Managing Dryland Salinity in Australia – 2006 Update

A Review of Advances in Salinity Research, Management, Capacity and Knowledge 2004-2006

A supplement to the National Dryland Salinity Program (NDSP) CD-ROM
Managing Dryland Salinity in Australia – Revised Edition

October 2006

National DRYLAND SALINITY Program
Know-how to tackle salinity

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Publication data: Munday B., 2006, *Managing Dryland Salinity in Australia – 2006 Update*; Land & Water Australia, Canberra.

ISBN: 1 921253 24 10

ISBN Electronic: 1 921253 25 8

Product code: PR061217

Designed and Typeset by: Design Scene

October 2006

Contents

Australia's National Dryland Salinity Program

Australia's National Dryland Salinity Program (NDSP) ran over two, five-year phases, commissioning, coordinating and managing 50 major research projects with an investment value of almost $25 million. In that time, it harnessed the skills and experience of nearly 200 researchers, technical assistants, consultants and policy advisors.

In 2004 the NDSP and its partners invested in a significant effort to synthesise salinity management information into a coherent and accessible form for the first time.

This comprehensive body of knowledge promotes the latest salinity management systems, data, technology and knowledge drawn from a decade of research and development through a focussed campaign of communication, knowledge transfer and building and supporting networks.

Key products include:

- *Dryland Salinity - On-Farm Decisions and Catchment Outcomes* – a Guide for Leading Producers and Advisors
- *Dryland Salinity and Catchment Management* - a Resource Directory and Action Manual for Catchment Managers
- *Breaking Ground - Key Findings from 10 Years of Australia's National Dryland Salinity Program*
- An interactive CD-ROM that complements the three manuals and contains nearly 200 research reports, the NDSP *TechNotes* fact sheets and numerous links to on-line resources and organisations and groups skilled in salinity management. These links plus a 'search' facility enable users to readily find the level of detail required. Maps, posters and a glossary of terms also feature on the CD-ROM.

The products complement the extensive salinity management and communication networks established by the program over the past 10 years, and are supported by a comprehensive website www.ndsp.gov.au.

Overview of Update

In the two years since the NDSP concluded, the issue of dryland salinity, its extent, risk and management options continues to hold its own in the headlines.

Dryland salinity remains a complex environmental issue. However, since the NDSP, significant investment in salinity research and development has been continued by many NDSP partners and other organisations, particularly in the areas of productive use of saline lands, engineering options, salinity mapping technology and understanding the place of salinity mitigation and management in the whole-of-catchment context.

Land & Water Australia, a founding partner in the NDSP, commissioned this updated version of the highly successful *Managing Dryland Salinity in Australia* resource kit published in 2004 to capture recent advances in salinity research.

Following extensive consultation with experts in salinity management, and significant desktop reviews, the 2006 Update adds more than 100 new research papers, journal articles and other resources of importance for management, research and policy. It contains new information about the extent of salinity on a state-by-state basis, the causes, the impacts and recommendations for the 'next steps' in relation to application of salinity research and development for management and capacity building.

THE EXTENT

The House of Representatives Standing Committee on Science and Innovation in 2004 expressed concern about the paucity of basic information on the current extent and trends with respect to salinity. The most often quoted data describing the extent of salinity in Australia is the *Australian Dryland Salinity Assessment 2000* from the National Land and Water Resources Audit (NLWRA). This was the first attempt to systematically integrate consistent data from across the nation and derive a truly national assessment of the size on the problem.

The NLRWA used the best science available at the time and represented a real breakthrough in raising awareness of the extent of salinity, the salinity hazard, and the possible risks. However science moves on, and this information, which underpinned much of the initial planning for salinity management, is being reviewed and updated using new and better modelling based on the latest data and longer trends.

It is now generally agreed that the total area at risk from salinity in Australia is probably less than that estimated by the Audit. A survey of farmers[1] also suggested that the area affected was considerably less than that estimated by the NLWRA.

The discrepancy can be partly explained by the different meanings attached to 'affected by salinity' and by the different methods of assessment. It also stems from the different scales at which the assessment is undertaken. Farmers are likely to assess the area affected at the paddock scale, whereas the NLWRA assessment was at a much coarser scale. For example, an Audit estimate of 100,000 hectares of salt-affected land in a region means that salinity is an issue across 100,000 ha, not that every one of those hectares is salt-affected.

Updating the NLWRA hazard assessment will also improve predictions in the likely trend in salinity, expressed in terms of the area at *risk*. There is evidence to suggest that the area at risk of salinity has also previously been over-estimated, particularly in the Murray-Darling Basin where water table trends were extrapolated mainly from data collected during the period from the early 1980s until the late 1990s. A report[2] evaluating salinity outcomes of regional investment notes that, for many sites, bore hydrographs followed an upward trend to historical highs during a period of above average rainfall but fell during the drier past decade. It is likely that the NLWRA, which used data from a 'wet' period, therefore presented a worse case scenario. Salinity is most likely a cyclical problem at a regional level, with wet periods in climate exacerbating the problem and dry spells causing a retraction. In some areas this trend has been further influenced by increased groundwater pumping following introduction of the 'Cap' on surface water diversions by the Murray-Darling Basin Commission.

While the threat from an expansion of salinity has recently eased, significant assets in regional and metropolitan areas are affected by salinity and a sequence of relatively wet years could see the problem of expansion return.

Discussion around the Audit data[3] has also been confused by media and other comment that fails to differentiate between salinity risk and salinity hazard.

A review of salinity mapping methods by Spies and Woodgate[4] has clarified the distinction by referring to the Australian and New Zealand Risk Management Standard: "A **hazard** is anything that can potentially cause harm to an asset. Salt is a hazard as it has the potential to cause harm to an asset if mobilised by water and transported to the asset. In the context of salinity we can define the level of **risk** as the degree of severity of a hazard as it adversely affects an asset (e.g. agricultural productivity) multiplied by the probability of occurrence of that hazard at a specific time in the future."

The significance of this definition is that it takes account of the vulnerability of the asset. For example, irrigated cropping or urban development can present a high risk for salinity, even when the hazard is quite low. On the other hand, the impact on a saltland pasture would be much less and the risk proportionately less. Spies and Woodgate note that "... ubiquitous maps of future risk are open to misinterpretation and may be misleading".

Monitoring and Mapping

The *National Dryland Salinity Data Infrastructure Project*[5, 6, 7] has refined the 'indicators' for salinity identified under the *National Monitoring and Evaluation Framework*. These indicators are:

- Depth to groundwater
- Groundwater electrical conductivity (EC)
- Location, size and intensity of salt-affected areas.

A discussion paper presented for endorsement by the NLWRA Advisory Council proposes a methodology for ensuring that the most appropriate monitoring locations, methods and sampling intervals will be selected for monitoring the potential for land salinity to develop, including areas of irrigation-induced salinity.

Following trials in four states, a final report will make recommendations on further trials and usefulness of the salinity indicators at regional and national levels.

A national review[4] of 31 salinity mapping techniques in the Australian context concluded that an integrated geoscience (systems) methodology, employing explicit 3-D mapping of landscape, salinity and groundwater elements, provides particularly valuable insights into salinity processes and salt store distribution, and is becoming increasingly important in salinity risk predictions. Integrated geoscience products have recently been successfully and cost effectively used to target salinity management interventions and revise salinity management plans.

Salt and groundwater mapping using airborne electromagnetic (AEM) surveys provide an underground picture of both where the salt is and the most likely flow paths that the groundwater (and salt) will move along. By combining the airborne survey data with an on-ground calibration drilling program, a three-dimensional map is built that reveals not only salt stores, but also the pathways that are most likely to deliver water and salt to streams[8].

Projects[9] in South Australia and Queensland have been undertaken to assess the effectiveness of airborne geophysics and integrated geoscience approaches for salinity mapping and management in a range of landscape, climate zone and land use settings.

Previous salinity investigations involving airborne geophysics have been effective at knowledge generation, but often ineffective in delivering outcomes for salinity management. This is partly because a better understanding of the sub-surface is only a first step in delivering outcomes, and because geophysics is only adding value to some of the knowledge already acquired[10].

These projects involved a staged and targeted approach, working within natural resource management policy frameworks, in close collaboration with local stakeholders. A common theme linking the projects was that they were not restricted to 'mapping salt' but were more concerned with gaining an understanding of the groundwater and salinity systems that prescribe water and salinity management practices.

The States

WESTERN AUSTRALIA

Hydrologists monitor a network of over 1000 strategically-placed bores throughout the WA agricultural areas[11]. Salinity risk, as indicated in part by water table levels, is declining in the eastern parts of the Northern Agricultural Region, but is either stable, or continues to climb, throughout most of the remainder of the agricultural areas, according to bore monitoring evidence.

In the Northern Agricultural Region, falling groundwater levels in monitoring bores have been found in the north-eastern Yilgarn since 2000, and considered to be linked to drier seasons. This reverses the trend noted from 1990 to 1999. In one area (Northampton Block), water table levels have declined to the point that an increased salinity risk is no longer likely in the short-term. By contrast, rising trends continue in the Perth basin, away from areas of groundwater extraction.

Monitoring of the Central Agricultural Region (1975-2000) indicates that up to 2000, bores in 22 catchments monitored showed either rising or stable trends. However since 2000, half of the 300 monitoring bores have stabilised, with about 30 per cent rising and 20 per cent falling slightly.

All bores with water tables deeper than 10 metres rose throughout a 25-year period, with most non-saline valleys retaining a significant risk. Groundwater in eastern catchments cleared since 1950 is still rising rapidly, but equilibrium has been reached in some older, western catchments.

In the South West, trends differ depending on location, with most monitoring bores rising by 0.2 to 0.4 m/yr in tributary valleys and uplands. Maximum rates of rise are rainfall-dependent and therefore tend to be lower in the east.

On the South Coast, the effects are still building from comparatively recent clearing, and sandplain areas are filling slowly. Once groundwater levels approach the surface, they then respond to rainfall and season.

In 2000, the NLWRA, using regional-scale water table levels, estimated that 3.5 million hectares or 18 per cent of WA agricultural areas were at risk of salinity, likely to rise to 4.2 Mha (21 per cent) by 2020 and 6.4 Mha (33 per cent) by 2050. This method aggregated large areas of land with rising groundwater, but did not specify risk at the catchment scale.

Estimates from Land Monitor[12] (1988-1998), based on satellite images and backed up by ground-truthing, have provided more accurate information. While not available at the time of publication of the NLWRA, Land Monitor estimates indicate that 1.05 Mha of both private and public land had become severely salt-affected by 1998, with 2.8 to 4.5 Mha identified as having a defined hazard. Actual areas at risk are likely to be lower, particularly if the climate continues to become drier. While Land Monitor is the most accurate overall measure, it under-estimates salinity in wetter areas, and over-estimates in some drier northern areas[13].

SOUTH AUSTRALIA

The NLWRA salinity report for SA was based on actual areas of salt-affected land determined from air photo interpretation and groundwater modelling, whereas other states reported risks of salinity based on depth to groundwater and water table trends. Interpretation of air photos enables land to be identified that is borderline for cropping or more severely affected by salinity. However, it is not as effective in identifying land that is affected to a lesser extent without detailed ground truthing. Consequently the NLWRA provided a conservative estimate, as it did not include those areas with a low level of salinity (e.g. where crop yields are reduced).

Based on refined databases[14], SA's state-wide estimate of the area affected by salinity is essentially unchanged from the NLWRA figures.

Groundwater monitoring data from different regions in SA show that in most cases water tables rose significantly in the exceptionally wet year of 1992. In the relatively dry period that has followed, some water tables have fallen, some have remained static, while some continue to rise. The influence of rainfall is apparent in all cases, but all situations need to be assessed in the context of the dominant groundwater flow system (local, intermediate or regional), the interval since widespread clearance of native vegetation and any changed land management practices that might affect recharge.

Soil salinity mapping for selected catchments shows that the areas displaying high levels of salinity, averaged over the upper six metres, have generally declined since baseline mapping in 1993.

The largest source of error in SA's salinity estimates still revolves around the difficulty in differentiating between naturally saline land and that affected by secondary salinity. Added to this is the difficulty in defining 'saline land' when there is such a range of saline conditions - from bare scald to land which is too saline for only some crops. Nonetheless, dryland salinity affects less than 5 per cent of agricultural land in SA, and even given the worst case scenario this is unlikely to change significantly over the next 50 years.

Approximately 75 per cent of the State's salt-affected land is in the Upper South East (USE) where there is extensive bore and rainfall data. The former show that the rising trend in almost all bores throughout the 1980s has reverted to a falling trend over the past decade, which happens to follow a similar pattern to the rainfall trends.

Since 1993 winter rainfall in the USE has been below average, and with talk of climate change there is concern that this might be the start of long term or even permanent lower rainfall. But rainfall data shows that the current dry period is not unlike the dry periods experienced in the early-1900s or from the mid-1930s to the mid-1940s, whereas the mid-1940s through to the mid-1970s was a significantly wetter period. Overall, the mean annual rainfall has scarcely changed in 100 years across the USE[15].

It would be foolish to ignore the possible consequences of climate change, but it is also very difficult to predict the outcomes. While there appears to be a distinct likelihood of temperature increase, there is very little indication of how rainfall will be affected. Many models point towards a likely reduction in annual rainfall, but there is also a strong suggestion of more frequent episodic events - periods of abnormally high rainfall - that tend to result in high levels of recharge.

VICTORIA

The extent of salinity in Victoria is shown on the Department of Sustainability and Environment website[16]. It notes that salinity mapping is on-going, with additional salinity sites known to exist but not yet recorded in the Glenelg, western Wimmera, western North Central and the North East regions.

Recent work identified the current area of land at high risk from developing salinity in the State's six National Action Plan (NAP) regions to be approximately 480,000 ha, compared with 897,000 ha and 2,146,000 ha for the same regions (under best and worst case scenarios, respectively) in the NLWRA *Australian Dryland Salinity Assessment 2000.*

The actual size of salt-affected sites varies from less than one hectare to more than 2000 ha. Half of the sites are smaller than 2 ha while just 3 per cent are larger than 100 ha.

Longer-term trend information of groundwater levels in North Central shows a marked shift compared to the previous two decades[17]. Throughout the 1970s and 1980s, rising groundwater trends were recorded across much of the region, however, since about 1994 this trend has been reversed. Water tables, even under discharge areas, have commonly fallen 2-4 metres or more, many recording their lowest ever levels.

Not only has the past decade been generally dry but there has also been no significant winter rainfall event recorded in North Central since 1996. Therefore, effective rainfall has been considerably reduced since 1996, possibly partly explaining the observed extent and degree of groundwater level decline.

A report evaluating salinity outcomes of regional investment[2] has used data from a representative bore in North Central to illustrate the close correlation between cumulative residual rainfall and water table elevation from 1987 until 2004. The water table was consistently rising until about 1997 and has fallen consistently since then. This pattern is also observed in many long-term groundwater monitoring bores across Victoria, but not all. Despite the relatively dry climate since about 1997, water tables in some dryland areas continue to rise.

NEW SOUTH WALES

In NSW, the findings of the 1999 *Murray-Darling Basin (MDB) Salinity Audit*[18] are being reviewed. The Audit was the basis of the interim end-of-valley targets in the NSW Salinity Strategy, the final end-of-valley targets set in the original Catchment Blueprints for inland valleys in NSW, and the targets notified to the Murray-Darling Basin Commission by NSW.

This 2006 Audit makes use of advances in scientific understanding of salinity, and data and technology improvements since the 1999 Audit was completed. For instance, the 1999 MDB Audit assumed rising water tables would affect the landscape uniformly, without regard to topographic constraints, and that recharge rates would continue to produce such large trends; whereas the 2006 Audit takes topographic and other constraints into account.

The first stage of the 2006 Audit comprises three independent studies examining the status and trends in stream salinity since 1995, groundwater levels and the expression of saline discharge areas. These studies were largely data-driven, analysing system components operating within climatic and topographic controls. Ability to identify "legacy of history" trend signals as evidence of a land use change was limited. This is not to say that land use is not a contributing factor to the trends, but simply that the coarseness of the data and the dominance of climate, topography and aquifer characteristics masks any evidence. Land use change impacts are being addressed in the second stage of the 2006 Audit using the simulation models *2CSalt* and *IQQM* to quantify the likely future behaviour in the system.

Preliminary results from the first stage of the 2006 Audit have been peer reviewed, confirming results in broad terms. However, the peer review also identified that more work is needed before firm conclusions can be drawn about specific catchments. The additional work is expected to be complete in late 2006.

These preliminary results show that some sub-catchments in the MDB have reached a new state of "dynamic equilibrium" having incurred the impacts of land clearing and showing groundwater levels fluctuating about a new average value in response to climate variability (i.e. to spells of wet weather and drought). Other sub-catchments show rising trends over the period since 1969, while the position for some is not yet clear. The overall impact of potentially rising trends is expected to be moderated by catchments in equilibrium and through dilution flows. Many of the "no change" catchments are important sources of fresh dilution flows and those catchments expected to exceed the current observed salinity range have, for the most part, lower relief and rainfall and therefore smaller flow contribution to the Basin as a whole.

The new findings also indicate that response times for the local scale fractured rock groundwater systems in eastern NSW are much shorter than previously thought, implying that well targeted investment will result in on-farm improvement in salinity in much shorter timeframes. As a result of the changes in predicted trends and response times, end-of-valley and within-valley salinity targets in some catchments may need revision.

The 2006 Audit found that salinity continues to impact on infrastructure and the environment, with approximately 62,000 ha of saline discharge sites mapped in both urban and rural environments study area, which comprises the eastern upland dryland catchments of the MDB in NSW. It should be noted that the findings from the 1999 MDB Audit based on the analysis of "current condition (1975 to 1995)" remain valid. This aspect of the earlier Audit was generally robust. For example, the work undertaken to prioritise salinity actions and investment between locations, using tools such as the Land Use Options Simulator, remains soundly based.

QUEENSLAND

Since the NLWRA *Australian Dryland Salinity Assessment 2000* and the release of salinity hazard maps[19] for four Queensland priority catchments in 2002, considerable salinity research has been conducted in Queensland. This research has substantially improved our knowledge of landscapes and their associated salinity processes, groundwater systems, and impacts of land use change.

Projects have been targeted at hydrogeological investigations, groundwater conceptual modelling, deep drainage direct measurement and modelling, quantifying recharge, landscape attributes, groundwater and surface water monitoring, airborne geophysics, and risk assessment frameworks[20, 21, 22, 23, 24, 25]. The focus has largely been on the Queensland Murray-Darling Basin, with some project work in the Great Barrier Reef catchments.

A network of strategically placed bores are monitored throughout Queensland—an additional 200 new monitoring bores have been sunk in the past five years. The drilling program has revealed more extensive areas of saline shallow groundwater (<50 m) in semi-confined and unconfined aquifers in the Border Rivers, Moonie and Balonne catchments than previously thought. Research indicates that salt will not be mobilised in the timeframe that was predicted in the NLWRA – in some areas it may be in the order of 100 years, rather than 50 years.

Deep drainage has been modelled and also directly measured by installing lysimeter networks and through chloride displacement in higher rainfall eastern catchments[26]. Deep drainage has been assessed under irrigation, dryland cropping, grazing and native vegetation. Studies have shown that deep drainage under irrigation is in the order of 10–20 times that under dryland cropping. Research has highlighted considerable lag times between land use change and mobilisation of salt and shallow groundwater.

Projects focusing on improvements to salinity modelling have been conducted with the *2CSalt* model being calibrated in the Hodgson Creek catchment and in several small Border Rivers catchments.

Examination of salt export/import ratios in the Queensland Murray-Darling Basin have shown that the eastern highlands are expressing salt ratios of approximately 2:1, while floodplain areas are net accumulators of salt (ratios less than 0.5:1). High levels of salt are a natural feature of many Queensland landscapes, particularly in floodplain areas. Atmospheric salt inputs due to rain have also been measured.

Salinity audits conducted in the Border Rivers and Moonie catchments during 2005 indicate that salinity risk is increasing in broadacre irrigation areas, as indicated by rising bores and by deep drainage studies. Rivers in these catchments are not showing any increased expression of salt. In these catchments, irrigation salinity is the major threat, while dryland salinity is a much lesser threat.

Additional research and investigations are required, particularly in irrigation areas, to quantify salinity risk both spatially and temporally throughout Queensland.

TASMANIA

The report *Extent and Impact of Dryland Salinity in Tasmania* published in 2002 as part of the NLWRA was based on actual areas of salt-affected private (agricultural and urban) land. The estimates in the report followed initial work[27] using land systems as the basis for assessment.

In late 2003 the 2000 NLWRA Audit figures were updated based on information provided by natural resource management (NRM) and Landcare groups and individuals using visual assessments. As a result of the review, the estimate of the area affected by salinity in Tasmania was revised from 53,500 to 73,800 ha[28]. This equates to approximately 4% of private land. It is likely that the apparent increase reflects a greater awareness of salinity and hence reporting of areas affected that were not reported in 2000.

Funding through the National Action Plan is enabling a salinity groundwater monitoring network in Tasmania's highest priority groundwater flow systems and catchments to inform predictive modelling.

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THE CAUSES

The House of Representatives Standing Committee on Science and Innovation[1] found in 2004 that "a consensus explanation of the salinity problem has developed which explains secondary, or human-induced, salinity as having resulted from changes to the hydrology of the Australian landscape caused by changed land use following European settlement. In this model, land clearing and the use of shallow-rooted annual crops and pastures alters the water balance in catchments, allowing excess water to enter the groundwater, thereby mobilising salt, which then rises to the land surface".

The Standing Committee also found a consensus explanation of the basic salinisation process and sources of salt (considered to be predominantly cyclic salt), despite a dissenting view suggesting that the dominant model has neglected "the role of rock weathering and the complexities of water-rock interaction–hydrogeochemistry" as an important source of salt other than sodium chloride. Two submitters also proposed to the Committee an alternative to the rising groundwater model, based exclusively on increased lateral flows of water through the soil, caused by land use impacts that degrade soil structure. In this model, tree clearing may exacerbate salinity but it is not the cause. Rather, 'rising groundwater levels and adverse salinity are symptoms of land degradation', which may be caused by other land use impacts such as grazing. The vast majority of debate around these issues on the *SALTlist* e-mail listserv managed by the CRC Salinity, the CRC's online forum[2], and in the media, supports the position endorsed by Standing Committee.

The Australian Government[3] response to the Standing Committee noted that the process of accreditation of regional plans and investment strategies is designed to ensure that plans are based on sound science. Within NAP regions, regional plans are specifically required to address issues of salinity. Salinity science is incorporated into regional plans through consultation between regional bodies and key stakeholders including academic/scientific communities, environmental groups, industry and state, territory and Australian government agencies.

Notwithstanding this ongoing debate, catchment characterisation has proved a particularly important tool for regional planning of responses to salinity. However, there remains a significant challenge in applying the groundwater flow system framework at the sub-catchment let alone property scale. This is further hindered by the often complex nature of the recharge-discharge process, the paucity of groundwater data that might shed light on the physical drivers and the scope of the salinity problem, and the scarcity of experts who can analyse the data and run predictive models[4].

Salinity in Australia has often been referred to 'as one of the most intractable environmental issues', but this is not the general perception conveyed by catchment management organisations[4]. This perhaps reflects the strong investment in underpinning science.

In South Australia[5] general salinity risk modelling for a range of catchments and sub-catchments has been based on knowledge of groundwater flow systems, but local risk assessment then focuses on factors such as:

- Current salinity
- Presence of shallow water tables
- Position in the landscape
- Salinity in adjacent mapping units
- The presence of salinity in the wider land system (indicating shallow groundwater in the region)
- Land type (e.g. old saline lakes, low lying coastal land).

Airborne geophysics has been strongly promoted by the Australian Government, particularly as a source of information to help protect water resources from salinity. This has the potential to help identify where and how much salt lies in the landscape, how it is mobilised, the paleochannels that transmit it, and the rate of delivery under feasible management options[6].

Targeting of on-ground action can then be assisted by a combination of airborne geophysics that can map the salt stores and conduits; drilling to calibrate the patterns revealed by airborne surveys and to establish the nature of the aquifers; and modelling water and salt movement for each groundwater flow system.

The question remains as to whether primary production enterprises and land management practices will have a significant effect on salinity compared with the influence of climate. Research reported earlier from *Managing Dryland Salinity in Australia* showed that water table changes in Western Slopes cropping areas of NSW is dominated by climate variability rather than land use[7].

Research conducted in the North Central region in Victoria[8] observed that while data indicates that climate is an important factor in falling water tables over the past decade, it is not the only significant factor. Earlier trial work at Burkes Flat had shown the strong correlation between increased perenniality and lowered water tables. More widely in the region increased perenniality together with increased capture of surface runoff (mainly dams) and groundwater (from bores and springs) have also possibly contributed to drawdown in at least some areas.

The work also noted the marked water table response to episodic events such as very wet years and argued that in lower permeability GFSs there is a relative disconnection of 'discharge' areas from the classic, upgradient 'recharge' areas. In such cases the discharge area "is in effect the master of its own destiny because it essentially concentrates salt (through evapotranspiration) and re-mobilises this salt with relatively minor input from lateral ground water sources." In such cases recharge control by the vegetative treatment of the upper catchment is unlikely to influence discharge in the lower catchment.

Research[9] has examined the relationship between palaeo-salinity and contemporary salinity to determine whether salinity in the WA wheatbelt is likely to expand beyond extant palaeo-salinity markers. The work found that modern salinity appears to be reoccupying landscapes made saline by ancient changes in climate. But whether salinity caused by clearing is likely to affect a greater area of land than that caused by climate remains unanswered, as comparative evidence is yet to be assessed. However, recurring distribution pattern and mode of occurrence of currently active saline seeps suggests greater expansion of saline land in the immediate future.

Researchers have also questioned the 'traditional' approach to salinity abatement focused primarily on the control of recharge in land not at risk of salinity[10]. In the broad valley floors and sedimentary plains of Australia's cropping regions (the areas most at risk of salinity), they state that recharge is mainly a one-dimensional process. Thus, offsite recharge management may have little or no impact on salinity outcomes for the areas at risk. The future of the broad valley floors will be most influenced by the management decisions of landholders in the valley floors. Similar comments have been made for the interdunal planes of South Australia's Upper South-east region[11].

The evolving understanding of these issues highlights the importance of well planned and long term monitoring of land management practices alongside groundwater and salinity impacts.

Chapter 2 - The Causes

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THE IMPACTS

In a submission to the Senate inquiry into the *The extent and economic impact of salinity in Australia* the CRC Salinity commented: "A more rigorous approach to determining the relative allocation of funding to different regions is required, and it should understand the inherent differences in regions across Australia. Some are water supply catchments at risk from river salinity where the catchment management approach is quite appropriate given externalities around the shared, high-value resources at risk. Typically this is the province of catchment management authorities (CMAs). Other regions, typically the drier zones, don't have a connected resource at risk and rational decision-making will be dominated by on-farm benefits and costs, or in the case of conservation areas and rural towns, onsite benefits and costs. In all cases, the funds allocation among regions should follow rigorous assessment of assets at risk, net benefits of actions and confidence in realising those outcomes."[1]

In a similar vein, the Australian National Audit Office found that "...close attention must be paid to building on recent research initiatives and actively encouraging regions to put in place measures that are well targeted and appropriate for the formidable challenges being presented to the NAP regions of Australia."[2]

Impact costs

One of the challenges in determining impact costs of salinity arises from the time lag between the cause and the effect, which in some situations will not be experienced for many decades. Similarly, quantifying the amelioration benefits can be difficult because of the significant time lag between the action and the result, further complicated by the possible influence of other land use and climatic factors.

In the Murray-Darling Basin the first Basin-wide 'Costs Audit' was completed in 2002. The MDBC has since published guidelines to quantify the full range of dryland and urban salinity impact costs in each catchment of the Basin[3]. These costs are associated with impacts from high saline water tables and impacts from saline water.

Guidelines for Identifying and Valuing the Impacts provides cost functions for making preliminary estimates of the impact costs of dryland salinity for agricultural producers. However, the Costs Audit found that some regional organisations have difficulty in identifying and valuing salinity impact costs, especially the level of impacts being incurred by urban stakeholders, municipal councils, State agencies and utilities. Many also demonstrate a low level of understanding of the processes causing urban salinity impacts[4].

These factors may result in regional plans underestimating the benefits of investing in salinity management. It may also lead to misallocation of investment, for example giving priority to minimising agricultural losses, when a higher level of economic loss is perhaps being incurred by urban stakeholders and public infrastructure agencies.

The Costs Audit Guidelines are applicable across Australia and come in two parts:

- Part 1 - *An Overview of the Dryland and Urban Salinity Costs in the Murray-Darling Basin* demonstrates how costs information can fit into the bigger picture of preparing a regional or local plan and possible cost sharing arrangements for implementing plans.
- Part 2 - *Guidelines for Identifying and Valuing the Impacts* provides detailed instructions, tools and questionnaires that skilled natural resource economists can use to estimate salinity impact costs on agricultural and non-agricultural stakeholders, cultural heritage and the environment.

The above information and tools can also be used, in combination with projections about future increases in salinity, to predict the costs and benefits of salinity amelioration programs over long periods, for example 30-50 years. Repeated applications of the Costs Audit Guidelines can also assist regional organisations to track the performance of salinity amelioration programs.

Investment strategies

A report[5] evaluating salinity outcomes of regional investment from a review of regional plans, found that some catchment management organisations still deal with salinity as an issue around which a program and actions have been developed. Conversely, other regional NRM bodies are increasingly addressing salinity as a threat to various assets (e.g. water, land) and developing programs and actions within that framework. Overall, the review found a weak link between management actions targets (MATs) and natural resource condition targets (RCTs). The related survey of eight regional case studies found that asset-based NRM planning approaches were common. While salinity and related water quality issues were not always identified as priorities in their own right, they were important in terms of the threat they posed to highly valued assets.

A recently conducted study[6] outlines an alternative framework for investment decisions aimed at landscape interventions in dryland salinity. While issue-based, the framework draws on contemporary NRM planning approaches that take an asset rather than a problem or issue perspective. This considers both the method and merit of intervening in salinity and other threats to asset condition. Investment decisions are based on the likely success and cost of intervening to protect or restore threatened assets. Decisions focus investment on threatened assets rather than those whose condition is likely to be maintained without intervention, are irrecoverably damaged, or have low value from economic, social and/or environmental perspectives. It also directs investment towards geographic areas and interventions in which there is relatively high confidence that intervention will be successful.

WA's *Salinity Investment Framework (SIF)* was developed in the context of its assets at risk if present groundwater trends continue, including farming land, water resources and natural wetlands[7]. Many unique habitats in one of the world's most bountiful regions of biodiversity are geographically restricted and isolated by clearing and now surrounded by severely salinised areas[8]. Tens of thousands of kilometres of road networks and up to 40 rural towns may also be degraded to some degree. The framework provides rigour and accountability into decision-making processes and guides investment. The *Resource Management Technical Report*[9] describes the assessment of salinity impacts on agricultural land and rural infrastructure for the SIF project (Phase 1) and provides:

- Spatial representation of areas of land and infrastructure salinity-affected or with a salinity hazard to underpin analysis in the Salinity Investment Framework
- Value of land and infrastructure at risk (where possible)
- Technically-feasible treatments
- Probability of adoption of those options
- Economic analysis.

Parallel analyses have been undertaken in WA of 'water resources and waterscapes' and on 'biodiversity and natural assets' respectively. A joint group also developed an approach for assessing the relationship between salinity and the 'socio-economic' assets of communities. Having analysed the area and value of land and infrastructure affected or with hazard, technically feasible treatments, probability of adoption of options, and economic analysis, the report draws the following conclusions:

- Salinity continues to either currently affect or threaten large areas of agricultural land and high value infrastructure.
- Most of the potential benefits (and losses avoided) for farmers stem from the containment of salinity. The greater benefits from recovery of salt-affected areas compared with improved management of saline areas might be outweighed by greater costs.
- Return on investment varies between zones, generally being least in the eastern zones.
- Improving either the technical feasibility or adoption rate greatly boosts the potential returns on investment.
- A more sensitive analytical tool is required to take better account of variations within regions.

Such subjective approaches involving multi-criteria analysis are useful, but there remains a challenge to achieve agreed valuations.

Some participants in case studies from WA[3] commented that "agricultural land appeared only to be valued (by SIF) for the direct economic activity generated and not for its heritage and amenity values for local residents. They were concerned that agricultural land was therefore undervalued and investment priorities were not truly representative."

Because environmental outcomes arising from land management practices are usually externalities that are not traded, they do not have a value determined in the market place. Ecosystem service approaches continue to attract interest[10], and progress has been made with the design of various market-based instruments. But the institutional transaction costs associated with monitoring, assessment and enforcement still limit their practical application[11]

The Senate enquiry into the *Extent and Economic Impact of Salinity in Australia* heard that "....the largest economic impacts of dryland salinity are not really on agricultural production... The largest economic impacts are likely to be on urban infrastructure and on other public assets such as biodiversity."[12] The report from the Senate Committee noted that urban salinity has been a neglected area in regard to community awareness, urban development, funding and mitigation. Four of the report's recommendations relate specifically to this issue.

In NSW, a comprehensive set of publications has been completed under the Local Government Salinity Initiative to assist workers in this field[13].

Predictive modelling

The performance of four catchment modelling approaches to estimating the impacts of land use and management change on stream flow and salinity regimes have been reviewed[14, 15]. Three approaches (*BC2C, enhanced BC2C* and *LUCICAT*) are based on a simple framework that assumes a single aquifer and requires minimal information and calibration, whereas the other approach (*CAT3D*) adopts a fully distributed highly parameterised catchment model with layered groundwater flow systems.

The simple frameworks, tested in the Gardiner sub-catchment within the Goulburn-Broken catchment of Victoria, enable rapid assessment of the response of catchments to land use change. They predict catchment water yield from readily available data sets and with minimum parameterisation and calibration. The fully distributed CAT3D framework provides more detailed temporal and spatial information within the catchment but calls on more intensive parameterisation and computational resources.

The four models have significant and complementary roles in informing natural resource managers of the likely effectiveness of landscape intervention strategies to manage catchment yields and salinity. However, the distributed model should be used in catchments where multiple aquifers interact, limiting the reliability of the simple frameworks, or where the simple framework indicates more detailed assessment is needed.

Targeting management actions to maximise return on investment has been assisted by further development of geophysical techniques. 3-D maps of the architecture of groundwater flow systems enable modelling of salt and water delivery. Enhanced soil maps – digital elevation model and geophysical data extending conventional soil information to more than 100 m – can, in favourable situations, lead to more efficient water resource management through groundwater recharge and retrieval[16].

One of the key assets to be protected in most catchments is surface water and many regional NRM plans have targets for the condition of this resource. While maintaining water quality for human and livestock consumption is a key issue for many catchments, there is also increasing interest in the lethal and sub-lethal effects of salinity on stream organisms. Stream macroinvertebrates in particular are often seen as key indicators of ecosystem health. A new process-based model has been developed for predicting the mortality of macroinvertebrates exposed to time-varying salinity[17]. This model shows promise as a framework for determining guidelines to protect stream macroinvertebrates but requires further testing and refinement.

The important issue of end-of-valley targets for salt loads have sometimes been set without a quantitative model of cause and effect, without regard for impacts on stream flow water volumes and without consideration of economic efficiency or the distribution of costs and benefits among stakeholders. In an important paper[18], researchers show how these questions may be treated simultaneously in an integrated framework accounting for the biophysical resource base and the opportunity costs of changing land use.

As a footnote to this discussion, the Murray-Darling Basin Commission's Independent Audit Group (IAG) for Salinity noted "the limited capacity and skills available for identifying and evaluating with-in valley trade-offs when making investment decisions in the regional plans. The IAG gained a distinct impression that staff and skills resources were already 'stretched' and that the level of support that regional groups would require to bring some robustness to the evaluations is unlikely to be satisfied in the immediate future."[19]

Chapter 3 - The Impacts

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Integration

Accreditation criteria for the NAP require regional bodies to demonstrate that their plans cover the full range of NRM issues and are underpinned by scientific analysis of natural resource conditions, problems and priorities.

The Australian Bureau of Statistics has compiled estimates from the first dedicated Natural Resource Management survey of activities and issues on Australian farms in 2004-05[1]. At the regional level, weeds and pests were consistently the most commonly reported NRM issue, although a question perhaps remains as to whether the weeds reported were all environmental weeds. The preliminary survey data aggregates "land and soil" so that it is not possible to assess how farmers are dealing with salinity and other specific issues.

The *Evaluation of Salinity Outcomes of Regional Investment*[2] notes that salinity interventions in dryland regions have traditionally addressed agricultural production and water salinity, but are increasingly being integrated with actions to protect other assets and address other threatening processes. NRM investment is increasingly influenced by asset-based planning and priority-setting approaches, which encourage interventions aimed at protecting or restoring assets that are threatened by salinity, such as water resources, wetlands, biodiversity, agricultural land and infrastructure.

The benefits of integrated NRM are generally acknowledged, but measuring these benefits and attributing them to actions presents some challenges. Governments need information to be able to assess whether their investment is making a difference to the condition of our natural environment, as well as its social and economic impacts. Land managers and regional groups also need the best available data and information and tools to help make sound investment decisions and trade-offs.

A *National Monitoring and Evaluation Framework* has been agreed by the Australian, State and Territory Governments[3] to monitor and report on the impact of the NAP and the Natural Heritage Trust (NHT). This Framework sets out broad 'Matters for Target' which are to be reported on, using a range of possible indicators. While the 'Matters for Target' represent a comprehensive set of natural resource issues, including social and economic aspects, they are still essentially theme based (e.g. salinity, soils, vegetation). In order to be able to make sense of all this information, we need to know how it can be integrated to give a better understanding of the overall condition of a catchment or region. Accordingly, one of the NLWRA's key activities is to develop nationally consistent, integrated resource condition reports – linking biophysical, social and economic information.

At a purely pragmatic level, many areas in Australia are experiencing an extended dry period. As discussed previously, in some situations water tables are falling significantly as a likely consequence and with this the threat of salinity is potentially losing urgency. Whether salinity is also declining in importance is a separate issue, but the SA Dryland Salinity Committee's 2005 Forum, *Lessons Learned in Managing On-ground Change for Salinity and Related Benefits,* heard several accounts of the declining interest in NAP and NHT funded projects directed at salinity as a single issue. Increasingly project officers are recognising the need to integrate salinity with related NRM and agricultural production issues in order to effectively engage landholders.

As the Forum heard, the paradox is that many professionals "are struggling to assimilate into the new regional processes and to embrace the paradigm shift from working within 'silos' (or within one's own area of expertise) to working within 'systems' (collaboratively to produce outcomes across all facets of NRM). If NRM workers, who live and breathe NRM on a daily basis, are still coming to grips with such changes and are challenged by the process then it is very likely that landholders, who may only get the occasional whiff of NRM, are also becoming discouraged with the level of change occurring."[4]

The search continues for ways to integrate deep-rooted perennial plants into the dryland farming systems using trees that can provide not only wood products, but also bioenergy, environmental services (such as carbon sequestration and biodiversity protection), along with recharge reduction. Modeling has been used to determine the optimal distribution of trees across the landscape, in terms of land suitability, their productivity, and proximity to existing processing and transport infrastructure[5]. Catchment scale landform datasets allow broadscale planning for new plant-based industries that also contribute to recharge reduction where it is most effective.

Landscape-scale NRM requires significant action by private landholders largely for public benefit, but the available incentives have generally failed to bring about this scale of activity. To ensure the sustainability of the environmental, economic and social systems in these regions, complex decisions have to be made about the nature and location of the actions required to meet multiple -objectives.

The *South Australian River Murray Corridor* project[6] adopted the concept of systematic regional planning to provide a structured and quantitative approach to redress regional threatening processes of biodiversity decline, river salinity, wind erosion and greenhouse gas. It identified the geographic priorities for NRM actions that most cost-effectively met multiple-objective regional targets based on established biophysical and economic principles. Systematic regional planning also estimated the cost of meeting regional targets and suggested policy instruments, especially market-based instruments that will provide the greatest chance that the targets will be met. For this study, three NRM actions (vegetation management and revegetation, biomass and fodder) addressed all four NRM objectives of biodiversity, salinity, wind erosion and carbon sequestration.

In evaluating the potential role of market-based approaches in achieving levels of revegetation required to satisfy the resource condition targets, investigations[7] concluded that auction or tender based instruments alone will yield a small contribution to NRM targets given current levels of funding. Similarly, there is limited potential for quantity-based cap and trade instruments due to limited differential in the marginal costs of revegetation, and limited numbers of potential traders.

The work found that to encourage the scale of revegetation required to meet resource condition targets, the revegetation needs to form the basis of an alternative farming system that is commercially viable. For large-scale adoption of these alternative farming systems, a biomass industry needs to be developed in the region and institutional barriers to trade in the European carbon market need to be removed (or the Australian market expanded). Furthermore, the actual level of adoption will be influenced by a number of complex, interacting factors such as individual attributes and behaviours, cultural norms, traditions and conventions, social institutions, the ease and predictability of land use change, and the effectiveness of communicating the economic benefits of new farming systems relative to current agricultural production.

Research has identified three key factors determining the viability of mallee biomass as a resource for bioenergy and industrial products[8,9]. The first is the economics of biomass production and utilisation along with eucalyptus oil and activated charcoal. Recent feasibility investigations indicate that mallee should be a competitive biomass feedstock. The second is its environmental performance as part of more sustainable agricultural systems. The third is its carbon and energy balances, which will determine whether it is a truly renewable resource.

Chapter 4 - The Next Steps - Integration

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Planning and Policy

The NAP and NHT are the main government programs aimed at managing salinity and surface water quality in Australia. The performance of investments in the regional components of these programs have been summarised to 30 June 2005[1,2], along with a summary of activities supported by these investments and Management Action Targets and Resource Condition Targets.

The Senate inquiry into *The Extent and Economic Impact of Salinity in Australia*[3] and a report[4] evaluating salinity outcomes of regional investment both strongly endorsed the regional delivery model. The Senate report recommends "...strengthen(ing) the accreditation process for regional bodies. The improved process will ensure that funding is conditional on rigorous investment planning where decisions are based on sound, up-to-date science; outcome focused; and subject to a cost-benefit analysis."

A salinity working paper[5] argues that "appropriate management and policy responses vary over a range of bio-physical and socio-economic conditions, and differ according to the resources at risk (protection of water resources, biodiversity, infrastructure, dispersed assets such as agricultural land, and salt-affected land)". It points out that extension and incentives based on currently available salinity management options are inappropriate in many situations. For much of the agricultural land that is at risk or is contributing to dryland salinity the greatest need is for research and development into improved salinity management technologies. Policy responses are outlined for four situations: recharge areas with salinity impacts on waterways; recharge areas with salinity impacts on relatively small-scale terrestrial assets; recharge areas with salinity impacts on dispersed assets such as agricultural land; and salt-affected agricultural land. The authors are currently involved in collaborative work with regional NRM bodies to validate and further develop the framework[6].

The development of a framework for setting end-of-valley targets for salt loads was discussed earlier under **Predictive modelling**[7]. From a planning perspective, this framework helps to inform policy-makers, landholders in catchments and downstream interests of the likely scope for, and costs of, altering stream water and salt flows from particular catchments. It demonstrates that there is a limited envelope within which water and salt targets are feasible in any catchment and each target presents different costs of attainment. The authors conclude with the home truth that significant reductions in stream salinity will require strategic land use change on a scale that will only occur if profitable to farmers. Their framework links the complex biology, which drives profitability at the whole farm level, with hydrology at sub-catchment and catchment scales. Such a framework can help land managers, regional NRM bodies and policy-makers quantify trade-offs and negotiate targets with downstream demands for water volume and water quality.

The social and industry diversity of 'the salinity landscape' has been underlined in a conference paper[8] describing major trends in farm productivity, amenity migration, demographic transitions and changes in community values within rural Victoria. These 'regions' are characterised by priorities based on dryland production, amenity, the transition between these two, and irrigation. The significance is that the populations in these different zones will have different priorities, different management tools and different skills to bring to the problem of salinity. The policy planning message for Victoria is likely to be mirrored in other states.

In Western Australia the *Catchment Demonstration Initiative (CDI)*[9] is demonstrating combinations of salinity management practices to recover saline land, restrict its development and allow profitable uses of saline land and water in the agricultural zone. This is a partnership between Government and NRM regions with co-investment in targeted, largescaled, catchment-based demonstrations of integrated salinity management practices. The CDI complements the *Engineering Evaluation Initiative* by including engineering options and building on other on-ground activities of the regional NRM groups.

Most modelling work on salinity management strategies now takes account of the practicality of the options as well as possible consequences for other natural resources. Increasingly, the possible economic and social impacts are also being considered. As an example[10,11], the impact of converting cleared upland in the Murray-Darling Basin to native vegetation has been examined in terms of the change made to salt generation and river salinity. Simulations for local groundwater flow systems where native vegetation has already been cleared show that in some areas where in-valley salinity would actually increase due to the fact that stable subterranean salt stores have been activated by rising groundwater and are now part of the near surface salt and water cycle. A return to pre-European water balance conditions does not remove or deactivate these stores therefore the salt discharge rates can remain high.

The *National Market Based Instruments (MBI)* Pilot Program[12] has tested and evaluated new policy mechanisms for the NAP. It has shown that markets can be designed and created through cap-and-trade systems (for point-source problems such as water rights), auctions (for non-point source problems such as dryland salinity) and offsets systems. It has highlighted the need to combine these different policy mechanisms to address complex NRM problems which have spatial and temporal impacts and are often difficult to observe and monitor.

The *Auction for Landscape Recovery (ALR)* was one of the 11 MBI pilot projects. The ALR was a multi-partner, multi-disciplinary research project which operationalised an auction-based field trial in the Intensive Land-use Zone of the North Eastern Wheatbelt Regional Organisation of Councils (NEWROC), a highly biodiverse landscape in the northeast wheatbelt of Western Australia threatened by salinity and the effects of large-scale clearing for agriculture. It was the first biodiversity/conservation auction trial to have been conducted in Western Australia. It successfully created a competitive market that was two to three times more efficient, in economic terms, than a fixed price scheme and demonstrated that it is possible to operationalise a Systematic Conservation Planning approach within a market-based instrument (auction) setting[13].

The dominant environmental issue in recent years has been the prospect of climate change[14]. The Australian Greenhouse Office warns "concentrations of greenhouse gases in the atmosphere are continuing to increase as a result of human actions. A future Australia will be warmer, mostly drier, and likely subject to more extreme weather events such as storms, drought and floods. The agriculture and forestry industries will need to manage additional climate risks, especially over the medium to longer term. There are also implications for managing natural resources including effects of climate change on salinity mitigation, water quality, carbon sequestration, and biodiversity conservation"[15].

Climate change which impacts on farm-level production and farm income in areas where salinity is currently a problem or a threat[16] will also affect the management options available to these farmers. At the same time, higher levels of carbon dioxide and altered rainfall patterns will have impacts that are currently far from certain.

Looking deeper into the crystal ball, work on 'futures'[17] argues that much of the uncertainty about future environmental challenges comes from our poor understanding of the ways in which changes in water, soil, biodiversity and climate might interact with one another and with social and economic systems.

"A likely implication of the ascendancy of Generation X is growing impatience with research and development that does not address policy and management goals. Research and development in recent years has been getting much better at identifying these objectives and what they mean for research design. Several high profile projects have shown that putting decision making and policy at the core of the research framework can have the advantage of exposing gaps in knowledge needed for good decisions but can have the disadvantage of stifling innovation and imagination.

"The mere existence of research is no guarantee that it will be used effectively. Futures analyses suggest several ways in which the role of science in society could change.

"The coming decades are likely to see increased professionalisation of politics (politics sharply honed to win votes using modern media and social technologies) and an increase in the role of skilled advocates to connect society with politicians. One challenge for science is to find ways to feed well-grounded scientific insights into this environment without compromising confidence in scientific method."

A conference paper[18] addresses the issue of political forces standing in the way of effective and efficient policies for dryland salinity. It notes that salinity policy continues to be influenced by tensions between urban and rural interests; short-term politics versus long-term salinity outcomes; crisis-driven politics versus slow and inexorable salinity processes; simplistic and one-size-fits-all political solutions versus complex and diverse salinity problems; the political imperative of 'winning' versus the reality that effective salinity policy will result in some losers; east versus west; and national versus state governments.

A lateral view of salinity management[19] analyses three quite different perceptions of the 'problem'. The traditional and mainstream 'positivist view' is that salinity has come about because we didn't understand the relationships between rainfall, vegetation systems, geology and groundwater hydrology. If we get our scientific understanding right, then we should have the basis for fixing the problem.

An alternative 'interpretivist view' is that salinity is only a problem if we perceive it as a problem. One group may look at a salt scald and see a degraded wasteland; another may look at it and see a form of artistic inspiration; and yet another may see a resource for saltland production. Furthermore, how we see salinity tomorrow may well be very different to how we see it now.

Thirdly, the 'critical theorist' might argue that the problem is not so much inappropriate land use, but the factors that lead us to the act of inappropriate land use. These factors have been encouraged by increased consumption, extractive resource use and the accedence of efficiency over sustainability. In this model the ideology of 'productivism' is the root cause of salinity.

Chapter 4 - The Next Steps - Planning and Policy

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Plants

RECHARGE

A scoping study[1] reviewed the role and potential of perennial pastures to eliminate or reduce recharge on a substantial scale. The study covered exotic and native herbaceous perennial pastures (legumes, grasses and forbs) and evaluated their potential, if known to:

- Extract sufficient water to minimise recharge
- Adapt to the prevailing soil and climatic constraints of the target zone (e.g. acidity, transient waterlogging, etc)
- Fit into and be more profitable than current or likely farming systems (particularly livestock utilisation).

The geographical area considered represents a diverse range of climates and soils. Lucerne is the most widely sown perennial in cropping areas, with exotic perennial grasses playing a small but growing role in eastern Australia. Expansion of the area under lucerne is restricted by a number of factors, including soil acidity, waterlogging, risk of bloat and susceptibility to set stocking. Native perennial grass pastures are widespread in the higher rainfall recharge areas of eastern Australia but these are often badly degraded and poorly managed, and are failing to prevent recharge.

The *Salinity Solutions Conference*[2] in Bendigo, Victoria, in August 2004 addressed many of the issues associated with plant-based management of salinity. This included the challenge of developing new trees and pastures and identifying when, where and how they will become a part of farming systems[3].

Perennial plants generally occupy only a small part of the agricultural landscape in Australia, largely because of the poor profitability of available options, especially in lower rainfall wheat-sheep zones. The opportunity to combat salinity has stimulated research into new land use systems based on a greatly expanded array of new perennial pastures and trees.

The most rapid and lowest risk results will come from innovation within commercially known species that fit established farming systems. Perennials that overcome soil constraints (such as infertility, acidity, sodicity and, of course, salinity) and climatic stresses (such as low rainfall) combined will be much slower to deliver. Particularly challenging are the new woody coppice crops for low rainfall zones which require new plants, systems and industries.

The search for new perennials inevitably extends overseas for additional options, but many environmental weeds are a result of deliberately introduced species escaping cultivation and naturalising in the Australian environment. Research reported in a journal paper[4] discusses four key areas where there is the potential for conflict between the maintenance of biodiversity in natural ecosystems and the development and introduction of new herbaceous perennials. It explores each of these issues within pre- and post-weed risk assessment, weed risk of translocating native species and field assessments of new species, and propose means for resolving the conflicts.

The *Potential of Current Perennial Farming Systems to Deliver Water Management and Biodiversity Outcomes*[5] paper presented at the Salinity Solutions Conference explored existing perennial plant-based farming systems within four climatic zones (western winter rainfall, south-eastern low to medium rainfall, south-eastern high rainfall and northern summer rainfall) in southern Australia to assess their potential to improve the management of dryland salinity.

Their modeling showed that if profit is to be the primary driver of adoption, the available options (lucerne and other perennial pastures, farm forestry, saltland pastures and forage shrubs) will fall short of existing hydrological targets in all but the higher rainfall zones. In the eastern zones the use of perennials is limited partly by the need to preserve freshwater flows to permanent river systems, and also by the high proportion of regional groundwater flow systems.

Local and intermediate groundwater flow systems in the western zone will better respond to individual action; however, the uptake will be limited because research into new perennial land use systems has over-emphasised water use to the neglect of farm profit. A more effective approach would be to manage dryland salinity as a side effect of commercially-viable farming systems. This approach would place more emphasis on the farming system than the paddock as it is at the farm-scale that land is managed and decisions made.

The challenges of reducing recharge with perennials was highlighted by a review of the Coorong District Salinity Strategy[6] that showed that since 1997 an estimated 100,000 ha of perennials (a large portion being dryland lucerne) has been established for the purposes of recharge reduction to control dryland salinity. Despite achieving a 20 per cent reduction in recharge by 2003, there was no discernible influence on regional groundwater levels. Based on the modelling study used for setting the recharge reduction targets, this lack of influence on regional groundwater trends is not unexpected. Monitoring networks at the property scale do show the influence of dryland lucerne in reducing water table levels where local groundwater flow systems are dominant.

The profitability of perennial pastures inevitably comes down to the profitability of the animals that graze them (or are fed to them as fodder). The *EverGraze* program[7] has used integrated bio-economic and hydrological modelling in the high rainfall zones in Victoria and Western Australia to show that selection of perennial pasture plants to match requirements of a highly productive livestock system significantly improves farm profit and reduces groundwater recharge[8].

The CRC Salinity has recently published *Lucerne Prospects - Drivers for widespread adoption of lucerne for profit and salinity management in the Australian wheatbelt.* This publication brings together existing knowledge about lucerne as a basis for spelling out its prospects as a profitable part of future farming systems. Concentrating on the mixed crop/livestock systems associated with the Australian 'wheatbelt', it also draw out the implications that are critical for many farmers - the role lucerne can play in managing dryland salinity and waterlogging.

The prospects for lucerne vary from region to region and then from farm to farm, but economic analyses predict the optimum area of lucerne on a typical farm for representative agro-climatic regions. The analyses also show the relative sensitivity of the profit predictions, region by region, to variations in the area under lucerne.

Each regional analysis is supported with a farmer case study, illustrating how the modelled predictions align with reality[9].

While there are fewer perennial plant options available in the low to medium rainfall zones, there could be new options for livestock based on a range of plant species that collectively provide resilience to the environment while maintaining profitable livestock production[10]. This is being explored in the *Enrich*[11] project that does not just focus on total feed production, but also investigates critical issues and opportunities such as timing, complementarity with other feeds, options for self medication for animal health and the significance of plant secondary compounds in grazing. This involves testing a broad range of promising shrub options. Because the outcome will be 'polycultures' of plants, each selected and grown for a specific purpose within the mix, the research is not constrained through traditional approaches to the feeding value of individual plants grown in monoculture.

The *FloraSearch* project[12] is developing commercially-viable, broad-scale woody perennial crops for low to medium rainfall agricultural areas of southern Australia. GIS-based economic modelling can now support the systematic regional evaluation of perennial crop options. Incorporating improved species knowledge including productivity estimates, product development and updated costs and returns, the current analysis shows that many

FloraSearch industries are profitable across vast regions of southern Australia. The economic returns of several industry types in the region are even competitive with existing land uses.

A conference paper[13] uses demographic data to conclude that a salinity mitigation strategy based on perennials might be less suited to the repopulating rural areas near to cities and regional centres, where amenity is a major factor in population growth. The author's argue that investment in recharge control based upon commercial pasture production or plantation forest industries is unlikely to match the aspirations of future residents. It may be that strategies aimed at low-cost re-establishment of native vegetation will be more appropriate, but even this will have limited application. Whatever the outcome, they conclude that any discussion of the applicability of plant-based management systems for dryland salinity must take account of social factors.

DISCHARGE

A review of the major issues impacting on the development of improved fodder species for saline environments has been conducted[14]. A key output from this review is identification of opportunities for and the constraints to advancement with grasses, legumes, herbs and shrubs.

The journal paper, *Multi-disciplinary Approaches Suggest Profitable and Sustainable Farming Systems for Valley Floors at Risk of Salinity*, [15], shows that to be sustainable and profitable, farming systems need to (i) target perennial plants to the valley floors and improve soil management to dry the root-zone, decrease recharge and minimise capillary rise; (ii) increase the discharge of groundwater from valley floors using deep drains and stands of perennial plants; (iii) improve surface water management to ameliorate waterlogging, inundation and flooding; and (iv) incorporate better plants and better agronomic methods in the growth of profitable salt tolerant crops and fodder plants.

It is important to redesign plant systems on salt-affected land such that there will be a range of plants from high feed value and moderately salt tolerant legumes, through to highly salt tolerant shrubs[8]. The type of plants that can be grown and the subsequent animal production potential depend on the many factors that contribute to the 'salinity stress index' of a site, including soil and groundwater salinity, the extent and duration of waterlogging and inundation, the pattern and quantity of annual rainfall, soil texture and chemistry, site topography and other site parameters. Where the salinity stress index is high, plant options will usually include a halophytic shrub that accumulates salt. High salt intakes by grazing ruminants depress feed intake and production, so that both high and low salt feeds should be available together, allowing ruminants to select a diet that optimises the overall feeding value.

A significant body of work on the agronomic and animal production issues relating to saltland has been undertaken through the *Sustainable Grazing on Saline Lands*[16] sub-program of Land, Water & Wool. The findings from this work will be comprehensively reported early in 2007.

Cropping on saline land is restricted by the low tolerance of crops to salinity and waterlogging. Prospects for improving salt tolerance in wheat and barley include the use of: (i) intra-specific variation, (ii) variation for salt tolerance in the progenitors of these cereals, (iii) wide-hybridisation with halophytic 'wild' relatives (an option for wheat, but not barley), and (iv) transgenic techniques. A review[17] of key traits contributing to salt tolerance, and sources of variation for these within the Triticeae family, has summarised recommendations for use of these traits in screening for salt tolerance. This is long term research, but the authors have assessed the potential of the approaches to deliver substantial improvements in salt tolerance, while emphasising the importance of adverse interactions between waterlogging and salinity. The potential to develop new crops from the diverse halophytic flora is also considered.

Any salinity management strategy based on perennials should take account of all the impacts of such a system. For the majority of agricultural land that is at risk or is contributing to dryland salinity, it is suggested that the most logical policy response is to invest in development to improve salinity management technologies, including research and development into new plant-based systems[18,19]. Situations where plant-based R&D for profitable farming systems is the best option include: (i) to reduce salinity impacts on water resources where groundwater systems are responsive and the dependence on fresh runoff for consumptive use is low; (ii) to protect infrastructure and biodiversity where there is relatively high responsiveness of groundwater and the urgency of response is low; (iii) to protect dispersed assets (e.g. agricultural land, most remnant vegetation on farms, flood risk mitigation) where profitable perennial plant options are lacking; and (iv) for land that is already salt-affected.

Chapter 4 - The Next Steps - Plants

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Engineering

In a submission to the House of Representatives Standing Committee on Science and Innovation[1] CSIRO commented: "given the immediacy of salinity risk and the impact of salinity on important built environments (e.g. 80 towns) and natural assets (e.g. key Ramsar wetlands), no solution involving recharge control will afford timely protection, and Australia will have to look to engineering approaches to protect these assets... large areas that are already affected, such as the regional valley systems in Western Australia, are in such an advanced state of salinisation that no form of recharge control is likely to maintain current farming enterprises."

In South Australia the bulk of NAP funding has been directed towards large-scale, State-run salinity mitigation infrastructure projects, such as groundwater interception schemes in the SA MDB region and the Upper South East drainage project[2].

Not withstanding this, the Senate Committee Report[3] noted that in the Upper South East "the community is divided, however, on the issue of constructing the remainder of the deep drain network".

In the case of the SA MDB, these projects aligned with regional priorities and hence were well-integrated into regional plans and activities. The Upper South East drainage project addressed salinity as a regionally-recognised priority issue; however, it was argued by some that its call on resources hampered investment in other regional NRM priorities.

In WA the Senate Committee heard the case for 'adapting to salinity', but also from the Wheatbelt Catchment Alliance arguing that salinity can and should be reversed with engineering solutions. While many drains in WA appear to be working, CSIRO[4] claimed that some have been constructed with limited planning and construction guidelines and, usually, little understanding of downstream effects and linkages.

In WA the *Engineering Evaluation Initiative (EEI)* is a $4 M priority project focused on finding and demonstrating better ways to implement engineering works to tackle salinity[5,6]. The objectives of the EEI are to review the current knowledge on engineering options to mitigate dryland salinity and to clarify 'best practice' by establishing demonstration sites for a range of engineering options. This initiative encompasses a range of on-ground projects to examine the performance of specific engineering options (deep drains, groundwater pumping, siphon and relief wells, and surface water management), to identify ways of disposing of the water safely, and ways to improve once saline soil. The EEI will also consider the most appropriate mechanism to provide a way of assessing the costs and benefits of regional drainage as well as evaluating potential downstream impacts.

Despite some evidence to suggest that engineering works are beneficial at paddock scale, there is less information on engineering works being beneficial at a regional scale[7].

Modelling has been used to evaluate the various methods of reaching salinity targets in the Collie and Denmark catchments in WA[8]. The options included revegetation, perennial pastures, commercial forest management, and engineering while the evaluation considered the economic costs-benefits, and the social, environmental and sustainable yield implications for each of these options.

The evaluation of the Collie River found that engineering solutions, such as groundwater pumping or water diversion, are hydrologically viable with minimal social disruption. The benefits of engineering solutions are that they achieve the salinity target much sooner, with fewer social impacts and receive greater stakeholder support. The disadvantages include higher cost, and the need for more rigorous environmental impact assessment – particularly in relation to off-site or downstream impacts. In contrast the vegetation options had positive environmental impacts but with significant social impacts.

The regional consequences of groundwater drainage leaving the farm has been investigated with respect to the impact on wetland environments in the wheatbelt of WA[9]. The report provides an assessment of two large deep drainage schemes within the lower reaches of the Bodallin and Elachbutting Catchments nearby to Merredin, wherein groups of isolated wetland basins have been utilised for evaporative saline drainage water disposal. In both cases, the storage capacity of the basins has been exceeded, leading to flooding and decline of the surrounding native vegetation.

Modelling indicates that groups of small wetlands basins can usually be used for saline drainage water disposal subject to three conditions. Firstly, catchment-wide surface run-off must be prohibited from entering the deep drain, or at least it must be removed from the drain before it discharges to the wetland basins. Failure to do so results in widespread flooding and loss of the surrounding native vegetation, as appears to have occurred in both of the study catchments. Secondly, large sections of deep drain should be constructed during summer, enabling significant evaporation of the initial pulse of water produced by valley floor dewatering, reducing the risk of flooding and vegetation death. Thirdly, the combined area of wetland basins used for evaporation must be sufficiently large to evaporate the groundwater conveyed by the deep drain, and furthermore, the drainage water must be distributed to all of the wetland basins more or less concurrently. This can be difficult to achieve, often involving the construction of numerous carefully surveyed channels to connect one basin to another, and perhaps also pumps where increases in elevation are involved.

Acid groundwater, that dissolves clays and minerals, has been encountered widely in drains built to counter salinity in the WA wheatbelt. Acid groundwater has been cited as a significant offsite risk as it has the potential to release metals and elements harmful to the flora and fauna that inhabit receiving areas.

A research project[10] to assess the causes and risks of acid groundwater and to identify management options is underway as part of the EEI. To date it has found that acidity is widespread, generally more pronounced in eastern areas and increasing in summer. There is also the potential for further acidification if drain sediments dry out, and in many cases metal and trace element levels were 10-100 times that in surface waters. Data analysis from the first 12 months of this project has enabled development of a broad set of assessment and management guidelines.

In the Upper South-east of SA investigations have been conducted on the possible environmental impacts associated with the occurrence of sulfidic materials in soils, sediments and drains of that region. Management options have been proposed in the form of a position paper[11]. In a second position paper[12] soil salinity, pH and sodicity in pre- and post- drainage environments have been reviewed. A general summary of broader impacts of the Upper South East drains is available in a fact sheet[13].

In WA the *Rural Towns - Liquid Assets* program is demonstrating how to control townsite salinity and produce returns from saline groundwater production.

The program has drawn on a review[14] of the efficiency and effectiveness of groundwater pumping to delay, contain or reverse the spread of land and water salinity in WA. The main conclusions and recommendations are based only on the case studies and are relevant only to the hydrogeology, climate and topography of the WA landscape:

- Effective groundwater pumping depends mainly on aquifer characteristics. The lateral extent of the water table lowering depends primarily on local hydrogeology and aquifer types.
- Groundwater pumping from paleochannels will only be effective in reducing surface dryland salinity if the overlying layer is pervious and not confining.

- The response time of a shallow water table to groundwater pumping depends on the degree of connectivity between the surficial sediments and paleochannel sediments.
- Lowering the hydraulic head in semi-confined aquifers and the watertable in unconfined aquifers does not necessarily result in the reclamation of agricultural land and its return to production as it may be difficult to leach the salt from the soil profile even after a sustained period with the water table at two metres below the surface.
- Groundwater pumping is often expensive compared to the local damage costs although it may be more economical than other engineering options for very valuable assets like the Wellington Reservoir water resource.
- Iron fouling reduces the life of pumps and pipes and increases the costs of pumping schemes.

The project, *WA Paleochannels for Salinity Mitigation*, is demonstrating the use, cost-effectiveness and practicality of geophysical methods to define the location and geometry of paleochannels. These are important for siting production bores designed to lower the saline water table below valuable agricultural land, providing an opportunity to improve soil health and productivity. Once paleochannels are located observation bores are logged to measure conductivity and pump tested to evaluate prospects for groundwater pumping and disposal[15,16].

Researchers are also using high-resolution, shallow-penetrating airborne electromagnetic data, processed using new 'constrained inversion' techniques, and integrated with other geoscientific data, to deliver a powerful predictive tool to aid the management and mitigation of sub-surface salinity (17). This new tool is a three-dimensional model of regolith architecture, salt stores, and groundwater salinity.

Groundwater flow system maps generally lack this 3-D information, restricting their value in supporting catchment and broader scale salinity management. The methodology utilises a hierarchical, multi-scale, multi-disciplinary mapping approach incorporating information from national to sub-catchment scales. This nested scale approach provides a framework for identifying the spatial extents of landscapes with similar 3-D regolith character, which then enables the design of more detailed farm and sub-catchment scale hydrogeological investigations to characterise the salinity processes.

The approach enables finite research resources to be used in areas most likely to characterise sub-catchments, and permits more rapid and reliable extrapolation of 3-D regolith, groundwater and salinity attributes[18].

The *Evaluation of Salinity Outcomes of Regional Investment*[2] found that studies that included airborne geophysics were generally recognised favourably by regional NRM bodies as showing promise or providing some useful information. However, it was sometimes not clear to case study participants that the value added by airborne geophysics *per se* was consistent with the cost of data acquisition.

Complex numerical modelling had been applied in some of the case study areas, but confidence in interpretation of this information ranges from low to high, depending on the rigour of modelling and the level of verification.

Saline water interception on the River Murray has been very effective in managing the impacts of salt in the environment by relocating salt and saline water from areas of high potential harm to areas of lower threat. Saline water interception provides basin-level salt management opportunities within socially-acceptable time scales provided there are safe locations to which the salt can be moved and provided there is community acceptance of the relative value of the receiving site and the assets to be protected[19].

In this context, airborne geophysical surveys of the SA Riverland region have been of significant benefit for the design of salt interception schemes[20]. The data revealed a series of linear stranded beach dune structures in the Loxton-Parilla Sands, occurring at the base of the Blanchetown Clay. Where saturated, coarser sediments within these strandlines offer zones of good hydraulic connection to aquifers feeding saline groundwater into the River Murray. Hence they offer a good target for groundwater pumping for salt interception. The airborne data and consequent hydrogeological investigations have contributed to the design of the Loxton and Bookpurnong salt interception schemes, with potential to inform other salt interception projects that are being considered in the central Murray Basin.

Chapter 4 - The Next Steps - Engineering

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