DWLBC REPORT

Bookpurnong Living Murray Pilot Project:

Artificial inundation of *Eucalyptus camaldulensis* on a floodplain to improve vegetation condition

2009/19

Government of South Australia
Department of Water, Land and Biodiversity Conservation

Bookpurnong Living Murray Pilot Project: Artificial inundation of *Eucalyptus camaldulensis* on a floodplain to improve vegetation condition

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Science, Monitoring and Information Division
Department of Water, Land and Biodiversity Conservation

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FOREWORD

South Australia's unique and precious natural resources are fundamental to the economic and social wellbeing of the State. It is critical that these resources are managed in a sustainable manner to safeguard them both for current users and for future generations.

The Department of Water, Land and Biodiversity Conservation (DWLBC) strives to ensure that our natural resources are managed so that they are available for all users, including the environment.

In order for us to best manage these natural resources it is imperative that we have a sound knowledge of their condition and how they are likely to respond to management changes. DWLBC scientific and technical staff continues to improve this knowledge through undertaking investigations, technical reviews and resource modelling.

Scott Ashby
CHIEF EXECUTIVE
DEPARTMENT OF WATER, LAND AND BIODIVERSITY CONSERVATION

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- Steve Clark for allowing the trial to be undertaken on Clark's Floodplain.

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SUMMARY

In 2002, the Living Murray Initiative was established as a response to the growing evidence that the River Murray system was in poor health. Research indicates a considerable dieback in vegetation, especially on the Lower Murray due to decreased floodplain flows and salinisation.

In 2005 as part of the Living Murray Works and Measures program, Clark's Floodplain at Bookpurnong was chosen to investigate four different groundwater/surface water manipulation trials and the effect of a floodplain Salt Interception Scheme (SIS). The trials were focused on collecting detailed information on groundwater, soil salinity and vegetation response to the trials. The knowledge gained from these investigations would then be transferred back to the Chowilla Floodplain, a Living Murray Icon Site, where a floodplain SIS and artificial inundation sites were being proposed.

The four Bookpurnong trials were focused on, Site A; artificial inundation of a floodplain depression, Site B; lateral recharge of a groundwater aquifer via groundwater extraction while also investigating the effect of SIS drawdown, Site D; artificial inundation of a flood runner while also investigating effect of SIS drawdown and, Site E; vertical recharge of an aquifer via injection. Three reports have been published outlining the methods, results and recommendations from the trials, however this report focuses on Site A. The main objectives of the Site A trial was to determine if artificially applying surface water to a floodplain reduces root zone salinity beneath the flooded area and whether *Eucalyptus camaldulensis* (river red gum) condition improves and is sustained after the event.

The study occurred over a three-year period, with an artificial inundation in the first and second year (2005 and 2006) followed by a 'dry' event in the third year (2007) where no environmental water was applied to the floodplain depression. The techniques used to monitor responses to inundation were; groundwater and surface water level and salinity, soil salinity, EM31 conductivity surveys, visual tree condition assessments, juvenile river red gum heights and understorey surveys.

In summary, the findings from the Site A trial of artificially inundating a wetland depression conclude that physical (water and soil) and biological (vegetation) processes respond favourably to flooding to improve tree condition. The improvement in tree condition and soil salinity was not sustained after two inundation events, as river red gum crown extent in the highest category (76 to 100%) decreased and soil conductivity increased during the 'dry' year (one year post the second inundation).

The main recommendation from the Site A trial is that artificial inundation as an intervention technique should be considered when vegetation starts to deteriorate and the majority of tree crown extents are measured to be 25-75% with a monitored declining trajectory. The findings from the Site A inundation trial found that trees with crown extent 25-75% have the highest chance of recovering during the intervention period.

Artificial inundation as an intervention technique was found to have some of the same advantages of a natural flood, with increases in tree condition, restoring understorey seed bank, decreasing soil and groundwater salinity and initiating river red gum germination.

1. INTRODUCTION

1.1 WHY PUMP WATER ON TO A FLOODPLAIN?

In 2002, the Living Murray Initiative was established as a response to the growing evidence that the River Murray system was in poor health. Research indicates a considerable dieback in vegetation, especially on the Lower Murray due to decreased floodplain flows and salinisation (Elridge et al, 1993; Jolly et al, 1993; Mensforth et al, 1994; Maheshwari et al, 1995; Jolly, 1996; Slavich et al, 1999a, Slavich et al, 1999b).

As part of the Living Murray Program, six icon sites were established which included the Chowilla-Lindsay-Wallpolla floodplain anabranch systems on the Lower Murray. In 2004, a trial of artificially inundating a floodplain anabranch[1] was undertaken at Monoman Island Horseshoe on the Chowilla Floodplain to improve the degraded health of *Eucalyptus camaldulensis* (river red gums) and *Eucalyptus largiflorens* (black box). The preliminary unpublished results of this trial indicated that the trial was successful in rejuvenating tree canopy, but more research on groundwater/surface water interactions, soil salinity and vegetative response to the artificial inundation was needed. Due to the success of watering Monoman Island Horseshoe, another eleven priority watering sites were watered on Chowilla Floodplain in 2005, where visual tree response was the only assessment undertaken

In 2005, as part of the Living Murray Works and Measures program, Clark's Floodplain at Bookpurnong (located ~80 km downstream of Chowilla) was chosen to investigate four different groundwater/surface water manipulation trials and the effect of a floodplain Salt Interception Scheme (SIS). The trials were focused on collecting detailed information on groundwater, soil salinity and vegetation response. The knowledge gained from these investigations would then be transferred back to the Chowilla Floodplain where additional inundation sites and a floodplain SIS for environmental outcomes were being considered. A summary of the four investigation trials that were undertaken at Bookpurnong are presented in the next section.

In 2009, artificially pumping water to floodplain depressions[1] to stall vegetation deterioration is common in South Australia with Chowilla Floodplain having 22 sites that receive pumped water to improve vegetation condition. The decision to pump water to these sites before the Bookpurnong trials were completed was based on preliminary results indicating that root zone salinity decreases and vegetation condition improves upon surface water being applied to a floodplain feature.

The main objective of the Site A trial was to determine if artificially applying surface water to a floodplain depression reduces root zone salinity beneath the flooded area and determine if river red gum condition improves and is sustained after the event.

[1] Throughout this report, areas on a floodplain that collect and hold water during overbank floods may be referred to as a floodplain feature, depression, anabranch or wetland. Specifically, the Site A floodplain feature is a depression that would have filled and held water pre-river regulation every 3 to 5 years. Currently it holds water during floods every 5-10 years meaning that it is not a typical wetland (see glossary) even though wetland type vegetation germinates when the depression is inundated.

1.2 DESCRIPTION OF THE BOOKPURNONG TRIALS

The Bookpurnong Floodplain, Living Murray Pilot Project was undertaken by DWLBC to inform floodplain management decisions for Living Murray Icon Sites, especially Chowilla Floodplain. The project scoping report produced by AWE (2005) highlighted five questions to be addressed by the Site A trial which will provide some of the section headings of this report:

- What is the impact of flooding on soil salinity?
- How do river red gums respond to flooding?
- What are the ecological responses to flooding?
- What impact does flooding have on river salinity?
- Will this approach provide methodologies that can be employed at other sites?

The Site A trial is one component of the Living Murray Pilot Project. The concepts of each Bookpurnong trial (Figure 1) are summarised:

Site A – Artificial inundation of a 3.7 ha topographic floodplain depression with a focus on improving the health of a low-level river red gum community. The aim was to leach salt from the soil profile and improve the salinity condition of the root zone to encourage tree rejuvenation and population replacement by providing favourable germination conditions.

Site B – Construction of a groundwater production well to induce the lateral movement of fresh river water through the connected floodplain aquifer, creating a fresh water lens (enhanced bank storage). Seventeen piezometers were installed in four transects to observe the surface and groundwater interactions across a broader area.

Site D – Artificial inundation of a dried creek system as a comparison with the Transect 3 vegetation communities for vegetation response due to groundwater freshening. Site D is a small subset area within the larger Site B study area and uses Transect 2 for its investigation.

Site E – Injection of fresh river water into a moderately saline floodplain aquifer via a five-point injection array, and the monitoring of vegetation health response of a stressed tree community. This trial had the most uncertainty, as success was reliant on the ability to inject a sufficient volume of water for freshening to occur.

Floodplain Salt Interception Scheme (SIS) – In an effort to reduce the immediate impact of river salt accession, there has been investment into design and construction of salt interception schemes along the River Murray. These aim to alter hydraulic gradients and intercept the movement of saline groundwater from the highland to the alluvium and river. The Bookpurnong SIS has seven highland and fifteen floodplain interception wells, six of which are on Clark's Floodplain within close proximity to the Living Murray investigation sites. Operation commenced in July 2005 with extraction rates of 2 – 3 L/s per well.

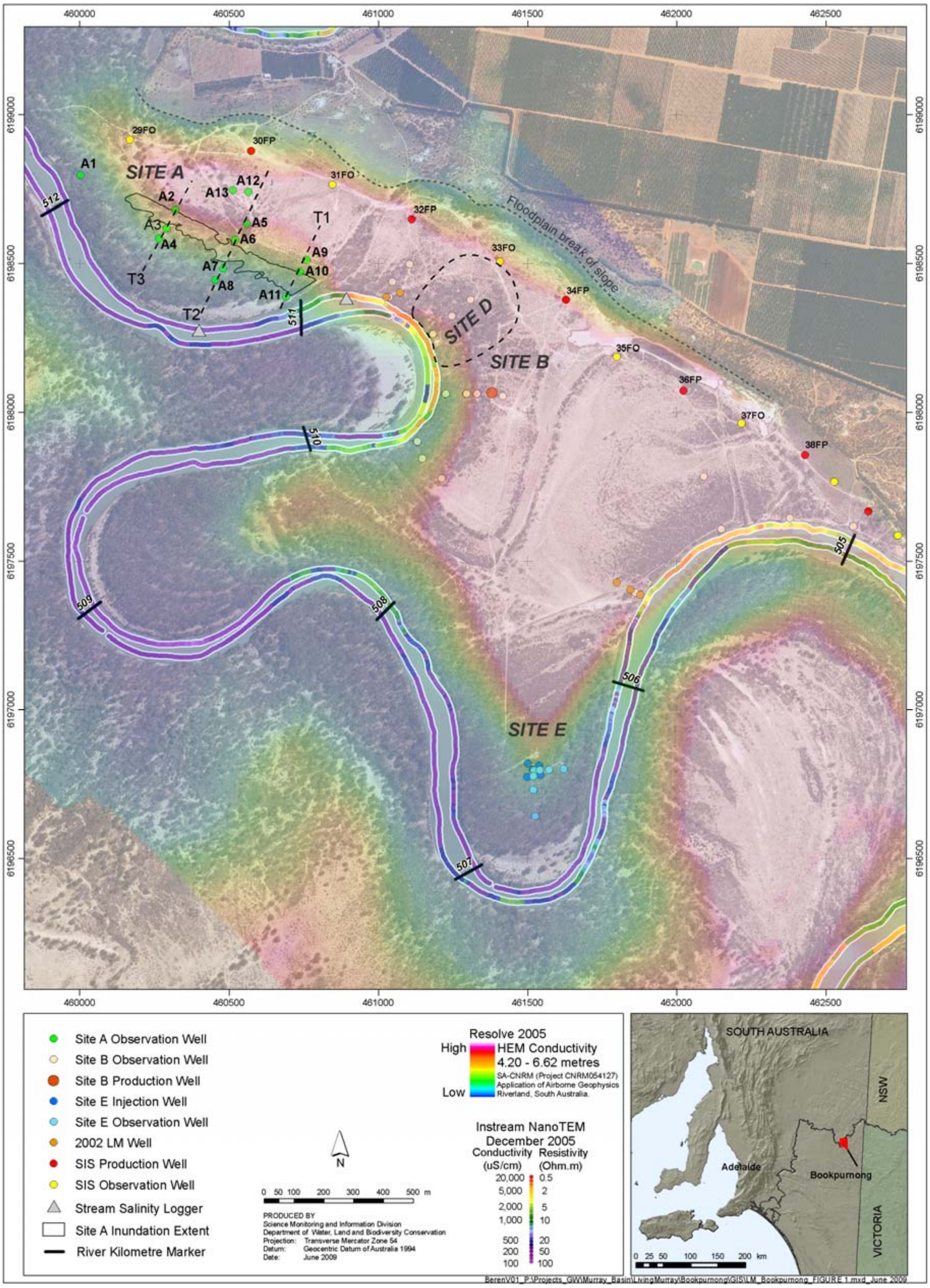


Figure 1. Overview of the manipulation trial sites on Clark's Floodplain, Bookpurnong.

1.3 STUDY SITE: RIVER RED GUM FLOODPLAIN COMMUNITY

Three reports will be produced detailing the results from Site A, Site B/D and Site E investigation trials. A detailed description of the study area can be found in the report produced on the Site E Injection Trial (Berens et al, 2009a).

The trial discussed in this report is focused on a depression dominated by river red gums, a floodplain feature located at the northern end of Clarks Floodplain near the river (Figure 1). The presence of river red gums at this site suggests that the floodplain depression historically would have naturally flooded every 3 to 5 years under pre river-regulation flow regimes. The feature fills from the southern end where a flood-runner channel exists. River red gums are densest at the southern end before turning into open woodland mid-way where older river red gums edge the depression. Juvenile river red gums are located at the mid and northern end of the depression, and most likely germinated from the 2000 River Murray flood event (S. Clark pers comm., 2005).

Pre-artificial inundation, most river red gum dieback in the floodplain feature was located at the southern end of the depression along the floodplain edge (Figure 2).

Figure 2. Dieback of *Eucalyptus camaldulensis*, river red gum (on the left), at the southern end of the inundation site (photo: Mel White)

2. METHODOLOGY

2.1 DELIVERY OF WATER

An 80 m earthen bank was constructed at the southern end of the floodplain feature where a flood runner normally fills the depression from the river. Topographically, this is the lowest point of the depression with the earth bank ensuring that water could be pumped from the river and held in the floodplain feature (Figure 3). The earthworks created an inundation zone that covered 3.7 ha of the depression with a 10.7 ML capacity.

The floodplain depression was watered three times with allocations being donated either from irrigation licences from the Bookpurnong/Lock4 Environmental Association, or as part of the environmental watering allocation for Chowilla. Water from the river was pumped over the earth bank to the depression (Figure 4). The constructed bank will be excavated before the next natural flood comes down the river. The first watering at the end of June 2005 (Table 2) will not be discussed in this report, as 12.9 ML infiltrated into the floodplain substrate. Thereafter, the two artificial floods kept the water level in the depression filled to the 12.0 m AHD contour, holding the water at ~1 m depth in the deepest point throughout the duration of pumping. The depression naturally dried within three to six months after each artificial flood (Table 1).

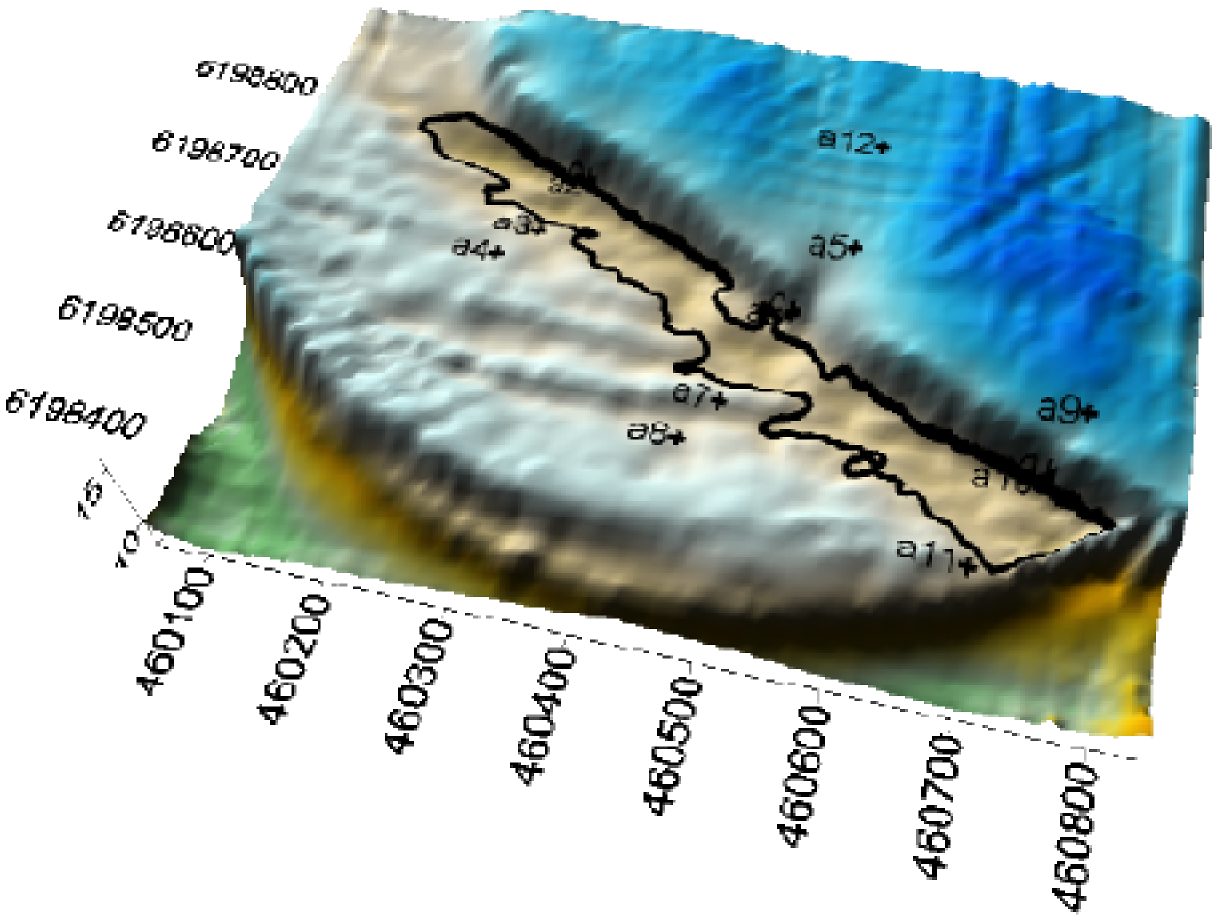


Figure 3. Digital Elevation Model (DEM) of the inundation zone on Clark's Floodplain, water enters the depression from the river near a11.

Figure 4. The left image is of the floodplain depression filling with water. The right image is of water being pumped from the river into the depression over the constructed earth bank.

Table 1. Details of the dates and amount of water delivered artificially to the study site

Date/s water was pumped into floodplain depression	Amount pumped (total)
29 June 2005	12.90 ML
25 July – 30 August 2005	29.97 ML
25 September – 5 December 2006	52.17 ML

2.2 GROUNDWATER COMPONENT

Observation wells were located along three transects dissecting the floodplain depression laterally (Figure 1). The twelve observation wells were constructed in June 2005 prior to the first artificial inundation of the depression in July 2005. Of the twelve observation wells, two were located at the very edge of the inundation zone (A2 and A10).

Supervised by AWE hydrogeologists, Underdale Drillers completed the Site A observation wells using a push tube auger to a depth approximately 1 m below the observed watertable. Observation wells were cased with 50 mm ID PVC with a 1 m slotted casing interval at the base, and a standpipe approximately 1 m high installed (Table 1).

Water level loggers were installed in observation wells A1, A2, A3, A5, A6, A7, A8, A10 and A11 at various times during the study. Manual recording of groundwater levels were made daily during the first inundation, extending to weekly post-inundation. Salinity monitoring did not commence until mid-way through the first inundation, and therefore no baseline salinity data exists.

Two alternative methods for salinity monitoring were undertaken. During the first inundation, the method of groundwater sampling was via bailing or pumping which was adopted before the salinity profile (sonding) method was tested. The preferred method for collecting salinity data was the pumping/bailing method, which was adopted for the second inundation.

Table 2. Observation well details

Name	Unit No.	GDA94 Easting	GDA94 Northing	TSP Ref Elevation (m AHD)	Ground Elevation (m AHD)	Drill Depth (m)	Completion Depth	Screen (m)
A1	702902159	459995	6198790	14.328	13.27	5.2	5.1	4.1 – 5.1
A2	702902160	460311	6198684	13.187	12.302	4.5	4.2	3.2 – 4.2
A3	702902161	460291	6198626	13.343	12.276	3.5	3	2 – 3
A4	702902162	460265	6198585	13.785	12.673	3.6	3.5	2.5 – 3.5
A5	702902163	460559	6198638	14.799	13.814	5.5	5	4 – 5
A6	702902164	460529	6198581	14.023	12.988	4	3.9	3 – 3.9
A7	702902165	460467	6198493	13.711	12.667	3.5	3.25	2.25 – 3.25
A8	702902166	460452	6198448	13.503	12.527	3.5	3.2	2.2 – 3.2
A9	702902167	460753	6198498	15.342	14.311	6.5	5.1	4.1 – 5.1
A10	702902168	460740	6198466	12.838	11.837	4	3.3	2.3 – 3.3
A11	702902169	460689	6198392	13.325	12.352	4.2	2.8	1.8 – 2.8
A12	702902170	460564	6198747	15.45	14.449	6	6	4.8 – 5.8

Geological logs are available through the World Wide Web at https://des.pir.sa.gov.au/deshome.html

2.3 SOIL SALINITY COMPONENT

2.3.1 SOIL SAMPLING

Soil samples were collected at each piezometer at the site to determine soil salinity. The methodology for collecting soil samples was the same across all the trial sites for the Bookpurnong Pilot Project. Soil samples where collected in 0.5 m increments from the unsaturated zone from all twelve wells during drilling in the Site A inundation trial zone. Subsequent samples were collected adjacent to the wells on a bi-annual cycle, coinciding with pre and post inundation until the trial was completed in March 2008.

Gravimetric water content (gg^{-1}) was measured by oven drying at 105°C for 24 hours. Matric potential (Ψ, MPa) was determined using the filter paper technique (Greacen et al., 1989). As described in Mensforth et al., (1994) and Holland et al., (2006), soil samples were analysed for matric potential (soil dryness) and osmotic potential (soil salinity), with the total soil water potential being the sum of these values. Total chloride was measured by ion chromatography, and then converted to the chloride concentration in the soil solution (mg L^{-1}) using the gravimetric water content. Osmotic potential (Ψ_π, MPa) was estimated from the chloride concentration of the soil solution (*[Cl⁻]* Mg L^{-1}), calculated using the Van't Hoff equation. This method assumes that all salts in the soil solution are present as NaCl and that the concentration used to calculate this relationship is appropriate for the range of soil salinities encountered by floodplain trees. Gravitational water potentials are not included as they are minimal in comparison to the measured matric and osmotic potentials.

2.3.2 GEOPHYSICAL SURVEYS

A Geonics EM31 conductivity meter was used to survey Site A on six occasions; June 2005, February 2006, September 2006, February 2007, September 2007 and March 2008. The surveys were carried out before and after the first and second inundations, and two distant non-inundations (dry period) respectively. This EM technique uses the induction of an electromagnetic field to sense the soils ability to conduct or resist electrical current. The EM31 has an effective depth of penetration of around 4 to 6 m, and the resultant apparent conductivity (or resistivity) is a bulk representation of this near surface zone. Variables that may typically influence the results of the EM31 surveys including groundwater level (decreases due to groundwater extraction at the SIS bores and in response to the changes in river level), variations in moisture and salt content due to downward leakage of the applied surface water or evapotranspiration, and the amount of clay content. The contribution of clay content to apparent conductivity is much reduced in soils with highly saline pore water (McNeill, 1980), and with the Murray trench alluvium consisting mainly of sands and localised clays of similar porosity, the water content in the saturated environment remains consistent, with salinity as the main driver of conductivity (Tan et al., 2009).

2.4 VEGETATION COMPONENT

2.4.1 RIVER RED GUMS

2.4.1.1 Monitoring

Located along the piezometer transects were three vegetation transects comprising 35 river red gums which were directly flooded. Three control vegetation transects were located out of the inundation zone to the north comprising 85 river red gums (Figure 5).

Thirty juvenile river red gums were monitored comprising 15 inundated and 15 control trees. At the start of the study, each tree was less than 1.5 m in height. Height was then measured throughout the course of the study with the results being analysed as the average height of the 10 trees under the different experimental influences (wet or dry).

Each tree was tagged, assigned a unique code and located using a GPS (Global Positioning System). Tree condition was tracked over time, allowing for direct comparison between assessment dates coinciding with the two artificial inundation events (Table 2).

The DWLBC tree health assessment method (Souter et al., 2009) is based on a conceptual model of declining tree health due to prevailing environmental conditions and behaviour in response to management intervention e.g. environmental watering. Tree health was measured as a combination of condition and response. Condition is assessed as crown extent and density assessed on a six-category scale (Table 4). Density was eliminated from this analysis as it was only measured on the last four assessment dates but it was used for the method development of visual tree assessments. Response is reflected as behavioural reaction to environmental changes e.g. epicormic growth can be a response to flooding, fire or rainfall. Six behavioural attributes are measured on a three-category scale (Table 5). The assessment of epicormic growth follows UN/ECE (2006) and bark condition (cracked or intact) was also recorded.

In addition to the visual tree assessments, photo-points were located at both ends of each river red gum transect. The photos taken over a three year time period show varying degrees of change and were used as a visual depiction of the sites, some of the photos are used in the report.

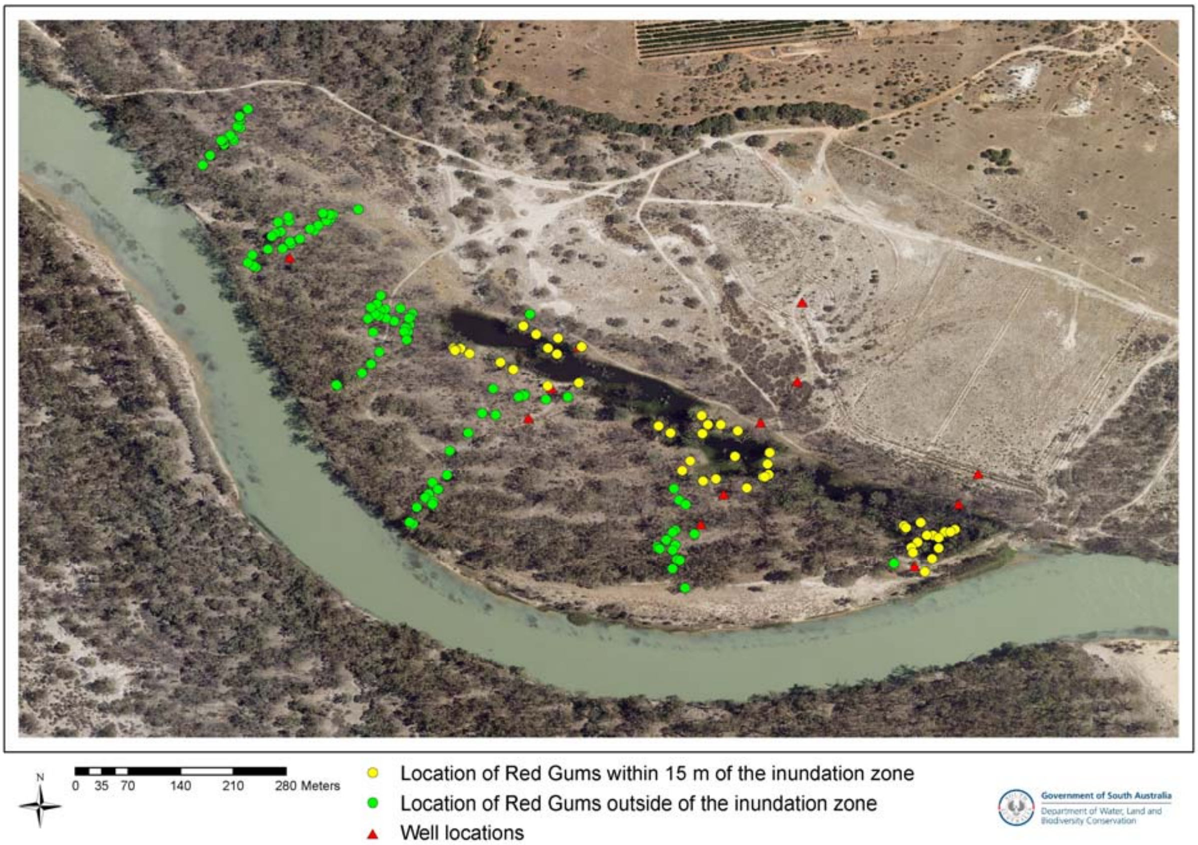


Figure 5. Location of *Eucalyptus camaldulensis* monitored at the Site A trial.

Table 3. Dates that *Eucalyptus camaldulensis* were monitored at the inundation site

Tree assessment dates
15 June 2005
Flooded – 25 July to 30 August 2005
13 October 2005
4 April 2006
6 September 2006
Flooded – 25 September to 5 December 2006
7 February 2007
22 March 2007
6 September 2007
5 March 2008

Table 4. Crown extent categories used in the tree health assessment

Category	Crown Extent
0	Absent (0%)
1	Minimal (~1~10%)
2	Sparse (~11~25%)
3	Moderate (~26~75%)
4	Major (~76~90%)
5	Maximum (~91~100%)

Table 5. Behavioural response scale

Category	Positive behaviour score (Epicormic growth, capsule development, flowering, seeding, crown growth)	Negative behaviour score (Crown dieback, leaf damage eg insect, mistletoe)	Description
1	0	0	Absent or scarce, effect not seen in a cursory manner
2	1	-1	Common, effect is clearly visible
3	2	-2	Abundant, effect dominates the appearance of the tree

2.4.1.2 Statistical Analysis

Trees recorded as cracked bark that showed no vegetative response throughout the duration of the field trial were eliminated from the analysis. Directly inundated trees and those within 15 m of the inundation zone, totalling 49 trees were analysed as being influenced by the artificial inundation (cf. Bacon et al, 1993; Mensforth et al, 1994). Trees not included in the inundation zone and the control trees, totalling 111 river red gums were analysed as being non-watered.

Markov modelling of tree crown extent and epicormic growth

Changes in tree crown extent and epicormic growth were modelled as a homogeneous, continuous-time, multistate Markov process. The model assumes that future states of the process depend on the current state, but not its history. The Markov model for crown extent comprises five states (Figure 6). State five comprises the combined categories 5 and 6 (Table 4) as an insufficient number of trees were observed in category six to develop an acceptable model. The Markov model for epicormic growth comprises three states (Figure 6b). A Markov model is based on a transition probability matrix which gives the probabilities of a system's future state from its current state.

The crown extent model is described by a transition intensity matrix, Q:

$$Q = \begin{pmatrix} -(q_{12}) & q_{12} & 0 & 0 & 0 \\ q_{21} & -(q_{21}+q_{23}) & q_{23} & 0 & 0 \\ 0 & q_{32} & -(q_{32}+q_{34}) & q_{34} & 0 \\ 0 & 0 & q_{43} & -(q_{43}+q_{45}) & q_{45} \\ 0 & 0 & 0 & q_{54} & -(q_{54}) \end{pmatrix}$$

where the rows sum to zero.

The epicormic growth model is described by a transition intensity matrix, *Q*:

$$Q = \begin{pmatrix} -(q_{12}) & q_{12} & 0 \\ q_{21} & -(q_{21}+q_{23}) & q_{23} \\ 0 & q_{32} & -(q_{32}) \end{pmatrix}$$

where the rows sum to zero.

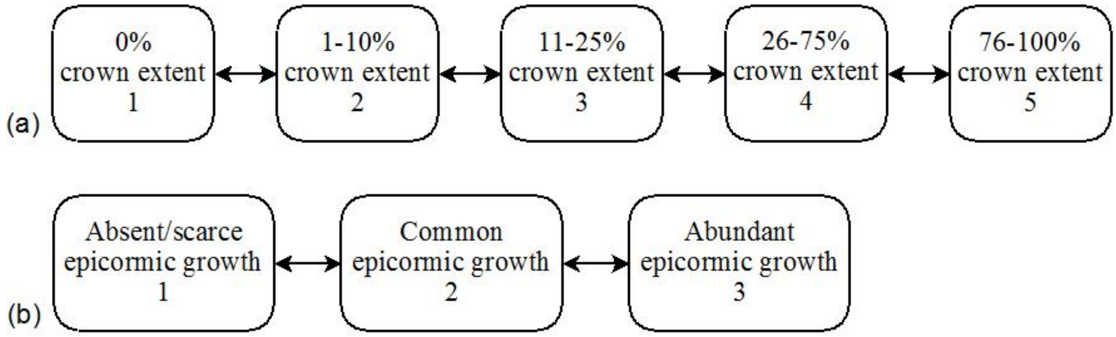


Figure 6. River red gum crown (a) extent and (b) epicormic growth Markov models

Modelling was undertaken using the msm package (Jackson et al. 2003) in the R statistical software package (R Development Core Team 2008). The msm package computes maximum likelihood estimates for *Q* from a transition probability matrix, P(t) (Jackson et al. 2003). Fitting the model involves finding values of the unknown transition intensities: *q*12, *q*21, *q*23, *q*32, *q*34, *q*43, *q*45, *q*54 for the extent model and *q*12, *q*21, *q*23, *q*32 for epicormic growth. To do this, msm requires a matrix of the same size as *Q*. The matrix contains zeros in the positions where the entries of *Q* are zero, and the diagonal entries are defined as minus the sum of all other entries in the row. As the likelihood is maximised by numerical methods, a set of initial transition intensity values is needed to start the search for a maximum. The 'crudeinits.msm' function was used for this purpose.

The effect of watering trees was determined by including trees that were affected by the artificial inundation, and those which remained dry as a covariate in the model. Inundated trees were either directly inundated or grew within 15 m of the edge of the pool. Differences between transition intensities for two models, no effect of inundation and inundation effect were compared for both crown extent and epicormic growth. Ratios of transition intensities were then calculated to determine whether progression or regression from a selected series of condition states was the more likely for the two models for crown extent and epicormic growth. Mean sojourn times, the average time spent in a particular state, were also estimated for both crown extent and epicormic growth models and compared.

Juvenile tree growth

We hypothesised that inundated juvenile river red gum would grow taller and that more would survive when compared to trees that relied entirely on rainfall. The height of fifteen trees in each of the inundated and dry areas of the floodplain were measured, once prior to the inundation and on a further five occasions at approximately six monthly intervals coinciding with adult tree surveys. We compared mean tree height between treatments and among survey times using repeated measures ANOVA. Sample time was the within subjects factor and treatment the between subjects factor. Since the first measures were taken before the experimental manipulation, we looked at significant time x treatment interaction effects to support the hypothesis. Tree heights were log (x+1) transformed prior to analysis to confer normality to the data and ensure homogeneity of variance. Sphericity of the data was assessed using Machuly's test. As data the assumption of sphericity was violated probabilities were adjusted based on the Greenhouse-Geisser and Huynh-Feldt epsilons. Post hoc testing was undertaken using Tukey HSD for unequal N (Spjotvoll/Stoline test).

2.4.2 UNDERSTOREY

2.4.2.1 Monitoring

Six vegetation transects were set across the study site. Each transect comprised five 1 x 1 m^2 quadrats spaced ten metres apart which ran perpendicular to the river and across the inundated area, and an adjacent area which remained dry. Each transect was spaced < 200 m apart. In each quadrat the identity of each plant taxon was identified to the lowest level practicable. Sampling occurred on eight occasions over three years. A survey was conducted once prior to the initial inundation and thereafter at biennial intervals (Table 6).

Table 6. Dates of when the floodplain depression was inundated and the coinciding tree condition assessments, understorey vegetation assessments and soil sampling surveys

Date	Inundation	Tree condition	Understorey vegetation	Soil survey
Jun-2005	*	*	*	*
Oct-2005		*		
Nov-2005				*
Dec-2005			*	
Apr-2006		*	*	*
Sep-2006	*	*	*	
Dec-2006				*
Feb-2007		*	*	
Mar-2007		*	*	
Apr-2007				*
Sep-2007		*	*	*
Mar-2008		*	*	*

2.4.2.2 Statistical Analysis

Multivariate methods were used to compare differences in the composition of the understorey vegetation community over time and between inundated and dry transects. A single combined sample was derived from each of the six transects for each survey. A transect sample comprised an estimate of the percent cover of each plant taxon by dividing the number of times each plant was recorded in each quadrat by the total number of quadrats (five). This percent cover data was arcsine-square root transformed and converted to a Bray-Curtis similarity matrix and analysed using Primer software (ver 6.1.6: Clarke 1993). The understorey vegetation community was classified by hierarchical agglomerative clustering. Ordination was undertaken using non–metric Multi-Dimensional Scaling (MDS) after 500 random starts. Differences between time and inundation groups were examined using two-way crossed ANalysis Of SIMilarity (ANOSIM, Clarke 1993). The SIMilarity PERcentages (SIMPER) procedure was used to determine which plant taxa contributed most to groups found by ANOSIM to be significant and with an R value of >0.5. SIMPER was used to identify taxa that made the highest contribution to the average similarity within a group. SIMPER was used to identify taxa that made the highest contribution to the average similarity within a group. Taxa with the highest average similarity/standard deviation ratio (greater than one if possible) are presented as typical of each group. Similarly taxa with the highest average dissimilarity/standard deviation ratios (greater than one if possible) are presented as between group discriminating taxa.

3. RESULTS AND DISCUSSION

3.1 WHAT IS THE IMPACT OF FLOODING ON SOIL SALINITY ?

To understand the processes of floodplain salinisation four different monitoring techniques were used; groundwater levels and salinity, soil salinity and geophysical surveys. The results from each of these sampling techniques are discussed individually in the following section.

3.1.1 GROUNDWATER LEVELS AND SALINITY

Groundwater level

Groundwater level results from the data logger time series data indicate that floodplain groundwater levels are responsive to river level variations at all sites, with the response magnitude decreasing with distance from the river. This indicates a strong connectivity between river level and floodplain groundwater level. Vertical groundwater recharge via surface water inundation, and groundwater level fluctuations as a result of the SIS operation, were observed in the data. During the period of both inundation events, a coincident river level rise (Figures. 7, 8, 9) occurred, complicating the distinction between groundwater response due to surface water application (recharge) or river level rise.

The initial 12.9 ML of water that was applied to the floodplain depression in June 2005 immediately infiltrated into the soil. This pre-watering in June was prior to both the significant river level fluctuation and the commencement of SIS operations. As a result of the initial 12.9 ML application in June 2005, fluctuations in groundwater level were measured in all piezometers excluding the control piezometer A1 (Figure 7). Soil water infiltration recharged the aquifer translating to a rise in groundwater levels during the 12.9 ML application. Groundwater response to the surface water application was greatest at wells nearest the inundation extent, specifically A2 where a fluctuation of more than 0.6 m was measured in June 2005 (Figure 1). Overall, groundwater response to watering was most pronounced along Transect 3.

The results from this study conclude that there was an initial response in groundwater levels when surface water was first applied to the floodplain depression during the pre-watering event in June 2005. Similar responses during the two subsequent inundation events cannot be wholly attributed to surface flooding as the consecutive inundations coincided with the commencement and cease to SIS pumping respectively.

A component of the study examined how the floodplain SIS operation affected groundwater levels across the inundation site. The SIS commenced operation mid-way through the first inundation and stopped mid-way during the second inundation due a fault in the SIS disposal pipeline. These fluctuations in SIS operation affected groundwater levels at Site A, which combined with river levels rise caused difficulties in interpreting groundwater level and salinity results in relation to inundation at the site.

Data from the SIS midpoint observation well (31FO) recorded groundwater levels to be above river levels prior to SIS commencement, with groundwater levels decreasing during SIS drawdown, and increasing post SIS shutdown (Figure 7). Groundwater level trends similar to those recorded at 31FO, were also measured at wells A2, A5, A6, A9, A10 and A12. The response measured indicates that groundwater levels in wells located between the inundation zone and the SIS extraction wells are predominately dominated by groundwater extraction. Groundwater levels in wells riverside of the inundation zone have a more distinct relationship to river level variation.

During the 'dry' period of the study when no water was applied to the floodplain depression in 2007/08, a decrease in water levels across all wells were recorded, correlating with the decease in river levels. The falling river levels contributed to several wells becoming dry. Deeper well completions would have enabled longer monitoring periods.

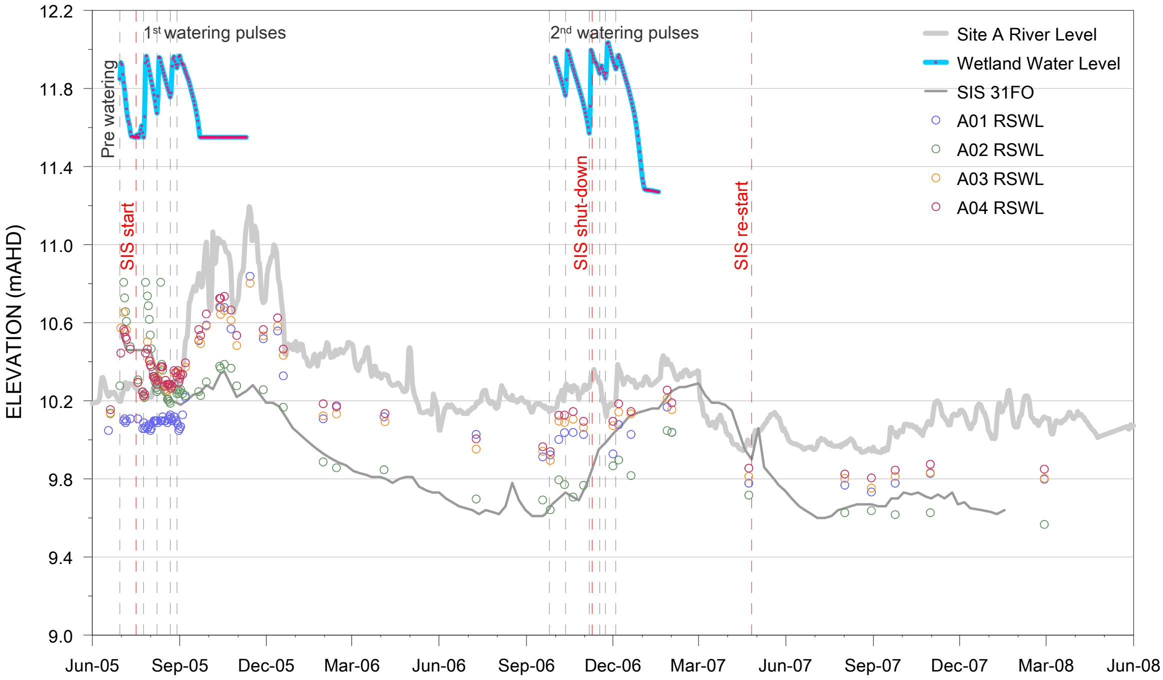


Figure 7. Groundwater hydrographs at Transect 3; A1, A2, A3, A4.

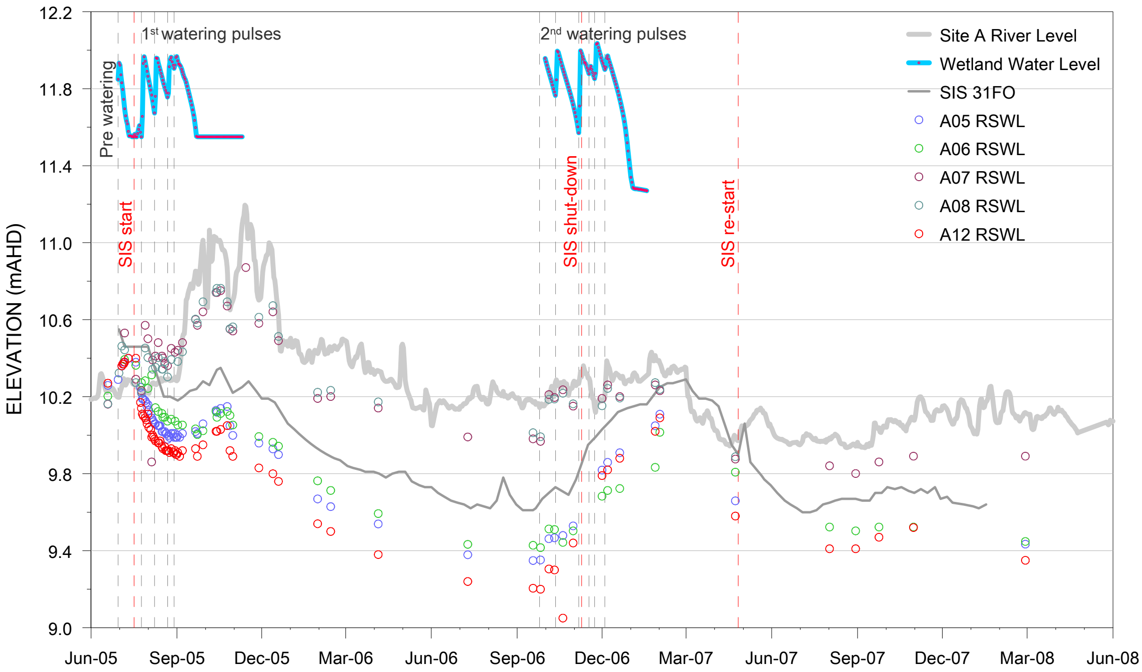


Figure 8. Groundwater hydrographs at Transect 2; A5, A6, A7, A8, A12.

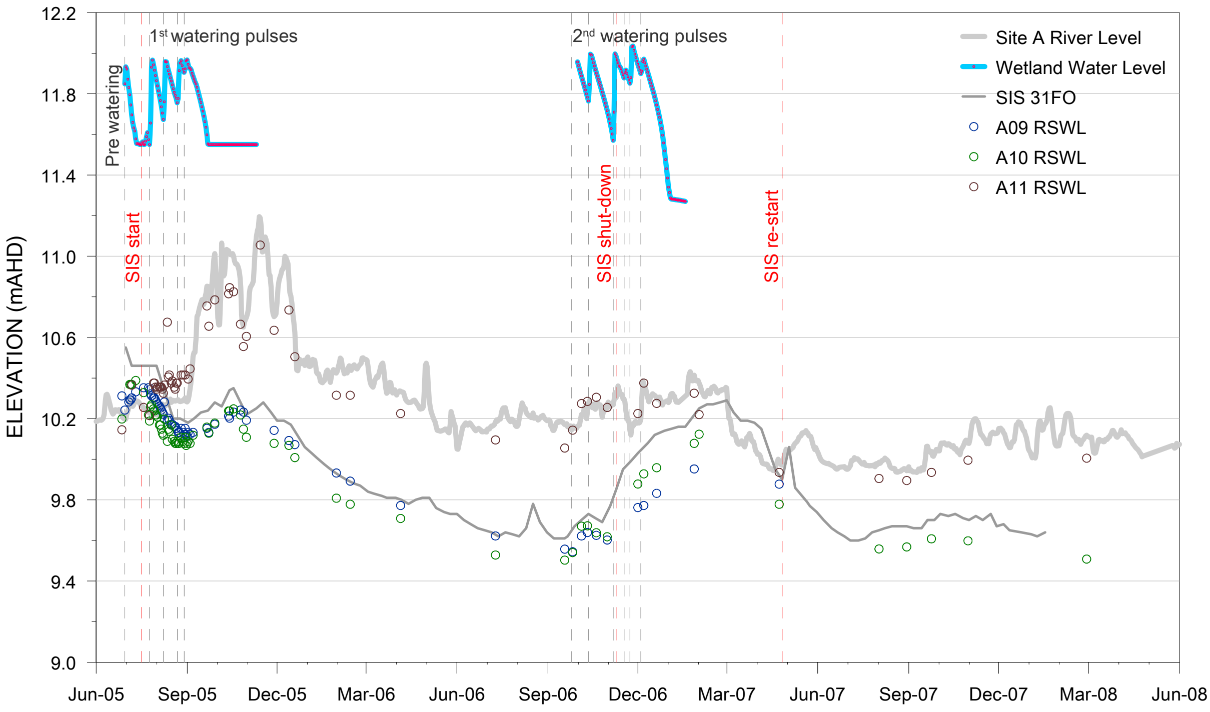


Figure 9. Groundwater hydrographs at Transect 1; A9, A10, A11.

Groundwater salinity

Groundwater salinity was not adequately monitored during the trial due to resource limitations. The screened intervals in observation wells were not ideal in all cases, and shortfalls in data collection and EC calibration made it difficult to analyse the data. Adequate groundwater monitoring was not in place prior to the commencement of the first inundation, and salinity data was not collected until the second application of surface water. In all transects, the data indicates a salinity gradient increasing away from the river.

From the available data, increases in salinity were observed at A2, A9, A10 and A11 as a result of the artificial inundation (Figure 10). This is consistent with salt mobilisation processes; A2 and A10 are on the very edge of the inundation zone and hence seepage and vertical recharge through the saline soil profile increased the groundwater level and salinity at these locations. Wells A9 and A11 are outside of the inundation zone but are located at the lowest point (both topographically and hydraulically). An increase in salinity in wells A9 and A11 indicates that groundwater discharges to the river from this area in the floodplain depression . These observations are also consistent with the patterns and interpretation from the geophysical surveys discussed in the next section. The impact of saline groundwater discharge into the river after a floodplain depression has been inundated is discussed in Section 3.4.

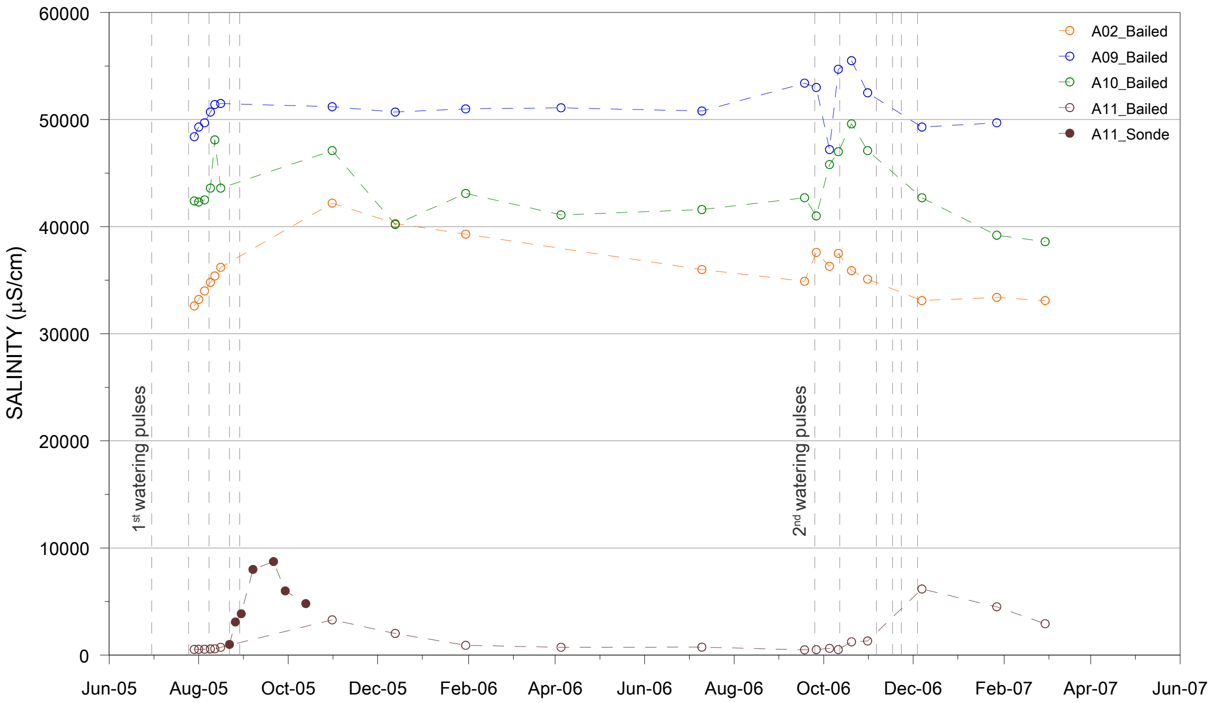


Figure 10. Bailed salinity data for A2, A9, A10 and A11, and sonde data for A2.

3.1.2 GEOPHYSICS

Electromagnetic EM31 surveys were conducted before and after both flooding events, with two additional surveys conducted to examine the response to the ‘dry’ period (Figure 11). The initial survey conducted just prior to the first application of water indicates that the profile beneath the inundation zone exhibits the highest electrical conductivity. North of the inundation zone (between A2 and A6), a thin less conductive (blue) anomaly is mapped in all six surveys representing a topographic rise toward the more elevated floodplain tier, and anticipated to have a increased depth to water table and reduced soil moisture.

At the northeastern boundary of the survey, high conductivity (red) zones are mapped in all six surveys. This region is known to host groundwater of high salinity in excess of 40 000 EC.

The February 2007 survey carried out following dissipation of water from the first flooding, shows a noticeable reduction in the bulk conductivity within the extents of the inundation zone. The change is most evident over the eastern half of the inundated area, which is more depressed topographically and the region where water pools the longest. Beyond the inundation zone, there is little interpretable difference between the first and second survey.

The September 2006 survey conducted shortly before the start of the second watering, shows no significant variation from the previous survey other than a nominal increase in conductivity (salinity) within the inundation extent (most noticeably at the north-western end), possibly due to an increase in soil salinity.

The fourth survey collected shortly after the second round of watering is similar to the second survey conducted after the first watering. The conductivity signature within the inundation zone reduced as a result of the applied water, while beyond the inundation extent, little change between previous surveys was observed.

The fifth and sixth surveys were conducted in September 2007 and March 2008, eight and fourteen months after the final input of the second watering. The pattern of conductivity outside of the inundation zone, as for the previous surveys, remained relatively unchanged. Within the inundation zone, the conductivity from the fourth to fifth survey and fifth to sixth surveys, progressively increases and could be indicative of an increase in soil salinity due to evapotranspiration processes in the absence of surface water recharge.

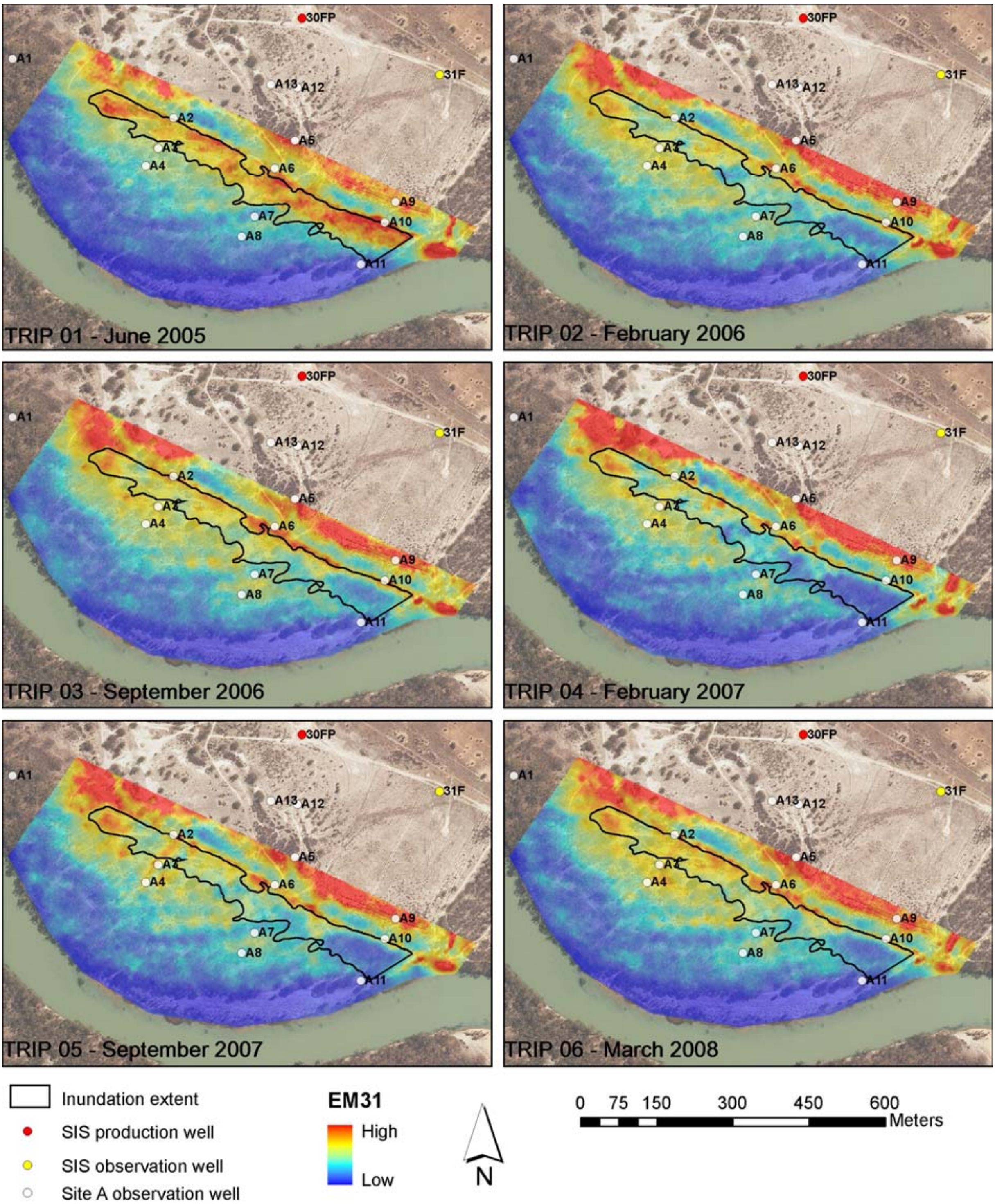


Figure 11. Temporal examination of Site A electrical conductivity using Geonics EM31.

3.1.3 SOIL SALINITY

The total soil water potential is used to indicate soil water availability for root uptake; a clear relationship is derived from the knowledge of a tree's predawn water potential, an integrated measure of soil water availability to vegetation (Eamus et al, 2006). The more negative the total soil water potential, the harder it is for plants to source water.

Results from the soil samples collected next to four of the twelve wells at Site A are presented in Figure 12, with results of all twelve sites found in Appendix A (Figure A1). Well A2 and A10 were located on the edge of the inundation zone and showed a decrease in salinity (osmotic potential) in the profile after the first and second inundations (November 2005 and April 2007) (Figure 12). Wells A4 and A8 located away from the inundation zone, show fairly stable salinity profiles throughout the inundation event. These results match the findings from the EM31 survey whereby soil salinity was found to decrease in the inundation zone post inundation.

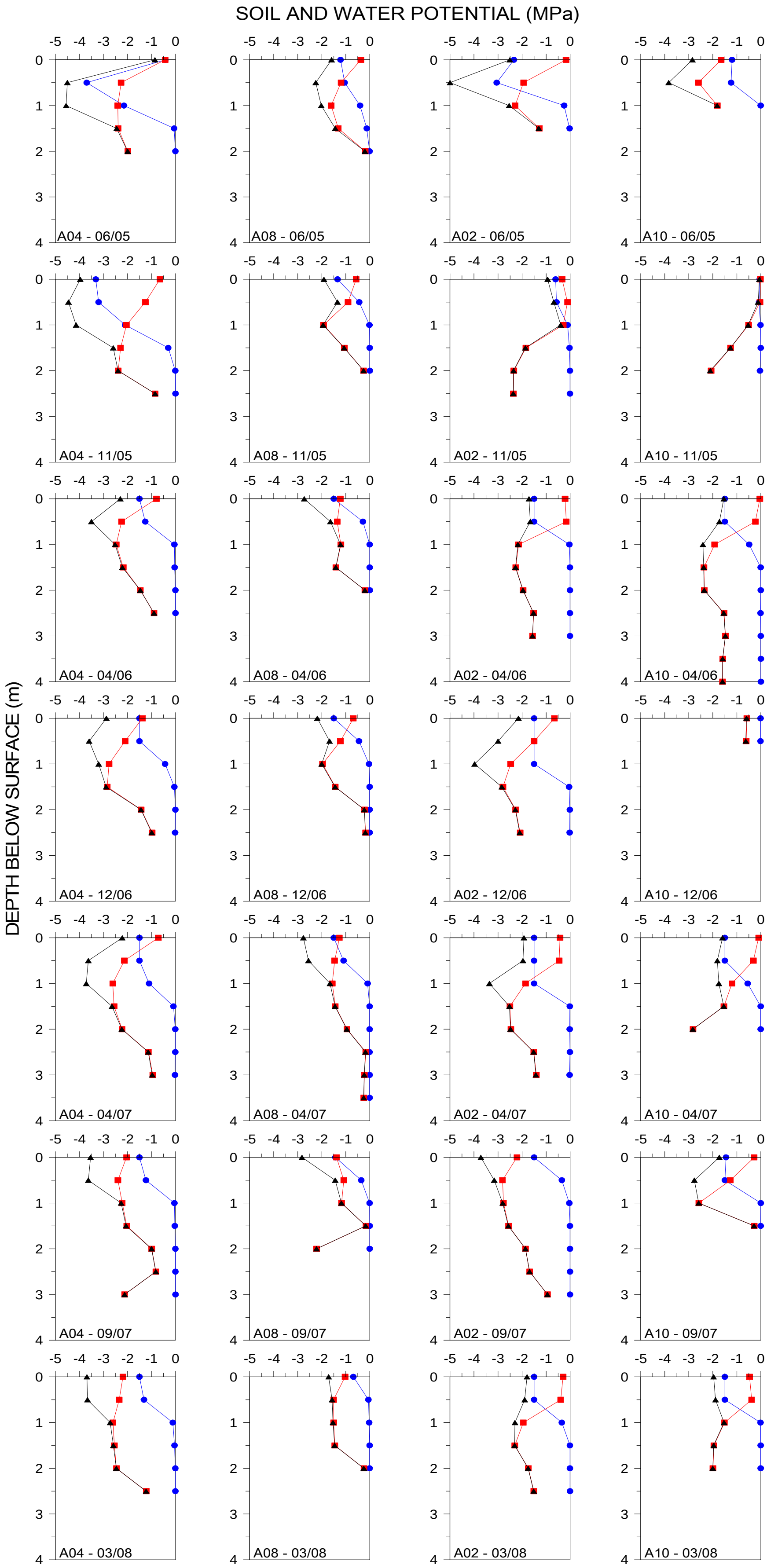


Figure 12. Soil salinity profiles of A4 and A8 (control zone) left, and A2 and A10 (inundation zone) on the right. Osmotic potential (■), matric potential (●) and total potential (▲).

3.2 HOW DO RIVER RED GUMS RESPOND TO ARTIFICIAL INUNDATION ?

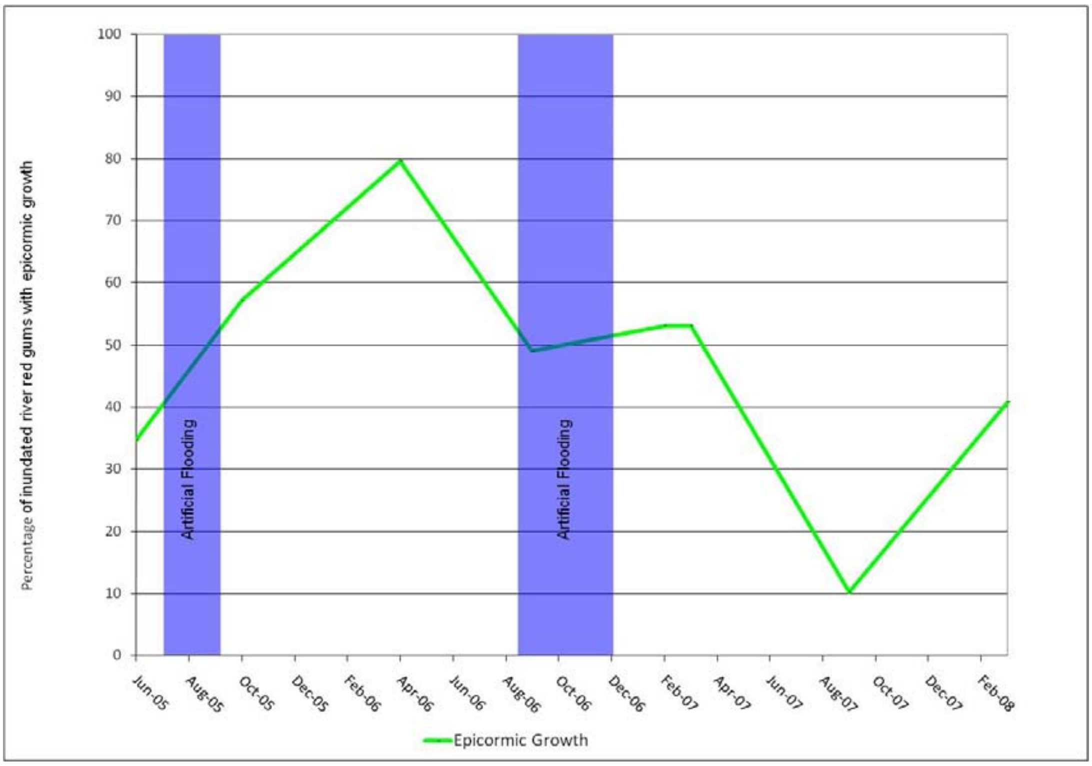
Visual tree condition assessments were made over three years, with artificial inundations in the first and second year, and a ‘dry’ event in the third year where no water was applied to the floodplain depression. Prior to artificial inundation, the last natural flood to inundate the study area was five years earlier in 2000.

3.2.1 RESPONSE IN EPICORMIC AND GROWTH CROWN EXTENT

River red gums responded to inundation with epicormic growth (Figure 13a). Epicormic growth recorded the highest peak after the first inundation, with the trees in crown extents of 1-10% and 11-25% having the highest proportion of epicormic growth (Figure 14). Some trees with 0% crown also responded to inundation by growing epicormic foliage. After the second inundation, there was a lesser peak in epicormic growth (Figure 13a) but with trees with crown extents 1-10%, 11-25% and 26-75% crown extent having a large proportion of epicormic foliage (Figure 14).

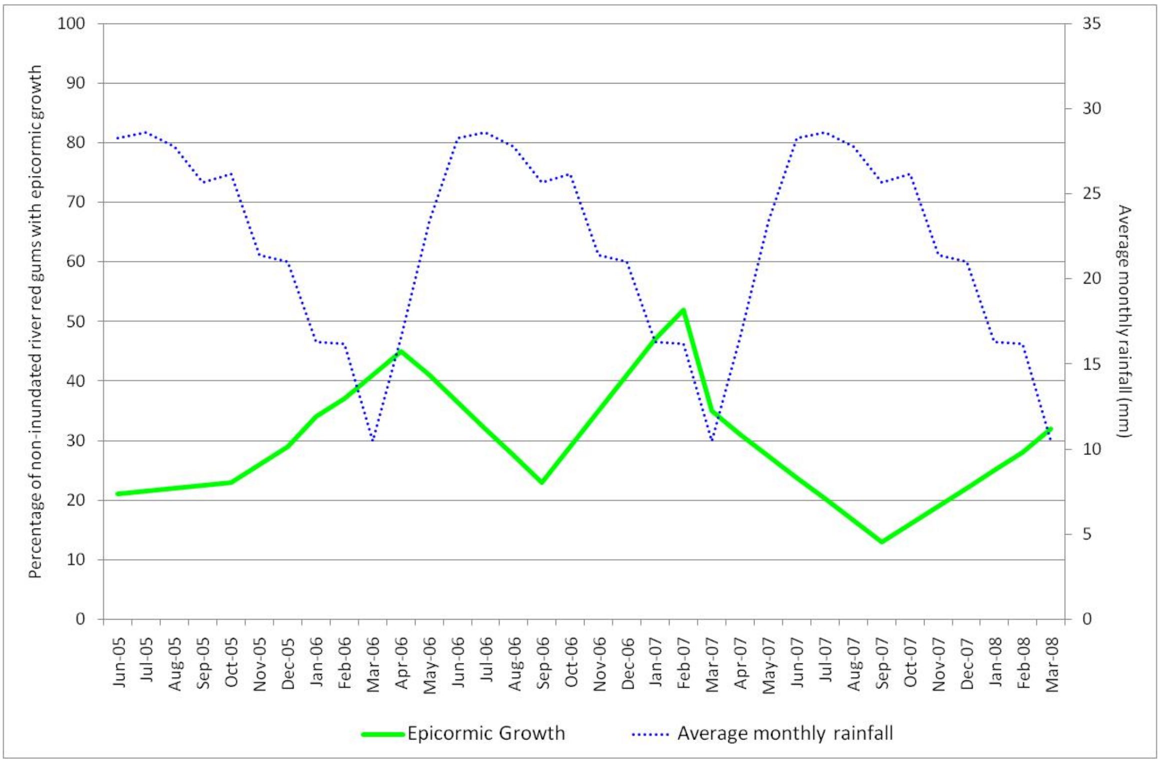
The non-inundated trees also grew epicormic growth which is probably linked to seasonal rainfall patterns (Figure 14b). Trees with crown extents 1-10% and 11-25% had the highest proportion of epicormic growth (Figure 16).

Overall, the greatest frequency of trees with epicormic growth were those that were inundated (Figure 14, 15 and 16). Artificial surface inundation can therefore promote recovery of river red gum crown condition.



a)

Figure 13. The percentage of the 49 inundated *Eucalyptus camaldulensis* (a) and the 111 control trees (b) that grew epicormic growth during the field trial



b)

Figure 13. The percentage of the 49 inundated *Eucalyptus camaldulensis* (a) and the 111 control trees (b) that grew epicormic growth during the field trial

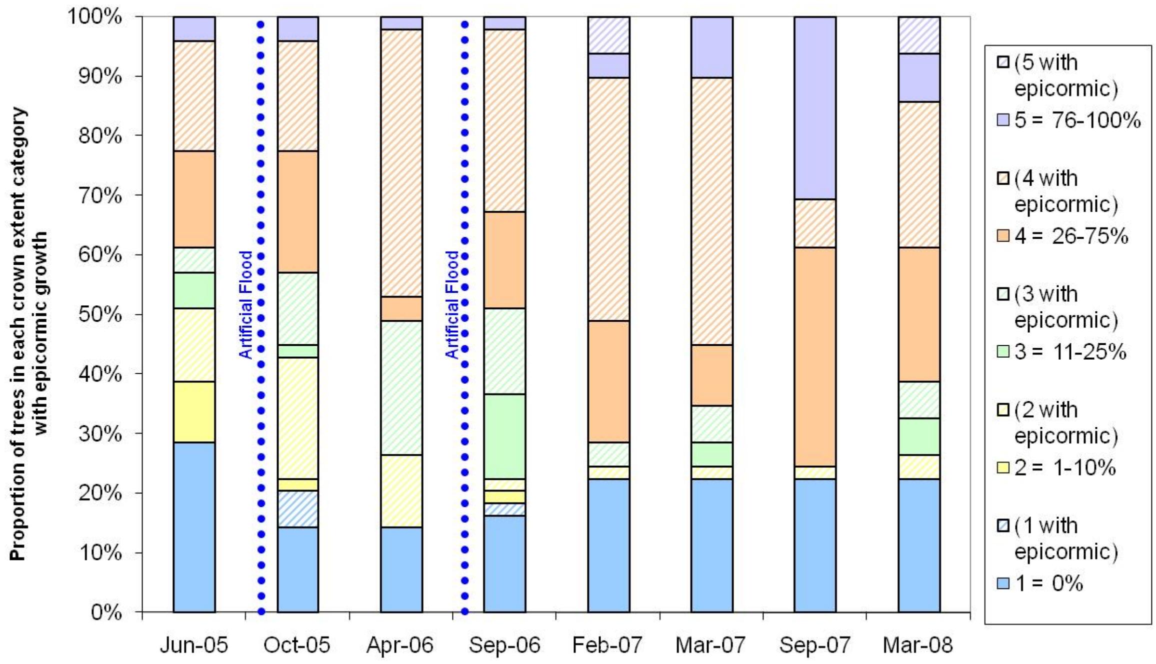


Figure 14. The proportion of 49 inundated trees recorded as having epicormic growth in each crown extent category during the study period

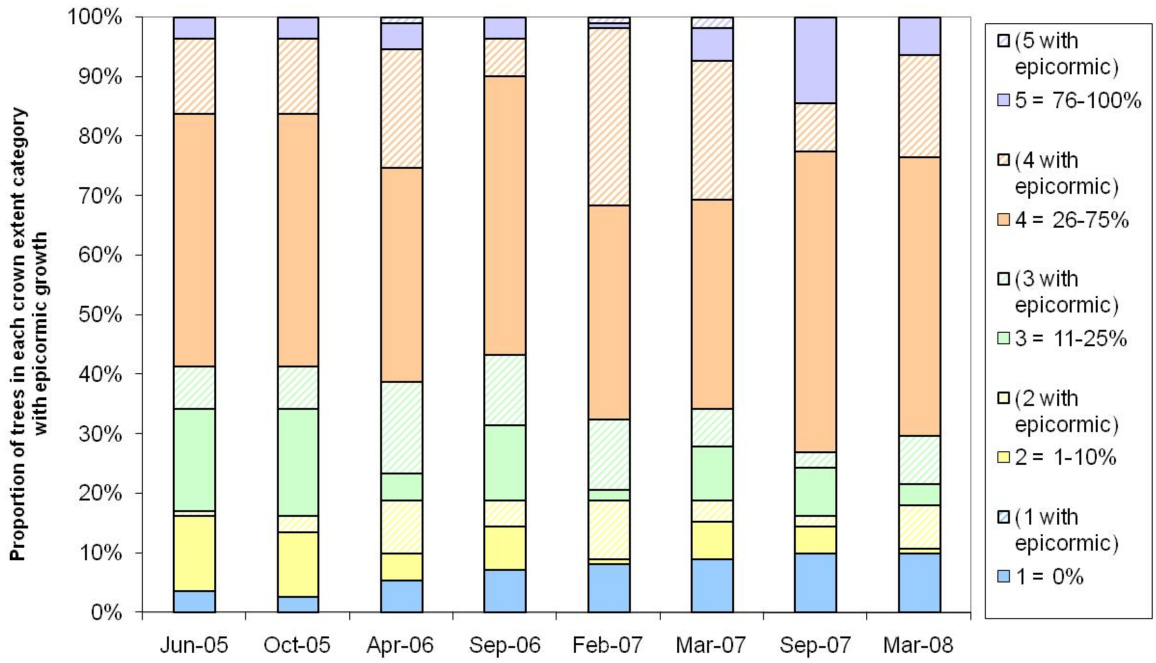


Figure 15. The proportion of 111 non-inundated trees recorded as having epicormic growth in each crown extent category during the study period

The following observations were made from the visual assessment of river red gum crown extent, before and after the artificial inundation events for the 49 trees that were inundated or within 15 m of the inundation zone (Figure 16):

- Prior to inundation, the majority of river red gums were in crown extent categories; 0%, 1-10% and 26-75%.
- After the first artificial inundation (from June 2005 to April 2006) there was a reduction in trees with 0% and 1-10% crown.
- After the first inundation (from June 2005 to April 2006) there was an increase in trees with 11-25% and 26-75% crown.
- After the second artificial inundation (from April 2006 to March 2007) there was a reduction in trees with 1-10% and 11-25% crown.
- After the second artificial inundation (from April 2006 to March 2007) there was an increase in trees with 0%, 26-75% and 76-90% crown.
- During the 'dry' spring when no water was applied (September 2007), one year since the previous inundation, trees with 0% and 1-10% crown had stabilised, and trees with 76-90% crown had further increased.
- By the end of the study (March 2008) one and half years after two consecutive inundations, some trees had reduced in condition to 11-25% and 26-75% crown, while others had further increased to the highest category of 91-100% crown.

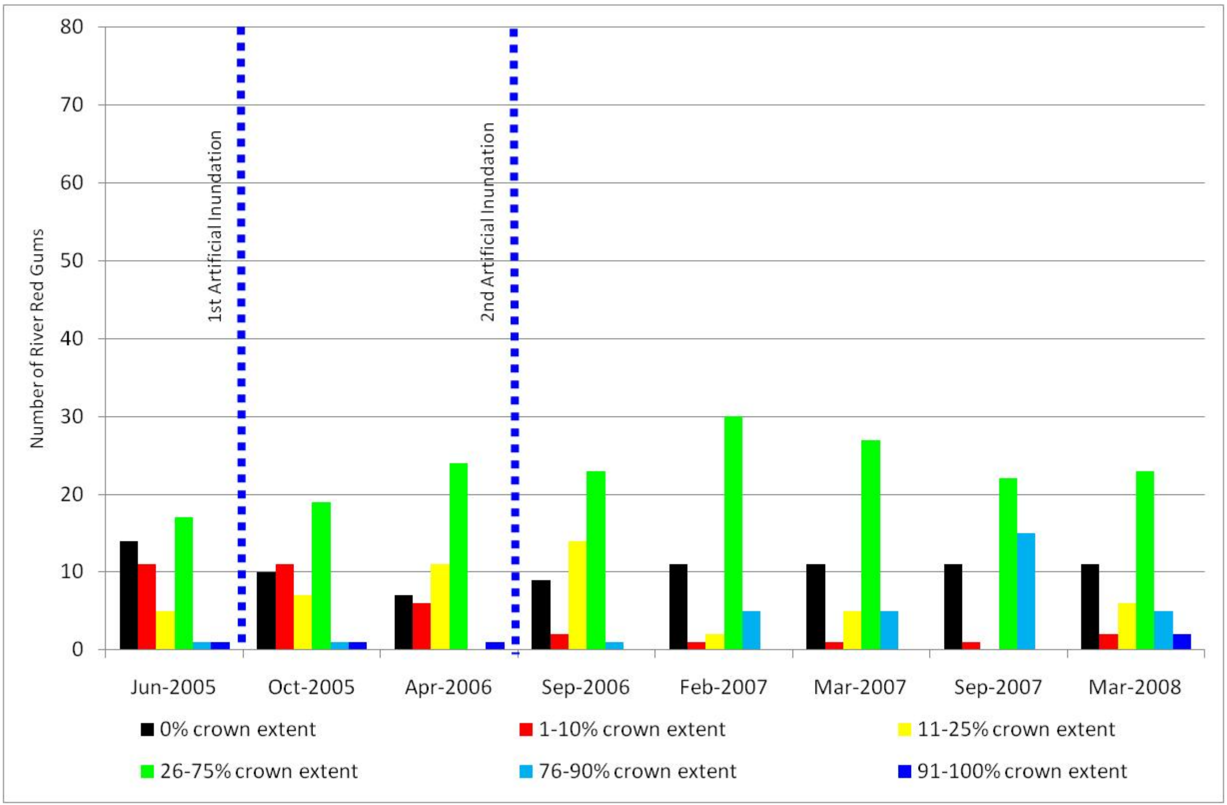


Figure 16. The number of inundated *Eucalyptus camaldulensis* from the 49 that were inundated (or within 15 m of inundation) in each crown extent category over the duration of the trial

The following observations were made from the visual assessment of river red gum crown extent for the 111 trees that were not inundated and were used as control trees (Figure 17):

- There was an increase in the number of trees with no foliage, 0% crown.
- There was a decrease in the number of trees with 1-10% crown.
- There was a decrease in the number of trees with 11-25% crown.
- There was an increase in the number of trees with 26-75% crown.
- The was an increase in the number of trees with 76-90% crown.
- By the end of the study (Mar-08) trees that were not inundated, were in better condition than at the start of the study, except for the increase in 0% crown class.

Even though the control trees improved in condition, the degree of improvement was less than what happened at the inundated site. After inundation, there was a notable decline in the number of trees in the lower classes (1-10% and 11-26%), indicating that these trees were more likely to transition to a higher crown class upon inundation (see next section). Inundation supported a greater recovery of tree condition at Site A.

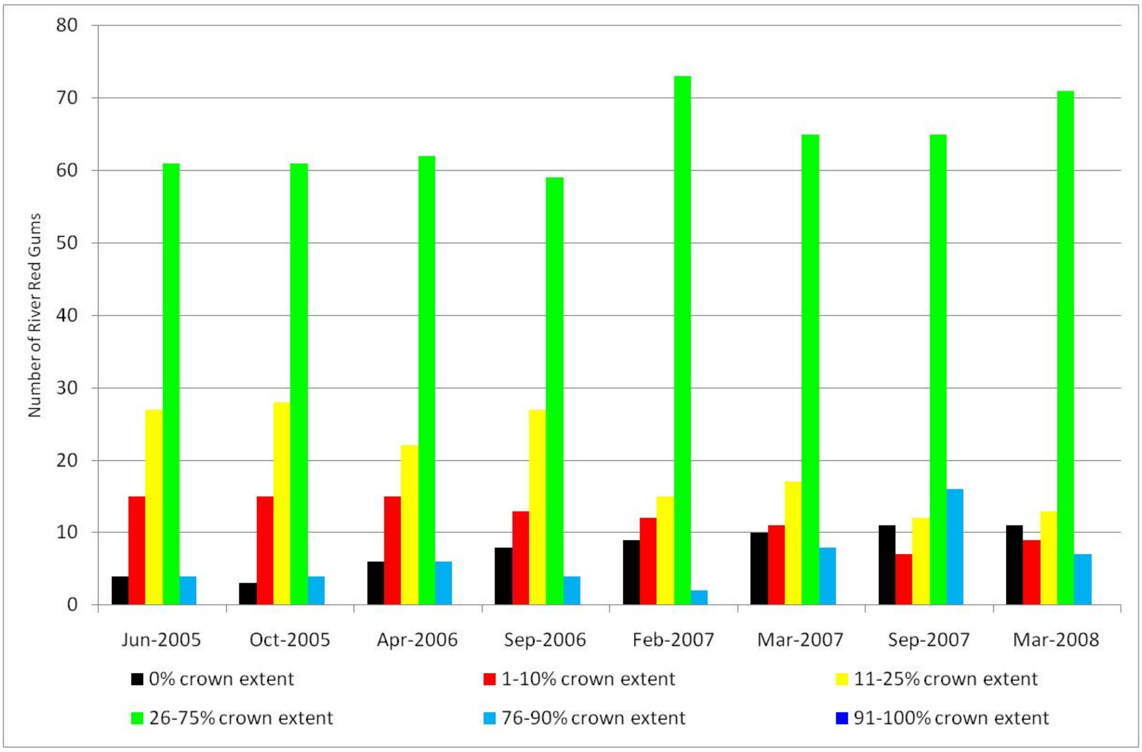


Figure 17. The number of non-inundated *Eucalyptus camaldulensis* from the 111 control trees in each crown extent category over the duration of the trial

3.2.2 TRANSITION OF TREES BETWEEN CROWN AND EPICORMIC CATEGORIES

3.2.2.1 Crown Extent

The transition of trees between crown extent categories was modelled for all trees (those inundated and those not), with the results finding that the majority of trees did not change crown extent category between surveys (Table 7).

Table 7 Frequency of *Eucalyptus camaldulensis* transition between each crown extent category/state over the three-year study period

Initial state	Crown extent	Frequencies for transitions to the following states:				
		1	**2**	**3**	**4**	**5**
1	0%	109	6	7	2	0
2	1-10%	14	88	15	4	0
3	11-25%	3	10	125	53	1
4	26-75%	2	2	32	532	40
5	76-100%	0	0	0	33	42

Even though the majority of trees did not change crown extent categories between surveys, it was deemed important for future interventions to know if the inundated trees were more likely to increase their crown cover after being flooded, than those trees that were not inundated. Visually, trees in the inundation zone looked to have benefited from flooding and were looking vibrant and healthy (Figure 18) and the data was modelled to see if trees did transition between crown states. The modelling outputs from the crown cover transition model are tabulated in Appendix A and are summarised below:

<u>Inundated trees:</u>

- All trees were more likely to increase in condition than decrease, with inundated trees having a greater likelihood of increasing crown condition than those not inundated.
- Significantly, inundated trees were more likely to transition from categories 2 to 3 and from 4 to 5 when compared to non-inundated trees.
- The transition from state 5 to 4 was significantly less likely for inundated trees when compared to non-inundated trees
- Excluding trees with 0% crown (that significantly stay in this state), the average time either an inundated or non-inundated tree spent in a particular state was longest for category 4 (26-75%).
- Inundated trees spent less time in each category than non-inundated trees due to the response of individuals.

<u>Non-inundated trees:</u>

- The transition from state 1 to 2 was the least likely.
- The transition from state 5 to 4 was the most likely.

Bookpurnong tree2_October 2005 | Bookpurnong tree2_April 2007

Bookpurnong tree_October 2005 | Bookpurnong tree_April 2007

Figure 18. Visual evidence of *Eucalyptus camaldulensis* in a lower crown extent category transitioning to a higher crown extent category over the duration of the study period.

3.2.2.2 Epicormic Growth

The transition of trees between epicormic growth categories was modelled for all trees (those inundated and those not). Few trees were recorded as having abundant epicormic growth (Table 8).

Table 8. Frequency of transitions between epicormic growth states

Initial state	Epicormic Growth	Frequencies for transitions to the following states:		
		1	2	3
1	Absent/Scarce	546	146	21
2	Common	136	183	24
3	Abundant	14	22	28

The modelling outputs from the epicormic growth transition models are tabulated in Appendix A and are summarised below:

- Trees recorded as having common epicormic growth tended to remain in this state between surveys.
- Both increases and decreases in epicormic state were observed, with the most frequent transition being from absent/scarce to common, and back again.
- Inundated trees were more likely to transition from common to abundant epicormic categories than the non-inundated trees
- The mean time non-inundated trees were modelled to spend in the absent/scarce epicormic state was one year, which was significantly longer than if the tree were recorded as having either common or abundant epicormic growth.

3.2.3 SUMMARY

The key findings from this study are:

- There was significantly more epicormic growth recorded for inundated trees than non-inundated trees.
- The peak in epicormic growth occurred after the first artificial inundation coinciding with a significant increase in inundated trees transitioning from 1-10% to 11-25% crown extent. This supports visual evidence of epicormic growth turning into crown if the epicormic growth can be supported with follow-up rainfall or inundation (Figure 19).
- After the second application of artificial floodwater, the frequency of trees in the highest category of 76-100% crown extent had increased. This suggests that more growth was obtained in the crown after two watering events, allowing trees to transition to the highest crown extent category. The frequency of trees in this category was not sustained after a ‘dry’ year, suggesting that initial interventions may need more than two consecutive floodings.
- Inundated trees had a greater likelihood of increasing crown condition than those not inundated.
- Inundated trees seemed to spend less time in each crown extent category, suggesting that these trees gained crown growth and improved condition.

- The mean time non-inundated trees spent in the absent/scarce epicormic state was one year, suggesting that even if non-inundated trees respond to rainfall, epicormic growth is not sustained in the long term.

A2.2_December 2005

A2.2_April 2007

Figure 19. Visual evidence of epicormic growth on *Eucalyptus camaldulensis* in 2005 (top) turning into canopy by 2007.

3.3 WHAT ARE THE ECOLOGICAL RESPONSES TO FLOODING ?

3.3.1 UNDERSTOREY VEGETATION

Findings from the statistical analysis of the understorey vegetation in response to inundation found that flooding shifted a typical chenopod floodplain community to a wetland/flood responder community. Thirteen months after the floodplain depression dried out from the second inundation, the vegetation composition of the flood responder community had started to revert back to the initial chenopod community. Those transects that were not inundated appeared to become more arid adapted in the absence of flooding.

Over the 33 months of surveying, 86 taxa were collected from the study site (Appendix C). Classifications of the 48 transect samples produced two major groups, separated into those that were dry (Group A) and those that were inundated (Group D: Table 9, Figure 20). The dry groups divided into two groups (B and C) based on location. The inundated groups divided into three groups (E, F and G) based on time (Table 9).

Table 9. Description of the understorey dendogram divisions

Group	Division	Description
A (dry)	B	T6 (control area)
	C	T4 and T5 (control area) plus T1, T2 and T3 surveys prior to 1st inundation
D (inundated)	E	Last surveys
	F	Mid to late surveys
	G	Early to mid surveys

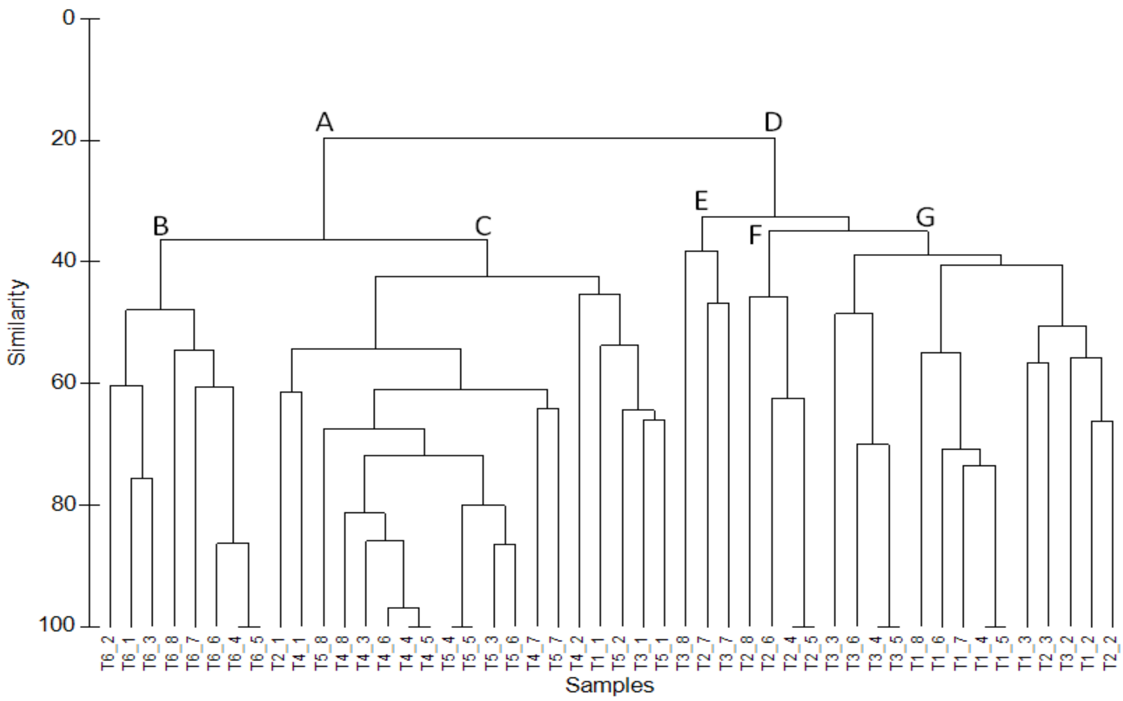


Figure 20. Understorey vegetation community dendrogram using Bray-Curtis similarity

Non-metric MDS ordination produced a 2-D solution with stress of 0.16 (Figure 21). A clear separation of inundated and dry samples was evident. Dry samples including those along inundated transects prior to inundation grouped to the left of the ordination. After initial watering, the inundated transect samples moved to the right of the plot. Whilst the behaviour of the inundated transect varied, all remained separated from the samples that remained dry (this suggests that they had yet to redevelop a dry community). Generally, transects which remained dry tended to move further to the left of the ordination plot over time, whilst transect six was distinct from transects four and five.

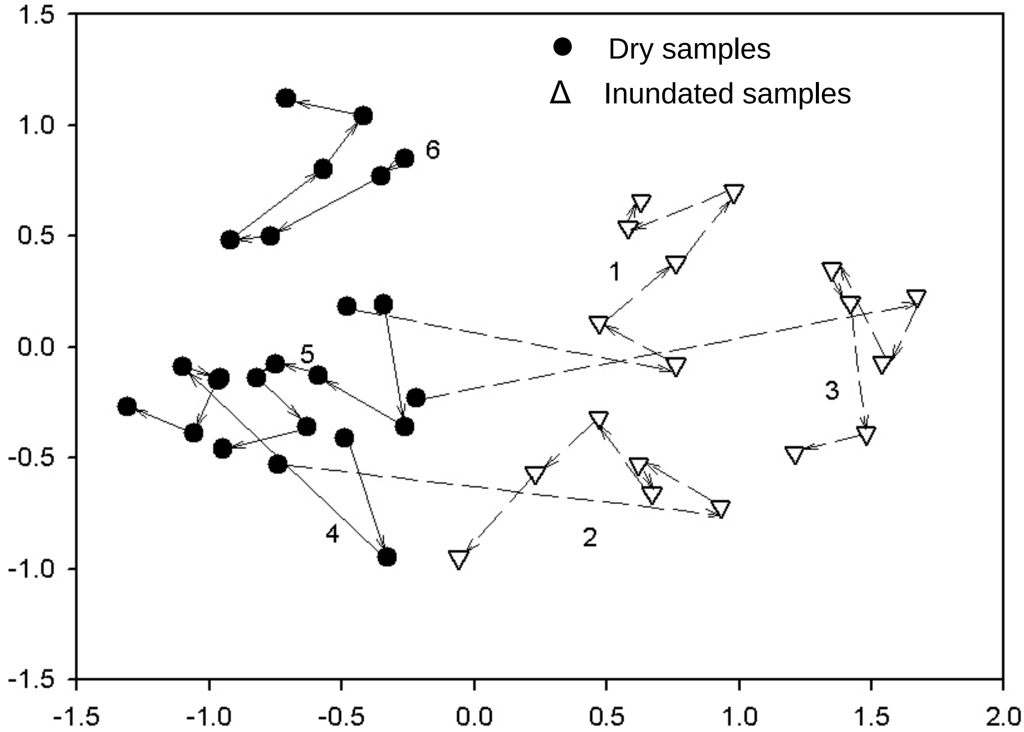


Figure 21. Two-dimensional MDS trajectory analysis of understorey vegetation community composition for inundated and dry transect samples. The numbers refer to the groups of transect samples over time.

Two-way crossed ANOSIM showed significant differences between survey across inundation (R = 0.248; P = 0.03) and inundation across surveys (R = 0.915; P = 0.001). Average similarity between inundated samples was 52.8% and dry samples 44.3%. *Alternanthera denticulata* was the highest contributor to the inundated group (Table 10) and was also the highest contributor to the dissimilarity between the dry and inundated groups not being present unless inundated (Table 11). Conversely, *Einardia nutans ssp*. was the highest contributor to the dry group and second highest contributor to the dissimilarity between the dry and inundated groups having a higher abundance in dry samples. *Atriplex suberecta*, *Centipeda minima* and *Brachyscome basaltica var. gracilis* were characteristic of inundated samples, seldom if ever occurring in dry samples. *Atriplex semibaccata* and *Setaria jubiflora* were more abundant for dry than inundated samples, although both were recorded for samples that had been inundated.

Table 10 Major SIMPER derived understorey vegetation taxa contributing to average similarity for inundation groups across time.

Group	Taxa	Average abundance	Average similarity	Similarity/ SD	Contribution %
Inundated	*Alternanthera denticulata*	0.65	9.15	1.84	20.64
Inundated	*Atriplex suberecta*	0.31	4.72	0.99	10.65
Inundated	*Centipeda minima*	0.26	3.20	1.21	7.23
Inundated	*Brachyscome basaltica* var. *gracilis*	0.23	3.03	0.95	6.83
Dry	*Einadia nutans* ssp.	0.69	18.04	2.20	34.84
Dry	*Atriplex semibaccata*	0.48	10.20	0.93	19.70
Dry	*Setaria jubiflora*	0.40	9.48	2.06	18.30

Table 11 Major SIMPER derived understorey vegetation taxa contributing to average dissimilarity for inundation groups across time.

	Dry	Inundated			
Taxa	Average abundance	Average abundance	Average dissimilarity	Dissimilarity/ SD	Contribution %
Alternanthera denticulata	0.00	0.65	8.00	2.07	10.02
Einadia nutans ssp.	0.69	0.22	6.29	1.70	7.87
Atriplex semibaccata	0.48	0.10	5.70	1.28	7.14
Atriplex suberecta	0.15	0.31	3.20	1.02	4.01
Centipeda minima	0.00	0.26	2.90	1.42	3.63
Setaria jubiflora	0.40	0.18	2.82	1.13	3.53
Lachnagrostis filiformis	0.01	0.27	2.73	1.09	3.42
Brachyscome basaltica var. *gracilis*	0.09	0.23	2.56	1.26	3.20
Cuscuta campestris	0.01	0.20	2.37	1.03	2.97
Enchylaena tomentosa var.	0.21	0.11	2.30	1.04	2.88

The understorey results grouped species accordingly to their functional type. Prior to artificial inundation, the area had not previously been flooded for five years since a natural flood in 2000. It can be assumed that the inundation zone in the 2000 flood saw a similar response to the artificial inundation in 2005.

Prior to artificial flooding, the understorey community was dominated by a native salt tolerant chenopod community e.g. *E. nutans* (Climbing Saltbush), *A. semibaccata* (Creeping Saltbush) and *S. jubiflora* (Warrego Grass). This chenopod type community also dominated the non-flooded areas during the inundation trial.

The results show, that after inundation the inundated area was dominated by native wetland type species e.g. *A. denticulate* (Lesser Joyweed), *A. suberecta* (Lagoon Saltbush), *C. minima* (Spreading Sneezeweed) and *B. basaltica* (Swamp Daisy). By the final survey, 18 months after inundation, the area was starting to revert back to a chenopod dominated community.

The two main weed species that dominated the area after first inundation was *Cuscuta campestris* (Dodder) and *Xanthium californicum* (Californian Burr). These were sprayed as part of the recovery program, but Dodder contributed to the overall results (Table 11), indicating that it was a dominate species at the site. It is therefore recommended that a weed management program is needed for floodplain sites that are watered for environmental reasons.

3.3.2 JUVENILE RIVER RED GUM AND GERMINATION RESPONSE

Thirty juvenile river red gums (height <1.5 m) were tagged and their height recorded throughout the duration of the trial, with 15 trees directly inundated and 15 trees located near transect 5 in the control area. Both stands of juvenile trees germinated from the 2000 flood event (S. Clark pers.comm.).

The mean height of the 30 trees at the start of the survey was 0.9 m (SE 0.05 m). This had increased a metre to 1.9 m (SE 0.07 m) by the final survey 32 months later. One of the inundated trees died and was omitted from further analysis, whilst all others survived and grew over the course of the survey (Figure 22).

Significant difference in inundation ($F_{1,27} = 13.59$; $P = 0.001$**), time ($F_{5,135} = 128.28$; $P < 0.001$***) and inundation by time ($F_{5,135} = 7.13$; $P < 0.001$***) were observed for juvenile river red gum height. Inundation occurred after time one and three (Fig 22). The height of inundated trees increased over time except between surveys 2-3, 4-5 and 5-6. Thus the only time when there was a difference in tree height between consecutive surveys after the site was inundated.

The height of the control trees also increased over time. Prior to the inundation there was no difference between the height of the inundation treatment and control trees. For all except the first survey, direct time comparisons between inundated and control trees show the inundated trees were significantly taller.

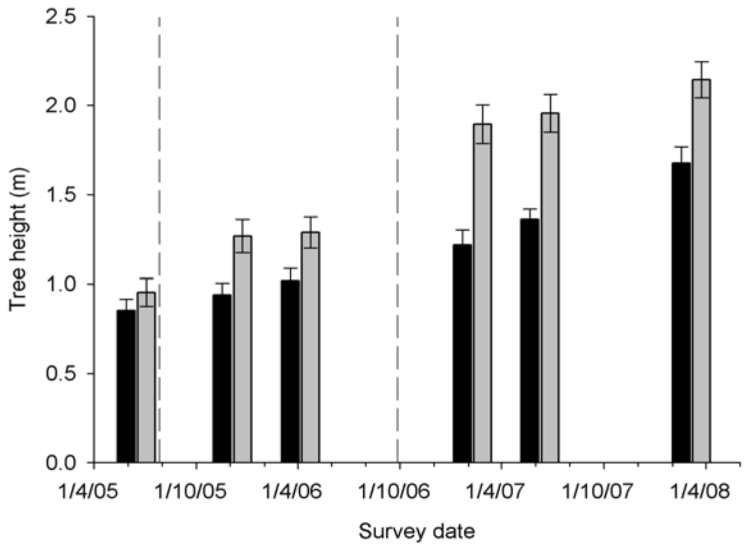


Figure 22. Mean (±SE) juvenile river red gum height; black bars, control trees; grey bars; inundated trees. The vertical dashed line represents the beginning of the two inundations.

During the final vegetation assessment in March 2008, a random walk was carried out across the area where river red gum germination had been noted from previous visits to the site. Germination of river red gums occurred after both inundation events, with the second inundation seeing most of the germinated trees from the first artificial inundation increased in height to over 1 m. From a random survey, more than 180 river red gum less than 1 m in height were considered to have germinated from the artificial inundation trials. The majority of germinated trees were found either on the embankment (constructed prior to the first inundation and used to contain water in the floodplain depression during the trial) or in the ‘dead’ zone, an area where major adult river red gum dieback had occurred prior to inundation.

3.4 WHAT IMPACT DOES FLOODING HAVE ON RIVER SALINITY ?

Two EC loggers were installed in the River Murray to examine the salinity impact of artificially inundating a floodplain feature that is located next to the river. One logger was installed immediately downstream of the watering trial site, with the second installed 500 m upstream in-line with transect two (Figure 1). Due to the high river flows that occurred during the first artificial inundation, no clear observation could be made during this period. The EC time series however, was successful in observing a minor localised instream salinity increase (20 EC, 8%) over the course of the second flooding event, a positive indication of mobilisation of salt from the floodplain to the river after artificial inundation of a floodplain feature.

4. CONCLUSIONS AND RECOMMENDATIONS

The key findings from each of the investigative components (groundwater, soils and vegetation) clearly indicate that the application of surface water recharged the aquifer beneath the inundation zone, and freshened the soil profile. This initiated a river red gum response of increased crown extent and epicormic growth.

After artificial inundation in 2005 and 2006, the investigation found that both tree and understorey communities responded to surface water flooding with growth and new species composition respectively. The main findings from the study were:

- After two consecutive artificial inundations, there was a significant increase in crown extent categories of 11-25% and 26-75%, with river red gums in these states more likely to transition to a higher higher crown extent condition.
- Inundation significantly increased the height of juvenile river red gums.
- After two inundations, the switch in understorey composition from saltbush/chenopod dominated to flood responder communities was also sustained, allowing the seed bank of the flood responder community to be reset. After a ‘dry’ year the understorey community was still dominated by flood responder species in the inundation zone, but was starting to transition back towards a drier chenopod community.

As found at the Site B trial (Berens et al, 2009b), the linkage of the groundwater freshening results and the tree response results suggest that trees within the 11-25% crown extent have the capacity to respond to an intervention by maintaining or improving condition. Once crown extents are <10%, trees do not appear to have the capacity to respond to an intervention. However, due to the time lag between planning and on-ground works, tree communities are likely to regress in crown condition. It is recommended therefore that intervention planning should focus on trees with a crown extent greater than 25%.

The recommendations from this study are that artificial inundation is an intervention technique that relieves the symptoms of current floodplain degradation on the Lower Murray. Tracking river red gum condition and soil salinity via EM31 techniques are recommended methodologies that can be used at other floodplain sites to determine if an intervention is needed before the threshold of river red gum deterioration starts (11 - 25% crown extent).

A. SOIL SALINITY

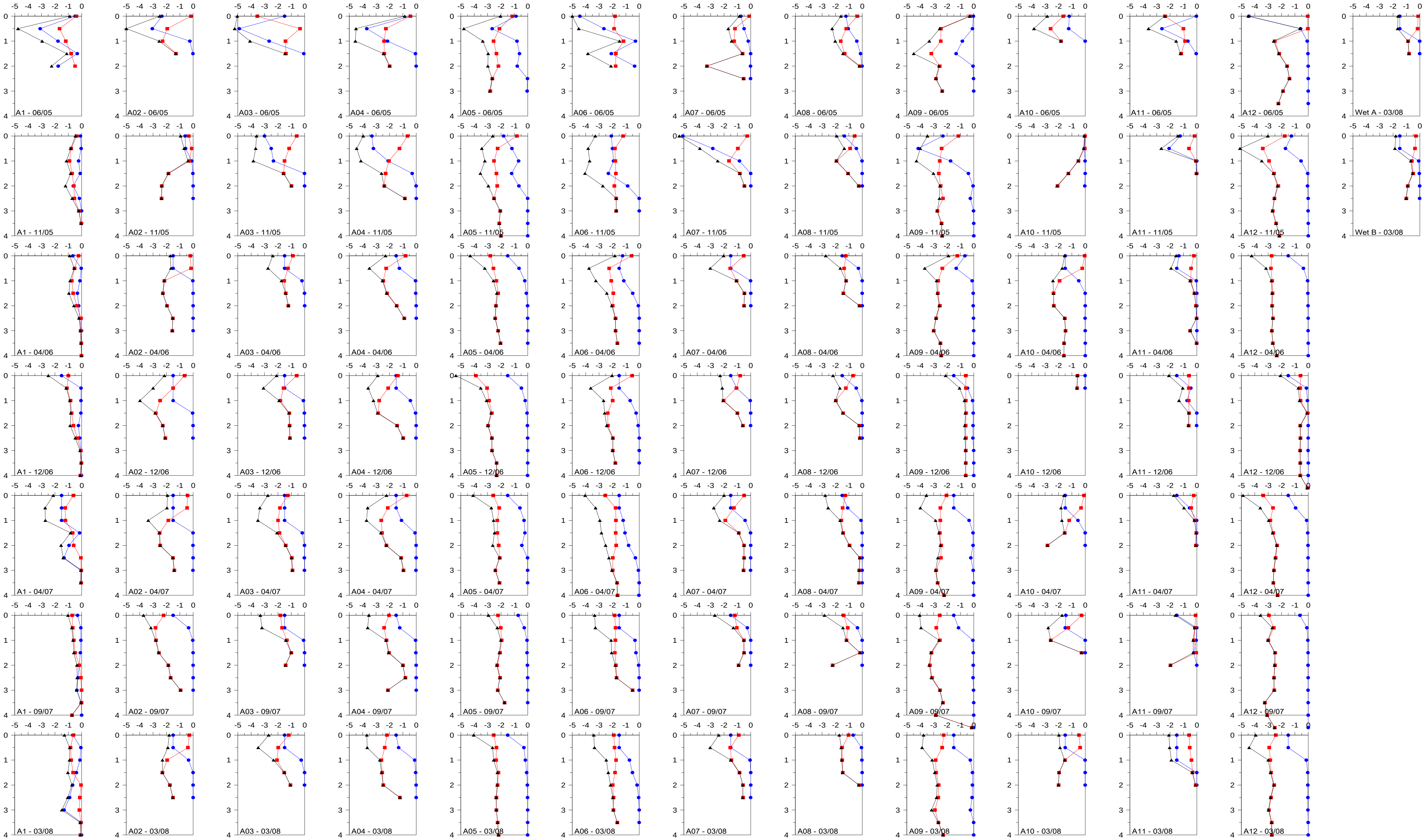


Figure A1. Soil salinity results collected next to the twelve wells during the study period.

B. TREE TRANSITION RESULTS

Table B1. Maximum likelihood estimates of red gum crown extent transition intensities for the no inundation effect and inundation Markov models (–2 time log likelihood: 1168.827; 95% confidence intervals in brackets).

State change	No inundation effect	Inundation effect
1➞2	0.191 (0.071–0.515)	1.814 (0.304–3.324)
2➞1	0.435 (0.265–0.714)	1.123 (0.132–2.115)
2➞3	0.434 (0.248–0.760)	2.208 (1.286–3.130)
3➞2	0.289 (0.175–0.476)	0.695 (-0.449–1.84)
3➞4	1.023 (0.787–1.329)	0.882 (0.341–1.423)
4➞3	0.209 (0.150–0.292)	0.933 (0.255–1.612)
4➞5	0.228 (0.160–0.325)	1.198 (0.521–1.876)
5➞4	1.61 (1.121–2.304)	0.323 (-0.3934–1.039)

Table B2. Ratio of transition intensities between crown extent states for the non inundation effect and inundation Markov models (95% confidence intervals in brackets).

State change comparison	No inundation effect	Inundation effect
2➞3 v 2➞1	0.999 (0.474–2.105)	2.119 (0.867–5.183)
3➞4 v 3➞2	3.545 (2.019–6.225)	4.034 (1.381–11.781)
4➞5 v 4➞3	1.09 (0.672–1.768)	1.31 (0.636–2.696)

Table B3. Crown extent model maximum likelihood estimates of mean sojourn times (years) for the non inundation effect and inundation Markov models (95% confidence intervals in brackets).

State	No inundation effect	Inundation effect
State 1	5.223 (1.942–14.078)	1.486 (0.860–2.567)
State 2	1.151 (0.791–1.675)	0.338 (0.221–0.517)
State 3	0.763 (0.604–0.963)	0.425 (0.284–0.635)
State 4	2.286 (1.789–2.921)	1.083 (0.749–1.565)
State 5	0.622 (0.434–0.892)	0.497 (0.287–0.862)

Table B4. Maximum likelihood estimates of epicormic growth transition intensities for the no inundation effect and inundation Markov models (–2 time log likelihood: 1570.475; 95% confidence intervals in brackets).

State change	No inundation effect	Inundation effect
1➞2	1.02 (0.845–1.232)	0.244 (-0.156–0.644)
2➞1	2.041 (1.683–2.476)	-0.1034 (-0.521–0.314)
2➞3	0.249 (0.089–0.69)	5.261 (3.063–7.46)
3➞2	4.124 (1.653–10.29)	1.927 (-0.158–4.012)

Table B5. Ratio of transition intensities between epicormic growth states for the non inundation effect and inundation Markov models (95% confidence intervals in brackets).

State change comparison	No inundation effect	Inundation effect
2➞3 v 2➞1	0.999 (0.474–2.105)	2.119 (0.867–5.183)

Table B6. Epicormic growth model maximum likelihood estimates of mean sojourn times (years) for the non inundation effect and inundation Markov models (95% confidence intervals in brackets).

State	No inundation effect	Inundation effect
State 1	0.98 (0.812–1.184)	0.828 (0.5967–1.148)
State 2	0.437 (0.356–0.535)	0.087 (0.019–0.396)
State 3	0.242 (0.097–0.605)	0.063 (0.011–0.386)

C. UNDERSTOREY SPECIES LIST

Table C1. Understorey species list for Site A from survey transects during the study period

Species	Common Name
Alternanthera denticulata	Lesser Joyweed
Alternanthera nodiflora	Common Joyweed
**Amsinckia angustifolia (calycina)*	Amsinckia calycina
Atriplex leptocarpa	Slender-fruited Saltbush
Atriplex lindleyi subsp lindleyi	
Atriplex semibaccata	Creeping Saltbush
Atriplex suberecta	Lagoon Saltbush
Brachyscome basaltica	Swamp Daisy
**Brassica tournefortii*	Mediterranean Turnip
**Bromus rubens*	Red Brome
Calotis cuneifolia	Purple Burr Daisy
**Centaurea calcitrapa*	Star Thistle
Centipeda cunninghamii	Common Sneezeweed
Centipeda minima	Spreading Sneezeweed
Chamaesyce drummondii	Caustic Weed
Chenopodium pumilio	Small Crumbweed
**Chondrilla juncea*	Skeleton Weed
**Cirsium vulgare*	Scotch Thistle
**Conyza bonariensis*	Flaxleaf Fleabane
Cotula australis	Common Cotula
**Cotula bipinnata*	Ferny Cotula
**Cuscuta campestris*	Dodder
Cyperus gymnocaulos	Spiny Sedge
Disphyma crassifolium subsp. clavellatum	Round leaf pigface; Noon flower
Dissocarpus paradoxus	Cannon-ball
Distichlis distichophylla	Australian Saltgrass
**Dittrichia graveolens*	Stinkwort
Dysphania glomulifera	
Eclipta platyglossa	
Einadia nutans	Climbing Saltbush
Eleocharis acuta	Common Spike-rush
Enchylaena tomentosa	Ruby Saltbush
Epaltes australis	Spreading Nutheads
Eucalyptus camaldulensis var. camaldulensis	River Red Gum
Euchiton involucratus	Star Cudweed
Exocarpos sparteus	Slender Cherry
Glinus lotoides	Hairy Carpet-weed
**Heliotropium curassavicum*	Smooth Heliotrope
**Heliotropium supinum*	Prostrate Heliotrope
**Hordeum glaucum*	Northern Barley Grass

Species	Common Name
**Hordeum leporinum*	Barley Grass
**Hypochaeris glabra*	Smooth Cats-ear
Juncus subsecundus	
Lachnagrostis filiformis	
**Lactuca serriola*	Prickly Lettuce
**Lepidium africanum*	
Lepidium pseudohyssopifolium	
Maireana brevifolia	Yanga Bush
Maireana ciliata	Fissure Weed
**Medicago minima*	Woolly Burr Medic
**Mesembryanthemum nodiflorum*	Small Ice-plant
Moss sp.	
Muehlenbeckia florulenta	Lignum
Myosurus minimus	Mouse Tail
Persicaria lapathifolia	Pale Knotweed
**Petrorhagia velutina (dubia)*	
**Phyla nodiflora*	
Picris squarrosa	
**Polygonum aviculare*	Wireweed
Polygonum plebeium	Small Knotweed
Pseudognaphalium luteoalbum	Jersey Cudweed
Ranunculus pentandrus	
**Reichardia tingitana*	False Sowthistle
Rorippa eustylis	
Salsola tragus	
Sclerolaena muricata var. muricata	Black Rolypoly
Senecio cunninghamii	
Senecio glossanthus	
Senecio lautus subsp spanomerus (pinnatifolius)	Variable Groundsel
Senecio quadridentatus	Cotton Fireweed
Senecio runcinifolius	Tall Groundsel
Setaria jubiflora	Warrego Grass
**Silene gallica*	
**Solanum nigrum*	Blackberry NightShade
**Sonchus oleraceus*	Common Sowthistle
**Spergularia diandra*	Lesser Sand Spurrey
Sporobolus mitchellii	Rats-tail Couch
**Verbena supina*	Trailing Verbena
**Vulpia bromoides*	Squirrel Tail Fescue, Silver Grass
**Vulpia myuros myuros*	Rat's Tail Fescue
Wahlenbergia fluminalis	River Bluebell
**Xanthium californicum*	Californian Burr

* represents an introduced species

UNITS OF MEASUREMENT

Units of measurement commonly used (SI and non-SI Australian legal)

Name of unit	Symbol	Definition in terms of other metric units	Quantity
day	d	24 h	time interval
gigalitre	GL	10^6 m^3	volume
gram	g	10^{-3} kg	mass
hectare	ha	10^4 m^2	area
hour	h	60 min	time interval
kilogram	kg	base unit	mass
kilolitre	kL	1 m^3	volume
kilometre	km	10^3 m	length
litre	L	10^{-3} m^3	volume
megalitre	ML	10^3 m^3	volume
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microlitre	µL	10^{-9} m^3	volume
milligram	mg	10^{-3} g	mass
millilitre	mL	10^{-6} m^3	volume
millimetre	mm	10^{-3} m	length
minute	min	60 s	time interval
second	s	base unit	time interval
tonne	t	1000 kg	mass
year	y	365 or 366 days	time interval

Shortened forms

~	approximately equal to
EC	electrical conductivity (µS/cm)
K	hydraulic conductivity (m/d)
pH	acidity
gg^{-1}	gravimetric water content
Ψ	matric potential (MPa)

GLOSSARY

Ambient — The background level of an environmental parameter (eg. a measure of water quality such as salinity)

Aquatic ecosystem — The stream channel, lake or estuary bed, water, and/or biotic communities, and the habitat features that occur therein

Aquifer — An underground layer of rock or sediment that holds water and allows water to percolate through

Aquifer, confined — Aquifer in which the upper surface is impervious (see 'confining layer') and the water is held at greater than atmospheric pressure; water in a penetrating well will rise above the surface of the aquifer

Aquifer, unconfined — Aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure

Artificial recharge — The process of artificially diverting water from the surface to an aquifer; artificial recharge can reduce evaporation losses and increase aquifer yield; see also 'natural recharge', 'aquifer'

Biodiversity — (1) The number and variety of organisms found within a specified geographic region. (2) The variability among living organisms on the earth, including the variability within and between species and within and between ecosystems

BoM — Bureau of Meteorology, Australia

Bore — See 'well'

Confining layer — A rock unit impervious to water, which forms the upper bound of a confined aquifer; a body of impermeable material adjacent to an aquifer; see also 'aquifer, confined'

CSIRO — Commonwealth Scientific and Industrial Research Organisation

Diversity — The distribution and abundance of different kinds of plant and animal species and communities in a specified area

d/s — Downstream

DWLBC — Department of Water, Land and Biodiversity Conservation (Government of South Australia)

EC — Electrical conductivity; 1 EC unit = 1 micro-Siemen per centimetre (µS/cm) measured at 25°C; commonly used as a measure of water salinity as it is quicker and easier than measurement by TDS

Ecological indicators — Plant or animal species, communities, or special habitats with a narrow range of ecological tolerance; for example, in forest areas, such indicators may be selected for emphasis and monitored during forest plan implementation because their presence and abundance serve as a barometer of ecological conditions within a management unit

Ecological processes — All biological, physical or chemical processes that maintain an ecosystem

Ecology — The study of the relationships between living organisms and their environment

Ecosystem — Any system in which there is an interdependence upon, and interaction between, living organisms and their immediate physical, chemical and biological environment

Ephemeral streams or wetlands — Those streams or wetlands that usually contain water only on an occasional basis after rainfall events. Many arid zone streams and wetlands are ephemeral.

Evapotranspiration — The total loss of water as a result of transpiration from plants and evaporation from land, and surface water bodies

Floodplain — Of a watercourse means: (1) floodplain (if any) of the watercourse identified in a catchment water management plan or a local water management plan; adopted under the Act; or (2) where (1) does not apply — the floodplain (if any) of the watercourse identified in a development plan under the *Development (SA) Act 1993*; or (3) where neither (1) nor (2) applies — the land adjoining the watercourse that is periodically subject to flooding from the watercourse

Flow regime — The character of the timing and amount of flow in a stream

Groundwater — Water occurring naturally below ground level or water pumped, diverted and released into a well for storage underground; see also 'underground water'

Habitat — The natural place or type of site in which an animal or plant, or communities of plants and animals, live

Hydraulic conductivity (K) — A measure of the ease of flow through aquifer material: high K indicates low resistance, or high flow conditions; measured in metres per day

Hydrogeology — The study of groundwater, which includes its occurrence, recharge and discharge processes, and the properties of aquifers; see also 'hydrology'

Hydrology — The study of the characteristics, occurrence, movement and utilisation of water on and below the Earth's surface and within its atmosphere; see also 'hydrogeology'

Hydrometric — Literally relating to water measurement, from the Greek words 'hydro' (water) and metrikos (measurement); see also DWLBC fact sheet FS1 <http://www.dwlbc.sa.gov.au/assets/files/fs0001_hydrometric_surface_water_monitoring.pdf>

Hydstra — A time series data management system that stores continuously recorded water-related data such as water level, salinity and temperature; it provides a powerful data analysis, modelling and simulation system; contains details of site locations, setup and other supporting information

Impact — A change in the chemical, physical, or biological quality or condition of a water body caused by external sources

Infrastructure — Artificial lakes; dams or reservoirs; embankments, walls, channels or other works; buildings or structures; or pipes, machinery or other equipment

Irrigation — Watering land by any means for the purpose of growing plants

Licence — A licence to take water in accordance with the Act; see also 'water licence'

MDBC — Murray–Darling Basin Commission

Model — A conceptual or mathematical means of understanding elements of the real world that allows for predictions of outcomes given certain conditions. Examples include estimating storm run-off, assessing the impacts of dams or predicting ecological response to environmental change

Monitoring — (1) The repeated measurement of parameters to assess the current status and changes over time of the parameters measured (2) Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, animals, and other living things

Native species — Any animal and plant species originally in Australia; see also 'indigenous species'

Natural recharge — The infiltration of water into an aquifer from the surface (rainfall, streamflow, irrigation etc). See also recharge area, artificial recharge

Natural resources — Soil, water resources, geological features and landscapes, native vegetation, native animals and other native organisms, ecosystems

NRM — Natural Resources Management; all activities that involve the use or development of natural resources and/or that impact on the state and condition of natural resources, whether positively or negatively

Observation well — A narrow well or piezometer whose sole function is to permit water level measurements

Obswell — Observation Well Network

Piezometer — A narrow tube, pipe or well; used for measuring moisture in soil, water levels in an aquifer, or pressure head in a tank, pipeline, etc

Population — (1) For the purposes of natural resources planning, the set of individuals of the same species that occurs within the natural resource of interest. (2) An aggregate of interbreeding individuals of a biological species within a specified location

Recharge area — The area of land from which water from the surface (rainfall, streamflow, irrigation, etc.) infiltrates into an aquifer. See also artificial recharge, natural recharge

Rehabilitation (of water bodies) — Actions that improve the ecological health of a water body by reinstating important elements of the environment that existed prior to European settlement

Restoration (of water bodies) — Actions that reinstate the pre-European condition of a water body

Riparian zone — That part of the landscape adjacent to a water body that influences and is influenced by watercourse processes. This can include landform, hydrological or vegetation definitions. It is commonly used to include the in-stream habitats, bed, banks and sometimes floodplains of watercourses

Surface water — (a) water flowing over land (except in a watercourse), (i) after having fallen as rain or hail or having precipitated in any another manner, (ii) or after rising to the surface naturally from underground; (b) water of the kind referred to in paragraph (a) that has been collected in a dam or reservoir

Sustainability — The ability of an ecosystem to maintain ecological processes and functions, biological diversity, and productivity over time

Taxa — General term for a group identified by taxonomy, which is the science of describing, naming and classifying organisms

Transmissivity (T) — A parameter indicating the ease of groundwater flow through a metre width of aquifer section

u/s — Upstream

Viable population — A population that has the estimated numbers and distribution of reproductive individuals to ensure the continued existence of the species throughout its existing range in the planning area

Water allocation — (1) In respect of a water licence means the quantity of water that the licensee is entitled to take and use pursuant to the licence. (2) In respect of water taken pursuant to an authorisation under s.11 means the maximum quantity of water that can be taken and used pursuant to the authorisation

Watercourse — A river, creek or other natural watercourse (whether modified or not) and includes: a dam or reservoir that collects water flowing in a watercourse; a lake through which water flows; a channel (but not a channel declared by regulation to be excluded from the this definition) into which the water of a watercourse has been diverted; and part of a watercourse

Water-dependent ecosystems — Those parts of the environment, the species composition and natural ecological processes, that are determined by the permanent or temporary presence of flowing or standing water, above or below ground; the in-stream areas of rivers, riparian vegetation, springs, wetlands, floodplains, estuaries and lakes are all water-dependent ecosystems

Water licence — A licence granted under the Act entitling the holder to take water from a prescribed watercourse, lake or well or to take surface water from a surface water prescribed area; this grants the licensee a right to take an allocation of water specified on the licence, which may also include conditions on the taking and use of that water; a water licence confers a property right on the holder of the licence and this right is separate from land title

Well — (1) An opening in the ground excavated for the purpose of obtaining access to underground water. (2) An opening in the ground excavated for some other purpose but that gives access to underground water. (3) A natural opening in the ground that gives access to underground water

Wetlands — Defined by the Act as a swamp or marsh and includes any land that is seasonally inundated with water. This definition encompasses a number of concepts that are more specifically described in the definition used in the Ramsar Convention on Wetlands of International Importance. This describes wetlands as areas of permanent or periodic to intermittent inundation, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tides does not exceed six metres.

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