CRESSWELL drives salinity! A personal view of dryland salinity in Australia

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Introduction

Too often, arguments over the causes and mitigation of salinity are divided, commonly based on experiential grounds and based on a specific region or outcome, and the generalisation that all salinity is the same. Much the way we talk of clouds, but rarely consider the disparate causes for their formation, so we talk of salinity, as if there were only a single type and single definable cause. The issue is rather that the word salinity has come to mean not just the expression of increased soluble salts in areas that they are not wanted, but with the processes that caused the symptom. Symptoms expressed locally may be the result of processes occurring extant to the area, region or beyond. They may be caused by natural phenomena, anthropogenically induced, or both. It pays to sit back and assess salinity in its various guises and remind ourselves of other variations on the theme, the myriad of possible causes and what the similarities and differences may be, and hence determine an appropriate mode of remediation or mitigation relevant to the situation.

Salinity classification schemes reflect bias in purpose, or bias in the experience of compilers, and the complexity serves to remind us that salinisation is not the product of a single process, but reflects the interaction of a number of different and often disparate processes with different drivers that merely share the ultimate attribute of salinising the landscape.

Australia exhibits the entire gamut of salinity expressions seen across the globe (Ghassemi, et al., 1995). Also, being only recently introduced to European farming practices can be examined from a natural vs. anthropogenic perspective. Hence, we have the opportunity to review salinity across a wide range of drivers responsible for its expression. Having compiled a list of relevant primary and secondary drivers for salinity across Australia, I was excited to discover, in this world of acronyms, that my name covered the gamut of drivers responsible for salinity across Australia, and, I believe, elsewhere.

Climate, rainfall and evaporation

Climate forcing and behaviour determines the critical Rainfall and Evaporation zones prone to salinisation processes. The significant differences between north and south Australia are the timing and intensity of rainfall, illustrated by 2 rainfall graphs in Figure 1. The north of Australia is dominated by high, but extremely variable rainfall patterns; the south by moderated and lower rainfall. This combined with seasonal rainfall that coincides with maximum evaporation in the north, compared to winter dominant rainfall in the south (Figure 2), means that it is the high extremes of rainfall that will drive salinity in the north, while the south can be more directly and continuously affected by positive rainfall balances.

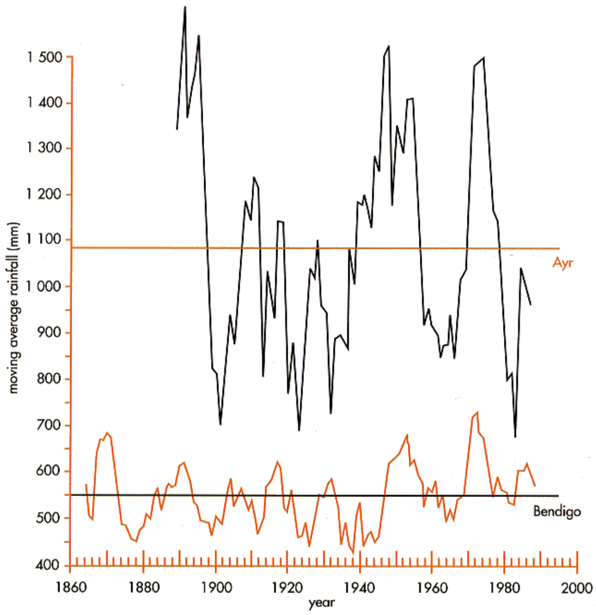

Figure 1 Annual variability in rainfall for northern (Ayr, Queensland) and southern (Bendigo, Victoria) sites, illustrating the extreme variability for northern Australia, but significantly higher rainfall regime. See text for discussion; Figure taken from QDNR, 1997.

High evaporation rates in the north also mean that the critical rainfall band in which dryland salinisation (defined as salinity generated through rising water-tables bringing salts to the root-zone) occurs is 700-1100mm/a, while in the south, this band generally occurs in the 400-800mm/a zone (Figure 2). Long-term variability in rainfall regime then determines whether a region is likely to exhibit rising or falling groundwater tables: an increased, or decreased, risk to dryland salinisation.

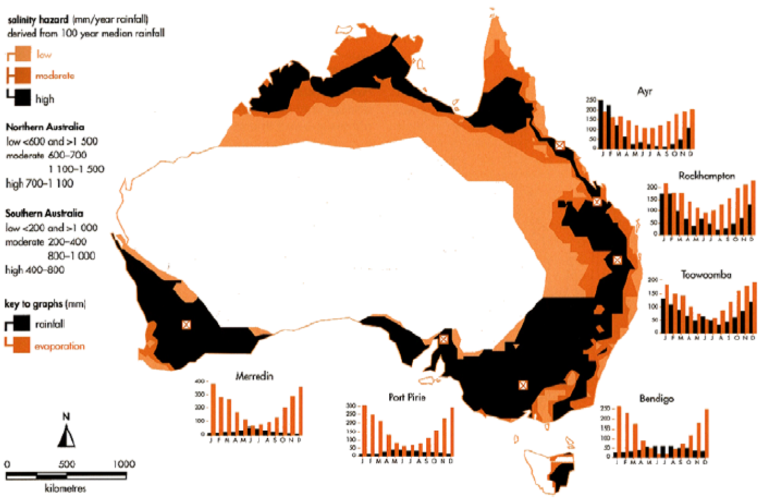

Figure 2 Australian dryland salinity hazard (QDNR, 1997). Also shown are monthly rainfall and evaporation charts across the country. Note the zone of higher risk in the north coincides with a higher rainfall zone as a consequence of summer rainfall dominance.

Salts, soils and water

Within these climate zones at high risk, we must then consider the **S**oils, in particular their propensity to contain, store or contribute **S**alt and **W**ater to the landscape. Naturally, water is a prime requisite for mobilisation of salts and re-distribution in soil profiles and through regolith, overland and via rivers and groundwater. The rate at which water moves through the landscape, or is retarded is of critical importance. Salinisation of Australia's waterways is both a direct (through mobilisation of surface salts to streams) and indirect (through increased base-flow from rising groundwaters) consequence of this.

A direct consequence of the disparity in climate regimes is an increased runoff component to northern Australia's water balance. In other words, a lower proportion of the total budget contributes to recharge of aquifers. Total volumes contributed to groundwater recharge across Australia, however, are comparable, but generally the greater total volume of rainfall in the north results in fresher waters entering the system when compared to southern regions. There are 2 major consequences of this with relevance to salinity: (i) Groundwaters are inherently fresher in the north, hence require greater evaporation to constitute a salinity risk; and (ii) Surface deposition of salts in the soil profile is reduced in the north as most salt will be washed off the catchment through stream flow. The latter process results in salt output to input ratios close to unity for the majority of catchments in the north where we have adequate data to evaluate. The former means that the salinising effects of irrigation and rising water tables in the north can be more readily ameliorated than in the south.

A further consequence of high run-off rates is illustrated in Figure 5, adapted from McNeil and Cox (2000). Compilation of chemistry data for samples at stream gauges across Queensland revealed a strong relationship between the concentration of salts in the waters and the dominant species contributing to salinity. Thus, fresher waters, generally associated with dominant overland flow and high flow rates, are dominated by bicarbonate anions, whilst more saline waters (though still comparatively fresh: <1500 mg/L), are dominated by chloride. This reflects, in part, the contribution of groundwaters (which are generally more chloride-rich) to base-flow dominated flow and the effect of evaporation, which drive up the total salinity, whilst exsolving CO2 and reducing the bicarbonate contribution through reactions with stream-bed sediments and carbonate precipitation.

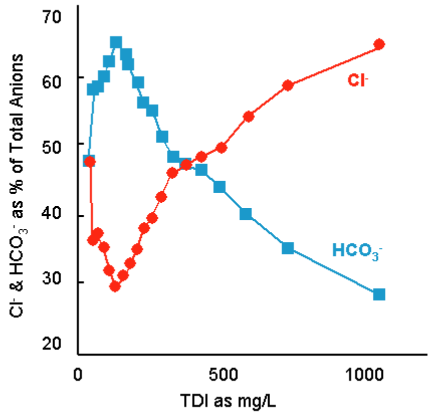

Figure 5 Median percentage of anions compared to salinity for nearly 34,000 surface water samples across Queensland (McNeil and Cox, 2000).

This process is seen worldwide and is referred as the 'Gibbs boomerang' effect (Gibbs 1970). Almost equal concentrations of chloride and bicarbonate in very fresh waters (<100 mg/L) reflect rainfall as the initial source of fresh surface waters.

Limited data exist on the quantity of salts stored in the landscape, though we may estimate amounts from local chloride profiles and soil salinity tests. Airborne electromagnetics (AEM) provide a means of showing spatial variability and has been calibrated in some areas giving confidence in the estimates of salt stored in the regolith. Thus, analysis of cores within AEM fly zones in NSW (2,000t/ha) and Victoria (3,000t/ha)(Cresswell *et al.* 2004) and Queensland (5,000t/ha)(Cresswell *et al.* 2007) and across salinised regions of WA (10,000t/ha)(Clarke *et al.* 2002) indicate that comparable amounts of salt are present in comparable landscapes and are commensurate with accumulation of cyclic salts over the past few hundred thousand years. Depth of regolith (weathering) seems to be an important criterion determining the total amount of salt in each region. Chlorine-36 data from cores in NSW give finite ages for the salt indicating that at least part of the salt is of a recent origin (Cresswell *et al.,* 2004). Recent analyses within shallow the unsaturated zone of NSW revealed significant chlorine-36 from nuclear bomb testing in the past 60 years (Lenahan *et al.*, this forum).

Equilibrium and landforms

Whether salt is mobilised or not, is a matter of **E**quilibrium, or perhaps lack thereof, and specifically how far from it a location, or catchment, has become. This is strongly dependent on the nature of the local and regional **L**andforms, study of which leads to the concept of groundwater flow systems (GFS), a primary indicator of the timeframes required for salinisation to occur an for remediation. The GFS approach (Coram, et al., 1998) was specifically developed to assess the time-frames for salinity development and incidentally for the potential time-frames required for remediation (Walker, et al., 2003). Catchments may be distinguished into local intermediate and regional systems, with correspondingly larger scales and hence time-frames for response. This approach has been successfully utilised in Australia to characterise those catchments at risk from rising water-table salinity and provide the potential time-frames involved both in salinisation and remediation (e.g., Clark, et al., 2002).

Land use and response

Finally, **L**and-use often provides a tipping point, but also drives mitigation strategies. Critical land use changes involve the replacement of native perennials with annual crops, and the realisation of this has resulted in significant development of perennial crops and re-vegetation of de-vegetated regions. Unfortunately, in many cases, the time for remediation will be a lot longer than that for destruction. In many cases, it is unlikely that salinised land can be recovered. A critical and emerging land use issue is urbanisation and increased infrastructural change to the landscape. The **R**esponse, both ours and the system's, determines the efficacy of our endeavours and constrains all the other drivers, hence helping to prioritise where intervention is warranted and useful, and what that intervention might be.

Conclusions

Across Australia, a number of independent and dependent drivers cause salinisation of the landscape. These drivers can be identified, but we must relate the efficacy of each and their inter-dependence for each location in which salinity occurs. The trick, as always, is to determine which drivers are prominent where and when and how they interact. The variability across Australia makes this an exacting process, often obvious in hindsight, but still often difficult to predict with certainty!

Across Australia, we may broadly define 3 regions with similar characteristics affecting the drivers (Table 1). Thus, the south-east (NSW, Victoria and South Australia) with moderate, winter rainfall, experiences low evaporation rates during peak rainfall months, and, hence, rapid recharge rates during wetter climate regimes. The north-east (Queensland) experiences highest rainfall in the summer, with recharge being relatively less than in the south, and with fresher waters. Salt accession to the landscape across all of Australia is high, however, so surface run-off can mobilise significant quantities of salt, and recharge can transport large volumes into the subsurface. This is impeded more in the south where sodosols predominate over vertisols, which however, can give greater shallow lateral transport of waters and salts to discharge zones. Salt balances for catchments across Australia indicate that the NE appears to be in reasonable equilibrium (output:input~1), while lower gradients and greater base-flow in the SE and SW have resulted in many catchments having high salt export factors as the landscape tries to recover from severe land use changes of the last century. Landscapes of the NE are dominated by relatively small (<5km) groundwater systems, while the SW has more intermediate (<50km) systems and the SE more regional (>50km) ones. Further, when we analyse the nature of farming practices that seem to be developing salinity issues, we find that irrigation dominate salinity issues in the NE and dryland systems in the SW. The SE has both influences significant in different areas.

Table 1 Variability in primary drivers for the three zones of Australia affected by salinity

	NE		SE		SW	
Climate	summer		winter		winter	
Rainfall	high		moderate		low	
Evaporation	high		low		low	
Salts	high		high		high	
Soils	vertisols	sodosols	sodosols	vertisols	sodosols	
Water	fresh		brackish		saline	
Equilibrium	good		bad		bad	
Landforms	local		local	regional	local	intermed
Land use	irrigation		irrig / dry		dry	
Response	*Silburn et al (this forum)*		variable		slow	

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