Preliminary investigation of moisture and salt profiles in the soils of primary salinity sites

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Abstract
Four sites have been established in western Victoria on primary or secondary salinity discharge sites (three on ephemeral lakes and one on a ridge/depression system) to monitor native vegetation response to varying salt and water-logged conditions. The results of initial soil profile examination to 1650 mm depth have been made on samples taken across transects from highest to lowest points, during late Summer-mid Autumn when the driest and most saline conditions of the year are expected. Sub-surface soil moisture levels and salt concentrations showed a general increase towards the lowest part of the landscape (lake bed or depression) except for one site when the opposite was true. This was the only site where the water-table did not occur within the sampling depth at any point on the transects and is the only site considered to be largely affected by secondary salinity. At the other sites, water-tables occurred at 900, 1350 or 1650 mm towards the lowest point of transects. Comparisons of soils to 450 mm depth (encompassing the main rooting depth for shrubs, herbs and grasses), from Spring to Autumn, displayed expected decreases in moisture for most sites and vegetation zones. Exceptions were found in the sub-surfaces below a *Eucalyptus largiflorens* and *Muehlenbeckia florulenta* zone (Lake Cope Cope) and in *Frankenia serpyllifolia* and *Halosarcia pergranulata* zones (Baileys Plain) where little change occurred. Salt profiles varied from site to site, with some vegetation zones showing increasing salt with depth and others showing decreasing salt with depth. Relationships between soil moisture and salinity and results of soil pH are presented for each depth and vegetation zone.

Key Words
Discharge, vegetation, salt-lake, water-table, salt-tolerance

Introduction
Dryland salinity has long been of concern in the Victorian landscape and considerable effort has been employed and is being employed to reduce water-table height in recharge areas and combat the soil and water degradation effects of salt on and from discharge sites. One of the methods used to rehabilitate secondary saline discharge sites is to establish salt tolerant plants, not only to provide ground cover but also for their agricultural production value. Until very recently, and with the exception of some native *Atriplex* (saltbush) and *Maireana* (bluebush) species, most revegetation has depended on the use of exotic species such as *Lophopyrum ponticum* (tall wheat-grass), *Puccinellia ciliata* (puccinellia) and *Trifolium fragiferum* (strawberry clover). Even currently, much attention is focused on the introduction of new exotic species, while little native vegetation is being explored for its potential in reclaiming salted sites. As part of the CRC Plant-based Management of Dryland Salinity, one project is examining the tolerance of native vegetation to salinity and water-logging under natural or primary saline conditions. A number of such sites have been selected in Western Australia and Victoria to monitor seasonal and yearly changes in root zone salinity and soil moisture and to examine the existing and changing patterns of plant species zonation in relation to these parameters. This paper reports on the initial soil measurements and plant zonation results obtained for the Victorian sites in the project.

Methods
Four salinity discharge sites were chosen across western Victoria to represent a range of native vegetation types and climatic conditions. Three sites were considered to be largely primary in nature (ie. natural sinks for salt discharged from the landscape) due to their existing vegetation but it is uncertain whether they have maintained long-term stability in this regard or not. One site, although supporting native species, shows evidence of increasing salinity over recent time (dead and dying *Eucalyptus camaldulensis*) and may therefore be considered to have a major secondary salinity component. The sites chosen for monitoring were; Western Victoria - Chinamans Swamp, Westmere (primary salinity); Wimmera – Mitre Lake, Natimuk (primary salinity); Mallee – Baileys Plain, Piangil (primary salinity) and Riverine Plain – Lake Cope Cope, Donald (largely if not entirely secondary salinity). For each site, a

typical transect was chosen that ran from the highest point to the lowest point in the landscape (eg. from lake bank upper slopes to lake bed). The major plant species growing along the transect were recorded and zones of similar vegetation type were identified.

Preliminary soil examination consisted of taking late winter to mid Spring (2003) composite spot (at least 15) soil samples for laboratory analysis from 0-100, 100-300 and 300-450 mm depths for each major vegetation type along a transect. This time of sampling was chosen to represent the wettest part of the season. Soil moisture, pH_w (1:5 soil:water), pH_c (1:5 soil:0.01M $CaCl_2$) and EC (electrical conductivity 1:5 soil:water) were measured for each sample. A repeated sampling was conducted in late Summer to early Autumn (2004) to represent the driest part of the year. In addition, the latter sampling was also accompanied by single auger hole samples from at least three locations along each transect. From these holes, soil samples were collected to represent each 150 mm depth to 1650 mm depth or as far as the water-table allowed such to be drawn. The auger samples were analysed similarly to the composites.

Results and Discussion

Tables 1-4 presents the results of the soil analysis over 450 mm depth for each vegetation zone for each site. Figures 1-4 shows the soil moisture and EC results for the auger samples for each profile and site.

Chinamans Swamp

Soil moisture increased along the transect as the swamp bed was approached in both Spring and Autumn (Table 1). Given the reasonable Summer rainfall in southern Victoria over the 2003-04 season, this is as expected, even though the swamp bed contained no standing water from mid Summer to late Autumn. Augering in mid Autumn located the water-table at the swamp edge at the 1650 mm depth extent of the auger (Figure 1), whereas in the Spring, the edge had standing water and the flats were almost saturated (Table 1). Except for the surface soil of fine sandy clay loam on the upper slopes, all other soils on site are light to medium cracking clays. If we assume a wilting point moisture level of about 30% for these soils, then water available for plants in Autumn could only be obtained below 1650 mm on the upper slopes but just below 300 mm for the flats and in the surface 150 mm for the swamp edge. These depths are consistent with rooting depths for the major plant species growing within these zones; deep rooted lignum (*Muehlenbeckia florulenta*) and cane-grass (*Eragrostis infecunda*) on the upper slopes, moderate rooted blown-grass and puccinellias (*Lachnagrostis robusta, Puccinellia stricta* var. *perlaxa* and *P. fasciculata*) on the flats and shallow rooted spurrey (*Spergularia marina*) on the lake edge.

Salinity also increased towards the swamp bed, but particularly so from the inner flats (Table 1). Spring salt levels are likely to affect salt-sensitive plant species on the swamp edge and inner flats at all depths to 450 mm but also at the 300-450 mm depth on the outer flats. Plants currently growing in these zones are confined to highly salt-tolerant species (spurrey and puccinellia). Autumn salt levels were only slightly higher than in Spring in these zones but the outer flats showed higher salt at all depths, as did the 350-450 mm depths on the slopes. Outer flat species have at least moderate salt-tolerance while the salt-sensitive lower slope species tend to have shallow root systems. Annual species (eg. *Holcus lanatus, Cirsium vulgare*) and new germinants of the short-term perennial grasses (eg *Lolium perenne*, *Puccinellia stricta*) on the flats and lower slopes should successfully establish in the Autumn/early Winter, particularly after a shower of rain has leached excess salt from the seeded surface soil. While the upper slope perennial species have deep root systems that penetrate the salted depth, they do have some salt-tolerance and can obviously survive these soil conditions.

Table 1. Soil moisture, pH_w, pH_c and EC for the transect at Chinamans Swamp in mid Spring 2003 and mid Autumn 2004.

Depth, mm	Moisture, %		pH_w		pH_c		EC, dS/m	
	spring	autumn	spring	autumn	spring	autumn	spring	autumn
Lignum/cane grass (mainly native) – upper slopes (subdued) swamp fringe								
0-100	24.8	8.4	7.3	6.7	6.5	6.1	0.17	0.13
100-300	25.3	11.5	7.7	7.2	6.7	6.4	0.17	0.14
300-450	25.9	19.9	7.7	7.4	6.9	6.9	0.30	0.44
Annual grasses/spear thistle (mainly exotic) – gravelly lower slopes (subdued)								
0-100	27.3	12.7	7.4	7.6	6.7	7.1	0.20	0.24
100-300	23.5	15.1	7.6	7.8	6.7	7.2	0.19	0.31
300-450	24.6	18.6	8.1	8.0	7.2	7.5	0.35	0.44
Blown-grass (mainly native) – outer swamp flats								
0-100	38.5	17.8	8.3	7.9	7.7	7.4	0.31	0.43
100-300	39.2	24.3	8.4	8.1	7.6	7.6	0.33	0.51
300-450	40.3	27.6	8.3	8.1	7.7	7.7	0.62	0.87
Puccinellia (native and exotic) – inner swamp flats								
0-100	42.9	17.5	8.2	7.9	7.9	7.7	1.6	1.7
100-300	42.1	23.9	8.0	7.9	7.7	7.7	1.7	2.0
300-450	40.8	29.9	7.8	7.8	7.6	7.5	2.5	2.5
Spurrey (mainly native) – edge of swamp bed								
0-100	56.7	21.5	8.0	7.8	7.9	7.7	4.4	5.7
100-300	44.3	31.5	7.7	7.8	7.6	7.7	4.2	4.9
300-450	44.9	35.7	7.4	7.6	7.3	7.5	4.5	4.6

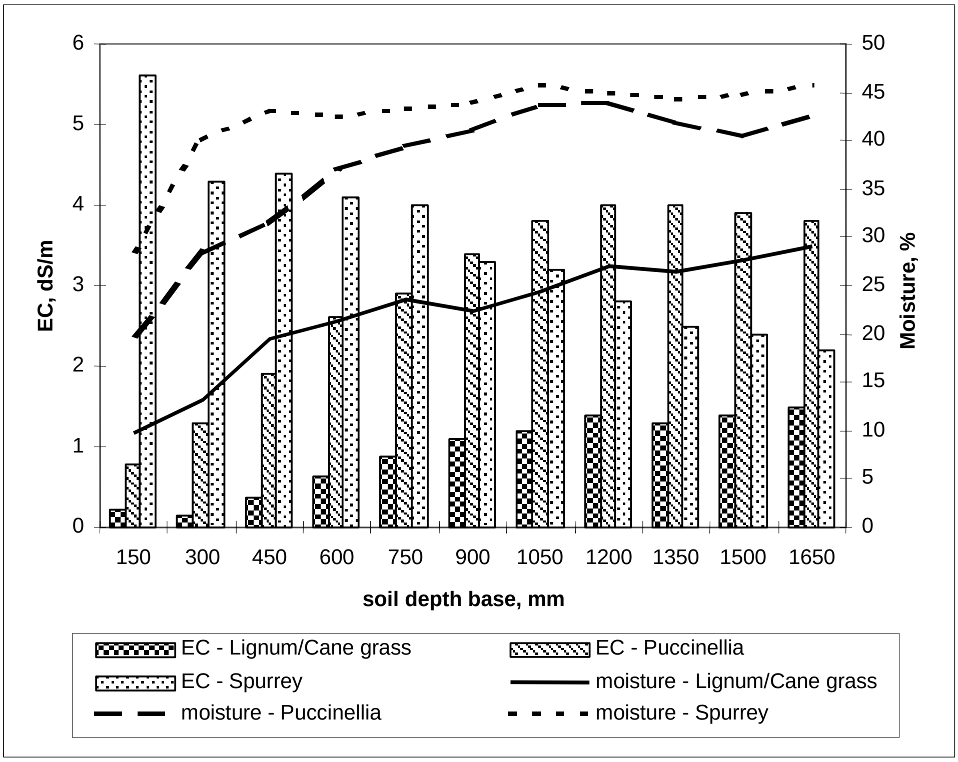

Figure 1. EC and moisture contents for 150 mm increments to 1650 mm depth for three vegetation zones at Chinamans Swamp in mid Autumn 2004.

Soil pH ranges from slightly acid to moderately alkaline in the top 450 mm of soil across the site (Table 1) but does get to strongly alkaline beneath the lignum at 900 mm depth (data not provided). Autumn pH was lower than Spring pH in some depths and zones but this was not uniformly so. The trend is for pH to increase with depth in the soils of the slopes but to be relatively uniform on the flats and decrease with depth on the swamp edge. When the swamp contains water, it has been observed to deposit a froth of bicarbonates to the surface of the edges and inner flats and this likely contributes to the pH regime as well as to the salt level.

Mitre Lake
The soils of the lake fringe and flat zones had similar moisture contents during Spring and again in Autumn, except that the inner flats during Autumn retained more moisture than the other zones, at least to 300 mm depth (Table 2). The slopes and lake edge dune had similar surface moisture levels in Spring but were higher in Autumn in the lake edge dune. Water-table levels in late Summer were at 1500 mm and 900 mm depths for the slopes and fringe/flats respectively, despite the widespread lack of rain for the previous 5 years (Figure 2). As most of the plant species on site are moderately to shallowly rooted (including the sedge; *Gahnia filum* and blown-grass; *Lachnagrostis billardierei*), a relatively high water-table is an advantage. Most of the soils on site were light to medium clays.

Table 2. Soil moisture, pH_w, pH_c and EC for the transect at Mitre Lake in early Spring 2003 and late Summer 2004.

Depth, mm	Moisture, %		pH_w		pH_c		EC, dS/m	
	spring	summer	spring	summer	spring	summer	spring	summer
Tussock Poa (mainly native) – slopes (gentle)								
0-100	41.1	8.3	8.7	8.6	8.1	8.0	0.38	0.31
100-300	36.4	14.7	9.4	9.1	8.6	8.3	0.60	0.61
300-450	33.7	16.4	9.7	9.4	8.7	8.5	0.97	0.85
Gahnia/Blown-grass (mainly native) – outer lake fringe								
0-100	54.4	14.7	9.3	9.4	8.6	8.8	0.76	2.4
100-300	49.5	25.6	9.4	9.6	9.4	8.9	1.1	1.6
300-450	47.0	24.3	9.4	9.5	8.6	8.8	1.1	1.1
Gahnia/Distichlis (mainly native) – inner lake fringe								
0-100	58.4	16.1	9.2	9.2	8.7	8.7	1.7	4.5
100-300	ns	24.0	ns	9.2	ns	8.8	ns	2.3
300-450	ns	24.8	ns	9.4	ns	8.8	ns	1.7
Sarcocornia/Distichlis (mainly native) – outer lake flats								
0-100	54.3	14.1	9.4	9.4	9.1	9.1	4.6	8.6
100-300	60.1	26.6	9.3	9.3	9.3	9.0	5.5	4.8
300-450	53.9	37.1	9.3	9.4	8.9	8.9	5.3	3.9
Sarcocornia (mainly native) – inner lake flats								
0-100	58.3	29.8	9.4	9.1	9.1	9.0	5.4	20
100-300	ns	42.9	ns	9.0	ns	8.8	ns	11
300-450	ns	44.9	ns	9.1	ns	8.8	ns	8.7
Halosarcia (native and exotic) – lake edge dune								
0-100	43.3	13.1	9.5	8.9	8.9	8.7	1.3	8.2
100-300	ns	24.9	ns	9.0	ns	8.8	ns	6.7
300-450	ns	45.0	ns	9.0	ns	8.8	ns	9.2

ns = not sampled

Except for the surface of the slopes, salt concentrations were high throughout the zones and depths and increased towards the lake (Table 2). Levels were extremely high on the flats and only supported a scattered population of the highly salt-tolerant *Sarcocornia quinqueflora* and *Wilsonia rotundifolia* with occasional patches of *Distichlis distichophylla*. Summer surface salt concentrations were two to four times higher than Spring concentrations on the fringe and flat zones and over six times higher on the lake edge dune. On the *Gahnia filum* fringe and *Sarcocornia* flats, salt levels tended to be highest on the surface, whereas for the more salt sensitive *Poa* grassland on the slopes, the top soil provided some relief from the higher salt at the base of the root zone. Soil pH was high to extremely high throughout the zones and depths of the site.

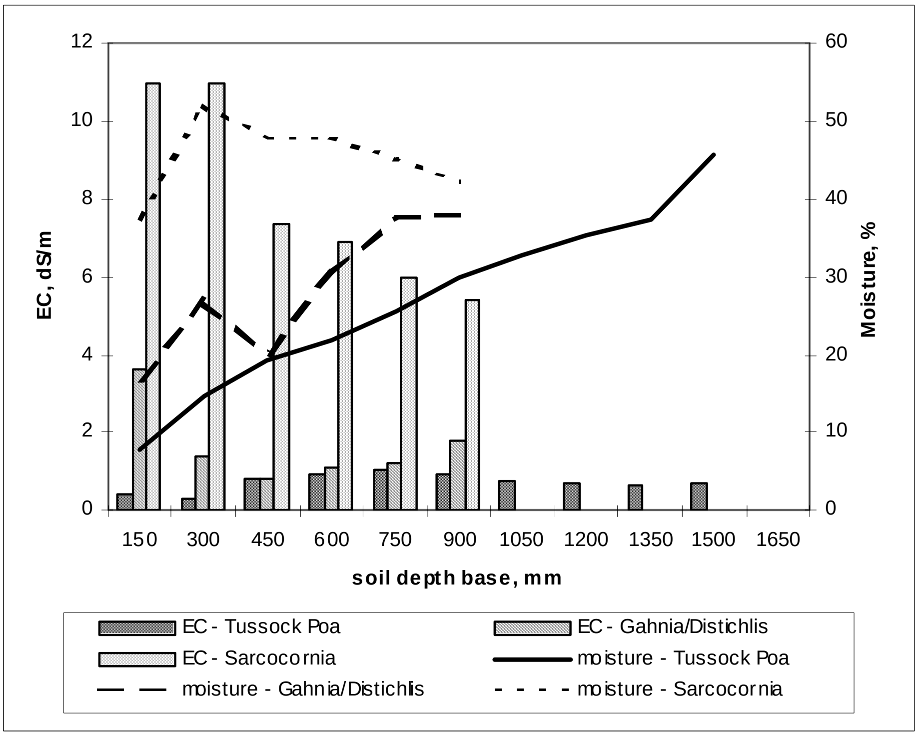

Figure 2. EC and moisture contents for 150 mm increments to 1650 mm depth or the water-table for three vegetation zones at Mitre Lake in late Summer 2004.

Baileys Plain

Moisture levels were low in surface soils in both Spring and Autumn due to the years of drought experienced by the site (Table 3). Nevertheless, the soils of the slopes did have two to six time's higher moisture in the Spring. The soils were largely of sandy clay loam to sandy clay texture and therefore might be expected to hold about 20-30% moisture at field capacity. Soil moisture increased with both depth and toward the lower parts of the landscape. Autumn augering revealed the water-table to be at 1350 mm on the *Halosarcia* flats (Figure 3) and it is likely that capillary movement from the water-table continues to provide moisture to the shrubs on site, even when conditions are dry.

Salt concentrations are high to very high for most depths and zones, except for the spear-grass slopes. The higher than expected EC readings for the upper slopes may be an artefact of the high carbonate content of this part of the landscape (fractured limestone from 400 mm depth). Salt tends to be highest in the surface 0-100 mm or the subsurface 300-450 mm depths but this is somewhat variable and changes between Spring and Autumn readings. As expected, salt levels increase as the soils dry out and particularly high salts are found in the surfaces of the lower slopes and flats in Autumn. These zones of the transect contain the most salt tolerant plant species on the site; most being woody shrubs or succulents (eg. *Nitraria billardierei*, *Frankenia serpyllifolia*, *Disphyma crassifolium*, and *Halosarcia pergranulata*) which confers drought-tolerance as well as salt-tolerance.

Upper and mid slope soils are mainly strongly alkaline, increasing gradually with depth to at least 450 mm. Lower slopes and bench zones show slightly to moderately alkaline pH increasing to 450 mm but decreasing rapidly to moderately acid after 600 mm (data not shown). Soils on the flats are variable, ranging in the surface from moderately alkaline to very strongly acid but all strongly to very strongly acid from 450 mm and deeper (data not shown). Preliminary testing of the samples from the flats indicate acid sulphate soils along with observations of gypsum lenses in the profiles.

Table 3. Soil moisture, pH_w, pH_c and EC for the transect at Baileys Plain in mid Spring 2003 and mid Autumn 2004.

Depth, mm	Moisture, %		pH_w		pH_c		EC, dS/m	
	spring	autumn	spring	autumn	spring	autumn	spring	autumn
Mallee (mainly native) – upper slopes								
0-100	6.5	1.6	8.6	8.2	8.2	8.0	0.41	0.78
100-300	7.6	7.5	9.0	8.6	8.4	8.3	0.78	1.1
300-450	8.4	ns	9.2	ns	8.6	ns	1.3	ns
Spear-grass (mainly native) – mid slopes								
0-100	5.7	0.9	8.6	8.4	8.1	8.0	0.25	0.17
100-300	8.0	1.6	8.8	8.4	8.1	8.0	0.14	0.17
300-450	8.9	2.8	9.0	8.6	8.2	8.1	0.15	0.23
Nitre Bush (mainly native) – bench								
0-100	7.2	4.0	8.1	8.3	8.0	8.2	2.8	7.5
100-300	11.6	8.0	8.3	8.5	8.2	8.3	4.1	3.8
300-450	17.0	7.5	8.4	8.5	8.3	8.3	5.0	4.4
Frankenia (mainly native) – lower slopes								
0-100	4.4	1.9	7.4	7.7	7.3	7.6	2.5	6.7
100-300	7.8	8.0	7.3	8.1	7.1	8.0	1.7	3.4
300-450	16.8	15.8	8.8	8.6	8.5	8.5	3.9	5.5
Halosarcia (mainly native) – flats								
0-100	14.5	9.8	8.4	8.5	8.4	8.4	5.8	12
100-300	14.4	8.8	7.2	8.1	7.0	8.1	3.7	5.6
300-450	24.0	19.4	6.6	7.8	6.5	7.7	5.6	8.2
Halosarcia/bare ground (mainly native) – flats								
0-100	19.7	20.3	4.6	5.7	4.6	5.6	8.6	15
100-300	21.5	20.1	4.6	5.3	4.5	5.2	4.6	5.7
300-450	28.8	28.8	4.7	6.6	4.5	6.5	5.8	5.8

ns = not sampled

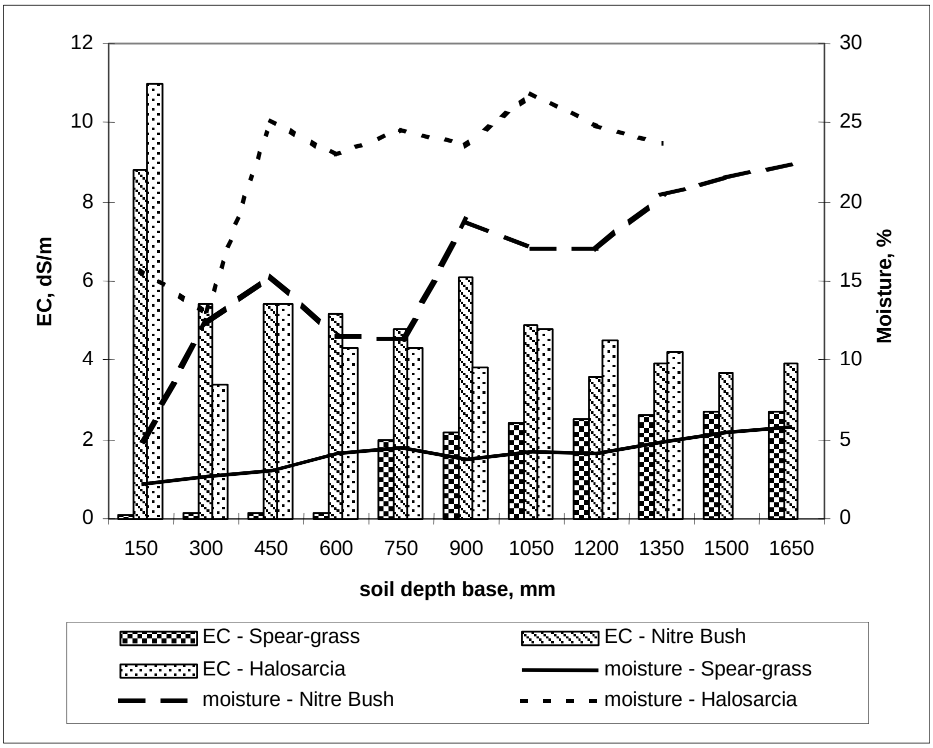

Figure 3. EC and moisture contents for 150 mm increments to 1650 mm depth or the water-table for three vegetation zones at Baileys Plain in mid Autumn 2004.

Lake Cope Cope
Despite the lack of rainfall over recent years, early Spring soil samples showed moderate levels of moisture (Table 4). Apart from sandy loam surface texture in the black-box/lignum zone, the remainder of soils were light medium clays, though some thin surface sand deposits were evident on the cleared area and on the lower slopes. Where re-sampled in late Spring, moisture levels had dropped away considerably and continued to decrease to the Autumn sampling. The late Spring and Autumn samples show evidence of the soils drying out from the surface down. Though moistures in the early Spring samples were variable with depth, there was some trend towards higher surface moistures compared to subsurfaces, consistent with the effects of light rainfall and surface runoff towards the lake bed. The cleared area (outside the black-box/lignum fringe and mainly supporting *Hordeum marinum* and other annual grasses) along with the lake edge and bed contained the highest moisture contents on site. Moisture in the top 300 mm beneath the blackbox/lignum (*Eucalyptus largiflorens and Muehlenbeckia florulenta*) gave consistently low results throughout the season, suggesting that surface roots of these species were particularly active. This may be because the subsoils were at wilting point moisture levels. Autumn augering failed to find the water-table within 1650 mm of the surface along the transect (Figure 4). Surprisingly, there was no difference in profile moisture between the red-gum (*Eucalyptus camaldulensis*) and Rats-tail grass (*Sporobolus mitchellii*) zones (Figure 4) despite their very different root systems. Again, available water may have been exhausted.

Soil salt contents decreased towards the lake bed, in contrast to the other sites. Salt concentrations were extremely high in the cleared area, throughout the profile (Figure 4) but whether this would migrate to the lake bed in a wet season is unknown. Salt concentrations at depth may be detrimental to red-gum growth and could be the cause of the die-back observed.
Soil pH ranges from slightly acid in the surface under the blackbox to strongly alkaline on the lake bed with general trends to increasing alkalinity with depth.

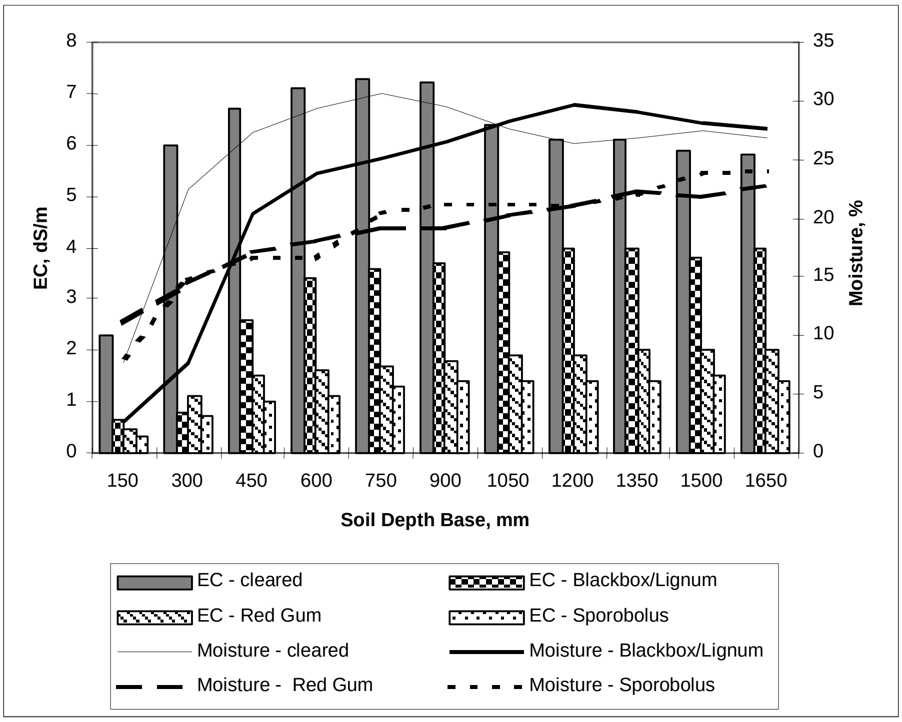

Figure 4. EC and moisture contents for 150 mm increments to 1650 mm depth for four vegetation zones at Lake Cope Cope in mid Autumn 2004.

Conclusions
Preliminary work on these sites has illustrated a wide range of soil and water conditions to which native plants have adapted. Continued monitoring and more specific studies will assist to understand the dynamics of the ecology of each site and provide clues to the parameter details required for rehabilitation of secondary saline sites.

Table 4. Soil moisture, pH_w, pH_c and EC for the transect at Lake Cope Cope in early (upper) and/or mid Spring (lower) 2003 and in mid Autumn 2004.

Depth, mm	Moisture, %		pH_w		pH_c		EC, dS/m	
	spring	autumn	spring	autumn	spring	autumn	spring	autumn
Cleared area (mainly exotic) – surrounds								
0-100	28.6 12.4	7.2	7.5 7.4	7.2	6.8 6.5	6.7	0.65 0.58	1.2
100-300	ns 23.6	14.5	ns 8.1	8.0	ns 7.7	7.7	ns 2.1	3.0
300-450	ns 28.1	19.0	ns 8.5	8.3	ns 8.3	8.1	ns 4.6	4.2
Blackbox/Lignum (mainly native) – lake fringe								
0-100	12.6 7.6	3.2	6.5 6.6	6.7	6.0 6.0	6.2	0.10 0.42	0.44
100-300	ns 10.5	9.1	ns 8.4	8.4	ns 8.9	7.6	ns 0.69	0.68
300-450	ns 20.2	19.8	ns 7.6	9.1	ns 8.2	8.6	ns 1.4	2.2
Red gum/cane grass (mainly native) – upper slopes (subdued)								
0-100	23.0 ns	6.4	8.0 ns	8.4	7.6 ns	7.8	0.28 ns	0.27
100-300	22.6 ns	13.8	8.6 ns	8.8	8.1 ns	8.2	0.61 ns	0.68
300-450	18.2 ns	17.1	8.6 ns	8.7	8.2 ns	8.2	0.94 ns	0.98
Dead red gum/annual grasses (native and exotic) – mid slopes (subdued)								
0-100	18.9 ns	4.9	8.8 ns	8.9	8.2 ns	8.2	0.20 ns	0.26
100-300	ns	9.7	ns	9.1	ns	8.4	ns	0.63
300-450	ns	12.6	ns	9.0	ns	8.4	ns	1.1
Sporobolus (native and exotic) – lower slopes (subdued)								
0-100	21.6 10.3	5.0	8.9 9.1	9.0	8.3 8.3	8.3	0.28 0.26	0.42
100-300	20.9 15.5	8.9	8.8 9.2	9.0	8.3 8.3	8.4	0.70 0.54	0.62
300-450	18.8 19.3	13.0	8.8 9.0	8.9	8.3 8.3	8.3	0.95 0.99	0.95
Lignum (native and exotic) – lake edge								
0-100	30.3 ns	7.1	9.0 ns	9.1	8.4 ns	8.4	0.59 ns	0.62
100-300	22.9 ns	12.1	8.6 ns	8.8	8.2 ns	8.3	1.5 ns	1.4
300-450	20.7 ns	13.5	8.7 ns	8.8	8.3 ns	8.3	1.4 ns	1.2
Halosarcia (native and exotic) – lake bed								
0-100	34.7 ns	10.2	8.5 ns	8.5	8.2 ns	8.2	2.3 ns	1.7
100-300	28.7 ns	14.0	8.5 ns	8.7	8.3 ns	8.3	2.9 ns	1.6
300-450	29.1 ns	16.3	8.7 ns	8.6	8.4 ns	8.2	2.0 ns	1.4

ns = not sampled

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