Does grazing perennial pastures on saline land affect farm salt and water balances?

Draft final report of the Salt and Water Movement and Site Characterisation Theme

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Contents

Preface

This document presents the key findings of the Salt and Water Movement Theme of the Sustainable Grazing on Saline Land (SGSL) programme, funded by Land Water and Wool, Land and Water Australia, Australian Wool Innovations Ltd., CSIRO, and the CRC for Plant Based Management of Saline Land. The material is based on the ain results of the experiments conducted at five sites within the SGSL programme, but with emphasis on results from the hydrological measurements taken in the NSW and WA1 experiments. This paper is one of a collection covering the Themes:

- Salt & water movement from salt land
- Siting, establishment and performance of salt land species
- Performance and utilisation of salt land pastures
- Biodiversity impacts from salt land pastures
- Economics of salt land pastures

Abstract

Salt and water fluxes

The hydrological impacts of salt land grazing systems were assessed at experiments undertaken in Western Australia, NSW, South Australia and Victoria. Experiments in WA and NSW aimed to quantify the off-site fluxes of salt and water, while the others aimed to monitor on-site changes to soil salinity and the watertable. The experiments ran from 2001 to 2007, and are the first to quantify the salt and water balances of salt land grazing systems. However, a range of extreme climatic conditions, from inundation to severe drought means that conclusions have been difficult to draw and probably a further two or three years of monitoring are required to complete the exercise. The overall conclusions are that implementing a salt land grazing system based on perennial fodder species raises the evaporative losses from the site slightly, and slightly reduces over-land flow from the site.

At both hydrological experimental sites, there may be an enhanced export of salt following site preparation for the planting of fodder species. Certainly, concentration of salts in the surface flows increased, but this may be due to the lesser water flowing off the sites, and total salt export may have increased only slightly or not at all. There was also substantial mobilisation of surface soil, leading to top-soil erosion and deposition in the channel and at the gauging structures following planting. While it is presumed this will settle down over subsequent seasons, data so far give no indication of how long this will take. However, given that the sites were planted two to three years ago, it is believed that a further three years would be adequate to demonstrate whether changes are significant and long-lasting. It is clear that, in future, greater effort should be taken to minimise this impact, which might otherwise negate beneficial environmental effects of the plantings. There appears to be little change in site salt storage, although due to inter-seasonal differences and the size of the fluxes relative to the storage it is really too early to draw clear conclusions on this. The nature of the data is such that there are significant uncertainties around the measurements that only time, with more measurements, will address.

There is a reduction in waterlogging and in average soil moisture storage above the watertable in the salt land pasture relative to neighbouring un-modified paddocks, and there are clear indications of groundwater use by saltbush under favourable circumstances. In NSW there was increased recharge following treatment, followed by greater groundwater uptake, but this was not observed in WA.

Site characteristics

The experiments also analysed a range of site characteristics that impact on the pasture and animal production from the monitored sites, and assessed the relative importance of various site factors in determining productivity and salinity. A multivariate analysis has been applied to the site variables common across all sites to determine the relationship between them and soil salinity, pasture production and animal production. Some latitude in balancing available resources and how far down the list of characterisation priorities was necessary, and inevitably there are some attributes that were not measured at some sites that, following our analysis, would now appear to be highly desirable. These will have to wait for SGSL2.

A subset of soil characteristics was analysed statistically to determine relationships between site physical and chemical characteristics and the apparent electrical conductivity (EC_a) measured by the EM38 electromagnetic probe. The most significant variable is depth to groundwater, with groundwater salinity somewhat less important. We have also undertaken an assessment of the significance of the EC_a as a primary indicator of land salinity.

Relationships between groundwater electrical conductivity (EC_w) and the concentration of total dissolved salts (TDS) have been determined for each site, and for the electrical conductivity of saturation extracts (EC_e) from soil and from extracts of 1g soil to 5 ml of water ($EC_{1:5}$), and for the conversion from $EC_{1:5}$ to EC_e.

1 Introduction

Secondary salinisation of agricultural land in Australia has now reached over 2Mha (McFarlane *et al.*, 2004). The cause is the replacement of native deep-rooted perennial vegetation with shallow rooted annual species. The new plants use less water than the natives, resulting in greater recharge, and a consequent rise in watertables bringing salts from deep in the profile to the surface. Proposed solutions to the “salinity problem” have been many and varied over many decades (Whittington, 1980, OPUS of the National Dryland Salinity Programme, NDSP). Masters *et al.* (2005) explored animal grazing systems as an approach to gaining production from saline land. Currently there is wide interest in drainage as a means of drying out waterlogged soils and draining away the salt, but this leaves the problem of where the hypersaline and often acidic water will drain to (Ali *et al.,* 2004a,b,c). There is also expanding interest in use of vegetative solutions, involving plantations to minimise recharge, and others to use up saline water. These plantations may be purely for environmental or aesthetic functions, but may also yield commercial crops such as timber, oils, and stock fodder. Soil conservation and erosion protection, aesthetic amenity, animal fodder, biodiversity and ecological amenity, and soil salinity and watertable control are all reasons cited by farmers for their investment in salt tolerant plantation establishment. It is the renewed interest in this latter approach that led to the formation of the Sustainable Grazing on Saline Lands (SGSL) programme. Under SGSL, experiments were established in WA, SA, Victoria and NSW, aimed at quantifying the commercial and other benefits of implementing a salt-tolerant pasture system, and on determining the biodiversity and off-site environmental impacts of such an activity.

As plants take up water they concentrate salt in their root zone (Morris and Thompson, 1983; Williamson, 1986). This salt accumulation may limit the ability of the plants to use water and to grow, and some modelling exercises have shown that under arid and semi-arid conditions, with little or no surplus water flushing salt from the root zone, groundwater uptake by vegetation may lead to “salting out” of the vegetation (Jolly et al., 1993; Thorburn *et al.*, 1995; Slavich, 1992; Silberstein *et al*., 1999). For long-term sustainability we require some mechanism to prevent excessive salt accumulation within the root zone of the plants, otherwise even the most salt tolerant, while perhaps surviving, will not take up much water. Depending on site conditions, and in the absence of periodic leaching events, such as heavy rainfall or flooding, within 4 to 30 years accumulation of salt within the root zone may result in the plants being no longer able to draw water from the watertable. The rate of salt accumulation is directly related to the groundwater usage by the plants and to the salt concentration within the water used.

There is also a fundamental conflict of interest between the use of plants to control waterlogging and salinity, by lowering or controlling watertables, and grazing these same plants for animal production. More water will be used by maximising leaf area on a site, whereas grazing requires the removal of leaves, which necessarily lessens the transpiration and water uptake by the plants. Slavich *et al.* (1999) found minimal water transpired (less than 0.3 mm day^{-1}) by two grazed stands of saltbush, and questioned the efficacy of treating saline land in this way if it is also expected that production will be gained. This question is at the heart of the aims of the SGSL programme, in which it is aimed to gain production while also improving saline land and environmental values. It is also one we report on in this synopsis.

In contrast to the findings of Slavich *et al.*, Barrett-Lennard and Malcolm (1999) reported substantial accumulation of salts within the root zone of salt bush (various *Atriplex* species), indicating up to 100 mm water uptake from the groundwater over two years.

The aim of the Salt and Water Movement Theme in SGSL is to quantify impact of grazing saline lands on salt and water fluxes from the site, and to try to assess the catchment scale implications of these. It has also drawn together the site characterisation that was undertaken to distil out the most significant attributes that should continue to be measured in future studies, and to help determine the primary variables in determining a salt land capability. This document brings together the results of the experiments in NSW and WA, with added information from the Victorian and South Australian experiments.

2 Theme Questions

The issues addressed under the Salt and Water Movement Theme of SGSL can be expressed in three questions:
Does implementing a salt land grazing system deliver a measurable change in salt and water export from the site?
Is there a quantitative change or just a qualitative (timing) change in salt export? and
Is there a concentration of salt within the root zone of trees that will limit the sustainability of saltbush or other fodder species in these environments?

In addition this Theme also considers the main site characterisation issues that have beset the assessment of salt land capability, and the development of a salt land "capability matrix" that brings together the critical parameters that govern the ultimate productivity of this part of the landscape.

2.1 Sites

The sites in SGSL were all assessed on the basis of the Site Characterisation Protocol (Silberstein *et al*., 2004), aim at determining (McKenzie *et al*. (2002b):

1. a basis for comparison between sites
2. a basis for extrapolation to other sites with similar site and soil characteristics
3. a means of grouping sites into some structure to assist measurement and analysis
4. insights into unusual observations at sites or soils

To detect changes in soils over time requires very good quality measurements taken at representative field sites over extended periods of time. It is essential that repeat measurements be taken at the same place and compared to give differences between individual sites over time. The comparison between the mean value across a number of sites at one time and the mean across the sites at a different time is likely to be ineffective (McKenzie *et al.*, 2002b). These principles have been applied to collect a set of site data that allows the comparison of results from the different sites in a systematic and statistically valid way. This report will not be able to cover the complete analysis, but this will be completed as the final Theme report (Pastures, Bennett and Barrett-Lennard) is completed later in 2007.

The physical and historical characterisation of a site can go on indefinitely, with increasing precision, and including more and more aspects. In practice, the realistic and practical degree of characterisation is determined by objectives of the study and the available resources. There have been inevitable compromises prioritising aspects which are locally most significant, and thought to have the greatest impact on the productivity from the sites in the experiments. These attributes have been given highest priority and were measured, or at least attempted, at all sites.

The analysis reported here is based fundamentally on the experience gained and measurements taken at the five SGSL experimental sites. Only two of these experiments (NSW and WA) included salt and water movement, and the NSW experiment was hampered by a seasonal drought that resulted in no water flow being measured in several of their plots in most years to date.

The site characteristics of all sites are given in Table 1.

Site	Area	Rainfall (mm/yr)	Watertable Depth (m)	Ground-water EC (mS/m)	Soil ECe (mS/m)
NSW Gumble	4 x 1ha	626	0.5-2	300-900	0-3,500
Avoca	2 x 5ha	585	1-3	300-1,100	0-1100
Vic Dunkeld	12 x 1ha	683	1-2	200	200-8,800
SA Mt Charles	21 x 2ha 3 x 5ha	475	0-1.5	100-2,000	100-2,700
WA Tammin	2 x 10ha 4 x 5ha	342	0.3-1.2	7,000	100-8,000
Yealering	2 x 26ha	362	0.5-1.2	2,500	200-3,000

2.2 Site Characterisation

Electromagnetic Induction measurements (EM)

The use of the EM38 and EM31 electromagnetic probes is widespread to indicate land salinity, but while the data generated and images produced provide useful local comparisons of more and less saline land (Figure 1), interpretation of the measurement has always been difficult to quantify (Bann and Field, 2006; Bennett and George, 1995). The EM38 and EM31 instruments give an "apparent electrical conductivity" (EC_a) of the soil within a depth zone depending on the mode of each instrument. The EM38 measures within 75 and 150cm of the surface, in horizontal and vertical modes, respectively, and the EM31 to 3m and 6m, in horizontal and vertical modes, respectively. The EM38, therefore, is used to indicate salinity within the root zone of plants, and the EM31 the more inherent salinity of the regolith that may have longer term implications for salinity at the site. The EC_a are usually used as an estimate of total salt storage within the soil depth, and the impact this will have on plant growth. The standard reference for soil salinity is measured as the electrical conductivity of a saturated water extract from the soil, EC_e (Bennett and George, 1995). EC_e is used to indicate likely impact on plant growth (Slavich and Pettersen, 1990;Richards, 1954).

In fact, the EC_a is influenced not only by the salt content in the soil, but also the moisture content, the soil mineral and clay content, the soil temperature, and how these are distributed through the depth within range of the instrument. As a consequence measurements taken at the same site at different times can give wildly varying results, due especially to different temperature, moisture, and salinity. Soil moisture is particularly important and hence a measurement in spring may give a very different result from a measurement in autumn, when the soil is at its driest. It is therefore essential that any comparison with actual soil conditions be made as close to the survey date as possible. The particular characteristics of the EM38 (combination of coil separation and frequency of the driver coil) lead to a greatest sensitivity to conditions between about 30 and 75 cm below the surface (Bennett and George, 1995; Bennet *et al.*, 2001). This, of course, is below the depth accessed by most grasses. Previous work has shown a good correlation between EM38 EC_a and pasture growth in irrigated areas (Don Bennett, personal communication), because the soil moisture is relatively constant, and the surface salinity is related to the salinity of the deeper soil that is being detected by the instrument.

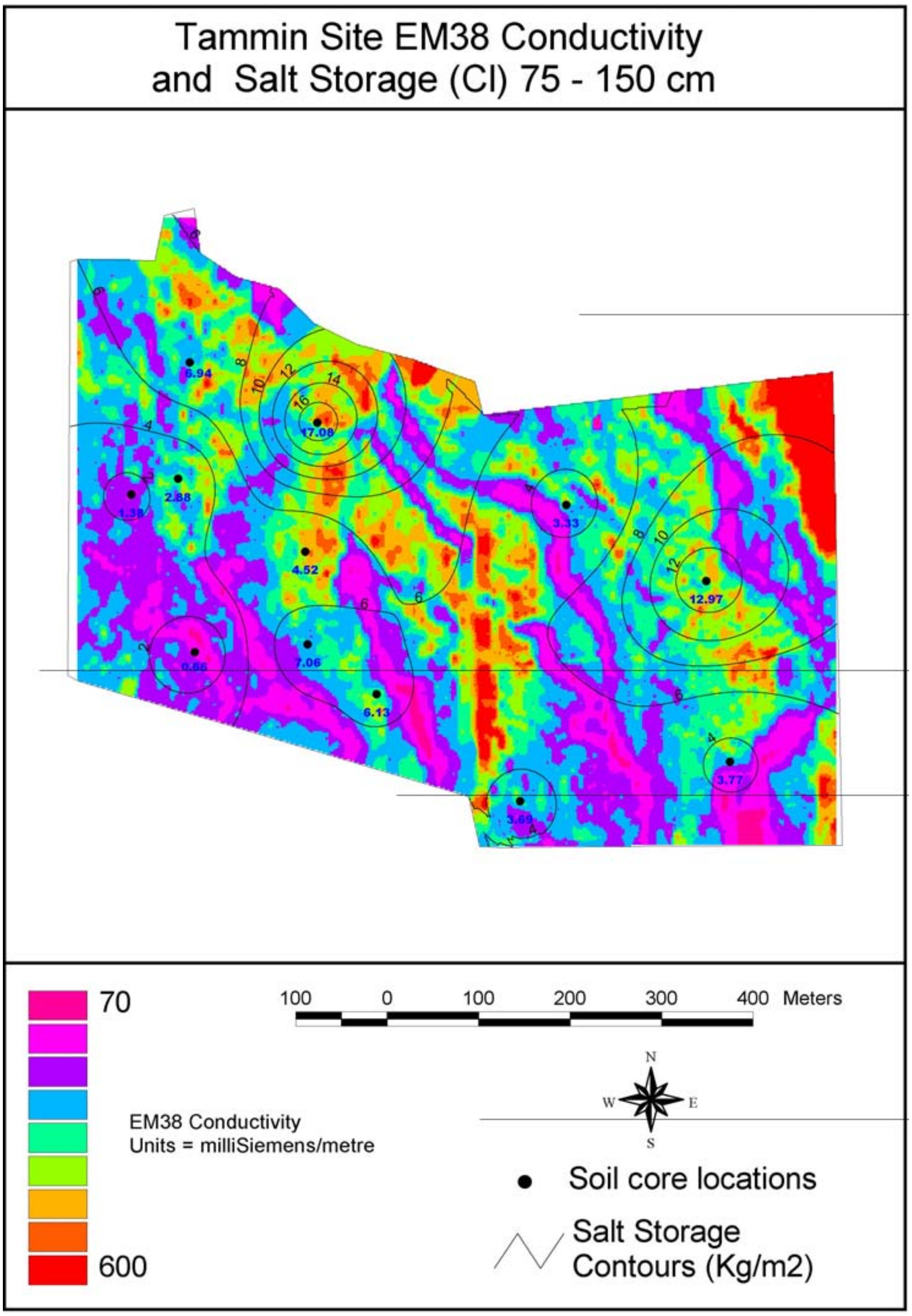

Figure 1. EM38 survey results at Tony York's property at Tammin. The contours of Cl^- determined from soil survey are also shown.

At the sites in SGSL a poor correlation was found between soil salt storage and EM38 reading in the surveys. The relationship between EC_a and soil EC_e was found, universally, to be best for the depth interval 50-75cm (or thereabouts). For example, for the NSW sites (**Figure 2**), they determined the relationship:

$$EC_a(V)= 50*M30+0.34*EC_e(30)+442*M60+2.5*EC_e(60)+\ldots \quad r=0.87$$

where $EC_e(30)$ is the EC_e of soil sampled from 0-30cm, $EC_e(60)$ for the interval 30-60 cm, and M30 and M60 are the moisture contents in these intervals, respectively.

We find similarly impressive relationships at other sites, but the problem is that it has been EC_e not EC_a that we have wanted to predict.

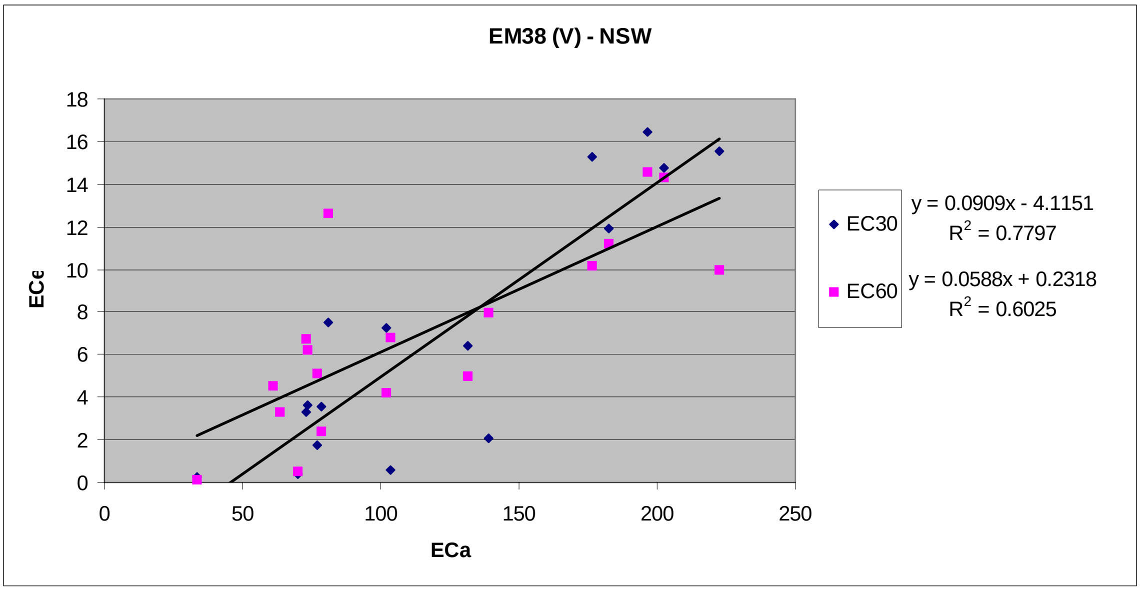

Figure 2. Relationship between EM38 EC_a and EC_e of soil at different depth intervals at Bray's Flat, NSW.

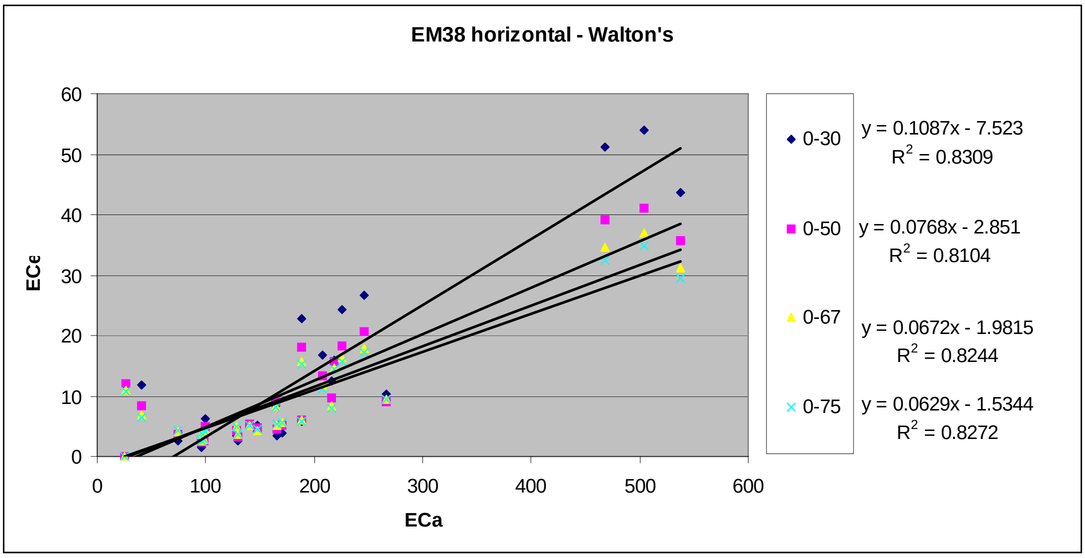

Figure 3. . Relationship between EM38 EC_a and EC_e of soil at different depth intervals from Chris Walton's farm, Yealering Western Australia.

However, the relationship between EM38 EC_a and EC_e at Tony York's farm (**Figure 4**), near Tammin, is nowhere near as clear, and this is believed to be due to small scale differences in texture.

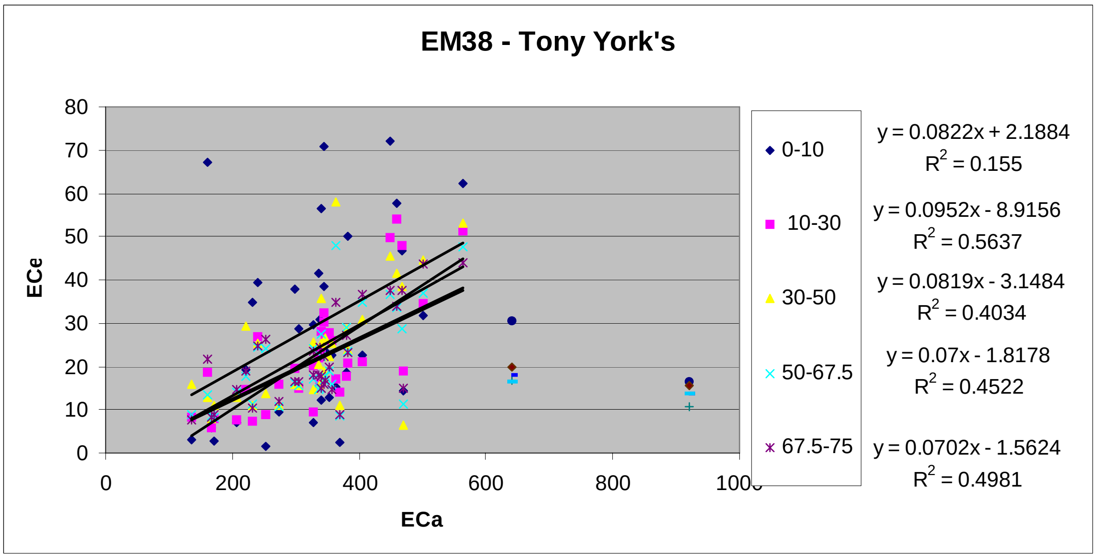

Figure 4. Relationship between EM38 EC_a and EC_e of soil at different depth intervals from soil at Tony York's, Tammin, WA.

Analysis undertaken as part of SGSL has led to the conclusion that it may be better to use EC_a data directly (with some other data if available) as a direct measure of land capability. This approach has the great advantage that the EM38 is a survey tool. Its use in land capability assessment has the potential to fast track salt land capability assessment.

Further assessing the sites, it has become apparent from the data collected at the SGSL sites that there is a clear relationship between the EC_a data and the average depth to the watertable and the average electrical conductivity of the groundwater (EC_w). Our aim is to establish multiple linear regressions of the form:

$$EC_{av} = a + b*WTD + c*EC_w.$$

Only a few sites have adequate data to test this, primarily the "transect sites" in the WA2 experiment. Preliminary analyses showed that EC_{av} values were log-linearly related to watertable depth (WTD). We therefore attempted to fit curves of the form:

$$\log_e(EC_{av}) = a + b*WTD + c*EC_w$$

Using all data sets we got a statistically significant relationship (all factors significant at $P < 0.001$) and Coefficient of Determination (r^2) value of 0.214. Removing the Melvin's Yealering data, all factors were still significant at $P < 0.001$, but the r^2 value rose to 0.898. It is suggested that there may be an aquitard at this site (Gerald Watson, personal communication, found during drilling) preventing groundwater rise, and indicating that the water level in the monitoring piezometers is in fact the confined piezometric level and not the actual watertable. This is to be tested in the next programme of drilling, and will be reported in a revised version of this report.

One way correlations of $\log_e(EC_{av})$ versus WTD were significant with a r^2 of 0.75. This is consistent with Nulsen's (1980) view that watertable depth is the major driver of surface soil condition.

2.3 Water Salinity

Salinity of water is routinely "measured" with an electrical conductivity meter, and reported in various "EC" units. EC is not really salinity, but can be interpreted as such if one knows a direct relation between water electrical conductivity and the concentration of total dissolved salts (TDS). The relationship between EC and TDS depends on the ion charge concentration in the water, not on the mass concentration indicated by TDS. If one knows the ionic species mix in the water one can determine a direct relationship. This depends on region, and so for each site in SGSL we present the relationships for converting EC into TDS.

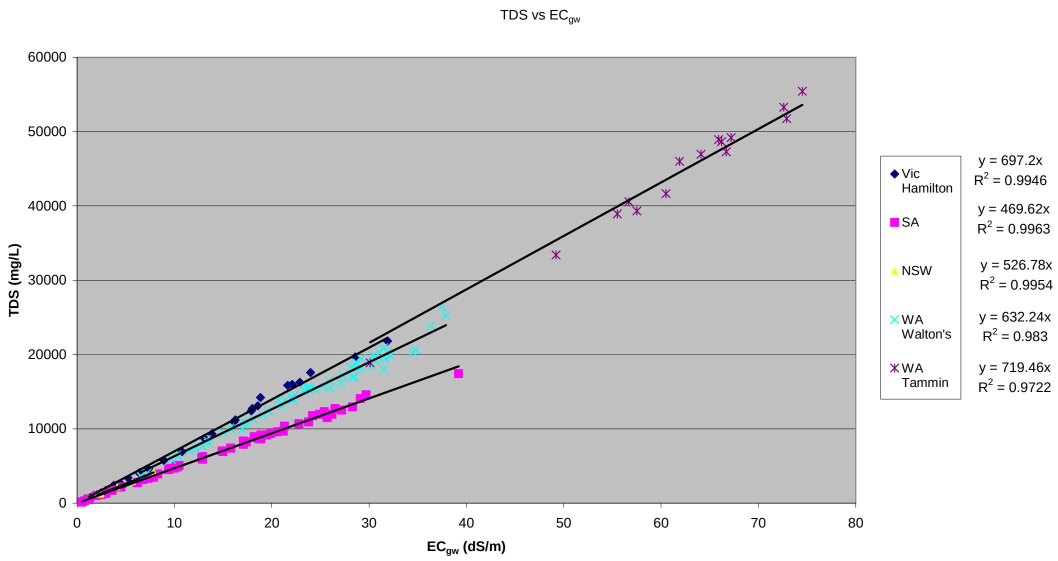

Figure 5. Relationship between water salinity and total dissolved salts for all sites.

It can be seen that the Victorian, NSW, and WA waters show very similar relationships, but South Australian water appears to be different. However, the NSW data are based on very few measurements, and there appears to be an ion imbalance in the SA data. We are checking these numbers and will amend the report as soon as we can confirm them.

3 Results

Here we report the primary findings to be assessed by the Theme, namely the off-site fluxes of salt and water resulting from the adoption of salt land grazing in the experiments in NSW and WA.

3.1 Runoff

At Gumble and at Chris Walton's at Yealering, salt and water flux off the paddocks has been measured throughout the experiments. Unfortunately, the drought in NSW meant that there was no runoff from several of the plots in several years. From the data we do have (Table 2) we can see that there was a decline in surface flow measured at both Gumble paired plots following treatment. The results from Avoca are inconclusive because of the seasonal differences. At Chris Walton's there was also a decline in surface flow following treatment although this was somewhat less than in NSW. This then is evidence that planting salt tolerant species on saline land does lead to a reduction in surface flow, and therefore a reduction in salty water contributed to streams.

Table 2. Change in water runoff due to planting salt tolerant fodder

Ratio of treated to control plots	Pre-treatment	Post-treatment
NSW – Gumble		
G1/G2	1.9	1.3
G3/G4	0.25	0.19
Avoca A1/A2	-	7
WA Walton's		
North/South	0.6	0.5

The situation is less clear for salt export from these sites. At Gumble there was a slight increase in salt export from one of the treated sites relative to its control plot and at the other no significant change (**Table 3**). At Chris Walton's the data appear to show a substantial decline in salt export, but once again the seasonal conditions were such that there is considerable uncertainty about the magnitude of this change.

Table 3. Change in salt export due to planting salt tolerant fodder

Ratio of treated to control plots	Pre-treatment	Post-treatment
NSW – Gumble		
G1/G2	0.9	0.9
G3/G4	0.07	0.1
Avoca A1/A2	-	7
WA Walton's		
North/South	0.2	0.1

The "double mass" plot is used to compare two locations or test areas against each other when a perfect match is not possible and replication is therefore not strictly valid. The cumulative change in one mass flux is plotted against that of another to show the comparative trends. It is a standard method to test treatments or other changes in conditions in hydrology. **Figure 6** shows the double mass plot for flow in the treated and untreated plots at Chris Walton's (WA). The graph suggests that the comparison between the treated (North) and untreated (South) plots remained relatively unchanged for two years until late 2005. This was when the saltbushes reached a significant size and the ratio of flows between the plots fell by about half.

The graph should be viewed with caution because of the significantly different seasons, with 2005 having by far the most rainfall. It is suggested that another year, at least, but more likely two or three are necessary to confirm this trend, or not. Flow from the NSW sites was significantly lower, and similar plots do not reveal adequate trends, and we refer only to **Table 2** above.

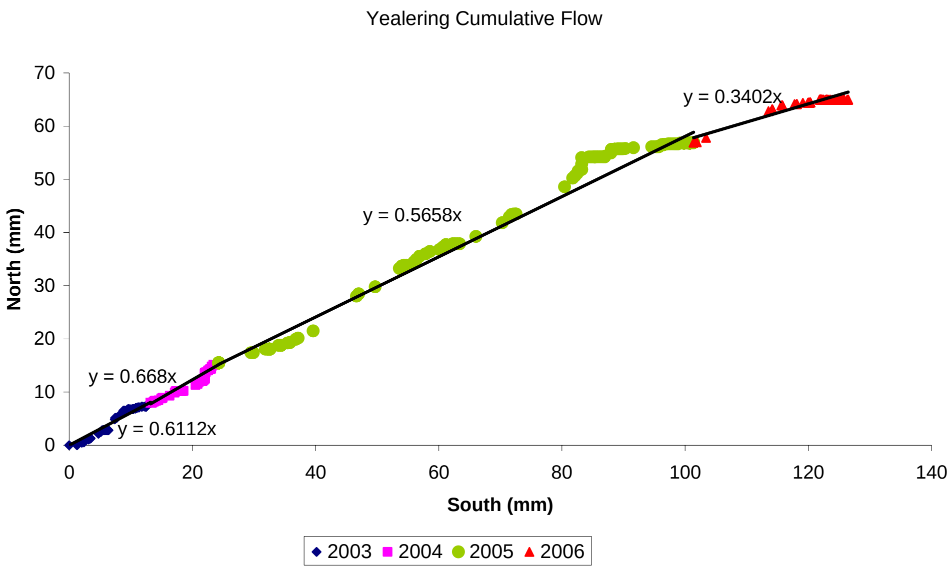

Figure 6. Comparison of cumulative runoff from the North (treated) plot against the South (control) at Walton's Yealering, WA.

Figure 7 shows that there is no measurable change in salt load from the treated plot relative to the untreated plot, except for an apparent decline in the wet year 2005. These data are currently being reanalysed to determine if the confidence can be improved, and the results will be reported later, but on the basis of these data at present we cannot see a significant decline in salt load leaving the treated plot, and hence there would not be a decline in stream salt load.

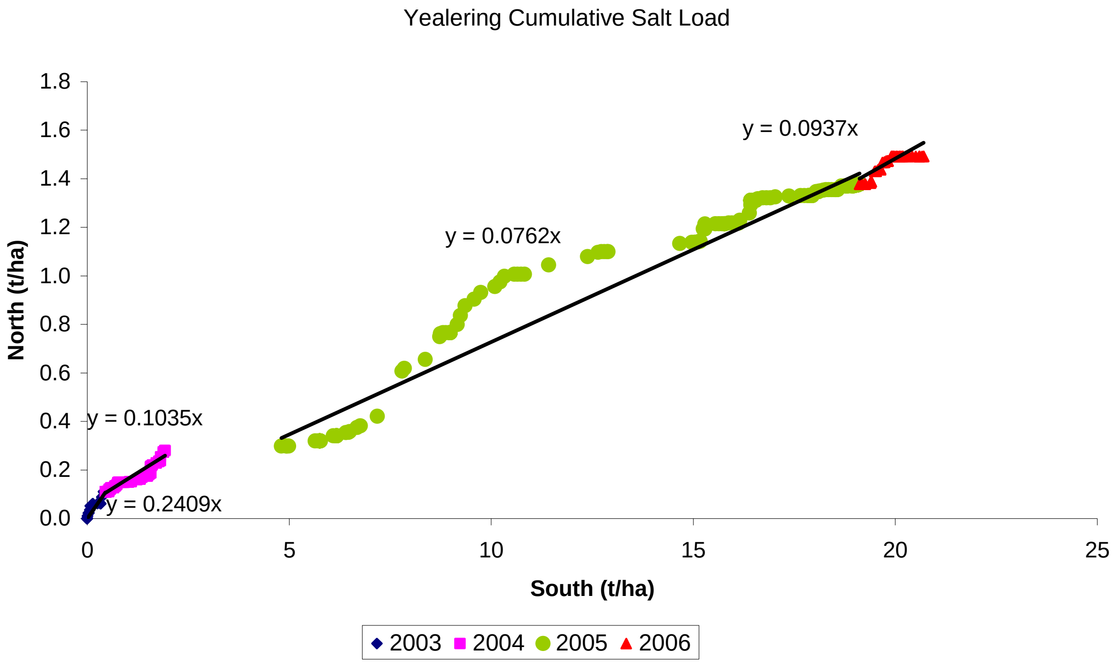

Figure 7. Comparison of cumulative salt load from the North (treated) plot against the South (control) at Walton's Yealering, WA.

3.2 Evapotranspiration

There has been a measurable increase in evapotranspiration in the treated plots at the NSW sites. This is less pronounced in WA. **Figures 8** and **9** show this for NSW and WA, and the data are summarised in **Table 4**. It should be noted that, as discussed in the site reports, both experiments suffered from equipment failure which impacted on the data. This was much more severe in WA than NSW, but the increase in total evaporation from the treated plots over their untreated companion is very clear in NSW, and much less so in WA. Further data are required to improve the confidence in these conclusions.

Table 4. Change in Evapotranspiration due to planting salt tolerant fodder

	Pre-treatment	Post-treatment
NSW – Gumble		
G1/G2	0.8	2.4
G3/G4	1.1	1.4
Avoca A1/A2	0.8	1
WA Walton's		
North/South	1?	1.1?

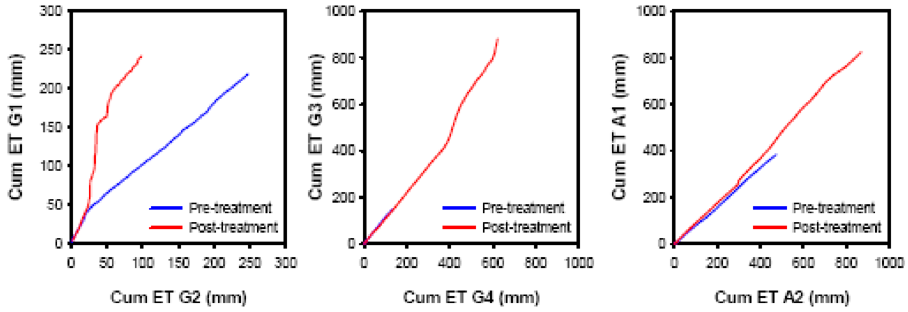

Figure 8. Comparison of cumulative evaporation flux from the treated plot against the control plots at Gumble, NSW.

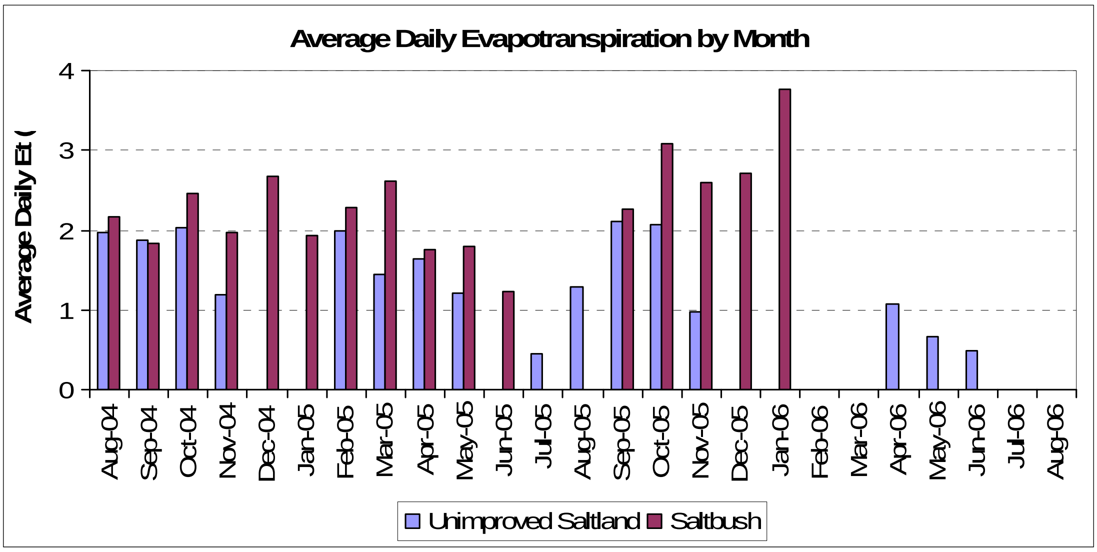

Figure 9. Comparison of cumulative evaporation flux from the treated plot against the control plot at Chris Walton's, WA.

3.3 Soil moisture and groundwater impact

Figure 10 and **11** show the soil moisture storage in the top 1 m of soil at Yealering and Tammin. While at Yealering there may be a decline in average moisture storage under the salt bush, the trend is not very clear as yet. At Tammin it is decidedly unclear. In fact, the control plot, which has a large proportion of blue bush, shows drier soil than the treated plots. The new saltbush planted has not thrived in the conditions, and this is likely to have impacted on the evaporation flux and consequently the soil moisture. This site appears to be dominated by inherent soil salinity, probably primary salinity, and a large groundwater capture with very high salinities. These other factors are likely to be dominating the site behaviour rather than the imposition of a new halophyte into the paddocks.

At Gumble in NSW, there is no significant trend (**Figure 12**). The treated plot, G1, appears to have lower moisture storage develop later in the experiment, relative to its control, G2, but this is not evident in G3 relative to G4.

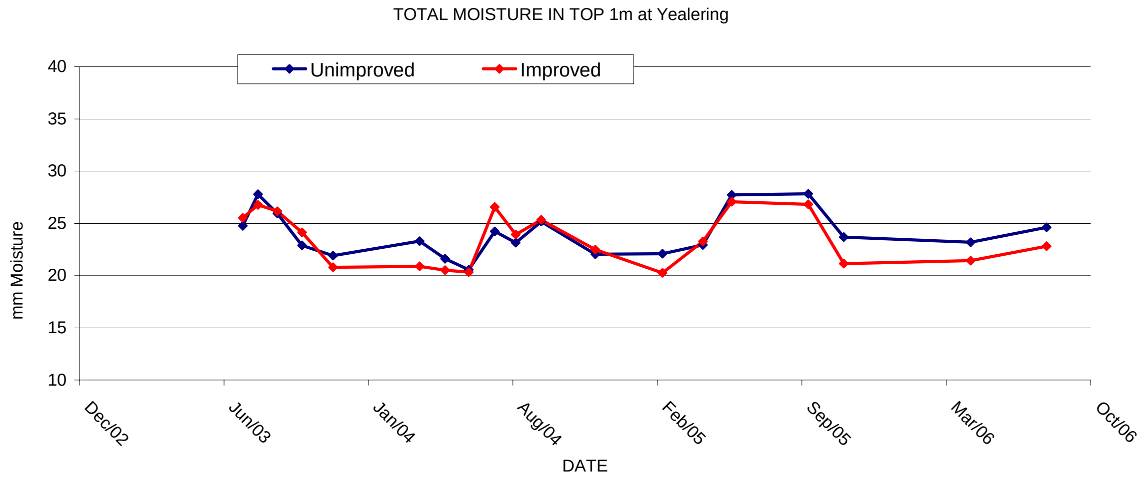

Figure 10. Soil moisture storage in the top 1m at Walton's, Yealering.

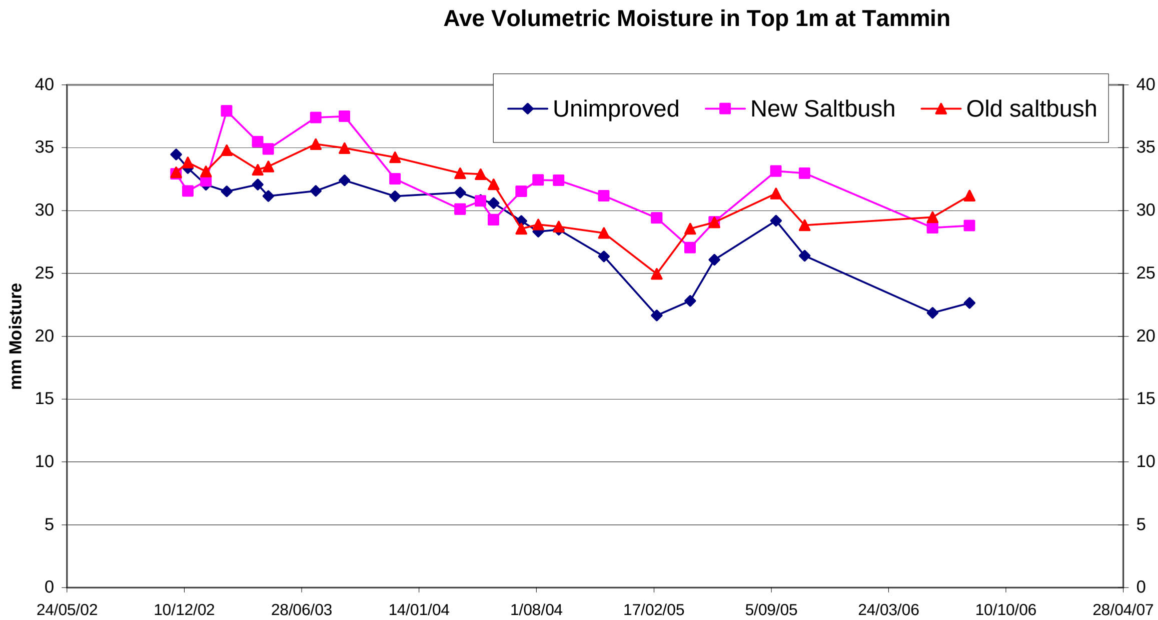

Figure 11. Soil moisture storage in the top 1m at York's, Tammin.

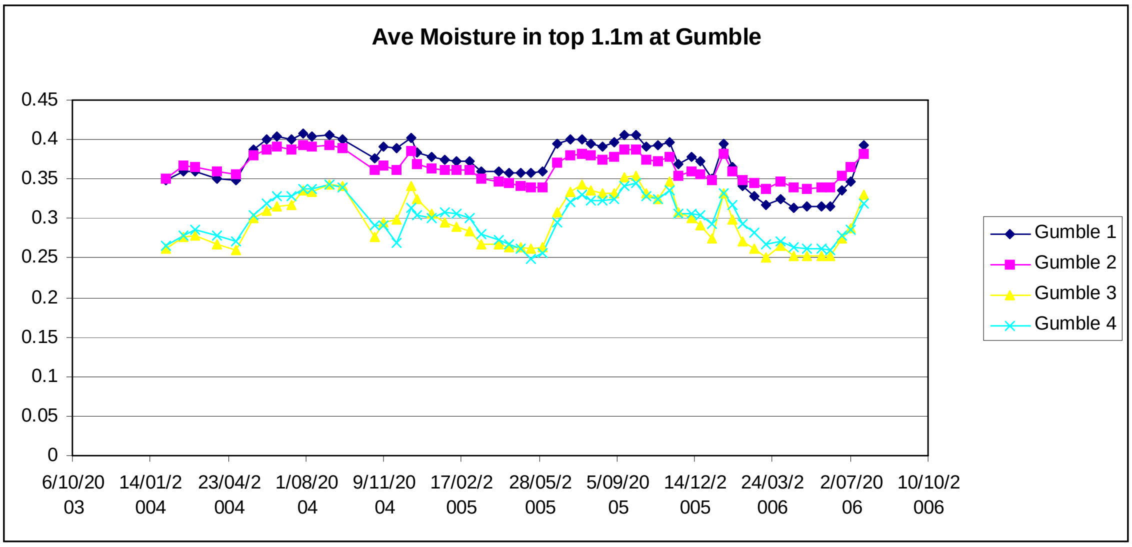

Figure 12. Soil moisture storage in the top 1m at York's, Tammin.

4 Discussion

The results collated here have been collated mainly from the SGSL experiments in NSW and WA, which were the only experiments attempting to measure materials balance and to do full site characterisation. The results of the site characterisation have not been analysed in detail here, except for the relationships between water and soil electrical conductivity and total dissolved salts, and between the apparent EC measured by the EM38 instrument and relevant site characteristics, including depth to groundwater, groundwater EC, soil ECe in depth intervals to 1m. The importance of various site characteristics for animal and pasture productivity and for biodiversity are discussed in the other SGSL Theme reports.

The results presented here are encouraging for our ability to improve management of saline land by the implementation of a salt land fodder system, and at the same time have an impact on evaporation and off-site flows. Increased evaporation should result in drying out the saline area encouraging other plants to colonise; this also results in lesser surface runoff carrying salt to the stream. However, our results have not shown a reduction in salt export, or at least not conclusively, and it may be that there is a reduction in water flow but not salt flow, and the remaining water leaving the site is more concentrated in salt, having no less impact on the ecology of the streams. There has been no measurable change in salt storage in the treated plots relative to the untreated, although the rate of off-site export of salts is so small relative to the total storage we would not expect to be able to see this for some time yet.

The changes on soil moisture accompanying the increased evaporation are less clear. This is presumably because the extra evaporation is being replaced by increased groundwater movement, and so the soil is only slightly drier as a result. The consequence of this may well be an increased salt accumulation in the unsaturated zone. This may eventually inhibit yhe growth of the salt tolerant fodder species, although Barrett-Lennard and Malcolm (1999) did not find this to be significant. It is possible that these effects will become more apparent in follow up measurements at the SGSL sites, particularly in WA but that is beyond the scope of this report. Subtle soil moisture changes, probably a more rapid drying in WA following treatment, less clear in NSW.

In summary, although we have seen good production, and encouraging signs as increased evaporation and accompanying slight decrease in soil water, it is too early to say conclusively that we have reduced waterlogging, and we cannot say anything about catchment scale impact except by inference from our plot scale results.

5 Conclusions

Experiments measuring the salt and water balance of salt land grazing systems have been run from 2002 to 2007 in NSW and WA. These are the first experiments to systematically attempt to measure the salt and water fluxes and complete these material balances for such systems. The extreme climatic conditions persisting through the SGSL experiments has made firm conclusions difficult to draw, but some clear patterns have emerged. The overall conclusions are that implementing a salt land grazing system based on perennial fodder species raises the evaporative losses from the site slightly, and slightly reduces over-land flow from the site. There appears to be little change in site salt storage, and total salt flux, although due to inter-seasonal differences and the size of the fluxes relative to the storage it is really too early to draw clear conclusions on this matter. In NSW there was increased recharge following treatment, but this was not observed in WA.

There was an enhanced export of salt, and surface soil, following disturbance associated with the site preparation and planting. It is expected that this will settle down over subsequent seasons, but we do not yet have an indication of how long this will take. Given that the sites were planted two to three years ago, it is believed that a further 3 years would be adequate to demonstrate whether changes are significant and long-lasting. It appears that the total salt export has not changed but because there is less water runoff from the plots, the concentration is greater.

Data from the neutron moisture meter on soil moisture content in the unsaturated zone indicate a reduction in waterlogging and in average soil moisture storage above the watertable in the salt land pasture relative to neighbouring un-modified paddocks. At some sites here are clear indications of groundwater use by saltbush under favourable circumstances. This could lead to salt accumulation within the root zone of the plants if occasional leaching events do not occur.

At each SGSL site an extensive range of site characteristics that were thought may impact on the pasture and animal production was collected. The relative importance of these in determining productivity and salinity has been assessed through multivariate analysis applied to the site variables common across all sites to determine the relationship between them and soil salinity, pasture production and animal production. Not all sites collected all data, in balancing available resources and how far down the list of characterisation priorities was necessary, and inevitably there are some attributes that were not measured at some sites that would now appear to be highly desirable. These will have to wait for SGSL2.

The use of EM38 as a widespread survey tool and the attempts to calibrate the measured ECa against soil saturation paste extracts EC (EC_e) has been discussed. A subset of soil characteristics was analysed statistically to determine relationships between site physical and chemical characteristics and the apparent electrical conductivity (EC_a) measured by the EM38 electromagnetic probe. The most significant variable is depth to groundwater, with groundwater salinity somewhat less important. We have also undertaken an assessment of the significance of the EC_a as a primary indicator of salinity of land. It is our conclusion that the ECa measured by the EM38 is likely to be a more robust, and certainly more easily obtained, parameter than ECe of soil samples across a paddock.

Relationships between groundwater electrical conductivity (EC_w) and the concentration of total dissolved salts (TDS) have been determined for each site, and for the electrical conductivity of saturation extracts (EC_e) from soil and from extracts of 1g soil to 5 ml of water ($EC_{1:5}$), and for the conversion from $EC_{1:5}$ to EC_e.

References

Bann, G.R., and Field, J.R., 2006. Dryland salinity in south-east Australia: Which scenario makes more sense?, Australian Earth Science Convention 2006, Melbourne Australia.

Barrett-Lennard, E.G., 2002. Restoration of saline land through revegetation. Agricultural Water Management, 53(1-3): 213-226.

Barrett-Lennard, E.G., 2003. The interaction between waterlogging and salinity in higher plants: Causes, consequences and implications. Plant and Soil, 253(1): 35-54.

Barrett-Lennard, E.G., and Malcolm, C.V., 1999. Increased concentrations of Chloride beneath stands of saltbushes (*Atriplex* species) suggest substantial use of groundwater. Australian Journal of Experimental Agriculture, 39(8): 949-955.

Bennett, D.L., and George, R.J., 1995. Using the EM38 to measure the effect of soil salinity on Eucalyptus globulus in south-western Australia. Agricultural Water Management, 27: 69-86.

Jolly, I.D., Walker, G.R., and Thorburn, P.J., 1993. Salt accumulation in semiarid floodplain soils with implications for forest health. Journal of Hydrology, 150: 589-614.

Masters, D.G., Norman, H.C., and Barrett-Lennard, E.G., 2005. Agricultural systems for saline soil: the potential role of livestock. Asian-Australasian Journal of Animal Sciences, 18(2): 296-300.

McKenzie, K.J., Coughlan, K.J., and Creswell, H.P., 2002. Soil physical measurement and interpretation for land evaluation. CSIRO Publishing, Collingwood, Vic., Australia.

Richards, L. A., (Editor), 1954. Diagnosis and improvement of saline and alkaline soils. Handbook No. 60, USDA, Washington, D.C..

Silberstein, R. P., Fitzpatrick, R., Beech, A., Barrett-Lennard, E., M[c]Caskill, M., M[c]Farlane, J., Maschmedt, D., Lambert, P., and Hatton, T.J., 2004. Site Characterisation Protocol for Sustainable Grazing on Saline Lands National Experimental Sites. Cooperative Research centre for Plant Based Management of Dryland Salinity.

Silberstein, R. P., George, R.J., M[c]Caskill, M., and Hatton, T.J., 2004. Materials Balance Protocol for Sustainable Grazing on Saline Lands National Experimental Sites. Cooperative Research centre for Plant Based Management of Dryland Salinity.

Silberstein, R.P., Vertessy, R.A., Morris, J.D., and Feikema, P.M., 1999. Modelling the effects of soil moisture and solute conditions on long-term tree growth and water use: a case study from the Shepparton irrigation area, Australia. Agricultural Water Management, 39(2-3): 283-315.

Slavich, P.G., and Petterson, G.H., 1990. Estimating average rootzone salinity from electromagnetic induction (EM-38) measurements. Australian Journal of Soil Research, 28(3): 453-463.

Slavich, P.G., and Petterson, G.H., 1990. Estimating solution extract salinity from soil paste electrical-conductivity - an evaluation of procedures. Australian Journal of Soil Research, 28(4): 517-522.

Thorburn, P.J., Walker, G.R., and Jolly, I.D., 1995. Uptake of saline groundwater by plants: an analytical model for semi-arid and arid areas. Plant and Soil, 175: 1-11.

Whittington, H.W., 1976. A Battle for Survival Against Salt Encroachment at "Spring Hill", Brookton, Western Australia.

Williamson, D. R., 1990. Salinity - an old environmental problem. CSIRO Division of Water Resources. Technical Memorandum No. 90/7, 10 pp.