Ecological Responses to Environmental Watering in the South Australian River Murray Valley

Final Report for Australian Water Environments and SA Water
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Acknowledgements

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Photographs by Anne Jensen

Cover photo: Healthy river red gum saplings (centre left of picture) on watered flood-runner at Rilli Reach (Stanitzkis), South Australian Riverland; photo taken during rising flood in December 2016 (see Figure 2 for comparison with initial seedlings in 2012)
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Ecological Responses to Environmental Watering in the South Australian River Murray Valley

Executive Summary

Water has been returned to the environment at multiple sites in the South Australian River Murray Valley since 2013. This project undertook a monitoring program designed to assess ecological responses to environmental watering within Salt Interception Scheme (SIS) influenced-zones, as part of a larger project undertaken by Australian Water Environments for SA Water, to evaluate the effect of SISs on groundwater, floodplain soil salinity and floodplain vegetation condition.

Monitoring was undertaken at 23 sample sites on 6 locations in the Riverland region of the South Australian River Murray Valley, from Waikerie to Loxton, with all locations within the zone of influence of SISs.

Water delivery at the monitored sites was coordinated by Nature Foundation SA (NFSA) through their Water For Nature initiative. SA Water was a key partner in on-ground delivery of environmental water, as well as coordinating operation of the SIS projects. A key focus of the environmental watering projects was on sustaining the mass germination of black box seedlings following the 2011 flood peak, when flows which peaked at 93,872 ML/d inundated black box communities at intermediate elevations on the Lower Murray floodplain.

Water delivery since 2013 has been focused on supporting regeneration triggered by the 2010-12 floods, primarily large fields of black box seedlings. These seedlings are seen as having special environmental value, as this was the first mass germination of black box since the early 1990s, and there are few surviving mature black box from seedlings which germinated in large flood events in the 1970s or 1990s. The recent peak in December 2016 of 94,865 ML/d inundated the same sites again for a short period, only 1-2 weeks' duration at the highest elevations of flood extent but up to 6 weeks at lower elevations.

The environmental watering projects also focused on improving the condition of stressed mature red gum and black box trees, promoting seed production and volume, and supporting healthy lignum shrublands.

Sampling sites and data collection were designed to cover a range of age and condition in the three key perennial floodplain plant species, viz. river red gum, black box and lignum. Monitoring covered the period March 2015 to June 2017, with a total of 15 monitoring visits needed to cover all sites in all seasons, due to access issues during wet conditions (rain or flood) and unusual flowering patterns which emerged. Parameters monitored focused on tree condition, phenological cycles to establish timing of flowering and subsequent maximum seed fall, and survival of seedlings germinated following the floods in 2010-2012.

At watered sites, floodplain vegetation showed significantly greater rates of growth and volumes of crops (buds, flowers and fruit containing seed) in mature trees, and stronger recovery from drought stress, compared to non-watered sites. Watered sites showed significantly higher canopy condition scores and a significantly more vigorous growth response following the 2016 flood event.

The background condition of vegetation communities across the floodplains, initially very stressed following the Millenium drought 2000-2010, improved due to the beneficial effects of the 2010-2012 series of flood events on soil moisture availability, combined with above average rainfall events in 2012 and 2014 and the 2016 flood event. However, a decline in condition was noted in the dry period between the 2010-12 floods and the 2016 flood.
Monitoring results supported all three hypotheses which were being tested, as discussed below. The vigorous growth in all three indicator species demonstrated that addition of water at the surface replenished and maintained soil moisture availability for access by the shallow root systems of red gum, black box and lignum (Hypothesis 1). Very high survival rates of 2011-germinated seedlings were recorded at both watered and non-watered sites, with negligible deaths recorded to June 2017.

Environmental watering during 2015-2017 was delivered to these sites by mid-summer as far as practical, based on evidence that late spring-early summer was a key production point in the phenological cycle for red gum and black box (Hypothesis 2). Eucalypts at watered sites demonstrated not only increased crop volumes but also started to develop dual crop cycles, thus with capacity to shed seed every year. Previous data collected in drought conditions indicated a single biennial cycle for red gum and black box, with seed shed every second year (Jensen et al. 2007).

Results from all sites confirmed that watering promoted seasonal leaf grown and development of bud crops (Hypothesis 3).

Data from this project also found that the sequence from bud to flower in healthy trees could be as short as 3-4 months, with one, two or three flowering events from the same bud crop, subject to local annual climatic conditions. With multiple flowering events, it is possible that seed release events could occur across different seasons from the one plant. If this becomes the case in future years, the timing of application of environmental water becomes less critical, with water in any season likely to be beneficial in supporting volume of crop production and retention of mature fruit on trees until timing of optimum seed release.

All floodplain ecosystems throughout the Riverland have shown improvement in condition since 2010, due to beneficial effects of flood events and unusual rainfall patterns. Seedlings generated in the 2010-2012 flood event are showing very high survival rates, whether watered or not. However, all watered sites have shown additional growth up to 2-3 times greater than non-watered sites, above the baseline improvement. Watered seedlings are 2-3 times more vigorous and taller than non-watered seedlings.

All floodplain sites have very large numbers of dead mature red gum and black box, and stressed mature trees mostly as a result of the Millenium drought. Survival of the current cohort of germinants will be critical to filling major age gaps in vegetation communities, to continue recruitment of dominant perennial trees and shrubs.

The from this project confirm the usefulness of using timing of key stages of phenological cycles to indicate optimum timing for application of limited environmental water to enhance natural germination events, and to sustain and improve health of key floodplain vegetation communities. The positive outcome is that the natural processes of seed production and vegetative growth are demonstrably still active when sufficient water is available, and environmental watering can be applied effectively to reinforce natural processes to support and maintain recruitment in floodplain vegetation communities.

The continuing beneficial impact of SISs in controlling the saline groundwater flux to floodplains will be essential to allow the development to maturity of hundreds of thousands of black box seedlings and saplings, to fill the generation gaps in black box communities which have not had successful widespread recruitment since the 1956 flood. Lignum communities have also had a big boost, with thousands of seedlings to complement vegetative reproduction. Red gum seedlings are also needed to survive to replace dead and stressed mature trees.

The SISs will be critical to minimising future salinity impacts on maturing seedlings and future volumes of seed crops from mature trees, particularly in extended dry periods between flood events.
Figure 1  Location of the Lower Murray Valley in South Australia, showing locations of environmental watering sites sampled March 2015 to June 2017

Locations
1  Clarks Floodplain
2  Rilli Reach Stanitzkis
3  Thiele Flat
4  Loxton Riverfront Reserve
5  Hart Lagoon
6  Ramco Lagoon

Figure 2  Red gum seedlings germinated under dead red gums along a flood-runner at Rilli Reach Stanitzkis in 2012 (left); following environmental watering in 2014-15 and 2015-16, had reached heights above 6-8 m June 2017 (right). See also cover photo
Introduction

Under the Water Act 2007 and the Murray-Darling Basin Plan (2013), water is being returned to the environment to mitigate the impacts of over-allocation of water from the river system. In addition, a series of salt interception schemes (SIS) has been constructed since the 1980s to reduce the rate of flow of highly saline groundwater entering the river mainstream.

This project undertook a monitoring program designed to assess ecological responses to environmental watering within zones of influence of salinity interception schemes. It forms an input to a larger project coordinated by Australian Water Environments for SA Water, to evaluate the environmental, social and economic benefits of salinity interception schemes, particularly in locations where environmental watering is occurring.

Water delivery at the monitored sites is coordinated by Nature Foundation SA (NFSA), which has a 10 GL/y water allocation for 5 years (2012-2017) from the Commonwealth Environmental Water Holder (CEWH). This allocation is managed through NFSA’s Water For Nature initiative, and SA Water is a key partner in on-ground delivery of water.

Management of SISs is coordinated for the Murray-Darling Basin Authority by SA Water regional staff in Berri.

Six sites were selected for monitoring in the Riverland region of the South Australian River Murray Valley, in locations within the zone of influence of salinity interception schemes. The sites were located in the Lock 4 -- Loxton reach downstream of Berri, and at Ramco Lagoon in the vicinity of Waikerie. Hart Lagoon, upstream of Ramco Lagoon, was monitored as a control site, with no environmental watering but with a salinity interception scheme. All sites were wholly or partially inundated during high river flows in 2011 and 2016.

Regional Context

The Murray-Darling Basin in south-eastern Australia has a catchment of more than 1,000,000 km², with the slow-flowing, turbid River Murray flowing more than 2300 km through semi-arid lowlands to the Murray Mouth in South Australia. The river meanders through a broad valley up to 10 km wide from the border for 375 km downstream to Overland Corner, and then is contained within a narrow gorge 1-2 km wide (the Murray Trench) for 220 km to Wellington, before discharging into Lake Alexandrina and eventually reaching the sea through a series of five barrages between barrier islands. The region of interest in this study is the Riverland region of the Lower Murray Valley, from the South Australian border with Victoria downstream past Waikerie (Figure 1). Individual study locations are described in detail in Appendix 1.

The Lower Murray Valley from Mildura to the river mouth is fully regulated by a series of weirs, as well as the barrages. The impact of river regulation, coupled with extensive upstream storages and high levels of water diversions have had major impacts on the flow regime, with very significant reductions in flood frequencies, duration and extent of inundation of floodplains. Environmental impacts have included serious decline in vegetation condition and lack of regeneration, and environmental watering aims to address these problems.

SISs are designed to intercept the accelerated flow of groundwater towards the river and floodplains, and to prevent discharge of highly saline groundwater to the mainstream or floodplains. The impact on riverine ecosystems of increased salinity on floodplains is exacerbated by the reduction in frequency and duration of freshwater inundation by small to medium floods.
Historic Floodplain Condition
The agreement to return water to the environment under the Water Act 2007 to compensate for changed flow regime acknowledges the impact of river regulation and water abstraction, which has reduced over-bank flows and flood events.

Over the past 90 years this altered water regime has resulted in lower-lying temporary wetlands becoming permanent, while also greatly reducing watering frequency and duration of higher elevation floodplain and wetland sites, and interrupting connectivity to the mainstream.

Regulated flows since the 1920s have had significant impacts in the Lower Murray downstream of Wentworth, including:

- changed water regime -- flow peaks delayed one month, meaning hotter, drier conditions on floodplain for germination & breeding
- flow peaks much less frequent, shorter duration, less moisture
- many wetlands permanently inundated by raised river levels, no longer temporary
- key floodplain plants not recruiting in sufficient numbers or in full range of habitats.

Vegetation Condition
A major impact of the changed water regime is the reduced frequency of flooding on the River Murray floodplain, which has caused very serious decline and death of floodplain vegetation. After fourteen years (1996-2010) without their key water source from flooding, river red gum and black box trees (Myrtaceae: Eucalyptus camaldulensis, E. largiflorens) were stressed and dying. Mature red gums on the floodplain require inundation of the floodplain every 2-3 years, while black box can endure 10 years without flooding, if there is local rainfall. During the drought years, lignum (Muehlenbeckia florulenta) was in a dormant state, with large areas of lignum communities appearing to be dead. These three species are the primary deep-rooted perennials of floodplain vegetation, and they are key indicators of ecosystem health.

Since the floods of 2010-2012, there has been significant regeneration of all three species, but it is patchy and its survival to reproductive age is dependent on continuing availability of water. Its value is heightened by the previous failure of regeneration following floods in the 1970s and 1990s. It has become apparent that black box in particular has not had significant survival to reproductive age (recruitment) since 1956.

Salinity Impacts
The Murray groundwater basin stores a very high volume of accumulated salt, and the River Murray is the natural drainage outlet for this salt to travel to the ocean. Water management actions and irrigation activities have mobilised significant quantities of this salt store and accelerated its movement towards the River. Salinity management has been a priority since the 1968 drought, when salinity levels exceeded the tolerance of salt-sensitive irrigated crops. SISs have been installed since the early 1980s to intercept and divert saline groundwater at a series of points along the length of the River in Victoria and South Australia.

The installation of these schemes has had the additional benefit of reducing the accumulation of salt on floodplains, thus improving the potential for recovery where environmental watering is applied to a floodplain protected by an adjacent SIS. While native floodplain plants have high tolerance for salinity, they cannot survive extended periods without fresh water, or with only extremely saline water as their only water source. Sites with rising groundwater levels and reduced fresh water inundation from floods have seen significant decline and death of floodplain vegetation.
Recent Context for Environmental Watering

The impacts of the historic changes in water regime on the Lower Murray led to reports in the late 1980s of declining vegetation condition (Margules & Partners, et al. 1990). This decline was significantly exacerbated by the Millennium drought (2000-mid 2010), with no effective over-bank flows from 1996 to 2010, causing severe damage and decline, particularly in floodplain vegetation communities of river red gum (Eucalyptus camaldulensis) and black box (E. largiflorens). By 2004, more than 70% of eucalypts were dead, dying or stressed (MDBC, 2003, 2005). Lignum (Muehlenbeckia florulenta) became dormant and failed to reproduce during drought conditions.

2011 Flood Peak

The extended extreme dry conditions of the Millennium drought were followed by above average rainfall and serial flood peaks from September 2010 to 2012, with the highest peak flow of 93,872 ML/day in February 2011 in the Riverland (Figures 3-4). As a result of these flood flows, there was a surge of regeneration in river red gum, black box and lignum, with particularly valuable regeneration in black box and lignum, given long gaps since the last significant regeneration events for these species.

The flood peaks in 2011 and 2012 were unusually late, in February and April respectively, and wetted areas did not dry out for more than 12 months. In addition, unusually high monthly rainfall in February 2012 and February 2014 provided an additional source of water to maintain the mass germination of seedlings triggered in February 2011.

Widespread over-bank flows occur in the Riverland reaches at flows >40,000 ML/d. The flow event mid-November 2010 to early May 2011, which peaked on 13 February 2011 at 93,872 GL/d, had continuous flows >40,000 ML/d for 170 days. The second peak of 60,070 ML/d on 3 April 2012 had 71 days of flows >40,000 ML/d from 22 March to 31 May 2012.

![Figure 3](flows.png)

Figure 3  Flows into South Australia from October 2010 to January 2017, showing peaks in February 2011, April and September 2012 and December 2016. No over-bank flows (>40,000 ML/d) were experienced from October 2012 to October 2016. (Data source: WaterConnect live river data)
2016 Flood Peak

The peak flow into South Australia on 30 November 2016 of 94,865 ML/d was marginally but not significantly higher than the peak of 93,872 ML/d in February 2011 (Figure 5). The primary difference between the two events was that the extended inundation of the 2011 flow event followed 10 years of severe drought, while the shorter 2016 event was just in time to reinforce the beneficial effects of the 2010-2012 flows, before vegetation condition began to decline due to reduced water availability. The 2016 event had continuous flows $>40,000$ ML/d for 75 days. It features a long slow increase in flows, but a very rapid recession, when levels dropped $>2$ m in 7 days and wetland cycles were terminated abruptly.

Figure 4  Detail of the 2011 flow event, with its extended slow rise and slow recession, giving 170 consecutive days of over-bank flows.  
(Data source: WaterConnect live river data)

Figure 5  The profile of the 2016 flow event, with a slow rise in levels from mid-October to the peak in late November-early December, and the sharp recession in mid-late December.  
(Data source: WaterConnect live river data)
Rainfall Influence

Local rainfall is also an important element in germination and survival of germinants, with above average rainfall >300 mm coinciding with high river flows associated with recruitment (survival to reproductive age) of both black box and red gum (George et al. 2005).

The most consistent long-term BOM data in the Riverland is from Renmark, with 118 years of records. Analysis of these data showed a historic pattern of highest monthly rainfall volumes in September and October, which would coincide with the highest likelihood of unregulated seasonal high river flows linked to rainfall and snow melt in the upper Murray catchment (Jensen 2008).

Climate data from the Loxton Research Centre provide a 30 year record located closer to the monitored sites (Appendix 2). The mean annual average rainfall is 262.8 mm. Examination of the rainfall patterns from 2000 to 2011 shows a highly variable pattern, with occasional high rainfall events in summer. Loxton rainfall figures for the monitoring period 2000-16 showed very significant anomalies from 30 year average monthly rainfall volumes, with extended dry periods punctuated by large spikes of a-seasonal monthly rainfall volumes far above the average (Figure 6). During this period, high summer monthly rainfall events (>2 x monthly mean) occurred in 2000, 2003, 2004, 2005, 2007, 2010-11 and 2011. Rainfall in spring was significantly less than mean in 2002, 2003, 2006, 2007, 2008 and 2011. Thus, average monthly rainfall volumes are not useful indicators of likely future conditions.

Above average local summer rainfall coincided with the flood events of February 2011 and April 2012, replenishing soil moisture availability. Although there was a period of 8 consecutive months of significantly below average rainfall in 2012-13, this was followed by significant winter and spring rainfall in 2013. 2014 was wet in the first half, with February rainfall 5x mean and April rainfall nearly 3x mean, followed by a dry period of 6 months in the last half of the year. Rain events in 2015 featured 2x mean falls in April and November. 2016 started with 2x mean rainfall in January, then three dry months, 2x mean rainfall in May, average rain through winter, then 5x mean rainfall in September, below mean in October and November, and close to mean for December 2016. The extreme rainfall spike in September 2016 preceded the flood event October-December 2016 which peaked at 94,865 ML/d and flooded the same extent of SA Riverland floodplains as the 2011 peak flow.

Regional rainfall in 2016 was 346 mm, compared to the 30 year annual average of 262.8 mm (Loxton Research Centre rainfall records, Bureau of Meteorology data). Exceptional monthly rain events occurred in January 2014 and September 2016, with extended dry periods from July to December 2014, May to October 2015 and February to May 2016.

No seasonal patterns of rainfall have emerged in the period 2000-2016. Very high rain events (>2x mean) have occurred in all months except July, viz. January (4), February (4), March (4), April (5), May (4), June (1), August (1), September (2), October (3). November (1), December (2). These include exceptional rain events (>5x mean) in January (1), February (2), September (1) and December (1).

Maximum temperatures in 2015-16 have been close to average, with above average temperatures in spring-summer 2015 coming after a period of 6 months of below average rainfall (Figure 7), coinciding with a decline in vegetation condition.

Conditions in 2011-12 and 2016 met the criteria for red gum and black box recruitment, with flows >40,000 ML/d and annual rainfall > 300mm for red gum, and >80,000 ML/d and annual rainfall >300 mm for black box (George et al. 2005). Extensive regeneration occurred following the 2010-12 flood series, but has not been found on any similar scale up to June 2016.
Figure 6  Loxton monthly rainfall records 2012-2016, showing dry periods (red circles) and exceptionally wet events (blue circles).
(Data source: Loxton Research Centre, Bureau of Meteorology)
Figure 7  Loxton monthly rainfall and mean maximum temperatures for 2015-16 (top graph), and comparisons with the 30 year averages for maximum mean monthly temperature and average monthly rainfall (lower graphs).
(Data source: Loxton Research Centre data, Bureau of Meteorology)
Location of Study Sites

Ecological responses to environmental watering were recorded March 2015 to June 2017 at 23 tree sample sites at six locations in the Riverland region of the River Murray Valley in South Australia, from near Berri to Ramco, downstream of Waikerie (Figure 1). These included four locations in the reach from Lock 4 to Loxton, at Clarks Floodplain, Rilli Reach Stanitzkis, Thiele Flat and Loxton Riverfront Reserve (Figure 8). Two locations were downstream of Waikerie, at Hart Lagoon and Ramco Lagoon.

The primary site with 14 tree sample sites is at Clarks Floodplain (500 ha), near Weir No 4 (at river distance 511 km). More detailed descriptions of each site are provided in Appendix 1.

The series of watering sites on the eastern floodplain of the River Murray Valley between Weir No 4 at Bookpurnong and Loxton are located on sections of floodplain which are held in both public and private ownership. Environmental watering on these sites complements the much larger government-funded Katfish Reach project on the western floodplain from Berri to Loxton. Complementary monitoring of the Rilli Lagoons site has been conducted by NFSA Water For Nature program since January 2016 (Jensen 2016b).

Locations in the Lock 4 to Loxton reach and the location at Ramco were linked to controlled environmental watering events within the influence of salinity interception schemes (SIS). Hart Lagoon near Waikerie is protected by an SIS but did not receive environmental water and thus provided a control sample location, in addition to dry control sample sites at other locations where feasible. Vegetation condition was assessed at these sites as part of a larger study of Murray Valley floodplain condition and its relation to groundwater salinity within SIS zones of influence, coordinated by Australian Water Environments for SA Water.

All sites were wholly or partially flooded for an extended period by the peak flow in February 2011 and inundated again for a brief period in December 2016 (Figure 2). Commonwealth environmental water was provided to environmental targets at these sites from an annual allocation to environmental charity Nature Foundation SA, and water was applied on the basis of environmental water requirements for the target vegetation communities (Jensen 2016b).

Sample data were collected at nominated intervals to cover seasonal variations over two years to establish baseline conditions and initial responses. Monthly measurements in summer were required to confirm key stages of phenological cycles, taken for a minimum of two years to cover seasonal and annual variation, to identify or confirm peak flowering/seed shed for each site (previously known to be in summer months for the Clarks Floodplain site, Nov-Dec for black box, Dec-Mar for red gum, Jensen et al. 2008b).
Figure 8  Monitoring sites located between Lock 4 at Bookpurnong and Loxton
Environmental Watering Projects
The selected sites being watered through the Water For Nature Initiative of Nature Foundation SA. Watering projects from 2013 were designed to value-add to flood benefit, increase survival of key species, improve health of stressed mature trees, and to build general ecosystem resilience (Figure 9).

Since the floods of 2010-2012, projects have been focused on maintaining natural regeneration and increasing survival rates of seedlings, with watering volumes applied in 2013-16 at the sampling sites listed in Table 1.

Table 1  Environmental Watering at Sampling Sites 2013-2016

<table>
<thead>
<tr>
<th>site</th>
<th>2013-14</th>
<th>2014-15</th>
<th>2015-16</th>
<th>Total (ML)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarks Floodplain</td>
<td>35.8</td>
<td>329.0</td>
<td>105.5</td>
<td>470.3</td>
</tr>
<tr>
<td>Loxton Riverfront Reserve floodplain</td>
<td>0.0</td>
<td>13.3</td>
<td>18.8</td>
<td>32.1</td>
</tr>
<tr>
<td>Loxton Riverfront Reserve lagoons</td>
<td>0.0</td>
<td>0.0</td>
<td>30.0</td>
<td>30.0</td>
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<tr>
<td>Ramco River Terrace</td>
<td>5.0</td>
<td>7.5</td>
<td>0.0</td>
<td>12.5</td>
</tr>
<tr>
<td>Rilli Reach Stanitzkis flood-runners</td>
<td>13.2</td>
<td>17.9</td>
<td>27.2</td>
<td>58.3</td>
</tr>
<tr>
<td>Rilli Reach Stanitzkis seedlings</td>
<td>9.8</td>
<td>7.2</td>
<td>12.1</td>
<td>29.1</td>
</tr>
<tr>
<td>Thiele Flat</td>
<td>0.0</td>
<td>32.6</td>
<td>42.9</td>
<td>75.5</td>
</tr>
<tr>
<td><strong>Total (ML)</strong></td>
<td><strong>167.8</strong></td>
<td><strong>1123.0</strong></td>
<td><strong>3281.9</strong></td>
<td><strong>4572.7</strong></td>
</tr>
</tbody>
</table>

Figure 9  Dramatic contrast between area above the water line of a watering event (left) and the area inundated for several weeks (right) at Clarks Floodplain
Target Species for Study

River Red Gum

The largest trees on the Murray floodplain are river red gum (Figure 10). The largest river red gum forests occur in the mid-Murray valley between Yarrawonga and Swan Hill, where the braided floodplains flood frequently and provide ideal growth habitat for tall, dense forest communities such as Barmah-Millewa Forests, where red gums have been intensively studied (Bren, 1988a, b; Dexter, 1978). Further downstream, the Lower Murray floodplain supports more open, shorter woodland river red gum communities such as on the Chowilla floodplain (Roberts, 2003).

River red gums are most vulnerable to drought, as they require frequent watering and so in this habitat favour areas on the floodplain where flood frequencies are approximately 1 in 2 y (Roberts & Marston, 2000). Red gums can produce floating, adventitious rootlets in water-logged soil, to cope with anoxia during prolonged flooding (Heinrich, 1990). Successful recruitment in the Lower Murray is associated with medium river flow events >40,000 ML d⁻¹ (George, 2004). The trees are stressed by saline groundwater (>20,000 µS cm⁻¹) within 2 m of the surface (Sharley & Huggan, 1995).

Black Box

In the southern and western floodplains of the Murray-Darling Basin, black box (Figure 11) is on higher elevations, with its distribution dictated by its relatively low flood tolerance, high drought tolerance and low transpiration rates. It usually forms open woodland stands, where canopy cover is less than 30% (Roberts & Marston, 2000). Black box is largely dependent on flooding for natural regeneration (Treloar, 1959), although local rainfall becomes critical between floods (Jensen et al., 1998). Black box is less affected by the loss of small floods than red gum (Cunningham et al., 1981), but its long term survival could be affected by reduced duration of larger floods (Roberts, 2003).

Black box relies on soil water during prolonged inter-flood dry periods (Slavich et al., 1999). It frequently demarcates the outer limits of larger floods and the extreme edge of the floodplain (Jensen, 1983; Slavich et al., 1999). Seedlings are generally successful as a narrow band along the high-water line of the flood of origin (Cunningham et al., 1981). Black box trees are more drought-tolerant, but they too are showing signs of water stress, although they are reputed to endure 10 years without flooding (George, 2004; George et al., 2005; MDBC, 2003). Recruitment is associated with river flows >80,000 ML d⁻¹ (George, 2004). Black box trees can subsist on soil water during dry periods (Slavich et al.,...
1999), but are stressed by saline groundwater (>40,000 µS cm\(^{-1}\)) within 2-4 m of the surface (Sharley & Huggan, 1995). Unlike red gums, black box cannot cope with anoxia during prolonged flooding (Heinrich, 1990), and the distributions of seedlings and mature trees often indicate the limits of the biggest floods (Slavich et al., 1999).

The extremely slow growth rate of black box meant that it was not of commercial interest, and consequently the species has not been studied with the same intensity as the commercially significant river red gum, so less is known about its phenology and recruitment process (Roberts & Marston, 2000).

**Lignum**

Lignum is a long-lived, deep-rooted perennial shrub that can attain 3 m height (Figure 12, Roberts & Marston, 2000). Lignum grows in characteristic shrublands on floodplains of the western Murray-Darling Basin, often in shallow clay pans. It grows best in local habitats subject to temporary ponding of water, after rain or flooding (Roberts & Marston, 2000). Lignum is typically found on swamps, river-flats, gibgas and other intermittently flooded areas. It is particularly common in the Murray-Darling Basin, including on grey cracking clays on the River Murray floodplain in South Australia, in zones with flood frequencies of approximately 3 in 10 y (Craig et al., 1991). The habit is distinctive, with multiple tangled woody stems (hence the common name), which remain leafless except when new growth occurs in response to significant local rains or river flooding (Roberts & Marston, 2000). The small leaves are shed again after flowering. Lignum appears to be opportunistic, ready to respond rapidly to either significant rains or floods (Southgate, 1988). Lignum reproduces sexually and vegetatively, with new plants striking from nodes on roots or on branches contacting the soil.
Water Requirements

The water requirements of river red gums and black box have been identified from a range of sources and are summarised in Figures 13-14 (Jensen et al. 2008 a,b, Telfer et al. 2015). The recommended water regimes are based on the natural hydrological cycle which delivered flood peaks to the Lower Murray Valley in late spring-early summer.

However, other factors to take into account include the pre-existing degree of water stress and tree health, antecedent conditions and likelihood of long term damage if water is not applied. Recent research has supplied some key information about the trigger points for stress and decline, for example more than five years without water for red gums from research by CSIRO on red gum watering at Yanga near Balranald (Baldwin et al., 2013, Wen et al., 2010). Watering trials for black box by DEWNR at Markaranka and Gerard in the SA Riverland have demonstrated the need for serial watering for 3 years or more to sustain improvement in condition (S. Gehrig, SARDI, T. Doody, CSIRO, pers comm, 2015).

Medium term watering cycles for red gum and black box are outlined in Figures 13 -14, depending on the current health of the target trees, and the stage of the phenological cycle (buds, flowers or fruit) (Jensen et al. 2007). Lignum has been observed to flower profusely in response to above-average rain in spring, while its first priority in response to available water is vigorous vegetative growth (Figure 12; Jensen 2008, Jensen et al. 2006), so watering for lignum is recommended from early spring.

Timing and duration of watering events has been keyed to the desired ecological objectives at individual sites, whether for improving and sustaining health of existing mature trees and plants, or sustaining existing seedlings and saplings, or generating new germination of seedlings.
SA Riverland Mature River Red Gum

Degraded woodland

Water in summer for 2 years, to generate seed, then 3 years to support seedlings, then 1 in 2 y for 8 years for recovery of mature trees

If seedlings present, water every summer for 3 years or until established

Healthy woodland

Water to maintain health 1 in 3 y (including any natural floods)

If seedlings present, water every summer for 3 years

Figure 13  WFN Guidelines for watering river red gum communities in the Lower Murray Valley

SA Riverland Mature Black Box

Degraded woodland

Water in summer for 2 years, to generate seed, then 3 years to support seedlings, then 1 in 3 y for 9 years for recovery of mature trees

If seedlings present, water every summer for 3 years or until established

Healthy woodland

Water to maintain health 1 in 5y (including any natural floods)

If seedlings present, water every summer for 3 years

Figure 14  WFN Guidelines for watering black box communities in the Lower Murray Valley
Monitoring Hypotheses

For assessment of the environmental response to watering, the vegetation targets were river red gums, black box and lignum, which are perennial, deep-rooted, water-dependent climax species and practical indicators for health of floodplain vegetation communities.

Watering was timed to support the long-term recruitment process, which is defined as survival of seedlings to maturity, with capacity for reproduction. For example, river red gums need to be 10-20 years old before producing seed, and black box take 20-30 years, depending on water availability (George 2004). The watering regime for each site was based on the working hypotheses outlined above relating to optimum timing to support crop volumes, promote germination and to support regeneration triggered by the 2011 flood peak.

Key parameters monitored in relation to the hypotheses listed below focused on vegetation responses, including germination of new seedlings, survival of 2011-germinated seedlings, survival of saplings, condition of mature trees, recovery of stressed trees, phenology cycles of key species (buds, flowers, fruit), and relative volumes of crops.

**Hypothesis 1:**
Addition of water to surface replenishes/maintains soil moisture availability in the unsaturated zone for access by shallow root systems of key floodplain species, leading to improved/maintained health, seed production, germination of seedlings and increased chance of survival of seedlings to eventual maturity (= recruitment, ie seed production)

**Hypothesis 2:**
Addition of water at key times in the phenological cycle can sustain or promote volumes of buds, flowers and seed production and germination success in healthy trees of key species

**Hypothesis 3:**
Addition of water will improve health in stressed trees by triggering new leaf growth and development of bud crops

**Monitoring frequency:**

Samples were taken at nominated intervals to cover seasonal variations over two years to establish baseline conditions and initial responses. Monthly measurements in summer were required to determine key stages of phenological cycles, for a minimum of two years to cover seasonal and annual variation, to identify peak flowering/seed shed for each site (known to be summer months for the Clarks Floodplain site, November in black box, December to March for red gum).
Methodology

Monitoring commenced in March 2015, with sites visited in May, July, September, November, December and January to cover all stages of phenological cycles and to establish key timing for flowering and subsequent maximum seed fall 12 months later. Monitoring in 2016 was quarterly, then continued in January, March and June 2017 to complete the project.

The environmental watering projects at the five watered locations included combinations of the following vegetation communities:

- open mature black box woodland
- 1990s immature black box woodland
- stressed tall closed black box woodland
- mixed red gum and black box woodland
- lignum shrubland
- black box seedlings
- red gum seedlings
- open stressed mature red gum woodland
- red gum 2004 regeneration
- stressed 1970s red gum tall woodland.

Watering occurred primarily at elevated floodplain sites within the 90,000 ML/d flood contour, but also included sites at small flood-runners, temporary wetlands, incised floodplain creeks and shallow creeks.

Phenological data was recorded each season for four groups of 3-5 river red gums and 20 groups of 4-5 black box trees across the habitat types and ecological communities at the six sites, to identify seasonality for each tree and to monitor the crop volume, as well as condition.

A rank scale (0-4) was used to indicate the relative volumes of buds, flowers, immature fruit, mature fruit with closed valves and fresh leaves. Scores were assigned as follows and data were plotted to assess seasonal and inter-annual patterns:

0 = absent
1= low volume (<25% of inflorescences)
2= medium volume (25-50%)
3 = high volume (50-75%)
4= very high volume (>75%).

Canopy condition and % epicormic growth were also scored and other variables such as local rainfall, inundation, soil moisture and insect herbivory were noted. A rank scale (1-5) was used to indicate the relative canopy condition, compatible with the vegetation condition scoring system used by the Department of Environment, Water & Natural Resources at other watered sites. Canopy condition cores were assigned as follows:

1 = 100% epicormic
2 = <25% of original canopy, >50% epicormic growth
3 = 25-49% original canopy, <50% epicormic growth
4 = 50-75% original canopy, <10% epicormic growth
5 = >75% of original canopy, < 5% epicormic growth.

Fields of germinated seedlings and multiple vegetation transects (5 @ 50x4 m, 9 @ 100x4 m) were monitored for survival from the germination event triggered by floods in 2010-2012.
Results
Overall, red gum and black box at watered sites showed significantly greater rates of growth and volumes of crops (buds, flowers and fruit containing seed) in mature trees, and stronger recovery from drought stress. Canopy condition was consistently better at watered sites in red gum, black box and lignum.

As outlined above, the primary target for environmental watering was stressed mature black box and black box regeneration, and most results reported here relate to this species. Average canopy condition scores (0-5) for groups of 5 mature black box at 6 monitored Riverland locations show 12 watered sample sites in significantly better condition (green series) compared to 6 non-watered sample sites (blue series) over the period May 2015 to June 2017 (Figure 15).

Underlying the comparatively better condition in watered sample groups, an identical initial downward trend occurred in canopy condition for both watered and non-watered groups, reflecting a prior period of 12 months of below average rainfall to March 2015 (Figure 16). Following above average monthly rainfall in November 2015 and January 2016, canopy condition in both groups started an upward trend, reinforced by high rainfall in May 2016 and exception rainfall in September 2016, with rainfall volume five times the 30 year average volume (Figure 3). This regional rainfall event had widespread beneficial effect on all floodplain vegetation through summer 2016-17, and reinforced the benefits of the 2016 flood event.

Figure 15   Comparison of mature black box condition at 12 watered sample sites (green series) and 6 non-watered sites (blue series), showing sustained significant improvement in condition at watered sites from May 2015 to June 2017
Evidence supporting Hypothesis 1

The vigorous growth in all three indicator species demonstrated that addition of water at the surface replenished and maintained soil moisture availability for access by the shallow root systems of red gum, black box and lignum (Hypothesis 1). Both eucalypt species demonstrated improved health and increased seed production, and mortality of 2011 seedlings was <5%. At watered sites, black box and red gum showed significantly greater rates of growth and volumes of crops (buds, flowers and fruit containing seed) in mature trees, and stronger recovery from drought stress, compared to non-watered sites. Watered sites showed significantly higher canopy condition scores than non-watered sites for both eucalypts and lignum (Figures 15-17).

Comparison of mature bud and closed mature fruit crop volumes for both black box and red gum at watered (light blue series) and non-watered (dark blue series) samples sites across all six Lower Murray Valley locations, showing significantly higher crop volumes and thus seed production at sites receiving environmental water (Figure 16).

Phenology results for black box found a mature bud crop in early summer 2015-16 as expected, with two consecutive crops of mature fruit through the whole sampling period, and two new bud and flower crops from September 2015. However, the subsequent crop of buds formed much earlier, peaking in winter and diminishing to the following summer 2016-17; a third bud crop also had a high volume in winter in June 2017 (Figure 17). Medium volume seed release occurred in December 2015, with possibly limited release in June 2016 and June 2017. Flowering (plotted as % of trees flowering in sample group) followed the pattern of bud crops with a lag time of only 4-12 weeks, much shorter than the 10-12 months lag time previously recorded in drought conditions.
Medium to high crop volumes of closed mature fruit indicated that adequate volumes of seed were available in summer 2015-16 and 2016-17, but only a few scattered newly germinated seedlings were found. Small patches of scattered individual black box and red gum seedlings were located in June 2017, following the December 2016 flood peak, but none on the mass scale of the 2011 germination event.

Very high survival rates of 2011-germinated seedlings were recorded at both watered and non-watered sites, with negligible deaths recorded to June 2017. This is thought to be due to the late timing of the 2011 and 2012 flood peaks, extended duration of inundation in the series of floods in 2010-12, followed by timely rainfall events. The timing of the 2016 flood event was critical to sustain seedlings and saplings following three relatively dry years with no over-bank flows and highly variable rainfall patterns (Figures 2 & 3).

There has been very high survival across germinated seedling fields, watered or not watered, due to follow-up rain events. However, watered seedlings are at least 2-3 times taller and significantly more vigorous than non-watered seedlings (watered black box 1-3 m, red gum 2-6 m tall), while non-watered seedlings in general are < 1 m tall and some individuals are still <100 mm tall and < 5 mm stem diameter at 5-6 years. As seedlings developed into saplings, natural thinning occurred, with the loss of approximately 50% of individuals within the expected range of 40-60% (George et al. 2005).
Numbers of black box and red gum seedlings in watered stressed closed black box woodland at Clarks Floodplain were recorded in healthy, stressed or dead condition along 3 transects (TR1-3, 100x4 m), counted from January 2015 to June 2017 (Figure 18). Overall results indicate >95% survival in black box (eg 58 out of 60, TR2) and >60% survival in healthy red gum seedlings (eg 10 out of 15, TR2). A significant shift from healthy to stressed condition in January 2017 reflects over-topping of smaller seedlings during the December 2016 flood peak, with inundated seedlings losing their leaves and re-shooting from the base after the flood receded. The largest number of healthy surviving seedlings occurred outside the closed canopy of the woodland, indicating shading and competition from the mature trees suppressed successful germination.

A stand of regenerated red gums germinated in response to environmental watering in 2004 at the Clarks site started producing seed in 2014 and had medium volume seed crops in 2016-17, giving the first demonstration of completion of the recruitment process to seed production for any monitored site. This occurred within the expected recruitment age of 10-20 years for red gum (George 2004).

Watered lignum demonstrated very strong vegetative growth responses, but limited flowering and seed production over the monitored period (Figure 19). Vigour in dry lignum control plants was significantly lower than watered lignum shrubs, and watered lignum (W) showed significantly higher % greenness compared to non-watered lignum (D). Non-watered lignum showed light flowering in spring 2016, coinciding with high above-average rainfall (Figure 3), but watered lignum concentrated physiological resources into vigorous vegetative growth rather than flowering, with strong verticals arching, re-shooting from nodes and forming the typical dense tangled habit. A limited number of new root clones were recorded at individual watered lignum shrubs, suggesting that vegetative reproduction was preferred over sexual reproduction in watered plants.

Figure 18  Survival of watered black box (BB) and red gum (RRG) seedlings at Clarks Floodplain from January 2015 to June 2017, with healthy (left), stressed (middle) and dead (right) scores along three transects (TR1-3) 100x4 m
Evidence supporting Hypothesis 2

Environmental watering during 2015-2017 was delivered to these sites by mid-summer as far as practical, based on evidence that late spring-early summer was a key production point in the phenological cycle for red gum and black box (Hypothesis 2). Eucalypts at watered sites demonstrated not only increased crop volumes but also started to develop dual crop cycles, thus with capacity to shed seed every year. Previous data collected in drought conditions indicated a single biennial cycle for red gum and black box, with seed shed every second year (Jensen et al. 2007).

Initially, up to March 2016, there was no change in the natural timing of crops at watered sites, confirming the predicted pattern of mostly summer flowering for both red gum and black box, with some variation from November to January in individual trees. Based on previous findings, these results suggested seed release would occur 12 months later, in summer 2016-17.

However, there was a very significant departure from the expected pattern from June 2016, when it was observed that ~70% of mature black box trees in the region flowered profusely in June, September and December. Monitoring results found individual trees flowering twice or three times from the same bud crop. The sequence from bud to flower was as short as 3-4 months for some trees, compared to the previously observed 12 months. Similar atypical stop-start multiple flowerings from the same bud crop were observed in other eucalypt species at different South Australian locations during this period, thought to be linked to atypical rainfall patterns and humidity levels in 2015-16 (Dr F Paton, University of Adelaide, pers comm. 2017, Ms H Merigot, University of Adelaide, unpubl data 2017).

Local Riverland rainfall patterns showed highly variable monthly volumes, with large anomalies compared to the 30 year average values (Figure 3). Rainfall 12 months prior to bud set is thought to be influential (Assoc Prof D Paton, University of Adelaide, pers comm. 2017), but no significant patterns could be detected in the 24 month data set to link bud set, crop volumes or percentage of trees with crops to prior rainfall events.
Evidence supporting Hypothesis 3

Results from all sites confirmed that watering promoted seasonal leaf growth and development of bud crops (Hypothesis 3). In water-stressed mature eucalypts, it had previously been observed that there was an immediate response to watering with vigorous epicormic leaf growth, where leaves grow directly from main branches, rather than from the tips. As the trees continued to access adequate water without further stress, the epicormic growth gradually converted to normal tip growth in the following season. Previously water-stressed trees can develop a new canopy and produce buds within 2-3 years, and eventually produce an entire new healthy canopy, provided further water stress or severe insect attack does not occur to interrupt that process (Jensen 2012, 2016).

At the Murray Valley monitoring sites, this transformation process was already underway in March 2015 for multiple stressed trees, with previous epicormic growth normalising and commencing growth from the tips by summer 2015-16, and normal bud crop development during 2016. No significant epicormic growth was recorded after July 2015 and the trend in condition scores continued to improve (Figure 4). No epicormic growth was observed in 2016, except for a few isolated instances of localised insect attack.

Evidence of Natural Thinning

Natural thinning was observed in one quadrat of dense river red gum seedlings, where approximately 50% of the original seedlings disappeared, which the survivors are now sturdy saplings with DBH ~100mm and height > 3 m (Figure 20). Similar thinning is becoming evident as saplings grow, with density reducing from <100 mm apart to 4-500 mm apart. This is within the expected range of 40-60% natural thinning rates (George et al. 2005).

Figure 20 Watered red gum seedlings which germinated after 2011 flood peak grew from 20-30 cm tall in March 2012 (left), to 4 m tall and self-thinned by September 2016 (right) on Clarks Floodplain main red gum flood-runner site
Conclusions
These data were collected March 2015 to June 2017 on the South Australia Murray River floodplain as part of a project by Australian Water Environments to evaluate the benefits of Salt Interception Schemes (SIS) on floodplain health for SA Water. All monitored sites were within the zone of influence of SIS installations.

At sites receiving environmental water, floodplain vegetation showed significantly greater rates of growth and volumes of crops (buds, flowers and fruit containing seed) in mature trees, and stronger recovery from drought stress, compared to non-watered sites. The primary response in healthy and recovering mature eucalypts to watering was increased growth rates and crop volumes of leaves, buds, flowers and fruit. Watered sites showed significantly higher canopy condition scores.

The background condition of vegetation communities across the floodplain sites monitored, initially very stressed following the Millenium drought 2000-2010, improved significantly due to the beneficial effects of the 2010-2012 series of flood events on soil moisture availability, combined with above average rainfall events in summer 2011, 2012 and 2014, and spring 2016, and a flood event in December 2016.

In stressed mature eucalypts, there was an immediate response to watering of epicormic leaf growth, where leaves grow directly from main branches, rather than from the tips. As the trees continued to access adequate water without further stress, the epicormic growth gradually converted to normal tip growth in the following season, and no significant epicormic scores were recorded after July 2015. All trees had normal leaf and crop development during 2016.

Data collected were designed confirm the working hypothesis that flowering and seed fall at Riverland sites occurs in summer months for red gums and most black box, while some individual black box trees flower in winter months. Initial data from monitoring March 2015 – March 2016 confirmed the expected pattern of mostly summer flowering for both red gum and black box.

However, results from June 2016 departed from the pattern, with >70% of black box trees in vigorous flower, departing from previous patterns, and this continued with flowering in September, December and January. Some individual trees flowered three times, some twice and some only once, assumed to be from the same bud crop developed in the previous summer. Similar departures from previous seasonal patterns in 2016 have been reported by other researchers at the University of Adelaide.

Rainfall patterns were analysed and showed highly variable monthly volumes with large anomalies compared to the 30 year average values. Analyses were conducted to assess the influence of rainfall on crop volumes, but no patterns were found which could be linked to the rainfall variations.

All three project hypotheses were supported, viz:
- addition of water at the surface replenished and maintained soil moisture availability for access by the shallow root systems of red gum, black box and lignum, supporting vigorous growth in all three species
- timing of watering supported annual cycles of crop production
- watering promoted seasonal leaf growth and development of bud crops.
All floodplain sites have very large numbers of dead mature red gum and black box, and stressed mature trees as a result of the Millenium drought. The survival of seedlings germinated as a result of the 2010-12 floods are thus critical to the long-term integrity and survival of key floodplain ecosystems.

Watered seedlings germinated after the 2010-2012 floods were found to be more than twice as tall and more vigorous than non-watered seedlings, increasing their chances of survival to reproductive age (20-30 years). Findings indicate very high survival rates of seedlings at both watered and non-watered sites, with negligible deaths recorded to March 2017. This is thought to be due to the timely rainfall events between the two flood events.

Natural thinning was observed in one quadrat of dense river red gum seedlings, where approximately 50% of the original seedlings disappeared, which the survivors are now sturdy saplings with DBH ~100mm and height > 3 m. All sapling fields has visibly thinned, with gaps between stems increasing from <20 mm to > 500 mm.

All floodplain ecosystems throughout the Riverland have shown improvement in condition since 2010, whether watered or not, due to beneficial effects of flood events and unusual rainfall patterns. All watered sites have shown additional growth up to 2-3 times greater than watered sites, above the baseline improvement. Seedlings generated in the 2010-2012 flood event are showing very high survival rates, and watered seedlings are also 2-3 times more vigorous and taller than non-watered seedlings.

The continuing beneficial impact of SIS schemes in controlling groundwater intrusion into floodplains will be essential to allow the development to maturity of hundreds of thousands of black box seedlings and saplings, to fill the generation gaps in black box communities which have not had successful widespread recruitment since the 1956 flood. Lignum communities have also had a big boost, with thousands of seedlings germinated to complement vegetative reproduction, but their survival and growth will depend on continued soil moisture availability. Red gum seedlings also need to survive, to replace dead and stressed mature trees.

Given the demonstrated negative impacts of saline intrusion into the root zone of mature trees on seed volume and the number of biennial crops carried, the SIS schemes will be critical for continuing to minimise future salinity impacts on maturing seedlings and future volumes of seed crops from mature trees, particularly in extended dry periods between flood events.
References


Appendix 1 Detailed Location Descriptions

Clarks Floodplain

Clarks Floodplain, on the River Murray near Berri, South Australia at river distance 506-516 km from the Murray mouth (Figs. 1-3). The site is a 270 ha complex of point bars, terraces, meander scrolls and flood runners (distributary channels), in an area where meanders have created sandy peninsulas supporting dense vegetation (Figure 3). It is downstream of Weir No 4 on the mainstream, constructed in 1929, one of a series of weirs which regulate the Lower River Murray. Prior to regulation, floods at this site occurred once in 2-3 y, but the frequency now is once in 4-5 y (Jensen et al., 2002).

This site has experienced a serious decline in vegetation health, with a dramatic tipping point reached between 2000 and 2004, when healthy mature red gum forest declined into a state of severe stress and death (Jensen 2008; Figures 4 & 5). Black box woodland and fringing tall red gum on the higher clay floodplain was declining and dying as saline groundwater was being displaced by irrigation drainage under the floodplain from the outer edge towards the river. Vegetation on the lower sandy peninsula (top centre, Figure 5), with the river on three sides replenishing the water table, was relatively healthy. A major flood runner allows water to short-cut across the peninsula in small floods >40,000

![Figure 3](https://example.com/figure3.jpg)  
*Clarks Floodplain, downstream of Weir No 4 on the River Murray mainstream (top centre of picture), includes three sandy peninsulas with river red gum forest and woodland, black box open woodland and lignum shrubland communities. Taken before the current decline in vegetation condition, this view shows denser, healthier communities, including tall forest, concentrated on inner bends where river water refreshes the shallow water table through sandy soils. Source: Department of Lands aerial photography 1988.*
ML d-1; but the last previous flows were in 1996. Vegetation decline accelerated significantly as the drought continued to 2010.

Clarks Floodplain has received environmental water since mid-2005, initially into the downstream end of the main red gum flood-runner, with extensive regeneration occurring in responses to a series of environmental watering events. This regeneration has been reinforced by natural floods in 2010-2012, which resulted in extensive, extended inundation over most of the site (Figure 6).

Clarks Floodplain is regarded as a flagship site for environmental watering, with a long history of multi-disciplinary investigations relating to sustainable management of environmental resources and management of local groundwater. It is of very high value as a demonstration site, where cause and effect are visible from a high point overlooking the floodplain (Figure 5). Environmental watering initially focused on limiting long term damage and loss of mature trees. Environmental watering is continuing, with a focus since 2013 on sustaining the extensive natural regeneration triggered by the recent floods.

![Aerial view of Clarks Floodplain in June 2004, looking north-west, with highland irrigation (lower right) and a pool of saline seepage on the adjacent lower-lying floodplain. The River Murray mainstream flows from right to left, with sandbars on each inner bend of the meander loops (centre left).](image)
Figure 5: Main flood runner at Clarks Floodplain with dead mature red gums on upper edge in 2004 (study site in Figure 5). Stressed red gums can be seen at lower elevations in the left middle distance. The dead trees appeared healthy in 2000, with no obvious signs of stress, but no small floods occurred from 1996 to 2010 to counteract saline groundwater moving into the root zones of the trees.

Figure 6: Location of sampling points at Clarks Floodplain -- transects (orange lines), photopoints (purple dots), black box groups (blue dots) and red gum groups (green dots).
Rilli Reach at Stanitskis
Rilli Reach is a floodplain unit on the eastern bank of the River Murray downstream of Weir No 4, between Berri and Loxton at 502-503 km from the Murray mouth. The current project is located on the upstream end of the area, covering approximately one-third of the floodplain unit, on the property of Nick Stanitski. The site includes temporary lagoons bordered by river red gums, flood runners flowing into lignum shrublands and higher elevations of the floodplain with mature black box woodland.

Figure 7 Location of Stanitski property at Rilli Reach (top); black box seedlings under mature woodland (lower left) and temporary lagoon in flood-runner bordered by dead mature red gums and newly germinated seedlings in 2012 (lower right). Cover photo gives distant view of red gum regeneration along flood-runner at right, 4-6 m high in 2016.
Thiele Flat
Thiele Flat is a floodplain unit on the eastern bank of the River Murray downstream of Weir No 4, just upstream of Loxton at 490-492 km from the Murray mouth. The current project is targeting regeneration of red gums and black box on the river terraces on the south-western section of the site. The tall red gum forest on the sand bar and adjacent inland terraces is extremely stressed and the miniature forest of red gum seedlings under dead and stressed mature trees is critical to the future health of the site. At slightly higher elevations on heavier clay soils further inland, thousands of black box seedlings also continue to survive.

The site includes public land managed as a recreation reserve by the District Council of Loxton Waikerie and the watered sites are accessible to the public.

Figure 8 Location of Thiele Flat upstream of Loxton (top); red gum regeneration (bottom left) in May 2014 and January 2017 (bottom right)
Loxton Riverfront Reserve

Loxton Riverfront Reserve is a floodplain unit on the southern bank of the River Murray 10 km downstream of Weir No 4, at Loxton at 487-489 km from the Murray mouth. The current watering project is targeting regeneration of black box and lignum on the higher elevations of the floodplain in the centre of the site. The existing scattered mature black box trees are relatively stressed and the large numbers of black box seedlings are critical to the future health of the site.

The site includes public land managed as a recreation reserve by the District Council of Loxton Waikerie and the watered sites are accessible to the public.

Figure 9  Location of Loxton Riverfront Reserve (top); thriving black box regeneration in April 2014 (foreground, left) and January 2016 (right)
Ramco River Terrace

Ramco River Terrace is a floodplain unit on the south-western bank of the River Murray 10 km downstream of Waikerie at 374-376 km from the Murray mouth. The current watering project is targeting regeneration of black box and lignum on the higher elevations of the floodplain in the centre of the site, and some red gums closer to the river. The existing scattered mature black box trees and riparian red gums are relatively stressed and the large numbers of black box and red gum seedlings are critical to the future health of the site.

The site includes public land managed as a recreation reserve by the District Council of Loxton Waikerie and the watered sites are accessible to the public.

Figure 10 Location of Ramco Lagoon downstream of Waikerie, and field of black box seedlings at watered site (September 2015)
Hart Lagoon
Hart Lagoon is a floodplain unit on the southern bank of the River Murray downstream of Waikerie at 378-381 km from the Murray mouth. This is the control site, with no environmental watering but with protection from a salinity interception scheme. The current project is monitoring survival and growth of regeneration of black box and lignum on the higher elevations of the floodplain in the west of the site. The existing scattered mature black box trees are relatively stressed and the large numbers of black box seedlings are critical to the future health of the site.

The site includes public land managed as a recreation reserve by the District Council of Loxton Waikerie and the monitored sites are accessible to the public.

Figure 11 Location of Hart Lagoon downstream of Waikerie (top), and field of black box seedlings at non-watered site (November 2015)
Appendix 2  BOM Rainfall Records for Loxton 2000-2012

Loxton Research Centre (024024) 2000 Rainfall (millimetres)

Loxton Research Centre (024024) 2001 Rainfall (millimetres)

Loxton Research Centre (024024) 2002 Rainfall (millimetres)

Loxton Research Centre (024024) 2003 Rainfall (millimetres)

Loxton Research Centre (024024) 2004 Rainfall (millimetres)
Appendix 3  Distribution of Sampling Sites

Figure 12  Distribution of types of sample sites for black box at Clarks Floodplain (CFP) and other regional sites (Loxton Riverfront Reserve (LRR), Thiele Flat (TF), Rilli Reach at Stanitskis (STA), Hart Lagoon (HL) and Ramco River Terrace (RRT))
Figure 14  Distribution of types of sample sites for river red gum at Clarks Floodplain (CFP) and Thiele Flat (TF)

Figure 13  Distribution of types of sample sites for lignum at Clarks Floodplain (CFP), Loxton Riverfront Reserve (LRR) and Hart Lagoon (HL)