Chapter 8

Implications of changes in climate for water availability and flooding regimes

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8.1 Overview

The river red gum forest ecosystems and the floodplains of the Riverina bioregion are already adjusting to the long-term impacts of river regulation and water extraction for irrigation, as well as a shift from winter/spring flooding to predominantly summer flooding. In addition, there has been natural variability in rainfall. The period since the 1950s although generally wetter than the 1900-1949 period saw a substantial reduction in the frequency, duration and magnitude of floods.

The current drought and future climate variability and predicted climate change will further reduce water availability for the majority of river red gum forests across the bioregion. Successful water reform will moderate this reduction if it can reduce water extraction by establishing sustainable diversion limits and return water to these over-stressed rivers.

This chapter supports Step 3 of the analytical framework by:

- outlining the characteristics and water requirements for each water management unit (WMU) and the forests associated with them
- assessing future water availability and flooding regimes under different climate scenarios
- assessing the likely impacts of future water availability for the forests
- discussing the dependence of the forests on groundwater.

The key findings of this chapter are:

- River regulation has fundamentally changed the flow regimes of the major rivers in the bioregion. The future health of the river red gum forests depends fundamentally on the success of COAG water reforms in restoring water to these stressed and over-allocated floodplain river ecosystems.

- A further substantial reduction in the magnitude, frequency and duration of floods can be expected under climate change for the majority of forest stands, particularly the larger forests of Millewa, Koondrook-Perricoota and Werai. Large ‘landscape restoration’ floods are unlikely to occur. However, the delivery of environmental water to the Millewa forests and intervention works at Koondrook-Perricoota will assist in maintaining some moderate-sized floods.

- A further reduction in flood extent, duration and frequency can also be expected under climate change for forest stands associated with the Murrumbidgee and Lachlan Rivers, and riparian zones along the Edward, Wakool and Murray Rivers downstream of the Koondrook-Perricoota forests.

- The forests along the upper Murray River are more resilient as local rainfall towards the east is comparatively higher and may increase. These forests can also access local shallow groundwater systems recharged by river levels kept high during summer to supply water for irrigation.

- Some river red gum communities are likely to be highly dependent on groundwater. There is evidence that river red gums in the Riverina bioregion use groundwater opportunistically as a water source in prolonged dry periods and times of water scarcity. Flooding is a significant recharge mechanism in some areas of the bioregion.

8.2 River regulation in the Murray-Darling Basin

As discussed in Chapter 2, the river red gum forests and associated ecosystems of the Riverina bioregion have developed as a result of the long-term, geomorphic evolution of the landscape and its associated flooding regimes.

River regulation has dramatically changed the flow regimes of the major rivers in the region. It is estimated that the total public storage in the Murray-Darling Basin’s larger storages (>10GL) is approximately 24,500 GL (GHD, 2009). This storage volume equates to approximately twice the average annual discharge of the Murray-Darling. The total annual flow at the River Murray mouth has been reduced by 61 per cent and the river now ceases to flow through the mouth 40 per cent of the time, compared with 1 per cent prior to water resource development (CSIRO, 2008a).

Table 8.1 shows the reductions in current flows compared with natural flows across all the major rivers in the basin.

The development of these storages and the water that is being extracted has greatly affected the natural flow and flooding frequency of rivers throughout the MDB. For example,
Chapter 8: Implications of changes in climate for water availability and flooding regimes

an 18,300 ML/day flood at Yarrawonga weir on the Murray occurred every 1.1 years in the pre-development (no regulation) flow history. That level of flood only occurs once every 2.6 years under current development conditions.

These systems are likely to decline further in health under climate change predictions. For example, modelling of the future flow regime for the CSIRO Murray-Darling Basin Sustainable Yields (MDBSY) Project using the best-estimate (median) 2030 climate scenario, indicates that that flooding (18,300 ML/day) at Yarrawonga will be reduced to one event every 3.5 years. For this assessment, the NRC has used the current level of development when modelling the likely impact of climate variability and change, as this is the best information currently available.

The top two panels of Figure 8.1 from MDBSY show how river regulation and water resource development have dramatically altered the relative proportions of river flow going to extractive water use, the river floodplains and wetland, and the end of system lakes, estuaries and marine environment respectively. The bottom two panels show how the two climate change prediction scenarios (continuation of the recent climate and median 2030 climate) may exacerbate this situation.

The figure demonstrates the greatest impact upon water used for the environment was the commencement of current development (river regulation) rather than climate change scenarios or the recent drought.

It is important to note that the end of system flows of water provide environmental, economic and social values to the coastal estuaries and the communities that rely upon them. As can be seen in Figure 8.1, the flow to the estuary and marine environment reduces dramatically upon commencement of river regulation and this situation continues under recent climate and dry extreme climate scenarios.

In the Murray system, the riverine and floodplain environment receives proportionally more water under the existing recent climate (1997–2006) than either the current development historical climate (1895–2006) or the 2030 dry extreme climate scenario.

Lower flows in the system are also important. Regulation has effectively eliminated all low-flow events in the major rivers, which has also helped to trigger significant ecological change. At Albury, downstream of Hume Reservoir, not only is the average annual flow 10 per cent higher than natural, the seasonal patterns are now virtually the reverse of natural conditions.

8.3 Ecological functions and the hydrology of red gum forests

Unconfined, meandering, lowland rivers such as the Murray River at Yarrawonga have a high natural frequency of out-of-channel flow. Typically, the geomorphology of such rivers evolves to form a channel capacity capable of carrying a one in two year flood event. Flows greater than this spill onto the floodplain via paleochannels and flood-runners. The subsequent return flows to the main river channel contribute to a whole suite of biological and geochemical functions.
Figure 8.1: Murray Darling Basin annual water availability, consumptive use, flows to floodplains and wetlands, flows to lakes, estuaries and marine environment over four climate and water resource development scenarios (courtesy of MDBA based on MDBSY Project data (CSIRO, 2008a))

Pre-development – historical climate (1895–2006)

Current development – historical climate (1895–2006)


Current development – 2030 median climate

Consumptive diversion
Return to riverine and floodplain environment
Flow to estuary and marine environment

Note: These percentages have been rounded down.

Courtesy of MDBA based on CSIRO Sustainable Yields Report (2008) Data
As illustrated in Figures 8.2 and 8.3, the ecology of both the river channel and floodplain is reliant upon the connectivity between the two systems created by reasonably frequent flooding. Flooding is essential in maintaining the character, diversity and resilience of the channel, wetlands and forests in these lowland river ecosystems.

The forest floodplains are the source of much of the primary productivity for the river and are the engine room for energy and the drivers of fundamental food webs. River red gum forests are potentially the key primary producers in the river floodplain ecosystems, supporting and driving other ecosystem processes (Hillman, T., pers. comm., 2009). For example, they produce organic carbon and other nutrients in the form of forest litter which is distributed across the floodplain in flooding events. It has been estimated that red gum forests produce 2-6 tonnes of litter per hectare, per year (O’Connell, 2003).

Thus, broad ecosystem services are derived from out of channel flows and sufficient volumes are required to connect the river channel and floodplain.
to the floodplain river red gum ecosystems as part of restoring health to the Murray, Murrumbidgee and Lachlan Rivers as a whole.

Hillman (unpub, 2009) has discussed both the different components of the river system and the different phases of an inundation event:

- River system components – water-shedding floodplain (in this case eucalypt forest, mainly red-gum), water-retaining floodplain (wetlands, backwaters, lakes), and channel (main stream and free-flowing anabranches).

- Inundation event phases – initial inundation, flooded period, receding inundation, post-inundation.

The different components and phases all play key roles in the ecological processes of river red gum forests, but also in the forests’ role in the broader riverine landscape.

Significant volumes of water will be needed to inundate large areas of floodplain ecosystems every two years or so as required to restore the ecological functions. However, this water is not completely “lost” from the river system as a considerable proportion of floodwaters return to the river. Whilst difficult to estimate based on current knowledge, it is expected that between 50 and 80 per cent of floodplain flows return to the river following a flood event. Actual return flows would be site specific and depend on flood duration and antecedent conditions, amongst other factors.

8.4 Water reforms to reconnect the rivers and floodplains

The future health of river red gums along the Murray River will be determined in large measure by the degree of success of the water reform program. These reforms include: The Living Murray Program; the National Water Initiative; the Commonwealth Water Act 2007 and the roles of the Murray Darling Basin Authority and National Water Commission; the Commonwealth Government’s ‘Water for the Future’ program; and the recovery of environmental water by the Commonwealth Environmental Water Holder.

The Living Murray (TLM) was established in 2002 as an intergovernmental agreement to recover water for the benefit of six ‘icon’ sites selected along the Murray River (refer Figure 8.4). The program’s first step, to recover 500 GL, commenced in 2004 and finishes in 2009. The MDBA recently confirmed that this 500GL target will be met through a range of measures, including market-based instruments and infrastructure works. It is understood that all existing projects under The Living Murray will be completed, but further environmental water initiatives will be developed in the context of the new Murray-Darling Basin Plan.

The TLM portfolio of recovered water is a mixture of high, medium, low and opportunistic (unregulated and supplementary) securities. Due to the nature of the various entitlements, the volumes available for use at icon sites at any particular time will vary depending on river flows, allocations and water management rules.

An independent review of TLM Initiative First Step, conducted by KPMG in April 2009, reported that the amount of water that may be available for environmental watering in spring 2009 was 3.55 GL (MDBA, 2009b). The review notes that in a wetter year, TLM portfolio could realise a significantly larger quantity of water for environmental watering, including opportunistic entitlements.

The Living Murray progress report (MDBA, Nov 2009) notes that the “current suite of projects will deliver 485 GL or 97 per cent of the 500 GL target over coming months”. However, of the 485 GL of licence entitlement, the MDBA Annual Environmental Watering Plan 2009–10 is currently forecasting the actual allocation amounts listed in Table 8.2 as being available for the coming seasons.

These amounts are orders of magnitude smaller than the actual volumes required to restore the ecological functions of red gum forests’ and the riverine environment.

To date, the water reforms envisaged in the National Water Initiative are making slow progress. The National Water Commission’s recent review of progress against the National Water Initiative found that “evidence suggests that limited real progress has been made in reducing the number of systems identified as over-allocated and over-used” (NWC, 2009). Water is being purchased and infrastructure is being built to improve flooding regimes and water management at sites such as Millewa and Koondrook-Perricoota. The focus is on recovering sufficient water to maintain a series of key water-dependent environmental assets.

Ultimately, the Australian Government’s water holdings will include its share of water savings made through the programs of the national water plan, ‘Water for the Future’. The Water for the Future framework was announced in April 2008 and will be delivered through a 10-year, $12.9 billion investment in strategic programs, improved water management arrangements and a commitment to deliver a range of water policy reforms in both rural and urban areas. The Australian Government has committed $3.1 billion over 10 years to purchase water in the Murray-Darling Basin through a program known as ‘Restoring the Balance in the Murray-Darling Basin’.

The Water Act 2007 establishes the Commonwealth Environmental Water Holder (CEWH) who will manage the Commonwealth’s environmental water to protect and restore the water-dependent environmental assets of the Murray-Darling Basin, and outside the Basin where the Commonwealth owns water. The water rights acquired by the Commonwealth through these programs will be managed by the CEWH. As at 30 September 2009, the water recovery program had secured

Table 8.2: Forecasted available TLM water 2009–2010

<table>
<thead>
<tr>
<th>Season</th>
<th>Forecast allocation amounts (GL)</th>
<th>Carryover availability (GL)</th>
<th>TOTAL (GL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring 2009</td>
<td>2.5–7</td>
<td>3</td>
<td>6–10</td>
</tr>
<tr>
<td>Autumn 2010</td>
<td>26–65</td>
<td>5.57</td>
<td>31–73</td>
</tr>
</tbody>
</table>
the purchase of 612 GL of water entitlements worth nearly $947 million.

In early 2009, the NSW Department of Environment, Climate Change and Water and the DEWHA signed a memorandum of understanding outlining their intended cooperation in the planning and managing of environmental water. Under this memorandum, allocations held by the CEWHA are being delivered for agreed environmental priorities in accordance with NSW Annual Environmental Watering Plans prepared for each valley.

It now falls to the Basin Plan and its successful implementation to continue this good work. With the Basin Plan expected to be completed in 2011, and implemented in 2014, the NRC can only speculate at this stage about its effects.

A CSIRO (2008) study indicates that the current surface water-sharing arrangements in the Murray-Darling Basin would generally protect consumptive water users from much of the anticipated impact of climate change, but offer little protection to riverine environments. Future water-sharing arrangements in the Basin will need to comply with the Basin Plan. In its Concept Statement for the Basin Plan the MDBA has stated that “it is likely that the Basin-wide sustainable diversion limit for both groundwater and surface water will be set at a level below the current level of use” (MDBA, 2009c).

### 8.5 Scale of water reform required to save the forests

In a system as large and complex as the Murray Darling Basin, water policy has many conflicting demands. After more than thirteen years of severe drought and record low flows all elements of this system are experiencing severe stress. It is a social choice how much water we extract from a river such as the Murray and how the remaining water is delivered in a re-constructed flow regime. It is this social choice that will determine the future of the red gum forest ecosystems more than any other factor.

Further complicating this social choice are the predictions of climate change. Given the most recent scientific information (Steffen 2009 & Allison et al 2009), long term management of the Murray and the red gum forests should at least be based on the ‘medium’ climate change scenario in the CSIRO Sustainable Yields project. Indeed it may well be prudent to adopt the ‘step change’ (1997 – 2006) scenario as many of the climate change indicators are tracking on a ‘worst case’ trajectory.

The science that informed the original The Living Murray process in 2002 stated that 1,500 GL would give the Murray a “moderate” chance of being ecologically healthy. This same science stated that in the order of 4,000 GL would be required to provide a high likelihood of a healthy river system to return key indicators of health to two-thirds of their natural level.

In Tables 8.6 and 8.7 the NRC has documented the flooding requirements of the largest red gum forests in the central Murray Barmah-Millewa icon site. Based on this information, the NRC calculates that to maintain their ecological character these forests require at least:
• smaller floods once every two years of say 20GL/day for between 60 to 150 days (ie total volumes of between 1,200 GL to 3,000 GL every two years), and
• a larger landscape restoration flood once in 11 years of 35GL/day for 90 days, plus a peak of 45GL/day for 15 days (ie about 3,825GL every 11 years).

Much of this water would eventually return to the river, bringing nutrients and carbon flows with it to recharge the river ecology. With re-use of this water, environmental watering of this level could fundamentally restore the natural flood regimes of the Ramsar-listed icon sites at Milawa, Perricoota-Koondrook and Werai forests in NSW, the Victorian forests of Gunbower and Barmah, and smaller river red gum forests along the riparian zone of the NSW /Victorian border and into South Australia.

The NRC calculates that to achieve these flooding regimes would require approximately 25 per cent of the long-term, median annual flow at Yarrawonga, or 2,000GL/year on average. This amount would need to be dedicated to sustaining essential floodplain ecosystem processes along the Murray River system. Achieving this challenging target will require the Murray-Darling Basin Authority to set appropriate Sustainable Diversion Limits and the Commonwealth Environmental Water Holder to recover and deliver to the Murray system appropriate amounts of environmental water.

Together, these two reform mechanisms need to ensure that an additional 1,200GL of water is made available to enhance current environmental water entitlements on the Murray system. Current environmental water entitlements include 500GL for the Murray River system as a whole under the Living Murray, 100GL for the Barmah-Millewa forests, and entitlements recently recovered by the Commonwealth Environmental Water Holder.

Without the allocation and delivery of these large volumes of water mimicking unregulated flood patterns, the iconic red gum forests of the Riverina region will continue their well progressed transformation to a less water dependent ecology. Detailed knowledge of the ‘ecosystem services’ provided by the riverine landscape is poor. The United Nations 2004 Millennium Ecosystem Assessment grouped ecosystem services into four broad categories:

• provisioning, such as the production of food and water
• regulating, such as the control of climate and disease
• supporting, such as nutrient cycles and crop pollination, and
• cultural, such as spiritual and recreational benefits.

Risk can be defined as the product of likelihood and consequence. As discussed above, climate science is showing an increased likelihood of a water scarce future and the best available knowledge is directing us toward managing on the basis of a ‘step change’ scenario and consequences this has for water availability. Consequence of the loss of ecosystem services if significant. Therefore we are facing a high, if not extreme risk, yet our management response in terms of water reform does not seem to align with this scale of risk both in terms of the scale and pace of reform required.

Without the allocation and delivery of large volumes of water we are likely to lose many critical ecosystem services. The scale of impact of these losses can be expected to be significant and permanent for a range of environmental, economic and social values.

8.6 Analysis of impacts to high flow events under climate change

Flooding is essential to maintaining the character, diversity and resilience, of lowland floodplain ecosystems including their channels, wetlands and forests. As explained in Chapters 2 and 4, ecosystem services are derived from flood flows. The NRC completed a simple statistical analysis for a range of flood flows using the River Analysis Package (eWater CRC, 2007) and the MDBSY Project data for Murray River flows at Yarrawonga (CSIRO, 2008a). The River Analysis Package assists river and water resource managers to undertake condition assessments, environmental flow planning and river restoration design.

Four flow scenarios were used in the analysis:

• Scenario P: Historic (pre 1997) climate without current water resource development extractions
• Scenario A: Historic (pre 1997) climate with current water resource development extractions
• Scenario B: Recent climate (1997 to 2006) “step change” with current water resource development extractions
• Scenario Cmid: Median 2030 climate change with current water resource development extractions.

These flow scenarios are equivalent to the CSIRO MDBSY climate scenarios as outlined in Chapter 7, including an additional Scenario P based on the historic climate without current water resource development.

A range of flood flows at Yarrawonga from 18,300 ML/day to 100,000 ML/day was assessed. In addition, the duration of flood events was tested from long (60 day events) to brief (1 day) flood pulses. The results of the analysis are presented in Table 8.3.

Some important observations from this analysis are:

• The smaller, long duration floods (20,000 ML/day, 60 days) occurred in “without development” conditions about every one to two years. Under 2030 climate change these events are predicted to occur once every 5 years and only once every 10 years under a step-change future (that is, if there were to be a long-term continuation of the recent climate).
• The very large ‘landscape restoration’ floods (100,000 ML/day, 10 days) occurred in “without development” conditions about once every 11 years. Under 2030 climate change and step change these events do not appear in the flow forecast modelling, that is, they are unlikely to occur.

The following sections present further analysis using these scenarios for each WMU.
Table 8.3: Analysis of flood flows at Yarrawonga for four climate and water resource development scenarios (Data courtesy of CSIRO)

<table>
<thead>
<tr>
<th>Flood magnitude</th>
<th>Season</th>
<th>Duration</th>
<th>Frequency</th>
<th>Average period between floods</th>
<th>Maximum period between floods</th>
<th>Frequency</th>
<th>Average period between floods</th>
<th>Maximum period between floods</th>
<th>Frequency</th>
<th>Average period between floods</th>
<th>Maximum period between floods</th>
</tr>
</thead>
<tbody>
<tr>
<td>ML/d</td>
<td></td>
<td></td>
<td></td>
<td>No. occurrences</td>
<td>Years</td>
<td>No. occurrences</td>
<td>Years</td>
<td>No. occurrences</td>
<td>Years</td>
<td>No. occurrences</td>
<td>Years</td>
</tr>
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<td>18,300</td>
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<td>18,300</td>
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<td>36</td>
<td>10.9</td>
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<td>8.2</td>
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<td>13.6</td>
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<td>25,300</td>
<td>45</td>
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<td>25</td>
<td>12.7</td>
<td>6</td>
<td>14.2</td>
<td>37.7</td>
<td>16</td>
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<td>35,000</td>
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<td>60+ days</td>
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<td>21</td>
<td>4.4</td>
<td>9</td>
<td>24.0</td>
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<td>38.6</td>
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<td>5</td>
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<td>54</td>
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<td>11</td>
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<td>4</td>
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<td>39</td>
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<td>53</td>
<td>1.8</td>
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</table>
8.7 Millewa forests

The assessment for Millewa forests includes:
• site characteristics and water requirements
• future water availability and flooding regimes
• the likely impacts of future water availability for the associated forests.

8.7.1 Site characteristics

The Barmah-Millewa forests and associated wetlands are maintained by the large volumes of water (regular flooding) when the Murray River exceeds channel capacity at the Barmah Choke. The Barmah Choke is a section of the Murray River with limited capacity to carry flows (MDBC, 2006a). The channel capacity of the Barmah Choke is approximately 10,400 ML/day at Yarrawonga Weir.

The surface hydrology of the forests involves an intricate arrangement of inflow sources and drainage routes. The regularity, extent, duration and season of flooding is governed by flow in the Murray River. Relatively small changes in topography influence the distribution and depth of flooding. Water passes over the floor of the forests as sheet flow in large floods, and through the forests predominantly as creek flow during small flood events.

Over 50 water management structures are currently present through the Barmah-Millewa forests. Primary structures are regulators with a discharge capacity generally greater than 100 ML/day and occur in anabranch streams near their exit point from the Murray River, Edward River and Gulpa Creek. The purposes of these structures are to maintain regulated flows within the stream, and to permit floods to pass into the forest (MDBC, 2006a). Secondary and tertiary regulating structures (with discharge capacity of <100 ML/day – for example, pipes, culverts, earthen banks and small regulators) are mostly situated in drainage features within the interior portions of the forest.

The main purpose of these structures is to manipulate water distribution and depth within localised areas, and to provide vehicle access (MDBC, 2006a). Once flows at Yarrawonga Weir exceed 10,400 ML/day (Barmah Choke capacity), the regulators are progressively opened to allow water to enter the forest. The majority of flood flow entering the Millewa forests leaves the Murray River and flows past Deniliquin in the Edward River. Flood flow then enters the Edward-Wakool system, passing through the Werai Forests system, before finally returning to the Murray River some 200 kilometres to the west at Wakool junction (GHD, 2009).

Since regulation of the Murray River, the natural hydrologic regime has been considerably altered. For example, under natural conditions, 70 per cent of the forest would be flooded for an average of 2.9 months in 78 per cent of years. Since regulation, this level of flooding is only experienced for an average of 1.3 months in 37 per cent of years. Overall, the frequency of flooding and the duration of inundation in the major vegetation communities have been significantly reduced.

Small localised flooding, covering less than 10 per cent of the forest, occurs approximately eight times more frequently since regulation began, and tends to occur between December and April (MDBC, 2008a). This unseasonal flooding generally occurs because of the rejection of pre-ordered irrigation supplies after rain. This typically causes the Murray River flows to increase from near-forest-channel capacity of about 10,400 ML/day to a flow of 12,000 to 15,000 ML/day or more for a period of up to about five to seven days. Unseasonal flooding may also arise in part from increased tributary flows. Agreement between Forests NSW and the Victorian Department of Sustainability and the Environment has allowed an arrangement to annually alternate the acceptance of any excess river flows during the unseasonal flooding period (December–April). This co-operative arrangement allows the wetlands in each state a better chance of drying every second year akin with a more natural regime (MDBC, 2006a).

The Living Murray interim ecological objective for Barmah-Millewa Icon Site is to enhance forest, fish and wildlife values, by ensuring:
• successful breeding of thousands of colonial waterbirds in at least three years in 10
• healthy vegetation in at least 55 per cent of the area of the forest (including virtually all of the giant rush, moira grass, river red gum forest and some river red gum woodland) (MDBC, 2006a).

Water requirements of the Millewa forests can generally be described as the flooding regime that occurred under natural (pre-regulation) conditions (MDBC, 2006a). For river red gum forests, inundation for up to five months in winter–spring, in approximately 40–92 per cent of years, would be ideal (Table 8.4).

Critical limits of acceptable change for river red gum forest and woodland across the NSW Central Murray State Forests were provided in the Draft Ecological Character Description (ECD) (GHD, 2009) and are shown in Table 8.5.

Bank undercutting at Millewa State Forest
These are initial values proposed for future refinement, and indicate that a minimum flood frequency of 50 per cent of years (for the appropriate duration and season) is required to maintain river red gum forest. This 50 per cent minimum flood frequency correlates well with the 40 per cent lower threshold stipulated in the Icon Site Management Plan (MDBC, 2006a).

The approximate flow levels required to inundate varying extents of forest in the combined Barmah-Millewa forests are provided in Table 8.8.

Based on these estimates, a summer–spring flood of 18,300 ML/day is needed to achieve the interim environmental objectives (55 per cent inundation), according to the Icon Site Management Plan (MDBC, 2006a). However, the most recent assessments by the MDBA and hydrological modelling indicate that environmental flows required to achieve the Barmah-Millewa objectives are likely to be much higher than the 18,300 ML/day (Water Technology 2009; Burns, I., MDBA, 2009, pers comm).

These estimates assume a design storm with a long return period which, in this case, is assumed to be 25 years. The ECD has not been formally endorsed by the Australian Administrative Authority for the Ramsar Convention (DEWHA).

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Table 8.4: Flood frequencies of the major Barmah-Millewa forest vegetation communities before river regulation (MDBC, 2006a)

<table>
<thead>
<tr>
<th>Vegetation community</th>
<th>Flood frequency (% of years with inundation)</th>
<th>Duration</th>
<th>Season</th>
</tr>
</thead>
<tbody>
<tr>
<td>Giant Rush</td>
<td>75–100%</td>
<td>7–10 months</td>
<td>Winter to mid-summer</td>
</tr>
<tr>
<td>Moira Grass</td>
<td>65–100%</td>
<td>5–9 months (no more than 10 months; min. depth 0.5 m)</td>
<td>Winter to mid-summer; 2–3 months dry in late summer to early autumn</td>
</tr>
<tr>
<td>River Red Gum forest</td>
<td>40–92%</td>
<td>5 months</td>
<td>Winter–spring</td>
</tr>
<tr>
<td>River Red Gum woodland</td>
<td>33–46%</td>
<td>1–2 months</td>
<td>Spring</td>
</tr>
<tr>
<td>River Red Gum/Black Box woodland</td>
<td>14–33%</td>
<td>1–4 months</td>
<td>Winter–spring</td>
</tr>
</tbody>
</table>

Table 8.5: Critical limits of acceptable change for red gum in NSW Central Murray State Forests (extracted from GHD, 2009)

<table>
<thead>
<tr>
<th>Sub-component /process</th>
<th>Adaptive management action</th>
<th>Optimum frequency (% of years)</th>
<th>Minimum frequency (% of years)</th>
<th>Optimum operating conditions</th>
<th>Environmental outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>River Red Gum Forest</td>
<td>Exceed channel capacity, flood lower parts of floodplain</td>
<td>70–90%</td>
<td>50%</td>
<td>Flood pulse in Aug–Dec Inundation less than 24 months</td>
<td>Watering of river red gums and other native plant species Magnitude (i.e. extent of flood) will determine extent of forest inundated</td>
</tr>
<tr>
<td>River Red Gum Woodland</td>
<td>Exceed channel capacity, achieve broad scale flooding</td>
<td>30–70%</td>
<td>20%</td>
<td>Flood pulse in Sep–Nov Inundation less than 24 months</td>
<td>Watering of river red gums and other native plant species</td>
</tr>
</tbody>
</table>

Table 8.6: Desired flow magnitude and flooding extent for Barmah-Millewa forests (MDBC, 2006a)*

<table>
<thead>
<tr>
<th>Flow at Yarrawonga Weir</th>
<th>Inundation extent</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10,600 ML/day</td>
<td>In-channel flows</td>
</tr>
<tr>
<td>10,600–18,300 ML/day</td>
<td>Inundates up to 55% of Barmah-Millewa Forest (this includes virtually all Giant Rush, Moira Grass, River Red Gum forest and some River Red Gum woodland)</td>
</tr>
<tr>
<td>18,300–25,300 ML/day</td>
<td>Inundates 55–66% of Barmah-Millewa Forest</td>
</tr>
<tr>
<td>&gt;25,300 ML/day</td>
<td>Inundates &gt;66% of Barmah-Millewa Forest</td>
</tr>
</tbody>
</table>

* Hydrological modeling for the Barmah-Millewa Forest has indicated that flows in the order of 35,000 ML/day are required to achieve the desired inundation extents to meet the objective of 55 per cent inundation (Water Technology, 2009).

1 The ECD has not been formally endorsed by the Australian Administrative Authority for the Ramsar Convention (DEWHA).
These assessments set out in Table 8.7 are part of the preliminary unpublished data analysis which has been undertaken for the development of the Murray-Darling Basin Plan. The analysis was based on the recent hydrological modelling by Water Technology (2009) conducted for the Barmah-Millewa forests.

Based on hydrological modelling (Water Technology, 2009) and MDBA analysis (MDBA, pers. comm.), flows of around 35,000 ML/day or greater will be needed to achieve the interim ecological objective for the combined Barmah-Millewa (see Table 8.7), which is effectively double the original estimate of 18,300 ML/day proposed in the Icon Site Management Plan.

Within the Millewa forests WMU, sub-units called water management areas (WMAs) delineate areas of the forest where points of inflow and outflow best segregate one section of the forest from another (Leslie and Harris, 1996). The concept of WMAs allows different management requirements and opportunities within each area to be recognised on a localised basis, and then integrated within the overall sphere of forest management (Leslie and Harris, 1996). Eight WMAs have been identified within the Millewa forests WMU, and overlying these are four more general WMAs identified by Forests NSW (Figure 8.5). For flows over 17,000 ML/day, the Millewa forests are typically treated as one unit; however lower flows can be managed in a more detailed way across the four inundation areas (Rodda, G., Forests NSW, 2009, pers comm).

**8.7.2 Future water availability**

The CSIRO MDBSY Project studied the flooding implications in Barmah-Millewa forests under a range of climate scenarios. Scenarios A, B and C (outlined in Chapter 7) are used in this assessment:

- Scenario A – historical climate with current development
- Scenario Cmid – future climate to 2030 with current development.

Implications on flooding for Barmah-Millewa forests were assessed for the beneficial spring–summer flood, defined as 18,300 ML/day (for a period of 60 days in August–December) at Yarrawonga Weir (Table 8.8). This is the volume that was initially understood to correspond with achieving the 55 per cent inundation of the forest required to achieve the interim ecological objective, based on the Icon Site Management Plan.
Results on the flood frequency under each of the scenarios are shown in Table 8.9.

Under scenarios B and Cmid (step-climate change and 2030 climate change), floods exceeding 18,300 ML/day are likely to occur less frequently, with a greater period between floods, and with a lower average flood volume per year and per event. The reduction in flood frequency is considerably more extreme under step-climate change (B) than modelled 2030 climate change (C), as would be expected, as step-climate change assumes a continuation of conditions from the last ten years.

Modelled scenarios include environmental water allocations for Barmah-Millewa forests. This included a 100 GL/year environmental water entitlement, plus a lower-security allocation of 50 GL to be provided in years where the irrigation water allocation in Victoria exceeds 130 per cent. The 100 GL/year of high-security water, and additional 50 GL (when triggered), is to be drawn equally from NSW and Victoria, and

Table 8.7: Requirements to meet Barmah-Millewa ecological objectives in relation to red gum forests based on preliminary MDBA analysis

<table>
<thead>
<tr>
<th>Objective</th>
<th>Area of inundation</th>
<th>Flow to achieve inundation</th>
<th>Duration</th>
<th>Frequency</th>
<th>Timing</th>
<th>Max time between events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy vegetation in at least 55% of the area of the forest</td>
<td>36,300 ha</td>
<td>Flow peaking at 45,000 ML/day with extended periods above 35,000 ML/day achieves approximately 64% total forest flooded.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>... including virtually all vegetation of the River Red Gum forest</td>
<td>Approx. 42,700 ha (with other types total 62,000 ha)</td>
<td>Flows 25,000–35,000 ML/day with peak of 45,000 ML/day. Achieves 71% inundation River Red Gum forest (64% total forest)</td>
<td>3 months total</td>
<td>1 in 3 years</td>
<td>Winter, spring</td>
<td>3 years</td>
</tr>
<tr>
<td>... including some vegetation of River Red Gum woodland</td>
<td>Approx. 13,700 ha (with other types total 62,000 ha)</td>
<td>Flow above 35,000 ML/day peaking above 45,000 ML/day. Achieves 50% inundation of River Red Gum woodland (64% total forest)</td>
<td>1 month</td>
<td>1 in 3 years</td>
<td>spring</td>
<td>4 years</td>
</tr>
</tbody>
</table>

Table 8.8: Barmah-Millewa beneficial flow event definition (CSIRO, 2008a)

<table>
<thead>
<tr>
<th>Flow event description</th>
<th>Flow event definition</th>
<th>Indicators reported</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beneficial spring–summer flood</td>
<td>Flows exceeding 18,300 ML/day for 60 days Aug–Dec at Yarrawonga Weir.</td>
<td>Average period between floods Maximum period between floods Average flood volume per year Average flood volume per event</td>
</tr>
</tbody>
</table>

Table 8.9: Barmah-Millewa forests results for floods exceeding 18,300 ML/day under Scenarios A, B and C, plus percentage change (from Scenario A) in indicator values for scenario Cmid (adapted from CSIRO 2008a)

<table>
<thead>
<tr>
<th>Barmah-Millewa Forest</th>
<th>A</th>
<th>B</th>
<th>Cmid</th>
<th>B</th>
<th>Cmid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floods exceeding 18,300 ML/day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average period between floods</td>
<td>3.5</td>
<td>4.55</td>
<td>3.96</td>
<td>30</td>
<td>13</td>
</tr>
<tr>
<td>Maximum period between floods</td>
<td>10.9</td>
<td>33.90</td>
<td>21.26</td>
<td>211</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average flood volume per year</td>
<td>291</td>
<td>55</td>
<td>148</td>
<td>-81</td>
<td>-49</td>
</tr>
<tr>
<td>Average flood volume per event</td>
<td>905</td>
<td>226</td>
<td>516</td>
<td>-75</td>
<td>-43</td>
</tr>
</tbody>
</table>
can be accrued in storage as an environmental water allocation kitty up to a maximum of 700 GL (MDBC, 2006a).

Additional environmental water not included in the modelling is the 500 GL/year to be recovered and applied to the six Icon Sites under the First Step decision of the Living Murray initiative. The Living Murray program has recently undertaken modelling which examined the degree to which environmental water requirements of the Icon Sites can be met with the 500 GL under historical climate conditions, and the potential impact of climate change (2030) (TLM, 2008). This modelling considered the feasibility and benefits of structural works proposals for the relevant Icon Sites.

As Barmah-Millewa does not have a defined structural proposal, no call on TLM water was modelled. Rather the focus was on other Icon Sites, with Barmah-Millewa being treated in a relatively passive context (including current operating rules and entitlements). However, overall it was felt that the Barmah-Millewa forests would benefit from the additional water recovery year and the operation of other structures (TLM, 2008).

Modelled future water availability of Commonwealth Environmental Water Holdings that will arise from its Water for the Future Program is not included in this analysis.

### 8.7.3 Future flooding regime

A floodplain inundation model for Barmah-Millewa forests has recently been completed (Water Technology, 2009). The calibrated modelling achieved a good reproduction of flooding extents compared to satellite-derived flood extent observations. The model outputs include flooding extents for a range of inundation levels based on flow volume at Yarrawonga Weir. The modelled inundation extents were overlaid on the vegetation group mapping (included in Chapter 4) to provide an indication of the extent of river red gum vegetation communities in Millewa Forest inundated by various flows in the Murray River channel.

The results are shown in Table 8.10. A comparison of these design flows with the predicted inundation extents for the combined Barmah-Millewa forests can also be made and is shown in the table.

The results of the Water Technology modelled inundation extents for the Millewa forests as shown in Table 8.10 indicate the following:

- At 15,000 ML/day (closest design flow to 18,300 ML/day), 46 per cent of river red gum very tall forest is inundated, plus 14 per cent of river red gum tall open forest (combined river red gum very tall forest and river red gum tall open forest inundated 16 per cent).
- At 25,000 ML/day, approximately 86 per cent of river red gum very tall forest is inundated, plus 32 per cent of river red gum tall open forest (combined 36 per cent), and 5 per cent of river red gum–box woodland.
- With flows up to 35,000 ML/day, approximately 90 per cent of river red gum very tall forest is inundated, plus 44 per cent of river red gum tall open forest (combined 47 per cent), and 7 per cent of river red gum–box woodland.
- Larger flows of 45,000 ML/day will inundate up to 96 per cent of river red gum very tall forest, plus 73 per cent of river red gum tall open forest (combined 59 per cent), and 21 per cent of river red gum–box woodland.

#### Table 8.10: Modelled inundation extent of river red gums in Millewa forests at various design flows (based on flow at Yarrawonga) that have been mapped (Water Technology, 2009). A comparison of approximate inundation extent for the combined Barmah-Millewa forests (MDBC, 2006a) is also shown.

<table>
<thead>
<tr>
<th>Design flows at Yarrawonga Weir</th>
<th>River Red Gum Very Tall Forest</th>
<th>River Red Gum Tall Open Forest</th>
<th>River Red Gum-box Woodland</th>
<th>Inundation extent for combined Barmah-Millewa forests</th>
</tr>
</thead>
<tbody>
<tr>
<td>ML/day</td>
<td>area (ha)</td>
<td>% area (ha)</td>
<td>% area (ha)</td>
<td>Based on MDBA preliminary analysis (except 60,000 ML/day – CSIRO analysis)</td>
</tr>
<tr>
<td>10,400</td>
<td></td>
<td></td>
<td></td>
<td>18,300 ML/day was the initial estimate to achieve 55% inundation extent of combined forest based on the Icon Site Management Plan.</td>
</tr>
<tr>
<td>13,000</td>
<td></td>
<td></td>
<td></td>
<td>Achieves 71% inundation of River Red Gum forest (corresponding with the ‘virtually all Red Gum Forest’ objective in the Icon Site Management Plan.</td>
</tr>
<tr>
<td>15,000</td>
<td>997</td>
<td>46</td>
<td>4,212</td>
<td>14 86 3</td>
</tr>
<tr>
<td>25,000</td>
<td>1,842</td>
<td>86</td>
<td>9,639</td>
<td>32 141 5</td>
</tr>
<tr>
<td>35,000</td>
<td>1,919</td>
<td>90</td>
<td>13,144</td>
<td>44 192 7</td>
</tr>
<tr>
<td>45,000</td>
<td>2,022</td>
<td>94</td>
<td>16,889</td>
<td>57 329 12</td>
</tr>
<tr>
<td>60,000</td>
<td>2,061</td>
<td>96</td>
<td>21,753</td>
<td>73 570 21</td>
</tr>
</tbody>
</table>

Flow required for 55% inundation extent based on CSIRO RiM-FIM modelling (Overton et al., 2006a)
Chapter 8: Implications of changes in climate for water availability and flooding regimes

The Water Technology modelling has not been the subject of widespread review and there is some uncertainty as to its accuracy. Additional floodplain inundation modelling by the CSIRO (Murray River Floodplain Inundation Model) indicates that perhaps even greater flood magnitudes will be required to achieve the equivalent inundation of the combined Barmah-Millewa forests than is predicted by the Water Technology modelling (Overton et al., 2006a). Thus, it is demonstrated that there is uncertainty in the modelled results, however the predictions all indicate that higher flows are required to inundate significant extents of the Barmah-Millewa forests.

To examine the future flood frequency of larger floods (>18,300 ML/day) under climate change (step-change and 2030 climate change), daily modelled streamflow data (1895–2006 at Yarrawonga Weir) were obtained for the CSIRO climate scenarios (A, B, Cmid) based on current development.

The differences in flood frequency for larger floods, in addition to the 18,300 ML/day, were compared across the different scenarios, to examine the likely impacts on inundation. This analysis was conducted using the River Analysis Package to determine the number of events in the flow series data. A two-day flood independence criterion was used in the River Analysis Package, and events were defined as noted in Table 8.11.

Floods are expected to become significantly less frequent under climate-change Scenarios B and Cmid. Slight differences in data reported for the 18,300 ML/day between this analysis and the CSIRO analysis (Table 8.9) are likely to be the result of subtleties in the data analysis process (e.g. flood independence). Larger floods are expected to occur much less frequently, with no floods of 60,000 ML/day (for 30 days) occurring under 2030 climate change (or step-climate change) (Table 8.11). There is a significant reduction in the frequency of naturally occurring floods between 25,000–45,000 ML/day under climate change scenarios B and Cmid. The approximate (modelled) extents of flood magnitudes in Table 8.11 are shown in Figures 8.6–8.10.

### Table 8.11: Flood frequency assessment under climate change scenarios

<table>
<thead>
<tr>
<th>Flood magnitude ML/day</th>
<th>Season</th>
<th>Duration</th>
<th>A (years)</th>
<th>B (years)</th>
<th>Cmid (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18,300</td>
<td>Aug–Dec</td>
<td>60 days+</td>
<td>2.6</td>
<td>8.2</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10.9</td>
<td>34.0</td>
<td>13.6</td>
</tr>
<tr>
<td>25,300</td>
<td>Aug–Dec</td>
<td>60 days+</td>
<td>3.2</td>
<td>14.2</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>12.7</td>
<td>37.7</td>
<td>17.6</td>
</tr>
<tr>
<td>45,000</td>
<td>Aug–Dec</td>
<td>60 days+</td>
<td>28.3</td>
<td>N/A*</td>
<td>17.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>38.7</td>
<td>N/A</td>
<td>17.9*</td>
</tr>
<tr>
<td>60,000</td>
<td>Aug–Dec</td>
<td>60 days+</td>
<td>19.3</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>37.8</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

*Same as average because only two events were recorded.

Additional flood magnitudes for which inundation extents are not available were assessed in Section 8.6. This analysis showed that the very large “landscape restoration” floods (100,000 ML/day for duration of ten days) are unlikely to occur under 2030 median climate change (scenario Cmid) or a climate under continuation of the recent drought (Scenario B).

Easement constraints upstream of Millewa forests also limit the potential for future large delivered floods. Current easement constraints of 25,000 ML/day between Hume Dam and Lake...
Mulwala limit the ability to manipulate the delivery of floods larger than 25,000 ML/day along this reach (Burns, I., MDBA, pers. comm., 2009). The delivery of floods larger than 25,000 ML/day to Millewa forests depends on contributing natural flood flows from the unregulated Ovens River being passed downstream of Lake Mulwala/Yarrawonga Weir. Under current river operation, ‘seasonal’ flood flows (floods occurring between May and December) from the Ovens catchment are passed, whilst between December and April the Murray River downstream of Yarrawonga Weir is operated at 10,600 ML/day to limit unseasonal flooding of the forests (Jones, M., MDBA, pers. comm., 2009).

It is understood that an expansion of easements up to a capacity of 40,000 ML/day is currently being investigated (Broekman, L., Forests NSW, pers. comm., 2009; Burns, I., MDBA, pers. comm., 2009). If easements are increased to allow increased flooding at 40,000 ML/day, a greater extent of vegetation could be inundated, in the order of the modelled extent for the 45,000 ML/day design flow (Table 8.10).

Estimating return flows to the Murray River for a flood event in the Millewa forests is not straightforward. Based on an analysis of gauged flows at downstream Yarrawonga, Barmah and Deniliquin, during a 25,000 ML/day flood measured at the downstream Yarrawonga gauge approximately 80 per cent of flows (20,000 ML/day) remain in the Murray/Edward river systems (passing either the Barmah or Deniliquin gauges) (MDBA, pers. comm., 2009). Not all 5,000 ML/day of ‘losses’ can be attributed to the Barmah-Millewa forests as losses would also occur due to other uses upstream of the forests. Actual return flows would be dependent on flood duration and antecedent conditions, amongst other factors. It should be noted that this figure cannot be extrapolated to higher flows as other processes appear to influence the contribution of flows to the Edward River above about 40,000 ML/day measured at the downstream Yarrawonga gauge.

While acknowledging that inundation of large areas of floodplain ecosystems on a biennial basis will require significant volumes of water, it should be recognised that diversions for environmental watering are not completely “lost” from the river system. A considerable proportion of floodwaters return to the river. Whilst difficult to estimate based on current knowledge, it is expected that between 50-80 per cent of floodplain flows return to the river following a flood event. Actual return flows would be site specific and depend on flood duration and antecedent conditions, amongst other factors.

8.7.4 Flooding conclusions

To achieve the interim ecological vegetation objectives for the Barmah-Millewa forests, flows in the order of 35,000 ML/day are likely to be required. These are significantly higher flows (effectively double) than the original 18,300 ML/day desirable flow event defined in the Icon Site Management Plan. Floods are expected to become significantly less frequent under climate-change Scenarios B and Cmid (see Table 8.11). Analysis conducted for this assessment has indicated that under 2030 climate change (Scenario Cmid), the average frequency of floods >25,000 ML/day may reduce from occurring every 3.2 years (under historic climate, scenario A) to every 5.4 years, with the maximum period between floods increasing from 12.7 to 17.6 years. Therefore inundation extents beyond 25,000 ML/day are unlikely to be achievable at the frequency required for sustaining river red gum vegetation.
Figure 8.6: Barmah–Millewa modelled inundation extents for NSW (NSW regulators open for flows <25,000 ML/day; all regulators open for flows >25,000 ML/day) (Water Technology, 2009)
Figure 8.7: Millewa-modelled inundation extent of floodplain vegetation communities for 15,000 ML/day (at Yarrawonga Weir), all NSW regulators open (adapted from Water Technology, 2009)
Figure 8.8: Millewa-modelled inundation extent of floodplain vegetation communities for 25,000 ML/day (at Yarrawonga Weir), all regulators open (adapted from Water Technology, 2009)
Figure 8.9: Millewa-modelled inundation extent of floodplain vegetation communities for 45,000 ML/day (at Yarrawonga Weir), all regulators open (adapted from Water Technology, 2009)
Figure 8.10: Milawa-modelled inundation extent of floodplain vegetation communities for 60,000 ML/day (at Yarrawonga Weir), all regulators open (adapted from Water Technology, 2009)
Given the current easement constraints of 25,000 ML/day between Hume Dam and Lake Mulwala, there is also limited potential to artificially deliver larger floods to the forest unless easements are increased. The delivery of floods larger than 25,000 ML/day to Milloka forests depends on contributing natural flood flows from the unregulated Ovens River being passed downstream of Lake Mulwala/Yarrawonga Weir.

While there is confidence that 18,300 ML/day can be delivered to the Barmah-Millewa forests into the future, based on the information gathered from this assessment, this type of flow is unlikely to achieve the vegetation element of the Living Murray Program ecological objectives for the combined forest. Regulator structures within Milloka forests may allow the distribution and depth of flood waters in localised areas to be manipulated.

At 25,000 ML/day, hydrodynamic modelling indicates that the extent of inundation in Milloka Forest includes 86 per cent of river red gum very tall forest, plus 32 per cent of river red gum tall open forest, and 5 per cent of river red gum-box woodland.

### 8.8 Koondrook-Perricoota and Campbells Island forests

The assessment for Koondrook-Perricoota and Campbells Island includes:

- site characteristics and water requirements
- future water availability and flooding regimes
- the likely impacts of future water availability for the associated forests.

#### 8.8.1 Site characteristics

The Gunbower-Koondrook-Perricoota Icon Site, composed of the Gunbower Forest in Victoria and the Koondrook-Perricoota

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**Table 8.12: Inundation of Koondrook-Perricoots forests** (MDBC, 2008, cited in GHD, 2009)

<table>
<thead>
<tr>
<th>River flow (ML/day)</th>
<th>Inflow to forest (ML/day)</th>
<th>Inundated area in hectares/% of total</th>
<th>River Red Gum forest</th>
<th>River Red Gum woodland</th>
<th>Total River Red Gum forest</th>
</tr>
</thead>
<tbody>
<tr>
<td>15,000</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>20,000a</td>
<td>300</td>
<td>500</td>
<td>2%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>25,000</td>
<td>1,500</td>
<td>1,030</td>
<td>54%</td>
<td>2,060</td>
<td>3,520</td>
</tr>
<tr>
<td>30,000b</td>
<td>3,800</td>
<td>1,330</td>
<td>70%</td>
<td>7,400</td>
<td>10,300</td>
</tr>
<tr>
<td>35,000</td>
<td>6,500</td>
<td>1,885</td>
<td>99%</td>
<td>16,245</td>
<td>25,000</td>
</tr>
</tbody>
</table>

a – inflows to forest via Burrumbarry Creek start at 16,000 ML/day
b – channel capacity of Murray River is 30,000 ML/day, beyond which overtopping and broad area flows commence

---

**Table 8.13: Natural (pre-regulation) flood frequencies of the Koondrook-Perricoota Forest vegetation communities** (MDBC, 2006b)

<table>
<thead>
<tr>
<th>Water regime class</th>
<th>Frequency</th>
<th>Duration</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>River Red Gum with flood dependent understorey</td>
<td>7–9 years in 10</td>
<td>4 months</td>
<td>Winter/spring</td>
</tr>
</tbody>
</table>

---

**Table 8.14: Target water requirements for meeting ecological objectives** (Forests NSW, 2008b)

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Measure</th>
<th>Target</th>
<th>Preferred</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extent</td>
<td>Proportion of River Red Gum forest (with water-dependent understorey) inundated</td>
<td>30%</td>
<td>&gt;70%</td>
</tr>
<tr>
<td>Timing and duration</td>
<td>Between August and December for at least three consecutive months</td>
<td>Sep, Oct and Nov</td>
<td>Aug–Sep, Oct, Nov–Dec</td>
</tr>
<tr>
<td>Frequency</td>
<td>Number of inundations</td>
<td>50% of natural</td>
<td>Natural precedent</td>
</tr>
<tr>
<td></td>
<td>Maximum period between inundations</td>
<td>4 years</td>
<td>Natural precedent</td>
</tr>
</tbody>
</table>

The objective is 55 per cent healthy vegetation, including virtually all river red gum forest and some woodland. This flow estimate is based on the recent hydrological modelling for the Barmah-Millewa Forest (Water Technology, 2009), and preliminary assessments conducted by the MDBA (Burns, I, MDBA, pers. comm., 2009).
forests in NSW covers approximately 50,000 hectares of Murray floodplain (MDBC, 2006b).

The Koondrook-Perricoota forests are State Forest, covering approximately 32,000 hectares. This area is managed by Forests NSW and is included in the NSW Central Murray State Forests Ramsar site. To the north-west of the Koondrook-Perricoota forests is the Campbells Island forest. These forests together incorporate the second largest area of river red gum forest after the Millewa forests.

The Koondrook-Perricoota forests are located downstream of the Hume and Dartmouth Dam and the Barmah Choke and has been significantly altered by river regulation (MDBC, 2006b). High banks on the river channel inhibit flooding by low flows from entering the forest. The decline in forest health was noted as early as 1948 in some areas (MDBC, 2006b).

Torrumburry Weir is located near the south-eastern end of the Koondrook-Perricoota forests. The weir is used to raise the level of the Murray River by approximately 6 metres (Forests NSW, 2008b). The flow at Torrumburry Weir depends largely on flows in the Murray River at Barmah and the flow from the Goulburn River that joins the Murray River near Echuca. The magnitude of flooding in the Koondrook-Perricoota forests is strongly dependent on whether flows in the Murray River and Goulburn River coincide (MDBC, 2005).

The flow of floodwater through the Koondrook-Perricoota forests is dominated by the Burrrumbury-Barber Creek system. Torrumburry Weir, being at the upstream end of Koondrook-Perricoota forests, creates a head of water to provide flow into the Burrrumbury Creek system which enters through two inflow effluents at Swan Lagoon when the Murray River flow exceeds 16,000 ML/day (Forests NSW, 2008b; GHD 2009). This flow does not inundate a significant portion of the forest, with broad area flows observed when the flows exceed channel capacity in the Murray (>30,000 ML/day) (GH, 2009). Table 8.12 shows the inundation of the forest at different flow rates of the Murray River.

Water requirements of Koondrook-Perricoota are targeted to achieving a closer representation of conditions that occurred under natural (pre-regulation) conditions (MDBC, 2006b). This comprises a cycle of regular periodic surface flooding in winter and spring, combined with annual summer/autumn drying (Table 8.13). Regulation and consumptive demands of the river have resulted in a decrease of the frequency of flooding to once every 10–12 years (DECC, 2008).

The Living Murray Program specifies that environmental water will be used for Koondrook-Perricoota forests to maintain and restore a mosaic of healthy floodplain communities:

- 80 per cent of permanent and semi-permanent wetlands in healthy condition
- 30 per cent of river red gum forest in healthy condition
- successful breeding of thousands of colonial waterbirds in at least three years in ten
- healthy populations of resident native fish in wetlands (MDBC, 2006b).

The water requirements to achieve these objectives are listed in Table 8.14.

The closer the flood frequency to the natural precedent, the greater the ability of the floodplain to maintain the functional, structural and compositional attributes of its natural state. However, Forests NSW considers the minimum target for reduced flood frequency to be half the natural frequency (Forests NSW, 2008b).

Optimum flooding for the Koondrook-Perricoota forest requires high flows in the Goulburn, medium to high flows in the Murray River and a high flow in the Wakool (Forestry Commission, 1992 cited Forests NSW, 2008b). It is technically difficult to supply the volume of water required to simulate a natural flood through deliberate releases (Forests NSW, 2008b).

There is no specific environmental water allocation for the Koondrook-Perricoota forests, and to date there has been no substantial recovered water under The Living Murray program, delivered to the site, despite the poor state of the health of the forest (MDBC, 2007a). There has been a minor 1 GL use of adaptive environment water to water Pollack Swamp in the north-west via private infrastructure on two occasions (MDBC, 2007a).

Forests NSW are currently undertaking a project to install new water management infrastructure to divert water into the Koondrook-Perricoota forest from the Torrumburry Weir pool. This is referred to as the Koondrook-Perricoota Flood Enhancement Works.

The Koondrook-Perricoota Forest Flood Enhancement Works aims to:

- maximise the effectiveness of more frequent lower flood peaks
- deliver water to 30–52 per cent of the forest
- connect the river with thousands of hectares of potential fish breeding habitat
- maintain waterbird breeding colonies
- maintain the essential process that sustains the forest
- restore and maintain foraging and breeding habitat across the forest for a range of species (Forests NSW, 2009b).

The completion of these works is critical to maintaining the ecological character of these forests.

The structural works will allow up to 6,000 ML/day flow to be passed through the constructed delivery channel. Forests NSW has outlined the main structural components of the proposal as:

- an excavated channel to connect Bullock Head Creek and the Burrrumbury Creek System to the Torrumburry Weir pool to enable the flow of water into the forest
- upstream structures to allow diversion of water into the forest from Torrumburry Weir and escape regulators at Swan Lagoon, to prevent flows re-entering the Murray River
- downstream structures to prevent water leaving the forest and to maximise return flows back to the Murray River. This will include a return channel and a floodway to increase water returns to the Murray River
- downstream stoplog regulators will be implemented to control the flow of the water out of the forest.
a levee around the downstream perimeter of the forest is required to protect adjoining properties from flooding (Forests NSW, 2009b).

Forests NSW completed the preliminary environmental assessment for this project in April 2009 and plan to complete construction by mid-2011.

8.8.2 Future water availability

The CSIRO MDBSY Project

The CSIRO MDBSY Project studied the flooding implications in Gunbower-Koondrook-Perricoota forests under a range of climate scenarios. These three scenarios are defined earlier in this chapter.

Implications on flooding for Gunbower-Koondrook-Perricoota forests were assessed for the beneficial spring-summer flood, defined as the 30,000 ML/day (for a period of 30 days in August–January). Table 8.15 shows the likely implications of each of the scenarios on the beneficial flood frequency. Under scenarios B and Cmid (step-climate change and 2030 climate change) floods exceeding 30,000 ML/day are likely to occur less frequently, and with a lower average flood volume per year and per event.

Future water availability for Gunbower-Koondrook-Perricoota forests under the CSIRO MDBSY assessment does not include:

• additional environmental water from the 500 GL/year to be recovered and applied to the six Icon Sites under The First Step decision of the Living Murray initiative

• future water availability of Commonwealth environmental water holdings that will arise from the Water for the Future Program, or

• operation of the Koondrook-Perricoota Forest Flood Enhancement Works.

The Living Murray Environmental Works and Measures Program

The Living Murray program has recently undertaken modelling that:

• examined the degree to which environmental water requirements of the Icon Sites can be met with the 500 GL under historical climate conditions, and the potential impact of climate change (to 2030), and

• indicates the feasibility and benefits of structural works proposals for the relevant Icon Sites, to inform investment decision-making under the Environmental Works and Measures Program (EWMP) (TLM, 2008).

Icon Site-specific infrastructure has been investigated under the EWMP to identify how the Icon Sites can be efficiently

Table 8.15: Environmental indicator values under Scenarios A, B and Cmid, plus per cent change (from Scenario A) in indicator values for Scenario Cmid (CSIRO, 2008a)

<table>
<thead>
<tr>
<th>Gunbower-Koondrook-Perricoota forests</th>
<th>A</th>
<th>B</th>
<th>Cmid</th>
<th>B</th>
<th>Cmid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average period between floods</td>
<td>3.8</td>
<td>5</td>
<td>4</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>Maximum period between floods</td>
<td>11.8</td>
<td>38</td>
<td>21</td>
<td>219</td>
<td>77</td>
</tr>
<tr>
<td>Average flood volume per years</td>
<td>118</td>
<td>12</td>
<td>57</td>
<td>-90</td>
<td>-52</td>
</tr>
<tr>
<td>Average flood volume per event</td>
<td>401</td>
<td>52</td>
<td>221</td>
<td>-87</td>
<td>-45</td>
</tr>
</tbody>
</table>

Note: this data does not include proposed flood enhancement works discussed
watered, given that floods from the river are no longer frequent enough to sustain the health of the system. The operation of the Koondrook-Perricoota Forests Flood Enhancement Works was modelled in this investigation.

Two levels of operation – a preferred operation and a minimum operation – have been modelled for each of the works and water proposals, so that a broad-sensitivity analysis could be undertaken for the investment decision. The preferred operating strategies reflect the operation of the water and work proposals and are used to test the feasibility of the proposals under the current climate. The minimum operating strategies represent the minimum water use/requirement needed to deliver the environmental outcomes that would support investment, and have been modelled using the 2030 median climate change scenario (Scenario Cmid) to conduct a sensitivity analysis to test the viability of structures in low water years.

The two operating strategies tested for the Koondrook-Perricoota Forest Flood Enhancement Works are listed in Table 8.16.

The objective of the study was to prove the feasibility of the works, and it was considered that if the tested flood events could be delivered, then the works were worth building. The modelling does not represent how the works would operate in reality and is not conclusive about the limits of what could be delivered.

The modelling found that the water requirements of Koondrook-Perricoota Forest (as per the operating strategies in Table 8.16) could be fully met by the 500 GL recovered by the First Step decision plus 70 GL of Murray River increased flows – component of the water recovered under the Snowy Water Inquiry Outcomes Implementation Deed if the proposed flood enhancement works are undertaken. The sites’ overall demand is lower than the volume of water recovered both under the preferred operation with the current climate scenario (Scenario A) and also for the minimum operating regime under a 2030 climate change scenario (Scenario Cmid).

The operation of the Koondrook-Perricoota Forests Flood Enhancement Works is detailed in the Preliminary Works Operation Plan (NSW Department of Commerce, 2009). As stated in the plan, the Flood Enhancement Works has been designed to provide the flexibility to operate within a range of flows to sustain a range of ecological processes, for example:

- frequent, low flows to maintain the wetland habitats occurring in lagoons, depressions and flood runners
- less frequent floods of medium magnitude to maintain the extent of the river red gum communities, with larger floods maintaining the extremities, and smaller floods supporting the core areas with flood-dependent understorey communities
- floods of long duration to cue and facilitate bird breeding.

The proposed scheme is capable of inundating up to 52 per cent of the forest (with the 6,000 ML/day event), but cannot maintain this extent. Maximum maintainable extent is 41 per cent, with this reducing quickly during the flood recession. The decision to water will be based on the water requirement of the ecological system and the availability of water, and it will be guided by the series of Watering Principles, and tempered by risk management strategies (NSW Department of Commerce, 2009). Unregulated water will be used when beneficial, and overbank flows will be favoured as a cue for initiating watering.

<table>
<thead>
<tr>
<th>Operating strategy</th>
<th>Preferred</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flood frequency</td>
<td>1 in 3 years</td>
<td>1 in 3 years</td>
</tr>
<tr>
<td>Intervention watering duration</td>
<td>105 days</td>
<td>100 days</td>
</tr>
<tr>
<td>Diversion rate</td>
<td>6,000 ML/day for 50 days, then 3,400 for 55 days</td>
<td>2,000 ML/day</td>
</tr>
<tr>
<td>Threshold/criteria to start operation</td>
<td>&gt;6,000 ML/day available flow at Torumberry</td>
<td>&gt;2,000 ML/day available flow at Torumberry</td>
</tr>
<tr>
<td>Threshold/criteria to stop operation</td>
<td>&gt;34,000 ML/day at Torumburry for 3 months</td>
<td>&gt;26,000 ML/day at Torumburry for 3 months</td>
</tr>
<tr>
<td>Maximum time between events</td>
<td>4 years</td>
<td>7 years</td>
</tr>
</tbody>
</table>

Koondrook State Forest on the Murray River

Table 8.16: Koondrook-Perricoota operating strategies assessed in TLM modelling (TLM, 2009)
Figure 8.11: Modelled maximum inundation extents for Koondrook-Perricoota – 2,000 ML/day (DHI Water and Environment, 2008)
Figure 8.12: Modelled maximum inundation extents for Koondrook-Perricoota – 6,000 ML/day (DHI Water and Environment, 2008)
The plan comments that the exact ecological outcomes of the proposed structures will be unknown until they have been operated in real time under a range of conditions. The exact nature of both unregulated and regulated river flows, and the quantum of environmental water available, is unknown. Consequently, operation of the structures will be altered in line with adaptive management principles in order to react to the ecological response observed.

### 8.8.3 Future flooding regime

A floodplain inundation model for Koondrook-Perricoota forests with the proposed Flood Enhancement Works was developed in 2008 for the NSW Department of Commerce (DHI Water and Environment, 2008). The model outputs include flooding extents for four flow options. Table 8.17 summarises the results of this model run.

The spatial data for maximum flood extents at 2,000 and 6,000 ML/day was overlaid on vegetation types mapped for this project to determine the extent of vegetation types inundated. Table 8.18 summarises the results of this assessment. Figures 8.11 and 8.12 map the inundation extent by vegetation type for these two flow rates.

Based on flood extent modelling, the peak flood event for the flood enhancement works (6,000 ML/day) would inundate 52 per cent of the Koondrook-Perricoota forests. This comprises inundation of 55 per cent river red gum tall open forest and 56 per cent of river red gum–box woodland. The minimum flood event (2,000 ML/day) would inundate 34 per cent of the Koondrook-Perricoota forests. This comprises inundation of 38 per cent river red gum tall open forest and 33 per cent of river red gum–box woodland.

<table>
<thead>
<tr>
<th>Water regime class</th>
<th>Frequency</th>
<th>Duration</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>6,000 ML/day</td>
<td>78.5</td>
<td>45</td>
<td>52</td>
</tr>
<tr>
<td>4,000 ML/day</td>
<td>78.45</td>
<td>75</td>
<td>47</td>
</tr>
<tr>
<td>3,000 ML/day</td>
<td>78.3</td>
<td>80</td>
<td>42</td>
</tr>
<tr>
<td>2,000 ML/day</td>
<td>78.1</td>
<td>80</td>
<td>34</td>
</tr>
</tbody>
</table>

Table 8.17: Flow component for steady state runs (DHI Water and Environment, 2008)

<table>
<thead>
<tr>
<th>Vegetation Group</th>
<th>Koondrook and Perricoota State Forests (Ha)</th>
<th>6,000 ML/day (Ha)</th>
<th>%</th>
<th>2,000 ML/day (Ha)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>River Red Gum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very Tall Forest</td>
<td>82</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>River Red Gum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tall Open Forest</td>
<td>25,979</td>
<td>14,263</td>
<td>55</td>
<td>9,754</td>
<td>38</td>
</tr>
<tr>
<td>River Red Gum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Woodland</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>River Red Gum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Box Woodland</td>
<td>4,010</td>
<td>2,258</td>
<td>56</td>
<td>1,319</td>
<td>33</td>
</tr>
</tbody>
</table>

Table 8.18: Vegetation groups inundated under 2,000 ML/day and 6,000 ML/day
Figure 8.13: Conceptual diagram illustrating hydrological links between Werai forests and Millewa forests (GHD, 2009)
Based on the proposed 6,000 ML/day flow event (reduced to 3,400 ML/day after 50 days) hydraulic modelling of the Flood Enhancement Works indicates that of the 466 GL diverted into the forest, an estimated 222 GL (that is, 48 per cent) will be returned directly to the Murray River (Forests NSW, 2008b).

8.8.4 Flooding conclusions

The majority of the river red gum sites (87 per cent) in Koondrook-Perricoota forests are unhealthy or stressed (Turner and Kathuria, 2008). Without the proposed flood enhancement works, floods of the necessary frequency, volume or duration to provide for the water requirements of significant areas of the forest will not occur. The Flood Enhancement Works will need to be undertaken for any significant improvement to the health of the Koondrook-Perricoota forests to be achieved.

The Living Murray modelling indicates that water requirements of Koondrook-Perricoota forests necessary to support the feasibility of the Flood Enhancement Works can be fully met by the 500 GL recovered by the First Step decision, plus the 70 GL of the Murray River Increased Flows – component. The frequency of flood events to be delivered and met in the modelling was approximately 1 in 3 years.

Based on flood extent modelling undertaken by DHI Water and Environment, the peak flood event for the flood enhancement works (6,000 ML/day) would inundate 52 per cent of the Koondrook-Perricoota forests. This comprises inundation of 55 per cent river red gum tall open forest and 56 per cent of river red gum–box woodland. The minimum flood event (2,000 ML/day) would inundate 34 per cent of the Koondrook-Perricoota forests. This comprises inundation of 38 per cent river red gum tall open forest and 33 per cent of river red gum–box woodland.

The Flood Enhancement Works will provide the flexibility to operate within a range of flows to sustain a range of ecological processes. A positive effect is expected once water is delivered. However, the exact ecological outcomes arising from operation of the proposed structures will be unknown until they have been operated in real time, under a range of conditions, and the operation of the structures will be altered in line with adaptive management principles to react to the observed ecological responses.

Significant improvements in forest health will not be achieved quickly. The Flood Enhancement Works are currently in the planning phase. Construction (estimated to be complete by mid 2011), testing, monitoring and adapting operation will follow and so there is a lengthy time period between now and effective operation of the works for significant improvement to the health of the Koondrook-Perricoota forests to be achieved.

8.9 Werai forests

The assessment for the Werai forests includes site characteristics and water requirements. Little is known of the future water availability and flooding regimes, so these areas have not been addressed.

8.9.1 Site characteristics

The Werai forests occupy an area of 11,403 hectares, including the Werai State Forest and Barratta Creek State Forest (GHD, 2009). The forests are situated approximately 46 kilometres northwest of Deniliquin, on the floodplain of the Edward and Niemur Rivers between Yadabal Lagoon and Morago (GHD, 2009). This site is not an Icon Site, however it has Ramsar-listed wetlands of international significance which include river red gum forest.

The Werai forests unit is hydrologically linked to the Millewa forests via the Edward River (Figure 8.13). When flow exceeds the Barmah Choke capacity (>10,400 ML/day at Yarrawonga Weir), substantial volumes of water are diverted down the Edward River and ultimately to the Werai Forests (GHD, 2009). The Bullatale Creek also brings water from central Millewa to the Edward River near Deniliquin during periods of high flow (GHD, 2009).

The Werai forests can be considered as having two commence-to-flow points. This means that low-flow and high-flow flooding can be managed differently.

Floodwater enters the forest via three effluents (Tumudgery Creek, Niemur River and Reed Beds Creek), all of which have regulator structures, as well as overbank flow. Generally, overbank flooding in the lower portions of the forest starts at about 2,900 ML/day at downstream Stevens Weir (downstream of Deniliquin) (GHD, 2009). Flows up to 13,000 ML/day constitute broad-area flooding (floodplain forests) (GHD, 2009). On average, the Werai forests are flooded 3 to 4 days after the Millewa forests are flooded.

Regulation has changed the flood regime of the Werai forests. Wetlands in the Werai forests that would have been inundated yearly are now only flooded infrequently (NSW MMWG, 2001). Flow events in the Edward River are not as variable as they have been, with flows at or near channel capacity for most of the year (VEAC, 2006).

There is no Environmental Water Allocation or water management plan in place for Werai forests.

8.6.2 Future water availability and flooding regime

As the Werai is hydrologically linked to the Millewa forests, future water availability in the Werai will be affected by water availability in the Murray River and Millewa forests. The reduction in the frequency of larger floods in Millewa Forest, particularly those >25,000 ML/day, will result in a subsequent reduction in flooding of the Werai. A more specific relationship between flooding in Millewa and flooding in the Werai is unknown at this time.

Hydrological modelling has not been undertaken for the Werai at the time of this investigation, therefore an assessment of specific flooding regimes and extents has not been possible.
8.10 Murrumbidgee River

The assessment for the Murrumbidgee River includes:

- site characteristics and water requirements
- environmental watering arrangements
- future water availability and flooding regimes
- the likely impacts of future water availability for the associated forests.

The Murrumbidgee River has two WMUs of interest:

- downstream of Narrandera
- the Lowbidgee/Yanga region.

Due to the availability of information on the Mid-Murrumbidgee Wetlands, this information is used to assess water availability and flooding regimes for the ‘downstream of Narrandera’ WMU.

8.10.1 Site characteristics

The Murrumbidgee River is located within southern NSW and its valley covers 87,348 square kilometres, or 8.2 per cent of the Murray-Darling Basin. The region is bounded to the east by the Great Dividing Range, to the north by the Lachlan region, and to the south and west by the Murray region.

The Murrumbidgee River rises in the Snowy Mountains to the east, and flows 1,600 kilometres westward across widening alluvial flats and onto broad plains towards its junction with the Lachlan and Murray rivers. The Lachlan confluence is in the Great Cumbung Swamp 50 kilometres north-east of Balranald. The Murray junction is about 85 kilometres further west, and this area constitutes the Lowbidgee. Figure 8.14 illustrates the river’s path.

Most of the nationally or internationally significant wetland areas are in the lower Murrumbidgee floodplain near Hay (Murray, 2008). The region includes the Fivebough and Tuckerbil Swamps Ramsar site, which is a non-riparian site near Leeton, the nationally significant Mid-Murrumbidgee Wetlands and Lowbidgee Floodplain along the Murrumbidgee River, and numerous smaller important wetlands.

The Murrumbidgee River is greatly affected by the dams of the Snowy Mountains Hydro-electric Scheme, plus diversions for irrigation and water supply, with a total of 14 dams and eight large weirs (Murrumbidgee CMA, 2008). The current level of surface water extraction in the Murrumbidgee River is relatively high, with 53 per cent of average available water being diverted for use (CSIRO, 2008b).

A study by Thornton et al. (1994, as cited in Murray, 2008) looked at hydrological changes and their effect on wetland bird breeding habitat in 96 river red gum wetlands between Wagga Wagga and Hay. The study showed that the present water regime was compromising river red gum health because it was keeping trees either too wet or too dry.
Improved knowledge of which wetlands fill at different river heights would assist in better targeting of environmental water (Murray, 2008). Murray (2008) mapped and categorised individual wetlands along the Murrumbidgee according to their hydrological category (how they receive water) and flow conditions. Maps provide information on wetland inundation for three different river flow scenarios at Wagga Wagga (up to 35,000 ML/day; up to 47,000 ML/day; and over 47,000 ML/day). The flow scenarios were based on targets set for environmental flows by the Murrumbidgee River Management Committee – Regulated (50,000 ML/day at Wagga Wagga) and physical constraints of the systems (32,000 ML/day at Gundagai). Relationships of the likely flow at Narrandera given a certain flow at Wagga are also provided.

Mid-Murrumbidgee Wetlands (downstream of Narrandera)

The Mid-Murrumbidgee Wetlands are an assemblage of lagoons and billabongs along the Murrumbidgee River, from Narrandera to Carrathool, with an estimated total area of 2,500 hectares. Wetlands are on the floodplain and receive flows from the river mostly during winter and spring floods. River red gum forest and woodlands dominate the vegetation of the area, with black box woodland being more marginal on the floodplain (CSIRO, 2008b; Environment Victoria, 2001). Land tenure is a mixture of State Forest, Crown reserves and freehold.

Commence-to-flow thresholds for billabongs and lagoons at several locations on the middle section of the Murrumbidgee River region are between 12 and 29 GL/day, and the Narrandera State Forest (a substantial wetland area) floods at 26.8 GL/day at the Narrandera gauge (CSIRO, 2008b; Hardwick et al., 2001).

The hydrology of the mid and lower Murrumbidgee floodplain wetlands has been altered by river regulation and development of irrigation areas (NSW DLWC, 1996b and AgriBusiness Task Force, 2000, as cited in Murray, 2008). This has included the occurrence of high flows in summer rather than late winter or early spring, and reductions in the flood peak heights of low and medium flood events (Murray, 2008). Since development and flow regulation commenced in the Murrumbidgee region, the average period between big floods that inundate the Mid-Murrumbidgee Wetlands has nearly doubled, and the maximum period between events has more than tripled (CSIRO, 2008b).

Lowbidgee/Yanga region

The Lowbidgee Floodplain is around the lower Murrumbidgee River, downstream of Maude, and covers some 200,000 hectares. The broader Lowbidgee is subdivided into the Nimmie-Pollen-Caira system near Maude Weir, and the Redbank-Yanga system further downstream. The floodplain receives floods overbank or via controlled diversions from Maude and Redbank weirs, which occurs most often during winter and spring (CSIRO, 2008b; Kingsford and Thomas, 2001).

Vegetation of the Nimmie-Pollen-Caira system is predominantly extensive areas of Lignum, however the Redbank-Yanga system is covered by river red gum forest and woodlands, with black box on the floodplain margins (CSIRO, 2008b; Environment Victoria, 2001). Land tenure is mostly freehold, although recently the NSW Government purchased much of the Redbank-Yanga portion (over 31,000 hectares) and dedicated a national park in 2005 (CSIRO, 2008b; DECC, 2007).

The Murrumbidgee River decreases in channel capacity in a downstream direction from a channel capacity of 35 GL/day at Hay to 20 GL/day at Maude Weir and 11 GL/day at Redbank Weir (CSIRO, 2008b; Kingsford and Thomas, 2001). Overbank flows onto the Lowbidgee Floodplain occurs at 20 GL/day (at Maude), although controlled diversions from both Maude and Redbank weirs can occur at much lower flow levels (CSIRO, 2008b).

Figure 8.14: Land use and key environmental assets in the Murrumbidgee River region (CSIRO, 2008b)
Chapter 8: Implications of changes in climate for water availability and flooding regimes

For the Lowbidgee Floodplain, the average period between high-flow events has more than tripled since flow regulation commenced and the maximum period between events has more than doubled (CSIRO, 2008b).

8.10.2 Environmental watering arrangements

Almost all of the wetlands along the mid-Murrumbidgee, downstream of Narrandera, don’t flood from regulated flows (Maguire, J, DECCW, pers. comm., 2009). Since the year 2000 there hasn’t been sufficient base flow in the Murrumbidgee River to enable effective flooding of the Mid-Murrumbidgee Wetlands. Further, there is little infrastructure along the mid-Murrumbidgee to assist managed flood events of the wetlands.

By contrast, large areas of floodplain in the Lowbidgee/Yanga and Nimmie-Pollen-Caira systems can be flooded via controlled diversions from Maude and Redbank weirs, with return flows to the river. Water releases in recent years have been directed to the Lowbidgee wetlands.

A summary of recent environmental water releases is provided in Table 8.19 below. With continued water shortages in the Murrumbidgee valley and the relative ease in directing water to large areas of the Lowbidgee, it is considered likely that mid-Murrumbidgee wetlands will continue to lose out on environmental water releases directed predominantly to the Lowbidgee.

Environmental water can be provided for the Murrumbidgee wetlands and forests through:

- environmental water allowances under the Water Sharing Plan (WSP)
- State Water through the NSW RiverBank program
- the CEWH under programs of the Water for the Future program
- the RiverReach project.

Water Sharing Plan (WSP)

WSPs provide water to support the ecological processes and environmental needs of rivers, and direct how extractive water is to be shared. The NSW Water Management Act 2000 requires that the sharing of water must protect the water source and its dependent ecosystems and that WSPs should establish specific environmental water rules.

The WSP for the Murrumbidgee Regulated River Water Source, commenced on 1 July 2004, and applies for 10 years. This WSP provides for environmental water allowances (EWAs) which are a volume of water in the dams that can be released when needed for environmental purposes. These purposes include assisting water bird breeding, flooding of wetlands, assisting fish passage or breeding, restoring water quality or maintaining flows in the lower reaches of the river which better reflect natural flows (NSW DWE, 2009).

The WSP was suspended in November 2006 due to extremely dry conditions (NSW DWE, 2009). One environmental water release was made in December 2005, prior to suspension of the WSP, totalling 14GL and inundating approximately 10,000 hectares of wetlands.

No water has been accredited to the EWA accounts in the last three years. At the time the WSP was suspended, the balance of water in the accounts was 110,000 ML (NSW DWE, 2009). Some of this water has been used to underpin water availability for critical needs in the Murrumbidgee valley during suspension of the WSP. The WSP will be reinstated when the EWA accounts are fully repaid and all high security needs are fully accounted for (DECC, 2008).

NSW RiverBank program

The NSW RiverBank program has been set up within DECCW to work within the established water access rights framework to buy water licences and manage them for environmental benefit.

The indicative investment target for RiverBank in the Murrumbidgee in 2009/10 is $8 million (DECCW, 2009). Target environmental assets in the Murrumbidgee for RiverBank 2009/10 are Yanga National Park and the Nimmie-Caira system, including areas of southern bell frog habitat; bird, fish and amphibian breeding locations; and river red gum forests and woodlands. These sites are the same as those for previous years.

The assets selected for watering under the RiverBank program reflect the relatively small amount of water that will be available to the program over this period (DECCW, 2009).

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Table 8.19: Summary of environmental water releases for Murrumbidgee environmental assets since suspension of the WSP in November 2006 (NSW DWE, 2009; Senator the Hon. Penny Wong, 28 October 2009; Maguire, J, DECCW, pers. comm., 2009)

<table>
<thead>
<tr>
<th>Date</th>
<th>Volume (ML)</th>
<th>Water Description</th>
<th>Location/Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov 2007–Apr 2008</td>
<td>8,800</td>
<td>NSW Critical water planning process, debited under EWA2 account</td>
<td>Support southern bell frog populations in Yanga National Park in the Lowbidgee</td>
</tr>
<tr>
<td>May–July 2009</td>
<td>25,000</td>
<td>WSP EWA</td>
<td>Yanga National Park and private land</td>
</tr>
<tr>
<td>Oct 2009</td>
<td>2,600</td>
<td>CEWH: 1,900 ML, WSP EWA: 1,700 ML</td>
<td>Yanga National Park/Lowbidgee floodplain to support southern bell frog populations, maintain and recover wetland habitat including river red gum</td>
</tr>
<tr>
<td>Nov 2009 (10 days)</td>
<td>600</td>
<td>WSP EWA</td>
<td>‘Piggy backed’ on top of 6,000 ML stock and domestic release</td>
</tr>
</tbody>
</table>
Commonwealth environmental water holdings

In October 2009, a total of 1.9 ML was provided to two sites in Yanga National Park on the Lowbidgee Floodplain from the Commonwealth’s environmental water holdings, purchased through the Australian Government’s Murray-Darling Basin water buyback program (Australian Government media release, 28 October 2009).

The two sites that received water contain river red gum and are important breeding areas for the southern bell frog, listed as an endangered species in NSW and as vulnerable under the EPBC Act. The sites were selected by the CEWH based on input by the NSW Government and advice from the Environmental Water Scientific Advisory Committee. The Commonwealth’s allocation of environmental water was in addition to 2GL provided by the NSW Department of Climate Change, Environment and Water.

Murrumbidgee RiverReach project

RiverReach is a joint project between the Murrumbidgee CMA and Murrumbidgee Irrigation funded by the Australian Government through the Australian Water Fund Water Smart Australia Program (DEWHA, 2009).

Table 8.20: Definition of environmental indicators (wetland commence to flood flows) assessed by CSIRO (CSIRO, 2008b)

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mid-Murrumbidgee Wetlands</strong></td>
<td></td>
</tr>
<tr>
<td>Average period between high-flow events</td>
<td>Average period (years) between flows exceeding 26.8 GL/day at Narrandera gauge</td>
</tr>
<tr>
<td>Maximum period between high-flow events</td>
<td>Maximum period (years) between flows exceeding 26.8 GL/day at Narrandera gauge</td>
</tr>
<tr>
<td>Average flooding volume per year</td>
<td>Average annual volume above 26.8 GL/day at Narrandera gauge</td>
</tr>
<tr>
<td>Average flooding volume per event</td>
<td>Average event volume above 26.8 GL/day at Narrandera gauge</td>
</tr>
<tr>
<td><strong>Lowbidgee Floodplain</strong></td>
<td></td>
</tr>
<tr>
<td>Average period between high-flow events</td>
<td>Average period (years) between flows exceeding 20 GL/day at Maude Weir</td>
</tr>
<tr>
<td>Maximum period between high-flow events</td>
<td>Maximum period (years) between flows exceeding 20 GL/day at Maude Weir</td>
</tr>
<tr>
<td>Average flooding volume per year</td>
<td>Average annual volume above 20 GL/day at Maude Weir</td>
</tr>
<tr>
<td>Average flooding volume per event</td>
<td>Average event volume above 20 GL/d at Maude Weir</td>
</tr>
</tbody>
</table>

Table 8.21: Environmental indicator values under climate-change Scenarios A, B and Cmid, and percentage change (from Scenario A) in indicator values under Scenarios B and Cmid (CSIRO, 2008b)

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>Cmid</th>
<th>B</th>
<th>Cmid</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mid-Murrumbidgee Wetlands</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average period between high-flow events</td>
<td>0.8</td>
<td>2.0</td>
<td>1.0</td>
<td>150</td>
<td>29</td>
</tr>
<tr>
<td>Maximum period between high-flow events</td>
<td>9.7</td>
<td>10.9</td>
<td>9.7</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Average flooding volume per year</td>
<td>652</td>
<td>202.1</td>
<td>443.4</td>
<td>-69</td>
<td>-32</td>
</tr>
<tr>
<td>Average flooding volume per event</td>
<td>525</td>
<td>383.3</td>
<td>451.5</td>
<td>-27</td>
<td>-14</td>
</tr>
<tr>
<td><strong>Lowbidgee Floodplain</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average period between high-flow events</td>
<td>1.5</td>
<td>3.5</td>
<td>1.7</td>
<td>133</td>
<td>16</td>
</tr>
<tr>
<td>Maximum period between high-flow events</td>
<td>10.5</td>
<td>16.2</td>
<td>10.5</td>
<td>54</td>
<td>0</td>
</tr>
<tr>
<td>Average flooding volume per year</td>
<td>509</td>
<td>132.3</td>
<td>341.0</td>
<td>-74</td>
<td>-33</td>
</tr>
<tr>
<td>Average flooding volume per event</td>
<td>785</td>
<td>486.7</td>
<td>604.5</td>
<td>-38</td>
<td>-23</td>
</tr>
</tbody>
</table>
The aim of the RiverReach project is to examine flexible and efficient approaches to offering water for environmental objectives and irrigators needs through innovative water products, giving preference to those that maintain existing irrigator rights. Water market products may supply an additional 40 GL of water during wet years to supplement environmental flows in the Murrumbidgee Valley. There is potential for the RiverReach products to augment the environmental water under the WSP or environmental water plans developed by DECCW regarding the environmental water they manage.

### 8.10.3 Future water availability

The CSIRO MDBSY Project studied the flooding implications for the Murrumbidgee River under a range of climate scenarios defined earlier in this chapter, in Scenarios A, B and Cmid.

Implications for flooding along the Murrumbidgee River was assessed based on flood frequencies exceeding 26.8 GL/d at Narrandra gauge and 20 GL/day at Maude Weir. These flood frequencies represent the commence-to-flow volumes for inundation of the wetlands. Table 8.20 presents the definition of environmental indicators used in this assessment.

Table 8.21 presents the likely flooding outcomes under each climate Scenario, A, B and Cmid. High-flow flooding sufficient to commence wetland inundation is likely to occur less frequently and be of lesser volumes (per year and per event) under climate change (Scenarios B and Cmid). This analysis does not include modelled future water availability of Commonwealth Environmental Water Holdings that will arise from its Water for the Future program. For the Mid-Murrumbidgee Wetlands, under scenario B (step-climate change) the average period between high flows would more than double to nearly two years, and the maximum period between events would increase slightly to nearly 11 years (CSIRO, 2008b). Average flooding volumes per event and per year would also be substantially reduced. Under scenario Cmid (2030 climate change) the average period between high flows would increase but the maximum period between events would not be affected (CSIRO, 2008b). The average flooding volume per year and per event would also be reduced, and so further degradation of these wetlands is likely.

For the Lowbidgee Floodplain, under Scenario B (step-climate change) the average period between high flows would more than double to 3.5 years, and the maximum period between these events would increase by over 50 per cent to more than 16 years (CSIRO, 2008b). Average flooding volumes per event and per year would also be substantially reduced. Under Scenario Cmid the average period between high flows would increase, but the maximum period between events would not be affected (CSIRO, 2008b). The average flooding volume per year and per events would also be reduced, and so further degradation to these wetlands is also likely.

### 8.10.4 Future flooding regime

The reduction in frequency and magnitude of future floods under climate change is likely to result in a reduction of the extent to which river red gum stands along the Murrumbidgee River will be inundated. A floodplain inundation model is not currently available for the Murrumbidgee River region, therefore detailed information on the extent of river red gums inundated at various flow levels is not feasible at this time.

Based on a recent internal DECCW study (DECCW, 2009), the refurbishment of existing water management infrastructure and water-flow gauging systems could provide more water to State Forests in the Murrumbidgee River (downstream of Narrandra) WMU. Cuba and MIA State Forests can be delivered environmental watering allocations via irrigation supply channels that occur on neighbouring properties. Areas of Woolooloolo State Forest are permanently inundated from Hay Weir pool and methods to allow periodic drying could also be investigated.

### 8.11 Lachlan River

The assessment for the Lachlan River includes:

- site characteristics and water requirements
- future water availability and flooding regimes
- the likely impacts of future water availability for the associated forests.

The Lachlan River has two WMUs of interest:

- Booligal Wetlands
- Great Cumbung Swamp.

### 8.11.1 Site characteristics

The Lachlan River region is located within central western NSW and covers 85,532 square kilometres, or 8 per cent of the Murray-Darling Basin. The region's topography varies from tablelands in the east, through the central slopes and onto the western plains where the Lachlan River terminates in the extensive wetlands of the Great Cumbung Swamp (Figure 8.15). Moon Moon and McFarlands State Forests receive over-bank flows from the river and are important ecological sites. State Forests further downstream are of poorer health (refer to Chapter 4).

The Lachlan region contains several large wetlands of national importance; however there are no wetlands classified as Ramsar sites of international significance (CSIRO, 2008c). The Booligal Wetlands and the Great Cumbung Swamp are amongst the most notable sites.

The Lachlan River is regulated with large storages, and flows are also affected by major water extractions (CSIRO, 2008c). The NSW Government recently decided to reduce flows from Wyangala Dam from 500 ML/day to approximately 250 ML/day (NSW Office of Water, 2009). This will result in no flows into Wallamundry Creek, Nerathong Creek and Wallaroi Creek; and a reduction in flows passing Condobolin.

### Booligal Wetlands

The Booligal Wetlands cover approximately 5,000 hectares on the lower Lachlan River, situated on the low-gradient braided channels of the Muggabah-Merrimajeel Creek, a distributary creek system which leaves the Lachlan River. The wetlands include the Booligal Swamp and Little Gum Swamp. The latter has a dominant over-storey of river red gum (CSIRO, 2008c; Magrath, 1992). Flood flows into the system are infrequent and the area drains rapidly once floods in the river recede (CSIRO, 2008c; Environment Australia, 2001).
Large-scale water bird breeding is understood to occur in the Booligal Wetlands when flows exceed 2,500 ML/day for a period of two months at the Booligal gauge (CSIRO, 2008c; Driver et al., 2005).

As a result of water resource development, the average period between winter-spring floods entering the Booligal wetlands has increased from 6.2 years to 8.3 years (34 per cent), and the maximum period between these events has increased from 18.7 to 22.2 years (9 per cent) (CSIRO 2008c).

These changes are consistent with observed substantial reductions in the frequency and size of waterbird breeding events in the Booligal wetlands.

### Great Cumbung Swamp

The Great Cumbung Swamp is around 16,000 hectares at the terminus of the Lachlan River and is adjacent to the Murrumbidgee River and the Lowbidgee Wetlands. The swamp is dependent on flood flows in the Lachlan River (CSIRO, 2008c; Environment Australia, 2001). River red gum and black box cover large areas of the swamp (CSIRO, 2008c). Broad-scale flooding of the swamp is understood to occur when flows exceed 3,000 ML/day at the Booligal gauge (CSIRO, 2008c; Brady et al., 1998), but an optimal duration has not been specified for these events.

The Great Cumbung Swamp has suffered from water regulation. There has been a substantial increase in the average period between winter-spring flood events from 1.2 years to 2.5 years (102 per cent) (CSIRO, 2008c). The maximum period between these events has also increased from 6.6 years to 16 years (143 per cent).

These changes are consistent with observed deterioration in the condition of vegetation in the Great Cumbung Swamp (CSIRO, 2008c).

#### 8.11.2 Future water availability

The CSIRO MDBSY Project completed an assessment of sustainable water yields in the Murray-Darling Basin. Climate and hydrological modelling was conducted for a range of scenarios including:

- Scenario A – historical climate, with current development
- Scenario Cmid – future climate to 2030, with current development.

Scenario B – step climate change was not modelled for the Lachlan.

Table 8.22 lists the environmental indicators used in this study. The Booligal wetlands flow used represents the trigger for water bird breeding in the wetlands. The Great Cumbung Swamp indicator corresponds to significant flooding in the swamp (CSIRO, 2008c).

Table 8.23 provides the modelled results for each indicator under climatic Scenarios A and Cmid. High-flow flooding sufficient to achieve water bird breeding and wetland inundation is, in general, likely to occur less frequently and be of lesser volumes per year (but not per event), under 2030 climate change (Scenario Cmid).

For the Booligal Wetlands, under 2030 climate change (Scenario Cmid) the average period between winter-spring inflows into the wetlands would increase by a further 24 per cent (CSIRO, 2008c), which would likely reduce the frequency of waterbird breeding events in these wetlands (CSIRO, 2008c). However, the maximum period between events would not be affected.

For the Great Cumbung Swamp, under 2030 climate change (Scenario Cmid) the average period between winter-spring flood events would increase by a further 24 per cent, and the maximum period between these events would increase by a further 16 per cent (CSIRO, 2008c). These increases are likely to have an...
adverse affect on the vegetation of the swamp, of which a large portion is river red gum, and its use by waterbirds (CSIRO, 2008c).

8.11.3 Future flooding regime

Future flooding is expected to decrease in frequency and magnitude (extent) under climate change. This is on top of already significant decreases which have occurred due to river regulation. This will likely reduce the extent to which river red gum stands along the Lachlan River are inundated. A floodplain inundation model is not currently available for the Lachlan region, therefore detailed information on the extent of river red gums inundated at various flow levels is not feasible at this time.

Table 8.22: Definition of environmental indicators assessed by CSIRO (CSIRO, 2008c)

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Booligal Wetlands indicators</strong></td>
<td></td>
</tr>
<tr>
<td>Average period between high-flow events</td>
<td>Average period (years between flows in excess of 2,500 ML/day at Booligal gauge for 2 months between 15 May to 15 November</td>
</tr>
<tr>
<td>Maximum period between high-flow events</td>
<td>Maximum period (years between flows in excess of 2,500 ML/day at Booligal gauge for 2 months between 15 May to 15 November</td>
</tr>
<tr>
<td>Average flooding volume per year</td>
<td>Average flow volume above 2,500 ML/day at Booligal gauge for two months between 15 May to 15 November per year</td>
</tr>
<tr>
<td>Average flooding volume per event</td>
<td>Average flow volume above 2,500 ML/day at Booligal gauge for two months between 15 May to 15 November per event</td>
</tr>
<tr>
<td><strong>Great Cumbung Swamp indicators</strong></td>
<td></td>
</tr>
<tr>
<td>Average period between high-flow events</td>
<td>Average period (years between flows in excess of 3,000 ML/day at Booligal gauge for 2 months between 15 May to 15 November</td>
</tr>
<tr>
<td>Maximum period between high-flow events</td>
<td>Maximum period (years between flows in excess of 3,000 ML/day at Booligal gauge for 2 months between 15 May to 15 November</td>
</tr>
<tr>
<td>Average flooding volume per year</td>
<td>Average flow volume above 3,000 ML/day at Booligal gauge for two months between 15 May to 15 November per year</td>
</tr>
<tr>
<td>Average flooding volume per event</td>
<td>Average flow volume above 3,000 ML/day at Booligal gauge for two months between 15 May to 15 November per event</td>
</tr>
</tbody>
</table>

Table 8.23: Environmental indicator values under Scenarios A and Cmid, and percentage change (from Scenario A) in indicator values under Scenario Cmid (CSIRO, 2008c)

<table>
<thead>
<tr>
<th>Name</th>
<th>A</th>
<th>Cmid</th>
<th>% change from A</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Booligal Wetlands indicators</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average period between high-flow events</td>
<td>8.3</td>
<td>10.3</td>
<td>24</td>
</tr>
<tr>
<td>Maximum period between high-flow events</td>
<td>22.2</td>
<td>22.2</td>
<td>0</td>
</tr>
<tr>
<td>GL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average flooding volume per year</td>
<td>40.7</td>
<td>32.2</td>
<td>-21</td>
</tr>
<tr>
<td>Average flooding volume per event</td>
<td>376</td>
<td>394.8</td>
<td>5</td>
</tr>
<tr>
<td><strong>Great Cumbung Swamp indicators</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average period between high-flow events</td>
<td>2.5</td>
<td>3.1</td>
<td>24</td>
</tr>
<tr>
<td>Maximum period between high-flow events</td>
<td>16</td>
<td>18.6</td>
<td>16</td>
</tr>
<tr>
<td>GL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average flooding volume per year</td>
<td>47</td>
<td>36.2</td>
<td>-23</td>
</tr>
<tr>
<td>Average flooding volume per event</td>
<td>124</td>
<td>119.0</td>
<td>-4</td>
</tr>
</tbody>
</table>
According to an internal study by DECCW (2009), only large-scale infrastructure to divert river flows will assist the resilience of the Lachlan River forests and the study suggested that it is not practical to consider such options.

This analysis does not include modelled future water availability of Commonwealth environmental water holdings that will arise from its Water for the Future program.

8.12 Other forests and riparian zones

Smaller river red gum forest stands are supported within the Upper and Lower Murray River riparian zone WMUs, and the Edward and Wakool River riparian zone WMU.

The assessment for these WMUs includes:

- site characteristics and the impact of regulation on water availability
- comments on implications for flooding where possible.

8.12.1 Upper Murray River riparian zone

The Upper Murray River riparian zone is located between Albury and Tocumwal. The flow regime of this zone is significantly modified by the storages of Hume Dam, Yarrawonga Weir and the Snowy Mountains Scheme. The National Land and Water Resources Audit 2000, in its hydrological disturbance index, rated the zone as moderately modified (NWC, 2007).

The effect of regulation varies throughout the zone. At Albury, the river flows have increased compared to natural flows as a result of extra water diverted from the Snowy Mountain Scheme. Downstream of Yarrawonga, annual flow is 25 per cent less than natural conditions, but summer flow is 19 per cent greater than natural (Gippel and Blackham, 2002). Flow variability has been decreased and water level is held at relatively constant near capacity discharge for much of the year. Seasonality has been altered, and the frequency and duration of winter-spring flooding has been reduced (Gippel and Blackham, 2002). The summer and autumn flows are higher than natural whilst winter and spring flows are lower. Overall, the average annual flow is approximately 6 per cent higher than natural conditions (MDBC, 2006c).

Regulation has increased the proportion of total flow passing down the river channel from about 88 per cent to 94 per cent. During high flows the remaining 6 per cent overtops the bank and inundates the floodplain (MDBC, 2006c).

As annual rainfall tends to increase and evaporation to decrease, from west to east and from north to south across the bioregion, the reliance of river red gum forests on surface flooding is reduced in the Upper Murray River riparian zone.

The analysis of forest condition in the bioregion undertaken by DECCW using SLATS (Pennay, 2009) and discussed in Chapter 4 indicates that the forests in the Upper Murray riparian zone are more resilient to climate change. The SLATS data available from 1988 to 2009 were used to observe changes
in projected foliage cover, indicative of condition and moisture stress in the river red gum forests of the bioregion. The Upper Murray forests exhibited a general slight increase in projected foliage cover over the period from 1988 to 2008 with slope values of 0.14 and 0.2. A stable or increased projected foliage cover over the past two decades, including the last decade of extreme drought and low flows, acts as a coarse indicator of forests that are more resistant to a water-constrained future environment (Pennay, 2009). The forests along the Upper Murray River riparian zone are included in this category.

The Barooga group of forests is known to be in good condition, and are comprised almost entirely of river red gum. Elsewhere, river red gums have been cleared over much of the floodplain and riparian zone. There are, however, isolated sections of riparian zone and floodplain that have reasonable indigenous vegetation associations, particularly toward the upstream and downstream ends (ID&A, 2001). Regeneration is notable in several areas within the zone. Woody weeds, predominantly willows, are scattered throughout this zone with several sections dominated by exotic vegetation (ID&A, 2001).

To meet its commitments downstream for town water supply, irrigation and environmental flows, the MDBA can legally release flows of up to 25,000 ML/day along the reach between Hume Dam and Lake Mulwala (Brown, P., GHD, pers. comm., 2009). This is known as the regulated channel capacity. One of the positive impacts of this release is the potential for survival of river red gum stands. This volume is historically regarded as bank full along this reach. Due to the passage of time and an aggrading channel bed, the definition of bank full has changed and a number of the Murray River channels have changed shape and dominance. Some of these channels are now located on private land. As a result, the 25,000 ML/day now impacts on private land. The MDBA has set up a framework and model for determining relief packages for landholders facing inundation and access issues due to the regulated river flow regimes (Brown, P., GHD, pers. comm., 2009). This 25,000 ML/day is the same easement constraint referenced earlier under the Barmah-Millewa discussion, and may be increased in the future.

The forests along this reach would receive flooding (by flows exceeding 25,000 ML/day) during spills from Hume Dam. However, the potential to provide environmental water during regulated periods is currently limited due to the current regulated channel capacity.

The local shallow groundwater systems would be augmented by high river levels over summer during irrigation releases, and this may also contribute to sustaining river red gum forests along this reach between Hume Dam and Lake Mulwala.

8.12.2 Wakool and Edward rivers riparian zone

Downstream of Deniliquin the Edward River emerges onto a broad, flat floodplain. Enclosed between the Edward and Murray Rivers and fed from the Edward River, the Wakool River is part of an extensive network of high-level anabranches. During major flood conditions, approximately 50 per cent of the total flow passing Deniliquin leaves the Edward River via the Wakool River and Yallakool Creek (MCM, 2006).

Parts of the Wakool River system adjoin the Koondrook-Perricoota forests, one of The Living Murray six icon sites, and comprises hundreds of kilometres of rivers and creeks. The river system and adjoining forest are recognised as having high ecological value (MDBC, 2007).

As a consequence of prolonged and extreme drought conditions and a high level of regulation upstream, the water in the system is diminishing to a series of disconnected waterholes (MDBC, 2007). In 2008, the continuous environmental flows for the system ceased. Now only occasional pulse flows are provided to the system (WSC, 2009). Options for infrastructure to effectively deliver environmental water allocations to this WMU are limited (DECCW, 2009).

8.12.3 Lower Murray River riparian zone

The forests contained within the Lower Murray River riparian zone are possibly the least frequently flooded and most stressed forests in the Riverina bioregion. The hydrological regime of this section has been significantly changed. Less than half the natural median annual discharge now reaches the border with South Australia (Gippel et al., 2002). Periods of prolonged low flow are more frequent. The frequency, duration and magnitude of all but the largest floods have been reduced (Gippel et al., 2002). This results in a reduction in the inundation extent and frequency of the adjacent floodplain and associated vegetation. Gol Gol, Euclon, Moorna and Lake Victoria State Forests are situated alongside weir pools so there are possible minor infrastructure options available to artificially flood these forests (DECCW, 2009). State Forests such as Ki, Mallee Cliffs and Manie can only receive water during very high Murray River flows. There are limited options for artificial flooding of the forests in the Lower Murray River riparian zone (DECCW, 2009).

8.13 Groundwater

There is evidence that river red gums use groundwater opportunistically as a water source in forests of the Riverina bioregion. As an environment dries, river red gums will make a transition from using water from the shallow unsaturated zone to using groundwater, provided that the quality is sufficiently fresh and watertable accessible. Hence, some communities can be highly dependent on groundwater in prolonged dry periods and times of water scarcity.

Flooding is a significant recharge mechanism in the shallow floodplain groundwater systems of the Riverina bioregion. Flood recharge is likely to be more significant than rainfall recharge and regional groundwater flow in some areas but this varies from site to site and is not yet well understood.

Groundwater levels in both deep and shallow aquifers in the Riverina bioregion are falling due to groundwater extraction and recent climatic conditions. The current and future impact on the floodplain ecosystems is not well understood, but it is likely that groundwater has and will become less accessible as a source of water for vegetation. This will have negative impacts on vegetation health if specific populations are dependent on this groundwater, to any degree, in times of water scarcity.

The following section outlines:

- the degree to which river red gum and other woodland forests of the Riverina bioregion are groundwater dependent ecosystems (GDEs)
- the geomorphological, hydrogeological, surface water flooding and groundwater processes and factors which affect this dependence
- case studies giving evidence of river red gum communities using groundwater as a water source are presented.
Figure 8.16: Geomorphic regions of the Murray Basin (Brown and Stephenson, 1991)

Figure 8.17: Conceptual model of shallow groundwater recharge (after Holland et al., 2006)
8.13.1 Geology and hydrogeology

The geomorphology and geology of the Murray Riverine plain (eastern Riverina bioregion) has been described by Pels (1964, 1966) while the Mallee and Murray Trench areas (western Riverina bioregion) have been described by Bowler and Magee (1978) and more recently Brown and Stephenson (1991) as shown in Figure 8.16. Although the regional geology of the two regions is quite different, the above mentioned studies and others since, have shown there to be similar variation in the presence and extent (horizontally and vertically) of clay and sand units within the current river floodplains. This has a significant impact on the hydrogeology of the area at a local scale and the mechanisms by which plant communities can access groundwater. Clay layers, for example, can restrict groundwater recharge but have deeper capillary fringes than sands, giving young plants access to deeper groundwater.

8.13.2 Groundwater recharge

There are three important large-scale recharge mechanisms which maintain the shallow floodplain groundwater of the Riverina bioregion. These are discharge from regional groundwater systems, diffuse recharge from rainfall and flood recharge. It is thought that regional discharge could be important if regional flows slow and levels fall (i.e. due to climate change, low rainfall periods, groundwater extraction) while the latter two mechanisms are thought to be the most significant on a local scale for the floodplain. Flood recharge is likely to dominate over rainfall recharge during floods. However, there are many areas of the floodplain which do not flood as frequently and historically are more likely to depend on rainfall recharge.

Any change in flood frequency or magnitude due to anthropogenic and climatic factors is likely to cause changes to the quality and levels of shallow groundwater. It is useful to describe the various sub-mechanisms of flood recharge since they influence the effectiveness of any given flood in recharging the shallow groundwater.

Local flood recharge to the lower Murray floodplain occurs through four main processes as shown in Figure 8.17. (after Holland et al., 2006). It is thought that these processes occur in a similar fashion across the floodplain systems upstream but clearly the complexity of local geomorphology, surface water and groundwater regimes will add variation to this simplified conceptual model. On the right-hand side of the figure (A), vertical recharge is shown to occur through both clays and sands during floods or periods of prolonged rainfall. Recharge through sands is generally more effective than through clays and significant diffusen recharge can occur in meander belt areas of previous river paths, breaks of slope and dune systems. Vertical recharge through clays (B) is initially dominated by flow through preferential pathways such as surface cracks which extend vertically and macropores which can then close as clays swell. Near the river, bank recharge (C) occurs through bank sediments can reach tens of meters horizontally into the aquifer during high flow or flooding events and potentially further when frequent or prolonged high flow and flooding occurs (depending on flood heights and the hydraulic properties of the bank sediments). The left side of the figure, recharge is a combination (D) of vertical recharge through clays (likely dominated by initial rapid recharge through cracks and macropores, followed by slower diffuse recharge) and bank recharge through bank sediments.

It is understood that the recharge to floodplain areas (observed as groundwater rise) is primarily dependent on the flood height and duration. This has been explored on the Lindsay-Mulcra-Wallpolla floodplains by Richardson et al. (2007) and other previous studies. The change in groundwater elevation was plotted against flow and a linear relationship was found for each monitoring bore. The increase in groundwater level with increase in flood height, is likely to be a combination of a pressure response in the aquifer and physical recharge to the aquifer from inundation. The increase in groundwater response with larger flows could be due to the inundation of specific areas of higher permeability soils where local recharge can occur more effectively.
Vertical recharge through these soils is thought to be the most effective recharge mechanism for floodplains and it may be possible to identify these areas and predict the flows required for them to become inundated. Studies of this nature have not been done to date. Richardson et al. (2007) found that the significance of the range of groundwater level changes for vegetation health would depend on factors including: depth to groundwater, groundwater salinity and soil type.

The water balance of the Koondrook-Perricoota forests are dominated by recharge from overbank river flows (Salient Solutions, 2007) and it is commonly assumed that flood recharge is an important mechanism for many of the floodplain areas in the Riverina bioregion.

8.13.3 Groundwater discharge

In reaches where the groundwater levels (both shallow local systems and regional systems) are above the levels of surface water features (such as creeks, oxbow lakes or rivers), groundwater discharge will occur. In the Mallee/Murray trench area of the Bioregion, regional groundwater generally flows towards the Murray River both horizontally and vertically upwards although the actual connection and dynamics of the flow towards or away from the river is variable. Discharge towards the Murray changes the salinity balance of shallow groundwater systems, dependent on flooding events and the effectiveness of local recharge. Hence, it is common for areas that do not receive regular recharge from river floods and are regional discharge zones such as the Lindsay River area, to be relatively barren landscapes due to higher salinities of shallow groundwater (Dudding, 1992).

In the eastern parts of the Riverina bioregion (that is the Riverine Plain) regional groundwater flow is generally parallel to the surface streams and at great depth. In these environments, the rivers and streams are connected to shallow groundwater systems that are closely controlled by surface water flows and are typically losing or maximum losing in the lower reaches (CSIRO, 2008d).

Evapotranspiration by deep rooted vegetation (i.e. river red gums and black box) is also a significant groundwater discharge mechanism (Hatton and Evans (1998); Holland et al. (2006); Mensforth et al. (1994); Thornburn et al. (1993); and others). As referenced in Salient Solutions (2007) data from the CSIRO has indicated that red gums may be able to transpire at rates up to 2mm/day from shallow water tables and riparian forests may have root systems that can access groundwater to depths of at least 13 metres. Similarly, Doody et al. (2006) have measured transpiration from river red gums of up to near 1.5 mm/day which is thought to be sourced from groundwater when shallow soil water is not available. Estimates of the groundwater use by plant communities on a larger scale have not been done and upscaling from measurements made on individual trees or forests can be problematic.

8.13.4 Current status and trend of groundwater in the bioregion

Over the last century, there has been a number of changes in surface water flow regimes and regional groundwater trends which have different impacts for shallow groundwater systems and the ecosystems of the Riverina bioregion.

Regional and local trends in groundwater levels

The regional groundwater trend across the NSW Riverina bioregion is generally falling in both deep and shallow aquifers (URS, 2008). Rates of decline vary widely and there are many exceptions but deeper aquifers have fallen by tens of metres with smaller declines in shallow aquifers as a result of

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**Figure 8.18: Location of Southern Riverine Plains groundwater model** (Goode and Barnett, 2008)
groundwater extraction and additionally from recent climate conditions. There has been a reversal of vertical gradients (from upwards to downwards) between shallow and deep aquifers in the Murray region of Victoria and NSW (Dudding (2004); Salient Solutions (2007)). This trend is most likely due to the high rates of groundwater extraction in the deeper aquifers for irrigation and a lag in the response of the shallow aquifers. This has the potential to decrease the occurrence of salinity issues in shallow aquifers in irrigation areas and conversely is likely to lead to increasing salinities in the deeper aquifers (as initiated by mixing with the now downward flowing saline groundwater).

The relevance or scale of these potential impacts on the Riverine Plain and Mallee has not been specifically assessed. Salient Solutions noted that the hydraulic gradient under the Koondrook-Perricoota forests has changed direction, and there is now a discharge of the shallow groundwater system to deeper layers, thus reducing the overall volume of shallow groundwater available for use by trees (Salient Solutions, 2007).

An assessment of the impact of groundwater pumping on the Southern Riverine Plain (amongst other components) was done by Goode and Barnett (2008) using MODFLOW (see Figure 8.18). The model showed that 42 per cent of current groundwater extraction (2004/2005 values), was sourced from river depletion and the bulk of the remainder from captured groundwater evapotranspiration. This finding is highly significant for ongoing survival of plant communities which are dependent on accessing this groundwater as either a primary or occasional water source.

There is some local variation in shallow floodplain aquifers (primarily along the Murray River) which have been heightened in some areas where discharge from irrigation groundwater mounds is occurring and where the installation of locks has permanently elevated river levels (URS, 2008). Many of the irrigation mounds have begun to or have dissipated between the two most recent Murray-Darling Basin Groundwater Status reports (Ife and Skelt, 2004; and URS, 2008).

The contrasting trends at the local scale cannot be broadly resolved since the dominance of one trend over another will depend on local hydrogeological and other conditions. More detailed and specific description and assessment of the spatial and temporal variation of these groundwater level trends are found in Ife and Skelt (2004) and more recently URS (2008).

**Local salinity impacts**

Along river reaches where, due to river regulation, river levels are moderated or adjacent to locks which result in a permanent heightening of the river level, the influence of bank recharge may have increased and widened the extent of near-river fresh shallow groundwater. Locally, these groundwater systems have been forced to re-equilibrate to higher river levels despite regional falling trends. It is possible that this has impacted the ability of shallow floodplain aquifers to discharge groundwater (which is often saline).
River regulation has also resulted in a decrease in the frequency and magnitude of flooding which results in less effective recharge events to the shallow floodplain groundwater systems (also in terms of frequency and magnitude). This reduces the availability of shallow (unsaturated zone) fresh water for use by trees and has had impacts to vegetation health in many areas. The higher groundwater levels across some of the floodplains have also brought the watertable to within capillary fringe distance of the ground surface.

When the watertable is close to the surface, evaporation and evapotranspiration concentrate the salts in the unsaturated zone of shallow soils. If this salt is not flushed via recharge events or flooding, then the salinity can have adverse impacts on vegetation communities. The groundwater salinity tolerances of black box and red gums are quite high as reported by Munday et al. (2008) being up to 55 dS/m and 30 dS/m respectively (as measured in the lower Murray part of the bioregion). However, it is doubtful that these species could survive and recruit new generations with water sources of this salinity (Lebbink and Lewin, 2008).

The dynamics of salt accumulating and flushing due to flooding has been studied in much detail in specific floodplain areas using a number of techniques such as WINDS modelling, airborne geophysics, mass balance and flux calculations (recently by Overton et al. (2006a); Munday et al. (2008); Salient Solutions (2007); Pritchard et al. (2009); Richardson et al. (2007); and others). Most of this work has been done in the Murray Trench where the salt load dynamics are influenced by groundwater mounding in irrigation areas (which have recently been found to be dissipating (URS, 2008) in addition to regional saline groundwater discharge.

The flooding frequency has been found to impact the salt loads associated with this discharge as described by Pritchard et al. (2009) for the Wallpolla, Mulcra and Lindsay floodplains. It was found that salt loads to surface water features were related primarily to the groundwater gradients which are dependent on flood frequencies (i.e. higher salt loads in early – mid 1990’s due to higher flood frequency and higher groundwater gradients compared to recent salt loads). The flooding events have the capacity to flush salts from the shallow soil and unsaturated zone, down to the shallow groundwater before the groundwater discharges to surface water features. A study by Passfield et al. (2008), modelled the effectiveness of flood frequency in leaching salts from the shallow soils. They found that the period of flooding was more important than the salinity of the flood water and suggest that the use of irrigation drainage water could be considered if it meant more frequent floods could occur.

8.13.5 Groundwater dependence of river red gum forests and woodlands

The long-term viability of any vegetation community is dependent on the availability of fresh water, whether from shallow or deeper unsaturated zone of soils, from the unsaturated capillary fringe above the watertable or the groundwater directly. Vegetation generally will access and use water sources which are of the lowest salinity with expenditure of the least amount of energy (that is, fresh and shallow before more saline and deep sources). Therefore, as an environment dries, shallow unsaturated soil water is commonly used by plants first. If this source is exhausted, then plants may transition to the use of groundwater as their primary water source (provided the groundwater is within reach of the root zone and sufficiently fresh). If shallow or deep unsaturated zone sources of water are regularly unavailable (i.e. periods of low rainfall and low flood frequency) then plant communities will be forced to make a transition to groundwater as a water source. At the same time, shallow groundwater levels are likely to be falling (due to lack of recharge). Hence, the plants may not be able to chase the watertable quickly enough to survive (as has been evident in the Banksia woodlands of Western Australia, see Eamus et al. (2006) and Fresh and Bertuch (2007).

The following paragraphs give examples of where groundwater has been shown to be a major source of water to river red gums in the Riverina bioregion.

Mensforth et al. (1994) showed that river red gums in the Chowilla floodplain more than 15 metres from the stream margin largely used groundwater (in summer and a combination of groundwater and rainfall-derived soil water in winter). Trees closer to the river used direct river water or flood-derived soil moisture. This work was indirectly supported by the work of Pritchard et al. (2009) via the analysis of bore hydrographs on the Lindsay–Wallpolla Floodplain.

It is thought that some stands of river red gums in the bioregion are maintained in good health by interactions with groundwater rather than through direct flooding. Wen et al (2009) found that the condition of some river red gum stands (close to the channel or permanent water bodies) was not significantly related to flooding history and might suggest that the predominant factor was groundwater. In the Ecological Character description of the lower Lachlan wetlands, Capon et al. (2009) suggested that areas of red gums in the Great Cumbung Swamp are likely to be groundwater dependent. This however requires further investigation as the long-term nature of this relationship has not been directly studied.

A conceptual understanding of groundwater behaviour in the Koondrook-Perricoota forests was developed by Salient Solutions (2007, 2008). These studies found that river red gum populations were likely to be accessing groundwater as a water source at depths of at least 13 metres below ground when shallower water sources were unavailable. The forests were found to be undergoing dynamic changes as a result of the surrounding irrigation development, the changes in flood frequency in the streams and rivers, and most significantly, the impacts from groundwater extraction to the east and south. The responses of vegetation communities to these changes (i.e., transition to groundwater use and impacts on vegetation health) are currently only reasonably understood. It is expected that this situation would be similar at the Milawa Forest and other sites in the region.

There is limited detailed understanding of the complex interactions between surface water and groundwater in the Riverina bioregion in regard to the impact on river red gum health with the exception of a limited number of sites which have been well studied (including Koondrook and Perricoota forests in NSW and others in Victoria (Wallpolla, Mulcra, Lindsay) and South Australia (Chowilla)). These are important processes in determining vegetation responses to a range of watering regimes, however methods for predicting responses on a large scale are limited. This is currently being investigated and assessed as part of the development of the Basin Plan by the MDBA and additionally, the NWC has initiated a project to identify the location and nature of groundwater dependent ecosystems on a national scale.
Chapter 8: Implications of changes in climate for water availability and flooding regimes

8.13.6 Quantifying river red gum groundwater use

From a water resource management perspective it is important to understand the water balance and water demand of each component of the hydrological system. This allows informed decisions to be made in regard to water requirements for agriculture, industry and environment for the current and future conditions. Additionally, if species such as river red gums are reliant on groundwater to maintain their health in times of water shortage, knowledge of these water requirements become extremely important if the populations are to survive. Historically, it has been difficult to close this water balance since groundwater evapotranspiration has been largely unknown, not considered or roughly estimated (Evans, pers. comm., 2009).

Measurements of evapotranspiration from plant communities has been done using field measurements of sap flow and pan evaporation measurements on a site by site basis or by comparison of historical aerial or satellite images on a larger scale. Although this has been useful for adding to the understanding of specific communities, it has not allowed an assessment of water use by vegetation on large spatial and temporal scales since up scaling can be problematic and detailed temporal data, unavailable.

An emerging methodology for calculating evapotranspiration has been developed by Waterwatch and recently implemented in Australia using Modus (or Landsat) imagery. The method is called Surface Energy Balance Algorithm for Land and has compared extremely well with other field based and modelling methods (see Evans et al., 2009). The method allows daily analysis at the resolution of the satellite image over broad spatial scales and it has the potential to be applied in a wide variety of applications in Australia (i.e. closing the water balance).

An example of this application is shown in Figure 8.19, from the preliminary results of the Water Balance Study for Murrumbidgee River (Sinclair Knight Merz, 2009). Thirty sites were randomly selected in the area near the Murrumbidgee River, with average rates for 10 sites from each category shown in the figure. It can be interpreted that the difference between the dryland evapotranspiration and the red gum evapotranspiration is roughly equivalent to groundwater evapotranspiration, assuming that these communities are using groundwater as their primary water source. More work is needed to confirm this assumption (i.e. compare with groundwater levels, antecedent conditions and hydrogeological and plant water use understanding) but the potential applications of this method are vast. A similar comparison was roughly applied in the Barmah Forest with a difference of 170 mm/year seen between a cleared area and red gum forests approximately 100 metres from the Murray River (Evans, pers. comm., 2009).

Future studies are required to quantify groundwater evapotranspiration to close the water balance and gain a large-scale, quantified understanding of current and likely future environmental water requirements under current and future climate conditions.

8.13.7 Potential impact of climate change on groundwater and groundwater-dependent ecosystems

The demand on water resources will undoubtedly increase as a result of climate change and put further pressure on both current water use practices and the environment. Groundwater extractions, reduced rainfall and reduced frequency and magnitude of flooding will all impact on groundwater levels and are likely to adversely impact the shallow groundwater systems and groundwater-dependent ecosystems of the Riverina bioregion.
In a study by the CSIRO which modelled groundwater recharge in the Murray-Darling Basin, it was determined that recharge to the groundwater system will decrease by a factor of 2–3 times the decrease in rainfall (Crosbie et al., 2008). Into the future, this likely decrease in recharge would lower regional groundwater levels and cause the nature of the surface water–groundwater interaction to change. For example, river reaches which are neutral or losing to the groundwater system may become losing and maximum losing, resulting in further reductions in river flows.

The further reductions in frequency and magnitude of surface flooding under climate change will also impact on recharge of groundwater in floodplain areas. Soil salinity issues are also likely to be heightened with greater water scarcity and the decreased frequency and magnitude of flood events.

The MDBSY Project for the Murray region found that “of the future developments considered, the increases in groundwater extraction would have noticeable impacts on the hydrology of some of the Icon Sites” (CSIRO, 2008d). One example of the likely outworking of this finding is that the groundwater levels under Barmah-Millewa and Gunbower-Koondrook-Perricoota forests would be expected to fall by up to one metre in addition to the reduction in groundwater level under current levels of groundwater extraction.

Groundwater modelling was undertaken as part of the MDBSY study to assess the relative impacts of various climate scenarios and groundwater pumping on the state of the groundwater resources in the Southern Riverine Plains (Goode and Barnett, 2008). The modelling demonstrated that 42 per cent of current groundwater pumping (2004/2005 values as current) was sourced from surface water sources (river depletion) and that under future scenario modelling this increased to 58 per cent. The majority of the remainder of the groundwater volume extracted was sourced from captured or reduced groundwater evapotranspiration. The study also suggested that groundwater evapotranspiration was the groundwater discharge process that is most sensitive to climate change, and that this is likely to be mostly realized by losses in water availability to groundwater-dependent ecosystems. The report concludes that “current groundwater use has already and will continue to cause significant drawdown in groundwater levels across the Riverine Plains. As a result continued groundwater extraction at current rates will draw heavily on surface water resources and is possibly already impacting GDEs.” River red gum forests including Koondrook-Perricoota are identified in this study as possible GDEs.