Salinity – Causes, effects, manifestations, remedies and revolutions

Proceedings of the seminar held at the Institution of Engineers, Australia, SA Division, Engineering House, 11 Bagot Street, North Adelaide SA 5006 on 14 July 2003

Organised by the Hydrological Society of South Australia Inc.; the Australian Geomechanics Society – South Australian Chapter; and the International Association of Hydrogeologists – Australian National Chapter

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Acknowledgments

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The Hydrological Society of South Australia Inc.

AUSTRALIAN GEOMECHANICS SOCIETY
South Australian Chapter

INTERNATIONAL ASSOCIATION OF HYDRO-GEOLOGISTS-AUSTRALIAN NATIONAL CHAPTER

Salinity

Causes, effects, manifestations, remedies and revolutions

Monday 14 July 2003
The Institution of Engineers, Australia, SA Division, North Adelaide, Australia

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Conference Gold Sponsor

SA Dryland Salinity Committee
A sub-committee of the
Soil Conservation Council of SA

The SA Dryland Salinity Committee
The Government of South Australia has made a major commitment to address dryland salinity through the implementation of the South Australian Dryland Salinity Strategy. PIRSA and the Soil Conservation Council of South Australia prepared the strategy after extensive consultation with rural communities.

The Soil Conservation Council established the SA Dryland Salinity Committee to oversee the implementation of the Strategy. The Committee:

- Monitors the actions addressing dryland salinity and reports on progress of the strategy.
- Identifies activities and programs needed to implement the strategy.
- Advises the Minister for Environment and Conservation of any gaps in current programs.
- Encourages the changes needed in land management and community action to manage dryland salinity.

The Committee provides an ideal forum for:

- Putting forward ideas that would enhance progress towards dryland salinity management (eg political, social, economic, institutional, communication issues, technical support and assistance).
- Identifying and raising issues that may be impeding progress with the management of dryland salinity.

For further information on the committee or to obtain a copy of the strategy contact Glenn Gale, Executive Officer, SA Dryland Salinity Committee, Department of Water, Land and Biodiversity Conservation, GPO Box 2834 ADELAIDE SA 5001 Ph (08) 8303 9345, email: gale.glenn@saugov.sa.gov.au

Or visit http://www.saltcontrolsa.com/index.html

National DRYLAND SALINITY Program

National Dryland Salinity Program – know-how to tackle salinity

In a recent ABC-TV documentary exploring the causes and impacts of dryland salinity, the series narrator and Australian actor David Wenham suggests that how Australia deals with the problem of dryland salinity may well go a long way in indicating where we are at as a nation.

"Planning for the next 50, 100 or 200 years is not an easy concept for a nation built on rugged individualism," Wenham comments.

But for the past decade, one of Australia's longest-running environmental research and development initiatives has shrugged aside individualism, instead working as a collaborative broker of knowledge in assisting governments, industry and communities to understand dryland salinity – and identify appropriate management strategies for overcoming, or learning to live with, this most serious issue.

Australia's National Dryland Salinity Program (NDSP), with the support of 14 government and industry investment partners, has broadened the national salinity research focus from causes and effects of salinity to encompass industry, engineering, policy, local government, environmental and regional dimensions integral to addressing dryland salinity in a comprehensive fashion.

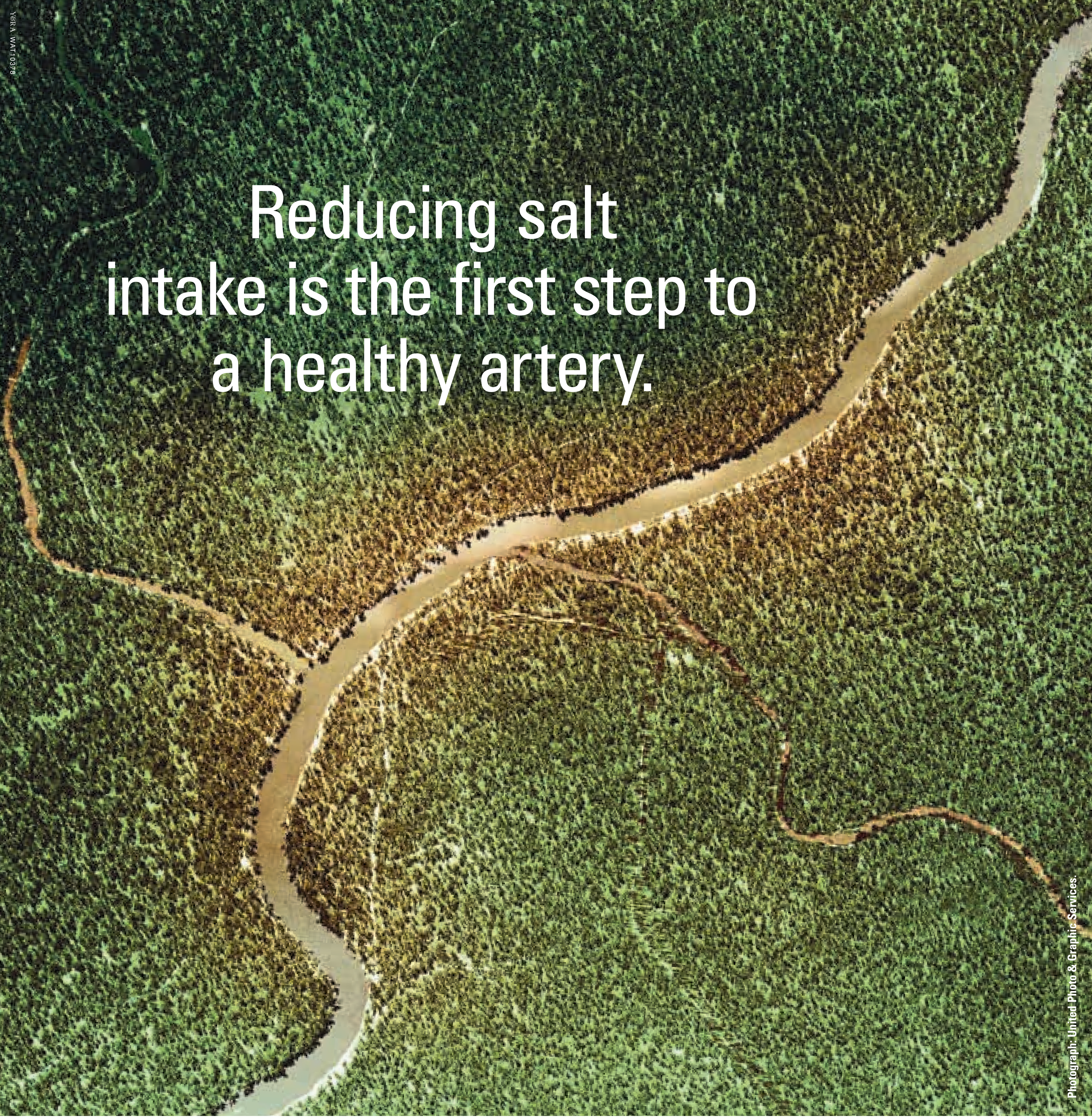
Over the past 10 years, the NDSP has supported around 50 research projects valued at almost $25 million. The second phase of the Program, which commenced in 1998, has supported 30 projects valued at about $15 million. During this time, nearly 300 researchers, technical assistants, consultants and policy makers have contributed to the program, and have significantly enhanced our understanding of dryland salinity and our knowledge of what might be done to manage it.

Work undertaken by hydrologists underpins major NDSP projects, such as *Tools for Improved Management of Dryland Salinity, Catchment Characterisation (Groundwater Flow Systems), Efficacy of Engineering Options for Management of Dryland Salinity* and *Opportunities for Productive Use of Saline Lands* have helped governments and communities to realise understand the salinity issue, and recognise significant opportunities for business through enterprises actually based upon salinity for those areas where 'living with salinity' has become a very real option.

NDSP has also supported major research and development initiatives to develop new predictive tools for catchment planning using airborne geophysics and the FLOWTUBE system, allowing salinity managers to make smarter investments in integrated salinity mitigation solutions.

In 2003-2004, the NDSP and its partners will invest in an accelerated communications and regional consultation program to synthesise and promote the latest salinity management systems, data, knowledge and technologies drawn from a decade of national and international research and development through a focussed campaign of communication, knowledge transfer and building and supporting networks.

To find out how the NDSP will be helping salinity managers to move ahead in 2003/04 and beyond, visit the NDSP on-line at **www.ndsp.gov.au**


Reducing salt
intake is the first step to
a healthy artery.
Photograph: United Photo & Graphic Services.

Avoiding the high cost of salinity by looking forward

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Summary
This paper reports on an evaluation of cost and feasibility of policy option to mitigate or avoid saline groundwater flows into the River Murray in South Australia and onto its floodplain. This included an initial screening of a wide range of policy options and detailed integrated hydro-geology-economics modelling of a short-list of options. Conclusions are that the costs of salinity mitigation that will be required to meet South Australian salinity obligations under the MDBC agreement on salinity will be very high ($130 - $247 million, 50 year NPV) in the absence of salinity policy intervention if significant expansion of irrigation, as has occurred in the recent past, continues. Policies to zone new development to lowest impact areas, charging irrigators to at least partially finance mitigation efforts, and rebates for irrigation drainage reduction can decrease these costs significantly.

1. RIVER SALINITY AND TECHNICAL SOLUTIONS

Salinity in groundwater below the River Murray in South Australia is very high, in some cases above the level of salt concentration found in seawater. Significant river salinity – the discharge of saline groundwater into the river and its floodplain – occurred in the South Australian River Murray even before European settlement. However, as shown in Figure 1, clearing of Mallee along with irrigation in the River corridor have created groundwater mounding that has greatly increased saline water flows to the River Murray and its floodplains.

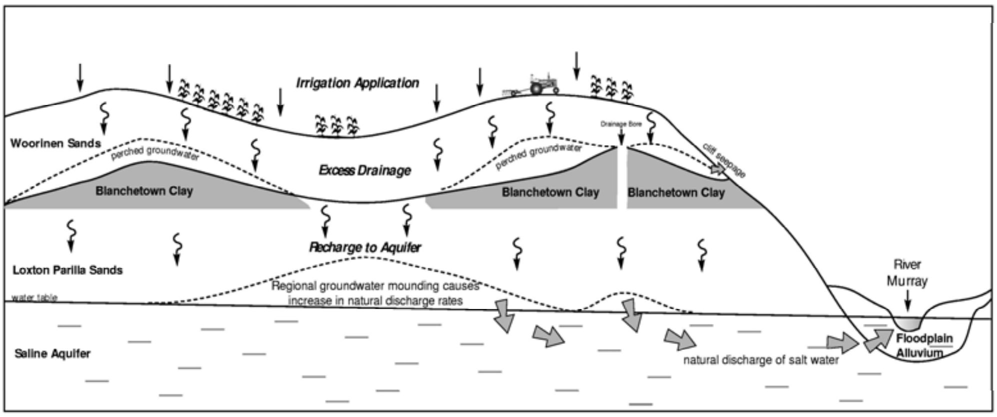

Figure 1: The relationship between irrigation and River salinity (source: Miles et al, 2001)

A significant load of salinity is on its way as the result of past irrigation and even more can be expected if there is further irrigation development in the Riverland. In the absence of any additional intervention, results would include River salinity above the level recommended for drinking water, reduced irrigated crop yields, and damage to water infrastructure in Adelaide and the iron triangle (MDBC, 1999).

It is increasingly clear that recharge from irrigation is also contributing to decline of the health of ecologically sensitive river floodplains and wetlands. Elevated groundwater mounds resulting from irrigation recharge are harming floodplains either by causing direct seepage of saline water onto the floodplain at the break of slope or by raising the level of saline water table below floodplains.

Technically, there are really only three options to deal with River salinity:

1. Control the symptom (discharge to River) with salt interception;
2. Control the causes by reducing recharge with:
   * Increased irrigation efficiency;
   * Revegetation of cleared mallee;
   * Location of irrigation where less recharge or less saline recharge results.
3. Dilute the salt in the River by increased flow.

2. OBJECTIVES OF THIS PAPER

This paper reports on the results of a CSIRO – DWLBC partnership to provide evaluation of irrigation salinity policy options. The brief for the project was to:

- Outline a wide range of potential salinity reduction and impact mitigation strategies and policy approaches;

- Provide an initial screening of options based on review of past experience with natural resource policy, stakeholder input and modelling of salinity benefits and mitigation costs;

- Identify a short-list of options for further evaluation based on the screening analysis;

- Model the costs of short list options to irrigators and the SA Government over a range of assumptions about values of key uncertain parameters.

3. RIVER SALINITY POLICY OPTIONS FOR SOUTH AUSTRALIA

South Australia is obligated under the *2001 Basin Salinity Management Strategy* (MDBC, 2001) to meet targets requiring essentially that State contributions to River salinity concentrations do not increase. In addition, the South Australian Government is committed to reversing the anticipated decline in River floodplain ecological health which will require reducing irrigation recharge in some instances along with other actions such as restoration of more natural flow regimes.

There are a range of policy approaches that can be taken to controlling saline irrigation drainage into the River and floodplains. In principle these can (and in some cases already do) include:

Government Mitigation Investment

The Government has in the past and will continue to makes investments in salt interception and saline water disposal. There is also the potential for environmental flows acquisition investment that may provide some salinity dilution, for example, through use of River Murray Levy revenues.

Irrigation efficiency as a water use condition A condition on water use in the *Water Allocation Plan for the River Murray* is irrigation efficiency exceeding 85% (Government of South Australia, 2001).

Charges

This could be similar to the Victorian Government approach that makes investments in salt interception and saline water disposal to offset irrigation salinity impacts and charges irrigators to compensate part or all of the cost. Variants of the charges approach could involve:

- Setting higher charge rates in areas where impact of irrigation is greater, and lower charge rates where irrigation impact is less as is done in Victoria (Sunraysia Rural Water Authority, 2002).

- Rebates on charges for actions that reduce recharge in proportion to the level of recharge reduction. In principle, rebates could be offered for increasing irrigation efficiency, revegetating cleared dryland areas close to the River, or providing dilution of River salinity with environmental flows.

Zoning

This would involve precluding irrigation in areas where salinity impacts on the River or floodplain were deemed too damaging or too expensive to mitigate. In addition. a zoning approach could involve differentially charging by "impact zones" where average salinities differ. This is the approach taken by the Sunraysia Rural Water Authority in Victoria.

Tradeable salinity credits

This approach would involve creating salinity credits for actions that reduce recharge or provide mitigation and debits for actions creating salinity impacts. Irrigators would have salinity accounts and a condition on further water use would be that salinity credits exceed debits. Irrigators could buy or sell credits much as they currently trade water.

4. INITIAL SCREENING OF OPTIONS

The entire range of salinity reduction, impact mitigation strategies and policies outlined above was evaluated against a set of five criteria:

- Environmental dependability – assuring individual salinity obligations will be satisfied and wetland protection goals will be met;

- Compliance flexibility – ensuring irrigators have widest possible choice of mitigation activities;

- Mitigation incentive compatibility – setting incentives that encourage continuing innovation of effective, low cost salinity impact reduction strategies;

- Administrative simplicity - assuring that salinity obligations are straightforward and inexpensive to administer and comply with;

- Equity – assuring that the approach taken is perceived to fairly balance the interests of all stake holders including irrigators, the environment and the SA Government.

Screening involved review of past experience with natural resource policy, stakeholder input and modelling of salinity benefits and mitigation costs. The analysis identified a set of options that appeared to be particularly challenging with respect to one or more criteria and a set of options that compared relatively favourably.

Recommendations from this stage of the research were:

To further explore zoning and charge approaches that included incentives for reducing salinity impact including:

- Charge rebates for irrigation efficiency in proportion to resultant reductions in recharge,

- Zoning areas based on average salinity load per ML of irrigation applied and differentially charging to reflect differences in salinity impact, and

Zoning areas where additional irrigation development is allowed and zones where it is precluded.

Interestingly, the concept of tradeable credits often hailed as the holy grail of efficiency by environmental economists, was rejected for initial consideration.

One reason for this was environmental dependability. Where impacts of a discharge to water or air are very local, the approach can be problematic because permitting trade can lead to a concentration of emissions at one spot where it is particularly harmful. This is the case for the River Murray in the Riverland as shown in Figure 2. Red lines and orange shading areas indicate areas where the floodplain would be at risk from saline groundwater discharge if irrigation took place and no mitigation action was taken.

The risk with a tradeable credit approach in this setting is that irrigators adjacent to at-risk floodplains could buy credits to offset salinity impacts in the River rather than provide mitigation even though this would not be protective of the floodplain.

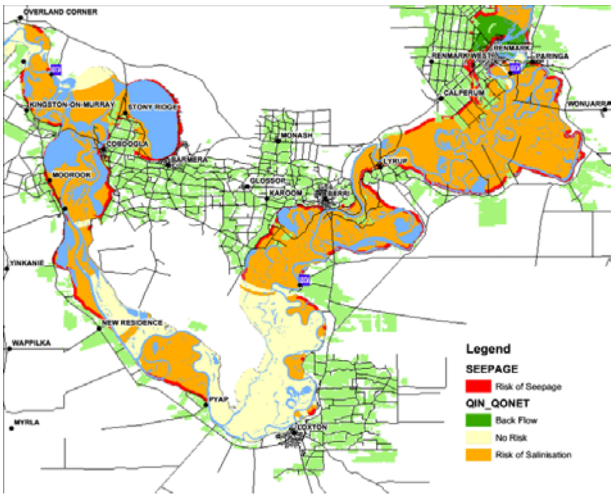

Figure 2: Floodplain salinity risk

In addition, tradeable credit systems are among the most administratively complex of options because an entire salinity property rights system is required to underpin the approach.

The charge approach with impact zones and with rebates for recharge reductions is preferred because it could be implemented in a way that is consistent with floodplain protection goals and still provide strong incentives to reduce salinity impacts. In addition the approach is administratively less burdensome in the sense that it doesn't require a complete salinity property rights system.

As mentioned above, rebates can in principle be offered for a range of activities that reduce salinity including decreasing irrigation drainage, revegetation, and providing dilution flows. Modelling for this project (Connor, 2003) suggested that there is a very limited scope for revegetation that will significantly reduce salinity in less than fifty years. Even less revegetation is justified based on the cost of future salt interception investment that would be required were the revegetation effort not made.

Whilst provision for dilution flows is also a technically feasible option, analysis provided by the MDBC using their River simulation capabilities lead to the conclusion that this approach would be prohibitively expensive if the purpose of flow was reducing River salinity concentrations alone.

The overall conclusion of the screening was to focus more detailed policy modelling on zoning, charges and rebates for irrigation recharge reduction.

5. POLICY MODELLING

The objective of this phase of the project was to assess the potential cost of alternative policy implementations under a range of assumptions about irrigation expansion in the future and values of key uncertain parameters.

The integrated hydrologic-economic model is shown conceptually in Figure 3.

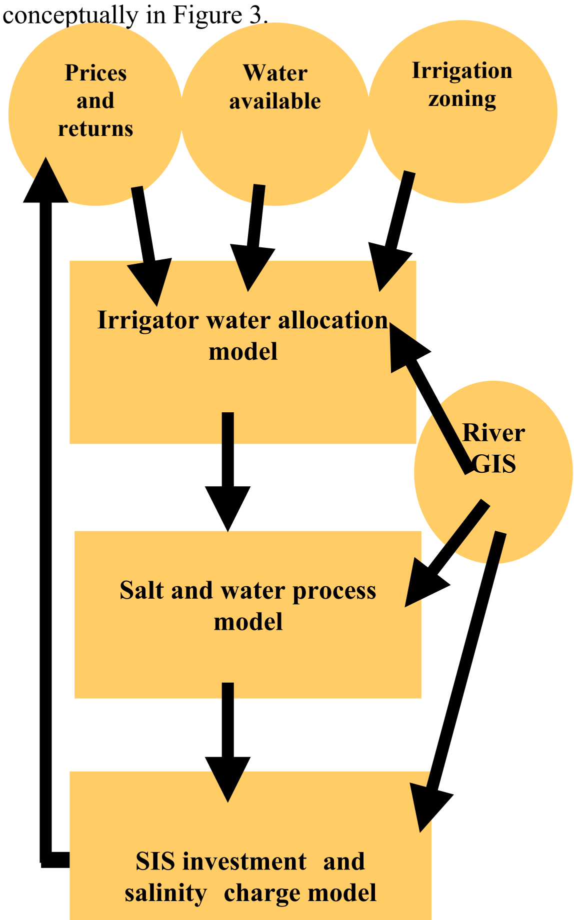

Figure 3: Conceptual representation of hydrologic economic policy model

In essence the model integrates information about the economics of irrigation and salt interception/drainage disposal with estimates of the salinity impact of irrigation. The entire modelling framework is spatially explicit, building on the State Department of Environment and Heritage GIS mapping of River corridor land use and hydrogeology (Miles, Kirk and Meldrum, 2001).

The irrigator water allocation component approximates irrigator decisions about how much irrigation to apply and where. For the sake of simplicity and because no complete survey records exist, all irrigation is assumed to be a rate of 8 ML/ha with 15% or 1.2 ML/ha draining below the root zone. The exception is rebate policy scenarios where half of all irrigators are assumed to achieve 90% irrigation efficiency in response to rebate incentives. Existing irrigation is assumed to continue in its current location in all scenarios. New irrigation development over the next ten years of 0GL and 76GL are modelled. The choice of location is based on a linear programming algorithm that simulates irrigator decisions to find the least expensive site given the cost of water delivery (higher further from the River) and zone differentiated salinity levy rates (lower further from the River).

The water and salt process component builds on hydrogeology modelling by CSIRO (Holland, 2003) and Australian Water Environments (AWE, 2003). Given assumptions about existing irrigation and projected growth, the model predicts loads of groundwater flux and salt to floodplains and the River. By drawing on the GIS cataloguing of spatial distribution of hydrogeology characteristics, differences in groundwater flux and salt load across locations are accounted for.

The SIS investment and salinity charges model has two functions:

1. To estimate the cost of providing salt interception capacity sufficient to offset any increase in groundwater flux that South Australia would be responsible for under the 2001 *Basin Salinity Management Strategy* (MDBC, 2001).
2. To estimate the irrigator salinity charge rates and costs to the SA Government of a range of approaches to sharing cost.

6. MODELLING RESULTS

Some results of modelling across a range of scenarios are shown in Figure 4. The bar graphs show the estimated net present value over 50 years of providing salinity impact mitigation. In each instance this involves the expense of the continued operation of the existing salt interception scheme at Woolpunda, and removal of several floodplain drainage disposal basins. Additional costs vary across scenarios depending on the level of expenditures that would be necessary for additional salt interception to achieve salinity goals in each modelled case.

Lower and upper bound estimates are provided to give a sense of the considerable uncertainty about the engineering efficiency of future salt interception schemes, and magnitude and timing of future impacts from current and future irrigation.

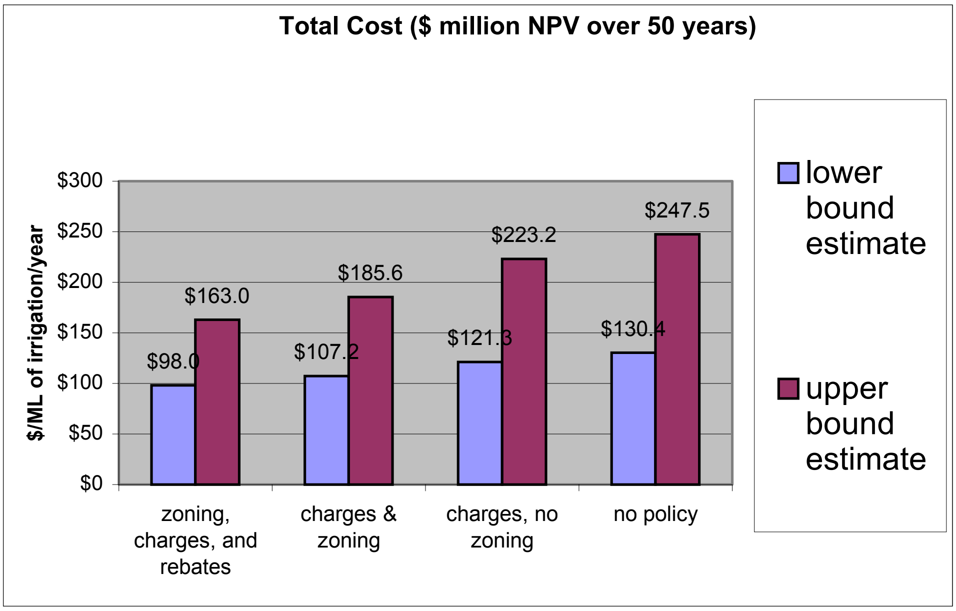

Figure 4: Results: the cost of mitigating salinity

The columns on the far right show that dealing with River salinity could become very expensive if significant irrigation development continues without further policy development. The results shows expected cost of meeting SA salinity obligations under the MDBC agreement if:

- an additional 76 GL of irrigation were brought in from interstate over the next ten years;
- location of new development was not zoned; and
- no salinity levy were implemented.

The second set of columns from the right show estimated cost of a policy involving impact zone differentiated salinity charges to cover the cost of mitigation but no zoning of where new irrigation can locate. These results suggest that charges alone would not lower the total cost or anticipated salinity load greatly. This is because building infrastructure and paying for energy to move water back away from the River to lower salinity impact areas is typically as expensive as (or more expensive than) paying salinity charges.

The third set of columns from the right shows the estimated cost of a policy involving impact zone based charges and zoning that precludes irrigation development in highest salinity impact areas. These result illustrate that precluding further development in the highest salinity impact areas with zoning is effective at a reducing future salinity loads and mitigation expenditures.

Finally, the columns on the far left show the estimated cost of a policy of zoning, charges and rebates for any new or existing irrigator who reduces drainage below a specified level. In the modelled scenario it is assumed that half of all new and existing irrigation achieves 90% efficiency in response to the rebate offer. Some additional savings are estimated to result from the rebate policy. However, saving potential is limited because irrigators are assumed to use water savings for additional irrigation development locally. This in turn increases salinity loading.

7. SUMMARY OF FINDINGS AND FUTURE CHALLENGES

The results of this research show that the costs of meeting salinity goals set for South Australia under the MDBC salinity agreement are likely to be significant. Policy interventions including salinity charges, zoning and rebates for improving irrigation efficiency can considerably reduce this cost.

At least three significant challenges will have to addressed before policy that effectively deals with salinity can be fully implemented:

Sharing policy costs

There are a number of possible arrangements for sharing the costs of mitigating salinity, including:

1. Salinity levy rates set to fully recover costs from irrigators,
2. Salinity levy rates that partially cover cost with the residual paid by tax-payers or urban water users,
3. Variants of options 1 and 2 above that involve lower levy rates for existing irrigators than for new development, and
4. Variants of any of the above options that involve differentiating charges based on impact zones.

Research currently underway to illustrate distribution of costs under a range of options will be used to facilitate discussions with stakeholders about this issue.

Administering policy

Results show that policies such as zoning, charges and rebates can reduce salinity loads and consequent requirements for expensive mitigation. However, significant cost and effort that will be required to implement policies including the development of additional water use monitoring and accounting procedures, zoning rules, and charge and rebate accounting procedures. There is a significant challenge associated with carefully designing policy to keep these costs down.

As the results table indicates, future costs of mitigating salinity impacts are uncertain. An additional administrative challenge involves designing ways to share this risk that provide certainty about costs for irrigators while equitably sharing unforeseen cost rises.

Holistic river management

The analysis presented here focuses on policies to avoid discharge of saline groundwater to floodplains and the River. Fully restoring River ecological health will require significant additional efforts including:

- Increasing the frequency of large water volume flood events to flush salts from wetlands and floodplain;
- Manipulating river level maintenance to periodically drain floodplains currently subject to longer than natural sustained high water tables; and
- Investing in infrastructure to allow maintenance of more natural wetting and drying regimes in sensitive riverine ecosystems.

The cost of the entire effort to restore River health will be significantly more than the cost estimates presented here. For example, significant expenditures on environmental flow acquisition will be required. A key future research challenge will involve exploring ways to coordinate salinity and environmental flow policy to maximise returns to joint investments and administration efforts.

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Upper South East dryland salinity and flood management plan

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Summary
Following expressions of concern from local landholders in the 1980's about decline in agricultural productivity it was discovered that vast areas of the Upper South East of South Australia were becoming degraded due to dryland salinisation. In response a Government/Community investigation revealed that the widespread clearance of native vegetation and the loss of perennial lucerne pastures due to aphid, coupled with a succession of very wet winters, had resulted in a rise in regional groundwater levels. It was concluded that 250,000 hectares of land was salinised and a further 175,000 hectares was at risk if no action was taken. A management plan, including drainage, revegetation, wetland management and saltland agronomy was developed to overcome the salinity and flooding problems. Implementation of the project commenced in 1995.

1. INTRODUCTION

Large areas of land have been degraded by salinisation in the Upper South East region as a result of the combined effects of high groundwater levels and flooding.

There was a significant increase in degradation during the early 1990's. A study in 1993 estimated the area of land affected by salinity to be 250,000 ha with a further 175,000 ha is at risk of degradation due to salinisation (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993). The land at risk currently supports productive agricultural pastures, remnant native vegetation and wetlands.

The study area covered over 680,000 ha to the west of the Keith-Naracoorte road, bounded by the Woods Well-Tintinara road to the north and the Kingston-Naracoorte road to the south.

Over 430 farm businesses, mainly based on beef and sheep grazing enterprises, are supported by the area, which has a rural population of about 2300. Service centres of Keith, Kingston, Tintinara and, to a lesser extent, Naracoorte and Lucindale rely heavily on the agricultural productivity of the land.

Much of the remnant native vegetation in the South East region is located within the study area. Almost 97,000 ha of native vegetation are protected in conservation or national parks, or under heritage agreements. Important wetlands exist in the watercourses, including the Watervalley Wetlands and others along the Bakers Range, Marcollat, Duck Island, West Avenue Range and Tilley Swamp Watercourses. The remnant native vegetation and wetlands in the area are considered to have very high conservation value, as well as supporting rare and endangered flora and fauna species. Wetland habitat and avifauna resources in the area are of international significance.

The accelerated rate of dryland salinisation in the regional is the result of a number of interacting and complex factors. Removal of nearly all of the native vegetation cover has caused increased groundwater recharge and the rise in groundwater levels. This effect has been exacerbated by the later loss of deep-rooted perennial lucerne due to the impact of the lucerne aphid in the later 1970's.

Wet winters and flooding also exacerbate the effect. Higher watertables also increase the rate of surface run-off during winter. Prolonged inundation can destroy ground cover, especially pastures. The salinisation process occurring through summer by evaporation brings more salt to the surface and so further destroys vegetation, which in turn results in more recharge and further raises groundwater levels.

Increasing areas of salinised land were observed following the 1988 floods and successive years of winter flooding, resulting in expressions of concern from the local community.

In 1991, the Upper South East Combined Councils Salinity Committee was formed to seek a government response to the problem.

The Natural Resources Council (formerly Land Resources Management Standing Committee) strongly supported the development of a management plan to address the dryland salinity and flooding problems. The then Minister of Water Resources and Environment and Planning directed that a draft Environmental Impact Statement should be prepared to evaluate the impacts of the proposed management plan.

2. MANAGEMENT PLAN

A draft Management Plan was developed by a community-based steering committee for the Natural Resources Council.

The Management Plan combines four key elements to achieve the best possible solution to dryland salinity and flooding problems while taking into account environmental, economic and social concerns. These elements must all be implemented for the solution to be effective.

The components of the management plan are:
- Surface water and wetland management;
- Coordinated drainage schemes;
- Agricultural production and on-farm measures; and
- Revegetation.

The primary objectives of the Management Plan are to:
- Reverse current trends of land degradation and consequent economic decline caused by salinity and flooding;
- Coordinate drainage and flood management;
- Protect native vegetation;
- Manage and reinstate wetlands to provide habitat and drought refuge for waterbirds; and
- Provide for community needs, in particular the need for a sustainable agricultural base.

The plan has been developed with a view to both short and long term impacts and will:
- Increase the economic return of the area with major pasture redevelopment programs which will yield a net present value of $8.5m over 30 years when compared with the 'do nothing' option;
- Avoid the predicted further 40-45% fall in stock carrying capacity in the region;
- Promote the development of saltland agronomy in the region – an essential requirement for sustainable agriculture;
- Protect remnant native vegetation;
- Provide an opportunity to use good quality surface water to enhance and sustain the biodiversity within wetlands;
- Provide the basis to coordinate, manage and promote wetland resources of international importance;
- Provide a focus for a major long term integrated regional revegetation program;
- Retain the socio-economic character of the region;
- Provide the basis for greater community cooperation and understanding of vegetation, land, water and environmental management; and
- Conserve the natural resources of the area for future generations.

2.1 Surface water and wetland management

The improved management of surface waters to reduce flooding impacts is to be achieved through a major environmental initiative. This is the Wetlands Waterlink, which will use good quality surface water in the watercourses for wetland conservation.

The Wetlands Waterlink is built on the concept of balancing conservation use of water for wetland management, with protection of agricultural land from excessive flooding. The two aims will be combined to produce a solution which has both environmental and agricultural benefits. The proposal is considered to have high potential for increasing tourism in the region, particularly ecotourism based on attractions of world significance.

In conjunction with surface drainage works it is proposed to create a wetland chain and associated habitat corridors from Bool Lagoon to the Coorong along the watercourses. This will provide a link between two wetlands of international importance, through several extended ribbons of swamps, lakes, marshes and native vegetation.

2.2 Co-ordinated drainage schemes

Groundwater levels and associated soil salinisation will be controlled by construction of a regional network of groundwater and surface water drains with outlets to the ocean and the Coorong.

Drainage is the central option that can maintain and improve agricultural productivity as well as reduce environmental degradation. The option is a pre-requisite to on-farm measures in the large salt-affected areas.

Drainage is the key measure which will facilitate all other components. Without improved drainage none of the other measures will be as effective.

Drainage within the study area will be integrated with the Wetlands Waterlink concept so that sufficient water is retained to maintain or improve wetland and native vegetation habitat.

2.3 Agricultural production and on-farm measures

A pasture redevelopment program using salt tolerant and perennial species will deliver increased agricultural productivity to underpin the economic viability of the management plan.

Once adequate drainage is in place, the establishment of salt tolerant pastures on saline land is essential to increase stocking rates.

The success of saltland agronomy (the establishment of salt tolerant grasses such as puccinellia and tall wheat grass and salt tolerant fodder shrubs, particularly *Atriplex* species) will depend upon landholders adopting a new system which involves different stock management and fertiliser practices from those of traditional pastures.

2.4 Revegetation

Revegetation to increase native vegetation and water use in recharge areas is a key component of the integrated management plan.

Revegetation is a high priority option to complement drainage and agricultural renovation and has the potential to be incorporated into both farm and regional revegetation plans. The protection of existing stands of native vegetation is a top priority, closely followed by rehabilitation of degraded areas.

Advice and assistance will be made available to landholders on ways to incorporate revegetation into their forward farm planning.

3. THE 'DO NOTHING' OPTION

The 'do nothing' option is based on observed dryland salinisation rates of salt-affected land in the study area.

Groundwater rises were derived from observed records and generally show average rises of about 0.5 m per decade, although in many areas the summer watertable has already arrived at or near the surface.

Potential agricultural losses over the next 10-20 years have been estimated to be:

- A loss of about 400,000 dse (dry sheep equivalent) carrying capacity – 40% of the current level;
- A long term loss of \$9.2m in annual farm gate income;
- A long term loss of \$5.9m in annual gross margins;
- A permanent loss of 14,500 ha (approximately 46%) of highly productive land (currently carrying 7.5 dse/ha);
- Productivity losses averaging 40% for approximately 150 farm businesses; and
- Long term loss of 100 jobs.

As the effects of salinity increase under a 'do nothing' option and the productivity of the area reduces, the smaller farming properties would become less viable. Increasingly, adjustment would occur with the small properties being taken up by larger landholders. With the high expense of establishing lucerne on the high ground and the limited production on the flats, these larger holdings would be run as 'station' type grazing enterprises. Management would involve even less labour with lower inputs and lower stocking rates.

If the farm establishment numbers decrease and sizes increase, the rural population would reduce. Consequently the service centres of Keith, Naracoorte, Lucindale and Tintinara would suffer.

4. ENVIRONMENTAL RISKS

The study area includes significant stands of remnant native vegetation, wetlands and conservation parks. These areas are already being affected by dryland salinity and flooding. Impacts are likely to increase in the future. Recent effects include increased frequency and volumes of flows to downstream wetlands, and local salinisation of low lying, landlocked swamps in the north.

Valuable wetlands exist along the Bakers Range and Marcollat Watercourses and on other watercourses. Earlier drainage works deprived these wetlands of water, but now increased surface water flows, due to uncoordinated private drainage works and rising watertables, feed water to these wetlands more often and with altered water quality.
Continued inundation and evaporation will lead to increased salinisation of the terminal wetlands in the longer term. Controlled and coordinated water management is necessary to maintain the integrity of many of the wetlands.

Implementation of management strategies that result in increased drainage will have environmental implications for the disposal of drainage waters. Disposal options include ocean outfalls, the Coorong or use of low lying areas as disposal basins. Such impacts must be balanced against the protection of the region's agricultural productivity and other social benefits.

5. GOVERNMENT APPROVAL

In June 1995 the State Government approved the staged implementation of the integrated catchment management plan. Because of the importance of the drainage component the State Government agreed to contribute financially to the \$24 million construction program. This approval was conditional upon the Commonwealth Government contributing 37½% of the cost and the local community contributing the remaining 25%.

The Commonwealth Government endorsed the management plan in July 1996 subject to a number of conditions, most of which were related to the protection of the environment, in particular the Coorong.

6. IMPLEMENTATION

Implementation of the management plan commenced in 1995 with the design of the first stage of the drainage component. Since then a total of 221 km of drains has been constructed and an additional 34 km of privately constructed drains acquired and incorporated into the regional drainage network.

The extent of the proposed drainage network, shown in Figure 1, has increased as more detailed investigation and consultation with landholders has occurred. The current proposal is for a further 350 km of drains to be constructed and 60 km of privately constructed drains upgraded for inclusion in the scheme.

Revegetation activity has been achieved via incentive grants to landholders. To date 6,560 ha of remnant native vegetation and 2,650 ha of wetlands have been protected by fencing. In addition, 16,500 ha of perennial pasture and 1,250 ha of native vegetation has been established.

7. REFERENCE

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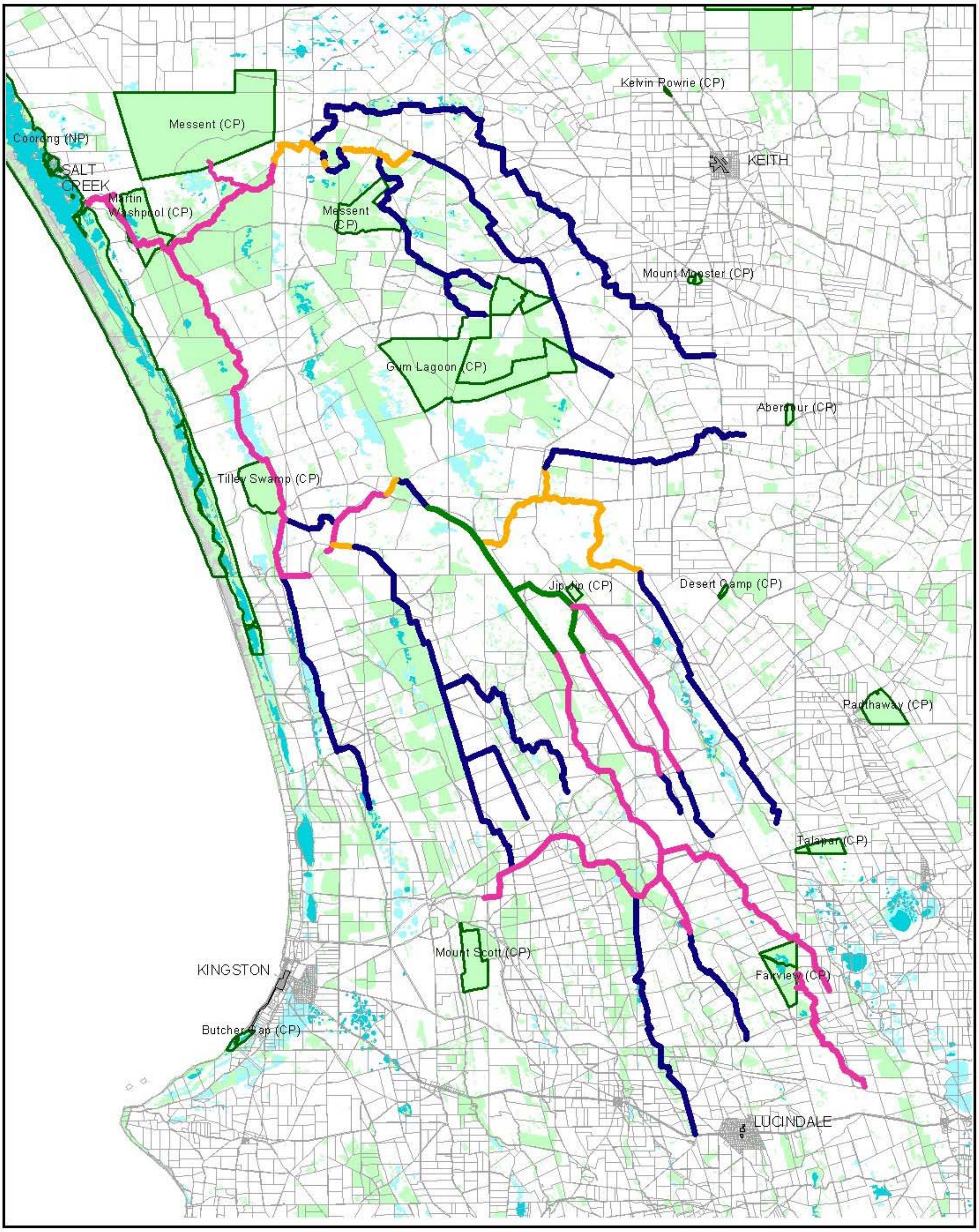

Figure 1: Extent of proposed drainage network of the Upper South East Dryland Salinity and Flood Management Plan

Holding the line for salinity in the River Murray in SA: illusion or reality?

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Summary
South Australia faces increased salt loads to the River Murray as a result of land clearing and in particular irrigation development. South Australia has made commitments at the Murray-Darling Basin level and the State level to hold the line on salinity levels, protect floodplains and wetlands from salinity impacts and to make irrigators more accountable for their salinity impacts.
To ensure that the objectives and targets set will be met, South Australia is developing new salinity management policies. South Australia is developing a salinity zoning system based on potential salt loads to the edge of the River valley, floodplain biodiversity value and capacity to absorb increased groundwater discharge and the capacity of salt interception schemes. Salinity charges need to be combined with rebates to encourage continued improvement. The charges need to be designed so that they provide incentives for new irrigation development in locate in low impact areas and recover the cost of the continued investment in salt interception schemes by South Australia.

1. INTRODUCTION

The River Murray in South Australia is a natural drain for salt moving through regional groundwater systems in the Murray-Darling Basin. Groundwater salinities in the South Australian portion of the Basin are high, in some cases exceeding that of seawater (greater than 50 000 EC (Electro-conductivity unit = µS/cm) therefore there is a significant natural inflow of salt to the River Murray in SA.

The rate of natural salt inflow to the River has been greatly increased by Mallee land clearing and irrigation developments. Both have contributed to rising groundwater levels, resulting in greater inflows of saline groundwater to the River.

Increased salinity of River water has a wide range of potential impacts such as:

- crop damage and reduced productivity for irrigators;
- increased maintenance costs for urban supplies and salinity above desirable maximum level for drinking water;
- increased costs for industrial users;
- deteriorating health of the floodplain: 30-50% of the floodplain is likely to be affected in 30-50 years; and
- reduced recreational, fauna and cultural values.

South Australia faces large future salt loads to the River Murray that have already been set in train as illustrated in figure 1. South Australia is not attempting to bring salt loads back to natural levels, but is committed to:

- ‘hold the line’–to maintain salinity in the River Murray at 2001 levels;
- protect and enhance the health of the River’s floodplain and wetlands from the impacts of salinity (Government of South Australia, 2001).

These goals, in themselves, present a big challenge for South Australia. Irrigation development, its location and practices, will in large part determine what the future additional salt loads will be to the River, and therefore the feasibility and costs to South Australia of meeting its salinity goals.

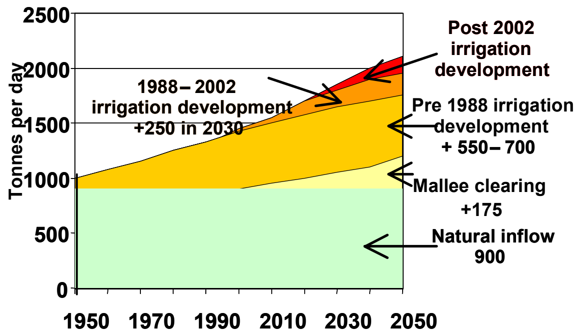

Figure 1: salt loads set in train (sources: AWE, 1999, Barnett et al, 2002)

A salinity management framework for the River Murray in SA will need to focus on:

- **Salinity zoning** to ensure new irrigation development does not occur in areas with high salinity and floodplain impact risk;
- **Salinity charges** to recover costs of investment in salt interception and to provide incentives for locating irrigation development in low salinity impact locations; and
- **Salinity rebates** to encourage on ground action, preferably at a district level, to minimize the salinity impacts of existing irrigation.

Without such policies, South Australia will face ever increasing salt loads and salinity mitigation costs and will not be able to maintain River salinity targets or protect the River’s floodplains and wetlands.

This paper describes how these policies are being developed.

2. SALINITY POLICY WITHIN THE MURRAY-DARLING BASIN

2.1 Policy development

The problem of increasing River Murray salinity has been recognised for over a decade and a range of policies and actions have been undertaken at the Murray-Darling Basin level to address the issue. The first step was the development of the Salinity and Drainage Strategy in 1988. Key elements of this strategy (Murray-Darling Basin Ministerial Council (MDBMC), 1989) are:

- New South Wales, Victoria and South Australia are accountable for the salinity impact of all future action after 1 January 1988;
- South Australia agreed to be salinity neutral;
- A joint program of salt interception schemes has been developed and paid for by the New South Wales, Victorian, South Australian and Commonwealth governments (for example, Woolpunda and Waikerie), reversing the salinity trend in the river over the period 1990-2000.

A Salinity Audit (Murray-Darling Basin Commission (MBDC), 1999) showed new threats to the River Murray and indicated that more work is needed to prevent salinity in the River increasing again (see figure 2).

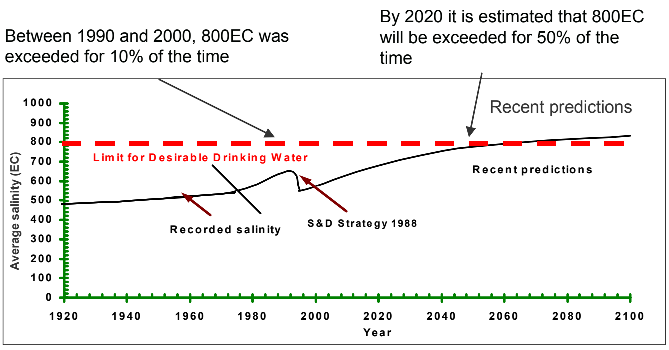

Figure 2: River Murray salinity impact trends (source: MDBC, 1999)

In response to the Salinity Audit, the Basin Salinity Management Strategy was agreed to in 2001 by the Murray-Darling Basin Ministerial Council (MDBMC, 2001). Key elements of this strategy are:

- A target to maintain River Murray salinity below 800 EC at Morgan for 95% of the time;
- All sources of salinity are to be accounted for, with:
  - a register for new developments after 1 January 1988, replacing the register that already exists under the Salinity and Drainage Strategy;
  - a register for salinity impacts resulting from decisions in the past, such as irrigation development before 1988 or land clearing;
- A new program of jointly funded salt interception schemes aimed at offsetting the salinity increases resulting from land clearing and irrigation developments before 1988, as well as providing some capacity to off-set salinity impacts from new (post-1988) developments.

2.2 South Australia's position

South Australia has seen significant irrigation developments since 1988, as a result of interstate water trade, activation of unused allocations and improved water use efficiency due to water delivery system upgrades in the irrigation districts.

Approximately 70 Gigalitres of water was traded permanently within and into South Australia between 1988 and 2001, leading to an additional 250 tonnes of salt/day reaching the River valley by 2032. Some of the impacts of this new development have been offset by improved water use efficiency and reduced losses from water delivery systems, but not all. SA faces a 4.7 EC debit in 2004, increasing to more than 20 EC by 2032 if no further action is undertaken.

South Australia needs to bring the salinity registers in balance. Construction of salt interception schemes and further improvements in water use efficiency can help to offset the impacts of existing irrigation development, but future irrigation development needs to be located in low salinity impact areas, otherwise it will not be possible to achieve the salinity objectives for the River Murray.

Failure by South Australia to meet its salinity obligations under the Murray-Darling Basin Agreement would have significant implications for the negotiation position about other critical issues, such as environmental flows.

2.3 Salinity management in Victoria

In the Nyah to the Border reach in Victoria, which covers the Sunraysia region, salinity management policies have been in place since 1993 as part of the Nyah to the Border Salinity Management Plan (SRWA, 2002). The policy consists of salinity zoning to direct water transfers away from high salinity impact locations and levies that provide incentives to irrigate in the lowest impact zones and to contribute to the cost of salt interception.

The zoning system consists of:

- A high salinity impact zone where no water can be traded into. Water can trade out or within the zone;
- Two lower salinity impact zones (LIZ 3 and 4) where water can be traded into subject to a cap;
- Two even lower salinity impact zones (LIZ 1 and 2) where water can be traded into without any cap.

Zones are based on hydrogeological modelling, which was signed off by the Murray-Darling Basin Commission.

A salinity levy applies to each trade into a zone: either a charge up front for 10 years or an annual charge.

- Annual charge varies from $6.41/ML to $35.24/ML. Slightly lower charges apply to temporary trade;
- Ten year up front charge varies from $ 26/ML to $260/ML and there is a $3.20/ML annual charge for operation and maintenance.

There is pressure on South Australia to adopt a similar set of policies.

3. SALINITY POLICY IN SOUTH AUSTRALIA

While each State is responsible for meeting the salinity targets agreed to in the Basin Salinity Management Strategy, exactly how this is achieved is 'State business'. South Australia has set out key elements of a River Murray salinity policy in a series of documents, as outlined below. Through this process, South Australia has determined to not only limit River salinity to 2001 levels (continuing to uphold the 800 EC target at Morgan), but also to protect the River's floodplain and wetlands from salinity impacts. In addition, South Australia has stated that irrigators should be accountable for offsetting their salinity impacts.

3.1 South Australian River Murray Salinity Strategy

Key elements of the Strategy are:

- Accountability for salinity impacts from irrigation practices is assigned to all irrigators;
- Protect floodplains and wetlands by preventing development in certain adjacent highland zones and prioritising salinity mitigation works;
- A range of mitigating actions will be pursued including revegetation, reducing irrigation drainage, investment in drainage management infrastructure, saline groundwater mitigation and purchase of credits (SA Government, 2001).

3.2 Select Committee on the Murray River

This Committee of Parliament was set up to investigate the key issues facing the River Murray in South Australia. Key recommendations of the Committee's report with regard to salinity are:

- Define areas of low, medium and high salinity impact risk, as proposed in the River Murray Salinity Strategy;
- Develop and implement effective planning and administrative policies and processes to:
    - ensure that all irrigators are accountable for the salinity impact resulting from their irrigation practices;
    - manage 'ribbon' development adjacent to the River Murray;
    - encourage existing irrigation development to move from areas of high impact to areas of low impact (Parliament of SA, 2001).

3.3 Water Allocation Plan for the River Murray Prescribed Watercourse

The Water Allocation Plan describes the criteria for the allocation and transfer of water from the River Murray Prescribed Watercourse.

Irrigators within the River Murray Irrigation Management Zone are required to offset salinity impacts and prevent or offset impacts on the floodplain.[1]

- All irrigators who obtained their allocation after 1 January 1988 need to undertake actions by 30 June 2003 to offset their salinity impacts on the River and the floodplain;
- Irrigators with pre-1988 developments are accountable for salinity impacts above 2002 levels and have until 2010 before their accountability comes into effect;
- Water transfers from 30 June 2003 will not be approved if they have detrimental impacts on the floodplain or if salinity impacts can not be offset.

4. NEW DIRECTIONS FOR SALINITY POLICY IN SA

Based on the policy directions at the Murray-Darling Basin and State level, a range of policies is now being pursued.

4.1 Salinity zoning

Salinity zoning can help to direct new irrigation development away from high salinity impact locations. Salinity impact needs to be expressed both in terms of salt to the river and floodplain salinisation risks. In addition, the presence or absence of salt interception capacity needs to be taken into account.

The Irrigation SIMPACT tool has been developed to predict the potential salt loads from new irrigation development to the edge of the River valley (Miles et al, 2001). **Figure 3** shows the process that is being modeled: irrigation leads to excess drainage, which leads to recharge to the groundwater, which leads to increased groundwater discharge to the edge of the River valley.

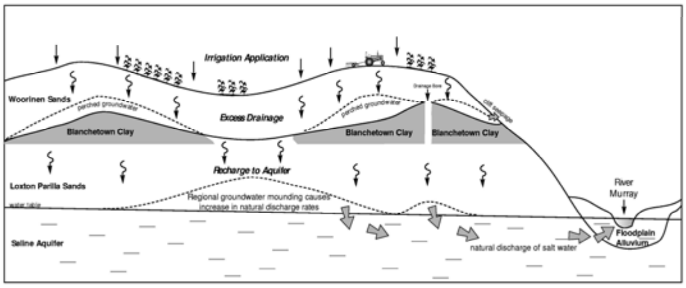

Figure 3: Relationship between irrigation and groundwater discharge (source: Miles et al, 2001)

The tool combines hydrogeological modelling and spatial information. The potential salt loads vary considerably, depending on the salinity of groundwater, drainage volume, distance from the River, depth to

1 The River Murray Irrigation Management Zone is defined in the River Murray Water Action Plan and contains all land within the River Murray Catchment Water Management Board boundary, except for the Lower Murray Reclaimed Area Irrigation Management Zone and the Angas Bremer Irrigation Management Zone.

groundwater and presence or absence of clay. This model can be used to identify areas of higher and lower salinity impacts.

The Irrigation SIMPACT tool does not provide an insight into floodplain salinisation risks. Another tool is used to provide this information, developed through the Floodplain Impacts Project (FIP) (Holland et al, 2003).

Figure 4 shows the processes described by this tool: increased groundwater discharge can lead to seepage, increased evapotranspiration or increased baseflow to the River. Floodplain salinisation risk depends mainly on the depth of the groundwater table below the surface of the floodplain. Wider floodplains are more at risk. Due to River regulation, some areas of the floodplain already experience very high groundwater levels, while others have "excess capacity": the groundwater discharge levels to the edge of the River valley can increase without impacting on floodplain health.

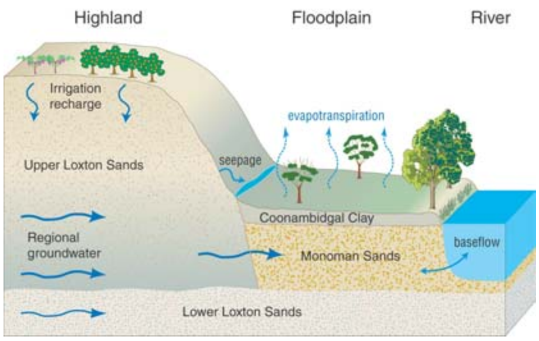

Figure 4: Impacts of increased groundwater discharge on the floodplain (source: Holland et al, 2003)

This model can be used to identify areas with low floodplain salinisation risks. It should be combined with information about floodplain and wetland health, conservation significance and rehabilitation potential where that information is available.

In addition to the Irrigation SIMPACT tool and the FIP tool, consideration should be given to whether a location is already protected by salt interception schemes. Interception schemes pump the regional saline groundwater and reduce saline discharge to the edge of the river valley. It is generally assumed that irrigation development can occur behind schemes, up to the capacity of the schemes to pump and dispose of the additional groundwater, without impacting on River salinity or increasing floodplain salinisation risks.

It is not possible to offset floodplain salinisation impacts resulting from irrigation at one site by undertaking action at different locations, but there is some opportunity to offset increased salt loads to the River at one site by using salt interception at another location to reduce natural or historic groundwater discharge. This works well when impacts from a low salinity impact location are offset by pumping highly saline groundwater elsewhere, because a relatively small volume of water needs to be pumped to capture the equivalent amount of salt.

Salinity zoning along the River Murray in South Australia will likely lead to:
Salt interception zones: where irrigation development can be allowed up to the capacity of the scheme;
High risk zones: where irrigation development is not allowed because of salt loads and floodplain salinisation risks; and
Low risk zones: where irrigation development can be allowed up to a level because it does not lead to high increases in salt loads to the River (and they can be offset by salt interception elsewhere) and the floodplain salinisation risk is low.

4.2 Salinity charges

South Australia is committed to significant investments in salt interception if the salinity targets for the River Murray are to be met. Based on the irrigation development already present, a range of schemes will need to be built or expanded, for example at Loxton, Bookpurnong and Woolpunda (Telfer et al, 2003).

A salinity charge could ensure that the cost of constructing, operating and maintaining salt interception schemes are met, at least to some extent, by the irrigators.

Even though the salinity impacts set in train as a result from future irrigation developments can take a long time to reach the River valley edge, it makes sense to apply a salinity charge from the start. The charge can be designed in such a way that sufficient funds are available when the salt interception capacity is needed. (Connor, 2002).

For existing irrigators, contributing to the cost of a salt interception scheme is one of the few feasible options to offset their salinity impacts. For new irrigation developments and to a lesser extent for existing irrigation developments, there is an opportunity to use charges to provide incentives for locating in the low salinity impact locations.

When designing a salinity levy, it is desirable to provide incentives for continuous improvement of irrigation practices to reduce salinity impacts. Salinity impacts can be significantly reduced by reducing drainage past the root zone. A rebate policy linked to the salinity charge for irrigators that can demonstrate drainage volume reductions below specified target levels is therefore being considered.

The Irrigation SIMACT model defines potential salt loads to the edge of the River valley and can be used to define salinity charge zones. The low risk zone and salt interception zone could be further subdivided and charges could be set for each zone so that there are incentives for irrigation development to locate in the lowest salinity impact locations, generally furthest away from the River and/or furthest downstream.

There are still discussions about distinguishing between existing and new irrigation developments and whether such a distinction should be temporary or permanent. One approach would be that existing irrigators cover the cost of operation and maintenance of schemes while new development pays for the full marginal cost of the additional salt interception capacity required. Another option would be to gradually change the contributions from existing irrigators to eventually also cover the full marginal cost.

The distinction in the Water Allocation Plan between pre1988 and post 1988 irrigation development, is logical when defining the State's accountability under the Murray-Darling Basin Agreement, but it does not appear to very practical or equitable when defining the irrigator's accountability for salinity impacts.

4.3 Implementing salinity zones and charges

The concept of salinity zoning, charges and rebates has been widely discussed with relevant stakeholders and received widespread in principle support. However, irrigators certainly argue for a combination of polluter and beneficiary pays when it comes to designing a salinity levy: all users of River Murray water benefit from reduced salinity and improved floodplain health.

Zoning policies are welcomed because they provide certainty for developers, but there are transitional issues that need to be dealt with when introducing such policies.

Both salinity zones and salinity charges will be discussed with all relevant stakeholders in the near future. The River Murray Bill includes provisions for both policy instruments. Salinity zoning can be implemented through the policies the Minister for the River Murray uses to guide the power of direction for all water transfers and changes in land use involving irrigation from the River Murray. The Minister can direct refusal of transfers or development approvals or impose conditions.

The option of a salinity charge is provided for as part of the existing catchment levy. The funds raised will have to be spent on actions that reduce salinity in the River Murray.

5. CONCLUSION

South Australia faces a major challenge if it wants to hold the line on salinity in the River Murray, particularly if the aim is to protect the floodplains from increased salinisation risks as well.

Significant commitments have been made at both the Murray-Darling Basin and State level. To meet these objectives and achieve the targets set, innovative salinity policy is needed, backed by good science and information.

A combination of salinity zoning, salinity charges and provisions for rebates to encourage continuous improvement provides the best chance for South Australia to be accountable for salinity impacts and to meet the salinity targets for the River Murray.

6. ACKNOWLEDGEMENTS

The author wishes to acknowledge the following people who have greatly contributed to the thinking about salinity management policies in South Australia:

- Phil Cole, Program Leader Salinity, Murray-Darling Division, DWLBC.
- Jeff Connor, Policy and Economic Research Unit, CSIRO
- Judith Kirk, Senior Policy Officer Salinity, Murray-Darling Division, DWLBC.

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Salt damp attack on concrete footings - a negative outcome of soil salinity

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Summary
Land clearance for urban and rural development has brought with it the attendant problem of dryland salinity and, in some regions, activation of the oxidation process in acid sulphate soils. Land development has also meant widespread irrigation practices have been employed to grow shallow rooted crops in rural areas and to give urban dwellers more free time with most households now having automated microirrigation systems. These practices in concert have lead to an upwards rise of the ground watertable bringing with it soluble salts which then concentrate in near surface soils. Thanks to the splendid research work and dissemination of advice by the Salt Damp Research Committee (SDRC) in the mid-late 1970s we, as a community in South Australia, learnt how to eradicate salt damp attack in new masonry and to effectively treat walls of our heritage buildings.

The emphasis of this earlier research work on masonry walls however, did not specifically extend to prevention or treatment methods for salt damp attack on exposed portions of concrete footings. This paper delves into salt damp attack of concrete footings and gives guidance on relatively simple and straightforward preventative/remedial measures that can be considered by building practitioners to manage the risk of concrete deterioration caused by salt damp.

(Keywords and phrases : dryland salinity, salts, salt damp, salt damp attack, slab edge dampness, salt hydration distress, concrete permeability, physical salt attack).

1. INTRODUCTION

Salt weathering, salt hydration distress[1] and slab edge dampness[13] are all synonyms used here or in the international arena to describe what South Australians since colonisation have always referred to as *Salt Damp* or *Salt Damp Attack*.

The potential for salt damp attack occurs in all porous building materials in semi-arid and arid climates where soluble salts in solution penetrate porous, permeable materials, such as concrete, stone, bricks, renders and mortars by capillary action and salt transfer mechanisms such as advection and diffusion. *Rising Damp* also occurs in many regions of the world. It is only when water soluble salts are carried in solution and the solution permeates into building materials that actual salt damp attack occurs. It is also important to appreciate that water in vapour form does not carry salts with it when vapour state transfer in a host medium takes place in response to suction (pF) variations.

Salts are only conveyed into and through a porous and permeable material when they are in solution. Therefore as water evaporates in vapour form from surface pore spaces in susceptible materials such as concrete, salt crystals are left behind to both grow and undergo crystalline phase change. The salt crystals exert a physical pressure and hence tensile stress on the host pores of a magnitude sufficient to cause surface exfoliation.

Salt damp attack has affected many historical monuments and old buildings because they have lacked effective barriers to the rise of salt laden moisture. It also attacks the exposed faces of current day concrete footings where encapsulation within a polythene underlay does not apply.

It is important that we deal appropriately with this cowardly and recalcitrant invader because salt damp attack, while of a cancerous nature, is nevertheless treatable or preventable if building practitioners pay the phenomenon the respect it rightly demands. At the end of the day we are all endeavouring to preserve the built environment for future generations, under the advancing threat and omnipresence of dryland salinity.

It is this ultimate degradation of permeable building components, such as concrete footings at exposed surfaces, which gave rise to the term “attack” when discussing salt damp. Salts derived from cations of sodium, calcium and magnesium and anions of sulphate, carbonate, nitrate and chloride have been identified in studies conducted in South Australia and elsewhere as being the destructive salt derivatives causing salt damp attack.

It is hoped that this paper will shed some further light on the attack mechanism and give an insight into at least one simple method of mitigation in relation to concrete footings.

2. BACKGROUND

Since colonisation, dwellings in many Adelaide suburbs have had to contend with salt damp attack on footings, slabs and masonry. They have also had to deal with the attendant cost to remedy such damage.

Mounting consumer concern in the early-mid 1970s saw the formation of the Salt Damp Research Committee (SDRC) by the state government of the day. The committee produced a total of three technical and informative reports[2, 3, 4] dealing with all aspects of what it referred to as the *scourge* of salt damp in South Australia.

The first report[2] described the widespread extent of the problem in metropolitan Adelaide at the time and discussed salt damp effects on the resale value of properties. It also mentioned possible health implications for occupants of salt damp affected buildings. The second report [3] was actually a publication of national conference proceedings for a conference on salt damp held in Adelaide on 20 and 21 March 1978. The third and final report[4] discussed various remedies that were in use by specialist treatment companies and how best to disseminate useful information into the community and to builders.

The terms of reference under which the SDRC undertook its tasks and reported to the government are of sufficient importance to replicate here. They are equally relevant to attack on concrete footings today.

Terms of Reference

1. Provision of information to the public, aimed at preventing salt damp attack in new buildings.
2. Provision of information aimed at reducing the likelihood of salt damp attack in existing buildings.
3. In the context of salt damp, promotion of superior building design and construction techniques and the dissemination of information to suitable institutions, designers and tradesmen.
4. Provision of information to the public on ineffectual cures or treatments currently being used.
5. Direction of research to produce convenient and economic salt damp repair methods.

The author's company has noted a steady increase in slab edge dampness (salt damp) investigations of concrete house footings over the past 5-10 years. It is anticipated that with land affected by the spread of dryland salinity[5] and the presence of acid sulphate soils[6] in coastal areas (and elsewhere) both rising in popularity with developers, this can only mean a concomitant increase in slab edge dampness problems in the future.

It is therefore important for all building practitioners to be vigilant in developing new and existing skills to adequately deal with the possibility of a renewed wave of salt damp attack, this time not concerning superstructure masonry but affecting exposed and unprotected parts of concrete footings.

3. WHAT IS SALT DAMP OR SALT DAMP ATTACK

Salt damp, or at least conditions that are conducive to ultimate salt damp attack, can be identified by the initial appearance at the concrete surface of blooms of white coloured fibrous looking or crystalline salt deposits usually in an irregular pattern or undulating line on exposed evaporative surfaces.

This can sometimes be as innocuous as salts contained in the material (e.g. concrete or masonry) leaching out when buildings are new, amounting to no serious consequences at any later time in the life of the structure. This is known as *efflorescence.* In most instances however, the initial appearance of salts on the exposed outer faces of concrete footings, or perhaps on the outer perimeters of floor slabs in the interior of a building, is a pointer to the inevitability of eventual salt damp attack that may escalate to a degree of severity that will result in progressive exfoliation at the concrete surface. This is what the author refers to as *slab edge dampness*.

In the author's opinion the accurate identification of salts involved in salt damp attack on concrete is only of academic importance. It is of lesser importance to the building practitioner than contemplation of preventative or remedial measures to mitigate surface deterioration following initial detection. After all, it is a surface (external) attack mechanism of a physical nature caused by the exertion of salt expansion pressure on surface pores and is readily detectable by visual and tactile means.

Slab edge dampness should not be confused with the more traditional internal sulphate attack of a concrete member in the presence of a sulphate enriched environment. Sulphate attack begins with micro cracking and proceeds to the eventual disintegration of the hardened mix, affecting the whole of a member such as a footing beam or slab, or both, and is not just surface deterioration at the exposed evaporative face.

This mechanism concerns the internal creation of crystalline ettringite and gypsum in a complex chemical reaction between the tricalcium aluminate (C_3A) in the cement and invasive sulphate salts forming calcium sulphoaluminate (CSA). The ettringite and gypsum cause a volume increase which ultimately leads to break-up of the mix from within.

The SDRC established what it referred to as an *equation* defining the *variables* involved in salt damp attack. It has well and truly stood the test of time and remains entirely valid for salt damp in concrete footings.

Salts + moisture + pervious material + evaporation = salt damp[3].

Should any one of the variables on the left hand side of the equation not be present, or available, then salt damp attack will not take hold.

4. THE SOURCES OF SALTS

Water soluble salts must be present in the ground or building materials, or both, for salt damp attack to initiate. Sources of salts in salt damp prone areas are derived from the following events.

4.1 The palaeogeography of a region

Many places in the world including Adelaide and Los Angeles, as just two examples, once had ancient sea water incursion over land that is now a plains or basin area ultimately cleared for development. With the progressive onset of climate change to semi-aridity salts accumulated to be leached down into the soil profile by rainfall and intermittent flooding events.

4.2 Weathering of high ground and acid sulphate soil processes

The Adelaide Plains and Los Angeles basin regions have accumulated weathered rock detritus, including salts, that have been washed down from the surrounding hilly slopes during the ancient weathering process. In some regions of the world, again using Adelaide and the LA basin USA as examples, pyrite (iron sulphide F_eS_2) has been deposited. When pyrite undergoes oxidation, sulphuric acid is generated as a bi-product with the chemical reaction represented as follows.

$$F_eS_2 + H_2O + 3\tfrac{1}{2}O_2 \xrightarrow{\text{Oxid}} H_2SO_4 + F_eSO_4$$

This sulphation process when activated can therefore be a ready source of sulphates which have been found to be the predominant salts involved in the most aggressive instances of salt damp attack.

Nationally, there is an estimated 40,000 squ. km of coastal acid sulphate soils containing well over one billion tonnes of sulphide compounds. If drained for future development these areas of land will become mobilised acid sulphate soils producing sulphates in significant quantities which will then become available to attack concrete footings.

4.3 Rising groundwater

Vegetation clearance and extensive use of irrigation have combined to cause groundwater tables to rise closer towards the soil surface. The clearing of land and gradually rising water tables are processes that have interfered with natural soil moisture depletion by evapotranspiration as the total number of trees and plants has been reduced from naturally occurring landscapes under the influence of urban sprawl and for farming.

R.A. Legg has postulated a soil moisture transmission model as a means of explaining the possible reason for the high capillary rise of saline groundwater working its way up to and beyond the soil surface to penetrate building footings and superstructure walls(7).

The model is reproduced as Fig. 1 with the author's acknowledgement of messrs. Legg, Cooke and Goudie regarding its creation and subsequent modification.

It has been postulated that rising groundwater brings with it dissolved salts which concentrate in the capillary fringe zone to eventually be drawn upwards by suction gradient towards the ground surface and within striking distance of shallow building footings.

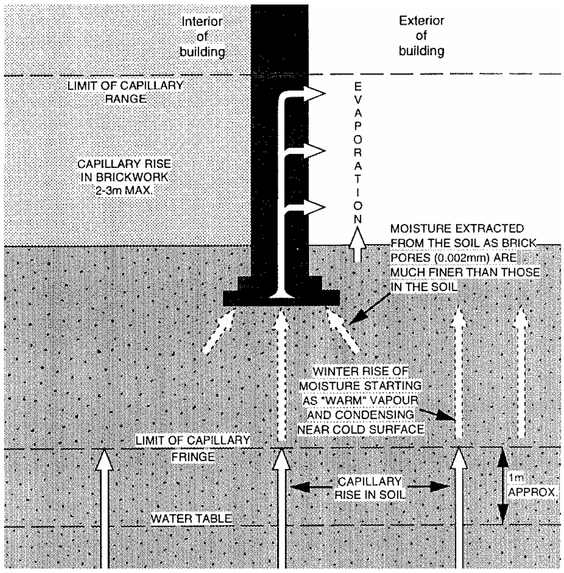


Figure 1: R.A. Legg's model explaining the capillary rise of moisture in buildings several metres above the watertable. Modified from Cooke (1994: figure 12.8) and by Goudie(7).

4.4 Salt spray

Air borne salt is deposited on our urban infrastructure in cities located close to the ocean and which have semi-arid and arid climates. Gypsum (calcium sulphate $CaSO_4.2H_2O$) is not very soluble in water but increases markedly in solubility when sodium chloride is present therefore coastal areas are more likely to suffer more from salt damp attack due to the influence of sea spray.

4.5 Industry and Vehicle Pollutants

Industrial and vehicular emissions of sulphides, nitrogenous compounds and carbon dioxide exacerbate salt concentrations when these pollutants infiltrate the soil or are deposited on our buildings.

4.6 Human intervention

The application to soil of ground improvement chemicals such as sulphates (e.g. gypsum), phosphates and nitrates as either soil conditioning agents or fertilizers can increase the overall concentration of salts in the near vicinity of building footings thus increasing susceptibility to salt damp attack.

5. THE PERMEABILITY OF CONCRETE FOOTINGS

Residential concrete footings and slabs are normally cast partially within the ground using pre-mixed grade N20 concrete(8). A means of protecting footing sub-beams and slabs from sources of groundwater using approved 0.2 mm thickness polythene underlays has been successfully employed by designers and builders in Australia for many years. There is however, at least one serious shortcoming of this technique relating to the termination point of the underlay in the case of raft type footings.

It is neither practical nor appropriate to carry the underlay up the outer (exposed) footing face after the edge formwork shuttering is removed. If this is done the underlay suffers from mechanical damage (ripping and tearing) and it deteriorates rapidly over time with constant uv exposure. Therefore, the upper, outer edge of a concrete raft footing is normally left unprotected against lateral transfer of dampness from perimeter pavements and basecourses (usually sand blends) that are placed against footings.

On clay sites with poor drainage a paving contractor may even create a moat effect by excavating the ground to lay the basecourse. The basecourse then collects surface runoff water from rain and garden watering and holds this moisture such that it remains in intimate contact with the most permeable upper section of the footing edge (the moat effect).

The processes of advection (moisture suction differential) and salt diffusion (concentration differential) described later in this paper then cause soluble salts from the ground that are being held in solution to be drawn into the concrete matrix via continuous capillary pathways (i.e. interconnecting voids).

The degree of permeability of concrete is therefore an important factor concerning moisture intrusion and diffusion through the edge beam footing or edge beam footing and slab edge in the case of raft footings.

The author understands that pre-mix concrete suppliers at least in South Australia, manufacture grade N20 concrete mixes using water:cement ratios (w/c) in the range 0.80-0.88. Figure 2 illustrates the relationship between permeability and w/c ratio. This clearly shows that w/c ratios in the 0.80-0.88 range are off the scale with respect to permeability rating so these mixes are considered highly permeable.

Table 1 shows the approximate age required to produce segmented (i.e. discontinuous) capillaries as gel paste reaction fills void pathways that would otherwise prevent moisture transmission into and through the mix. It can be seen that for w/c ratios in excess of 0.70 segmentation of capillaries can never be achieved.

It is most likely that designers and builders will not elect to specify and build with stronger concretes that will have lower w/c ratios due to the associated cost increase. In Section 8 of this paper the author discusses a more economical alternative that has thus far proven to be an effective preventative measure when properly applied.

6. SALT EFFECTS

In porous building materials containing water soluble salt crystals that are in equilibrium with a saturated

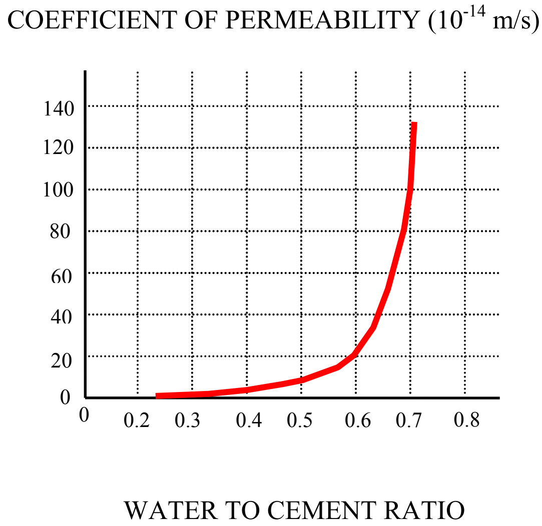


Figure 2: *Effect of Water-Cement Ratio on Permeability of Cement Paste*[9]

solution, larger crystals will grow in size at the expense of smaller. In specific building materials such as grade N20 concrete there will always be an assemblage of macro and micro porous regions. Such materials are highly susceptible to salt damp attack as both crystalline growth and salt hydration pressures are exerted on host pores whenever moisture evaporation takes place on exposed concrete surfaces, leaving behind a concentration of salt crystals.

Concrete has a tensile strength in the range 2-4 MPa while volume change of the most common destructive salt, solium sulphate (Na_2SO_4) is around 315% (Table 2) with an accompanying hydration pressure, as it phase changes from its anhydrous form (thenardite) to its hydrated form (mirabilite $Na_2SO_4.10H_2O$), ranging up to 48 MPa[7].

The pore pressures produced therefore greatly exceed the tensile strength of concrete thus the reason for ready exfoliation of an exposed concrete surface when subjected to salt damp attack.

It is interesting to examine other hydration volume increases for selected salts known to cause salt damp attack. Table 2 shows these volume changes.

Water/Cement ratio by weight	Time required
0.40	3 days
0.45	7 days
0.50	14 days
0.60	6 months
0.70	1 year
over 0.70	impossible

Table 1: Approximate age required to produce maturity at which capillaries become segmented[9].

Salt	Molecular weight	Hydrate	Formula weight of hydrate	Density	Density of hydrate	Volume change (%)
Na_2CO_3	106.00	$Na_2CO_3.10H_2O$	286.16	2.53	1.44	374.7
Na_2SO_4	142.00	$Na_2SO_4.10H_2O$	322.20	2.68	1.46	315.0
$CaCl_2$	110.99	$CaCl_2.2H_2O$	147.03	2.15	0.84	241.1
$MgSO_4$	120.37	$MgSO_4.7H_2O$	246.48	2.66	1.68	223.2
$CaSO_4$	136.14	$CaSO_4.2H_2O$	172.17	2.61	2.32	42.3

Table 2: Hydration volume increase for selected common salts known to cause salt damp(7).

Considering further the destructive thenardite/mirabilite hydration process as a type example of crystalline phase transformation in surface pores, it is well worth considering why this particular salt and others like it (Table 2) are so destructive and so prevalently encountered when salt damp attack occurs in places like South Australia, Southern California and other regions of the world with semi-arid (Mediterranean) climates. At least one of the most conspicuous reasons is indicated by the range of relative humidities and temperatures at which phase transformation for sodium sulphate occurs. This is illustrated in Figure 3.

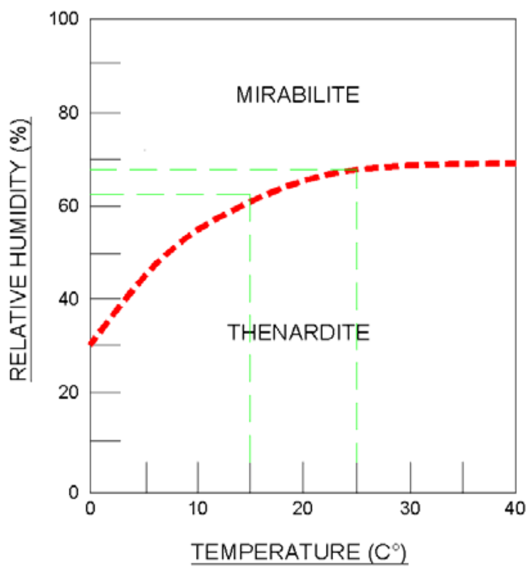


Figure 3:. Temperature-Relative Humidity phase diagram for thenardite/mirabilite(10)

This figure clearly shows that phase transformation for sodium sulphate occurs in a temperature range of 15-25°C at relative humidities from 60-70%. Such conditions are commonplace in semi-arid climates and may occur 3 or 4 times over the course of a day in Adelaide at certain times of the year.

7. THE CONCEPT OF SUCTION AND FLOW PATHWAYS

The negative pressure or suction head (pF) causing moisture to be sucked into a porous and permeable partially saturated material such as concrete or masonry has been shown(11) to be expressed by the formula

$$h = -2\,\sigma/\rho g r$$

where h = suction in metres of head,
σ= the surface tension of water in N/metre.
ρ = specific mass of water in kg/m^3,
g = gravitational constant in m/s^{-2}, and
r = capillary radius in metres

It can therefore be identified that the height of capillary rise is inversely proportional to the capillary radius meaning a greater rise in smaller diameter interconnected pores and a lesser rise in larger diameter pores.

In any partially saturated solid such as concrete the capillaries are occupied by both water and air with a curved meniscus interface between them. Surface tension exerts pulling forces on this meniscus effectively drawing moisture deeper into the material working against gravity, resistance to flow, or pressure of entrapped air, or all three. The meniscus remains curved and the capillary held water remains in tension until the capillary is filled to the point of satisfying the suction head differential.

It is now prudent to consider the most probable flow pathways for saline moisture in a concrete edge footing founded within partially saturated ground under the influence of differential suction pressures acting at the concrete and soil boundaries.

The author is aware of at least one such study(12) that has been done on what is known in Southern California as a typical stem wall footing. This footing type is not dissimilar to what we in Australia refer to as a raft footing. The one exception being the termination point of the vapour proof polythene underlay. The Americans stop it at the outer extremity of the floor slab so that it does not continue beneath the edge beam (i.e. stem wall). In Australia it is common to protect all but the upper outer edge of a raft footing from soil contact with the concrete soffit.

Figures 4 and 5 are reproductions of the results obtained for the study undertaken on Southern Californian stem wall footings.

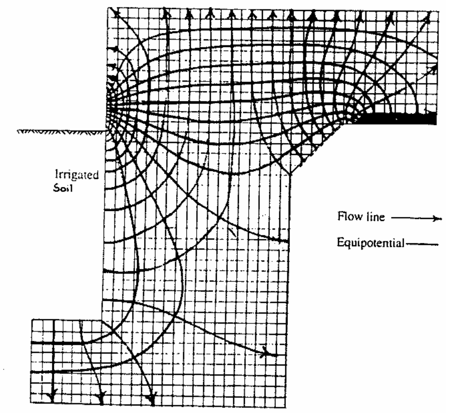


Figure 4: Evaporation at top and side. Moisture barrier in place beneath slab *(Case iv)*[12].

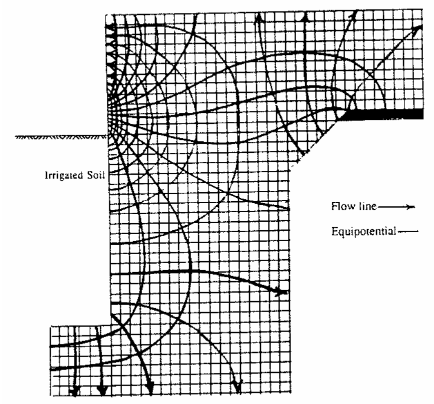


Figure 5: Evaporation at top and side. Moisture barrier in place beneath slab. Higher suction at sides *(Case v)*[12].

Solute (dissolved salt) transport is always at least in part, advective. That is, it occurs under the influence of an hydraulic gradient with the saline solution moving from regions of high to low energy potential or, better put, from regions of low to higher suction (pF) at a rate proportional to the hydraulic conductivity of the capillaries. Suction driven hydraulic gradients of this kind in a permeable transfer media such as concrete are important because they ultimately determine where evaporation will occur and where it will be accentuated.

At evaporative surfaces where the solute (salt) is deposited in pores and the solvent (water) evaporates as vapour, high suctions (i.e. negative pore pressures) develop.

Invasive saline moisture therefore flows from wetter (more saturated) regions with low moisture suctions towards drier areas with correspondingly higher moisture suctions. This defines the *advective* process.

Salts can also be transported by *diffusion*. This is solute movement induced by a salt concentration gradient. Salts will move at a rate proportional to a certain diffusion constant from areas of high to areas of low solute concentration. Advection and diffusion may, and usually do, occur simultaneously.

Evaporation at flow boundaries therefore causes salts to precipitate out in increasing concentration within surface pore spaces. This is why crystalline expansive pressures cause cyclic and progressive exfoliation of the surface layer.

The results shown above in Figures 4 and 5 are consistent with observations made by the author in several field investigations of concrete footings displaying slab edge dampness deterioration. Damage to concrete raft footings is most often identified on the external upper exposed edge of perimeter beam footings and also in the interior of dwellings along perimeter strips of floor of approximately 300 mm in width within the dwelling footprint. The high concentration of flow lines terminating at the slab surface near the outer edge as shown in Figure 4 support the author's field observations with respect to internal floor damage while Figure 5 represents the author's findings for strip footings or for exposed outer edges of raft footings with 150 mm or more of unprotected concrete extending above finished pavement level. Note the high concentration of flow lines terminating at the exposed outer edge.

8. PREVENTION AND REMEDIAL TREATMENT OF SLAB EDGE DAMPNESS

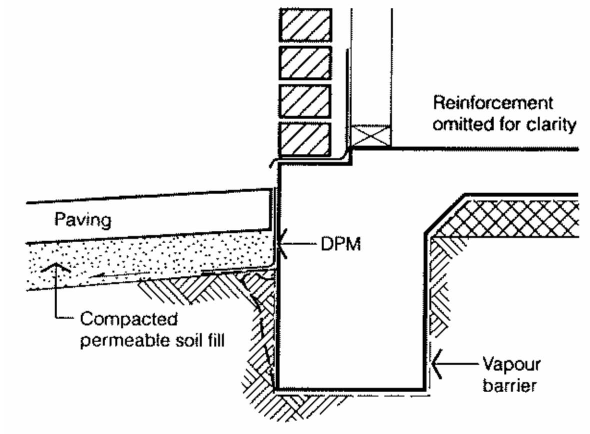
Slab edge dampness is terminology that was created by the author to describe salt damp attack of perimeter concrete footings.

In terms of slab edge dampness *prevention*, CIA Practice Note 30[13] provides an outline scope of works with sketches detailing the installation of a separate (from the slab underlay) vertical damp proof membrane (dpm) immediately adjacent the exposed vertical face of an edge footing to inhibit lateral transfer of dampness from the ground, paving basecourse and paving itself, into the edge footing. The dpm is bricklayers viscourse, an embossed 0.5 mm thickness polythene membrane.

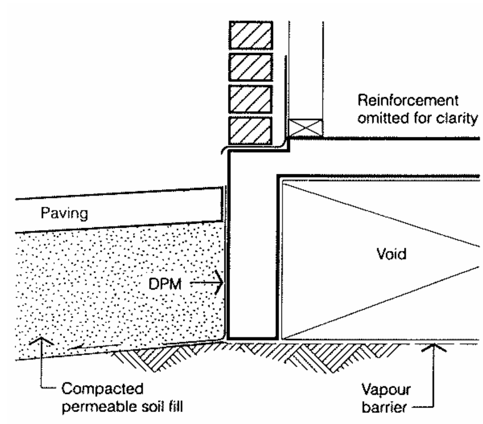
When installed properly and in strict accordance with the detailed sketch, reproduced as Figure 6, this method has performed exceptionally well and is a low cost alternative to using higher strength and more expensive concrete.

In terms of *remedial* work after detection of slab edge dampness a similar approach to that shown in Figure 6 is recommended but should also include the following additional steps.

- After removing or re-profiling of the over-pour concrete to slope away from the edge footing, thoroughly clean the concrete face and apply a polymer modified cementitious fairing mortar (there are many good proprietary brands) to achieve a smooth skim coat rendered finish and allow this to cure under polythene for three days. Remove the polythene and allow the thin render coat to dry.



Raft Footing Option



Waffle Footing Option

Figure 6: Placement of vertical dpm to inhibit lateral moisture transfer to edge footing[13].

- Apply two coats of an elastomeric bituminous emulsion in opposing orthogonal directions (to eliminate pinholing) to the smooth render finish then place the prescribed viscourse dpm sheet in position as protection for the bituminous waterproofing. Proceed with backfilling, compaction, termite spraying and finally pavement replacement. Trim off any excess upstand of dpm protruding above pavement level. Only carry bituminous waterproofing to the proposed top of pavement level and not beyond.

For strip and pad footing system designs a prudent preventative measure would be to always specify an approved polythene underlay for protection from saline ground. This, for some curious reason, does not seem to have been adopted as an industry standard by the building industry in South Australia when constructing this type of footing system.

Retrofit repair can be carried out by placement of a 12-15 mm thickness sacrificial render which serves the purpose of moving the evaporative surface out and away from the structural concrete, thus protecting it as the sacrificial render progressively exfoliates and attracts salts to its own evaporative surface. To be sacrificial this render application must of course be relatively weaker than the structural concrete it is protecting. A 1c:2l:9s mix would be appropriate for most situations.

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Biodiversity impacts from salinity and implementation of drainage solutions

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Summary
Salinisation manifests itself in various forms on the natural environment. Decreased stream and wetland water quality, additional saline groundwater discharge sites, loss of native fish and invertebrate fauna, waterlogged seasonal wetlands and degradation of aquatic and riparian vegetation communities. Implementation of landscape drainage and complementary land management activities can remedy some of the negative biodiversity outcomes of salinity.

The Upper South East Dryland Salinity and Flood Management Plan (1993) was developed to address issues of rising saline groundwaters, flooding of agricultural land, wetland rehabilitation, revegetation and saltland agronomy. In 1998, implementation of the plan commenced with construction of the Fairview Drain. As drainage works proceed, biological and hydrological investigations have been undertaken to determine the impacts of salinity, optimum drainage alignments, measures to mitigate impacts of drain construction and potential wetland restoration works.

Notwithstanding pre-drainage investigations and detailed planning, environmentally negative implications do arise from salinity mitigation drainage schemes. Vegetation clearance for drainage construction, barriers to faunal ranges, surface flow disruptions, dieback of lowland vegetation, increased pondage in wetland basins and altered wetland salinity regimes of receiving waters can all occur as by-products of drainage. To mitigate these aspects, measures such as water regulating structures, drain re-alignment, fauna crossings, drainbank revegetation, de-stocking and development of wetland management plans can all be implemented complementary to the drainage works. Implementation of a comprehensive ecosystem health monitoring program will record the response of vegetation and animal communities. It also provides feedback to better manage drainage infrastructure and the natural environment.

Large and visionary capital works programs can be effective in bringing about immediate relief to the symptoms of rising saline groundwaters. These works provide an opportunity to instigate regional-scale modifications to the hydrological cycle through large revegetation and wetland management works. Environmental investigations show implementation of the Upper South East Scheme has had immediate negative and positive impacts upon shrubland and wetland health. Improvements in drain design, vegetation management, water management and environmental monitoring should allow regional groundwater rises to be controlled while allowing long-term protection and conservation of natural ecosystems.

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A Spatial Information Framework for Salinity in SA

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Summary
Salinity has been mapped across SA's temperate zone as part of a wider land and soil assessment process. The scale of mapping allows for State, regional and sub-regional overviews of water table induced salinity. The extent and severity of salinity can now be directly compared between areas across the State – with obvious implications for allocation of government and community resources. Recharge potential, and other key land and soil attributes that can assist in the targeting of recharge reduction strategies, have also been mapped. A model of salinity risk has been developed. GIS analyses of this spatial data have revealed that there are 633,000 ha of 'saline land' in SA's temperate zone, and that 336,000 ha of this can be considered secondary salinity. Salinity risk modeling has estimated that 292,000 ha are at very high to high risk of increased salinisation – these are the areas that are a short to medium term risk of significant decline in productivity and biodiversity in the event of rising water tables. A discussion on options for tackling salinity and water quality issues highlights the need to focus recharge reduction strategies on non-saline recharge areas on agricultural land, and on the benefits of matching land type with land use, particularly in mallee areas.

1. INTRODUCTION

Until quite recently, the only visual estimate of the extent of salinisation in South Australia's temperate zone was hand-drawn on an A4 size map. This representation of salinity (see Figure 1) was used in the Decade of Landcare Plan in 1991 to highlight the importance of the salinity issue in SA. At the time salinity was thought to affect 225,000 ha (State Dryland Salinity Committee 1990).

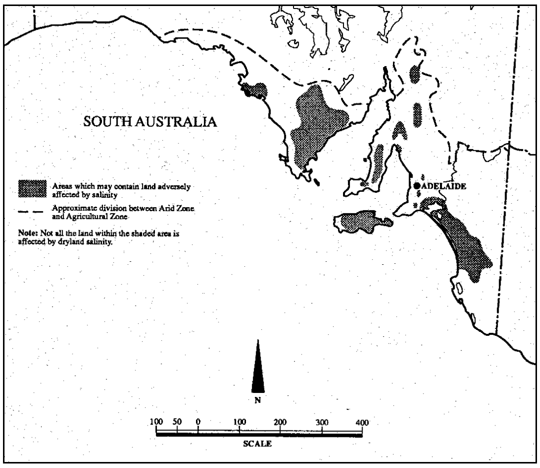

Figure 1: The extent of salinity in SA's temperate zone. (Source: Landcare 1991)

This spatial coverage gave an overview of the areas where land salinisation was known to occur. However, information at such a coarse scale could not be used to satisfactorily rank the importance of salinity as a natural resource issue, or to target on-ground works to ameliorate salinisation and enhance water quality. There was also no attempt to estimate the severity of salinity in different areas, nor to distinguish between primary (natural) and secondary (European induced) salinity. Nor was there any attempt to estimate the risk of further salinisation.

Later in the 1990s, to fulfill State requirements for the National Land and Water Audit, a more detailed analysis of salinity in SA was undertaken. Salinity was graded as present or absent. Also, some attempt was made to estimate the area at risk of further salinisation. However, this analysis of salinity was also done at a relatively broad scale. It was estimated that 326,000 ha were affected by dryland salinity, and was predicted that about 520,000 ha would be affected before equilibrium between discharge and recharge was reached (Soil Conservation Council of South Australia 2001).

More recently, the Soil and Land Information group of the Department of Water, Land and Biodiversity Conservation has completed detailed salinity mapping information for all of SA's temperate zone (Soil and Land Information 2002b and c). Salinity has been mapped as part of a wider land and soil mapping program. This twelve-year mapping program assessed a range of key land and soil attributes, including salinity induced by water tables (see Maschmedt 1998 and Soil and Land Information 2002a, b and c). Figure 2 gives an overview of the spatial data collected and compiled for salinity in SA's temperate zone. The main areas of primary and secondary salinity are also highlighted.

Analyses of these spatial data using GIS (Geographical Information System) technology has revealed that there are 633,000 ha of 'saline land' in SA's temperate zone, and that 336,000 ha of this can be considered secondary salinity. Salinity risk modeling has estimated that 292,000 ha of SA's temperate zone are at very high to high risk of increased salinisation. These are the areas that are a short to medium term risk of significant decline in productivity and biodiversity in the event of rising water tables.

The key program outcomes for salinity include:

- salinity mapped at a scale suitable for State, regional and sub-regional overviews (1:50,000 scale in the Mount Lofty Ranges, South East and Kangaroo Island, and 1:100,000 scale in the Northern Agricultural Districts, Yorke Peninsula, Eyre Peninsula and the Murray Mallee);
- both the extent and severity of salinity have been mapped (see Figure 2);

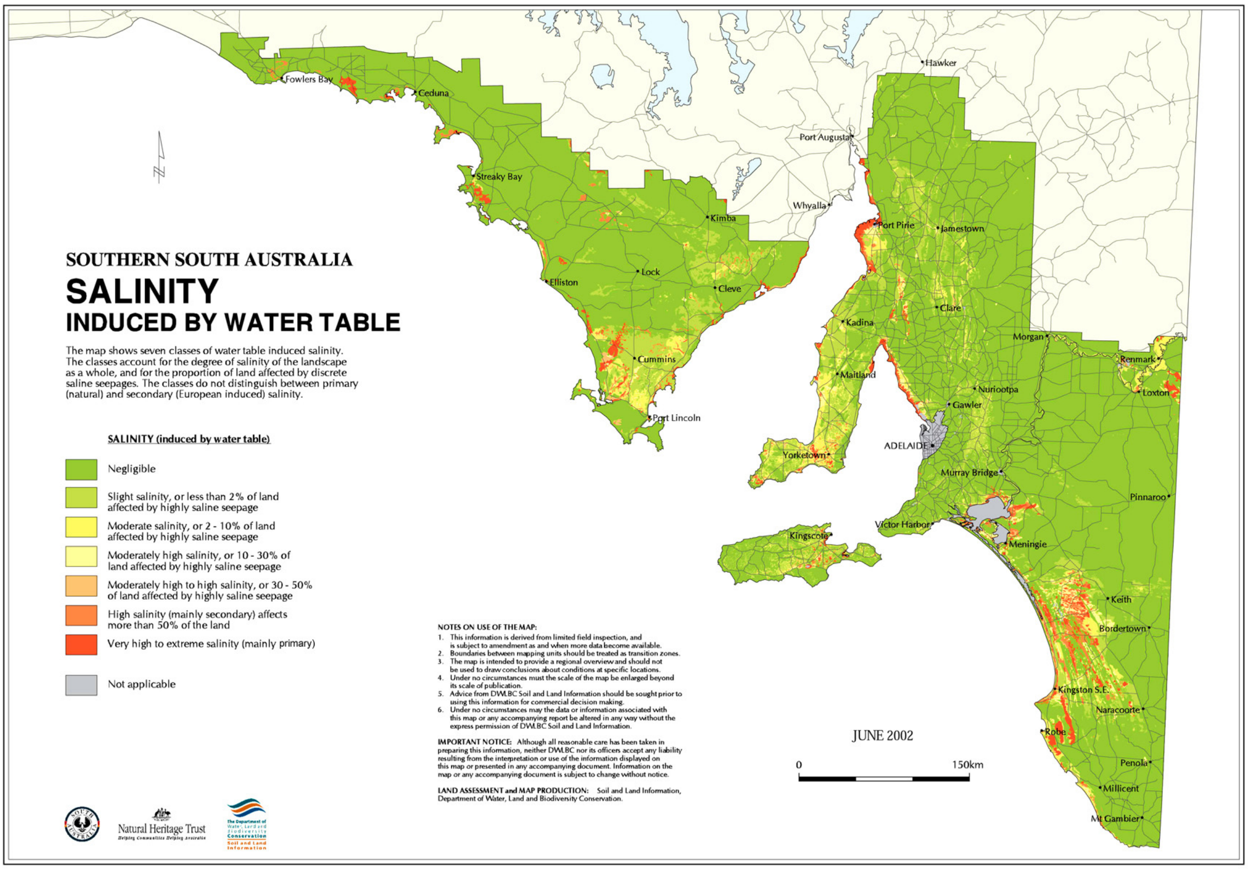

Figure 2: Salinity induced by water table – an overview of more detailed spatial data. Also highlighting the main areas of primary and secondary salinity. (After: Soil and Land Information 2002b)

- a seven category system for classifying the severity of salinity has been developed (see Table 1);
- a consistent methodology for assessing salinity has been used throughout the mapped area, thereby allowing direct comparisons of the extent and severity of salinity between areas across the State;
- salinity has been mapped as part of a wider land assessment program, and as such the extent of the problem can be readily compared to other natural resource issues (eg soil acidity, waterlogging, dry saline land, boron and sodium toxicities, soil physical condition, water and wind erosion potential, etc) – this is of enormous benefit in ensuring effective allocation of government and community resources;
- saline land has been characterized (eg the nature of salinity and other key land and soil characteristics, including soil type, have been assessed for areas affected by salinity);
- recharge areas have been characterized;
- on-ground works to ameliorate salinity and enhance water quality can be better targeted;
- a definition of what constitutes 'saline land' has been formulated (see Table 4);
- salinity classifications can be used as a basis to distinguish between primary and secondary salinity;
- salinity, and other land and soil information compiled as part of the State land and soil mapping program, has been used to develop of a salinity risk model.

Table 1: Criteria for the assessment of the severity of water table induced salinity. (After: Soil and Land Information 2002a)

Water Table Induced Salinity			
Salinity Category	Classification Criteria		Land Class
	Vegetation indicators	Indicative ECe (dS/m)	
Low	No evidence of salt effects.	<2 (surface) <4 (subsoil)	1-s
Moderately low	Subsoil salinity – deep rooted horticultural species and pasture legumes affected.	<4 (surface) 4-8 (subsoil)	2-s
Moderate	Subsoil salinity with raised topsoil salinity levels. Many field crops and lucerne affected. Halophytic species such as sea barley grass can be evident.	4-8 (surface) 8-16 (subsoil)	3-s
Moderately high	Too salty for most field crops and lucerne. Halophytes are common (eg sea barley grass, curly rye grass and salt water couch). Strawberry clover productivity is diminished.	8-16 (surface) 16-32 (subsoil)	4-s
High	Land dominated by halophytes with bare areas. Sea barley grass often dominates. Samphire & ice plant can be evident. This land will support productive species such as Puccinellia, tall wheat grass, etc.	16-32 (surface) >32 (subsoil)	5-s
Very high	Land is too salty for any productive plants and supports only samphire, swamp tea-tree or similar halophytes.	>32 (surface) Any (subsoil)	7-s
Extreme	Bare salt encrusted surface.	Any	8-s

2. SPATIAL INFORMATION DEVELOPMENT

2.1 Salinity mapping

Soil and Land Information group salinity mapping has been developed within a soil landscape mapping framework. Soil landscape map units have been defined throughout SA's temperate zone. These have been rated for the extent and severity of salinity using a seven category classification scheme (see Table 1). Components of soil landscape map units are also described and classified where necessary (eg in dunefield landscapes).

A soil landscape map unit defines a specific combination of geological setting, land type, topography, soil, and other key land and soil characteristics (or attributes). Baseline mapping is produced at 1:50,000 or 1:100,000 scale. Mapping is based upon ground-truthing and air-photo-interpretation of topography, geology, soils and landscapes at 1:40,000 scale. Salinisation of land is particularly conspicuous on air-photographs. In many instances of 'marginal' salinity where halophytic vegetation is not obvious, it is much easier to discern salinity from air-photo-interpretation than from on-ground observation.

Data collection included the description of more than 28,000 soil profiles, the description and comprehensive chemical analyses of over 800 soil characterisation sites (Soil and Land Information 2002d) including ECe and EC(1:5) measurements, tens-of-thousands of routine soil salinity tests (EC(1:5)), and tens-of-thousands of field observations.

2.2 Salinity statistical data

There is now comprehensive and consistent data for water table induced salinity across SA's temperate zone. The extent and severity of salinity in one part of the State can now be directly compared to another. Calculations using GIS technology can be made upon soil landscape map unit salinity classifications.

Due to the fact that salinity has been mapped as part of a wider land assessment program, the extent and severity of salinity can now be compared to the extent and severity of other natural resource management issues to assist the efficient allocation of government and community resources. For example, this data can be used as a basis to compare the environmental and economic consequences of water table induced salinity to other land and soil issues (eg acidity or dry saline land) within a region or sub-region to help target resource allocation. In addition, this land assessment information can be used to help direct on-ground works to areas where the greatest natural resource benefits will accrue.

An overview of the salinity statistics for SA's temperate zone and biophysical regions is given in Table 2. Biophysical regions, as determined by the Soil and Land Information group, are based upon the State land and soil mapping framework and define the major landscape / geological / soil / vegetation boundaries of SA's temperate zone.

The various types of dryland salinity have been defined and named (Working Party on Dryland Salting in Australia 1982), with later modifications in SA (Matheson 1984), however, a consistent definition of what constitutes water table induced saline land is needed for data reporting purposes. For example, salinity management plans produced by the Rural Solutions SA Salinity Program as part of the National Action Plan for Salinity and Water Quality need to consistently document salinity and salinity risk data (see Harding et al 2003 for the most recent example of such a plan). The Rural Solutions SA Salinity Program and the Soil and Land Information group have decided upon criteria for 'saline land' (see Table 3). All land classified as class 4 salinity or above is considered 'saline land'. In these areas, water tables are generally within 2 m of the land surface. Land classified as class 2 or 3 salinity is considered to have 'sub-clinical' salinity.

Table 2: An overview of salinity statistics.

SALINITY STATISTICS – Southern SA – Biophysical Regions
Source: DWLBC 'Soil and Land Information' mapping program

Region	Salinity Classes								Total (ha)
	s=1	s=2	s=3	s=4	s=5	s=7	s=8	s=X	
Out of Regions	0	0	0	0	0	0	0	58,990	58,990
Central	589,232	9,120	3,499	1,864	4,282	1,499	555	10,707	620,758
EP	4,432,948	84,201	2,233	2,874	43,512	49,168	42,490	116	4,657,541
KI	307,387	76,238	30,465	9,586	5,539	5,997	1,606	4,621	441,439
Mallee	2,661,907	34,374	55,597	7,652	15,283	19,581	4,783	103,682	2,902,858
Northern	2,788,383	274,935	41,602	38,651	20,889	34,655	19,392	7,109	3,225,616
SE	2,506,887	164,645	106,229	49,012	89,568	66,228	29,611	24,832	3,037,013
YP	314,158	287,861	130,367	34,374	12,887	10,974	10,050	3,150	803,821
Totals	13,600,900	931,375	369,992	144,013	191,961	188,101	108,487	213,206	15,748,036

Table 3: Salinity data analyses.

DATA ANALYSIS – Southern SA:

Type of Salinity	Land Classes	Area (hectares)
No evidence of salinity	s=1	13,600,900
Subclinical or slight salinity	s=2 + s=3	1,301,367
'Saline land' (primary and secondary)	s=4 + s=5 + s=7 + s=8	632,562
- primary salinity	s=7 + s=8	296,588
- secondary salinity	s=4 + s=5	335,974

More detailed descriptions of various forms of water table induced salinity are given in Table 4.

Table 4: Definitions of various forms of water table induced salinity.

DEFINITIONS:

Land with no evidence of salinity
These areas are designated as class 1 land. This is land which shows no evidence of being affected by water table-induced salinity.

Subclinical or slight salinity
These areas are designated as class 2 or 3 salinity. This is land where most species of annual crop and pasture plants can be grown, but usually with restricted growth due to elevated salinity levels in the soil profile. Halophytic vegetation may not be present. This is known as subclinical or slight salinity.

'Saline land' (primary and secondary salinity)
These areas are designated as class 4 through to class 8 salinity. This is land that is readily identifiable as 'saline land' by a conversant observer. It includes both primary and secondary salinity. Water tables are generally within 2 metres of the land surface. These areas range from land which can only be cropped with tolerant annual species in suitable years, to land which is salt-encrusted and bare of vegetation. The presence of halophytic vegetation is one of the key indicators of 'saline land'.

primary salinity
These areas are generally designated as class 7 or 8 salinity. This is land which is presumed to have exhibited saline characteristics since before clearing and settlement. Primary salinity encompasses coastal swamps and ancient inland salt lakes, is easy to recognise as salt affected, and is typically very highly to extremely saline.

secondary salinity
These areas are generally designated as class 4 or 5 salinity. This is land which is presumed not to have exhibited obvious saline characteristics before clearing and settlement, but which is now exhibiting saline characteristics due to increased recharge into groundwater and the resultant rise in water table levels. Secondary salinity mostly encompasses saline land that is not a coastal swamp or an ancient salt lake. The figures given for areas affected by secondary salinity in the tables above are only estimates, since the true extent could only be known if extensive hydrological measurements had been taken over an extended period.

2.3 Salinity risk modeling

Mapping salinity as part of a wider land assessment program allows models to be developed which analyse geological setting, topography, land type, and land and soil characteristics (or attributes). A range of comparable data sets compiled at a consistent and relatively detailed spatial scale allow for reliable and realistic modeling.

A salinity risk model has been developed which analyses a range of landscape characteristics to produce risk categories. The model analyses the present extent and severity of salinity within each soil landscape map unit (which implicitly also assesses depth to groundwater), position in the landscape, the presence or absence of salinity in adjacent land units, the presence or absence of salinity in the encompassing land system, and land type or geological setting.

Six risk categories have been developed, along with two categories of land which are already mostly highly to extremely saline (see Table 5). The risk categories describe the consequences for land salinisation <u>if</u> water tables were to rise.

It can be assumed that water tables have risen at least to some extent in all catchments where perennial native vegetation has been replaced by annual crops and pastures. However, in most catchments in SA the data are not available to determine whether water table levels are still rising or have reached equilibrium.

Table 5: Salinity risk category descriptions.

SALINITY RISK CATEGORY DESCRIPTIONS:

RISK OF INCREASED SALINIZATION – IN THE EVENT OF RISING WATER TABLES		
SR=1	Low	Land which shows little to no evidence of salinisation, and is considered to have little risk of becoming saline.
SR=2	Moderately Low	Land which presently shows little to no evidence of salinisation, but is at **POSSIBLE** risk of becoming increasingly saline if water tables rise significantly.
SR=3	Moderate	Land which already has somewhat raised subsoil salinity levels, which may be the result of relatively shallow water tables, and if so, is at risk of becoming increasingly saline if water tables rise.
SR=4	Moderately High	Land which already has raised subsoil salinity levels resulting from relatively shallow saline water tables, and is at risk of becoming increasingly saline if water tables rise.
SR=5	High	Land which is often already too saline for some field crops, and is at risk of becoming highly saline if water tables rise.
SR=6	Very High	Land which is already too saline for many field crops, typically including significant areas of highly saline to extremely saline land, and is at risk of becoming increasingly saline if water tables rise even a small amount.
LAND WHICH IS ALREADY MOSTLY HIGHLY TO EXTREMELY SALINE		
SR=A1	Mostly highly saline land. At least 50% highly saline land - with up to 100% highly to very highly saline land.	
SR=A2	Mostly very highly to extremely saline land. Greater than 90% highly to extremely saline land - with at least 50% very highly saline land.	
SR=X	Not applicable (Unmapped urban, lakes, etc.)	

The highest risk category encompasses land that is already saline to some degree, and would be the first land lost to agricultural crop production if water tables were to rise. These are the areas most at risk of significant lost productivity and biodiversity given even a small rise in water table levels.

Spatial coverages of salinity risk are available at 1:50,000 or 1:100,000 scale, and as State or regional overviews. Analyses of salinity risk data for SA's temperate zone are shown in Table 6.

If a high resolution Digital Terrain Model (eg to less than 1 m vertical resolution) was available for all of SA's temperate zone, this could be incorporated into the salinity risk model to enhance risk assessment.

Table 6: Salinity risk data analyses.

DATA ANALYSIS – Southern SA:

Salinity Risk Grouping Descriptions	Salinity Risk Groupings	Area (hectares)
No evidence of salinity at present, with little to no risk of increased salinity levels.	SR=1	10,098,233
Minor risk areas. Little to no evidence of salinity at present, with minor risk of increased salinity levels. Saline water tables would need to rise significantly to seriously affect productivity and biodiversity in these areas. [Long-term risk.]	SR=2	3,380,313
Moderate risk areas. Raised subsoil salinity levels at present. Moderate risk of increased salinity levels. Saline water tables would need to rise considerably to seriously affect productivity and biodiversity in these areas. [Medium to long-term risk.]	SR=3 + SR=4	1,286,838
High risk areas. Raised soil salinity levels at present. High risk of increased salinity levels. Saline water tables would need to rise a small to moderate amount to seriously impact upon productivity and biodiversity in these areas. [Short to medium term risk].	SR=5 + SR=6	292,354
Land which is already highly saline	SR=A1 + SR=A2	486,809

2.4 Recharge mapping

Another of the land and soil attributes mapped as part of the State land and soil mapping program is recharge potential. Soil water holding capacity, soil permeability, and substrate permeability have been assessed for each soil landscape map unit to provide a rating for recharge potential (Soil and Land Information 2002a).

Spatial assessments of recharge can be used to help target areas where the growth of deep rooted perennials would optimize salinity and water quality outcomes.

3. DISCUSSION

3.1 Use of salinity, salinity risk and recharge data

Salinity, salinity risk and recharge data – as well as the other data collected and compiled as part of the wider State land and soil mapping program – can be used in a range of ways, for example:

- to help prioritize and target on-ground works for amelioration of salinity and water quality problems (eg targeting priority areas for recharge reduction);
- to assist prioritisation of natural resource management issues to improve resource allocation and the targeting of on-ground actions;
- to assist the development of policy and strategic planning;
- to provide benchmarking for monitoring programs;
- to assist with target setting;
- to provide input data into plant performance potential models;
- to assist the process of matching land type to land use;
- to provide input data for a range of other models (eg risk to infrastructure from salinisation);
- to justify project/program proposals.

3.2 Recharge reduction and the matching of land use to land type

As is well known, the change from perennial native vegetation to annual crops and pastures has increased recharge and lead to higher groundwater levels. This has resulted in land salinisation in some areas, and water quality problems, particularly in the River Murray. (Cook et al 2001).

Recharge into groundwater needs to be reduced to impact upon the salinity problem. Overuse of irrigation water and the poor water use efficiency of both dryland and irrigated crops and pastures are the main contributors to the problem of high recharge.

Viable solutions to this situation in the Murray-Darling Basin include compulsory soil moisture monitoring linked to irrigation scheduling, and a regulated or incentive-based move from inefficient forms of irrigation to efficient forms (eg drip systems). This would result in a large reduction in the quantity of irrigation water used (without impacting upon yields), and hence decrease recharge and seepage into the River Murray, and have the benefit of being economically sound. An alternative would be to increase the price of irrigation water. This is likely to lead to a decrease in use of irrigation water, however, it is unlikely to be popular or necessarily economically sound.

The vast majority of land in the settled areas of the SA Mallee is used for dryland agriculture. Recharge reduction in these areas can be achieved via land use change (from annual to perennial plants) and via the growth of more vigorous crops and pastures (increasing water use through the use of improved species or improved land management practices). For land managers to undertake major land use change, they need to have access to viable alternative productive plants.

Matching land use to land type is a viable strategy for recharge reduction in much of the SA Mallee. The nature of many mallee landscapes lends itself to this form of land management, for example, using deep rooted perennials on high recharge stony patches and sand dunes. Such practices would reduce recharge, help to stabilize wind erosion prone soil, and remove stony patches and sand dunes from production which is often not economic (eg growing wheat and barley on sand dunes). The State land and soil mapping framework can be used to assess land types. Plant potential performance models, using salinity, recharge potential, and other land and soil attribute information, can then be used to assess land use options.

The present square and rectangular cadastre-based land management areas are one of the greatest impediments to the adoption of land management systems based on natural land type boundaries. Perceived difficulty with managing odd-shaped land areas with modern large machinery, or managing several land types within a single paddock area, is also an issue. In addition, economic analyses of alternative land use options may be required before land managers commit to major land use change.

Another major impediment to the adoption of land use options which replace shallow rooted annual crops and pastures with deep rooted perennials, is the lack of viable plant options. In SA lucerne is the main option. More economic perennial options are needed before deep rooted higher water use plants become widespread in dryland agricultural areas.

The recent publicity about salinity has focused attention on the issue – many land managers now realize and acknowledge that they have saline areas on their land. As a consequence, much effort in recent times has been placed on the management of 'unsightly' discharge areas. Although this can increase productivity and biodiversity on saline land, major improvements in salinity and water quality are only likely to be achieved by tackling recharge reduction via land use and land management change in recharge areas (that is, those areas which in the main are not affected by water table salinity).

Soil constraints in non-saline areas – both physical and chemical – impede the productivity and water use of crop and pasture plants. The land and soil attribute mapping information spatially describes these soil constraints (Soil and Land Information 2002a, b, c and d).

A range of measures could be used to target recharge reduction in the non-saline agricultural areas via improved water use, for example:

- a change in dominant land use from annual crops and pastures to deeper rooted perennials;
- the development of improved crop and pasture species which better tolerate the often hostile subsoil environment roots encounter in SA soils;
- the development of new economic plant species from native plants which have natural tolerance of adverse subsoil conditions;
- improved land management practices such as improved fertility management;
- amelioration of subsoil physical constraints with deep placement of soil conditioners (eg gypsum).

The vast area of land that could be involved in such strategies indicates that major improvements in salinity and water quality could be achieved in the medium to long term through recharge reduction via such measures.

4. ACKNOWLEDGEMENTS

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The role of NyPa *Distichlis spp.* cultivars in altering groundwater & soil conditions – a work in progress

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Summary
This paper reports the results of work carried out to investigate the role of economically useful cultivars of *Distichlis spp* in the rapidly growing areas of agricultural and urban land afflicted with dry land salinity from rising saline aquifers. It reviews work in the USA and Mexico with swamp grasses, explains how they are able to thrive in wet saline environments and how some have been selectively bred for different purposes. It briefly reports work being undertaken in Australia to evaluate the productive uses of the plants under different climate, soil and water conditions and discusses the impact of the plants on water use, salt movement, soil structure and drainage. It is concluded that these NyPa *Distichlis spp* halophytes warrant much more investigation as a cost effective means to address saline discharge areas in Australia, both with regard to traditional productive uses and rehabilitation on a stand-alone basis, and for reducing the cost and improving the effectiveness and sustainability of engineering approaches specifically designed to reduce saline discharge areas by draining water.

1. INTRODUCTION

There is a thriving but somewhat sterile debate about the relative merits of plant-based versus engineering solutions to the negative impact of rising saline groundwater on agricultural and urban lands, and other salty land resulting from human activity. The purpose of this paper is to discuss the plant mechanisms that enable some plants to survive indefinitely in such sites and to speculate about the ability of some of these plants to reverse the processes that have led to these difficulties in some areas. Based on some preliminary results from work in Southern Australia and in the USA, the paper suggests that plants and engineering solutions are not mutually exclusive, and may have applications in a wide range of situations where salt water and soils have been impacted by rapid human-induced change, at least in conditions of high sunlight.

2. PLANTS AND SALINE ENVIRONMENTS

The mechanisms by which plants tolerate saline conditions are multifaceted, related to whole plant responses and not well understood (Tanji 1990[i]). Most plant breeding and plant domestication work has been carried out on plants adapted to fresh water, so called 'glycophytes', and well drained sites (a relevant exception being rice which is adapted to wet sites). This may be because the process began accidentally around human settlements that are necessarily located near fresh water (Yensen 2002)[ii], or because salt tolerance requires plant energy, which is thus less available to a by-product useful to humans. However, early forms of plant life may have begun in shallow saline areas and some have retained these evolutionary adaptations. Although several are highly productive, such as mangroves, few now produce much of value to humans.

Wet saline areas are, by contrast to the areas cultivated by humans, poorly drained and, in dry climates along the sea shore, highly saline. Salts are toxic to cellular processes at higher concentrations and plants that have naturally adapted to these sites have one or more of these characteristics:

- developed cellular processes to partition salt into vacuoles or to exclude salt at the root zone so it does not impact on cell growth (Hanson et al 1976[iii]);
- evolved *aerenchyma* tissue, which contains spaces in the roots that permit gas exchange in anaerobic conditions (a quality possessed by rice). See Photo 1 below;

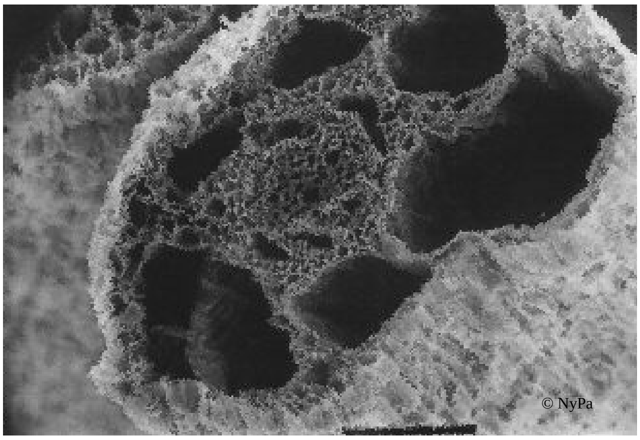


Photo 1: *aerenchyma* shown in *Melaleuca halmaturorum* (Atwill (eds) et al 1999[iv])

- salt glands that enable partitioned salt to be exuded at the leaf surface (Liphschitz et al 1982[v]);
- a poorly understood capacity to utilize light energy for carbon sequestration and respiration in salty environments (Kemp & Cunningham 1981[vi]);
- a deep root structure that provides drought resistance and a means of colonising salty marsh regions (Hansen et al 1976);
- patterns of growth and regrowth whereby the rhizomes periodically senesce and die leaving behind drain lines filled with dead organic matter while new roots grow nearby; a cumulative process known as a *rhizocanicular percolation*

effect, which over time creates or restores soil structure and drainage (Yensen 1999[vii]).

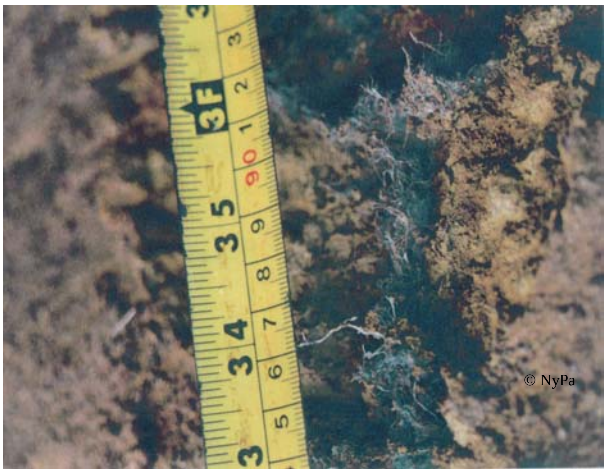


Photo 2: Rhizocanicular effect - detail at 1 metre, WA

It is suggested there is a difference between salt tolerant plants that develop a passive tolerance to periodic salinity and those that actively modify their environment to facilitate their survival and spread. Almost all plants adapted to desert regions have necessarily retained or developed a capacity to tolerate fluctuating salinity, such as many Australian trees and shrubs. These have usually achieved salt tolerance via the cellular process but this requires periodic flushing with fresh water to survive, particularly for plants that exclude salt at the root zone. Some plants such as *Puccinellia ciliate* have evolved shallow root structures that enable more regular flushing from light rain and exhibit some *aerenchyma*. These do not move the salt but rather 'live with it', and provide some useful grazing while breaking up the feedback process of salt deposition that leads to salt scalds.

Plants that modify their root environment such as salt bush (*Atriplex spp)* are able to use salty water for respiration indefinitely by passing some salt through their system. Ferdowsian has shown salt bush is able to mimic the original native vegetation in maintaining the saline water table below the capillary fringe in some areas of the broad valley bottoms of the Western Australian wheat belt, thus ultimately reducing salt deposition (Ferdowsian et al 2002[viii]).

However most deep rooted halophytic plants do not tolerate the anaerobic conditions of wet saline sites, and without an effective salt gland are not particularly efficient at moving this salt out of the plant again, which limits respiration and so production in conditions of high salinity in the groundwater. This is an important consideration in the salt water discharge zones associated with dry land salinity, in urban areas where leakage below lawns and gardens are creating saline water mounds that damage infrastructure, and in some oil polluted sites or degraded mine sites where salinity is inhibiting rehabilitation.

Distichlis spicata is a particularly successful adaptation to wet sites that have become inhospitable to most plants due to salinity. The species has adapted to a very wide climatic range from Canada to South America (there is even a relation that crossed the pacific to Hawaii and Australia, *Distichlis distichophlla*), but is particularly successful in hot littoral regions such as the Gulf of California, and marsh areas where salt continues to accumulate through drainage and evaporation, at least where the salinity does not exceed ocean levels.

While it is the *integration of responses in the whole plant* (to quote Tanji 1990) that is probably responsible for the *Distichlis spp* capacity to survive in highly saline sites, they possess two of the characteristics that enable it to modify a saline environment to an exceptional degree:

- their bi-cellular salt gland, the mechanism by which they pass salt through their system during respiration, is at least twice as efficient (in the sense of salt secreted over internal salt content) as the next nearest competitor (*Aeluropus litoralis*) according to Liphschitz et al, and almost 100 times as efficient as species thought of as having some productive use of benefit to humans such as *Paspalum spp* (Liphschitz et al 1982);
- its rhizocanicular percolation effect is particularly pronounced, providing measurable net gains in drainage to previously impacted soils in serial biological concentration of irrigation drainage water projects in USA (Yensen 2001).

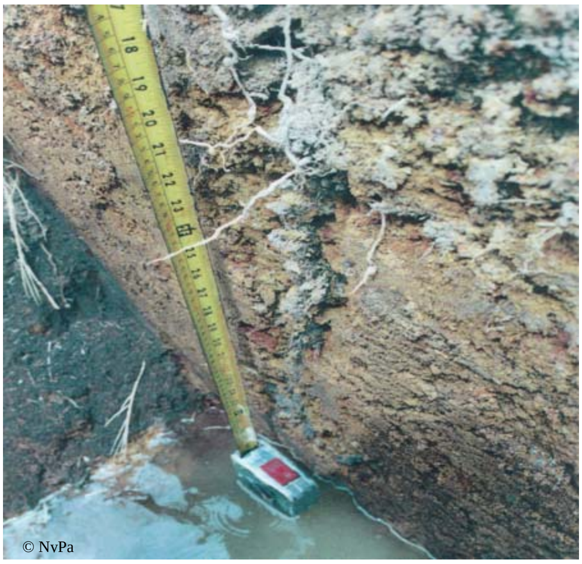


Photo 3: Rhizocanicular percolation effect - new soil structure to the water table. Wickepin, WA

3. WORK IN USA AND MEXICO

Speculation appeared as early as 1956 that *Distichlis spp* might be selected for productive use in saline marsh areas, based on its drought and salinity tolerance and reserve feed value (Nielson quoted in Hansen 1976), although little was done until Yensen began in 1975. He focused initially on the grain variety *Distichlis palmeri* (NyPa 'Wild Wheat®' granted the first US patent for a plant in 1988[ix]), and from the 1990s on its value as forage and turf. He undertook a breeding program with hundreds of plants collected from all over the USA and Mexico and selected one that exhibited qualities as productive and nutritious forage (NyPa™ Forage) and another showing qualities as a drought resistant, low growing turf (NyPa Turf). Work on the nutritive value and production resulting from these selections is reported in Yensen (1998[x]).

Work in the USA on these two varieties has focused as much on their use in land rehabilitation as their productive use. Work in the San Joachim valley in California has shown its value as a constituent part of systems to concentrate drainage effluent water prior to disposal thus reducing pumping costs while providing valuable fodder and improving infiltration (Cervinka et al 1999[xi]). This is part of a systems approach to the disposal of saline groundwater that features the recovery of valuable products from each stage of concentration of the water from a mildly saline effluent, to hyper-saline water or salt for economic disposal. The class of systems is known as Serial Biological Concentration (SBC) and is being investigated in several parts of Australia. This work in California has also shown how *Distichlis spp* can provide a source of organic feedstock for algae, the basis of food supply for Artemia, another part of a SBC system.

Photo 4: NyPa Forage hay, California

More recent work in the US has focused on the use of the forage in the rehabilitation of land degraded by saline water associated with oil drilling in Arkansas and Oklahoma. Here the plant was grown in bituminous, oil soaked saline land to 'open it up' to drainage and allow natural microbiological processes to act on the impacted bituminous residues of oil exploration resulting from the early parts of the last century (Yensen et al 2002[xii]).

4. EVALUATION IN AUSTRALIA

Work with *Distichlis spp* in Australia, begun in 1994, confirmed that the four 'domesticated' varieties would grow and produce valuable products. Two of these, NyPa™ Forage and NyPa Turf have been assessed as having a low weed risk relative to other introduced salt tolerant grasses, as they are male 'clones' and reproduce only vegetatively and in saline conditions (Virtue et al 2002[xiii]). One of the others, *Distichlis palmeri* was selected as a high yielding cereal grain variety, while the fourth was a high seeding variety (since discontinued). The purpose of the work was to evaluate the plants for productive use in rehabilitation of highly saline sites in WA, SA and Victoria (Leake et al 2002[xiv] and Sargeant 2003[xv]).

Photo 5: *Distichlis* NyPa forage in a salt pan, WA

5. METHODS

The methodology in Australia followed the standard approach to investigating a new species. It gathered information to provide a basis for further analysis while enabling decisions to be made as to the uses to which *Distichlis spp* might be put within Australia and the methods of commercialization. The initial trials were established in the three southern states and were followed with more detailed glasshouse investigations and analysis of the nutritional qualities of the forage and the milling qualities of the grain. The work is ongoing and new work to study the use of the NyPa Turf in urban landscapes has commenced, while work to investigate the use of all the plants in SBC systems is in planning, particularly in Western Australia.

6. RESULTS

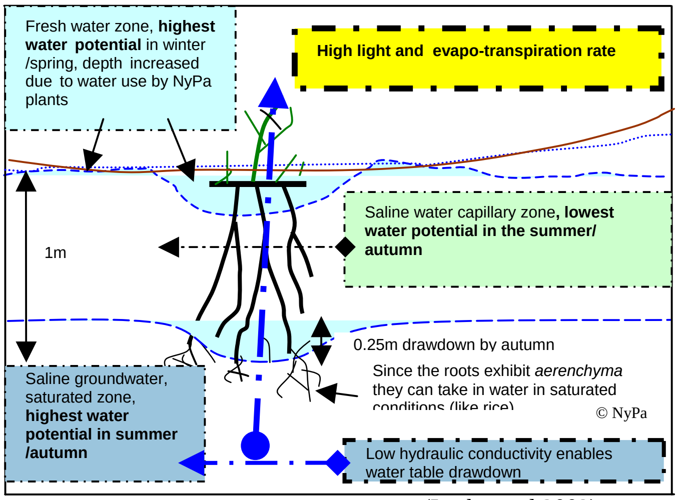
The Australian work reported here addressed both the productive and environmental impact of the use of *Distichlis spp* in saline discharge areas. The ecological range in Australia was estimated to be where saline groundwater of between about 10 mol/m^3 salinity up to almost 1.5 times ocean water salinity (800mol/m^3), within about one metre of the surface. The plants grew most actively in conditions where the temperature was above 27°C, in bright sunlight and where the groundwater contains salt.

The Forage was observed to yield up to about 25MT green matter (13.5 MT/ha dm) of forage with a protein content of between 5% and 17% and with a digestibility of between 45% and 60% with the best results to date in WA. This concurs with results in the USA and Mexico (Yensen 1998). The results in Australia were variable and depended on nutrition and on other factors not yet well understood (Leake et al 2002).

The *Distichlis* grain exhibited similar growth characteristics in Australia as in the USA, Mexico and Morocco sites (Yensen 1998), and is the subject of a current study assisted by AusIndustry to prove its future as a commercial cereal crop in Australia.

The results relevant to the impact of the *Distichlis spp* cultivars in Australia on groundwater conditions were as follows:

- in each state of Australia, the plants were observed to send roots down between one and two metres until the plants had reached the saline water table where they developed a fine-hair root structure, through which the plants apparently draw saline water when stores of fresh water become exhausted (see Figure 6.1).



(Leake et al 2002)

Figure 6.1 Plant access to a saturated saline aquifer

- in each Australian state the roots displayed the rhizocanicular effect noted in the USA and Mexico and, based on observation, this gradually improved soil structure and organic content. This is shown in Photos 2 and 3 above. It was noted that at this site worms re-occupied the soil within three years of establishment of *Distichlis*;
- in all states, observations suggested the plants used significant saline water when growing actively, particularly in the summer. Near Wickepin Western Australia, anecdotal evidence suggests that the plant was able to depress and hold the water level to about half a metre below the surrounding land in an area where water normally seeped from the surface in winter;
- in each state, the plants have been observed to exude salt at the leaf surface. This seemed to be in proportion to the rate of growth, which was proportional to temperature.

Photo 6: *Distichlis* NyPa Forage with salt on leaves

7. DISCUSSION

7.1 Water use

As discussed above, it has been suggested that salt bush (*Atriplex spp*) is able to mimic the native vegetation in its capacity to keep the saline aquifer below the capillary fringe in the broad valley bottoms of the WA wheat belt where there is little lateral movement of the aquifer. However, salt bush is not able to perform this service in regions that are frequently waterlogged, as the anaerobic conditions in saturated zones limit growth of such plants (Barrett Lennard 1986[xvi]). It was also noted that production, and so water use, is reduced when the water table moves appreciably below the root depth (Ferdowsian et al 2002).

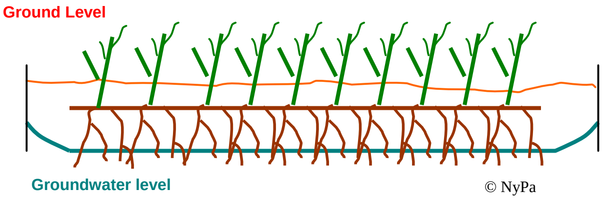


Figure 7.1: Diagram suggested by Ferdowsian to illustrate impact on broad valley bottoms in the WA wheatbelt (Ferdowsian 2002 pers comm).

Distichlis spp compliments this capacity of salt bush in the most active discharge zone, while providing very useful production in the summer months when little grows. Figure 7.1 illustrates how this impact can occur on a landscape scale. Their deep root structure (up to 2 metres) combined with *aerenchyma* is an unusual combination which provides the plants with the capacity to access saline groundwater in the saturated zone, at least when fresher surface water is not available. The mechanism by which the plants are considered to be able to access this saline water from the saturated zone is depicted in Figure 6.1. In such saturated zones the *Distichlis spp* plants growth is not limited by access to water.

As discussed above, the existence of the plant's efficient salt gland is also fundamental to the plant's capacity to respire and grow effectively in saline water. It seems from observation that the plant draws all of the salt in the water it uses through the plant and exudes it to blow away or drop to the ground. Thus salt does not seem to accumulate in the root zone (this has not been measured). This impact on salt movement is discussed further below.

The quantity of water used by the plant has also not been measured definitively for any particular site but, as stated, has been observed to depress the aquifer at the Wickepin site where the surface used to be damp at almost all times. It is suggested that, where the plant has access to permanent saline groundwater, its water use will be a function of the Annual Point Potential Evapotranspiration[1] (ET potential) modified by actual temperature (since *Distichlis spp* is known to perform better at temperatures over 27°C) and the salinity content of the water (since salt binds water requiring more energy for evaporation to occur).

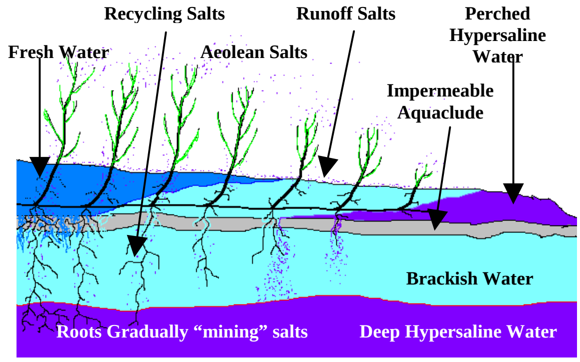
Wickepin has an average annual point potential ET of 1800 mm pa. This represents the maximum amount of soil water that a crop could evapo-transpire over a year given an unlimited supply of fresh water to the crop.

[1] *The Bureau of Meteorology defines point potential Evapotranspiration (ET) as the ET that would take place, if there was an unlimited water supply, from an area so small that the local ET effects do not alter local air mass. It is assumed that latent and sensible heat transfers within the height of measurement are through convection only*.

This limit is determined by the latitude of Wickepin (incoming solar radiation) and climate factors. The actual average annual ET for Wickepin is 300-400 mm pa. This represents the actual amount of fresh water that a crop will evapo-transpire, given the limited availability of water (rainfall). Now in addition to the usual soil moisture store, *Distichlis spp* has access to an additional source of soil water, namely saline groundwater. Thus, the actual ET will be higher than 300-400 mm pa, but it will be less than 1800 mm pa because of the extra energy required to move saline water through the plant. For the sake of demonstration, assume that the actual ET is the average of these two limits, say 1000 mm pa.

7.2 Salt Movement

The implied salt movement is also very significant. The salinity of groundwater at Wickepin lies between 10,000 mg/L and 16,000 mg/L. Adopting the lower limit, actual ET by *Distichlis spp* at Wickepin may be moving some 10 kg of salt per square metre (100 tonnes per hectare) from the groundwater to the leaf surface per year.



(Yensen et al 2002)

Figure 7.2 Salt Flow Possibilities with *Distichlis spp*

Where is all this salt going? Some is clearly rejoining atmospheric salt movement. Something between 4.2 (desert inland) or 12.9 kg (Eriksson 1958[xvii]) and 730 kg (Waisel 1972[xviii]) of salt per ha per year falls on the land from atmospheric sources depending on distance from the coast and rainfall. Some of it washes into creek lines during significant rain events (as salt deposited on the surface is now moving) and some washes back into the ground as the *Distichlis spp* plants modify the drainage (this impact on drainage is discussed below).

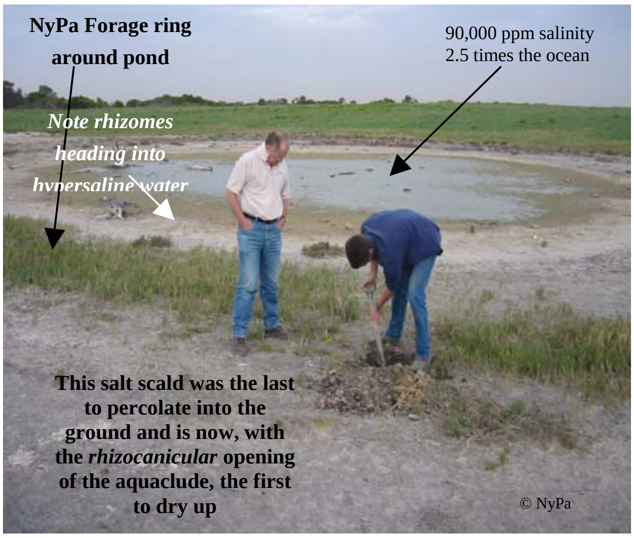
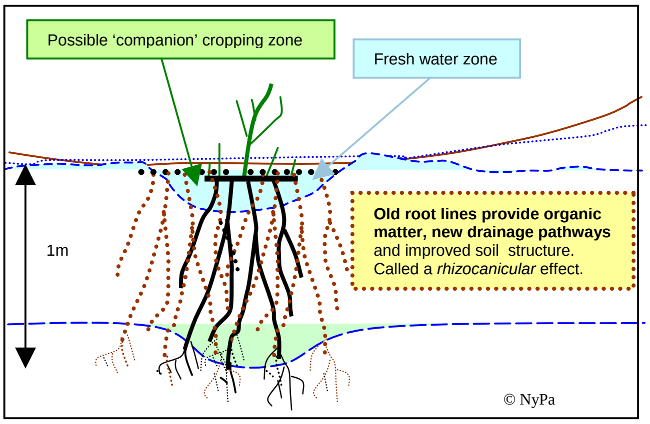


Photo 7: Meningie, South Australia 2002

The salt movement possibilities are depicted in Figure 7.2. The net change in salt movement in a site is clearly related to and less than, the net change in water use and will vary between different locations depending on wind, rainfall and soil structure. This may be considered as either a significant speeding up of the process of ridding the landscape of the salt emerging at the surface from rising saline groundwater (as in WA), or a reversal of the process where salt deposited on slopes washed down into lower lying areas when the vegetation was cleared in many other areas in Australia.

7.3 Drainage Changes

The rhizocanicular percolation effect on soil structure appears to be cumulative and to have different impacts depending on clay content and the degree to which the clays have flocculated due to the salt. In sandy areas the impact is quite slight while in highly impacted former irrigation areas the effect takes some years to become apparent. The process by which we suggest these occur are depicted in Figure 7.3.



(Leake et al 2002)

Figure 7.3: The rhizocanicular percolation effect

The impacts of the effect in different locations are suggested to include:

- in sandy areas, the soil above the lateral rhizome seems to lose its salinity so that fresh water plants are often seen to re-establish. This may point to the possibility of companion cropping with a winter active cereal, such as barley, or a water logging tolerant legume such as balansa clover (*Trifolium michelianum*). There is not much impact on drainage but worms and other organically active carbon processes increase markedly. This effect appears within a couple of years. The companion cropping idea has yet to be tested;
- in deeper impacted clay conditions the full root structure takes several years to establish but the process enables the plants to colonise nearby clay areas where the plants did not originally establish, perhaps due to a higher salinity level or some nutrition deficiency. Drainage does improve where the drained water has an exit point from the site or where it can move down into a lower aquifer as a result of opening up the soil as depicted in Figure 7.3 and Photo 7;
- in former flood irrigated land where salt has resulted in deflocculated clay and reduced water infiltration, the effect has been seen to assist leaching salt from the site, although the effect of improving infiltration rates observed in Mexico has not yet been observed in former irrigated land in Australia, as plants have only been established there for less than two years.

7.4 Financial Benefits

The main financial benefit of the use of the NyPa Forage is the production of green forage in the summer months when little else grows in the southern states without irrigation.

Observation trials of the NyPa Turf suggest that its main financial benefit will be the ability to grow an amenity grass using treated effluent water, or drained or pumped saline groundwater without deflocculating the clay and reducing infiltration. Indeed it seems likely that such sites will be rehabilitated by using this grass. The use of saline groundwater to irrigate the NyPa Turf will tend to reduce the damaging saline groundwater mounds and enable a saving in the use of valuable fresh water for this purpose, the use of which is now building these mounds in many rural towns in Australia.

The main financial benefit of the use of the NyPa Wild Wheat will be the establishment of a new non-gluten high fibre cereal crop in some areas where cereal growing has ceased or is ceasing due to salinity.

These financial benefits would tend to reduce the cost of associated drainage.

8. CONCLUSION

It has often been observed that Australia's rapidly salinising landscape requires a rethink of our farming systems. The use of deeper rooted perennial plants that can reduce aquifer recharge, halophytes in general, and the NyPa *Distichlis spp* plants in particular, offer an approach that may be implemented individually for financial gain while impacting positively on saline water discharge on a landscape scale.

The work is still preliminary but the indications are that the plants have uses in both plant-based attempts to use such land and water profitably and in engineering based efforts to reduce the water and salt loads. This is due to their impact on drainage and soil structure in both agricultural and urban settings.

9. ACKNOWLEDGEMENTS

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Thanks are due to Raymond Matthews who took photograph numbers 2, 3 and 6, and to Dr Nick Yensen who took photograph numbers 4 and 7.

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Salt interception – why, how and where

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Summary
Salt Interception Schemes (SIS) are large-scale interventions in complex subsurface systems of aquifer and aquitards, and the boundary conditions to which the schemes will respond are changing through time. The Murray Basin community has built many schemes, and is proposing to build many more. Investment in careful and considered investigation strategies will usually pay off in the form of a scheme that addresses the core of the problem, and allows flexibility to adapt as the boundary conditions change. Collateral benefits can be built into the scheme design (e.g. floodplain health improvements), and will continue to do so as the understanding of key unknown processes emerge. Results from Department of Water, Land and Biodiversity Conservation (DWLBC) and Murray Darling Basin Commission (MDBC) funded Regional Disposal Strategy will be discussed, identifying the likely scale of interception requirements over the next 50 years.

1. WHY SALT INTERCEPTION?

We are facing twin threats from salinisation: degradation of our water and of our land.

Salt interception schemes are aimed primarily at reducing the impact of salinisation on our rivers. Salt interception is an inescapable component of maintenance of our urban and rural societies. Nine salt interception schemes have been built in the Murray Darling Basin, and more are proposed. Salt Interception Schemes can achieve:

- Reductions in river salinity;
- Improvements in environmental health; and
- Protection against land salinisation and waterlogging.

In designing schemes, we plan for the infrastructure to have a life of 50 to 100 years. We therefore envisage that the schemes will be providing protection for that period of time.

We are now, after 100 years of changes in land use, able to understand and quantify the major processes that lead to unacceptable resource impacts (i.e. land and water salinisation). We know how to intervene in the processes to provide protection from these impacts at some points in space. We know that salt interception schemes can be designed to achieve salinity reductions within days of scheme start-up (eg Waikerie Salt Interception Scheme), and we can quantify the future impact of this interception (i.e. the return of water from disposal basins to the river (eg Stockyard Plain). These latter impacts will occur sometime after 100 years from now.

Envisage what our society and landscape will look like in 20 years or 50 years from now, or 100 years. Difficult to impossible to contemplate? There are few other fields of science, politics or social management that can even attempt to predict what will happen in 5 years, let alone predict with reasonable accuracy what will happen in 100 years. Remember also that the problem we are dealing with has been caused by actions over the last 100 years. The landscape, land use, and society's needs and wants will change significantly over the next 100 years. Within the context of this inevitable (probably drastic, possibly calamitous) change, it is difficult to become perturbed about manageable impacts. We have a significant threat today, and we must address and negate that threat. In doing so, we are beholden to implement change so we minimise the future impacts.

Salt interception schemes are a central part of the solution to rising river salinity. They are an integral feature because they can rapidly reduce salt loads discharging to the river. Alternative and complementary strategies include improved irrigation efficiency and revegetation. Improving irrigation efficiency is essential across the basin, with efficiency targets constantly revised upward of 85%. Revegetation, while appealing for the collateral benefits of improved biodiversity and aesthetic values, unfortunately has a long lead time, and is unable to cope with the large volumes of water emanating from consolidated irrigation districts.

While salt interception is not the perfect solution, it is an integral component in our management strategies for the years to come. I would prefer solutions that are less dependent on electrical energy. However, given the inevitable, we need to focus our efforts on improving the efficiency of salt interception, and managing the impacts of the interception, so we leave the smallest possible legacy for those who come after us.

2. HOW – THE PRINCIPLES OF INTERCEPTION DESIGN

Three over-riding principles have emerged from the investigation, design, construction and review of salt interception schemes over the last 15 years:

- Understand the processes;
- Design conservatively; and
- Monitor and review.

2.1 Understanding the processes

Developing robust concepts

Salt interception schemes require a considerable investment in investigation, more so than for structures such as bridges or dams. This investment is required because we are dealing with natural materials that have a high degree of variability in their properties. The hydraulic conductivity of earth materials can vary over some 13 orders of magnitude, which is second only to astronomy in the breadth of scale. This variability is (inconveniently) a property of materials buried beneath the surface, and measurement of their properties is therefore difficult, time consuming and expensive. Drilling rigs, careful bore design, and the conduct of carefully controlled aquifer tests are prerequisites for a successful design.

The aim of the investigation program is to understand the processes and mechanisms whereby salt (contained in saline groundwater) moves from the hinterland into the river. To this end, the investigation process should inform the development of two conceptual models: a physical hydrogeological model; and a groundwater flow model.

The physical hydrogeological model aims to reflect the stratigraphy (ie the sequence of layering of the geologic materials), structure (i.e. the bending, faulting or other deformations of the layers), and finally the hydrostratigraphy (ie the disposition of aquifers and aquitards within the stratigraphic and structural framework). Each phase of investigation should result in improvements or upgrades of the conceptual understanding of the system. This physical framework is essential if the scheme design is to be appropriate to the circumstances.

In parallel with development of the physical model, the investigations need to provide information on groundwater flow and salinity distributions within the hydrostratigraphic units. Perhaps more importantly, particularly where the salt interception schemes are developed within irrigation areas, is the need to understand the movement of water between hydrostratigraphic units. For example, at Waikerie the development of the physical and groundwater flow models lead to the conclusion that most of the salt load (>100 tonnes of salt per day) was discharging to the river from an aquifer that underlay the river, and was separated from the river valley sediments by a persistent (although hydraulically variable) aquitard. As a consequence, the interception scheme design was radically modified from earlier concepts. The scheme achieved effective interception within seven days of startup in 1992.

The groundwater flows within irrigation areas are rather more complicated than in areas without irrigation. Where irrigation is absent, lateral groundwater flow dominates (ie most water moves laterally through the aquifers). However in irrigation areas, where drainage water is dumped on top of the regional flow systems, the importance of vertical flows (ie between aquifers) is significantly increased. The rates of flow, and the spatial distribution of the flow between aquifers, are controlled by the properties of the intervening aquitard. In the irrigation areas, the properties of the aquitards therefore become as important as the properties of the aquifers. Efficient designs are unlikely to emerge unless data is collected on the hydraulic properties of both the aquifers and aquitards.

The hydraulic properties of the aquitards are difficult to measure without conducting long-term (i.e. at least seven day) aquifer tests, with water levels measured in piezometers completed across the same hydrostratigraphic unit as is being pumped. It takes this long (and longer where the aquitards are tight) for the effects of interaquifer leakage to become diagnostic. Piezometers should be one to two aquifer thicknesses from the production bore, and preferably oriented in different radial directions from the production bore.

Develop investigations and designs incrementally, and analyse data carefully at each stage

The most efficient method for developing an SIS design is to collect data incrementally. The incremental approach is favoured over a large, predetermined program. It is favoured because the actions (that achieve a maximum reduction in uncertainty with a minimum of expenditure) change as the understanding of the system evolves. Therefore, continual review of new data in the context of existing data and existing uncertainty, will lead to modifications to existing work programs and the development of hitherto unidentified investigation priorities.

The understanding of groundwater systems will evolve as data is collected and analysed, and as a consequence the SIS design may change. Sometimes this change will be radical, as has happened at Waikerie.

Constrain the solution

In developing the scheme design, it is important to constrain the solution using as many data sets as possible. These data sets can provide independent or co-dependant perspectives on the water and salt budgets that underpin scheme development. During the early stages of design this is especially important, because the relatively expensive exercise of collecting aquifer parameters needs to be undertaken in the right locations and in the right aquifer(s).

The data sets that can be employed to constrain the solution include: spatial distribution of aquifers and aquitards; measured hydraulic properties of aquifers and aquitards; head distributions in aquifers; salinity distributions in aquifers; water level and salinity trends through time in aquifers; irrigation drainage data (where appropriate); salinity distributions within the river; river salinity trends with time; groundwater geochemistry (both spatial and time variant); patterns of seepage from groundwater systems; backwater and lagoon salinities; vegetation health patterns.

It is unwise to rely on hydraulic data and/or groundwater model results alone, or indeed any single data set.

Primary and secondary design objectives

In the past, the principal design objective has been to prevent saline groundwater entering the river. However, as we improve our ability to manage the groundwater systems, and increase our understanding of current processes and our responsibilities to future generations, secondary design objectives are emerging.

Firstly, we must manage the groundwater systems so we move saline groundwater from aquifers and leave fresh or brackish drainage water in place in the aquifers. There are two good reasons for this. We need to leave the fresher water in place (beneath the irrigation districts) as a potential future resource for irrigation. In addition, if we manage the irrigation districts in conjunction with the salt interception schemes, there will come a time where the fresher drainage water has flushed through the aquifers and emerges at the river. When this happens, the salt loads discharging to the river will significantly reduce (as salinities reduce from say 20,000 mg/L to say 5,000 mg/L) and we can then turn the schemes off. While this is taking the long view, with the flushing taking 75 years or more to occur, there is no reason to disregard the more benefits of conserving the brackish water when there is little or no cost to the present day. Groundwater interception must evolve to ensure that we manage not only the river salinity, but also the potential resources that have collected beneath the irrigation districts.

The current drought conditions highlight the value of any potential water resource. Careful management of the water resource beneath irrigation districts can provide a relatively low salinity resource, providing a relatively low salinity supply that can be blended into the raw supply in such emergency situations.

Secondly, we must be designing to achieve collateral environmental benefits. There is some research under way now that builds the identification of correlations between vegetation health decline on the floodplain and the development of irrigation on the adjacent highlands. This work, which also builds on earlier research at Chowilla, focuses on the Bookpurnong area (immediately east of Berri). At Bookpurnong, we are building on the design lessons learnt from Waikerie, and anticipate that we can prepare a design that will deliver both environmental benefits and river salinity reductions. This is an important progression in our design objectives.

2.2 DESIGN CONSERVATIVELY

The greatest certainty we face is that the need for SIS's will increase, and that the volume pumped from any one scheme is likely to increase rather than decrease for the next few decades. This reflects both the emerging menace of mallee clearance and increased discharge from the mallee areas, and the likely expansion of irrigation in areas where the environmental impacts have been (partially or wholly) addressed. In operating the Woolpunda and Waikerie SIS's, the conservative approach (particularly to pipe sizing) has been utilised, both to bring forward the timing of outcomes, and to extend the breadth of salt interception. Pipeline costs are a significant component of total scheme cost, however increases in pipe costs due to incremental increases in the pipeline capacity are comparatively small (compared to initial pipe supply and lay costs). If lower flows are pumped than expected, power costs are marginally reduced because friction losses are reduced. However if the pumped volume exceeds the pipeline design capacity, then either booster pumps are required (with high friction losses and therefore operational costs) or a parallel pipeline has to be laid. Balancing this trend to conservative design is the economic argument that suggests that delaying commitment of capital can be cost effective if the delay is (approximately) ten years or more.

Also, we understand little about the role of the floodplain in storing and releasing salt. This can occur in backwaters and lagoons (as we have recently quantified at Ramco Lagoon at Waikerie), and in the unsaturated zone in the floodplains (which is currently being researched for the first time in this context). It is clear that the salt loads measured in the rivers are an underestimate of the salt load contained in the groundwater discharging toward the rivers. In South Australia, numerical groundwater modelling suggests a consistent 30% underestimate of salt in the river compared to groundwater fluxes.

2.3 MONITOR AND REVIEW

The Woolpunda SIS is the largest salt interception scheme in the world, and salt interception schemes are the largest groundwater experiments that many of us are likely to see.

It is tempting to "set and forget" the SIS's, and this has happened. However, the schemes are intervening in the groundwater processes and influence those processes. In addition, the boundary conditions that affect the scheme (notably recharge rates) change over time. It is important to develop monitoring strategies that provide information on the operational performance of the scheme (ie pump life, power costs etc). It is as important to collect information on the performance of the hydrogeological system (ie changes in water level and salinity, changes in bore performance, changes in river salinity patterns and vegetation health patterns). This data needs major review at regular intervals (every five to ten years), in addition to ongoing review and assessment.

3. CONCLUSION

Salt Interception Schemes are large-scale interventions in complex subsurface systems of aquifer and aquitards, and the boundary conditions to which the schemes will respond are changing through time.

The Murray Basin community has built many schemes, and is proposing to build many more. Investment in careful and considered investigation strategies will usually pay off in the form of a scheme that addresses the core of the problem, and allows flexibility to adapt as the boundary conditions change. Collateral benefits can be built into the scheme design, and will continue to do so as the understanding of key unknown processes emerge. The model of SIS's as solely state owned and operated infrastructure is likely to evolve to include third party delivery. This change is likely to be linked, possibly at a later time, to salinity credit trading.

4. ACKNOWLEDGEMENTS

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Salinity trends in surface water of the Mount Lofty Ranges

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[2]CSIRO Land and Water

Summary:
Two complementary methods for indicating whether the salinity of streamflows is undergoing change are described. One is the imbalance between salt load input from rainfall over salt load outflow in the stream, the other is trend analysis of salinity concentrations, allowing for factors such as flow and season. Data for the Mount Lofty Ranges are limited, disparate and the data collected in different manners and old records are no longer readily available, although data are probably the most extensive in South Australia. Hence, many calculated trends statically not significant except for a few where salinity concentrations are declining. Nevertheless, relatively pristine catchments show expected characteristics of relatively low salinity, insignificant trends, and salt output in balance with input. The salinity imbalances are caused not only by mobilisation of stored salt due to higher recharge, but also by weathering, erosion, and flow abstractions. The methodology presented enables speculation of additional factors and possibly extension to the impact of Global Climate Change.

1. INTRODUCTION

Salinisation can be caused in several ways:

- by clearing deep-rooted vegetation which allows higher recharge; irrigation (in dry areas, where it is excess of that which can be used by the crops); seepage from irrigation channels and water impounded by weirs and dams. The water which percolates beyond the root zone results in rising water tables, thereby:
  - redissolving salt accumulated below the root zone to express at ground (eg Coorong);
  - increasing the hydraulic head to discharge saline ground water into watercourses (eg the River Murray at Waikerie);
- by clearing vegetation which allows higher recharge, or excessive irrigation, sending a pulse of saline water from dissolved accumulated salt to the groundwater (eg Murray Mallee);
- geological weathering;
- extracting groundwater from unconfined aquifers for irrigation, concentrating salts through evapo-transpiration, and discharging this back into the aquifer (eg Padthaway).

Implicit in the first two mechanisms is that there is a source of salt in the soil profile to be dissolved, which does not occur in some areas.

Surface water is generally relatively fresh and is salinised by mixing with baseflow of the much higher salinity groundwater, or redissolving surface salt accumulated by evaporation. In addition, apparent salinisation can occur through land use practices. If fresh water is captured and abstracted, for example in farm dams, it will reduce the amount available for dilution of groundwater outflows downstream. Conversely, dams may capture the saline low flows but large flows can continue downstream.

Because Australia is geologically an old continent, with land management practices which are assumed not to have changed significantly over the last 40 000 years until European settlement, it is assumed that an equilibrium had been established between salt entering the landscape from rainfall and salt outflows in streams and groundwater. Eventually, stability in the recently changed land uses and practices will establish a new equilibrium in salt outflows. Where it is due to accumulated salt being removed from the soil profile, stream salinity will initially increase followed eventually by a decrease, to stabilise at a lower level than preclearing. However, it may take decades to centuries for this new equilibrium to be established, other factors being constant. In the meantime, the water may be rendered unfit for human use or damage natural ecosystems.

In many cases under current land management practice, the salt that would otherwise have flowed to sea is now held in the catchment as the water is used for irrigation or evaporated and the salt remains behind. Eventually the salt may find its way back to the stream. For example, salt from irrigation drainage pumped to the Noora (River Murray) evaporation basin south of Renmark is estimated will return underground to the River Murray in about three centuries, sparking need for new remedial measures. In the case of the Mount Lofty Ranges, however, much of the water (and its salt) is abstracted to the Adelaide Plains, of which a substantial proportion is converted to sewage and disposed to sea.

Natural ecosystems will have adapted to the range and variability of the salinity encountered under natural conditions. However, they will be affected by long-term changes, whether up or down, often in conjunction with changes in the flow pattern due to abstractions and channel modification. Unfortunately, State of the Environment has reported palatability of the water as a measure of its environmental quality. For human use, corrosion and scaling increase, and crop yield, livestock yield and palatability of water decrease, for increasing salinity above a threshold. The limiting salinity varies from 500 mg/L for human drinking (based on palatability), from about 175-3500 mg/L for irrigation (depending on crop, irrigation method, soil and ionic composition of water), and 6000-13 000 mg/L for sheep.

The purpose of the salinity investigations reported herein was to determine the risk to human use and ecological health, and priorities for remedial measures.

2. DATA COLLECTION

2.1 Surface flow and salinity

The salinisation of surface water is a classic example of the interaction of flow quality with flow quantity, but analyses of their interdependence is made more difficult by data storage and responsibilities fragmented across government agencies, with different core functions.

Clearing of native vegetation began in the Mount Lofty Ranges almost immediately the land was colonised by Europeans in the 1830s. Salinity measurements are known to have been taken around Adelaide as early as the late 1800s, but concurrent flow measurements are not known to be available.

Flow and salinity data are more readily available from the mid-1970s when the International Decade of Hydrology was established and digitisation began for computer storage on the SAQUADAT system of the State Water Laboratory of the Engineering and Water Supply Department. Water quality data were collected on regular visits to sites, usually weekly, to critical water supply locations. Hydrologists read salinity by field meter when maintaining flow-gauging stations, which was at that time about monthly. Some stations were also fitted with chart recorders at the time, but few were digitised. In the early 1990s, more instruments for salinity were installed, to include flow activated automatic sampling, either flow proportional or composite. The latter was used for reasons of economy of chemical analyses, and is useful to calculate loads, but averages out concentrations. “Continuous” salinity recording was introduced following data analyses in the 1990s (van der Wel 1989, Williamson 1990).

Because the early data collection required a site visit, data is biased to low flows. Large flows tend to be missing because the site would have been inaccessible. The ephemeral nature of many South Australian streams means that in several months there may be no flow. Alternatively, construction of flow gauging weirs, or their location at natural rock crops means that low flows could be the hyporheic flows forced to the surface.

2.2 Rainfall and salinity

Collection of daily rainfall has been widespread since the beginning of colonisation, notwithstanding that it was at locations convenient to human settlement. Often the data collection network missed out the higher rainfall areas on topographically difficult terrain, resulting in a bias to lower rainfall in a catchment. It is increasingly sparse in the less settled areas.

There has been no regular collection of rainfall salinity data. In the early 1980s rainfall quality data from a few locations around metropolitan Adelaide were collected by the State Water Laboratory and assessed by van der Wel (1989). Tiller and Smith (1989) collected data from stations in a transect across the Mount Lofty Ranges to the River Murray. This work was extended by Kayaalp and Bye (1995) to separate dry chloride accession to the landscape from wet accession in rainfall. They compared the results with the formula relating chloride outfall to distance from the coast derived by Hutton (1976) from work in Victoria. Hutton, and Kayaalp and Bye found that saltfall (up to 500 km from the coast) was a result of seaspray. Inland, the work of Blackburn and McLeod (1983) including some stations in South Australia along the River Murray, found that saltfall was heavily influenced by recycled salt from the landscape. Despite the changes in chloride concentration with location, Williamson et al (1987) concluded that the average annual salt concentrations are generally independent of the quantity of rainfall within 70 km of the coast. Hence in the calculations reported here (van der Wel 1989, and Williamson 1990) applied a uniform chloride content of 4.9 mg/L converted to total dissolved solids (TDS) by a factor of 2.55, except where measured data was available.

3. METHODOLOGY

3.1 Conductivity and salinity

Salinity was converted to TDS by the regression equation developed by the State Water Laboratory for South Australian streams dominated by sodium chloride (most streams except those originating in Queensland)

$$S=0.548E+2.2\times10^{-6}E^2-2.06\times10^{-12}E^3 \qquad (1)$$

where

S is TDS in mg/L;

E is salinity in electro-conductivity units (EC=μS/cm at 25°C).

Where both E and S (as summation of ions analysed by chromatography) are available, it indicates an accuracy within about 20%.

3.2 Salt imbalances

Two methods have been used for estimating whether salt in surface water is out of balance with salt coming in from rainfall: input output ratios and trend analysis.

3.2.1 Input/output ratios

In this method, total dissolved solid loads in rainfall are compared to that in the streamflow, on an annual basis.

Input salt load was estimated as the product of rainfall salinity and rainfall. Total rainfall was determined by allocating individual rainfall stations to parts of the catchment using the Thiessen polygon method.

Output salt load was estimated to be that carried in the surface outflow. From grab samples, a relationship was determined between instantaneous flow and salinity (as shown in figure 2) and applying that to the flow volume over discrete intervals of the instantaneous flow range. Hall (1970) gave a number of formulae for salinity-discharge relationships. The one adopted here assumed a dilution of an inflow of constant salinity by a zero salinity flow, which is a reasonable approximation since the salinity of initial surface runoff is low compared to groundwater inflow in most cases. In a limited number of cases, a polynomial curve was fitted.

A number of assumptions are implicit in this method. Omission of groundwater outflow and abstractions causes an underestimation of salt outflow. It is further assumed that the climate has been constant over a considerable period that established equilibrium prior to a disturbance causing the salt imbalance.

3.2.2 Trend analysis

The salinity concentration in the stream flow is assumed to comprise a number of additive components, including flow, time and seasonality.

Van der Wel (1989) established an arbitrary formula summing a number of supposedly statistically independent components:

$$\log S = a + b \log(Q) + c \sin(m) + d \cos(m) + e\,(t) \qquad (2)$$

where:

S is TDS (mg/L)

Q is the instantaneous flow (m^3/s)

m is the day in the year converted to angular measure

t is date (years); and

a, b, c, d and e are constants which can be obtained by linear regression.

Sinusoidal component substitutes for a number of effects, such as autocorrelation between stream salinity, wetting up of the soil in winter of the Mediterranean climates by small rainfall amounts, which are by themselves insufficient to cause recharge (which typically occurs in a >30 mm event), and abstraction for irrigation which occurs seasonally. Kayaalp and Bye (1995) found that rainfall chloride was correlated to average wind speed and had a quarterly cycle. A single annual sine wave may not accurately reflect such phenomena, but the direct rainfall salinity is a small component of the streamflow salinity.

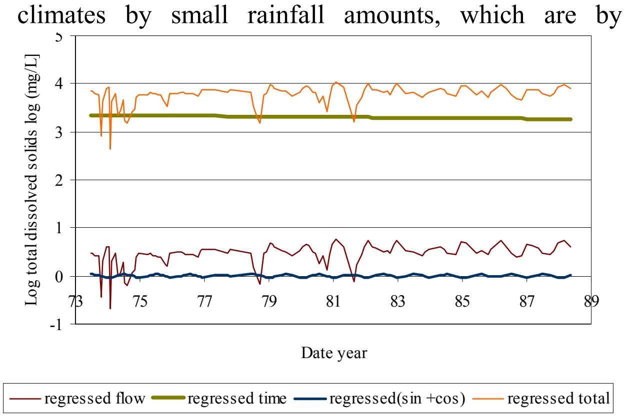

Figure 1: Typical components of salinity. Light River at Kapunda

This method could be used in spreadsheets. More sophisticated statistical packages would allow more complex formula described by Hall (1970). Figure 1 is an example of the stream salinity separated into the above components.

This method was modified by Morton (1997) to include smoothing splines as follows:

$$\ln(E)=\alpha+S(\text{time}; df_t)+S(\ln(\text{flow}); df_f)+ \beta\sin(2\pi\ \text{month}/12)+ \gamma\cos(2\pi\ \text{month}/12)+ \varepsilon \qquad (3)$$

where:

ln is the natural logarithm

E is salinity as electro-conductivity units averaged over a month

time is in years

month has values of 1 to 12

S(t; df_t) is a smoothing spline of *ln(EC)* versus *time* with df_t degrees of freedom,

S(ln(*flow*); df_f) is a smoothing spline of *ln(EC)* versus *ln(flow)* with df_f degrees of freedom;

α, β, γ are linear regression coefficients and ε is the residual error.

The terms df_t and df_f are smoothing parameters that determine the shape of the splines fitted to the data. Morton's (1997) recommended values of 4 for df_t and 2 for df_f as adequate for data sets of the length used in this project. The method made adjustments for autocorrelation and "missing" data (which may be zero flow).

4. RESULTS

Investigation of water quality downstream of streams regulated with major dams or carrying discharge from piped inflows from the River Murray has been excluded. Nevertheless, flow regimes have been modified and volumes abstracted through increasing farm dam development, particularly subsequent to the calculations of the O/I ratios in 1990, which may influence the trend lines.

Figure 2 illustrates the variation of salinity concentrations in stream flow with instantaneous flow (based on data up to 1989). The slope of the line is an indication of the groundwater salinity and volume relative to the dilution flows.

From the graph it can be seen that with the more saline streams there are large reductions in salinity with higher flows, rendering some of the water useful for human purposes, but the amount of this volume may be small

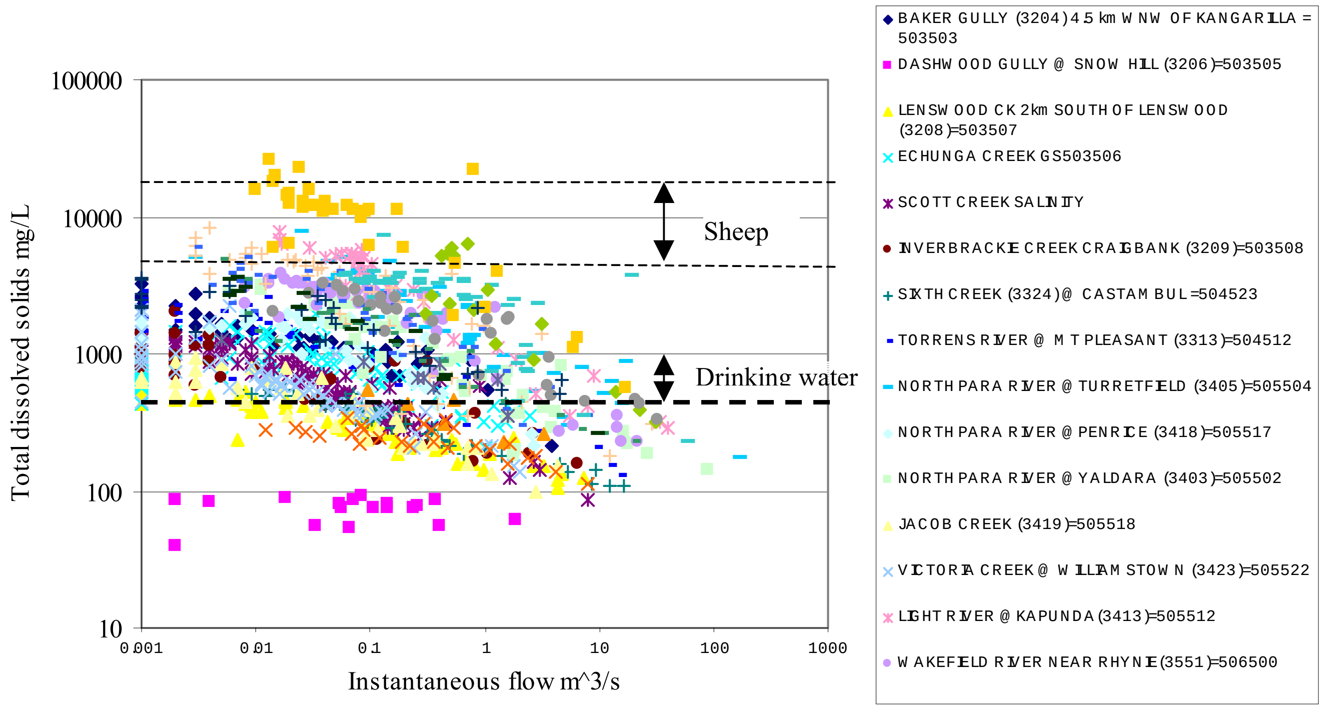

Figure 2: variation of salinity with instantaneous flow

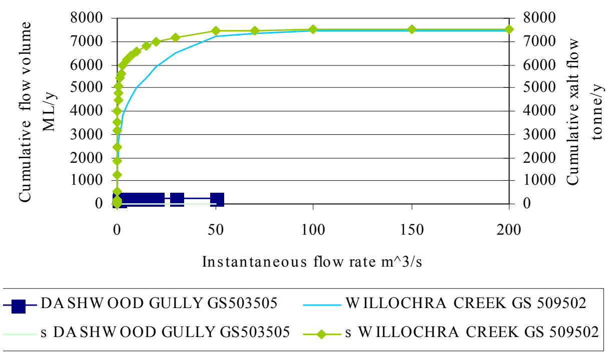

Figure 3: flow volume and salt load (denoted by s prior to catchment name) carried up to various instantaneous flow rates.

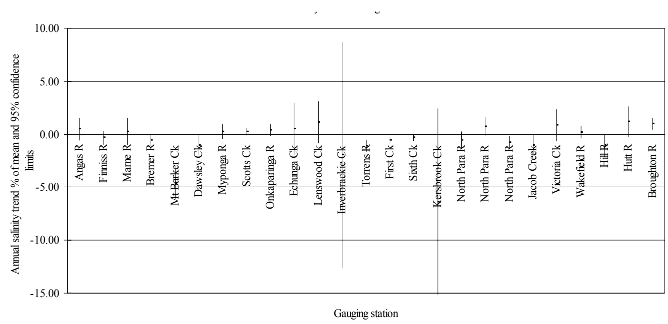

Figure 4: salinity trends as percentage of mean salinity and significance at 95% confidence limits, by catchment

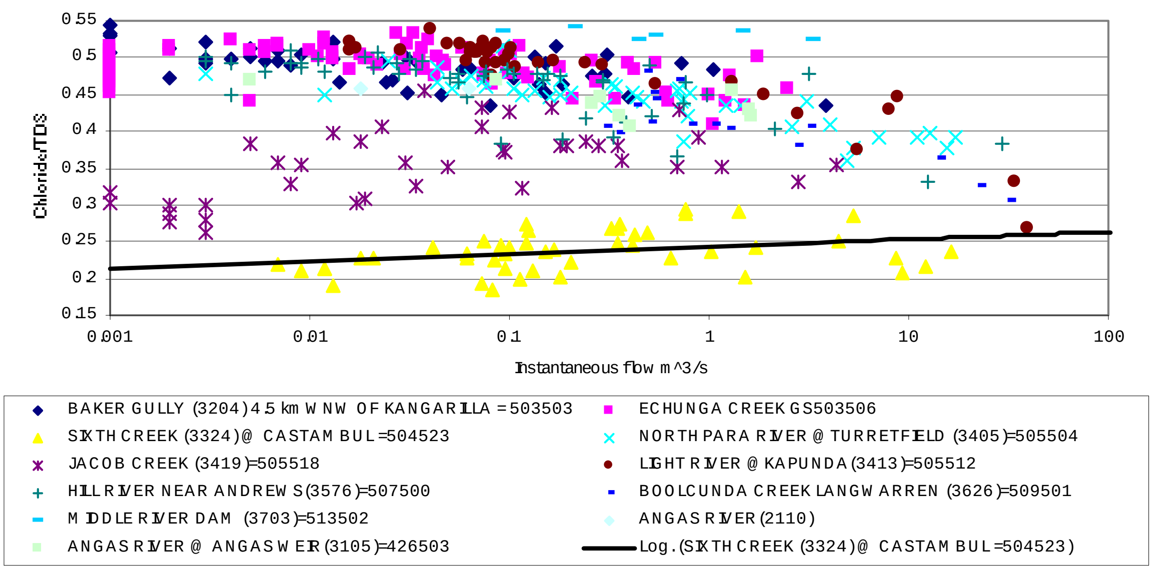

Figure 6: variation of ratio of chloride to total dissolved solids with instantaneous flow

and infrequent. Large salt loads are carried in large flows, despite their low salinity. However, because of their infrequent nature, the proportion of salt on an average annual basis is small. Figure 3 illustrates the volumes of water and salt load carried at increasing flow rates, showing that most of the salt load is carried by the lower flows

Table 1 shows averaged output/input ratios and trends. It is indicated that undisturbed catchments such as Rocky River on Kangaroo Island, and catchments of largely old regrowth woodland, such as First Creek at Waterfall Gully, or forested catchments such as Dashwood Gully have relatively low salinities (around the low hundreds mg/L), negligible trend and salt output matching input. The trends and their significance are plotted in Figure 4. Only some trends were significant and these were with declining salinity.

Other catchments have high salt O/I load ratios, although the concentration trend may now be declining. The non-linear trends are also affected by events such as the drought in 1982-83. There is some mismatch between trends determined from “continuous” data and grab samples where there is overlap, as shown in Figure 5.

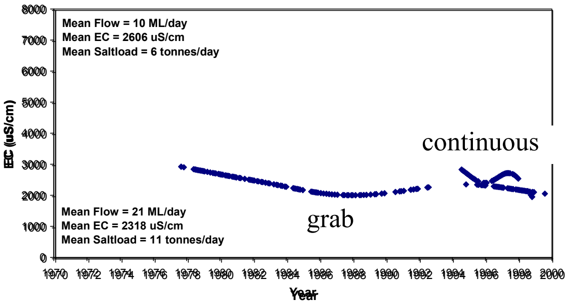

Figure 5: Trend analysis using method of Morton. North Para River at Penrice superimposing grab sample and continuous sample monitoring.

The ratios of chloride to TDS concentration (Cl/TDS) against instantaneous flow are plotted in figure 6. The ratio for seasalt is 0.56 and in rainfall 0.4 (for Onkaparinga site in Blackburn and McLeod 1983). In the streamflow, Cl/TDS ratio generally declines with instantaneous flow, indicating entrainment of surface pollutants or erosion. Exceptions are Deep Creek at Castambul and Dawesley Creek at Brukunga, where the ratio is consistently low, indicating geological weathering sources. It is known that Dawesley Creek had mineral inflows due to weathering of pyrites exposed through mining.

5. DISCUSSION

Given the sources of error in the data and approximations of the calculation method, only salt output to input ratios greater that two should be considered significant.

The data shows that, in the Mount Lofty catchments, salinity balances have been disturbed, but that the peak salinity concentrations may have been reached for current practices and climate, as suggested by the lack of significant increasing salinity trends.

The data could be further analysed to determine the relative contributions of groundwater, surface water and weathering/erosion products. This would enable assessment of changes likely under Global Climate Change.

More frequent measurement of salinity in rainfall would give a greater understanding of variations and sources of salt. Given the nature of the other approximations and assumptions, great accuracy in data measurement is not required.

6. CONCLUSIONS

Salinisation of water resources distinctively shows the importance of the interaction of flow and water quality, but whose measurement has traditionally been handled by different government agencies.

Two methods are described for indicating salt disturbance in the landscape. They are complementary. A high load output of salt relative to input may nevertheless be past the peak of salt production and show declining salt concentrations over the short period of record since the disturbance was initiated.

The O/I method shows most catchments analysed are out of balance except those that have not been disturbed such as Rocky River on Kangaroo Island, or the regrowth woodland catchment of First Creek above Waterfall Gully (Torrens catchment). These also show relatively low salinity and close to zero trend.

Trends in salinity concentrations in surface water of the Mount Lofty Ranges are variable. Only those with declining trends were statistically significant.

Further work is required to separate the causes of salinity which may include remobilisation of built-up salt, geological weathering, anthropogenic applications, or abstractions of the lower saline flows. Further work is also required to determine the role of recent past climatic shifts in affecting the present trends, and their use in predicting changes due to Global Climate Change. Abstraction of unrecorded data from past records of flow and regular collection of rainfall salinity would assist.

7. ACKNOWLEDGMENTS

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Table 1: Output/Input load ratios and trends for catchment

			Reference	Williamson 1990		Jolly et al 2000						
						grab	grab	grab	continuous			
Flow gauging station	**Location**	**Station number**	**Type of salinity sampling**	**Output /input salt**	**mean TDS mg/L**	**mean EC**	**annual trend EC/ year**	**95% confidence limit EC**	**mean EC**	**annual trend EC/ year**	**95% confidence limit EC**	**grab significant**
Angas R	Angas weir	426503	grab	4	720	1426	7	15				
Finniss R	Yundi	426504	grab	8.2	630	1254	-4	8				
Marne R	Cambrai	426529	grab	3.4	890	3302	9	42				
Bremer R	Hartley	426533	grab, continuous	5.7	970	3330	-18	19	3794	-31	144	
Mt Barker Ck	Mt Barker	426557	grab	5.5	620	2490	-115	35				*
Dawesley Ck	Brukunga Downstream	426558	grab	7.6	870	3417	-35	31				*
Angas R	Angas Plains	426629	continuous						3092	178	458	
Myponga R	Myponga Reservoir upstream	502502	grab			736	2	5				
Scotts Ck	Scotts Bottom	503502	grab, continuous	4	310	1242	3	4	1147	6	18	
Baker Gully		503503	grab	4.6	550							
Onkaparinga R	Houlgrave Weir	503504	grab, continuous			738	3	4	702	-3	4	
Dashwood Gully		503505	grab	0.5	80							
Echunga Ck	Mt Bold Reservoir upstream	503506	grab, continuous	4.8	490	1637	8	40	2060	-202	152	
Lenswood Ck	Lenswood	503507	grab	5.1	240	617	7	12				
Inverbrackie Ck	Craigbank	503508	grab	4.7	370	1601	-31	171				
Torrens R	Mt Pleasant	504512	grab	4.6	510	2922	-32	16				*
First Ck	Waterfall Gully	504517	grab	1.7	110	335	-2	1				*

Table 1: Output/Input load ratios and trends for catchment (continued)												
			Reference	Williamson 1990		Jolly et al 2000						
						grab	grab	grab	continuous			
Flow gauging station	**Location**	**Station number**	**Type of salinity sampling**	**Output /input salt**	**mean TDS mg/L**	**mean EC**	**annual trend EC/ year**	**95% confi dence limit EC**	**mean EC**	**annual trend EC/ year**	**95% confi dence limit EC**	**grab significa nt**
Sixth Ck	Castambul	504523	grab	3.8	240	656	-2	2				
Kersbrook Ck	Millbrook Reservoir upstream	504525	grab, continuous			1524	-97	134	2061	866	363	
North Para R	Yaldara	505502	grab, continuous	3.1	540	2934	-17	24	4529	-145	132	
North Para R	Turretfield	505504	grab, continuous	3.7	900	4814	34	43	5883	414	501	
North Para R	Penrice	505517	grab, continuous	5	620	2318	-18	14	2606	-69	78	*
Jacob Creek	Kitchener	505518	grab	4.2	230	878	-9	8				*
Victoria Ck	Williams-town	505522	grab	3.8	360	1526	13	23				
North Para R	Mt McKenzie	505533	continuous						2576	47	121	
Tanunda Creek	Bethany	505535	continuous						1598	-67	100	
North Para R	Tanunda	505536	continuous						4362	-340	144	
Wakefield R	Rhynie	506500	grab	2.8	1100	4349	9	25				
Hill R	Andrews	507500	grab	2.4	730	5702	-61	61				
Hutt R	Spalding	507501	grab	2.4	590	4220	51	60				
Broughton R	Mooroola	507503	grab	2.5	1200	5035	50	26				*
Willochra R		509502	grab	1	2460							
Tod R	Toolilie Gully	512503	continuous						15327	1062	674	
Tod R	Diversion Weir	512504	continuous						10432	943	388	
Rocky R		513501		0.5	230							

Impact of a tree plantation on dryland salinity at "Mt Eagle" (near Keyneton, SA)

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Summary
The Mt Eagle subcatchment occurs in the headwaters of the North Para River catchment and is affected by dryland salinity. A quarter of the catchment was revegetated in the early 1990s. Groundwater levels have been monitored since then on both this and a nearby control catchment. Although seasonal influences are overprinting land use change, watertables have decreased relative to the control catchment. Even if watertables rise again in the future, a much flatter hydraulic gradient should see significantly reduced groundwater discharge. However, FLOWTUBE modelling indicates that the proportion of trees is not enough to completely stop discharge occurring in this catchment.

1. INTRODUCTION
In the Mount Lofty Ranges, dryland salinity is often expressed as waterlogged valleys supporting thick or patchy sea barley grass. Reclamation has traditionally involved planting the discharge areas with trees. There are few documented examples of planting trees in the recharge areas.

2. HISTORICAL BACKGROUND

2.1 Area description
The Mt Eagle subcatchment is a small 40ha first order catchment in the headwaters of the North Para River catchment. (It lies near the watershed between the Gawler River catchment and the Murray Basin hills catchments). Annual rainfall is 550 mm.

Land clearing was carried out on the Mitchell property between 1919 and 1940 (NDSP, 2002). Dryland salinity was first observed in 1964 and expanded during the 1970s and 1980s.

It is likely that groundwater started rising during the 1930's, especially following wetter years. By the 1960's groundwater would probably having risen by 10m, and reached the surface in the valleys with saline seeps developing at the break in slope and at valley constrictions. Waterlogging would also have been exacerbated by the development of shallow watertables beneath valleys.

2.2 Methods
Approximately 5000 trees were planted along the rocky ridge of the catchment in the Springs of 1991 and 1992. In total, 10 ha of land (about 25% of the catchment) were planted at an average density of 500 stems/ha.

Seedlings of ten mainly indigenous species were placed according to micro topography with high water use trees (*E. globulus* and *E. cladocalyx*) being planted in hillside valleys and mallee *spp* higher up on the drier ridge top. Tagasaste was planted at the northern end of the tree block.

Piezometer installation commenced in 1989 with further additions at later dates. These have been monitored continuously since then. A control subcatchment has also been monitored. Land use has been mainly annual pasture with minimal cropping in the control catchment.

3. GROUNDWATER RESPONSES
The local fractured rock groundwater system responds rapidly to seasonal rainfall. The threshold monthly rainfall for recharge to occur is 50-100 mm. However, a wet month of at least 100 mm is required to cause significant recharge (ie a distinct peak in the groundwater hydrograph).

Although recharge to the unconfined aquifer occurs over the whole catchment, the rocky ridge may act as a high recharge area. Perched watertables occur on the steep slopes in wet winters.

The hydrographs indicate that a run of near or below average seasons has seen a steadily falling groundwater trend over the past 10 years. Seasonal conditions are therefore overprinting land use change and the impact of treatments is therefore difficult to determine.

3.1 Recharge areas
Comparison of site E1 in the tree plantation and site B1 in the control catchment indicate that groundwater levels have fallen by 7.3m at E1 and 5.1m at B1 in the upper slopes of the two catchments between May 1992 and May 2003.

There has been a net fall in groundwater levels of 2.2m beneath the trees relative to the crop/pasture land use. The simple water budget calculator (Dooley, 1999) indicates that this land use change has reduced recharge by about 25% over the catchment area.

3.2 Discharge areas

Groundwater converges and discharges at break in slope and at valley constrictions caused by bedrock highs.

Comparison of site E2C downslope of the tree plantation and site B2C in the control catchment indicate that groundwater levels have fallen by 6.1m at E2 and 3.0m at B2 between May 1992 and May 2003.

Site E2 was a saline seep in 1992 with a piezometric head above ground surface. By 2003 the valley has dried considerably and normal annuals have replaced the barley grass and bare areas. At site B2C in the control catchment, the valley is still wet and mildly saline.

3.3 Groundwater contour map

In 1992, groundwater flowed from the ridgeline converging into the lower catchment. A zone of steeper hydraulic gradients occurred near the break in slope, possibly representing a low K_s zone at the boundary of the fractured rock and saprolite clay aquifer.

By 2003, a very subdued cone of depression had developed below the central lower slopes of the tree plantation. A slight groundwater mound has also formed along the break in slope (near site E2).

There has been a subtle gradient reversal with groundwater changing direction and flowing from the old discharge area (E2) back toward the recharge area (E1). In 1992, E1 was +0.7m relative to E2, but in 2003, E1 is –0.5m relative to E2.

4. FLOWTUBE MODELLING

A number of scenarios were modeled using FLOWTUBE (Dawes *et al*, 2000) including revegetation of top quarter, top half, bottom half and entire catchment. For revegetation of the top quarter of the catchment, modelling predicted:

- Biggest reduction of watertable in first 5 years
- Equilibrium after ~ 10-20 years
- Groundwater still discharges in the catchment.

If the top half of the catchment were revegetated, modelling predicted:

- Equilibrium after ~50 years
- Groundwater stops discharging to the surface in the upland parts of the catchment
- Significant lowering of watertable in upper half of catchment
- Waterlogged area remains in lower third of catchment.

The modelling results indicate that if the entire catchment were revegetated, then the watertable in the lower third of the catchment would significantly be reduced.

5. DISCUSSION

Treatment of high recharge areas (eg planting trees on rocky ridges) is not always guaranteed of success. Groundwater connection between the fractured rock aquifer of the rocky ridge and the alluvial/saprolite clay aquifer in the adjacent valley may be complex.

At Burkes Flat in Victoria, watertables dropped by 5-6m beneath the slopes after 10 years, but this was not translated to the valley floor in the first 10 years (Reid, 1995). However, the seeps did not expand in size because the hydraulic gradient was now much flatter and hence the groundwater flux to the discharge areas was much smaller.

FLOWTUBE modelling indicatives that with between a quarter and a half of the catchment revegetated, groundwater discharge will be reduced, but shallow watertables are likely to remain over the lower third of the catchment.

The impact of future wet years will test the system as watertables are still falling steadily as at May 2003. It remains to be seen if the trees will have a sufficient buffering capacity to prevent groundwater levels from returning to the pre-1993 levels.

If the hydraulic gradient to the valley floor continues to flatten, the groundwater flux will decrease and hence the rate of discharge will lessen. Although watertables may remain shallow, it is hoped that the area of saltland will be prevented from continuing to spread.

6. CONCLUSIONS

FLOWTUBE has predicted the impact of revegetating different areas and proportions of the catchment. Although seasonal influences are overprinting land use change, results to date suggest that watertables have decreased relative to the control catchment and groundwater discharge has been reduced. Even if watertables rise again following wet seasons, a much flatter hydraulic gradient should see significantly reduced groundwater discharge.

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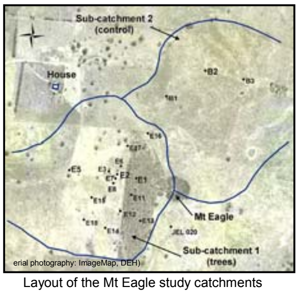
Impact of a tree plantation on dryland salinity at “Mt Eagle” (near Keyneton SA)

Chris Henschke *, Chris Smitt **, Peter Ciganovic *
(* Rural Solutions SA; **CSIRO Land and Water)

Background

In the Mt Lofty Ranges, dryland salinity is often expressed as waterlogged valleys or discharge zones at the break of slope.

Reclamation has traditionally focussed on planting trees in discharge areas, while there are few documented examples of tree plantings in higher recharge areas.



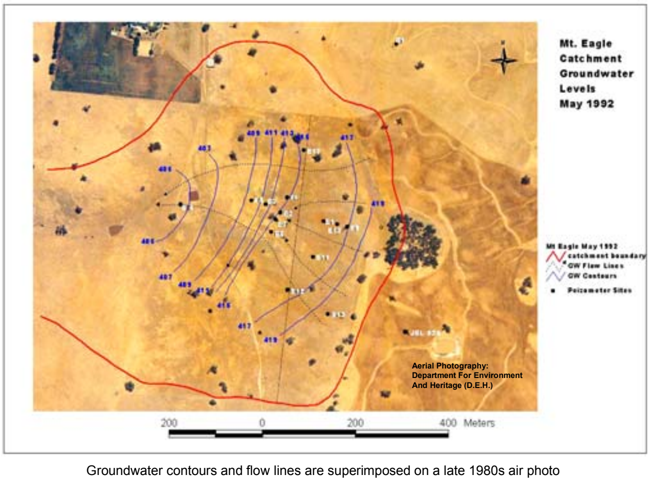
Layout of the Mt Eagle study catchments

This 13 year study investigates the effects of revegetation of the upper quarter (high recharge potential zone) of the Mt Eagle sub-catchment (1).

Prior to revegetation

Groundwater flows from the rocky ridge and converges towards discharge areas at site E2 and below site E5.

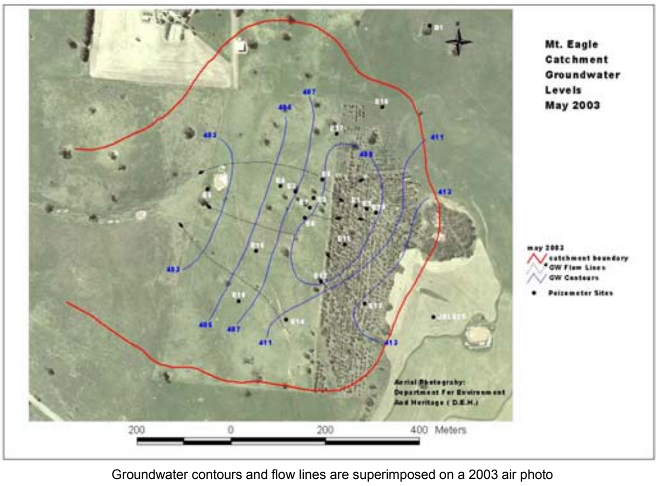

Drilling piezometers at site E1
on the rocky ridge – Feb 1990



Groundwater contours and flow lines are superimposed on a late 1980s air photo

Following revegetation

Following revegetation, saline discharge areas retreated and groundwater levels showed significant drops, compared to a neighbouring untreated catchment. In the past 10 years a watertable depression has developed beneath the trees and there is a gradient reversal from a groundwater mound at site E2 back into the trees.



Groundwater contours and flow lines are superimposed on a 2003 air photo

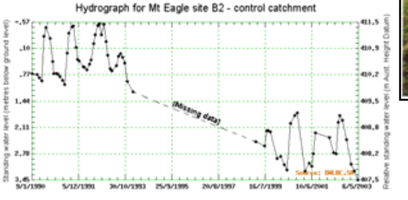
Discharge area hydrographs

At Site E2 (downslope from the trees), the discharge at the break of slope has disappeared and groundwater levels have fallen by 6m since 1992.


Discharge at site E2 – Sep 1991


Wet seepage area has gone
at site E2 – Jun 2003

At Site B2, the discharge area in the control catchment, groundwater levels have fallen by 3m since 1992 due to a run of dry seasons.

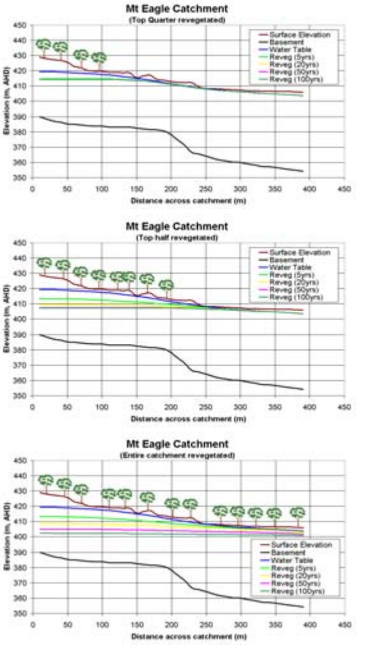



Site B2 in control catchment
remains saline & waterlogged

FLOWTUBE modelling

Predicts that revegetation of the top quarter of the catchment is not enough to completely stop discharge occurring when wet seasons return again in the future.

Other revegetation scenarios have been modelled, to demonstrate likely impacts of changing land use on the catchment water balance.



FLOWTUBE modelling predicts watertable changes
under different revegetation scenarios

Conclusions

While seasonal influences are overprinting land use change, results to date suggest that watertables have decreased relative to the control catchment and groundwater discharge has been reduced.

Even if watertables rise again following wet seasons, a much flatter hydraulic gradient should see significantly reduced groundwater discharge.

CSIRO

RURAL SOLUTIONS SA

Low Recharge Farming

"Its all about reducing the amount of water leakage on the farm"

High Leakage = rising watertables = salinity and waterlogging = problems!

To reduce the amount of leakage under crops and pastures – maximise water use

HOW?

1. Ensure crop and pasture productivity

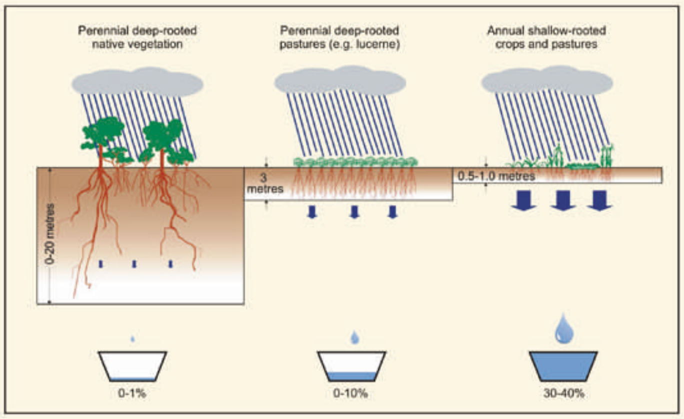
- Adjust seed-rates for maximum yields
- Adjust fertiliser applications
- Manage pest and diseases
- Introduce tighter rotations
- Limit fallows
- Consider phase farming with lucerne
- Consider summer cropping

2. Increase the area of perennials on the farm

Perennials to consider are:

- Dryland lucerne
- Saltbush
- Primrose
- Phalaris
- Native vegetation - trees, shrubs, grasses

Lucerne at Karkoo. Lucerne is a highly productive perennial pasture that can significantly reduce recharge.



Rainfall leaked by various plant systems

Saltbush is useful for stock feed & shelter and as a tool in reducing recharge. Saltbush can also be established around discharge sites.

Higher crop productivity almost always equates to higher water use, which in turn reduces leakage.

Low Recharge Farming = Sustainablity and Profitability

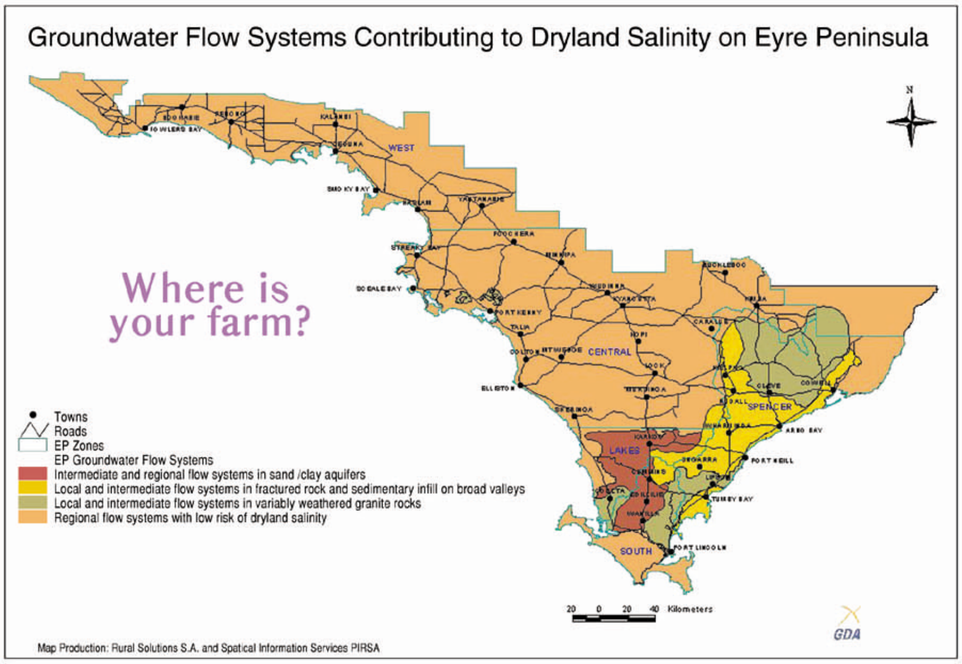
The Department of Water, Land and Biodiversity Conservation

EYRE PENINSULA NATURAL RESOURCE MANAGEMENT

Understanding groundwater flow systems is vital for sound management of

DRYLAND SALINITY

Salt affected Redgums at Cummins
Correct management of such areas will depend upon knowledge of the type of groundwater flow system.



Where do you fit in the table? find your best management practice

	Local - Intermediate	Local - Intermediate	Intermediate - Regional
Aquifer	Weathered granitic rock	Fractured rock & infill	Sand/clay aquifers
Approx distance recharge - discharge	1-5km	3-10km	10-30km
Catchment size	Small	Small to Medium	Medium to Large
Landscape	Hilly Uplands	Alluvial Plains	Broad Riverine Floodplains
Examples	Coulta, Upper Wanilla, Tod River Salt Creek (South of Ungarra), Upper Driver River, Eastern Cleve Hills (Salt Ck North)	Lower Driver River, Yeldulknie Creek, Dutton River/Byrnes Bay, Salt Ck (including Butler Tanks), Cockaleechie Flat	Cummins Wanilla Basin, Salt Creek system east of Karkoo (Brooker Catchment)
Risk of further spread	Moderate risk	Moderate to High risk	High risk
Best Management Practice	High water use farming systems • Introduce more perennials • Phase farming with lucerne • Summer cropping • Interception plantings	• High Water Use options to hill-slopes & ridges above saline seeps • Drainage options possible – seek advice. • Saltland agronomy • Saline Industries	• Recharge reduction required over very large areas • Revegetation of large sandhills will reduce local recharge • Drainage options - seek advice • Saltland agronomy • Saline industries

Address salinity issues wisely - make every effort count!

The Department of Water, Land and Biodiversity Conservation

EYRE PENINSULA NATURAL RESOURCE MANAGEMENT

Applying geophysics to support salinity management in SA

Background

Whilst much is known of the processes leading to salinity throughout SA, implementation and prioritisation of salinity management often requires detailed spatial knowledge of where measures are best targeted.

With the promise of obtaining cost effective spatial information to assist with salinity management, airborne geophysics are being put to the test in the $3.8M, NAP funded, SA Salt Mapping and Management Support Project.

Five sites across the state have been chosen to trial the technology which, if successful, could have potential applications on a broader scale.

Aims

This Project represents the first major geophysics study designed to address specifically targeted salinity management outcomes.

Different management issues at each site required tailored approaches:

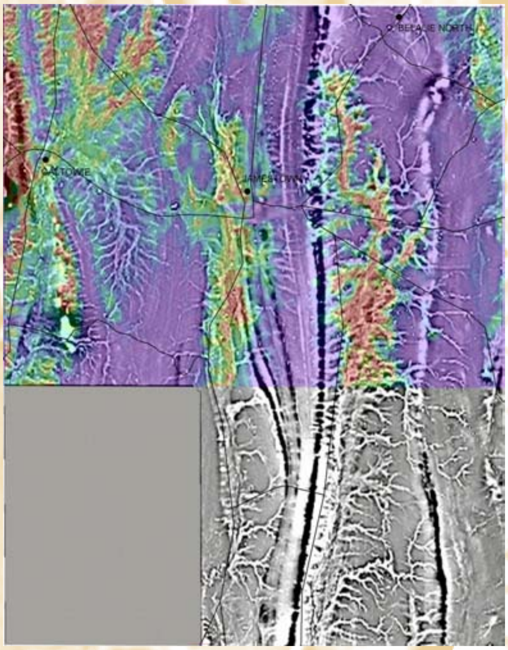
In the Riverland mapping the shallow subsurface Blanchetown Clay will assist future irrigation planning and efficiency improvements to reduce recharge and the impact of high salt loads being driven into the River Murray.

At Tintinara two sites are under investigation: in the east, mapping subsurface clay will enable irrigation planners to protect the local underlying fresh groundwater resource from salinisation; and in the west the focus is on identifying native vegetation at risk from salinity.

In the Angas-Bremer Plains the dominant recharge mechanisms for the locally important irrigation aquifers are being probed.

At Jamestown, mapping of subsurface features associated with the movement of groundwater, will help in the assessment of recharge control options for localised areas of salinity.

In the Bremer Hills, project aims were to identify and map the causes of saline input to streams, including zones of deeply weathered rock.

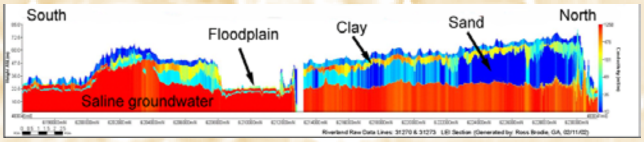


Magnetics can provide insight into the 'underground plumbing' or groundwater flow systems by picking up tiny magnetic fields often associated with geological features such as the iron oxide coated pebbles lying in ancient buried drainage lines around Jamestown. When combined with depth-related Electromagnetics information this can indicate the presence of saline groundwater.

Outcomes

With verification by ground-truthing (drilling, ground EM, etc.) and consensus with existing information, results to date for many of the sites have exceeded expectations.

Electromagnetics data in the Riverland has produced a good match with existing maps of the Blanchetown Clay and has the potential to improve map resolution.

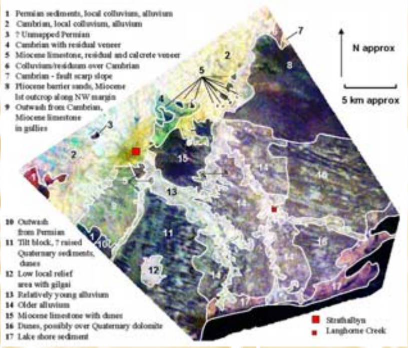


Electromagnetics are able to identify 3 dimensional zones of conductivity and can map potential zones of high salt storage or conducting material such as clay or minerals.

At the Tintinara East site significant insight has been obtained into the thickness and extent of the sub-surface clay. In the West site, zones of shallow saline groundwater were successfully detected and the impacts on native vegetation are being assessed.

In the Angas-Bremer Plains zones of salinity surrounding the irrigation aquifer correlate well with existing groundwater monitoring data and survey results indicate where studies into recharge should proceed.

Paleochannels buried beneath the valleys of the Jamestown region appear to alleviate potential for salinity where drainage is good and exacerbate salinity problems where they converge into 'bottlenecks'.



Radiometrics detects radioactivity from 3 naturally occurring radioactive elements (Potassium, Thorium and Uranium) and provides information about surface soil chemistry. This is useful for identifying soil types or drainage patterns that may be linked to salinity.

In the Bremer Hills, radiometrics has successfully identified zones of deep weathering, which (in combination with certain rainfall and drainage conditions) are associated with high salt fluxes to streams.

The project hopes to further investigate how geophysical techniques can be made more cost effective, while obtaining significant outcomes for salinity management.

Ground-truthing is essential

Final project results are expected in December 2003.

Further information can be obtained from
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