SALINITY: WHERE ARE WE NOW?

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ABSTRACT

Salinity is probably one of the most, if not *the* most, critical environmental issues that Australia has ever faced. Whilst the problem was identified for the first time in 1924 (W.E. Woods) and has been studied since then, it is only in the last ten years that the gravity of the issue has become fully realised. In December 1998, the issue of salinity was put before the Federal Government by the Prime Minister's Science, Engineering and Innovation Council (PMSEIC, 1999), acknowledging the complexity and seriousness of the problem and registering the need for government action. The National Land and Water Resources Audit (NLWRA) in 2000 painted a very grim picture of the current situation and future prospects. All of this did not look good but action was needed, otherwise the situation would degrade even further, with tremendous consequences for the environment and rural and urban communities. The National Action Plan for Salinity and Water Quality (NAP, 2000), drawn up by the Council of Australian Governments, provides a basis for a national approach to salinity and water quality solutions by engaging the Commonwealth, States, Territories and communities.

The NAP triggered a flurry of activities, instigating the war on salt. From an outsiders' vantage point, this frantic activity might appear somewhat chaotic, and at times, it probably is (the take-home message from farmers at the Salinity Summit in Brisbane last month was: "Put science in, take politics out", 'Canberra Times', August 3, 2002), but the move is definitely in the right direction. Scientists have been put under the spotlight. They informed the community of the seriousness of the problem, but at the same time, answers were also expected, and these are not so readily available. This is an unenviable situation because a diagnosis is often easier to pose than to cure. The current line of research in salinity in both Commonwealth and State agencies is definitely solution-oriented, based on decades of strategic research. In the last two years, a stream of extremely valuable concepts and predictive tools for salinity assessment and management have been developed and are already being applied in several major projects that have strong linkages to policy development. The aim of the game is to determine what can be done where, in order to prioritise work and funding, and science is on its way to provide the needed hierarchy of answers. On the scientific front, some significant advances in the battle against salinity have been made in the last two years. Importantly, it is recognised that biophysical evaluations and modelling scenarios have to be coupled with socio-economic research, as ultimately the community will decide upon what can and can't be done.

Initially, fighting the salinity battle appeared daunting and the prospects rather poor, and it is recognised that it is an uphill battle. There will probably be more losers than winners, but coming to terms with the facts is an essential first step. The current dynamics in the Salinity epic suggest that attainment of the latter is imperative. Provided the focus, enthusiasm and momentum are maintained, broad-scale positive outcomes can be expected.

THE SITUATION

NLWRA

We have known about the problem of salinity since the 1920s but only recently has there been a concerted effort to document the magnitude and seriousness of the problem nationwide. We are only just beginning to comprehend the economic, social and environmental impact engendered by the broad extent of salinisation of our lands and streams. In December 1998 the issue of salinity was put before the Federal Government by the Prime Minister's Science, Engineering and Innovation Council (PMSEIC, 1999), acknowledging the complexity and seriousness of the problem and registering the need for government action. In 2000 the National Land and Water Resources Audit (NLWRA) quantified the extent of salinity as part of an appraisal of Australia's current natural resources. Based on the best available data from the States and Territories, the Audit records approximately 5.7 million hectares (ha) of land having a high salinity hazard. A potential area of 17 million ha will be at risk by the year 2050.

The impact of salinity on agricultural land (5 million ha nationwide, predicted to approach 14 million ha by 2050). In addition, substantial areas of remnant native forests, streams and lakes, rural and urban infrastructure, and wetland ecosystems are also being degraded by high saline watertables. Up to a fourfold expansion of this damage and degradation is projected for the next 50 years.

Western Australia has, by far, the largest area at risk of salinity, both now (4 million ha) and predicted over the next 50 years (9 million ha). The severity of the problem in WA is, in part, a legacy of a protracted history of primary salinity in this flat, ancient and deeply weathered landscape. In the last century or so this vulnerable terrain has become intensely overprinted with secondary salinity – or *induced* salinity – in response to agricultural development. In WA now, 80% of the remaining native vegetation on farms and 50% on public lands is at risk.

The situation is particularly acute in the south-western region of WA, where 16% of the land is currently in danger of developing salinity from shallow watertables; this area may spread to 33% by 2050 (NLWRA). The south-west is one of the great biodiversity centers of the world, rich in distinctive plants and animals. Many of these unique habitats are now geographically restricted and have become isolated from interconnecting corridors. Some of these refugia are surrounded by severely salinised areas, including salt lake chains that infill ancient palaeochannel networks. Contemporary riverbeds and banks are commonly eroded, and over half of WA's usable water is already saline, brackish or marginal.

Groundwater Flow Systems and Case Studies

An important component of the NLWRA Dryland Salinity Theme addressed the need to understand salinity across the whole Australian landscape and to provide a coherent framework in which this understanding could be refined, spatially and temporally. The Groundwater Flow Systems (GFS) classification (Coram *et al.*, 2000) is a national-scale framework that is now gaining wide acceptance. The GFS scheme stemmed from the development of a National Classification of Catchments (NCC) which was funded by Land and Water Australia (LWA) and the Rural Industries Research and Development Corporation, RIRDC (Coram, 1998). The NCC is a compendium of hydrogeological conceptual models that describe the physical characteristics of groundwater-related salinisation scenarios across Australia. The subsequently-developed GFS framework is based on geology, geomorphology and elevation, and provides an overview of groundwater provinces in which the processes driving salinity can be characterised.

Fundamental to the hydrologic behaviour of a system are parameters such as length of groundwater flow paths, aquifer permeability and hydraulic gradients for groundwater flow. The understanding of how groundwater systems behave in response to changing recharge dynamics and how excess water from perturbed recharge regimes is distributed is based on detailed catchment case studies representing different groundwater flow systems. Case studies were implemented by the NLWRA to evaluate both the GFS and the application of catchment water balance modelling. The salinity case studies involved collaborative teams that included State and CSIRO scientists. Selected catchments represented diverse flow system types distributed across Australia: Lake Warden, Esperance, WA (Short *et al.*, 2000); Wanilla, SA (Stauffacher *et al.*, 2000); Kamarooka, Victoria (Hekmeijer *et al.*, 2001); and Upper Billabong, NSW (Baker *et al.*, 2001).

The GFS, combined with our understanding of how different systems behave that we derived from the case studies, now serves as a basis for more detailed hydrogeologic classification of provinces. Importantly, this recent work identifies systems where particular management activities are expected to lead to similar responses and provides a framework not only for progressively more refined levels of understanding but also for on-ground action. Current solution-oriented research developments revolving around the GFS approach to salinity management are outlined further below.

THE INITIATIVES

Commonwealth NAP

The National Action Plan for Salinity and Water Quality (NAP, 2000), drawn up by the Council of Australian Governments, provides a basis for a national approach to salinity and water quality solutions by engaging the Commonwealth, States, Territories and communities. It represents an initial step in identifying high priority, immediate actions to deal with salinity, particularly dryland salinity, in key regions across Australia. The NAP is aimed at helping regional communities to prevent, stabilize and reverse trends in dryland salinity where they affect the sustainability of production, biological diversity and/or infrastructure.

The NAP is a broad-scale, comprehensive response to the threat of salinity. The focus is on 21 priority regions across Australia – five of these in WA. The plan fosters the development of community-based integrated plans to tackle salinity in the respective regions. These regional plans will vary substantially from catchment to catchment so that the particular needs of each area can be met and realistic targets can be set.

MDBC

The Murray-Darling Basin Commission (MDBC) is an autonomous organisation representing the governments of SA, Victoria, NSW and Queensland on matters relating to the use of water and land in the Murray-Darling Basin. The Commission advises its Ministerial Council (MDBMC) in relation to the planning, development and management of the Basin's natural resources. In 1985 the MDBMC assigned a high priority to the coordinated management of salinity and waterlogging problems in the Basin. The first MDB Salinity and Drainage Strategy was adopted in 1988 (MDBC, 1987; 1988). A subsequent Strategy noted that, in the 10 years to 1999, the initial Strategy had achieved a net reduction in River Murray salinity (MDBMC, 1999a).

The Salinity Audit for the Murray-Darling Basin provides trends, river valley by river valley, for salt mobilisation in the landscape and its expression in the Basin's rivers and the land surface (MDBMC, 1999b). Whilst salinity is most conspicuous in the form of dryland salinisation with visible degradation of soils and loss of biodiversity, greater economic impacts are likely to be associated with increasing river salinity and the effects this is having on irrigation, urban water supplies and aquatic biodiversity. The Basin Audit provides predictions for increases in salinity if there are no new preventative management interventions. For example, it predicts that the average salinity of the lower River Murray will exceed the 800 EC threshold for desirable drinking water quality in the decades ahead. The Audit provided the basis for framing of the Basin Salinity Management Strategy for 2001-2015 (MDBMC, 2001). This Strategy provides a 15-year Basin-wide framework for implementing the NAP, State Salinity Strategies (SA, Victoria, SW and Queensland), and regional salinity or catchment management plans. A key feature of this current Strategy is the adoption of salinity targets for each tributary valley and a Basin target for the Lower Murray to maintain the salinity at less than EC 800 µS/cm (*i.e.*, drinking water quality) for 95% of the time. The targets are a way of measuring progress of actions across the Basin and a basis for accountability for the partner Governments.

NDSP
The National Dryland Salinity Program (NDSP), initiated by Land and Water Australia (LWA), was established in 1993 to facilitate cooperative research across disciplines, organisational boundaries and State borders to address the management of dryland salinity. Research is directed towards investigating the causes of and solutions to dryland salinity. The focus of the second phase of the program (1998-2003) is on knowledge gaps in our understanding of the causes and impacts of dryland salinity and on investigating socio-economic issues associated with management of saline regions.

State Salinity Strategies
State Salinity Strategies for the control and management of salinity are now in place in most States. Typically, the State Strategies: outline the key issues pertaining to natural resource management of respective regions; delineate the actions being undertaken and planned towards desired outcomes and solutions; set priorities, targets and regulations for catchments; and highlight regional imperatives in terms of needed scientific research.

For example, the WA State Salinity Strategy was released by the State Salinity Council in 2000. This Strategy is based on a clear identification of the major impacts of salinity in WA in terms of: the magnitude of the hydrologic imbalance; biophysical impacts (water resources, biodiversity and increased flood risk); economic impacts (agricultural productivity, infrastructure); and social impacts (families, communities, recreation and tourism). Three goals are at the core of the Strategy: to manage recharge; to manage discharge; and to ensure a partnership approach between the State Salinity Council, Catchment Management Authorities, and Communities so that all major concerns – agricultural productivity, biodiversity, water quality, infrastructure – are represented (State Salinity Council, 2000a). With the WA Salinity Strategy as a framework, Salinity Actions (State Salinity Council, 2000b) have been outlined to manage salinity, for community action, and for monitoring and evaluation of strategies and actions. These two foundation documents are supported by a Guide for Land Managers (State Salinity Council, 2000c) that provides reference points for adaptive agricultural practices, for local groundwater management, and for productive use of saline land and water.

SOLUTION ORIENTED RESEARCH

The take-home message from farmers at the Salinity Summit in Brisbane last month was: "Put science in, take politics out" ('Canberra Times', August 3, 2002). This stance seems to be widely echoed by stakeholders elsewhere across the continent. Rural, regional and urban communities realize that, without more research, farmers, catchment managers and water resource suppliers cannot make informed decisions and change their practices appropriately to avert the salinity problem.

We are at the stage in tackling the science of salinity where sound research must be directed towards realistic broad-scale solutions. We have moved beyond reductionist thinking, aware that complex systems cannot be understood in terms of their simple components, but only through integrated research and foresight. Solution packages must be developed for entire catchments and regions, not for scattered postage-stamp patches across the continent.

Catchment Characterisation for Salinity Management
No blanket recipes or 'silver bullets' are appropriate for dealing with salinity in this complex Australian landscape. The National Classification of Catchments (Coram, 1998) and Groundwater Flow Systems Classification (Coram, *et al.*, 2000) provide a basis for our current solution-oriented research. This foundation work brings together the best available groundwater information relevant to salinity processes and salinity management. Areas that behave in a similar manner have been defined spatially for the whole of Australia. Maps have been generated at different scales relevant to State and regional managers such that the distribution of analogous catchments are now identified. Current Catchment Characterisation research,

spearheaded by CSIRO in collaboration with State scientists, and under the auspices of the MDBC, is aimed at providing a link between the spatial classification system and development of predictive capabilities to prioritise regional targets for management (Walker *et al.*, 2002). The project draws upon the results of CSIRO's research on stream salinity trends and catchment salt balances (*e.g.*, Jolly *et al.*, 2001; Walker, 2001) and complementary research on recharge and discharge processes.

This Catchment Characterisation for Salinity Management research project comprises three-stages. The first stage has recently been completed, and involved the investigation of physical processes in well-studied catchments to provide dryland salinity 'risk factors' for each GFS type. The second stage involves applying this knowledge to other catchments of similar type for which there is little data. Thirdly, salinity management guidelines can subsequently be generated for each GFS type so that the most appropriate land uses can be put into effect in the best locations to redress salinity.

Management options include afforestation, agroforestry, perennial pasture systems and engineering schemes to reduce recharge and lower watertables, and utilisation of irredeemable saline land and waters for commercial endeavours. Our Catchment Characterisation work breaks the landscape up into components best suited to the different management options, based on our current knowledge. The magnitude and timing of salinity impacts are related to groundwater characteristics, and the 'landscape components' are essentially different parts of the hydrogeologic system. The variation in the way that groundwater processes operate needs to be part of the characterisation of catchments. To date, these variable aspects of catchment behaviour have been assessed and modelled for five GFS within the Murray-Darling Basin: Axe Creek, Victoria (Hekmeijer and Dawes, 2002a) and South Loddon Plains, Victoria (Hekmeijer and Dawes, 2002b); Kyeamba Creek, NSW (Cresswell *et al.*, 2002) and Liverpool Plains, NSW (Stauffacher *et al.*, 2001); and Brymaroo, Queensland (Smitt *et al.*, 2002). In addition, the case studies carried out for the GFS development, cited above, are included in the second stage of the Catchment Characterisation project to incorporate distinctive catchments in WA and SA. The emphasis for the final year of this research is now on the transferability of these models to widespread catchments of each GFS type to predict salinisation risk and provide appropriate management options in unstudied catchments. Ultimately, the effectiveness of salt-mitigation schemes in different parts of the landscape will be able to be assessed to augment future planning for emerging areas at risk.

Biophysical Capacity to Change

The Biophysical Capacity to Change (BCC) model is currently being implemented at CSIRO within the Cooperative Research Centre for Catchment Hydrology (CRCCH) as part of the Catchment Characterisation project. The BCC model links changes in land use to changes in streamflow and salt load. The aim is to facilitate prioritisation of areas for tree planting within larger catchments by enabling catchment managers to conduct rapid assessments of the gross change in salt and water balances in response to land use changes, particularly reforestation, prior to actually implementing the on ground-works.

The BCC model utilises a digital elevation model (DEM) of the catchment, the regional GFS map, interpolated average annual rainfall, tree cover or land use datasets, and groundwater characteristics (hydraulic conductivity, aquifer dimensions, watertable levels and gradients, and groundwater salinity). The latter datasets, the hydrogeologic parameters, enable the time lag in the response of a system to induced hydrologic change to be accommodated. Thus, the BCC model uses datasets that are often already available, and is not reliant on ever-more refined (and increasingly expensive) information about the *status quo* of a given catchment. The emphasis, instead, is on the capacity of the catchment to respond to land use change and on the timeframe in which this change might be expected to occur. The model is designed to be a highly portable and adaptable package. Outputs can be used as a "sieve" to help rank catchments according to their capacity to respond to land use change. This work will ultimately integrate with current

CSIRO and CRCCH Catchment Characterisation research on the effects of land use changes on catchment water yield and salt load (*e.g.*, Zhang *et al.*, 2001; Stirzaker *et al.*, 2002).

Airborne Geophysics

The first trial of airborne geophysical techniques in salinity investigations was carried out in 1997-1998 as the National Airborne Geophysics Project (NAGP) under the NDSP, with financial support from Federal and State governments. The airborne investigations utilised magnetics, gamma-ray spectrometry (radiometrics) and electromagnetic (AEM) techniques in five catchments in WA, Queensland, NSW and Victoria. The DIGHEM helicopter-mounted and SALTMAP fixed-wing AEM systems were utilised for the surveys. The cost of acquisition, processing, analysis and validation of the airborne geophysics data was $7-11 per hectare (George *et al.*, 1998). Magnetics and gamma-ray spectrometry already have established reputations as being valuable in geoscientific investigations, including hydrogeology, whereas the application of electromagnetics (both ground EM and AEM) has a more variable potential. The NAGP concluded that the AEM data provided useful information about salt stores and regolith features in the study areas. Notwithstanding, a cautionary note was also issued about the need for skilled interpreters to guide the analyses and to ensure that sound decisions were made on the basis of the datasets (George *et al.*, 1998). At the completion of the NAGP, George *et al.* (1999) concluded that 12 biophysical datasets – including the three geophysical datasets – were required for effective application of geophysics for salinity management.

The potential for airborne geophysics techniques to provide new insights into the subsurface geology and regolith and into the distribution of salt and saline groundwater has gained wider attention since the NAGP in 1998. Recent years have also brought rapid development in the AEM technology in particular. Conductivity maps (rather than "salt maps" *per se*) can be generated from AEM measurements for depths of more than 100 m below the ground surface. Difficulties experienced in the NAGP with the capability of the precursor AEM systems to quantify electrical conductivity in the upper 5-10 metres are being addressed with the new TEMPEST AEM system and with developments in data processing techniques. It needs to be emphasized, however, that the collected AEM data is extremely complex and requires ground-truthing and validation to be of use. Clearly, knowledge of the geology, the groundwater system, the regolith, salinities of groundwaters and soils, the biophysical make-up of catchments, and the magnitude of temporal fluxes in physical processes is required before remotely-sensed geophysical measurements can be incorporated into land use decision-making for salinity management.

The AEM technology is still evolving and is still relatively expensive. The method can provide unique information about the distribution of salt and saline groundwater when used in conjunction with drillhole data and actual salinity measurements of groundwaters and regolith materials across the survey area. A new phase of trials is now underway in two Murray-Darling Basin – CSIRO *Heartlands* (see below) catchments: Upper Billabong Creek, NSW, and Honeysuckle Creek, Victoria. The application of these airborne geophysics surveys, utilising the high resolution TEMPEST AEM system, will be assessed in these areas where the salinity hazard is relatively severe and where local communities are committed to immediate implementation of on-ground works to offset further degradation of their lands and waterways. Additional airborne geophysics surveys are also currently underway in five catchments in SA in strategically important areas of the NAP Priority Regions.

Heartlands and Healthy Country initiatives

The *Heartlands* initiative is a >5-year program combining research and on-ground works towards sustainable land use in the Murray-Darling Basin. *Heartlands* is part of the CSIRO *Healthy Country ('Revitalising our Landscapes')* Flagship Program, one of seven overarching, multi-divisional programs directed at issues of National importance. The Flagship Programs are underpinned by development of long-term science/technology/engineering capabilities to respond to issues in which Australia must take a global lead.

The *Heartlands* project is run as a consortium led by CSIRO and the MDBC, with the participation of State Natural Resource Management agencies, Catchment Management Boards, Landcare groups and landholders. Research components being led by CSIRO involve the Divisions of Land & Water, Forestry & Forestry Products, and Sustainable Ecosystems. The research and on-ground works are directed towards the development of new systems of land use that are more resource efficient than current practices, and that provide both environmental and economic benefits. Particular focus is given to reversing the trend of environmental degradation caused by dryland salinity through targeted revegetation and modified agricultural systems. The latter incorporates expertise on the establishment of farm forestry in low rainfall zones on cleared agricultural land, and planting of appropriate species, for both commercial profit and landscape rehabilitation.

The groundwater processes component of the *Heartlands* project is aimed at determining spatially explicit recharge targets to ameliorate salinisation. In focus catchments, this work is presently in the process of integrating conventional hydrogeological techniques with high-resolution airborne geophysics datasets to map the subsurface and define the groundwater systems and key salinity processes. Knowledge transfer from our detailed understanding of how these groundwater systems behave will utilise the GFS framework along with the methodologies and modelling capabilities of the Catchment Characterisation project (outlined above).

In collaboration with Landcare personnel, *Heartlands* aims to motivate and enable communities to develop skills and plans to deal with deterioration of their lands and waterways. The objective is to build the capacity of local communities to acknowledge and deal with the problem as well as assisting with planning and implementation of integrated, catchment-level solutions, rather than piecemeal application of remedies.

A major component of the *Heartlands* project – and hence the commitment of several years – involves assessment of the effectiveness of the developed landscape design strategies through monitoring of catchment functioning. Other components revolve around the transfer of knowledge beyond the focus catchments and beyond the Murray-Darling Basin.

Coupling Economics and Biophysical work

Socio-economic research and development in the CSIRO Division of Land & Water is conducted by the Policy and Economic Research Unit (PERU). The focus is on economic and policy issues relating to natural resource management, founded on the notion that an interdisciplinary approach is essential to understanding the driving factors behind sound natural resource management. In the first instance, the priority is to understand the causes of natural resource degradation, and then develop potential solutions which combine policy, economic management and sound science. For example, it is important to know how much salinity is costing Australia, and how much it will cost to combat. The benefits of remedial works need to be assessed and the limited available funds need to be channeled to highest priority areas.

PERU recently released a series of new datasets and maps (1 km^2 resolution grid) to integrate natural resource and agricultural information as part of the NLWRA. An accompanying final report documents the value of returns to land and water and costs of degradation nationwide (Hajkowicz and Young, 2002). The report relates to the economic aspects of natural resource management in Australia, focusing on resources used to support agriculture and resources impacted by agriculture.

CRC for Plant-based Management of Dryland Salinity

The Cooperative Research Center (CRC) for Plant-based Management of Dryland Salinity examines the use of perennial plants to manage saline land. The aim is to develop new land use systems that mimic the processes of natural ecosystems. Research projects include: examination of the functioning of native ecosystems in recharge areas, with an emphasis on water use, and investigation of the mechanisms by which species tolerate the combined stresses of salinity and waterlogging. The objective is to develop new perennial-based land use systems, utilising a range of woody and herbaceous plants that can function as ‘biological water pumps’ and provide profitable and environmentally viable farming systems.

SO FAR, AND WHERE TO GO…?

The NAP acted as a nationwide wake-up call in the fight against salinity and the resulting State Salinity management Strategies provide a framework to address the issue. The scientific community received the message that solutions are needed and the translation from strategic to applied research in the salinity area is well on its way. Communities are more aware then ever of the problem, and motivation is strong, but we have to keep the momentum going. Ultimately, to maintain focus and enthusiasm, the key word is “expectation management”. As with all environmental issues, salinity is a result of a complex maze of interlinked biophysical processes. The spatial and temporal scales of these processes are extremely diverse, and, more often than not, are difficult to comprehend. Although science has made tremendous inroads in process understanding, more time and resources will be needed to enhance our understanding and management capacity. Also, whilst from a biophysical point of view there might be very effective solutions, these will commonly not be matched by the socio-economic realities of rural Australia. This is why the future in the salinity battle has to be paved with realism and the messages and actions need to be adapted as societal values change with time.

The bottom line is that we will have to learn to live with salt. In some cases, there will be biological solutions like reafforestation, perennials, native vegetation, etc. In other cases, engineering solutions such as groundwater pumping, drainage, etc. will provide relief, but above and for all, a cultural shift is needed that will change the collective perception of salinity from a nuisance to a resource. That will open the gate for new research directions in both biophysical and socio-economic areas and, in the future, provide the currently elusive *solution*.

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