



Floodwater infiltration through root channels on a sodic clay floodplain and the influence on a local tree species *Eucalyptus largiflorens*

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Abstract

Dieback of riparian species on floodplains has been attributed to increased soil salinisation due to raised groundwater levels, resulting from irrigation and river regulation. This is exacerbated by a reduction in flooding frequency and duration of inundation. For the Chowilla floodplain on the River Murray raised water tables have increased the amount of salts mobilised in the soil profile, causing the trees to experience salt induced water stress. For the trees to survive in the long term, salts need to be leached from the root zone.

This study investigated whether floodwater infiltrates through channels created by *E. largiflorens* (black box) roots, flushing salts away from roots, thereby allowing the trees to increase their water uptake. Trees at different sites on the floodplain were artificially flooded, by pumping 1.5 kL of creek water into impoundments constructed around the trees. Gas exchange parameters, and pre-dawn and midday water potential were measured the day before, the day after and one week after the artificial flood and compared against trees that were not flooded. Pre-dawn and midday water potentials were also measured one month after the flood. After flooding, the trees experienced less water stress, indicated by an increase in water potential of less than 0.2 MPa, in comparison to non-flooded control trees. However, this response was not evident one month after flooding. The response to flooding did not result in increased rates of transpiration, stomatal conductance or photosynthesis, even though flooding effectively doubled the trees yearly water supply.

The infiltration of floodwater in the impoundments around *E. largiflorens* was also compared to that of impoundments on bare ground. Floodwater infiltrated 2 – 17 times faster around trees than on adjacent bare ground, for parts of the floodplain not grazed by livestock. Tracer dye experiments indicated that bulk flow of water through pores down the profile was the reason for the enhanced infiltration. Flooding leached salts in direct vicinity of tree roots, but only leached small amounts of salts from the bulk soil.

Introduction

Eucalyptus largiflorens (black box), the dominant tree species on the Chowilla floodplain, is suffering a decline in health. In 1990, Margules et al. (1990) estimated that 40% of the population was unhealthy. Jolly et al. (1993) attributed the dieback to increased

salinisation of the floodplain, caused by river regulation. River regulation has reduced the frequency of medium to large size floods, in the region, by 30% (Ohlmeyer, 1991) and raised watertables beneath the floodplain (Margules et al., 1990). Raised watertables increase the amount of salts mobilised in the soil profile. Groundwater, carrying dissolved salts, moves through the soil profile by the processes of capillary rise and evapotranspiration. Salts accumulate in the root zone, whilst the water is discharged to the atmo-

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sphere (Slavich et al., 1999; Thorburn et al., 1995). *E. largiflorens* is salt tolerant (Blake, 1981) by excluding salts from being taken up by the roots (Streeter et al., 1996) and uses groundwater as its main source of water (Thorburn et al., 1993). The accumulation of salts in the root zone lowers the osmotic potential of the soil water. Unless salts are leached from the root zone, the osmotic potential will become so negative that the trees will be unable to extract water from the soil profile, causing physiological drought and eventual death.

It was assumed that natural floods ameliorated the effects of soil salinisation by leaching salts from the soil profile (Jolly et al., 1996). Slavich et al. (1999) modelled the response of *E. largiflorens* to floods, which was estimated to last for 12 years, with the trees having increased transpiration rates. However, *E. largiflorens* did not respond to the 1992 flood on Chowilla floodplain. After floodwaters had receded, the transpiration rates of flooded trees, measured using sapflow sensors, did not increase in comparison to trees at non-flooded sites (Jolly and Walker, 1996). Flooded trees did, however, alter their source of water and used flood-derived soil water, as indicated by isotope analysis (Jolly and Walker, 1996). Transpiration rates, also recorded with sapflow sensors, were measured during the 1993 flood. After the floodwaters had receded, Akeroyd et al. (1998) observed increased transpiration rates at two of six sites investigated. However, one of those sites was the control site and was not flooded. Akeroyd et al. (1998) also measured pre-dawn water potential, after flooding, which was less negative than is usually observed for that time of year. These studies highlight one of the main disadvantages of carrying out field research during actual floods, the lack of appropriate controls. Control trees were at different sites. The less negative water potentials may not have been entirely due to the flooding, as in the past, flooding events have been preceded by greater than average rainfall (Jolly and Walker, 1996). Therefore, control trees would also have less negative water potentials.

Research into the mechanisms of floodwater infiltration during actual floods at Chowilla, in 1990 and 1992, indicated that floodwater did not infiltrate to depths greater than 0.7 m. Also, gross leaching of salts, to the watertable, does not occur over much of the floodplain (Jolly et al., 1994; Jolly and Walker, 1996). Akeroyd et al. (1998) observed some leaching during the longer duration 1993 flood, but only at the two sites with lower soil clay contents. To sur-

vive in the long-term, salts must be leached from the root zone, for *E. largiflorens* to overcome salt-induced water stress. Utilisation of flood-derived water suggests that salts are leached from the root zone, but the mechanisms for this are unknown.

We propose that shrinkage cracks in clay soils, root channels and other holes in the soil, created by biota (biopores), provide preferential infiltration pathways for floodwater. Clay soils shrink as they dry. Tree roots may also shrink when experiencing drought, retracting from the soil and providing potential conduits for infiltration of floodwaters. Although these 'channels' would be small, they could be sufficient for floodwaters to flush salts from the immediate vicinity of roots, thereby allowing trees to take up floodwater. Water preferentially flows through macropores in soil profiles and macropores increase infiltration rates into the soil surface (Edwards et al., 1988a,b; Ela et al., 1992; Germann et al., 1984; Ghodrati and Jury, 1990; Heathman et al., 1995; Quisenberry et al., 1994). Ant biopores also increase the infiltration rate of ponded water (Lobry de Bruyn and Conacher, 1994). Increased water infiltration, due to old root channels, under different cropping systems has been observed (Mitchell et al., 1995) and during rainstorms in the tropics, old tree root channels formed the major sites of infiltration (Van Noordwijk et al., 1991). Hulugalle et al. (2001) observed that the salinity of soil adjacent to cracks was lower than in bulk soil, also providing support for our hypothesis that the infiltration of water via root channels could leach salts away from roots.

We hypothesised that: (1) floodwater infiltrates preferentially via root channels so that water should infiltrate faster around trees, than on bare ground; (2) salts would be leached from the immediate vicinity of roots; (3) flooded trees would display increased water potentials and show physiological indications of being less water stressed. To overcome the problem of the lack of appropriate controls during actual floods, we artificially flooded individual trees and adjacent bare ground on Chowilla floodplain. We measured floodwater infiltration rates and depth of floodwater infiltration using pre- and post-flood soil water content and a dye tracer. We also measured pre- and post-flood soluble salt content. To determine the short-term response of *E. largiflorens* to flooding we measured gas exchange parameters of flooded and non-flooded trees at the same site.

Materials and methods

Site description

The Chowilla Anabranh encompasses approximately 200 km² of saline, semi-arid floodplain adjacent to the Murray River, on the South Australia/New South Wales border. Within the floodplain, a system of streams branch away from the Murray River, above Lock 6, which join to form Chowilla Creek. Chowilla Creek discharges into the Murray River, downstream of Lock 6.

The Chowilla floodplain overlies a sequence of aquifers that discharge saline groundwater into the River Murray (Jarwal et al., 1996). The uppermost aquifer (Monoman Formation) is composed of alluvial sand and is overlain by a layer of grey, cracking, clay soils (Coonambidgal Clay) (Hollingsworth et al., 1990). The clay soils are highly sodic, with an exchangeable sodium percentage greater than 15 (Jolly et al., 1996). The Coonambidgal Clay has minimal profile development and can be up to 5 m in depth. Watertables beneath the floodplain predominantly reside within the Coonambidgal Clay layer.

The Chowilla region has an average annual rainfall of 260 mm (Bureau of Meteorology 2000) and experiences mild, wet winters and dry summers.

The artificial flooding experiments were carried out at four sites on the Chowilla floodplain. The sites were chosen based on their accessibility and proximity to creeks for a source of water for flooding experiments. The locations of the study sites were adjacent to Monoman Creek (Site 1), Punkah Creek (Site 2), Big Hunchee Creek – downstream (Site 3) and Big Hunchee Creek – upstream (Site 4). A description of the sites is given in Table 1.

Artificial flooding

Two pairs of trees were selected at each site, with the exception of Site 1, where only one pair of trees was studied. Each pair of trees consisted of a non-flooded tree (control) and a tree that was flooded. Trees of each pair were within 60 m of each other and of similar size and health. The individual pairs of trees represented seven replicates of the flooding experiment.

An impoundment to hold ponded water was assembled around one tree from each pair. An impoundment was also assembled on open bare ground, adjacent to each flooded tree, to investigate infiltration of floodwater in the absence of tree roots.

Impoundments were constructed from sheets of zinc-aluminium coated steel (0.004 m × 10 m × 0.4 m), to form a 3 m -diameter container. The impoundment was buried 5 – 10 cm into the soil and the soil surface was compacted to prevent lateral leakage.

Creek water (1500 L) was pumped into the impoundment from the adjacent creek. To reduce disturbance to the soil surface, the end of the pipe was positioned inside a bucket, where the overflow from the bucket filled the impoundment. The creek water was mixed with 100 mL rhodamine WT dye, placed in the bucket.

The time to pump 1500 L of water into impoundments took between 28 and 40 min, depending on the pump rate and head. After pumping, the height of the water within the impoundment was recorded over time, until infiltration was complete.

The salinity of the creek water, used for flooding, was measured at each site.

Physiological measurements

Pre-dawn and midday water potentials of the control and flooded trees of each pair were measured using a Scholander Pressure Bomb (Scholander et al., 1965). Measurements were carried out the day prior to flooding, and one day, one week and one month after flooding. At Site 3, rainfall prevented the midday measurement one week after the flood. At site 4, rainfall restricted access to the floodplain for follow-up measurements for nearly three weeks after the flood.

Stomatal conductance (g), transpiration (E) and photosynthetic rate (A) were recorded mid-morning, near midday and mid-afternoon, using an IRGA (infrared gas analyser) (Analytical Development Company). Measurements were taken the day before the flood, one day and one week after the flood. Measurements for each time of day were averaged from five different leaves in direct sunlight. The mean daily water use efficiency (WUE) (Assimilation/Evaporation) was also calculated for each tree before and after flooding.

Soil properties

Soils were sampled at 10 cm intervals to a 1 m depth, using a 7 cm-diameter hand-auger. Two locations, 1 m from the outside of each impoundment were sampled prior to flooding, and two locations were sampled inside each impoundment the day after the floodwater had infiltrated. At one of the locations, at each site,

Table 1. Description of sites used for flooding experiments and climatic conditions during the study periods

	Site 1	Site 2	Site 3	Site 4
Location	Monoman Creek S 33° 58' E 140° 52'	Punkah Creek S 33° 56' E 140° 56'	Big Hunchee Creek (downstream) S 34° 03' E 140° 46'	Big Hunchee Creek (upstream) S 34° 03' E 140° 47'
Vegetation description	Elevated band of <i>E. largiflorens</i> parallel to creek, neighbouring floodplain dominated by <i>Muehlenbeckia florulenta</i> .	Large community of <i>E. largiflorens</i> and <i>E. camaldulensis</i> . Extensive ground-cover of small grasses, herbaceous plants and leaf litter.	<i>E. largiflorens</i> and <i>E. camaldulensis</i> community. Predominant ground-cover of <i>Disphyma crassifolium</i> . Open floodplain extending beyond the tree-line, consisting of grasses and forbs.	<i>E. largiflorens</i> and <i>E. camaldulensis</i> community. Predominant ground-cover of <i>Disphyma crassifolium</i> . Open floodplain extending beyond the tree-line, consisting of grasses and forbs.
Grazing activity	Grazed by sheep.	Livestock excluded since 1992.	Livestock excluded since 1992/93.	Livestock excluded since 1992/93.
Date of flooding experiment	28–31 March 2000	16–19 May 2000	25–28 June 2000	10–14 July 2000
Maximum daily temperature during study period (°C)	21–24	18–21	14–19	15–17
Total rainfall for the month after flooding study (mm)	1	18	27	19
Approximate daily potential evaporation during study period (mm/day)	4	2	2	2
Watertable depth (m)	3.6	4.4	3.9	4.0
Groundwater salinity (dS m ⁻¹)	35.1	45.7	49.5	53.6

sampling extended to the watertable and the salinity of the groundwater measured.

The gravimetric water content of each soil sample (pre and post-flood) was determined by oven drying soil for 24 h at 105 °C. Soluble salts in each soil sample were extracted using a 1:5 ratio of soil to de-ionised water. Solutions were rotated at 125 rpm on an orbital shaker (Ratek Orbital Mixer Incubator) for one hour and filtered through Whatman's no. 1 filter

paper. The electrical conductivity (EC) of soil extracts, creek water and groundwater at each site, was determined using a digital conductivity meter (T.P.S. model 2100). Rhodamine WT dye was detected in soil extracts using fluorescence spectrophotometry (Hitachi F4000) (Smart and Laidlaw, 1977), after flocculating clay particles from the solution using a small amount of dry CaCl₂.

Table 2. Comparison between bare ground and under trees, for time for water to infiltrate the ground and height of water in each impoundment, after pumping ceased, and steady state flow-rate (floodwater infiltration rate). Steady state flow-rate was calculated using volume of water pumped into impoundment, impoundment area and total time for all water to infiltrate (including pumping time)

Site	Time for Water to Infiltrate*		Floodwater Height*		Steady State Flow-Rate	
	(hours)		(mm)		(mm/hour)	
	Bare ground	Under Tree	Bare ground	Under Tree	Bare ground	Under Tree
1	5.8	6.9	180	120	32	27
2a	5.4	0.5	130	65	33	171
2b	17.9	0.4	100	10	11	194
3a	4.9	0.9	190	100	37	132
3b	3.8	0.4	100	90	46	207
4a	1.8	0.6	130	80	81	165
4b	4.0	0.3	140	50	44	225

* After pumping ceased.

Statistical analysis

Paired samples t-tests were performed on physiological measurements, taken at the same time, on adjacent control and flooded trees. To test whether relative differences between control and flooded trees were due to the flooding, all physiological measurements were normalised and expressed as a ratio relative to the measurement taken the day prior to flooding. The normalised water potential was analysed using paired t-tests as the data met the assumptions of normality. Normalised transpiration, stomatal conductance, photosynthetic rate and WUE were analysed using Wilcoxon non-parametric tests due to the strong departures from normality of the within pairs differences. All analysis was performed using SPSS version 10.0.

Results

Artificial flooding

With the exception of Site 1, the infiltration rate around trees was higher than on bare ground (Table 2). At Site 1, some lateral leakage of water occurred from the impoundment confounding results. The ponded water receded within 1 hour around the trees, but took 2–18 h to infiltrate on bare ground. The height of floodwater reached between 10 and 19 cm in impoundments on bare-ground, but only reached heights of 1–12 cm around trees, indicating rapid infiltration rates. The infiltration rate around one of the trees at Site 2 was almost equivalent to the pumping rate and so only pools of water formed on the soil surface.

During filling of the impoundments, rhodamine-stained water was observed inside some of the soil core holes, dug at a distance of 1 m from the outside of the impoundments, and in some instances could be seen trickling into the holes where small roots had been severed by the auger. The salinity of this water was 6–38 times greater than the creek water used to fill the impoundment (Table 3). This lateral movement of water occurred near flooded trees, with 10 of the 14 soil-core holes containing floodwater, but not near impoundments on bare ground. Where water did collect near impoundments on bare ground (3 out of 14 soil core holes), tree roots had been observed in the soil cores.

Post-flood soil water content and relative fluorescence intensity of soil solution extracts were used to determine the depth of infiltration of floodwater, into the bulk soil. In general, post-flood soil water content indicated that floodwater infiltrated deeper on bare ground (> 1 m) than around trees (0.8 m) (Figure 1). This is probably due to a higher proportion of floodwater infiltrating beneath trees through root channels, than as diffuse flow and therefore, not wetting the bulk soil profile. The greatest concentrations of rhodamine WT dye were present at shallower depths in the soil profile beneath bare ground (< 0.4 m) than beneath trees (> 0.7 m) (Figure 2).

Pre- and post-flood electrical conductivity of soil solution extracts show that no significant amounts of salts were leached from the bulk of the soil profile (Figure 3). Salts tended to accumulate in the profile below 0.6 m, beneath bare ground impound-

Table 3. Electrical conductivity (EC) of creek water and water samples collected at the base of soil core holes. Two 1 m deep soil core holes, located 180 degrees apart and 1 m outside of each impoundment, were dug prior to flooding. During impoundment flooding with local creek water, some holes filled with rhodamine-stained water and the EC was measured. Monoman Creek (Site 1), Punkah Creek (Site 2), Big Huncheon Creek downstream (Site 3) and Big Huncheon Creek upstream (Site 4). Subscript letters denote different pairs of impoundments at the same site

Site	Creek water EC (dS m ⁻¹)	Conditions at the base of holes, or EC (dS m ⁻¹) of water samples			
		Bare ground		Under Tree	
		Hole 1	Hole 2	Hole 1	Hole 2
1	0.51	Dry	Dry	WT	Dry
2 _a	0.40	Dry	Dry	WT*	4.03
2 _b	0.40	Dry	Moist	3.41	5.99
3 _a	0.28	Dry	Dry	WT*	3.75
3 _b	0.28	1.68	Dry	1.82	10.51
4 _a	0.37	Dry	Moist	WT	3.25
4 _b	0.37	Dry	Dry	Dry	Moist

‘WT’ indicates that hole was dug to the watertable and sample of groundwater collected prior to flooding.

* Indicates rhodamine-stained water was present at the water table after flooding.

‘Dry’ indicates that the hole was dry, i.e. no water was present in the hole after flooding.

‘Moist’ indicates that there was some water in the bottom of the hole after flooding, but of insufficient quantity to sample

ments, whereas soil salt contents were generally lower beneath trees, below 0.5 m.

Physiological measurements

Pre-dawn water potential prior to flooding varied by site and time and ranged from -2.0 MPa at Punkah Creek to -3.4 MPa at Big Huncheon Creek (upstream) (Table 4). Analysis of the normalised values showed that the predawn water potential, of flooded trees, was generally less negative after flooding, in comparison to non-flooded trees (Figure 4). This difference was only significant the day after and one week after the flood ($P = 0.024$, $P = 0.039$, respectively).

The water potential of flooded and non-flooded trees was more negative at midday than pre-dawn, and ranged from -2.6 MPa at Punkah Creek to -4.0 MPa at Monoman Creek (Table 4). The normalised midday water potential of non-flooded and flooded trees was significantly different ($P = 0.005$), but only one day after the flood (Figure 4).

Transpiration and photosynthetic rates and stomatal conductance generally decreased throughout the day, with the highest measurements recorded mid-morning. Trends were observed within the paired trees that indicated both non-flooded and flooded trees were responding similarly to their environment, which was

reflected in non-significant differences for normalised transpiration, photosynthesis and stomatal conductance and WUE ($P > 0.05$) with respect to treatment (Figure 5).

Discussion

Comparison of pre- and post-flood soil water contents indicated that floodwater infiltrated deeper beneath bare ground than trees (Figure 1). However, if water had flowed through root channels, the bulk soil would not have been thoroughly wetted. The use of rhodamine dye in the floodwater provided evidence that the mechanism of floodwater infiltration beneath trees was different to beneath bare ground (Figure 2). The distribution of the dye concentration correlates to predominantly diffuse flow, through the soil profile, beneath bare ground, with the concentration being greater at shallower depths and decreasing with depth. In comparison, dye concentration increased with depth, beneath trees, with a maximum at approximately 0.85 m (Figure 2). Since rhodamine is adsorbed to clay particles (Trudgill, 1987) the presence of high concentrations of the dye deeper in the profile, under flooded trees, indicates that the water carrying the dye to these depths was moving rapidly

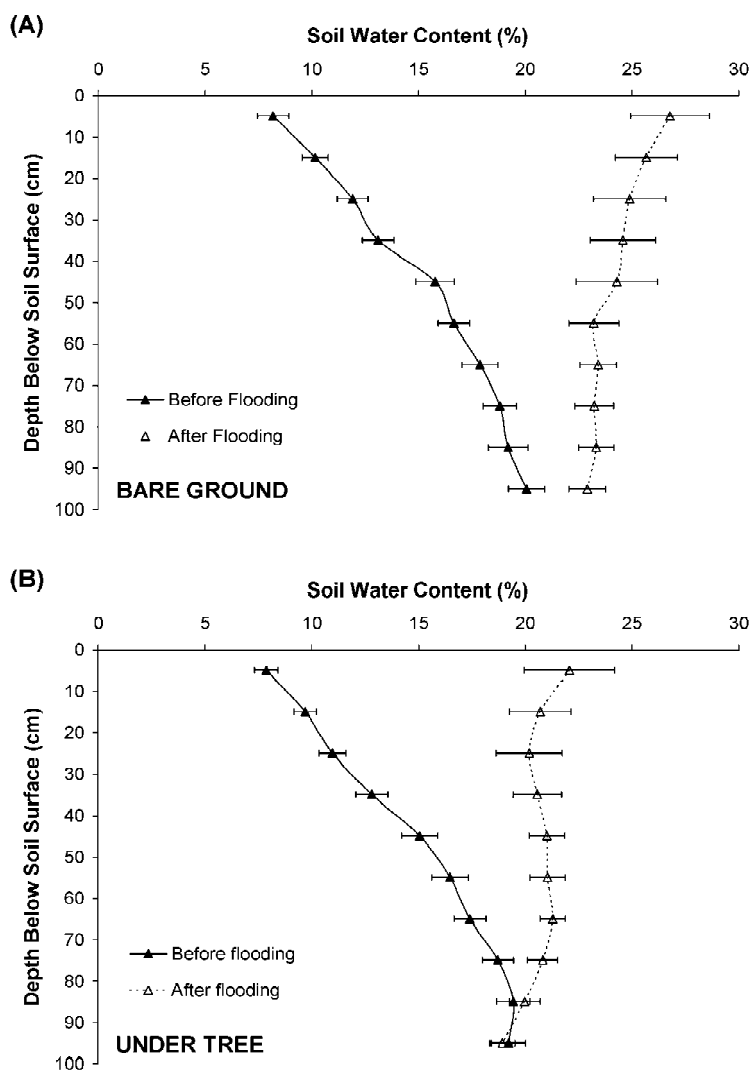


Figure 1. Soil water content measured the day before and the day after flooding, from all sites. Error bars represent (± 1) SEM, $n = 14$. (A) Impoundments on bare ground. (B) Impoundments around trees.

through the profile, as would be expected if the water moved predominately through root channels.

The presence of rhodamine-stained water in holes outside of the impoundments that was collected near trees and not bare ground, also indicated that tree roots played a dominant role. The water had electrical conductivities far greater than that of the creek water pumped into the impoundment. This observation indicates that salts in the root zone were flushed by the floodwater, even though bulk leaching of the soil profile was not observed (Table 3, Figure 3).

In all but one artificial flooding event, the presence of trees increased the infiltration of water into

the soil profile. At Site 1, ponded water in the impoundment on bare ground infiltrated the soil surface quicker than water ponded around the tree, which is contrary to what was expected. The infiltration from both impoundments also generally took longer than at the other sites (Table 2). This may have been due to soil compaction by stock traffic at Site 1 (Table 1).

The investigations of the response of *E. largiflorens* to flooding, during floods of the Chowilla floodplain, in 1992 and 1993, did not clearly demonstrate that this tree species responds to flooding in the short-term. Akeroyd et al. (1998) only measured water potential after flooding and so did not have

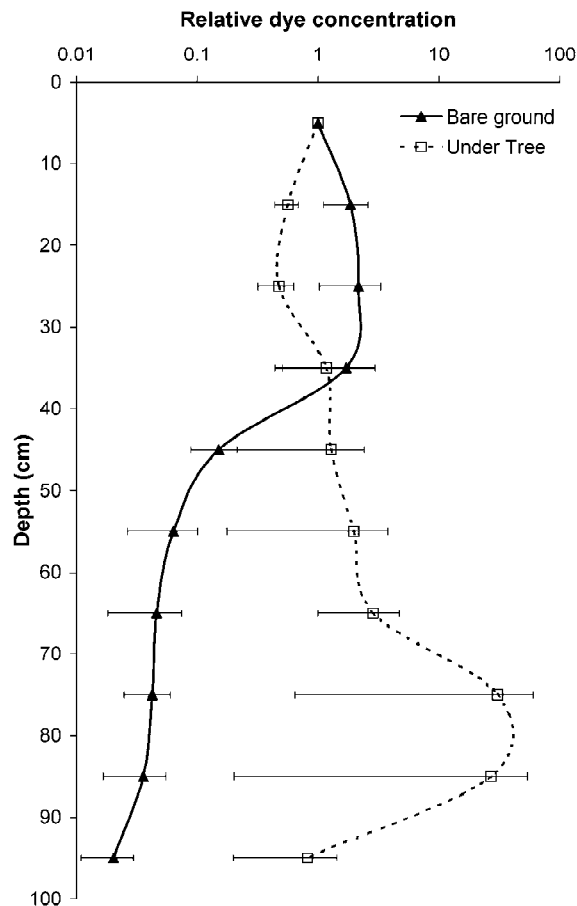


Figure 2. Relative concentration of Rhodamine WT dye in soil profiles the day after flooding, from soil cores taken within impoundments on bare ground (solid symbols) or impoundments under trees (open symbols). The concentration at 5 cm intervals in soil depth were made relative to the concentration measured in the first 5 cm. Error bars represent ± 1 SEM, $n = 12$.

pre-flood measurements to compare these against, but stated that trees were less stressed for that time of year. Slavich et al. (1999) used modelling to show that the trees benefit from flooding, with increased transpiration rates, but studies during actual floods failed to show this response in the short-term (Akeroyd et al., 1998; Jolly and Walker, 1996). However, the actual floods created problems for the researchers, limiting the type of physiological measurements taken and preventing comparison of those measurements against true control trees (i.e. trees that were not flooded, but were located at the same sites as those that were flooded). Transpiration rates were measured using sapflow sensors and their reliability has since been brought into question when used on stressed trees

(Streeter et al., 1996) or when flow-rates are low (Burgess et al., 1998). This study conducted controlled artificial floods on individual trees and a wider range of physiological measurements were taken to detect whether there was a change in plant water status, as a result of the flooding.

After flooding, trees had slightly less negative pre-dawn and midday water potentials relative to their initial values and relative to non-flooded trees, indicating that the flooded trees were experiencing less water stress as a result of flooding. However, the magnitude of the change in water potential of flooded trees was only small (< 0.2 MPa) and the response was short-lived (not significant after one month). Zubrinich et al. (2000) measured the water potential of *E. largiflorens* during the night, which reached a stable plateau, suggesting that the plant had reached equilibration. Therefore, we can assume that the predawn water potential is a reliable indicator of the soil water potential, where the trees were extracting water and that they were probably utilising the flood-derived water. Previous research has shown that *E. largiflorens* has an opportunistic water use strategy, and is able to take advantage of more freely available water (Jolly and Walker, 1996; Streeter et al., 1999; Thorburn et al., 1993; Zubrinich et al., 2000).

The amount of water (200 mm) that was pumped onto the flooded trees is almost equivalent to the mean annual rainfall for the region and so the flooding experiments effectively doubled the trees yearly water supply. Despite this there was no significant change in any of the gas exchange parameters measured, as a result of the flood. These findings suggest that the volume of water or its method of application in the flooding experiments was not sufficient to considerably alter the trees daily water use. Whilst salts were leached from the immediate vicinity of some roots, the majority of these roots may not have been active or the floodwater may have drained away from regions where roots could extract the water. Thorburn and Ehleringer's (1995) investigation into the activity of roots in different areas of the soil profile and their influence on canopy water sources indicated that root presence does not necessarily correspond with root activity. *E. largiflorens* roots penetrate to the groundwater so that water draining along root channels may find its way eventually to the groundwater. Zubrinich et al. (2000) indicated that *E. largiflorens* is also reliant on surface roots and responds to events that affect soil moisture in the surface horizon. *E. largiflorens* surface roots can extend far beyond the reaches of the canopy

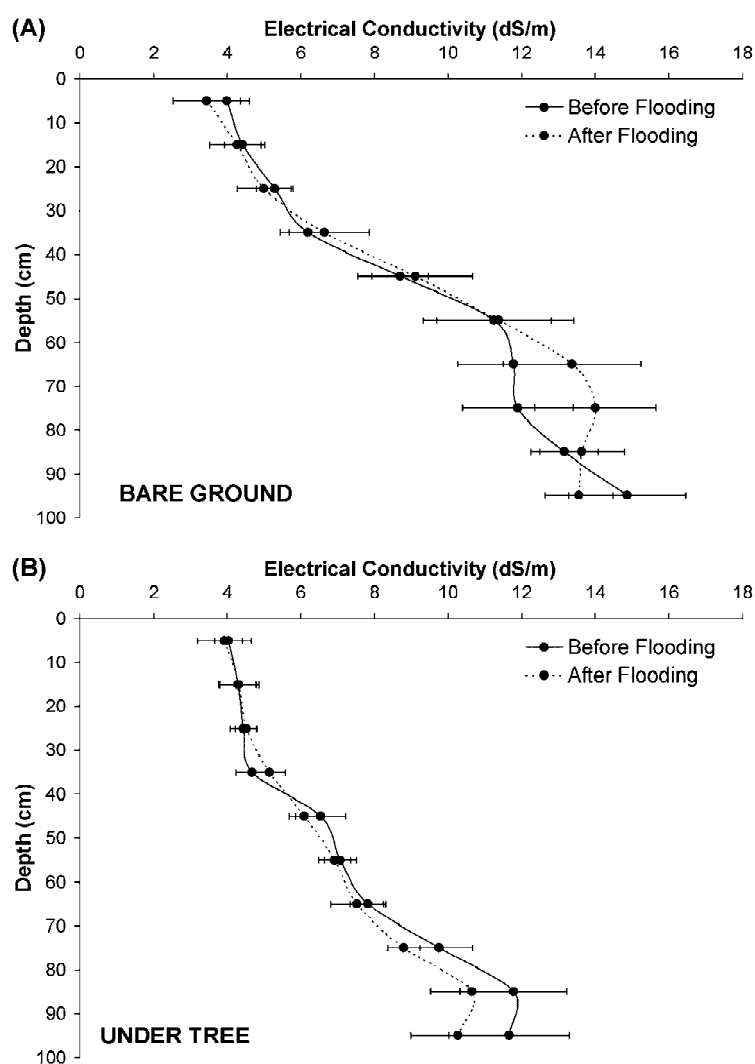


Figure 3. The electrical conductivity of the soil profile the day before flooding (outside of the impoundments) and the day after flooding (from within the impoundments), from soil cores taken for bare ground (A) or under trees (B). Error bars represent ± 1 SEM, $n = 14$.

Table 4. Mean transpiration, photosynthesis, stomatal conductance, water use efficiency and water potential, for trees that were flooded or not flooded (control), at all sites one week after flooding. Transpiration, photosynthesis and stomatal conductance are the mean instantaneous rates measured at mid-morning. Values in parentheses represent 1 SEM, $n = 5-7$

Physiological response	Treatment	
	Non-Flooded Tree	Flooded Tree
Transpiration Rate ($\text{mmol m}^{-2} \text{s}^{-1}$)	1.3 (± 0.3)	1.2 (± 0.2)
Stomatal Conductance ($\text{mmol m}^{-2} \text{s}^{-1}$)	83.8 (± 14.3)	92.3 (± 17.4)
Photosynthetic Rate ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	9.3 (± 0.9)	8.8 (± 1.5)
Water Use Efficiency ($\mu\text{mol mmol}^{-1} \times 10^3$)	9.5 (± 1.1)	8.1 (± 0.8)
Predawn Water Potential (MPa)	-2.7 (± 0.1)	-2.4 (± 0.1)
Midday Water Potential (MPa)	-2.8 (± 0.1)	-2.8 (± 0.3)

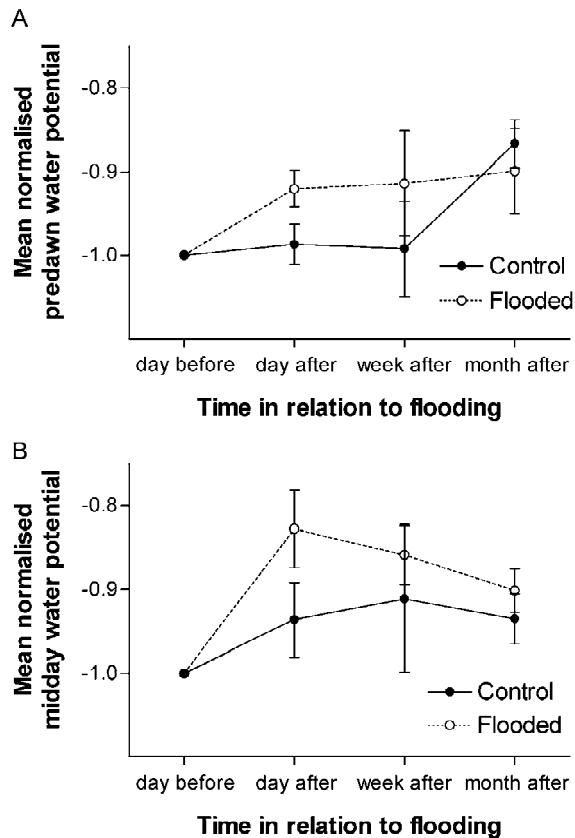


Figure 4. Relative differences of water potential between control (closed circles) and artificially flooded trees (open circles) over time, with respect to time of flooding. Normalised predawn water potential (A) and midday water potential (B). Normalised values are expressed as a ratio of the absolute value measured the day before flooding. The absolute values the day before flooding (i.e. where the normalised value = -1.0) are $-2.74 (\pm 0.16)$ and $-2.72 (\pm 0.18)$ MPa for control and flooded trees, respectively. Error bars represent (\pm) 1 SEM, $n = 5-7$.

and so water from our flooding experiments may not have reached the active regions of root water uptake.

Where trees are reliant on highly saline groundwater, *E. largiflorens* have conservative water use with low transpiration rates, which do not fluctuate with season or potential evaporation (Streeter et al., 1996; Thorburn et al., 1993). Streeter et al. (1996) suggested that *E. largiflorens* survive in saline environments at the expense of transpiration, by reducing stomatal conductance. Our flooding experiments alleviated, to some extent, the salt-induced water stress (indicated by the change in water potential) and provided these trees with a more freely available source of water. *E. largiflorens* operate with a high proportion of embolised xylem (Zubrinich et al., 2000), which could limit

positive transpiration responses to more available soil water. Thus, if trees were at their maximum capacity for transpiration, a short-term response to flooding may not be observed. However, in response to rainfall, rapid increases in stomatal conductance and water potential have been observed (Streeter et al., 1996; Zubrinich et al., 2000). Therefore, we also expected to see an increase in water-use after flooding. Rainfall is different to our flooding experiments, in that rainfall wets the bulk surface soil beyond the canopy, and so more surface roots may be active beyond the canopy. Rainfall could also influence plant water use if foliar absorption of water occurs. Boucher et al. (1995) and Munné-Bosch et al. (1999) have demonstrated the importance of foliar absorption of dew in alleviating water stress, which increased shoot water potential, stomatal conductance and root growth of water-stressed *Pinus strobus* seedlings. It would be worth investigating this further with irrigation experiments to determine why *E. largiflorens* do not increase their transpiration rate after flooding but do respond to rainfall.

Although, in the short-term *E. largiflorens* do not increase their daily water use in response to flooding, the infiltration of water by preferential flow paths created by tree roots is important for long-term survival of tree communities. Salts are leached from the immediate vicinity of roots, allowing roots to take up the new source of water. Root channels mediate a system, which ameliorates the effects of soil salinisation by increasing the infiltration of floodwaters. Therefore, the presence of trees on the floodplain, are in themselves, the key to their long-term survival.

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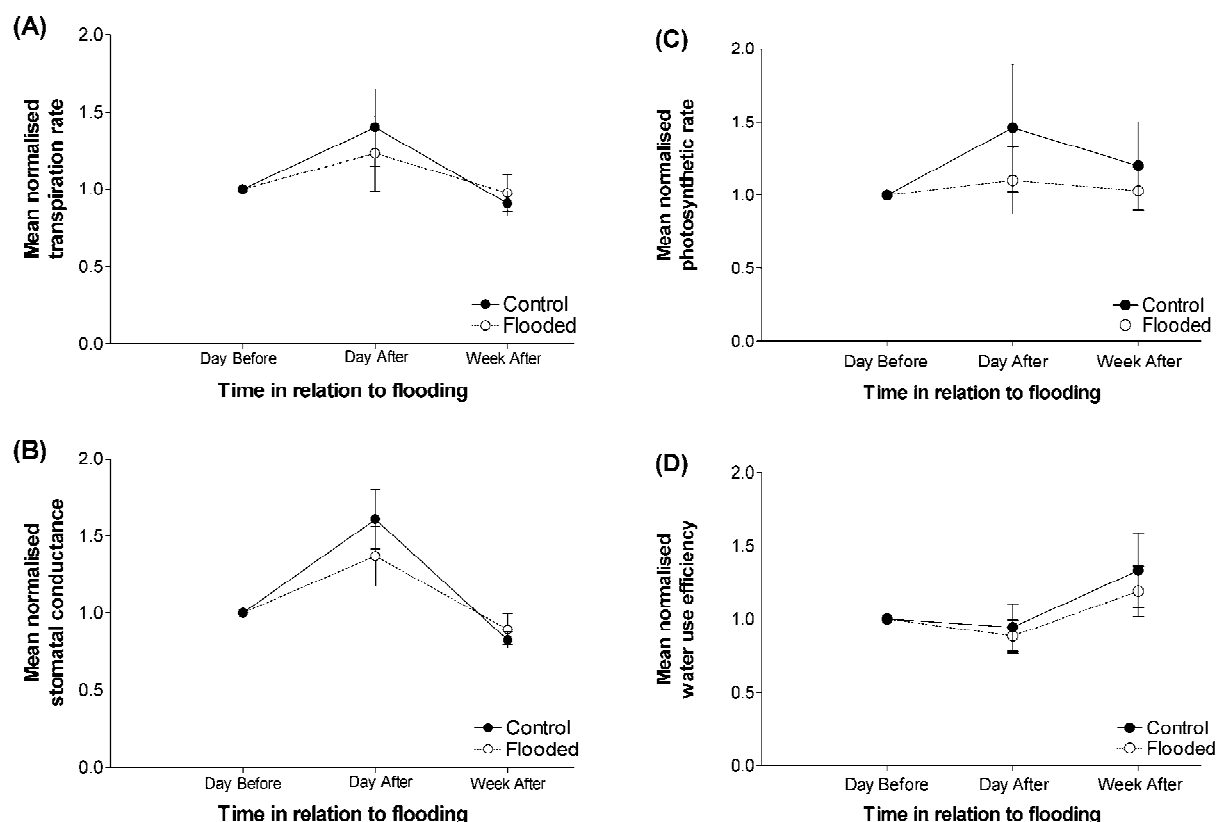


Figure 5. Relative physiological response of trees that were flooded with creek water (open circles) or not flooded (closed circles). (A) Transpiration rate; (B) Stomatal conductance; (C) Photosynthetic rate; (D) Daily water use efficiency. Normalised rates are expressed as a ratio of the absolute rate measured the day before flooding. The absolute rates measured the day before flooding (i.e. where the normalised rate = 1.0) are $1.8 (\pm 0.5)$ and $1.7 (\pm 0.4) \text{ mmol m}^{-2} \text{ s}^{-1}$ for transpiration; $119.7 (\pm 10.4)$ and $128.0 (\pm 25.9) \text{ mmol m}^{-2} \text{ s}^{-1}$ for stomatal conductance; $9.5 (\pm 2.1)$ and $9.5 (\pm 1.9) \mu\text{mol m}^{-2} \text{ s}^{-1}$ for photosynthesis; $8.0 \times 10^3 (\pm 1.1)$ and $7.3 \times 10^3 (\pm 0.7) \mu\text{mol mmol}^{-1}$ for water use efficiency; for control and flooded trees respectively. Error bars represent $(\pm) 1 \text{ SEM}$, $n = 5-7$.

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