DWLBC REPORT

Bookpurnong Living Murray Pilot Project:

A trial of three floodplain water management techniques to improve vegetation condition

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

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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 River Murray due to decreases in river flows and floodplain inundation. The Living Murray program identified six icon sites including the Chowilla-Lindsay-Wallpolla floodplain anabranch systems on the Lower River Murray. In an effort to restore vegetation condition to the degraded Chowilla Floodplain, 22 sites were artificially inundated with diverted river water, an allocation of environmental water for the floodplain system. Building on the positive tree condition outcomes at these sites, alternate methods of water delivery were considered that would freshen groundwater at sites where inundation was not a viable option.

To examine options for the delivery of environmental water, the Bookpurnong Living Murray Project initiated four management intervention trial sites (Sites A, B, D and E). The collective outcome for all the trials was to determine the effectiveness and applicability of different floodplain management approaches towards the improvement of deteriorating vegetation condition.

The Site B investigation encompassed three groundwater management techniques within a high-level mixed riparian community comprising of *Eucalyptus camaldulensis* (river red gum), *Eucalyptus largiflorens* (black box) and *Acacia stenophylla* (river cooba). Three piezometer and associated vegetation transects were used to monitor the influence of the different management techniques in operation, with a fourth transect used as an experimental control. Transect 1 was located nearest to production wells of the Bookpurnong floodplain Salt Interception Scheme (SIS), where the observation of groundwater lowering due to SIS groundwater extraction was expected. Transect 2, the focus of the Site D investigation, was located adjacent to flood runner creeks that were artificially inundated. At Transect 3, a Living Murray production well (LM well) was installed 180 m from the riverbank to pump saline groundwater into the existing SIS disposal line.

Living Murray pumping was designed to lower the groundwater and create a groundwater gradient away from the river to promote fresh river water mobilisation towards the production well. The aim was to freshen the saline floodplain aquifer by creating a lens of freshwater accessible by vegetation roots.

The main hydrogeological findings from the trials undertaken at the three transects were:

- The results of the Transect 1 trial, found that SIS influenced a reduction in groundwater levels along the transect, though the groundwater remained predominately saline (in excess of 50,000 EC) along the transect.
- At Transect 2, after artificial inundation the soil profile and groundwater were both temporarily freshened, with the denser saline water being displaced lower in the aquifer.
- At Transect 3, a freshwater lens was created in the LM well zone with groundwater salinity reduced by two orders of magnitude from above 50 000 EC to below 500 EC in some places. The results have shown that groundwater salinity can be reduced by the extraction of groundwater to laterally recharge an aquifer with river water.

The Site B trials in general found that:

- Floodplain groundwater levels at Site B responded rapidly to fluctuations in river level, with increasingly subdued responses in wells located at greater distances from the river (also found in the Site A trial).
- Soil profile sampling found that there are large, relatively immobile stores of salt in the floodplain soils. Trees located near the river (in the flushed zone) are in areas where soil water is more accessible (generally, > -2 MPa), whereby the presence of a fresher aquifer zone from the river reduces the accumulation of salt due to evapotranspiration.
- Understorey vegetation located on higher floodplain areas (less inundation frequency), still exhibit species richness and diversity during periods of drought when good rainfall or artificial inundation was experienced.
- A collaborative project run though the Centre for Natural Resources Management, measured physiological indicators of tree stress. Trees at Site B had negative pre-dawn water potentials lower than previous studies for river red gums in this type of environment, indicating that a) the soil water availability tolerances for river red gums in this environment are higher than previously thought, and b) river red gums at the site are under extreme salinity and drought stress.
- The major findings from the monitoring of crown extent condition of river red gum, river cooba and black box found that with or without groundwater freshening trees with <10% crown extent declined in condition.
- Trees with 11-25% crown extent both maintained and improved condition, when the groundwater was freshened. While without freshening, trees with 11-25% crown extent would decline in condition.
- With groundwater freshening, trees with >26% crown extent were more likely to maintain or improve condition. While without groundwater freshening, trees with >26% crown extent were more likely to maintain or decline in condition.

The Bookpurnong trials at Site B have provided information on alternative approaches to manage the condition of a floodplain environment. The applicability of the results to other sites will depend on the required outcome of an intervention and the site's geomorphology, local aquifer conditions and vegetation condition. Broadly, the results have shown that a single inundation caused an immediate tree response and temporary soil water freshening but no long-term outcomes were achieved. It is not an advised technique for long-term condition management, unless a number of consecutive inundations can be guaranteed. The lateral recharge trial is in support of this advice, where the observation over a longer period of soil profile and groundwater freshening, trees were able to maintain and improve condition. Continued removal of salt from the root zone via natural flooding, artificial inundation or bank storage techniques, is key in maintaining tree community condition on the Lower Murray.

The results from this study suggest that there needs to be a shift in focus on how vegetation communities on the Lower Murray are managed. Recovery interventions will be more successful and cost effective when targeted at tree communities with crown extents greater than 25%. These more resilient communities should be managed to sustain their condition and function as an ecosystem.

1. INTRODUCTION

On the Lower Murray River in South Australia, supporting evidence of floodplain degradation from decreased floodplain flows and salinisation has been researched for more than 15 years (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). In response to the decline in river and floodplain condition along the Murray River, the Living Murray Initiative was established in 2002. The Initiative focus is on recovering 500 gigalitres of water for the river, specifically for the benefit of plants and animals, along with improving the environment at six icon sites.

One of the icon sites on the Lower Murray is the Chowilla-Lindsay-Wallpolla Floodplain anabranch system. In an effort to restore vegetation condition at degraded wetland and floodplain features, and as part of the environmental water allocation, 22 sites on the Chowilla Floodplain are being artificially inundated with water pumped from the river. Inundating large expanses of floodplain or small distinct wetlands has been instrumental in rejuvenating vegetation and freshening previously saline groundwater. Taking the positive results from the surface inundation trials, alternate methods to freshen groundwater were then proposed for areas where surface inundation is not viable.

1.1 DESCRIPTION OF THE BOOKPURNONG TRIALS

Clark's Floodplain at Bookpurnong, which is located approximately 80 km downstream from Chowilla Floodplain, was chosen as a site for detailed investigations in different groundwater management techniques (Figure 1). The trials were to compare the effectiveness of different methods of delivering water to improve vegetation condition. A summary of the trials and the main findings are described below:

Floodplain Salt Interception Scheme (SIS)

Clark's floodplain at Bookpurnong had a constructed floodplain SIS — a reason why the site was chosen for the management trials. The floodplain SIS aims to reduce hydraulic gradients and intercept the movement of saline groundwater from the irrigated highland areas to the alluvium (floodplain and river). The Bookpurnong SIS has seven highland and 16 floodplain interception wells, six of which are on Clark's Floodplain. Operation of the SIS commenced in July 2005 with extraction rates of 2 – 3 L/s per well.

Site A

Artificial inundation of a 3.7 ha topographic floodplain depression with a focus on improving the health of a 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. The main findings of the surface inundation trial was that salt temporarily leached from the root zone, tree condition improved and germination occurred (White et al, 2009).

Site B

The subject of this report is Site B with a detailed description of the trial in the next section. In summary Site B was investigated over four transects to observe the surface and groundwater interactions of three different groundwater management techniques.

Site D

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

Site E

Trialled the injection of fresh river water into a moderately saline floodplain aquifer via a five point injection array whilst monitoring the response of a stressed tree community (Berens et al., 2009a). This trial had the most uncertainty, as success was reliant on the ability to inject a sufficient volume of water for freshening to occur. The main finding from this trial was that injection resulted in localised and short-lived freshening of the groundwater that reduced salinity in the associated capillary fringe. It did not result in an improvement in tree condition, as the observed trees were beyond the lateral extent of the freshening and were unable to access the water (Berens et al., 2009b).

1.2 SITE B TRIAL

This report is focuses on the investigation of a mixed riparian community comprising of river red gums (*Eucalyptus camaldulensis*), black box (*Eucalyptus largiflorens*) and river cooba (*Acacia stenoplylla*). The site is located on an outside bend of the Murray River at Clark's Floodplain (Figure 1). The presence of river red gums at this site suggests that the flood runners located at Transect 2 (Site D) would have naturally flooded approximately every five years under pre-regulation flow regimes. The occurrence of dead river red gums further from the river channel at the riparian edge of Transect 3 and 4, where no flood runners exist, suggests that historically (pre-regulation) the aquifer was regularly freshened allowing river red gum survival on this elevated part of the floodplain. The 200 m wide riparian zone indicates a previous condition of river to groundwater connectivity whereby fresh river water flushed the floodplain aquifer, which is supported by groundwater simulations of pre irrigation periods.

The Site B trial investigated three groundwater management techniques. Piezometer transects were constructed at the three different management techniques with a fourth transect used as a experimental control (Figure 1). The specific investigation at each transect at Site B are summarised as:

- Transect 1 (Wells B1, B2 and B3)

  The Transect 1 investigation was to determine the groundwater, soil salinity and vegetation response to groundwater lowering. An SIS production well was located relatively close to Transect 1 and it was anticipated that the groundwater would be lowered (drawdown) along this transect due to SIS pumping.

- Transect 2/ Site D (Wells B4, B5, B6)

  Transect 2 monitored the response of groundwater, soil salinity and vegetation to artificial inundation of flood runners. It was unknown if SIS-induced groundwater lowering and groundwater freshening from the Transect 3 trial would affect this transect.

- Transect 3 (Wells B7, B8, B9, Living Murray production well and B25)

  The trial along this transect included the construction of a Living Murray production well (LM well), installed180 m from the river to pump saline groundwater via the SIS disposal line. The aim to induce groundwater lowering and create a groundwater gradient away from the river. It was hypothesised that fresh river water would be drawn towards the production well, freshening the saline floodplain aquifer and creating a lens of freshwater that trees could access in the capillary zone.

- Transect 4 (Wells B10, B11 and B12)

  A control transect intended to have a negligible influence from the trial operations.

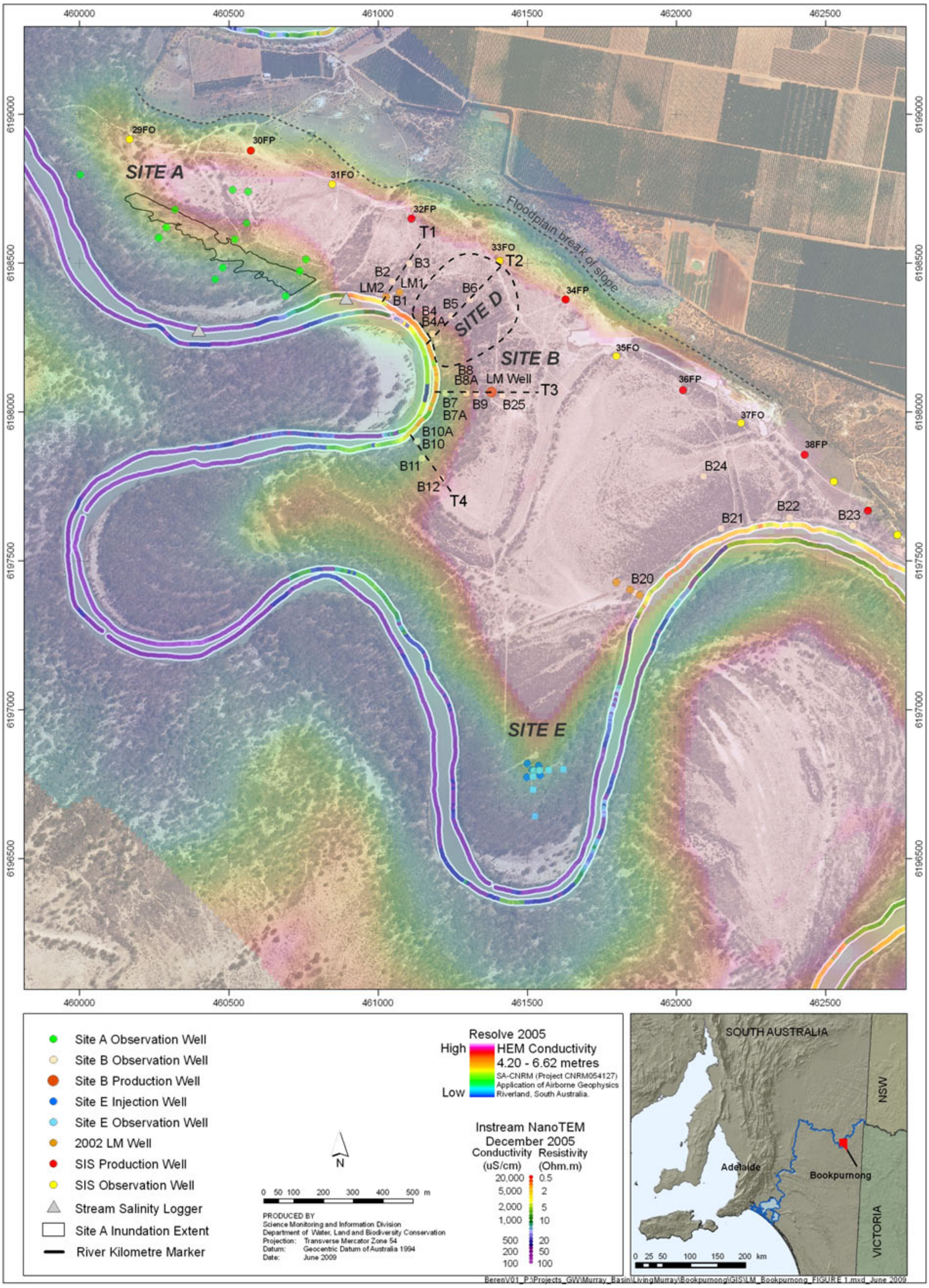


Figure 1. Site location of manipulation trials on Clark's Floodplain, Bookpurnong

2. METHODOLOGY

2.1 GROUNDWATER

2.1.1 MODELLING

To examine the interaction between the floodplain aquifer and surface water, and the impacts from the SIS and the Living Murray well operation, several groundwater model simulations were undertaken. Visual Modflow was used with model inputs and parameters derived from an existing groundwater model that was developed to assist in the design of the Loxton Salt Interception Scheme (Yan et al., 2005). The model domain was 6.4 km x 4.5 km in extent and was divided into 25 m grid cells (Figure 2).

The Visual Modflow extension MT3D solute transport and Mod Path particle tracking were used to simulate the effect of SIS pumping. In particular, the model was used to examine the rate at which fresh river water may be transported through the floodplain aquifer. Model outputs were generated for the pre-irrigation condition, recent irrigation conditions prior to SIS pumping, and scenarios of SIS pumping after 1, 2, 3, 4, 5 and 10 years of groundwater interception. Additional simulations were run for a smaller model domain focusing on the Site B investigation area.

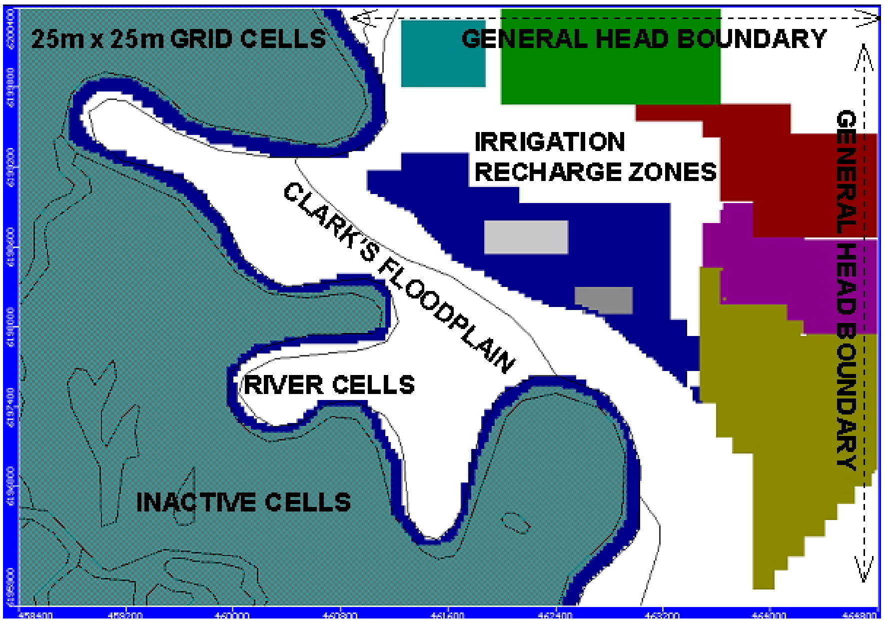


Figure 2. Model domain used in the Bookpurnong simulations.

2.1.2 WELL CONSTRUCTION AND MONITORING

Appropriately specified infrastructure was needed to match monitoring methodologies. With consideration of the range of water levels and salinity likely to be experienced, well screen were suitably placed to cover the intervals of interest. Short screened wells allow for groundwater sampling from discrete intervals presenting the opportunity for lab analysis of more complex parameters. Whereas long screened wells allow information from a broader region of the aquifer, important for the observation of stratified water columns common in floodplain aquifers of the Murray Basin.

Site B wells were constructed during November and December 2005 by Olympic Boring under the supervision of DWLBC staff, with the exception of wells B1, B2 and B3, that were drilled during the Site A construction. Well completion summaries are provided in Appendix A. Geological logs are available through the World Wide Web at https://des.pir.sa.gov.au/deshome.html. Observation wells were designed to monitor groundwater freshening, which was anticipated to occur at the top of water table, thus the well screen intervals commenced above the watertable. At paired sites (such as B8 and B8A) a long screen (~9 m) and a short screen (~3 m) well were constructed to satisfy sampling requirements of both the DWLBC and CSIRO investigations.

The production well was drilled in January 2006 to a maximum depth of 18 m. At the base of this interval, an increasingly silty material grading into the Bookpurnong Clay Beds was interpreted at 15 m. A 3 m wire-wound stainless steel screen was set from 9 to 12 m to incorporate the most permeable material (construction and geological logs are presented in Appendix A).

Site B observation wells (Figure. 1) were monitored for groundwater level and salinity using a variety of techniques. Groundwater loggers were placed in wells over the course of the trial with reference levels and well locations occasionally altered as required. Water level loggers were placed in wells B1, B5, B6 and B10, with dual salinity/water level loggers located in wells B7, B8, B8A, B9 and B25. The CSIRO/CNRM project (Centre for Natural Resource Management) placed level loggers in wells B4A, B5, B7A and B10A. Monthly groundwater sampling of EC using the sonde technique and water levels provided baseline data prior to the production well being switched on in August 2006.

2.2 SOIL SALINITY COMPONENT

The methodology for collecting soil samples was identical 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 13 wells (including the production well) during drilling. Subsequent samples were collected adjacent to the wells at every six months.

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, calculated using the Vant Hoff equation. This method assumes that all salts in the soil solution are present as sodium chloride 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 GEOPHYSICAL SURVEYS

2.3.1 EM31

A Geonics EM31 conductivity meter was used to map the near surface response to groundwater pumping from the Living Murray well in September 2006, November 2007 and March 2008. The September 2006 and March 2008 (1st and 3rd) surveys were restricted to Transect 3, whilst the November 2007 survey covered the whole of Site B.

The EM31 operates on the principles of electromagnetic induction, whereby alternating currents in the transmitter coil induce time varying magnetics fields, which in turn induce a small electrical current within the earth. These currents generate a secondary magnetic field, which is sensed at the receiver together with the primary field, the ratio of which indicates the grounds conductivity (McNeill, 1980a). The instrumentation is able to remotely sense the subsurface ability to conduct electrical current as a bulk property, which can be used to infer groundwater and soil parameters including salinity distribution. The instrument uses a single operating frequency and information is collected as a single ‘bulk’ conductivity representing response from approximately 2 – 6 m.

2.3.2 NANOTEM

The Zonge Engineering NanoTEM system was used to collect all TEM (Transient or Time Domain Electromagnetics) data using a variety of configurations. The acquisition of TEM data has been part of a collaborative investigation between the University of Adelaide and DWLBC.

The NanoTEM is a fast sampling TEM system specifically designed for high resolution and shallow investigation (Hatch et al., 2006). The conventional system configuration for collecting ‘static’ data uses a 20 m by 20 m single turn transmitting loop, and a 5 m by 5 m single turn receiving loop, which provides a typical exploration depth of 50 – 80 m below ground surface. Static acquisition is the traditional method of acquisition, but towed versions both for land and water have been developed over recent years with numerous applications in the western Murray Basin (Telfer et al., 2004; Berens and Hatch, 2006). All acquired data require a level of pre-processing and are then inverted using Zonge’s STEMINV program (MacInnes, 2001).

The in-river system uses a 7.5 m by 7.5 m transmitting antenna and a 2.5 m by 2.5 m receiving antenna mounted on a stiff floatation PVC framework. Data are acquired in a nearly continuous mode providing a sounding approximately every 5 – 8 m and an investigation depth of around 20 m. By reducing the size of the rig, the altered system can be used on land towed behind an ATV. The towed land system presently uses a three turn 3 m by 3 m transmitter and three turn 1 m by 1 m receiving antenna that can be fixed in loop or out of loop (Hatch et al., 2007) (Figure 3). The smaller system collects data every 3 – 4 seconds and has an investigation depth of approx 10 m.

Figure 3. Photograph of the towed land NanoTEM system.

2.3.3 AIRBORNE ELECTROMAGNETICS (AEM)

Airborne geophysical surveys were conducted on three occasions over Clark's Floodplain to examine the effectiveness of two different airborne electromagnetic (AEM) systems for mapping floodplain and groundwater salinity. Data from the Fugro RESOLVE system (a frequency domain helicopter EM system), were acquired in July 2005 and again in 2008, with data from the University of Aarhus SkyTEM system (a time domain helicopter EM system), collected in September 2006. The surveys have been undertaken as part of a collaborative investigation between CSIRO and DWLBC, supported by the SA Centre for Natural Resources Management (Project #054127), with the aim of understanding how airborne geophysical systems and data can inform floodplain hydrogeology and processes.

The Fugro RESOLVE helicopter EM system (Figure 4) is particularly suited to high resolution mapping of near surface conductivity to a depth of 40 – 50 metres in floodplain settings typical of the Murray Basin. RESOLVE is a six frequency EM system with coil pairs mounted in a 'bird' and towed beneath a helicopter at an nominal altitude of 30 m. Five horizontal coplanar coils measured a EM response at 390 Hz, 1798 Hz, 8177 Hz, 39470 Hz and 132700 Hz, and one coaxial coil pair at 3242 Hz (Fitzpatrick et al., 2007a). EM data acquired by this system can be inverted using a variety of approximate or full inversions (e.g. The Holistic inversion algorithm (Brodie and Sambridge, 2006), the Spatially Constrained Inversion (Viezzoli et al. in press), or EMFlow (Macnae et al., 1998)). Interval–conductivity images are produced for a variety of depths from these inversions, showing how ground conductivity varies across the floodplain as a function of depth.

In 2005, 26 lines (plus seven orthogonal tie lines) of data orientated NW-SE at a line spacing of 100 m were acquired, with the survey repeated in 2008 again using 26 lines at a line spacing of 100 m.

The SkyTEM system (Figure 4) was employed at Bookpurnong to investigate the benefits of characterising the hydrogeology with information from greater depths than can be obtained from the RESOLVE system. Like the RESOLVE system, it is also capable of measuring near surface conductivities. The SkyTEM system is carried as a sling load towed beneath the helicopter at a nominal survey height of 30 m (Sorensen and Auken, 2004), but was flown between 40 and 60 m for the Bookpurnong survey due to the height of the tree canopy. Mounted on a light wooden frame, the transmitter is a four turn 16 x 16 m^2 eight sided loop and is divided into segments to allow transmission in dual mode, low moment (single turn) and high moment (four turns), allowing for sequential shallow and deep investigation. The receiver loop is rigidly mounted at the rear and above the transmitter loop in a near null position relative to the primary field.

For Bookpurnong, the low and high moment transmitter base frequency, peak current and turn off time were 222.22 Hz, 40 A, 4 µs and 25 Hz, 90 A, 29 µs respectively (Munday et al., 2007). Twenty nine lines of SkyTEM data were collected at 100 m spacing in a similar orientation to the RESOLVE dataset. One orthogonal tie line and two calibration lines coincident to RESOLVE lines were also collected. The SkyTEM data were processed using the University of Aarhus Hydrogeophysics Group spatially constrained inversion (SCI) with a four layer model based on the results of an earlier fast multilayered 1D inversion (Viezzoli et al., 2009)

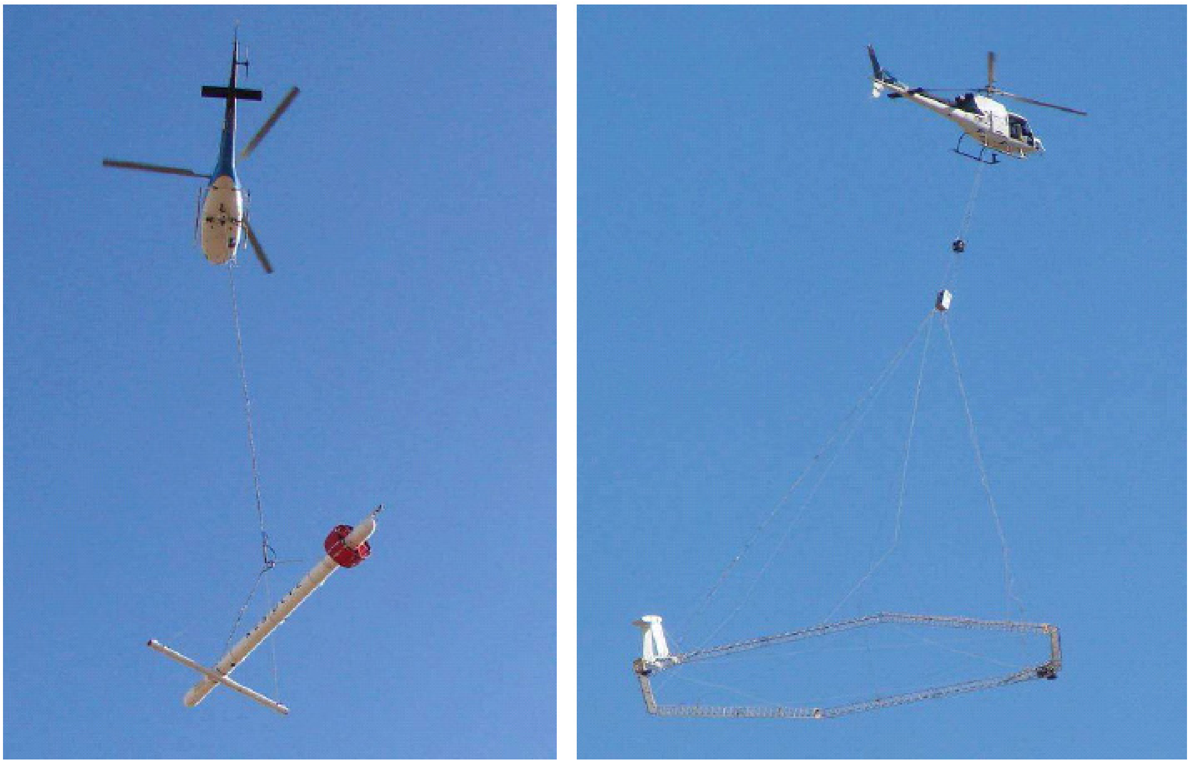


Figure 4. Photograph of the RESOLVE (left) and SkyTEM (right) systems airborne (Fitzpatrick et al., 2007b).

2.4 VEGETATION COMPONENT

2.4.1 TREES

Along each of the four transects (as described in Section 1.3), approximately 60 trees were monitored with an even distribution of species where possible (river red gum, black box and river cooba). Most transects were dominated by black box, with only Transect 1 having one river red gum present. Transect 2 (Site D) located adjacent to flood-runner creeks, had two transects of trees monitored along two flood-runners (Figure 5).

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. 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 1) although density was eliminated from this analysis as it was only measured on the last four assessment dates. Trees recorded with cracked bark that showed no vegetative response throughout the duration of the field trial, were eliminated from the analysis. 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 2). 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 transect. The photo-points taken over a three year time period show varying degrees of change and were used as a visual and qualitative depiction of the sites and hence will not be presented in this report.

Table 1. Crown extent categories used in the tree health assessment (Souter et al, 2009)

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

Table 2. Behavioural response scale (Souter et al, 2009)

Category	Positive behaviour score (epicormic growth; capsule development, flowering, seeding; crown growth)	Negative behaviour score (crown dieback; leaf damage, mistletoe)	Description
1	0	0	Absent or scarce, effect is 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

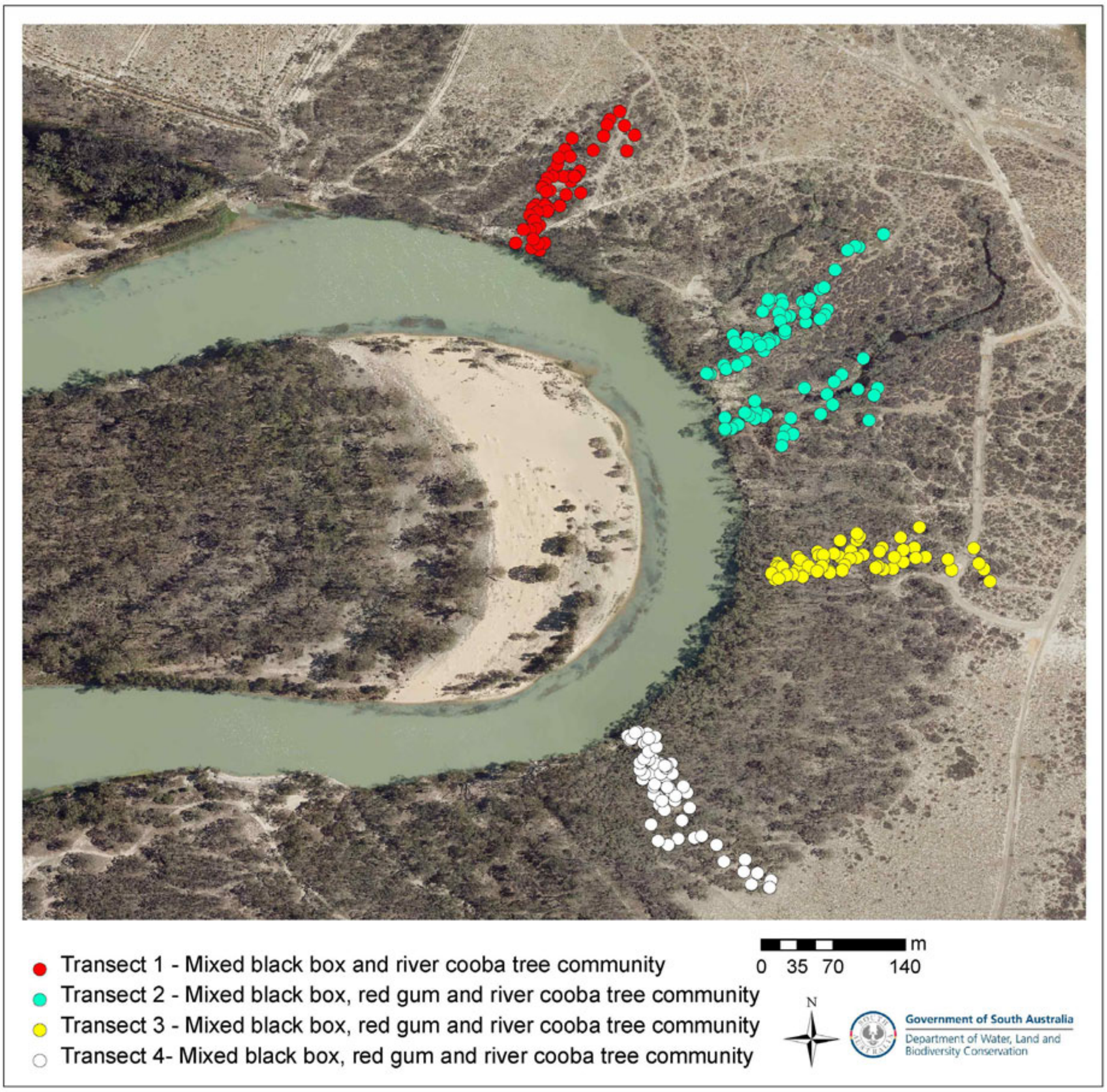


Figure 5. Location of trees and transects at Site B

Statistical Analysis

At Transect 4 (control transect), no groundwater management trials were performed. Changes in tree condition at Transect 4 were used in the statistical analysis against the effect of groundwater lowering at Transect 1, and lateral recharge at Transect 3.

At Transect 1, the effects of pumping from the nearby SIS scheme were assessed for 50 trees, which comprised 1 river red gum, 32 black box and 17 river cooba and were contrasted to the control transect (Transect 4).

At Transect 2, directly inundated trees and those within 15 m of the flood runner, totalling 44 trees (18 river red gum, 8 black box, 18 cooba) were analysed as being influenced by the artificial inundation and groundwater lowering (cf. White et al, 2009, Bacon et al, 1993; Mensforth et al, 1994). Trees at Transect 2 not within the inundation area of influence, totalling 36 trees (13 river red gum, 10 black box, 13 cooba) were analysed as being non-watered.

At Transect 3, the effect of the production well was assessed for 60 trees, which comprised 17 river red gum, 23 black box and 20 cooba and were contrasted to the control transect (Transect 4).

Markov modelling of tree crown extent and epicormic growth

Changes in tree crown extent and epicormic growth were modelled as an 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 of five states (Figure 6.1a and Table 3). The Markov model for epicormic growth comprises three states (Figure 6b and Table 3). 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*:

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

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.

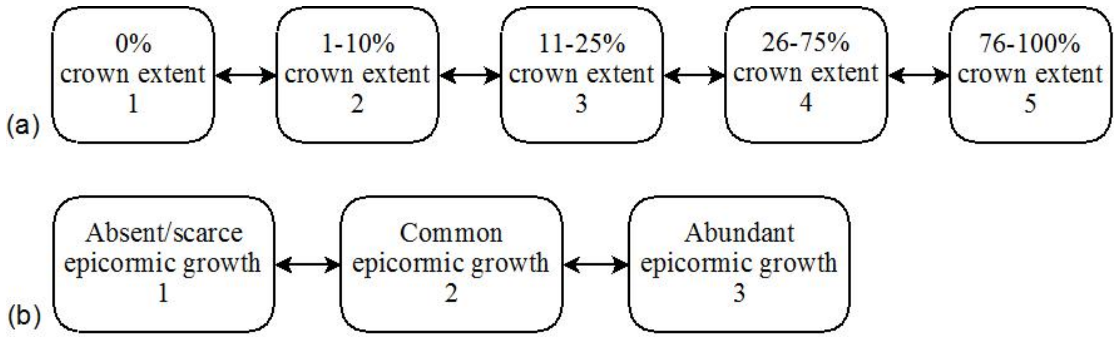


Figure 6a. River red gum, black box and river cooba crown (a) five state extent model and (b) epicormic growth Markov models

Table 3. Category scale for river red gum, black box and river cooba, crown extent and epicormic growth

Category	Crown extent	Epicormic growth
1	0%	Absent/Scarce
2	1-10%	Common
3	11-25%	Abundant
4	26-75%	
5	76-100%	

The Markov model for crown extent comprises of five states (Figure 6.2a). The Markov modelling for Transect 2, four states were modelled that combined Categories 4 and 5 (Table 3) as insufficient trees were observed in Categories 5 to develop an acceptable model. The Markov model for epicormic growth comprises three states (Figure 7b). 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:

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

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.

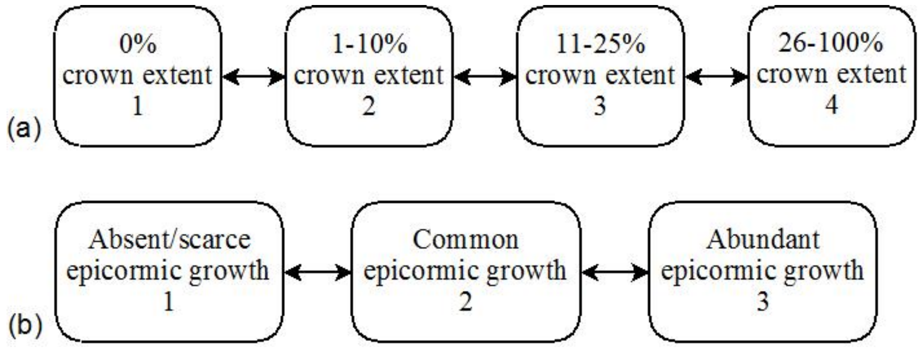


Figure 6b. River red gum, black box and river cooba crown (a) four state extent model and (b) epicormic growth Markov models

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: q12, q21, q23, q32, q34, q43 for the crown extent model and q12, q21, q23, q32 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 SIS drawdown (Transect 1) and LM lateral recharge (Transect 3) was determined by comparing trees in those transects to trees in the control transect (Transect 4) as a covariate in the model. The effect of SIS drawdown and inundating trees (Transect 2), was determined by including trees which were affected by the artificial filling of the flood runner, 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 flood runner.

Differences between transition intensities for the two models during the three analyses (Transect 1, Transect 2 and Transect 3); no experimental effect (either control transect or no inundation) and experimental effect (SIS drawdown or inundation or LM well) at each transect were compared for both crown extent and epicormic growth. The no experimental effect are both the experimental (trees at each transect) and control trees combined. The experimental effect was examined as a covariate. 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 modelled time spent in a particular state, were also estimated for both crown extent and epicormic growth models and compared.

2.4.2 UNDERSTOREY

The four vegetation transects were set across the study site. Each transect comprised eleven 1 x 1 m^2 quadrats spaced 10 m apart which ran perpendicular to the river. Each transect was spaced approximately 200 m apart. In each quadrat, the identity of each plant taxon was identified to the lowest level practicable. The vegetation community was sampled on four occasions over three years, at roughly six month intervals.

Prior to analysis, a single combined sample was derived from each of the four 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 a quadrat by the total number of quadrats (eleven).

Species richness and Shannon diversity (log base e) were calculated for each transect sample over the four sampling periods. Multivariate methods were used to compare differences in the composition of the understorey vegetation community over time and between transects. The percent cover of each combined transect sample 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. Data were presented to show the trajectory of each sample over time and as an environmental bubble plot, overlaying each sample with the rainfall in the three months prior to sampling. Differences between time and transects were examined using two-way crossed ANalysis Of SIMilarity with no replicates (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.

2.5 GROUNDWATER INTERCEPTION

The Bookpurnong SIS is designed to intercept the discharge of saline groundwater flowing towards the River Murray over the river kilometre reach 501 to 521 (Figure 1). Groundwater modelling for the Bookpurnong reach completed in April 2007, was used to predict salinity impacts on the river from the groundwater system for scenarios 'with' and 'without' SIS operation. Under natural conditions, without the salinity impact of irrigation development and native vegetation clearing, the modelled salt load to the river for the Bookpurnong reach is 16.5 tonnes/day. Salinity impacts for current and future scenarios (Table 4) highlight the increasing impact if no salinity mitigation intervention were adopted, and the resultant reduction in salinity impact due to the operation of the SIS scheme as it is currently constructed. The model results have required simplification of processes, assumptions and average conditions in the model development, and should not be treated as absolute values, an important consideration when applying the results for decision making (Yan and Vears DWLBC 2008, pers. Comm.).

Table 4. Modelled salt loads to river from the groundwater system along the Bookpurnong reach.

Simulation Year	With no intervention (tonnes/day)	With constructed SIS (tonnes/day)
2009	79.	13.
2050	132.2	24.8
2100	140.	26.

Floodplain SIS production wells on Clark's Floodplain were installed in January 2004 as part of the broader Bookpurnong SIS scheme which also includes Ajax-Achilles, Stanitzki's, Graetz's and Western's Floodplains (AWE, 2004). The Bookpurnong SIS includes seven highland and 15 floodplain wells, of which six are located on Clark's Floodplain. The SIS began groundwater extraction in July 2005. The three western-most SIS wells on Clark's Floodplain (30FP, 32FP and 34FP) operated at 1 – 3 L/s, whilst the eastern wells (36FP, 38FP and 42FP) operated at 2 – 5 L/s.

The cumulative extraction volume for all Clark's Floodplain SIS wells and the Living Murray production well is presented in Figure 7. The graph indicates relatively steady increase in extracted volume, and highlights periods of SIS shutdown (seen as plateaus on the graph). The most significant production halt was identified between November 2006 and May 2007, when a fault in the SIS disposal line prompted all wells to cease operation for a six month period.

Smaller production halts can be identified, but are typically limited to one to two month periods, and are only restricted to one or two SIS wells. SIS well 34FP (closest to Site B) had the most extensive down time, being out of operation for 20 months of the 43 month period between August 2005 and March 2009. Cumulative discharge from the six Clark's Floodplain SIS wells until the 12th March 2009 was 1430 ML.

The LM production well commenced operation on August 1st 2006 at a pumping rate of 4 L/s. Due to a fault in the SIS disposal line, the well ceased operation between November 20th 2006 and May 18th 2007. Whilst in operation, the LM well typically pumped between 4 and 5 L/s and extracted a total of 254 ML until 12th March 2009.

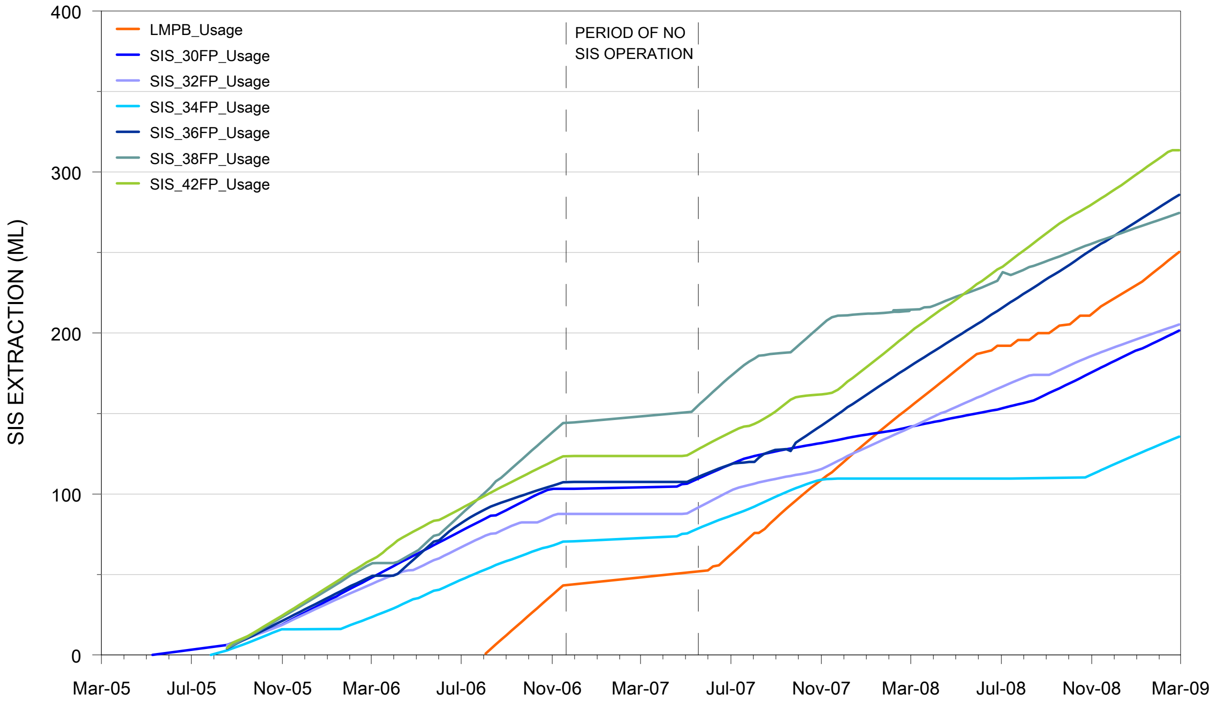


Figure 7. SIS extractions volumes

3. RESULTS

3.1 GROUNDWATER MODELLING

Groundwater model simulations can be used to conceptualise past, current and future condition and river salt loads of a study region. Broader scale simulations examined condition before and after irrigation development and the extent of groundwater freshening due to SIS groundwater extraction (Figure 8a/b and Figure 9a/b), with the 10 yr SIS pumping scenario simulating a similar flush zone extent to that of the pre irrigation scenario.

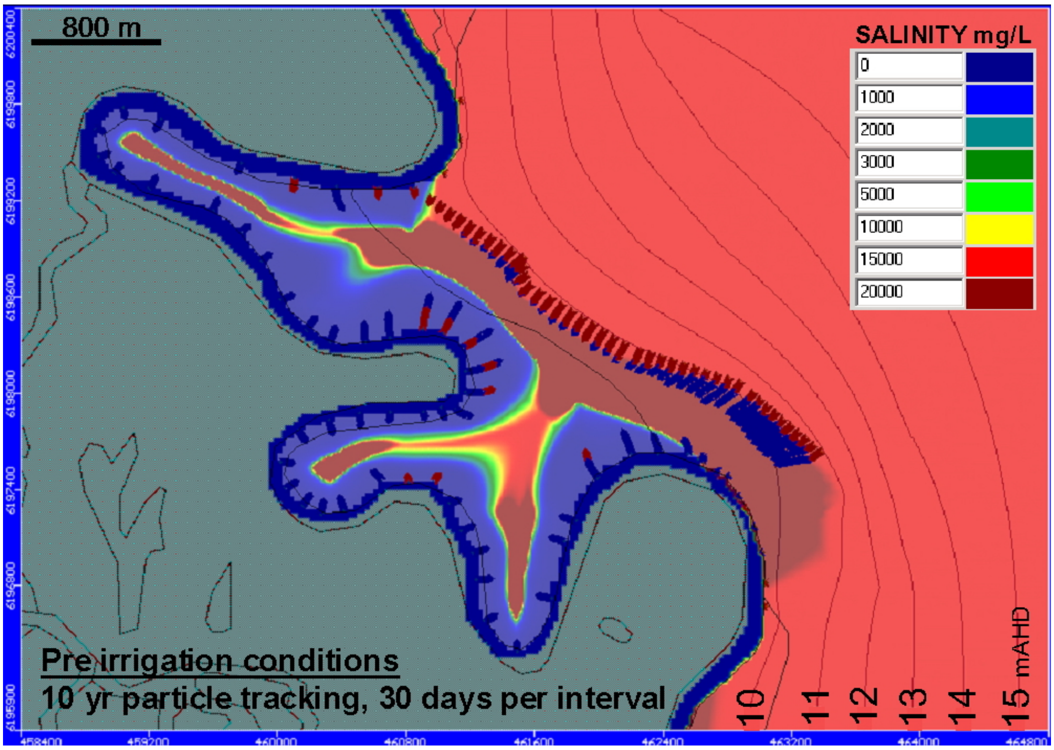


Figure 8a. MT3D and particle tracking simulations for pre irrigation conditions.

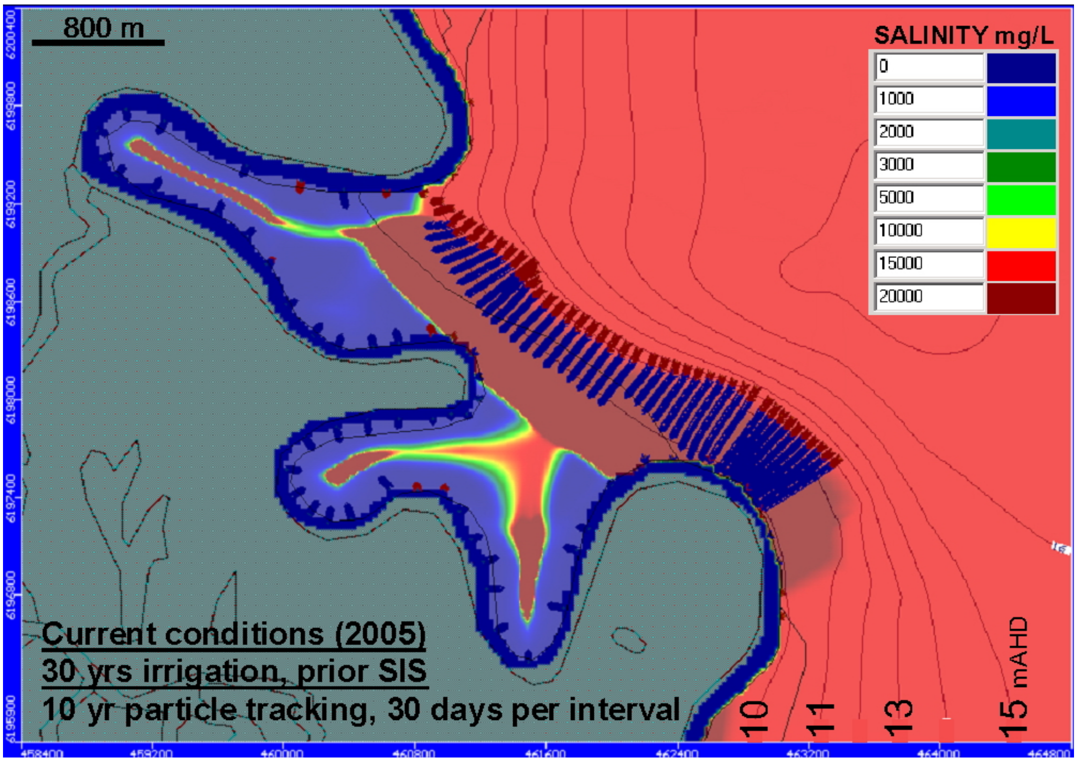


Figure 8b. **MT3D and particle tracking simulations for current condition (2005), 30 years of irrigation and prior to SIS pumping.**

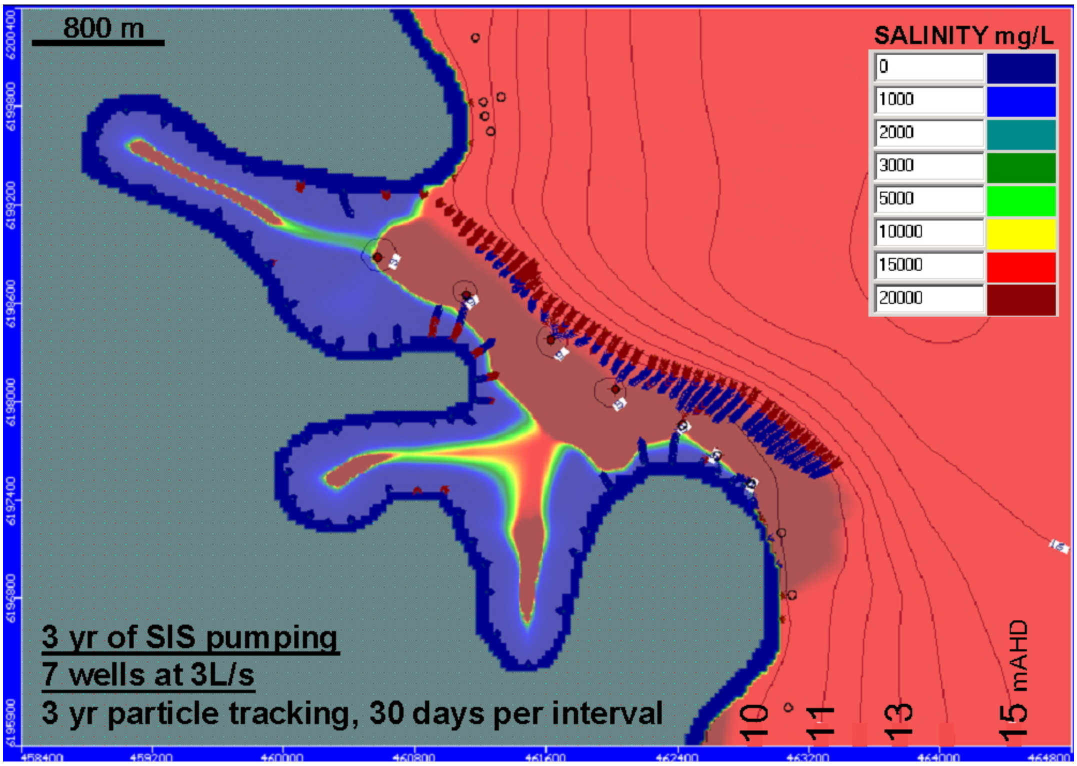


Figure 9a. **MT3D and particle tracking simulation for 3 years of SIS pumping from 7 production wells at 3 L/s**

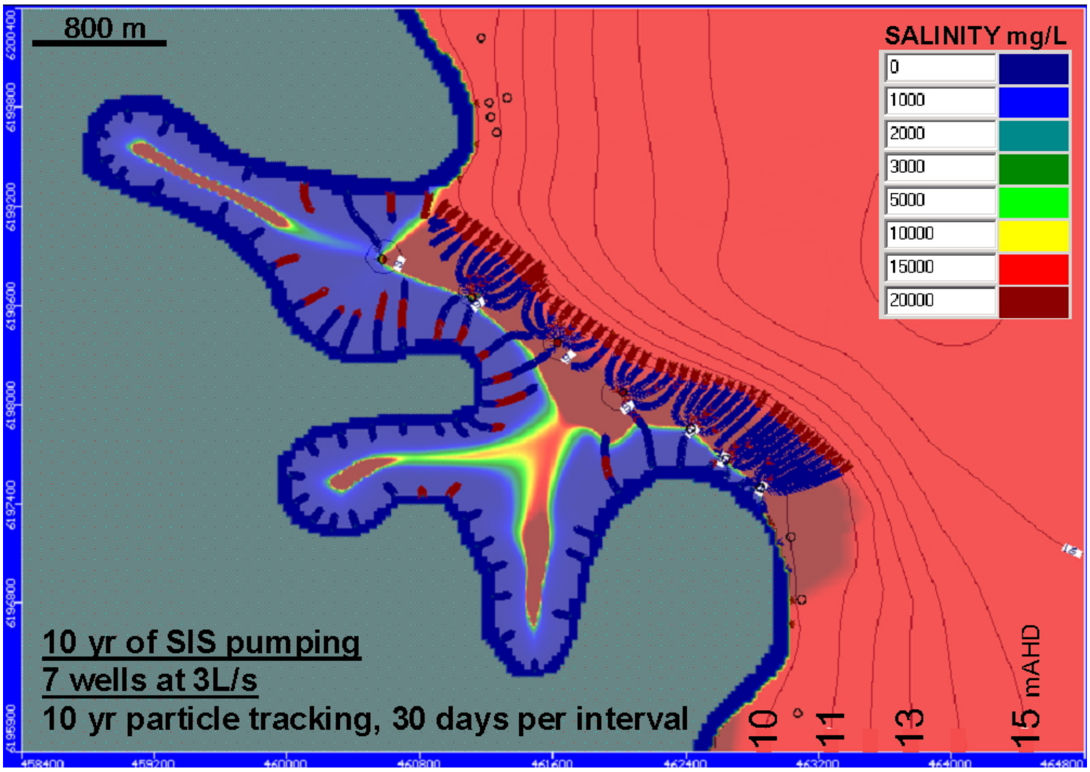


Figure 9b. **MT3D and particle tracking simulation for 10 years of SIS pumping from 7 production wells at 3 L/s.**

Smaller scale simulations were effective in examining the hydraulic behaviour in response to Living Murray well pumping, and examine model parameter sensitivity. The initial Site B specific Mod Path particle tracking scenarios examined sensitivity of the river conductance parameter (using values between 1000 m^2/day and 1 m^2/day), defined as the connectivity between the surface and groundwater (Figure 10). The results indicate little difference between the use of 1000 m^2/day and 100 m^2/day, but an increasing resistance to movement of water from the river for simulations using river conductance's of 10 m^2/day and 1 m^2/day.

Further simulations adopted a consistent river conductance value of 100 m^2/day while varying the Living Murray well pumping rate to 1, 2, 3 and 5 L/s (Figure 11). Results are from one year simulations with particle intervals (nodes) representing 30 days. Simulated pumping from the Living Murray well at 5 L/s and a river conductance of 100 m^2/day tracked particles (or induced water) to 160 m from the rivers edge, almost as far as the production well. Reduced pumping rates of between 2 and 3 L/s indicated induced flow to approximately the mid point of the riparian zone, or the middle of Transect 3 near B8. Groundwater salinity profiles (Section 3.1.b) indicate in February 2008 (Figure 18), 19 months after the start of LM pumping (at 4 L/s), including 6 months of shut down that the bulk of groundwater freshening was within 160 m of the riverbank.

Simulation of SIS pumping alone for one year resulted in movement of fresh river water into the floodplain aquifer to a distance of around 50 m (Figure 12). The groundwater salinity profile of July 2007, one year after the start of SIS pumping shows the bulk of freshening to be within 60 m of the riverbank (Figure 18).

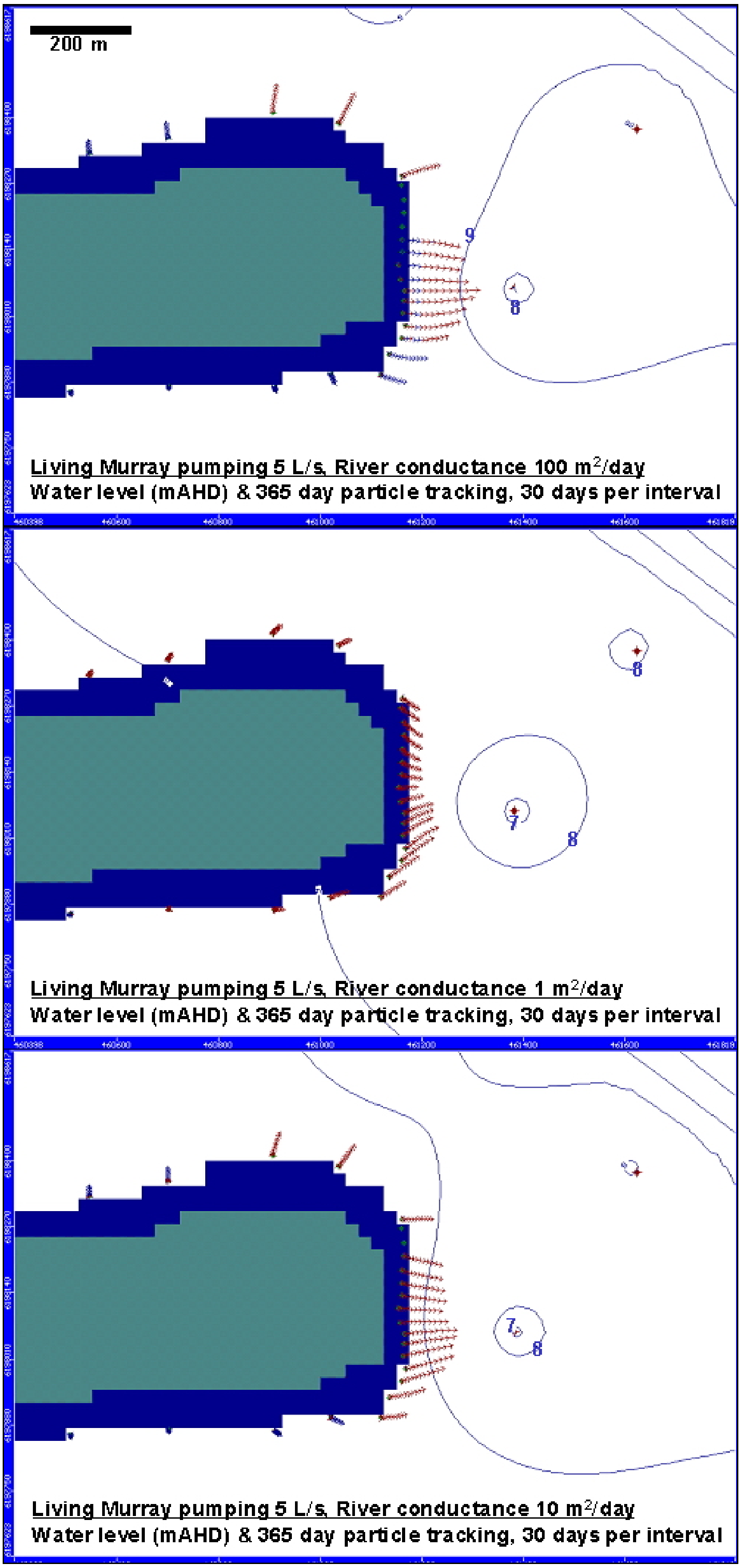


Figure 10. Site B model simulation to test the sensitivity of river and aquifer connectivity

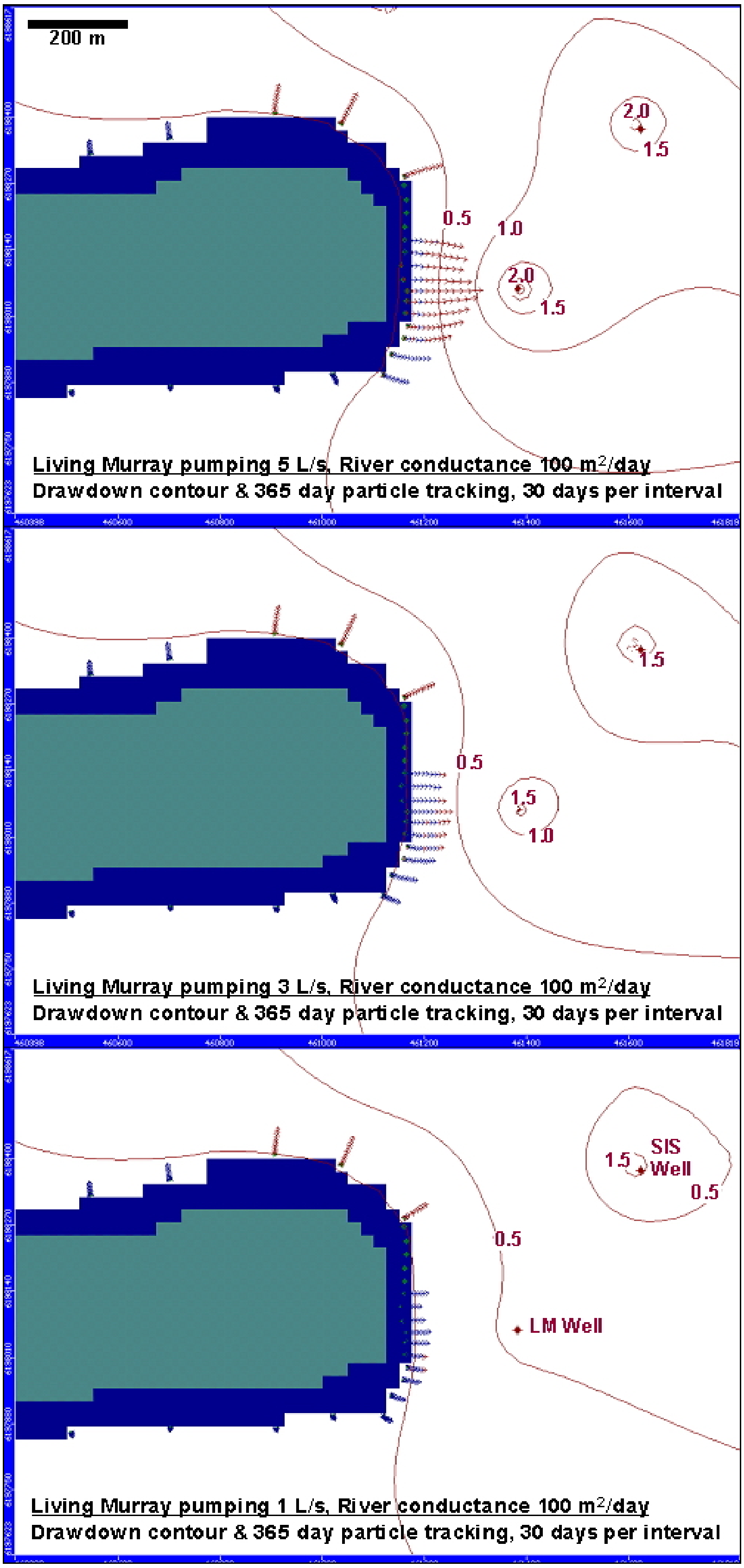


Figure 11. Site B model simulations to test the sensitivity of Living Murray well groundwater extraction

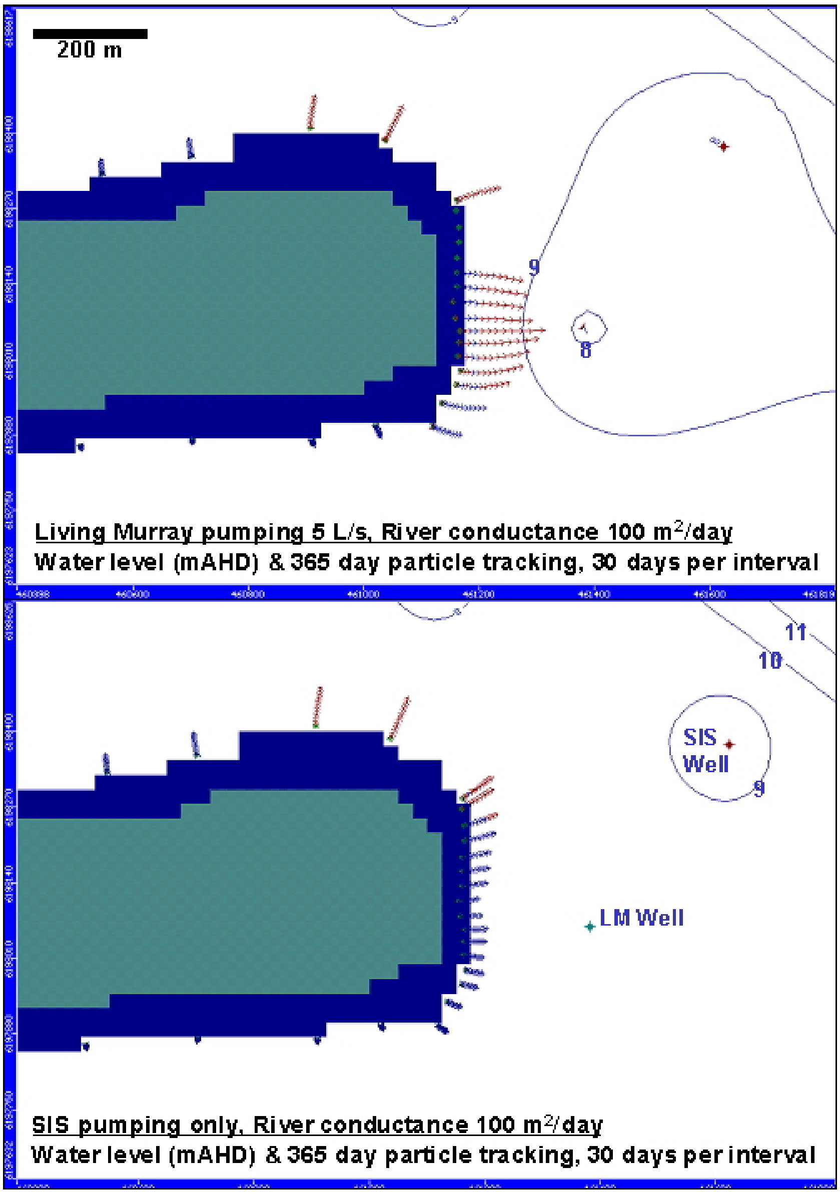


Figure 12. Site B model comparison of SIS only to Living Murray groundwater extraction.

3.2 GROUNDWATER LEVEL

As found in the Site A trial (White et al, 2009), floodplain groundwater levels at Site B respond rapidly to fluctuations in river level, with increasingly subdued responses in wells located at greater distances from the river.

At Transect 1, wells B1, B2 and B3 showed some drawdown due to SIS pumping.

The following observations were made from wells located on the edge of the river (B1, B4, B7, B10):

- During periods of river level recession, groundwater levels remain above river level, indicating a degree of hydraulic resistance at the riverbank and aquifer interface, allowing a loss of groundwater to the river.
- Conversely during periods of river level rise, the relatively lower groundwater levels promote recharge from the river into bank storage.

3.2.1 SALT INTERCEPTION SCHEME

SA Water manage the operation, maintenance and regular monitoring of the SIS. Extraction wells 30FP, 32FP, 34FP, 36FP, 38FP and 42FP operate on Clark's Floodplain, with wells 32FP, 34FP and 36FP being closest to the Site B trial (Figure 1). A hydrograph of manual readings collected at midpoint observation wells 29FO, 31FO, 33FO, 35FO and 37FO show levels below recorded river levels (Figure 13). During the period of no SIS groundwater pumping, levels are seen to quickly recover to be near or above river level.

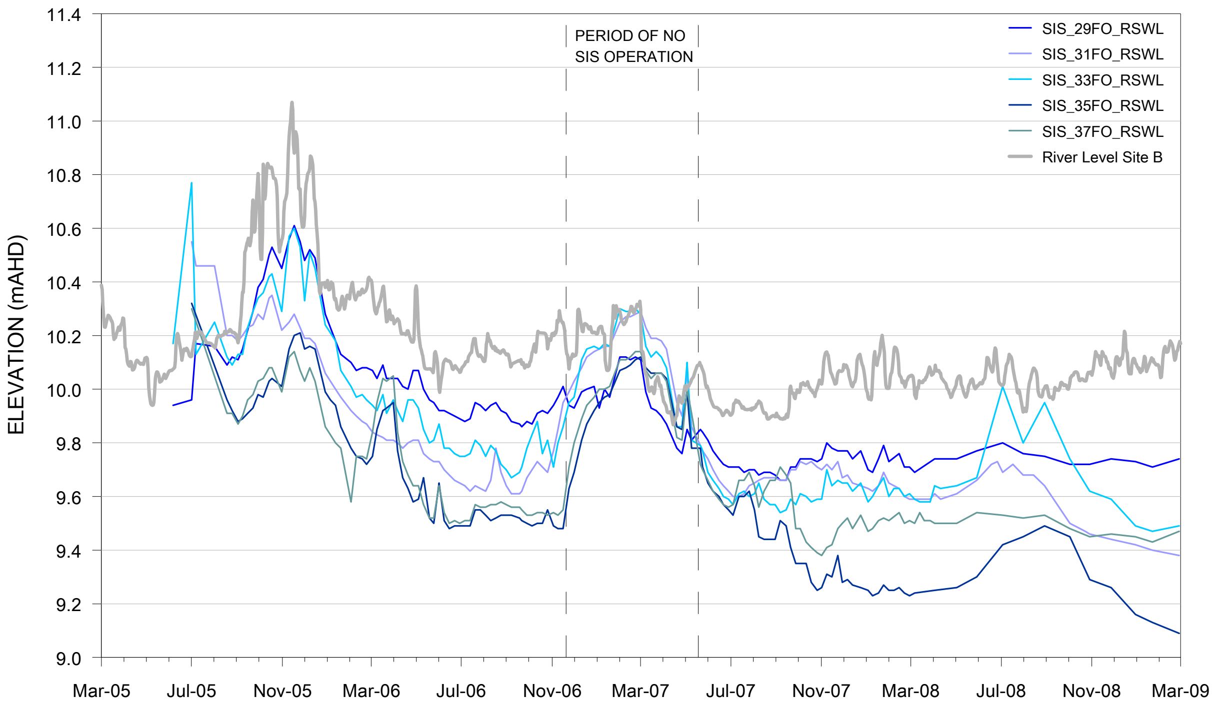


Figure 13. Salt interception scheme observation well hydrographs

3.2.2 TRANSECT 1 – SIS ONLY

The location of Transect 1 was chosen so that apart from river level fluctuations, the SIS operation would present the main external stress on groundwater. Following SIS commencement in July 2005, a watertable gradient away from the river developed with observation well B3 being up to 0.5 m below the observed river level (Figure 14). From June and November 2006, under relatively stable river levels, observations indicate a groundwater gradient away from the river between B1 (at the riverbank) and B3 of 0.4 m over a distance of 130 m (3 x 10^{-3}).

During the SIS shutdown from November 2006 to May 2007, groundwater levels across Transect 1 indicated a reduced gradient with B1, B2, and B3 at similar elevations. Monthly means of the B1 hydrograph (Figure 14) indicate groundwater elevations were greater than river levels during February, March and April 2007, indicating gaining stream conditions with the B1 and SIS midpoint hydrographs above the recorded river level. Following the reinstatement of the SIS in May 2007, recorded levels of Transect 1 wells indicate the losing stream gradient was rapidly restored and maintained in the absence of further SIS stoppages.

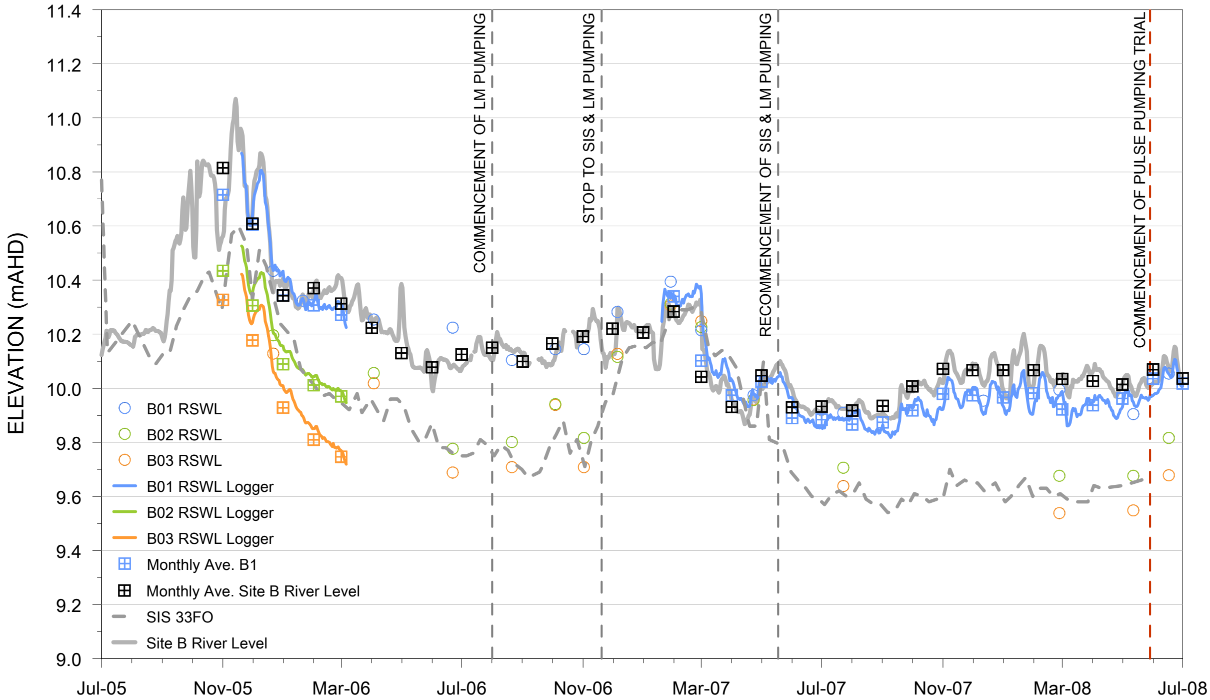


Figure 14. Transect 1 observation well and river levels.

3.2.3 TRANSECT 2 – SITE D

The location for Transect 2 observation wells were chosen to investigate the groundwater response to the Site D trial (creek flooding), which was examined in detail by CSIRO (Holland et al. 2009). Transect 2 dissects the midpoint between SIS production wells 32FP and 34FP, with SIS midpoint observation well 33FO in alignment with Transect 2 observation wells (Figure 1).

The hydrographs indicate that SIS extractions reduced groundwater levels across the transect, forming a gradient away from the river of around 0.3 m over 170 m (Figure 15). The distance from the production wells 32FP and 34FP to the nearest observation well B6, is 340 m and 320 m respectively. The SIS- induced groundwater gradient away from the river was less than that observed at Transect 1.

Monthly averages of the logged data relative to mean river level showed that during the study period, floodplain groundwater levels were at all times lower than recorded river levels, excluding the months January to April 2007 when the SIS was shutdown (Figure 15).

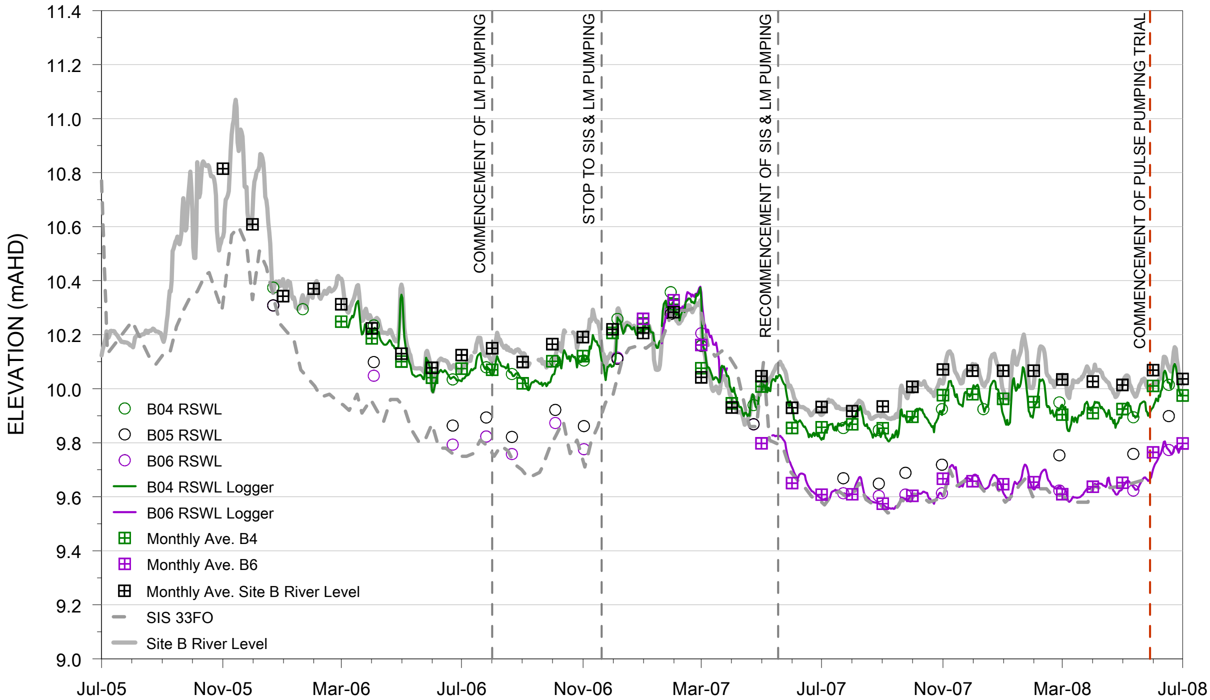


Figure 15. Transect 2 observation well and river levels.

3.2.4 TRANSECT 3 – LIVING MURRAY WELL

Transect 3 was observed in most detail with the operation of the Living Murray production well presenting a considerable additional stress on the groundwater. Groundwater loggers were installed in all wells for most of the trial period.

Prior to the commencement of Living Murray well pumping in August 2006, SIS wells across the floodplain had been operating since July 2005 (approx 13 months), and produced a groundwater gradient away from the river of 0.3 m over 190 m between B7 and B25 (Figure 16). As a result of LM pumping commencing in August 2006, the gradient increased to 0.7 m between B7 and B25 by November 2006. Following the period of SIS shutdown, the increased groundwater gradient was reinstated within one month.

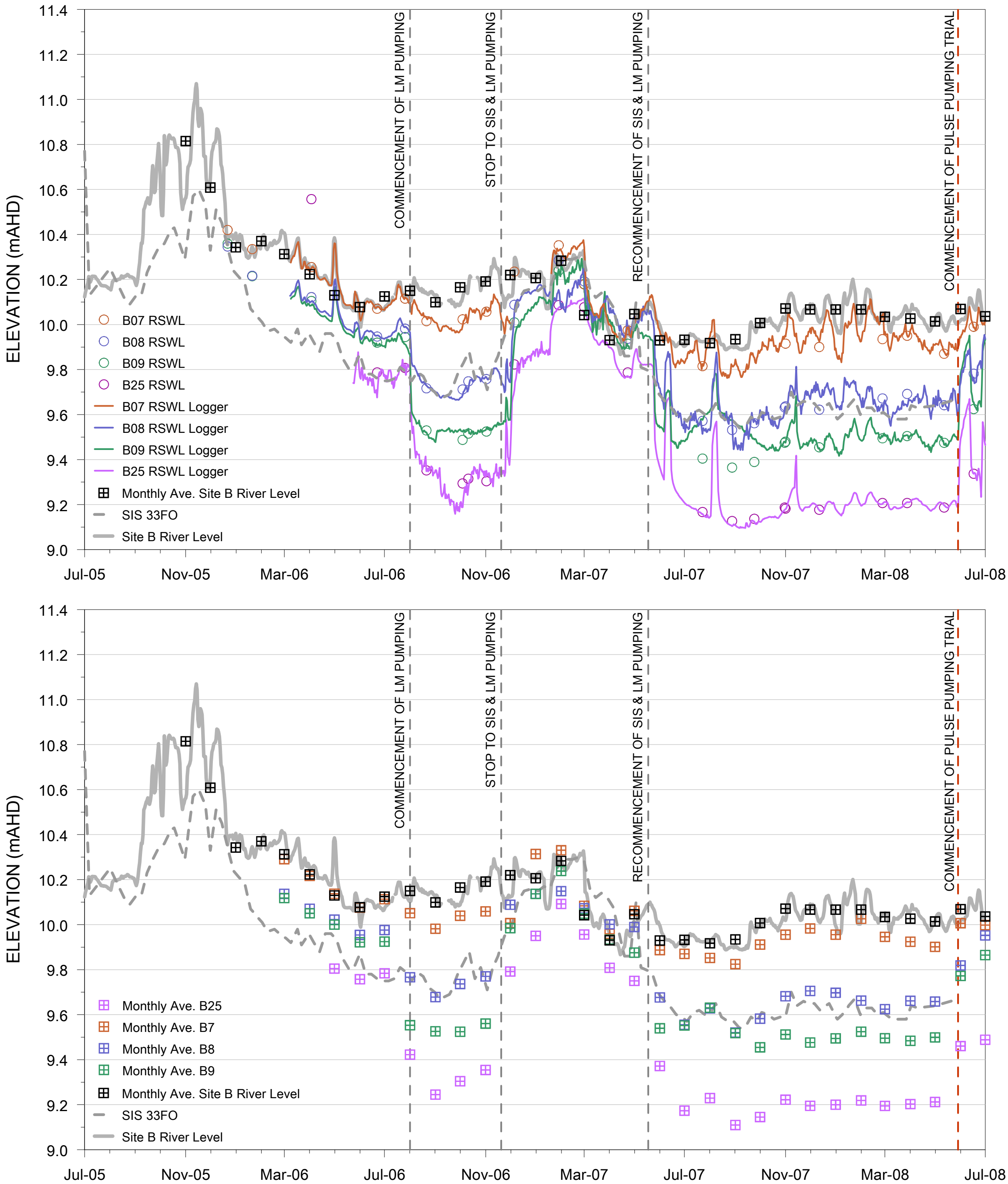


Figure 16. Transect 3 observation well and river levels.

3.2.5 TRANSECT 4 – CONTROL

Transect 4 was designed as a control transect, intended to be beyond significant influence of the SIS, LM pumping and the other trials. The B10 riverbank hydrograph (Figure 17) indicates that the groundwater elevation was significantly less affected along Transect 4 due to SIS pumping than at the other transects. Nearer to the SIS pumping wells, manual observations at B12 suggest some drawdown during the SIS operation. The B10 levels remained above observed river levels for the period prior to LM pumping, indicating little SIS influence over the first year of operation. From November 2007 to July 2008, a period of relatively constant SIS and LM pumping, B10 levels were slightly but consistently below the recorded river level indicating a gradient away from the river.

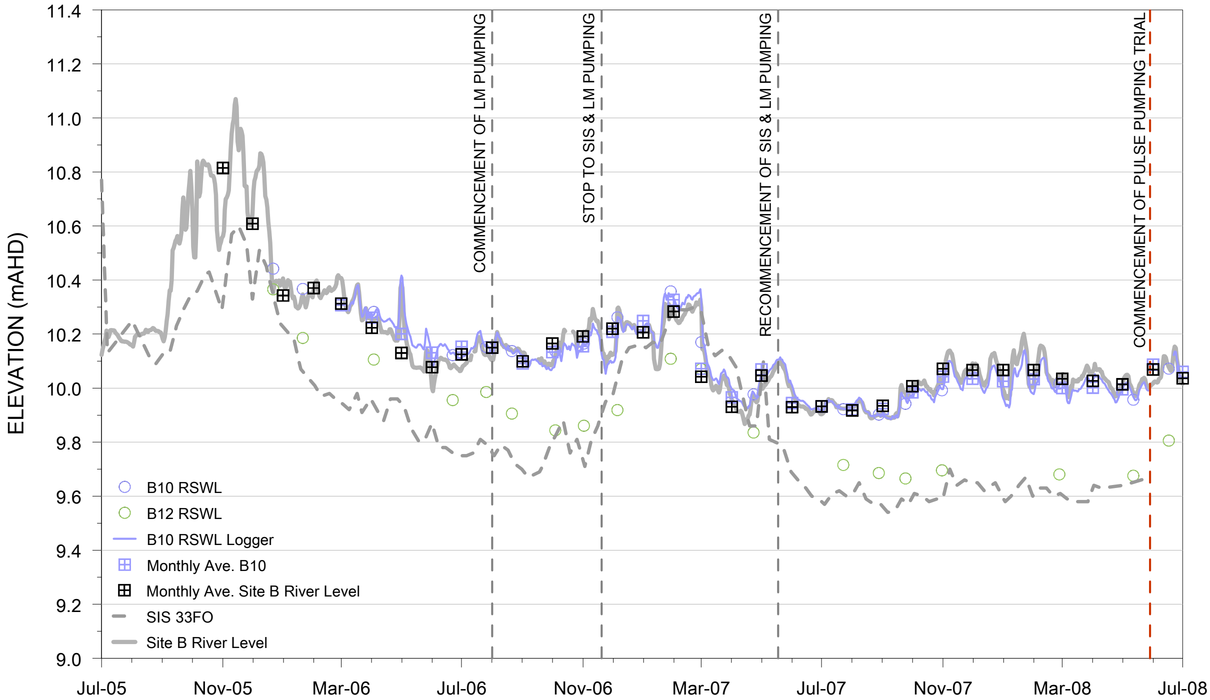


Figure 17. Transect 4 observation well and river levels.

3.3 GROUNDWATER SALINITY

Groundwater salinity was monitored using Solinst groundwater loggers for continuous time series, and a YSI XLM600 multi-parameter downhole profiler. Downhole profiling (sonding) was used to examine vertical stratification with observations made on 19 occasions during the period from January 2006 to December 2008. Salinity loggers were predominately concentrated in Transect 3. Periodic sonding was sufficient to indicate temporal variations in salinity at the other transects. Sonde profiles proved to be more informative than discrete logger information.

Groundwater salinity was used to delineate the interface between the natural saline floodplain groundwater and the low salinity induced bank recharge. The pH parameter was also collected during sonding. At higher salinities (> 50 000 EC), some discrepancies exist in the sonde salinity data. This is because a 6,000 EC calibrating solution was chosen for the one-point calibration to best represent the fresh and saline interface. Consequently, values above 50 000 EC are suggested to represent a uniform high salinity.

Transect 3 sonde profile data was gridded using the Golden Software Surfer package to produce 2D representations of the groundwater lens for all monitoring dates, with a selection presented in Figure 18. Grids are produced using a 1 x 1 m cell size and a Kriging algorithm with default settings. Contours are filled with the colour stretch capped at 40 000 EC to eliminate high salinity range inaccuracies. Figure 18 is used to best represent the evolution of the fresh water lens (bank storage) as a result of groundwater extraction from the floodplain aquifer. Detailed observations for the transect are based on individual sonde profiles (Figure 19).

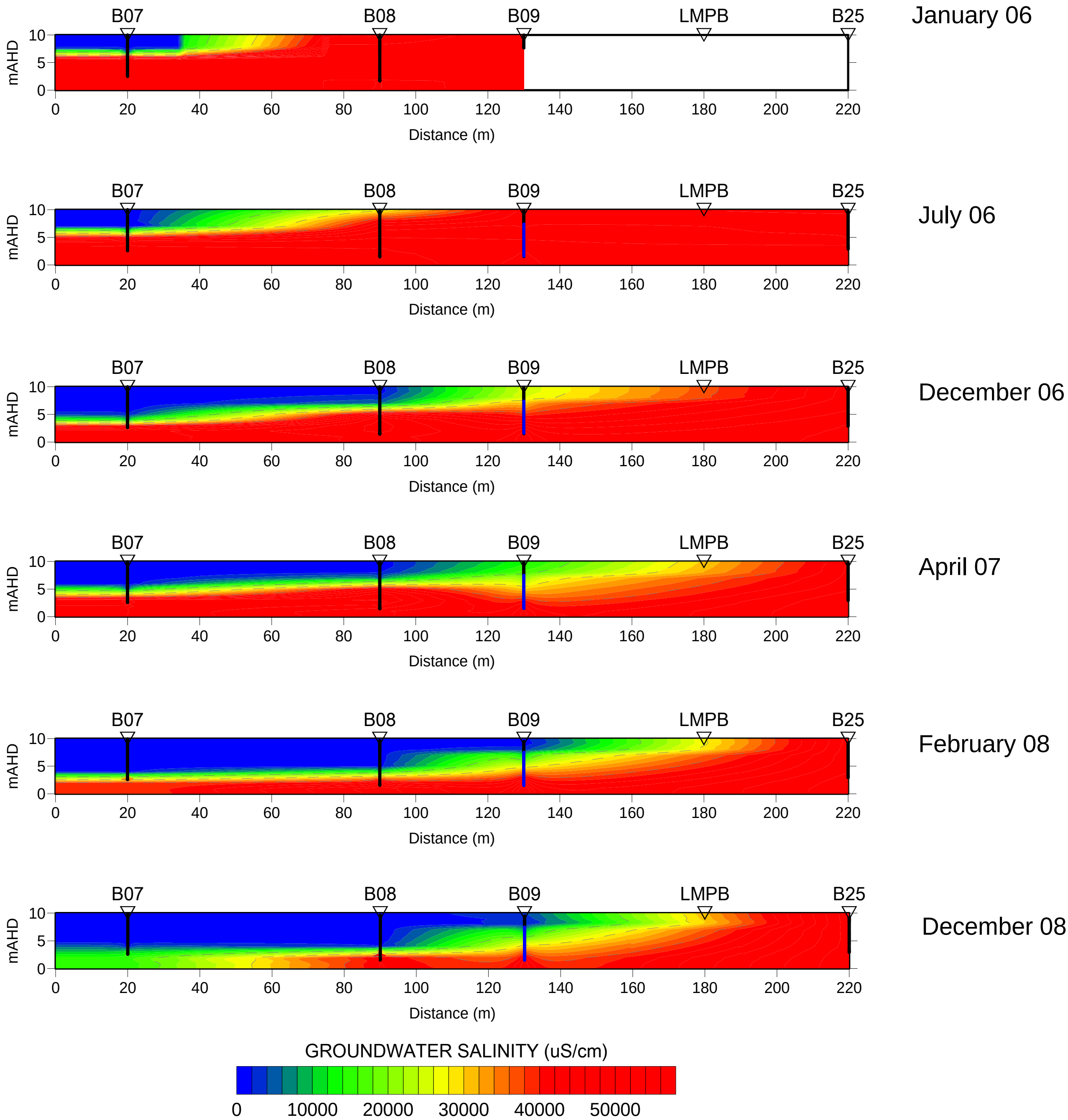


Figure 18. Transect 3 sonde profile data indicating freshwater lens development resulting from Living Murray pumping.

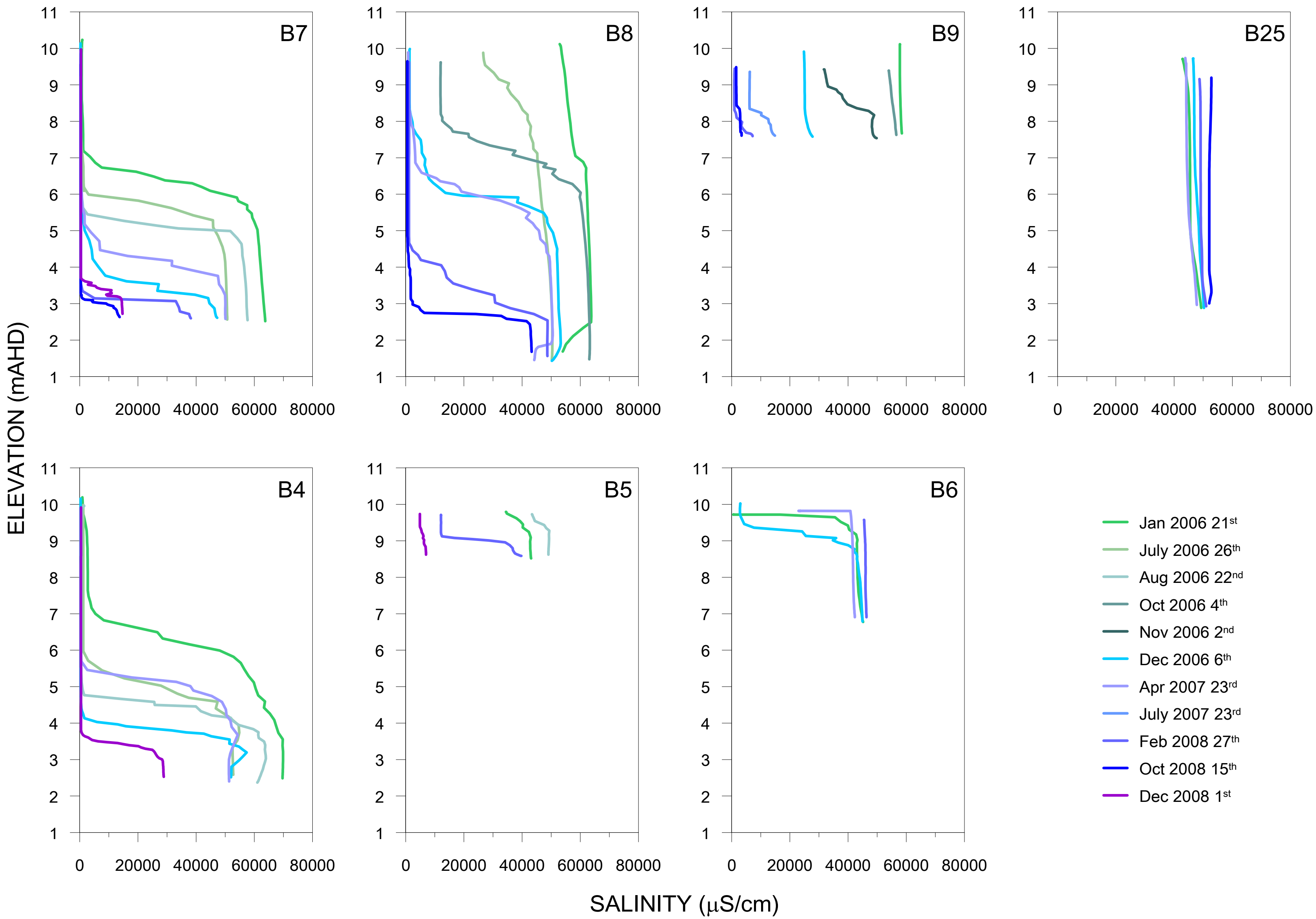


Figure 19. Selection of individual sonde profiles for a selection of Site B observation wells.

3.3.1 TRANSECT 1

Little variation in groundwater salinity was observed in Transect 1. Observation wells B2 and B3 did not have any notable salinity variation, remaining above 50 000 EC for the duration of the trial. Regular sonding indicated that the shallow B1 piezometer had a salinity of around 20 000 EC in January 2006, 6 months after the commencement of nearby SIS pumping. The following observation in August 2006 indicated the B1 salinity had reduced to around 5,000 EC. Over the remainder of the observations until December 2008, the salinity at the riverbank piezometer only gradually reduced to a minimum salinity of around 2,500 EC. The adjacent observation well LM2 (which was screened over a longer and deeper interval), had salinities below 1,000 EC in January 2007 over the same interval as B1.

3.3.2 TRANSECT 2

Sonde profiles indicate a reduction in salinity as a result of SIS and LM pumping. The initial B4 profile of January 2006 (six months after the SIS started pumping) was stratified with a fresh upper 3 m (< 5,000 EC), increasing to over > 50 000 EC at depth (Figure 19). Without baseline (pre-SIS) profiles, it is difficult to quantify the influence of SIS pumping, however it is suggested that this stretch of the river (Site B, river km 510 – 511 in Figure 1) was previously a gaining reach with inflows from the adjacent saline floodplain aquifer. Evidence for this has been provided from a number of investigations including Airborne EM (Munday et al., 2006a), instream NanoTEM and sediment coring (Berens and Hatch, 2006), Run of River salt loads (Porter, 2001) and Modelled Baseflow (Doble et al., 2006; Yan et al., 2005).

In July 2006 prior to LM pumping, the B4 profile shows increased freshening with the upper fresh component (< 5,000 EC) two metres thicker than the previous observation. In December 2006 shortly after the SIS and LM pumping was halted, there was a further freshening with the upper 6 m of profile to below 500 EC, indicating that the rate of freshening had increased as a result of LM pumping.

Following an extended halt in SIS and LM pumping for 5 months, the April 2007 B4 salinity profile indicates a shrinking of the freshwater lens, with the profile similar to that observed earlier in July 2006. When pumping was reinstated in May 2007, there was an increase in groundwater freshening up until the last monitoring date in December 2008. Although the vertical thickness of B4 freshening did not increased greatly from December 2007, the deeper salinity reduced from over 50 000 EC to below 30 000 EC.

At B5 (100 m from the river bank), early salinity profiles indicated some minor salinity stratification of the water column, with the upper component marginally fresher than the base of the profile. This suggests some influence of SIS pumping on salinity at this site despite the salinity being above 40 000 EC. By February 2008 following a period of constant SIS and LM pumping, it was apparent that the salinity at the top of the watertable at B5 reduced to less than 15 000 EC. The December 2008 profile indicated a further salinity reduction due to groundwater extraction, with the entire profile less than 10 000 EC.

At B6 (200 m from the river bank), early profiles indicated a groundwater salinity below 50 000 EC. The December 2006 profile displayed some stratification with freshening at the top of the profile. This date coincides with the Site D creek flooding trial along Transect 2 when it was observed that surface water had pooled around the B6 casing, with some fresh water recharge likely to have occurred. By April 2007 and February 2008, the salinity at B6 had returned to its previous saline condition (> 50,000 EC).

3.3.3 TRANSECT 3

Transect 3 had the most salinity observations recorded from both continuous logger data and down-hole profiles.

3.3.3.1 Prior to Living Murray production well pumping

The initial monitoring occurred six months after the commencement of the floodplain SIS, and approximately six month before the commencement of the LM pumping. It showed the B7 (riverbank) groundwater profile was stratified with the salinity in the top 3 m less than 1,000 EC, rapidly increasing to a salinity in excess of 50 000 EC. Just before the LM well started operation, the July 2006 profile showed that SIS operation had increased the vertical extent of freshening at B7 by approximately one metre.

At B8 (90 m from the river bank), the January 2006 profile revealed a fairly uniform profile of salinity greater than 50 000 EC. In July 2006, some freshening began to occur independent of LM pumping (Figures 18, 19). The shallow piezometer B9 (130 m from the riverbank) provided salinity data of the top 2 m of the watertable showing that prior to LM pumping, no freshening had been observed with salinities greater than 50 000 EC.

3.3.3.2 Groundwater salinity response to Living Murray pumping

The LM pumping increased the rate of groundwater freshening at B7 compared to SIS only pumping. Shortly after the SIS and LM pumping had stopped, the December 2006 profile observed salinities less than 1,000 EC over the upper 5 m, stratifying to above 50 000 EC at greater depth.

At B8, the October 2006 and December 2006 profiles (Figure 19) showed ongoing freshening over the vertical profile, with salinities less than 500 EC over the top 4 m. At this time (December 2006) following four months of LM pumping, B9 also observed some freshening, recording a reduction in the upper part of the profile to 30 000 EC.

3.3.3.3 After SIS and Living Murray shutdown

At B7, the April 2007 data showed a slight reduction of the fresh water lens (bank storage) as a result of SIS and LM extraction being halted. B8 showed that by April 2007 (after five months of no extraction), the depth of freshening had decreased across the transect but had spread laterally by dispersion. The B9 salinity continued to decrease slightly whilst no extraction occurred due to dispersion.

The fresh water lens that had developed from the LM and SIS pumping did not rapidly recede or return to the river as groundwater accession (or loss of bank storage). This was assisted by the fact that there was no significant recession in river level during this period, which would have otherwise contribute to enhanced groundwater accession to the river.

3.3.3.4 Reinstating of the SIS and Living Murray pumping

At B7 after the reinstatement of SIS and LM pumping, the groundwater continued to freshen until the last monitoring in December 2008, when almost the full profile had a salinity less than 500 EC. By December 2008, a significant component of the B8 profile was fresh (< 1000 EC) and at B9, salinity had reduced to around 2,500 EC.

Observation well B25 was installed as a control inland of the LM well and displayed no significant change in EC levels which remained above 50 000 EC throughout the study period.

3.3.4 TRANSECT 4

Transect 4 was installed as a control transect but was not isolated from salinity reductions, with some freshening observed at riverbank well B10 and midpoint well CF5 (a replacement for the damaged B11). B12 observed no freshening, remaining above 50 000 EC.

The B10 January 2006 profile showed a gradual increase in salinity from fresh (< 1000 EC) at the top, to saline (> 50 000 EC) at depth. As a result of SIS pumping, the July 2006 profile decreased in salinity to display a more distinct salinity stratification, with the upper 4 m below 1,000 EC. Additional pumping of the LM well only gradually reduced salinity at B10 such that in October 2007, the full saturated 5 m profile (excluding the sump) was less than 500 EC.

Monitoring of B11 commenced in January 2006 with high salinities around 35 000 EC. By December 2006, a gradual reduction to 25 000 EC was observed whilst SIS and LM extractions were in operation. At this point observations were switched to CF5, a deeper well which was not screened over the upper interval. CF5 observations for latter half of 2008 indicated that the salinities were typically less the 5,000 EC.

3.4 GEOPHYSICS

The application of geophysical techniques to characterise a highly salinised floodplain was carried out with a variety of electromagnetic systems. From small to large scale investigation, the EM31, NanoTEM and HEM systems respectively, were able to map the conductivity variation of the subsurface. The EM31 is quick and easy to deploy and provided a snapshot of the top 4 – 6 m, typically representing the soil and upper levels of groundwater. The NanoTEM proved versatile allowing various configurations to explore depths in excess of 40 m below ground. The smaller towed rigs have a reduced investigation depth and are able to survey tens of kilometres a day. HEM surveys require a larger investment but provide large quantities of vertical and horizontal data that could not be easily acquired otherwise. The airborne systems can collect hundreds of kilometres of data a day, and overcome access and navigation issues that would otherwise limit ground surveys. The larger AEM system footprint results in a reduced spatial resolution, but the regional dataset can be combined with existing point information such as groundwater salinity or vegetation health to produce floodplain scale maps of bio-physical properties.

Geophysical (EM) sensed conductivity, or its inverse resistivity, from environments such as Clark’s floodplain, is typically very closely linked to variation in floodplain salinity and the depth to saline sources within the floodplain.

3.4.1 ELECTROMAGNETICS EM31

A Geonics EM31 conductivity survey was conducted over Site B in November 2007 (Figure 20). Depending on subsurface conductivity, the EM31 has a limited penetration depth of approximately 4 – 6 m, which yields a bulk conductivity representation of that shallow interval. Variables that may typically influence the results of the EM31 survey include groundwater depth and salinity, variations in soil moisture and salinity, and the clay content. The contribution of clay content to apparent conductivity is greatly reduced in soils with highly saline pore water (McNeill, 1980). With the Murray trench alluvium consisting mainly of sands and localised clays of similar porosity, the water content in the saturated environment is most likely consistent, leaving salinity as the main driver of conductivity (Tan et al., 2009).

The Site B survey in November 2007 displays a distinct zone of low conductivity along the eastern margin abutting the river channel (Figure 20). This suggests the presence of fresh water within the floodplain aquifer (bank storage) and is supported by groundwater salinity data collected at the riverbank piezometers at that time. The most striking feature is the broader low conductivity feature seen about the axis of Transect 3, extending towards B9. This result correlates with pumping from the Living Murray well that induced fresh groundwater flow towards the well. The fresh anomaly (blue) extends between B8 and B9, whereas the December 2007 groundwater salinity section (Figure 21) indicates freshening of groundwater beyond B9. The groundwater data shows only a thin vertical extent of fresh water underlain by saline groundwater that is likely to be within the detection range of the EM31, which could mask the shallower and limited fresh layer.

Secondary features include high conductivity strips that extent laterally away from the river channel, north and south of Transect 2 and one aligned with Transect 1. Also ‘lighter’ low conductivity features (light blue) extend further towards the middle of the floodplain. The high conductivity features are related to dry flood runner creeks that are lower in elevation. The cause of the lower conductivity features is unclear, but several coincide with the bank locations of the flood runner creeks and are likely to represent location of higher elevation. In other locations, preferential zones of higher hydraulic conductivity aquifer material may control the distribution of bank storage, creating an irregular distribution of fresh water. More detail may be revealed if the conductivity image is draped over a high resolution topography surface such as LiDAR.

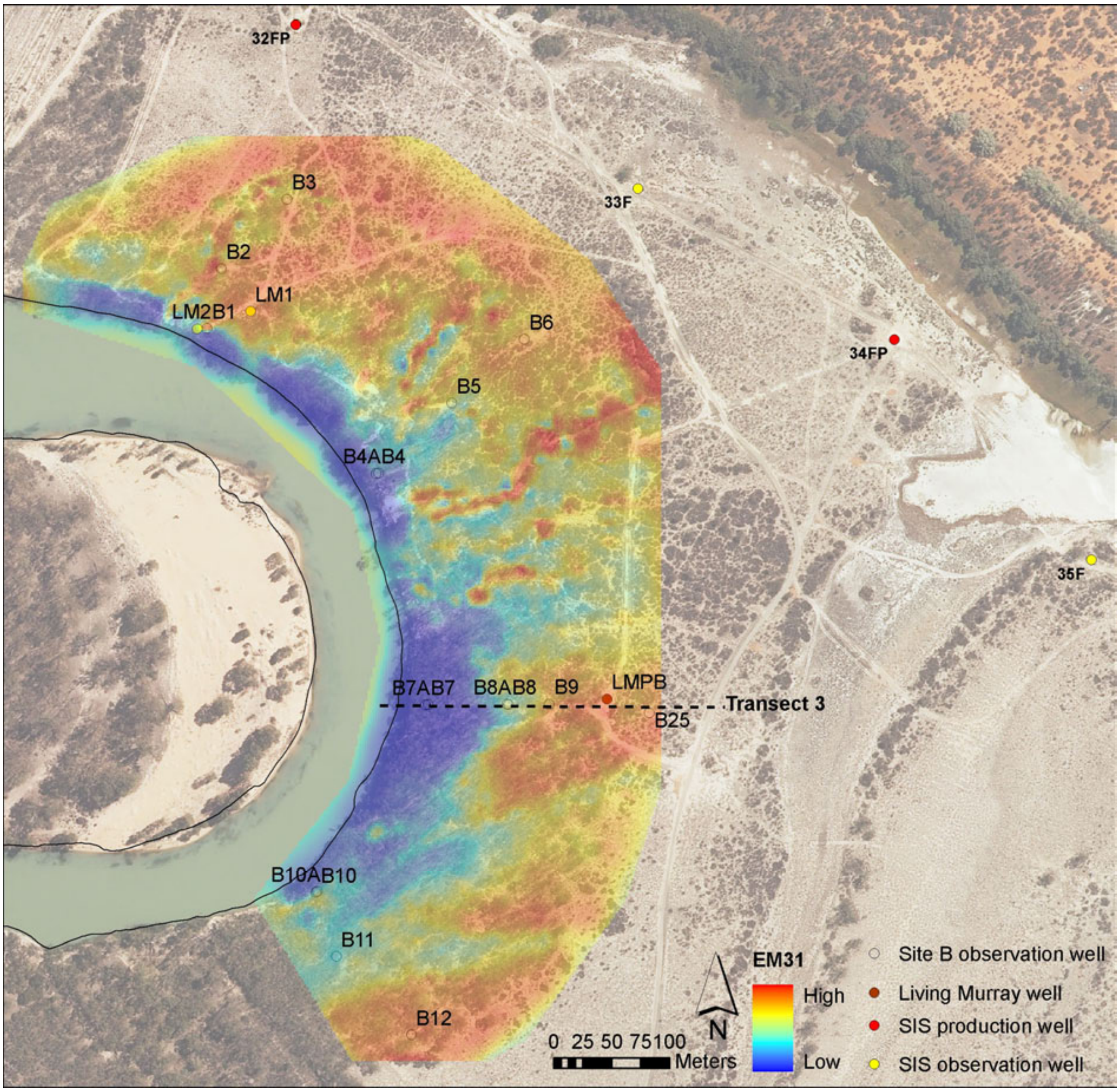


Figure 20. November 2007 EM31 Site B survey.

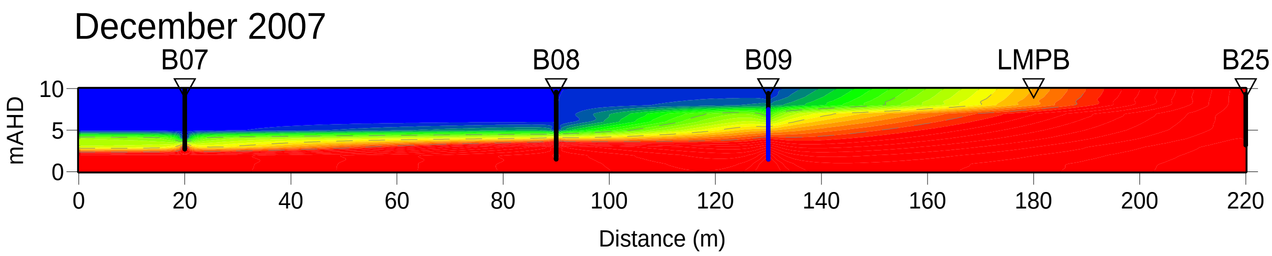


Figure 21. December 2007 groundwater sonde profile showing fresh water lens distribution.

3.4.2 NANOTEM

The NanoTEM (Transient Electromagnetics) system was used to collect a number of data sets using both traditional static loop methods and recently developed towed in-stream and land systems.

3.4.2.1 Land Surveys

Surveying using a 20 x 20 m static loop was carried out on three occasions in November 2005, November 2007 and December 2008. The 2007 and 2008 surveys focused only on Transect 3, whilst the initial survey in 2005 collected information along each of the four transects at Site B. The 3 x 3 m towed loop surveys occurred on three occasions in July 2006, November 2007 and December 2008. Data were acquired across most of Clark's Floodplain on existing vehicular tracks and on each occasion, special effort were made to acquire a line of data along Transect 3.

Profile sections along Transect 3 were used to compare the methodologies of groundwater sampling, static NanoTEM and towed NanoTEM (Figure 22). In all cases, there is a favourable comparison with good consistency between the monitoring methods. A resistivity contour interval of 3.5 Ω.m is annotated on the TEM profiles for comparison. The groundwater salinity data from January 2006 and the static NanoTEM resistivity profile from November 2005 show good correlation with a shallow fresher region extending to about the midpoint between B7 and B8.

The July 2006 groundwater salinity profile and towed TEM profile are also similar in character, both displaying a shallow fresher zone extending beyond B8.

The most recent December 2008 profiles detected the greatest amount of freshening in all cases. In the groundwater data, a thick low conductivity zone exists beyond B8, thinning towards the LM well. The December 2008 water sample from the LM well shows a reduction in salinity from the initial 2006 sample of greater than 50 000 EC, to less than 40 000 EC. The towed rig profile suggests freshening to a similar extent, but as an inclined feature. This would be consistent with the actual situation where a groundwater gradient would exist due to drawdown at the pumping well. A similar reality is difficult to replicate with the groundwater profiles due to the method of data collation. The December 2008 static TEM profile also displays some downward dip, but the extent of interpreted freshening does not match the groundwater and towed profiles in this instance.

The three methods were able to observe the evolution of the fresh water lens. In most groundwater investigations, preference would be given to the collection of groundwater data, however the funding for drilling closely spaced observation wells is not always available. This highlights the advantage of geophysical monitoring where temporal investigation can be used over long transects to provide information between validation points such as observation wells.

3.4.2.2 In-stream Surveys

A dual-run in-stream dataset was acquired in December 2005 (Figure 1) and is currently the most recent dataset through this river reach. Previous surveys along this reach were completed in September 2003 (Berens and Hatch, 2006) and February 2004 (Telfer et al., 2004). The 2003 survey incorporated a follow up in-stream coring validation program, which successfully linked sediment pore water salinity to the observed geophysical response, which assisted in formulating interpretations of losing and gaining stream conditions.

There is no notable variation between the three surveys (2003, 2004, 2005) relevant to the purpose of this report. The consistent results indicates high conductivity zones between river kilometres 510 and 511, and downstream of 506, which were interpreted as locations of saline groundwater accession to the river. This interpretation is supported by groundwater modelling at Bookpurnong (Doble 2006; Yan et al., 2005) and Run or River results (Porter, 2001), which together support the effectiveness of the in-stream geophysical method for examining salt accession risk. A good correlation between the in-stream data set and the broad scale AEM dataset is also observed (Figure 1).

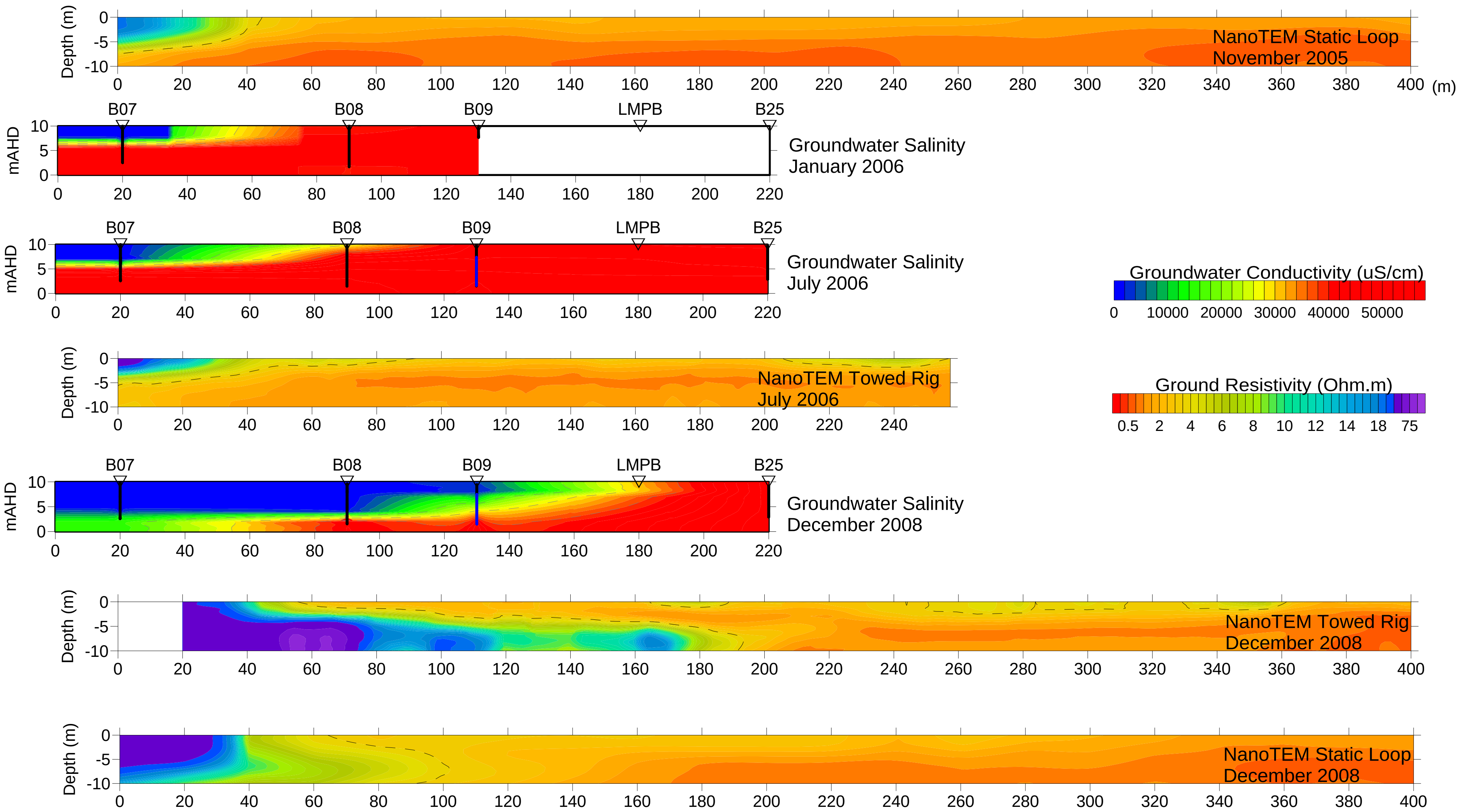


Figure 22. Comparison between geophysical monitoring (EM31 and NanoTEM) with groundwater salinity monitoring.

3.4.3 HELICOPTER ELECTROMAGNETICS (HEM)

RESOLVE frequency domain helicopter EM (HEM) data were acquired in July 2005 prior to the investigation trials and commencement of the SIS operation, and again in August 2008 after most trial investigations and three years of SIS operation. The SkyTEM time domain helicopter EM system was used to acquire HEM data in September 2006 to compare system effectiveness. At the time of writing, final outputs for the SkyTEM were not available.

3.4.3.1 Resolve 2005 and 2008 surveys

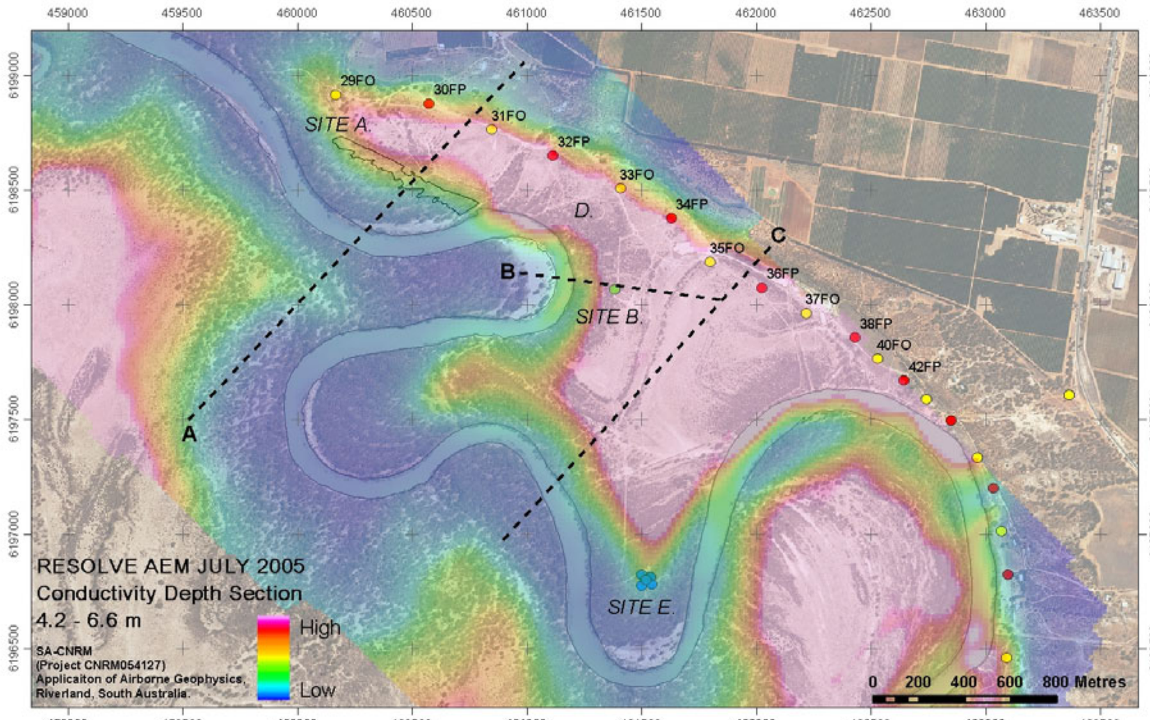
RESOLVE data are presented as planar grids representing discrete depth intervals. The holistic inversion algorithm (Brodie and Sambridge, 2006) was used to produce the interval conductivities with the 4.2 – 6.6 m and 6.6 – 9.3 m bands presented in Figures 23 and 24.

Generally, the main features of the conductivity distribution for the upper 10 m remain relatively consistent for each survey. The profiles presented are characterised by a wide low conductivity zone (blue) that parallels the meandering main river channel and extends out 500 m in some places. These areas are identified as flushed zones adjoining losing stream sections and are characterised by low levels of salt in the floodplain sediments.

Flushed zones are largely present surrounding Clark’s Floodplain, except at locations where the river meanders close to the Bookpurnong highlands between river kilometres 510 and 511, and downstream of 506 (Figure 24). At these points and across the inner floodplain, the conductivity intervals are highly conductive, reflecting the high concentration of salt in the near surface sediments and groundwater beneath. There is a close relationship between areas of the floodplain with high conductivity, and reaches of the river with high sediment conductivity. These correspond to gaining reaches where baseflow from the regional groundwater system discharges salt into the river (Munday et al., 2006b). Temporal variations between the 2005 and 2008 datasets are observed east of river kilometre 510 to 511, and north and south downstream of river kilometre 506.

Often at greater depths, and underlying the upper conductive regions, a reduction in conductivity is observed. This is most likely not real and is a consequence of the system reaching the inductive limit where the system cannot resolve what is happening at depths beneath such a significant conductor.

Rather than depth slices, the inverted resolve data can be presented as conductivity depth sections (Figure 25) similar to the groundwater and NanoTEM profile sections (Figure 22). This allows patterns of groundwater salinity and their relationship to vegetation density to be examined. The conductivity depth sections across the floodplain (line location shown Figure 23) illustrate the relationship between ground conductivity, inferred groundwater flow and vegetation health (Munday et al., 2007). Using the 2005 RESOLVE data, section A was derived from the EMFlow transform, whilst sections B and C were derived from holistic inversion results.



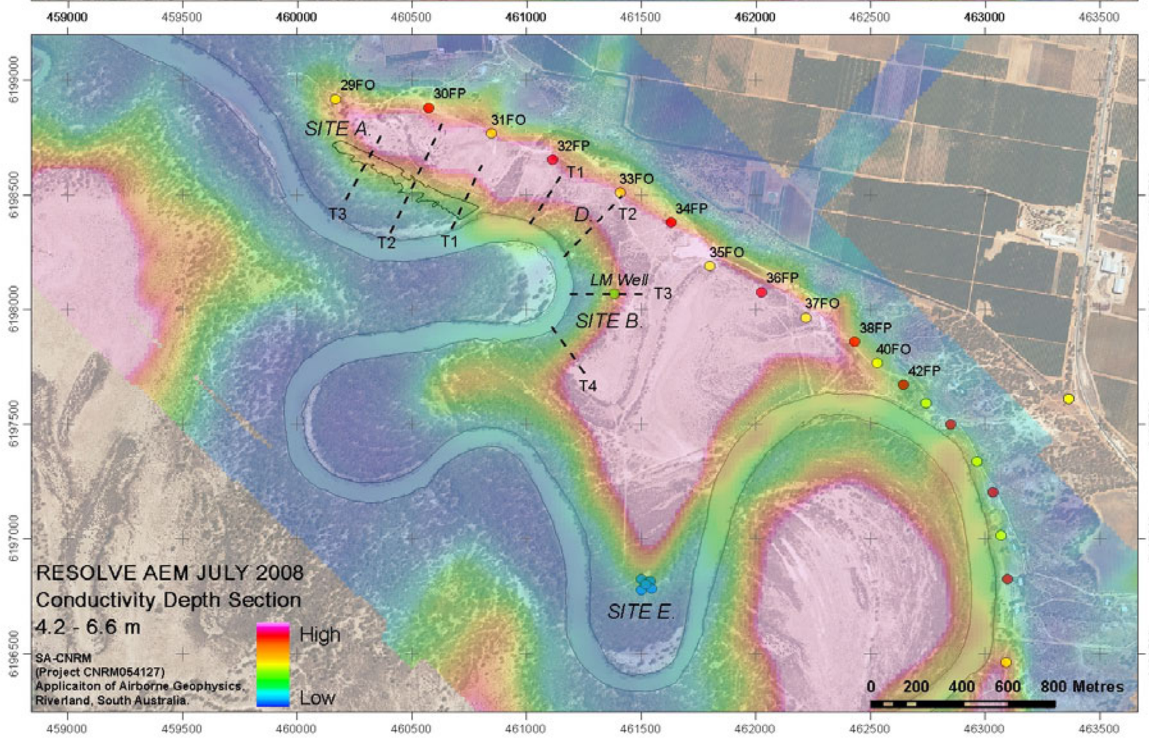


Figure 23. Conductivity interval 4.2 m to 6.6 m for 2005 and 2008 RESOLVE HEM survey.

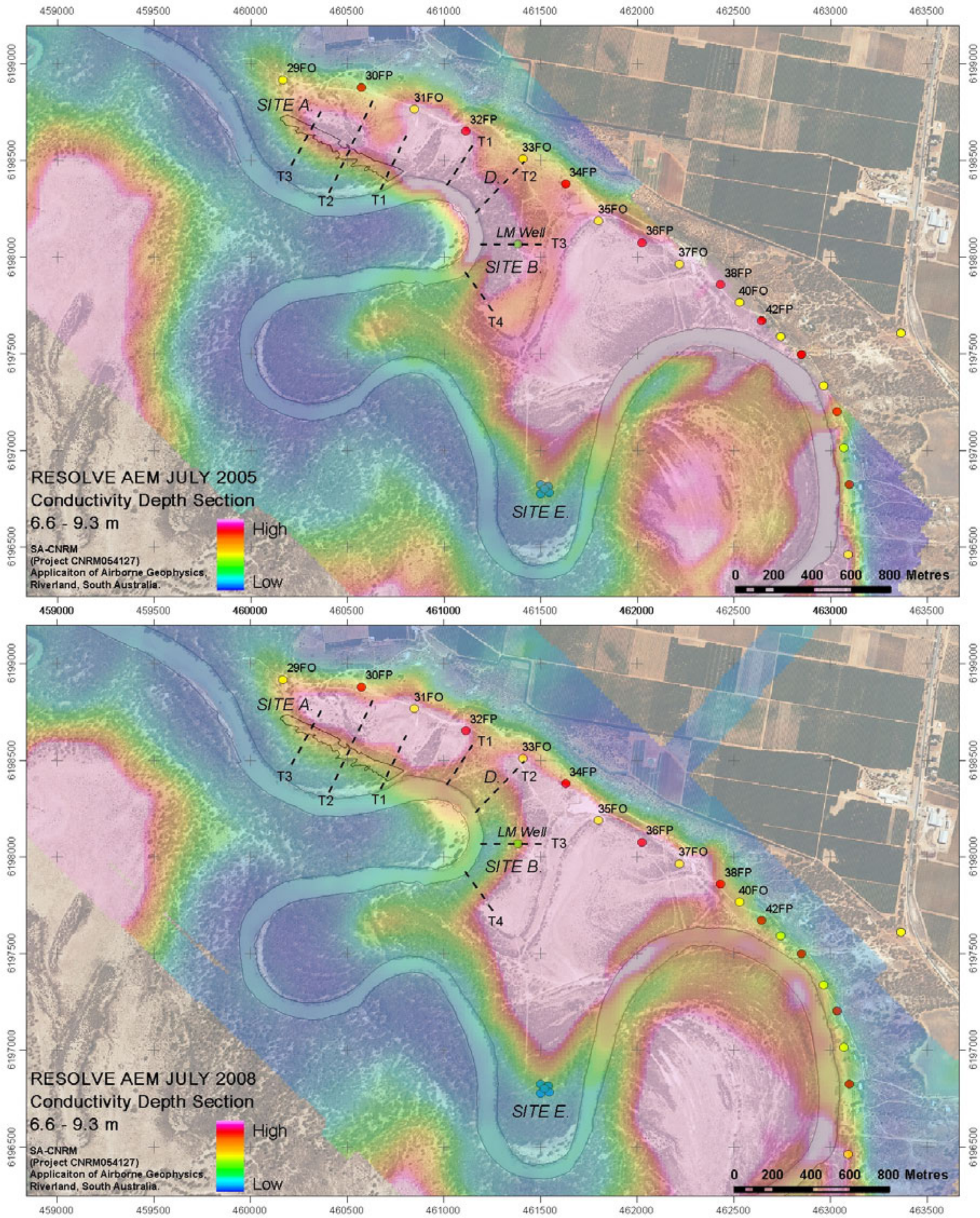


Figure 24. Conductivity interval 6.6 m to 9.3 m for 2005 and 2008 RESOLVE HEM survey.

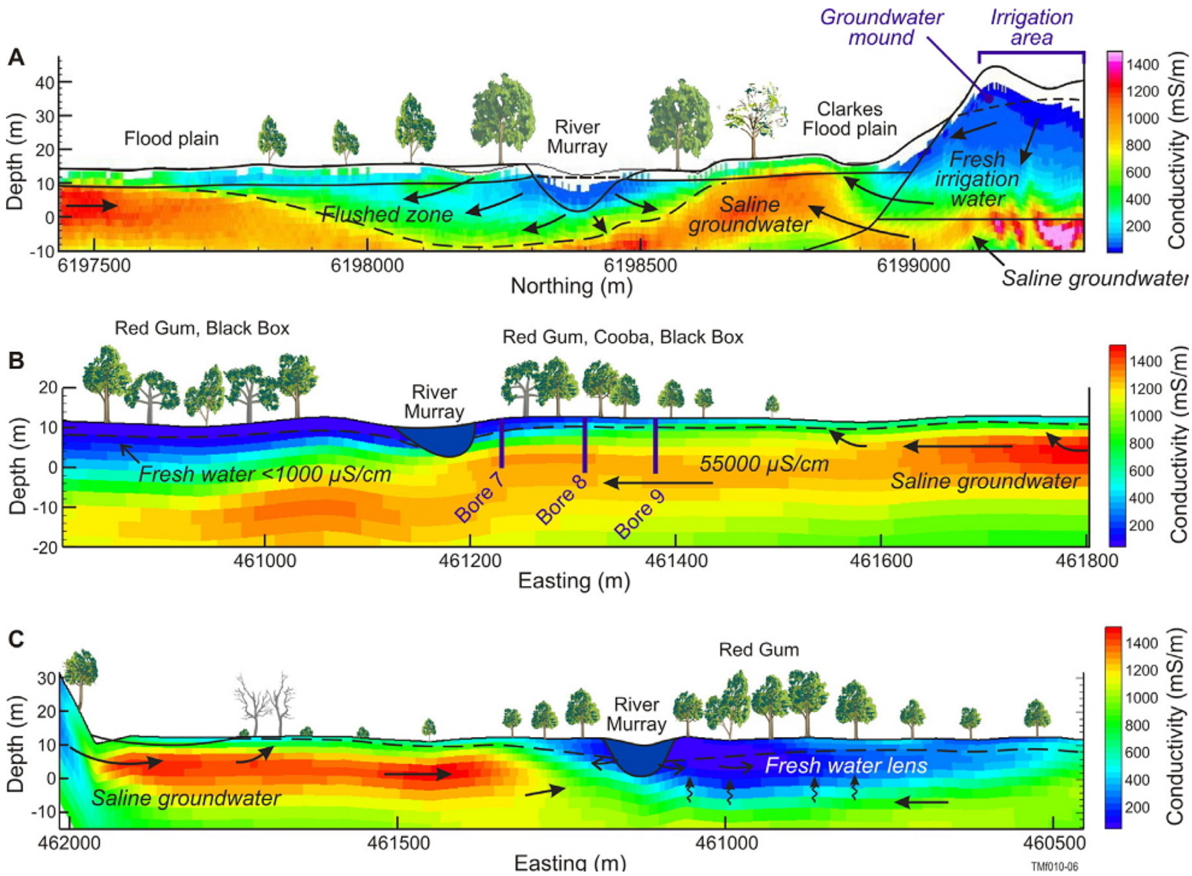


Figure 25. Conductivity depth sections across Bookpurnong Floodplain.

3.4.4 SOIL SALINITY

As mentioned previously, the geophysical surveys give a good understanding of changes in conductivity (salinity) across the landscape and the response to intervention techniques. However, specific soil cores give an insight into salinity changes at each well across each transect over shorter time intervals. Soil cores were collected every six months at each of the fourteen observation wells at Site B. Samples taken at every 0.5 m depth were analysed for osmotic and matric potential with the graphed results presented in Appendix B (Figure A1). The profiles presented encompass the root zone of the trees, as the last sample was collected at the top of the watertable. A summary of the results at the start, middle and end of the study period is presented below for each transect.

The total soil water potential (a combination of osmotic and matric potential) is used to indicate soil water availability for root uptake; a clear relationship is derived from the knowledge of a tree's pre-dawn water potential which is 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.

Previous studies in similar environments have found river red gum pre-dawn water potentials around –2 MPa (Mensforth et al, 1994, Holland et al, 2006). Pre-dawn water potentials at Site B measured by the CNRM collaborative project (Holland et al. 2009), varied from –5.38 MPa for black box, –4.81 MPa for river cooba, and –3.61 for river red gum. The values measured by Holland (2009) are greater than those previously found for river red gums, indicating that a) the soil water availability tolerances for river red gums in this environment are higher than previously thought, and b) the trees at the site are under extreme salinity and drought stress.

3.4.4.1 Transect 1 (SIS groundwater lowering) soil salinity cores

The osmotic potential down the profile and across the transect from B1 (river) to B3 (riparian edge on the floodplain) did not greatly change over the survey period, except for B2 and B3 becoming slightly more saline mid-profile at a depth of 0.5-1.5 m (Figure 26). Groundwater lowering at Transect 1 did not remove salt from the soil profile and total soil water potential in the root zone was predominantly less than –3 MPa throughout all the profiles (Figure 26), making it harder for trees to source water along this transect. In the top two metres of the profiles, salt load is greater, indicating evapotranspiration is probably drawing salt up the profile. It is assumed that trees are most likely sourcing water from the 'fresher' capillary zone (note the deepest soil sample is collected just above the water table). This hypotheses is quantified, as new tree roots were often found evading piezometers at this depth when bailing wells for EC samples.

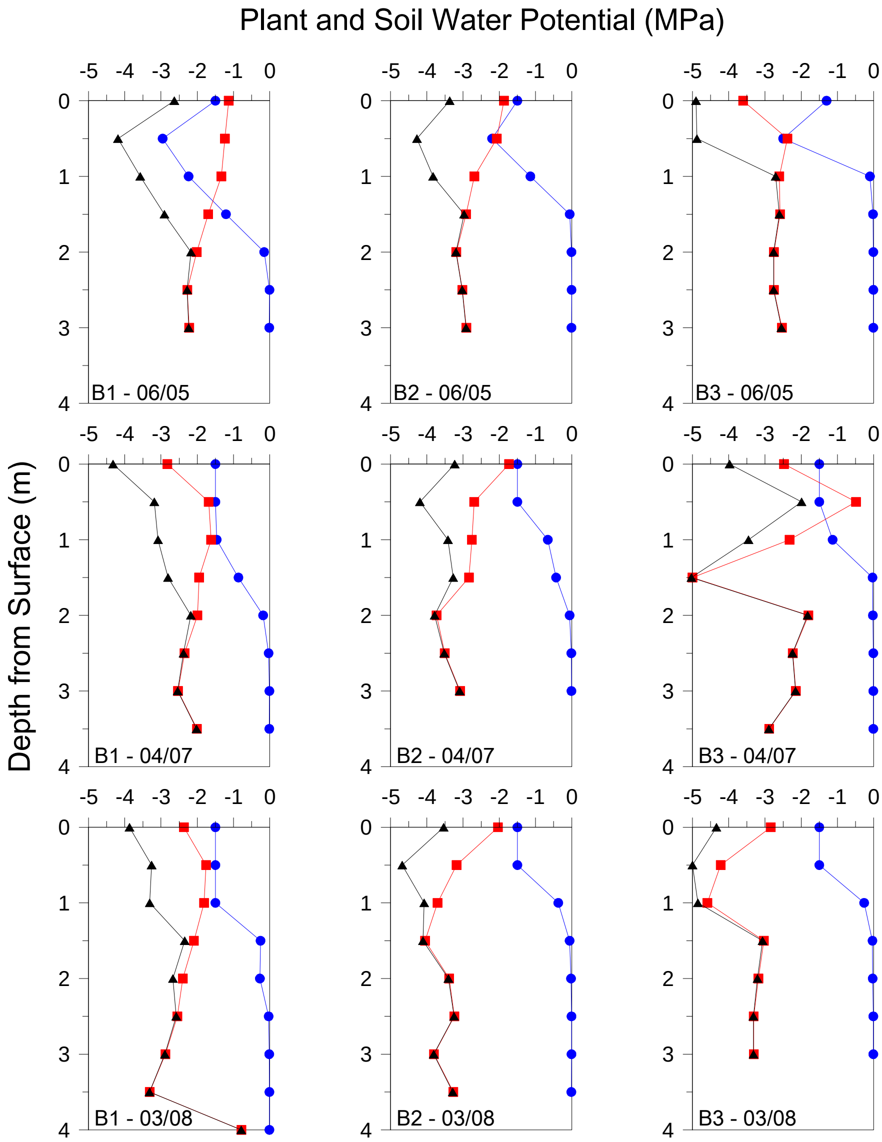


Figure 26. Soil salinity profiles of Transect 1 (SIS drawdown). From left to right; B1 (river), B2 (mid) and B3 (floodplain), and top to bottom June 2005, April 2007 and March 2008. Osmotic potential (■), matric potential (●) and total potential (▲) are represented.

3.4.4.2 Transect 2 (SIS drawdown and inundation) soil salinity cores

The osmotic potential down the profile and across the transect from B4 (river) to B6 (riparian edge on the floodplain) did not greatly change over the survey period, except for B6 which was inundated as part of the flood runner watering in Sept-Dec 2006 (depth 0.5-1.5 m) (Figure 27). Inundation temporarily freshened the soil profile until the following spring in September 2007 (See Appendix B, Figure B2). Total soil water potential in the root zone was predominantly greater than –3 MPa at the river (B4), and greater than –4 MPa at B5 and B6, allowing trees to source water better along this transect when compared to Transect 1 (note upper limits of; –5.38 MPa for black box, -4.81 MPa for river cooba, and –3.61 for river red gum).

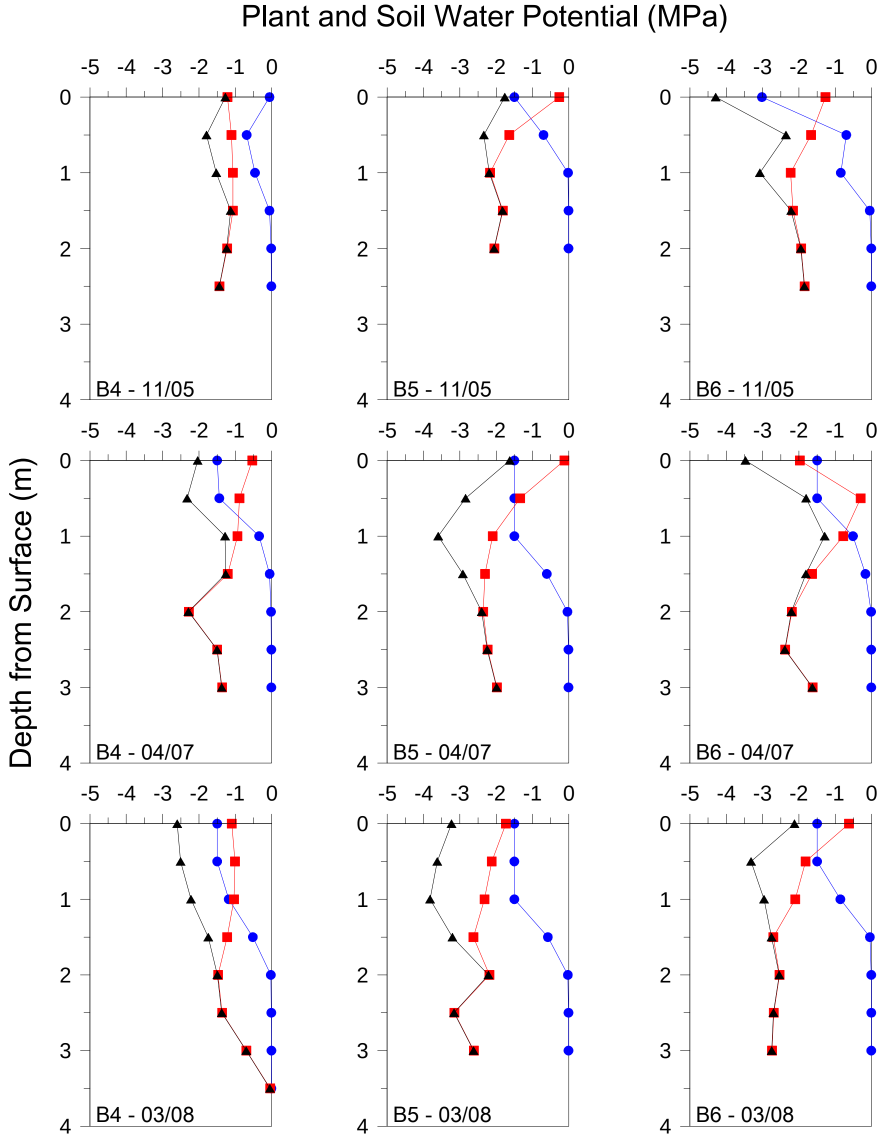


Figure 27. Soil salinity profiles of Transect 1 (SIS drawdown). From left to right; B1 (river), B2 (mid) and B3 (floodplain), and top to bottom June 2005, April 2007 and March 2008. Osmotic potential (■), matric potential (●) and total potential (▲) are represented.

3.4.4.3 Transect 3 (lateral recharge) soil salinity cores

The osmotic potential down the profile did not greatly change at the two edge wells B7 (river) and B25 (floodplain); B7 remained fresh, while B25 stayed saline as it was out of the LM well influence zone (Figure 28). Wells B8 and B9 were in the area influenced by the groundwater freshening, and the soil profiles changed in osmotic potential in the upper profiles mid-way through the study (04/07 = April 2007). By the end of the study, B8 and B9 had both freshened at the bottom of the profile allowing tree water use for roots at this depth (Figure 28). Overall, trees near the river and within the area influenced by the groundwater freshening have total soil water potential at differing depths of greater than –2 MPa, allowing for better tree water use (Figure 28). It is assumed that trees are most likely sourcing water from the 'fresher' capillary zone (last sample was the watertable).

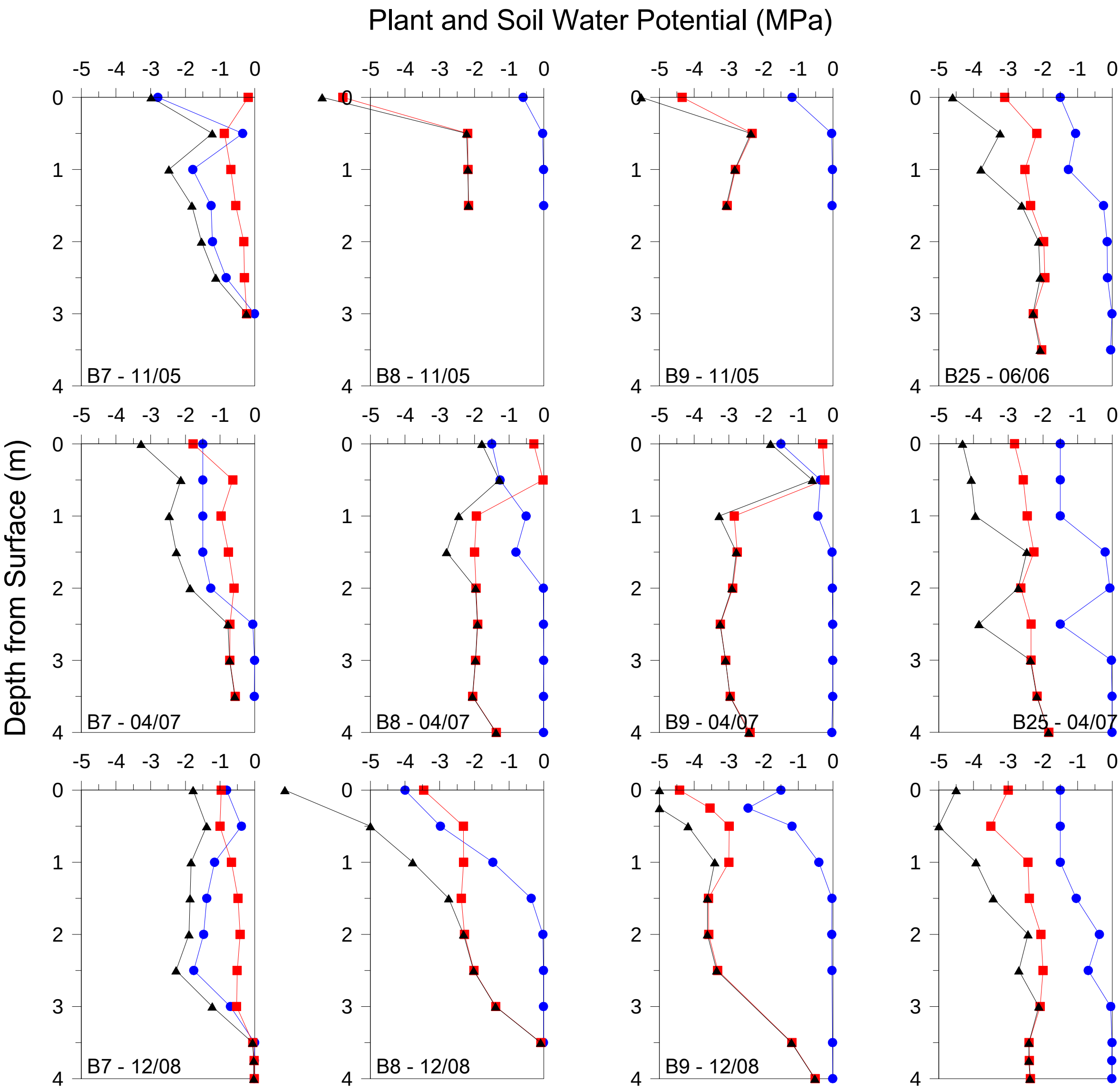


Figure 28. Soil salinity profiles of Transect 1 (SIS drawdown). From left to right; B1 (river), B2 (mid) and B3 (floodplain), and top to bottom June 2005, April 2007 and March 2008. Osmotic potential (■), matric potential (●) and total potential (▲) are represented.

3.4.4.4 Transect 4 (control) soil salinity cores

At the control transect, the osmotic potential down the profile did not greatly change from wells B10 (river) and B12 (floodplain) (Figure 29). The total soil water potential shifted at both B11 and B12 by the end of the study, towards drier conditions in the upper profile (B12) and the mid profile (B11). The shift seen in December 2008 at B12 had started in April 2007. The best location for tree water use at Transect 4 was near the river at B10 and the midpoint (B11) where the total potential was consistently greater than – 3 MPa (Figure 29).

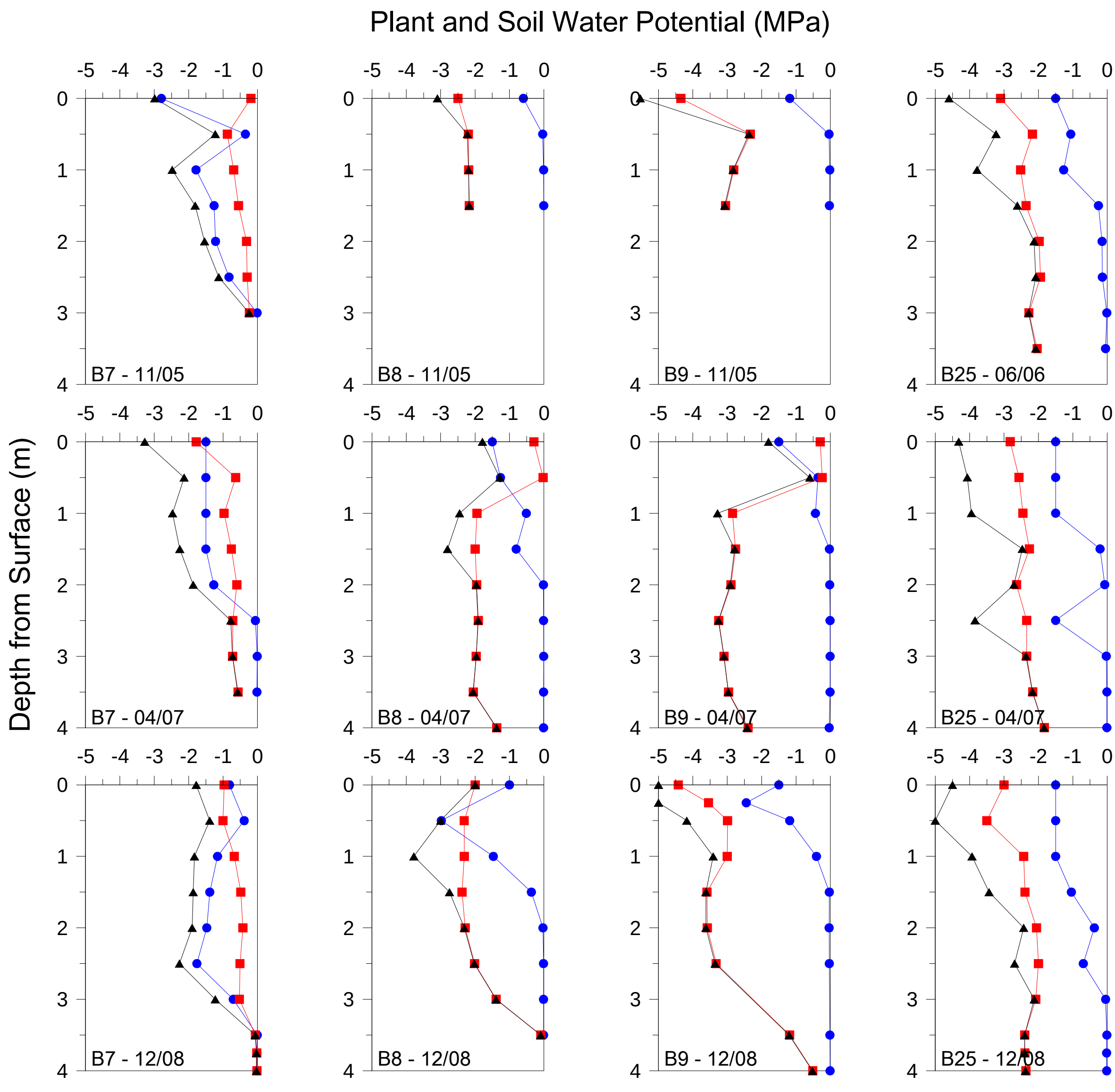


Figure 29. Soil salinity profiles of Transect 1 (SIS drawdown). From left to right; B1 (river), B2 (mid) and B3 (floodplain), and top to bottom June 2005, April 2007 and March 2008. Osmotic potential (■), matric potential (●) and total potential (▲) are represented.

In conclusion, the soil profile analysis at Site B presented in this report and from Holland et al. (2009) found:

- Average soil chloride values were generally constant through time.
- The profiles illustrate there are large, relatively immobile stores of salt in the floodplain soils.

- The only significant decrease in soil chloride stores were observed at well B6 (inundated) and at wells B8 and B9 (lateral recharge). The decrease in salt in these soil profiles brought the total water use potential into a range accessible for trees.
- Trees located near the river (in the flushed zone) are in areas where soil water use is more accessible (generally, > -2 MPa), indicating river water freshens the soil profile along the bank edge.

3.5 VEGETATION

3.5.1 FREQUENCY OF TREE CONDITION

The four transects of mixed tree species, river red gum, black box and river cooba at Site B showed some broad similarities in epicormic response and crown extent frequencies over the study period, the frequency of all trees and epicormic growth patterns are provided in the appendix (Appendix Figure C1). In all transects, epicormic growth peaked in April 2006 and then declined afterwards, with another smaller peak in March 2008 (Appendix Figure C1). These two peaks in epicormic growth were graphed against deviation of monthly annual rainfall to determine if rainfall coincided with the epicormic growth peaks.

The higher frequency of epicormic growth in April 2006 could be due to above average rainfall over the autumn period of 2006 (Figure 30), with a lesser peak in March 2008 due to below average rainfall over that autumn. A reason for a peak in epicormic growth may be attributed to a seasonal response for these stressed tree communities, with autumn (March/April) being the time when epicormic growth was recorded at its highest. In autumn of 2007, the tree assessment was undertaken a month early in summer (February) which could explain why a peak in epicormic growth wasn't recorded.

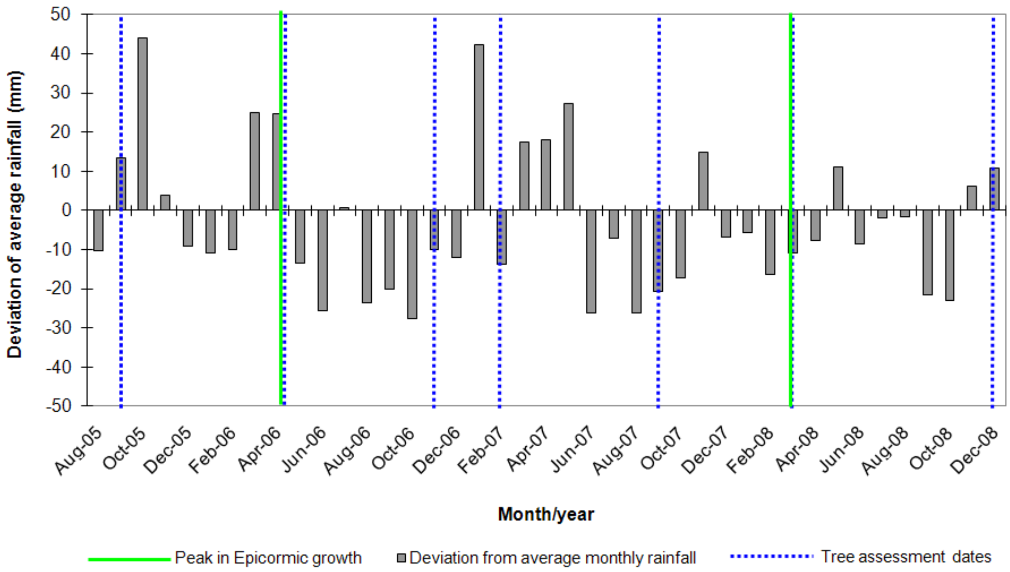


Figure 30. Monthly rainfall recorded at the nearest BoM station (Loxton 024024), depicted as the deviation from the average monthly rainfall. Trees assessment dates and peaks recorded in epicormic growth are also shown

To determine the individual species response to the different interventions, the frequency of each species in each crown extent state was determined (Figure 31a and Figure 31b) and is described in Section 3.5.1.1. The transition of crown extent for each individual within each species from their starting crown state from the first survey to the last survey was also evaluated (Figures 32a, 32b and 32c) and is described in Section 3.5.1.2.

3.5.1.1 Tree condition change in response to the interventions

Transect 1

At Transect 1 (Figure 31a), only one river red gum was growing at the site on the river bank. The river red gum started in poor condition (1-10% crown extent), though improved to 26-75% crown extent (Figure 31a) after the above average rainfall of January 2007 (Figure 30). By the end of the study the river red gum had declined to crown extent state 11-25% (Figure 31a).

River cooba at Transect 1, in states one (1-10%), two (11-25%) and three (26-75%) all declined in condition, with an overall increase in dead trees (0% crown) at the site (Figure 31a). The frequency of black box with 0% crown at Transect 1 also steadily increased.

Black box increased in condition to 26-75% crown extent in February and September 2007 (Figure 31a) which coincided with above average rainfall in summer and autumn in 2007 (Figure. 30). The September response is probably a seasonal delay to the autumn rainfall, as crown was found to rarely change during the cooler months of winter at all the study sites, Site A and E included.

Transect 2

At Transect 2 (Figure 31a), river red gum dominated the frequency of trees in the lower states, 0%, 1-10% and 11-25% crown extents. Improvement in river red gum condition was seen after November 2006 which coincided with the artificial inundation of the flood runners at this site from 25th September to 5th December. The response from inundation was maintained till the following spring, but was not sustained over the summer of 2007/08. By December 2008, some condition had been sustained from the inundation, though the frequency of dead river red gums at the site had increased.

River Cooba at Transect 2 were mostly in good condition with the majority of trees having greater than 26% crown extents. The response to inundation, is the same delayed pattern as seen in the river red gums, with changes in condition seen in February 2007, 2 months after water had stopped pumping into the flood runners. Condition in response to inundation was maintained until the following spring, though by December 2008, some decline in condition had occurred.

The same pattern that occurred in river cooba at Transect 2 was also seen in black box. Inundation increased the frequency of trees in the higher extent class 76-90%, which was maintained for one year. By December 2008, some decline in condition had occurred, though most black box in 76-90% crown extent had increased to the highest state, 91-100%.

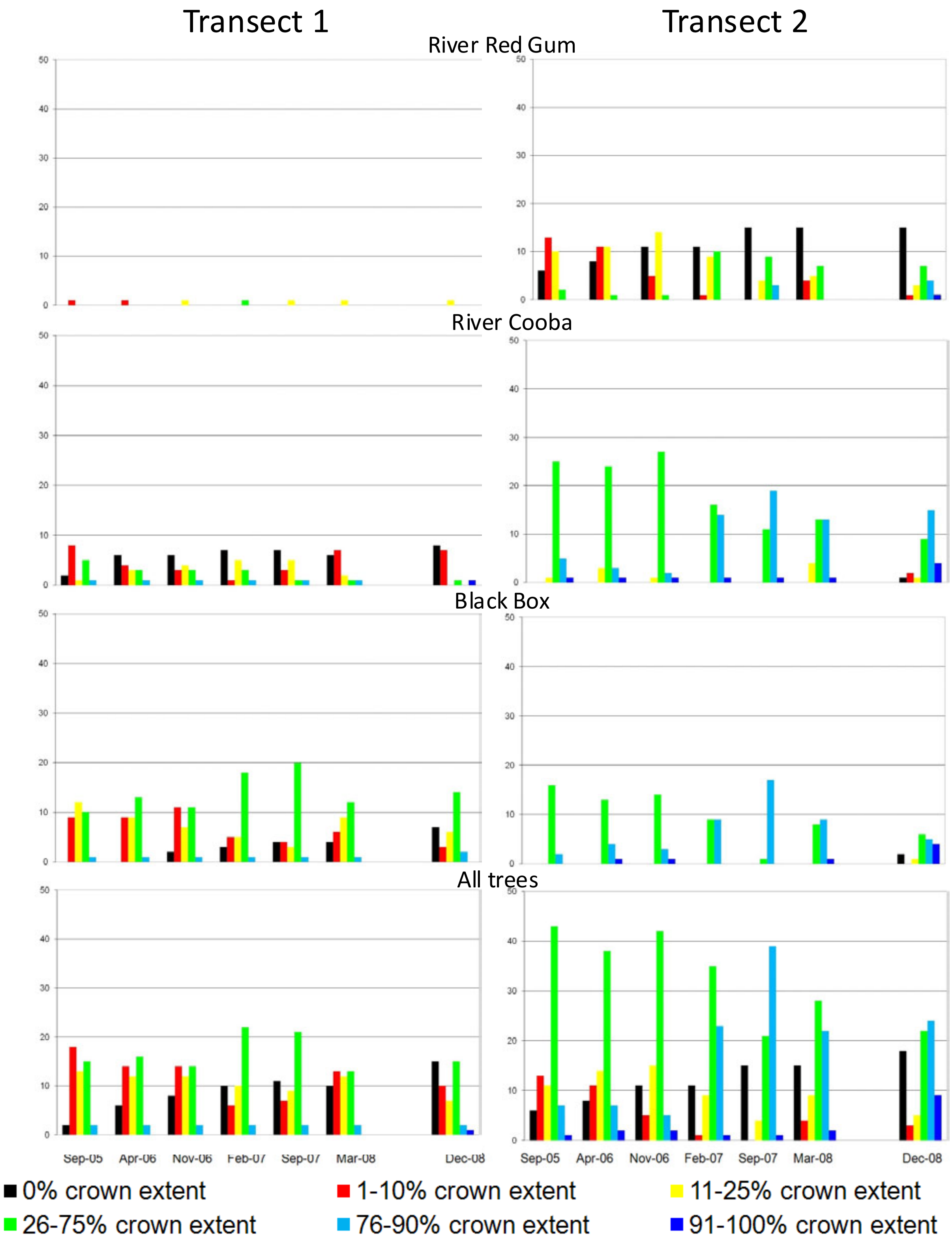


Figure 31a. Crown extent classes for river red gum (top), river cooba (middle), black box (lower) and all three species combined (bottom) for Transect 1 (left) and Transect 2 (right) throughout the duration of the trials

Transect 3

At Transect 3 (Figure 31b), after the Living Murray well was switched on in August 2006, the frequency of river red gums in the lower states 1-10% crown extent declined and the rate of dieback of trees (0% crown) became steady (from November 2006 – May 2008). From February 2007, condition was maintained at the site until December 2008. In December 2008, a decline in river red gum condition states was observed which can be attributed to the pulse pumping trial, whereby the LM well was turned on and off on a 2-week schedule to fluctuate the water table and try to decrease salt in the root zone.

The frequency of river cooba in with 0% crown was also maintained after the LM well was switched on in August 2006. River Cooba at Transect 3 (Figure 31b) showed continued improvement in the higher crown extent classes until the end of the study, including throughout the duration of the pulse pumping trial.

Black box at Transect 3 showed steady improvement in crown condition throughout the duration of the trial, with notable increases in condition after February 2007, which could be attributed to both rainfall (Figure 30) and the freshening of the groundwater profile further along the transect (Figure 18) and hence into the riparian zone more dense with black box. The pulse pumping trial continued to improve black box condition at Transect 3.

Transect 4

The nearby pumping of the LM well, influenced groundwater salinity reductions beyond the mid-point well, but stayed saline at the edge of the riparian zone. Groundwater freshening to this extent was not anticipated from the operation of the LM and SIS wells. The level of freshening was less extensive in comparison to Transect 3.

An improvement in river red gum condition at Transect 4 was observed towards the end of the trial in May 2008 (Figure 31b). From September 2007, the rate of decline in trees with 0% crown was observed. Both of these observations can be attributed to a delayed response in freshening of groundwater due to the influence LM well pumping.

River cooba at Transect 4 started to increase in crown extent condition after February 2007, which can be attributed to both LM well pumping and the above average rainfall for January 2007. By the end of the trial, cooba condition at Transect 4 was in notable better condition than at the start of the trial (Figure 31b).

Black box condition at Transect 4 started to improve in condition from November 2006 which was maintained throughout the duration of the trial (Figure 31b). This improvement in condition coincided when the zone of area influenced by the LM well expanded into Transect 4.

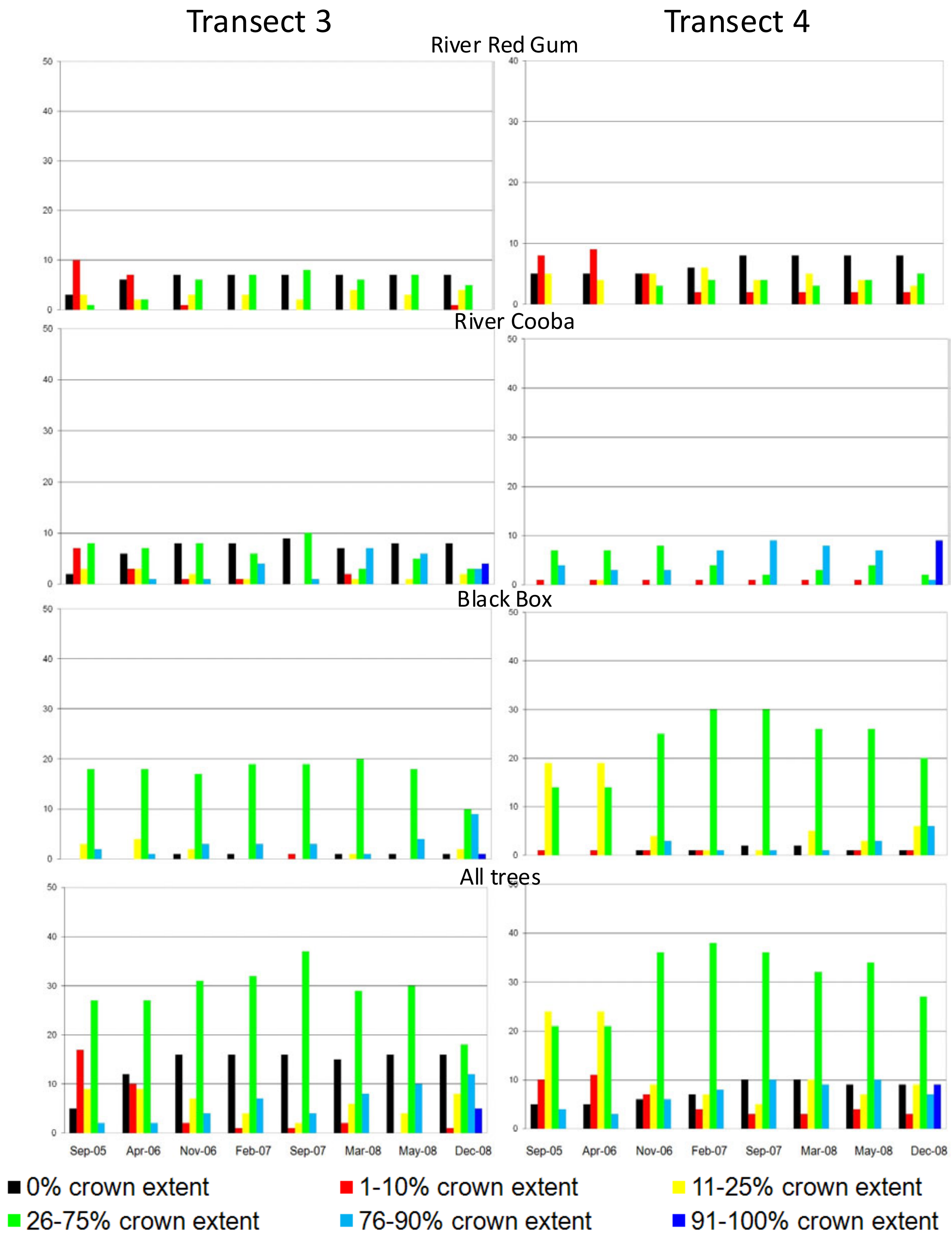


Figure 31b. Crown extent classes for river red gum (top), river cooba (middle), black box (lower) and all three species combined (bottom) for Transect 3 (left) and Transect 4 (right) throughout the duration of the trials

3.5.1.2 Tree transition patterns

River Red Gum

Across all transects 32 river red gums started in state 1, crown extent 1-10% (Figure 32). By the end of the study, 14 of these river red gums had declined into 0% crown, four trees maintained condition and 14 trees improved in condition. Crown extent state 1-10% for river red gums was the threshold for either tree improvement or decline.

Across all transects 16 river red gums started in state 2, crown extent 11-15%. By the end of the study, one of these river red gums had declined in condition, one tree maintained condition and 14 trees had improved condition. River red gums in crown extent state 11-25% were found to improve in condition.

Across all transects three river red gums started in state 3, crown extent 26-75%. By the end of the study, one of the trees had declined in condition, with the remaining two trees maintaining condition.

River Cooba

Across all transects 16 river cooba’s started in state 1, crown extent 1-10% (Figure 33). By the end of the study, 12 of these cooba’s had declined into 0% crown, two trees maintained condition and two trees improved in condition. Crown extent state 1-10% for river cooba was the threshold for tree condition regression.

Across all transects five river cooba’s started in state 2, crown extent 11-15%. By the end of the study, one of these trees had declined in condition, one tree maintained condition and three trees had improved condition. River cooba in crown extent state 11-25% was found to improve in condition.

Across all transects 45 river cooba’s started in state 3, crown extent 26-75%. By the end of the study, seven trees had declined in condition, 13 trees maintained condition and 25 trees had improved condition. River Cooba in crown extent state 26-75% was found to improve in condition.

Across all transects nine river cooba’s started in state 4, crown extent 76-90%. By the end of the study, one tree had declined in condition, two trees maintained condition and six trees had improved condition. River Cooba in crown extent state 76-90% were found to improve in condition.

Black Box

Across all transects 10 black box started in state 1, crown extent 1-10% (Figure 34). By the end of the study, six of these black boxes had declined into 0% crown, one tree maintained condition and three trees improved in condition. Crown extent state 1-10% for black box was the threshold for tree condition regression.

Across all transects 34 black box started in state 2, crown extent 11-15%. By the end of the study, six of these trees had declined in condition, ten trees maintained condition and 18 trees had improved condition. Black box in crown extent state 11-25% was found to either maintain or improve in condition.

Across all transects 57 black box started in state 3, crown extent 26-75%. By the end of the study, three trees had declined in condition, 30 trees maintained condition and 24 trees had improved condition. Black box in crown extent state 26-75% was found to either maintain or improve in condition.

Across all transects four black box started in state 4, crown extent 76-90%. By the end of the study, one tree had declined in condition, two trees maintained condition and one tree had improved condition. Black box in crown extent state 76-90% was found to maintain condition.

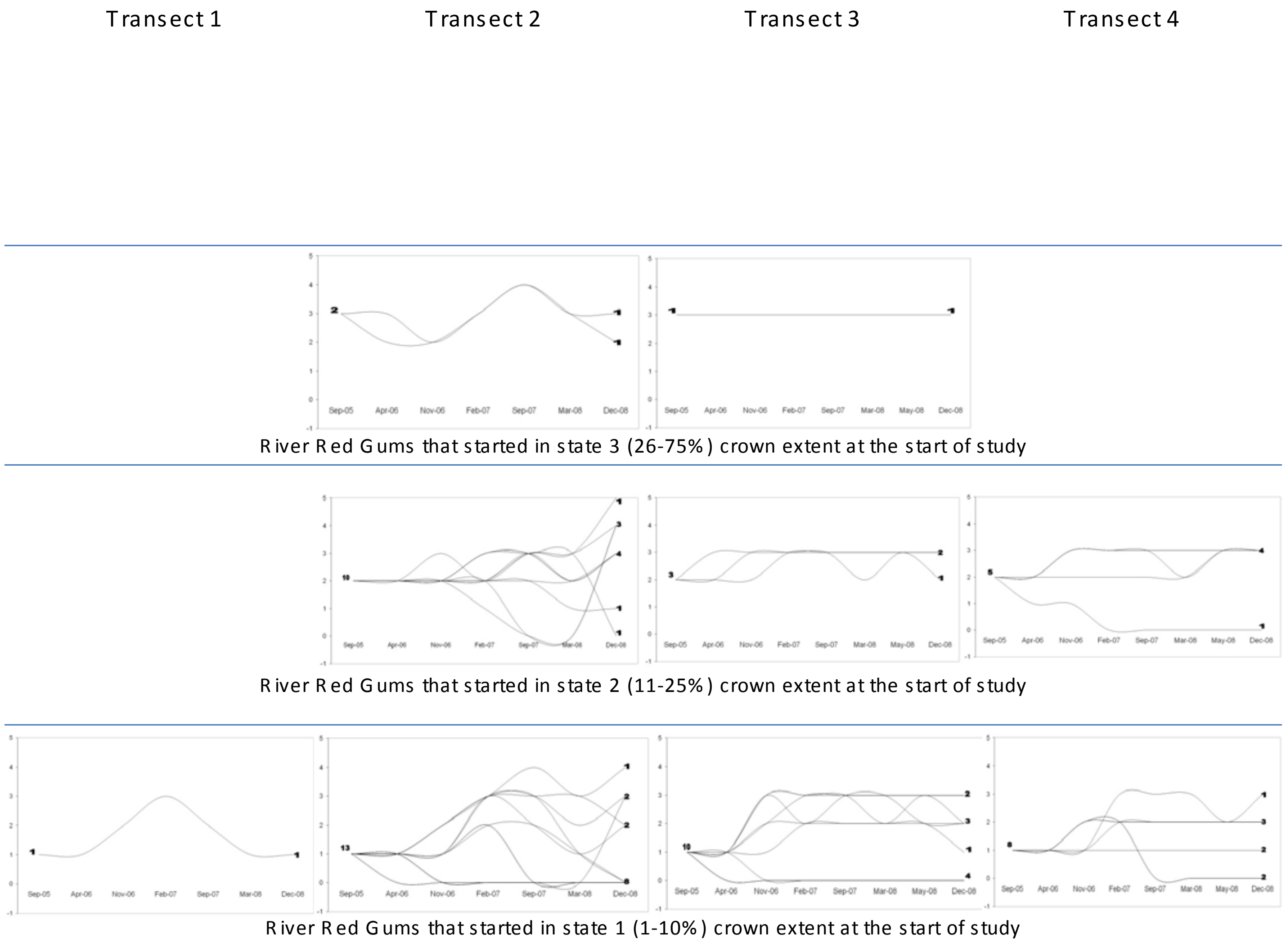


Figure 32. River red gum transition curves, for those trees starting in state 1 (bottom), 2 (lower), 3 (middle) and 4 (top), with crown extent classes also depicted for each Transect; 1 - 4 (left to right).

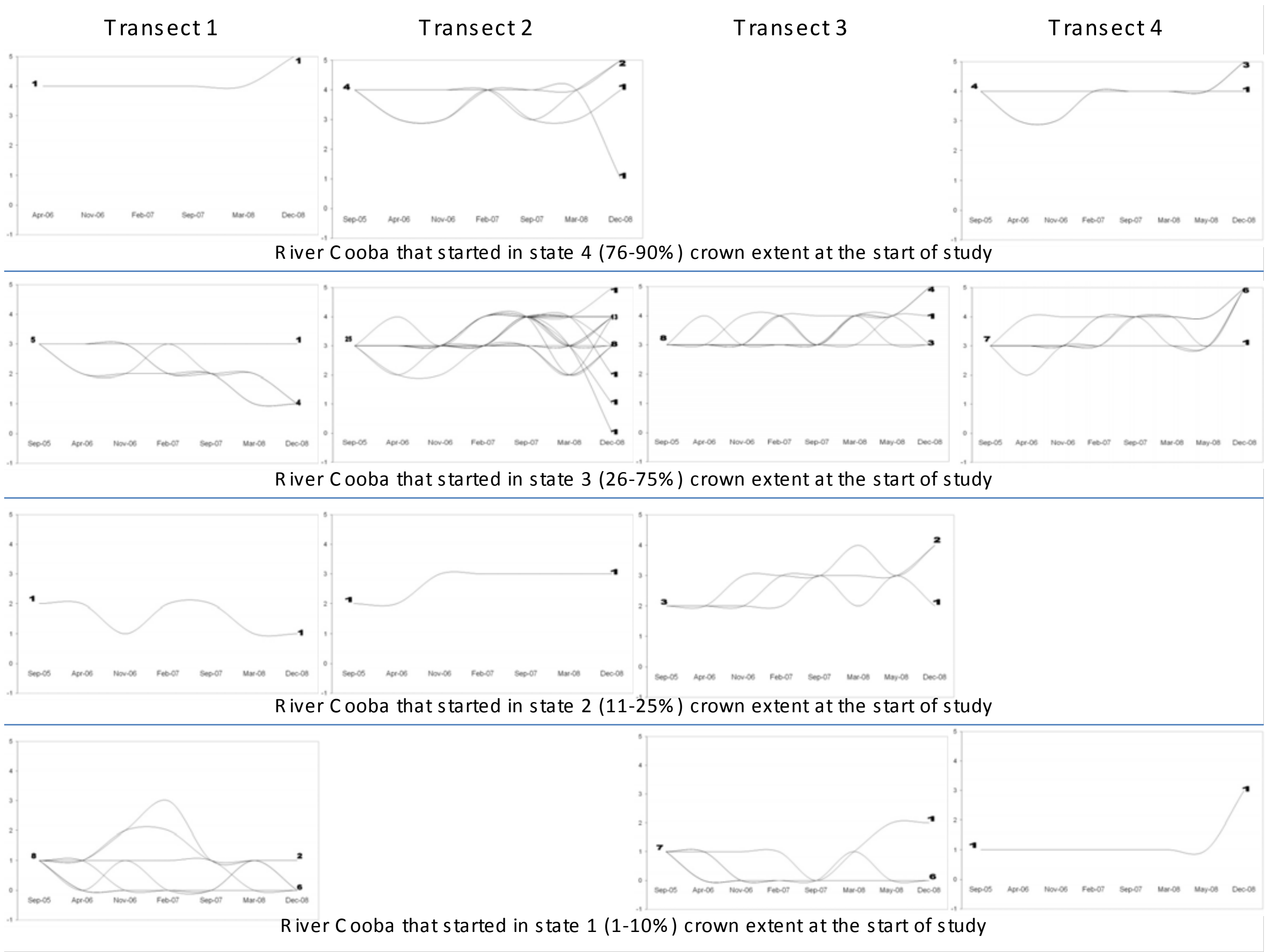


Figure 33. River cooba transition curves, for those trees starting in state 1 (bottom), 2 (lower), 3 (middle) and 4 (top), with crown extent classes also depicted for each Transect; 1 - 4 (left to right).

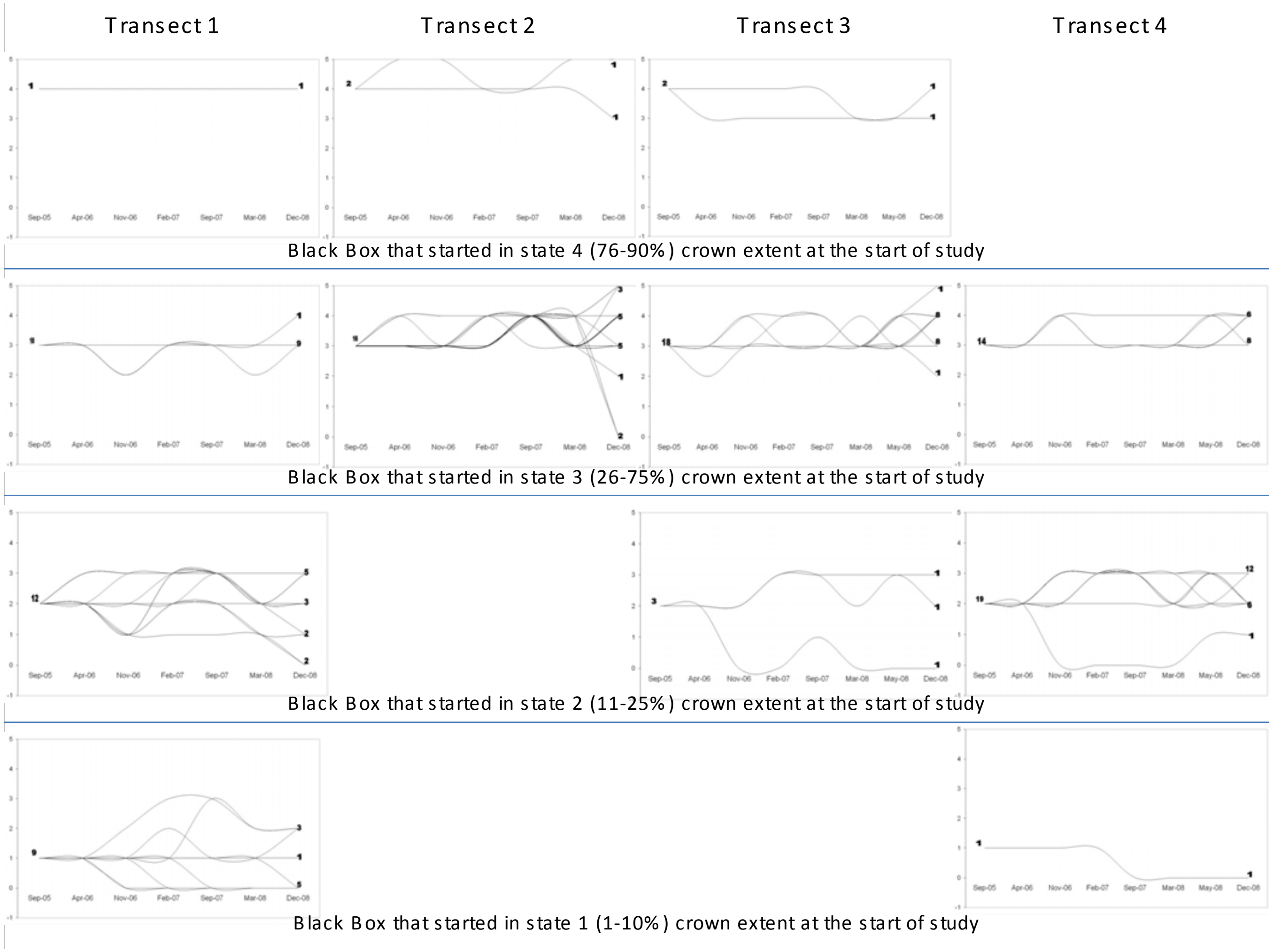


Figure 34. Black box transition curves, for those trees starting in state 1 (bottom), 2 (lower), 3 (middle) and 4 (top), with crown extent classes also depicted for each Transect; 1 - 4 (left to right).

3.5.2 STATISTICAL TREE TRANSITION MODEL

3.5.2.1 Transect 1

The likelihood of an individual tree moving from one crown extent category to another was modelled for each tree in Transect 1 and compared to trees at Transect 4, the control transect which was under no experimental influences (referred to as no-SIS). Transect 1 was under the influence of groundwater lowering from the SIS.

At Transect 1, the transition model found that the majority of trees did not change crown extent state between surveys (Table 5). When a tree did transition between crown extent categories, there was no consistent pattern to what state it transitioned to i.e. both higher and lower states were recorded.

Modelled changes in tree crown extent could not be discerned at Transect 1, suggesting that the effect of the SIS groundwater drawdown did not have a major impact on tree crown condition. The results from the crown extent transition models (see Appendix C, Tables C1, C2 and C3) are summarised as:

- The highest number of increasing transitions was from state 3 to 4 (Table 5).
- The highest number of declining transitions was from state 4 to 3 (Table 5).
- If trees were likely to transition to a higher state at Transect 1 (SIS), it was from state 3-4 (Table C1).
- If trees were likely to transition to a lower state at Transect 1 (SIS), it was from state 3-2 (Table C1).
- There was no difference in the ratio of transition intensities between Transect 1 (SIS) and Transect 4 (no-SIS) (Table C2).
- At Transect 1 (SIS), trees spent significantly more time in state 1 and state 4 (Table C3).

Table 5. Frequencies of transitions between crown extent states for all trees at Transect 1

Initial state	Crown extent	Frequencies for transitions to the following states:				
		1	2	3	4	5
1	0%	44	3	0	0	0
2	1-10%	16	45	9	3	0
3	11-25%	0	17	34	16	0
4	26-75%	0	1	17	82	1
5	76-100%	0	0	0	0	12

The majority of trees in Transect 1 had absent/scarce epicormic growth over the survey period (Table 6). Those that did change epicormic growth category, tended to move between the absent/scarce and common states (see Appendix C, Tables C4, C5 and C6).

Trees with epicormic growth at Transect 4 (under no effect of SIS drawdown) were more likely to decrease than increase in epicormic growth (Table C4).

There was no difference in the mean sojourn times of trees spending time with epicormic growth under the no SIS and SIS models. In both cases, trees spent longer in the absent/scarce epicormic growth state than in either of the higher categories (Table C6).

Table 6. Frequencies of transitions between epicormic growth states for all trees at Transect 1

Initial state	Crown extent	Frequencies for transitions to the following states:		
		1	2	3
1	Absent/Scarce	171	21	9
2	Common	30	49	2
3	Abundant	1	13	4

3.5.2.2 Transect 2

The likelihood of an individual tree moving from one crown extent category to another was modelled for each tree at Transect 2, with those affected by inundation (trees within 15 m of the flood runners) compared to trees at Transect 2 not affected by inundation (>15 m from the flood runners; cf. White et al, 2009, Bacon et al, 1993; Mensforth et al, 1994).

The majority of trees at Transect 2 did not change crown extent state between surveys (Table 7). Transitions from both lower to higher states and higher to lower states were observed, although decreases outnumbered increases, with no trees observed to increase from state 3 to 4. Inundated trees in state 2, did respond to flooding. The results from the transition models (see Appendix C, Tables C7, C8 and C9) are summarised as:

- Overall, the highest number of transitions for trees was decreases from states 4 to 1, and 2 to 1 (Table 7).
- The only state change to a higher state for inundated trees was from state 2 to 3, though no trees in state 3 transitioned to state 4 (Table C7).
- For trees that were not inundated, the change from state 3 to 2 was the most likely transition, being five times more likely than the increase from state 2 to 3 (Table C7).
- For both inundated and non-inundated trees in state 2 (1-10%), the likelihood of a decrease in state was higher than an increase ie. a transition from state 2 to 1, rather than 2 to 3 (Table C8).
- Non-inundated trees were modelled to spend an average of six years and eight months in state 1, which was significantly longer than the time they spent in either states 2, 3 or 4. The same pattern was observed for inundated trees suggesting that once trees have 0% crown, the likelihood of growing crown is scarce (Table C9).

Table 7. Frequencies of transitions between crown extent states for all trees at Transect 2

Initial state	Crown extent	Frequencies for transitions to the following states:			
		1	2	3	4
1	0%	137	3	2	0
2	1-10%	17	18	8	0
3	11-25%	6	5	19	0
4	26-100%	17	5	4	23

The majority of trees at Transect 2 had absent/scarce epicormic growth over the survey period and did not change state between dates (Table 8). Trees with common epicormic growth tended to decline to scarce or no growth, or remain the same between surveys (see Appendix C, Tables C10, C11 and C12).

Both increases and decreases in epicormic state were observed, most frequently between absent/scare and common epicormic growth and back again (Table C10). Trees with abundant epicormic growth were much less common than those with either of the lower two categories (Table 8).

Under no inundation, trees were more likely to decrease in epicormic growth states than increase. This contrasted to the inundation effect model, where trees were more likely to increase in epicormic state than decrease (Table C10).

The mean time trees spent with absent/scarce epicormic growth was almost three years for the no inundation effect model, which was significantly longer than the time spent in either the common or abundant states. The same pattern was observed for the trees affected by the inundation (Table C12).

Table 8. Frequencies of transitions between epicormic growth states for all trees at Transect 2

Initial state	Crown extent	Frequencies for transitions to the following states:		
		1	2	3
1	Absent/Scarce	161	16	11
2	Common	24	11	8
3	Abundant	5	10	18

3.5.2.3 Transect 3

The likelihood of an individual tree moving from one crown extent category to another was modelled for each tree in Transect 3 and compared to trees at Transect 4, the control transect (referred to as no-LM well) which was under no experimental influences. Transect 3 was under the influence of lateral groundwater recharge.

The Living Murray production well had a minor effect on trees transitioning between states at Transect 3, with the model suggesting an increased probability that trees in the second highest category would increase their extent when compared the to no effect model (control Transect 4). The modelling suggests that lateral recharge does not initiate epicormic growth, rather epicormic growth was less likely to decrease i.e. the response was sustained.

The majority of trees did not change crown extent state between surveys (Table 9). Transitions from both lower to higher states and higher to lower states were observed with the most frequent transition being an increase from state 4 to 5, followed by an increase from state 3 to 4 (Table 9). The results from the transition models (see Appendix C, Tables C13, C14 and C15) are summarised as:

- The highest number of declining transitions was from state 4 to 3 (Table 9).
- There was no significant difference between any of the transitions for the LM well effect model (Table C13).
- Under the influence of LM well for transitions out of states 3 and 4, an increase was more likely than a decrease (Table 9).
- Trees spent significantly longer in the 0% crown extent state than any of the other states, followed by state 4 (Table C15).

Table 9. Frequencies of transitions between crown extent states for all trees at Transect 3

Initial state	Crown extent	Frequencies for transitions to the following states:				
		1	2	3	4	5
1	0%	76	3	0	0	0
2	1-10%	6	3	4	3	0
3	11-25%	1	1	16	13	0
4	26-75%	0	0	10	117	23
5	76-100%	0	0	0	7	17

The majority of trees had absent/scarce epicormic growth over the survey period (Table 10). Those that did change tended to move between the absent/scarce and common states. Trees with abundant epicormic growth were much less common than those with either of the lower two categories (Table 10).

When the effect of the LM well was not considered trees, were more likely to decline in state than increase (Appendix C, Table C16). There was no difference between the ratio of transition intensities for a change out of state 2 for the no LM well effect and LM well models (Table C17). In both cases, a decline was more likely than an increase.

There was no difference in the mean sojourn times between the no LM well effect and LM well models (Table C18). For both effects, trees spent significantly longer with absent/scarce epicormic growth than in any of the other two states. The no LM well effect trees (Transect 4) spent longer with common epicormic growth than the LM well trees (Transect 3), although this was marginally non-significant.

Table 10. Frequencies of transitions between epicormic growth states for all trees at Transect 3

Initial state	Crown extent	Frequencies for transitions to the following states:		
		1	2	3
1	Absent/Scarce	164	26	1
2	Common	29	39	13
3	Abundant	8	10	10

3.5.3 UNDERSTOREY

Over the 30 month duration of surveys, 58 taxa were collected from the study site (see Appendix D for species list). Species richness ranged from 27 species collected along Transect 1 during the first survey, to 3 along Transect 4 in the last survey (Table 11). Diversity was highest in Transect 2 during the first survey and lowest in Transect 4 in the last survey. Both richness and diversity declined from Transect 1 to 4, and over time. The decline in these parameters was sharpest for Transects 1, 3 and 4. Transect 2 declined more gradually, most likely due to the effect of the flood runner inundation which promoted understorey growth in some quadrats. There was a minor increase in both richness and diversity in survey 3, which most likely coincided with an increase in monthly rainfall.

Table 11. Species richness and Shannon diversity value for each transect sample over the four surveys.

	Survey 1	Survey 2	Survey 3	Survey 4
Richness				
Transect 1	27	6	8	4
Transect 2	32	24	19	8
Transect 3	20	7	10	7
Transect 4	15	7	8	3
Shannon Diversity				
Transect 1	3.15	1.64	1.93	1.29
Transect 2	3.36	3.06	2.85	2.01
Transect 3	2.93	1.86	2.25	1.84
Transect 4	2.57	1.83	1.95	0.95

Classification of the 16 transect samples produced two major groups separated by time, with samples collected during the first survey (group A), and those collected in the final three surveys (group B: Figure 35). The final three survey groups split into two groups according to transect, with the remaining Transect 4 samples (group C) separated from Transects 1, 2 and 3 (group D) samples. Samples from each transect tended to cluster together in lower order groups.

In Figure 35, the sample labels are the transect sample: T1-T4; followed by the time of sampling.

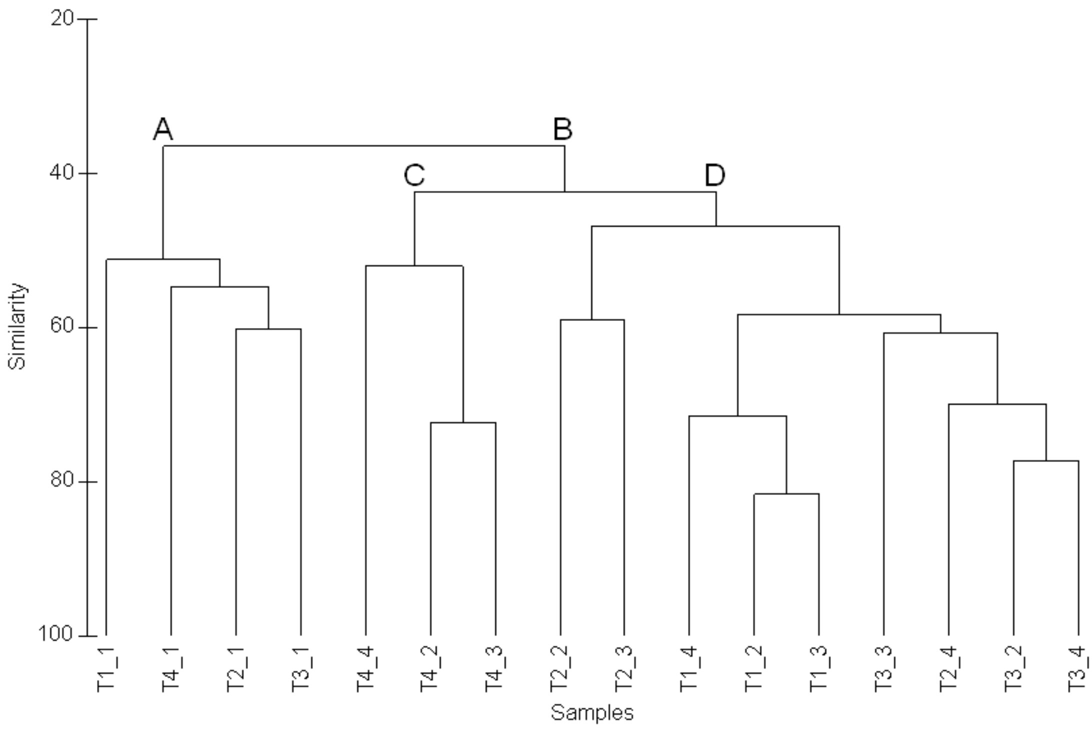


Figure 35. Understorey vegetation community dendrogram using Bray-Curtis similarity.

Non-metric MDS ordination produced a 2-D solution with stress of 0.11 (Figure 36). Each of the four transects followed a similar trajectory over time, from the left to the right and bottom to the top of the ordination space. A reversal in this trend was evident between the second and third surveys for Transects 1, 3 and 4. The environment bubble plot of rainfall three months prior to each survey shows that the initial surveyed samples corresponds with high rainfall to the left of the plot, and samples with lower rainfall plotting to the right (Figure 37).

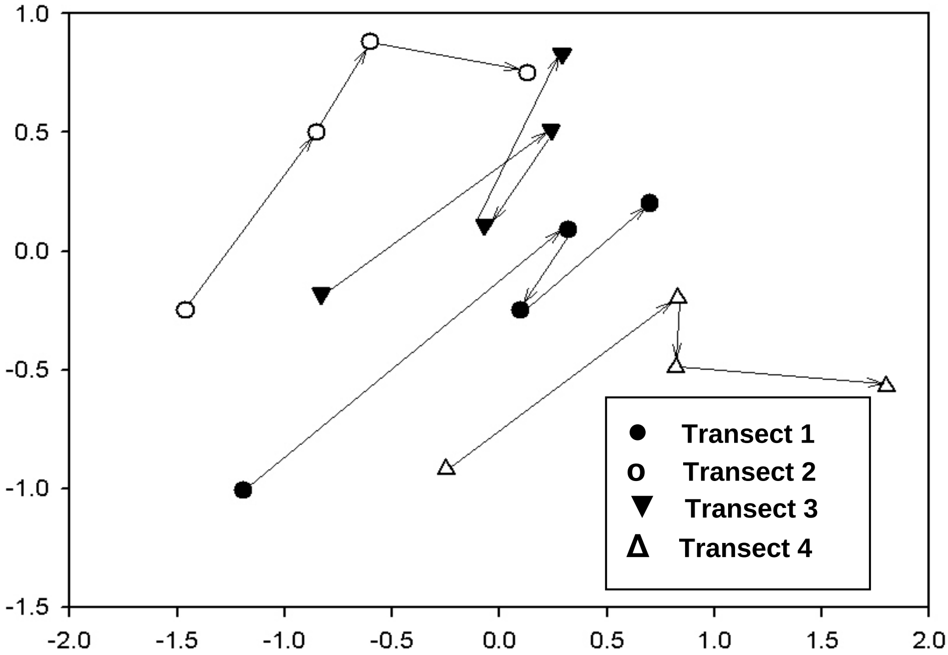


Figure 36. Two-dimensional MDS trajectory analysis of understorey vegetation community composition for the four transects.

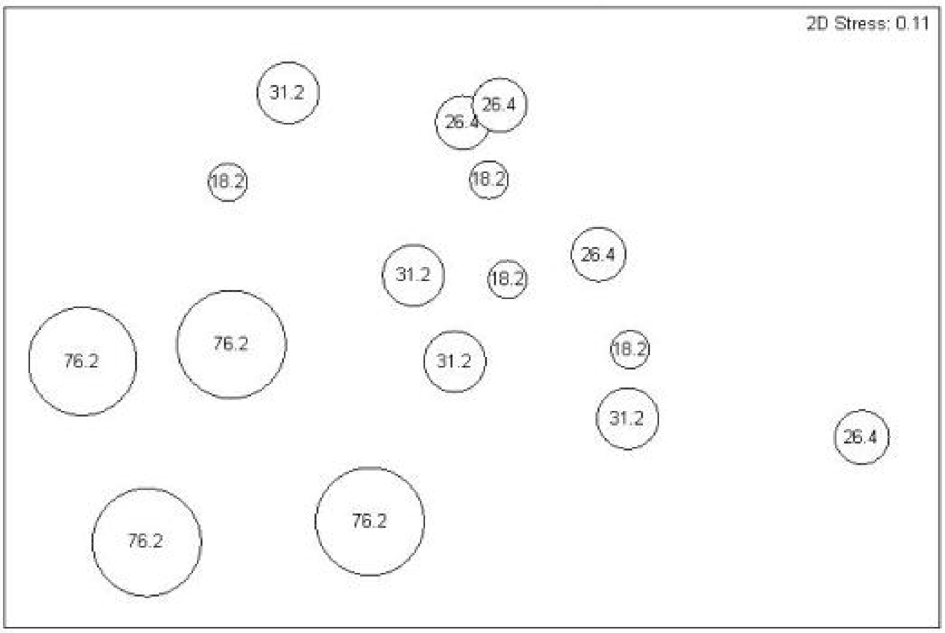


Figure 37. Two-dimensional MDS bubble plot of rainfall three months prior to sampling understorey vegetation community composition for the four transects.

In Figure 34, the size of the bubbles represents the relative difference in rainfall, the value of which is depicted at the centre of each plot in mm. Two-way crossed ANOSIM showed significant differences between time across transect (R = 0.629; P = 0.005) but not transect across time (R = 0.114; P = 0.31). The highest dissimilarity between surveys was for the first and last surveys (65.50%). Differences between the first and subsequent surveys were characterised by the disappearance of a large number of taxa after the first survey (Tables 12, 13 and 14). The level of dissimilarity between the second third and fourth surveys was lower than the first and subsequent surveys (Tables 15, 16 and 17).

In conclusion, understorey richness and diversity changed over the study period driven by rainfall resulting in a reduction in species diversity over time as rain decreased. Groundwater lowering at Transect 1 and groundwater freshening at Transect 3 had no effect on the understorey vegetation. The difference in richness between transects coincides with some transects, especially Transect 1, having a more open canopy which when combined with higher rainfall at the start of the study, favoured understorey species. The slow decline in the richness and diversity of Transect 2 was due to inundation of the flood runners, which promoted understorey growth in flooded quadrats. The findings from this study indicate that understorey vegetation located on higher floodplain areas (less inundation frequency), still exhibit species richness and diversity during periods of drought when good rainfall or inundation is experienced.

Table 12. Major SIMPER derived understorey vegetation taxa contributing to average dissimilarity for time1 and 2 groups across transects. Average dissimilarity 50.04%.

	Time 1	**Time 2**			
Taxa	**Average abundance**	**Average abundance**	**Average dissimilarity**	**Dissimilarity/ SD**	**Contribution %**
Lepidium pseudohyssopifolium	0.63	0.05	5.37	1.74	10.73
Sonchus oleraceus	0.49	0.00	3.98	2.80	7.95
Crassula colligata ssp. colligata	0.49	0.00	3.87	3.75	7.74
Cotula bipinnata	0.39	0.00	3.61	1.90	7.22
Petrorhagia dubia	0.35	0.00	2.85	8.25	5.70
Hypochaeris glabra	0.33	0.00	2.30	1.46	4.59
Vulpia myuros f. myuros	0.23	0.00	2.19	1.32	4.38
Calandrinia eremaea	0.17	0.05	1.59	1.17	3.18
Einadia nutans ssp.	0.64	0.53	0.97	2.08	1.95

Table 13. Major SIMPER derived understorey vegetation taxa contributing to average dissimilarity for time1 and 3 groups across transects. Average dissimilarity 48.90%.

	Time 1	Time 3			
Taxa	**Average abundance**	**Average abundance**	**Average dissimilarity**	**Dissimilarity/ SD**	**Contribution %**
Lepidium pseudohyssopifolium	0.63	0.10	4.29	2.05	8.77
Sonchus oleraceus	0.49	0.05	3.60	2.68	7.37
Cotula bipinnata	0.39	0.00	3.50	1.96	7.16
Petrorhagia dubia	0.35	0.00	2.78	12.86	5.69
Crassula colligata ssp. colligata	0.49	0.14	2.60	2.71	5.31
Hypochaeris glabra	0.33	0.00	2.30	1.43	4.71
Vulpia myuros f. myuros	0.23	0.00	2.14	1.36	0.23
Senecio glossanthus	0.26	0.00	1.88	1.34	3.84
Atriplex semibaccata	0.57	0.42	1.72	1.85	3.51
Bromus rubens	0.14	0.12	1.24	1.01	2.54

Table 14. Major SIMPER derived understorey vegetation taxa contributing to average dissimilarity for time1 and 4 groups across transects. Average dissimilarity 65.50%.

	Time 1	Time 4			
Taxa	**Average abundance**	**Average abundance**	**Average dissimilarity**	**Dissimilarity/ SD**	**Contribution %**
Lepidium pseudohyssopifolium	0.63	0.00	6.43	2.02	9.82
Sonchus oleraceus	0.49	0.00	4.50	3.42	6.87
Crassula colligata ssp. colligata	0.49	0.00	4.39	4.97	6.70
Cotula bipinnata	0.39	0.00	4.16	1.78	6.35
Petrorhagia dubia	0.35	0.00	3.25	30.37	4.97
Atriplex semibaccata	0.57	0.27	3.17	1.19	4.83
Hypochaeris glabra	0.33	0.00	2.74	1.44	4.18
Vulpia myuros f. myuros	0.23	0.00	2.54	1.33	3.88
Senecio glossanthus	0.26	0.00	2.14	1.36	3.27
Einadia nutans ssp.	0.64	0.43	1.95	2.84	2.98

Table 15. Major SIMPER derived understorey vegetation taxa contributing to average dissimilarity for time2 and 3 groups across transects. Average dissimilarity 30.14%.

Taxa	Time 2 Average abundance	Time 3 Average abundance	Average dissimilarity	Dissimilarity/ SD	Contribution %
Calandrinia eremaea	0.05	0.17	3.06	1.13	10.16
Lepidium pseudohyssopifolium	0.05	0.10	2.29	1.23	7.58
Crassula colligata ssp. colligata	0.00	0.14	2.21	0.85	7.33
Einadia nutans ssp.	0.53	0.57	1.65	2.50	5.49
Atriplex semibaccata	0.48	0.42	1.42	1.87	4.70

Table 16. Major SIMPER derived understorey vegetation taxa contributing to average dissimilarity for time2 and 4 groups across transects. Average dissimilarity 37.08%.

Taxa	Time 2 Average abundance	Time 4 Average abundance	Average dissimilarity	Dissimilarity / SD	Contribution %
Atriplex semibaccata	0.48	0.27	5.03	0.97	13.57
Spergularia rubra	0.15	0.00	3.70	0.61	9.99
Einadia nutans ssp.	0.53	0.43	1.95	2.07	5.25
Setaria jubiflora	0.10	0.10	1.61	0.80	4.35
Picris squarrosa	0.10	0.00	1.55	0.78	4.19

Table 17. Major SIMPER derived understorey vegetation taxa contributing to average dissimilarity for time3 and 4 groups across transects. Average dissimilarity 40.03%.

Taxa	Time 3 Average abundance	Time 4 Average abundance	Average dissimilarity	Dissimilarity/ SD	Contribution %
Atriplex semibaccata	0.42	0.27	5.02	0.87	12.53
Calandrinia eremaea	0.17	0.00	3.00	0.85	7.49
Spergularia rubra	0.14	0.00	2.87	0.76	7.16
Einadia nutans ssp.	0.57	0.43	2.50	2.78	6.25
Crassula colligata ssp. *colligata*	0.14	0.00	2.46	0.86	6.15

4. CONCLUSIONS

The following provides a conclusion of the specific outcomes at each transect of the three groundwater management techniques investigated at Site B.

4.1 TRANSECT 1

The nearby pumping of the SIS, influenced a reduction in groundwater levels. Groundwater salinity along the transect remained predominately unaltered, except at the riverbank where some freshening was observed. The soil sampling showed that no salt was removed from the soil in the root zone (upper 4 m).

The groundwater and soil salinity results substantiate tree condition at the site. Soil water potential results were predominately less than -3 MPa throughout the profiles reducing the ability of trees to extract water from the root zone. The majority (~65%) of trees at Transect 1, were in a poor state (<25% crown extent) throughout the study. The frequency of dead trees (0% crown) increased during the study. The tree transition modelling supported these results, as once trees lost their entire crown extent they did not respond. Trees spent more time in state 4 (26-75% crown extent) than the other foliage states. Epicormic growth patterns at Transect 1 indicated that a combination of climate (rainfall) and seasons most likely initiated epicormic growth during the two peak periods of April 2006 and March 2008.

The moderately saline surface soil supported a chenopod community (saltbushes). A more open tree canopy along the transect supported a more diverse taxa of vegetation species, especially after rainfall events.

4.2 TRANSECT 2 (SITE D)

At Transect 2 after the inundation event, the soil profile and groundwater were both temporarily freshened. The vertical recharge is likely to have mobilised some salts from the soil profile into the groundwater aquifer.

Total soil water potential in the root zone was predominantly greater than –2 MPa at the river (B4), and greater than –4 MPa at well B5 and B6, giving trees a fresher source of water when compared to Transect 1. Approximately 35% of trees throughout the study had crown extents less than 25%. The frequency of dead trees (0% crown) increased during the study. The tree transition modelling supported these results, as once trees lost their entire crown extent they did not respond. No inundated trees in state 3 (11-25% crown) responded to flooding, but a small proportion of trees in state 2 (1-10% crown) did respond to flooding. Trees spent more time in state 4 (26-75% crown extent) than the other foliage states. The improved condition of trees after inundation was maintained until the following spring for river red gum and cooba, and the following autumn for black box. Two years after inundation, all species had started to show some level of crown extent decline, but were overall in better condition than before inundation.

Inundation promoted understorey growth with the chenopod community switching to a flood responder (wetland type) community within the inundated area. The understorey response indicates that the floodplain seed bank was intact and can withstand long periods of dryness, as the last inundation of the area would have most likely been 14 years ago during the 1993 flood.

4.3 TRANSECT 3

Groundwater salinity along the Living Murray well transect was reduced notably, in some places by two orders of magnitude from above 50 000 EC to below 500 EC. SIS and LM groundwater extraction lowered groundwater levels across the transect with those closest to the LM well most influenced. The geophysics, groundwater and soil information indicated a reduction of shallow salinity within the area influenced by the LM well.

Total soil water potential in the root zone was predominantly greater than –2 MPa between the river and the LM well, giving trees a fresher source of water when compared to Transect 1. These soil water potential results did not extend to B25 which was beyond the extent of LM well groundwater freshening.

The groundwater and soil salinity results correlate to the changes in tree condition at the site. At the start of the study ~50% of trees were in poor condition (<25% crown), by the end of the study ~40% of trees were in poor condition. The frequency of dead trees (0% crown) increased throughout the study, through further decline/death levelled out after the LM well started operating. The tree transition modelling supported these results, as once trees lost their crown they did not respond. As found at the other transects, trees spent more time in state 4 (26-75% crown extent) than the other foliage states. For river red gum, cooba and black box; crown extent condition for all species was maintained during the operation of the LM well; river red gum condition declined during the pulse pumping trial; whereby for cooba and black box crown condition improved as a result of the pulse pumping. Transect3, was the only transect where epicormic growth was being maintained by the end of the study. The survival of epicormic growth would be due to the increased soil water availability from the LM well, which is similar to Site A the other Bookpurnong trial, whereby after two consecutive inundations, epicormic growth was maintained due to the freshened soil profile (White et al, 2009).

The canopy was more closed in along Transect 3, supporting a less diverse understorey community that was dominated by salt tolerant species (chenopods). Transect 3, was the only transect where epicormic growth on trees was being maintained by the end of the study period compared to the other transects.

4.4 TRANSECT 4

Transect 4 was the control site but the nearby pumping of the LM well influenced a reduction in groundwater salinity at the site. Groundwater freshening to this extent was not anticipated from the operation of the LM and SIS wells but occurred due to the geophysical characteristics of good river and floodplain aquifer connection at the site. The level of freshening was less extensive in comparison to Transect 3 but the aquifer was freshened to the middle of the riparian zone, but stayed saline at the riparian edge.

The soil water potential results were predominately greater than -3 MPa between the river and the transect midpoint, making it easier for trees to source water from the root zone.

The overall frequency of trees with less than 10% crown was ~20% throughout the study. The frequency of dead trees (0% crown) increased during the study, through the rate of decline levelled out. In general, all species were in better condition at the end of the study period than at the start, due to the evidence of the LM well zone of influence extending into Transect 4.

The moderately saline surface soil supported a chenopod community that was dominated by salt tolerant species. A closed in canopy along the transect supported limited understorey species diversity.

4.5 OVERALL TREATMENT FINDINGS

The most successful intervention of freshening saline groundwater was the lateral recharge method at Transect 3. The success of the lateral recharge trial at Site B was duly dependant on the site hydrogeology and connectivity with the Murray River. The Site B trial site had both favourable aquifer hydraulic properties and good aquifer and stream connectivity, which will not always be the case at other sites due to the variation in floodplain environments. The occurrence of tree populations (especially river red gums) adjacent to rivers and creeks is an indicator that some degree of stream and aquifer connectivity exists. The suitability of applying this floodplain intervention technique to other sites can be determined by these factors. The use of geophysical surveys and groundwater modelling can provide important information for the site selection and the design of infrastructure. The zone influenced by the LM well at Transect 3 extended into Transect 4, whereby the best results of tree response to an intervention was found. Trees at Transect 4 were in a good condition at the start of the trial, with tree condition significantly improving at the site due to the groundwater freshening.

The inundation of the flood runners at Transect 2, was the second most successful trial in freshening the saline groundwater. However there was only a temporary reduction in both groundwater salinity and soil conductivity with a consequential short term improvement in tree condition at the site. The improved soil water and tree condition was maintained at the site until the following spring, one year after inundation. Black box condition was further maintained for another six months, supporting the evidence that this species can tolerate higher salinities.

The operation of the floodplain SIS was successful in lowering the groundwater levels at the site. However the trial was least successful in improving tree condition due to the high soil conductivity maintained in the soil profile. This trial has highlighted that for vegetation to improve on floodplains in the Lower Murray, some type of groundwater freshening process needs to occur.

The overall patterns observed in tree condition at Sites B and D correlates to levels of soil and groundwater salinity. Groundwater freshening was a result of four processes which were:

- Displacement of saline groundwater via extraction.
- Inducement of river water into the upper part of the floodplain aquifer.
- A dilution front at the interface between the pre-existing saline groundwater and the induced river water.
- Surface inundation and rainfall leaching of salts downward into the deeper aquifer. Rainfall leaching was not measured within this trial, but trees were found to respond to rainfall events.

Groundwater lowering took place at Transect 1 but this process alone did not result in groundwater freshening. Groundwater freshening occurred at Transect 2, 3 and 4. Groundwater freshening greatly influenced the response in tree condition at Sites B and D.

The major findings from monitoring the crown extent condition of river red gum, river cooba and black box were:

- Without groundwater freshening, trees with <10% crown extent declined in condition.
- Without groundwater freshening, trees with 11-25% crown extent declined in condition.
- Without groundwater freshening, trees with >26% crown extent were more likely to maintain or decline in condition.
- With groundwater freshening, trees with <10% crown extent declined in condition.
- With groundwater freshening, trees with 11-25% crown extent both maintained and improved condition.
- With groundwater freshening, trees with >26% crown extent were more likely to maintain or improve condition.

5. RECOMMENDATIONS

Identifying resilient landscapes that respond better to interventions is key in the current drought and low flow environment of the Murray River in South Australia.

The results of the trial have shown that groundwater depth can be altered by SIS drawdown. Surface inundation temporarily improves soil and groundwater salinity. Importantly, the trial has also shown that groundwater salinity can be reduced by the extraction of groundwater to laterally recharge an aquifer with river water, enhancing bank storage. The applicability of these environmental watering methodologies to other sites will need to consider geomorphology, local aquifer characteristics and vegetation condition.

If lateral recharge as a management technique is applied to other floodplains, it is recommended that the required output of the intervention be defined. Groundwater freshening alone does not promote full ecological functioning of floodplain communities (i.e. germination and recruitment of species) and requires inundation to be incorporated into the management plan.

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. Once crown extents are <10%, trees do not 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, therefore it is recommended that intervention planning should focus on trees with a crown extent greater than 25%.

The results from this study suggest that there is a shift in paradigm on how vegetation communities on the Lower Murray River are managed. Rather than trying to recover tree populations in very poor condition, it is suggested that targeting tree communities in moderate to poor condition will provide a greater tree condition response.

Applying the techniques trialled in this study; geophysics, groundwater modelling and vegetation mapping, can give NRM managers tools to identify where these resilient communities exist in the landscape and the current salinity stress they are under. This will improve the cost effectiveness of intervention projects.

APPENDICES

A. GROUNDWATER WELL CONSTRUCTION SUMMARY

Table A1. Well construction summary for wells installed on the Bookpurnong floodplain for this pilot project

Name	Unit No.	Easting	Northing	Reference Elevation (mAHD)	Ground Elevation (mAHD)	Depth (m)	Drilled Diameter (mm)	Drilling Method	Completion Date	Casing Start (m)	Casing End (m)	PVC Casing Diameter (mm)	Screen From (m)	Screen To (m)	Screen Type	Aquifer Monitored
B 1	702902137	461038	6198388	15.37	14.37	5.85	50	BDE+PUT	28/06/2005	-1.00	4.9	50	4.9	5.9	PVC SC	Qam(MON)
B 2	702902138	461068	6198440	14.78	13.82	4.65	50	BDE+PUT	21/06/2005	-0.96	4	50	4	5	PVC SC	Qam(MON)
B 3	702902139	461093	6198505	14.52	13.56	5.1	50	BDE+PUT	20/06/2005	-0.96	4.1	50	4.1	5.1	PVC SC	Qam(MON)
B 4	702902141	461180	6198274	14.79	13.91	13	150	RTM	28/11/2005	-0.88	2.5	80	2.5	12	PVC SC	Qam(MON)
B 4A	702902140	461180	6198274	14.83	13.94	6	150	RTM	28/11/2005	-0.89	2	80	2	6	PVC SB+SC	Qam(MON)
B 5	702902142	461242	6198321	14.64	13.7	5.2	150	RTM	28/11/2005	-0.94	1.7	80	1.7	5.2	PVC SB+SC	Qam(MON)
B 6	702902143	461299	6198376	13.93	13.00	5.8	150	RTM	01/12/2005	-0.93	2.3	80	2.3	5.8	PVC SB+SC	Qam(MON)
B 7	702902145	461235	6198069	14.87	13.86	11.8	150	RTM	25/11/2005	-1.01	1.8	80	1.8	11.8	PVC SB+SC	Qam(MON)
B 7A	702902144	461235	6198069	14.92	13.98	5.6	150	RTM	25/11/2005	-0.94	2	80	2	5.6	PVC SB+SC	Qam(MON)
B 8	702902147	461299	6198074	14.49	13.49	12.5	80	RTM	26/11/2005	-0.98	2.5	80	2.5	12.5	PVC SB+SC	Qam(MON)
B 8A	702902146	461299	6198071	14.53	13.55	6	150	RTM	27/11/2005	-0.98	2	80	2	6	PVC SB+SC	Qam(MON)
B 9	702902148	461383	6198064	14.51	13.54	5.7	150	RTM	28/11/2005	-0.98	2.2	80	2.2	6	PVC SB+SC	Qam(MON)
B 10	702902150	461126	6197884	15.17	14.27	11.5	150	RTM	24/11/2005	-0.90	4.5	80	4.5	11.5	PVC SB+SC	Qam(MON)
B 10A	702902149	461126	6197884	15.17	14.27	7.15	150	RTM	24/11/2005	-0.90	3.35	80	3.35	7.15	PVC SB+SC	Qam(MON)
B 11	702902151	461147	6197845	15.00	14.22	5.6	50	BDE+PUT	28/06/2005	-0.78	4.6	50	4.6	5.6	PVC SC	Qam(MON)
B 12	702902152	461207	6197776	14.91	14.05	6.7	150	RTM	24/12/2005	-0.85	3	80	3	6.7	PVC SB+SC	Qam(MON)
B 21	702902154	462130	6197608	13.64	12.65	13	150	RTM	29/11/2005	-0.99	2	80	2	13	PVC SB+SC	Qam(MON)
B 22	702902155	462394	6197651	13.88	13.00	12.4	150	RTM	30/11/2005	-0.88	2.5	80	2.5	12.4	PVC SB+SC	Qam(MON)
B 23	702902156	462599	6197617	13.83	12.90	13	150	RTM	30/11/2005	-0.92	3.1	80	3.1	13	PVC SB+SC	Qam(MON)
B 24	702902157	462095	6197749	14.45	13.50	12	150	RTM	01/12/2005	-0.95	2.2	80	2.2	12	PVC SB+SC	Qam(MON)
B 25	702902232	461417	6198055	14.47	13.34	10.5	135	RTM	04/04/2006	-1.13	2.5	80	2.5	10.5	PVC SB+SC	Qam(MON)
LMPB	702902158	461383	6198062	13.60	13.38	14	225	RTM	05/01/2006	-0.30	14	200	9	12	SST SC	Qam(MON)
CF 5	702901306	461151	6197845	14.94	14.18	10		AUG	17/09/1998	-0.76	10	50	7	10	PVC SC	Qam(MON)
LM 2	702902027	461027	6198387			14.5		RTM	26/05/2004		14.5	80	10.5	13.5	PVC S	Qam(MON)

B. SOIL SALINITY RESULTS

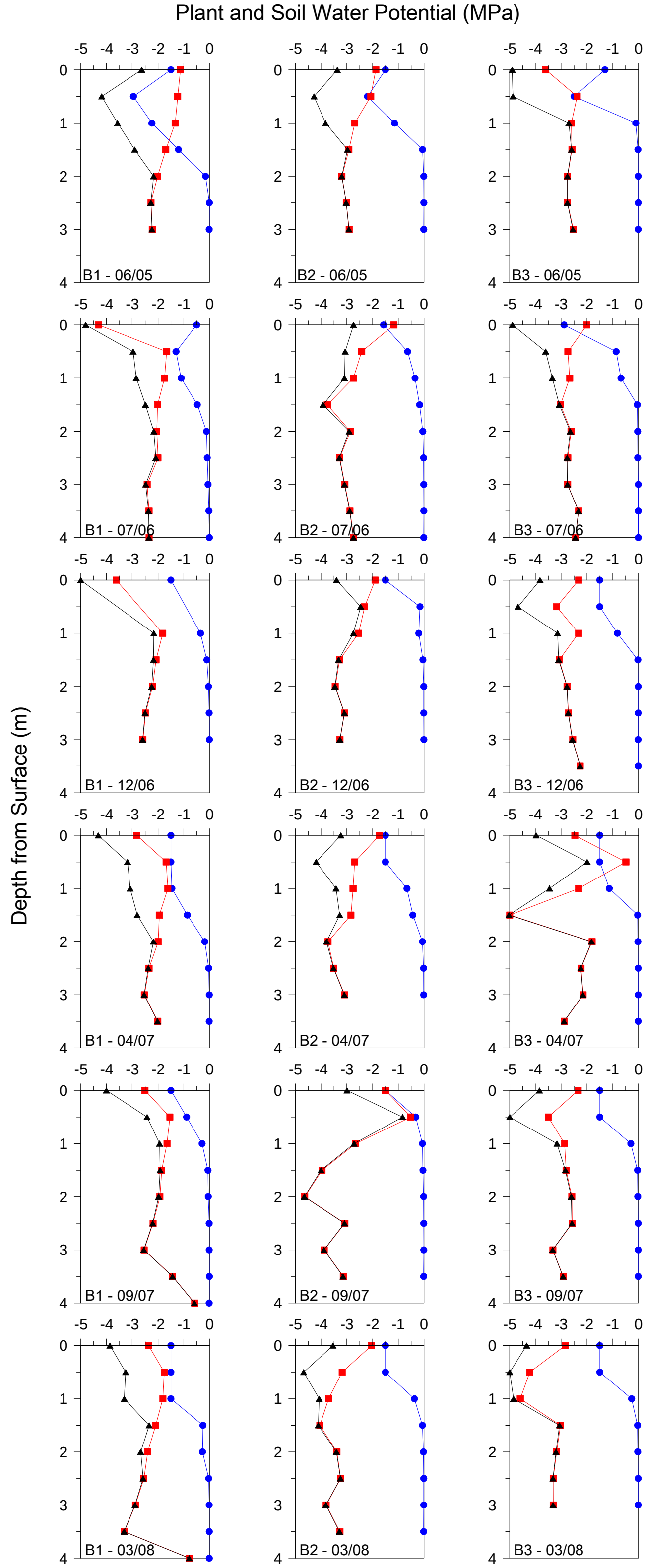


Figure B1. Soil salinity profiles of Transect 1 (SIS drawdown). From left to right; B1 (river), B2 (mid) and B3 (floodplain). Osmotic potential (■), matric potential (●) and total potential (▲) are represented.

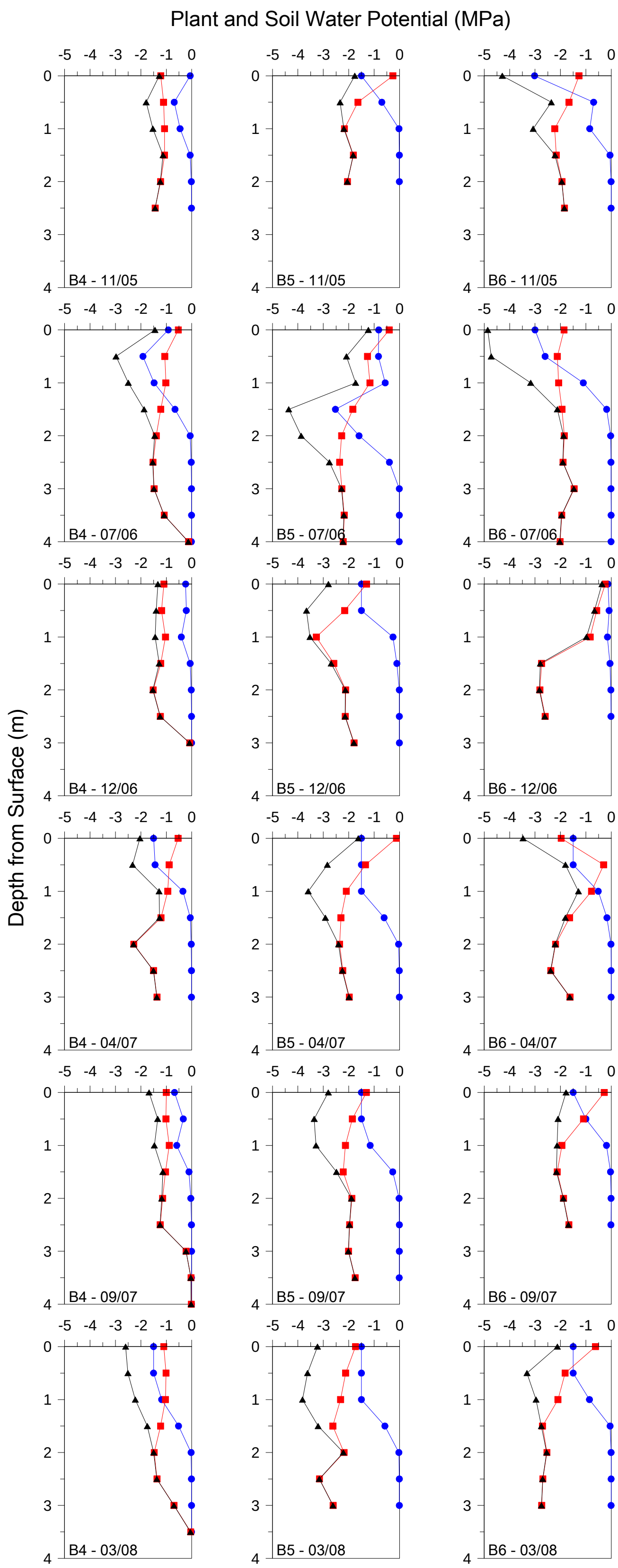


Figure B2. Soil salinity profiles of Transect 2 (inundation of flood-runners). From left to right; B4 (river), B5 (mid) and B6 (floodplain). Osmotic potential (■), matric potential (●) and total potential (▲) are represented.

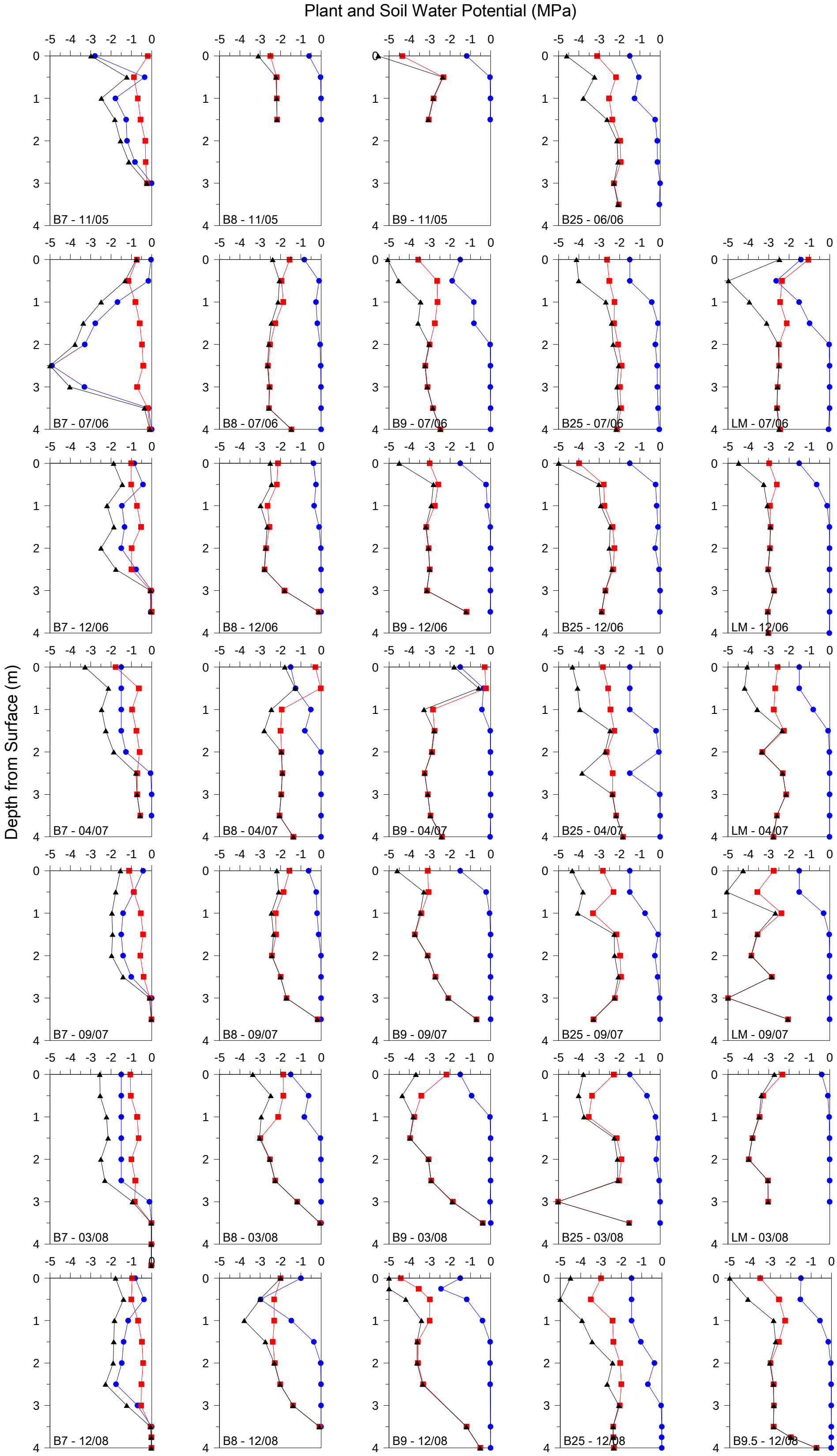


Figure B3. Soil salinity profiles of Transect 3 (LM well lateral recharge). From left to right; B7 (river), B8 (mid), B9 (river side of LM well), B25 (floodplain side of LM well), LM well and B9.5 (at LM well). Osmotic potential (■), matric potential (●) and total potential (▲) are represented.

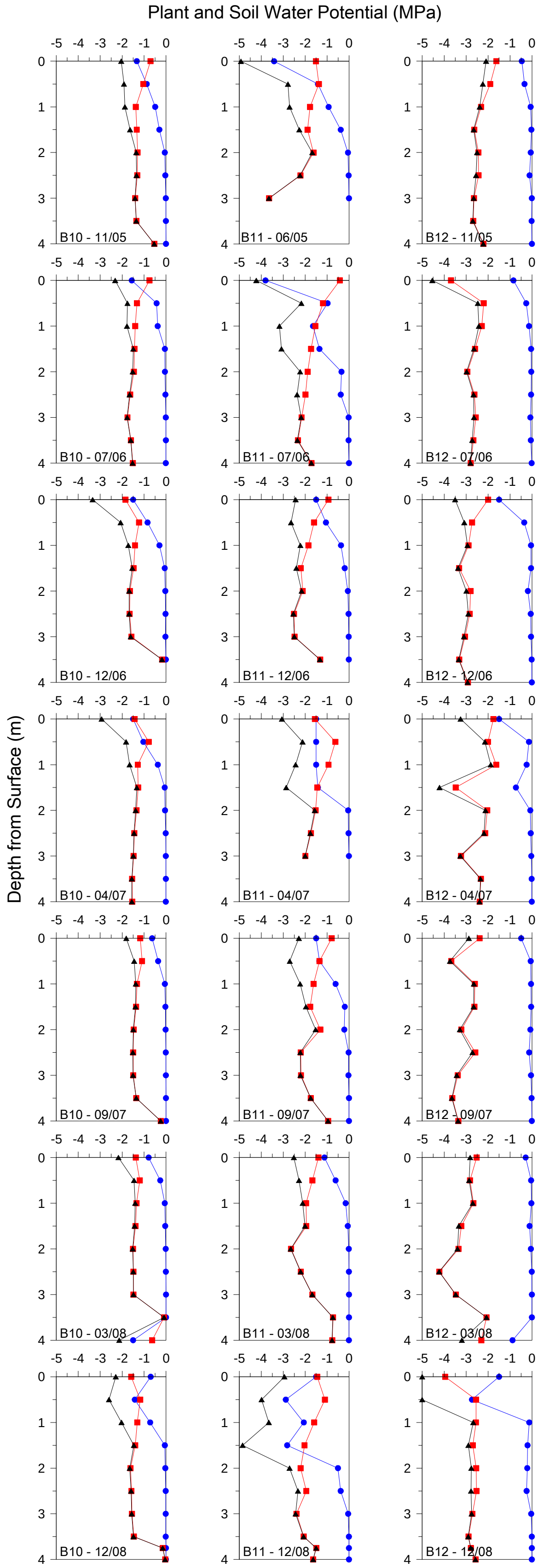
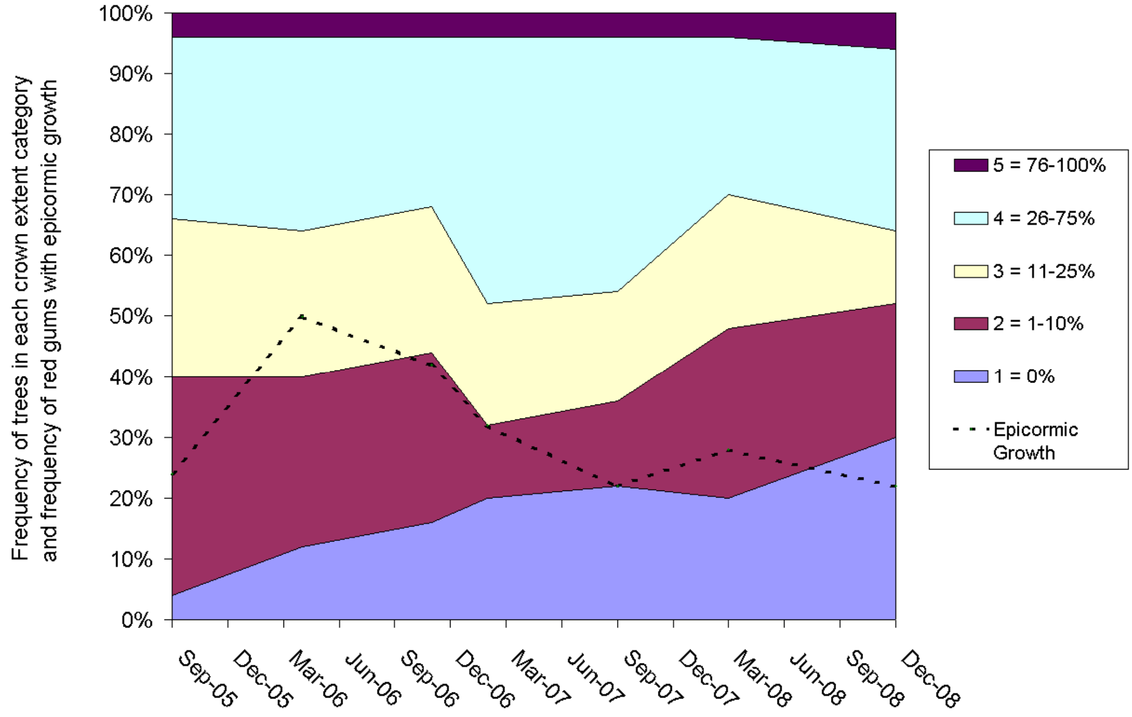
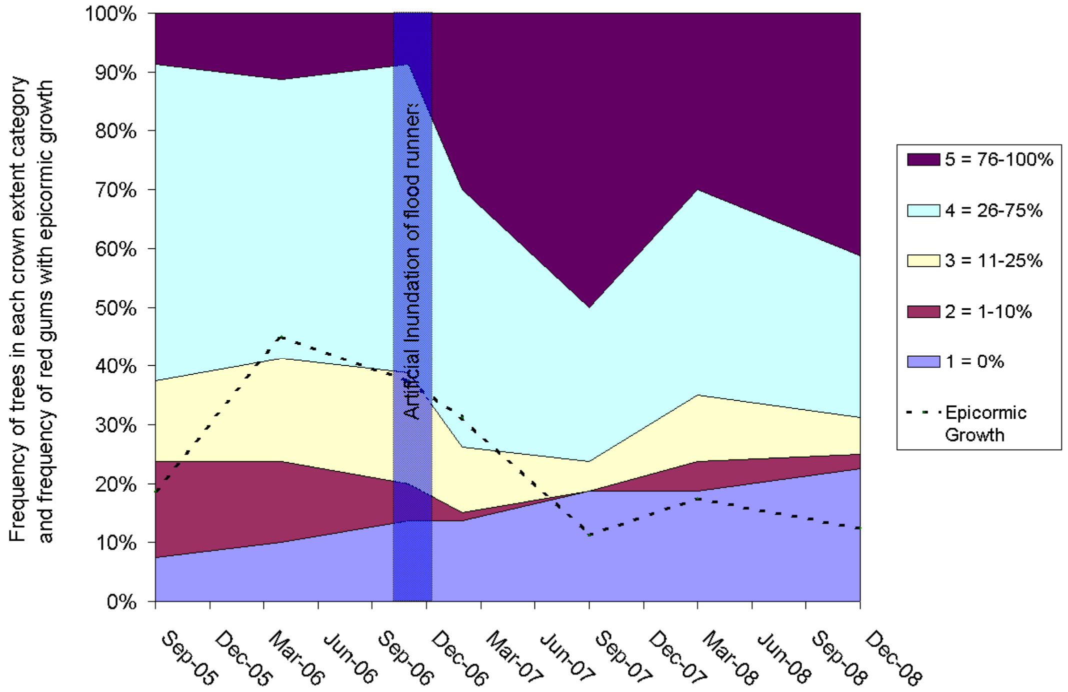


Figure B4. Soil salinity profiles of Transect 4 (control). From left to right; B10 (river), B11 (mid) and B12 (floodplain). Osmotic potential (■), matric potential (●) and total potential (▲) are represented.

C. VEGETATION RESULTS

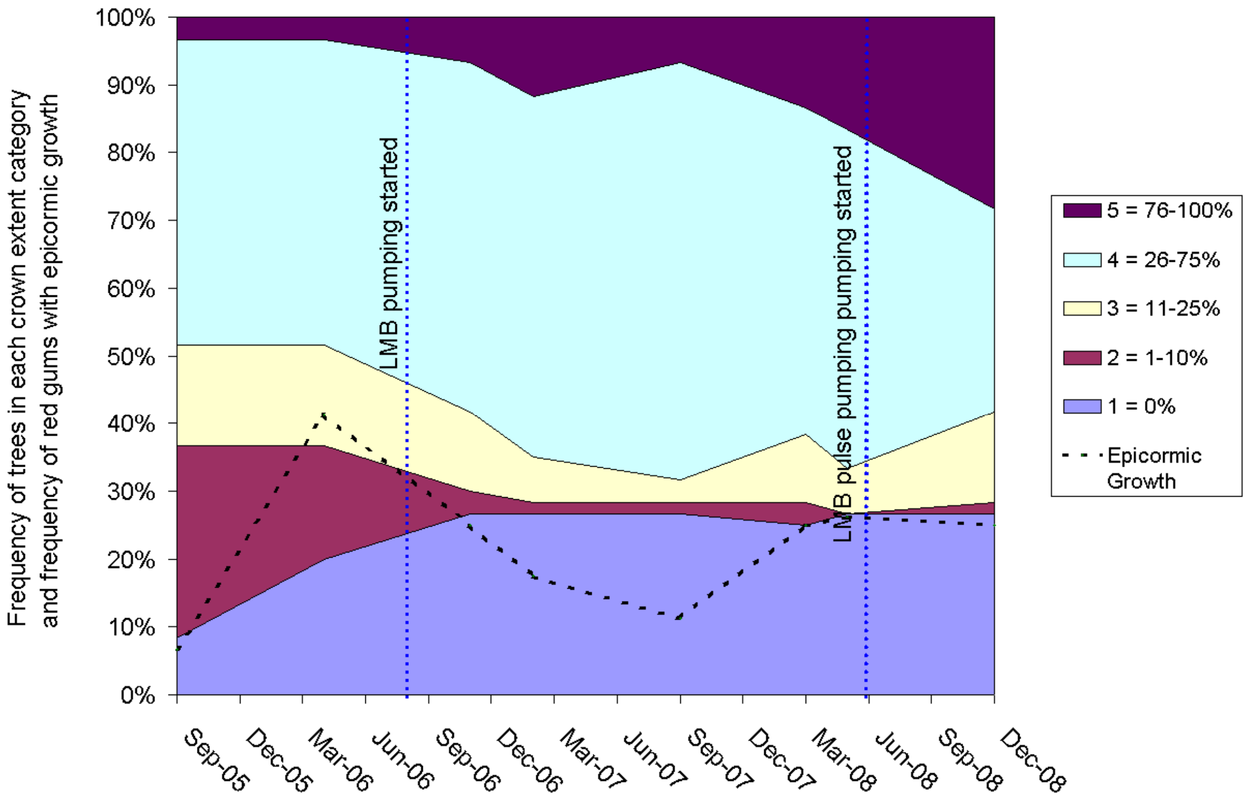


a) Transect 1

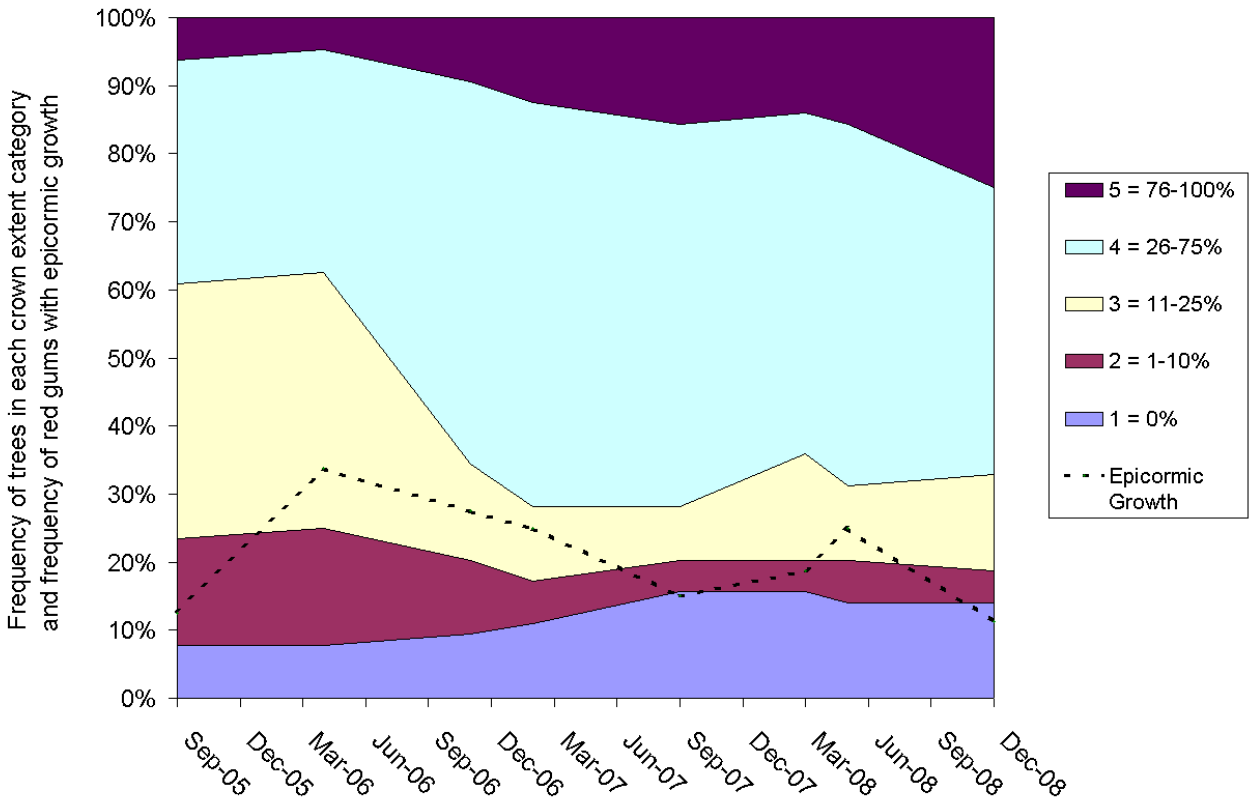


b) Transect 2

Figure C1. Frequency of trees in each crown extent category during the study period, a) Transect 1, b) Transect 2



c) Transect 3



d) Transect 4

Figure C1. Frequency of trees in each crown extent category during the study period, a) Transect 3, b) Transect 4

STATISTICAL ANALYSIS RESULTS

Transect 1

Table C1. Maximum likelihood estimates crown extent transition intensities for the no SIS effect and SIS Markov models (–2 time log likelihood: 871.51; 95% confidence intervals in brackets).

State change	No SIS effect transition rates	SIS effect transition rates	Log linear effect of SIS
1➞2	0.09 (0.03–0.26)	0.13 (0.04–0.41)	0.69 (-1.42–2.80)
2➞1	0.39 (0.24–0.64)	0.45 (0.27–0.75)	0.24 (-0.70–1.18)
2➞3	0.44 (0.27–0.72)	0.40 (0.22–0.75)	-0.17 (-1.10–0.79)
3➞2	0.29 (0.17–0.51)	0.67 (0.41–1.09)	1.50 (0.47–2.54)
3➞4	0.75 (0.55–1.03)	0.75 (0.46–1.23)	0.002 (-0.06–0.63)
4➞3	0.21 (0.14–0.33)	0.47 (0.29–0.76)	1.40 (0.56–2.25)
4➞5	0.05 (0.02–0.19)	0.01 (0.001–0.16)	-3.06 (-5.90–-0.23)
5➞4	1.60 (0.05–0.53)	0.09 (0.01–1.13)	-0.94 (-3.59–1.71)

Table C2. 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 SIS effect	SIS effect
2➞3 v 2➞1	1.13 (0.56–2.24)	0.90 (0.41–1.99)
3➞4 v 3➞2	2.60 (1.39–4.90)	1.12 (0.57–2.22)
4➞5 v 4➞3	0.25 (0.07–0.95)	0.02 (0.001–0.35)

Table C3. Crown extent model maximum likelihood estimates of mean sojourn times (years) for the non SIS effect and SIS Markov models (95% confidence intervals in brackets).

State	No SIS effect	SIS effect
State 1	11.74 (3.87–35.60)	7.96 (2.45–25.82)
State 2	1.20 (0.85–1.70)	1.17 (0.79–1.75)
State 3	0.96 (0.73–1.26)	0.70 (0.49–0.99)
State 4	3.78 (2.44–5.84)	2.11 (1.30–3.40)
State 5	6.25 (1.87–20.89)	10.58 (0.88–126.78)

Table C4. Maximum likelihood estimates of epicormic growth transition intensities for the no SIS effect and SIS Markov models (–2 time log likelihood: 784.984; 95% confidence intervals in brackets).

State change	No SIS effect transition rates	SIS effect transition rates	Log linear effect of SIS
1➞2	0.41 (0.31–0.53)	0.40 (0.27–0.58)	-0.04 (-0.56–0.49)
2➞1	1.13 (0.87–1.47)	0.99 (0.67–1.45)	-0.25 (-0.77–0.28)
2➞3	0.37 (0.18–0.76)	0.77 (0.27–2.21)	1.31 (-0.11–2.72)
3➞2	2.95 (1.68–5.18)	4.53 (1.82–11.27)	0.77 (-0.39–1.92)

Table C5. Ratio of transition intensities between epicormic growth states for the no SIS effect and SIS Markov models (95% confidence intervals in brackets).

State change comparison	No SIS effect	SIS effect
2➞1 v 2➞3	3.05 (1.44–6.42)	1.28 (0.42–3.85)

Table C6. Epicormic growth model maximum likelihood estimates of mean sojourn times (years) for the non SIS effect and SIS Markov models (95% confidence intervals in brackets).

State	No SIS effect	SIS effect
State 1	2.47 (1.90–3.20)	2.52 (1.72–3.70)
State 2	0.66 (0.51–0.87)	0.57 (0.34–0.95)
State 3	0.34 (0.19–0.60)	0.22 (0.09–0.55)

Transect 2

Table C7. Maximum likelihood estimates crown extent transition intensities for the no inundation effect and inundation Markov models (–2 time log likelihood: 596.17; 95% confidence intervals in brackets).

State change	No-inundation effect transition rates	Inundation effect transition rates	Log linear effect of Inundation
1➞2	0.15 (0.07–0.33)	0.06 (0.01–0.23)	-1.90 (-3.40–-0.40)
2➞1	2.72 (2.06–3.59)	2.32 (1.65–3.26)	-0.35 (-0.92–0.22)
2➞3	0.63 (0.24–1.71)	0.87 (0.32–2.38)	0.70 (-1.39–2.79)
3➞2	3.22 (2.32–4.46)	2.50 (1.59–3.94)	-0.56 (-1.21–0.09)
3➞4	0	0	0
4➞3	1.71 (1.29–2.27)	1.73 (1.18–2.56)	0.03 (-0.54–0.60)

Table C8. 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➞1 v 2➞3	4.3 (1.155–11.96)	2.67 (0.96–7.44)

Table C9. 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	6.72 (3.06–14.77)	15.82 (4.44–56.37)
State 2	0.30 (0.22–0.40)	0.31 (0.21–0.46)
State 3	0.31 (0.22–0.43)	0.40 (0.25–0.63)
State 4	0.58 (0.44–0.78)	0.58 (0.39–0.85)

Table C10. Maximum likelihood estimates of epicormic growth transition intensities for the no inundation effect and inundation Markov models (–2 time log likelihood: 481.214; 95% confidence intervals in brackets).

State change	No inundation effect transition rates	Inundation effect transition rates	Log linear effect of Inundation
1➞2	0.34 (0.24–0.49)	0.47 (0.29–0.76)	0.72 (-0.02–1.45)
2➞1	1.69 (1.20–2.39)	2.54 (1.59–4.06)	0.90 (0.22–1.59)
2➞3	0.74 (0.40–1.36)	1.50 (0.83–2.69)	1.58 (0.29–2.87)
3➞2	1.46 (0.64–3.32)	1.37 (0.73–2.54)	-0.15 (-1.92–1.63)

Table C11. 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➞1 v 2➞3	2.30 (1.17–4.53)	1.70 (0.84–3.44)

Table C12. 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	2.92 (2.04–4.21)	2.12 (1.31–3.43)
State 2	0.41 (0.30–0.56)	0.25 (0.17–0.36)
State 3	0.69 (0.30–1.56)	0.73 (0.39–1.36)

Transect 3

Table C13. Maximum likelihood estimates crown extent transition intensities for the no LM well effect and LM well Markov models (–2 time log likelihood: 946.17; 95% confidence intervals in brackets).

State change	No LM bore effect transition rates	LM bore effect transition rates	Log linear effect of LM bore
1➞2	0.05 (0.01–0.18)	0.03 (0.004–0.23)	-1.12 (-3.64–1.39)
2➞1	0.63 (0.39–1.03)	1.23 (0.72–2.09)	1.37 (0.37–2.37)
2➞3	0.43 (0.24–0.77)	0.39 (0.15–0.97)	-0.21 (-1.37–0.96)
3➞2	0.06 (0.01–0.28)	0.03 (0.002–0.47)	-1.57 (-4.52–1.39)
3➞4	0.868 (0.63–1.20)	1.00 (0.60–1.67)	0.30 (-0.35–0.95)
4➞3	0.14 (0.09–0.22)	0.17 (0.09–0.30)	0.41 (-0.51–1.34)
4➞5	0.28 (0.20–0.39)	0.38 (0.25–0.59)	1.46 (0.38–2.54)
5➞4	0.53 (0.31–0.91)	1.08 (0.60–1.95)	0.646 (0.01–1.29)

Table C14. Ratio of transition intensities between crown extent states for the no LM well effect and LM well Markov models (95% confidence intervals in brackets).

State change comparison	No LM well effect	LM well effect
2➞3 v 2➞1	0.68 (0.32–1.45)	0.32 (0.11–0.90)
3➞4 v 3➞2	14.17 (3.0–66.94)	34.87 (2.03–599.5)
4➞5 v 4➞3	2.05 (1.17–3.58)	2.29 (1.10–4.77)

Table C15. Crown extent model maximum likelihood estimates of mean sojourn times (years) for the no LM well effect and LM well Markov models (95% confidence intervals in brackets).

State	No LM well effect	LM well effect
State 1	20.03 (5.61–71.53)	34.43 (4.42–268.44)
State 2	0.94 (0.65–1.38)	0.62 (0.39–0.99)
State 3	1.08 (0.78–1.48)	0.97 (0.59–1.60)
State 4	2.40 (1.84–3.12)	1.82 (1.28–2.59)
State 5	1.88 (1.10–3.20)	0.97 (0.51–1.67)

Table C16. Maximum likelihood estimates of epicormic growth transition intensities for the no LM well effect and LM well Markov models (–2 time log likelihood: 784.984; 95% confidence intervals in brackets).

State change	No LM bore effect transition rates	LM bore effect transition rates	Log linear effect of LM bore
1➞2	0.56 (0.41–0.72)	0.88 (0.64–1.22)	0.93 (0.44–1.42)
2➞1	1.59 (1.23–2.06)	2.16 (1.48–3.15)	0.63 (0.11–1.15)
2➞3	0.67 (0.37–1.21)	1.48 (0.79–2.77)	1.66 (0.45–2.87)
3➞2	3.26 (2.01–5.29)	3.58 (1.87–6.85)	0.19 (-0.78–1.17)

Table C17. Ratio of transition intensities between epicormic growth states for the no LM well effect and LM well Markov models (95% confidence intervals in brackets).

State change comparison	No LMPB effect	LMPB effect
2➞1 v 2➞3	2.39 (1.25–4.56)	1.45 (0.69–3.04)

Table C18. Epicormic growth model maximum likelihood estimates of mean sojourn times (years) for the no LM well effect and LM well Markov models (95% confidence intervals in brackets).

State	No LM well effect	LM well effect
State 1	1.78 (1.39–2.27)	1.13 (0.82–1.57)
State 2	0.44 (0.34–0.57)	0.27 (0.20–0.38)
State 3	0.31 (0.19–0.50)	0.28 (0.15–0.53)

D. UNDERSTOREY SPECIES LIST

Table D1. Understorey species list for Site B from survey transects during the study period

Species	Common Name
Acacia stenophylla	River Cooba
**Arctotheca calendula*	Capeweed, Cape Dandelion
Atriplex semibaccata	Creeping Saltbush
Austrostipa sp.	
**Brassica tournefortii*	Mediterranean Turnip
**Bromus rubens*	Red Brome
Bulbine bulbosa	Native Leek
Bulbine semibarbata	Native Leek, Wild Onion, Leek Lily
Calandrinia eremaea	Small Purslane
Calotis cuneifolia	Purple Burr Daisy
**Centaurea melitensis*	Maltese Cockspur
Centipeda minima	Spreading Sneezeweed
Chamaesyce drummondii	Caustic Weed
Cotula australis	Common Cotula
Cotula bipinnata	Ferny Cotula
Crassula colligata ssp. colligata	
Cyperus gymnocaulos	Spiny Sedge
**Ehrharta longiflora*	Annual Veldtgrass
Einadia nutans ssp.	Climbing Saltbush
Eleocharis acuta	Common Spike-rush
Enchylaena tomentosa var.	Ruby Saltbush
Eucalyptus camaldulensis var. camaldulensis	River Red Gum
Eucalyptus largiflorens	Black Box
Euchiton involucratus	Star Cudweed
**Gazania rigens*	Treasure Flower
Hordeum glaucum	Northern Barley Grass
Hypochaeris glabra	Smooth Cats-ear
Isolepis sp.	
Lachnagrostis filiformis	
Lepidium pseudohyssopifolium	Peppercress
**Medicago minima var. minima*	Woolly Burr Medic
**Mesembryanthemum nodiflorum*	Small Ice Plant
Moss sp.	
Muehlenbeckia florulenta	Lignum
**Petrorhagia dubia*	
**Phyla nodiflora*	Lippia
Picris squarrosa	
Plantago cunninghamii	Sago-weed

Species	Common Name
Pseudognaphalium luteoalbum	Jersey Cudweed
**Reichardia tingitana*	False Sowthistle
Rorippa eustylis	
**Schismus barbatus*	Arabian Grass
Sclerolaena muricata var. muricata	Black Rolypoly
Senecio cunninghamii	Bushy Groundsel
Senecio glossanthus	
Senecio pinnatifolius	Variable Groundsel
Setaria jubiflora	Warrego Grass
**Silene gallica*	
**Sonchus oleraceus*	Common Sowthistle
**Spergularia diandra*	Lesser Sand Spurrey
**Spergularia rubra*	Sand Spurrey
Sporobolus mitchellii	Rats-tail Couch
Stemodia florulenta	Blue-rod
**Vulpia bromoides*	Squirrel Tail Fescue, Silver Grass
**Vulpia myuros f. 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

ANOSIM — Analysis of similarities (ANOSIM) provides a way to test statistically whether there is a significant difference between two or more groups of sampling units.

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 test — A hydrological test performed on a well, aimed to increase the understanding of the aquifer properties, including any interference between wells, and to more accurately estimate the sustainable use of the water resources available for development from the well

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

Aquitard — A layer in the geological profile that separates two aquifers and restricts the flow between them

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

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

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

Epicormic growth — The sprouting of new shoots from the main trunk or primary (and less commonly secondary) branches of the tree. Epicormic growth is produced by a tree under physiological stress. The extent to which a tree has the capacity to produce epicormic growth depends on the prevailing conditions and the trees physiological capacity to respond.

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

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

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>

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

MDBA — Murray-Darling Basin Authority

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

MODFLOW — The U.S. Geological Survey modular finite difference flow model, which is a computer code that solves the groundwater flow equation

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

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

Obswell — Observation Well Network

Permeability — A measure of the ease with which water flows through an aquifer or aquitard, measured in m^2/d

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

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

SA Water — South Australian Water Corporation (Government of South Australia)

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

TDS — Total dissolved solids, measured in milligrams per litre (mg/L); a measure of water salinity

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

Underground water (groundwater) — Water occurring naturally below ground level or water pumped, diverted or released into a well for storage underground

Water body — Includes watercourses, riparian zones, floodplains, wetlands, estuaries, lakes and groundwater aquifers

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

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