this produce only marginal increases in outcome.

  The Lower Darling has similar behaviour, although significant improvements are seen for flows up to 30,000 ML/d.

- **Category 2 — Measurable Benefit – Upper Murray and Goulburn**
  The Upper Murray and Goulburn both have a linear improvement with flow, indicating that constraints relaxation in these systems results in a measurable increase in the delivery of

target events to the Lower Murray. Virtually all successful events in the model scenarios required significant flows from at least one of these two regions.

Duration distribution does not have as great an impact on flow deliverability, that is flows from these two regions do not need to occur for as long as the Murrumbidgee and Lower Darling. Typical duration values maximise the probability of successful flow delivery at 40 – 60d and 20 – 40d for the Upper Murray and Goulburn respectively.

Figure 23 shows a schematic representation of the way in which each of the four regions contributes to the delivery of a successful high flow event at the SA Border, with flow thresholds and durations for each.

The way in which the long duration low flow threshold contributions of the Murrumbidgee and Lower Darling make up the bulk of the base-flow is clear. The Upper Murray contributes the bulk of the overall event, a supporting role which defines the shape, and the Goulburn contributes to building the peak.
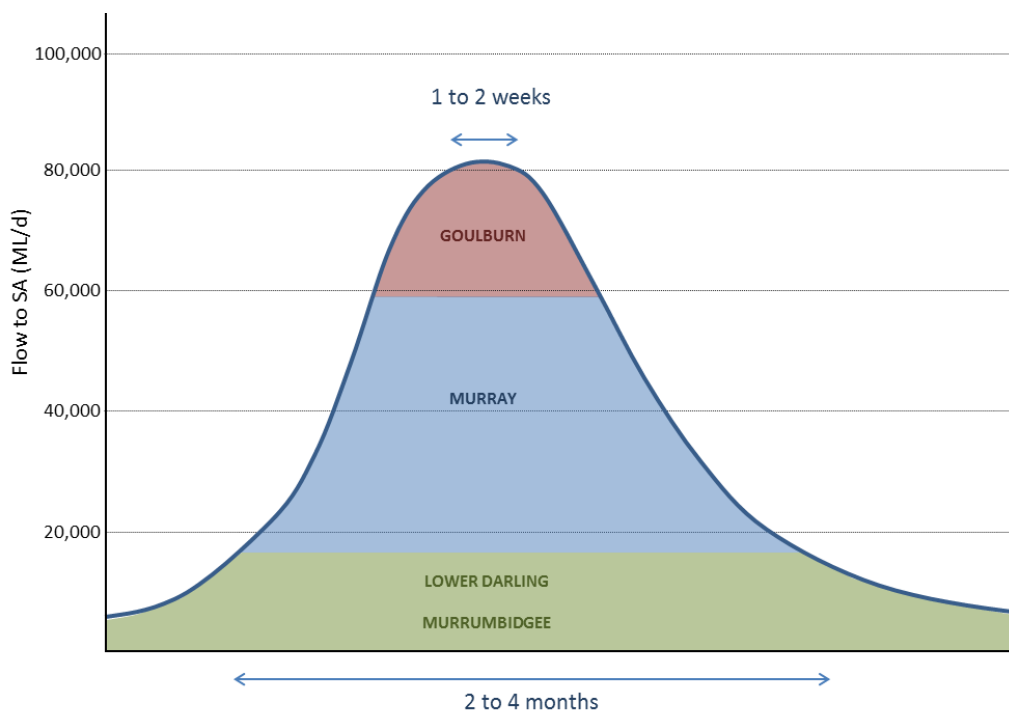

Figure 24: Indicative contribution (typical peak flow and duration) from each of the four regions to building an 80,000 ML/d event at the SA border.

To operationally build such an event, the probability of success is greatly increased if flow conditions have the following general properties. Note however the total volumes of water required are very large, they cannot be delivered purely from regulated releases. The Upper Murray and Goulburn are the drivers of the event, and must be experiencing unregulated flows for successful flow delivery to be maximised.

Table 14 summarises the flow conditions for each region which maximises the probability of event delivery, the point at which additional flow produces only marginal benefit, defined as dotted lines in Figure 18 to Figure 21. They are listed in order of priority to achieve those aims described above.

Table 13: Flow thresholds and durations required to maximise the chance of delivering a ≥60,000 ML/d event to the SA border, based on modelled successful events, in order of priority to successful flow delivery.

Overall Priority	Region	Flow (ML/d)	Duration (d)	Chance of correlation with ≥60,000 ML/d SA border event
1	Upper Murray	65,000	~40 – 60	95%
2	Goulburn	60,000	~20 – 40	85%
3	Lower Darling	30,000	~20 – 100	70%
4	Murrumbidgee	18,000	~50 – 100	75%

In comparison the flows considered by the CMS produce a 55%, 55%, 40% and 60% chance of correlating with a ≥60,000 ML/d SA border flow event for the four regions respectively. These percentages indicate that it is possible to achieve the target event in the Lower Murray with the CMS-identified flows, but only if flow management between the tributaries is carefully coordinated.

Summary

This report presents results of analysis into the hydrological character of the Upper Murray, Goulburn, Murrumbidgee and Lower Darling, specifically their ability to deliver high flow events (of ≥60,000 ML/d) to the SA border.

Basin Plan modelling (Without-Development, Baseline and BP-2800) was analysed to determine the events that successfully occurred in 114 years of hydrograph. The total overall contribution each region made to each of those events was determined in detail. Recommendations were then made on how to best maximise the chance of event delivery. It was also possible to outline the improvement in flow delivery resulting from flows considered by the CMS.

Flow volumes required are very high, significant unregulated flow from at least one region is required for maximising the chance of successful flow delivery. For each region in turn (in order of priority for successful flow delivery):

- **Upper Murray:** This region is usually the dominant contributor to a target event in the Lower Murray providing the bulk of flow and determining the event shape. The characteristics of the Lower Murray flow can usually be directly correlated with those in the Upper Murray. An increase in flow leads to a linear increase in the probability of a successful event.

- **Goulburn:** Has a similar effect as the Upper Murray. However, contributory flows have a relatively short duration (i.e. a few weeks) but a high peak. Flows from this region are usually required to provide the 'cap' for the Lower Murray event. As for the Upper Murray, an increase in flow in the Goulburn leads to a linear improvement in the chance of a high flow event being successful at the SA border.

- **Murrumbidgee & Lower Darling:** Flows from these regions usually have a relatively low peak but long duration. These regions perform a 'channel-filling' role in which the foundation for a higher flow event is provided by long events lasting two to four months. Large improvements in the chance of the event being successful are seen for increased flow, up to a clear break point with limited improvements beyond.

Appendix D: Approaches used to estimate mitigation costs

Estimates of the costs of easements with landholders

The costs of easements were estimated using a model developed by GHD. This model considered how changes in the flow regime would affect the worth of the affected land. It took into account in particular the impacts of different flow scenarios on agricultural activities.

The method essentially modelled how changes in flows would affect agricultural activities, and from that, derived an estimate of the costs of easements.

Key inputs to the model included inundation maps corresponding to specified flow rates; spatial data on different land uses; hydrological data relating to "baseline" and "CMS" flow regimes; and data on land worth and gross margins.

The modelling was undertaken at a regional scale. During the feasibility phase, if it is decided that easements should be pursued as a mitigation option, more detailed work would be undertaken including for a sample of landholders at a property by property level.

Estimates of the costs of infrastructure works

The costs of infrastructure works were estimated using a model developed by URS Australia. This model assumed that "unit rates" can be used to estimate the costs of infrastructure work on most structures – e.g. roads, bridges, crossings.

Recognising that "unit rates" cannot be used to estimate the costs of some more specific works that may be required (e.g. upgrades to regulators), URS estimated those costs separately.

For the purposes of pre-feasibility cost estimates, URS made some broad informed assumptions regarding the types of actions that would be appropriate to deal with specific impacts – for example what types of bridge or road works would be required.

Key inputs to the model included inundation maps corresponding to specific flow rates; spatial data on the location and specifications of infrastructure (e.g. roads, bridges, crossings); hydrological data relating to "baseline" and "CMS" flow regimes; and data on the "unit rates" associated with different infrastructure works, drawing on accepted industry references (e.g. Rawlinson's Australia Construction Handbook).

The modelling was undertaken at a regional scale. During the feasibility phase, if it is decided that infrastructure works should be pursued as a mitigation option, more detailed work would be undertaken.

Further details of the approach used to estimate the costs of mitigation activities are in a separate Cost Estimates Report.