FLOODPLAIN RESPONSE AND RECOVERY: COMPARISON BETWEEN NATURAL AND ARTIFICIAL FLOODS

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Abstract

The natural flow regime of the lower River Murray has been significantly altered due to abstraction and river regulation with the magnitude and duration of overbank floods decreasing and average interval between floods increasing. Overbank flows were largely absent between 1994 and 2010 during the "Millennium Drought", which resulted in severe stress and decline in the condition of long-lived vegetation on the floodplain. Artificial watering, which involved pumping water from the river into temporary floodplain wetlands, was used to improve tree condition and promote recruitment of native floodplain and amphibious understorey plants in selected areas. Similarly, groundwater management, where groundwater production bores lowered the floodplain water table, was used to draw low salinity river water into the floodplain aquifer to improve tree water availability. This study revisited artificial watering and groundwater management sites inundated by the flood in 2010/11 to compare the response of the floodplain to natural floods and previous management. This report presents a preliminary analysis of the data collected during this study and is presented in two parts:

1. Comparison of changes to soils, groundwater, understorey vegetation community composition and tree condition at the Bookpurnong floodplain after artificial watering and groundwater management from 2005 – 2008 and after the 2010/11 flood.

2. Comparison of changes to understorey vegetation community composition following the 2010/11 flood at the Chowilla (artificial watering from 2004 - 2010) and Pike (no artificial watering) floodplains.

Overbank flooding reduced soil and groundwater salinities in three ways: 1) bank recharge; 2) vertical infiltration from the surface; and 3) movement of low salinity groundwater upwards into the unsaturated zone, which increased tree water availability. The extent and degree of soil and groundwater freshening after the flood exceeded observations made after artificial watering and groundwater management at Bookpurnong during the drought. The tree canopy did not respond to the increased water availability after the flood as expected due to the high water tables caused by the elevated river levels that persisted during this study. Elevated water tables create waterlogged conditions, which are known to reduce tree health and vigour. It is likely that when river levels fall, that increased tree water availability will improve the canopy condition of the floodplain trees.

The understorey plant community responded to flooding at Pike and Chowilla, with increases in species richness recorded at both sites. The change in floristic composition before and after the 2010/11 flood was greater at Pike than at Chowilla. This was because artificial watering maintained more floodplain and amphibious species at Chowilla prior to the 2010/11 flood compared to at Pike, which was not inundated until the 2010/11 flood. The sedge, *Eleocharis acuta* was the only species that was present exclusively in areas that were artificially watered and the amphibious fern *Marsilea angustifolia* was present in greater numbers in areas that were artificially watered, but was present on both floodplains after the flood.

This study has shown that increases in tree water availability after flooding were greater than after artificial watering and groundwater management. However, increases in tree water availability caused by artificial watering and groundwater management were critical for the maintenance of long-lived tree and shrub water sources in high priority areas between floods. In the case of the floodplain understorey plant community, it retained the capacity to respond to flooding despite an extended period without overbank flooding or artificial watering. However, artificial watering of high priority areas provides important benefits for riverine and terrestrial trophodynamics and to maintain local propagule banks (or provide a source of propagules for downstream floodplains).

1. Introduction

Changes to floodplain hydrology have lead to a decline in the condition of the dominant riparian tree species (*Eucalyptus largiflorens,* black box; *E. camaldulensis,* river red gum; and *Acacia stenophylla,* river cooba) in the lower River Murray. Less than a quarter of all trees along the lower River Murray floodplain were classified as healthy in 2002/03 (Smith and Kenny 2005). River regulation and diversions for consumptive use have had negative environmental impacts on floodplain biota by changing the extent, duration and timing of inundation (Bren 1992; Bunn and Arthington 2002; George *et al.* 2005; Kingsford 2000; Shafroth *et al.* 2002; Walker 1985; Walker and Thoms 1993; Rood and Mahoney 1990; Rood *et al.* 1995).

In arid and semi-arid regions, river regulation and nearby irrigated agriculture can increase soil and groundwater salinity in floodplains, further reducing water availability for riparian vegetation (Busch and Smith 1995; Jolly et al. 1993). Increased soil and groundwater salinity increases osmotic potentials, which is equivalent to osmotic drought (Munns 1993). Riparian vegetation restoration needs to manage surface water – groundwater interactions to increase plant water availability. *A. stenophylla*, *E. camaldulensis* and *E. largiflorens* adopt an opportunistic water use strategy, using low salinity water sources when available (Doody *et al.* 2009; Holland *et al.* 2006; Mensforth *et al.* 1994; Thorburn *et al.* 1993; Holland *et al.* 2009a). This means that measurements of soil and groundwater salinities can be used to assess the effect of flooding or groundwater management on the riparian tree communities. During the Bookpurnong Experiment, *E. largiflorens* significantly increased predawn twig water potentials in response to a decrease in groundwater salinity (Doody *et al.* 2009; Holland *et al.* 2009b), indicating a reduction in tree water stress.

The reduction in flooding frequency has also had serious implications for the understorey floodplain community. The lack of regular flooding is an example of a ramp disturbance, similar to drought where the force of the disturbance increases as soil moisture decreases (Lake *et al.* 2006). The understorey vegetation of the River Murray floodplain, similar to other floodplain systems, is adapted to periodic replenishing disturbances that remove much of the extant vegetation and leave open areas with high soil moisture for new plants to colonise (e.g. Gippel and Blackham 2002; Shafroth *et al.* 2002; Dixon 2003; Nicol 2004; Lake *et al.* 2006). The majority of the floodplain understorey species in the Murray-Darling Basin are short-lived annuals, which will not germinate under water and die when flooded but germinate as flood waters recede (but not in response to rainfall); and therefore, require flooding to regenerate (Nicol 2004). These species are adapted to regular disturbance by floods (an example of Grime's (1979) r-selected species) and will be replaced by more drought tolerant species if flooding frequencies are reduced. There is anecdotal evidence to suggest that during the drought, many terrestrial, drought tolerant species (e.g. *Atriplex* spp. *Sclerolaena divaricata*, *Maireana* spp.) became more dominant in the floodplain environment (James Robertson pers. comm.; Gehrig *et al.* 2012).

A project co-funded by the Murray Darling Basin Commission, The Living Murray (TLM) Initiative, the South Australian Government's Centre for Natural Resource Management and the CSIRO Water for a Healthy Country Flagship investigated how the floodplain aquifer and tree communities responded to improved flooding regimes and groundwater management at Bookpurnong (Holland *et al.* 2009b). In addition, the Department for Water, Land and Biodiversity Conservation (DWLBC) established understorey monitoring sites to investigate the response of the understorey vegetation to these management actions (Berens *et al.* 2009a; Berens *et al.* 2009b; White *et al.* 2009). However, these projects did not experience a natural flood during the three-year experimental period. Instead, the project assessed the floodplain and vegetation response to artificial watering and groundwater management. In addition, condition and intervention monitoring funded by TLM and South Australian Murray Darling Basin Natural Resources Management Board (SAMDBNRMB) collected information regarding floodplain understorey communities of the Chowilla and Pike floodplains in response to artificial watering and extended periods without flooding (Marsland 2010; Nicol *et al.* 2010b; Gehrig *et al.* 2012).

The Goyder Murray Flood Ecology Project was initiated in response to the overbank flows (peak flow 94 GL d^{-1}) that occurred in 2010/11 following above average rainfall and high storage levels in the Murray-Darling Basin. This flood provided an opportunity to build on previous work by CSIRO, Department for Water (DfW), South Australian Murray Darling Basin Natural Resource Management Board, South Australian Research and Development Institute (SARDI) and Murray Darling Basin Authority (MDBA) to compare the floodplain and vegetation response to natural and artificial floods. The objective of Task T2 was to collect data to compare the response of the floodplain to natural and artificial floods by revisiting the Bookpurnong, Chowilla and Pike floodplains following the 2010/11 flood. There were two parts to the project:

1. At the Bookpurnong site, soil, groundwater and vegetation measurements were made to investigate the floodplain and vegetation response to natural flooding and groundwater management. The detailed ecophysiological measurements used to detect subtle changes in tree water availability between 2005 and 2008 were not appropriate after the flood due to the increased water availability. Instead, changes to long term tree water sources; specifically the degree of salt leaching and bank recharge following the flood in 2010/11 were compared to previously measured responses to artificial watering and groundwater management. These measurements will improve our understanding of the processes that control long term water availability in the floodplain tree communities.

2. Sites in the Chowilla and Pike systems were revisited following the natural flood in 2010/11 to compare the response of understorey vegetation in areas where artificial watering had (Chowilla) and had not (Pike) occurred. The understorey vegetation community data collected from these sites will improve our understanding of the effectiveness of artificial watering in comparison to natural over-bank floods for maintaining floodplain vegetation communities during low flows.

This report is a presentation of the data collected during this project, with a preliminary ecological analysis and interpretation. This data lays the foundation for future biophysical and ecological response modelling designed to improve our understanding and management of the lower River Murray floodplain.

2. Methods

Study sites

This study occurred on the Bookpurnong, Pike and Chowilla floodplains located in the floodplain (or valley section) of the South Australian River Murray (Figure 1).

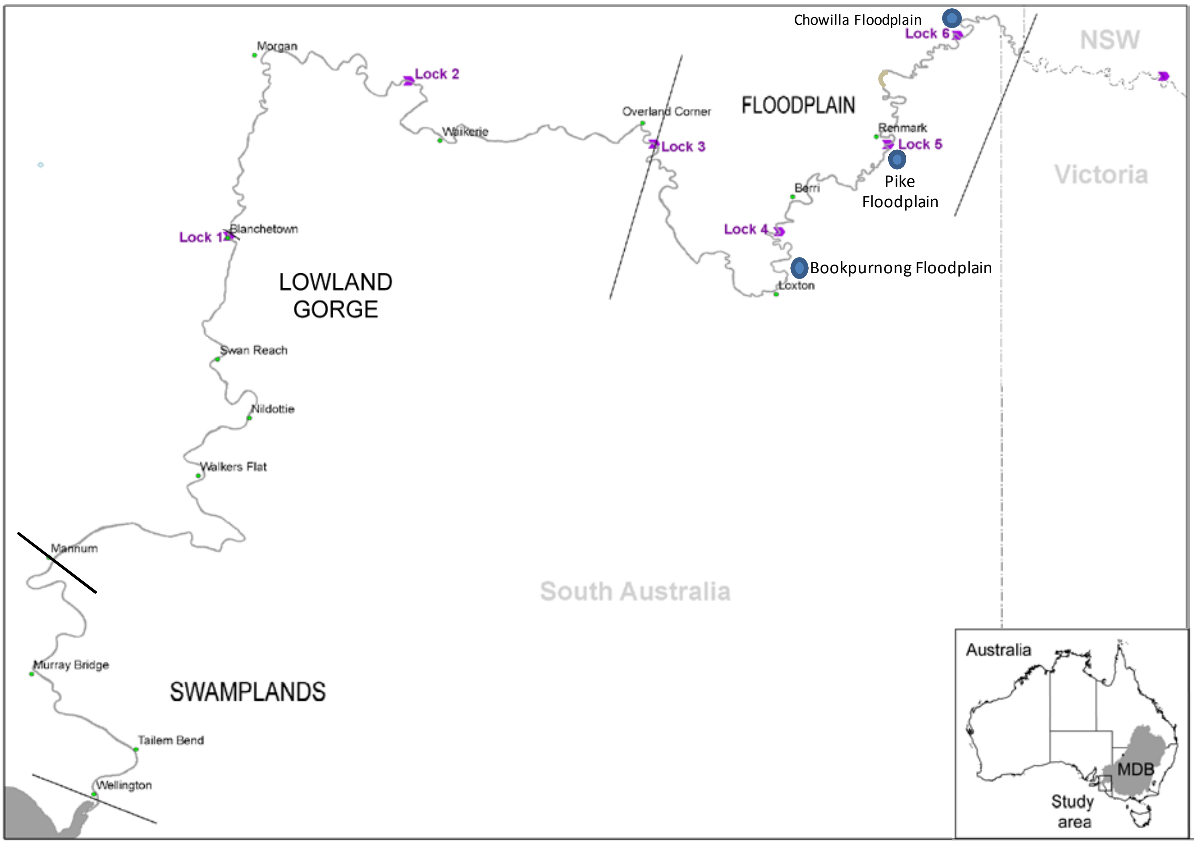


Figure 1 The Lower River Murray and geomorphic regions in South Australia; inset shows extent and position of the Murray-Darling Basin in Australia. Sites are represented by the blue circles.

The floodplains of the lower River Murray are vegetated by a mixture of *E. camaldulensis*, *E. largiflorens*, *A. stenophylla* and *Muehlenbeckia florulenta* (lignum) (O'Malley and Sheldon 1990). *E. camaldulensis* cover ~ 26% of the vegetated area (Smith and Kenny, 2005) and tend to grow in less saline, more frequently flooded parts of the floodplain, typically adjacent to water courses. Whereas, *E. largiflorens* cover ~ 38% of the vegetated area (Smith and Kenny, 2005) and are found at higher elevations away from the creeks, but with access to shallow groundwater (Slavich *et al.* 1999). *A. stenophylla* covers ~10% of the vegetated area and predominantly grows in association with *E. largiflorens* and/or *E. camaldulensis* (Smith and Kenny, 2005). *M. florulenta* cover ~14% of the vegetated area (Smith and Kenny, 2005) and grow in the lower, more frequently flooded areas of the floodplain (Craig *et al.* 1991). The 2002/03 DEH vegetation survey of the lower River Murray floodplain found that 49% of *E. camaldulensis*, 50% of *A. stenophylla* and 62% of *E. largiflorens* trees were unhealthy or dead (Smith and Kenny, 2005).

The climate in the lower River Murray is semi–arid with mild winters and long hot summers. Annual potential pan evaporation (1900 – 2000 mm) is over seven times the average annual rainfall (250 – 260 mm). Annual rainfall is highly variable, with Bureau of Meteorology records showing annual rainfall ranging between 87 and 556 mm since 1963 at Loxton (BoM Station 024024). Rainfall during the measurement period was above average, with 477 mm falling in 2010 and 389 mm in 2011

(Loxton Station 024024, Bureau of Meteorology 2012). Similarly, River Murray flows were above average, peaking at 94 GL d^{-1} in February 2011 and remaining high (10 – 40 GL d^{-1}) during 2011 (DfW 2012).

Soils on the lower River Murray floodplain generally consist of micaceous cracking clay deposits, known as the Coonambidgal Clay. This surficial clay layer can be up to 5 m thick, being thickest around relict and existing wetlands, with typically low hydraulic conductivity values (0.05–0.1 m d^{-1}; Doble *et al.* 2006). The Coonambidgal Clay overlies the Monoman Formation, an aquifer unit composed of unconsolidated sand deposits with variable clay and silt content that is hydraulically connected to surface water bodies on the floodplain (Jarwal *et al.* 1996). The Monoman Formation can be up to 30 m thick with a hydraulic conductivity of 10–35 m d^{-1}; Doble *et al.* 2006). Within the River Murray valley, the Monoman Formation aquifer is in direct contact with the regional Loxton-Parilla Sands and Murray Group aquifers. Groundwater salinities in the region range from relatively fresh in parts of the floodplain aquifer nearest the water bodies, to in excess of sea water salinity in parts of the regional and floodplain aquifers.

Bookpurnong

The Bookpurnong floodplain is located between the townships of Berri and Loxton and covers an area of approximately ~5 km^2 on the northern side of the River Murray, downstream of Lock and Weir No. 4. The Bookpurnong floodplain is ungrazed, privately owned and largely undeveloped, with the exception of an area that was levelled and cleared for irrigation near Site A (Figure 2). Drainage below the adjoining Bookpurnong Irrigation District, developed in 1964, created a localised groundwater mound in the regional Loxton-Parilla Sands aquifer, increasing the hydraulic gradient towards the floodplain and causing seepage of saline groundwater at the edge of the river valley. In order to maintain River Murray water quality, the Bookpurnong floodplain salt interception scheme (SIS) was constructed in 2005 to reduce the hydraulic gradient that drives the regional saline groundwater towards the River Murray by maintaining the water table between the SIS bores at river level. The SIS bores were operational between August 2005 and November 2006 and between May 2007 and the flood in 2010/11. An additional groundwater production bore (LM) was constructed at Transect B3 approximately 180 m from the river bank and connected to the SIS to lower water tables along Transect B3 by ~1 m. This hydraulic gradient was used to create a layer of fresh groundwater above the native saline groundwater. The LM bore was operational between August 2006 and November 2006 and between May 2007 and the flood in 2010/11. SIS and LM bore operation had not recommenced by the end of 2011.

Goyder Murray Flood Ecology Task T2 revisited two of the Bookpurnong experimental sites, Site A and Site B. Figure 2 shows the approximate extent of the flood to give an indication of which piezometers were inundated during the flood based on a 94 GL d^{-1} flood in the RiM FiM dataset (Overton *et al.* 2006). The floodplain was inaccessible due to flooding for most of 2011, with the vegetation and groundwater sampling trip delayed until early September 2011 and the soil sampling trip delayed until vehicular access was possible in late October 2011 (Figure 3).

- At Site A, a 3.7 ha topographical depression was artificially watered in 2005 and 2006 before being flooded naturally in 2010/11. Artificial watering maintained water at ~1 m maximum depth in the wetland during pumping, before the depression dried naturally within three to six months (White *et al.* 2009). Natural floodwaters inundated a larger area and persisted in the wetland until the end of 2011. Groundwater and vegetation monitoring sites were arranged in transects perpendicular to the wetland. Transects A1 – A3 were partially inundated by artificial watering and natural flooding. The control transects, A4 - A6 were not inundated by artificial watering, but were inundated by the natural flood.
- At Site B, the experimental design consisted of four transects of three or four piezometers each, that were aligned perpendicular to the river. Changes in aquifer and vegetation

conditions near the river (10-20 m from the river), in the middle of the riparian zone (70-110 m from the river) and at the distal edge of the riparian zone (130-190 m from the river) (Figure 2) were measured between December 2005 and December 2008 and between December 2010 and October 2011 (this report). Transect B2 was partially inundated by artificial watering in September 2006, before the flood runner creeks dried naturally within three to four months (Holland *et al.* 2009b). All transects were partially inundated by the natural flood in 2010/11.

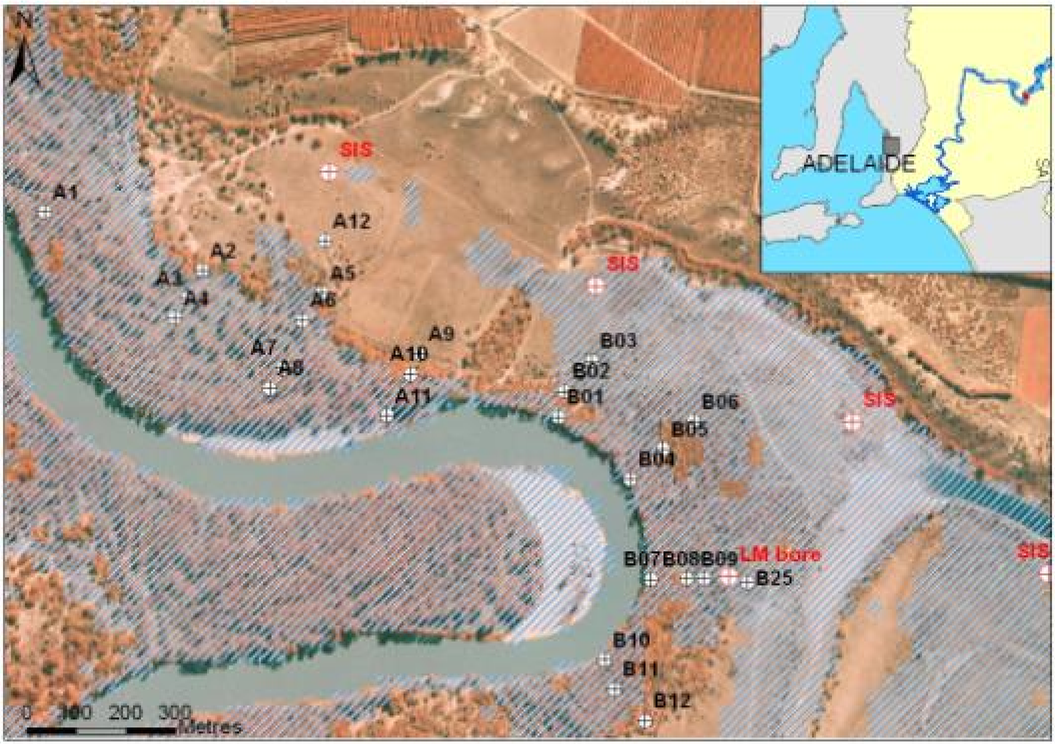


Figure 2 Location of piezometers at Site A and Site B at Bookpurnong. The blue hatching indicates the approximate extent of a 94 GL d^{-1} flood (RiM FiM Overton *et al.* 2006). The inset map shows the location of the Bookpurnong floodplain in the South Australian Riverland.

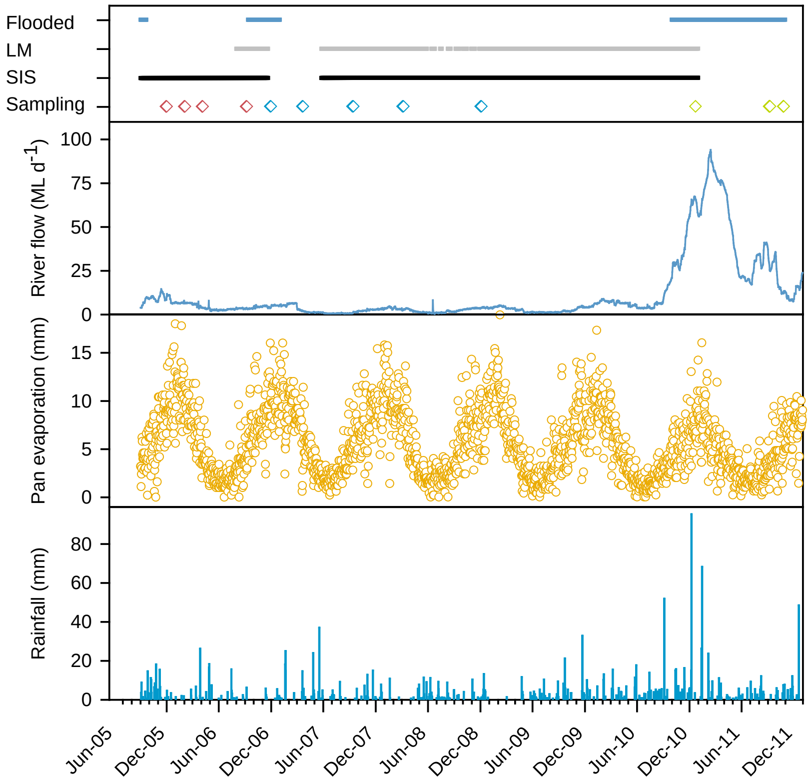


Figure 3 Bookpurnong project timeline. Timing of flooding, LM and SIS production bore operation, Bookpurnong sampling trips, river flow to South Australia (Station A4260200, DfW 2012), daily pan evaporation and rainfall at Loxton (Station 024024, SILO, 2012).

Groundwater and surface water

Surface water was collected by taking a grab sample from the River Murray near piezometer B01 in December 2010 and September 2011. Piezometers used for groundwater sampling were screened to a depth of 1 – 3 m below the water table. The locations of the piezometers used in this study are shown in Figure 2. Groundwater loggers were installed into existing piezometers on 22 December 2010 to monitor changes in groundwater levels and electrical conductivity during the flood. Groundwater levels were recorded manually using a Solinst dip meter (Solinst Canada Ltd, Georgetown Ontario) prior to pumping for groundwater sampling. Groundwater samples were collected after purging approximately three well volumes from each piezometer in September and October 2011. Groundwater electrical conductivity measurements were made by DWLBC staff who recorded salinity profiles using a YSI 600XL multiparameter (temperature, conductivity, depth) sonde (YSI Inc. Yellowsprings, Ohio) at approximately 0.1 m intervals below the water table.

Water samples for major ion chemistry were filtered through a 0.45 μm membrane filter in the field, with two samples collected, one with the addition of hydrochloric acid to bring the sample to a pH of ~2. Cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) were analysed by ion chromatography and HCO^- (as titration alkalinity) by potentiometric titration to a fixed end point of pH = 4.2. Cl^- was analysed by ion chromatography. Major ion chemistry was used to calculate total dissolved solids values of water samples.

An unfiltered sample was collected for stable isotope analysis in a 25 ml glass McKartney jar. The δ^2H and $\delta^{18}O$ content of water was determined by mass spectrometric techniques at the CSIRO laboratory in Adelaide, South Australia. δ^2H water samples were equilibrated with hydrogen using a platinum catalyst for ~1 hour using the automated water equilibration system (WES). $\delta^{18}O$ water samples were equilibrated with CO_2 at 50°C for 8 hours using WES, following Epstein and Mayeda

(1953), and analysed using a dual inlet stable isotope gas ratio mass spectrometer (PDZ Europa Ltd, UK). Isotopic concentrations are expressed as delta (δ) values per mille (‰) relative to the international standard, SMOW (Vienna – Standard Mean Ocean Water). Delta values are calculated using the following formula:

$$\delta = \left[\frac{R_i}{R_s - 1} \right] \text{x}\ 1000$$

where R_i is the ratio of the heavy to the light isotope in a sample and R_s the same ratio in the standard. Analytical uncertainty for naturally occurring waters is $\pm$ 1.0 ‰ (1 sd) for δ^2H and $\pm$ 0.15 ‰ (1 sd) for δ^{18}O.

Soils

Soil profiles were taken from near each piezometer using mechanical push tubes in October 2011. Soils were sampled at 0.5 m increments from the surface to the saturated zone (typically 3–4 m depth). Gravimetric water content (g g^{-1}) was measured by oven drying at 105°C for 24 h. Matric potential (Ψ_m, MPa) was determined using the 'filter paper' technique (Greacen *et al.* 1989). Total chloride was measured by ion chromatography, and then converted to the chloride concentration in the soil solution (mg L^{-1}) using the gravimetric water content. Osmotic potential (Ψ_π, MPa) was estimated from the chloride concentration of the soil solution ($[Cl^-]$, mg L^{-1}), calculated using the Van't Hoff equation and an osmolality of 1.848 Os kg water^{-1} for a 0.995 M NaCl solution at 20°C, which has an osmotic potential of 4.524 MPa. This relationship was used to calculate the effective osmotic potential of the soil water chloride concentration as:

$$\psi_\pi = [Cl^-] * \frac{4.524}{35.45}$$

This method assumes that all salts in the soil solution are present as NaCl and that the concentration used to calculate this relationship is appropriate for the range of soil salinities encountered by floodplain trees. Total soil water potential (Ψ, MPa) was obtained by summing the matric and osmotic potentials. Gravitational water potentials (0.01 MPa m^{-1}) are not included in this value as they are small (< 0.05 MPa) in comparison to measured matric and osmotic potentials.

Average soil chloride (S_{Cl^-}; kg Cl^- m^{-3}) values were calculated from the chloride concentration of the soil solution ($[Cl^-]$, mg L^{-1}), the soil sample gravimetric water content (g g^{-1}) and an assumed soil bulk density of 1500 kg m^{-3} using:

$$S_{Cl^-} = [Cl^-] * \theta_g * 1500 * 10^{-6} .$$

The physiological tolerance of the floodplain tree species is approximately –2.5 MPa for *E. camaldulensis* (Mensforth *et al.* 1994; Holland *et al.* 2009a; Doody *et al.* 2009) and –4.0 MPa for *A. stenophylla* and *E. largiflorens* (Doody *et al.* 2009; Miller *et al.* 2003; Holland *et al.* 2009b; Holland *et al.* 2006; Bramley *et al.* 2003; Zubrinich *et al.* 2000). This equates to soil chloride values of approximately 20 g Cl L^{-1} and 30 g Cl L^{-1}, respectively.

Vegetation

Six vegetation transects were established at Site A, and four vegetation transects at Site B to monitor vegetation response to management during the Bookpurnong Experiment (Berens *et al.* 2009; White *et al.* 2009). Each transect was approximately 200 m apart and aligned perpendicular to the river. The health of individually marked trees at Site A (200 trees) and Site B (240 trees) was reassessed in September 2011 using a combination of condition and response based on a model of declining tree health (Souter *et al.* 2010; Berens *et al.* 2009). Observations of bark form, presence of tip growth, reproductive status, canopy cover, canopy density and epicormic growth were made for all trees that could be located (Table 1). Tree health is reported in three bands: no live canopy, 1-25% live canopy and >25% live canopy.

Table 1 Tree health assessment criteria (Souter *et al.* 2010)

Species	Bark Form	Reproductive Status	Canopy Cover	Canopy Density	Epicormic Growth
A. stenophylla	Long term dead	None	Full canopy of dead leaves, no live leaves	Dead	No epicormic growth
E. camaldulensis	Cracked bark	Buds	No canopy, sparse dead leaves	No canopy/dead canopy	Minimal (11-25%)
E. largiflorens	Intact bark	Flowers	Sparse live canopy <10% cover of live leaves	Sparse (<10%)	Moderate (26-75%)
		Mature Buds	Minimal cover (10-25%)	Minimal (1-25%)	Dense (76-100%)
			Moderate cover (26-75%)	Moderate (26-75%)	
			Full cover (76-100%)	Dense (76-100%)	

Stem diameters of trees in the five water balance plots (Doody *et al.* 2009;, Holland *et al.* 2011) and the 240 individually marked trees at Site B were measured at breast height (1.3 m) in September 2011. Stem diameters were used to calculate stem basal area over bark (BAOB) and plot total basal area, both an indication of tree growth.

Understorey vegetation transects comprised eleven 1 x 1 m^2 quadrats spaced 10 m apart along the ten Site A and B transects. In each quadrat, the identity of each plant species was identified to the lowest level practicable and percentage cover estimated (Berens *et al.* 2009; White *et al.* 2009). Understorey vegetation was surveyed on eight occasions between 2005 and 2008 (White *et al.* 2009), and after the flood in October 2011. Site A was located in a flood runner, which was inundated at the time of sampling and Site B was located on a relatively flat area of floodplain that was dry at the time of sampling. Only Transects A1, A2 and A6 at Site A and Transects B1 – B4 at Site B were surveyed as the other transects were still inundated. A species list for both sites in Bookpurnong is presented. Species were also classified into functional groups (*sensu* Nicol *et al.* 2010b). Due to most of Site A being inundated at the time of sampling, no spatial or temporal comparisons of the plant community were made.

Pike and Chowilla

The Pike and Chowilla systems are large (4,000 and 16,500 ha respectively) floodplain and anabranch systems that bypass one of the low level weirs (Pike bypasses Lock 5 and Chowilla bypasses Lock 6) that regulate water levels in the lower River Murray (Figure 1). The floodplains are generally undeveloped (with the exception of grazing by domestic stock) and both contain a diversity of hydraulic habitats (fast flowing anabranches, slow flowing anabranches, permanent backwaters, temporary wetlands and floodplains) in a relatively small area (Sheldon and Lloyd 1990; Ecological Associates 2008).

The Pike floodplain is located between the townships of Remark and Berri in South Australia (Figure 4). Water enters the Pike system through two inlet creeks immediately above Lock 5, traversing Mundic Creek then flowing through to the Upper Pike which then diverges to the River Murray and the Lower Pike (Ecological Associates, 2008). A series of creeks and billabongs are fed by these major creeks, and at high river levels water also spreads into low-lying woodlands and wetlands.

Vegetation on the Pike floodplain includes a range of vegetation types including *E. largiflorens* (black box) woodlands, *E. camaldulensis* var. *camaldulensis* (river red gum) woodlands, *Atriplex* spp. (saltbush) shrublands and a range of aquatic and riparian vegetation types associated with the various temporary and permanent wetlands (Ecological Associates, 2008).

The Chowilla system is located upstream of Renmark and water enters the system through 13 different creeks upstream of Lock 6 and exits the system through Chowilla Creek downstream of Lock 6 (Figure 5). A complex of perennial and ephemeral waterbodies consisting of creeks, backwaters, billabongs, lakes and floodplains exist within the system (Sheldon and Lloyd 1990). The area supports a large range of species across many taxonomic groups and forms part of the Riverland Ramsar site, a wetland of international significance under the RAMSAR convention (O'Malley and Sheldon 1990). Vegetation on the Chowilla floodplain includes a range of vegetation types including *E. largiflorens* (black box) woodlands, *E. camaldulensis* var. *camaldulensis* (river red gum) woodlands, *Atriplex* spp. (saltbush) shrublands and a range of aquatic and riparian vegetation types associated with the various temporary and permanent wetlands (O'Malley and Sheldon 1990; Roberts and Ludwig 1990; Roberts and Ludwig 1991).

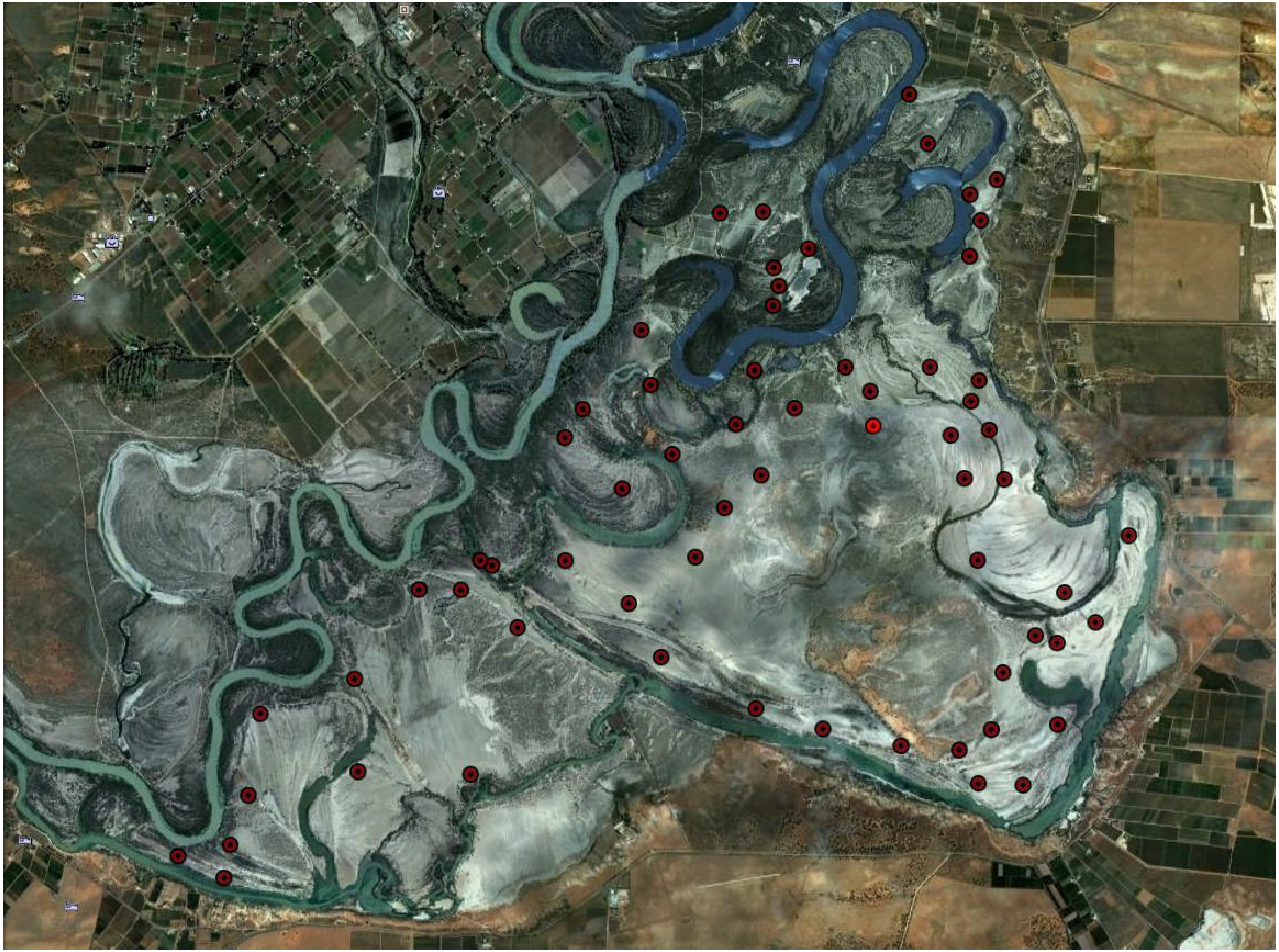


Figure 4 Aerial photograph of the Pike floodplain in February 2010. Red dots indicate floodplain vegetation monitoring sites.

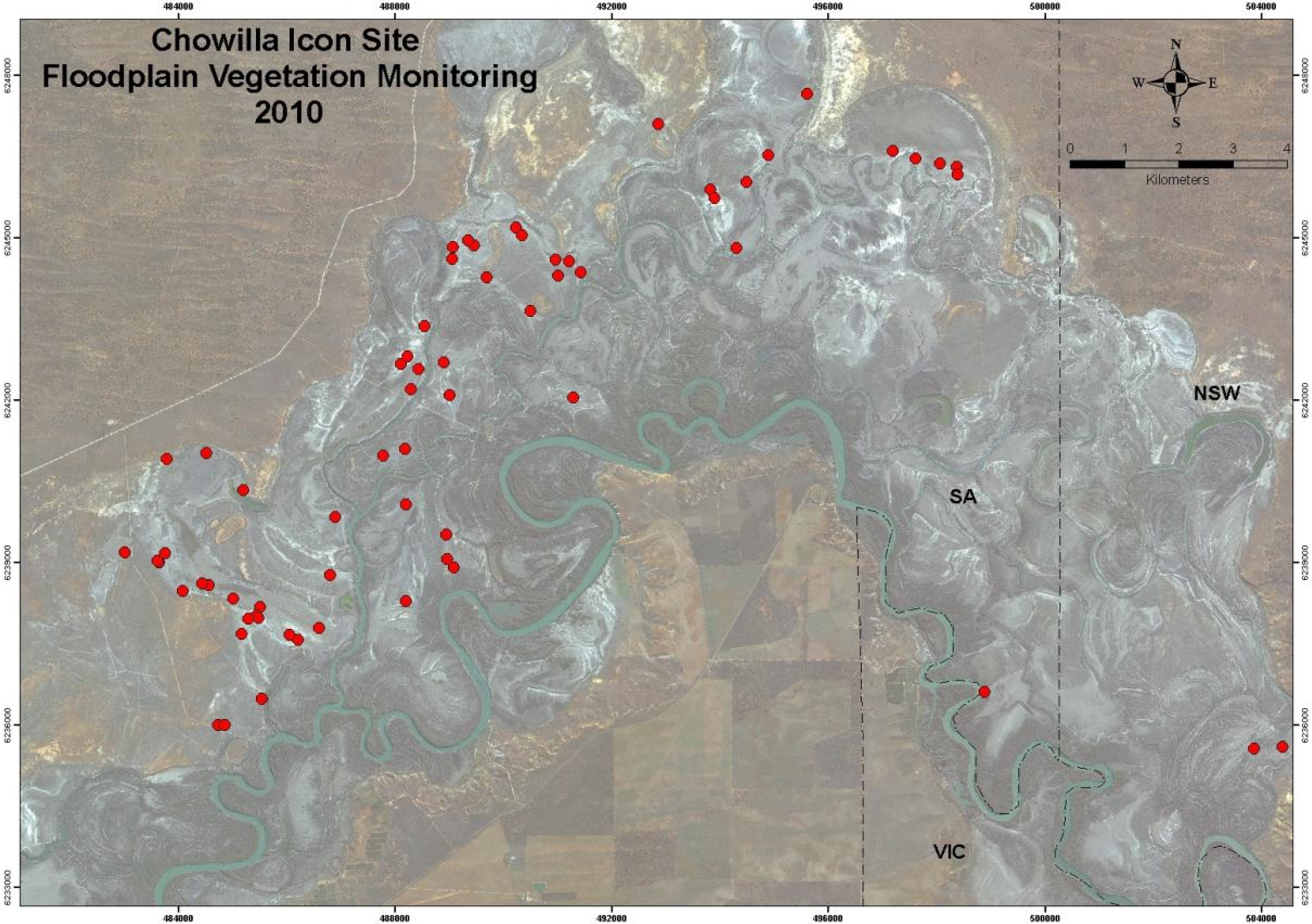


Figure 5 Aerial photograph of the Chowilla floodplain in February 2010. Red dots indicate floodplain vegetation monitoring sites. Map sourced from ArcGIS version 9.3.1 (Department of Heritage server: http://imagemapsa.deh.sa.gov.au).

The Chowilla and Pike floodplains have been severely impacted by river regulation and water abstraction, particularly the reduction in frequency and duration of overbank flows and subsequent changes to ground water levels and salinities (e.g. Sheldon and Lloyd 1990; Eldridge *et al.* 1993; Sharley and Huggan 1995; Taylor *et al.* 1996; Kingsford 2000; Overton and Jolly 2004; Cale 2009). Historically flows of 50 GL day^{-1}, which would inundate approximately 30% of the Chowilla floodplain, occurred on average once every two years and large floods of 100 GL day^{-1}, which occurred on average once every three years, now occur on average every three and ten years respectively (Sharley and Huggan 1995). The "Millennium Drought", coupled with river regulation and water abstraction, resulted in an absence of large overbank flows in the lower River Murray between 1996 and 2010.

Prior to the 2010/11 flood, the Pike and Chowilla floodplains were both showing severe signs of degradation with large areas of floodplain dominated by salt tolerant species and bare soil (Marsland 2010; Nicol *et al.* 2010a; Gehrig *et al.* 2012). However, the Chowilla system has received 27,417 ML of environmental water since the 2005-06 water year that has been pumped (or where possible gravity fed) into temporary wetlands (artificial watering) (Table 2). The primary aim of the artificial watering was to improve the condition of perennial overstorey vegetation, but there were also benefits for the understorey vegetation (Nicol *et al.* 2010b). Artificial watering reinstated the flooding disturbance (at the wetland scale) that was been lost from the majority of the floodplain during the drought, which resulted in a reduction in the abundance of terrestrial species and a corresponding increase in amphibious and floodplain species (Nicol *et al.* 2010b).

Table 2 Volumes of water pumped or gravity fed into temporary wetlands and area inundated on the Chowilla floodplain from the 2005-06 to 2011-12 water years (*total area artificially flooded = total area of wetlands that received environmental water, *i.e* some wetlands were watered more than once).

Water Year	Volume (ML)	Wetlands Watered	Area Artificially Flooded (ha)
2005-06	2,427	Brandy Bottle Waterhole, Chowilla Island Loop, Chowilla Oxbow, Kulcurna BB Floodrunner, Kulcurna, Kulcurna Sand Hill Runner, Lake Littra, Monoman Depression, Monoman Island Horseshoe, Punkah Creek Depression, Werta Wert Wetland	293
2006-07	0	–	0
2007-08	2,290	Lake Littra, Monoman Island Horseshoe, Punkah Creek Aquadam, Twin Creeks, Werta Wert Wetland	185
2008-09	4,333	Brandy Bottle Waterhole, Chowilla Horseshoe, Chowilla Island Loop, Chowilla Oxbow, Coppermine Complex, Gum Flat, Kulcurna, Lock 6 Depression, Monoman Depression, Pilby Creek, Pilby Lagoon, Pipeclay Creek Billabong, Punkah Creek Aquadam, Punkah Creek Depression, Punkah Creek Floodrunner, Punkah Island Horseshoe, Slaney Billabong, Woolshed Creek	1,177
2009-10	13,238	Coombool Swamp, Coppermine Waterhole, Kulcurna, Lake Limbra, Lake Littra, Monoman Island Horseshoe, Pilby Lagoon, Punkah Creek Aquadam, Twin Creeks, Werta Wert Wetland	1,053
2010-11	2,189	Chowilla Horseshoe, Chowilla Island Loop, Chowilla Oxbow, Coombool Swamp, Coppermine Complex, Gum Flat, Kulcurna, Lake Limbra, Lake Littra, Lock 6 Depression, Lock 6 Swamp, Monoman Depression, Monoman Island Horseshoe, Pilby Creek, Pipeclay Creek Billabong, Punkah Creek Aquadam, Punkah Creek Depression, Punkah Creek Floodrunner, Punkah Island Horseshoe, Slaney Billabong, Twin Creeks, Werta Wert Wetland, Woolshed Creek	2,020
2011-12	2,940	Coombool Swamp	430
Total	**27,417**		**2,175***

Understorey vegetation

Vegetation survey methods were the same as those used for other vegetation monitoring projects undertaken upstream of Wellington, namely Chowilla vegetation condition monitoring (Weedon and Nicol 2006; Weedon *et al.* 2007; Marsland *et al.* 2008; Marsland *et al.* 2009; Gehrig *et al.* 2010; Gehrig *et al.* 2012), Chowilla environmental watering (Nicol *et al.* 2010b), Chowilla fish and aquatic macrophyte works and measures understorey vegetation surveys (Zampatti *et al.* 2011), drought monitoring of wetlands downstream of Lock 1 (Nicol 2010), Markaranka Flat floodplain monitoring (Marsland and Nicol 2009) and Pike floodplain condition monitoring (Marsland 2010). The use of consistent methods enabled quantitative comparisons to be made between the Pike and Chowilla floodplains.

Sites were established in open areas across the Pike (Figure 4) and Chowilla floodplains (Figure 5) so that they:

- were located in areas that would be inundated by overbank flows
- had no tree overstorey
- were accessible by 4WD vehicle during dry conditions
- covered a range of vegetation types and grazing histories.

At each site three 15m x 1m quadrats were surveyed. Quadrats were arranged in a straight line parallel to elevation contours 50m apart. Each quadrat was divided into 15, 1m x 1m cells. The presence of each species that had live plants rooted within each cell was recorded to give a total score out of 15 for each quadrat. Cells containing no live plants were given a bare soil score of one. Sites were surveyed in January 2010 (pre-flood) and August 2011 (post-flood). Post-flood surveys were undertaken in August due to high river levels in January 2011, which prevented access. It was assumed that changes due to flooding would exceed seasonal differences, which are known to be small because there are few winter annuals in the floodplain (or valley section) of the South Australian River Murray (Nicol *et al.* 2010; Zampatti *et al.* 2011).

Plants were identified using keys in Cunningham *et al.* (1992), Jessop and Toelken (1986) and Jessop *et al.* (2006). In some cases, due to immature individuals or lack of floral structures, plants were identified to genus only. Nomenclature follows Barker *et al.* (2005).

Data Analysis

The differences in floristic composition between floodplains (Pike and Chowilla) and years (2010 to 2011) were analysed using non-metric multi-dimensional scaling (NMS) ordination (McCune *et al.* 2002) and two-factor PERMANOVA (Anderson 2001; Anderson and Ter Braak 2003). Sites were also categorised on the basis of inundation history (watered (2010 only), watered + flooded (2011 only), flooded (2011 only) and unflooded) (Table 4; Table 4) and year and plant communities compared using NMS ordination and Group Average Clustering. Bubble plots displaying mean abundances of key species for each of the inundation history, year and site categories were constructed on the NMS ordination to show which taxa were causing any differences in plant communities between the aforementioned groups. All multivariate analyses used Bray-Curtis (1957) similarities to construct the similarity matrix and were undertaken using the package PRIMER version 6.1.12 (Clarke and Gorley 2006).

The aforementioned multivariate statistical analyses summarise complex multivariate data and present it in a fashion that can be displayed in two or three dimensions or as a probability. Detailed explanations of the techniques used to analyses differences in the understorey plant community are presented in McCune *et al.* (2002).

Table 3 List of Chowilla floodplain sites (surveyed in 2011) and inundation history (*Unflooded (2010 and 2011)* = sites that remained dry throughout survey period (2006 – 2011); *Unflooded (2010) Flooded (2011)* = sites flooded in 2010/11; *Watered 2010 + Flooded 2011* = sites watered in spring 2006, re-watered in spring 2009 and flooded in 2010/11. CC = Coppermine Complex; GF = Gum Flat) (from Gehrig *et al.* 2012).

	Not watered (2006 – 2010) Unflooded (2011)	*Not watered (2006 – 2010) Flooded (2011)*	*Watered (2006 – 2010) Flooded (2011)*
Site ID	4, 5, 6, 7, 8, 9, 11, 15, 16, 21, 25, 26, 38, 45, 52, 57, 58, 74, 76, 80, 82, 83, 84	1, 3, 10, 13, 14, 20, 27, 28, 29, 30, 31, 32, 33, 34, 36, 39, 40, 41, 44, 46, 47, 48, 49, 50, 51, 55, 56, 59, 60, 61, 75, 79, 85	CC: 2, 19, 22, 23 GF: 62, 63, 64, 65
Total	**23**	**33**	**8**

Table 4 List of Pike floodplain sites (surveyed in 2011) and inundation history (*Unflooded* = sites that remained dry throughout survey period across 2010-2011 and *Flooded* = sites flooded in 2010/11).

	Not watered (2006 – 2010) Unflooded (2011)	*Not watered (2006 – 2010) Flooded (2011)*
Site ID	1, 2, 3, 23, 27, 35, 39, 42, 43, 44	4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 24, 25, 26, 28, 29, 30, 31, 32, 34, 37, 38, 40, 41, 54, 56, 58, 59, 60, 61, 65
Total	10	39

*Note: Site IDs 33, 36, 45, 46, 47, 48, 49, 50, 51, 52, 53, 55, 57, 62, 63, 64 were not able to be surveyed in 2011.

3. Results

The results of Task T2 are presented in two parts:

1. Bookpurnong groundwater, surface water, soil and vegetation results for Sites A and B are presented including data collected between 2005 and 2008.

2. Pike and Chowilla understorey vegetation is compared between 2010 (pre-flooding) and 2011 (post flooding) for different inundation histories.

Bookpurnong

Groundwater and surface water

Groundwater salinity at Site A after the flood ranged between 1760 and 43,100 µS cm^{-1} (Table 5), being freshest where the wetland meets the river along Transect A1 and most saline at the distal edge of Transect A2. Eight of the 12 piezometers at Site A were inundated by the flood in 2010/11.

Table 5 Site A total dissolved solids (TDS, mg L^{-1}) and electrical conductivity (EC, µS cm^{-1}) for groundwater and surface water samples taken from the Bookpurnong floodplain in 2007, 2008 and 2011. The TDS and EC values are shown because TDS was not sampled on all dates. Shaded rows indicate the site was flooded. Transect number and distance to the river is shown for reference.

Piezometer	Transect	Dist to river	2007 (TDS)	2008 (TDS)	2011 (TDS)	2007 (EC)	2008 (EC)	2011 (EC)
Site A								
A1	A0	65	–	–	1585	480	340	3240
A2	A3	310	–	–	3005	39,300	33,100	5010
A3	A3	245	–	–	13,305	24,500	26,500	21,150
A4	A3	200	–	–	10,190	20,100	23,400	16,780
A5	A2	380	–	–	28,950	46,800	46,700	37,690
A6	A2	315	–	–	26,270	39,100	38,200	32,220
A7	A2	200	–	–	7060	13,170	14,730	12,170
A8	A2	150	–	–	2875	5870	5700	5270
A9	A1	205	–	–	31,885	51,000	–	38,740
A10	A1	170	–	–	6960	43,100	38,600	11,260
A11	A1	65	–	–	940	910	2930	1760
A12	A2	475	–	–	35,205	50,100	46,000	43,100
	River Murray	0	240	110	70	150	515	275

Along Transect A1, groundwater salinity between 2007 and 2011 was relatively constant near the river (1760 µS cm^{-1} at A11) and saline at the distal edge (>40,000 µS cm^{-1} at A9). Groundwater freshening was observed in the middle of Transect A1 at piezometer A10, where groundwater salinities fell from 38,600 $\mu S\ cm^{-1}$ in 2007 to 11,260 $\mu S\ cm^{-1}$ in 2011 (Figure 6). Groundwater freshening occurred at A10 even though the piezometer was not flooded in 2010/11, which indicates that there was lateral movement of water from the wetland into the floodplain aquifer at this site.

Groundwater salinities along Transect A2 were relatively unchanged between 2007 and 2011 in four of the five piezometers, despite three of these piezometers being flooded in 2010/11 (Figure 7). This indicates that vertical recharge through the soil profile, or leakage down the outside of the piezometer casings did not affect the measured groundwater salinity values. A small decrease in groundwater salinity was observed in piezometer A5 that was not flooded, but is located near a small depression and creek that were flooded, which suggests that there was lateral movement of water from this water body into the floodplain aquifer.

Small decreases in groundwater salinity were observed in the three piezometers along Transect A3 after being inundated in the 2010/11 flood. The greatest decrease in groundwater salinity occurred in piezometer A2 on the northern bank of the wetland, falling from 33,100 $\mu S\ cm^{-1}$ in 2007 to 5010 $\mu S\ cm^{-1}$ in 2011 (Figure 8). Piezometer A2 was flooded and is located on the edge of the wetland. This means that the observed groundwater freshening was most probably caused by a combination of lateral bank recharge or vertical infiltration of water through the soil profile. It may also have been caused by leakage down the outside of the piezometer casing, however this is unlikely as the soil chloride values at A2 also decreased.

There was an increase in groundwater salinity at the Site A control piezometer (A1), from 340 to 3240 $\mu S\ cm^{-1}$ between 2007 and 2011 (Figure 8). This increase in groundwater salinity may be caused by mixing of salt from the soil profile with the groundwater due to vertical infiltration when piezometer A1 was flooded in 2010/11.

River levels rose by over 2 m above normal pool level to 14.46 m AHD at the gauging station downstream of Lock 4 (Figure 6). Prior to the 2010/11 flood, groundwater gradients were away from the River Murray along Transects A1, A2 and A3. Groundwater levels were 0.2 to 0.3 m below river level nearest the river, increasing to 0.3 to 0.7 m below river level at the distal edges of the transects. The groundwater level at the control site (A1) was also 0.3 m below river level prior to the flood. Groundwater hydraulic gradients were reversed once River Murray water levels fell in October / November 2011. During this period, groundwater levels were up to 0.4 m above river level.

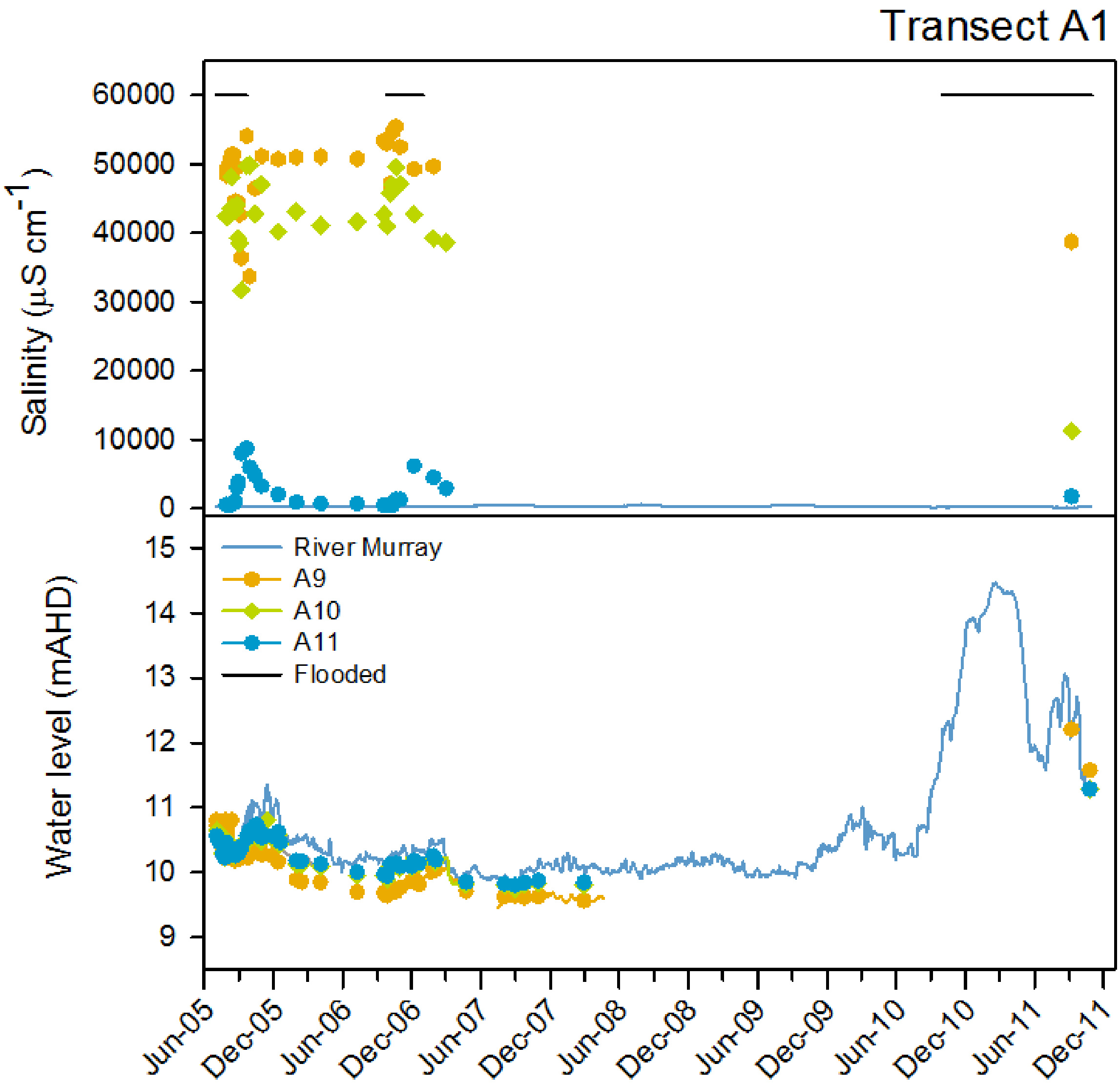


Figure 6 Transect A1 groundwater salinity (µS cm^{-1}) and water level (m AHD) measured in each piezometer between June 2005 and December 2011. River Murray water levels and wetland flooding are shown for reference.

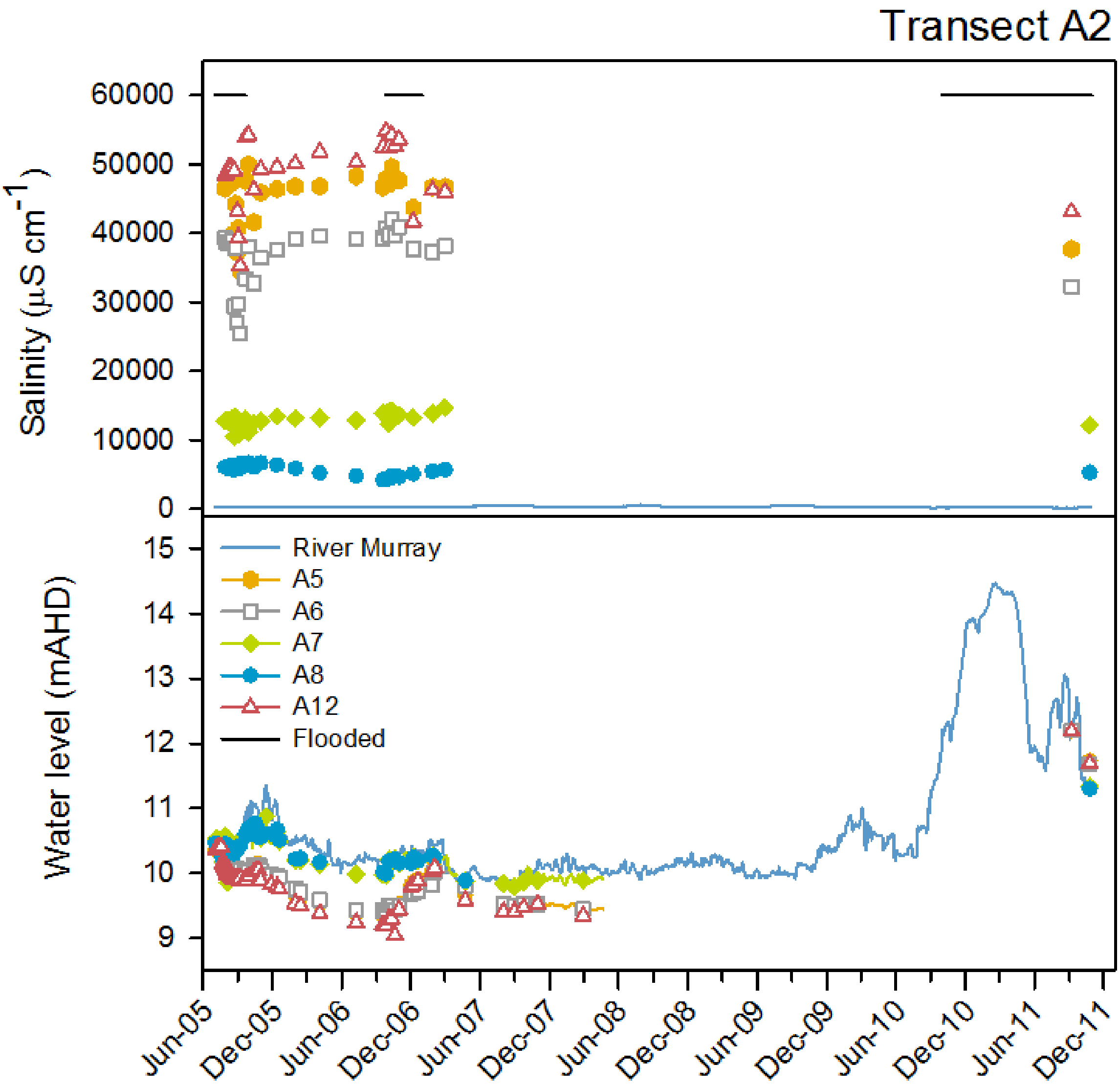


Figure 7 Transect A2 groundwater salinity (µS cm^{-1}) and water level (m AHD) measured in each piezometer between June 2005 and December 2011. River Murray water levels and wetland flooding are shown for reference.

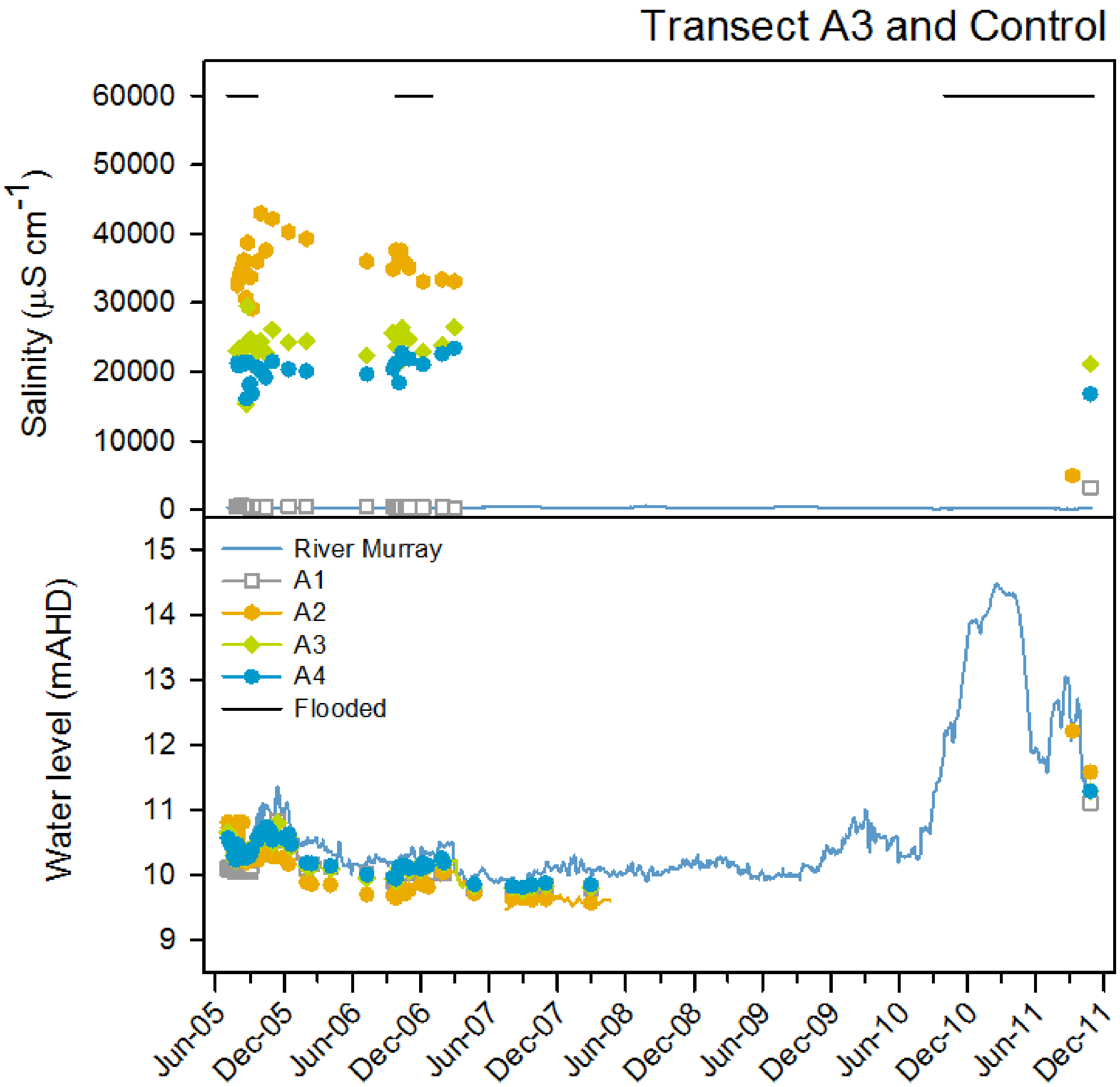


Figure 8 Transect A3 groundwater salinity (µS cm^{-1}) and water level (m AHD) measured in each piezometer between June 2005 and December 2011. River Murray water levels and wetland flooding are shown for reference.

At Site B, with the exception of Transect B1, groundwater salinity after the flood was relatively fresh in the piezometers near the river (410 – 860 μS cm^{-1}; Table 6) and in the middle of the riparian zone (620 – 1760 μS cm^{-1}). Groundwater salinities along Transect B1 were 3040 μS cm^{-1} near the river, 34,800 μS cm^{-1} in the middle of the transect and 22,100 μS cm^{-1} at the distal edge of the riparian zone. Groundwater salinities at the distal edge of the riparian zone were freshest at Transect B2 (5020 μS cm^{-1}) and most saline at Transect B4 (49,100 μS cm^{-1}). Six of the 13 piezometers at Site B were inundated by the flood in 2010/11. Flooded sites were located at the distal edge of Transects B1, B2 and B3, near the edge of the river along Transect B2 and in the middle of Transect B3. None of the piezometers along Transect B4 were flooded in 2010/11, indicating that this transect is more elevated.

Table 6 Site B total dissolved solids (mg L^{-1}) and electrical conductivity (EC, μS cm^{-1}) for groundwater and surface water samples taken from the Bookpurnong floodplain in 2006, 2007, 2008 and 2011. The TDS and EC values are shown because TDS was not sampled on all dates. Shaded rows indicate the site was flooded. Transect number and distance to the river is shown for reference.

Piezometer	Transect	Dist to river	2006 (TDS)	2007 (TDS)	2008 (TDS)	2011 (TDS)	2006 (EC)	2007 (EC)	2008 (EC)	2011 (EC)
Site B										
B01	B1	15	9,890	2,715	2,290	1,595	13,570	4085	3420	3040
B02	B1	70	35,670	dry	dry	21,390	41,310	dry	dry	34,800
B03	B1	150	38,415	dry	dry	14,340	41,470	dry	dry	22,100
B04	B2	20	320	295	275	195	765	705	660	470
B05	B2	110	27,210	28,840	7,780	890	32,660	33,890	13,160	1760
B06	B2	190	37,235	33,295	31,395	2,725	41,530	38,870	41,080	5020
B07	B3	20	120	205	150	155	320	445	400	410
B08	B3	90	36,680	385	410	295	41,270	820	885	620
B09	B3	130	37,935	2,320	585	450	41,440	4069	1265	910
B25	B3	180	–	36,285	34,310	22,050	–	41,570	43,940	33,600
B10	B4	20	120	135	275	400	334	330	605	860
B11	B4	90	20,160	29,365	22,525	800	26,040	36,000	31,430	1610
B12	B4	180	33,280	32,460	31,095	34,275	39,410	37,830	39,820	49,100
	River Murray	0	110	240	110	70	150	262	515	275

Modest decreases in groundwater salinity were observed along Transect B1 after the flood, falling from 44,900 to 34,800 μS cm^{-1} in the middle of the riparian zone (B02), and from 43,600 to 22,100 μS cm^{-1} at the distal edge of the riparian zone (B03) between 2008 and 2011 (Figure 9). Piezometer B02 was not flooded, which suggests that the decrease in groundwater salinity was caused by lateral recharge from the nearby flood runner creek. Piezometer B03 was inundated and is also located near this flood runner creek, which means that the observed reduction in groundwater salinity could have been caused by lateral recharge from the creek, or vertical infiltration through the soil profile. It is also possible that leakage down the outside of the piezometer casing occurred during the flood, however this is unlikely as the soil chloride values at B02 also decreased.

Larger declines in groundwater salinity occurred along Transect B2 between 2008 and 2011, falling from 4900 to 1750 μS cm^{-1} in the middle of the riparian zone (B05) and from 46,750 to 5020 μS cm^{-1} at the distal edge of the riparian zone (B06) (Figure 10). B05 in the middle of the riparian zone was not flooded in 2010/11, which suggests that the groundwater freshening was caused by lateral recharge from the nearby creek. Groundwater freshening was observed in B06 at the distal edge of the riparian zone when it was flooded in 2006 and 2010/11. It is most likely that this was caused by vertical infiltration of floodwater through the soil profile, although it may also indicate that leakage down the outside of the piezometer casing occurred.

Groundwater freshening along Transect B3 extended to the most distal piezometer, with groundwater salinity decreasing from 52,650 to 33,600 μS cm^{-1} at B25 (Figure 11). The hydraulic gradient created by the LM production bore maintained the low groundwater salinity across the riparian zone at Transect B3. It appears that the increased hydraulic gradient created by the flood displaced the fresh groundwater beyond the LM production bore to reduce groundwater salinities at B25. Alternatively, B25 was inundated during the 2010/11 flood, and therefore vertical infiltration of floodwater through the soil profile or possibly leakage down the outside of the piezometer casing may have reduced groundwater salinities.

Transect B4 was not inundated during the 2010/11 flood. However, groundwater salinity in the middle of the riparian zone fell from 31,430 to 1610 μS cm^{-1} between 2008 and 2011 (Figure 12). It is likely that this was caused by the lateral movement of low salinity groundwater away from the river in response to the hydraulic gradient caused by the flood. In contrast, groundwater at the distal edge of Transect B4 (B12) remained saline, being 46,400 μS cm^{-1} in 2008 and 49,100 μS cm^{-1} in 2011.

The stable isotope of water analyses indicate that the water sampled from the River Murray during the flood in 2010 (–23.2‰ δ^2H) and after the flood in 2011 (–29.0‰ δ^2H) had undergone minimal evaporation in comparison to values measured during the drought (–1.2‰ δ^2H in 2008) (Figure 9). δ^2H values along Transect B1 ranged between –20.4 and –17.1‰ δ^2H (Figure 9). The δ^2H values at B01 and B02 sampled in 2011 (both –20.4‰ δ^2H) appear to be a mixture of resident groundwater (–13.1‰ δ^2H at B01 in 2008) and floodwater. The origin of the groundwater at the distal edge of the riparian zone at Transect B1 (–17.1‰ δ^2H in B03) appears to be a mixture of isotopically depleted floodwater and resident groundwater from nearer the river. Alternatively, it may represent a mixture of floodwater and isotopically enriched soil water that infiltrated by bank recharge from the nearby creek, or through vertical flow paths. The isotopically enriched groundwater at the distal edge of the riparian zone indicates that the observed groundwater freshening at B03 was not caused by leakage down the outside of the piezometer casing during the flood.

At Transect B2, the δ^2H value at B04 near the river (–17.9‰ δ^2H) represents a mixture of resident groundwater (–15.0‰ δ^2H in 2008) and isotopically depleted floodwater (Figure 10), indicating that bank recharge occurred during the flood. The δ^2H values and groundwater freshening observed in the middle (–3.0‰ δ^2H) and distal (–9.7‰ δ^2H) parts of the riparian zone at Transect B2 indicate mixing of the resident groundwater (–16.7‰ δ^2H at B05 and –26.7‰ δ^2H at B06 in 2008) with isotopically enriched water. Evaporated floodwaters recharged from the nearby creek during artificial watering in 2006 (–8.2 to –3.1‰ δ^2H) are a likely source. The isotopically enriched groundwater at the distal edge of the riparian zone is not consistent with leakage down the outside of the piezometer casing during the flood.

There is strong evidence of lateral mixing along Transect B3 (Figure 11). Firstly, the groundwater δ^2H value (–26.1‰ δ^2H) near the river is similar to the measured floodwater value. Secondly, the δ^2H values in the middle and distal parts of the riparian zone measured after the flood (–18.6 to –11.3‰ δ^2H) represent a mixture of resident groundwater from across the riparian zone (–27.0 to –4.0‰ δ^2H in 2008). All of the groundwater samples were isotopically enriched (–26.1 to –11.3‰ δ^2H) relative to the measured floodwater samples, which indicates that leakage down the outside of the piezometer casing did not occur during the flood.

At Transect B4, there is evidence of bank recharge of isotopically depleted floodwater near the river (–25.5‰ δ^2H at B10) and displacement of resident groundwater from near the river (–4.2‰ δ^2H at B10 in 2008) towards the middle of the riparian zone (–5.4‰ δ^2H at B11 in 2011). In contrast to other Site B transects, groundwater freshening and movement of isotopically depleted groundwater did not extend to the distal edge (–29.0‰ δ^2H at B12 in 2011) of the riparian zone at Transect B4 (Figure 12). This is consistent with the use of Transect B4 as a reference transect between 2005 and 2008, as it is most distant from the groundwater production bores.

Groundwater levels at Site B along all transects prior to flooding were below river level by 0.2 to 0.4 m near the river, 0.4 to 0.7 m in the middle of the riparian zone, and 0.5 to 1.0 m at the distal edge of the riparian zone (Figure 9-12). During the rising flood stage in late 2010, river levels were 0.4 to 1.1 m above groundwater levels at Transect B4. During the flood recession, there was a reversal of hydraulic gradients, raising groundwater levels above river level by 0.4 m at Transect B1, 0.3 to 0.4 m at B2, by 0.4 to 0.6 m at B3 and by 0.2 to 0.4 m at B4 in late 2011.

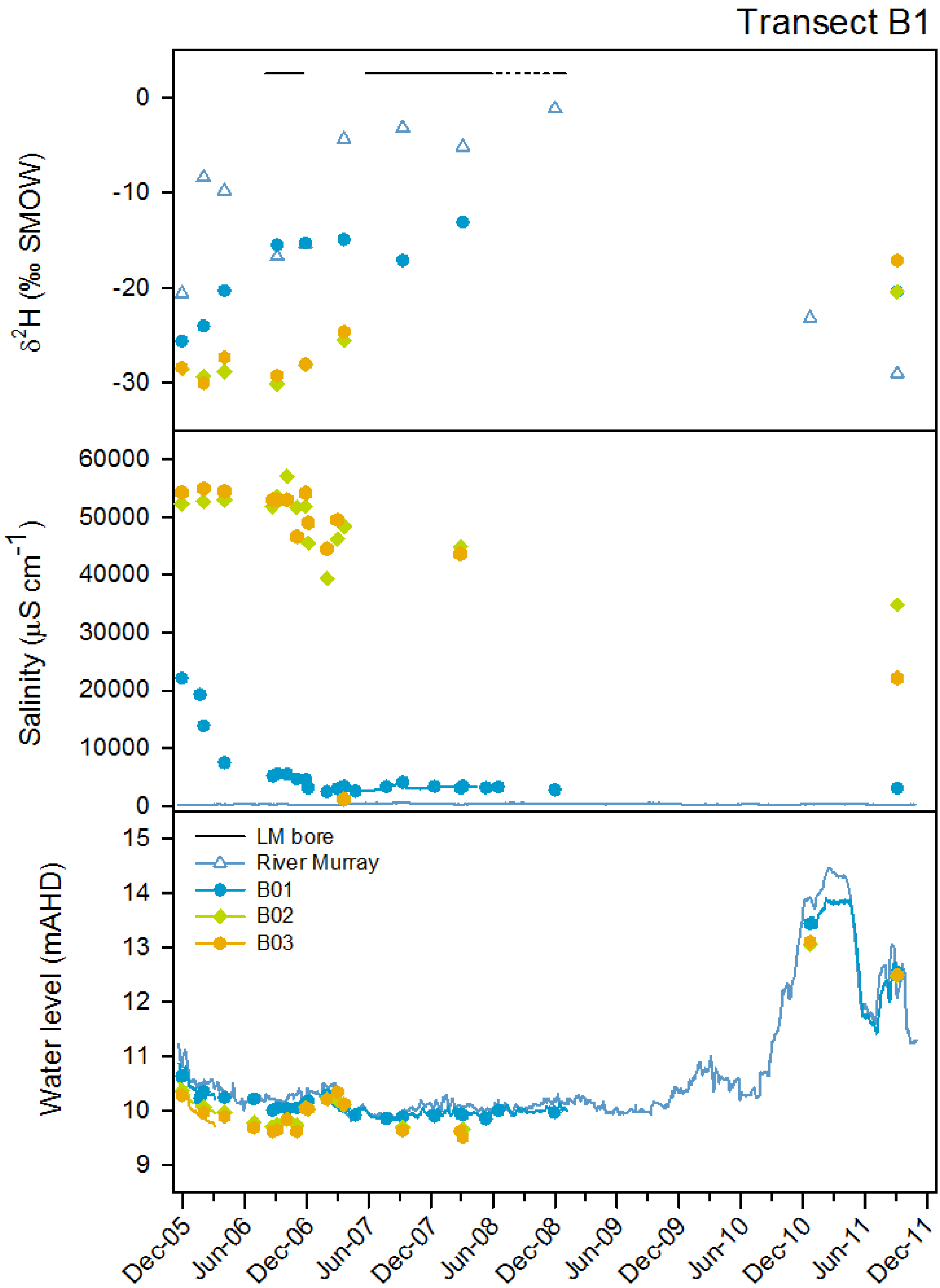


Figure 9 Transect B1 groundwater δ^2H (‰ vSMOW), salinity (µS cm^{-1}) and water level (m AHD) measured between June 2005 and December 2011. River Murray water levels and SIS operation are shown for reference.

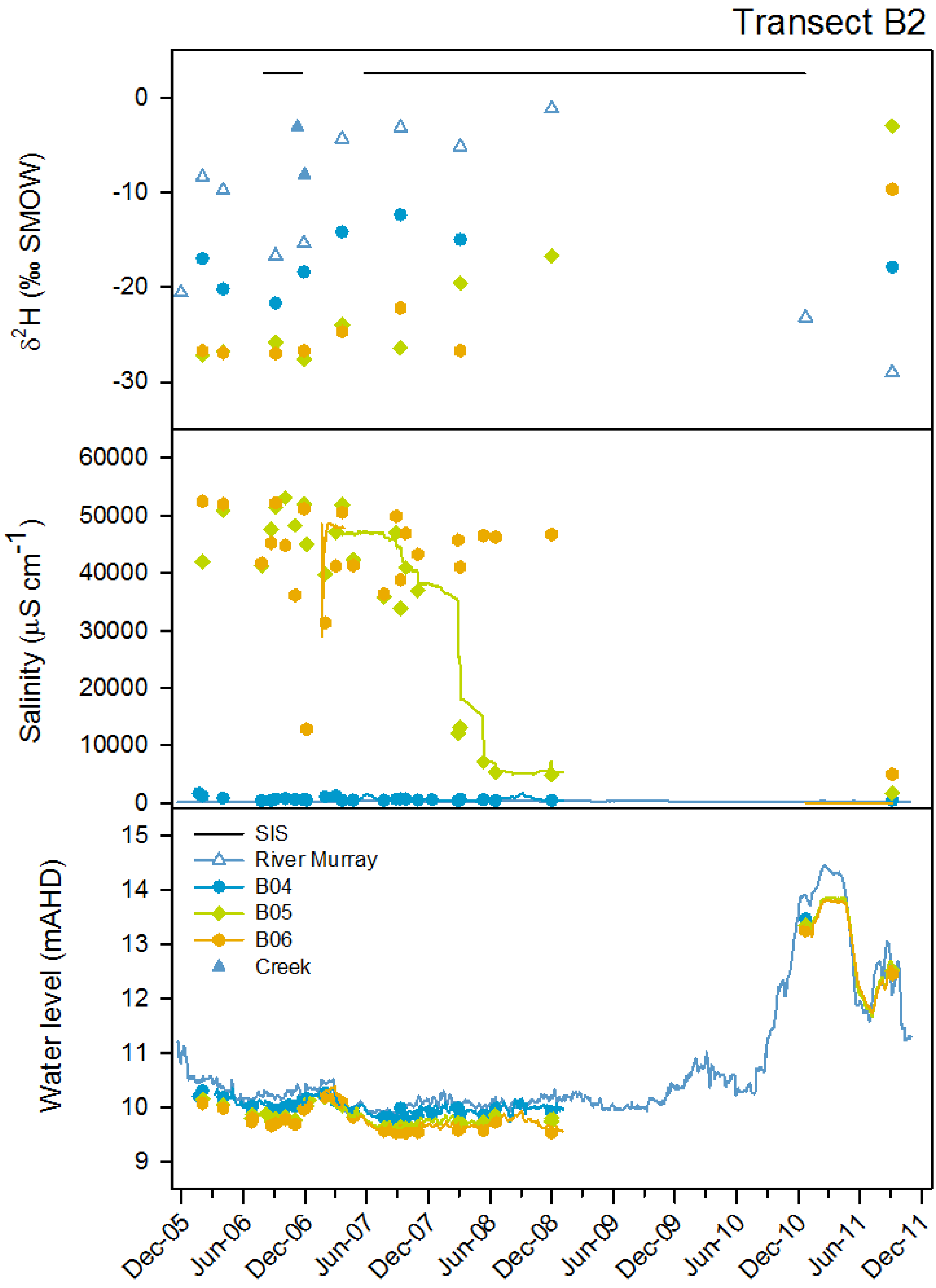


Figure 10 Transect B2 groundwater δ^2H (‰ vSMOW), salinity (µS cm^{-1}) and water level (m AHD) measured between June 2005 and December 2011. River Murray water levels and SIS operation are shown for reference.

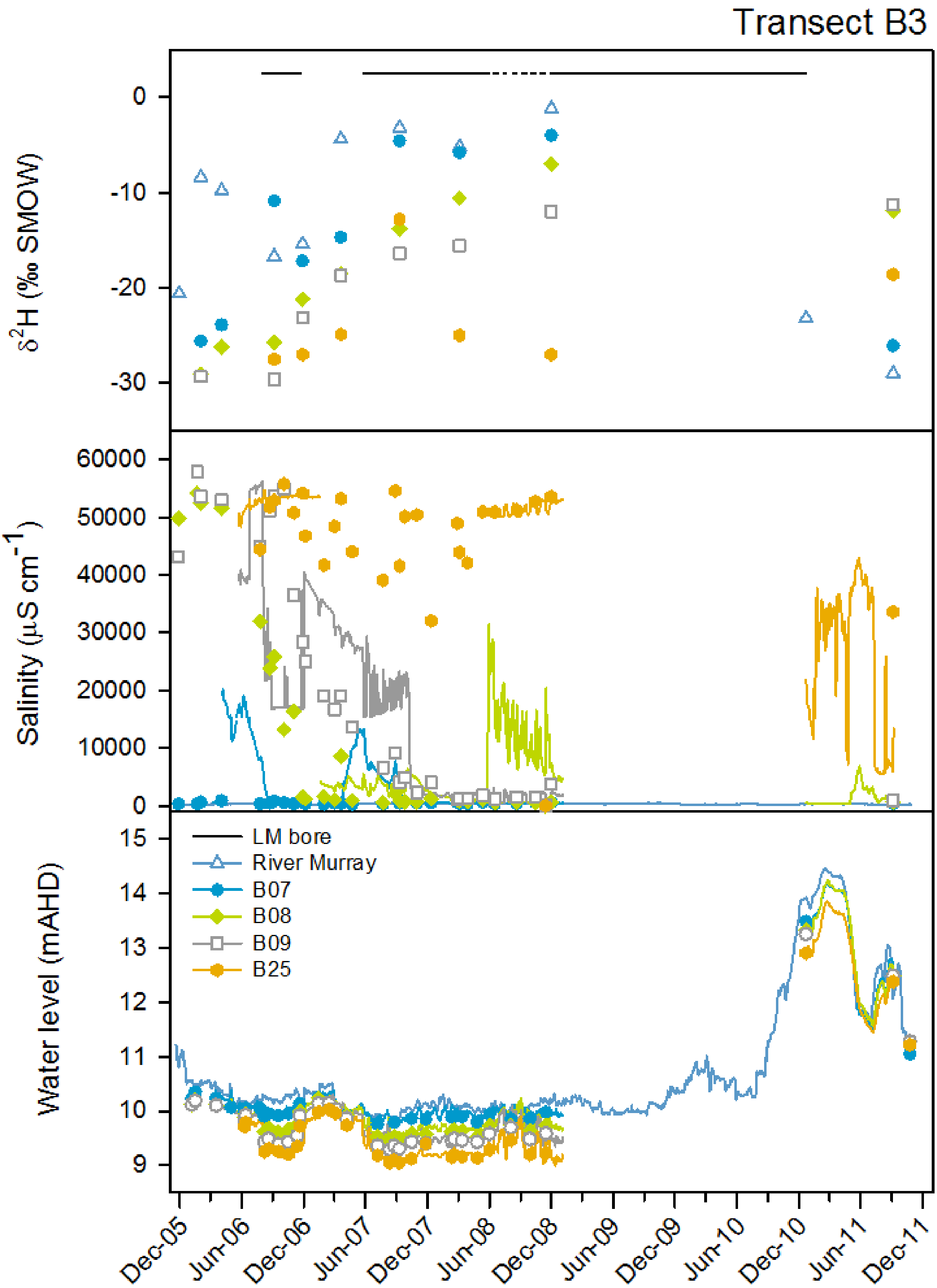


Figure 11 Transect B3 groundwater δ^{2}H (‰ vSMOW), salinity (µS cm^{-1}) and water level (m AHD) measured between June 2005 and December 2011. River Murray water levels and LM bore operation are shown for reference.

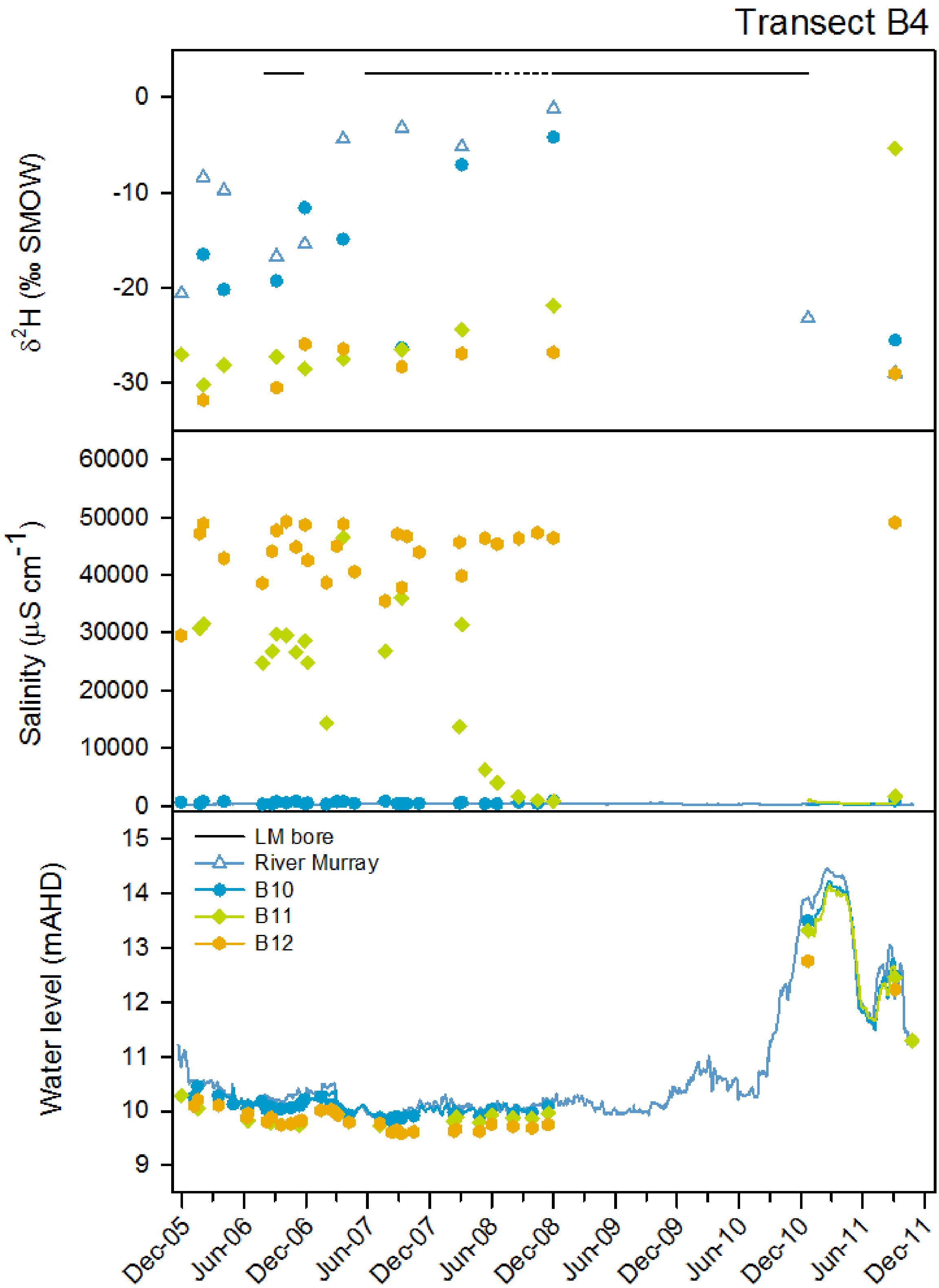


Figure 12 Transect B4 groundwater δ^2H (‰ vSMOW), salinity (µS cm^{-1}) and water level (mAHD) measured between June 2005 and December 2011. River Murray water levels and SIS operation are shown for reference.

Soils

At Transect A1, there was a reduction in stored soil chloride at A11 following inundation from 1.0 kg Cl^- m^{-3} in 2008 to 0.2 kg Cl^- m^{-3} in 2011 (Figure 13). The low salinity and consistent soil chloride profile suggests good mixing of soil water, possibly from vertical infiltration from the surface and / or vertical movement of low salinity groundwater upwards as the water table rose during the flood (Figure 14). Despite not being flooded, stored soil chloride at A10 decreased from 9 kg Cl^- m^{-3} in 2008 to 0.7 kg Cl^- m^{-3} in 2011 (Figure 13). The soil profile shows a reduction in soil chloride values between ~0.5 m depth and the water table, which suggests that there was lateral movement of low salinity water from the wetland through the bank in response to the 2 m rise in river levels during the flood (Figure 15). The increase in stored chloride observed at A9 from 10.6 kg Cl^- m^{-3} in 2008 to 13.5 kg Cl^- m^{-3} in 2011 (Figure 13) appears to be caused by the movement of high salinity groundwater up through the soil profile during the flood.

Flooding inundated three of the five piezometers along Transect A2, reducing stored chloride values from 7.7 kg Cl^- m^{-3} in 2008 to 4.6 kg Cl^- m^{-3} at A6 in 2011, from 3.9 kg Cl^- m^{-3} in 2008 to 0.6 kg Cl^- m^{-3} in 2011 at A7 and from 5.9 kg Cl^- m^{-3} in 2008 to 4.1 kg Cl^- m^{-3} in 2011 at A8 (Figure 13). The soil chloride profiles indicate that there was vertical movement of low salinity water from the surface to ~3.0 m depth at A6, to the maximum depth of 2.0 m at A7 and to ~1.5 m depth at A8 (Figure 14). Stored choride values were unchanged at A5 and A12 that were not flooded, with soil chloride profiles being consistent with previously measured profiles (Figure 15).

All three piezometers along Transect A3 were inundated during the flood in 2010/11. Flooding reduced stored chloride values from between 8.5 and 11.2 kg Cl^- m^{-3} in 2008 to between 2.5 and 4.3 kg Cl^- m^{-3} in 2011 at A2, A3 and A4 (Figure 13). The soil chloride profiles indicate freshening between 1.5 and 2.5 m depth at A2, between the surface and 2.0 m depth at A3 and between the surface and 1.5 m depth at A4 (Figure 14). This is consistent with bank recharge from the wetland at A2 and vertical infiltration of low salinity water during the flood at A3 and A4.

The Site A control site, A1 was inundated during the 2010/11 flood. Despite this, the stored chloride value (1.4 kg Cl^- m^{-3}) was unchanged between 2008 and 2011 (Figure 13). The soil chloride profile shows that there was a reduction in soil chloride values between the surface and ~1.5 m depth, suggesting that there was some movement of salt within this low salinity profile (Figure 14). This is consistent with the increase in groundwater salinity observed at A1 after the 2010/11 flood.

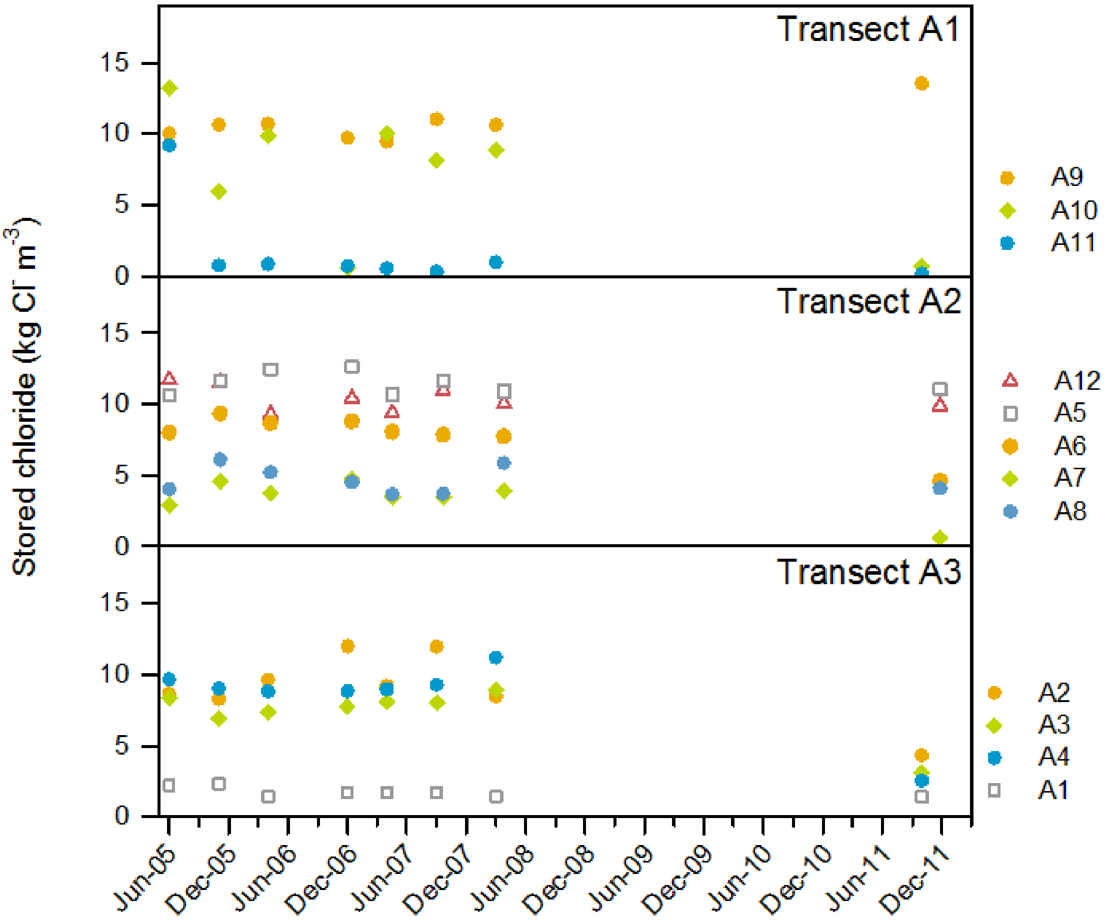


Figure 13 Site A soil chloride values (kg Cl^{-} m^{-3}) for soil profiles sampled between June 2005 and December 2011.

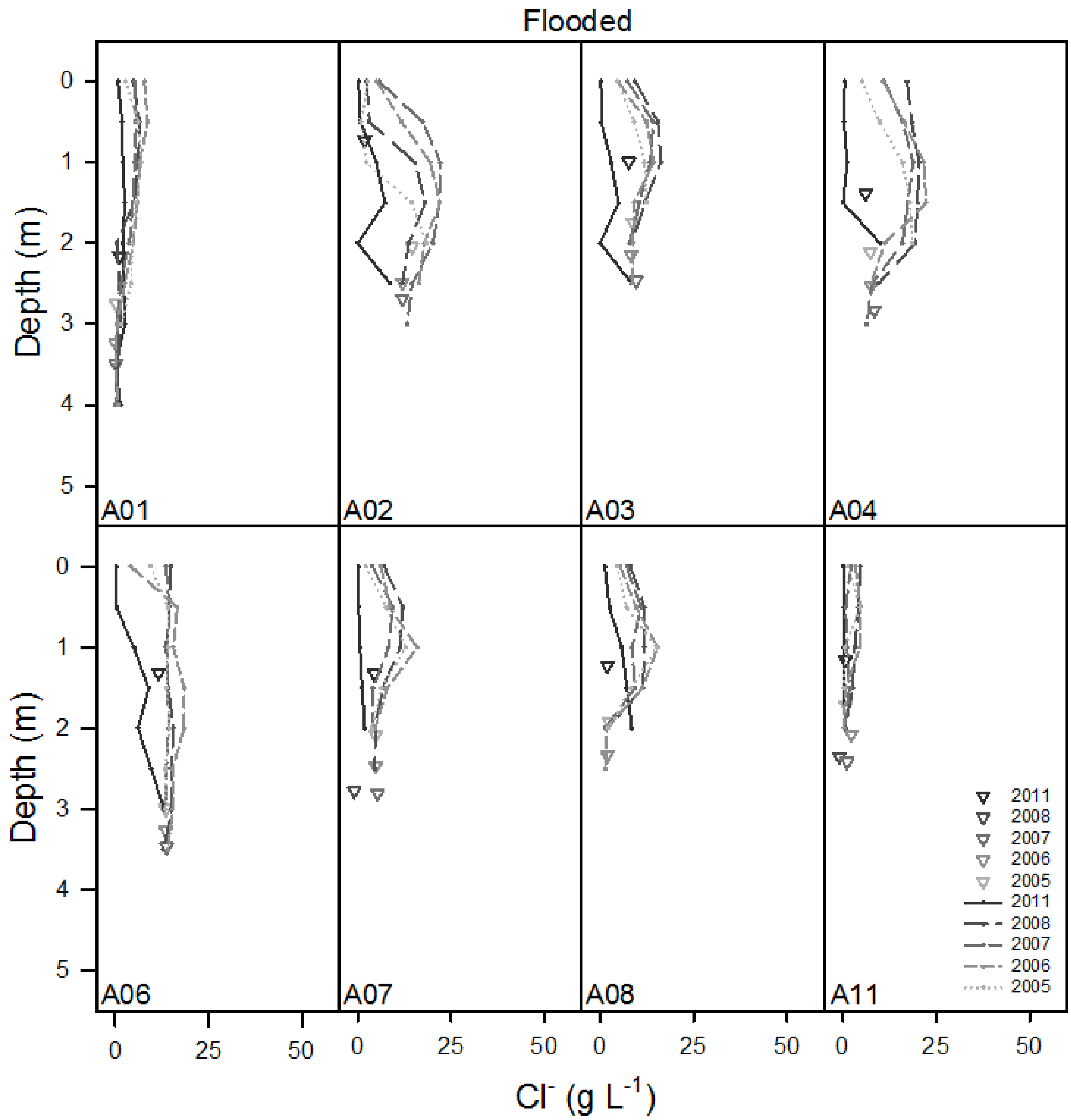


Figure 14 Flooded Site A soil chloride profiles (g Cl^{-} L^{-1}) sampled between June 2005 and December 2011.

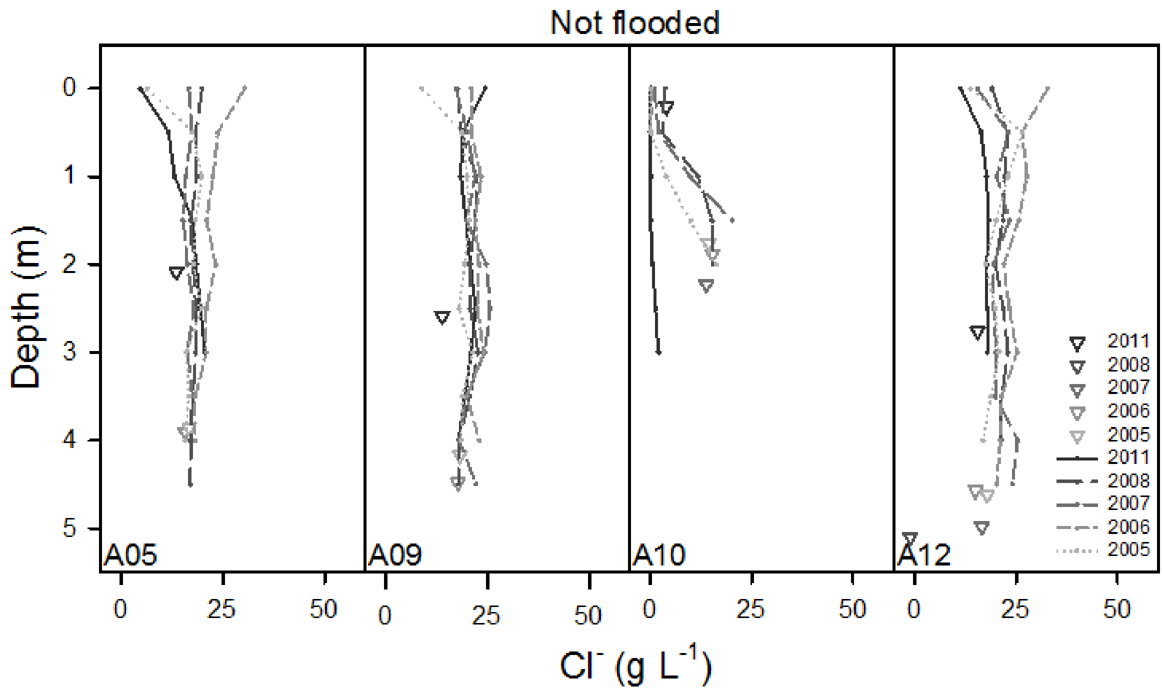


Figure 15 Not flooded Site A soil chloride profiles (g Cl^- L^{-1}) sampled between June 2005 and December 2011.

Flooding reduced stored chloride values along Transect B1, from 17.9 kg Cl^- m^{-3} in 2008 to 14.9 kg Cl^- m^{-3} in 2011 at B01 near the river, from 8.6 kg Cl^- m^{-3} in 2008 to 6.8 kg Cl^- m^{-3} in 2011 at B02 in the middle of the transect, and from 16.0 kg Cl^- m^{-3} in 2008 to 9.6 kg Cl^- m^{-3} in 2011 at B03 at the distal edge of the riparian zone (Figure 16). The soil chloride profiles indicate removal of salt from between 1.5 m and 3.0 m depth at B01, small decreases in soil chloride values throughout the entire profile at B02, and vertical movement of floodwater from the surface to ~2.0 m depth at B03 (Figure 17 and Figure 18). This is consistent with bank recharge from the river at B01, bank recharge from the nearby creek or vertical movement of low salinity groundwater from the water table through the soil profile at B02 and vertical infiltration of floodwater from the surface at B03.

Stored chloride values at all sites along Transect B2 fell from 4.9 kg Cl^- m^{-3} in 2008 to 3.5 kg Cl^- m^{-3} in 2011 at B04, from 13.0 kg Cl^- m^{-3} in 2008 to 7.6 kg Cl^- m^{-3} in 2011 at B05 and from 14.3 kg Cl^- m^{-3} in 2008 to 9.3 kg Cl^- m^{-3} in 2011 at B06 (Figure 16). The river and distal sites along Transect B2 were inundated during the 2010/11 flood. This is consistent with the soil chloride profiles, which show leaching of salts from the soil surface to the water table at B04 and to a depth of ~1.0 m at B06 (Figure 17). There was a reduction in soil chloride values between 2.5 and 3.0 m depth in the soil profile from B06, which may indicate upward movement of low salinity groundwater from the water table in response to elevated flood levels. The B06 soil profile taken in 2011 after the flood has a similar shape to that taken in 2006 after artificial watering, with low salinity soil between the surface and 1.0 m depth and a salt bulge below 1.5 m depth. The reduction in stored chloride observed at B05 appears to have been caused by the vertical movement of low salinity groundwater from the water table through the soil profile to within 0.5 m of the surface during the flood.

Reductions in stored chloride values were observed at the three sites along Transect B3 (B08, B09 and B25) that were inundated during the 2010/11 flood. Stored chloride values fell from 7.2 kg Cl^- m^{-3} in 2008 to 4.2 kg Cl^- m^{-3} in 2011 at B08, from 12.1 kg Cl^- m^{-3} in 2008 to 7.6 kg Cl^- m^{-3} in 2011 at B09 and from 17.0 kg Cl^- m^{-3} in 2008 to 4.0 kg Cl^- m^{-3} in 2011 at B25 (Figure 16). The soil chloride profiles show that there was leaching of salt by vertical movement of flood water from the surface and by the vertical movement of low salinity groundwater from the water table through the soil profile to within 0.5 m of the surface during the flood.

Flooding did not inundate the sites at Transect B4. Despite this, reductions in stored chloride values were observed at all three sites (Figure 16). The soil chloride profiles show that there was leaching of salts between 0.5 m depth and 2.0 m at B10, and 3.0 m at B11 and B12 (Figure 18). This is consistent with the vertical movement of low salinity groundwater from the water table through the soil profile to within 0.5 m of the surface during the flood.

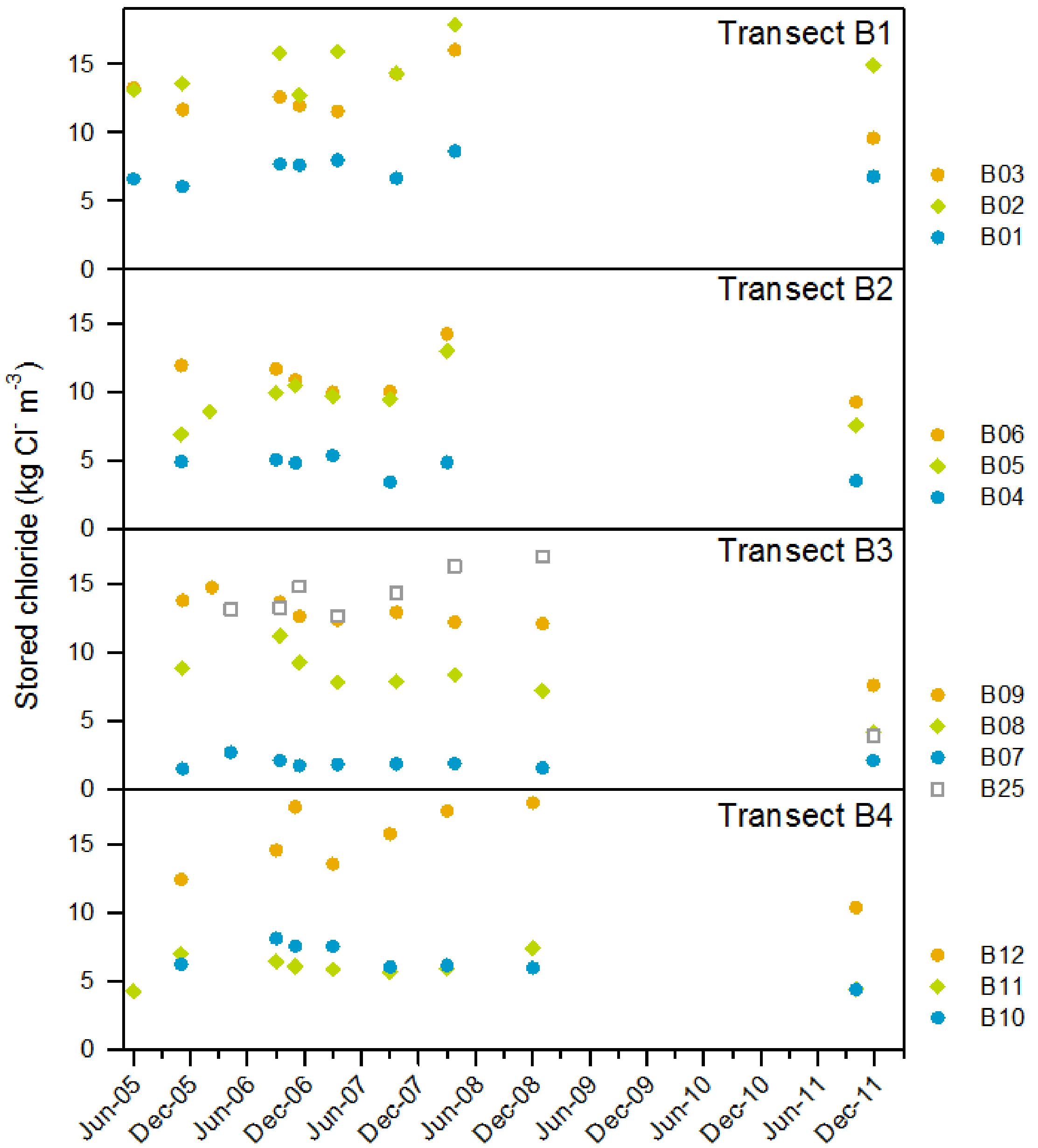


Figure 16 Site B soil chloride values (kg Cl^{-} m^{-3}) for soil profiles sampled between June 2005 and December 2011.

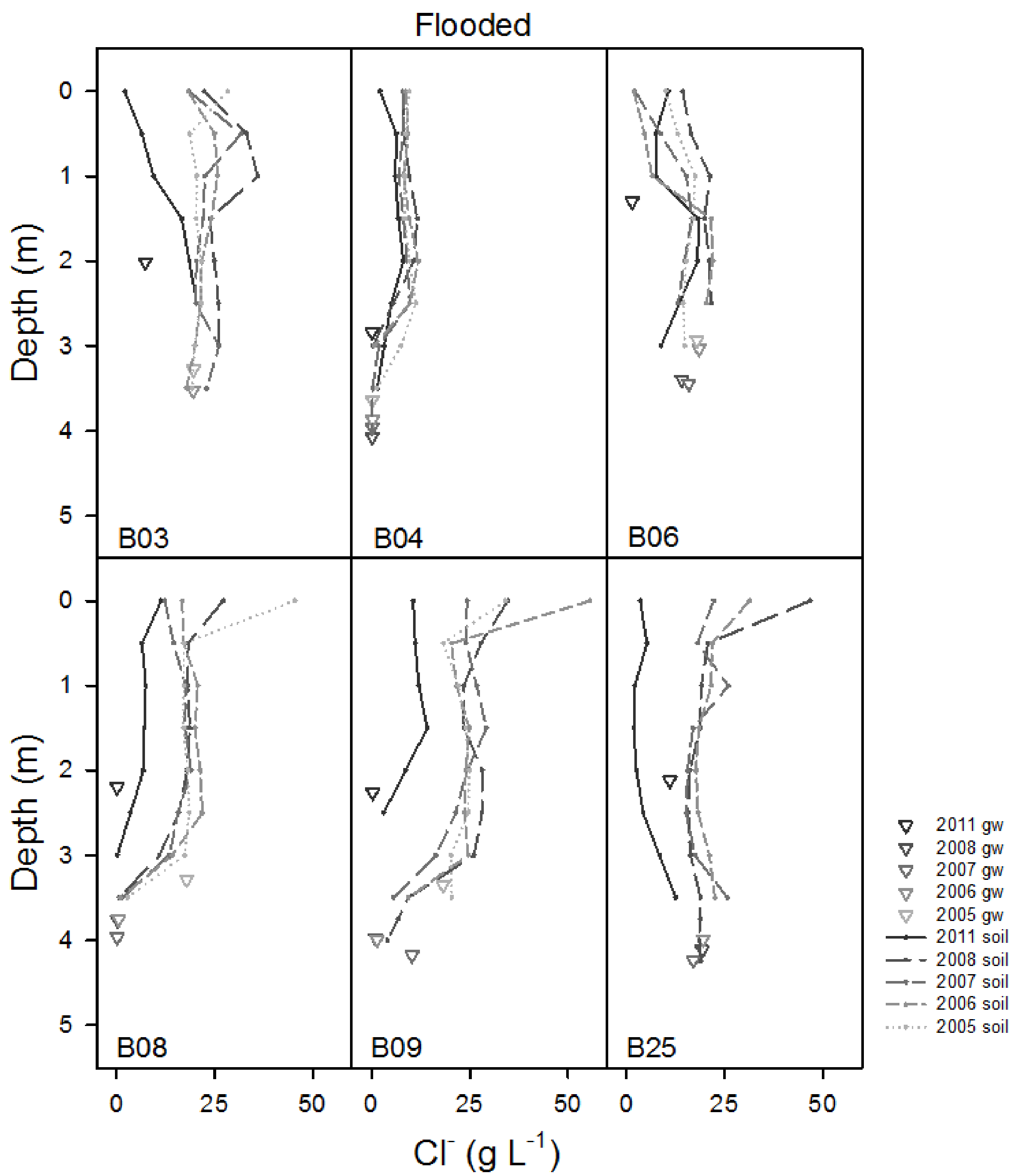


Figure 17 Flooded Site B soil chloride profiles (g Cl^{-} L^{-1}) sampled between June 2005 and December 2011.

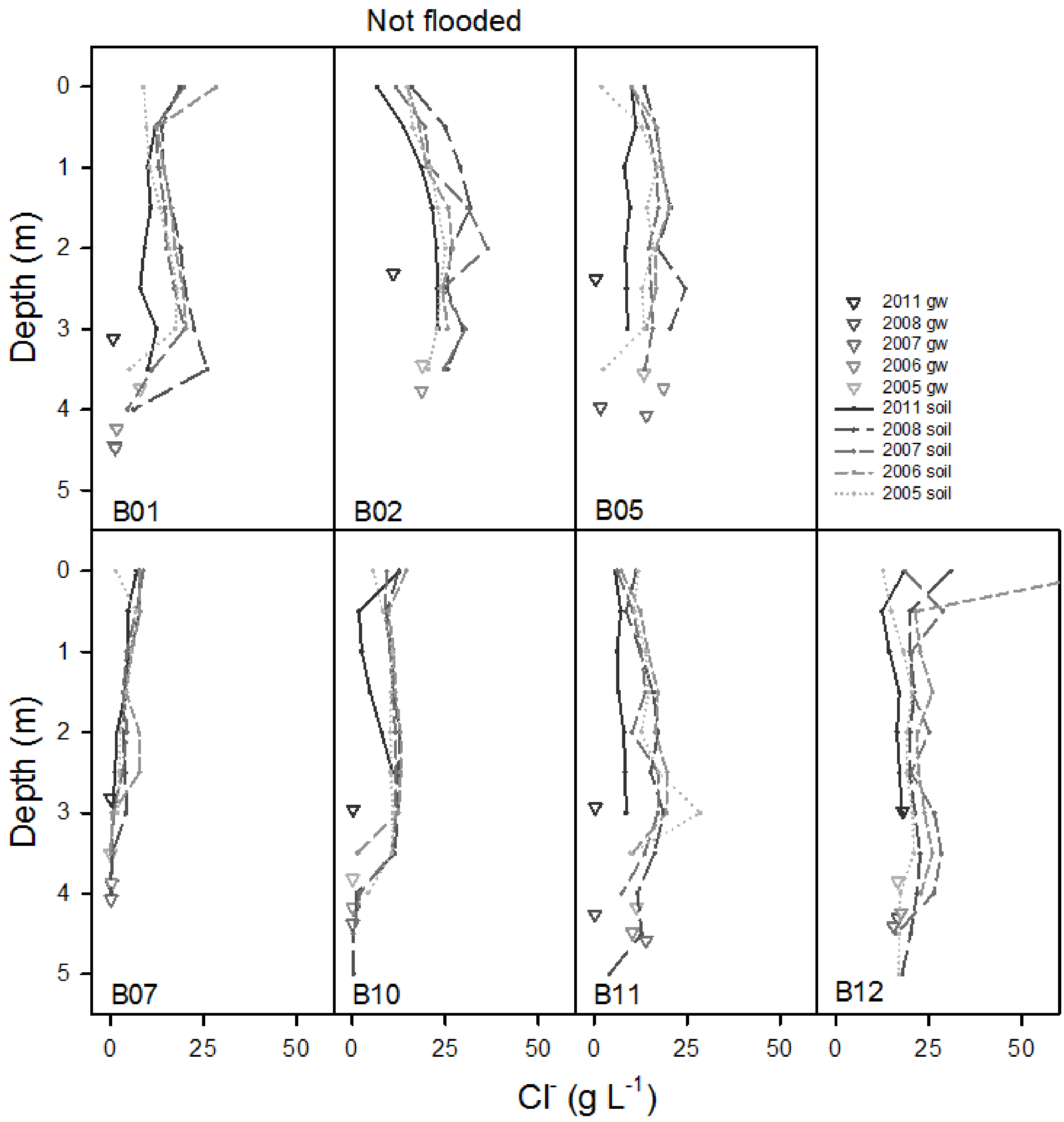


Figure 18 Not flooded Site B soil chloride profiles (g Cl^{-} L^{-1}) sampled between June 2005 and December 2011.

Tree health

Tree health was generally poor at the start of monitoring in 2005, with over 40% of the trees along Transects A1-A3 having no live canopy (Figure 19). Tree health at the three control transects was better, with only 9 of the 80 trees having no live canopy in 2005. Over the three years of the experiment, there was a small improvement in tree health, with the number of trees with moderate to maximum (>25%) live canopy peaking at 56% along Transects A1-A3 and at 64% along Transect A4-A6 in September 2007. Between 2007 and 2011, there was a decline in tree health at Site A, with the number of trees with no live canopy increasing from 47 to 59 along Transects A1-A3 and from 15 to 21 along Transects A4-A6. Anecdotally, the flood did not appear to improve tree health at Site A, with few trees showing signs of a response to the flood, and recent dieback was observed. The soil and groundwater results show that there was a period of persistent high water tables caused by elevated river levels in the eight months between the flood peak in February 2011 and monitoring in

September / October 2011. Elevated water tables create waterlogged conditions, which in combination with salinity are known to reduce plant growth and water use (van der Moezel *et al.* 1988; Marcar 1993; Bell 1999). Therefore, it is likely that when river levels fall, increased tree water availability will improve the canopy condition of the floodplain trees.

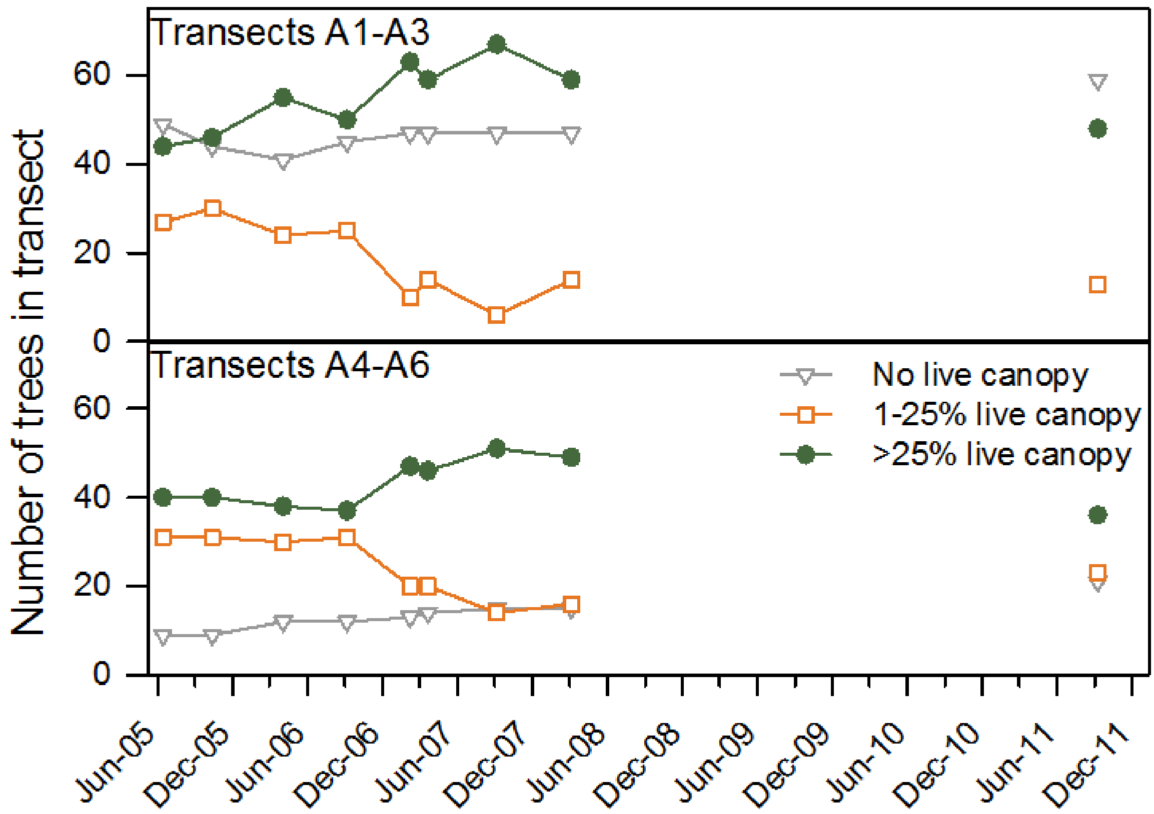


Figure 19 Site A changes in canopy condition between June 2005 and December 2011 at the treatment (A1-A3) and control (A4-A6) transects.

At the start of the Bookpurnong Experiment, tree health was generally poor, with most of the trees having less than 25% live canopy along the treatment (B1 – 68%, B2 – 45% and B3 – 55%) and control (B4, 62%) transects (Figure 20). Over the three years of the experiment, increases in the proportion of trees with >25% live canopy were observed at Transects B1 (+4%), B2 (+7%), B3 (+11%) and B4 (+27%). The increase in the number of trees with more than 25% live canopy observed at Transects B3 and B4 was caused by the transition of trees from the 1-25% live canopy class to the >25% live canopy class, indicating an improvement in tree health at these transects. There was a decrease in the number of trees with minimal to sparse (1-25%) live canopy at all four transects between December 2005 and December 2008. Increases in the proportion of trees with no live canopy over this time period were observed at Transects B1 (+25%), B2 (+13%), B3 (+17%) and B4 (+6%). Between 2008 and after the flood in 2011, there was an increase in the proportion of trees with no live canopy at Transect B1 (+9%) and B4 (+3%). Similarly, there were fewer trees with >25% live canopy at Transects B1 (–12%), B2 (–2%), B3 (–9%) and B4 (–12%). With the exception of Transect B1, there was an increase in the number of trees with moderate to maximum (>25%) live canopy at Transects B2, B3 and B4 between 2005 and 2011. At the same time, there was an increase in the number of trees with no live canopy, demonstrating the effect of the regional drought. These increases came from the intermediate canopy class, with some continuing to decline and some improving in response to increased water availability associated with artificial watering and groundwater management.

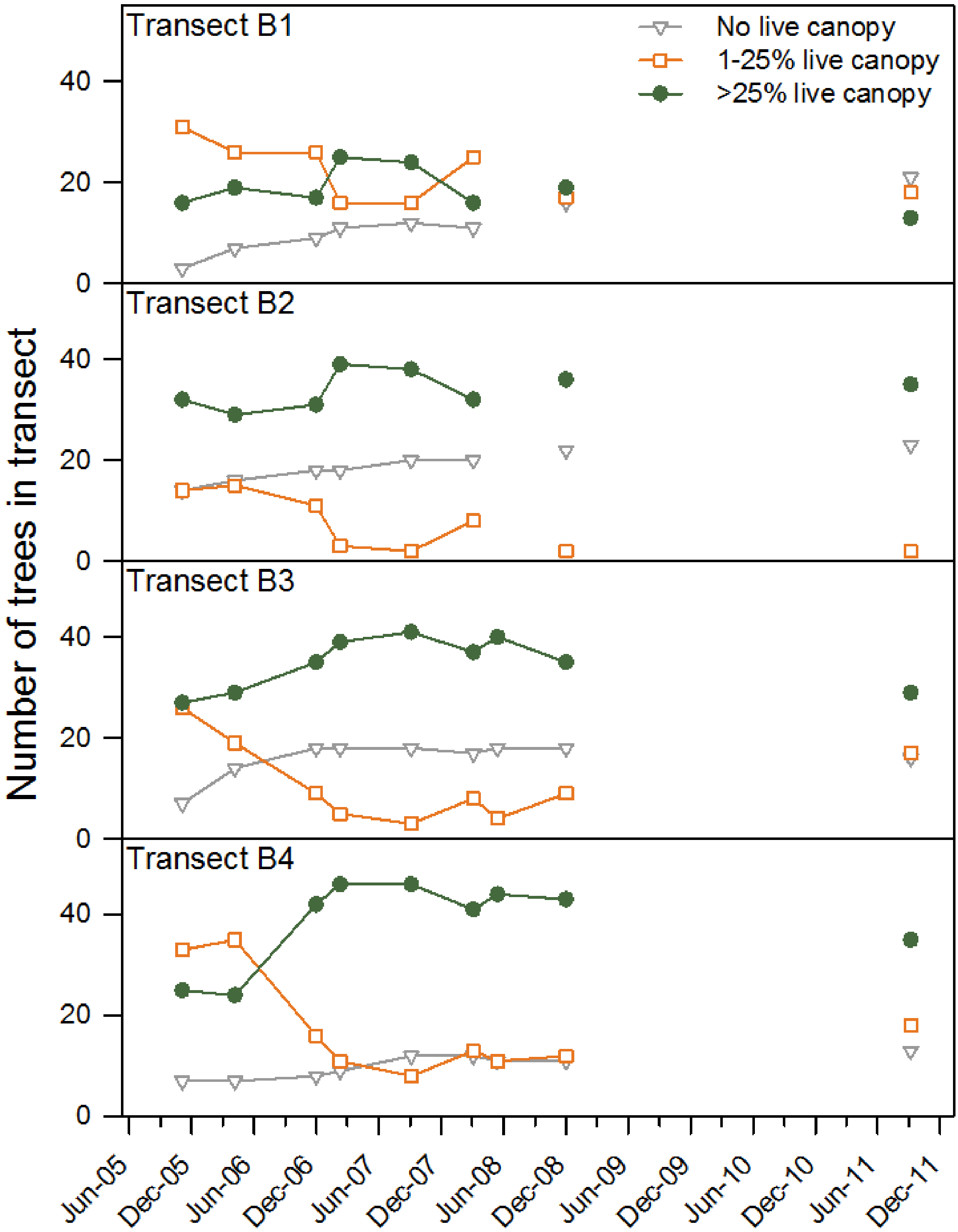


Figure 20 Site B changes in canopy condition between June 2005 and December 2011.

Changes in DBH or BAOB were used to detect long term tree growth at Site B. Between 2008 and 2011 at B05 in the middle of Transect B2, *A. stenophylla* BAOB increased by 16% (Figure 21). Whereas, the death of two of the *E. camaldulensis* trees in this plot reduced *E. camaldulensis* BAOB by 14% over this period. Along Transect B3, BAOB increased between 2007 and 2008 at all three plots. In contrast, between 2008 and 2011, BAOB of all three species at B07 near the river decreased; with total plot BAOB falling by 7%. In the middle of the riparian zone along Transect B3 at B08, BAOB of *A. stenophylla and E. largiflorens* increased, with *A. stenophylla* BAOB doubling and total plot BAOB increasing by 25% between 2007 and 2011. At the distal edge of the riparian zone along Transect B3, there were small increases in *A. stenophylla and E. largiflorens* BAOB between 2007 and 2008. Between 2008 and 2011, there was a small decrease in *A. stenophylla* BAOB, whereas *E. largiflorens* BAOB increased by 11%, increasing total plot BAOB by 10%. Near the river along the control transect (B4), *A. stenophylla* BAOB increased by 33%, *E. camaldulensis* BAOB decreased by 55% (including two dead trees) and *E. largiflorens* BAOB decreased by 26%, resulting in a decrease in total plot BAOB of 16%. Tree growth as measured by an increase in plot BAOB occurred in the middle and distal parts of Transect B3, where groundwater freshening was greatest,

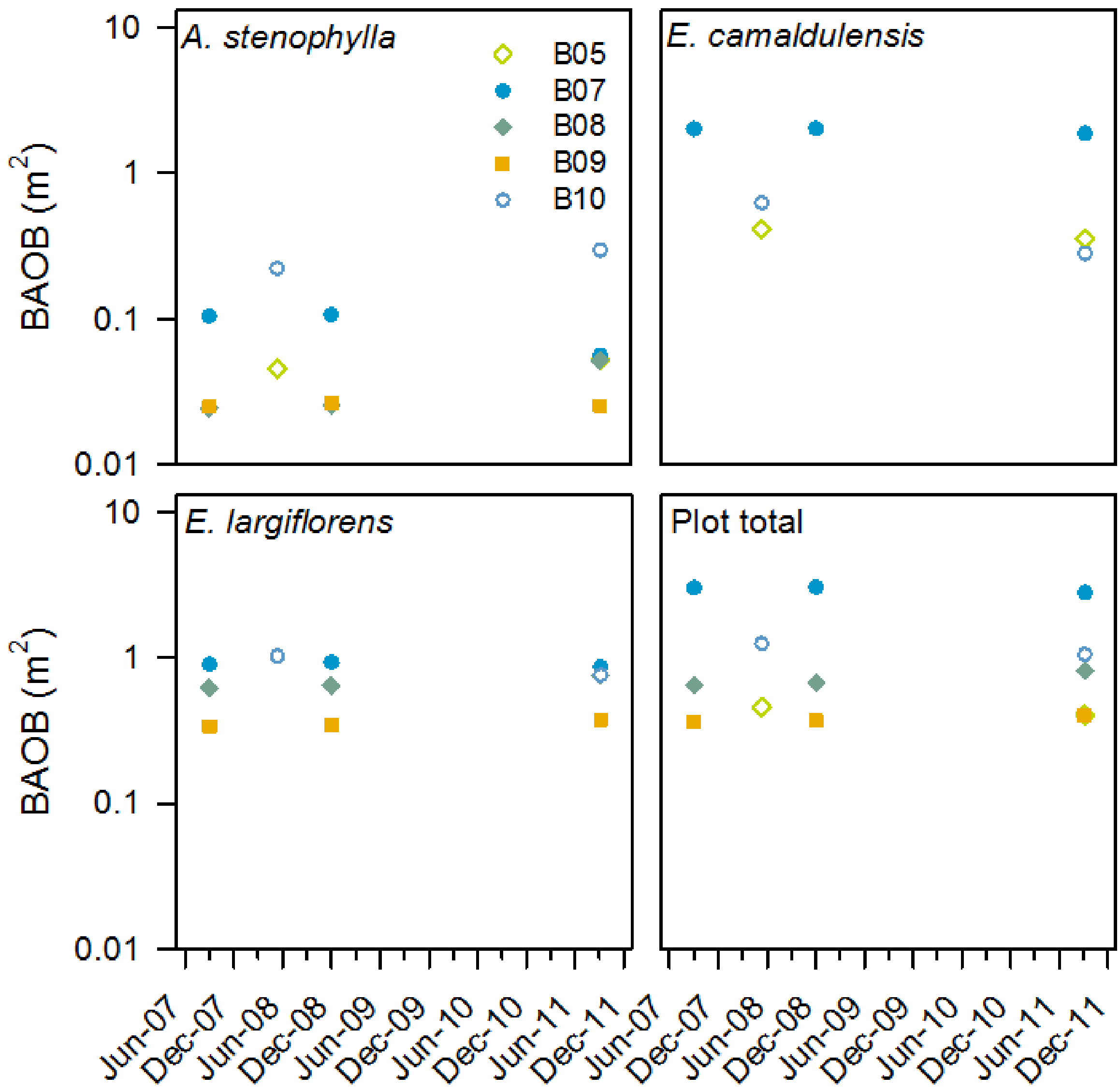


Figure 21 Site B changes in plot basal area over bark (BAOB, m^2) for *A. stenophylla, E. camaldulensis, E.* largiflorens and plot total between September 2007 and September 2011. Note the semi-logarithmic plot.

Understorey Vegetation

Detailed analysis of the changes of the understorey plant community through time and in response to the different management actions at Bookpurnong was not able to be undertaken due to:

- Persistent flooding of Site A, which prevented many floodplain understorey species from germinating.
- Orientation of the understorey vegetation transects perpendicular to the river comparing the plant community at horizontal distances from the river, rather than comparing between elevations (vertical distances) like the standard vegetation monitoring surveys undertaken at the Pike and Chowilla floodplains.

A total of 40 species (including eight exotics) were recorded in quadrats on the Bookpurnong floodplain (Appendix A). Site B was more species rich than Site A, although there were a greater proportion of amphibious and floodplain species at Site A (Appendix B). Understorey species were present at both sites on the Bookpurnong floodplain that recruited in response to receding flood waters, all of which were only recorded in areas that were watered (Site A) prior to the flood (White *et al.* 2009).

Pike and Chowilla Floodplains

The understorey plant community across both floodplains at each survey date were spatially variable. However, the understorey plant community across the entire floodplain (at each location) was significantly different between floodplains, between years and there was a significant interaction (Table 7). This indicates that the change in the understorey plant community through time was not consistent between the different floodplains. NMS ordination (Figure 22) shows that there was a large difference between plant communities on the Pike and Chowilla floodplains on each survey date. However, there was a greater change in floristic composition between survey dates for the Pike floodplain (Figure 22).

Table 7 PERMANOVA results comparing the understorey plant communities on the Pike and Chowilla floodplains in January 2010 and August 2011.

Source	*df*	*Pseudo-F*	*P*
Location	1,701	34.544	<0.001
Survey Date	1,701	43.587	<0.001
Location x Survey Date	1,701	11.998	<0.001

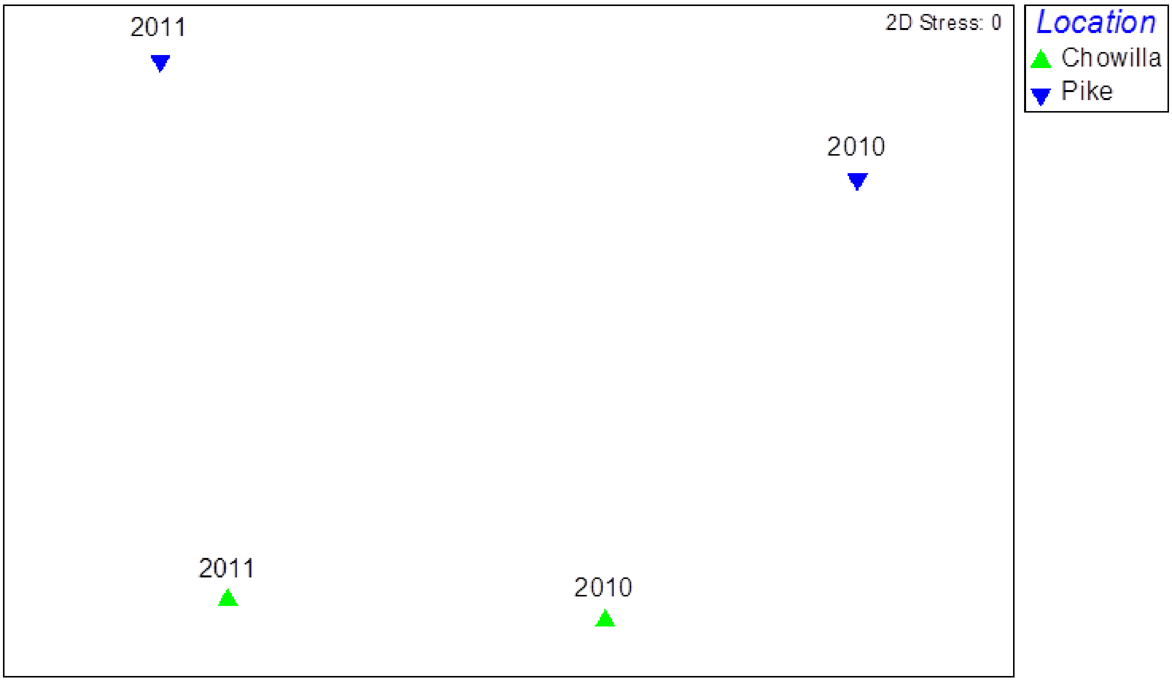


Figure 22 NMS ordination comparing understorey floristic composition between survey dates (2010 and 2011) on the Pike and Chowilla Floodplains (data were pooled for each floodplain and year for clarity).

More understorey taxa were observed in 2010 on the Chowilla floodplain (43 taxa) than on the Pike floodplain (24 taxa). However, after the flood in 2011, the number of taxa was similar between floodplains, with 66 taxa on the Chowilla floodplain and 68 taxa on the Pike floodplain (

Appendix C). Several floodplain and amphibious taxa that were recorded on the Chowilla floodplain in 2010 (*Ammania multiflora, Calotis scapigera, Goodenia gracilis, Marsilea angustifolia, Mimulus repens, M. florulenta, Muehlenbeckia horrida, Phyla canescens, Senecio runcinifolius* and *Tetragonia tetragonoides*) were also present in 2011 but only present on the Pike floodplain after the flood. Furthermore, the native floodplain and amphibious species: *Calotis cuneifolia, Cyperus gymnocaulos, E. camaldulensis* var. *camaldulensis, Euchiton involucratus, Lachnagrostis filiformis* and *Pycnosorus* spp. were present on the Chowilla floodplain in 2010 and 2011, but were only present on the Pike floodplain after the flood in 2011 (

Appendix C). The smaller NMS ordination distance between the 2010 and 2011 surveys on the Chowilla floodplain compared to the Pike floodplain (Figure 22) represents the greater change in floristic composition observed on the Pike floodplain compared to at Chowilla due to flooding (the source of the significant interaction Table 7).

Comparison of the plant communities in areas with different inundation histories

Two large areas of the Chowilla floodplain (Coppermine Complex and Gum Flat) were watered by pumping (artificial watering) in spring 2006; resulting in a total of eight sites being inundated. The same two areas were watered again in spring 2009 but to a greater depth, resulting in an additional three (11 in total) sites being inundated. Flooding from August 2010 to May 2011 inundated over 65% of the understorey vegetation monitoring sites on the Chowilla Floodplain (Table 3).

No artificial watering was undertaken on the Pike Floodplain; meaning that no sites had been inundated prior to the 2010/11 flood. During the 2010/11 flood over 60% of the vegetation condition monitoring sites on the Pike floodplain were inundated (Table 4).

Cluster analysis identified two groups (with a similarity of 25%) that corresponded to whether the site had been watered (2006 – 2010) or flooded (2011) prior to being surveyed (Figure 23). Note that the flooded sites sampled in 2010 before the flood (e.g. Surveyed 2010 Not watered (2006 – 2010) flooded (2011) had not been inundated. The group that contained the sites that were flooded in 2011 was sub-divided into two groups with a similarity of 40%: one group contained sites that had been watered or flooded, the other group contained sites that were only naturally flooded (Figure 23).

The NMS ordination shows three distinct groups that correspond to the three groups identified by cluster analysis at a similarity of 40%. The x axis of the ordination corresponds to flooding (natural or artificial) frequency with sites that were not flooded forming a group to the right of the ordination, sites that were only flooded naturally are in the centre and sites that were watered or flooded are to the left of the ordination (Figure 24). The y axis corresponds to site conditions, with the Pike sites located toward the top of the ordination and Chowilla sites toward the bottom (Figure 24).

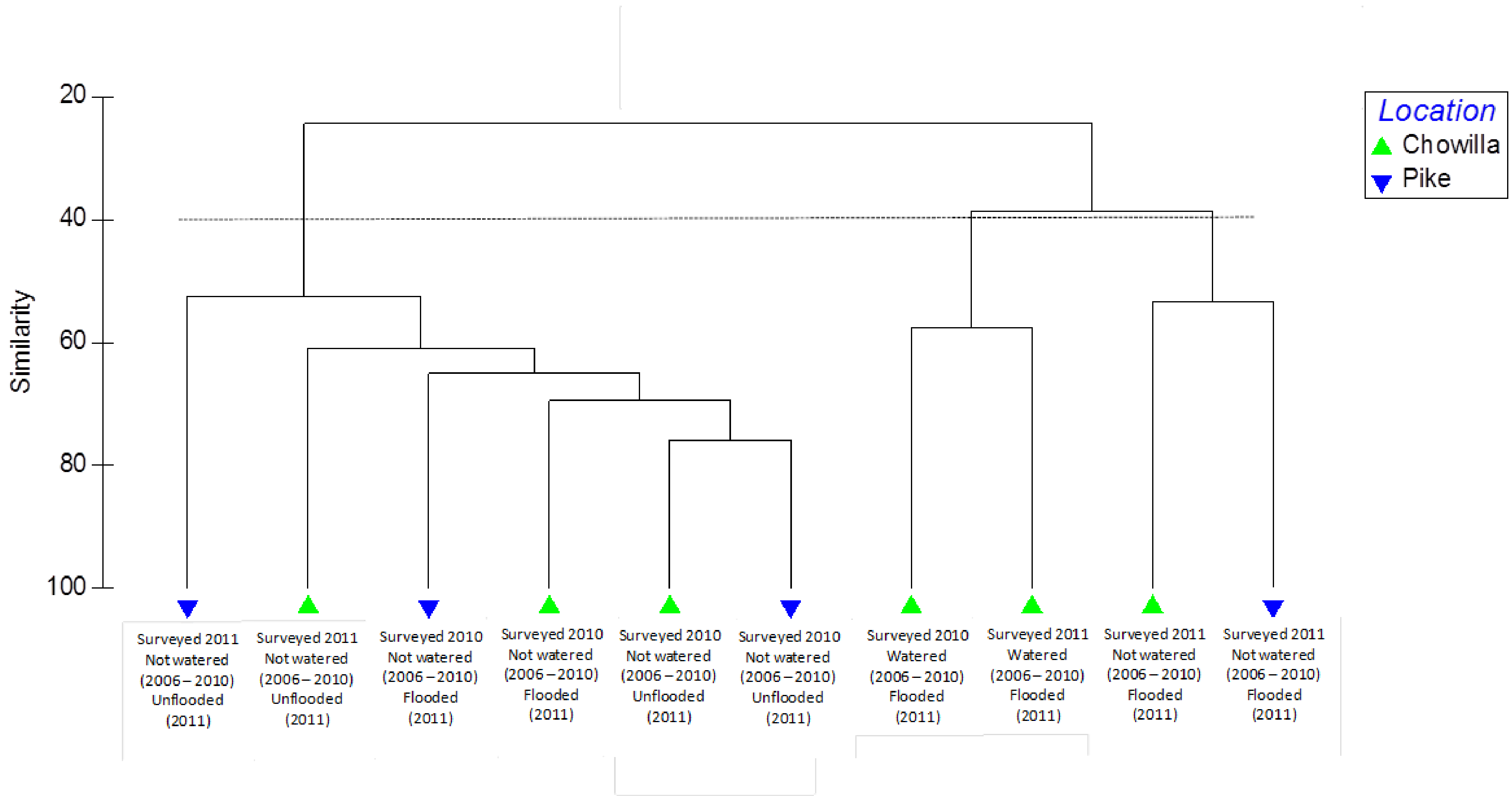


Figure 23 Group Average Cluster analysis comparing the plant communities on the Pike and Chowilla floodplains between survey dates (2010 and 2011) and inundation histories. Note that the dashed line denotes the 40% similarity level that defines the groups identified on the NMS ordination in Figure 24.

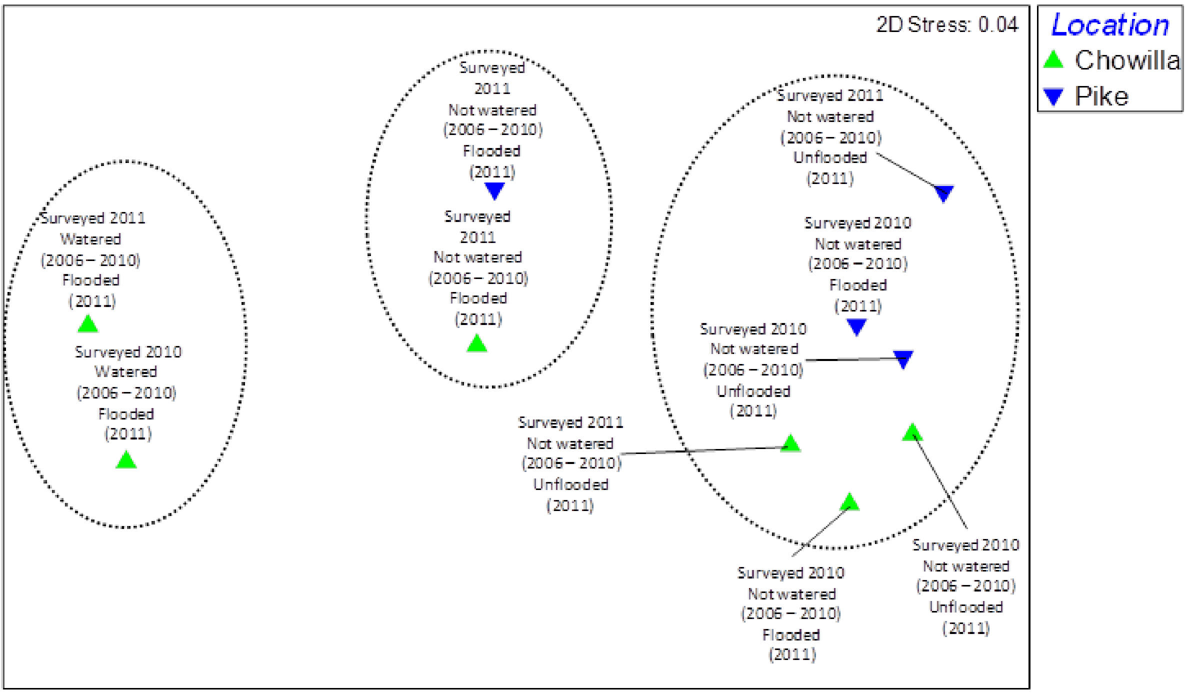


Figure 24 NMS ordination comparing the plant communities on the Pike and Chowilla Floodplains between survey dates (2010 and 2011) and inundation history (dashed ovals represent the group average cluster analysis groups with a similarity of 40% in Figure 23).

Several taxa, such as *Atriplex* spp. were widespread across both floodplains and all inundation histories and survey dates (Figure 25). *Sclerolaena divaricata, Sclerolaena brachyptera* and *Sclerolaena stelligera* also showed similar abundance patterns. However, in the flooded and watered sites, these species were only present as seedlings that germinated after water levels had receded.

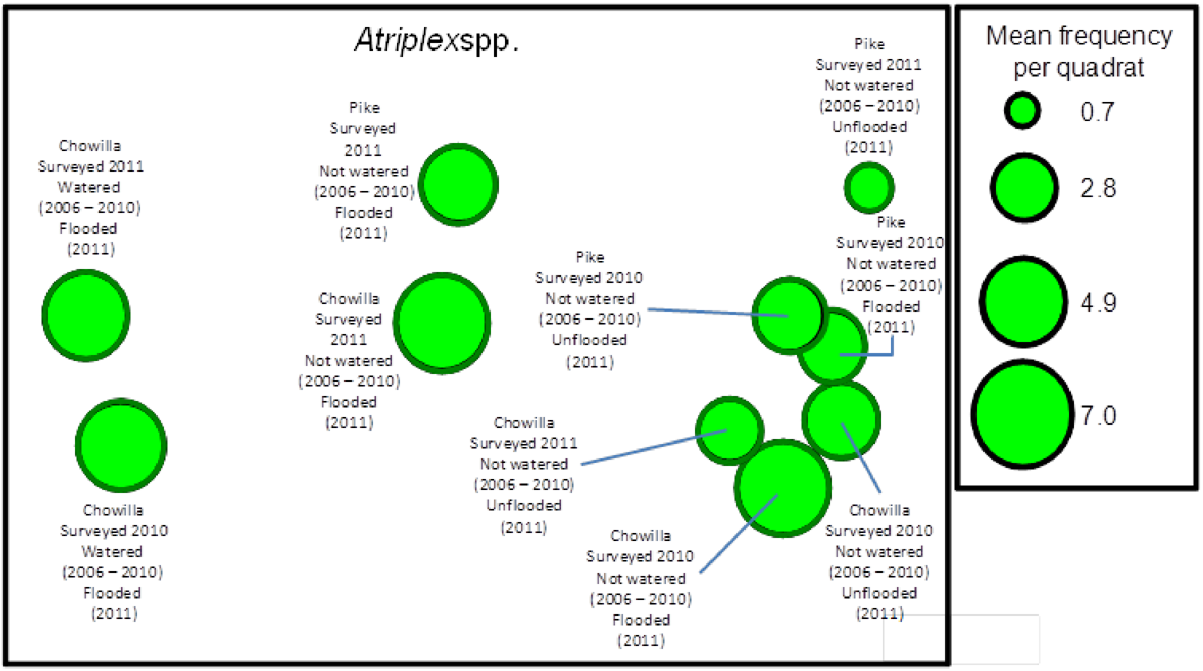


Figure 25 *Atriplex* spp. bubble plot (bubble size represents mean frequency per quadrat) showing frequency at unflooded, flooded or artificially watered sites on the Chowilla and Pike Floodplains in 2010 and 2011.

Bare soil was more abundant in areas that had not been flooded before they were surveyed (Figure 26). Similarly the salt tolerant terrestrial taxa *Frankenia pauciflora, Salsola kali* var. *kali* and

Pachycornia triandra were more abundant in sites that had not been flooded before they were surveyed across the Pike and Chowilla Floodplains and showed similar patterns to bare soil.

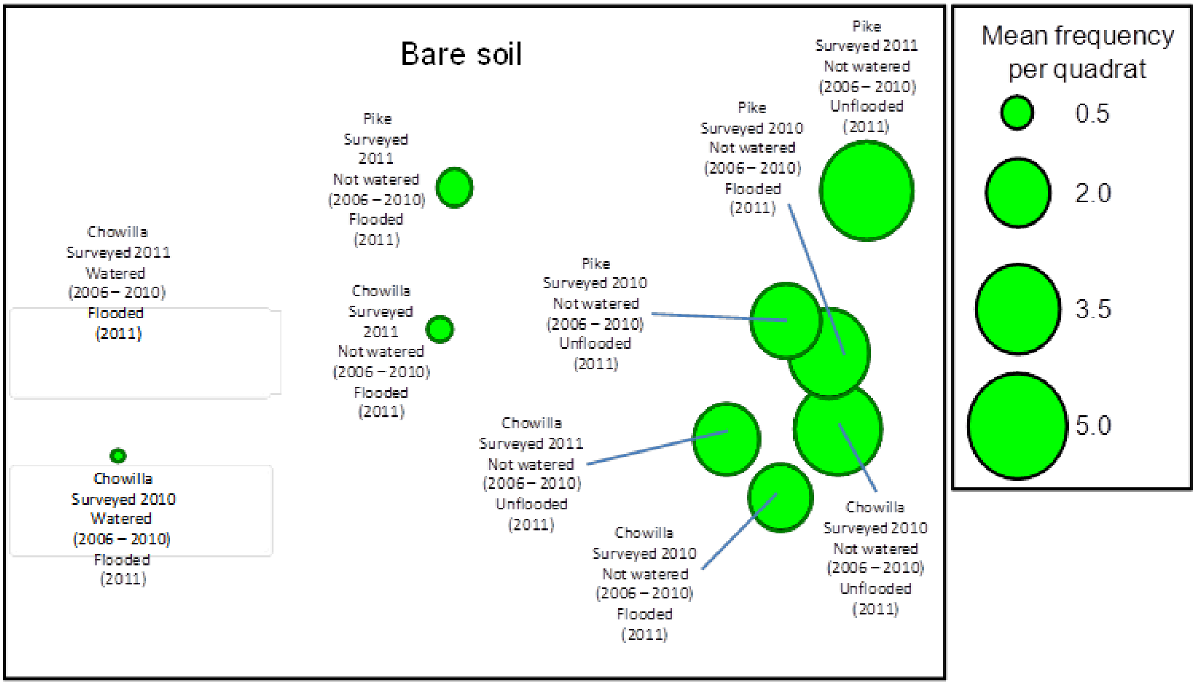


Figure 26 Bare soil (or unvegetated) bubble plot showing frequency of quadrats for unflooded, flooded or artificially watered sites on the Chowilla and Pike floodplains in 2010 and 2011.

Numerous species such as *Senecio cunninghamii* (Figure 27) were present on both the Pike and Chowilla Floodplains only in areas that were naturally flooded (2010/11 flood). *Calotis hispidula, Crassula sieberiana, Goodenia gracilis, Mollugo cerviana, M. florulenta, Neogunnia septifraga, Nothoscordum borbonicum, Phyla canescens, Rorippa palustris* and *Iseotopsis graminifolia* also showed similar distribution and abundance patterns to *Senecio cunninghamii*.

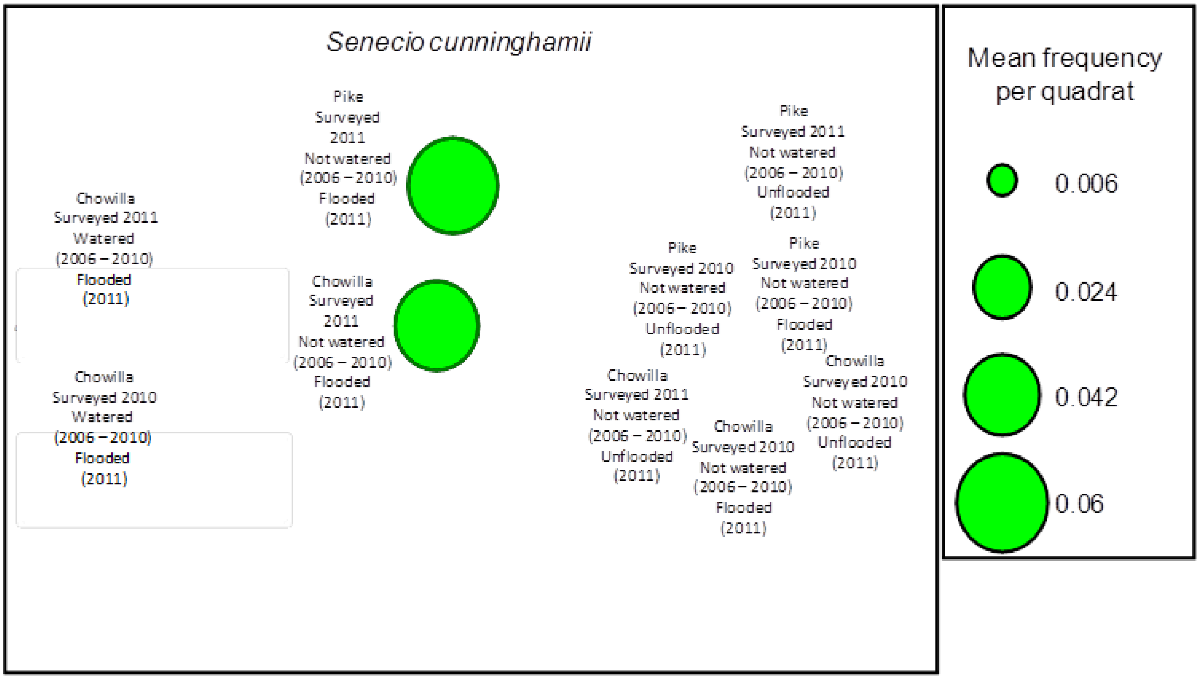


Figure 27 *Senecio cunninghamii* bubble plot showing frequency of unflooded, flooded or artificially watered sites in Chowilla and Pike floodplains in 2010 and 2011.

Four species: *Pycnosorus* sp. (Figure 28), *Calotis cuneifolia, Lachnagrostis filiformis* and *Myriophyllum verrucosum* were only recorded from the Pike floodplain in areas that were naturally flooded (2010/11 flood). In addition, *E. camaldulensis* var. *camaldulensis* was only recorded on the Pike floodplain (

Appendix C); however, this species was observed on the Chowilla floodplain but not present in any quadrats.

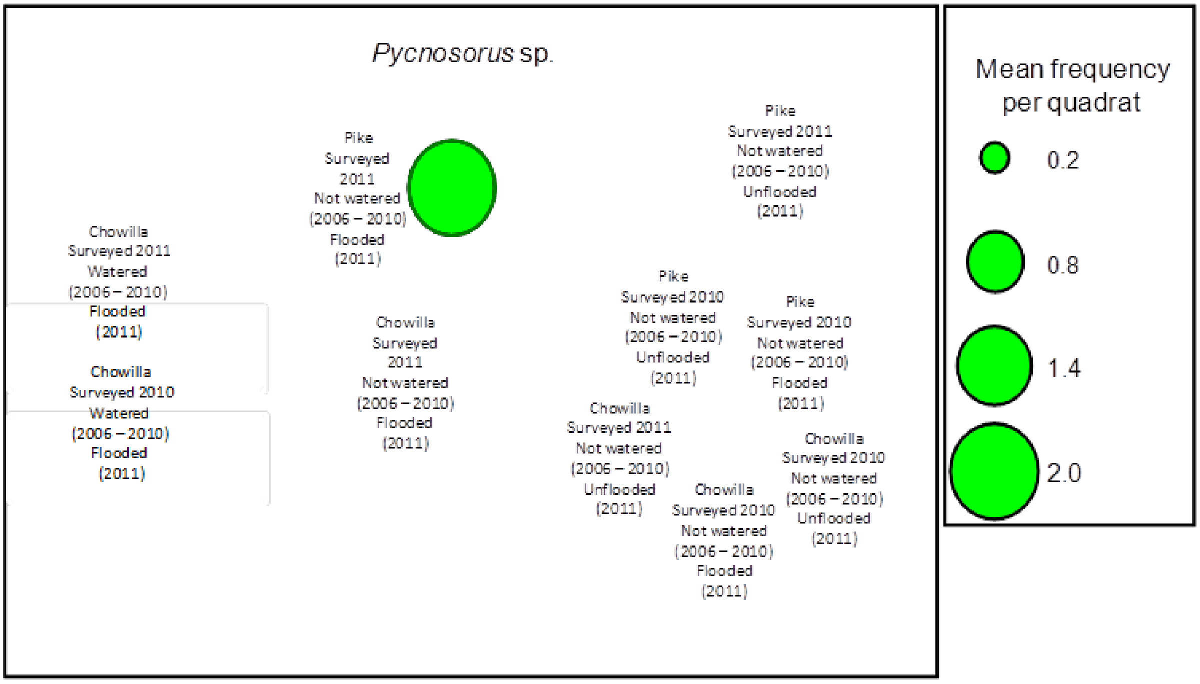


Figure 28 *Pycnosorus* sp. bubble plot showing frequency of unflooded, flooded or artificially watered sites in Chowilla and Pike floodplains in 2010 and 2011.

Similarly there were species that were only recorded on the Chowilla Floodplain; however, they were often present across a number of inundation history classes. These species include: *Calotis scapigera* (Figure 29), *Craspedia chrysantha, Cyperus difformis, Isolepis hookeriana* and *Solanum lacunarium.*

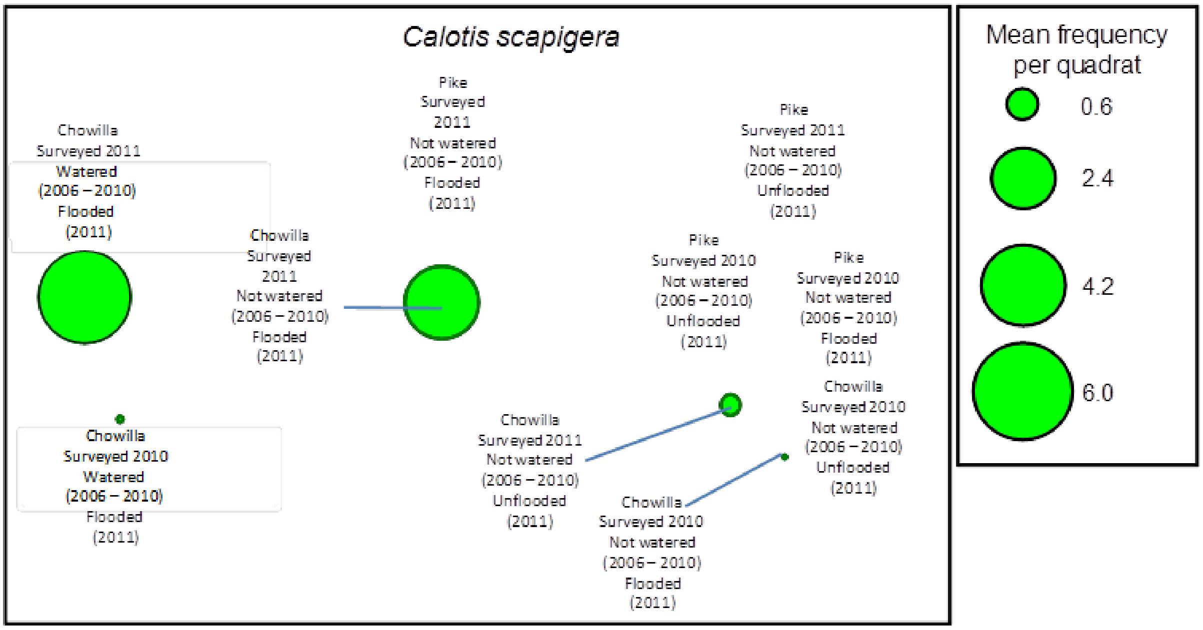


Figure 29 *Calotis scapigera* bubble plot showing frequency of unflooded, flooded or artificially watered sites in Chowilla and Pike floodplains in 2010 and 2011.

Numerous species recruited in response to watering or flooding and were present on both the Pike and Chowilla Floodplains. For example, *Ammania multiflora* (Figure 30) was present on both floodplains in areas that were watered and flooded. Other species that showed similar distribution patterns include: *Alternanthera denticulata, Centipeda minima, Sporobolus mitchellii, Mimulus repens, Cotula australis, Plantago cunninghamii, Tetragonia tetragonioides and Marsilea angustifolia.* However, *Marsilea angustifolia* was more abundant in areas that were watered (the presence at an unflooded site was due to pooling of local runoff) (Figure 31).

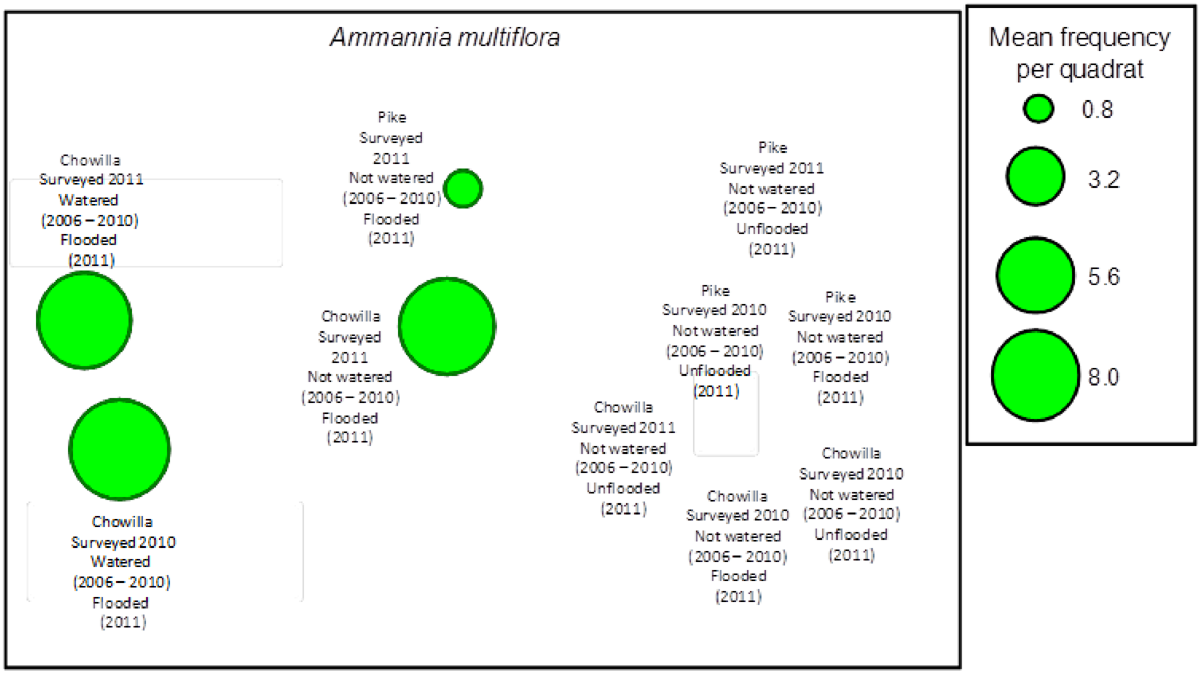


Figure 30 *Ammannia multiflora* bubble plot showing frequency of unflooded, flooded or artificially watered sites in Chowilla and Pike floodplains in 2010 and 2011.

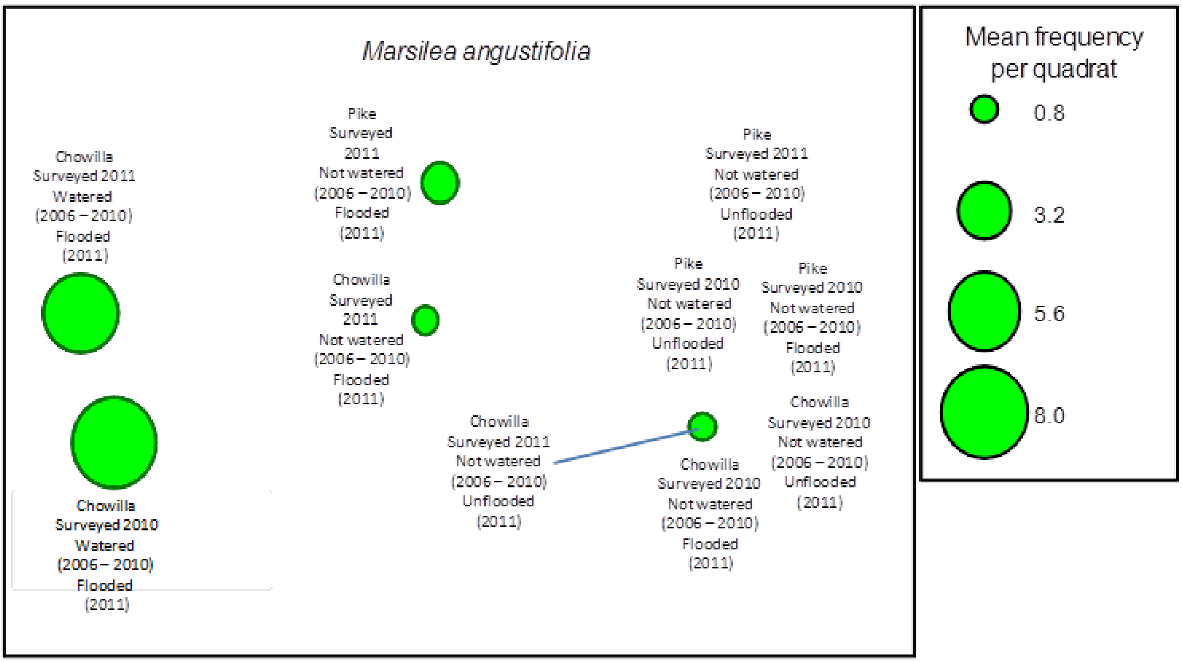


Figure 31 *Marsilea angustifolia* bubble plot showing frequency of unflooded, flooded or artificially watered sites in Chowilla and Pike floodplains in 2010 and 2011.

Eleocharis acuta was the only species that was present exclusively in areas that were artificially watered (Figure 32).

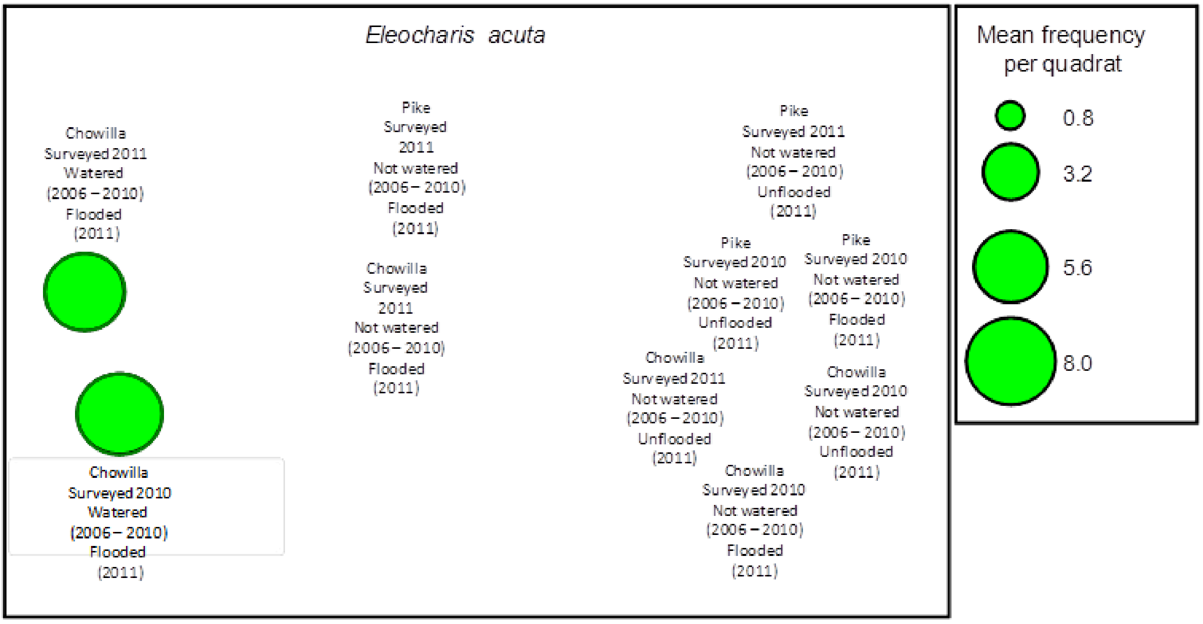


Figure 32 *Eleocharis acuta* bubble plot showing frequency of unflooded, flooded or artificially watered sites in Chowilla and Pike floodplains in 2010 and 2011.

4. Discussion

Below is a preliminary ecological analysis and interpretation of the data collected during this study.

Floodplain response to artificial watering, groundwater management and natural flooding at Bookpurnong

Analysis of the combination of groundwater and soil responses to overbank flooding identified three mechanisms that reduced soil and groundwater salinities: 1) bank recharge; 2) vertical infiltration from the surface; and 3) movement of low salinity groundwater upwards into the unsaturated zone as discussed below. It is important to understand the extent and degree of soil and groundwater freshening caused by these recharge mechanisms as they support the long term health of the floodplain trees (Doody *et al.* 2009; Holland *et al.* 2006; 2009a; Mensforth *et al.* 1994; Thorburn *et al.* 1993). The extent and degree of soil and groundwater freshening after the flood exceeded observations made after artificial watering and groundwater management at Bookpurnong during the drought. However, tree health did not improve in the eight months between the flood peak in February 2011 and monitoring in September / October 2011. The soil and groundwater results show that there was a period of persistent high water tables caused by elevated river levels following the flood peak. Elevated water tables create waterlogged conditions, which in combination with salinity are known to reduce plant growth and water use (van der Moezel *et al.* 1988; Marcar 1993; Bell 1999). Therefore, when river levels fall, increased water availability will increase the canopy condition of the floodplain trees.

Bank recharge occurs when the river level is raised above the floodplain water table, creating an hydraulic gradient to move low salinity river water into the banks of the river and creek (Lamontagne et al. 2005; Holland *et al.* 2009a). This creates a layer of low salinity groundwater above the more saline groundwater, which is an important water source for riparian vegetation between floods (Doody *et al.* 2009; Holland *et al.* 2006; 2009a; Mensforth *et al.* 1994; Thorburn *et al.* 1993). The extent of groundwater freshening by bank recharge observed in this study ranged from less than 20 m at Transect B1 to over 200 m at Transect B3. This exceeds the 50 m bank recharge zone observed at Chowilla (Holland *et al.* 2009a) and the 130 m band of groundwater freshening observed at Transect B3 in 2008 (Doody *et al.* 2009; Holland *et al.* 2009b; 2011).

Vertical infiltration of overbank floodwaters from the soil surface resulted in a reduction in stored soil chloride at all of the flooded locations at Sites A and B, with the exception of low salinity sites (A1, A8 and B04). Vertical infiltration reduced soil chloride concentrations to a maximum depth of 1.0 to 2.5 m at Site A and to 0.5 to 3.5 m at Site B. On average, vertical infiltration reduced average stored chloride values by 55% at Site A and 40% at Site B. Limited salt leaching by overbank flooding had previously been observed at Chowilla at sites with sandy soils (Akeroyd *et al.* 1993).

Several soil chloride profiles indicated that upward movement of low salinity groundwater into the unsaturated zone reduced soil chloride values above the historical water table level. Groundwater levels rose by over 2 m above normal pool level during the flood in response to the hydraulic gradient created by the River Murray flood water level. This occurred at four sites on the edge of the wetland at Site A (A2, A3, A6 and A10) and at six sites in the middle and distal parts of the riparian zone at Site B (B06, B08, B09, B10, B11 and B12). Upward movement of low salinity groundwater reduced soil chloride concentrations in the 1.0 – 2.5 m of unsaturated zone above the water table. This has not been previously documented on the lower River Murray floodplain.

Understorey vegetation response to artificial watering and natural flooding

Flooding, either natural or artificial, resulted in large changes in the understorey plant community on both the Pike and Chowilla floodplains. The ordination analyses showed that there was a large increase in species richness post flooding and this difference was even greater on Pike compared to Chowilla (

Appendix C). However, it should be noted that species richness on both floodplains was very low during dry years (i.e. unflooded and no watering) and the smaller change in the understorey plant community on the Chowilla floodplain post flooding was due to the watering interventions (Gehrig *et al.* 2012). For example, in 2009 only 17 species were recorded on the Chowilla floodplain when surveyed despite being artificially watered in spring 2006 but species richness increased to 44 in 2011 in response to watering for a second time in spring 2010 (Gehrig *et al.* 2012). The response observed on the Pike floodplain suggests the understorey plant community retained the capacity to respond to flooding even in areas that had not been inundated for 14 years. It is unknown whether the response of the understorey plant community was due to recruitment from the resident seed bank or whether propagules were transported to the sites by hydrochory (dispersal by water) (or a combination of the two). Sediment samples were not taken prior to the flood to assess the resident seed but observations from both floodplains showed higher species richness in quadrats that include strandlines (J. Nicol pers. obs.).

Nicol *et al.* (2010b) reported very little recruitment of *E. camaldulensis* and no recruitment of *Acacia stenophylla, M. florulenta* and *E. largiflorens* at sites artificially flooded on the Chowilla floodplain. At sites where *E. camaldulensis* seedlings were observed, the distribution was patchy and numbers were low (Nicol *et al.* 2010b). However, large numbers of *E. camaldulensis* (seedlings were not present in quadrats on the Chowilla floodplain but were observed in large numbers outside of quadrats) and *M. florulenta* seedlings were observed on both floodplains following natural flooding (2010/11 flood). In addition, *A. stenophylla* and *E. largiflorens* seedlings were observed on both floodplains but were not present in quadrats (pers. obs.).

Results from the latest round of The Living Murray vegetation condition monitoring for the Chowilla floodplain (undertaken in February 2012) showed that the response of the understorey vegetation is short-lived (Gehrig *et al.*2012), which is expected due to the annual life history of most floodplain species (e.g. Cunningham *et al.* 1992). Species richness declined from 66 species in 2011 to 51 in 2012; nevertheless, this was the second highest species richness recorded since 2006 when the condition monitoring program commenced. However, the decline in species richness after artificial watering was much greater compared with decline recorded one year after the 2010/11 flood. A total of 48 species were recorded on the Chowilla floodplain in summer 2007 after watering in spring 2006 and in the following survey (summer 2008) was 21, which declined to 17 in 2009 (Gehrig *et al.* 2012). Species richness would be expected to further decline in the absence of natural or artificial watering due to most species being short-lived (e.g. Cunningham *et al.* 1992).

Effectiveness of artificial watering for maintaining floodplain vegetation communities during low flows

Eleocharis acuta was the only understorey species that was present exclusively in areas that were artificially watered and *Marsilea angustifolia* was present in higher abundances. *Eleocharis acuta* is common around the edges of permanent wetlands in the Chowilla system (Zampatti *et al.* 2011) and *Marsilea angustifolia,* whilst more abundant in watered areas, did recruit in response to natural flooding on both floodplains. Therefore, artificial watering did not result in recruitment of additional species or prevent species from becoming locally extinct. The data presented in this report may not present a strong case for artificial watering to maintain understorey vegetation. However, artificial watering may be important to maintain the resident seed bank of understorey species during periods of extended drought. The improved seed bank resulting from artificial watering may also provide a source of propagules for downstream areas of the floodplain. Furthermore, artificial watering may be required for the floodplain to provide ecosystem services (e.g. primary productivity that provides carbon for the terrestrial food web).

There are significant benefits from artificial watering to maintain long-lived tree and shrub species such as *A. stenophylla, E. camaldulensis, E. largiflorens* and *M. florulenta*. These species require flooding more frequently than is provided under the current regulated conditions (Roberts and Marston 2011) and, unlike most understorey species, do not form long-lived seed banks (Nicol 2004; Chong and Walker 2005). Therefore, artificial watering is an appropriate management action to maintain critical areas of long-lived species in between natural floods but it is not a substitute for regular natural floods. Artificial watering inundates a small area of floodplain compared to a natural flood, often requires the construction of banks to hold water in temporary wetlands, generally needs pumps to move water into above pool level wetlands and only inundates areas of floodplain that retain water (water shedding areas are unable to be managed in this manner).

Artificial watering and groundwater management at Bookpurnong between 2005 and 2008 increased the extent of low salinity groundwater, which was used by the floodplain trees (Berens *et al.* 2009a; Doody *et al.* 2009; Holland *et al.* 2009; White *et al.* 2009). Artificial watering to promote bank recharge is known to increase the extent and degree of groundwater freshening in floodplain environments. Low salinity groundwater is an important source of water to sustain riparian tree communities between natural floods (Holland *et al.* 2009). Groundwater freshening due to groundwater management at Bookpurnong continued between 2008 and 2010 and was supplemented by vertical infiltration, upward movement of low salinity groundwater and bank recharge during the flood. The increase in tree basal area observed at Transect B3 between 2008 and 2011 highlights the importance of a low salinity groundwater source for growth and survival of long-lived floodplain tree species.

Artificial watering to promote recruitment of flood dependent understorey vegetation may also be important to maintain floodplain function; however, there is little information regarding the role of understorey vegetation in floodplain function. After a natural flood or artificial watering, a large amount of carbon is fixed on the floodplain, some of which will be returned to the river in subsequent floods and provide an important carbon source for the riverine food web (*sensu* Junk et al. 1989). In addition, after an overbank flow, the River Murray floodplain is probably orders of magnitude more productive than the surrounding terrestrial ecosystem. Therefore, prior to regulation, the River Murray floodplain was probably an important source of carbon for the terrestrial ecosystem. Whilst artificial watering does not inundate the area of a natural flood (e.g. the Chowilla floodplain where 2,175 ha was artificially watered between 2005/06 and 2011/12 compared with >11,000 ha inundated by the 2010/11 flood), it may be important to maintain floodplain function at a reduced level to enable the floodplain to partially fulfil some of the ecosystem services it provided prior to river regulation and function at a higher level during the next flood.

5. References

Akeroyd MD, Tyerman SD, Walker GR, Jolly ID (1998) Impact of flooding on the water use of semi-arid riparian eucalypts*. Journal of Hydrology* **206:** 104-117

Anderson MJ (2001). A new method for non-parametric analysis of variance. *Austral Ecology* **26:** 32-46.

Anderson MJ and Ter Braak CJF. (2003). Permutation tests for multi-factorial analysis of variance. *Journal of Statistical Computation and Simulation* **73:** 85-113.

Barker WR, Barker RM, Jessop JP, Vonow HP (2005) Census of South Australian Vascular Plants (5.00 edn). (Botanic Gardens of Adelaide and State Herbarium: Adelaide).

Bell DT. (1999). Australian trees for the rehabilitation of waterlogged and salinity-damaged landscapes. *Australian Journal of Botany* **47:** 697-716.

Berens V, White M, Souter N. (2009a) Bookpurnong Living Murray Pilot Project: a trial of three floodplain water management techniques to improve vegetation condition. Department of Water, Land and Biodiversity Conservation, 2009/21, Adelaide.

Berens V, White M, Rammers N, Souter N, Paterson P. (2009b). Bookpurnong Living MurrayPilot Project: injection of river water into the floodplain aquifer to improve vegetation condition. Department of Water, Land and Biodiversity Conservation, 2009/20, Adelaide.

Bramley H, Hutson J, Tyerman SD (2003) Floodwater infiltration through root channels on a sodic clay floodplain and the influence on a local tree species *Eucalyptus largiflorens*. *Plant and Soil* **253:** 275-286

Bray JR and Curtis JT. (1957). An ordination of the upland forest communities of southern Wisconsin. *Ecological Monographs* **27:** 325-349.

Bren LJ (1992) Tree invasion of an intermittent wetland in relation to changes in the flooding frequency of the River Murray, Australia. *Australian Journal of Ecology* **17:** 395-408

Bunn SE, Arthington AH (2002) Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management* **30:** 492-507

Bureau of Meteorology. (2012). Climate averages for Loxton Research Centre (024024). http://www.bom.gov.au/climate/averages/

Busch DE, Smith SD (1995) Mechanisms associated with decline of woody species in riparian ecosystems of the southwestern U.S. *Ecological Monographs* **65:** 347-370

Cale B (2009). Literature review of the current and historic flooding regime and required hydrological regime of ecological assets on the Chowilla Floodplain. South Australian Murray-Darling Basin Natural Resources Management Board, Berri.

Chong C , Walker KF (2005) Does lignum rely on a soil seed bank? Germination and reproductive phenology of *Muehlenbeckia florulenta* (Polygonaceae). *Australian Journal of Botany* **53:** 407-415.

Clarke KR and Gorley RN. (2006). PRIMER version 6.1.12. (PRIMER-E Ltd: Plymouth).

Craig AE, Walker KF and Boulton AJ. (1991). Effects of edaphic factors and flood frequency on the abundance of lignum (*Muehlenbeckia florulenta* Meissner) (Polygonaceae) on the River Murray floodplain, South Australia. *Australian Journal of Botany* **39:** 431-443.

Cunningham GM, Mulham WE, Milthorpe PL and Leigh JH (1992). Plants of Western New South Wales. (CSIRO Publishing: Collingwood).

DFW (2012) Surface water archive. http://e-nrims.dwlbc.sa.gov.au/.

Dixon MD (2003) Effects of flow pattern on riparian seedling recruitment on sandbars in the Wisconsin River, Wisconsin, USA. *Wetlands* **23:** 125-139.

Doble RC, Simmons CT, Jolly ID, Walker GR (2006) Spatial relationships between vegetation cover and irrigation-induced groundwater discharge on a semi-arid floodplain, Australia. *Journal of Hydrology* **329:** 75-97.

Doody TM, Holland KL, Benyon RG, Jolly ID (2009) Effect of groundwater freshening on riparian vegetation water balance. *Hydrological Processes* **23:** 3485-3499.

Ecological Associates (2008) Pike River floodplain Management Plan. South Australian Murray-Darling Basin Natural Resources Management Board, Berri.

Eldridge SR, Thorburn PJ, McEwan KL, Hatton TJ (1993) Health and structure of *Eucalyptus* communities on Chowilla and Monoman Island of the River Murray floodplain, South Australia. Australia Commonwealth Scientific and Industrial Research Organization Division of Water Resources, 93-3, Adelaide.

Epstein S, Mayeda T (1953) Variations of the 18O/16O ratio in natural waters. *Geochimica et Cosmochimica Acta* **4:** 213.

Gehrig SL, Marsland KB, Nicol JM, Weedon JT (2010) Chowilla Icon Site – floodplain vegetation monitoring, 2010 interim report. South Australian Research and Development Institute (Aquatic Sciences), SARDI Publication No. F2010/000279-1, Adelaide.

Gehrig SL, Marsland KB, Nicol JM, Weedon JT (2012) Chowilla Icon Site-floodplain vegetation monitoring, 2011 interim report. South Australian Research and Development Institute (Aquatic Sciences), SARDI Publication No. F2010/000279-2, Adelaide.

George AK, Walker KF, Lewis MM (2005) Population status of eucalypt trees on the River Murray floodplain, South Australia. *River Research and Applications* **21**: 271-282

Gippel CJ, Blackham D (2002) Review of environmental impacts of flow regulation and other water resource developments in the River Murray and Lower Darling River system. Murray Darling Basin Commission, Canberra.

Greacen EL, Walker GR, Cook PG (1989) Evaluation of the filter paper method for measuring soil water suction. In International meeting at University of Utah on measurement of soil and plant water status, pp 137 - 145. Utah.

Grime JP (1979) Plant Stategies and Vegetation Processes. (John Wiley and Sons Ltd: Chichester).

Holland KL, Charles AH, Jolly ID, Overton IC, Gehrig S, Simmons CT.(2009a). Effectiveness of artificial watering of a semi-arid saline wetland for managing riparian vegetation health. *Hydrological Processes* **23:** 3474-3484.

Holland KL, Doody TM, Jolly ID. (2011). Transpiration water use and ecophysiology of riparian vegetation at the Bookpurnong floodplain. CSIRO Water for a Healthy Country National Research Flagship: Adelaide. 29 pp. http://www.clw.csiro.au/publications/waterforahealthycountry/2011/wfhc-Bookpurnong-floodplain-transect-3.pdf

Holland KL, Doody TM, McEwan KL, Jolly ID, White M, Berens V, Souter NJ (2009) Response of the River Murray floodplain to flooding and groundwater management: field investigations. CSIRO Water for a Healthy Country National Research Flagship: Adelaide. 65 pp. http://www.clw.csiro.au/publications/waterforahealthycountry/2009/wfhc-response-river-murray-floodplain.pdf

Jarwal SD, Walker GR, Jolly ID (1996) Chapter 2. General Site Description. Salt and water movement in the Chowilla floodplain (Eds GR Walker, ID Jolly & SD Jarwal), pp. 5-16. CSIRO Division of Water Resources.

Jessop J, Dashorst GRM, James FR (2006) Grasses of South Australia. An illustrated guide to the native and naturalised species. (Wakefield Press: Adelaide).

Jessop JP, Tolken HR (1986) The Flora of South Australia. (Government of South Australia Printer: Adelaide).

Jolly ID, Walker GR, Thorburn PJ (1993) Salt accumulation in semi-arid floodplain soils with implications for forest health. *Journal of Hydrology* **150:** 589-614.

Junk, WJ, Bayley, PB, Sparks, RE (1989) The flood pulse concept in river-floodplain systems. In 'Proceedings of the International Large River Symposium. Canadian Special Publication Fisheries and Aquatic Sciences 106'. (Ed. Dodge, D.P.) pp. 110-127.

Kingsford RT (2000) Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. *Austral Ecology* **25:** 109-127.

Lake PS, Bond N, Reich P (2006) Floods down rivers: from damaging to replenishing forces. *Advances in Ecological Research* **39:** 41-62.

Lamontagne S, Leaney FW, Herczeg AL (2005) Groundwater-surface water interactions in a large semi-arid floodplain: Implications for salinity management. *Hydrological Processes* **19:** 3063-3080.

Marcar NE (1993) Waterlogging modifies growth, wateruse and ion concentrations in seedlings of salt treated *Eucalyptus camaldulensis, E. tereticornis, E. robusta* and *E. globulus*. *Australian Journal of Plant Physiology* **20**: 1-13.

Marsland K, Nicol J, Weedon J (2009) Chowilla Icon Site - floodplain Vegetation Monitoring 2009 Interim Report. South Australian Research and Development Institute (Aquatic Sciences), F2007/000543-4, Adelaide.

Marsland K (2010) Pike floodplain understorey vegetation condition monitoring: 2010 preliminary report. South Australian Murray Darling Basin Natural Resources Management Board, Berri.

Marsland KB, Nicol JM (2009) Markaranka Flat floodplain vegetation monitoring-initial survey. South Australian Research and Development Institute (Aquatic Sciences), F2008/000059-2, Adelaide.

Marsland KB, Nicol JM, Weedon JT (2008) Chowilla Icon Site – floodplain vegetation monitoring 2007-08 interim report. South Australian Research and Development Institute (Aquatic Sciences), SARDI Publication Number F2007/000543-3, Adelaide.

McCune B, Grace JB and Urban DL. (2002) Analysis of Ecological Communities. (MjM Software Design: Gleneden Beach, Oregon).

Mensforth LJ, Thorburn PJ, Tyerman SD, Walker GR (1994) Sources of water used by riparian *Eucalyptus camaldulensis* overlying highly saline groundwater. *Oecologia* **100:** 21-28.

Miller AC, Watling JR, Overton IC, Sinclair R (2003) Does water status of *Eucalyptus largiflorens* (Myrtaceae) affect infection by the mistletoe *Amyema miquelii* (Loranthaceae)? *Functional Plant Biology* **30:** 1239-1247. doi:Doi 10.1071/Fp03117.

Munns R (1993) Physiological processes limiting plant growth in saline soils: some dogmas and hypotheses. *Plant, Cell and Environment* **16:** 15-24.

Nicol JM, Doody TM, Overton IC (2010a) An evaluation of the Chowilla Creek environmental regulator on floodplain understorey vegetation. South Australian Research and Development Institute (Aquatic Sciences), SARDI Publication Number F2010/000317-1, Adelaide.

Nicol JM, Marsland KB, Weedon JT (2010b) Understorey vegetation monitoring of Chowilla environmental watering sites 2004-08. South Australian Research and Development Institute, SARDI Publication Number F2010/000632-1, Adelaide.

Nicol JM (2004) Vegetation Dynamics of the Menindee Lakes with Reference to the Seed Bank. PhD thesis, The University of Adelaide.

Nicol JM (2010) Vegetation monitoring of River Murray Wetlands downstream of Lock 1. South Australian Research and Development Institute (Aquatic Sciences), F2009/000416-1, Adelaide.

O'Malley C, Sheldon F (1990) Chowilla floodplain biological study. Nature Conservation Society of South Australia, Adelaide.

Overton IC, Jolly ID (2004) Integrated studies of floodplain vegetation health, saline groundwater and flooding on the Chowilla Floodplain, South Australia. CSIRO Land and Water, 20/04, Adelaide.

Overton IC, McEwan KL, Gabrovsek C and Sherrah JR (2006) The River Murray floodplain Inundation Model - Hume Dam to Lower Lakes. CSIRO Water for a Healthy Country Technical Report. Canberra.

Roberts J, Ludwig J (1990) Aquatic macrophyte communities. In 'Chowilla floodplain Biological Study'. (Eds O'Malley C and Sheldon F.) pp. 137-142. (Nature Conservation Society of South Australia Inc.: Adelaide).

Roberts J, Ludwig JA (1991) Riparian vegetation along current-exposure gradients in floodplain wetlands of the River Murray, Australia. *Journal of Ecology* **79**: 117-127.

Roberts J, Marston F (2011) Water regime for wetland and floodplain plants: a source book for the Murray-Darling Basin. National Water Commission, Canberra.

Rood SB, Mahoney JM (1990) Collapse of riparian poplar forest downstream from dams in western prairies: Probable causes and prospects for mitigation. *Environmental Management* **14:** 451-464.

Rood SB, Mahoney JM, Reid DE, Zilm L (1995) Instream flows and the decline of riparian cottonwoods along the St-Mary River, Alberta. *Canadian Journal of Botany-Revue Canadienne De Botanique* **73:** 1250-1260.

Shafroth, PB, Stromberg JC, Patten DT (2002) Riparian vegetation response to altered disturbance and stress regimes. *Ecological Applications* **12**: 107-123.

Sharley T, Huggan C (1995) Chowilla Resource Management Plan. Murray Darling Basin Commission, Canberra.

Sheldon F, Lloyd L (1990) Physical Limnology and Aquatic Habitats. In 'Chowilla floodplain Biological Study'. (Eds O'Malley, C. and Sheldon, F.) pp. 119-136. (Nature Conservation Society of South Australia: Adelaide).

Slavich PG, Walker GR, Jolly ID, Hatton TJ, Dawes WRJ (1999) Dynamics of *E. largiflorens* growth and water use in response to modified watertable and flooding regimes on a saline floodplain. *Agricultural Water Management* **39:** 245-264.

Smith FM, Kenny SK (2005) Floristic vegetation and tree health mapping, River Murray Floodplain, South Australia. Department for Environment and Heritage, Adelaide.

Souter NJ, Watts RA, White M, George AK, McNicol KJ (2010) A conceptual model of tree behaviomproves the visual assessment of tree condition. *Ecological Indicators* **10:** 1064-1067.

Taylor PJ, Walker GR, Hodgson G, Hatton TJ, Correll RL (1996) Testing of a GIS model of *E. largiflorens* health on a semiarid, saline floodplain. *Environmental Management* **20:** 553-564.

Thorburn PJ, Hatton TJ, Walker GR (1993) Combining measurements of transpiration and stable isotopes of water to determine groundwater discharge from forests. Journal of Hydrology 150:563-587

van der Moezel PG, Pearce-Pinto GVN, Bell DT (1991). Screening for salt and waterlogging tolerance in Eucalyptus and Melaleuca species. *Forest Ecology and Management* **40:** 27-37.

Walker KF (1985) A review of the ecological effects of river regulation in Australia. *Hydrobiologia* **125:** 111-129.

Walker KF, Thoms MC (1993) Environmental effects of flow regulation on the lower River Murray, Australia. *Regulated Rivers: Research and Management* **8:** 103-119.

Weedon JT, Nicol JM (2006) Chowilla Significant Ecological Asset – floodplain vegetation monitoring interim report. South Australian Research and Development Institute (Aquatic Sciences), RD06/0334, Adelaide.

Weedon JT, Nicol, JM, Marsland KB (2007). Chowilla Icon Site – floodplain Vegetation Monitoring 2006-07 Interim Report. South Australian Research and Development Institute (Aquatic Sciences), F2007/000543-1, Adelaide.

White M, Berens V, Souter N (2009) Bookpurnong Living Murray Pilot Project: Artificial inundation of *E. camaldulensis* on a floodplain to improve vegetation condition. Department of Water, Land and Biodiversity Conservation, 2009/19, Adelaide.

Zampatti BP, Leigh SL, Nicol JM (2011) Fish and aquatic macrophyte communities in the Chowilla Anabranch System, South Australia: a report on investigations from 2004 – 2007. South Australian Research and Development Institute (Aquatic Sciences) SARDI Publication No. F2010/000719-1, Adelaide.

Zubrinich TM, Loveys BR, Gallasch S, Seekamp JV, Tyerman SD (2000) Tolerance of salinised floodplain conditions in a naturally occurring Eucalyptus hybrid related to lowered plant water potential. Tree Physiology 20:953-963.

Appendices

Appendix A Site A species presence/absence and functional groups on the Bookpurnong floodplain between 2005 and 2011.

SPECIES	Functional Group	Dec-05	Apr-06	Feb-07	Mar-07	Sep-07	Mar-08	Oct-11
Alternanthera denticulata	Floodplain	x	x		x		x	
Alternanthera nodiflora	Floodplain	x	x		x			
Atriplex leptocarpa	Floodplain	x	x					
Atriplex lindleyi ssp. *lindleyi*	Floodplain	x	x					
Atriplex semibaccata	Floodplain	x	x	x	x	x	x	
Atriplex suberecta	Floodplain	x	x	x	x	x	x	x
Azolla filiculoides	Floating							x
Brachyscome basaltica var. *gracilis*	Floodplain	x	x	x	x	x	x	
*Brassica tournefortii**	Terrestrial dry		x			x		
*Bromus rubens**	Terrestrial dry	x	x			x		
Calotis cuneifolia	Floodplain		x	x	x			x
*Centaurea calcitrapa**	Terrestrial damp					x		
Centipeda cunninghamii	Floodplain	x	x	x	x			
Centipeda minima	Floodplain	x	x	x	x	x		x
Chamaesyce drummondii	Floodplain	x		x	x	x	x	x
Dysphania pumilio	Floodplain			x	x			
*Chondrilla juncea**	Terrestrial dry				x			
*Cirsium vulgare**	Terrestrial damp							
*Conyza bonariensis**	Terrestrial damp		x		x			x
Cotula australis	Amphibious							
*Cotula bipinnata**	Amphibious		x					
*Cuscuta campestris**	Parasitic	x	x	x	x		x	
Cyperus gymnocaulos	Amphibious	x	x	x	x	x	x	x
Disphyma crassifolium ssp. *clavellatum*	Terrestrial dry			x		x	x	
Dissocarpus paradoxus	Terrestrial dry			x				
Distichlis distichophylla	Floodplain			x	x	x	x	
*Dittrichia graveolens**	Floodplain			x	x	x	x	
Dysphania glomulifera	Floodplain	x						
Eclipta platyglossa	Terrestrial dry				x			
Einadia nutans ssp. *nutans*	Terrestrial dry	x	x	x	x	x	x	x
Eleocharis acuta	Amphibious	x		x	x	x		
Enchylaena tomentosa	Terrestrial dry	x	x	x	x	x	x	
Epaltes australis	Floodplain		x		x	x		x
Eucalyptus camaldulensis var. *camaldulensis*	Amphibious	x		x	x	x	x	x
Euchiton involucratus	Floodplain	x						x
Exocarpos sparteus	Terrestrial dry						x	
Glinus lotoides	Floodplain	x	x	x	x			
*Heliotropium curassavicum**	Floodplain		x					
*Heliotropium supinum**	Floodplain			x	x			
*Hordeum glaucum**	Terrestrial dry					x		
*Hordeum leporinum**	Terrestrial dry	x						
*Hypochaeris glabra**	Terrestrial dry	x				x	x	
Juncus subsecundus	Amphibious			x		x		
Lachnagrostis filiformis	Floodplain	x	x	x	x	x		x
*Lactuca saligna**	Terrestrial dry							x
*Lactuca serriola**	Terrestrial dry			x	x	x		
*Lepidium africanum**	Terrestrial dry	x						
Lepidium pseudohyssopifolium	Floodplain					x		
Maireana brevifolia	Terrestrial dry		x	x	x	x	x	
Medicago minima var. *minima**	Terrestrial dry			x		x		
*Mesembryanthemum nodiflorum**	Terrestrial dry	x				x		
Mimulus repens	Amphibious							x
Morgania floribunda	Floodplain							x
Muehlenbeckia florulenta	Amphibious	x	x	x	x	x	x	
Myosurus australis	Floodplain							
Persicaria lapathifolia	Amphibious	x						
*Petrorhagia dubia**	Terrestrial dry	x						
Phyla nodiflora	Terrestrial dry			x	x	x	x	
Picris squarrosa	Terrestrial damp	x	x	x	x	x	x	
*Polygonum aviculare**	Terrestrial		x					
Polygonum plebeium	Floodplain							
*Polypogon monspeliensis**	Amphibious							x
Helichrysum luteoalbum	Floodplain	x	x					x

SPECIES	Functional Group	Dec-05	Apr-06	Feb-07	Mar-07	Sep-07	Mar-08	Oct-11
Ranunculus pentandrus	Amphibious					x		
*Reichardia tingitana**	Terrestrial dry			x				
Rorippa eustylis	Floodplain	x						
*Rorippa palustris**	Floodplain							x
Salsola tragus	Amphibious		x	x	x	x	x	
Sclerolaena muricata var. *muricata*	Terrestrial dry			x	x	x		
Senecio cunninghamii	Floodplain	x	x					x
Senecio glossanthus	Floodplain	x						
Senecio runcinifolius	Floodplain	x				x		x
Setaria jubiflora	Terrestrial dry	x	x	x	x	x	x	
*Silene gallica**	Floodplain					x		
*Solanum nigrum**	Terrestrial dry	x	x		x	x		
*Sonchus oleraceus**	Terrestrial dry			x	x	x		
*Spergularia rubra**	Terrestrial dry	x	x			x		
Sporobolus mitchellii	Floodplain	x	x	x	x	x	x	x
Trachymene cyanopetula	Floodplain							x
Verbena supina var. *supina**	Terrestrial damp		x					
Vulpia bromoides	Terrestrial dry					x		
Vulpia myuros f. *myuros**	Terrestrial dry	x	x	x	x			
*Wahlenbergia fluminalis**	Floodplain	x	x	x	x	x	x	x
*Xanthium californicum**	Floodplain	x		x	x			x
Number of species		**41**	**36**	**37**	**39**	**41**	**23**	**24**

* denotes exotic species

Appendix B Site B species presence/absence and functional groups on the Bookpurnong floodplain between 2005 and 2011.

Species	Functional Group	Sep-05	Nov-06	Sep-07	Mar-08	Oct-11
*Arctotheca calendula**	Terrestrial dry	x				
Atriplex semibaccata	Terrestrial dry	x	x	x	x	
Atriplex stipitata	Terrestrial dry					x
Atriplex suberecta	Floodplain					x
Austrostipa sp.	Terrestrial dry	x				
Brachyscome basaltica	Floodplain					x
*Bromus rubens**	Terrestrial damp	x		x		
Bulbine bulbosa	Terrestrial dry					
Bulbine semibarbata	Terrestrial dry	x	x			
Calandrinia eremaea	Terrestrial dry	x	x	x		
Calotis cuneifolia	Floodplain	x	x	x	x	
Calotis hispidula	Floodplain					x
*Centaurea melitensis**	Terrestrial damp		x			
Centipeda minima	Floodplain		x	x		x
Chamaesyce drummondii	Floodplain			x		
*Conyza bonariensis**	Terrestrial					x
Cotula australis	Amphibious			x		
*Cotula bipinnata**	Amphibious	x	x			
Craspedia chrysantha	Floodplain					x
Crassula colligata ssp. *colligata*	Amphibious	x	x	x		
Cyperus gymnocaulos	Amphibious	x	x	x	x	
Disphyma crassifolium	Terrestrial dry					x
Dissocarpus paradoxus	Terrestrial dry					x
*Ehrharta longiflora**	Terrestrial dry	x				
Einadia nutans	Terrestrial dry	x	x	x	x	x
Eleocharis acuta	Amphibious		x			
Enchylaena tomentosa	Terrestrial dry	x	x	x	x	x
Epaltes australis	Floodplain					x
Eucalyptus camaldulensis var. *camaldulensis*	Amphibious					x
Eucalyptus largiflorens	Amphibious	x				
Euchiton involucratus	Floodplain	x				x
*Gazania rigens**	Terrestrial dry	x	x	x		
Gunniopsis septifraga	Floodplain					x
*Heliotropium curassivicum**	Floodplain					x
*Hordeum glaucum**	Terrestrial dry	x		x		
*Hypochaeris glabra**	Terrestrial dry	x				
Isolepis sp.	Amphibious		x			
Lachnagrostis filiformis	Floodplain	x		x		x
*Lactuca saligna**	Terrestrial dry					x

Species	Functional Group	Sep-05	Nov-06	Sep-07	Mar-08	Oct-11
Lepidium pseudohyssopifolium	Floodplain	x	x	x		
Medicago minima var. *minima**	Terrestrial dry	x				
*Mesembryanthemum nodiflorum**	Terrestrial dry	x		x		
Mollugo cerviana	Floodplain					x
Muehlenbeckia florulenta	Amphibious	x	x			x
*Petrorhagia dubia**	Terrestrial dry	x				
*Phyla nodiflora**	Terrestrial dry	x	x	x	x	
Picris hieracoides	Terrestrial damp					x
Picris squarrosa	Terrestrial damp	x	x			
Plantago cunninghamii	Floodplain	x	x			
Helichrysum luteo-album	Floodplain	x				x
*Reichardia tingitana**	Terrestrial dry		x			
Rorippa eustylis	Floodplain	x				
*Rorippa palustris**	Floodplain					x
Rumex bidens	Amphibious					x
Schismus barbatus	Terrestrial dry	x				
Sclerolaena divaricata	Terrestrial dry					x
Sclerolaena muricata var. *muricata*	Terrestrial dry	x				
Senecio cunninghamii	Floodplain	x	x	x		x
Senecio glossanthus	Floodplain	x	x			
Senecio pinnatifolius	Floodplain	x	x			
Senecio runcinifolius	Floodplain					x
Setaria jubiflora	Terrestrial dry	x	x	x	x	
*Silene gallica**	Floodplain			x		
*Sonchus oleraceus**	Terrestrial dry	x		x		x
Spergularia diandra	Terrestrial dry	x		x	x	
*Spergularia marina**	Terrestrial dry					x
Spergularia rubra	Terrestrial dry	x	x	x		
Sporobolus mitchellii	Floodplain	x	x	x	x	
Stemodia florulenta	Floodplain				x	
Tetragonia tetragonoides	Terrestrial dry					x
Vulpia bromoides	Terrestrial dry	x		x		
Vulpia myuros f. *myuros*	Terrestrial dry	x				
Wahlenbergia fluminalis	Floodplain	x				x
*Xanthium californicum**	Floodplain		x			
Number of species		**42**	**27**	**25**	**10**	**31**

Appendix C Species presence/absence at Pike and Chowilla floodplains.

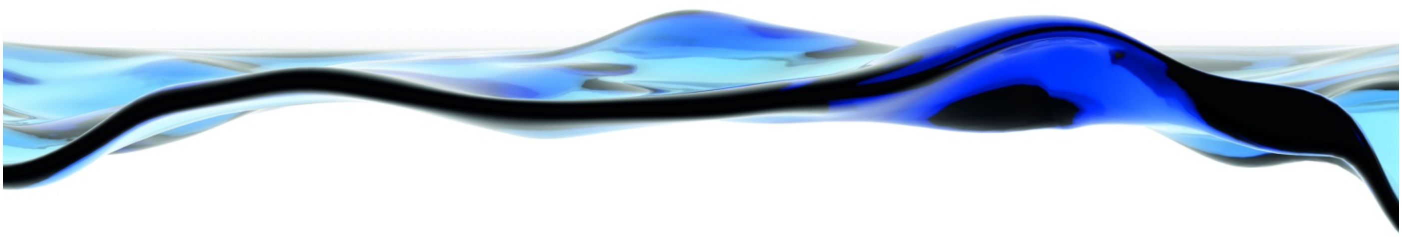
		Chowilla		Pike	
Scientific Name		**2010**	**2011**	**2010**	**2011**
Alternanthera denticulata	Floodplain	x	x	x	x
Ammannia multiflora	Floodplain	x	x		x
*Asphodelus fistulosus**	Terrestrial dry		x		
*Atriplex prostrata**	Floodplain			x	x
Atriplex spp.	Terrestrial	x	x	x	x
Atriplex suberecta	Floodplain		x		x
Brachyscome basaltica	Floodplain	x	x	x	x
Brachyscome dentata	Floodplain	x			
Calotis cuneifolia	Floodplain				x
Calotis hispidula	Floodplain		x		x
Calotis scapigera	Floodplain	x	x		
*Carrichtera annua**	Terrestrial dry				x
Centipeda minima	Floodplain	x	x	x	x
*Centaurium tenuiflorum**	Terrestrial damp	x			
Chenopodium nitrariaceum	Terrestrial dry	x	x		
Dysphania pumilio	Floodplain		x		x
*Conyza bonariensis**	Terrestrial damp	x	x		x
Cotula australis	Amphibious		x		x
Crassula helmsii	Amphibious		x		x
Crassula sieberiana[§]	Amphibious		x		
Craspedia chrysantha	Floodplain	x	x		
Cyperus difformis	Amphibious	x	x		
Cyperus gymnocaulos	Amphibious				x
Disphyma crassifolium ssp. *clavellatum*	Terrestrial dry	x	x	x	x
Einadia nutans	Terrestrial dry				x
Eleocharis acuta	Amphibious	x	x		
Enchylaena tomentosa	Terrestrial dry	x	x	x	
Enneapogon nigricans	Terrestrial dry		x		x
Epaltes australis	Floodplain		x	x	x
Eragrostis australasica	Floodplain	x	x		
*Erodium cicutarium**	Floodplain		x		x
Eucalyptus camaldulensis var. *camaldulensis*	Floodplain				x
Euchiton involucratus	Floodplain				x
Chamaesyce drummondii	Floodplain		x		x
Frankenia pauciflora	Terrestrial dry	x	x	x	x
Glinus lotoides	Floodplain		x	x	
Goodenia gracilis	Floodplain	x	x		x
Tecticornia pergranulata ssp. *pergranulata*	Amphibious			x	x
*Heliotropium amplexicaule**	Floodplain		x		x
*Heliotropium curassavicum**	Floodplain		x	x	x
*Heliotropium europaeum**	Floodplain	x			x
*Hordeum vulgare**	Terrestrial dry				x
*Hypochaeris glabra**	Terrestrial dry		x		x
Isoetopsis graminifolia	Floodplain		x		x
Isolepis hookeriana	Amphibious	x	x		
Lachnagrostis filiformis	Floodplain				x
*Lactuca saligna**	Terrestrial dry				x
Limosella australis	Amphibious		x		
Ludwigia peploides ssp. *montevidensis*	Amphibious				x
Maireana spp.	Terrestrial	x	x	x	x
Marsilea angustifolia	Amphibious	x	x		x
Medicago spp.*	Terrestrial		x		
Mentha australis	Amphibious		x		
*Mesembryanthemum crystallinum**	Terrestrial dry			x	
Mimulus repens	Amphibious	x	x		x
Mollugo cerviana	Floodplain		x		x
Muehlenbeckia florulenta	Amphibious	x	x		x
Muehlenbeckia horrida[¥]	Amphibious	x	x		x
Myosurus australis	Floodplain		x		x
Myriophyllum verrucosum	Amphibious				x
Neogunnia septifraga	Floodplain		x		
*Nothoscordum borbonicum**	Terrestrial dry		x		x
Osteocarpum acropterum var. *acropterum*	Floodplain	x			x
Pachycornia triandra	Terrestrial dry	x	x	x	x
*Phyla canescens**	Terrestrial dry	x	x		x
Phyllanthus lacunaris	Floodplain	x			x
Picris angustifolia	Terrestrial damp		x		

Scientific Name		Chowilla 2010	Chowilla 2011	Pike 2010	Pike 2011
Plantago cunninghamii	Floodplain		x		x
*Polypogon monspeliensis**	Amphibious	x			
Polygonum plebeium	Floodplain	x			x
Helichrysum luteo-album	Floodplain		x		x
Pycnosorus spp.	Floodplain				x
*Reichardia tingitana**	Terrestrial dry				x
Rhagodia spinescens	Terrestrial dry	x			
*Rorippa palustris**	Floodplain		x		x
Rumex bidens	Amphibious		x		x
Salsola kali var. *kali*	Terrestrial dry	x	x	x	
Sclerolaena brachyptera	Terrestrial dry	x	x	x	x
Sclerolaena divaricata	Terrestrial dry	x	x	x	x
Sclerolaena stelligera	Terrestrial dry	x	x	x	x
Scleroblitum atriplicinum	Floodplain		x		x
Senecio cunninghamii	Floodplain		x		x
Senecio runcinifolius	Floodplain	x	x		x
Senecio sp.	Floodplain			x	
Sida ammophila	Terrestrial dry	x			
Solanum lacunarium	Floodplain	x	x		
*Sonchus oleraceus**	Terrestrial dry				x
*Spergularia marina**	Terrestrial dry		x	x	x
Sporobolus mitchellii	Floodplain	x	x	x	x
*Taraxacum officinale**	Terrestrial damp		x		
Tetragonia tetragonioides	Floodplain	x	x		x
Trachymene cyanopetula	Floodplain		x		x
Typha domingensis	Emergent	x			
Wahlenbergia fluminalis	Floodplain		x		x
Number of species		**43**	**66**	**24**	**68**

*denotes exotic species

§ denotes listed as endangered in South Australia

¥ denotes listed as rare in South Australia



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