IMPROVING SALINITY HAZARD PREDICTIONS BY FACTORING IN A RANGE OF HUMAN IMPACTS IN THE CONTEXT OF CLIMATE CHANGE

Ken Lawrie[1] & Martin Williams[2]

[1]CRC LEME, Geoscience Australia, PO Box 378, Canberra, ACT, 2601
[2]CRC LEME, Geography and Environmental Studies, University of Adelaide, SA, 5005

SUMMARY

Predictions of climate change in Australia point to a significant warming, a decrease in precipitation and an increase in evaporation in many areas of S, SW and SE Australia over the next century and beyond, unless greenhouse gas emissions are significantly reduced. Precipitation amount and intensity are predicted to increase in regions of summer rainfall, mostly the tropical northern third of the continent. Recent climate change is already affecting many physical and biological systems, especially in the SW, and this 'hot and dry' event in the winter rainfall regions is likely to have further significant impacts on human and natural systems. The predicted change will result in a climate different from that generally reconstructed for the Holocene and Late Pleistocene in Australia, where increases in salinity levels in our SE Australian riverine systems appear to correlate with cold dry events rather than a hot dry climate. It is therefore likely that the impacts of salinity in our natural systems over the next century and beyond in SE Australia may be quite different to those events recorded in the Late Quaternary geological record. The rates of change and the ability of our natural systems to respond to these changes remain problematic.

Local climate variability and future and past climate changes have not yet been factored into salinity hazard and risk mapping, yet these may prove vital in predicting and assessing the extent of the salinity problem and the scale of and location of investment required to manage the problem. This issue compounds the problems created by a paucity of other temporal and spatial data that has severely restricted the reliability of salinity hazard predictions, particularly at sub-catchment scales.

Disentangling the relative contributions and effects of human impacts on salinity and groundwater changes is a difficult exercise. To date most salinity hazard mapping and predictions have not considered some of the variables that might significantly affect the reliability of these constructs and predictions due to data limitations. This paper examines these issues, discusses ways in which improvements to predictions may be made through a combination of maximizing the use of existing data, the use of other proxies and new data acquisition. We argue that some attempt must be made to account for these issues in salinity hazard/risk predictions, and/or the uncertainties that arise from these data gaps must be made more explicit to help data acquisition strategies, and policy, management and investment planning.

INTRODUCTION

The National Land & Water Resources Audit (2000) provided the first national perspective on salinity hazard in Australia. The Audit incorporated results from individual State studies including reports on the 'Extent and Impact of Dryland Salinity', the 'Salinity Audit of the Murray Darling Basin' and other State-based reports on Salt Load (Csaky 2003). However, there was no consistent national approach taken in the Audit, with very different methods applied in individual States due at least in part to data limitations. This difference in methodologies has been accentuated more recently through the development of other salinity hazard mapping and prediction methods within individual States, and within individual catchments. In part to address this issue, a national review documenting the salinity mapping techniques and approaches has recently been carried out (Spies & Woodgate 2004). However, while noting the value of integrated, multi-disciplinary approaches to salinity mapping, assessment and prediction, it was not within the scope of the review to examine the fundamental gaps in the approaches currently taken in making salinity hazard predictions.

Policy makers appear to regard the NLWRA (2000) as a comprehensive study of dryland salinity in Australia. However, to salinity researchers it was obvious that the reliability of the predictions is severely limited by both spatial and temporal data availability, with significant gaps recognized (Lawrie *et al.* 2003a, b, Csaky 2003). Largely due to these data gaps, use of the NLWRA dryland salinity and water table hazard maps and predictions was intended primarily for National, State and catchment scale analysis and policy setting (NLWRA 2000). Subsequent use of the data for sub-catchment and local scale purposes appears to stem from failure to appreciate the reliability issues that result from the data limitations.

In: Roach I.C. ed. 2004. *Regolith 2004*. CRC LEME, pp. 199-203.

Within the salinity research community, there is a general recognition that the process of producing salinity hazard maps in Australia is at best an iterative process, and largely dependent on data availability. Methods of assessment range from those models designed to improve rapid catchment assessments (e.g., the Cooperative Research Centre for Catchment Hydrology—CRC CH's—Project 2C), to regional and site specific studies that have focused on understanding salinity and groundwater systems at local and/or sub-catchment scales underpinned by significant new data acquisition (Lawrie *et al.* 2000, Fitzpatrick *et al.* 2004, Munday *et al.* 2004). Moreover, recent studies suggest that the NLWRA (2000) salinity hazard predictions may even have significant limitations for broad scale planning and prioritization purposes (Heislers & Brewin 2003, Clifton & Heislers 2004, Lawrie *et al.* 2003).

More broadly, human influences, including climate change, have been predicted to impact on surface hydrology (Keyworth 2004; Table 1). These predicted changes in surface water inflows for the Murray-Darling Basin highlight the significance of climate impacts and human intervention on overall catchment water balance and environmental flows. By 2020, it is anticipated that 2620 GL/annum will be lost to river inflows. In contrast the Living Murray Initiative to 'restore environmental flows' is negotiating for returns of 500 GL/annum in the same timeframe. These reductions in river inflows must also affect catchment hydrogeology and salinity hazard predictions. These issues and data limitations discussed in this paper also have importance for broader NRM issues such as the monitoring and assessment of catchment condition, biodiversity/ecosystem protection, and for assessing the sustainability of groundwater resources.

Table 1: Predicted changes in water inflows to the Murray-Darling basin (S. Keyworth, 9th Murray-Darling Basin Groundwater Workshop, 2004).

Process	**Gigalitre/annum inflows by 2020**
Climate change	-1100
Reforestation	-330
Water use growth	-510 (groundwater)
New farm dams	-250
Bushfire impact (03)	-130
TOTAL IMPACT	**-2620 GL/annum**

CLIMATE CHANGE

Since the 1970s there has been a net decrease in precipitation over the SW of Western Australia of the order of 20%, with a concomitant decrease in runoff replenishment to reservoirs, and moves to invest substantially in a major desalinization plant. This decrease in winter rain is associated with a southward displacement of the air mass systems that bring winter rainfall to southern Australia (Pittock 2003). The best climate predictions for 2030 point to a probable 20% decrease in winter rain over SW and S central Australia, increasing to a possible 60% decrease by 2070 (Hennesy 2003).

The recent drought over a 6-7 year period in Victoria has highlighted the need to resolve the relative contribution of climate change to measured and predicted changes to water table levels, and predicted salinity discharge and hazard. The issue is not easy to resolve, as the NLWRA (2000) salinity hazard maps in Victoria are based largely on simple linear extrapolation of (pre-drought) hydrograph trends, with no errors calculated, and trend analysis performed on records monitored for less than 25 years (Reid 2004). Furthermore, pre-European water table levels are not recorded, despite some historical records suggesting some significant water table rises (> 20 m) in regional flow systems in Victoria over the last 100 years (Macumber 1991). Further complications arise because some aquifers are also utilized as groundwater resources (Reid 2004). The lack of long-term monitoring of piezometers, and patchy rainfall records for the first century of European settlement, significantly complicate predictions of water table rise and salinity discharge. This generally means that temporal analysis and estimates of rates of change of water tables are not well constrained, and must rely on historical records and/or biophysical proxies and/or models. Furthermore, the impacts of episodic recharge events may lead to significant abrupt changes in water table rise (Macumber 1991), and the periodicity and spatial extent of these events is largely unknown.

Predictions of climate change in southern Australia point to a significant warming, a decrease in precipitation and increase in evaporation in many areas of Australia over the next century (Pittock 2003, Hennessy 2003, Hennessy *et al*. 2004). Recent climate changes have already affected many physical and biological systems, including stream runoff and salinities (S. Halse *pers. comm*. 2004) and groundwater levels (Reid 2004), and this 'hot and dry' event is likely to have further significant impacts on human and natural systems (Hennesey 2003, Hennesey *et al.* 2004). Recent climate warming has been attributed to global increases in CO_2 levels (IPCC 2001), and this event is superimposed on a post-1840 dry cycle in Australia, the previous Holocene climate record being generally wetter in Australia (Jones 2004).

The predicted climate differs significantly from the Late Pleistocene in Australia, which although generally drier, was also colder (Williams 2001). Late Pleistocene wetland/riverine salinity increases appear to coincide with these colder, drier episodes (Bowler 1981). Further resolution of climate records in the Holocene and Late Pleistocene appear possible through integration with palaeoliminology studies of crater lakes and diatoms (Jones *et al*. 2001, Tibby & Reid 2004).In these prior cold, dry salinity events, reductions in surface water volume may have led to increased salinity levels, while freshwater riverine and lake ecosystems may have been maintained in part by snow melt waters (Jones 2004). In dry, cold climate events, the importance of discharge from slow-moving regional groundwater flow systems may also play an important role in either contributing to salinity discharge (less runoff to dilute saline groundwater inputs), or sustaining local ecosystems (where groundwaters are of good quality).

The Late Pleistocene climate was drier and colder than today, and the Holocene was generally wetter, and characterized by wide ranges in precipitation/evaporation (P/E) ratios (de Deckker *et al.* 1988, Jones *et al*. 2004). Palaeo-climatic evidence suggests that previous climate events associated with significant drying of the continent and salinity discharge in wetland and riverine environments in SE Australia were cold arid events, with river systems and associated ecosystems maintained by snow melt (Jones *pers. comm.* 2004). A reduction in water volume in rivers is likely to lead to an increase in salt concentrations (Jones 2004), however, the timescales upon which many of the regional groundwater flow systems respond may somewhat offset these effects.

Both the temperature *maxima* predicted in the climate change models and the rates of change may be particularly important in looking for analogues in the geological record and in modeling future responses of natural systems. The rates of temperature increase predicted for the coming century, always assuming a doubling of CO_2, and assuming equilibrium, could amount to up to 6°C within 50-100 years (Hennesey 2003). This rate of change is fast, but possibly not unprecedented from the Quaternary record, at least in high latitudes. However, the temperature maxima may be more extreme than experienced in the Late Quaternary.

SALINITY HAZARD MAPPING METHODS

Salinity Hazard Mapping methodologies in Australia include salt load studies, trend-based methodologies, strongly inverse methods, composite index methods and integrated geoscience approaches. Reviews of these methodologies are summarized elsewhere (Lawrie *et al.* 2000, 2003a, Csaky 2003, Spiess & Woodgate 2004). The Composite Index approach has further developed from using surface features to incorporating subsurface attributes to acknowledging assets for risk assessments (Heislers & Brewin 2003, Clifton & Heislers 2004).

Figure 1 summarises the limitations and assumptions of the current methods, and lists the suggested improvements that might be made in predicting salinity hazard. Essentially, all methods are limited by data availability, particularly at sub-catchment scales, while most methodologies are heavily weighted towards present-day climate data and use of surface datasets. A paucity of sub-surface spatial data restricts the applicability of these methods to broad catchment-scale planning, and a general lack of temporal data severely restricts risk predictions at all scales. Most methods fail to incorporate groundwater process understanding, also limiting utility for risk prediction (Lawrie *et al.* 2003a,b). The reliability of these predictions is usually not stated, however, some may only have 5-20 % confidence levels for some existing salinity/water table hazard maps (Lawrie *et al*. 2003a, b).

CONCLUSIONS

If the factors discussed in the paper above are significant within any catchment, then they must at least be accounted for in salinity hazard/risk predictions, even if the data is not available to measure their impacts. It is argued that clear articulation as to limitations of the hazard/risk maps is essential to: (1) provide greater clarity of the limitations of existing constructs to land managers and policy developers; and, (2) provide funding bodies with clear guidelines on data gaps and the implications of these funding and investment strategies that may be limited by data availability. These data limitations have importance for broader NRM issues such as the monitoring and assessment of catchment condition, biodiversity/ecosystem protection and for assessing the limits of groundwater resource exploitation.

Acknowledgements: this paper is published with the permission of the CEOs of CRC LEME and Geoscience Australia.

SALINITY HAZARD/RISK PREDICTIONS/ASSESSMENTS

Current methods, assumptions and limitations

- Most methodologies are heavily weighted towards present-day climate data and use of surface datasets, are limited by a paucity of sub-surface geospatial (regolith and salt store) data, a general lack of temporal data and limited conceptual groundwater process understanding
- For sub-catchment scale management interventions and asset protection, the fundamental problem remains the lack of key datasets at appropriate scales

Salinity Hazard/Risk predictions- suggested improvements in predicting water table change/discharge

- Climate change responses- Australian Holocene/Quaternary records using palaeo-climate reference data (ranging from instrumental precipitation/evaporation records, historical data, geological data: palaeo-limnology studies eg on crater lakes, wetlands)
- Measuring irrigation impacts (NLWRA (2001) only considered dryland salinity inputs/impacts) on water tables and discharge
- Regolith issues: regolith architecture, regolith material compositions and hydraulic conductivities, regolith aquifer and aquitard (facies) models, rock properties to measure and predict zones of variable water saturation, salt store data, rates and process models of salt accumulation and mobility, calibration and/or prediction of GFS response times
- Groundwater resource data (aquifers may have conjunctive use and highly variable water quality)
- Post-European (+ post-aboriginal?) human impacts within Australia: land use/vegetation changes, and their impact on rates of change and scale nature of hydrogeological processes (soil loss and consequent changes in recharge/soil infiltration characteristics, hill-slope runoff characteristics and in-river morphology, soil biological activity, soil and regolith geochemistry, and changes in salinity processes
- Impacts of data scale and use of raster datasets (eg DEMs) may be very significant in modeling land surfaces and water tables
- Water table records: conflicting data: can we identify palaeo-water table levels (post-European markers) ?; collation of pre-instrument data (ie pre 1970s)
- Land Use data significant scale limitations presently on mapping current land use
- Local variability in climate models

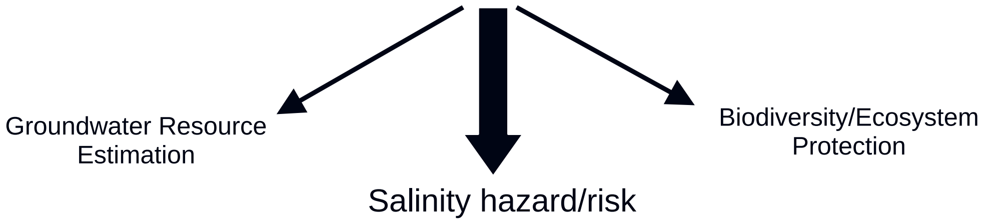

Figure 1: Diagram summarizing the factors not currently considered in most salinity hazard predictions. These data also have potential to contribute to groundwater resource assessments and biodiversity/ecosystem protection and/or restoration.

REFERENCES

BOWLER J.M. 1981 Australian salt lakes: a palaeohydrological approach. *Hydrobiologia* **82**, 431-444.

CSAKY D. 2003. Salinity Hazard Mapping Methodologies: Past, Present and Future. *CRC LEME* **Technical Report**. Unpublished, 52p.

CSAKY D & PLEASE P. 2003. Salinity Hazard Mapping Methodologies: Past, Present and Future. *In:* ROACH I.C. ed. *Advances in Regolith.* CRC LEME, pp. 82-83.

DE DECKKER P., KERSHAW A.P. & WILLIAMS M.A.J. 1988. Past environmental analogues. *In:* PEARMAN G.I. ed. *Greenhouse: Planning for Climate Change.* E.J. Brill, Leiden, pp. 473-488.

HEISLERS D. & BREWIN D. 2003. Corangamite salinity hazard and asset risk assessment. *Department of Primary Industries, Victoria*.

CLIFTON C. & HEISLERS D. 2004. *ASSALT*: an asset based salinity priority setting approach. *In: 9th Murray-Darling Basin Groundwater Worskhop*, 2004.

HENNESSY K. 2003. Climate Change and its predicted effects on water resources. *In: Water, the Australian Dilemma*. Proceedings of the Annual Symposium of the Academy of Technological Sciences and Engineering, 17-18th Nov., Melbourne.19p.

HENNESSY K., PAGE C., MCINNES R., JONES J., BATHOLS D., COLLINS D. & JONES D. 2004. *Climate Change in New South Wales*. Consultancy Report to New South Wales Greenhouse Office, CSIRO Publishing, 45p.

JONES R.N., MCMAHON T.A. & BOWLER J. 2001. Modelling historical lake levels and recent climate change at three closed lakes, Western Victoria, Australia (c. 1840-1990). *J. Hydrology* **246,** 159-180.

LAWRIE K.C., MUNDAY T.J., DENT D.L., GIBSON D.L., BRODIE R.C., WILFORD J., REILLY N.S, CHAN R.A. & BAKER P. 2000. A 'Geological Systems' approach to understanding the processes involved in land and water salinisation in areas of complex regolith- the Gilmore Project, central-west NSW. *AGSO Research Newsletter* **32**, p. 13-32, May 2000.

LAWRIE K.C., WILKES P., LANE R., CORAM J., PAIN C., FITZPATRICK A., GRAY M., WILFORD J., BECKETT K. & MUNDAY T. 2003a. *A Submission to the National Review of Salinity Mapping Methdologies in the Australian Context* **Submission 20,** 300p.

LAWRIE K.C., PLEASE P. & CORAM J. 2003b. Groundwater quality (salinity) and distribution in Australia, 2003. *In: Water, the Australian Dilemma*. Proceedings of the Annual Symposium of the Academy of Technological Sciences and Engineering, 17-18th Nov., Melbourne.

MACUMBER P.G. 1991. Interaction between ground water and surface systems in northern Victoria. *Victorian Department of Environment and Conservation*. 345p.

PITTOCK, A.B. (ed), 2003. Climate Change: An Australian Guide to the Science and Potential Impacts. *Australian Greenhouse Office, Canberra*, 239 p.

IPCC 2001. *Climate Change 2001 Synthesis Report*. Contributions of Working Groups I, II and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change. World Meteorological Organisation and United Nations Environment Programme. Cambridge University Press, 397 p.

NATIONAL LAND AND WATER RESOURCES AUDIT (2000). Australian Dryland Salinity Assessment, 2000. **Technical Report**. *National Land and Water Resources Audit.*

REID M. 2004. What is the groundwater record telling us in northern Victoria ? *Salinity Solutions Conference, Bendigo, 2004* **Abstracts,** p. 38.

SPIESS B. & WOODGATE P. 2004. National Review of Salinity Mapping Methodologies. *Report to the Academy of Sciences*.

TIBBY J. & REID M.A. 2004. A model for inferring past conductivity in low salinity waters derived from Murray River (Australia) diatom plankton. *Marine and Freshwater Research* **55,** 597-607.

WILLIAMS M.A.J. 2001. Morphoclimatic maps at 18 ka, 9 ka & 0 ka. *In:* J.J.Veevers. *Atlas of Billion-year earth history of Australia and neighbours in Gondwanaland* . GEMOC Press, Sydney, pp. 45-48.