Dryland salinity on the uplands of southern Australia: a top-down soil degradation process, or a bottom-up deep hydrology (groundwater) process?

Glen R. Bann and John B. Field.

Fenner School of Environment and Society, Australian National University. Canberra 0200

Abstract

In southern Australia, secondary dryland salinity has been universally linked to excess (deep) water movement in the landscape post European settlement. The reason is reported to be the extensive clearing of perennial vegetation (trees). This perception has been formulated into a simplistic, general, conceptual model to explain the formation of dryland salinity; the Rising Groundwater Model (RGM). To date, dryland salinity management strategies across southern Australia are generally targeted solely on this consensus RGM. These activities traditionally involve the planting of 'deep rooted' perennial vegetation across the hills ('recharge zones') and around the salinised zones ('discharge zones'). The objective is to reduce the amount of recharge occurring on the cleared hills and increase the vertical distance to the (ground) water-table at the discharge zones somewhere downslope. Pedological processes are rarely considered in these management activities (i.e. amelioration), and management of vegetation locally on and near the saline site is considered too difficult and ineffective a way to control water in the landscape. Water is recognized as the obvious critical factor in salinity accession and dictates outbreaks, being the 'salt transporter', but it is not necessarily the underlying cause of the increased soil salinity, especially where excess groundwater movement does not apply. This paper investigates relationships between soil/surface water, soil chemical, physical and biological attributes and vegetation parameters. Salinised and non salinised grassy woodland sites on the Southern Tablelands of New South Wales were investigated. Results suggest that increased salinity in these agricultural landscapes is a symptom of the localized, compounding effects of intensive agricultural practices (clearing, tillage and overstocking) causing degradation to soils (i.e. reduced health) and vegetation and significantly altering soil surface hydrology. Symptoms include, reduced soil organic matter (SOM) and soil organic carbon (SOC), reduced soil nitrogen, compaction and/or erosion of the A_0 and A_1 horizons with exposure of sodic, dispersible, poorly structured A_2 and sometimes B horizons (on duplex soils), altered pH levels, altered cation and anion levels, increased EC levels, and reduction in vegetative cover. Soil microbial activity is also reduced and altered. In many cases, sodium chloride, the generally designated culprit to all the problems, is not the major salt, indicating that other (toxic or reduced levels) salts also require monitoring. Using geophysical, hydrological and biological evidence, no link was found indicating that upland dryland salinity expressions are due to rising groundwater. The predominant water movement in these landscapes is surface (runoff) and lateral interflow above the semi-impermeable clay-rich B horizons. Seasonal perched water tables are common but unlikely to be a result of deeper groundwater. Sustainable remediation and management activities must be approached holistically, addressing surface water movement and use, soil health and, in endangered ecosystems, endemic vegetation. This can only be achieved following appropriate stock management.

Introduction: A big (ongoing) problem.

Secondary dryland salinity in southeastern Australia has been a high priority environmental concern for a number of decades, yet controversies still shroud a number of issues. These include the processes involved (and causes) which induce salinised soils, and consequently, its effects on the environment (biodiversity) and the way in which it is mapped and managed. Dryland salinity generally occurs in the low to medium average annual rainfall agricultural zones, where pastoralism and cropping are the dominant landuse. Much of this agriculture has been developed on low fertility, sodic duplex soils that are considered to be marginally productive, especially during drier years (drought). Although dryland salinity has been universally attributed to rising groundwater from excess water accumulation in the landscape post European settlement, many studies and insurgent management activities suggest that increased soil salinisation in southeastern Australia and indeed many upland landscapes across southern Australia, is another symptom attributed to, or a consequence of, localized surface water problems (Figure 1) and soil and vegetation degradation (e.g. Wagner 2001, 2005; Kreeb *et al*. 1995; Murray 1996; Bann and Field 2006a,b, 2007; Rengasamy 2006; Andrews 2006; Fitzpatrick 2008; Meadows 2008). This paper investigates the effects of soil degradation and associated increased salinity levels on soil biotic and abiotic parameters. Implications for sustainable management activities are discussed.

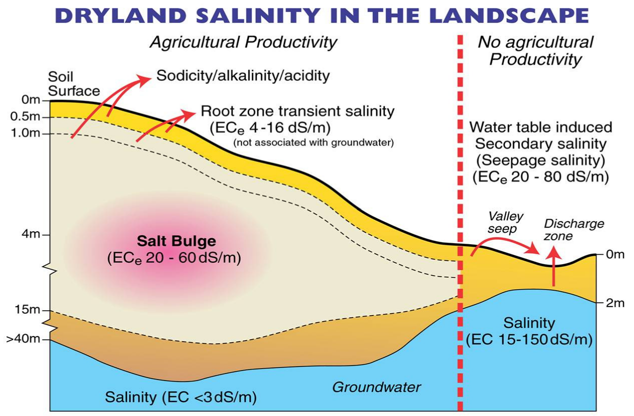

Figure 1. Transient (or surface water) salinity operates above the B horizon, which is often relatively impermeable due to the high clay proportion. This type of salinity, which has nothing to do with rising groundwater, can also occur in the lower parts of the landscape (drainage lines) where duplex soils are common (Rengasamy 2006).

Sites and methods

Many sites showing signs of dryland salinity were inspected across southeastern Australia. Nearly all sites were associated with heavy grazing by domestic livestock and many scalded areas have formed from, or contiguous to, vehicle tracks (i.e. soil degradation). Many sites inspected were not associated with cleared upper slopes (e.g. Figure 2). Ten salinised and non salinised sites (all reserves) were chosen for intensive research into salinity and regolith processes, in the agricultural zone on the Southern Tablelands NSW (STNSW), in the Upper Murray Darling Basin (Murrumbidgee/Lachlan Catchments). Most sites chosen were in a relatively non-degraded state, with remnant Yellow Box (*Eucalyptus melliodora*)/Red Gum (*E. blakelyi*) Grassy Woodlands, which are listed as an Endangered Ecological Community. Three sites had soil works installed to address surface water flow and had been partially revegetated. A suite of holistic biotic and abiotic metrics, including soil field and laboratory analyses, piezometer water table monitoring, electromagnetic induction surveys (EM31 and EM38) were undertaken during autumn and spring in 2005 and various fauna and flora surveys were performed along 50m long transects during 2004-2007. A selection of these metrics are shown in Table 1, with a results summary.

Figure 2. Dicks Creek, between the ACT and Yass, one of the most visited saline sites in NSW, if not Australia. Princes, Prime Ministers and Premiers visit the site. However, EM38 and EM31 surveys indicate low salinity levels. The site suffers severe soil erosion due to lateral movement of surface water. Note the forested ridges. The site is presently grazed by sheep, despite almost zero productivity. Revegetation attempts on the hillslopes (to the left of the photo) have done nothing to ameliorate the soil degradation problem downslope.

Table 1. Important metrics and a results summary showing the differences between relatively non-degraded soils (i.e. with an A_0 and/or A_1 horizon) and degraded soils (compacted or removed A_0/A_1 horizon) at salinised and non salinised grassy woodland sites on the STNSW. Scalds (degraded salinised areas) are included under soils without A_0/A_1 horizons.

Measurement	With A_0/A_1 horizon	Without A_0/A_1 horizon
A_0 and A_1 horizons	Present	Very thin or absent
Soil EC (1:5 – soil : water)	Generally Low levels	Low to High levels
Soil pH	slightly acidic to neutral	Acidic to extremely alkaline
EM38 (0.75m and 1.5m depth)	Low readings (non saline)	Low to High readings (saline?)
EM31 (3m and 6m depth)	Low - High readings (trees)	Low to High readings (saline?)
Soil structure	Good to very good (trees)	Very poor to poor
Soil surface compaction	Very low to high	Generally high to very high
Soil surface dispersibility	Low (slake and ASWAT)	Low to Very High
Runoff	Low to High	Low to Very High
Erosion (wind and water)	Usually low levels	Usually High (wind / water)
Soil bulk respiration (CO_2)	High rates	Low rates
Active bacterial biomass	Low levels	Zero to Low levels
Active fungal biomass	Generally zero levels	Low levels
Total fungal biomass	Very low - high	High to Very High
Total actinobacteria biomass	Zero to low levels	Low to Medium levels
Total Na	Zero to low levels	Med to Very High levels
Total Mg	Low to high levels	High to Very High levels
Exchangeable Ca	Low to High levels	Nil to low levels
Exchangeable K	Generally low levels	Low to Very High levels
Exchangeable Mg	Generally low to medium	Zero to Very High levels
Exchangeable Na	Nil to low levels	Generally High to Very High levels
Total N	Low to very high levels	Zero to High levels
SO_4	Generally zero levels	Generally High to Very High levels
Br	Generally zero - low levels	Generally High levels
Cl	Generally low levels	Generally High to Very High levels
H_2O_2 (organic material; yes/no)	Always a reaction	Nil/small reaction (zero? organics)
Soil Evaporation Potential	Low rates	High to Very High rates

Results and Discussion: Soil degradation

Results indicate that increased salinity levels on the STNSW are highly variable both temporally and spatially (horizontally and vertically), and are associated with localized soil degradation (Figure 2). Increased soil salinities are generally absent where A_0 and/or A_1 horizons are present (such as beneath trees and grass tussocks). Degraded scalded areas generally lack an A_1 horizon, exposing sodic, bleached, infertile, dispersible A_2 horizons with poor structure, low amounts of SOM, SOC and total N and P, altered pH ($pH_{(w)}$ 3.8 - 10.6 from the top 5cm soil; up to $pH_{(w)}$ 11.2 at 25cm depth), and low levels of soil microbial activity. Soil cation and anion contents analyses indicate that these are usually altered at degraded sites, including the cations Na, Mg, Ca, Fe, Al, and K and anions Cl, Br, F, SO_4 and NO_3. It is clear that many salts are present in the landscape, some of which are more toxic to plants, than simply NaCl *per se*.

The EM38/31 surveys indicated considerable temporal and spatial (horizontal and vertical) variation and show an inverse relationship between soil surface EC levels with the depth of the EM readings (i.e. decreased association from EM38 to EM31). Depth analyses between different seasons (moisture regimes) indicate that the predominant change between seasons occurred within the surface ~1m. Piezometer measurements support this, showing that the predominant water movement in these landscapes occurs as lateral interflow on top of the semi-impermeable clay-rich B horizon. Runoff following rain events is also considerable, especially where surfaces are bare and compacted (such as scalds). Seasonal perched water tables are common and no evidence was found linking rising groundwater to the saline areas.

All evidence indicates that the problem is associated with soil and vegetation degradation, causing increased surface evaporation rates and subsequent salt deposition (i.e. evaporites) derived from the surficial hydrological flow. A Soil Evaporation Potentiality Index (SEPI) was derived from a number of the indicators, thence used in the analyses, whence it yielded strong correlations with many of the biotic and abiotic attributes. An increased SEPI was associated with soil and vegetation degradation. This degradation is a consequence of a decline in soil biological, chemical and physical properties, which is predominantly process driven from the surface downwards. Much of this degradation is attributed to the compounding effects of many years of agricultural activities; vegetation and soil modification, water diversion and extraction, and stock (over) grazing and cropping. In addition, the historical effects of rabbits on the topsoil and vegetation are also likely to compound the degradation. Therefore, sustainable management needs to acknowledge the causes of these symptoms and address them appropriately.

Conclusions: Management – to improve soil 'health' and reduce surface evaporation
Soil salinity on the STNSW appears to be just one of a number of symptoms of soil and vegetation degradation caused from agricultural activities, predominantly intensive stock (over) grazing and cropping on marginal and probably already degraded land. Salinised areas often occur where rising groundwater is not the critical issue, rather, soil and vegetation degradation with increased soil evaporation subsequent to increased soil compaction and exposure, reduced organic matter (removal of A_0/A_1 horizons, occasionally the A_2) and nutrient (N, P, K) levels and altered pH levels and cation and anion concentrations. Increased evaporation rates allow increased evaporite deposition, which includes, but is not limited to NaCl. As salinity expressions on the STNSW are generally small and localized and often occur in low lying (sometimes seasonally swampy) areas of the landscape, where dispersible sodic duplex soils are common, stock control is critical for sustainable soil and groundcover management. Sites that are managed for excessive surface water flow (e.g. with the use of soil works and/or revegetation), improved soil health (e.g. increased organic matter and improved soil structure and increased water and nutrient retention) with stock exclusion usually respond favourably and relatively quickly (Figure 3).

Figure 3. Management activities focusing on grazing management and soil amelioration, in this case using exotic grass species and endemic tree species to remediate degraded salinised area to the left, and achieving desired outcomes within a relatively short time period.

References

Andrews P (2006) 'Back from the brink: how Australia's landscape can be saved'. Harper Collins Pub., Sydney.

Bann G, Field J (2006a) Dryland salinity in SE Australia: which scenario makes more sense? Australian Earth Sciences Conv. Proceedings, Melbourne. 9p. Published on disc. (available: www.saltlandgenie.com)

Bann GR, Field JB (2006b) Dryland salinity in south-east Australia: a soil degradation and surface water process? CRC LEME Symposium, Hahndorf, S.A. R. Fitzpatrick (Ed.). Canberra 5p.

Bann G, Field J (2007) Dryland salinisation in SE Australia: fallacies, problems and subsequent sustainable management. *International Journal of Environmental, Economic & Social Sustainability* **3**(2), 155-163.

Fitzpatrick RW (2008) Soils and natural resource management. In 'Regolith Science'. (Eds KM Scott, CF Pain). pp.307-340. (CSIRO, Melbourne).

Kreeb KH, Whalley RDB, Charley JL (1995) Some investigations into soil and vegetation relationships associated with alkaline-saline soil surfaces in the Walcha area, Northern Tablelands, New South Wales. *Australian Journal of Agricultural Research*, **46**(1), 209-224.

Meadows N (2008) Identifying and managing soil salinity at multiple scales on King Island, Tasmania. MSc thesis unpublished. University of Tasmania, Hobart.

Murray J (1996) Survey and reclamation of saline/alkaline scalds in the Uralla/Walcha district of Northern New South Wales. PhD thesis, Dept Botany, University New England. Unpub.

Rengasamy P (2006) World salinisation with emphasis on Australia. *J. of Exp. Botany* **57**(5), 1017 – 1023.

Wagner R (2001) Dryland salinity in the south-east region of NSW. MSc Thesis, unpub, CRES, ANU, Canberra.

Wagner R (2005) If the salt loses its savor? *Farm Policy Journal*. **2**(4), 7-17.