Murray Darling 1995 Workshop

Extended Abstracts

Wagga Wagga 11-13 September

Record No. 1995/61

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AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

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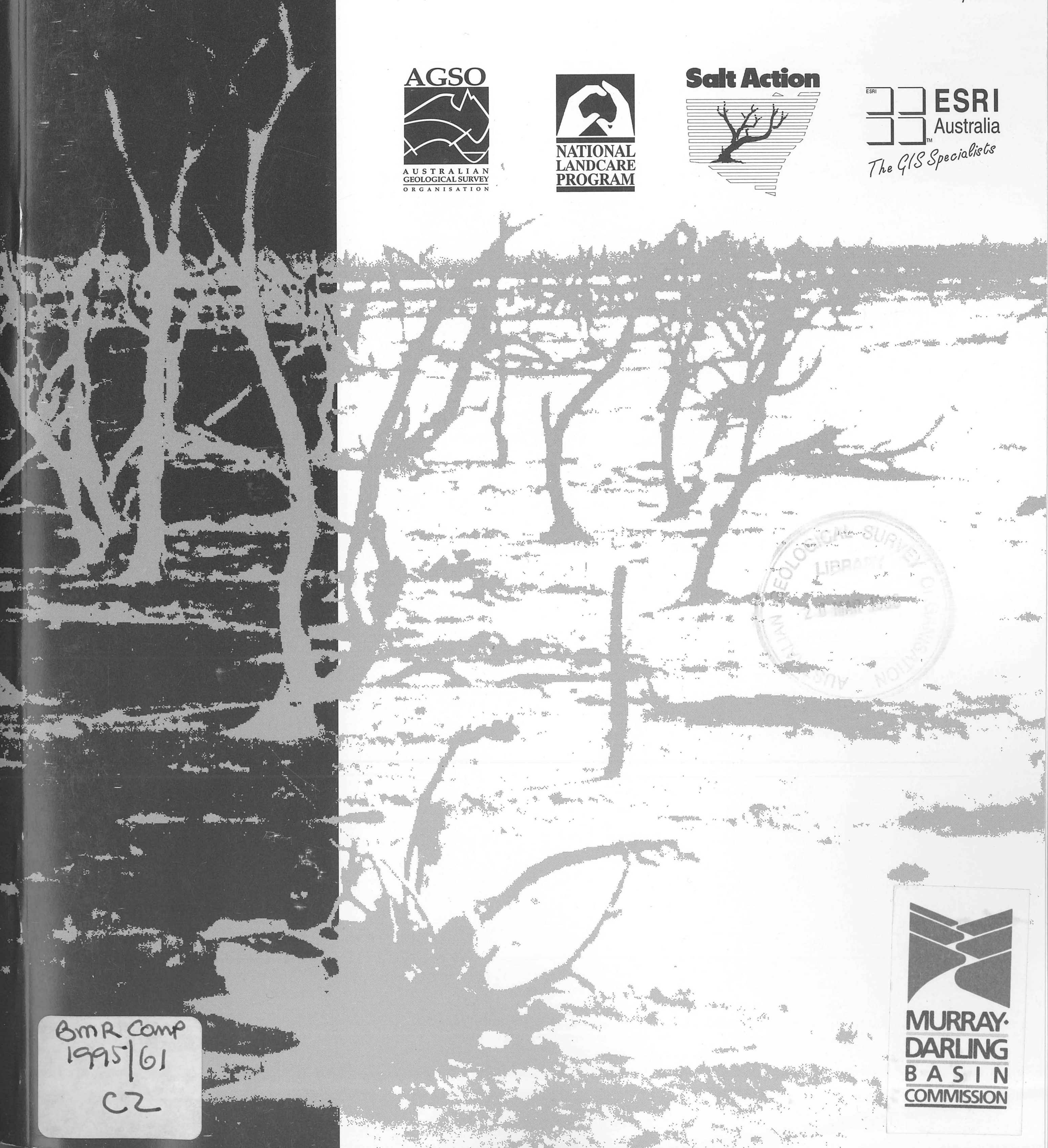

MURRAY-DARLING BASIN COMMISSION

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Environmental Geoscience & Groundwater Division
Australian Geological Survey Organisation

Murray-Darling 95 Workshop

Groundwater and the Community

This is the fourth in a series of workshops organised under the banner of the Murray-Darling Basin Commission's Groundwater Working Group. These, together with the successful Murray Basin 88 conference in Canberra, have tracked the progression of the integration of science and knowledge into day-to-day management.

The first workshop was held in Moama, NSW, in 1986 and was marked by a dominantly hydrogeological audience sharing uni-disciplinary knowledge of the way the aquifers of the Murray Basin fitted together, and their role in the salinisation process. The second workshop, held in Mildura, Vic, in 1990, provided an interface between the soils and hydrogeology disciplines both in the area of irrigation management and in dryland catchment studies.

The third workshop, held in Renmark, SA, in 1992, marked a full technical integration of the physical sciences with strong input from the biological sciences especially in the area of agronomic control of dryland salinity.

This fourth workshop shows the continuing evolution of the efforts in the Murray-Darling Basin by now involving the community - the ultimate natural resource managers - as equal partners in the knowledge process.

The papers arranged in this volume show a breadth and depth reflecting the vast amount of resources invested over the previous years. Funding of this magnitude may never be available in the same form in the future. This places a challenge on all of us to now maximise our information and start achieving results on the ground.

The Workshop has been possible through the efforts of a hard-working organising committee from the Australian Geological Survey Organisation, Canberra and through the generosity of a number of sponsors. Major sponsors are the National Landcare Program, Salt Action NSW, the Rotary Club of Hall, ESRI and AGSO. Minor sponsors are Monitor Sensors and Water Resources Branch, Dept of Land and Water Conservation, NSW.

Your organising committee is Evert Bleys, Richard Cooper, Ross Brodie, Vicki Manson, Warren Overton, Stephen Hostetler, John Bauld, Ray Evans (all from AGSO), and Australian Convention and Travel Services Pty Ltd. Jenny Lane also helped with organisation while employed at AGSO.

Murray Darling 1995 - Groundwater and the Community

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Perennial Pastures in the Upper Murray

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Jo Millar, Charles Sturt University, Albury

Establishing perennial pasture is one of the "tools in the tool kit" available to land managers attempting to reduce groundwater accessions from hilly agricultural land. However, it has not been universally adopted by farmers. Why ?

This paper provides some answers. It presents relevant results from a mail survey conducted last year by Agriculture Victoria (Allan, Millar & Noble, 1995). It was undertaken to provide baseline information for, and guidance to, a National Landcare Program funded project which promotes the establishment and management of perennial pastures in the Upper Murray area. This covers the Victorian catchments of the Murray and Mitta Mitta rivers east of the Hume Weir.

Of the 439 surveys delivered to landholders, 193 were completed and returned, giving a 44% response rate. Data were analysed by Charles Sturt University using SPSS software.

Where perennial pastures are found

Four types of pasture were defined in the survey booklet. These were:

Introduced perennial pasture: mainly sown to perennial grasses (eg phalaris)and legumes (eg. sub-clover).
Improved pastures: pasture including annuals with a history of phosphorus application.
Declining pasture: previously sown, but now mainly weeds or undesirable grasses
Native/Unimproved pasture: mainly Australian native grasses or a mixture of native and self sown introduced grasses.

Respondents were asked to estimate the areas of flat, medium and steep land on their farms, and the area of each pasture type within these. Figure 1 summaries the results.

Introduced perennials are estimated to account for 20% of the total pasture, with most occurring on flat and undulating land. Observation suggests that much of this pasture is based on perennial ryegrass. Steep land, the likely recharge area, carries mostly unimproved/native grass. If these pastures are based on naturalised annuals such as silver grass (*Vulpia sp)* and capeweed there are implications for both soil erosion and groundwater recharge, and perennial pasture establishment should be promoted. Where the

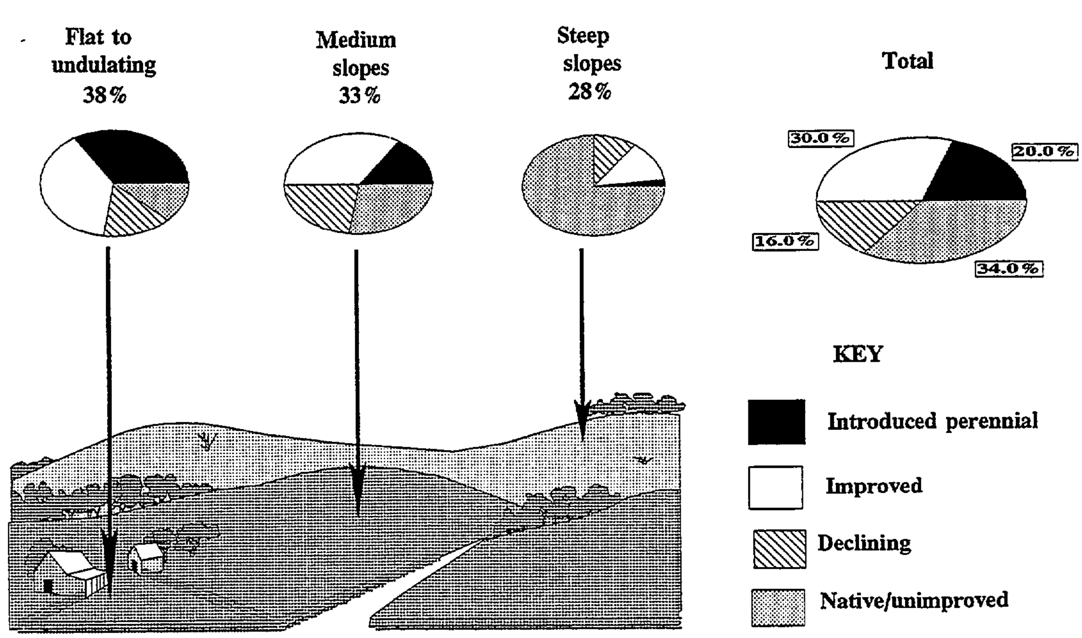

Figure 1: Land and pasture types

"unimproved/native pasture" is based on native perennials such as Red grass (*Bothriochloa macra*) and Weeping grass (*Microlaeana stipoides*) appropriate management becomes the main issue. That pasture management in general needs consideration is implied by the identification of decline in 16% of all pastures. About 25% of pasture on steep land falls into this category.

How much pasture is being sown?

60% of respondents who had sown perennial pasture had done so in the three years to January 1993. 2 442 ha were sown in this period, with a mean area sown on each property of approximately 14.3 ha per year.

Why do farmers sow perennial pastures?

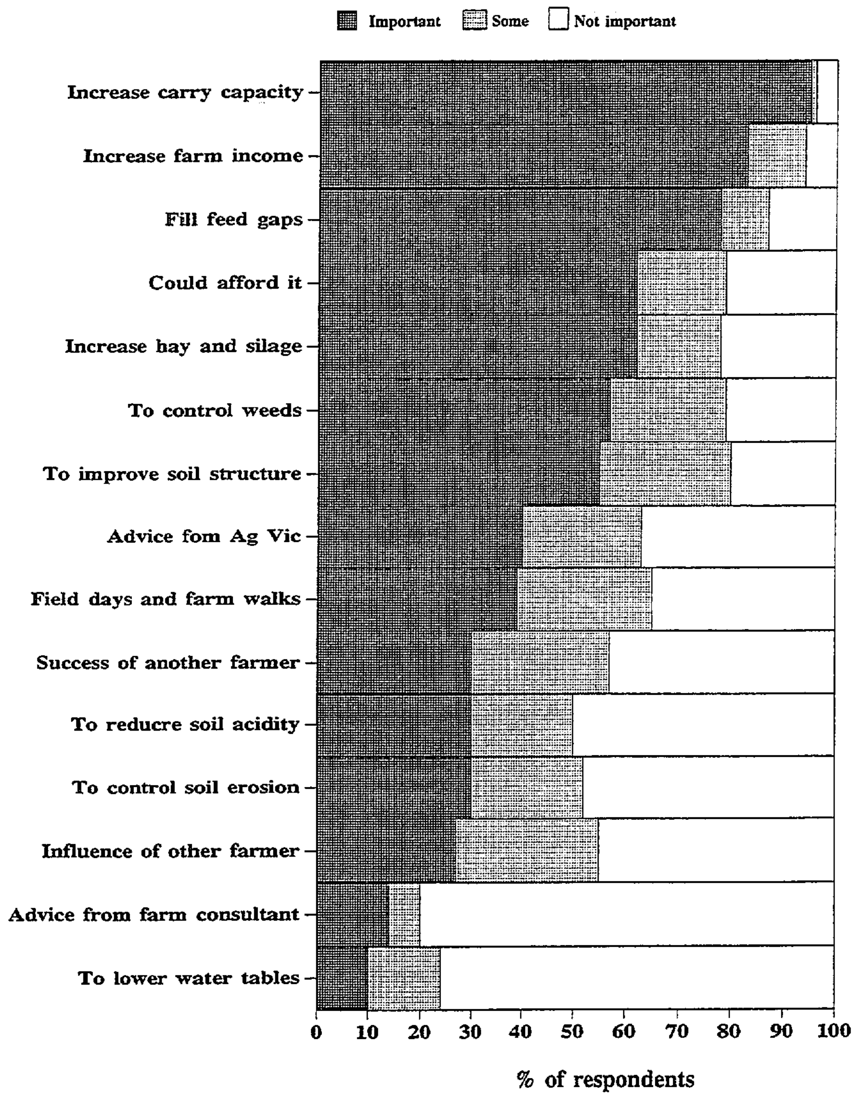

Figure 2: Reasons for sowing perennial pasture

Respondents were asked about the importance or otherwise of a variety of factors when deciding whether to sow pastures. Their responses are summarised in Figure 2, which suggests that the primary considerations at decision time are financial. Increasing carrying capacity was considered an important factor by 96% of farmers. Increasing net farm income (94%), and filling seasonal feed gaps (86%) were also important issues. Sustainability reasons did not rate as highly as financial ones but were still important to many farmers. 80% considered the soil structural benefits as an important factor in decision making, and 52% thought that way about soil erosion control. Lowering water tables was a notable exception, being considered unimportant by most people. Although there is no salinity problem in the area waterlogging exists and causes economic loss. The reasons for this apparent disregard may need further investigation.

Why don't farmers plant perennial pastures?

64% of respondents had decided not to sow perennial pasture at some stage in the five years to January 1993. These farmers were asked to rate the importance of a number of issues relating to their decision.

The expense of establishment was an important deterrent to 82% of farmers (Figure 3). Lack of time (69%) and lack of equipment (66%) were also significant. Perhaps the most unexpected finding was that over one third of farmers feel they lack sufficient information to sow perennial pastures.

Pasture management

Management issues were also explored through the survey. Increased fertiliser requirements of perennial pastures was an important management concern to 61% of respondents, with doubt about the persistence of sown grasses (60%) and sown legumes (60%) also rating highly. Toxicity of grasses, increased time and skills required to manage pastures, increased paddock subdivision, increased stocking rates and excessive seasonal growth all caused some concern to over 40% of farmers.

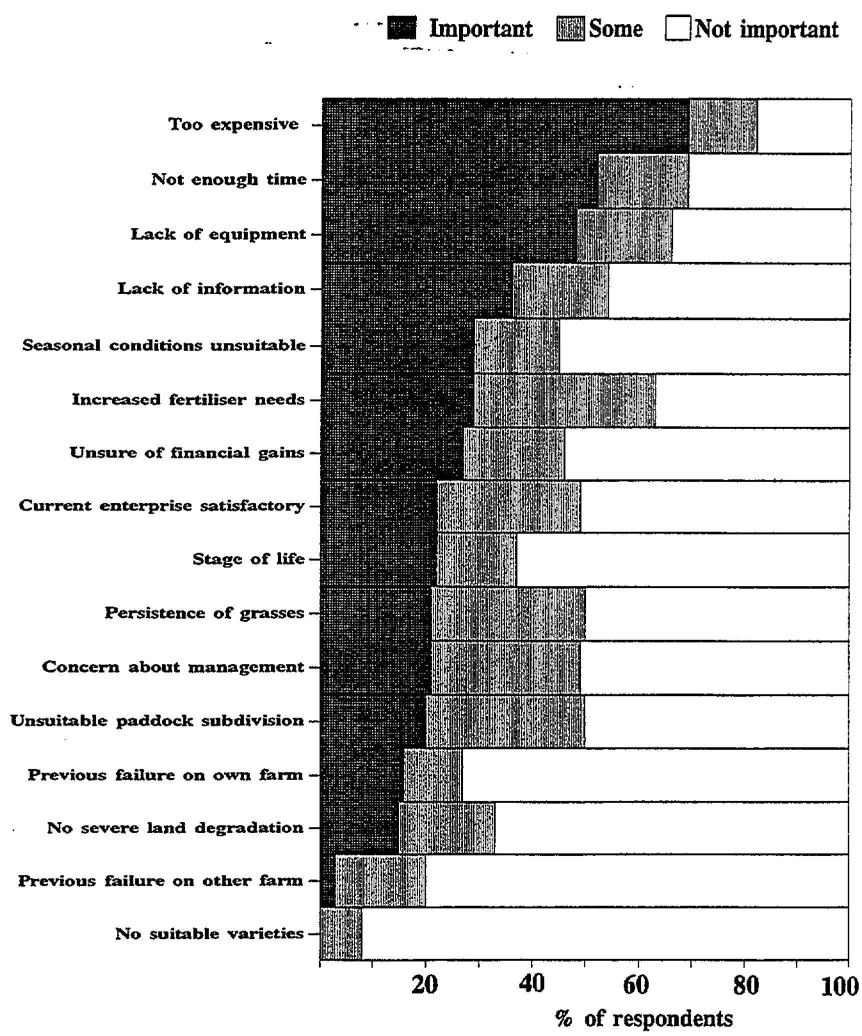

Figure 3: Reasons for not sowing perennial pasture

Information sources

Only 35% of respondents had sought information on pasture management issues. Agriculture Victoria was used by 63% of these, other farmers by 28%, farm suppliers by 26% and private consultants by 25%. When asked about pasture information in general, newspapers and magazines were used by 86% of farmers, as were friends and relatives. 80% considered government advisory staff as important sources of information (Figure 4).

Perennial Pasture Promotion and Adoption

88% of respondents indicated that they will or may sow perennial pastures in the next five years. Farm cash flows will be a major, but not the only, influence on the rates of perennial pasture establishment. 54% of respondents worked off-farm, with the majority of these stating that both partners worked between 15 and 40 hours per week off-farm. This may explain the importance placed on "lack of time" as a reason for not sowing pasture. It has implications for both the establishment and management of perennial pastures, and for pasture promotion in the area.

A number of recommendations were made at the conclusion of the Upper Murray Survey Report, focussing on improving information exchange between pasture advisers and farmers, and addressing major barriers to sowing..

Key recommendations include:

*Tailor extension messages to meet the needs of target groups such as those who have never sown pastures, local groups such as Landcare, small property owners, hill country owners and those who work off-farm

*Use printed material in preference to radio or television to deliver general information

*Emphasise the long term environmental benefits of perennial pastures

*Facilitate equipment and information networks

*Develop pasture monitoring programs as an aid to pasture management

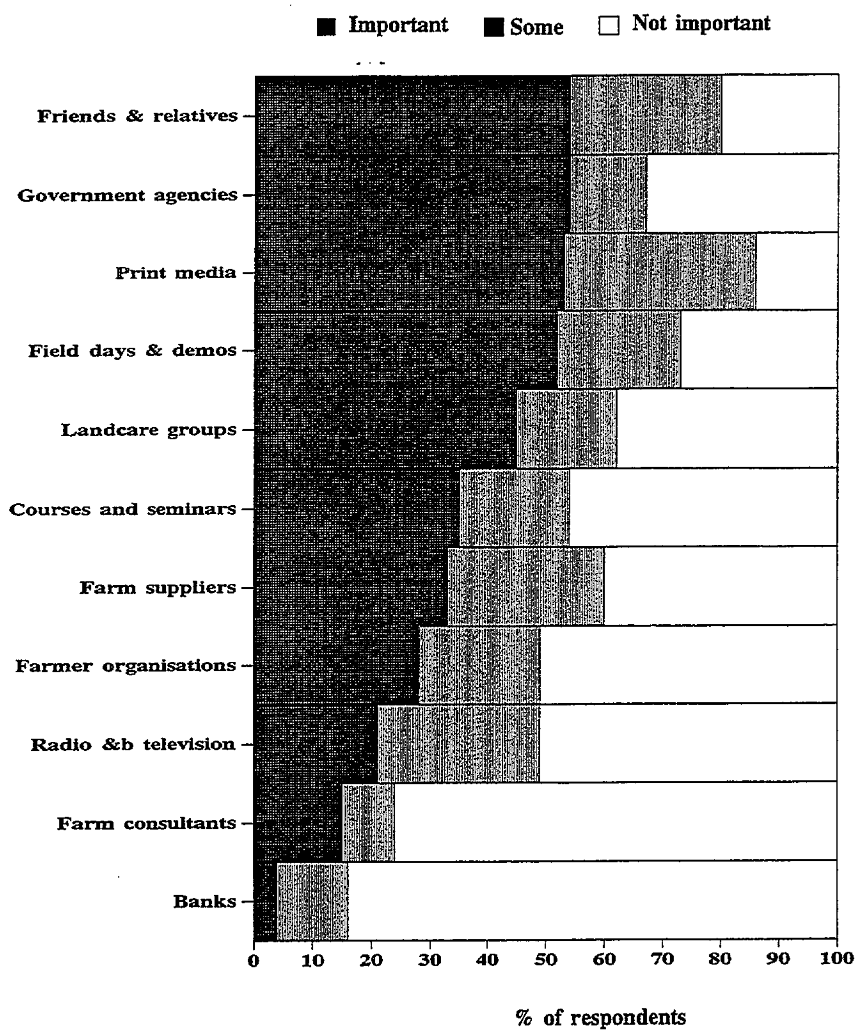

Figure 4: Sources of information on perennial pastures

Conclusion

Although the farmer responses presented here relate to the Upper Murray area, the authors believe that these recommendations are useful for all people who wish to promote perennial pastures to enhance natural resource management.

References

Allan, C., Millar, J. & Noble, P. *Perennial Pastures in the Upper Murray:* Agriculture Victoria, Wodonga, 1995.

Victorian Dryland Salinity Mapping and Monitoring

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1. Introduction

A comprehensive program for the mapping of dryland salinity in Victoria has almost been completed. Discharge site boundaries have been recorded at 1:25 000. The sites were then entered onto the CNR Geographic Information System to enable rapid compilation of discharge maps for specified areas, and maps of discharge overlaid with other attributes such as geology or land cover.

This paper details the mapping procedure and results, and the next stage of the program which is monitoring dryland salinity. Monitoring is occurring at two levels: - intensive monitoring of pegged sites (plots), and rapid remapping of approximately 10% of the discharge sites in Victoria.

The first level involves the selection of 50 representative discharge sites in Victoria for five-yearly visits. These discharge sites are pegged in the field, and surveyed for an accurate record of size, location and severity, from which to measure change.

The remapping exercise will be conducted every five years on a random subsample of the total known discharge sites. The sites will be rapidly remapped using a Global Positioning System (GPS), to provide a coarse assessment of change in area. The community will be called upon to assist in the field work.

2. Dryland Salinity Mapping

Locating Discharge Sites in the Field

Four sources of information were utilized to locate discharge sites in a region:

1. Geological information and aerial photographs were utilized to conduct broad reconnaissance of the regions to locate apparent discharge sites.
2. Local landholder responses were sought on the location of discharge through mailouts, LandCare groups, and articles in local newspapers.
3. Existing CNR knowledge or records on known sites.
4. The remaining sites were located by systematic traverses in each of the regions.

At each of the discharge sites an examination and record was made of evidence for dryland salinity.

Recognizing and Assessing Salinity

There were five major indicators of salinity:

1. Salt stains and/or encrustations.
2. Vegetation
   The presence of salt tolerant plants, and the absence of salt-sensitive plants in, and their presence outside, the discharge site.
3. Position in the landscape
   Topographically low sites e.g. drainage lines, break-of-slope.
4. Surface moisture
   Distinguishing groundwater from surface water and recent rainfall.
5. Bare soil

Vegetation was also used to assess the level of salinity at a site. The three classes of salinity (see Table 1) are based on known field tolerances of a range of plant species, a method developed (Matters, 1987) for conditions within Victoria.

Soil salinity class	EC 1:5 (μScm^{-1})
1	300-600
2	600-1400
3	>1400

Table 1: Soil salinity classes

Soil testing was conducted where there was uncertainity as to what class the site was in, or whether there was salinity at all.

Recording Salinity

Because of the small size of most of the discharge sites (50% are less than 2 ha), the standard scale adopted for recording data was 1:25 000. Sites were recorded on aerial photos then transferred to base maps.

A datacard was provided to describe the sites using the following characteristics: plants found, presence of salt or water, landscape position, type of salinity, landholder details, land-use, recorder details, and date.

Digitizing

The library of salinity maps have been entered into the CNR Geographic Information System (GIS), through a process of digitizing whereby a mouse is run around every discharge site.

Global Positioning System

Using Global Positioning System (GPS) technology, any observable feature currently available such as salinity may be located to an accuracy of ± 5 m, which is compatible with existing map bases held in the CNR Geographic Information System (GIS). CLPR is developing a methodology for mapping saline discharge using GPS technology and then downloading the data directly onto the GIS. Software packages such as Arcview and Arc/Info are capable of producing high quality maps and performing functions such as area calculation from the digital data. This will be more accurate and efficient than previous mapping techniques which required several draftings and tracings of the sites to produce a final map, and calculations of area.

Determining the Origin of Salinity

Primary, also known as natural, salinity occurred before European settlement, and is found extensively in the north-west (the Mallee), on the coast, and on the western plains of Victoria.

As the aim of the project was to document secondary salinity, an effort was made to distinguish it from primary sites in the field. Primary salinity however may also have a secondary (induced) component.

Dryland Salinity in Victoria

The total area of secondary dryland salinity in Victoria is around 120 000 hectares. This figure is calculated from the mapping and estimates for Glenelg and Mallee Regions. This result is 20% above the original estimate of 100 000 ha (using data collated from regional sources at the beginning of the project) and compares to the estimate for irrigation salinity of approximately 140 000 hectares (Government of Victoria, 1988). The salinity area is 1.0% of the total cleared or naturally treeless, non-irrigation, non-urban land (also referred to as dryland agricultural area) in the state. The results are presented by salinity region in Table 2 and Map 1.

Salinity Plan Region	Secondary Salting in Dryland Agricultural Areas
Avoca	5 570
Avon-Richardson	10 500
Campaspe	3 200
Corangamite	10 900
Glenelg	20 000
Goulburn	3 500
Lake Wellington	10 000
Loddon	7 400
Mallee	15 000
North-East	250
South-East	10 000
Wimmera	13 000

Table 2: Secondary Dryland Salinity by Salinity Plan Region (areas in hectares)

The mapping project has confirmed or exceeded original estimates within each of the Regions. In most cases the area was greater than originally believed due to:

1. inclusion of low level salt-affected land in this mapping project, which is not as visually apparent as the higher classes, and has tended to be overlooked in previous surveys;
2. discovery of previously unknown discharge sites;
3. the process of committing the known sites to maps revealed more salinity than previously had been thought to exist.
4. estimates of area originally being made. All areas in the Victorian Dryland Salinity Database have been measured from maps.

The Victorian Dryland Salinity Database

The Victorian Dryland Salinity Database, held at CLPR, consists of every mapped discharge site in the State. The record for each site includes a unique number, an area in hectares, an Easting and a Northing. A salinity class is allocated for some of the sites mapped before 1989, and all of the sites mapped after the commencement of the project. Sites that were assessed as being by area > 95% primary salinity, or due to irrigation or seepage from a water supply channel, have been recorded, but are not included on the database.

Five thousand discharge sites, encompassing a total area of 85 000 ha, have been located.

The sites range in size from less than one hectare, up to two thousand hectares. However, fifty percent are less than two hectares in size. and only one-quarter of the sites are greater than 25 hectares.

At this stage 75% (by area) of total estimated dryland salinity in the State has been mapped. Regions with a large area to survey and a large estimate of salinity (Mallee and Glenelg) are yet to complete discharge assessment.

Even in those Regions where assessment has been substantially completed, further sites may be located in the future. The database will need to be updated regularly for this reason, and also because of the active nature of many discharge sites.

The map references of each site on the database, has been combined with a broad analysis of salinity in Glenelg Region, to produce Map 2 using GIS.

3. Monitoring salinity

Monitoring is occurring at two levels. To obtain accurate measurements of change, fifty discharge sites will be pegged and revisited. To complement this quality of data, a rapid, repeatable survey of approximately 10% of all known discharge sites will occur.

Monitoring plots

The intensive long-term monitoring of saline discharge plots is an attempt to estimate the rate of change of salt affected area within salinity management regions across Victoria. Also it will be used to help monitor the effectiveness of salinity control works, and the regional salinity plans.

Good site selection is critical to the success of this monitoring approach. There have been an initial 50 monitoring sites selected. Sites are allocated within salinity management regions using the Land Management Unit (LMU) structure as a framework. An LMU is an area that is deemed to have similar geology, topography, land-use and groundwater processes. Sites are selected after consultation with the project hydrogeologist and local CNR staff. Where a treated plot exists, an untreated discharge site will be paired as a control in the same LMU. This allows an assessment of the effects of any salinity control works.

Using the mapping method outlined previously, sites are mapped using a Sokkia total station and GPS. The first of two site plans is produced, showing the vegetation assessment overlaying topographic and any other relevant site detail.

Electromagnetic surveys are carried out on site using an EM38 to map apparent soil conductivity in the likely plant root zone (0-60 cm). A second map at the same scale as the vegetation and topography is produced, showing the vegetation assessment overlying contours of apparent soil conductivity values.

Each site will be photographed from replicatable points to give a visual account of any changes at the site.

If there are no suitable bores on site already, at least one bore is drilled to enable any surface changes to be related to changes in groundwater levels. Where possible, sites that have an existing bore network and a good history of groundwater monitoring are selected.

Soil sampling is carried out at each site to corroborate the vegetation assessment.

History of landuse, and the year the discharge site appeared (if known) are collected from the landholder, and, along with information on the nature of the groundwater system and rainfall, used in data analysis.

Remapping sample

Still in the early planning stages, this component of the project is envisaged to remap approximately 10% of the known sites in the state, to complement detailed results from the monitoring plots. Discharge sites will be selected at random, and remapped using GPS.

Results from the plots and remapping will provide an assessment of treatment, and when applied to the Victorian Dryland Salinity Database, will enable an estimate of the total area of salinity, for use in strategic planning, and economic and environmental analysis.

4. Future Work

A manual for mapping dryland salinity has been prepared, and training in this and GPS will enable community members to do mapping in their local area that will be compatible with the existing statewide database.

Community mapping has application to the completion of the statewide mapping, and the subsequent remapping of a sample of sites under the monitoring component.

Community involvement would make data collection more efficient and cost effective. CLPR could then process the collected data and provide hard copy maps and data sets back to the community. A useful spinoff of the proposed community mapping scheme, is that skills learned by community members could be used to construct a complete inventory of land management issues in their local catchment. This would provide a powerful management tool for combating future land management issues.

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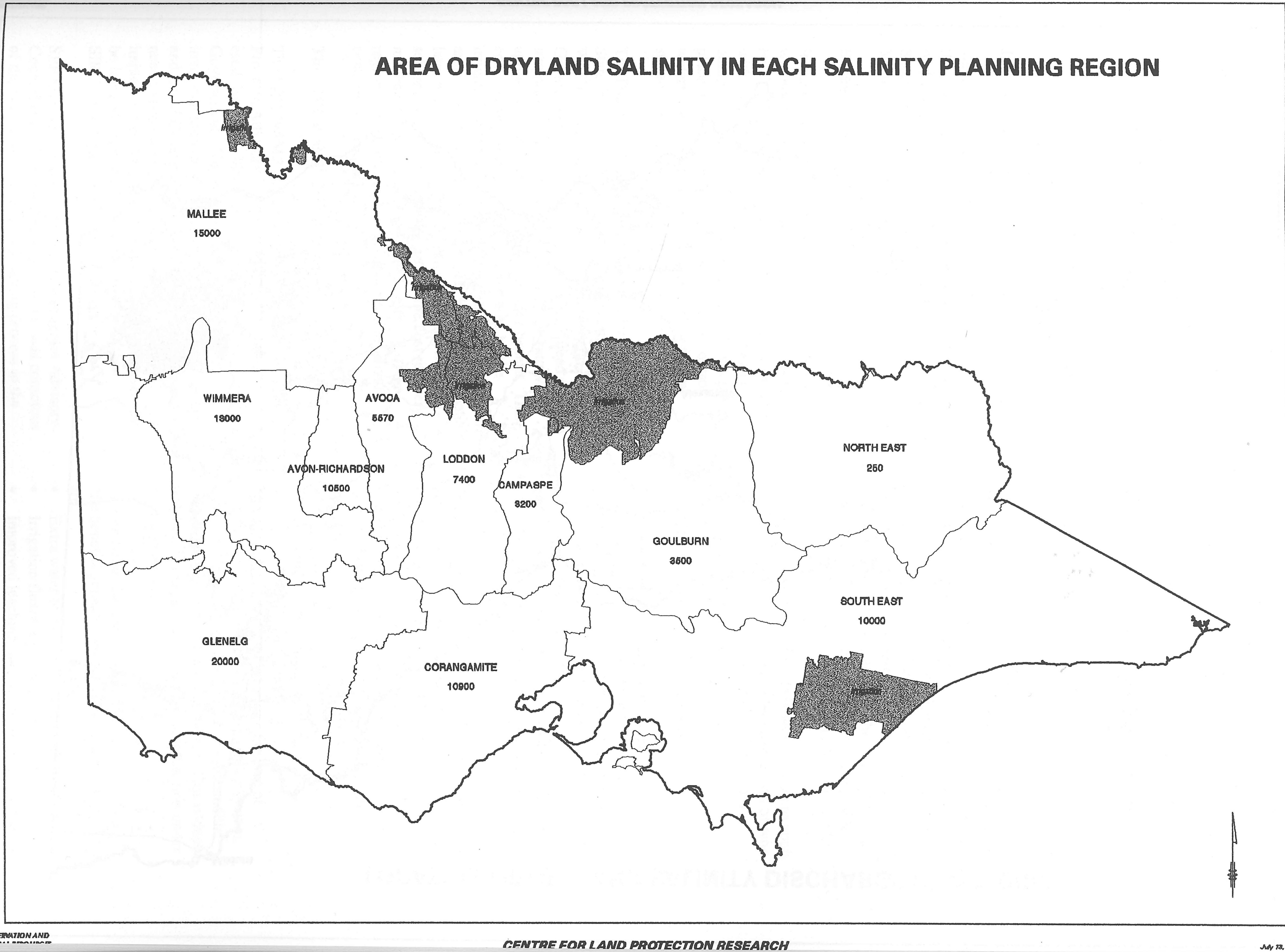
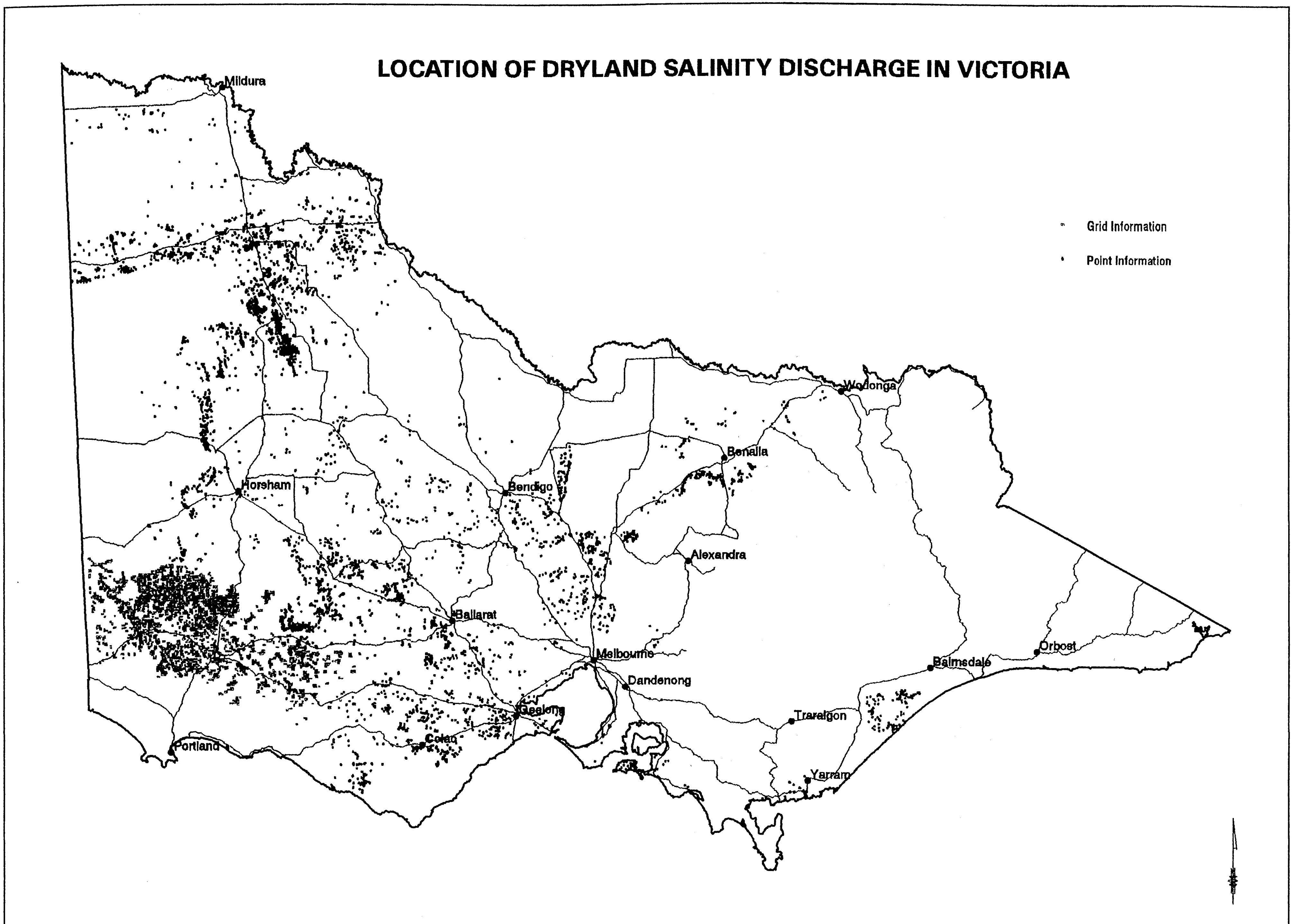


Map 1: Area of salinity in each Salinity Planning Region

Map 2: Location of Dryland Salinity Discharge in Victoria



Sharing the Costs of Groundwater Pumping in the Shepparton Irrigation Region Land and Water Salinity Management Plan

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Introduction

Developing acceptable and equitable cost-sharing for the Sub-Surface Drainage Program has proven to be one of the biggest challenges for the implementation of the Shepparton Irrigation Region Land and Water Salinity Management Plan (SIRLWSMP).

Background

In the early 1970's the region experienced a series of wet winters which caused a dramatic rise in watertable levels. This was devastating for the fruit growing areas with 30% of the fruit trees dying. A groundwater pumping scheme (referred to as "Phase A") was put in place in the intensive horticultural areas to control watertable levels to around 2 metres below natural surface for the majority of each year.

The Phase A scheme was implemented by the (then) State Rivers and Water Supply Commission (SR & WSC), jointly funded by the State and Federal Governments. The operating costs were spread over the irrigation community in a special drainage rate which applied equally regardless of the level of benefit. This cost-sharing arrangement was undertaken by the irrigation community with the understanding that pasture areas would receive similar groundwater protection at a later time under a "Phase B" scheme. The Phase B scheme was never implemented, but the cost recovery mechanisms for Phase A remained, with 4% of the region's irrigation area receiving protection, with the costs recovered from all.

The SIRLWSMP Cost-sharing

The SIRLWSMP was developed by the Salinity Pilot Program Advisory Council (SPPAC) which was established in 1986 as an initiative of the Victorian State Government. This was a co-operative approach involving landholders, industry and the State, Federal and Local Governments. SPPAC was conscious of the need to produce a plan which could and would be implemented. This meant the plan needed to be seen to be fair and equitable by all those involved. The SIRLWSMP was launched in 1989.

SPPAC was replaced by the Salinity Program Advisory Council (SPAC) in January 1991. SPAC was conscious of the need to put the decision-making process in the hands of the regional community.

With the advent of the SIRLWSMP the cost-sharing of the groundwater schemes was revised in line with the principle of "beneficiary pays". Those getting more measurable benefit pay proportionally more than those receiving a lesser level of service. All irrigators still contribute to salinity control works via a "Salinity Levy" added to their water rate notice. This is based on the fact that all irrigators are contributing to the problem and so should contribute towards amelioration works.

The beneficiary pays principle is very difficult to apply in practice where there are no clear indications of who will and who won't benefit from salinity control activities and to what degree.

The Sub-surface Drainage Program

Within the Sub-surface Drainage Program there are two sub-programs. These relate to private and public pumping of groundwater for salinity control in pasture areas. The private pumping program aims to encourage groundwater extraction from shallow aquifers (to 25 metres), with regular use of groundwater for irrigation and participation in approved winter salt disposal programs.

The public pumping program enables the extraction of groundwater from shallow aquifers that are too saline for private use (3,500-10,000EC). Under this program, the groundwater is distributed through the public irrigation system for summer re-use, and then via the drainage system during winter for approved salt disposal.

The Benefits

The overriding benefit is that within the area of influence of a shallow groundwater pumping system, irrigated agriculture is more likely to be sustainable, even in the presence of high watertables. This is due to the ability to maintain a viable leaching fraction under these conditions.

Private Groundwater Pumping Benefits
The benefits gained from private groundwater pumping are:

- Extra water to supplement irrigation supplies;
- Irrigation flexibility - water on demand;
- Improved leaching, and therefore salinity control or protection, especially in summer;

- Reduced waterlogging - winter, early spring;
- Salt Balance - disposing of a volume of groundwater in winter to offset the salt imported through irrigation water in summer.

Public Pumping Program
The benefits of public pumps are:
- Salinity Control in areas where private pumps are not viable options
- Possible waterlogging control when winter pumping is permitted
- Extra irrigation water to supplement district channel supplies
- Regional salt balance - uptake of regional Salt Disposal Entitlements
- Increased community cooperation

Identifying the "Beneficiaries"
"Beneficiaries" under the SIRLWSMP are divided into three groups:
- Regional Irrigators
- Direct Beneficiaries
- Local Government

The "Regional Irrigators" include all licensed irrigators in the Shepparton Irrigation Region (SIR). The SIR is split into four Irrigation Districts: Central Goulburn, Rochester, Shepparton and Murray Valley. All irrigators contribute to the salinity problem to some extent. They also indirectly benefit from salinity control works in their districts.

"Direct beneficiaries" include those whose land is receiving a measurable drawdown in aquifer (groundwater) pressure.

"Local Government" receives benefits in the form of road pavement protection, sustained or improved agricultural values and optimistic rural communities.

The Costs

The costs generally involved in the Sub-surface Drainage Program include:
- Regional Salt Disposal Entitlement (SDE) costs - to fund salt interception works;
- Local Salt Disposal Allocation costs - monitoring SDE uptake and preventing illegal disposal;
- Exploration costs - searching for pumpable aquifers;
- Operating and maintaining pumps, motors and below-ground works;
- The capital cost of installing groundwater pumping systems;
- Program administration and monitoring;

Complexities in estimating costs and benefits

Introduction
Hydrogeology in practice is an inexact science. The benefits of groundwater pumping for salinity control are difficult to accurately measure without expensive detailed investigations. To keep costs down, the effects of pumping are often based on the "extrapolation of data". Scientists base the level of salinity control on the level of drawdown in aquifer pressure, not on the direct effect on the shallow watertable. The smallest measurable pressure drawdown which can be recorded with any confidence is a drawdown of 10cm. This concept can be difficult to grasp by those not directly employed in this field. It is especially difficult because all the activity is happening underground.

Private Pumping Program
Encouraging private pumping would be simple enough if "all groundwater pumping was good". However, there are a number of complicating factors. For example, aquifers can be "overpumped". Over-enthusiastic pumping risks deteriorating groundwater quality through drawing more saline groundwater laterally or from below. Requiring or encouraging extra pumping such as is required for winter disposal opportunities (SDAs) could exacerbate this problem.

Landholders also risk lowering plant productivity and impairing soil structure by applying saline groundwater at either too high a salinity or by using inadvisable irrigation techniques (eg alternating irrigations of straight groundwater with straight channel water; using overhead sprinklers during periods of high evaporation).

Part of the implementation of the program involves community education about groundwater pumping. Highlighting these "management" issues helps landholders make the best decisions about the management of their aquifers. However, at the same time, people could become hesitant to pump groundwater as part of the Sub-surface Drainage Program, especially when channel irrigation supplies are usually readily available and complication-free.

The areas at greatest risk from salinity are those with high and rapidly rising watertables. In the SIR, these areas are seen as having priority for investment of salinity resources over areas with deeper watertables. Traditional pumping areas with good, pumpable aquifers tend to have relatively low watertable levels. In these areas, the availability and quality of this extra resource provides substantial incentive for private investment. The investment of SIRLWSMP resources in these areas on the basis of salinity control is more difficult to justify. On the other hand, the lower watertable levels and low incidence of salinity may be linked to the activity and investment of private pumpers. There is an argument that this effort should be somehow acknowledged in cost-sharing.

Public Pumping Program
The Public Pumping Program is still in the early days of implementation. As more Public Pumps are investigated and installed, there appear to be just as many

challenging problems to tackle as with the Private Program.

The main issue is the disposal of the groundwater in summer. Some channels serve private groundwater pumpers who depend on the freshness of the channel water to maximise their use of groundwater. More saline channel water reduces the "shandying" capacity, therefore reducing the amount of groundwater that can be used at each irrigation. So, in some situations, the costs of channel disposal have to take into account the effects on downstream private groundwater pumpers.

The other problem arises where there is no suitable channel disposal, or it is at some distance from the best pumping site. In the beginning, the program assumed that disposal via the nearest drain would be the acceptable alternative. This is made difficult by the increasing interest in using drainage water to supplement farm irrigation supplies. The controlling water authority, Goulburn-Murray Water, does not guarantee drain diverters either quantity or quality of supply through the regional drainage system.

SPAC wants to encourage drain diversion to minimise the amount of salt leaving the region in summer. The Plan also works in conjunction with the developing Nutrient Management Strategy. In light of growing concern over nutrient management in the region, drainage diversion is likely to play a key role in preventing nutrients leaving catchments. Disposing saline groundwater via the drainage system without regard to the impact on drainage diversion would therefore be contradictory to improved catchment management. Acceptable compromises will have to be found.

Currently each potential public pump site is assessed on a case-by-case basis and this is likely to continue. A range of agencies and community based groups are approached for comment, including: Department of Conservation & Natural Resources, the relevant Goulburn-Murray Water Services Committee and the Community Surface Drainage Group (if appropriate).

Implementation & Achievements

The first five years of implementation of the Sub-surface Drainage Program have seen 66 new private groundwater pumps installed and 30 upgraded to provide salinity protection and an additional water resource for the irrigation of pasture. An additional 12 private pumps were installed on horticultural properties along with 9ha of tile drains. Approximately 350 pumpers (about half of the existing licensed pumpers) are participating in the winter salt disposal program.

Seven public pumps have been commissioned and a further 20 are in various stages of feasibility investigation and completion.

Overview and history of Program incentives

The cost-sharing and incentives need to be simple enough to administer and to explain. Results must be measurable to account for the costs and, above all, the program must send the right message to the community regarding the role of groundwater pumping in salinity control. This can be difficult when every aquifer is different and all situations are variable. As the program moves through implementation the incentives are constantly being reviewed to ensure they are environmentally, economically and socially acceptable.

Private Pumping Program

To encourage owners of existing licensed groundwater sites to make more consistent use of them, a "Groundwater Pump Incentive Scheme" (GPIS) was developed. It was initially based on a straight $6/ML pumped, up to a maximum of 100 ML. This was modified in 1991/92 to take into account the sustainable use of groundwater. This includes the salinity of the groundwater and encourages participation in the winter disposal program. The revised program was $4.00/ML of groundwater pumped and used at a dilution of 800EC, with no upper volume limit.

A review of the Sub-surface Drainage Program in 1993 identified that the pumping incentive was paying those who would have pumped regardless of the extra incentives. Those who only wanted to use the pumps as a drought reserve were still not motivated to use their pumps more often. The GPIS program has since been reviewed and was discontinued after the irrigation season of 1994/95.

Alternative operating incentives will be developed when the SIR has been declared a Groundwater Supply Protection Area. This will allow the development of a range of licensing measures to promote consistent, responsible groundwater pumping.

To encourage the installation of new private pumps, SPAC incorporated other incentives in the Sub-surface Drainage Program; the Farm Exploratory Drilling Service (FEDS); the Groundwater Exploration Grant Scheme (GEGS) and the Capital Grants Program.

The purpose of FEDS is to reduce the financial risk involved in looking for groundwater. Under this scheme farmers pay a deposit of $750. Drilling and investigations are carried out by hydrogeological consultants. If groundwater of agreed quality and quantity is located, the $750 is retained; if no groundwater is found, or it is too saline for private use, the $750 is refunded. Currently the average waiting period for exploratory drilling is about 14 months, depending on the prioritisation category.

GEGS is an alternative to this scheme and enables farmers to employ their own drilling contractors. Under this scheme if a suitable site is found and an approved system installed within 2 years, the farmer will be reimbursed 80% of exploration costs up to $4,000 per property. If no suitable site is located, the reimbursement is 50% up to $2,000 per property.

Other subsidised exploration assistance include pump tests by the consultants at 25% of actual cost, and electromagnetic surveys at $50 per property. So far all these exploratory and investigatory programs have proven to be attractive and effective for both landholders and the SIRLWSMP.

Capital Grants provide incentives for farmers in areas at risk from rising watertables to develop and use groundwater sites. Grants are available to install new shallow groundwater pumping systems, to convert to electrically powered systems, to upgrade existing systems and to repair below-ground works. There is no assistance for replacing or repairing worn out or missing pumps and motors. The grants started initially as a maximum grant of 20% of the capital cost of installation of a new system. This was subsequently revised upwards to 80% based on $200/ML of "safe" irrigation groundwater volumes.

The "safe" limit was deemed to be 800EC, which is the maximum limit for white clover on a free draining clay loam. Although this builds in the concept of sustainable applied water salinity it doesn't reflect the ability of the aquifer to sustain pumping without drawing water and hence salt, from adjacent aquifers.

There are sites in the region with virtually unlimited volumes of groundwater with salinity less than 800EC. Sites of this quality have significant private benefits to the irrigator which would more than justify private investment. To balance the contribution from the SIRLWSMP, a ceiling of $30,000 was applied.

After reviewing the impact of the grants and the message it was sending to pumpers, a further modification was made in 1992/3. An upper limit was placed on the volume of groundwater used that can attract the incentives. This limitation is linked to the regional recharge rates which range between 1-3ML per hectare approximately. This limit aims to protect aquifers from overpumping and to alert pumpers to the risks. The onus is then on the pumper as to whether to pump a greater volume and risk degrading the aquifer in the long term. Therefore, capital grants of $200/ML up to 80% of the total capital cost (within the $30,000 ceiling) had a maximum use of 3ML of groundwater per hectare imposed on them.

At a grant level of 80%, the Sub-surface Drainage Program was basically assuming a private benefit of 20%. In most cases, the private benefit to irrigators of the supplementary irrigation water is substantial. After considering all the factors, the maximum grant payable is being reduced to 65% over a 3 year period (currently 75% and will drop back to 70% for the 1995/96 financial year - subject to assessment of impact on the participation rates). At 65% of the capital cost, this assumes a more realistic private benefit of 35%.

The final capital grant payable is restricted by the 800EC safe volume; the $30,000 ceiling; the 3ML/ha or the 75% (currently) of capital cost, whichever is the lowest.

Example of grant payment
20 ha of summer pasture at 10ML/ha annual water requirement = 200ML total annual water use.

Typical groundwater pump with a salinity of 2,200EC; channel salinity of 100EC.

Safe volume of groundwater used at a "safe 800EC" applied water salinity = 66.5 ML groundwater at 2,200EC plus 133.5 ML of channel water at 100EC.

Assume Total capital cost	= $22,000
75% of $22,000	= $16,500
66.5 ML at $200/ML	= $13,333

3ML groundwater/ha limit = 20 ha x 3ML = 60ML	
60ML x $200/ML	= $12,000

The maximum grant payable in this instance would be limited by the 3ML/ha restriction to $12,000 because it is the lowest figure. This works out at about 55% of the total capital cost.

If the farmer could increase the area commanded by the pump, the level of grant would be greater, *provided that the site could yield the volumes required.* An increase in area of 10ha would bump the total grant payable up to the 75% upper limit which in the example below is $16,500.

30ha x 3ML groundwater/ha	= 90ML
90ML x $200/ML	= $18000
75% of total cost	= $16,500

Initially, to be eligible to receive GPIS, and as part of the agreement for the payment of a Capital Grant, pumpers were obliged to take up a Salt Disposal Allocation (SDA) and operate their pumps during approved winter disposal periods.

The aim of the winter pumping is to balance the salt brought into the region during the irrigation season. Pumpers can discharge a volume of groundwater calculated to contain the equivalent volume of salt as was imported during the summer.

However, the problem of determining which aquifers are at risk of rapid deterioration as a result of increased pumping activity complicates the requirement for winter salt disposal. The program cannot inadvertently encourage activities which are not sustainable. Some farmers are more concerned about waterlogging in late winter/spring and are prepared to pump large volumes with little regard for the impact on long term aquifer quality.

While SPAC wants to maximise uptake of SDA's it does not want this at the expense of the quality of the resource. The requirement for farmers to take up SDA's in order to receive the financial incentives could be interpreted as inadvertently causing farmers to overpump their aquifers. To avoid this, SDA's have now been made voluntary but are encouraged where deemed to be "technically appropriate".

Prioritisation

As a way of ensuring that salinity resources are being invested in areas at risk of salinity, a prioritisation process, based on the depth to the regional watertable from natural surface was developed. This process has four categories:

Cat. 1	watertable less than 1 metre from surface;
Cat. 2	watertable less than 2 metres
Cat. 3	watertable between 2 and 3 metres
Cat. 4	watertable greater than 3 metres

Members of registered landcare groups and groups of farmers who have received priority status through the program are given highest priority. These groups are an effective way of implementing this program and provide links to other programs in the SIRLWSMP.

Public Pumping Program

The original Public Pumping Program was the Phase A program, set up in the late 1970's to protect the horticultural areas from the rising watertables.

As mentioned earlier, these pumps were installed and operated by the (then) SR & WSC. Local landholders had very little involvement, and paid the same level of rates as farmers in other parts of the region. The contributions to the running of these pumps did not reflect the amount of benefit received.

This was not considered to be an equitable long term cost-sharing arrangement. To reflect the concept of "beneficiary pays", the costs for Public Pumps were apportioned to 3 main categories of beneficiaries:

Direct Beneficiaries	-	41.5%
Regional Irrigators	-	41.5%
Local Government	-	17%

The direct beneficiaries costs are then further divided on the basis of the level of service. The closer to the centre of the pump, the greater the leaching benefit and degree of watertable control. The area of measurable drawdown in aquifer pressure defines the landholders likely to receive a salinity benefit from the pump operation. These landholders should contribute significantly to the pump operation. Those closer to the pump should pay proportionally more than those on the perimeter of the area of influence.

The costs of operating and servicing the Public Pumps are averaged within each Irrigation District (Murray Valley, Central-Goulburn, Shepparton and Rochester). Average annual pump costs are about $6-7000, including overhead costs, depreciation and operation, depending on the extent of operation. For example horticultural pumps would operate more frequently to achieve watertable control than those in pasture areas which provide salinity control.

On current costs (1994/95), the direct beneficiaries have to contribute about $2,700 per annum. This is then levied 50% on area of land and level of service, and 50% on ML of annual water used (to build in an incentive to use irrigation water efficiently).

Regional Irrigators are charged a Salinity Levy based on their total annual water use. The levy is set for each Irrigation District according to the salinity control works in the District.

Summary

The SIRLWSMP is one of the first salinity management plans to develop a comprehensive Sub-surface Drainage Program. It has approached the difficult task of adopting the "beneficiary pays" principle of cost-sharing by developing a cost-sharing and incentive package that is sending the right message to the community. As a result, the SIR community is taking more responsibility for the costs of salinity control projects and setting standards for other regions to follow.

Protection of Groundwater Resources in the Duddo Limestone Aquifer

Carolyn Balint, Department of Conservation and Natural Resources, Ouyen.
Robert Briggs, Wimmera Mallee Water, Ouyen.
Alan Burstall, Mallee Dryland Salinity Management Plan Implementation Group, Member, Underbool.

Summary

A major objective of the Mallee Dryland Salinity Management Plan is to protect the Duddo Limestone Aquifer by sealing two hundred abandoned bores over the next ten years.

The Duddo Aquifer in the Western Mallee provides the stock and domestic water supply for the communities to the West of Underbool and into South Australia. The Mallee community initiated the protection of this valuable resource and has been successful in obtaining Federal and State Government funding.

The decommissioning of the bores is necessary because the rusted casings of abandoned groundwater bores allow accessions from shallow saline aquifers to pollute the fresh water limestone aquifer. The location and sealing of the disused bores is contracted and managed locally.

This is the first project of its type in Victoria and has been well supported by the wider Mallee community and the Federal and State Governments.

The Victorian Mallee

The Victorian Mallee is situated in the North West corner of the state, (See Figure 1.) Having an area of more than four million hectares. The landuse is primarily dryland cropping on cleared private land and nature conservation on public land. Irrigated horticulture exists in a narrow band adjoining the Murray River.

Figure 1: The Mallee is situated in the North West of Victoria.

The topography of the Mallee is generally flat but interspersed with east west dune systems and ancient lunettes. The climate is semi arid with an average of 300 millimetres annually with rain evenly spread over the year.
Mallee soils are generally alkaline with many containing calcareous layers of limestone rubble. The region is devoid of any permanent water courses apart from the Murray River. (Rowan, 1963)

The Settlement of the Area

The Western Mallee was settled early in this century, although Murrayville including Cow Plains was settled and stocked in the late 1850's. (Kenyon, 1982) Much of the area was rapidly cleared and developed for agriculture with the development of the Railway. The line from Ouyen to Murrayville was built in four years, from 1908 to 1912. (Kenyon, 1982)

Water supply was a major issue for the early settlers. Initial surveys for bore water were unsuccessful. Exploration drilling between 1884 to 1891 confirmed that the groundwater aquifer present beneath Nhill and Bordertown extended in a northerly direction. This is believed to be part of the Murray Group Limestone Aquifer. The Government established bores and tanks to provide water for the settlers and their stock. (Kenyon, 1982)

The Duddo Limestone Aquifer

The Duddo Limestone Aquifer is situated in the western and central sections of the Murray Groundwater Basin. The mid Miocene limestone deposits reach 150 metres in thickness to the west of Murrayville. (HydroTechnology, 1994)

The Duddo Limestone Aquifer is confined at its base by the Ettrick Formation Aquitard and is overlain by the Winnambool Formation Aquitard. (Foley and Robinson, 1993) The Duddo Limestone Aquifer lies west of the towns of Wemen, Ouyen and Hopetoun. The groundwater flows for the aquifer are in a North - Westerly direction towards South Australia. (Robinson, 1992a) Recharge to the Duddo Limestone occurs in the Northern Wimmera and little recharge to the aquifer is thought to occur in the Mallee. (HydroTechnology, 1994) See Figure 2.

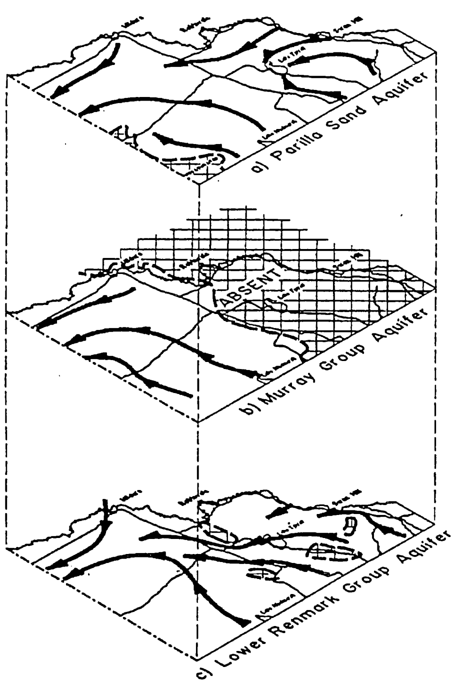

Figure 2: Groundwater Flow Direction in the three principal aquifers in the Victorian Mallee

The Duddo Limestone Aquifer is used for stock and domestic water supply for the communities of Murrayville and townships to the West of Underbool. The open channel system of the Wimmera Mallee Stock and Domestic Water Supply terminates to the east of Underbool.

The salinity of the Duddo Limestone Aquifer increases from 1,000 microSeimens/cm in the Big Desert to more than 35,000 microSeimens/cm in the Sunset Country. This is due to leakage of saline groundwater from the Parilla Sand Aquifer where the surrounding aquitard is more permeable.. In the Murrayville and Underbool area where the limestone aquifer is used for stock and domestic water supply, the groundwater salinity is approximately 3,000 microSeimens/cm. (HydroTechnology, 1994)

To the immediate North and East of Murrayville, groundwater observation bores in the Duddo Limestone Aquifer indicate a rising trend of around 0.1 metres a year. The Duddo Limestone in the South displays rises of approximately 0.01 metres per year. (Robinson, April 1992)

The Mallee Dryland Salinity Management Plan

The planning process for the Mallee Dryland Salinity Management Plan began in November 1991. A Community Working Group (now known as the Implementation Group) was comprised of representatives from local communities and community groups. An Inception Report and Discussion Paper were published in 1992 and the draft Mallee Dryland Salinity Management Plan was released in January 1993.

The aim of the plan is to reduce groundwater recharge accessions by increasing crop and pasture water use and to maintain and enhance remnant native vegetation.

One of the objectives of the Plan is to prevent contamination of the Duddo Limestone Aquifer from the overlying saline Parilla Sands Aquifer. (Mallee Dryland Salinity Community Working Group, 1993) The Plan provides the framework for locating and decommissioning of abandoned groundwater bores in the Western Mallee. Two hundred bores during the next ten years are to be sealed to prevent further contamination. See Figure 3.

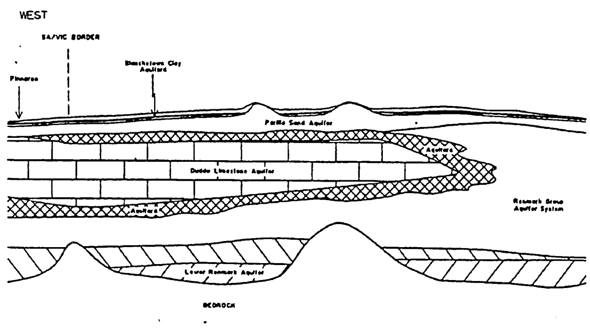

Figure 3: Generalised Cross-Section showing the Victorian Mallee.

The Program For Sealing Abandoned Bores

Results of salinity monitoring by HydroTechnology from 1990 to 1992 indicated there was an increase in salinity in the Duddo Limestone Aquifer. Bore hydrographs indicated no change in the regional flow system so another cause had to be found. The most plausible explanation for the increase in salt concentration was that abandoned bores were defective and allowing contamination from the overlying saline aquifer. Saline groundwater corrodes the bore casing allowing contamination of the fresher Duddo Limestone Aquifer with water from the highly saline Parilla Sands Aquifer. (HydroTechnology, 1994)

The Mallee Dryland Salinity Management Plan Implementation Group applied for funds in 1992 to decommission twenty abandoned bores each year. The Implementation Group was successful in obtaining funding from the State Salinity Budget and the Natural Resource Management Strategy to carry out the project. The next task for the Implementation Group was to discuss the formation of a contract and tender system for the works. The contract and tender process were developed by the Implementation Group, Wimmera Mallee Water and the Department of Conservation and Natural Resources over a period of three months. The successful contractors were members of the Western Mallee community.

The local community continues to be involved in the process of locating the abandoned bores. Much of the information is anecdotal with local community historians relating stories of early settlers and pioneers.

The number of abandoned bores in the Western Mallee was estimated to be two hundred. That figure now appears to be conservative, with landholders and members of the community locating more of the abandoned bores.

Once the location of a bore has been determined, the old casing is redrilled to ensure there are no obstructions. A number of abandoned bores have been found to have axles, sticks and pieces of wood, gelignite and fencing materials inserted in the bore holes. If a bore is unable to be redrilled because of an obstruction, the bore is noted and mapped. The sealing of the obstructed bore will be examined again when additional funds become available to carry out more extensive excavation and drilling.

In many cases, redrilling brings large volumes of the corroded casing debris to the surface. In one instance it was possible to view saline water (40,000 EC) from the Parilla Sand Aquifer flowing through the rusted casing down into the bore. (Pers comm. Alan Burstall, 1995)

The program for sealing abandoned bores began in May 1994. More than thirty bores have been redrilled and decommissioned by June 1995. The cost of sealing each bore averaged $2,800. Ninety percent of bores attempted have been successfully sealed.

Contract hydrogeologists implement monitoring programs recording the water quality and flow rates of the Duddo Limestone Aquifer. The monitoring project is part of an extensive program for monitoring the performance implementing the Mallee Dryland Salinity Management Plan.

The Future

The decommissioning of the abandoned bores in the Western Mallee will continue with assistance from the State and Federal Government. The Implementation Group will continue to oversee the project and the future direction of the plan.

It is anticipated that a small number of individual decommissioned bores will undergo close scrutiny to determine the effectiveness of the program. An observation bore will be established in close proximity to each sealed bore. Groundwater monitoring may provide some more data to aid in the protection of the Duddo Limestone Aquifer.

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Agroforestry Studies for Groundwater Recharge Control near Albury

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Introduction

Tree planting in catchments affected by dryland salting has been shown to lower groundwater levels (Schofield, 1991). However, effective salinity control often requires planting trees on substantial areas of the landscape previously used for agriculture. The integration of timber production with grazing (agroforestry) provides a possible economic solution to this problem. However there are many uncertainties regarding the use of agroforestry for salinity control, particularly the most reliable positions in the landscape for tree growth and reliable predictions of the hydrologic effects.

This paper reports interim results of groundwater monitoring in a salt affected catchment where *Pinus radiata* was established for commercial pulpwood and sawlog production. Numerous similar commercial ventures have been established in the Albury district, with the potential for many more. While these ventures are economic in their own right, any observed lowering of groundwater levels would represent additional on and off-site benefits and provide additional encouragement for landholders to undertake agroforestry as a land management option for control of dryland salinity.

Site Description

The project is located 23 km north-west of Albury, N.S.W. within a 126 ha catchment on the property 'Mirradong'. The site was almost totally cleared of trees about 50-80 years ago and saline areas now occur in some flowlines. Phalaris (*Phalaris aquatica* cv. Australian) was planted in 1991 over approximately 20% of the catchment in lower parts. Annual pastures predominate over the rest of the site. The long term (1893-1991) annual average rainfall for the site is 571 mm and the average annual pan evaporation for Albury (1862-1969) is 1142 mm.

Soil types occurring on ridges and upper slopes are mainly shallow loams (Um) and hard pedal red duplex soils (Dr 2). On lower slopes and drainage lines, hard pedal yellow (Dy 2) and mottled yellow (Dy 3.4) duplex soils are common.

Experimental Methods

Hydrogeological and Electromagnetic Surveys

A hydrogeological survey was carried out in January, 1989 to identify groundwater recharge areas. Field observations, complemented by aerial photograph interpretation, were made of rock fracture intensity and direction, plus strata dip and strike angle. An electromagnetic induction survey of the catchment was carried out in January, 1989 to assist the identification of groundwater recharge zones. A Geonics model EM34/3 instrument operated at 10 m intercoil spacing was used. Readings were taken every 10 m along transects spaced 50 to 100 m apart. Soil samples collected during bore installation were analysed for electrical conductivity ($EC_{1:5}$) to aid interpretation of electromagnetic data.

Plantation Establishment

Block plantings of *Pinus radiata* were undertaken in 1989 under a joint venture between A.N.M. Forests Pty. Ltd. and P. and G. Lavis. The plantation was established on mid to upper slopes in areas identified as having high to moderate groundwater recharge potential (see catchment survey results). Trees were planted closely spaced at a density of 1,600 stems ha^{-1} with the objective of maximising soil water use. A total of 17% of the catchment was planted to pines (Fig. 1). Survival of the trees ranged from 60-100%. Limited observations indicate tree growth rates compare favourably with those obtained in higher rainfall areas where pines are usually grown.

Rainfall and Groundwater Monitoring

Rainfall has been continuously recorded with a pluviometer located on the southern catchment boundary. The groundwater bore network within the catchment consists of four shallow bores (bore 1 to 4) located outside the pine plantation in colluvial material in drainage lines to depths of 6 to 10 m and four deeper bores (bore 5 to 8) located within, or immediately adjacent to, the pine plantation (Fig. 1). Bore 5 was installed into fractured rock and screened from 56 to 62 m depth. Bores 6, 7 and 8 were installed into weathered material overlying the fractured rock and screened for a length of 10 m at depths varying from 15 to 35 m.

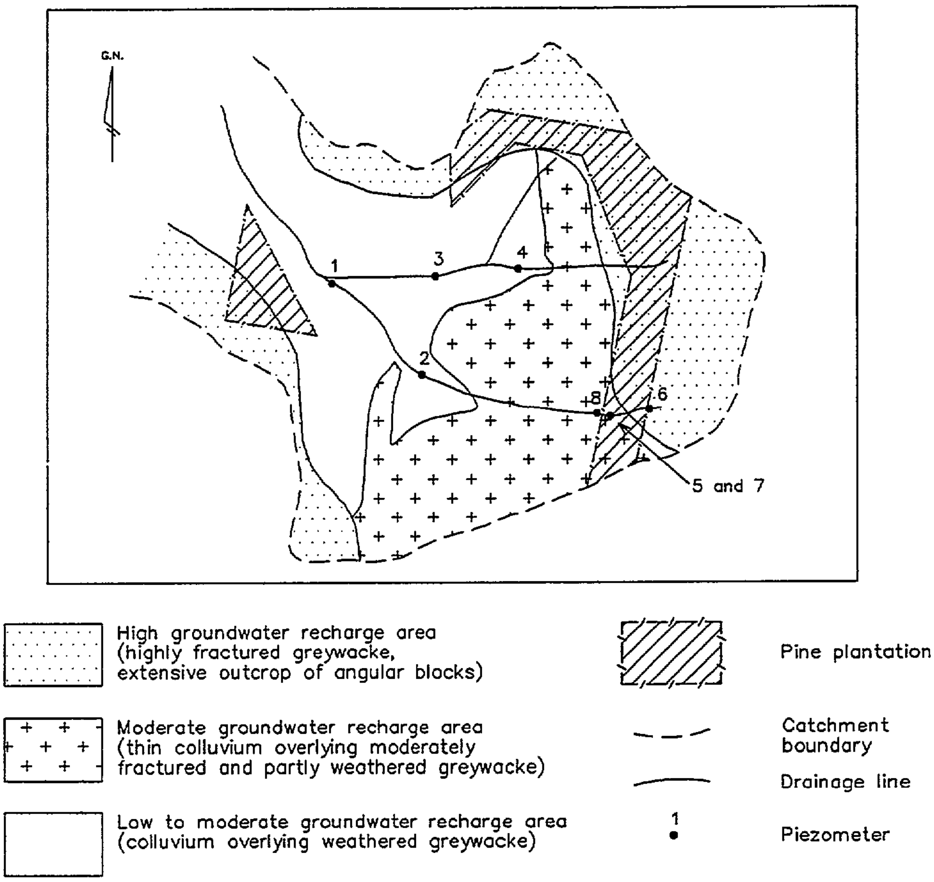

Fig. 1. Groundwater recharge zones identified from hydrogeological characteristics, pine plantations and bore locations within catchment.

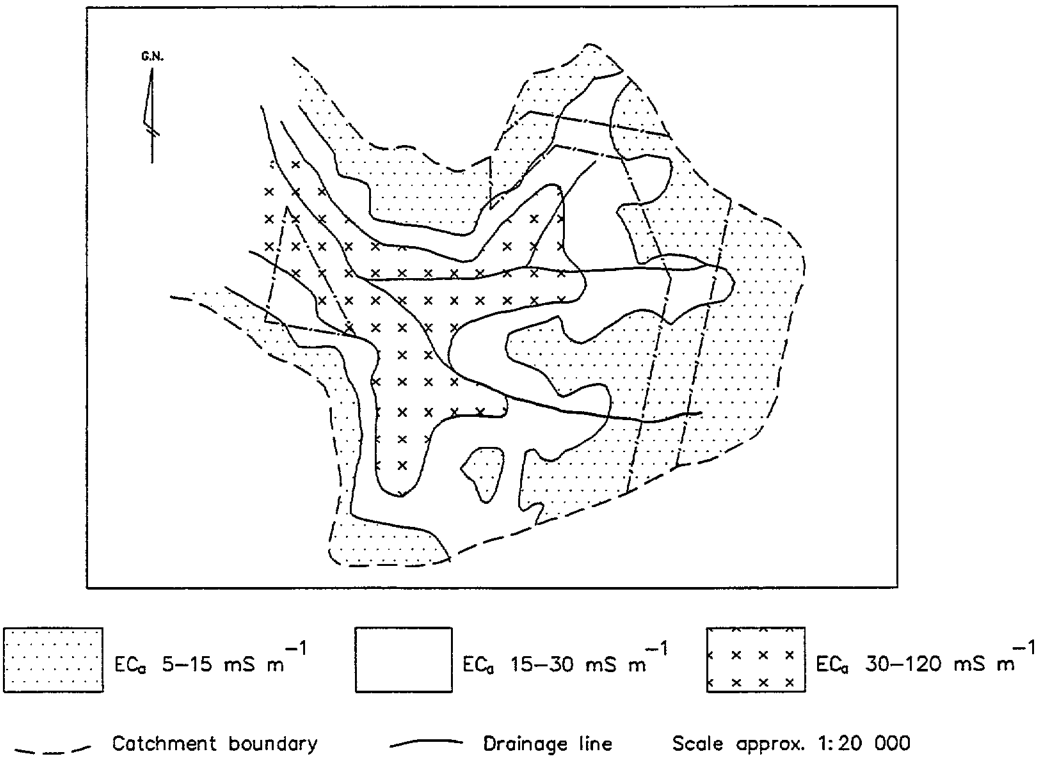

Fig. 2. Apparent electrical conductivity (EC$_a$) of catchment.

Monitoring of groundwater bores commenced in January, 1990 (bore 1 to 4), April, 1991 (bore 5) and August, 1994 (bore 6 to 8). Piezometric level was measured daily with automated equipment. Missing data for bore 5 for the period 1/8/91 to 20/11/91 was extrapolated from manual observations. To facilitate interpretation of piezometric data samples for conductivity and major ion analysis were collected in June, 1994 following bailing dry (bore 1 to 4) or pumping two to three volumes (bore 5 to 8).

Observations, Results and Discussion

Catchment Surveys

The geology of the catchment consists of Ordovician greywacke and phyllite. These have undergone multiple episodes of deformation under heat and pressure and are now highly dipping and extensively fractured. High, moderate and low groundwater recharge areas were identified from hydrogeological characteristics (Fig. 1). High recharge areas occur on higher ridges and upper slopes while moderate recharge areas were identified on mid to upper slopes in the upper half of the catchment. Low groundwater recharge areas occur on mid to lower slopes and adjacent to discharge areas in flowlines.

Three zones of apparent electrical conductivity (EC_a)to a depth of 7.5 m were arbitrarily defined from the electromagnetic survey (Fig. 2). These correlated very well with the groundwater recharge zones identified during the hydrogeological survey. EC_a values in the high and medium recharge zones were 5-15 and 15-30 mS m^{-1} respectively, while EC_a values in the low groundwater recharge zones and discharge areas ranged from 30-120 mS m^{-1}. Electrical conductivity ($EC_{1:5}$) values of soil samples collected during bore installation are shown in Fig. 3. The salt profile shape of bore 1 indicates upward water movement dominates and is typical of sites with a shallow water table. Salts have accumulated near the surface due to evapotranspiration. Salt profiles at bores 2 and 6 are well leached and indicate considerable deep drainage occurs at these sites. This data supports the groundwater recharge zones indicated by the electromagnetic survey.

Groundwater Hydrology

Results of major ion analyses of groundwaters were plottted on Piper, Durov and Stiff diagrams (not presented) to facilitate classification, and three groundwater groups were identified. Groundwater flow patterns within the catchment were estimated from this data (Fig. 4). Groundwater from bores 2 and 4 contained comparatively more bicarbonate than the other bores, indicating the residence time of water is less. Groundwater at these sites is believed to be dominated by shallow interflow and very local recharge. Groundwater at bore 5 was characterised by lower total dissolved solids, indicating recharge is from areas up gradient containing lower concentrations of salts. Alternatively, concentration of salts may be occurring at this site but not yet apparent

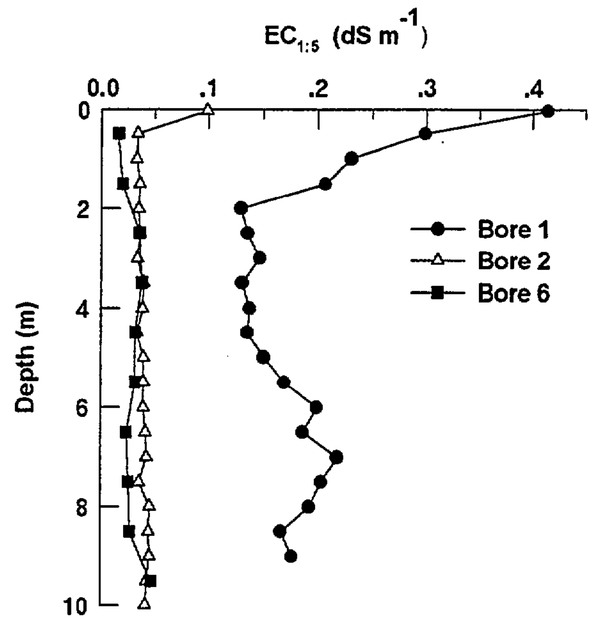

Fig. 3. Electrical conductivity ($EC_{1:5}$) of soil samples collected during bore installation

in the deepest (> 50 m) part of the aquifer. Groundwaters at bores 1, 3, 6, 7 and 8 were sodium chloride dominant and similar in other chemical properties. The data indicate groundwater at these sites is interconnected and derived from local recharge within the catchment.

Rainfall and Groundwater Levels Response

The average rainfall over the period 1990-94 of 632 mm was 11% above the long term average of 571 mm. Compared with the long term average, annual rainfall varied from 35% lower in 1994 to 40% higher in 1992. Monthly rainfall and long term monthly median rainfall are shown in Fig. 5. The below average rainfall received during 1994/95 is clearly evident.

Daily piezometric level variation in two bores is shown in Fig. 5. Bore 5 water levels showed overall a reasonably quick response to rainfall in winter and early spring, with water levels rising within about a month of significant rain and reaching a peak some three to four months later in October or November. Water levels steadily declined over the late spring, summer and autumn period, with deepest levels recorded during the period June to August. The effect of below average rainfall during 1994/95 is clearly evident with water levels continuing to fall up to at least the end of May, 1995. The amount of seasonal variation in water levels reduced progressively down slope from fluctuations of up to 4.86 m in bore 5 (typical of recharge areas) to 1 to 0.5 m at bore 1 (discharge area).

Estimates of groundwater recharge obtained from analysis of bore 5 hydrographs indicate recharge for the years 1991 to 1994 was 76, 97, 31 and 6 mm respectively. These estimates are based on a porosity value for the fractured rock aquifer of 2%. Recharge as a percentage of annual rainfall for these years was 14, 12, 5 and 2% respectively. While this technique provides a guide only to

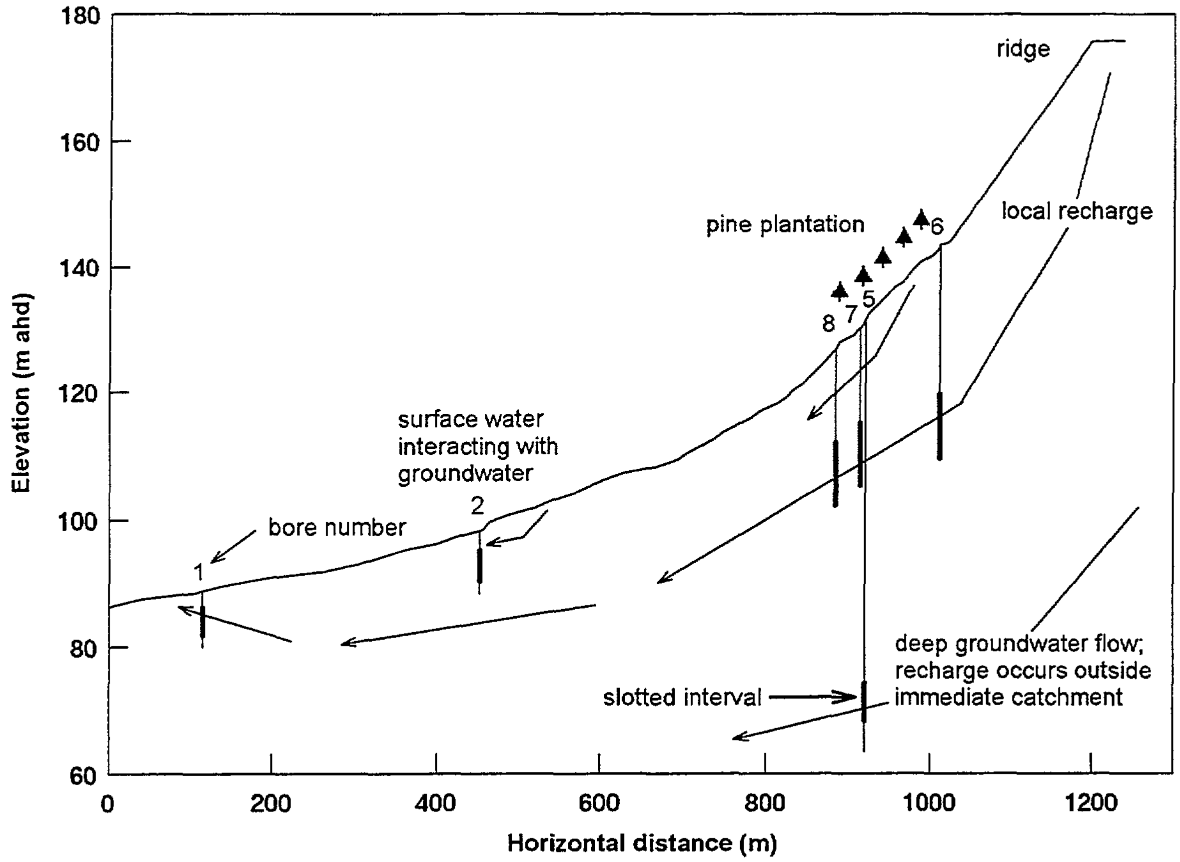

Fig. 4. Section along drainage line showing pine plantation, groundwater observation bores and groundwater flow.

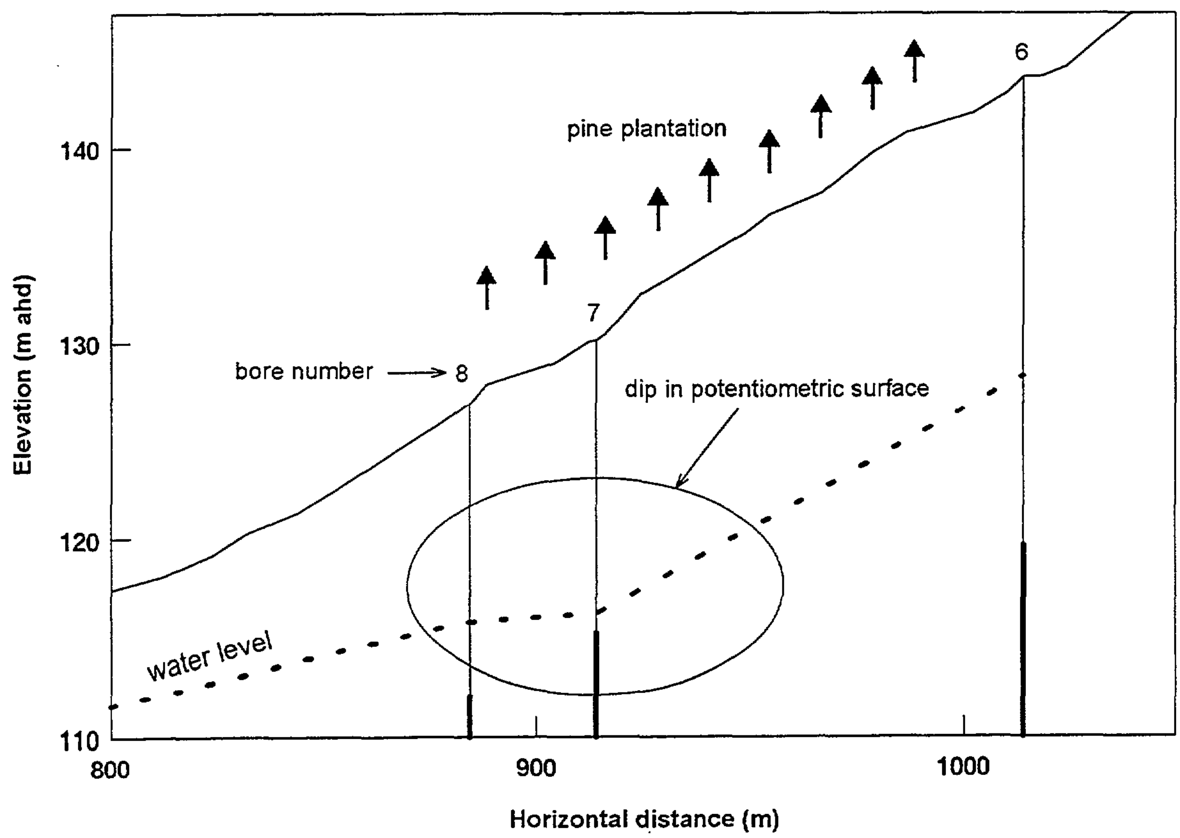

Fig. 6. Potentiometric surface beneath pine plantation at 21 April, 1995.

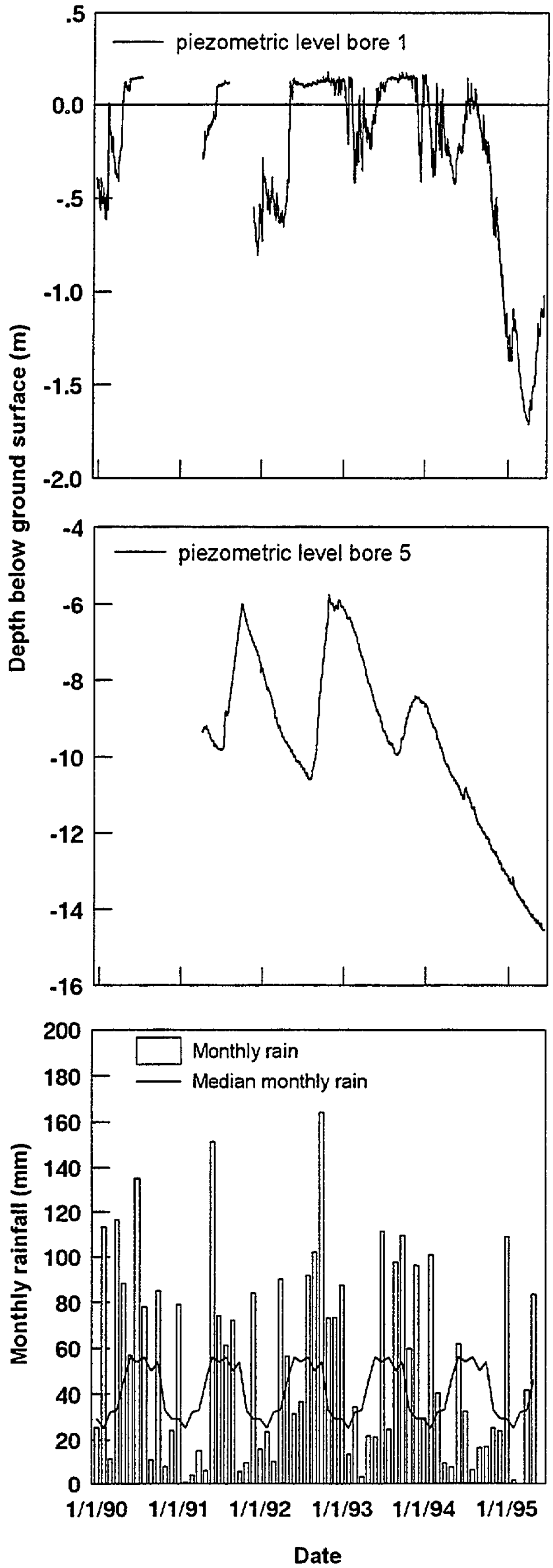

Fig. 5. Piezometric level variation in two bores, monthly rainfall and monthly median rainfall.

the amount of recharge, it does indicate that significant temporal variability occurs.

Daily piezometric levels for bores 6, 7 and 8 (data not presented) since September, 1994 show identical trends to bore 5. Any effect of the pines on lowering the height of the water table should be first evident in these bores, but results are too short term to show any trends to date. However, the dip in the potentiometric surface under the pine plantation near bore 7 (Fig. 6) indicates some lowering of the water table may be occurring. This could be achieved by the pine plantation reducing recharge to the point where groundwater outflow from the area planted exceeds recharge. There is also the possibility that the trees may directly transpire groundwater. As the plantation grows its canopy mass will increase to a maximum at about age 6 or 7 years, at which time the water use potential of the plantation could be up to 1 000 mm yr^{-1} greater than rainfall. This estimate is based on water use budgets for a pine plantation irrigated with waste water near A.N.M.'s Albury mill. A number of physical and biological factors will influence water use. In addition to canopy mass, stomatal control may also be influential, particularly during periods of low relative humidity. It is anticipated that ground water levels, at least in the vicinity of the plantation, will be lowered.

Plantation Management

Plantation management at this site may vary from that normally used in higher rainfall areas. If water becomes limiting to tree survival, water use can be reduced by decreasing canopy mass through either pruning to remove green crown, or thinning to remove whole trees, or a combination of both. Current plans include thinning the plantation to remove pulp and sawlogs in three stages commencing at around age 14 years, with a clearfell at age 30 years. The timing of the first thinning will, however, depend on how quickly trees reach merchantable size. An earlier non-commercial thinning may be desirable if greatly reduced tree growth or mortality results from lack of water. This will be compounded in a drought year. In areas of existing low tree survival thinning to overcome a water deficit may not be necessary. Current plans include pruning to remove lower branches and selective pruning of final crop trees in fully stocked areas to produce higher value sawlogs. Soil moisture measurements will be an important management tool, particularly if trends can be established to help predict when thinning or pruning to avoid moisture stress is required.

Acknowledgments

We thank P. and G. Lavis on whose property the study catchment is located and K. Holbrook for computer drafting. We acknowledge financial support of the Salt Action program.

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The Rise and Rise of Confined Aquifer Pressures - Why?

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Widespread rises in regional water tables in response to clearance of native vegetation have been well documented throughout the Murray Basin. In South Australia, rises have been monitored in two areas (Fig. 1). The most dramatic have occurred on the low lying Coastal Plain on the southwest margin of the Murray Basin where the depth to the water table is generally less than 40 m and the rainfall recorded is from 400-500 mm/year. Consistent rises of 10-15 cm/year have been monitored, even though the rainfall has been below average for the nine years preceding 1992. In the Riverland area, where the depth to the watertable is similarly less than 40 m, more gradual rises of 1-2 cm/year have been measured which may be due to the lower rainfall of about 250 mm/year and/or the presence of Blanchetown Clay.

Coincident with these watertable rises have been other changes. In some areas of the Coastal Plain, the salinity of the unconfined aquifer has risen by 700 mg/L, in other areas, it has decreased by 330 mg/L - trends which will make an interesting contribution to the current study on the potential salinization of the unconfined aquifer by the downward salt flux. (see papers by Leaney and Love, this volume)

Of more immediate interest however, is the rising trend in the underlying confined aquifer water levels in areas (Fig. 2) where watertables are also rising. One might expect that the rising trends would be caused by downward leakage from the overlying watertable aquifers. Figure 2 shows however, that these rises are occurring in areas of upward leakage from the confined aquifers.

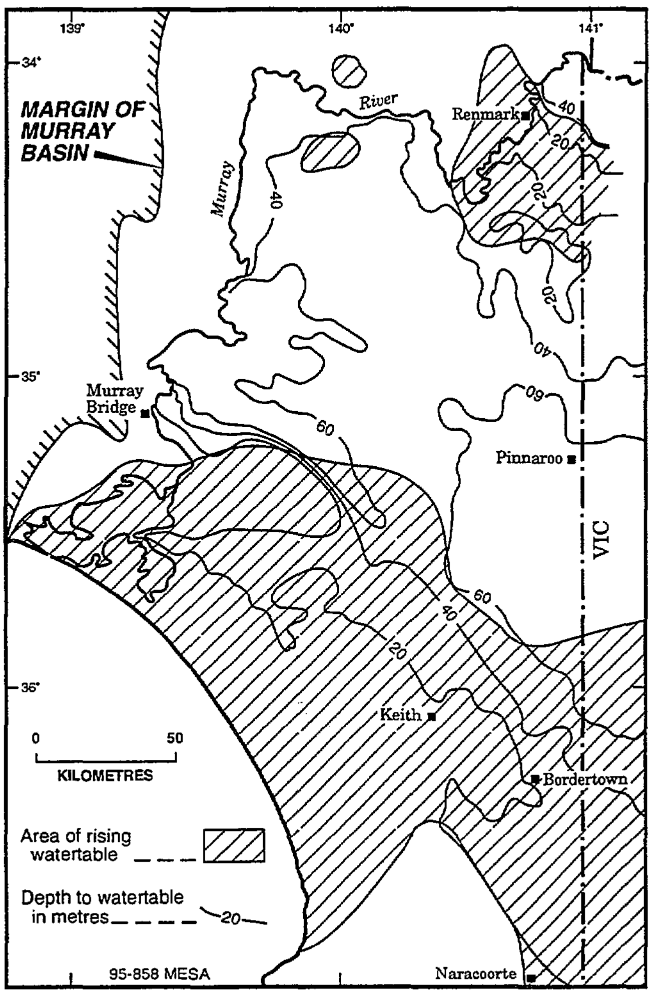

Figure 1: Areas of rising watertable

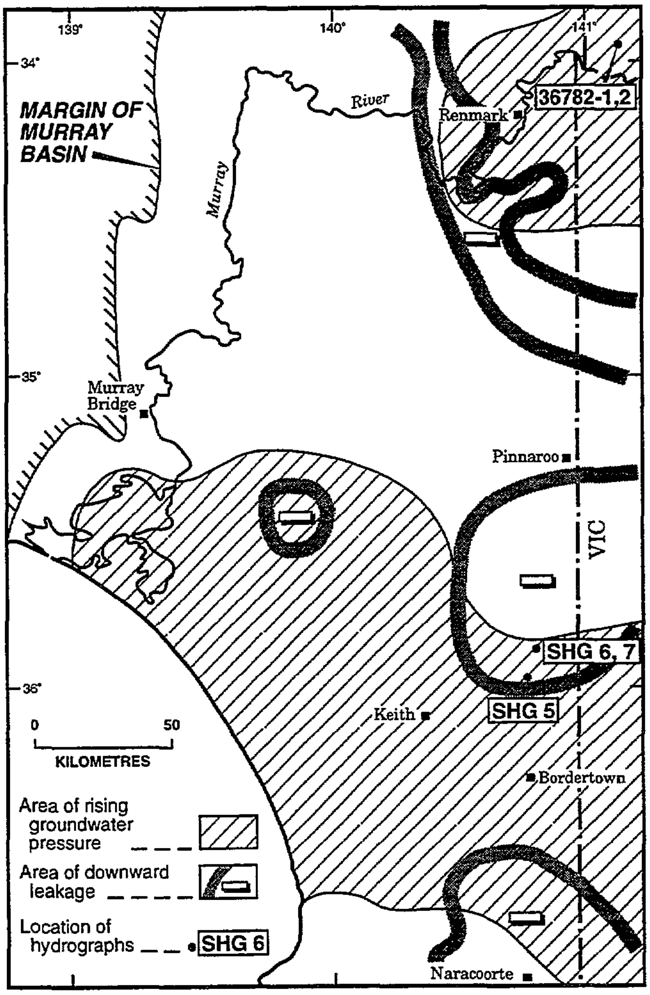

Figure 2: Areas of rising confined aquifer pressures

Another possible cause could be the rapid transmission downgradient of pressure increases due to increased recharge in the recharge areas. This is an unlikely cause because the type of response and the magnitude of response vary greatly throughout the area and are not uniform as one would expect for a confined aquifer with one main recharge area in southwest Victoria.

It is proposed that the rising pressures in the confined aquifers are caused by the increased load in the overlying unconfined aquifer (due to increased recharge and storage) which compresses the elastic confined aquifer and increases the hydrostatic pressure.

Overseas studies have shown that confined aquifers can act as giant weighing lysimeters. In Canada, van der Kamp and Maathuis (1991) postulated that annual head fluctuations in the deep confined aquifers reflect changes in the mechanical load on the formations caused by seasonal changes of the soil moisture, snow and storage at the water table. In New Zealand, Bardsley and Campbell (1994) took the aquifer lysimeter concept further and suggested that it could be used for water balance studies on a local scale.

Figure 3 shows paired hydrographs from adjacent observation wells completed in different aquifers in different parts of the basin as shown in Figure. Holes SHG 5 (unconfined Murray Gp Lst), SHG 6 (confined Renmark Gp) and SHG 7 (semi-confined Murray Gp Lst) all show very similar rising trends. Although the head difference (density corrected) is - 1.5 m which indicates downward leakage, the actual flux would be only be 0.2 mm/year (assuming a Kv of 10^{-6} m/day for the Ettrick Formation).

Holes 36782-1 (unconfined Pliocene Sands) and 36782-2 (confined Murray Group limestone) also show very similar trends. Here, the head difference is + 4.7 m, indicating upward leakage with a calculated flux of 4 mm/year (assuming 10^{-5} m/day for Kv of the Bookpurnong Beds).

These hydrographs are just some examples of the coincident rising trends in two different unconfined/confined aquifer systems which give strong support to the mechanism of hydrostatic loading as the cause.

The ramifications are not too disastrous at the moment. The head difference between the two aquifers remains relatively constant and therefore actual flows between the aquifers will not change dramatically. The increase in confined pressures relative to ground level would make any deep drainage less efficient in the future. In localised areas where the watertable is held constant but is surrounded by regional watertable rises, (by drainage systems in irrigation areas or by evaporative discharge in salinized areas), the upward discharge from the confined aquifers will be enhanced because of the regional increase in confined aquifer pressures.

Bardsley, W.E. and Campbell, D.I., 1994. A new method for measuring near surface moisture budgets in hydrological systems. Journal of Hydrology, 154: 245-254.

van der Kamp, G. and Moathius, H., 1991. Annual fluctuations of groundwater levels as a result of loading by surface moisture. Journal of Hydrology, 127: 137-152.

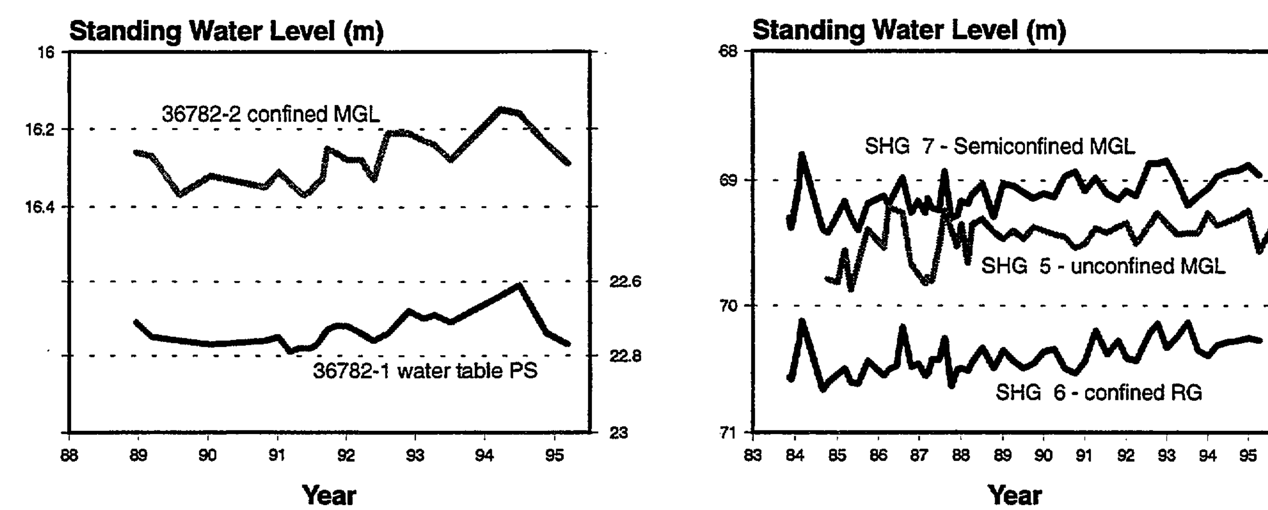

Figure 3: Hydrographs

Shepparton East: Groundwater Quality through Space and Time

John Bauld[1], Mark W Sandstrom[2] and Mark Reid[3]*

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The Shepparton East area covers about 10,000 hectares. It lies within the Goulburn-Broken Catchment and its land use is principally orcharding and dairying. The shallow aquifer systems of the Shepparton Formation are highly variable and complex, comprising a heterogeneous assemblage dominated by alluvial clays and loams but interpenetrated by a discontinuous network of narrow, more transmissive channel deposits known as "shoestring sands". In the course of groundwater quality assessment investigations in the Goulburn-Broken Catchment several shallow observation bores in the Shepparton East area were sampled on three or more occasions over a period of about four years. Ground waters acquired from these bores were analysed for a range of water quality indicators. This paper will focus on nitrate-N and pesticides.

Nitrate concentrations in ground waters underlying forest or grassland in North America are reported to be generally less than 2 mg/L NO_3-N, while concentrations greater than 3 mg/L are considered to be indicative of contamination by human activities. Overall, ground waters from ca half of the Shepparton East bores contained > 3 mg/L nitrate-N (concentration range was 0.1-70.0 mg/L). Nitrate-N concentrations at individual sites exhibited a variety of patterns with elapsed time ranging from relatively stable to fluctuating.

Similar temporal patterns were observed with pesticide concentrations. Pesticide detections were overwhelmingly dominated by the triazine herbicides, principally atrazine, simazine and their metabolites. Overall, about half of the ground water samples acquired from Shepparton East observation bores were contaminated with triazine herbicides, albeit generally at quite low concentrations. One site, which was sampled at six different times, invariably contained simazine at concentrations ranging from ca 200-950 ng/L. Temporal fluctuation in simazine concentration was quite different to that observed for nitrate-N at the same site.

Factors that affect leaching fractions in areas where groundwater pumps operate.

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Abstract

Soil sampling was undertaken to determine the leaching fraction at sites where groundwater pumping and reuse have been practiced for more than 10 years. The factors that affect leaching fractions in these areas (viz. applied water salinity, soil type, and distance from a groundwater pump) are discussed. Leaching fractions were found to vary from almost 0% to 12%. In general leaching fractions were low, since potential crop water use was greater than the annual depth of applied irrigation water and soils had low conductivity. The leaching fraction was found to be significantly affected by applied water salinity and the distance to the nearest groundwater pump. No significant difference was found between mean leaching fractions on heavy and light duplex soils.

Introduction

Groundwater pumping and its subsequent reuse can result in rapid increases in groundwater salinity. An empirical relationship is being developed that relates leaching fraction to applied water salinity, soil type and distance from the nearest groundwater pump. The leaching fraction (LF) is the fraction of applied water that passes below the crop rootzone. This empirical leaching fraction relationship will be used to develop management guidelines that improve the sustainability of groundwater pumping. This paper shows the effect of applied water salinity, soil type and distance from the nearest groundwater pump on leaching fractions measured in the field.

Background

Groundwater pumping provides salinity control by reducing underlying aquifer pressure, thus increasing rootzone leaching. Salt disposal to the Murray River through surface drains is limited in the Shepparton Irrigation Region (SIR) to an amount approximately equal to salt inputs to the Region. For optimum management of water resources, management plans developed for the SIR consider that it is necessary to reuse groundwater in conjunction with good quality channel water for irrigation (conjunctive water use or CWU). The resulting higher applied water salinity can adversely affect crop yields. In addition, groundwater pumping and its subsequent reuse can lead to rapid increases in groundwater salinity, thus making the practice not sustainable. Therefore, it is important to develop management guidelines that allow farmers to implement groundwater pumping as a sustainable salinity control option, while retaining full crop yield. Such guidelines currently do not exist in the Shepparton Irrigation Region.

Prendergast et al. (1994) developed a lumped parameter model to investigate factors that affect the sustainability of groundwater pumping. They found the main factors that lead to increases in groundwater salinity over time are:

a) salt inputs to the groundwater system from irrigation water and rainfall,

b) the spatial relationship between the conjunctive use system and the regional groundwater, and the resulting groundwater leakage into or out of the system, and

c) spatial constriction of the area of conjunctive water use.

Spatial constriction of the area of reuse occurs when groundwater reuse is over a smaller area than the area of influence of the groundwater pump. Upward leakage into the pumped aquifer does not contribute to rootzone leaching and therefore is called non-leaching recharge (NLR). Best pump management requires that NLR is minimised, and that pumped groundwater is reused over the full area of influence of the pump.

NLR can be calculated by summing the elements of the water budget, including aquifer recharge and groundwater withdrawal through pumping. Aquifer recharge can be approximated by the leaching fraction in areas where pumped aquifers are close to the surface. For a given crop and depth of applied irrigation water, LF is a function of applied water salinity, soil type and distance from a groundwater pump. A numerical groundwater model is to be used to simulate the water budget, as it provides the best means of spatially accounting for the variation in LF, upward leakage, lateral groundwater flows and surface management, likely to be encountered in the field. Simulation of the water budget to calculate NLR requires quantification of LF, and an understanding of how LF changes under different pumping scenarios.

Materials and Methods.

Location of experiment.

The Tongala groundwater / reuse project area was initiated in 1980 to combat salinity problems. The Tongala project area is located in the Shepparton Irrigation Region of northern Victoria, just east of the township of Tongala (Fig. 1). The project area is approximately 610 hectares in size, with most of the land being used for growing perennial pastures. The first groundwater pump was installed in 1980. Seventeen groundwater pumps had been installed by the end of the 1991-92 irrigation season. Historically, most of the pumped groundwater has been reused for irrigation. Since commencement of groundwater pumping a significant decrease in soil salinity has been recorded. At the same time there has been a significant increase in groundwater salinity (Norman et al. 1993). Therefore, while groundwater pumping in the Tongala project area is providing salinity control, under current management this practice is not sustainable.

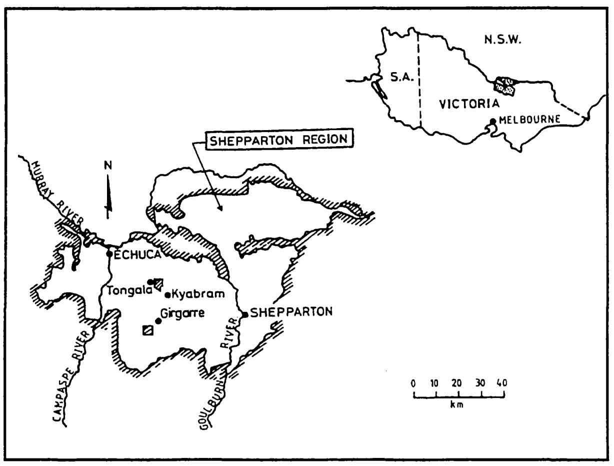

Figure 1. Location of the Tongala project area.

Leaching Fraction.

Prendergast et al. (1995), Lyle et al. (1986) and Noble et al. (1989) found that leaching fraction calculated using a steady state model closely approximates LF calculated using non-steady state theory. Norman et al. (1993) found that soil salinity had reached steady state in the Tongala project area after two years of reuse.

In this paper leaching fractions are calculated using a well accepted steady state model. This model assumes that the total mass of chloride stored in a finite volume of soil is constant over time, and that groundwater flow occurs only in the vertical direction (1-dimensional flow). The finite volume used to calculate LF in this instance is the top 90 cm of the soil profile, over a unit area. Annual chloride input to the finite volume is through irrigation and rainfall, and is calculated by multiplying the total annual volume of applied water (Vw; includes rainfall) by the average chloride concentration of applied water. Annual chloride output will be through deep percolation of groundwater (below 90 cm), and is calculated by multiplying the annual volume of deep percolation (Vz) by its chloride concentration (Cz).

$$Vw.Cw = Vz.Cz \qquad (Eq.1)$$

LF is the fraction of applied water that passes below the bottom of the rootzone (Eq. 2).

$$LF = \frac{Vz}{Vw} \qquad (Eq.2)$$

From Eq. 1 and 2,

$$LF = \frac{Vz}{Vw} = \frac{Cw}{Cz} \qquad (Eq.3)$$

Two hundred and forty two soil samples were taken in May 1995 from flood irrigated bays in the Tongala project area. Soil chloride concentration was measured over the 60 to 90 cm range of these soil samples in a 1:5 soil/water suspension.

Applied water salinity

Average applied water salinity is calculated by dividing the total mass of salt applied to the bay by the total volume of applied water. Sources of salt and water included in this calculation are pumped groundwater (reuse), good quality channel water, surface drainage water and rainfall. The amount of reuse was determined from a survey of farmers in the project area. Reuse practice was limited by farm layout such that groundwater was often only reused over part of a farm.

Soil type.

Soil type was recorded at each sampling site. Two predominant soil types were found in the project area, Shepparton fine sandy loam (Sfsl) and Lemnos loam (Ll). Sfsl is a relatively light duplex soil formed by stream levee deposits. LL is a heavier soil, with higher clay content and poorer internal drainage (Skene and Poutsma, 1962). In addition, smaller areas of East Shepparton fine sandy loam, Goulburn clay loam and Sandmount sand were found in the project area.

Statistical analysis.

Mean leaching fractions were compared for light and heavy soils using a two-sample T-test. Mean LF on bays irrigated with channel water were also compared to LF on bays with groundwater reuse using a two-sample T-test. Linear regression analysis was used to compare the relationship between LF and pump distance, for the two levels of applied water salinity. All data was log-transformed to homogenize residuals. Genstat 5 (Release 3.1), Lawes Agricultural Trust (Rothamsted Experimental Station) was used for statistical analysis.

Results and discussion.

The effect of applied water salinity on LF.

Leaching fractions are compared for sites irrigated with groundwater reuse (average EC = 1 dS/m) and sites irrigated with good quality channel water (EC = 0.1 dS/m). The mean leaching fraction calculated for sites with groundwater reuse was significantly higher ($p < 0.001$) than the mean leaching fraction of sites irrigated with channel water (mean $LF_{reuse} = 0.04$; $LF_{channel} = 0.01$). Prendergast et al. (1995), Lyle et al. (1986) and Noble et al. (1989) also found leaching fractions to increase with applied water salinity.

The effect of soil type on LF.

Lighter soils would be expected to have greater leaching fractions than heavier clay soils since they have greater soil hydraulic conductivity. However, no significant difference was found between the mean leaching fraction of heavy (Ll) and light (Sfsl) soils, for both paddocks irrigated with shandied groundwater ($p = 0.44$), and paddocks irrigated with channel water ($p = 0.6$). A possible explanation for this is that both Ll and Sfsl are duplex soils with a heavy clay B-horizon from 20 to 50 cm depth. It is considered that this clay layer is controlling leaching fractions.

The effect of distance to the nearest groundwater pump on LF.

Aquifer drawdown resulting from groundwater pumping will reduce as distance from the pump increases. Therefore, it is expected that leaching fraction decreases as distance from the pump increases. For sites that historically reused groundwater, leaching fractions decreased significantly ($p < 0.001$) with increasing distance from the nearest groundwater pump. However, for sites irrigated with channel water, leaching fraction increased significantly ($p = 0.003$) as the distance from the groundwater pump increased (Fig. 2). We cannot explain this significant increase in leaching fraction on bays irrigated with good quality channel water.

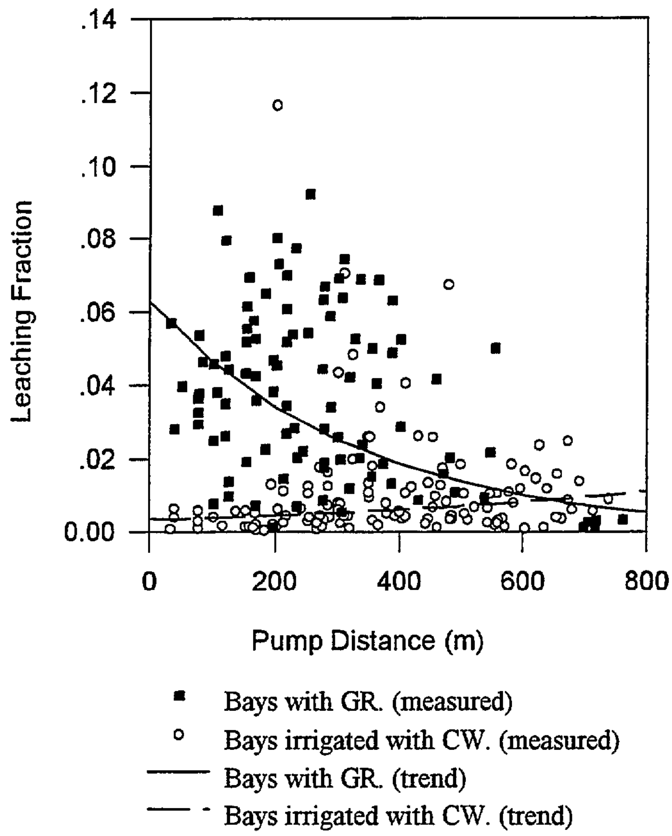

Fig. 2. The effect of distance from the groundwater pump on LF. Leaching fractions for two levels of applied water salinity are plotted: channel water (CW; EC = 0.1 dS/m) and groundwater reuse (GR; average EC = 1 dS/m). The slopes and intercepts for the trends of the different levels of applied water salinity were significantly different (slope: $p < 0.001$; intercept; $p < 0.001$).

LF on bays with groundwater reuse is expected to be affected more by groundwater pumping than bays irrigated with channel water in the Tongala project area. This is because the average annual depth of applied irrigation water (600 mm) is less than potential crop water use (800-1000 mm). Therefore, under channel water irrigation, most soil moisture is removed through plant evapo-transpiration during the irrigation season, thus there is little leaching. Groundwater pumping under these conditions is not likely to increase summer rootzone leaching. Groundwater reuse is likely to lead to higher soil salinity, and therefore lower plant water use. Rootzone leaching during summer is likely to be higher if plant water use is reduced, particularly near a groundwater pump.

There is much unexplained variation in the data. Some of this is due to the uncertainty in estimating applied water salinity. Some of the noise may also be attributable to the atypical climatic conditions experienced prior to soil sampling. Heavier than normal rains fell in Spring 1994, leading to heavy flooding. It was much drier than normal from Spring 1994 up to the time of soil sampling. These atypical conditions may have vitiated the steady state assumption.

The analysis presented in this paper assumed that there were only two levels of applied water salinity; channel water and groundwater reuse. However, bays throughout the project area received a wide range of applied water salinities, depending on farm layout and on irrigation management. Assuming applied water salinity was at one of these two levels would introduce some variation into the results.

An initial attempt was made to fit a regression model that expressed LF as a function of applied water salinity, soil type and distance from the nearest groundwater pump. However, no regression model adequately described the data. To improve the fit of the regression model estimates of applied water salinity are being improved and there has been increased replication of the data set.

Acknowledgments

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GROUNDWATER MANAGEMENT IN THE UPPER LACHLAN VALLEY

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1.0 INTRODUCTION

The main tool for management of groundwater resources in New South Wales is to review the groundwater allocation guidelines for all users pumping groundwater from alluvial sediments. The allocation guidelines are aimed chiefly at groundwater users who wish to pump from production bores for purposes other than stock and domestic purposes. This could be for irrigation, town water supply, mining or industrial purposes.

The existing allocation guidelines have operated since 1983/84 and new strategies need to be introduced in some areas to regulate groundwater use and review allocations, particularly in areas of increasing development. Review of existing allocation policies, considers current government objectives, community and environmental values, and available data.

The purpose of water management is to plan for water use to sustain human activity and for productive uses (ie. town water supply, agriculture, industry, recreation and others). It should generate outputs which are socially, economically and environmentally sound as well as valued by the community. Development and use of natural resources should contribute to the quality of life of the whole community. The community within the study area should be involved throughout the decision making and management process.

The area covered in this investigation is Groundwater Management Area (GWMA) 011, which covers the alluvial sediments of the Upper Lachlan Valley. It extends from Cowra in the east, Condobolin and Forbes in the north, Stockinbingal in the south, and the Lake Cargelligo in the west.

Water level rises and salinisation are a feature of the Upper Lachlan Valley and some of its tributaries. Large rises have been recorded in areas close to the River when flooding occurs, and also in the Jemalong-Wyldes Plains Irrigation District and around the town of Forbes.

2.0 BACKGROUND

Test drilling for groundwater by the then Water Conservation and Irrigation Commission (WC&IC) commenced in a co-ordinated fashion in 1957, as discussed by Williamson (1986). However, it was not until 1974 that the (regional) groundwater investigation bores were constructed in such a way that they could be used for long term monitoring. Since 1957 extensive drilling has been carried out, as well as seismic refraction surveys, ongoing water level monitoring and salinity measurements. All this information, combined with estimates of the volume of water being extracted (obtained through groundwater returns over the last decade), allows for a good understanding of the alluvial groundwater resource and the way it changes over time.

The alluvium within the Upper Lachlan Valley occupies over 4000 km^2, covering most of the area between Lake Cargelligo, Stockinbingal, Forbes and Cowra, as shown in Figure 1. This area is referred to as Groundwater Management Area 011 (GWMA 011). The initial volumetric policy for the Upper Lachlan Valley was introduced in 1983/84. However in 1992, GWMA 011 was divided into 8 zones to assist in management of similar hydrogeological units. The Lachlan Valley was declared a "restricted sub-surface water area" in November 1984, under the provisions of Section 117A of the Water Act (1912).

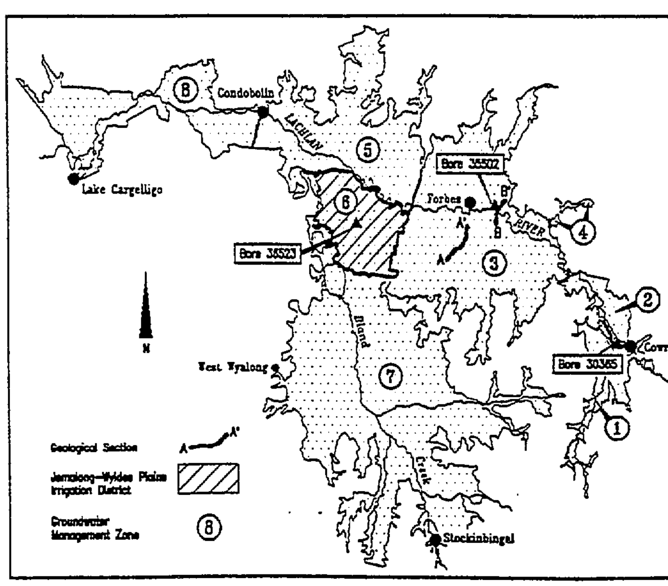

Figure 1: Locality Plan for GWMA 011

The current allocation policy allows groundwater users to extract a certain volume of water depending on historical usage, the size of their property and the hydrogeological zone. Conjunctive users of river and groundwater are allowed to use more groundwater in drought seasons to compensate for the shortfall in their surface water allocations.

3.0 OVERVIEW OF STUDY AREA

3.1 Climate

The Upper Lachlan Valley has a Mediterranean to semi-arid climate, with a seasonal rainfall maximum during the summer months. The highest rainfall values are recorded in the headwater region and decreases westward. There is considerable seasonal variability in rainfall across the Valley, which is prone to periods of severe drought as well as very wet periods. The year 1990 was a period of extensive flooding, where most rainfall occurred in April.

Rainfall-runoff relationships are complex and are influenced by evaporation, transpiration, preceding soil moisture conditions and infiltration losses (particularly within stream channels). The Lachlan and Belubula Rivers are regulated from water stored in Wyangala and Carcoar Dams, respectively. Over 53,000 ha of land is irrigated along the Lachlan River in the study area by private irrigators. Irrigation commenced in the government operated Jemalong - Wyldes Plains Irrigation District in 1944. It covers an area of 88,500 ha (shown as Zone 6 in Figure 1) of which 18,700 Ha is irrigated. It uses about 52,000 ML annually, diverted from the weir at Jemalong Gap and delivered via a gravity fed channel system. A total of 280 km of channel carries the water to 153 farms. Flow in the Lachlan River upstream of Forbes for the last 13 years highlights the significant flooding event in 1990, which is also recognised in the bore hydrographs for bores monitoring the alluvial sediments.

3.2 Geology and Hydrogeology

The alluvial sediments of the Lachlan River Valley have been accumulating for more than 17 million years. During that time the river channel has meandered over the flood plain, depositing sand, gravel and clay across the whole area. The most significant ancient river course, or palaeochannel, was eroded into the underlying rock more than 50 million years ago. The palaeochannel is up to 120 metres deep. The alluvium of the present day Upper Lachlan Valley spreads out as a defined alluvial plain downstream from Cowra.

Framework tectonics (major earth movements) have played the primary role in the distribution and thickness of the sediments. Movement on major geological faults, i.e. along the western side of Lake Cowal trending to the immediate east of Condobolin, and immediately downstream of Cowra trending along the axis of Back Creek, have caused dramatic changes in alluvial thickness. For the Condobolin fault, the palaeochannel is reduced in profile from a wide and deep valley with 120 metres of sediments to a very narrow channel with most of the alluvium having a thickness of less than 40 metres.

The sediments can be divided into two formations on the basis of age and composition. The distribution of these sediments is shown in cross-sections of the Valley in Figure 2. They indicate that the alluvial sediments within the Upper Lachlan Valley were formed within a well developed valley-in-valley structure.

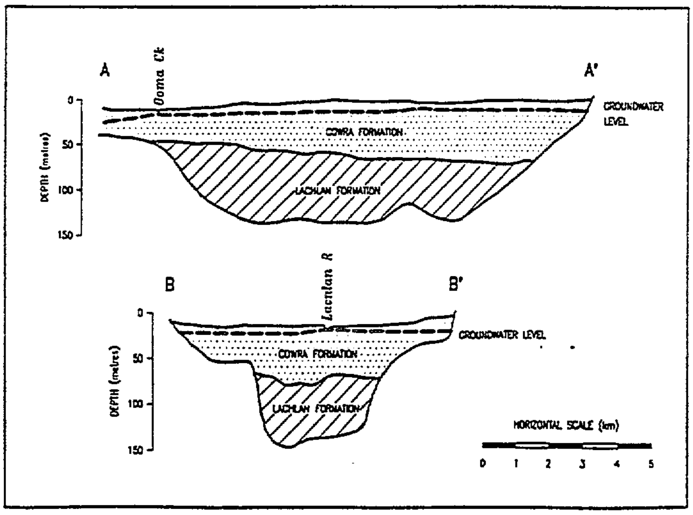

Figure 2: Geological Cross-Section through Lachlan Valley

The older (deeper) sediments are called the Lachlan Formation and tend to be confined to the palaeochannel (i.e. an ancient channel system) and are up to 70 metres thick. The Lachlan Formation is the most productive and used aquifer in the Valley. Yields may be up to 200 Litres per second (L/s) from suitably constructed bores.

The Cowra Formation, unconformably overlies the Lachlan Formation and basement rocks. It is generally less than 30-40m thick, although it is up to 64m thick in the Forbes area. The aquifers associated with the Cowra Formation rarely yield as more than 40 L/s.

Recharge to the alluvial aquifers occurs mainly through infiltration of rainfall, infiltration of slope runoff, streams during high flow stages and overbank flooding events due to river recharge in the area as discussed by Williamson (1986). Discharge from the aquifer system occurs by drainage to stream beds, underflow through the Valley, evapotranspiration, and bore/well extraction.

4.0 REVIEW OF AVAILABLE DATA

Groundwater from the alluvium of the Upper Lachlan Valley is used predominantly for irrigation, however it also provides the water supply for many towns and small rural communities such as Canowindra (borefield at Bangaroo); Grenfell (borefield at Goologong); Eugowra (borefield at Eugowra); and Parkes and Forbes (borefields near Forbes). Smaller abstraction volumes, are used for industry, recreation, and stock and domestic requirements.

Bish et al., 1994 shows that the usage values for each zones are considerably less than the amount allocated to each zone. The year 1992/93 was a year of flooding and surface water allocation was 120%. The figures are therefore not representative of the trend for groundwater usage and can be used for comparison purposes only.

The groundwater usage data has been collected on a reliable basis from the 1986/87 season to the present. The volumes of water usage are given in Figure 3 on a zone by zone basis. The largest volumes are being abstracted from zone 3, with abstraction from zone 2 providing most of the remaining high yield use. Usage in zones 1, 4 and 6 are minor but may be locally significant. There has been declining use in zone 5 over the period of record although it is understood that this area still has a reasonable level of installed pumping capacity. The current level of development in zone 7 remains unclear and there appears to have been no development in zone 8.

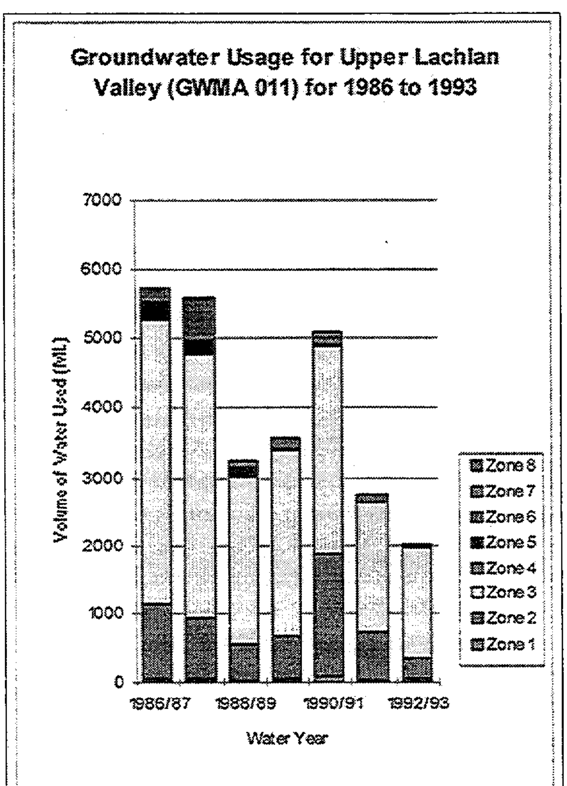

Figure 3: Water Usage in GWMA 011

The Department of Land and Water Conservation (formerly Department of Water Resources) monitors water levels at over 50 sites in the Upper Lachlan Valley, and at most sites there are multi-level piezometers tapping shallow, intermediate and deep aquifer zones. Between June 1986 and December 1993, water levels were steady or rose by up to 2 m over much of the area. A considerable rise in water levels is apparent over the entire management area during the high recharge events in (April) 1990. High water levels in zone 6 resulting in salinisation of arable land and saline discharge to local surface water bodies are priority issues which are currently being addressed by the Land and Water Management Plan.

5.0 ALLOCATION POLICY REVIEW PROCESS

In its role as the State's water manager, the DLWC is producing Strategic Water Resource Management Plans that focus on the most important water resource issues in each catchment. For the Lachlan Valley, groundwater management is a critical issue and has a high priority.

There are three main objectives of this policy review:

1. To review the volumes available for allocation in Groundwater Management Area (GWMA) 011.

2. To encourage groundwater use relative to the volume of water already allocated.

3. To ensure groundwater use is sustainable over the long term with regard to economic, environmental and social factors.

The allocation review process is initiated by the preparation of a Status Report, which outlines the hydrogeological framework in which the groundwater occurs, summarises the existing allocation policy, and the usage and water level changes which have occurred during the currency of the existing allocation policy. In addition, findings from other Departmental studies that impact on the use of groundwater in the Upper Lachlan Valley, such as salinity investigations, are also briefly discussed. A description of water level behaviour and usage in recent years has been given in the 1994 status report (Bish et al., 1994).

The second stage of the allocation policy review process was the distribution of a questionnaire to the community for comments. The questionnaire was designed to provide information on the importance of particular issues in regards to long term sustainability of the groundwater resource, to the community. Also the questionnaire provided an opportunity for the community to bring attention to their own concerns.

Groundwater management and the attitude of the community have changed since the original volumetric policy was introduced in 1983/84. The need to maintain the resource in the long term has been recognised and appropriate changes in the allocation policy for the Upper Lachlan are now required.

Following on from the status report and data obtained from the community questionnaire, was a discussion paper. The main objective of the Discussion Paper is to review the groundwater allocation guidelines for all users pumping groundwater from alluvial sediments in the Upper Lachlan Valley and present new strategies to regulate groundwater use and review allocations, particularly in areas of increasing development.

A number of general management principles are adopted by the Department in developing options to review the allocation policy. These principles include: the need for equity; approaches; and environmental protection. Three approaches can be used to determine groundwater allocations: safe yield;, sustainable yield; or controlled depletion.

For the Upper Lachlan Valley, the current entitlement volumes are 34893 ML/yr increasing to 69559 ML/yr in a worst drought season. If these entitlements were pumped each year, significant water level declines would occur locally even though the pumped volumes would be much less than the storage in the alluvium. In addition there would be large impacts on stream flow, wetlands and other users. The policy review will focus on the option of increasing entitlements to sustainable levels in each of the management zones.

Following, adoption of an appropriate option(s) presented in the discussion paper, is the development of the allocation policy. This policy incorporates all the elements necessary for implementation of the policy to sustain the groundwater resources in the Upper Lachlan Valley in the long term. Discussion is still continuing on the most acceptable option.

The policy may be expanded into a full aquifer management plan for the groundwater area depending on the assessed priority of the other groundwater issues.

6.0 CONCLUSIONS

At completion of this paper, the option to be included in the allocation policy for the Upper Lachlan Valley (GWMA 011) was still being discussed by the Department's Regional staff and the community advisory committee. The objectives of the policy have generally been agreed, however the most appropriate options to be implemented still require resolution.

In the meantime, the interim allocation policy which was introduced in 1986 (WRC, 1986) is still in force. It is envisaged that another review will be undertaken approximately 5 years from release of this revised allocation policy.

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Application of Hydrogeological Concepts to Control Watertable Problems in Developing Land and Water Management Plans in the Murray Region

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INTRODUCTION

Rising water levels, shallow watertable areas, waterlogging and soil salinisation have reduced the agricultural production in the Murray Region and degraded the environment causing serious concerns amongst the community. After the European settlement, much of the country which was a virgin forest was cleared for agricultural, industrial and commercial activities. With the introduction of irrigation in 1930s the water usage increased considerably which has accelerated the problems.

There are four Irrigation Districts (Berriquin, Denimein, Deniboota and Wakool) in the Murray Region covering an area of over 920,000 ha in southern New South Wales. The area is one of the major rice producing areas in Australia with other enterprises like cereals, dairy and wool.

The main irrigation water supply is the Mulwala Canal which off takes from the Murray River at Yarrawonga Weir near Mulwala. The irrigation system contains the main Mulwala Canal and the subsidiary channel system which is purely earthen structures and operates on a gravity feed basis. The main Mulwala Canal is capable of carrying 10,000 ML/day. Some areas receive water from adjoining rivers or creeks however they are outside the irrigation districts.

In 1994 116,000 ha of land had shallow watertables with risk of soil salinisation. It is estimated that the affected area will increase to 303,000 ha in 25 years (by 2020).

Community based Land and Water Management Plans (LWMP) are being developed to address these issues for the sustainable development of the districts. These plans consider five major options which are surface drainage, sub surface drainage, on farm management, infrastructure development and institutional arrangements for their developments. This paper discusses the sub surface drainage option study carried out for the Wakool Irrigation District in developing a LWMP.

PHYSIOGRAPHY, GEOLOGY AND HYDROGEOLOGY

Apart from the isolated hills at the eastern boundary, the study area is relatively a flat terrain with the gentle slope towards the West. The area is located north of the Murray River and a number of tributaries of the Murray River flowing in the area from east to west. The average annual rainfall is about 400 mm.

The study area is in the central part of the Murray Geological Basin which is a saucer shaped depression. The basin is filled by a sequence of sediments which started to fill in early Tertiary period, 60 Million years ago (Brown & Stephenson, 1991)). The maximum known thickness of these sediments is about 600m. Because of the closed nature of the Basin, there is no outlet to release the additional groundwater in the basin. Furthermore, there are physical barriers to deep groundwater flow in the form of a basement ridge west of Wakool and an impermeable clay barrier (Geera clay) further west. Figure 1 shows a slice through the Murray Basin to indicate major stratigraphic sequences. Consequently there are major groundwater discharges towards the surface. Some of these cause saline inflows to rivers and creeks. But in some areas the upward flow of groundwater from the deep aquifer system is dissipated into the shallow aquifer system, influencing water level and salinity of the shallow aquifer. In the Wakool District the groundwater discharge component is major though recharge also occurs in some parts of the area. However, at present the Murray Region overall has a net recharge.

There are 3 main hydrogeological units in the area as discussed below.

The Olney Formation (the upper part of the Renmark Group) overlies the basement rock of siltstone, shale, schists and granite at a depth from about 140 to 350 m and consists of sand and gravel layers interbedded with carbonaceous clay layers. The Formation constitutes important aquifers where low salinity (around 1000 ppm) groundwater is available. However, groundwater salinity in the west is higher (up to 23,400 mg/L) compared to the eastern areas of the basin.

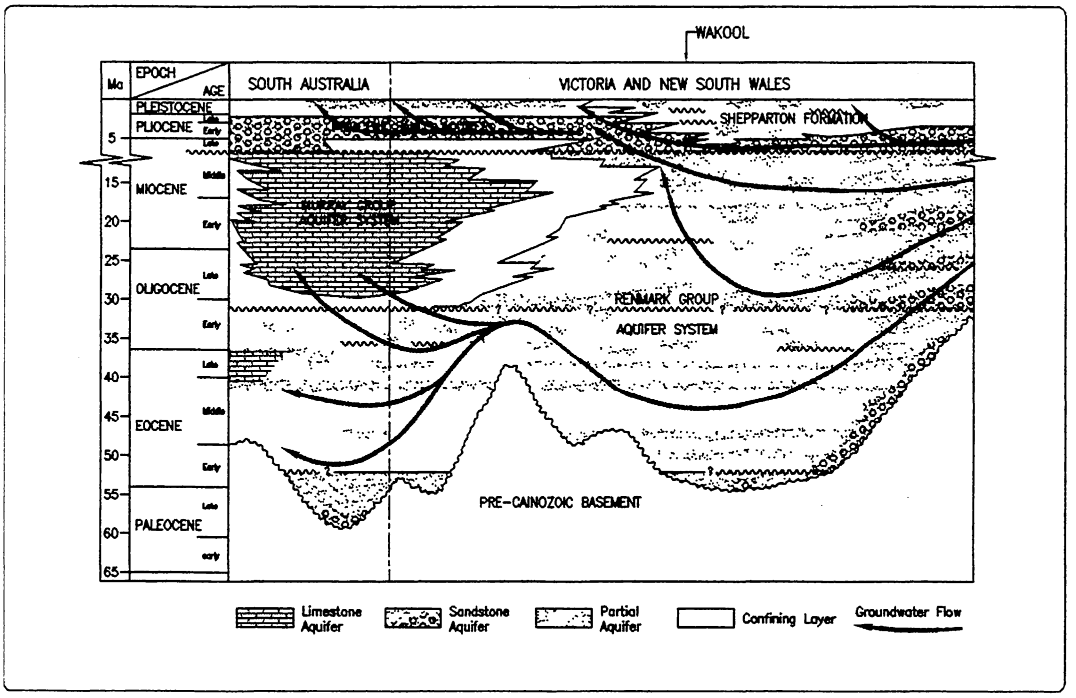

Figure 1 Geological cross section of the Murray Basin (Brown & Stephenson, 1991))

The Calivil Formation (also known as the Pliocene Sand) consists of sand and gravel, interbedded with kaolinitic clay. It unconformably overlies the Olney Formation from about 70 to 140 m. This formation is an important source of groundwater within the Murray Region. High yields of low saline water are possible. Groundwater salinity ranges from 900 ppm in the East to 3500 ppm in the West.

The Shepparton Formation represents the most recent (Pliocene to Recent) major phase of fluvial (river) sedimentation. The Shepparton Formation overlies the Calivil Formation and consists of clay and silty clays interbedded with sand layers. The base of the Shepparton Formation is up to 70 m deep.

Two types of abandoned stream/river channels have been identified in the Shepparton Formation. One type is known as **prior streams** which are remnants of older channels, abandoned at some considerable time in the past (Pels, 1964). The other type is **ancestral rivers** or recently abandoned rivers/streams. The distribution of prior streams and ancestral rivers (Butler et al, 1973) shows that they are in the direction of south-east to north-west.

Water bearing layers within the Shepparton Formation vary in thickness from very thin to 6 m and in width from a few metres up to 400 m. Transmissivities of aquifers in prior stream deposits range from 250 to 900 m^2/d, averaging 500 m^2/d. Groundwater salinities are higher than that of deep aquifers and range up to 51,000 ppm. Prior stream aquifers can be used to pump groundwater to control watertables. Public pump sites and private spearpoints in the area are located either on the main prior streams or on shoestring aquifers partially or directly connected to the main prior stream. Due to their shoestring nature, the aquifers are highly variable in space (thickness and depth) and soils are not homogenous in texture. Therefore, the occurrence of aquifers and their hydrogeological characteristics are quite complex.

In 1980, 45,200 ha of land within the Murray Region had shallow watertables. This had increased to 91,300 ha in 1990. In July 1994, 116,000 ha were affected. If nothing is done to control the situation it is estimated that 33% of the total area of the districts would have shallow watertables by the year 2020. Figure 2 shows the shallow watertable situation in the Murray Region. A primary objective of the LWMP is to formulate a strategy to manage watertable and associated problems.

Groundwater pumping can lower the watertable in areas where aquifer potential exists. Sub-surface drainage has been recognised by Land and Water Management Plan Committees being fundamental to the success of controlling existing watertable problems.

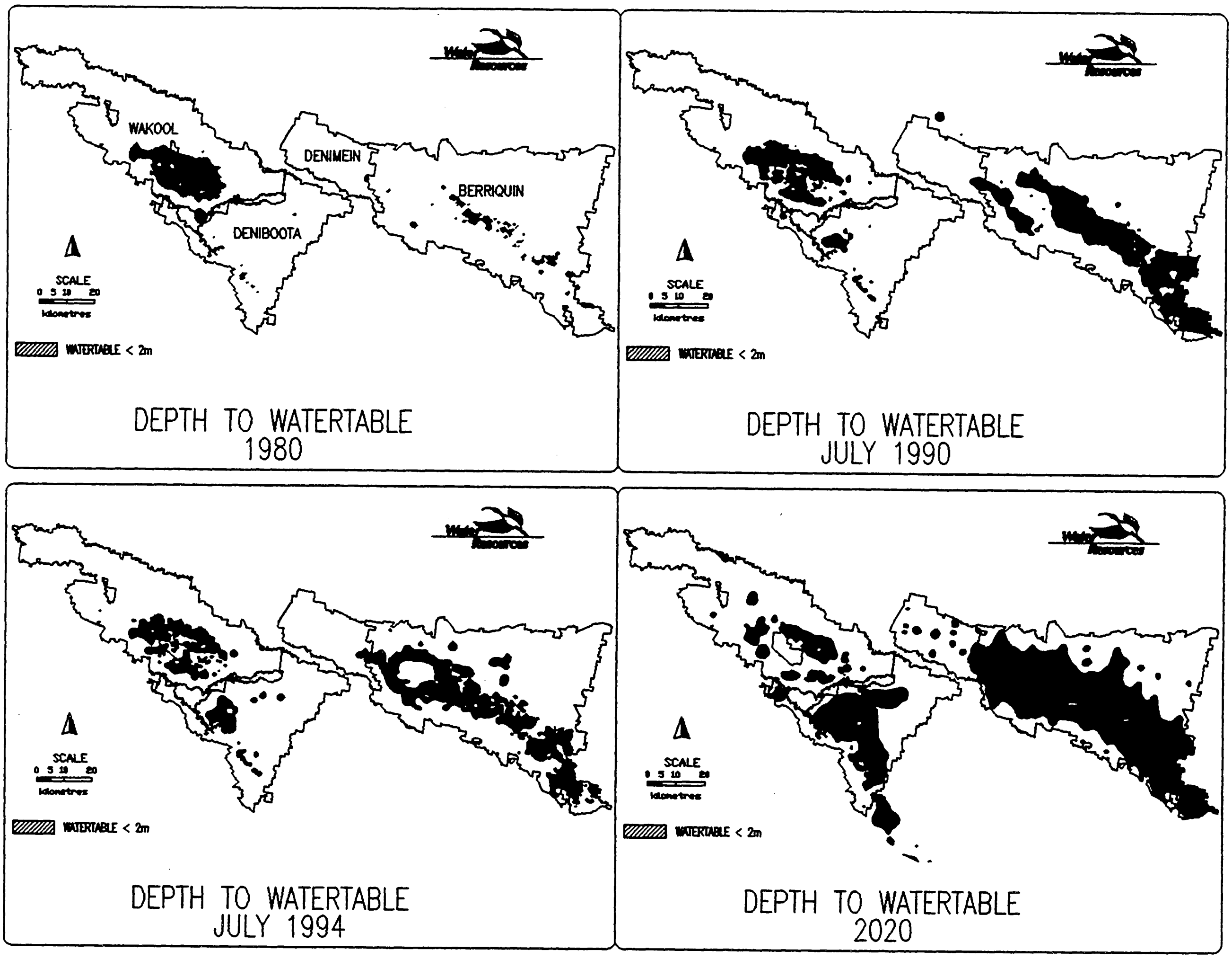

Figure 2 Shallow Watertable area (<2m area) of the Murray Region

Groundwater system in each district receives more water every year. It is estimated that approximately 273,000 ML is adding to the groundwater system annually within the four irrigation districts which needs to be handled for controlling watertable problems. This indicates that the groundwater system is in 'imbalance'. Table 1 shows the estimated groundwater accessions in each district. It is estimated that the Berriquin Irrigation District alone receives nearly 135,000 ML/yr. The Denimein Irrigation District (the smallest) receives only 18,000 ML/yr. The net groundwater accession depends on the activities carried out in each district, natural hydrogeological and environmental conditions and the size of the area.

SUB SURFACE DRAINAGE IN WAKOOL LWMP

The following paragraphs describe the results of sub surface drainage study carried out in developing LWMP for Wakool as an example to show how groundwater pumping can be included in the Plan.

Table 1 Estimated annual groundwater accessions

District	Berriquin	Denimein	Wakool	Cadell (including Deniboota)	Total
Size (ha)	320,000	59,000	220,000	322,000	921,000
Groundwater accession (ML/yr)	135,000	18,000	50,000	70,000	273,000

The LWMP area covers nearly 220,000 ha including the Wakool Irrigation District, Tullakool Irrigation Area and river pumpers of Wakool, Edward and Niemur Rivers. In Wakool, water levels were rising at an average rate of 70 mm/yr with alarming rates up to 400 mm/yr in some areas. The Wakool Tullakool Sub Surface Drainage Scheme (WTSSDS) which commenced operation from 1980 consists of 60 pump sites. It has been successful in controlling water levels over 20,000 ha directly and over 40,000 ha indirectly. However, problems are developing in other areas. It is predicted that over 26,000 ha of land will be affected (excluding the Scheme area) by the year 2020. Natural hydrogeological conditions, intense irrigation, lack of proper land and water management practices have contributed to these problems.

The increased infiltration to the watertable causes the rapid rise of water levels. It is estimated that nearly 50,000 ML of water is being added to the area annually. Of that, the WTSSDS pumps nearly 12,500 ML into two evaporation basins. The remaining 37,500 ML has to be dealt with to control current watertable problems.

It is more cost effective retarding watertable accessions than by pumping groundwater once it has reached the watertable. However, once shallow watertables occur, some pumping must take place if long term agricultural sustainability is to be achieved. Groundwater pumping is economical when the groundwater is of good quality, and can be used for irrigation.

Sub surface drainage potential was estimated in terms of transmissivity (T). When the transmissivity is higher than 200m^2/d the area was considered having moderate potential and when T is 100-200m^2/d, the area was considered having low potential. Geophysical surveys (EM-34) were carried out in selected areas and 30 sites were selected for test drilling. Results indicated that a series of prior streams (main or shoe-string branches) traverses through the area showing good aquifer characteristics for pumping.

Sub surface drainage for watertable control is feasible in 18,150 ha of the area affected by watertables shallower than 2m. It is also possible in 32,100 ha of the area affected by 2-3m watertables. However, 18,700 ha (watertables up to 3 m) showed no sub surface drainage potential. Of that, an area of 9600 ha needs immediate watertable control (watertable within 2m) which has to be addressed by other options.

It is proposed to provide incentives if groundwater is pumped for reuse (on farm) and controlling watertable problems. On farm disposal of saline groundwater is preferred and off property disposal is discouraged.

Sub surface drainage study developed six sub surface drainage management zones combining shallow watertable areas and aquifer transmissivity. A total of 157 pumpsites were proposed within four sub surface management zones to control current shallow watertables in the Wakool LWMP area. Those pump sites are expected to pump nearly 15,000 ML/yr having 0.3 million tones of salt to control watertables up to 2m and 39,000 ML/yr of water having 0.9 million tonnes of salt to control watertables up to 3m. Two zones were identified as no potential for groundwater pumping. Airlift pumping (for low yielding aquifers) is suggested in low aquifer potential areas. Table 2 shows the division of sub surface drainage management zones.

Table 2 Sub Surface Drainage Management Zones

SSD Mgt Zone	Area (ha)	Depth to watertable (m)	Aquifer Transmissivity T(m2/d)	Aquifer potential for groundwater pumping	Comments
A	7700	0-2m	T>200	Yes	Groundwater pumping technically feasible
B	10450	0-2m	200>T>100	Yes	"
C	15450	2-3m	T>200	Yes	"
D	16650	2-3m	200>T>100	Yes	"
E	9600	0-2m	T<100	No	Groundwater pumping technically not feasible
F	9100	2-3m	T<100	No	"

Table 3 Distribution of Pump Sites in Each Sub Surface Drainage Management Zone

SSD MGT ZONE		Re Use	Surface Drainage	Directly to WTSSDS Evap. Basins	Connect to WTSSDS Pipe Line		On farm Evap. Ponds	Total
					Stage I	Stage II		
A	*No. of Pump Sites*	*1*	*1*	*4*	*3*	*3*	*17*	*29*
	Volume of Water (ML/yr)	250	250	1000	750	750	4250	7250
	Salt Load (t/yr)	75	868	28172	12243	15435	87737	144529
B	*No. of Pump Sites*	*1*	*2*	*10*	*1*	*1*	*20*	*35*
	Volume of Water (ML/yr)	250	500	2500	250	250	5000	8750
	Salt Load (t/yr)	180	2113	72677	5994	7792	129737	218493
C	*No. of Pump Sites*	*0*	*2*	*4*	*2*	*3*	*26*	*37*
	Volume of Water (ML/yr)	0	500	1000	500	750	6500	9250
	Salt Load (t/yr)	0	1911	28322	10490	13187	175961	229870
D	*No. of Pump Sites*	*1*	*4*	*4*	*1*	*2*	*44*	*56*
	Volume of Water (ML/yr)	250	1000	1000	250	500	11000	14000
	Salt Load (t/yr)	180	4986	31319	5470	14535	300902	357391
	Total Pump Sites	***3***	***9***	***22***	***7***	***9***	***107***	***157***
	Total Volume (ML/yr)	**750**	**2250**	**5500**	**1750**	**2250**	**26750**	**39250**
	Total Salt Load (t/yr)	**435**	**9877**	**160489**	**34196**	**50949**	**694337**	**950283**

The study reported various methods for disposal/management of salty groundwater. Groundwater in Wakool is highly saline. Only one site would have low salinity groundwater that should be directly reused on farm. Two sites would expect marginally high saline groundwater which can be disposed into irrigation channels. Disposing into public drains would be expensive, though 9 sites have been nominated. However this has to be further investigated. A previous study showed that the pipeline to the sea is not economically viable. There are 38 sites proposed to connect to the existing WTSSDS. The most appropriate method for the other 107 sites would be to install small scale on farm evaporation ponds. These ponds should be smaller, with an average size within 10-20 ha of the serviced area. Table 3 shows the distribution of proposed pump sites in each management zone.

It is estimated that the proposed sub surface drainage programme would cost nearly 8.7 million dollars (1994 values). This includes investigation, construction and installation of 157 pump sites having 30 conventional and 127 airlift pumps. It is anticipated that the project would expand over 14 years and construction of 107 evaporation ponds would cost around $34.8 million.

Deep drainage is one of the options to consider with the sub surface drainage option in controlling shallow watertable problems. The deep drainage involves pumping deep groundwater (especially from the Calivil Formation) to drain water in the shallow aquifers (especially in the upper Shepparton Formation). This option depends mainly on the interaction between the two aquifer systems, or the permeability of intervening clay layers and the hydraulic pressure difference between two aquifers. This aspect has to be further investigated.

The assessment of each option is being continued. That includes the economic viability of the sub surface drainage programme and the management of effluent under each management zone.

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Effluent Irrigation: Implications for Groundwater

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Introduction

In recent years, eutrophication of river systems has caused frequent and large blooms of toxic blue-green algae in many parts of Australia, particularly in the Murray Darling Basin. A major cause of this eutrophication has been the discharge of nutrients into rivers, much of which comes from sewage effluent (GH&D, 1991). Increasingly, public opinion and environmental regulations require the development of methods other than river discharge to deal with sewage effluent. The use of treated, or partially treated, sewage effluent for irrigating productive agricultural or forest crops is a major alternative to disposal. Irrigation of tree plantations has become one of the most popular of the irrigation options. Stewart & Boardman (1991) reported more than 50 operational or research plantations, occupying nearly 500 ha. Since then, this area has more than trebled.

While removing nutrients from the river, other environmental problems may be caused if effluent irrigation is not carefully managed. These include increased recharge to the groundwater accompanied by salts and nitrate, accumulation of salt and other chemicals (such as sodium and phosphorus) in the soil, and the associated increased risk of runoff of these contaminants into waterways. Depending on the source of the effluent, other contaminants such as heavy metals and toxic organic chemicals may also accumulate in the soil or be leached to the groundwater. These are usually not a concern with sewage effluent, however, which is the topic of this paper.

This paper outlines the potential impacts on groundwater of irrigation with sewage effluent. It then describes a research project, currently underway near Wagga Wagga, in which groundwater impact and its sources are being quantified in a carefully managed effluent-irrigated plantation trial.

Potential Impact on Groundwater

Increased recharge to groundwater is an inevitable consequence of irrigation. Even if the irrigation supply is matched to crop or tree water demand, continuously wet soil greatly increases the likelihood of rainfall-induced recharge. Furthermore, some deep drainage of water past the root zone is essential to prevent the accumulation of salts. However, poor irrigation management, leading to application of water in excess of demand, may cause large increases in recharge rates.

Perhaps of greater concern is the chemical composition of the deep drainage water when it leaves the root zone. The two most likely contaminants arising from irrigation with sewage effluent in inland Australia are salt and nitrate. Water supplies in inland Australia normally contain a relatively high salinity (by drinking water standards) and sewage treatment concentrates the salt, particularly when water is kept in storage ponds during a dry summer. Typically, the electrical conductivity (EC) of sewage effluent is in excess of 0.5 dS m^{-1}. Further concentration, by evapotranspiration, after irrigation of effluent will result in a much higher salinity in the groundwater recharge. The total amount of salt that must be leached from the profile to prevent soil salinisation depends on the application rate of effluent. The concentration of salt in the recharge water also depends on the relative amounts of rainfall and irrigation applied and on the leaching fraction, that is the fraction of the total water loading that drains to the groundwater.

Estimating the likely amount and concentration of nitrate in the recharge to groundwater is even more complicated. As well as depending on the hydraulic loading and the leaching fraction, the amount and concentration of nitrate is determined by a complex series of nitrogen (N) cycling processes. Although the form of nitrogen in sewage effluent is often dominated by ammonium, this is rapidly converted to nitrate in the soil environment. As well as being applied in the effluent, nitrogen is generated in the soil by the mineralisation of soil organic matter, a process that is enhanced by irrigation.

A number of processes then operate to remove nitrogen from soil solution and to avoid potential loss by leaching. The extent of ammonia volatilisation, during and immediately after irrigation, depends principally on the pH of the soil and effluent and the weather conditions at the time. Denitrification, a microbially-induced process whereby nitrate is converted to N_2, is dependent on temperature, soil water content, and the supply of organic substrate for the microorganisms. Storage of nitrogen in plants, their residues, and soil organic matter can also limit the amount of nitrate available for leaching.

Managing the processes mentioned above so that there is no nitrate leached beyond the root zone is a difficult, if not impossible, task. It is further complicated by the fact that the concentration of N in the effluent is likely to be sufficiently high that, when multiplied by the optimum irrigation rate, it provides an amount of N in excess of plant demand. This is exacerbated because the N demand by plants is not constant. For a crop or pasture N demand cycles annually between a minimum and maximum uptake related to plant growth, while for trees the demand increases over a period of two to four years and then decreases unless foliage and litter are removed. In summary, nitrate leaching to groundwater can be minimised by careful management, but not necessarily eliminated.

Mitigation of actual impact

While leaching of salt and nitrate has the potential to affect the quality of groundwater, the actual impact will depend on a range of other factors. These include the depth of the water table and quality of groundwater prior to irrigation, aquifer permeability and hydraulic gradient, extent of the irrigation area, proximity to discharge zones, and proximity to water supply wells. These factors determine the likelihood of a groundwater mound developing, the amount of dilution of the inflowing contaminated water, and the likelihood of contaminated water finding its way into rivers and/or drinking water supplies.

The Wagga Effluent Plantation Project

In 1991, CSIRO established a project to assess many aspects of effluent-irrigated plantations, including rates of tree growth and quality of timber produced, as well as issues of sustainability such as changes in soil properties (salinity, sodicity, acidity, phosphorous accumulation), N budgets, and impact on groundwater (Myers et al., 1992; Polglase et al., 1994). The key aim of the project is the development of guidelines for the design and management of such plantations.

Trial design and management

The experimental site was established in August-September 1991 adjacent to the sewage treatment works at Forest Hill, about 10 km east of Wagga Wagga. Mean annual rainfall in the region is 570 mm and is slightly winter dominant while mean annual pan evaporation is 1860 mm. Monthly net evaporation (pan evaporation minus rainfall) ranges from zero in the winter months (May to August) to > 250 mm in December and January. Before establishment, the site was under improved pasture. It is gently sloping (5%) to the east and the soils are a mixture of Red Chromosols and Red Kandosols (Isbell, 1993) [Red podzolics and Red earths]. Typically a sandy loam or sandy clay loam A horizon (~ 0.4 m thick) overlies a sandy to medium clay B horizon. The soils are highly permeable, with a mean saturated hydraulic conductivity of 850 mm day^{-1} in the A horizon decreasing to 35 mm day^{-1} at 0.8 - 1.2 m.

There are four different trials at the site: (i) a rates trial (1.4 ha; effluent applied at different hydraulic loading rates) using *Pinus radiata* (radiata pine), (ii) a rates trial (also 1.4 ha) using *Eucalyptus grandis* (flooded gum), (iii) a clone trial (1.1 ha) of radiata pine, and (iv) a species trial (0.6 ha). Most of the results presented here come from the rates trials, but the groundwater is potentially affected by them all. Each rates trial was configured in a semi-randomised block design of 4 treatments x 2 replicates (Fig. 1).

The key (medium, M) treatment in each rates trial is irrigated with effluent at the estimated water-use rate of the plantation less rainfall. The high (H) treatment receives nominally twice as much effluent as M, while the low (L) receives half as much as the M. The fourth treatment (W) is bore water irrigation, also at the water-use rate of the plantation less rainfall. Plantation water use for the purpose of scheduling irrigation is estimated using a water balance approach every two weeks. It is based on measured rainfall, estimated canopy interception, calculated irrigation applied and

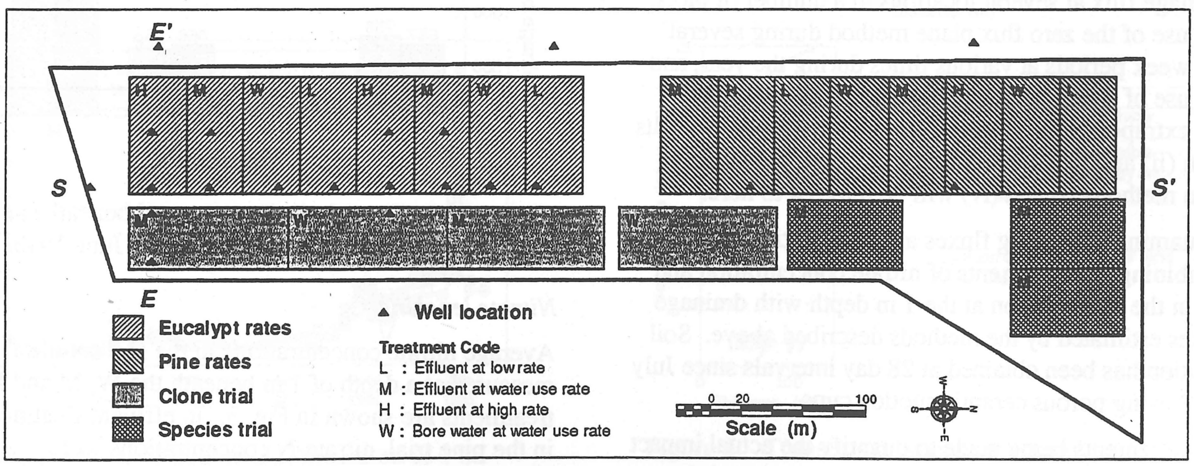

Figure 1: Site layout showing locations of monitoring wells and transects in Fig. 5.

changes in soil water storage calculated from neutron probe measurements. All treatments were irrigated weekly until summer 1994/95 when irrigation was applied twice each week.

Average salinity and nitrogen concentrations of the effluent and bore water are presented in Table 1, and cumulative hydraulic, salt and nitrogen loads for selected treatments in Table 2.

Table 1. Average chemical characteristics of the effluent and borewater.

Parameter	Effluent		Bore water	
	91-93	93-95	91-93	93-95
EC (dS m^{-1})	0.54	0.97	0.74	0.76
Total N (mg L^{-1})	8.2	13.3	-	-

Table 2. Total loadings for the medium treatments. (Estimates for 1993-1995 subject to final analyses)

	Pines		Eucalypts	
Parameter	91-93	93-95	91-93	93-95
Rainfall (mm)	1357	1288	1357	1288
Irrigation (mm)	1142	2058	1385	2214
Salt (t ha^{-1})	4.4	14.4	6.1	15.1
Nitrogen (kg ha^{-1})	116	302	160	317

Measurements relevant to groundwater impact

Measurements are being made to quantify the processes that may have a direct impact on groundwater, namely deep drainage and leaching of nitrate and salt below the root zone. Measurements of root density have shown that 95% of root mass is above 0.6 m, and we have defined 1 m as being below the root zone.

Deep drainage is a difficult process to quantify and because of its importance a number of complementary measurement techniques are being applied. These include: (i) the chloride mass balance method to obtain cumulative drainage between intensive soil samplings at two year intervals, (ii) measurement of hydraulic gradients at 1 m every two weeks and combining them with estimated hydraulic conductivities to calculate drainage flux at several locations in a number of plots, (iii) use of the zero flux plane method during several one week periods at various times during the year, and (iv) use of a carefully validated model to interpolate and extrapolate the results from other methods. Results from (ii) and (iii) are still being collated; only results from methods (i) and (iv) will be referred to here.

Contaminant leaching fluxes are being estimated by combining measurements of nitrate concentration and EC in the soil solution at the 1 m depth with drainage fluxes estimated by the methods described above. Soil solution has been obtained at 28 day intervals since July 1992 using porous ceramic suction cups.

Measurements being made to quantify the actual impact on groundwater are depth to the water table, and the nitrate and salt concentration of the shallow groundwater. A network of 22 water table monitoring wells was established between November 1993 and February 1994 at locations chosen to best delineate the water table. Each well was cased with 50 mm PVC pipe slotted over the bottom 2 to 4 m, packed with 6 mm gravel and sealed with concrete. The wells vary between 4 and 18 m in depth, but most are in the range 10 to 13 m. All are monitored routinely using a manual depth gauge, and wells at key locations have been fitted with data loggers.

Samples are collected at approximately 3 month intervals from those wells with sufficient water to obtain a reliable sample. Before collection a volume of water equal to between 2 and 2.5 times the volume of water in the well and gravel pack is pumped out. A range of chemical analyses, including nitrogen concentration and EC, are performed on these samples following filtering.

Preliminary Results

Deep drainage

Results from the chloride mass balance method summarise cumulative drainage for the first two years of the trial (June 1991 to June 1993, Fig. 2). As expected, there was a strong relationship between drainage and irrigation treatment. Drainage was similar for the W and M treatments for both tree species, and corresponded to approximately 25% of the combined rainfall and irrigation for that period. Drainage from the L treatments was less than 5% of the hydraulic load. Modelling suggests that in the absence of irrigation and trees drainage would be similar to that measured in the L treatment. In the H treatments, which for this period received ~ 60% more irrigation than the M treatments, drainage increased by 140% to 220%. Thus irrigation in excess of the water-use rate resulted in a disproportionate increase in drainage.

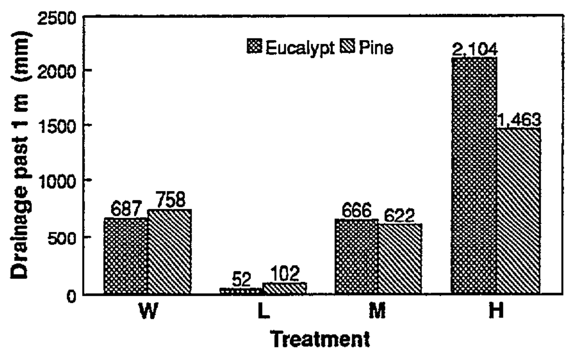

Figure 2: Deep drainage measured beneath each treatment between June 1991 and June 1993.

Nitrate leaching

Average nitrate concentrations in the soil solution measured at a depth of 1 m beneath the W, M and H treatments are shown in Fig. 3. In effluent treatments in the pine trial, nitrate-N concentrations were generally less than 5 mg L^{-1} until early in the 1994/95 irrigation season. After this time, concentrations

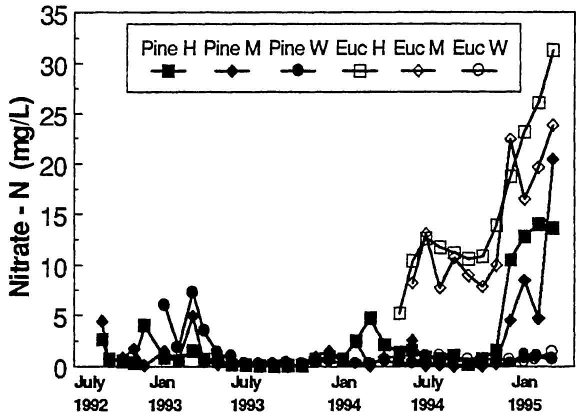

Figure 3: Soil solution nitrate concentrations measured at 1 m.

exceeded 10 mg L^{-1}. In the eucalypt trial, measurements did not commence until April 1994, at which time concentrations were just below 10 mg L^{-1}, but they increased to about 30 mg L^{-1} by March 1995.

These nitrate concentrations were coupled with deep drainage fluxes (predicted by numerical simulation) to estimate amounts of nitrate-N leaving the root zone. Although approximate at this stage, the modelled deep drainage is adequate to indicate the magnitude of nitrate leaching. Results for the pines where measurements are most complete, suggest that 20 kg ha^{-1} of nitrate-N was lost from the M treatment and 75 kg ha^{-1} from the H treatment between July 1992 and February 1995. This represents 8% (M) and 16% (H) of the N applied over this period.

Salt leaching

Average EC measured in the soil solution (Fig. 4) remained steady at between 0.5 to 1 dS m^{-1} in all treatments of both species until early 1994. Large increases after that time correspond with decreased leaching through the dry year of 1994. The decrease observed after January 1995 corresponds to extra leaching applied to the plots to avoid salt stress in the trees. Cumulative salt fluxes below the root zone, calculated in the same way as nitrate fluxes, were 8.3 t ha^{-1} for pine M and 17.2 t ha^{-1} for pine H treatments

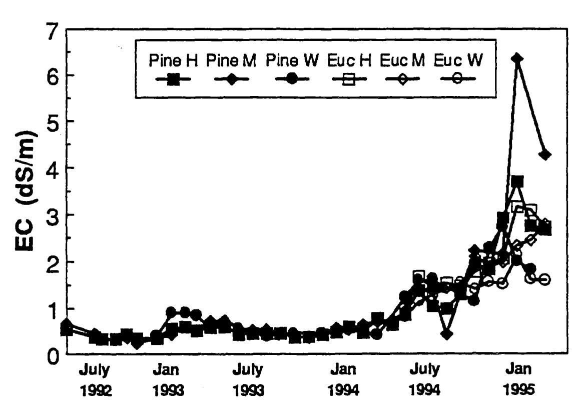

Figure 4: Soil solution EC measured at 1 m.

(80% and 90%, respectively, of salt applied in the corresponding period).

Water table height

Although the first water table monitoring wells were not installed until November 1993, there is good evidence that the water table was deeper than 12 m below the soil surface prior to establishment of the plantation. When installation of water table monitoring wells was completed in February 1994, a water table mound was found beneath the lower end of the eucalypt rates trial (Fig. 5). This mound was highest beneath the H treatments, and deepest (>10 m below ground surface) in the northern-most eucalypt plot. The shallowest depth recorded was 1.3 m below the surface in March 1994. Although there have been fluctuations, the water table height has declined since this time, partly because of the dry season, and partly because the magnitude of the H treatment was reduced. Beneath the pines, the water table has remained at 12 to 13 m below the surface since observations began.

The height of the water table in all wells has been observed to respond both to heavy irrigations and to large rainfall events. The reason for the higher water table beneath the eucalypts compared with the pines is unclear. It may be related to the greater drainage indicated in Fig. 2, or be a result of different soil and aquifer properties. There is a semi-permeable clay layer beneath the site that is shallower under the eucalypts. Furthermore the strata beneath the B horizon have finer texture and lower water storage capacity under the eucalypts than the pines.

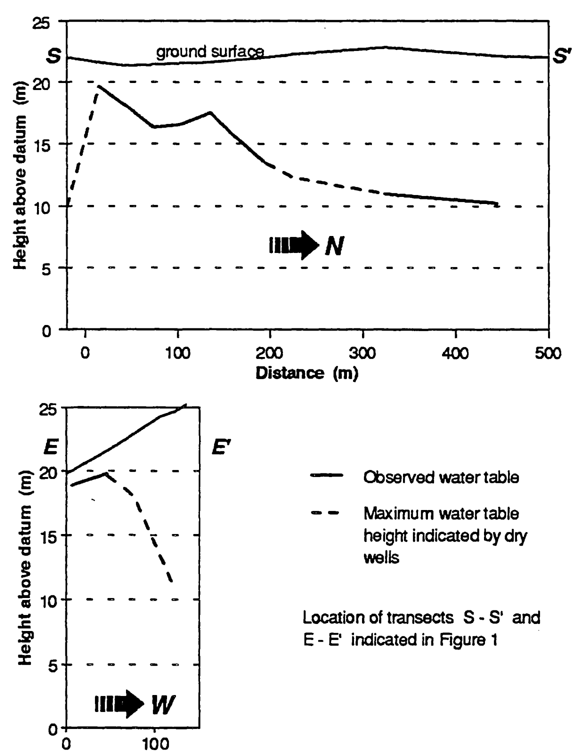

Figure 5: Transects of water table height above an arbitrary datum on 30 March 1994.

Groundwater quality

Nitrate-N concentrations under the eucalypt treatments (Fig. 6) increased steadily during the first 12 months of sampling. Increases were greater for higher irrigation rates. Comparison with Fig. 3 suggests that there is perhaps about a 12-month lag between the increase in nitrate-N in the soil solution at 1 m and the that in the groundwater. To date the concentration has been below the recommended drinking water limit of 10 mg L^{-1}.

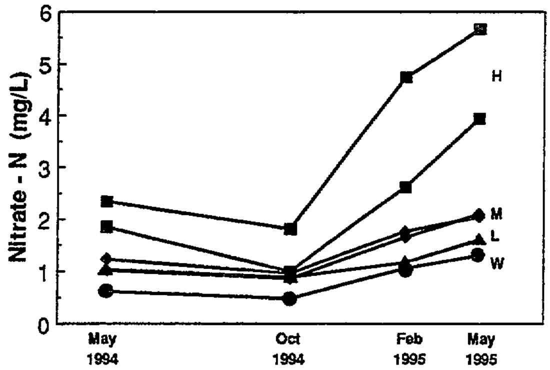

Figure 6: Nitrate-N concentrations in groundwater beneath the eucalypt plots.

No increase has yet been observed in groundwater salinity. In the period between October 1994 and May 1995 EC was roughly constant at about 1 dS m^{-1} with only a small treatment effect. This is similar to the soil solution EC up to May 1994 (Fig. 4). If there is a 12 month lag between the soil solution at 1 m and the groundwater, as suggested above, then from Fig. 4 the groundwater EC would be expected to increase soon.

Conclusions

There have been large amounts of drainage under the M treatments in which the amount of irrigation was matched as closely as possible to the water use of the plantations. This is inevitable under irrigation because the soil profile is kept wetter than normal so that it has less capacity for storing water in the root zone when there is rain. The treatments to which 60% more irrigation was applied resulted in 140% to 220% more drainage than the M treatments. Drainage led to an elevated water table, particularly under the eucalypts.

To date, cumulative leaching of nitrate-N in the pine M treatments has been small compared with total additions of N in the effluent, unlike the case for salt. This resulted, in part, from low concentrations of nitrate-N during periods of high drainage, and only small drainage when concentrations were high (summer 1995). Although concentrations in excess of the recommended limit of 10 mg L^{-1} nitrate-N have been observed below the root zone in most plots, this has not yet been reflected in the groundwater. In the H treatments, significant drainage coupled with high concentrations of nitrate-N during the latter part of the study increased nitrate-N in groundwater. Although this is an extreme treatment, it indicates the risks associated with irrigation in excess of the water-use rate. It is not yet clear whether the smaller increase in nitrate-N in groundwater under the M treatments may have included a contribution from groundwater under the adjacent H treatments.

While substantial amounts of salt have been applied to the site and leached, the salinity of the groundwater is as yet unaffected. However, the EC of soil solution at 1 m has increased considerably in the last year and this is expected to be reflected in the groundwater within the next 6 months.

Acknowledgments

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A New Approach to Modelling Recharge and Determining Salt Distribution in Catchments from Stream Data Analysis

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Introduction

There are numerous approaches to calculate the water and salt balance of a catchment. Many of them, however, rely on gross estimates from monthly or annual data. More recently physically based hydrological modelling have provided a way to simulate hydrologic data and solve the equations for surface and subsurface flow over a dense numerical grid system, allowing catchments to be modelled more accurately than traditional lumped parameter models. They can also provide water balance calculations at small time steps (eg. daily time steps).

These models, however, may not truly reflect aspects of the water balance that are difficult to measure or define, such as the recharge component or source of salt in the discharging stream. While scientists have a firm understanding of how recharge takes place and can describe the process adequately, the methods to determine the rate and quantity of recharge from a given rain event still elude the scientific community. Also, knowledge of the spatial and temporal distribution of salt in a catchment that finds its way via flow paths to the stream is unclear. These two aspects of catchment hydrological processes are important information for land managers who need to know the effects of specific land management practices on recharge areas to the whole catchment. It may also be important for the land manager to know how to reduce salt export from the catchment, ie. what the off-site impacts are, because of pressures from local Total Catchment Management or Landcare Groups.

This paper and presentation is a preliminary examination of new ways of characterising and quantifying recharge as well as showing a way of using stream water chemistry data to determine the spatial and temporal distribution of salts within a catchment affected by dryland salinity. It also discusses a potentially new conceptual framework developed from this data for modelling water and salt distribution in a catchment.

Study location, field monitoring and methods

Hydrogeological investigations in a 72ha headwater section of Williams Creek, near Yass, were undertaken as a pilot study to examine groundwater recharge and discharge characteristics and to identify hydrologic and salt flow paths that eventually discharge into the stream and progress out of the catchment.

A useful means of examining groundwater flow paths and recharge-discharge characteristics within a catchment was found to be in setting up a series of nested piezometers in transects perpendicular to drainage in the catchment. The transects consisted of two nests on each side of the stream channel, one on the upper slope and the other downslope near the stream.

Skill and experience is required to adequately set up a monitoring and sampling network to adequately analyse the hydrological components of a catchment. Initially, it is important to know what kind of information is required to be collected for a catchment affected by dryland salinity that will guide land management decisions. The decisions that will need to be made about specific land management practices will relate to on-site hydrological characteristics and off-site impacts associated with management of the land.

The hydrological components of the catchment, ie. groundwater, rainwater, soil moisture, and streamwater were monitored and samples from these components were collected and analysed for deuterium and major ion chemistry. These data were used to determine end members that could reflect the analysed stream chemistry. The idea is that the stream chemistry is a mix between end members from the various parts of the hydrological cycle, the proportions depending on the season and antecedent moisture conditions in the catchment.

Recharge analysis and results

Periodic sampling and analysis of deuterium in groundwaters from the nested piezometers showed that some piezometers are affected by specific rain events and others are not. When correlated with water levels in each nest, it was found that those sites that have an upward vertical hydraulic gradient do not have any significant change in deuterium signature, and are therefore considered groundwater discharge areas. Where the hydraulic gradient is downward, a recharge potential from specific rain events is possible. This was confirmed by the deuterium signature in the shallow nested piezometers with a downward vertical hydraulic gradient (Piezometer 1-a in Table 1.). The deuterium signature in the groundwater can be interpreted as a linear mix between rain event water and pre-rain event water. The amount of rain that recharges the groundwater system can be considered a proportion (Q_{RAIN}/Q_{RES}) governed by the equation:

$$\frac{Q_{RAIN}}{Q_{RES}} = \left(\frac{C_{RES} - C_{GW}}{C_{RAIN} - C_{GW}}\right) \quad \text{....................(1)}$$

where C_{RES} is the isotopic concentration in the groundwater reservoir after a rain event, C_{RAIN} is the isotopic concentration in the rain event, and C_{GW} is the isotopic concentration in the groundwater reservoir prior to the rain event.

Results from this study have shown that there is potential for applying this technique to assess:

1) which sites are recharging the groundwater system or not and to identify specific rain events that have recharged the groundwater system.

2) the degree of recharge or proportion of mix between pre-rain event water in the groundwater system and water from a particular rain event

3) the threshold rain amount required in a given season, or with varying degrees of antecedent soil moisture, to recharge the groundwater system

An example of interpreting the data from Table 1 can be seen by examining the data from piezometer 1-a between the 15/10/91 and 8/11/91. The initial groundwater deuterium content sampled on the 15/10/91 was -26.1$^{o}/_{oo}$. The next time the piezometer was sampled on the 8/11/91 the groundwater deuterium content had enriched to -16.6 $^{o}/_{oo}$. Only five rain events had taken place within this period of time. The first two were insignificant with only 1.3mm and 1mm of rainfall respectively. These events would not have had any effect on recharging the groundwater system and were insignificant in increasing the soil moisture as observed by evaporation rates and tensiometer measurements at this time. The following three rain events were significant for wetting the soil profile and recharging the shallow groundwater. No effect on these events was observed on the intermediate zone. All three rain events were enriched in deuterium relative to the initial groundwater deuterium content. It is probable that the most significant event of the three in recharging the groundwater was the last since it had the most rainfall (20mm). Nevertheless, assuming that all three events recharged the groundwater, a weighted mean average deuterium content was calculated from these. This value was found to be -0.58 $^{o}/_{oo}$. If the resultant deuterium content in the shallow groundwater was found to be -16.6$^{o}/_{oo}$, and started at -26.1 $^{o}/_{oo}$, the percentage recharge from these rain events using equation (1) is approximately 37%. That is, the shallow groundwater was mixed with 37% of rain water that has fallen from the three events occurring on the 30/10/91, 2/11/91, and 3/11/91 with a high probability that most of this mix resulted from the last rain event. The rest of the data can be analysed in the same way.

On further examination of water level data (Table 2) and correlating this with the changing deuterium signature in the shallow groundwater, just below the water table (piezometer 1-a), revealed that although specific rain water was recharging the groundwater system, water levels were in fact decreasing. This lead to the idea that recharge needs to be defined in a new way to describe realistically what hydrological processes are occuring in the system. Without the deuterium analysis it would not be known that rain water from specific events was reaching the groundwater system, and without water level data the deuterium data would be interpreted as providing evidence that the groundwater system was being recharged, ie. water is being added to the groundwater storage. Although water is being added, more is being discharged, resulting in no real recharge to the groundwater reservoir. There are of course times when rain events produce a nett inrease in groundwater storage, and a rise in the water table is observed. In these circumstances, this is considered to be true recharge to the groundwater reservoir.

In essence, the combined data has shown the need to use the term "effective recharge". This can be defined as the nett increase (or decrease) of a groundwater system as a result of one or more rain events. Effective recharge can be described as the difference between the rain amount reaching the water table and the sum of rain that does not reach the water table plus groundwater discharge. The key term in this definition is groundwater discharge from the system. If the groundwater discharge is greater than the amount of rain water reaching the water table, the nett storage of groundwater is negative.

The model that emerges from this data is that the groundwater system is continually cycled by pulses of rainfall input to a mixing groundwater reservoir. As the water moves through the system, baseflow increases until the groundwater discharge becomes greater than recharge, resulting in a lowering of groundwater levels. The stream baseflow proportion begins to decrease as the hydraulic gradient decreases. The discharge area contracts, providing a greater potential for recharge, and the cycle continues.

The development of new concepts

This has lead to the need to define flow systems in a wholistic approach, that incorporates the specific recharge and discharge unit within a catchment. With the advance of physically based hydrological models, these can be modelled as stream tubes, that are self contained hydrological flowpath units of downward, lateral and upward flowing components.

Within a single stream tube it should be possible to define and quantify the volumes of water moving through the system, as well as estimate the residence time of specific rain event water that moves through the system. Such a model allows rain events to be added to the groundwater system at the downward hydraulic gradient end of the stream tube, but also allows a nett decrease in the groundwater storage through groundwater discharge in the part of the stream tube that has an upward hydraulic gradient. Thus a quantified recharge-discharge cell is defined and the associated area of each process can be identified by a moving boundary within the stream tube.

The analysis of a single stream tube is just one of many that constitute a catchment. If the analysis described is performed on each stream tube, the whole catchment can be defined in terms of recharge and discharge areas and the hydrological components can be quantified for the whole catchment.

Stream chemistry analysis

Stream hydrograph separation is usually achieved by graphical techniques and was initially introduced by Hewlett and Hibbert (1967). In the past, the simple mass balance approach using a two component mixing model between pre-event water and rain event water, using natural isotopic tracers, provided a simple means of determining the proportion of baseflow to rain event water that contributed to streamflow generation. According to Sklash (1990), tracer studies can improve runoff apportioning by tracing the movement of water through the various pathways in a catchment. This mass balance approach was adopted by Bradd et al., (1993) to examine proportional contribution of rain and groundwater to streamflow generation in streams from several dryland salinised catchments in NSW. The hydrograph separations were used to estimate the groundwater component of salt export from the catchment.

Harris et al., (1995) proposed a new hydrograph separation method for runoff source modelling based on continuous open isotope mixing using the "variable source area" concept (from Hewlett and Hibbert, 1967), and three isotopic reservoirs. This method takes into account temporal variations in the isotopic compositions of rainfall and of the reservoirs which contribute to streamflow. The approach is fundamentally different from the previous methods based on two or three reservoir batch mixing models because the isotopic reservoirs vary continuously in composition and size and because the amounts of water and tracer are conserved at all times (Harris et al., (1995). This approach is expected to more realistically quantify the components of the stream hydrograph because it is based on a more accurate catchment model description (ie. the variable source area concept). A similar approach is adopted in this paper presented.

Streamflow is considered to result from the mix of surface and subsurface flow in varying proportions, depending on the season or catchment characteristics during storm events such as antecedent moisture conditions. The streamflow mechanisms can be categorised into two groups based on whether a mechanism is "quickflow" (rapid conversion or "new" water) or "delayed flow" (slow conversion or "old" water). Examples of quickflow processes are partial area overland flow, saturated overland flow and macropore flow, while delayed flow is usually related to subsurface flow as either soil moisture or groundwater.

While isotopes have been useful in identifying the proportion of "old" and "new" water in the stream through time, stream chemistry can be used to identify the salt source areas. By monitoring the hydrological components in a catchment it is possible to identify the source of salts in the stream by the use of end member chemical characteristics. As mentioned previously, stream chemistry can be considered the resultant mix of waters from all sources within a catchment. In the study area at Williams Creek described earlier, a number of potential salt source areas were sampled to determine the potential end-member geochemistry. These included soil moisture at various depths, groundwater at various depths, and overland flow.

The chemical data was analysed in terms of seasonal time frames and relationships between chemical ionic species were examined. Those ions that show high linearity (ie. highly correlated) can be described in terms of a two component mixing model, and may be related to a straight dilution from two distinct sources. This is interpreted as a simple dilution between rainwater with a short residence time in the soil moisture zone and chemical bedrock dissolution. Occassionally, the data can be found to envelope between three end members. Thus stream samples have in this case varying proportions of three different salt sources. The third component in this case may be associated with the humus layer in certain parts of the catchment.

Temporal changes in stream chemistry reflect changes in stream source areas either at the storm event scale or seasonal scale. These usually reflect the moisture conditions of the catchment. Details of the results will be presented.

The implications of using this technique is that by identifying the source areas for stream salt loads both spatially and temporally, we can be more specific as to the way the land can be managed spatially and temporally to minimise salt migration to streams from specific source areas.

Concluding Discussion

Two important issues relating to catchment hydrological and geochemical processes has been discussed in this presentation. The first discussion demonstrates a method for identifying and quantifying recharge to the groundwater reservoir using deuterium analysis and water level data. Results have revealed that the recharge definition needs to take into account the nett rise or fall of the water table along with residence times of influx water to the groundwater reservoir. This has lead to the need to use the term "effective recharge" to describe water flow through a catchment.

The second discussion describes a way to look at stream chemistry data. Stream water is considered in this paper to represent a mix of waters from all sources within a catchment. By examining the stream chemistry data along with data collected from potential source areas known as end members, it is possible to determine where the salt in the stream is coming from in the catchment both spatially and temporally. This information can aid land managers in developing practices that minimise salt migration to the stream from specific source areas.

Acknowledgements

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Table 1. Deuterium data for transect of nested piezometers through time in WC-72.

Date	1-a	1-b	1-c	2-a	2-b	2-c	3-a	3-b	3-c	4-a	4-b	4-c
1/9/91	-46.8	-41.1	-40.9	-37.9	-40.7	-43.5	-45.4	-41.7	-47.0	-41.3	-44.7	-45.1
24/9/91	-34.5	-41.9	-41.2	-41.8	-40.8	-41.9	-45.6	-40.4	-46.6	-42.3	-43.4	-44.9
15/10/91	-26.1	-	-34.8	-34.4	-32.4	-37.2	-37.1	-39.4	-40.1	-35.6	-36.9	-37.9
8/11/91	-16.6	-36.0	-37.3	-36.5	-35.8	-38.4	-38.4	-39.1	-40.5	-36.1	-38.5	-41.3
30/1/92	-27.9	dry	-39.6	-35.9	-35.1	-39.1	-43.0	-43.0	-42.3	-39.7	-39.5	-41.7
16/2/92	-33.3	dry	-39.0	-37.8	-43.6	-42.8	-42.3	-43.6	-42.8	-38.1	-43.6	-40.9
11/3/92	-35.1	dry	-36.6	-41.2	-42.0	-44.0	-43.3	-46.5	-44.0	-41.8	-43.5	-44.1
24/4/92	dry	dry	-42.8	-40.7	-41.6	-43.6	-45.5	-46.8	-43.6	-43.1	-43.2	-44.0

Table 2. Standing water level data (below ground level) for transect of nested piezometers through time in WC-72.

Date	1-a	1-b	1-c	2-a	2-b	2-c	3-a	3-b	3-c	4-a	4-b	4-c
1/9/91	0.23	0.80	1.51	0	+0.17	+0.50	0.10	+0.22	0.48	+0.40	+0.25	+0.50
24/9/91	0.42	0.81	1.05	0.06	+0.31	+0.50	+0.14	+0.13	+0.50	+0.13	+0.38	+0.50
15/10/91	0.79	1.32	1.64	0.21	+0.03	+0.48	-0.21	+0.13	+0.41	0.21	+0.13	+0.50
8/11/91	1.48	1.72	2.22	0.36	0.24	+0.12	0.34	+0.02	+0.32	0.32	0.03	+0.24
30/1/92	0.68	dry	2.85	0.93	0.84	0.78	0.56	0.03	+0.33	0.76	0.49	0.36
16/2/92	0.56	dry	2.90	0.76	0.66	0.44	0.40	0.06	+0.23	0.78	0.50	0.37
11/3/92	0.63	dry	2.99	0.76	0.65	0.44	0.46	0.01	+0.19	0.75	0.56	0.41
24/4/92	dry	dry	3.29	1.18	0.95	0.74	0.60	0.07	+0.24	1.07	0.86	0.78

The Progression From Site Investigations to GIS Analysis to Map Dryland Salinity Hazard in NSW

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Introduction

Since 1988, the Hydrogeology Unit of the Department of Land and Water Conservation (LAWC) has been carrying out both broad scale and site specific investigations into dryland salinity processes under a Natural Resource Management Strategy (NRMS) program. The work program was divided into two categories, a) Reconnaissance groundwater level surveys in various rock units throughout the State of NSW, and b) Site investigations in specific catchments within the survey areas.

The objectives of the investigations relating to this paper were to: a) determine the extent of regional groundwater level rises, b) establish regional recharge response to various rock types for cleared and uncleared areas, c) examine the specific catchment environmental and hydrological processes that lead to dryland salinity, and d) use the information gained from this study to develop and produce a dryland salinity hazard map for the State of NSW.

The production of a Dryland Salinity Hazard map for the State of NSW was considered a necessary outcome from these investigations to provide information at the State/Murray-Darling Basin level on the extent and severity of salting within different regions of NSW as well as predict areas with high potential for future salting. The Murray-Darling Basin Commission requires information at this scale in order to determine which projects should be funded and their priority. A Statewide Dryland Salinity Hazard map would indeed show areas of major concern for more detailed project submissions to be focussed on, particularly when considering Land and Water Management Plans or Catchment Action Plans submitted by community Landcare groups.

The NSW Dryland Salinity Hazard map is the first to be produced for the State of NSW. It is the first of its kind in terms of methodology used to create the map based on a combined statistical "weights of evidence" approach and GIS overlay technique. Tickell (1994) did, however, produce a Dryland Salinity Hazard map for Northern Territory, but used a subjective rating of land attributes and GIS overlay techniques.

This map should not be considered static but rather a first edition that can be modified relatively easy on the GIS as more data becomes available for land attributes throughout the State.

Dryland Salinity Site Investigations

Site investigations were covered by statewide groundwater level monitoring to assess the extent of regional groundwater level rises and to examine regional recharge response to broad scale land clearing. Emphasis was placed on rising water table information as this was seen to be the main cause of dryland salinity. The reconnaissance survey areas and the associated groundwater level changes are presented in Figure 1. It was also recognised that correlations can be made between dryland salinity occurrence and certain physiographic features such as geology, soils, climate, landform, vegetation, land use and hydrogeology. More specifically, it was identified that certain combinations of these features or land attributes correlate with broad scale dryland salinity occurrence. Some of the typical findings from the Reconnaissance surveys are discussed below.

a) A direct relationship exists between winter dominant rainfall that occurs in the south of the State and the large number of dryland salinity sites in this area. The reason for this is the fact that there is significantly less potential for groundwater recharge in the north of the State given the high potential evaporation that occurs in summer when most of the rain falls. This reduces the amount of water available for groundwater recharge.

b) Long term climatic data for various regions in the State has provided indirect information on temporal recharge. Thr typical pattern for rainfall during this century is that below average rain had fallen from 1900-1940's and from the 1940's a much wetter than average period has taken place. This can be interpreted as meaning that there has been more opportunity for groundwater recharge in the second half of the century.

c) The geological rock unit that shows the greatest regional groundwater level rise is the Ordovician fractured rock meta-sediments. This fact should not be taken in isolation from other land attribute data that is also related to these areas such as landform type, associated soil types and vegetation.

d) Observations of dryland salinity occurrence showed that relationships exist between the occurrence of salinity and the interaction of particular land attributes and environmental features. The combination of broad scale land features that were observed to have a high incidence of dryland salinity are; Ordovician meta-sediments with yellow and red texture contrast soils, grazing lands that have had natural vegetation cleared

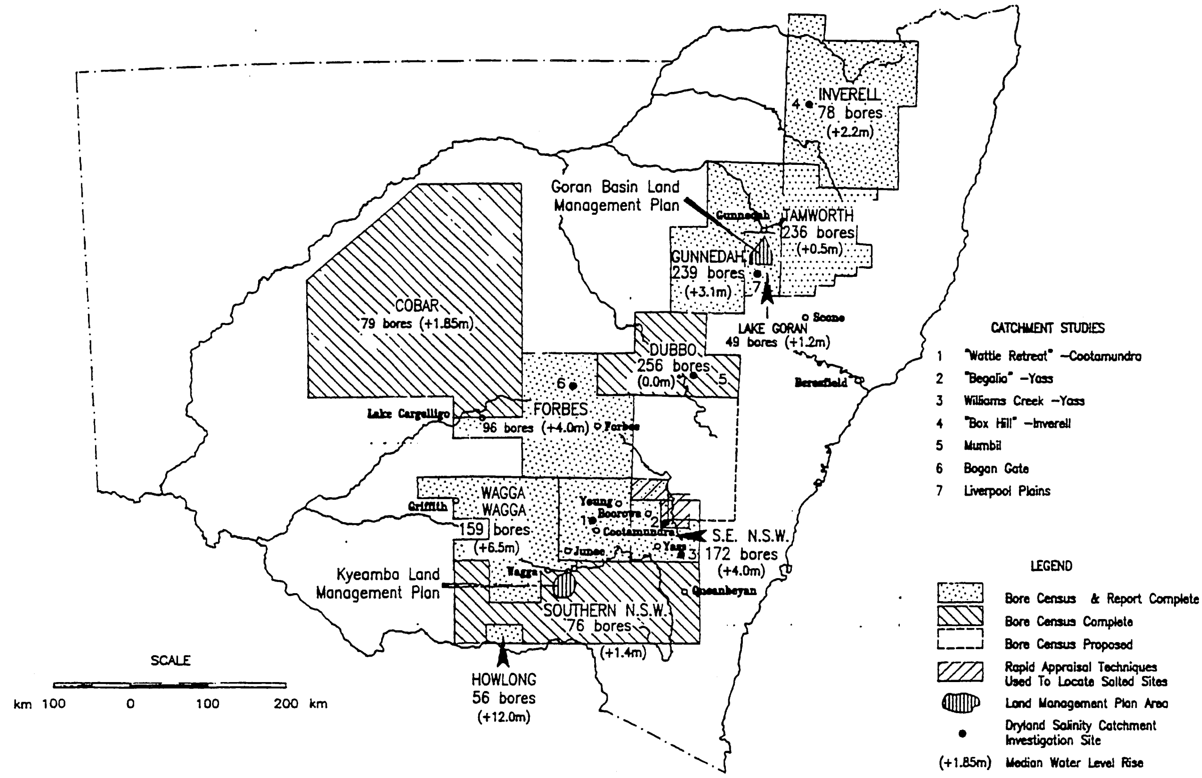

Figure 1. Reconnaissance survey areas investigated with associated distribution of groundwater level changes.

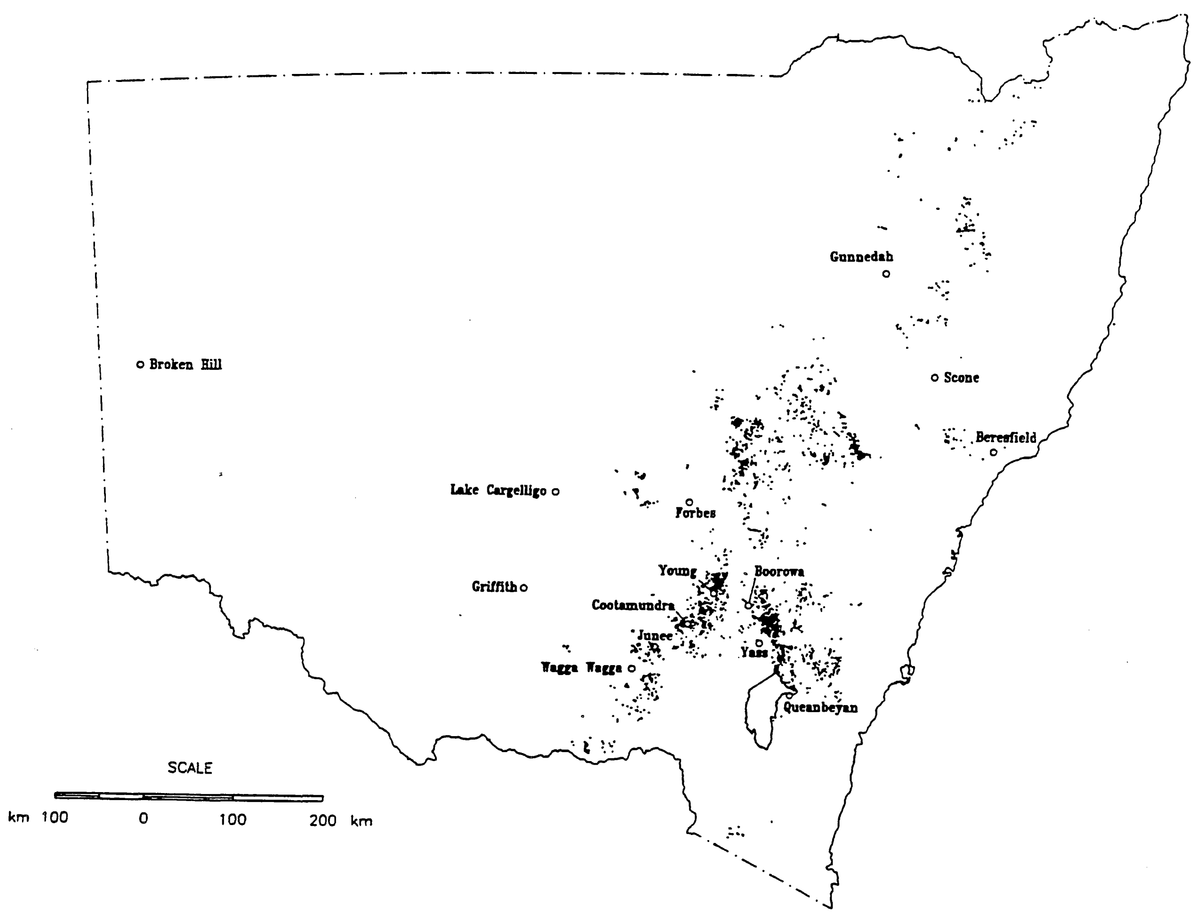

Figure 2. The occurrence of dryland salinity currently mapped in NSW. This map was used as the reponse map in the weights of evidence analysis.

from the high parts of the catchment (recharge areas), within a rainfall zone of 600-700mm per annum and in rolling hill and tableland country.

The more detailed site investigations within specific catchments affected by dryland salinity showed that these broader scale features described above needed to be defined into more specific characteristics. Catchment features such as shallow water tables, low slopes, break of slope, change in geology, or location of faults and dykes all contribute to dryland salinity occurrence. Therefore, when mapping dryland salinity potential at this scale, these features need to be included in mapping rather than relying on broader scale map features. At the State scale however, it is more appropriate and valid to use the broad scale land features.

Method for developing the NSW Dryland Salinity Hazard Map

The approach taken for the NSW Dryland Salinity Hazard map was a statistical method based on "weights of evidence". This type of statistical analysis was first developed for medical diagnosis, (Spiegelhalter, 1986) and was extended to deal with spatial prediction, 'diagnosing' mineral deposits using the 'symptons' of geological, geophysical and geochemical signatures as applied by Agterberg (1989), and Bonham-Carter et al., (1988). The weights of evidence approach has been used more recently by Barber et al., (1994) to determine and create regional groundwater vulnerability maps in relation to groundwater protection. This technique is now, through this study, being applied to dryland salinity hazard mapping.

The weights of evidence method as applied to spatial data is dependent on having a response variable or map (in this case, the dryland salinity occurrence map as seen in Figure 2) and several predictor variables or maps that relate to dryland salinity. The weights of evidence calculations involve several steps: 1) The estimation of a prior probability of salinity hazard in a unit area, given no further information, ie. the area of salinity divided by the total study area; 2) The calculation of positive weights for each class on a predictor map, ie. the proportion of salinity area on each class within an attribute map (eg. the salinity area on the class 'Ordovician metasediments' within the geology attribute map, or the class 'red-brown earths' within the soil attribute map etc.); 3) The addition of each weight from a map class and the final calculation of posterior probabilities for each unique class combination by overlaying of predictor maps in the GIS. 4) The posterior probabilities are then sorted and grouped into four classes; very high, high, moderate, and low.

A FORTRAN program has been developed by the Hydrogeology Unit of LAWC to accept ascii attribute data files created by the GIS (GENAMAP) and calculate the weights, posterior probabilities and sort into four categories of dryland salinity hazard for NSW.

The predictor maps chosen for relating to dryland salinity in NSW were geology, soils, land use, rainfall, natural vegetation, groundwater resources, and landforms. These are the broad scale features that were found to be most responsible for the occurrence of dryland salinity from the reconnaissance site investigation studies. These features have been mapped at 1:2 500 000 for the State. To decrease the complexity and number of possible combinations in the final overlay map, some classes with no, or negligible, dryland salinity occurrence were combined before performing the weights of evidence analysis. A schematic representation of how maps are overlaid with the GIS to produce the final combination map which becomes the Dryland Salinity Hazard map is illustrated in Figure 3.

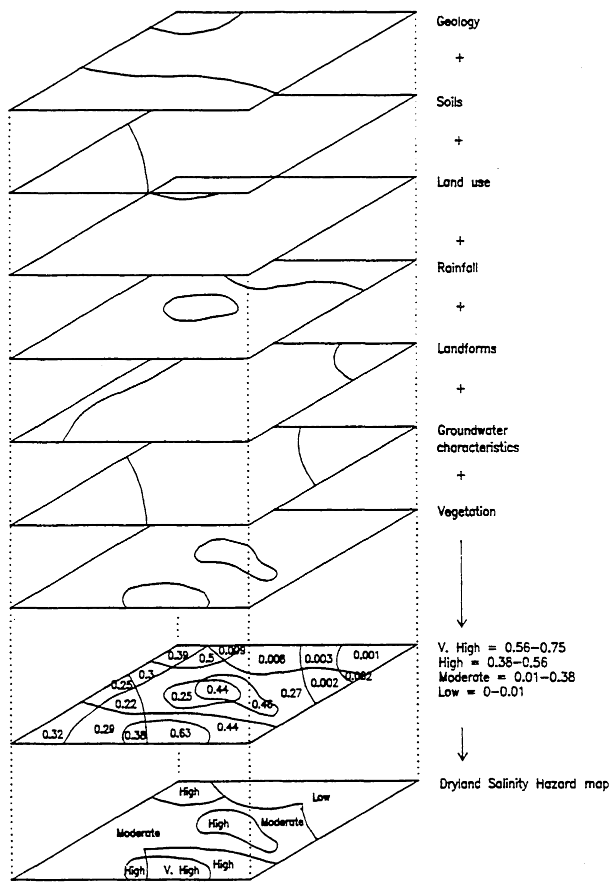

Figure 3. Schematic representation of overlaying maps in the GIS to produce the final Dryland Salinity Map.

The main advantage of using weights of evidence as a method of combining maps is that the method is relatively objective, and avoids subjective choice of weighting the land attributes from human experience only.

Catchment scale dryland salinity hazard mapping

The weights of evidence technique can also be applied to map dryland salinity hazard at the catchment scale. Work is currently underway to produce a dryland salinity hazard map for the Yass River Valley. The key difference between the development of a dryland salinity hazard map for the Yass River Valley and a statewide dryland salinity hazard map is in the choice of predictor maps used to compare to dryland salinity occurrence (the response map) as well as the scale of mapping used to produce the predictor map data.

The predictor maps that should be ideally used at this scale for dryland salinity potential include depth to water table, slope, soils, geology, land use and vegetation cover. Since the water table map is currently unavailable for this area, the first attempt at developing a dryland salinity hazard map for the area will be based on hydrologically homogeneous units which are defined by the GIS as a combination of the other land attribute data, ie. slope, soils, geology, land use and vegetation cover. Dryland salinity occurrence is then compared to each land attribute class, as done on the statewide scale, but then the probabilities of dryland salinity occurrence are related to hydrologically homogeneous similar units.

Observations made on the NSW Dryland Salinity Hazard Map

As mentioned, the dryland salinity hazard index has been categorised into four groupings of probability ranges; low, moderate, high, and very high. A black and white version of the map is presented in Figure 4 There was over 250,000 land attribute combinations possible with associated probabilities for NSW. The probability range for all these combinations was between 0 and 0.75 as calculated from the weights of evidence method. Initially, the four categories were chosen by equally dividing this probability range (ie. Low = 0 - 0.1875, moderate = 0.1875 - 0.375, high = 0.375 - 0.5625, and very high = 0.5625 - 0.75. In doing this, it was found that many of the current occurrences of dryland salinity fell within the low index category. To incorporate more land attribute combinations, the moderate probability range was decreased to 0.01 to capture approximately 500 more combinations. 55% of the current known (ie. mapped) dryland salinity occurrence was found to lie on land attribute combinations with probabilities ranging from between 0.01 and 0.75. GIS processing time made it difficult to decrease the probability range any further. Nevertheless, probabilities below 0.01 were considered too low. This simply means that those areas that lie within the low dryland salinity hazard index category are not exempt from possible future occurrence of dryland salinity. Rather, this category defines the land attribute combinations that have the lowest probability or likelihood of its occurrence relative to other land attribute combinations.

Dryland salinity has the potential to occur in a large area across the upland areas of NSW. Currently, approximately 250km^2 of NSW is affected by dryland salinity. The NSW Dryland Salinity map predicts that 50,000km^2 of land has the potential of being affected by dryland salinity that lies within the moderate to very high category. The river basins most susceptible to dryland salinity are seen to be the Lachlan, Murrumbidgee and the Macquarie river basins. Dryland salinity potential is less in the north of the State as seen by the less density of the hazard index as well as the lower degree of the index, ie. predominantly moderate rating.

Areas of major concern that have a high to very high dryland salinity hazard index are found in a north-south belt just north of Canberra (Yass River Valley), and in the southwestern part of the Lachlan River catchment, east of Wagga Wagga in the Murrumbidgee River catchment, and east of Dubbo in the Macquarie River catchment. It is suggested that these areas should be closely monitored for potential changes in the hydrological balance if dryland salinity has not already occurred in parts of these places.

The physiographic and land attribute combinations that have the highest posterior probabilities and hence greatest potential for dryland salinity to occur in the future, were found to be variations between only a few classes within the different attribute maps. These were generally Ordovician or Silurian fractured rock sediments (and occassionally granites) from the geology map, yellow and red texture contrast soils from the soils map, limited grazing and cropping from the land use map, the rainfall zone between 600-700mm of rain per year from the rainfall map, low hills and ridges from the landform map, groundwater of low to moderate yield and water quality between 1000-3000mg/L from the groundwater resource map, and grasslands of 30-70% cover from the natural vegetation map.

Discussion

In producing a NSW Dryland Salinity Hazard map with the aid of GIS technology, new areas susceptible to dryland salinity are identified and highlighted by varying degrees of probability of occurrence. This has been based on the recognition from site investigation studies that the current occurrence of dryland salinity correlates to specific combinations of land and physiographic attributes.

The advantage of using a GIS system to map this information is that it can quickly identify these combinations by readily overlaying attribute maps of large areas that would normally be a very time consuming task by using manual methods. It also has the advantage of being dynamic, that is, as more accurate and detailed data becomes available, it will be a relatively quick and easy task to edit the map.

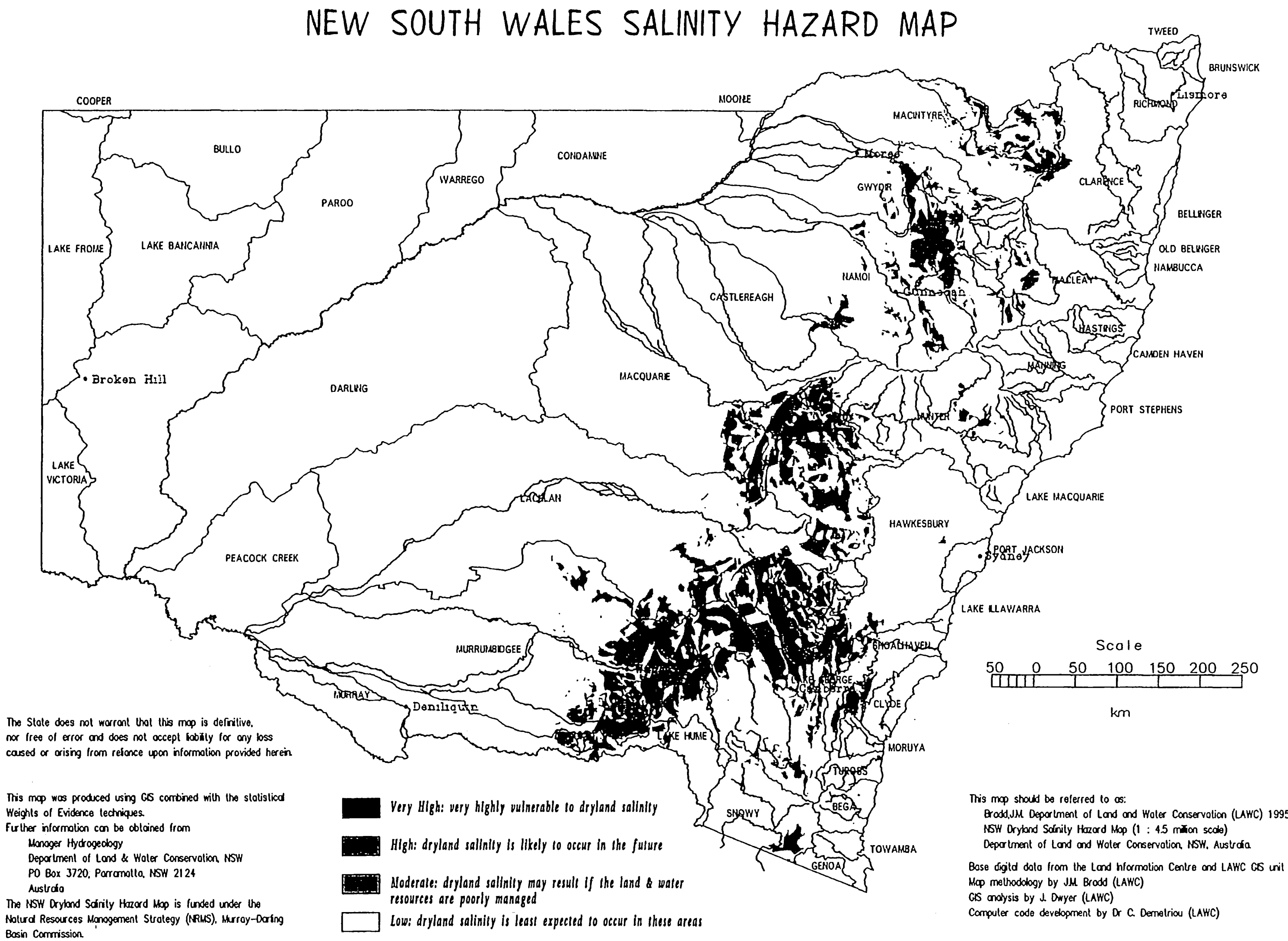

Figure 4. The first edition of the NSW Dryland Salinity Hazard Map.

The NSW Dryland Salinity Hazard map is available through the Hydrogeology Unit of the Department of Land and Water Conservation.

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A Community Action Programme to Study and Manage Rising Watertables in Irrigated Lands of the Macquarie Valley.

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1. Introduction

The irrigated lands of the Lower Macquarie Valley cover an area of 80,000 hectares and extend from Narromine to the Macquarie Marshes, between the Bogan River and the Marthaguy Creek. There are some 300 irrigators in this area. During the 1994/95 season, they grew cotton in approximately half of the area, while the other half was used to grow wheat and summer crops such as soybeans, sunflower and corn, in addition to citrus, vegetables, lucerne and pasture.

During the decades of the 70's and 80's, the Department of Land and Water Conservation (LAWC) installed a number of piezometers to the west, north and south of Narromine. The monitoring of the groundwater levels during the following 20 years (DWR, 1987; Salas, 1992) suggested that the region's watertable is rising 30 cm/year on average, and in some places up to 50 cm/year.

As a result, the Macquarie Valley Landcare Group was formed in 1992. The Group, in conjunction with the LAWC and NSW Agriculture, enhanced the groundwater investigations and expanded the groundwater monitoring network. Since 1992, 57 additional piezometers were drilled between Narromine and the Macquarie Marshes. Located within 30 kilometres of the Macquarie River, the majority of these piezometers intercepted shallow aquifers to a depth of 30 metres.

The groundwater investigation project has now a large community involvement. Some 20 landholders measure water levels in piezometers within their area every three months. The information is provided to the LAWC and disseminated within the general community by workshops and regular newsletters.

2. Geology, geomorphology and soils.

The irrigated areas cover a large alluvial floodplain. A number of geological, geomorphological and pedological studies have been carried out in the general region (IESC 1986, McKenzie 1992; Sherwin 1995 and Watkins 1994). The average height of the plain is approximately 230 m above sea level and the topography is essentially planar and formed by Tertiary and Quaternary alluvial materials.

These Cainozoic sediments fill-in old river valleys that eroded Palaeozoic and Mesozoic (Great Artesian Basin) rocks before the beginning of the Pliocene, 5.3 million years ago. The contours of the bedrock underlying the sediments (DWR, 1987), suggest that the ancestral Macquarie Valley was excavated to a depth of at least 140 metres below the present land surface. Near Narromine, the course of this buried valley coincided with the course of the Boggy Cowal. Further downstream, the ancestral Macquarie River's possibly followed the course of the Bogan River.

The geomorphology provides clues to the understanding of aquifer characteristics and potential recharge areas. McKenzie (1992) identified 3 pedoderms having an impact on soil and aquifer distribution throughout the study area.

PEDODERM	GEOMORPHIC PROCESS	AGE (YEARS)
Old Alluvium	Coarse bedload deposition	130,000 to 25,000
Trangie Cowal	Fine bedload deposition	25,000 to 15,000
-----	Transitional period	15,000 to 10,000
Contemporary Macquarie	Transport of suspended sediment; channel incision	10,000 to present

Within these pedoderms there is a range of soil types ranging between grey cracking clays, red brown earths and alluvial loam soils. Irrigation recharge perhaps only occurs in significant quantities in areas adjacent to cowals (recently abandoned river-channels). This possibility is currently being investigated by the LAWC and by NSW Agriculture.

The hydrogeology of the area is complex. In their present stage, the investigations have defined two main aquifer systems in the Quaternary sediments:

- a shallow alluvial aquifer associated with the above pedoderms ranging in depth from 10 to 30 metres, and

- a deeper alluvial aquifer that shows great potential for high yielding irrigation bores and can be found at depths ranging from 40 to 80 metres.

A third very deep aquifer system, the Pliocene Lachlan Formation (DWR, 1987) may be found beyond 80 metres in the deepest parts of the Tertiary palaeovalleys. Some of the deep aquifers may be hydraulically connected to the Mesozoic sandstones of the Great Artesian Basin.

3. Groundwater trends in shallow and deep aquifers

Only six piezometers have measured water levels in the shallow aquifer since 1987 and therefore the information available is limited and cannot be used to estimate long term trends. The watertable in these piezometers, however has been rising on average 30 cm/year.

Figure 1 presents groundwater contours that show depths to the watertable in the shallow aquifer. In general, the highest groundwater levels are found in the vicinity of the Macquarie River.

In three areas the shallow aquifers form mounds where groundwater levels are found at depths of less than 5 metres from the surface. These mounded areas are periodically flooded by the Macquarie River, which suggests that the flooding may be the main source of groundwater recharge. However, the 17,000 hectares overlying the two mounds between Narromine and Warren are also intensively irrigated. Thus, groundwater levels in these areas will be carefully be monitored to signal any potential salinity problems in these areas.

The piezometric levels of the deep aquifers have been monitored since the early 1970's. On average, these levels have risen 25 cm/year. As with the shallow aquifers, large rises have occurred near the river, suggesting that there is an hydraulic connection between the deep aquifers and the river. Nevertheless, the largest rises were measured in an area away from the river, crossed by the Boggy and Backwater Cowals, some 20 kilometres west of Narromine.

4. Groundwater Management Zones

The correlation of hydrogeological, geomorphological and pedological information with hydrological, flooding and irrigation information will provide a basis for defining groundwater management zones. The control of water input and water extraction in these zones will allow changes to the rising trend of the watertable.

A preliminary attempt to subdivide the land into groundwater management zones is proposed here as an example. These zones will define areas requiring special management policies and/or further investigation. The boundaries of the different zones are presented if Figure 2 but, since in some areas only 12 months of groundwater readings are available, these boundaries are tentative only. As shown in the table below, the classification is based on the position of the water table in relation to the land's surface, and on its tendency to rise or to be stable.

Zone	Depth to the Water Table (m)	Shallow Aquifer	Deep Aquifer
A	0-5	Rising	Rising
B	5-20	Rising	Rising
C	>20	Unsaturated	Rising
D	>20	Unsaturated	Stable

5. Macquarie Valley Groundwater Pumping Project

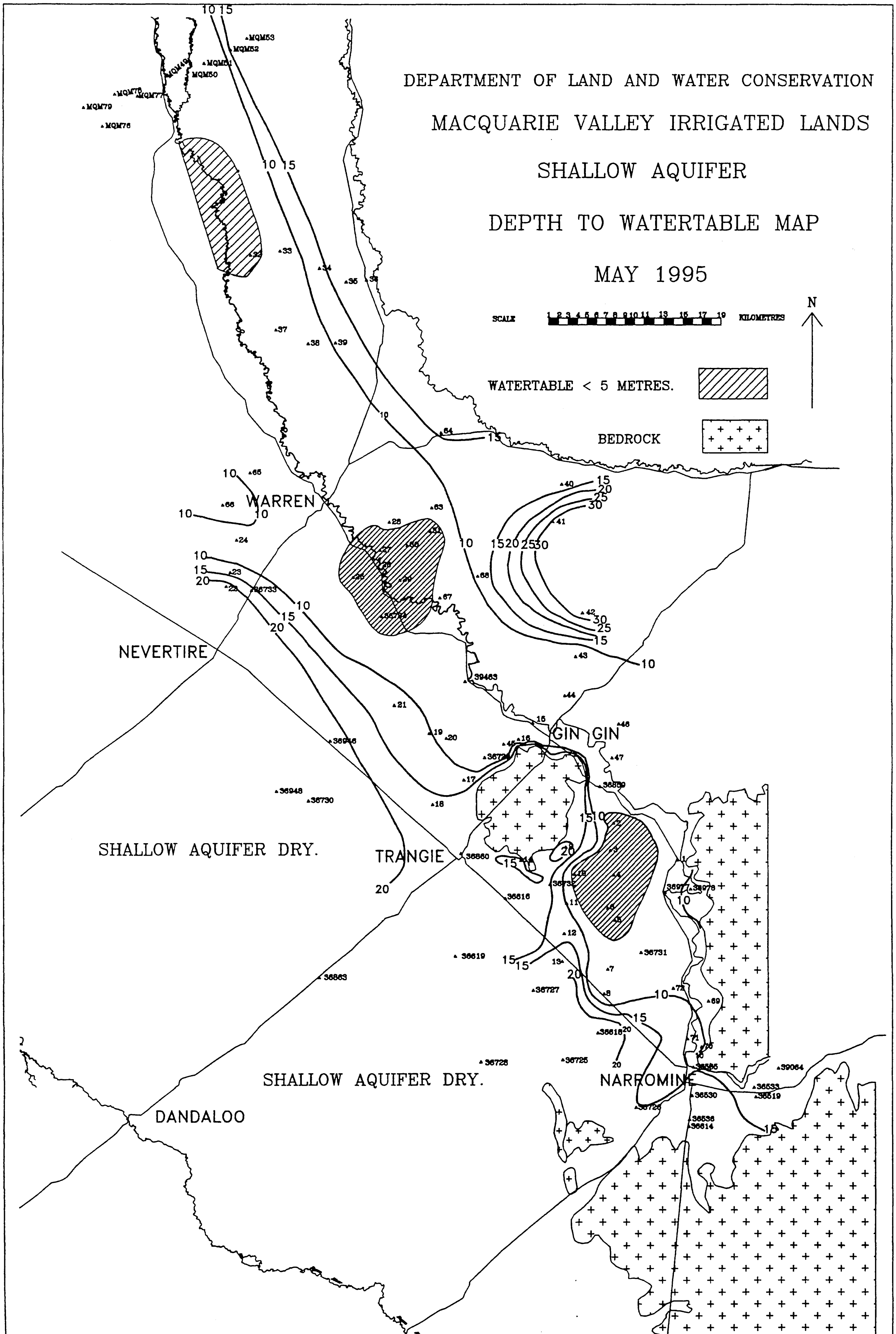
Surface water allocations are likely to be very small during the current drought. Therefore, groundwater pumping will significantly increase during the 1995/1996 irrigation season.

As aquifer characteristics are largely unknown in the Lower Macquarie area, an intensive monitoring programme has been implemented by the LAWC and by the landholders that use groundwater for irrigation. At present the landholders are periodically reading the water levels in monitoring bores and piezometers located in their land. This information, combined with the data provided by automatic water level recorders, is being utilised to determine aquifer transmissivity and storativity values. These values will be used to adjust groundwater models; estimate recharge; determine safe yields and predict interference effects between bores. The information will be also used to develop long-term guidelines that will optimise groundwater extraction rates; control water table rises and prevent over pumping and aquifer depletion. In summation, the combined work of landholders and the LAWC will provide the basis for developing a realistic licensing guidelines and a groundwater management policy for the Lower Macquarie area.

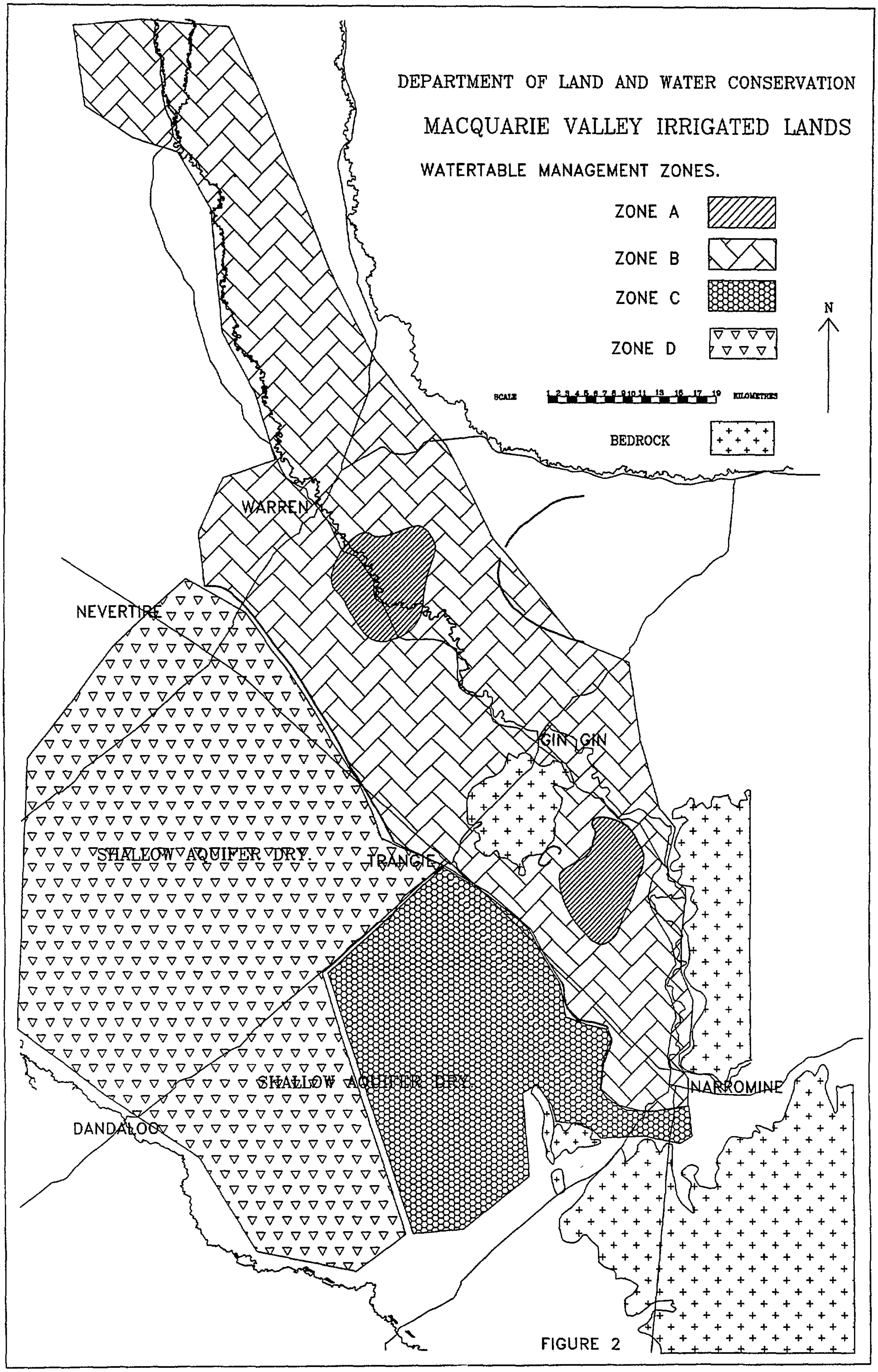
6. Conclusions

Groundwater Levels within the Macquarie Valley are generally rising. Shallow aquifer are rising on average 30 cm/year and deep aquifers 25 cm/year. An area of 17,000 hectares, where the watertable at present is within 5 metres of the land surface, has been identified as a high priority groundwater management zone.

The LAWC and local irrigators have implemented a groundwater monitoring programme that will rapidly identify additional areas where rising watertables may become a problem in the future. Groundwater levels in observation bores in the vicinity of production bores are also being monitored. This information will be used to develop a realistic groundwater policy and a licensing



DEPARTMENT OF LAND AND WATER CONSERVATION
MACQUARIE VALLEY IRRIGATED LANDS
SHALLOW AQUIFER
DEPTH TO WATERTABLE MAP
MAY 1995
SCALE
KILOMETRES
N
WATERTABLE < 5 METRES.
BEDROCK
WARREN
NEVERTIRE
GIN GIN
TRANGIE
NARROMINE
DANDALOO
SHALLOW AQUIFER DRY.
SHALLOW AQUIFER DRY.
FIGURE 1.


DEPARTMENT OF LAND AND WATER CONSERVATION
MACQUARIE VALLEY IRRIGATED LANDS
WATERTABLE MANAGEMENT ZONES.
ZONE A
ZONE B
ZONE C
ZONE D
BEDROCK
N
KILOMETRES
WARREN
NEVERTIRE
GIN GIN
SHALLOW AQUIFER DRY.
TRANGIE
SHALLOW AQUIFER DRY.
NARROMINE
DANDALOO
FIGURE 2

strategy that will be well suited to the particular characteristics of the Lower Macquarie aquifer system.

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Adjoining recharge and discharge systems at the southern margin of the Murray Basin.

by
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Abstract

At the southern margin of the Murray Basin is the principal recharge area for the marine province, marked by an exposed unconfined aquifer and represented by ridges of Parilla Sand, a series of aligned fresh water lakes (<1000mg/L TDS) and an extensive aeolian sand sheet of Lowan Sand. On the eastern boundary of the recharge zone is a prominent and elongated groundwater discharge area occupying a relic broad stream valley named the Douglas Depression.

The Douglas Depression includes a series of brackish to hypersaline throughflow lakes; northward the Wimmera River occupies the Depression and itself receives groundwater discharge, especially via the deeper pools. (Anderson and Morison, 1988; Strudwick, 1992).

Introduction

In very simple terms there are regional groundwater recharge areas around the periphery of Murray Basin, mostly coinciding with the entry of rivers to the Murray basin from the surrounding highlands, where there is groundwater of low salinity increasing to higher salinity along the flowpaths to regional discharge zones towards the centre of the basin (Evans and Kellet, 1989; Lawrence, 1975).

It has been known for a long time that there is a marked departure from this general pattern of groundwater salinity in the south western part of the Murray Basin (Gloe, 1947, McCauley et al 1992), where there is an extensive area of low salinity groundwater in both the Parilla Sand and the Duddo Limestone and associated low salinity ephemeral lakes adjacent to a elongated zone of high salinity groundwater and associated high salinity lakes. This paper examines the cause of this sharp transition in salinity of groundwater and lakes in terms of recharge and discharge zones and the controlling geologic factors.

Recharge systems

The recharge area in the southern part of the Murray Basin, in the Wimmera Region, has been known from the regional water table contours for the Parilla Sand and the potentiometric surface of the semi-confined to confined Duddo Limestone aquifer and its equivalents (Gloe, 1947; Lawrence, 1975; McCauley et al, 1992). This area has an average precipitation of 400-500mm/yr and a mean potential evaporation of 1500 mm/yr.

Recharge occurs via two processes: one directly from ephemeral lakes (<1000mg/L TDS) and the other by infiltration of rainwater. The ephemeral lakes occupy the corridors between the ridges of Parilla Sand. These lakes are fed by local runoff from the ridges and the infrequent surface flow along the corridors at times of high rainfall. In the case of the Bates, Karnak, North Charman, Miga and Wombelano lakes for example, their elevation 10-15m higher than the adjacent groundwater and the recharge flux is in response to a downward and lateral hydraulic gradient.

Chloride balance calculations on Waits Lake and at Ratzcastle indicate that the recharge although impeded by the Shepparton Formation is of the order of 640± 230mm/yr (Thorne, 1992).

The other recharge process is through the unsaturated zone from precipitation occurring over the Pliocene stranded coastal ridges and the bevelled surface of the Parilla Sand across the "Little Desert" where it has a thin cover of Lowan Sand. The water table throughout most of this area is >10m below the ground surface and is likely to have been deeper prior to European settlement.

The salinity of the groundwater in the lakes and the unconfined aquifer is usually in the range of 1000 - 4000 mg/L TDS; the relative chemical composition of the groundwater is similar to that of seawater except that there has been enrichment of calcium relative to chloride and depletion of potassium relative to chloride. This similarity to seawater composition is attributed to cyclic salt origin, although for the deeper and finer marine Geera Clay in the eastern part of study region where the salinity of groundwater could be of connate origin. There is generally an increase in salinity along the flowpaths, except for the lower salinity groundwater beneath the "Little Desert", due to evaporative processes reflecting the decreasing P/E ratio northward.

Discharge systems

To the immediate east of the extensive recharge area is the Douglas Depression, which has the form of an broad belt extending northward form the Dundas Highlands. It is over 100km long, 4-5 km across and of the order of 30m lower than the surrounding landscape and slopes to the north. This Depression represents a relic stream valley which had its source in the Dundas Highlands (Kotsonis, pers comm). It is oriented at least in the southern part NNE-SSW and truncates the stranded coastal ridges of Parilla Sand. The surface water catchment that once fed the northerly flowing stream during the Pleistocene was later to be captured by the Glenelg River (Hills 1975) and diverted to south. Hence there is now no surface water flow along this valley. A thin cover of alluvial sediments of the Shepparton

Formation occupies the Douglas Depression unconformably overlying the eroded Parilla Sand.

A chain of saline to hypersaline lakes (Olivers, Wyn Wyn, Mitre, East Mitre, Bow, White, Centre and North) occupy the lowest parts of the Douglas Depression between the Dundas Plateau and Quantong. Brackish lakes such as Natimuk Mullancoree and Jaracteer are at intermediate elevations and this is reflected by their intermediate groundwater salinity. Northward of Quantong the Douglas Depression is occupied by the Wimmera River.

Saline groundwater, concentrated by evapotranspiration and the possible influence of connate water in the finer grained equivalents of the Duddo Limestone underlie the relic valley. Groundwater flows eastward form the regional recharge area to the Douglas Depression, with the lakes representing groundwater discharge. To the north the saline discharge is to the Wimmera River aligned by gypsum playas occupying the relic valley.

The hydrologic and salt budgets and complementary flownet analysis have been made on one of these salinas - Mitre lake -which has a mean surface area is 3km2. They indicate that the input of groundwater and precipitation to this salina is 800-840ML/yr. Of this input most leaves by evaporation and the remaining 40 - 65 ML/yr leaves the lake and rejoins the groundwater system to flow northward along the Douglas Depression. Some of the groundwater outflow provides inflow to the next salina down gradient, to the north.

Bromide ratios used in preference to chloride rations because chloride does not behave conservatively at higher salinities indicate that calcium is removed form the lake water during evaporative concentration. Also the higher Cl/Br at lake full stage compared with lake low stage is accounted for by halite dissolution.

There is evidence form the lunettes that these lakes have been saline up to 25000 years. Salt accumulation in the lakes is not preserved and this removal is accounted for by removal by wind and groundwater outflow.

The Wimmera River as indicated by Anderson and Morison (1988) and Strudwick (1992) receives saline groundwater in the deeper pools along the tract form Quantong to Jeparit. For these pools eg. Tarranyurk and Polkemment, the water is stratified, especially during the summer months when there is low stream flow and the water at the surface can be <1000mg.L TDS and at the base of the pools can be in excess of 5000mg/L TDS. Partial flushing occurs at times of higher streamflow.

Conclusions

The low topography near the margin of the basin has induced major discharge areas close to the periphery of the Murray Basin.

There is association of high salinity lakes with underlying high salinity groundwater in the Douglas Depression, likewise there is an association of fresh ephemeral lakes with low salinity groundwater in the recharge zone.

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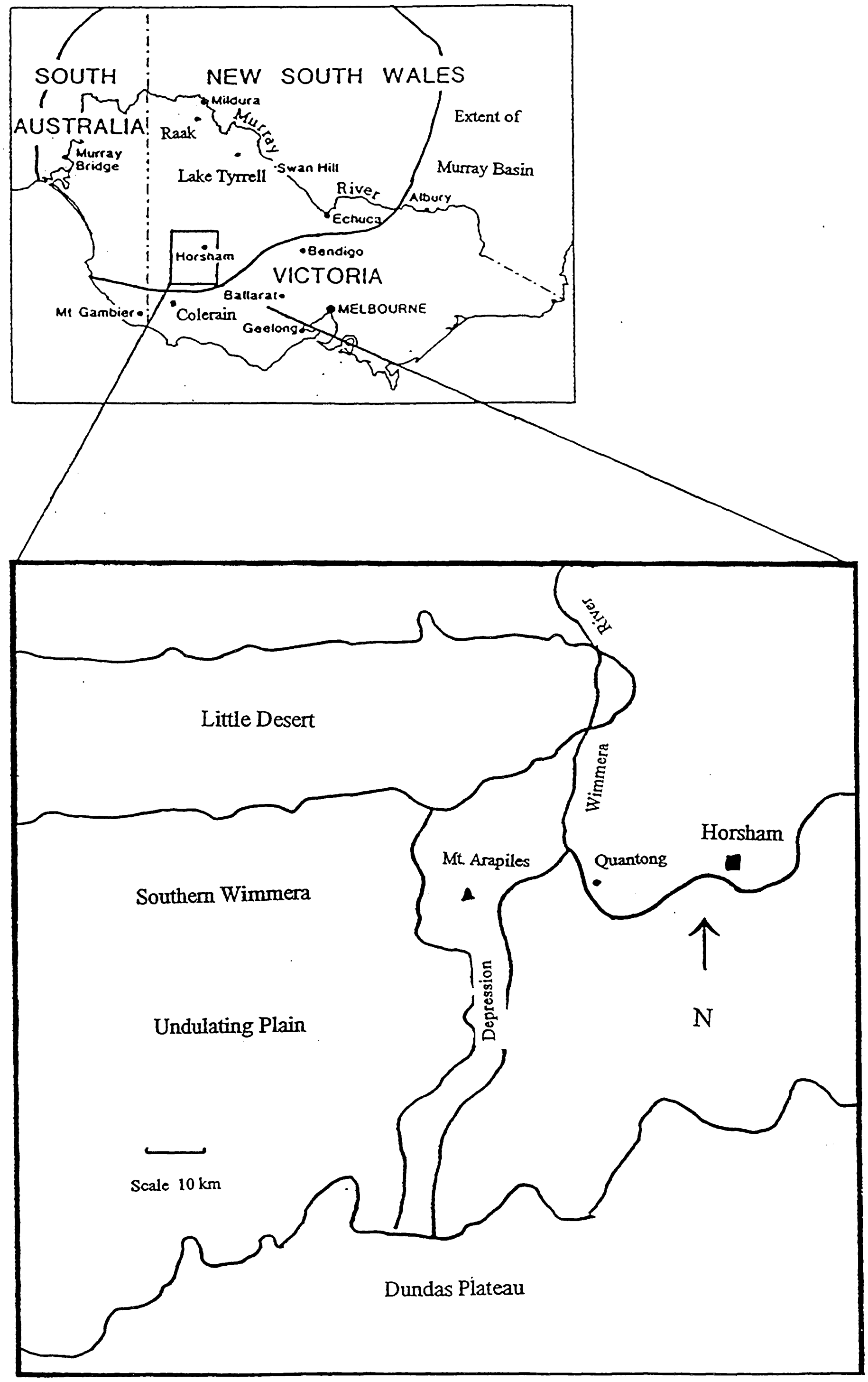

Figure 1 Location map.

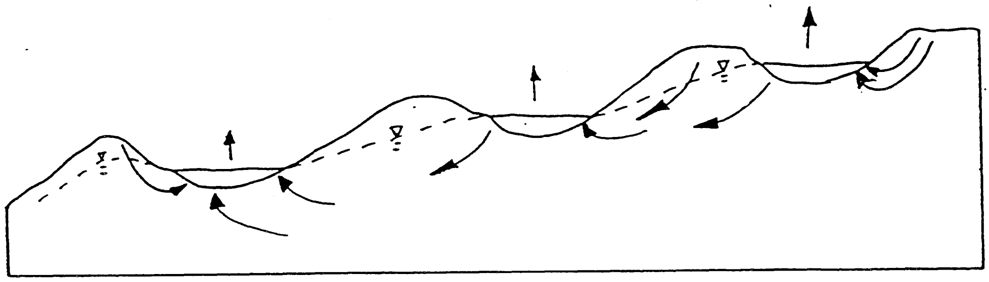

Figure 2. Schematic diagram of groundwater / lake interaction along the Douglas Depression.

Groundwater Sustainability Strategies in the Lower Namoi Valley, New South Wales

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Abstract

The Lower Namoi Valley contains one of the most developed groundwater system in New South Wales. Almost 560 piezometers are used by the Department of Land and Water Conservation to monitor groundwater level behaviour on a regular basis. Also over 470 high yield bores in the valley are metered to give accurate usage data.

Currently, groundwater allocations in the valley exceed the sustainable yield of the aquifer system and a review of the allocation policy in 1995 will adjust allocations to sustainable levels.

Abstraction above recharge under the strategies of "SustainableYield" and "Controlled Depletion" are managed in the Lower Namoi Valley due to the widespread bore monitoring network, accurate annual groundwater usage figures and an allocation policy which reflects community involvement.

Introduction

One of the most vexing problems in managing the groundwater system in the Lower Namoi Valley has been, and continues to be how much water can the aquifer system supply safely, on a sustainable annual basis without permanently damaging the aquifer or lowering the quality of the water. This is of particular concern in the Lower Namoi Valley where substantial agricultural development has occurred that relies heavily on groundwater, especially during the drier years.

The concept of sustainability of an aquifer should not be based solely on the sustainability of abstraction. Aquifer management must take into account groundwater quality as well as the complex interaction of human society with the groundwater/surface water environments. Sustainability should also be defined in terms of social, economic and environmental sustainability - all are linked.

The subject of this paper is the sustainability strategies as they relate to volumes of water pumped in the Lower Namoi Valley on an annual basis. It will show that abstraction above recharge should not necessarily be considered as excessive or be prohibited in all cases and that it can be managed over the longer term. A sustainability model is presented which links the strategies using data from the Lower Namoi Valley.

Location

The Lower Namoi Valley is one of the most productive groundwater areas in New South Wales. It includes an alluvial aquifer system of approximately 5100 km^2 in area containing at least three main aquifers with varying depths to 130 metres capable of yielding large supplies of low salinity groundwater to suitably constructed bores. It is referred to as Groundwater Management Area 001 (GWMA 001) as shown in Figure 1.

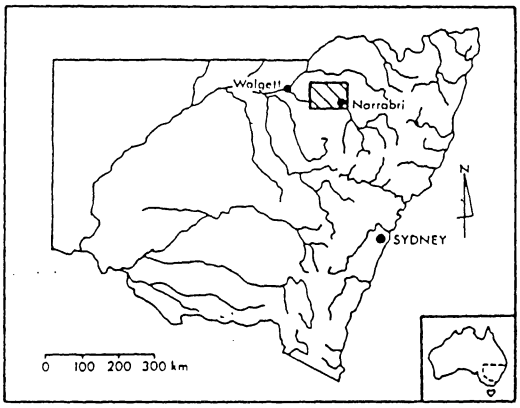

Figure 1: Locality map of GWMA 001

The primary aquifers of GWMA 001 consist of sand and gravel of the Narrabri, Gunnedah and Cubbaroo Formations (Merrick et al, 1986) with an estimated 20 million megalitres in storage (Ross and Little, 1993) of which one third is designated to high yield irrigation pumping.

There are 560 piezometers established at 240 sites throughout the valley over 20 years ago which are regularly monitored by the Department of Land and Water Conservation (LAWC) for groundwater level behaviour and water quality determinations. In addition, over 470 high yield private bores are licensed and metered, and inspected regularly to ensure compliance with the licence conditions and give accurate pumping data. All water level and usage data is quality assured and maintained in primary and regional data bases.

Groundwater allocations and usage

Groundwater is allocated per property as a groundwater-only allocation and a conjunctive groundwater/surface water allocation. Currently, 156,000 megalitres per year (ML/yr) are allocated in a normal year (100% surface water availability). In times of surface water shortages, irrigators with access to both surface water and groundwater are permitted to make up some of their surface water by groundwater, increasing the allocation to 208,000 ML/yr in dry years (0% surface water availability).

Groundwater abstraction has increased substantially from around 70,000 megalitres (ML) prior to the drought in 1991/92, to 105,000 ML during the drought in 1992/93 to approximately 138,000 ML at the height of the drought in 1993/94. Usage in 1994/95 is anticipated to be in the order of 160,000 ML. The sustainable yield for the aquifer system is presently estimated at 120,000 ML/yr.

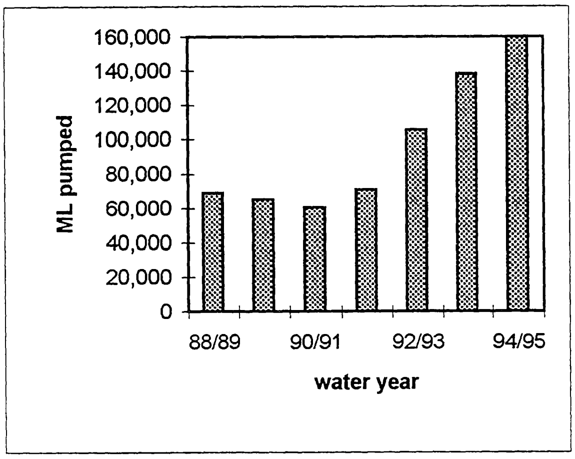

Table 1: Groundwater usage in GWMA 001, 1988/89 to 1993/94 with anticipated usage in 1994/95

A review of the Groundwater Allocation Policy has commenced to reduce allocations to the sustainable level. Communication and consultation with the community is maintained through the Lower Namoi Valley Groundwater Advisory Association (LNVGAA) which represents groundwater users in the valley.

Sustainability strategies

The strategy of "Safe Yield" is a complex function and is usually defined as the annual abstraction of groundwater that does not exceed the average annual recharge to that aquifer. It does not allow for utilisation of any storage component and should not be considered as a fixed value. Water needs may change with time as the socoi-economic framework develops and adapts to water availability. Management policies in the Lower Namoi Valley are long term, taking into account periods of normal rainfall and periods of drought. The fact that recharge measurements are only "best estimates" and there are sometimes long delay times to see the effects of recharge, the safe yield strategy is not the preferred strategy in large storage aquifer systems such as the Lower Namoi Valley in the context of maximizing sustainable development. This strategy may however, be appropriate in small , unconfined aquifer systems with little storage availability.

Optimum management of the Lower Namoi Valley therefore lies between the extremes of 'Safe Yield" and "Mining". It is clear that any groundwater development will result in some water level declines which may even be desirable in some aquifers to maximize recharge and reduce salinity.

In the Lower Namoi Valley, abstraction above the "Safe Yield" - that is, utilisation of the recharge plus a component of storage is required for maximum sustainable development . This leads to the second level strategy - Sustainable Yield .

Sustainable Yield

The concept behind this strategy is to allow the water levels to fluctuate between irrigation periods and between major recharge events. When a new recharge event occurs it will normally fill the aquifer close to its original level resulting in a oscillating water level as shown in Figure 2. This pattern is sustainable in the long term and shows that extraction above annual recharge can be managed.

During normal rainfall and 100% surface water availability, groundwater extraction is at a minimum. During a drought however or when recharge is significantly less than the annual average , the recovery phase is not of long enough duration between irrigation periods to allow restoration of water levels to the normal position, hence the long term decline now being experienced in many areas of the Lower Namoi Valley as shown in Figure 3.

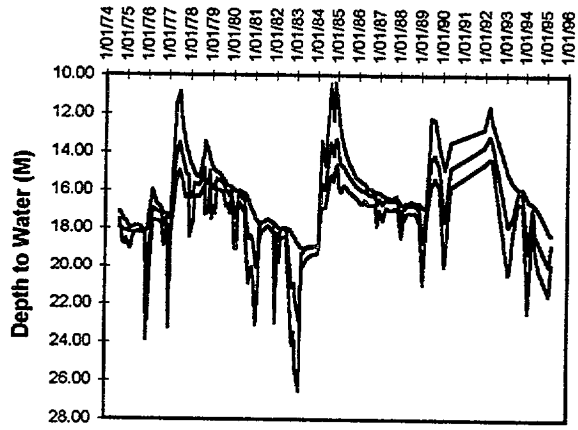

Figure 2: Representative hydrograph demonstrating oscillating water levels

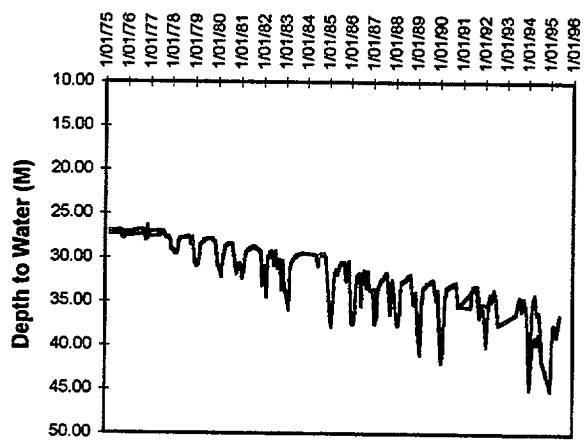

Figure 3: Representative hydrograph demonstrating continuous water level declines

Prolonged dry seasons with little or no surface water availability will cause groundwater extractions to increase as they have done in the last few years of drought in the Lower Namoi Valley. Further abstractions can now be allowed as we move into the third level of sustainability strategies which we call "Controlled Depletion".

Controlled Depletion

The main difference between Controlled Depletion and Sustainable Yield is that in Controlled Depletion a significant proportion of the aquifer storage as well as all of the recharge is extracted and groundwater levels are allowed to be drawn down regionally to lower operating levels on a more permanent basis.

The main criteria is that this strategy is of limited duration and can be used as a buffer against drought as long as careful assessments can be made and reductions in abstractions can also be implemented when and where necessary. Equity of access in existing shallow stock and domestic bores may have to be dealt with under these strategies.

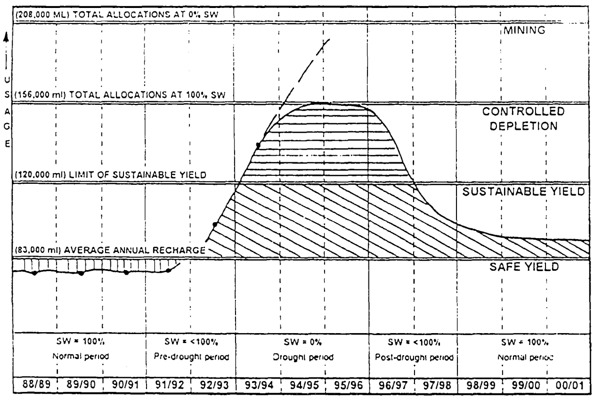

Figure 4: Sustainability strategies over time

Figure 4 relates the three strategies in one diagram to show that it is possible to utilize all three during a management period of wet and dry years.

Mining

Mining of the resource is not a management strategy that is used in the Lower Namoi Valley. However due to a combination of prolonged drought , record high cotton prices , changed water use practices and continued abstraction during the off-irrigation period to fill on-farm storages, winter recovery has not occured in two particular zones.

A major problem in the Lower Namoi Valley is that abtraction points are not spread equally throughout the valley and there are local "hot spots" where the number of high-yield bores are concentrated causing local drawdown greater than expected.

Local de-watering of the shallow aquifer and aquitard in this area has resulted in a some minor subsidence of 50mm or more over a 360 km^2 area with a maximum of 210mm in one bore site (Ross and Jeffery, 1991).

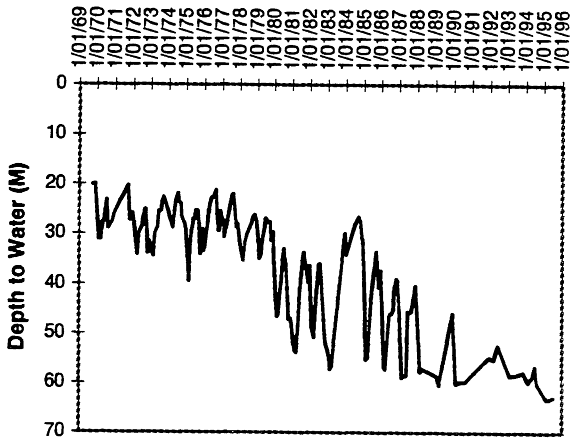

Figure 5. Representative hydrograph showing minimal recovery

In recognition of this, the Department implemented a ban on pumping in this zone during the winter season to assist recovery of water levels and to allow an assessment to be made of the situation. The ban was implemented following full consultation with the community leaders and water users who agreed to stop pumping immediately. A potentially difficult situation was alleviated through active communication with those concerned.

Sustainable Aquifer Development -Community perceptions

The concept of sustainable aquifer development is not always easy to define and may in fact be difficult to explain to the community in the face of declining water levels. The community's perception of sustainable aquifer development may be poles apart from a water managers definition. The roles of agencies as water managers is not only to manage the groundwater resource in accordance with sustainability criteria, but also to maintain a communication, education and consultation process with the community. Any necessary adjustments to allocations or difficult policy decisions are made easier and more acceptable to an informed community .

One Resouce Policy

The "One Resource" concept which is linked to sustainable aquifer development is the conjunctive use of groundwater and surface water. This concept is sometimes difficult to explain to a community in which many regard surface water and groundwater as separate entities, both physically and legally, requiring separate management policies. Adopting a one resource policy with community endorsement is the most productive way to manage water resources and balance groundwater conservation and development within the framework of surface water development and conservation.

In the Lower Namoi Valley a conjunctive use of groundwater and surface water recognizes the one resource, however separate management policies are still in place which are not interactive. Whilst this situation remains, sustainable aquifer development is jeopardized, contributing to resource depletion.

Conclusions

Abstraction of groundwater above recharge in large reservoirs can be managed for limited periods when effective data collection systems are in place and quality assurance of such data can be maintained. Abstractions above the safe yield therefore requires extremely careful hydrogeological assessments , careful monitoring of water behaviour , accurate water usage measurements and the mechanisms and political will to make adjustments to pumping when and where necessary .

Lessons learnt during the worst drought that the valley has experienced, and continues to endure, have shown that management strategies must be continuously reviewed as community attitudes change. It is clear that the Department's role is also changing from water management to water conservation.

In the past "Controlled Depletion" was seen as an effective means of managing the resource as a short term drought relief strategy. However, as the community is now moving rapidly in the direction of conservation of the resource, the "Sustainable Yield" strategy is seen as being more in line with this new direction. In recognition of this, the Lower Namoi Valley Groundwater Allocation Policy review will endeavour to reduce allocations to the "Sustainable Yield" of the aquifer whilst implementing tougher pumping restrictions when necessary in areas where the resource is seriously depleted.

Summary

In summary, it is no longer sufficient to try to quantify the various sustainability strategies in terms of volumes that can be extracted safely from an aquifer. It must be continuously recognized that in most cases, aquifer development deals with an integrated groundwater/surface water system and generally under normal circumstances, during development, any change to one will have an impact on the other. Sustainability strategies must therefore take into account the effects of groundwater development on surface water and vice versa. The community must recognize that the surface water environment is inextricably linked to, and in some cases, is dependent on, the groundwater environment.

The volumetric sustainability of the Lower Namoi Valley aquifer system is managed over the long term. Extractions above normal recharge are not prohibited as the management strategies now in place allow for the temporary utilisation of aquifer storage during dry years as a buffer against drought. The long term sustainability model allows for overdraft of storage provided it is replaced during normal rainfall years. This management strategy is possible only because of the widespread monitoring and metering networks in the Lower Namoi Valley and the Department's policy of community communication and consultation.

Future Directions

The Department of Land and Water Conservation is committed to full economic development of the Lower Namoi Valley with the provisions that reasonable groundwater pumping levels are maintained, water quality does not deteriorate below its beneficial uses, there are no adverse environmental impacts on surface and groundwater environments and water availability for all users is maintained and improved.

Full economic development of the Lower Namoi Valley, with the appropriate restrictions, will therefore be restricted to the reasonably anticipated average of long-term natural recharge plus a component of storage during dry periods.

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Title: Catchment Planning - The Boorowa Experience

Roger Clark (President, Boorowa Community Landcare Group Incorporated)

1. Background

The Boorowa Landcare group was formed 5 - 6 years ago, by a small group of people with serious concerns about major land degradation issues in the Boorowa district. These issues included dryland salinity, soil acidification, tree decline and associated loss of native habitat, and the general sustainability of current resource management strategies. The enormity of the problems facing the district dictated an overall catchment approach.

2. Planning Phase

In conjunction with the Rye Park Landcare group, a Salt Action grant was obtained in 1992 to "Prepare a Catchment Plan for salinity control in the Boorowa River Catchment". Mr. John Powell was engaged to carry out this task.

2.1 Mapping

This project involved the detailed mapping of all members properties in the Boorowa - Rye Park groups. Features mapped included minor, moderate and severe salinity and their areas. Indicators used were the varying degrees of salt tolerant vegetation, soil erosion and waterlogging. Other features mapped included piezometer locations, salinity levels in streams, bores and dams, property boundaries, ownership and subjectively assessed areas of high recharge. All this data was mapped on to 1:20 000 aerial photographs and later on to 1:100 000 map.

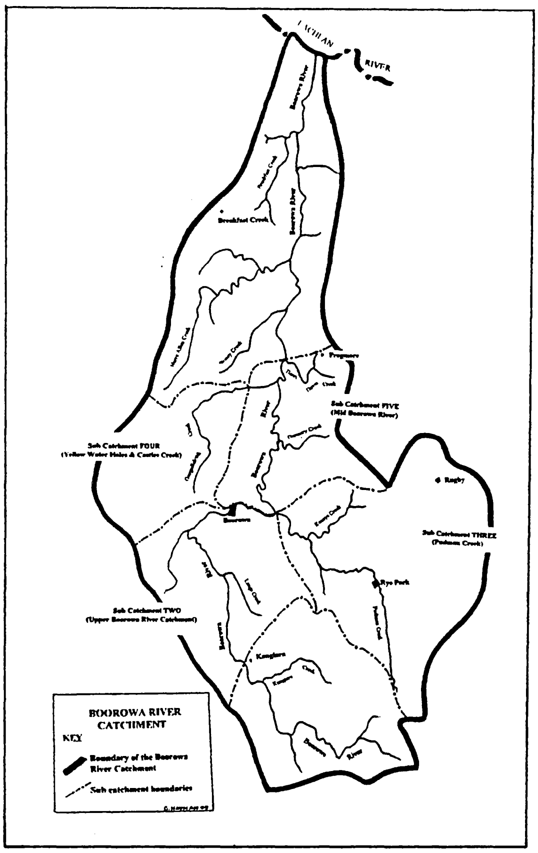

Figure One: The Boorowa River Catchment showing subcatchment boundaries.
Subcatchments 2,3,4 & 5 were found to be most affected by dryland salinity.

2.2 Goal Setting

In a consultative process between group members and the Project Officer a series of goals were established to carry the group into the short to medium term. Goals established were (Powell, 1992):

2.2.1 Split the Boorowa catchment into seven smaller subcatchments to enable more efficient identification, treatment programs and prioritisation to occur. Catchment numbers 2, 3, 4, 5 surrounding the Boorowa township were found to be the worst affected (Fig. 1)

2.2.2 Initially concentrate works programs on establishing perennial pastures upslope from saline discharge areas, utilising trees and salt tolerant pastures where necessary to reclaim and stabilise discharge sites.

2.2.3 Implementation to occur through the whole farm planning process, on an individual property basis.

2.2.4 Applying for funds to implement works programs and fund a project officer to aid in the implementation phase of the Boorowa River Salinity Catchment Plan.

This mapping and goal setting exercise formed the basis of our catchment plan. To be effective these plans must remain flexible, adapting to new research findings, if and when necessary.

2.3 Demonstration and Research Sites

Running concurrently with the development of the catchment plan are a number of demonstration and research sites designed to provide best bet options for the implementation phase of the project.

2.3.1 Allendale Demonstration Site

Funded by the National Landcare Program the aim was to find an economical way to control dryland salinity on a small well defined subcatchment. Management options used include deep-rooted perennial pastures, strip cropping and agroforestry on recharge areas. Discharge areas having salt tolerant pastures, shrubs and trees established. Grazing and crop production records will be kept for the life of the project, expected to be at least ten years. Soil and watertable monitoring will assist in project evaluation. An EM survey will be produced at the start and finish of the project. This site is now well established.

Recently a Salt Action grant was obtained to enable Mr. Basil Baldwin from the University of Sydney to carry out a detailed monitoring project on this site. This small well defined catchment is already beginning to demonstrate to local and surrounding groups, what the best bet options may be for the treatment of many land degradation issues on a total catchment basis. This site has had numerous field days with over 750 farmers, students and government agency staff visiting the project over the last two years.

2.3.2 Piezometer Monitoring Network

Many members have installed piezometers and continue to monitor them at monthly intervals for level fluctuations and salinity. This information will go on a Department of Land and Water Conservation (LAWC) database. Trends relative to resource management strategies in the area will hopefully emerge over time.

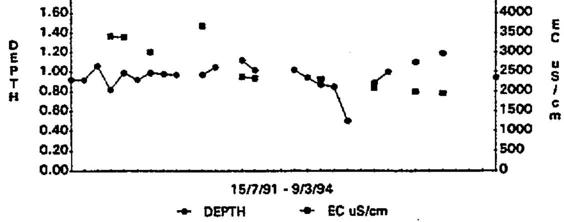

Figure Two: Information gathered to date from a piezometer at "Allendale" Boorowa.

2.3.3 Direct Seeding Trees - Trials

Trials have been conducted on several properties to establish the reliability and growth of direct seeded trees. The cost effectiveness of this process has also been established. A cost effective method was urgently required for large scale tree establishment.

2.3.4 Community Grasses Project

Boorowa has one of 19 paddock sites aiming to accelerate the adoption of low input, persistent, palatable perennial grasses, for already cleared uplands in the high rainfall recharge areas of the Murray-Darling Basin. This project was funded by the Murray-Darling Basin Commission.

2.3.5 Salt Loads in the Boorowa River

The Boorowa River enters the Lachlan at Cowra. Salt loads in the Lachlan River at this point vary considerably. Sampling from a rainfall event (Joyce & McAuliffe, 1993) of 87 mm over 24 hours provided an insight into the quantities of salt in the River system. Prior to the event salt exported from the Boorowa River at 126 T/day made up approximately 15% of the salt passing through Cowra. Directly after the event the proportion of salt from the Boorowa River increased to 5953 T/day or approximately 41% of the salt in the Lachlan River at Cowra.

Mr Ray Evans of the Australian Geological Survey Organisation is currently studying salt loads within the Boorowa River catchment. More information on this subject will be made available as his work progresses.

2.3.6 Local Watertable Status

Water table levels vary seasonably and are dependant upon local geology. In the Boorowa area there have been long term water table rises in the Ordovician and Silurian provinces. On the basis of water level trends it is expected that dryland salinity will continue to expand in the low lying areas of these provinces (Scott, 1991).
Water tables are now generally less than five metres from the surface (Scott, 1991) and in many areas ground water is under positive pressure. One local property observed a water level rise in a bore of three metres over seven years (Russell pers com, 1995).

Recent remapping of surface indicators of salinityon three propertiessuggests that salinity has spread at a rate of 10-30% annually since 1992 (Hayman, 1995 unpublished).

Better documentation of water tables will accumulate as piezometers continue to be monitored by Landcare members.

2.3.7 Pasture and Tree Survey

Figure Three highlights the amount of pasture and tree establishment being funded by the National Landcare Program between 1993 and 1997. From a survey conducted in 1994 it is evident that there is a great deal of perennial pasture and tree establishment occurring besides that which is funded by the National Landcare Program. In 1994 2102 ha of deep rooted perennial pasture was sown, 25% of this was partially funded. A further 3090 ha was planned for 1995 with 23% of it partially funded (Hayman, 1994).

The survey also indicated that 54% of those who responded have an annual tree planting program in place on their property (Hayman, 1994).

	Pasture (ha)	Trees
YEAR 1 1993-94	609	18.5 ha
YEAR 2 1994-95	1220	2500 trees
YEAR 3 1995-96	1030	30.3 ha
YEAR 4 1996-97	526	

NB: Stage I of the plan runs from 1993 until 1996 involving 23 properties. Stage II runs from 1994 until 1997 involving a further 28 properties.

Figure Three: Pasture & tree establishment partially funded by the National Landcare Programme,.

	Community contrib.	C&LM's contrib.	NLP NRMS
YEAR 1 1993-94	$97 350	$25 740	$137 139
YEAR 2 1994-95	$233 248	$16 300	$204 847
YEAR3 1995-96	$196 890	$16 300	$190 912
YEAR 4 1996-97	$89 939	$300	$72 970
TOTAL	$617 427	$58 640	$605 868

NB: Funding to employ a Project Officer is included in Years 1 - 3 allocation.

Figure Four: Funding provided by the National Landcare Programme's Natural Resource Management Strategy, C&LM and the community for the implementation of the Boorowa River Salinity Catchment Plan.

3. Implementation Phase

Two funding applications to the National Landcare Program (Natural Resource Management Strategy) and the then Department of Conservation and Land Management (now LAWC) have been successful, resulting in the commencement of phase one of the Boorowa River Salinity Catchment Project. This program will run from 1993 until 1997. It involved the appointment of a Project Officer (Miss Gillian Hayman) and assistance in funding large scale pasture and tree establishment on the four worst affected subcatchments.

3.1 Community Purchase - Direct Seeder

As the catchment plan has developed a distinct need for a large scale, cost effective method of tree establishment was evident. Having proved the effectiveness of direct seeding trees, we set about putting together a sponsorship portfolio to present to prospective sponsors. This program was successful in raising $9,000.00 and enabled the purchase of a Rodden III direct seeder. Nine major sponsors including local businesses, Shire Council and the Lachlan Catchment Management Committee made this possible.

3.2 Growing Community Awareness

Due in part to a steady flow of information and communication between Landcare and the community, environmental awareness and enthusiasm has increased markedly. Beginning with John Powell's work and continued by our current Project Officer, Gillian Hayman, community involvement and commitment is snowballing. The local Council has been increasingly supportive, culminating recently with a successful initiative by Council to obtain funding through the National Landcare Program for "The Re-establishment of Superb Parrot Habitat" on Main Road 248. This project effectively ties road re-construction with the treatment of waterlogging, salinisation and bird habitat re-creation. Greening Australia, Boorowa Landcare, Boorowa Council and all Boorowa district schools contributed to this project. This project culminated in a commemoration ceremony marking the Australia Remembers campaign, held on 5 May this year. Every school child in the Boorowa district planted a tree on this day.

4. Continued Development of the Catchment Plan

A successful plan is not one that stays static but grows with group and community awareness and enthusiasm.

4.1 Better Recharge Area Identification

Funds have been applied for to produce a hydrogeological map of the Boorowa River catchment. This map is seen as critical in order to make informed decisions on where to site large scale revegetation projects and land management options. Better recharge identification is essential for prioritising future actions.

4.2 Landcare Groups in the Boorowa River Catchment

Recently the five Landcare groups in the Boorowa River catchment met and formed a regional association in order to present coherent, prioritised action plans to the Lachlan Catchment Management Committee for consideration. This regional approach to planning will aid in identifying major problem areas and targeting the worst affected ones.

4.3 Instant Survey

The Instant Survey computer program and satellite imagery for the Boorowa catchment has been purchased recently. The catchment plan is currently being entered on to this system and will allow much greater flexibility, with many more options for catchment planning available.

4.4 Perceived Problems

4.4.1 Economic Data Availability

Although we have a research project aimed at the economic evaluation of the best bet systems being used in our catchment plan, no results are available as yet, nor will be for several years to come. It is very difficult to get any worthwhile economic data on the systems being used. When trying to promote new resource management systems, it becomes very difficult when there is insufficient economic data to back up out 'best bet' options. Surely this information must be available somewhere. This type of research if completed is certainly not getting to the end user.

4.4.2 Continuity of Funding for Project Officer and Implementation Programs

The necessity to produce long term plans and the very short term nature of funding for management and implementation are definitely at odds with each other. Implementation programs such as the Boorowa River Salinity Catchment Plan would be very difficult without a Project Officer to manage the program.

5. Conclusion

The Boorowa Community Landcare group has been very fortunate in having the support of numerous government agencies and community members. Their constant support and guidance is greatly valued.

Let us continue to awaken the sleeping giant of community awareness, as they are our greatest ally in the political decision making process.

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Evaluation of the Potential of Break of Slope Forestry in Catchment Salinity Control

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Introduction

The Goulburn Dryland Salinity Management Plan (GDSMP - SPPAC 1989) canvassed three main salinity management options for upland areas of the Goulburn catchment;

- high density non-commercial tree growing,
- low density tree growing in existing pastures,
- perennial pasture establishment.

Adoption of the latter two recommendations by landholders has been far slower than anticipated in the salinity management plan (Feehan *et al.* 1993). This is the result of adverse economic conditions, the cost and difficulty of implementing these measures and doubts as to their effectiveness in providing long-term protection from recharge. Adoption of high density tree growing has exceeded implementation targets. Nevertheless this is a non-commercial management option and hence its adoption will not be extensive enough to control groundwater recharge across the high recharge zone of the Goulburn catchment.

Since implementation of the GDSMP began in 1989, there has been growing interest in the use of *commercial* tree growing in the management of dryland salinity. Several options exist, including the use of commercial plantations, timberbelts or agroforests to reduce recharge and the use of such systems to intercept and evaporate groundwater that would otherwise increase salinity risk lower in the landscape.

Break of slope forestry

Dyson (1992) proposed the establishment of timberbelts at break of slope (BOS) positions in certain landscapes. In some upland areas of low permeability bedrock (e.g. granites, rhyodacites, rhyolites), most groundwater movement is through the colluvium overlying that bedrock. The change in hydraulic gradient at the break of slope in the landscape results in groundwater mounding - the presence of high water tables. In many landscapes, this groundwater is quite fresh. Timberbelts established at the BOS have the potential to draw on and evaporate this water before it contributes to higher groundwater pressures and salinity in lower parts of the landscape. Additional water availability also offers the potential of enhancing tree growth and so improving commercial prospects for BOS forestry.

The required hydrogeological setting for BOS forestry in the Goulburn catchment is found along the western and northern fringe of the Strathbogie Ranges. Local landholders here hope ultimately to develop private forestry (or agroforestry) as an economically viable and (more) environmentally sustainable industry in their area.

BOS forestry has potential applications in areas of suitable geology and geomorphology outside the Goulburn catchment. However only a very few trial plantings have taken place outside the that catchment.

This paper reports on progress with investigations into the effectiveness of BOS forestry in catchment salinity control. This work commenced in 1994.

The Warrenbayne-Boho Landcare Group area

Investigations into the effectiveness of BOS forestry are centred on the Warrenbayne-Boho Landcare Group area, in north-eastern Victoria. The uplands in this area are formed from acid igneous lavas, mainly Devonian rhyodacite (Rundle and Rowe 1974) which have low permeability and constitute only a minor aquifer. The major aquifer systems are contained within the weathered zone and colluvium overlying this bedrock, and within the Riverine Plain sediments which flank the uplands to the north. Average annual rainfall varies between about 750 mm on the nearby plains to over 1200 mm at the tops of ridges (Rundle and Rowe 1974).

In cleared agricultural land, both the colluvial and plains aquifers display rising trends in water levels. The plains aquifers show consistent long term rises in the order of 0.1-0.2 m/y over the last 12 years of monitoring; these rises are considered to be an up-gradient response to filling of the regional aquifer system. The unconfined upper slope colluvial show marked variations due to seasonal recharge, with long term trends ranging up to 0.1 m/y. At the lower slope-plain interface the aquifer systems are generally semi-confined with fluctuating water levels which are often above ground surface at least once yearly. Salinity discharge is concentrated along the lower slope-plain interface. Eighty-five sites, ranging in size from 0.3 to 65 ha have been mapped (912 ha in total).

Some 49 ha of BOS plantation has been established in the Warrenbayne-Boho area since 1992. Interest in BOS forestry has grown to the point where 70 ha of plantation are expected to be established in 1995 (Lumsdon MS). Most of the earlier plantings were of *Eucalyptus globulus* (Blue Gum), but a wider range of eucalypts, as well as *Pinus radiata*, have been used in more recent plantings (Lumsdon MS).

Methods and materials

Detailed site water balance investigations are being carried out on two BOS plantations in the Warrenbayne area. Both plantations are located at the break of slope in north to north-west facing landscapes. The *E.globulus* plantations at both sites were established in August 1993 at roughly 1100 trees/ha (3 m spacing).

Measurement plots were established to determine whether there was variation in tree growth or stand water balance with distance into the plantation. Three plots were established at site 1, at the bottom, middle and top of the plantation (plots 1, 2 and 3). A further two plots were established at site 2, at the bottom and top of the plantation (plots 4 and 5).

Tree dimensions were assessed at the time of plot establishment and again in April 1995. The over bark stem diameter at breast height (dbh) was recorded for all trees in the plots. Heights of the five fattest trees on each plot were measured by clinometer to determine the mean predominant height (pdh).

Average leaf area index of each plot is estimated periodically by light interception techniques. Leaf area of each of the trees on which transpiration is being measured was assessed using the non-destructive "reference module" technique of Andrew *et al.* (1979) in December 1994.

Transpiration by trees was estimated from measurements of sap flow (e.g. Edwards and Warwick 1984) at both study sites. Commercially available heat pulse units were used ("Custom" and "Greenspan" instruments).

Sap flow measurements commenced at both sites in September 1994. Two instruments were deployed on each plot. Sap flow is measured at 30 minute intervals over three weeks. Measurements are taken on eight trees in each plot over a three month period.

Interception of rainfall by trees was determined in all five plots from the difference between rainfall in the open and the sum of throughfall and stemflow. Throughfall was collected in 3 m lengths of 0.1 m wide roof guttering and stored in 45 l drums. Stemflow was collected in collars made from 18 mm wide rubber car door seals that were stapled to the stem of the trees and sealed with a silicone sealant. Measurements commenced in October 1994.

Patterns of soil water depletion on each plot are investigated using gypsum blocks. Four gypsum blocks were installed at each depth of sampling (25, 50, 100 and 150 cm - site 1 only).

Groundwater information was obtained from monitoring bore transects located within and immediately downslope from the two BOS plantations. Where sufficient thickness of aquifer was encountered, both deep (approx. 20m depth) and shallow (approx 10m depth) bores were drilled at a site. The bores are monitored monthly for water level, and annually for salinity.

Tree growth and dimensions

Growth of the trees in the two plantations under detailed investigation has been quite outstanding. The tallest trees in the plantations have grown to heights in excess of 12 m during the three years since planting. Stem diameters of many of the larger trees exceed 11 cm.

Average values of stem diameter and plot predominant height and growth during the 1994/5 are given in Table 1. Trees grew quite well during that period despite rainfall (in 1994) being 300 mm less than average. Stem diameter across the two sites increased by an average of about 0.5 cm and predominant height increased by between 1 and 2.5 m.

Table 1. Size and growth of trees and their crowns at study sites, Warrenbayne.

Plot	Diameter (cm)			Predominant height (m)			Leaf area	
	Aug 94	Apr 95	Growth	Aug 94	Apr 95	Growth	Tree[1]	Plot[2]
1	8.30	8.75	0.45	9.50	10.34	0.84	24.8	1.79
2	8.38	8.82	0.44	8.88	10.34	1.46	19.2	2.03
3	7.55	8.16	0.66	8.26	9.32	1.06	17.3	1.32
Site 1	8.08	8.57		8.88	10.00			
4	6.80	7.59	0.79	7.66	10.06	2.40	18.1	1.59
5	7.92	8.34	0.42	7.22	9.72	2.50	20.1	1.70
Site 2	7.36	7.97		7.44	9.89			

1. Tree leaf area (m^2/tree) in December 1994
2. Plot LAI in June 1995

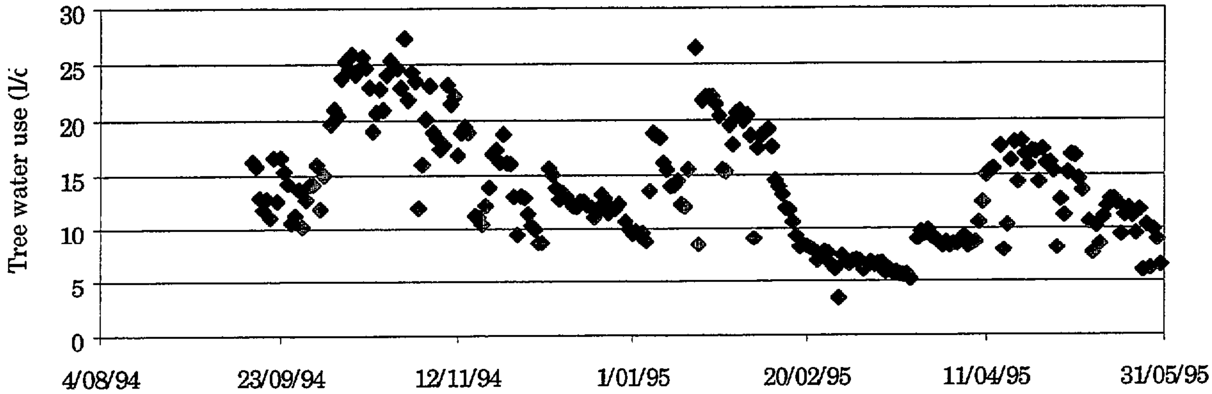

Figure 1. Variation in average daily transpiration rate by *E.globulus* trees in plot 3, Warrenbayne.

Total leaf area of trees on which transpiration measurements are being carried ranged between about 14 and 30 m^2. Average leaf area declined with distance upslope at site 1 and increased with distance upslope at site 2 (Table 1). Plot LAI remained varied between about 1.1 and 1.8 at the time of the first measurement in February 1995. LAI changed little between February and early June on site 2, but increased at site 1 by an average of about 0.3 units during May 1995, presumably in response to the autumn break (Table 1).

Despite the large rainfall deficit the only trees succumbing to the adverse conditions during the summer of 1994/5 were those already suppressed by competition.

Transpiration and interception

Up to two values of daily transpiration per plot are recorded each day. Figure 1 provides an example of how the daily average of these values varied during the study period. Patterns of variation in transpiration rates over the study period were similar for all plots.

Transpiration rates on all five plots ranged between about 5 l/tree/d and about 25 l/tree/d. Three peaks in daily transpiration were observed;

- Spring 1994 - where high rates of transpiration coincided with mild weather conditions and moderate soil water availability.
- Late January 1995 - where high rates of transpiration followed substantial rainfall in that month (91 mm).
- Mid-autumn 1995 - higher rates of transpiration followed the autumn break and remained while weather conditions were mild.

Low and/or declining transpiration rates were associated with the very warm and dry weather experienced in December 1994 and the very dry period between mid-February and early April 1995. Average transpiration rates over the sampling period are given in Table 2. These values ranged between 10.8 and 13.7 l/tree/d.

Table 2. Average tree and plot transpiration rates and total transpiration during the study period.

Plot	Average daily transpiration l/tree/d (s.e.)	Plot transpiration (mm) normalised by dbh[1]	
		Daily ave	Total[2]
1	11.13 (0.34)	1.11	286
2	10.84 (0.28)	1.11	287
3	13.72 (0.34)	1.33	342
Site 1	11.90	1.18	305
4	12.45 (0.34)	1.35	349
5	12.30 (0.31)	1.33	343
Site 2	12.38	1.34	346

1. Estimate of plot transpiration based on average transpiration per tree per unit dbh and the average diameter and number of trees per plot.
2. Total is calculated for a 258 day period between September 1994 and May 1995.

Plot transpiration, that is transpiration per unit ground area, was estimated by normalising transpiration per tree by stem diameter - to account for the influence of tree size on transpiration rates. Individual tree transpiration was divided by dbh and the average value of this parameter per plot then multiplied by the average dbh and subsequently divided by the average space occupied by each tree.

Total transpiration over the period for which data is currently available ranged between 286 and 349 mm. Total plot transpiration was about 40 mm/y less at site 1 than at site 2. Total rainfall was approximately 400 mm during the corresponding period.

Interception, the difference between rainfall in the open and the sum of throughfall and stem flow, ranged

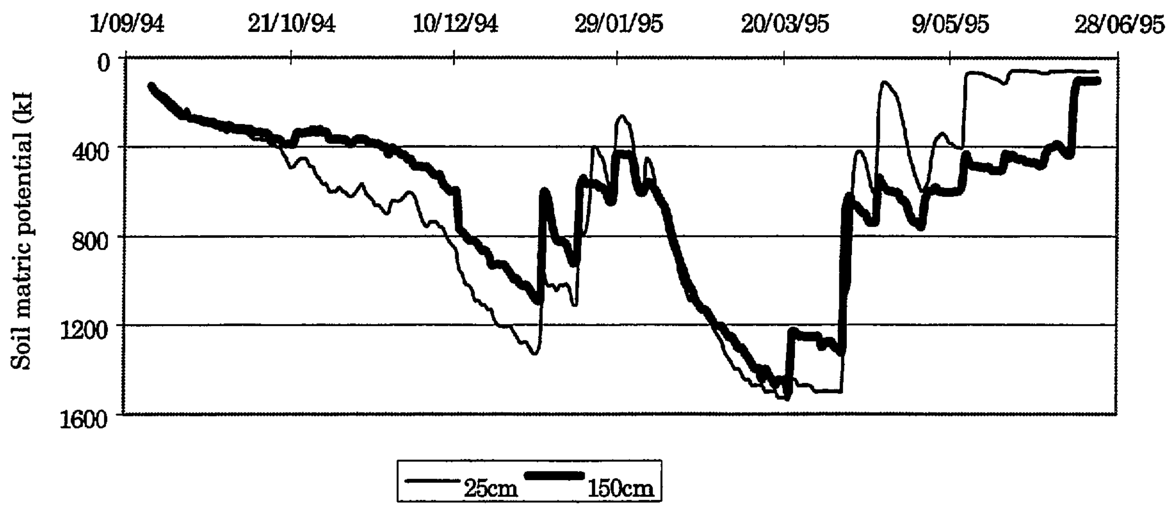

Figure 2. Changes in soil matric potential below break of slope plantation (plot 3) at Warrenbayne. Data shown for 25 and 150 cm depths.

between about 10 and 40 mm between October 1994 and May 1995. Most of this was recorded during May 1995, when there was a large number of low intensity rainfall events. Total interception ranged between about 3 and 13% of rainfall overall (data does not include January).

Total evaporation (interception plus transpiration) accounted for between about 75 and 95% of rainfall during the study period.

Soil water

Variation in soil matric potential for 25 and 150 cm depths is shown in Figure 2, using plot 3 as an example. Patterns of soil water depletion were similar across all five plots.

Figure 2 showed two main periods of drying over the summer-autumn period. The soil profile dried extensively under the prevailing warm and dry conditions during December 1994. Rain during January 1995 substantially reduced the soil water deficit. The soil profile dried to wilting point during March 1995. Autumn rains rapidly wet up the top of the soil profile. There was a delay of 4-6 weeks in the soil at 150 cm wetting up. By mid-June the soil at 150 cm was still not quite saturated.

Groundwater

Variation in groundwater levels in a transect of three bores at the site 2 are shown in Figure 3, together with a hydrograph from an untreated area.

All three transect bores show little response rainfall in 1994/5. The water levels display a sustained downward trend from January 1994. Bore 8453d (at BOS, below plantation) shows a decrease in groundwater levels of approximately 2 m during 1994. Bores 8454d and 8455d, which are located 50 and 100m downslope of the plantation respectively, suggest that the plantation may depress water tables over a significant down-gradient area. A bore located in a cleared area within the same sub-catchment shows a modest seasonal rise in watertables and little or no sign of net fall.

DISCUSSION

The objective of break of slope forestry is to provide a commercially viable and environmentally sustainable alternative to conventional farm management practices in areas with geology suited to BOS forestry. It seeks to improve the sustainability of land management by reducing salinity risk by both of the following;

- reducing or eliminating recharge to groundwater from within the plantations themselves,
- establishing trees that will intercept and evaporate groundwater sourced from upper parts of the landscape.

There is not *yet* clear evidence *from this study* that BOS forestry will be effective in fully achieving the above objective. However, the study is far from complete and has, to date, been conducted in a period of unusually low rainfall. The BOS plantations under investigation are also only three years old and may presently be too young to have the desired water balance effects.

The main findings of the first year of this study are as follows.

a) *Tree growth* - growth of trees at the two study sites has been outstanding. Even under dry conditions in 1994, predominant height increased by 1-2.5 m.

b) *Tree survival* - That young trees can withstand the severe environmental stresses experienced during 1994/5 suggests that even without access to additional water from the water table (as appears to have been the case), *E.globulus* trees

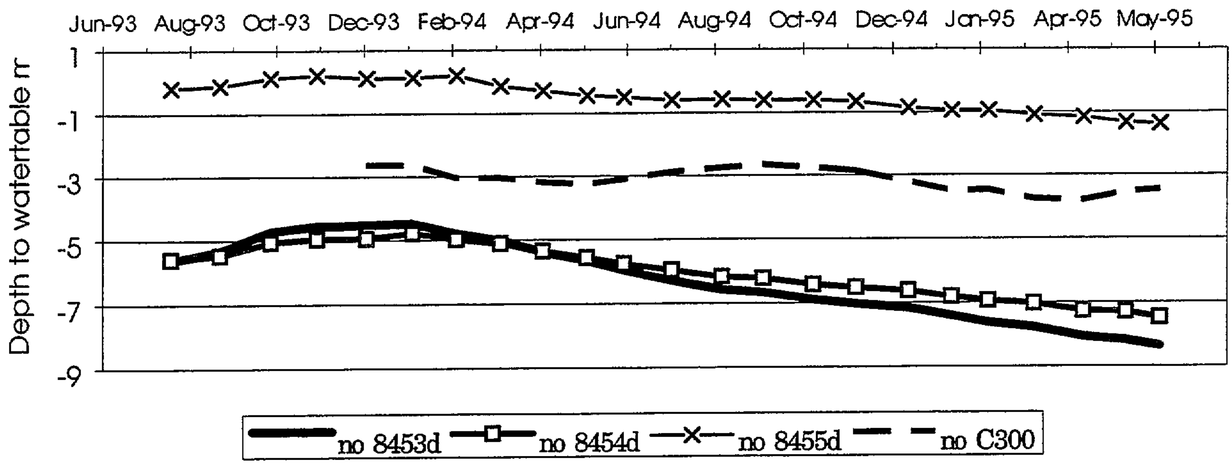

Figure 3. Hydrographs from a transect of 3 bores at the site 1 BOS plantation, Warrenbayne. Also shown is a hydrograph from an untreated area (Bore C300).

may survive to a merchantable age and grow acceptably well in the Warrenbayne area.

c) *Tree water uptake* - By combining transpiration by the trees and the evaporation of water intercepted by their crowns it is possible to demonstrate that these three-year-old BOS plantations evaporated 75-95% of rainfall during the study period. Transpiration rates during late summer and early autumn were very low and were clearly limited by low water availability. Further evaporation would have been possible had more water been available.

d) *Use of groundwater by BOS plantations* - Rates of transpiration by trees in all plots were very low in autumn. Although there was some evidence (not reported here) that groundwater uptake was occurring, it was, at best, at a minimal rate.

Groundwater levels within or near the two BOS plantations fell by 2-3 m during 1994. Water tables had fallen to over 7 m by May 1995. The great depth to groundwater coupled with low summer transpiration rates suggests that the water table had become too deep for the trees to take up water *at this stage in their development.*

The evidence that BOS plantations will be effective in reducing salinity risk in treated catchment areas is scant at present, but are nonetheless positive. Plantations have survived well and are growing rapidly. Although rates of water uptake by trees in the plantations have not been high, water tables within and below BOS plantations have been dropping at greater rates than in untreated areas.

ACKNOWLEDGMENTS

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Strontium and Sulphur isotopes as tracers of flow systems in regional aquifers, South-western Murray basin

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Introduction

The Mallee region of South Australia extends over 25,000 Km^2 of the south west Murray basin (Fig 1). Groundwater is the primary water resource in the area for irrigation, domestic, stock and municipal use. The regional groundwater system comprises of the unconfined Murray Group aquifer overlying the confined Renmark Group aquifer separated by a 20-30 m thick confined layer (Barnett, 1983).

The Murray Group is the only aquifer extensively exploited because of its easier access, high productivity and good water quality. Groundwater salinity in the Murray Group aquifer changes systematically as it moves along the hydraulic gradient, ranging from less than 1000 mg/l near the basin margins to more than 20,000 mg/l, 300 km down gradient. The aim of this paper is to investigate regional scale groundwater processes affecting the concentration and composition of dissolved solutes in the Murray Group aquifer.

Although the cause for increasing dryland salinity in some parts of the basin is well known e.g. (Allison 1985), very few studies concerning hydrochemistry and salinisation of groundwater in the study area have been published so far (Kellet, 1990., Leaney, 1994). Because hydrochemistry and stable isotopes alone are not sufficient to distinguish waters from the Murray Group and Renmark Group (Herczeg, 1989), we explore the possible use of other isotope systems ($^{87}Sr/^{86}Sr$ and $\delta^{34}S$), to evaluate physical and chemical processes occurring in the Murray Group aquifer system to establish flow systems and inter-aquifer mixing with the Renmark Group.

Background

The isotopic ratio of dissolved strontium in groundwater depends on the respective contribution of different minerals to dissolved Sr. Strontium-87 and strontium-86 are stable isotopes of strontium, and the strontium isotopic ratio of minerals varies as a result of the

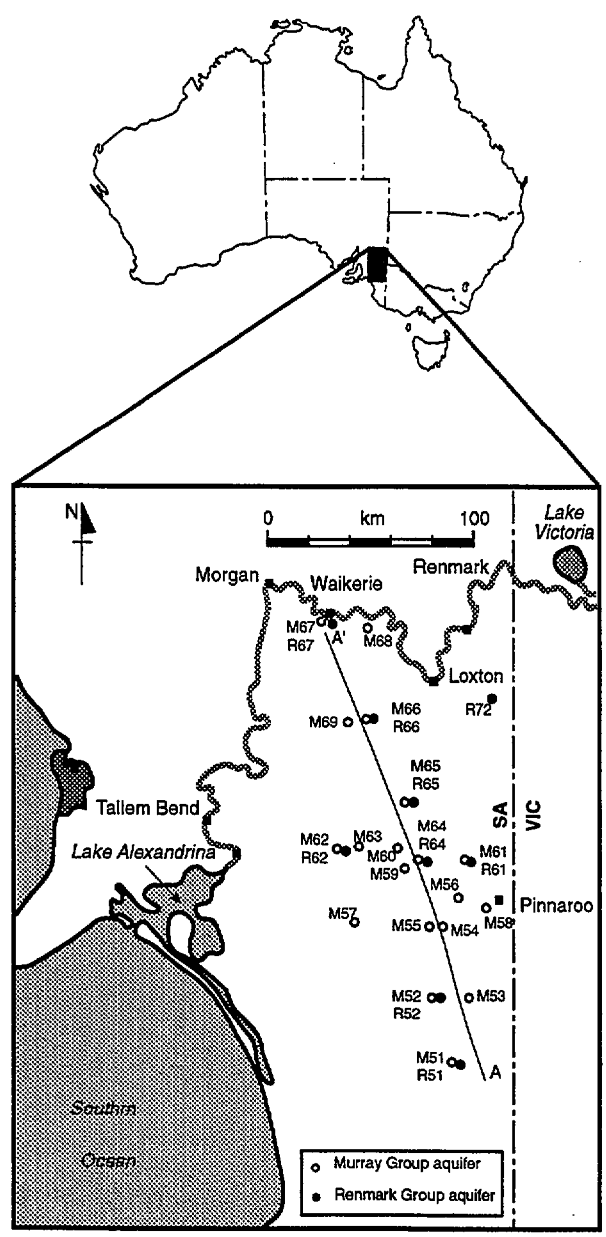

Figure 1. Location of the study area, south west Murray Basin, and groundwater sampling locations

formation of radiogenic ^{87}Sr by the decay of naturally occurring ^{87}Rb. For this reason the strontium isotopic ratio in a rock or mineral depends on it's age and Rb/Sr ratio of that rock or mineral (Faure, 1986).
The $^{87}Sr/^{86}Sr$ ratio of marine carbonates ranges from 0.7068 for Permian to 0.7091 for Precambrian carbonate minerals. Other rock forming minerals tend to have wider range of $^{87}Sr/^{86}Sr$ ratio (0.6990 to >0.9000), and Sr in groundwater will be modified depending on the degree of reaction with these aquifer minerals.

The lack of significant mass fractionation of the strontium isotope in response to physical processes provides an excellent tracer to assess the degree and extent of water-rock interaction in the aquifer. If groundwater has reached equilibrium with the aquifer matrix then the water should have the same $^{87}Sr/^{86}Sr$ signature as the aquifer matrix. If, on the other hand, exchange has occurred with some minerals but not with others, then the groundwater and total rock matrix will not have the same value.

The difference in the environment of deposition of the Murray Group and Renmark Group sediments, leads to a distinct difference in their rock geochemistry and consequently to a dissimilarity in their strontium isotope signatures. The Renmark Group is a Paleocene fluviolacustrine deposit, and consists mainly of quartz minor carbonate and feldspar, with trace amounts of clay minerals and organic substances. In contrast, the Murray Group limestone is marine to marginal-marine deposit, overlying unconformably on the Renmark group consisting mainly of carbonate minerals, minor quartz and trace amounts of clay minerals.

The $^{87}Sr/^{86}Sr$ ratio of marine carbonate from the Murray Group limestone is identical to that of sea water at the time of deposition (Oligocene-Middle Miocene) ~ 0.7080. Groundwater in contact with this formation will have the same signature giving sufficient time to equilibrate. In contrast, the $^{87}Sr/^{86}Sr$ signature of the Renmark Group groundwaters depends on initial strontium isotope ratios in recharge water plus, rubidium content, and the age of the Rb-bearing minerals in the aquifer sediments.

Murray aquifer	Distance Km	TDS (ppm)	Cl^- (mmol/l)	SO_4^{-2} (mmol/l)	SO_4^{2-}/Cl^-	Sr (μmol/l)	$\delta^{34}S$ (‰,CTD)	$^{87}Sr/^{86}Sr$ Carbonate	$^{87}Sr/^{86}Sr$ Groundwater	$\delta^{18}O$ (‰,SMOW)	δ^2H (‰,SMOW)
M51	100	747	6.2	0.5	0.09	11.3	13.1	0.70861±9	0.70879±8	-5.91	-38.3
M52	125	836	8.6	0.5	0.05	11.0	14.5	0.70862±8	0.70902±5	-6.35	-38.1
M53	130	875	8.9	0.5	0.05	11.9	11.8		0.70906±2	-6.02	-38.6
M54	170	970	9.0	0.9	0.10	5.5	12.4		0.70927±4	-6.18	-39.0
M56	170	729	6.4	0.6	0.10	6.4	13.2		0.70931±3	-5.90	-39.7
M55	170	949	9.1	0.8	0.08	3.2	14.6		0.70951±8	-5.95	-40.7
M57	170	794	5.9	0.9	0.15	29.0	10.1		0.70880±13	-5.54	-42.1
M58	170	789	5.8	1.0	0.16	12.0	0.3		0.70890±8	-5.86	-40.4
M59	190	1920	24.5	1.9	0.08	16.0	12.5		0.70933±6	-5.59	-40.1
M61	200	1265	14.7	1.2	0.08	14.0	14.8	0.70872±18	0.70921±3	-5.78	-40.3
M62	230	2238	25.1	1.9	0.08	22.0	11.7		0.70898±7	-5.05	-37.1
M63	230	2325	27.5	2.3	0.08	15.0	6.1		0.70924±8	-5.29	-38.3
M64	210	2017	25.7	1.9	0.07	14.0	14.2	0.70841±22	0.70926±4	-5.78	-41.6
M65	250	1675	16.9	2.0	0.12	13.0	7.0	0.70884±14	0.70903±8	-5.59	-39.3
M66	280	5746	72.8	5.1	0.07	55.0	18.6	0.70843±8	0.70869±12	-5.00	-36.9
M69	280	5672	71.1	6.4	0.09	63.0	18.4		0.70865±3	-4.74	-36.9
M67	310	21975	339.7	24.3	0.07	236.0	26.0		0.71114±22	-4.37	-35.2
M68	300	21129	347.0	10.5	0.03	289.0	6.7		0.70970±4	-4.47	-36.0
Renmark aquifer											
R51	100	860	8.7	0.6	0.07	6.7	14.9	0.70825±16	0.70969±10	-5.64	-38.7
R64	210	1151	11.6	0.9	0.08	7.1	17.4	0.70848±30	0.70977±7	-6.09	-41.0
R61	200	1242	11.7	0.5	0.05	4.6	38.5		0.70957±10	-6.42	-43.1
R62	230	2128	19.8	1.0	0.05	1.0	34.3		0.70982±6	-6.48	-40.5
R65	250	1855	15.3	0.3	0.02	0.5	56.4	0.70842±8	0.70926±9	-6.01	-41.0
R66	280	3213	36.7	1.2	0.03	6.6	51.7	0.70908±21	0.70950±5	-5.98	-38.5
R67	310	15043	233.7	12.8	0.06	147.0	21.3		0.71044±10	-4.48	-39.3
R72	300	4511	66.5	2.0	0.03	32.4	36.7		0.71092±24	-5.83	-37.1

Table 1. Salinity, Cl^-, SO_4^{2-}, $^{87}Sr/^{86}Sr$, $\delta^{34}S$, $\delta^{18}O$, and δ^2H of groundwater, and $^{87}Sr/^{86}Sr$ ratios of carbonate component of aquifer matrix from the Murray and Renmark Group aquifers. The results of chemical analysis are quoted in millimoles or micromoles per litre (as indicated). TDS is expressed in parts per million and is calculated by summing the major cations and anions. Distance refers to the approximate distance of the well along a AA' transect. The $\delta^{34}S$ is the sulphur isotope composition of sulphate expressed in per mil notation relative to standard Canyon Diablo Troilite (CDT). Errors for $^{87}Sr/^{86}Sr$ ratio are 2σ mean and apply to the last decimal place.

The $\delta^{34}S$ for dissolved sulphate in groundwater depends on the origin of sulphate in the recharge water, and subsequent geochemical reactions affecting SO_4^{2-} within the aquifer. $\delta^{34}S$ values of precipitation approximate that of marine sulphate ($\delta^{34}S \sim 20‰$) in coastal environments (Nriagu, 1992). The variability of redox conditions throughout the two aquifer systems in the Mallee area may modify the signature of $\delta^{34}S$ and concentration of sulphate for each aquifer. In the anaerobic Renmark Group aquifer, $\delta^{34}S$ will be enriched through the preferential bacterial reduction of isotopically light SO_4^{2-} molecules. In contrast, groundwater in the more oxidised Murray group aquifer will have the same $\delta^{34}S$ values as that of SO_4^{2-} in precipitation which eventually recharges the Murray aquifer. Oxidation of organic S compounds or sulphide minerals (pyrite), can contribute and change $\delta^{34}S$ values of oxidising groundwater.

RESULTS AND DISCUSSION

Stable isotopes ($\delta^{18}O$ and $\delta^{2}H$)

Some chemical and isotopic results for the Murray and Renmark aquifer systems from the Mallee region are presented in (Table 1). The data represents a transect for the Murray aquifer, along an inferred flow line from the basin margin down gradient towards the River Murray (Fig 1). The stable isotope data obtained from both aquifer systems are summarised in (Fig 2).

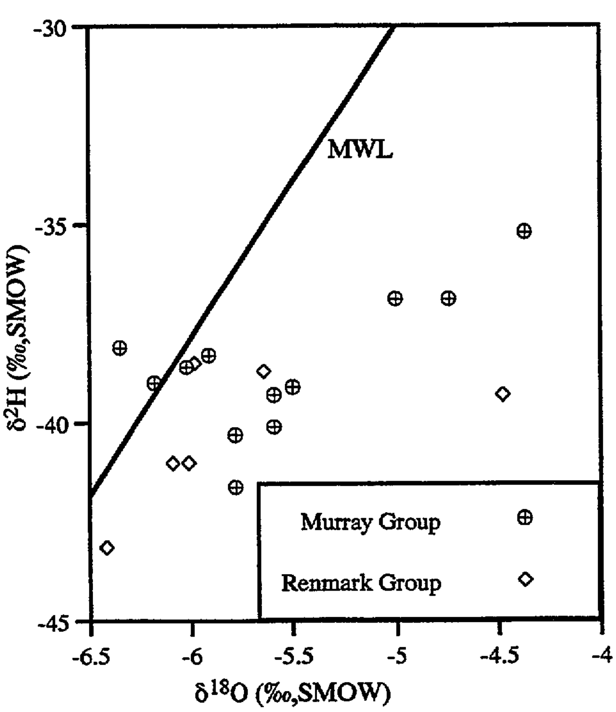

Figure 2. Deuterium and Oxygen-18 Composition of Groundwater

Deuterium and oxygen-18 isotopic ratios of water from the Murray aquifer and the Renmark aquifer systems suggest that, the waters in both aquifer systems are of meteoric origin. They plot slightly to the right of the MWL (Meteoric-Water line) which is caused by evaporation occurring prior to recharge to the aquifer. Groundwater from the Murray aquifer represents addition of increasingly evaporated water along the flow system which also adds increasing amounts of dissolved solutes to the groundwater.

Strontium isotopes

Strontium concentrations in the Murray Group aquifer range from 3.2 μmol/l to 289 μmol/l. Groundwater in the Renmark aquifer contains less strontium with the highest value of 147 μmol/l. The isotope ratio versus Sr concentration (Fig 3), shows that the Sr isotope values for the Renmark aquifer are generally more

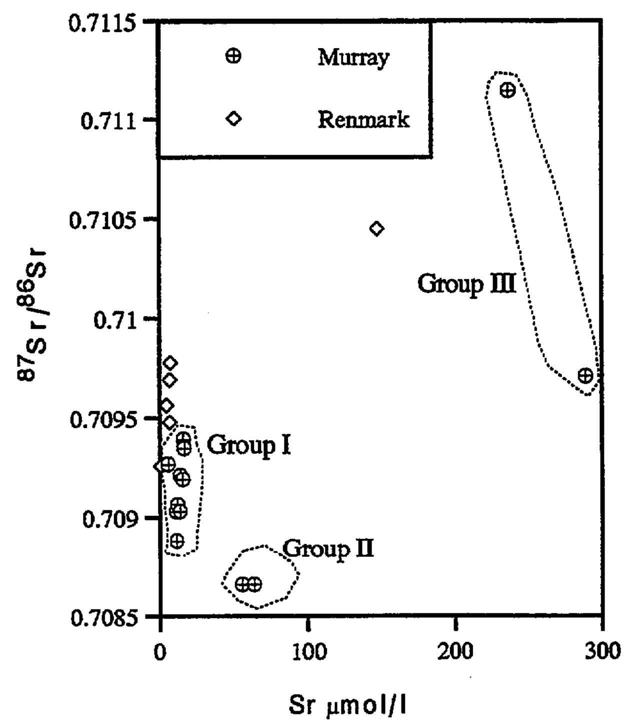

Figure 3. $^{87}Sr/^{86}Sr$ ratios vs. Sr content of groundwaters from the Murray and Renmark Group aquifer systems. For comparison, the figure shows the three distinct groups for the Murray aquifer

radiogenic ranging from (0.70926±9 to 0.71092±24) than the corresponding water samples from the Murray aquifer. This may be due to interaction with the aquifer matrix over a long period of time which has a higher Sr isotopic ratio than the matrix in the Murray aquifer.

Sr concentrations and $^{87}Sr/^{86}Sr$ ratios of the Murray Group aquifer samples can be divided into three groups (Fig 3). The majority of the samples fall into group I which covers the first 200 km of the main flow line. Sr concentrations of this group are between 3 and 28 μmol/l with the Sr isotope ratio between 0.70879±8 and 0.70951±8. The high $^{87}Sr/^{86}Sr$ ratio in this group (higher than the corresponding host rocks $^{87}Sr/^{86}Sr$

ratio), could be due to mixing, where one end member represents groundwater equilibrated with Miocene limestone with $^{87}Sr/^{86}Sr$ ratio 0.70843±8 to 0.70884±14 (Table 1), and the second end member is derived from minerals containing more radiogenic values (>0.7096) such as feldspar or mica. $^{87}Sr/^{86}Sr$ ratios of group II , (M66 and M69 at Maggea 280 km) are ~0.70867 with higher strontium concentrations than the first group. These groundwaters may have approached equilibrium with the carbonate component of the host rocks(Table 1).

The third group represents two wells at the end of the flow line 300km and 310 km near the River Murray M67 and M68 (Fig 4). The high $^{87}Sr/^{86}Sr$ values 0.70970±4 and .71114±22 may be due to upward leakage from the Renmark Group aquifer. The $^{87}Sr/^{86}Sr$ ratio of these samples are in agreement with the hydraulic data, which indicates the potential for upward leakage from the Renmark aquifer in this region (Barnett 1994).

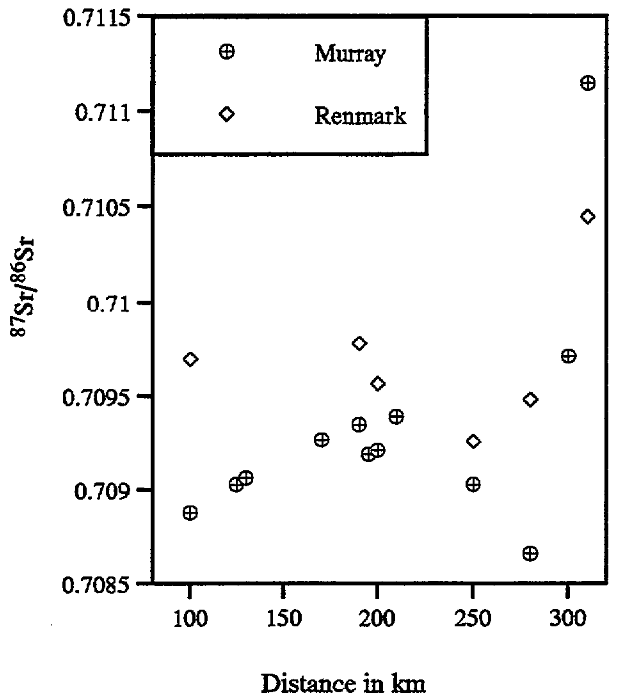

Figure 4. $^{87}Sr/^{86}Sr$ ratio of the groundwater from the Murray and Renmark Group aquifers along the AA" transect

Sulphur isotopes

SO_4^{2-}/Cl^- ratios in the Murray and Renmark aquifers display considerable variation along the flow line (Fig 5). At well M64, 210 km from the basin margin the SO_4^{2-}/Cl^- ratio for both aquifers are identical, then the SO_4^{2-}/Cl^- ratio decreases in the Renmark aquifer while the Murray group aquifer remains about the same except for wells at Maggea 280 km.

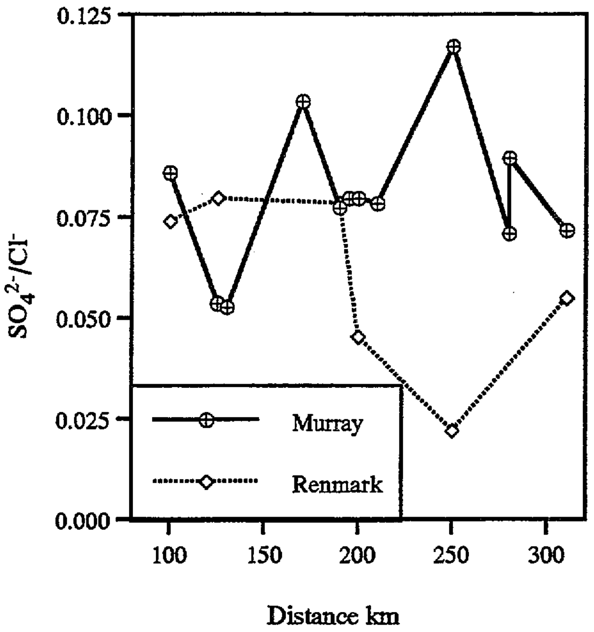

Figure 5. SO_4^{2-}/Cl^- ratio of the groundwateralong the AA' transect

The sulphur isotope content of sulphate from most wells within the Murray aquifer, indicates that almost all the sulphate is derived from cyclic salt plus oxidation of organic sulphur ($\delta^{34}S$ =+6 to +15‰), and very little sulphate is derived from oxidation of sulphide (Table1). All Renmark aquifer samples exhibit $\delta^{34}S$ value in the range of +18 to +55 ‰, and are significantly enriched relative to the values obtained for the Murray Group aquifer (+6 to + 18‰). All of the enriched values correspond to low SO_4^{2-}/Cl^- ratios (Fig 6.) which indicates sulphate reduction.

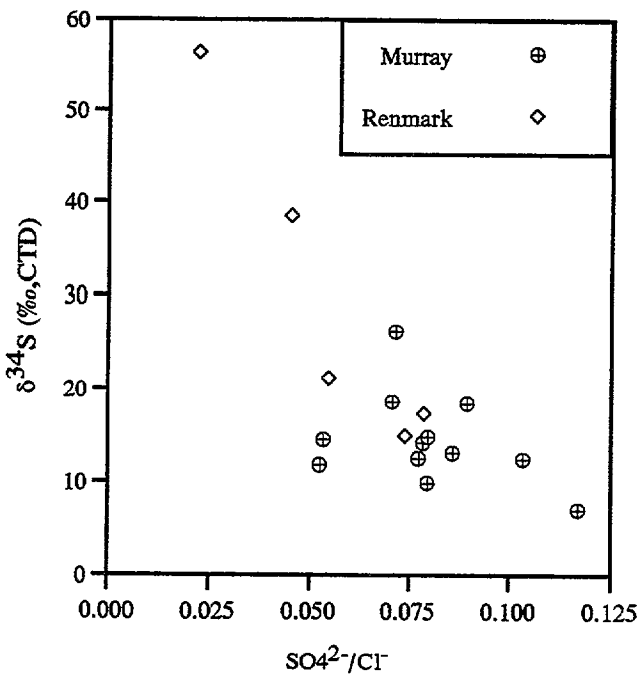

Figure 6. SO_4^{2-}/Cl^- vs. $\delta^{34}S$ of the groundwater from the Murray and Renmark Group aquifer systems

Increasing $\delta^{34}S$ values and decreasing SO_4^{2-}/Cl^- ratios indicate increasing fraction of SO_4^{2-} reduced within the Renmark aquifer. $\delta^{34}S$ values for the up gradient part of the Renmark aquifer which range from (+15 to +20‰) are in agreement with the hydraulic head distribution which indicates that there is potential for downward leakage from the Murray aquifer in this area (Barnett 1994).

The high $\delta^{34}S$ value +26‰ for well M67 from the Murray Group aquifer near the River Murray indicates upward leakage from the Renmark Group aquifer, and is in agreement with results obtained from strontium isotopes.

Conclusions

1.Groundwater from the Murray Group aquifer in the Mallee region has a higher $^{87}Sr/^{86}Sr$ ratio than the limestone host rocks except for two samples. Addition of relatively higher $^{87}Sr/^{86}Sr$ from local recharge in the middle of the study area at Mulpata is believed to be the reason for a higher strontium ratio. In contrast the $^{87}Sr/^{86}Sr$ ratio of the groundwaters from the Renmark aquifer indicate that the bulk of the strontium probably derived from dissolution of the aquifer matrix. The results of strontium isotope demonstrate the utility of strontium isotopes as an indicator of the source of different water bodies, as well as the nature and extent of water-rock interaction.

2.The sulphur isotope data presented here has enabled us to characterise the two distinct sulphur isotopic composition in the Murray and Renmark aquifers. The isotopic signature in both aquifer systems are distinct and reflect the source of sulphate in the groundwater and can be used to estimate the extent of inter- aquifer mixing in some parts of the basin.

3.Isotopes of sulphur and strontium show some promise as tracers of mixing and delineation of flow systems and inter-aquifer mixing where other conservative technique are not possible.

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Risk Analysis for Dryland Salinity Development in the Murray Darling Basin
Overview of the Loddon-Campaspe Study

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Introduction

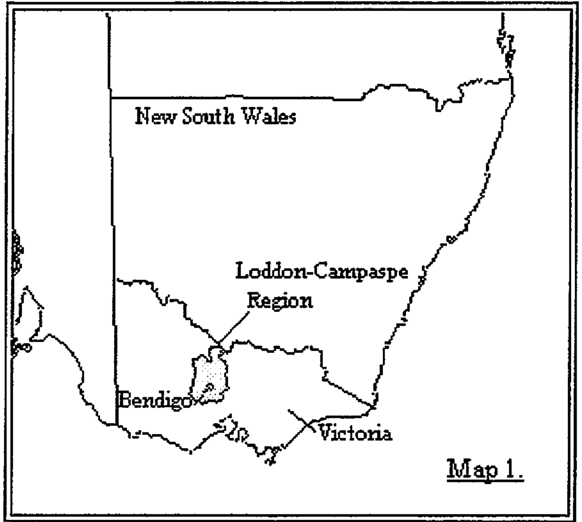
Dryland salinisation, rising saline water tables, and soil erosion, have been attributed to the loss of deep rooted perennial vegetation through changes in land use since European settlement. The Murray Darling Basin Commission (MDBC) Dryland Salinity Working Group have recognised the need for a predictive framework to assess the risk of salinity in the catchments of the MDB. Such a framework should not only predict trends under current landuse practices but also predict responses to changing landuse. This paper presents an overview and initial report of the work done so far for NRMS project M4066 in the Loddon and Campaspe Catchments in Northern Victoria

The Study Area.

The Loddon and Campaspe River catchments in Victoria, form part of the southern rim of the Murray Darling Basin. These catchments are adjacent, draining northwards from the Great Dividing Range to the Murray River. The two catchments make up a region of about 18600 sq km, however some 5000 sq km in the north is under, or influenced by, irrigation. The northern boundary of the dryland study area is defined by the channels, roads and property boundaries that define the limits of irrigation. (see Map 1.)

The climate of the region is Mediterranean, with annual rainfall ranging from 400 mm on the plains in the north, to about 1200 mm in the ranges in the south.

The catchments are geomorphically complex, but dominated by areas of Quaternary sediments having gentle relief. In the south, hills and ridges are mainly formed from Ordivician sediments with intrusions of Devonian granitics.



Map 1.

Soils of the region trend from red sodic duplex soils with calcareous subsoils in the northern plains and acidic, gradational and duplex soils in the southern hills.

Native vegetation of much of the region has been cleared for agriculture. Where land is too steep or soils are too poor, much of the area remains forested. Groundwater tables in the northern plains are high and rising as a result of increased recharge higher up in the catchments. Water accedes to the watertable and moves north to the plains through deep leads.

The Project Philosophy

In order to model the behaviour of any system one must understand the important processes and interactions that drive and control that system. This approach has not been attempted in regional salinity risk assessment because of the complexity of the natural systems involved. The size of the changes in recharge, and hence saline watertable rises, depends upon the complex interactions between hydrogeology, soil properties, climate, topography and vegetation. To be able to predict change, one must have a model incorporating these interactions. The model should be able to describe movement of water and salt in saturated and unsaturated soil zones. It should describe the trends under current conditions and be able to predict the responses of the system to changes in vegetation management. Such models have been developed at the point and small catchment scale (Hatton et. al 1992).

It was necessary to develop a regional approach to apply process models. Understanding gained at the local scale can be applied where the appropriate regional processes are identified. Regional scale predictions should be based on appropriate 'regional' information where the limitations of the scale of the data used are recognised. The challenge has been to adapt our ideas and methods to this framework.

The Project Approach

The stated objectives of the project are:

- To combine a model for soil water and salt balances with a groundwater model to predict recharge and discharge.
- To test the model using existing data from priority catchments in NSW and Victoria.
- Use tested models to evaluate salinisation risk under various management options.
- To test a remote sensing technique for predicting groundwater trends.

In order to achieve these objectives the work has been divided into four components. These are introduced in the following paragraphs.

Hydrogeomorphic Mapping

Hydrogeomorphic unit (HGU) mapping (Salama et al 1995) is a technique developed to utilise the relationship between the ground surface and the groundwater table. In essence the shape of the land surface is a function of the underlying geology and the climatic conditions causing it to weather. Landform may be used to classify areas in to 'hydrogeomorphic units', where the water table, within areas classed as one unit, is expected to behave in the same way. In practice 'hydrogeomorphic units' are derived by classifying a catchment into slope classes with the aid of a digital elevation model . It is then a matter of establishing a regression relationship between the groundwater and the surface within each unit using bore data. The HGUs may be used in combination with other land feature classifications (eg. stream and ridge lines, geology, vegetation, elevation classes) to improve the regression between groundwater and land surface. Once the regressions for each class are established a waterlevel map for the catchment can be produced.

Flownet Modelling

With a water level map produced it is then necessary to derive a flownet that establishes the flow direction and hydraulic gradients that exist in the groundwater surface for the catchment. With the addition of the estimates of recharge and transmissivity it is possible to estimate catchment discharge and watertable trends. To predict the effects of changing landuse, recharge rates are altered to reflect the change. These changes alter the watertable surface, the gradients and fluxes and hence the discharge.

Recharge Modelling

The key variable in modelling water table trends is the net recharge rate to the aquifers. The hydroecological model WAVES (Dawes & Short 1993), which integrates land cover, soils and climate to create a water and solute balance was used to predict recharge rates for the range of conditions present and possible for the Loddon-Campaspe region. Even with generalisation needed for regional study, extensive scenario modelling was necessary to predict recharge rates for: 4 vegetation types; 4 precipation classes; 9 hydrogeomorphic units and 6 geology classes. The result has been the production of a matrix of recharge covering the range of existing and possible environmental conditions within the study area. This matrix is then coupled to the Flownet model where the recharge is imposed spatially according to the land classification.

Remote Sensing.

There are two uses of remote sensing in the project. First is the production of regional land surface temperature index maps using thermal time series data. These data, combined with data on watertable levels, climate, and landcover will be used to look at regional groundwater fluctuations. The results will be used to compare with the outputs of the discharge modelling. Second is to provide an estimate of Leaf Area Index (LAI) for landuse classes at points throughout the growing season. These estimates are to be used to impose vegetative cover in recharge modelling. This work is ongoing as data are still being acquired.

The Outcomes

The products of this project are provided at the Campaspe and Loddon catchment scale and at subcatchment level (subcatchments defined by RWC Victoria).

At regional scale we have produced:

- Maps of Hydrogeomorphic units;
- Current Groundwater Levels and
- Flow Nets of current groundwater conditions.
- A matrix of net recharge estimates for all current and possible Land use and environmental conditions within the Loddon-Campaspe Region.
- Modelling software, complete with manuals, providing an environment to allow manipulative scenario simulation for estimating groundwater flows, discharge and water logging consequences.

This is the work we are reporting on at the Wagga Workshop.

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Geological Controls on Hydrogeomorphic Classification of the Loddon and Campaspe Catchments

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A methodology has been developed directly from the geomorphology and hydrogeology of catchments and the understanding of how these systems control groundwater and solute movement in the landscape.

The methodology takes account of the important role geology has in forming topography through differential weathering, erosion and deposition. These in turn influence the formation of the geomorphic and hydrogeomorphic characteristics of the catchments. The methodology has been applied to map the hydrogeomorphology of the Loddon and Campaspe catchment in Victoria.

Lying within the structural entity of the Lachlan Fold Belt of south-eastern Australia, the Loddon and Campaspe dryland catchments of North-Central Victoria are underlain by a thick basement of Palaeozoic fractured rocks, which forms 70% the landsurface. Some 80% of these fractured rocks are Ordovician (quartz turbidite) sedimentary rocks which display a range of strong northerly trending steeply dipping folds and faults. These include a fault bounded sliver of Cambrian volcanics and metasediments forming the north eastern boundary of the catchments. Intruding these rocks are late Devonian granitoids, which account for the remaining 15% of the outcropping Palaeozoic fractured rock landscape. Flanking these rocks are near flat lying (Cainozoic unconsolidated rocks, which have been covered by Tertiary basalt flows in the south part of the catchment.

Groundwater movement in the Cainozoic unconsolidated and fractured rocks is dominated by horizontal flow. Whereas groundwater flow in the highly deformed Palaeozoic rocks is modified by a series of structural and lithological boundaries which are aligned mostly according to the dominance of east-west compressive and extensional forces operating during the history of the Lachlan Fold Belt. Structural and lithological features which control the hydrogeomorphic parameters ie slope, curvature, break of slope etc.., determine the scale of discretisation required for hydrogeomorphic mapping and flow net modelling

Preferential Flow of Nutrients into Groundwater in Victoria's Western District

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Key Words

Victorian Soils, Soil Classification, Soil Description, Preferential Flow, Sampling Methods, Nutrients, Environmental Pollution.

Abstract

This project investigates preferential transport mechanisms for nutrients (NO_3^-, PO_4^{3-}) though soil to groundwater using the methods of Shippitalo, et al., (1990), Wildenschild, et al., (1994) and, Brownman, et al., (1994). Recent experiments suggest that nutrients may reach groundwater in much shorter times than the current models predict. These findings indicate we may be significantly under-estimating the risk of groundwater contamination. An experimental program has been proposed to study heterogeneous transport in soils. This study will enable evaluation of the impact of farm activities on groundwater of Victoria's Western District. To date, preliminary research has been conducted with the main body of research still to be undertaken. Undisturbed soil columns (0.06m^3) have been collected from two sites in the Western District. They will be examined for nutrient retention by addition of N, P compounds to the soil's surface. These columns will be subjected to a series of simulated rainfalls representative of the area. Preferential flow of water is examined by monitoring water applications and outputs, and is apparent for a column already studied. This column was collected from the Tower Hill State Game Reserve, west of Warrnambool. This soil shows distinct differences in physical and chemical characteristics to that sampled from Grassmere, north of Warrnambool. This soil column will be analysed for preferential flow patterns along with a third sample collected from Curdie Vale, east of Warrnambool in the near future.

Introduction

During recent years, worldwide concern has been focussed on the potential for contamination of surface waters and groundwater by agricultural chemicals in runoff and soil water (Bergstrom and Jarvis, 1993). Regardless of the application mode, a portion of all nutrients eventually penetrates deep into the soil. After soil interception, the interaction of complex chemical and physical processes determine whether the nutrients remain there or are transported to the groundwater. Some persistent and mobile nutrients can be transported long distances by soil water and may be detected far from the application site Physical and chemical heterogeneity of the natural environment makes the accurate prediction of the fate of nutrients and other chemicals very difficult.

Modelling solute and nutrient transport is difficult due to the complicated networks of interconnected pathways in the soil which can transmit water and its solutes at varying velocities. Preferential pathways resulting from biological and geological activity, such as sub-surface erosion, faults and fractures, shrink-swell cracks, animal burrows, worm holes, decaying roots, etc, may transmit water and solutes at very much higher rates than those anticipated by current theory. Water and chemicals that travel in these pathways often bypass the bulk of the soil matrix and may reach the groundwater in very short times. For example, detectable and in some cases, large concentrations of the biocides, dichlorprop and bentazon were found in Swedish clay and peat monoliths in the first autumn drainage water (Bergstrom and Jarvis, 1993). Even in relatively uniform sandy profiles, non-homogeneous flow patterns are also found.

Edwards, et al., (1988) found that higher infiltration rates were obtained when increased rainfall application rates were applied. Different water distributions were a result of macropores such as wormholes. Quisenberry, et al., (1991) found that water and solutes initially moved down uniformly in the upper soil-horizon but in the lower (argillic) horizon, more than 75% of the water and solutes moved through less than 25% of the soil matrix.

When bromide was added as a ponded irrigation, the travel-depth bromide concentration curves produced were bimodal, showing a much greater variability between cores. These differences were attributed to differences in shape and variability to the presence of preferential flow (Hamdi, et al., 1994).

Brownman, et al., (1994) gave a comprehensive analysis of some of the more common methods for detection of preferential flow. He points out the problems associated with core size, fillers, sampling methods, and rain simulators. Our method takes these factors into account.

Objectives of this Research Program

The broad research objective of this study is to explore the extent that soil heterogeneities influence the transport of nutrients in natural soils. Specific research objectives are:

Research Objective 1: To develop experimental procedures to monitor and measure nutrient flow through the vadose zone (i.e., the unsaturated zone that lies between the soil surface and the water table).

Research Objective 2: To examine the inter-relationships between macropores and other preferred channels and the surrounding soil structure on nutrient adsorption and transport in soils typically exposed to regular nutrient application in Victoria's Western District.

Research Objective 3: To find what percentage of the vadose zone of these soils is typically involved in the transport of pesticides.

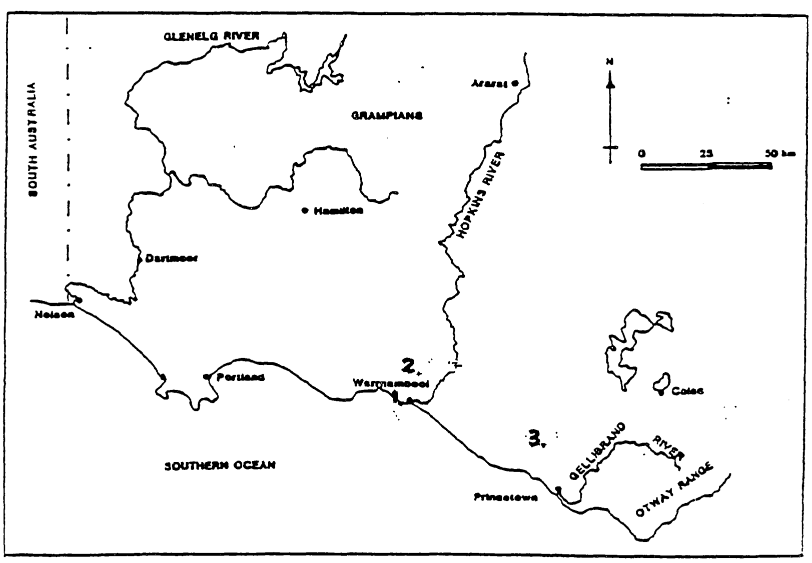
Research Objective 4: To examine the impact of different agricultural practices on nutrient transport (e.g., application rate and application method).

Research Objective 5: To test the limits of applicability of current solute transport models and to suggest new analytical and numerical procedures that explicitly incorporate preferential flow into the transport process.

Methodology

Our study will be conducted on soils sampled near Tower Hill, Warrnambool; Grassmere; and Curdie Vale. These areas are located in Victoria's Western District (Figure 1) and are surrounded by market gardens and dairy farms. Tower Hill is a volcano thought to have erupted about 20ka BP. It has an underlying Upper Tertiary Limestone aquifer, used for both domestic and stock purposes.

Figure 1. Western District of Victoria
Showing Sampling Sites (numbered):
1. Tower Hill; 2. Grassmere; 3. Curdie Vale.



A sandy soil developed on the crater's tuff has already been sampled. It is known to have a large number of fractures which make preferential flow highly likely and nutrient contamination possibile. Some springs from this aquifer emerge in the Tower Hill Reserve increasing the potential for eutrophication. In contrast, the Grassmere site is located in a rich dairy farming region on a gently undulating basalt plain, and the Curdie Vale site is on a Tertiary limestone undulating plain also used for dairy production. From these an overall representaion of the district and paterns and produced can be observed. A generalisation about the area may be produced by mathematical models based on this. This information has important implications for land management in this rich predominantly dairy farming region. We report here details of a study just commenced (March, 1995) along with preliminary data on preferential flow in one soil core.

It is common practice to examine nutrient mobility by conducting short term leaching tests on homogenous soils in a laboratory. However, the environmental conditions in such tests may be quite different from natural soils and field conditions. Thus the mobility predicted by such laboratory experiments may not reflect the behaviour in field conditions. For our experimental program, undisturbed soil cores are extracted from the field sites and surface-fluxes which emulate field conditions and application rates are applied. The advantage of taking undisturbed soil columns is that they preserve the natural macroporous structure of the soil. These preserved soils offer a better means of studying preferential flow of nutrients under field conditions (Steenhuis, et al.; 1991).

A multi-segment percolation system or Preferential Flow Sampling Unit (PFSU) has been constructed to sample nutrients in soils (Figure 2). Such units have been successfully applied to study the transport of fertilisers and tracers (eg., bromide) in Vadose Zone experiments (Shippitalo, et al.; 1990). Undisturbed soil cores (eg., 42.5cm x 42.5cm x 32.0cm) from the selected field sites, Tower Hill and Grassmere have been collected. The soil core is carefully encased in a wooden box (Figure 2). The space between the water-proofed box and the soil column is filled with nonreactive polyurethane foam filler to prevent deterioration of the soil structure during transport and analysis (Shippitalo, et al.; 1990). Twenty-five individual fibreglass wick lysimeters were placed in a 5 x 5 grid covering the basal surface area of the sampling unit, subdividing it into 25 discrete cells.

The wick lysimeter (Figure 3) is used to collect water and chemicals from the soils. The wicks provide a capillary (transport force) equivalent to that found in natural soils in the field and thus can be used to sample unsaturated flow. The wick lysimeter consists of an individual wick glued to a stainless steel base plate that is firmly pressed against the soil surface by a spring. Each lysimeter collects moisture and chemicals in the neighbourhood of the wick. The use of wicks provides several desirable properties. Unlike previous suction lysimetry systems, the wick system samples the soil continuously without the need to re-establish a vacuum periodically. Being a porous medium, the wicks have been shown to provide boundary conditions which mimic those found in the undisturbed soil.

Figure 2. PFTU

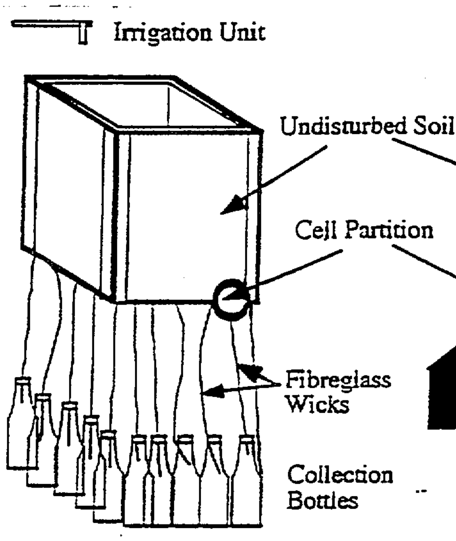
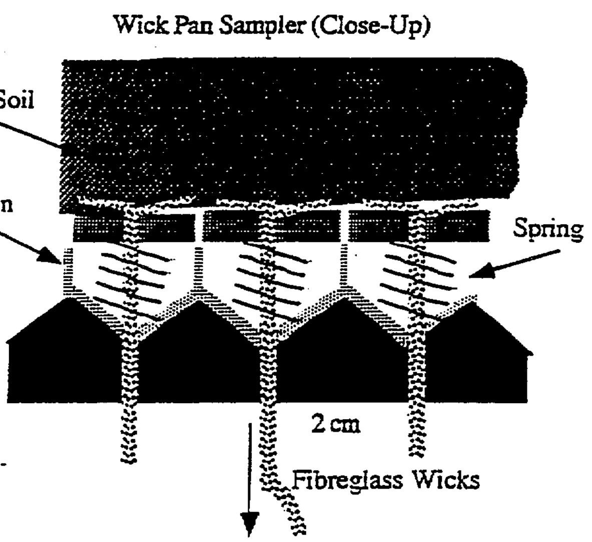


Figure 3. Wick Apparatus



The soil cores are irrigated by a drip irrigation system connected to a peristaltic pump, and the nutrient flux is controlled by the concentration of test nutrient in the irrigation water. The unit can be used to sample a wide variety of flow patterns and offers a more realistic portrayal of field conditions.

Two nutrients most commonly added to the soil's surface are nitrogen and phosphorous. These will be added as inorganic salts, at different rates, to the soil columns. Emphasis on the detection of these nutrients in groundwater is important because they contribute to algal blooms and eutrophication of natural waterways. The analysis of nutrients collected in sampling bottles will be by ion chromatography. Experimentation will include determination of soil characteristics (pH, moisture content, organic carbon, particle size, phosphorous and nitrogen retention indices and Munsell colour), the examination of preferential flow patterns, and the results of variations in application rate from the rain simulator to the soils surface (simulating seasonal patterns). Tracers of varying concentrations will be applied to the soil's surface and their retention examined.

At the end of the flow experimentation (approximately 12 months), the soil will be dyed, dismantled and photographed to identify the macropore structure and preferential flow patterns throughout the column. Soil staining can be undertaken by impregnating the soil core with paraffin or resin containing anthracene, a fluorescent dye. A photograph is taken of the soil surface under UV light and the surface soil is then shaved to say a depth of 5 mm using a router. The new surface is carefully cleaned and another photograph is taken. This process, called serial-sectioning, continues until the entire soil column has been photographed. The intensity of the illumination of the anthracene provides an indication of the relative rate of diffusion between the macropores and surrounding soil matrix and transport within the macropores.

After the serial-sectioning, the photographs will be digitised and enhancement software used to identify and group pixel's into macropores. The software can also be used to calculate hole areas and perimeters. These parameters can then be used to develop algorithms for determining equivalent hole diameters, porosity and circulatory indexes (Vermeul, et al., 1993). A three-dimensional computer image of the soil core displaying macroporous paths will then be constructed.

The experimental program is designed to gain a clear understanding of the physical and chemical processes of nutrient transport in natural soils. Depending on time constraints, mathematical models to determine solute transport may be developed. These should be able to simulate the effects of natural heterogeneities in the soil layer by identification of paths responsible for transport of water and solutes.

Preliminary Results

From a preliminary study carried out on a soil column taken from Tower Hill, Warrnambool, preferential flow was apparent. The soil characteristics of the sample were determined indicate that it is slightly basic, had a moisture content of 15 $\pm$ 2%, and an organic carbon content of 8.0 $\pm$1.8%. The colour of field samples ranged from 10 YR 3/4 (Dark Yellowish Brown) to 7.5 YR 4/6 (Strong Brown) at 20cm and 30cm depths respectively. Particle size determinations indicated a broad range of diameters with the greatest percentage (55-77%) of grains being <0.0173cm. Figure 4 indicates there was a large difference in water volumes collected from the different cells during a trial irrigation experiment. This trend continued for four simulated rainfall events (1.16$\pm$0.10 cm/hr). Analysis of Variance was used to show that the volumes obtained were significantly different, indicating that preferential flow occurred in the soil column. Outer cells may be subjected to "edge effects" and so the central 9 cells were examined separately. Figure 5 shows that there is still a large degree of difference between the volumes collected in these cells alone. Analysis of Variance results still indicated preferential flow (p-value 0.000).

To date (July 1995) two soil columns have been collected from a non-tilled farm site at Grassmere. There is a distinct difference between soils from the Tower Hill site and the Grassmere site with respect to chemical characteristics. The Grassmere site has a more acidic soil, a much higher moisture content (16-30%), the colour ranges from 7.5 YR 3/4 Dark Brown to 10 YR 3/2 Very Dark Greyish Brown to 10 YR 2/1 Black . There is a much higher percentage of clay (up to 70%) with particle size <38um. Over the next one year period, the preferential flow patterns, retention indices, and organic carbon content for the Grassmere site and the Curdie Vale site will be determined.

Figure 4. Water Volumes Collected for the 25 Cells for a Tower Hill Soil

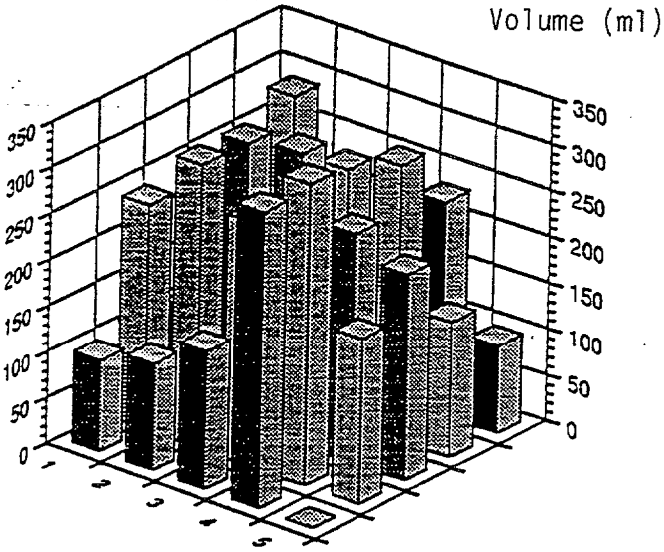
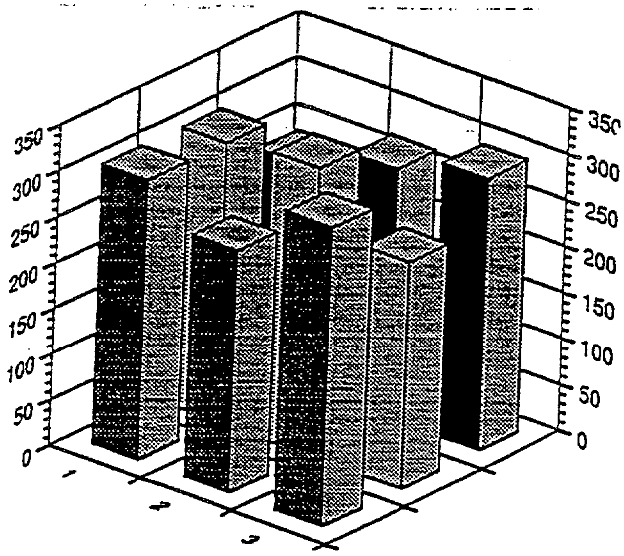


Figure 5. Water Volumes Collected for the 9 Central Cells of a Tower Hill Soil



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Do we really know how dryland catchments work?

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The need to start action in dryland catchment management is now paramount. The community effort to develop detailed Catchment Management Plans is gathering pace. Governments are now requiring that funds be allocated to on-ground works according to an Action Plan.

Generally, the action plans are dealing with problems whose solutions still lie in the *best bet* category. Research and investigation is now also starting to respond to this Community-led stimuli. Of critical importance to the long-term success of these plans are the range of premises that underlie the *best bet* options.

This paper looks at one of those premises - how a catchment's water and salt is being redistributed under present day conditions.

The Boorowa River Catchment covers about 1600 km^2 centred around the township of Boorowa, between Yass and Cowra in the central western slopes of New South Wales. The Boorowa River is a tributary of the Lachlan River joining the main stream just below Wyangla Dam. The Boorowa River has three major tributaries - the Breakfast Creek and Narrallan Creek to the northern end and the Pudmans Creek draining the south eastern parts.

The Catchment lies within a slightly winter dominant rainfall area with average annual rainfall ranging between 730 mm in the south east to about 600 mm in the north west of the catchment. The land use within the catchment is predominantly wool production with some mixed sheep and cropping in areas with better soils. A large proportion of the native vegetation has been cleared.

The catchment is composed predominantly of mid-Silurian acid volcanics of the Douro Group. These dacite and rhyodacite ashflow tuffs are bounded to the east by a block of Ordovician sandstones and siltstones of the Jerrawa Beds. Granite intrusions of the Wyangla Batholith are found in the north of the catchment and these are bounded by tuffs and shales of the Ordovician Kenyu Group. A late Miocene valley fill basalt occurs at the extreme northern end of the catchment, overlying sub-basaltic river gravels.

Weathering is complex within the catchment. The Boorowa River has incised into the less competent granites of the northern end, continuing the late Tertiary Lachlan River plain found around Cowra back into the catchment. This valley has been subsequently filled by basalt. Post basaltic incision has further increased relief in the northern parts of the catchment. The southern parts of the catchment, especially in the Pudmans Creek Catchment and around Boorowa itself, are dominated by broad open stream valleys with rolling/undulating hills. Remnant residuals provide some higher country.

Soils tend to be skeletal on the higher slopes and red/brown and yellow texture contrast toward the valley footslopes and floors. Highly erodable yellow solodics are associated with the Kenyu Formation, and sandier variants are found on the granitic country. The red/brown solodic soils of the southern catchment exhibit iron-rich pisolitic horizons overlying dense plastic clays with occasional carbonate nodules.

The hydrogeology of the catchment is dominated by a fractured rock aquifer displaying local flow system characteristics - that is, groundwater flow being controlled by topography with recharge and discharge within the one flow system being separated by a matter of kilometres. The distribution of colluvial materials and weathering has led to the development of shallow unconsolidated aquifers in most areas. These are generally confined to lower slopes and valley floors. The degree of connection between the shallow 'soil' aquifer and the deeper fractured rock aquifer varies between unconnected (hence perched) and fully connected. In most valley floor situations, there is an upwards flow potential between the two aquifers. Generally, the shallow soil aquifer is more saline than the fractured rock aquifer. The freshest water in the deeper aquifer is found under the higher relief areas, the more saline is found in the bottom of the broader valleys.

The catchment is currently undergoing degradation at an alarming rate. A study in 1992 by Powell found that of the landcare properties surveyed, most had some form of land degradation. As a percentage of the total catchment about 3 to 5 % was found to be salinised, with an expected rate of increase of about 5 to 10 % per year. Subsequent work on some badly affected properties by Hayman (pers comm) has shown that the area of degradation is doubling within 3 years, though this may not be the norm.

Another major concern within the catchment relates to the rate at which salt is being transported via the River. Estimates of salt load indicate that about half of the salinity in the Lachlan River at Cowra originates from the Boorowa Catchment. No rigorous estimates of total annual salt load are available, however initial estimates indicate that of the order of 100,000 tonnes of salt are being transported out of the catchment each year.

How can these types of systems be managed? Traditional models of fractured rock catchments suggest a process of identifying areas that contribute large amounts of water to the groundwater system and subsequent definition of adequate recharge control measures via land management options within these areas. This approach assumes, in terms of the physical processes, that recharge areas are discrete and identifiable and that salt distribution is somehow spatially uniform so that the diminution of the high water fluxes will cause a decrease of the high salt fluxes. The approach also assumes that, if there is heterogeneity in the catchment, that the key contributing areas can be spatially defined and dealt with individually. This introduces one of the major problems within the management of these catchments - What are the significant criteria that describe the spatial character of the catchment?

Traditional views of the way rivers flow through catchments suggest that surface water in the upper parts of the catchment are fresher than surface waters in the lower parts. As well, in the more humid landscapes, surface water is expected to be less saline than groundwater. Any base-flow that enters a stream from groundwater is most likely to be more saline than the water already in the stream.

Figure 1 shows Boorowa River salinity (as electrical conductivity) from 1993 to present as a longitudinal profile from its junction with the Lachlan River to its head water. Flow conditions over that period have ranged from high in July 93, June - July 1995 to low in April 1995 (no flow for most of its length). The July 1994 to April 1995 is a succession of data as the river system dried out during the significant drought of that time.

Of note in figure 1 is the shape of the profile up until April 1995. This shape shows that the salinity of the river was highest in its headwaters region (greater than 110 km river distance). This high salinity gradually decreased to a low at about 90 to 100 km river distance, then rose to a constant level starting at about 70 km river distance. This point marks a major change in a number of conditions - geology changes from volcanics above this point to granite below, the river becomes increasingly incised below this point, and the Pudmans Creek system joins the river.

For the stretch of river from 90 to 110 km river distance, the Boorowa River contains the freshest water. That is, all the major tributaries in terms of water volume contain water more saline than the main stream. This presents a conservation of salt mass problem unless dilution is involved. Groundwater of a lesser salinity is the most likely mechanism to account for this dilution. Indeed this stretch of the river is incised below a major weathered zone into fresher bedrock indicating that fresher deeper groundwater may be able to more easily enter the river.

The rising trend of river salinity from about 90 to 70 km river distance indicates an area where major salt flux is occurring. This area corresponds with previously identified *at risk* zones (Powell).

The salinity profile changed little as the drought of 1994-95 took hold. As river flow decreased, salinity increased (with the shape of the profile remaining the same) up until November 1994. The profile for April 1995 shows a surprising trend of lower salinities. At this time the river had dried at most locations and the values represent pits dug in the bed of the river (water levels were generally about 10 cm below the bed of the river). This may give an indication of the salinity of the groundwater flux entering the river.

The high flow conditions of winter 1995 have freshened the river considerably. Salinities have fallen everywhere and in July 1995 the high salinities in the headwaters of the catchment have disappeared.

These trends lead to a number of conclusions.

The salt flux process in the upper parts of the catchment may be different from those in the lower parts. Combining the river salinities with casual observations of river flow suggests that the major salt influx to the river is occurring in the region between 70 and 90 km river distance - also the area where the spread of dryland salinisation is most rapid. The unexpected low salinities at the height of the drought suggest that the main salt contributor to the river had dried up at that time. This appears to be consistent with observations that the shallow aquifer had also substantially dried during that time. Groundwater influx to the river in it's mid to upper reaches is a significant contributor of fresh water to the river. The rainfall experienced during the period May to July 1995 had effectively flushed available salt from the upper-most parts of the catchment.

This provides some important information to the community group devising the action plan for catchment management. Land management options to control groundwater levels can be targetted to intercept areas of high salt flux to the river. However, not all areas should be so targetted as reducing groundwater inflows in the mid to upper sections of the river may in fact increase river salinities. Of major importance to any salt flow reduction is the drying out of the shallow aquifer. Finally, actions in the upper catchment may provide significant dividends over those in the lower catchment.

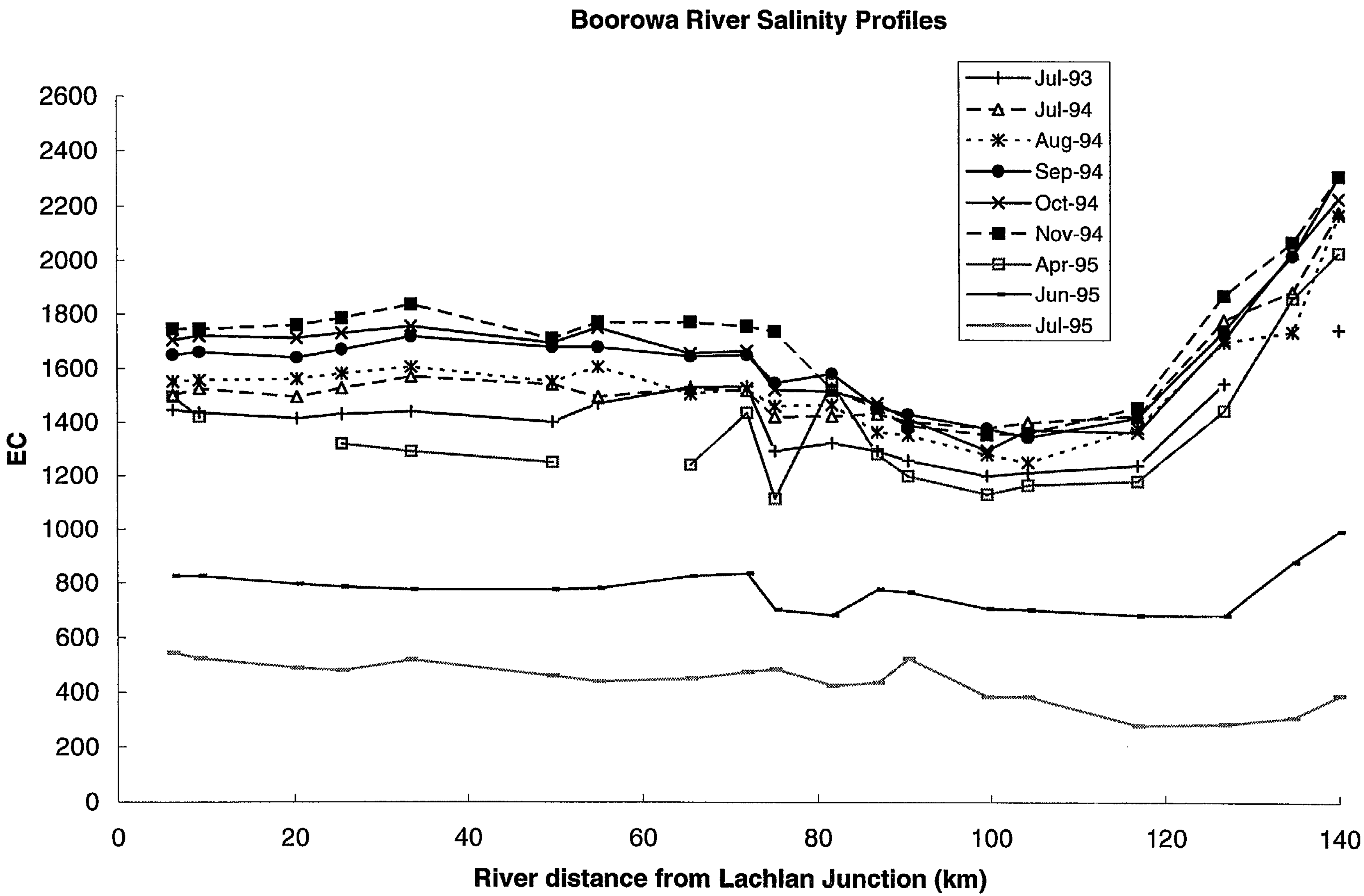

Figure 1: Longtitudinal Salinity Profiles of the Boorowa River showing variations of salinity during the drought of 1994/95

MANAGING GROUNDWATER: HOW MUCH IS ENOUGH?

Judy Frankenberg and Maree Shelley
West Hume Landcare Group

The West Hume Landcare Group is approximately 40km west of Albury, in the Southwest Slopes region of NSW. Three sub-catchments are included in the area, which totals 69,000 hectares. The group was established in 1989. There are about 160 farms and farmlets in the area, 50-60% of which are financial members of the group. The main enterprises are sheep, wheat and cattle, and total value of production in the area is $11 million (1992/93) (Woodhill et al 1994).

Since it was established, West Hume has been very active and successful in attracting funding for projects. The group has organised over 240 activities and managed seventeen different projects with funding totalling approximately $500,000. This funding has been used for coordination of group activities, drainage works, revegetation, catchment planning, farm demonstrations, and a roadside vegetation survey. The activities of the group have been reported on or publicised in over 70 different articles or media items. Over 200,000 trees have been planted by the group, which represents an increase in tree cover of 0.7% of the West Hume area.

Groundwater Issues.

Rising watertables and salinisation are a major and escalating problem in the area. A bore survey carried out in 1990 over part of the West Hume area showed that bores had risen an average of 60 cm/year, and that approximately 4% of the area had water tables within 2 metres of the surface (Williams 1990). Predictions for the year 2020, based on a no action scenario suggested that water tables will then be at the surface over close to 34% of the area.

The problems associated with high water tables and salinisation are already being experienced by many landholders. These include:

- water-logging, with the associated loss of productivity,
- former cropping land now suitable only for grazing,
- problems with access across wet paddocks,
- death of mature trees,
- increasing road and track maintenance costs,
- salinisation and increasing risk of erosion in creeks.
- increasing discharge of salt to the River Murray.

Understanding the Causes

The understanding of the causes of these increasing problems varies within the membership of the group. The standard explanation - decreased water use by vegetation following clearing and consequent increase in recharge to the groundwater, is not universally accepted. The "Dartmouth connection" ("they built the Dartmouth Dam and it filled just as our problems started) still has some currency in the pub.

Local apparent anomalies in ground water behaviour and confusion in relating cause and effect, and relative time scales, exacerbate the problem. Some landholders have a healthy scepticism of "experts". None-the-less, some of these are the most enthusiastic members of the group.

Choosing Appropriate Responses.

We have generally adopted the standard remedies for rising groundwater. These include restoring perennial vegetation, using high water-using species, changes in farming practices, improving soil structure and fertility, and farm and catchment planning.

But we cannot be sure how much is enough. We have planted at least 200,000 trees in West Hume in the last 6 years, but this only represents about 0.7% of the area. There is only about 0.8% natural tree cover. There is still a long way to go to achieve 10%, or even 6% tree cover. Will 10% be enough to make a difference? At 50,000 trees a year, if we could afford this or the funding continues, it will take 40 years. Is this too long, and will the damage be irreversible by then?

We are talking serious money. If the cost of tree planting is taken at $2/tree, which is less than the generally accepted rate, the cost/hectare at 500 trees/hectare is $1000.

5% of the catchment is 1380 hectares.

Therefore the cost of planting 5% of West Hume is $1,380,000.

The cost of planting 10% of West Hume is $2,760,000.

The cost of planting 15% of West Hume is $4,140,000.

Perennial pastures are the other major land use strategy recommended for reduction in recharge. For those who can afford the establishment costs there is an undoubted productivity bonus, but we have no information on the proportion of the area which should be sown down for recharge control, and how significantly the management of the pasture affects the water use.

The cost of perennial pasture establishment is $148/hectare ($319 with lime) (Woodhill et al 1994).

The cost of establishing perennial pasture on 30% of West Hume area (20,000 hectares) at $148 is $2,960,000.

Can the farmers of West Hume afford to spend $4 million over the next 20 years? Or should it be $7 million? Or will even this amount of effort be inadequate? It could be important to know. Over the last year or so most farms in the area have had a negative income.

Can cropping be continued in West Hume or must we convert to 100% perennial pasture and trees to draw down the water tables? Few farmers would believe that they could afford to do this.

How important is the position of trees or perennial pasture in the landscape? If key sites can be identified, and they belong to non-co-operators, or farmers without the resources required, how can we compensate elsewhere? Should we concentrate on rocky ridges or break of slope? One may be better in the long term but the other may give quicker results by keeping land in production.

Even if we succeed in planting 10% tree cover by 2020, at least half of these trees will still be less than 10 years old. and none will be over 30 years old. How effective will they be?

How easily will we be able to recognise a real improvement if we get one? We have some piezometers and measure them more or less often. The water level went down during the drought but will come up again. We need to learn to understand the short term fluctuations before we can recognise long term trends. How soon can we realistically expect some response? It is hard to go on measuring something on a monthly basis if there is not likely to be a real change for 10 years.

There are a large number of questions such as these, many of which we realise may be unanswerable. Some are site specific and need local interpretation of the results of research in other areas. Others probably could be answered now if the information was easily accessible. We recognise that many have no answer yet but are not sure which ones.

There are also questions about equity. Should there be different constraints on land management options for landholders at the top of the catchment compared to those at the bottom of the catchment? How responsible must we be for the impacts on the areas further downstream of our small catchments? We need to understand how critical the situation is and how urgently action is required, so that we can judge the implications of non-involvement by some landholders. Here of course we stray into the politics of the problem.

It may be that depending on changes in vegetation to halt the water table rise is impractical, because we can't plant enough, it is totally uneconomic, or it wouldn't work anyway. If that is the case and engineering solutions, or no solution at all, is the real answer, the quicker we know the better, so that rural reconstruction can start in earnest. If drainage is the only solution we, or those downstream, have a problem.

These unanswered questions affect the credibility of landcare with landholders.

Sources of information

Many of the questions I have raised are probably our problem. The answers may be readily available, but we haven't found them. If that is the case, we need to ask ourselves why.

As a group maybe we don't put enough effort into it. We have a part-time coordinator. She is flat out keeping up with all the things we want to do. Planting 50,000 trees takes some organising, and we have to prepare a Land and Water Management Plan if we are to continue to receive Landcare funding.

We have local Agency extension staff. They are also very busy and don't come round looking for work. If we don't know what the questions are they have more urgent things to do than come to us with answers.

I suppose we need more aggressive extension, or information through other channels and we should be more demanding. Most of the newsletters which arrive from many sources are full of cheery encouragement and good news stories about what groups are doing. There is not much hard technical information which can help us.

The Landcare News for the Riverina and Southwest was useful but no longer exists, and we miss it. The Australian Journal of Soil and Water Conservation is another source of technical information which reaches us but with only occasional direct relevance and is not very reader friendly for many landholders.

In summary, we are concerned that the job ahead of us may be too big and too expensive, and won't achieve the required result. On the other hand, what we are doing may be adequate and may achieve quite quickly a reversal of the ground water rises which are threatening our future viability.

We lack the technical information we need to evaluate the situation and we need reassurance that we are not wasting our time and money.

We believe that there is a real need for better information to flow down to the landcare level, in a form that we can apply to our problems. More interpretation and more extension is required, and undoubtedly more research, both pure and applied. The need is urgent, not only for landholders, but also for administrators and politicians, who must support our efforts. The price of failure will be great for the whole community.

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Comparison of Diffuse Groundwater Discharge from Trees and Bare Soil in South East Queensland: Preliminary Results

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Introduction

Tree clearing in South East Queensland has increased water table recharge in catchments, leading to rising water tables in lower parts of the catchments (Thorburn 1991, Gordon 1991). In farming areas, shallow saline water tables can reduce, or totally inhibit productivity. The extent of salinity and the impact of shallow saline water tables on farm productivity depend on numerous factors including soil type, local geology, land topography and land use. These saline outbreaks have the potential to increase in size if they are not contained through effective management practices.

The best on site management strategy is to maximise water table discharge. Two of the possible methods of water table discharge are; (1) capillary rise of water upwards through the soil and subsequent evaporation from bare surface layers, and (2) water transpired by vegetation. The most active role in management to date in South East Queensland has been to plant salt tolerant vegetation in saline areas. Trees are thought to be more effective in water table diffuse discharge than pastures or bare soil evaporation (the do nothing management option), due to their ability to extract water from deeper in the soil profile. The different quantities of water discharged from these different management options is important in selecting an effective management strategy.

This study describes a comparison of diffuse discharge under contrasting management strategies, at site in South East Queensland. Only preliminary results from spring 1994 are presented. The study is continuing to establish longer-term trends.

Materials and Methods

Three field sites were studied in South East Queensland (Figure 1). All field sites showed varying degrees of surface scalding. To manage the shallow water tables trees were planted at all sites, on average 8 years ago. Stock have minimal access to all sites.

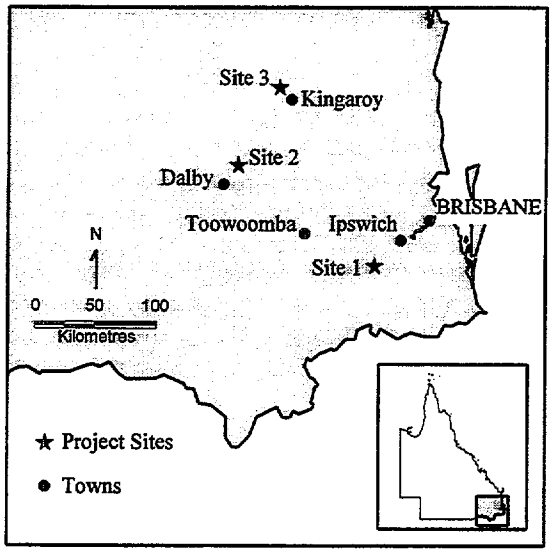

Figure 1. Location of the study sites

Groundwater discharge was measured under two management practices at each site; (1) on scalded, non vegetated areas, and (2) in an area established with salt tolerant trees. At Site 1 there were two different tree species studied (Table 1). Plots were established in each of the treed and bare areas at each site (i.e. three plots at Site 1 and two at Sites 2 and 3. Tree plot densities varied between sites. Other relevant site information is shown in Table 1.

Diffuse groundwater discharge rates were estimated in the treed areas, following the method of Thorburn *et al.* (1993). Transpiration was estimated by sapflow-velocity data-loggers, installed in trees of various sizes in each plot. Sapflow data were continuously collected between September and December 1994. The individual tree measurements were scaled up to the total plot area, based on measured sap flux densities and the total plot sapwood area. Identification of the proportion of xylem water that was taken up from the water table was estimated by measuring stable oxygen and hydrogen isotope ratios. This involves comparing the isotopic composition of tree twigs, groundwater and soil profile water. Soil profiles down to a maximum of

2 m were taken for isotopic analysis in September and December. Tree twig and groundwater samples were taken for isotope analysis at the same time, as well as on a fortnightly to monthly basis between September and December. The top 30 cm of a soil profile is expected to be the most dynamic area in regard to isotopic composition changes, thus in October and November the top 30 cm was also sampled.

Diffuse discharge from the bare, scalded areas was estimated from soil chloride profiles. The increase in soil chloride between over time was related to the groundwater chloride concentration to determine diffuse discharge rates (after Talsma 1963). At each site, five soil profiles were sampled and bulked. Samples were taken at 10 cm increments to 80 cm, then 20 cm increments to 2 m. These chloride profiles were taken in June and December 1994.

The water table depth and salinity was also recorded at each sampling time.

Average pan evaporation increased from approximately 6 to 8 mm/d at Sites 1 and 3, and 8 to 10 mm/d at Site 2 during the study period. There was an average rainfall of 130 mm across all sites over the 3 month period.

Results

The isotopic composition of the soil profiles at the three sites did not change significantly between September and December. Figure 2 shows the soil hydrogen isotope profiles for Site 3; Sites 1 and 2 were similar. There was also no significant change in twig isotope ratios relative to the variation in the soil profile during the study period (Figure 3).

The twig isotope ratios for Site 3 are very similar to the groundwater and the lower layers of the soil profile (Figure 2) indicating that most of the water is taken up from the water table at this site. At Sites 1 and 2 however the twig isotope ratios were similar to the soil at 30-50 cm depth. Over this depth range, soil water was most likely a mixture of groundwater from capillary rise and some surface water. Thus the trees were using a mixture of both surface soil water and groundwater in approximately equal proportions at these two sites (Table 2). The relative uniformity of the twig water isotopic compositions in each plot between September and December indicate that the proportions of groundwater taken up by the trees remained constant during the study period

Transpiration rates in the *Eucalyptus camaldulensis* at Sites 1 and 2 did not increase significantly during the study as expected with the change of season from spring to summer (Table 2). *Casuarina glauca* at Site 1 transpired at twice the rate during December compared to September. At site 3, *C. glauca* transpiration increased by approximately 25% over the same time period.

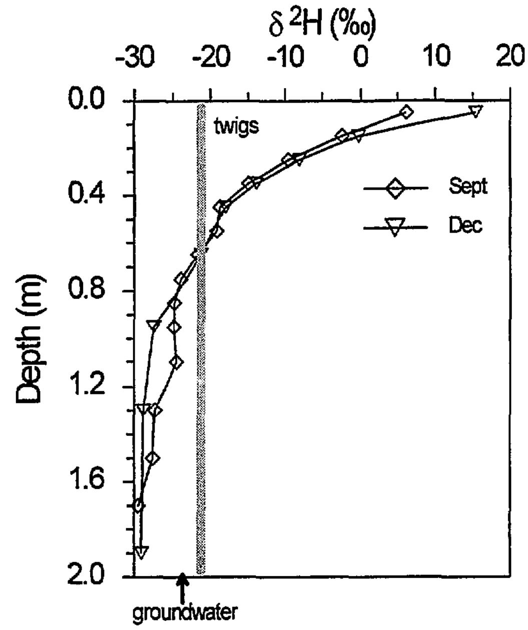

Figure 2. Profile of soil δ^2H values in the soil at Site 3 in September and December 1994, with average twig (vertical bar) and groundwater (arrow) δ^2H values also shown.

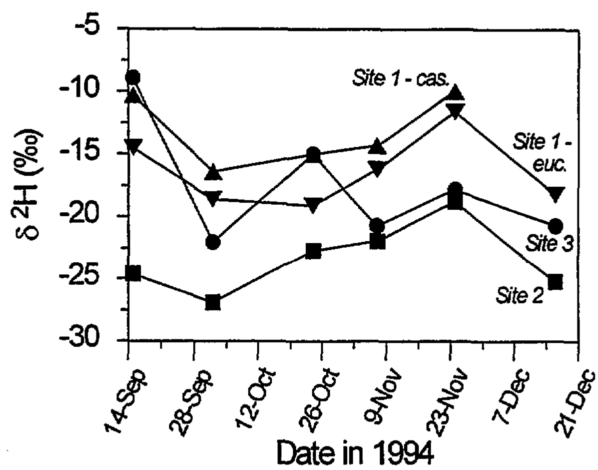

Figure 3. δ^2H values of twig water in all plots between September and December 1994.

The transpiration data were combined with the water uptake proportion (Table 2) to indicate diffuse groundwater discharge rates over the study period. These ranged from 0.1 to 2.3 mm/d between the sites (Table 2).

At Site 1, the soil chloride decreased between June and December (Figure 4), indicating that recharge had occurred (i.e. negative discharge, Table 2).

Groundwater was being discharged from the other two sites.

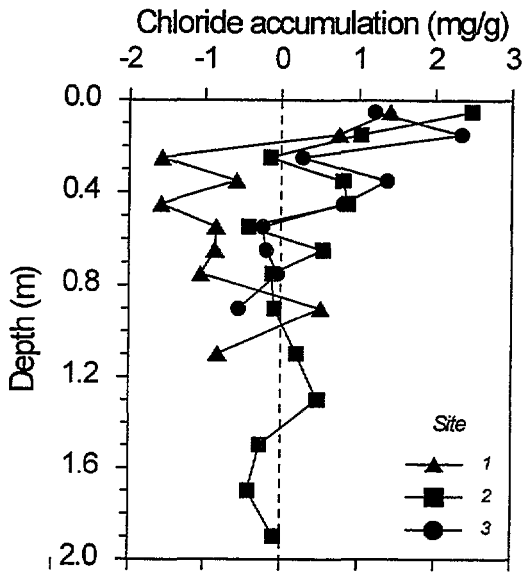

Figure 4. Difference in soil chloride profiles (accumulation) between September and December 1994 in the bare soil plots at each site.

Discussion

There were large differences in discharge between the treed and bare plots at all sites. The groundwater was being recharged through the bare soil at Site 1, compared to low rates of diffuse discharge from both tree species (Table 2). Discharge was also enhanced under the trees at Site 3. At Site 2 however, the discharge from the bare soil was higher than from the trees.

The diffuse discharge rate from the bare soil at Site 2 was higher than expected from previous studies, considering the water table depth. The water table at Site 2 was approximately 3 m deep so discharge rates are likely to be 0.4-0.1 mm/d (Thorburn et al. 1992). The higher measured rates may be the result of errors caused by spatial variability of the soil chloride profiles. (This is a potential problem with this method used to determine diffuse discharge). If evaporation rates from the bare soil plot were similar to the expected values, the trees would also be enhancing discharge at this site.

The rate at which trees discharge groundwater depends on site specific factors, such as water table depth, water table salinity, water relations of the particular species (Thorburn *et al.* 1995). The lower discharge rates from the trees at Sites 1 and 2 would be due to the greater groundwater depth (Table 1) at these sites. Also, trees were spaced more widely so the leaf area index at the site would not be as great as at Site 3 where the trees formed a closed canopy.

The results presented in this paper come from only a limited study time. Thus, they should only be considered preliminary. However, they give an indication of the extent to which management practices can influence diffuse discharge of groundwater in areas affected by dryland salinity. Further measurements are being made in the plots described here, and in pasture plots, to allow a more thorough comparison of diffuse discharge process under different land management practices.

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Table 1. Details of climate, species planted and water table conditions at the study sites

Site	Species	Tree Density (Tree/m^2)	Annual Rainfall (mm/yr)	Annual Evaporation (mm/d)	Average Water Table Depth (m)	Groundwater Chloride (g/l)	Groundwater Salinity (dS/m)
1	a) *Eucalyptus camaldulensis*	0.03	811	1640	2.9	1.5	4.8
	b) *Casuarina glauca*	0.03					
2	*Eucalyptus camaldulensis*	0.05	647	1780	3.0	2.0	6.2
3	*Casuarina glauca*	0.10	755	1590	1.6	3.2	11.1

Table 2. Proportion of groundwater transpired, transpiration and groundwater discharge from the plots

Site	Proportion groundwater	Transpiration (mm/d)			Diffuse Discharge (mm/d)	
		September	December	Average	Trees	Bare
1a	50	0.2	0.2	0.2	0.1	-2.3
1b	50	0.3	0.8	0.5	0.2	
2	50	1.2	1.4	1.3	0.6	1.3
3	100	2.0	2.5	2.2	2.2	0.2

Community Involvement in Developing a Management Strategy for an Overdeveloped Groundwater System

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Abstract

The Condamine Groundwater Management Area in the headwaters of the Murray - Darling System has been the subject of considerable assessment and management development over the past 25 years. During this time over use of the sustainable available supply has occured.

The need to further identify and consider various management responses arises from the continued depletion of the resource unit and concerns for the general sustainability of existing irrigation development.

Stronger community consultation and involvment approaches were chosen to provide the vehicle for developing new management directions. The paper will explore the processes involved.

Introduction

The Condamine Groundwater Management Area or CGMA is situated in the upper reaches of the Murray Darling Basin. It is one of the largest groundwater systems in Queensland with 200 irrigators using an average of 50000 megalitres per annum to irrigate 15000 - 18000 hectares of cotton, grain, and assorted other crops. Additionally the Towns of Dalby, Pittsworth, and Millmerran source their Town Water Supply requirements from the CGMA. Consequently the long term sustainability of the groundwater resources of the area is of paramount importance to its social and economic viability.

The CGMA has been the subject of considerable assessment and management development since irrigation extractions commenced some 35 years ago. During this time the situation has developed where overuse of the sustainable available supply has occurred. As a result water levels have fallen to such an extent that in the more shallow zones irrigation is becoming uneconomic whilst in the deeper sections pumping costs are escalating.
Previous management responses to deal with the unsustainable use of groundwater in this area have largely been developed by Government for the water user community. As a result they have met with varying degrees of acceptance. Over the past eighteen months the groundwater user community in partnership with the Queensland Department of Primary Industries (QDPI) has developed a strategy for the future management of the groundwater resource in this area. The strategy forms a framework for working towards the long term sustainable use of the available groundwater resource and promotes more effective management of the resource now and into the future. This paper discusses the community consultation and involvement approaches that were chosen as the vehicle for promoting the development of the new management directions.

Groundwater Development History

In March 1960, part of the Condamine Groundwater Area, and in September 1966 the remainder of the area, was declared under Part VII of the Water Act as a district of sub artesian supply. From that time all existing and proposed irrigation bores required licensing. By early 1969 the aquifer in the central area of the system was seriously depleted and the need to restrict the issue of new irrigation bore licenses became obvious.

In April 1970 as a result of continuing depletion of the resource an area known as the Condamine Restricted License Area (CRLA) was defined and an embargo was placed on the issue of new irrigation licenses in this area. By the late 1970's water levels had fallen as much as 20 metres in the central part of the main irrigation area. Water meters were installed to collect data on water use, and with a view to reducing the demand on the groundwater system. The meters were installed during 1978/79 throughout the area of substantial development which was more extensive than the CRLA, and which is now called the Condamine Groundwater Management Area (CGMA).

Groundwater charges were introduced in 1980 and excess water use charges were applied from 1982. The introduction of metering and water charges had a marked affect on groundwater use. Average annual use fell from an estimated 75000 megalitres prior to 1980, to approximately 42500 megalitres for the period 1980 - 1989.

Various initiatives involving the 'exchange' of groundwater allocations for surface water have been introduced to reduce the over-exploitation of the groundwater system. These initiatives involve the substitution of groundwater entitlement with:-

- water harvesting rights for licensees riparian to the Condamine River.
- regulated water supplies and water harvesting supplied through the North Branch Diversion Scheme.

Despite the management controls that have been introduced, water levels have continued to decline at a significant rate in the central part of the CGMA. In other parts of the area water levels have remained static and in isolated areas have exhibited minor water level rises. In 1991 the CGMA was divided into 5 sub areas in acknowledgment of the differing hydrologic regimes in terms of water level behaviour, water use patterns and water availability (see figure 1). Formation of the sub areas has enabled specific management strategies to be developed that target problem areas within individual sub areas.

Table 1 details allocation, use and available supply details for each of the sub areas.

Sub Area	No of Allocation Holders	Allocation (ML)	Available Supply (ML/a)	Average Use (ML/a)
1	14	3419	3475	809
2	32	10847	3888	3936
3	159	51911	14125	36680
4	28	5107	2938	1380
5	7	944	3353	41
Total	240	72228	27779	42846

Table 1: CGMA - Sub Area Statistics

The imbalance of allocation and use in comparison to availability of supply clearly displays the level of over development within the system. This imbalance is particularly evident in sub area 3 which basically overlies the central water level depression.

Options Paper 'Future Directions - Sustain or Bust'

In late 1993 the QDPI in conjunction with the Condamine River Basin Irrigators Association hosted a forum to discuss options for the future management of the groundwater resources within sub area 3. As a result of the forum an options paper entitled 'Future Directions - Sustain or Bust' was released to groundwater irrigators. The paper described two divergent management goals.

- Goal 1: To mine the resource to some self regulating equilibrium state.
- Goal 2: To control use so that sustainable extraction and current levels of access are maintained.

Each of the goals was accompanied by a range of management responses. The paper provided irrigators with a greater awareness of the issues pertaining to the area and explored possible future management directions. In essence it enabled irrigators to get 'up to speed' with possible management scenarios and provided them with the necessary background information to make informed decisions. The paper also provided a mechanism for the promotion of a future public forum to discuss the management options in greater detail.

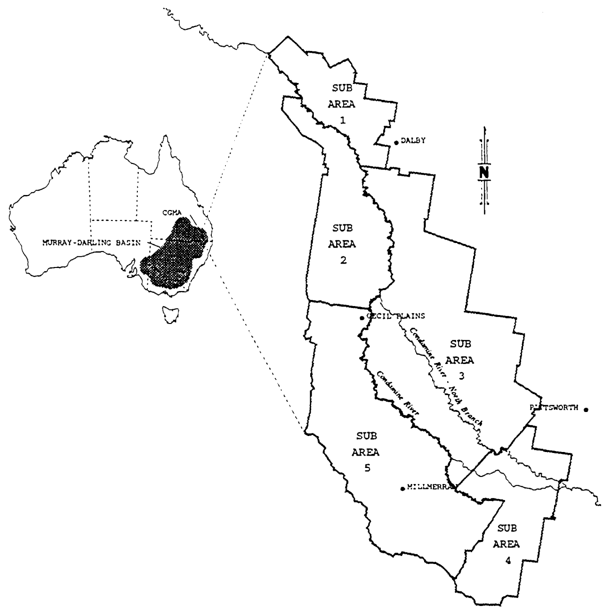


Figure 1: Condamine Groundwater Management Area

Development of a Community Consultation Process

As stated previously past management plans had basically been developed by Government for the Water User Community and had often been unsuccessful in achieving there objectives. It was necessary to develop a process that would produce a joint QDPI - Water User Community plan with ownership and input by both parties. There were a number of considerations that needed to be taken into account in developing such a process. These included:

- Not all irrigators were represented by a single organisation although many were represented by the Condamine River Basin Irrigators Association.
- A public forum consisting of 100 plus irrigators and other interest groups is difficult to control
- All stakeholders needed to have input to the process.
- Dominant individuals and groups were capable of setting the agenda and influencing the outcomes.
- Aggrieved parties could focus on unpopular historical decisions by Government rather than proactive future planning.
- The inexperience of QDPI Water Resources staff in the use of group extension techniques and the consequential initial reluctance to try something different

Taking into account the above factors, a process to develop future management directions for the area was designed. Details of the implementation of the process are outlined below.

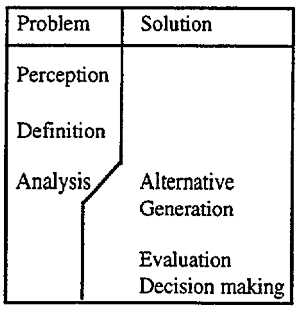
- All groundwater users were invited to a Public Meeting at a central location within the CGMA.
- On arrival meeting participants were seated at tables in groups of eight to ten. This enabled all participants to provide input to the process. It also negated the influence that dominant individuals or groups can have on more traditional public meetings.
- The meeting was coordinated by a neutral facilitator with a neutral recorder. QDPI staff were seated within the groups and participated as group members. This forced the focus on to the job at hand and not past historical problems.
- Groundrules were set and agreed upon at the commencement of the meeting. The groundrules outlined how participants were to interact with each other eg. no side conversations.
- An extension process called 'The Interactive Problem Solving Model' (*Ching 1991*) was used to identify, define and analyse problems in the area. Input to each stage of the process was obtained from the participants in groups and the meeting record was displayed on butchers paper. Once the problems in the area were clearly defined, specific solutions were more likely to eventuate. A 'road map' of the process of the 'Interactive Problem Solving Model' in developing management strategies for the CGMA is described below.

The Interactive Problem Solving Model

Meeting 1, 100+ participants including four from the Department of Primary Industries
Facilitator: David Stanfield
Recorder: Marta Flores Alonso
Meeting Theme: 'Managing Falling Groundwater Levels in CGMA Sub Areas 3'.

1. Introduction of the facilitator and recorder and their roles; obtain participants expectations of the meeting; explain and develop the groundrules.

2. The problem solving model is explained to meeting participants:

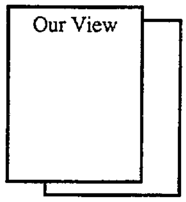


Perception

3. Each participant to personally (3 mins) write down or think about 'My view of the problem is ...'

4. Write down in your small group all the different views on butchers paper (Write big!), Different is good! (15mins)

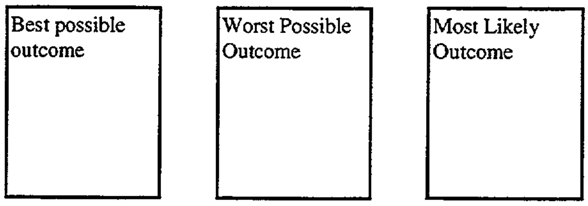
Each Table



5. Now personally (3 mins) think about tackling the problem. What is the best possible outcome? Worst possible outcome? Most likely outcome?

6. Write down all the different views again.(20mins)

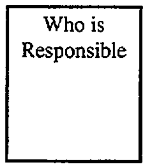
Each Table



7. Personally (3 mins) think about 'Who is responsible for tackling this problem?'

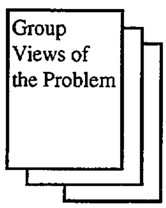
8. Write down all different views around your table.(5mins)

Each Table

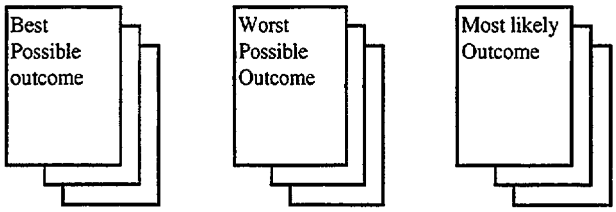


9. Report to the larger group your group's conclusions to 4, 6, and 8.

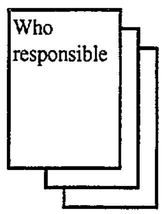
Meeting Summary of conclusions to 4



Meeting Summary of conclusions to 6



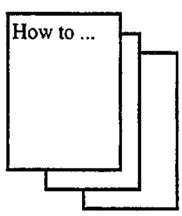
Meeting summary of conclusions to 8



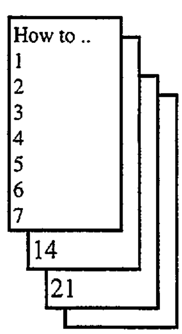
Definition

10. Back in your small groups define the problem as an open question 'The problem is how to ...' (this is putting boundaries around solvable problems).(15mins)

Each Table

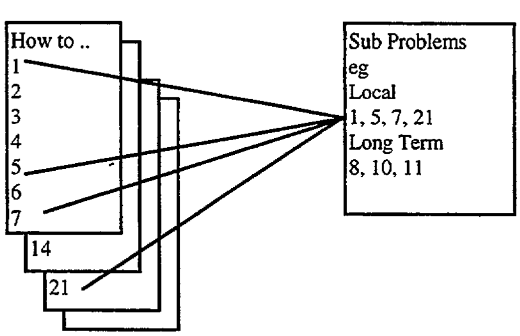


11. Report back the 'How to ...'s' to the meeting. Group summary to conclusions of 10 (Number them).(20mins)



Analysis

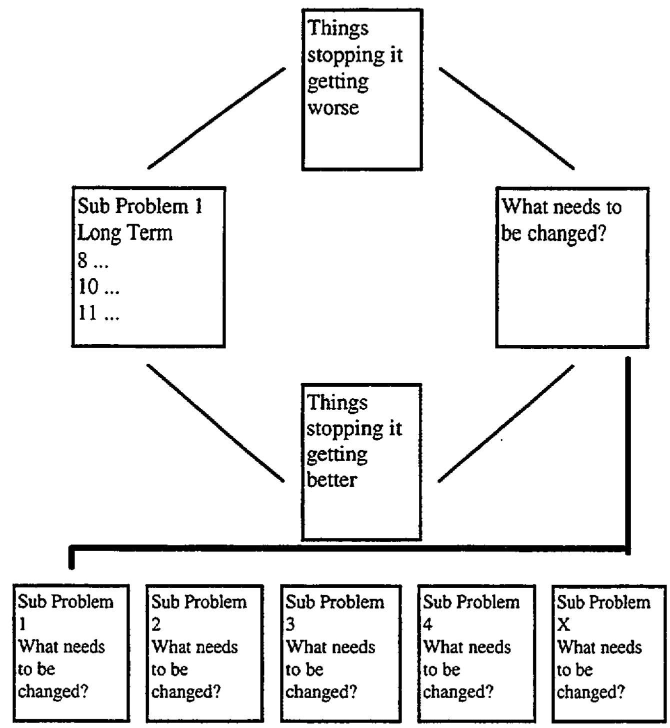
12. Create 'Sub Problems' by grouping 'How to's' under headings



13. Prioritise the 'Sub Problems'. Select the top 1/3 to 1/2 by voting n/3 (*if you could wave a wand and solve 1/3rd of these problems, which would you choose to give us the greatest movement forward*?).

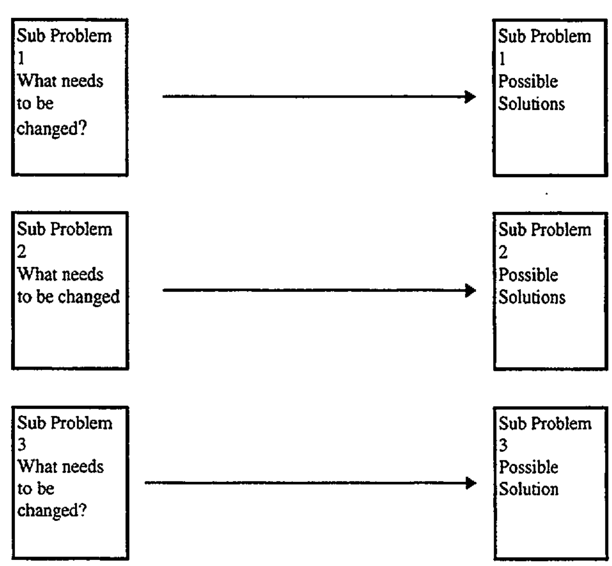
<u>The public meeting finished here. The working party continued this process at their first meeting.</u>

14. Handle each Sub Problem separately, starting with the highest priority one. Do a Force - field analysis on each one.



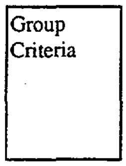
Alternative Generation

15. Brainstorm a list of 'Possible Solutions' to Sub Problems 1, 2, 3 ...

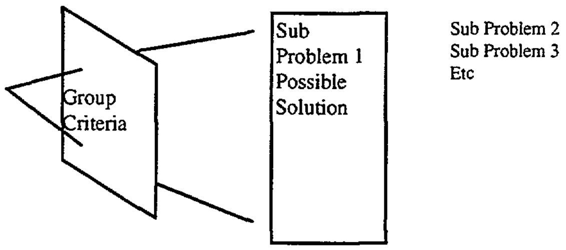


Evaluation

16. Identify group criteria. 'What criteria are we going to use to sort through the possible solutions to find the best ones?'



17. Examine 'Possible Solutions' lists using the group criteria. Select the groups solution/s to each Issue.



Decision Making

18. To each solution allocate: Who is responsible? By when? Who needs to be informed?

19. Where to from here?
Eg. How and to who do you want these results distributed?

Meeting Results

- Participants at the public meeting reached the problem analysis stage of the process. A working party made up of 16 participants with 'energy and interest' was formed to continue through all stages of the problem solving model and to ultimately develop future management strategies. QDPI staff participated as team members within the working party.
- The working party met three times. The management strategies they developed form the framework of the groundwater management plan operating in the CGMA today.
- The working party reported their strategies back to a further public meeting. Following some fine tuning the strategies were given a mandate by the water user community.
- At all times public meeting participants and Sub Area 3 irrigators were kept informed of the status of the process. They were able to provide input into the process through discussions with working party members, attendance at public meetings and submissions to the QDPI.
- A further public meeting held in September 1994 resulted in the formation of a Groundwater Advisory Committee which provides ongoing advice and input to the QDPI on the management of the groundwater resources in the area. The committee consists of 4 representatives from Sub Area 3, one representative from each of the other four sub areas, and a representative from local government, stock and domestic users, and the QDPI. The levels of representation were negotiated by meeting participants.
- Although some of the strategies implemented will result in hardship to some irrigators (reduction of announced allocations to 70% by the 1996/97 water year) the management strategies developed have been accepted by the vast majority of the water user community in sub area 3. Indeed many of the principles developed have been extended to all five sub areas within the CGMA.

Conclusions

The use of strong community consultation techniques in the Condamine Groundwater Management Area has resulted in the development of management strategies that will promote a more sustainable groundwater system for the future. The successful completion and implementation of the plan can be attributed to:-

- Careful planning and development of a transparent problem solving process
- Use of a neutral facilitator and recorder to coordinate the process
- Resulting in the Water User Community having input into and ownership of the strategies developed.

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Field Techniques for Monitoring Land Based Effluent Re-Use

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Abstract

In order to effectively manage an effluent based re-use system certain physical parameters of the soil need to be regularly monitored to ensure environmental regulations are met and optimum use of effluent is obtained. Parameters such as infiltration rates (hydraulic loading) and soil water quality can be readily monitored and an introduction to these principles will be offered.

The method of determining soil moisture content by different techniques is described with attention given to the neutron probe (NP), time-domain reflectometry (TDR) and frequency domain (Capacitance) techniques in particular. The choice of instrumentation for soil moisture determination will depend on the consideration of factors such as: the level of information required (either an absolute or relative moisture measurement); physical limitations of different techniques; the amount of data needed to objectively decide upon an irrigation regime; the initial cost of the instrument and sampling; the reliability of the instrument; and the ease of use of the instrument in the field. In land disposal systems it is important that collected data is correctly tabulated and displayed to allow correct system decisions.

Key Words

effluent re-use, frequency domain, FD, irrigation, neutron probe, NP, permeameters, soil moisture, suction lysimeters, time domain reflectometry, TDR.

Introduction

Measuring moisture content of the soil is an important aspect of effluent management. Too much effluent leads to environmental and agronomic problems such as ground water recharge, nutrient movement and poor growth rate of the irrigated crop. The reduced daily water use of plants increases the area of irrigated land required to dispose of a given volume of water increasing the capital cost of land based waste water re-use systems.

Currently there are many and varied methods for determining soil water content on a volume basis (θ_V, m^3m^{-3}) or a tension basis (kPa or bar) as described by Gardener (1986). The basic objective of irrigation scheduling is to minimise water stress of the plant, that of over irrigation, and under irrigation. If effluent is applied accurately to meet plant needs the overall area to be committed to irrigation, whilst maintaining environmental integrity, will actually be reduced. Simply, optimum plant growth will lead to maximum sustainable effluent re-use with time.

The ability to accurately measure soil water movement and content, plant size and condition is an integral mechanism in the process of developing an irrigation scheduling program that allows a better understanding of plant and soil water relations. From this basis, an understanding of plant agronomy is developed.

In re-use systems the nutrient load is generally of greater concern than water use. It is important to effectively monitor the quality of the water in the soil. A simple method utilising suction lysimeters, soil water samplers, is finding acceptance in solute transport studies.

Measuring Water Entry into Soil

In designing sound irrigation systems it is essential that a good understanding of the physical parameters of the soil is obtained. The ability of a soil to accept effluent will be determined by its hydraulic properties. The hydraulic conductivity and sorptivity of a soil will influence the irrigation rates before ponding and runoff occurs. This paper does not attempt to explain the procedure of measuring hydraulic properties in the soil, it simply aims to introduce the reader to the concept of measurement. For detailed discussion of hydraulic conductivity measured by permeameters see Stolte et al. (1994), Reynolds et al. (1992) and White et al. (1992).

Measuring Water Quality in the Unsaturated Zone

In effluent re-use schemes an important consideration is the potential for groundwater contamination due to solute transport. Effluent generally contains high loads of nitrogen (in various forms) and phosphorous. In a majority of situations the phosphorous is adsorbed to soil particles becoming insoluble with respect to the soil solution. Nitrogen is however, more mobile in the soil and leaching to the groundwater tables is a serious concern. The ability to measure for various contaminants in the unsaturated soil zone above the water table allows accurate mapping through the profile. Remediation can be instigated before the contaminants reach the water table.

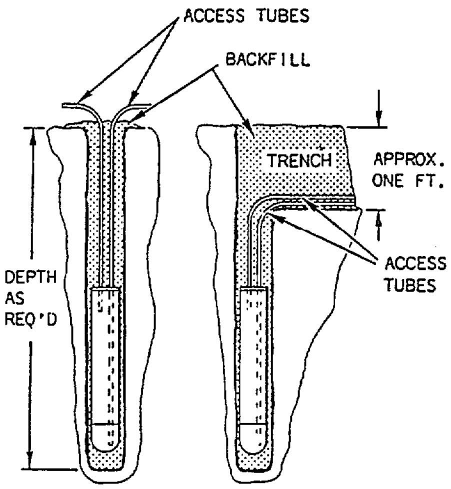

Figure 1. A suction lysimeter for obtaining soil water samples in the unsaturated zone, (SEC).

The principle of measuring soil water quality in the unsaturated zone utilises suction lysimeters (soil water samplers). As shown in Figure 1, by sealing a lysimeter and evacuating it (up to 85 kPa) a water sample is obtained as water moves through a porous material (commonly ceramic) into the chamber. A tube is then inserted into the lysimeter and the water is extracted and analysed in the laboratory for contaminants. By placing lysimeters at various depths in the soil profile the rate of movement of contaminants can be observed with time. For further detail on using suction lysimeters see Wilson et al. (1995) and McGuire & Lowery (1992).

Measuring Soil Moisture Content

Objective soil moisture measurement can be undertaken with simple tools, for example a soil auger, or complex tools that record measurement of soil moisture on a volumetric basis. The method of measurement is simply a device allowing moisture determination in an objective fashion. It is important that measurements are made regularly and recorded systematically to allow improvement in irrigation scheduling and soil/plant management decisions.

The Neutron Probe (NP)

An established technique that is used extensively throughout Australia. The technique is based on the measurement of fast moving neutrons (generated from an Americium 241/Beryllium source) that are slowed (thermalised) in the soil by an elastic collision with existing Hydrogen particles in the soil. Hydrogen (H^+) is present in the soil as a constituent of:

soil organic matter;
soil clay minerals and;
water.

Water is the only form of H^+ that will change from measurement to measurement. Therefore any change in the counts recorded by the NP is due to a change in the moisture with an increase in counts relating to an increase in moisture content.

In the field aluminium tubes are inserted into the soil and stoppered to minimise water entry. Readings are taken at depths down the profile (e.g. 20 cm, 30 cm, 40 cm, 50 cm, 60 cm, 80 cm, 100 cm and 120 cm) with a sixteen second count. The three aluminium tubes are then averaged to counter the effect of spatial variability reducing the representative value of the measured moisture content data.

Measurements are taken two to four times a week and information is down-loaded to a personal computer for interpretation. Use of the NP technique for vadose (unsaturated) zone monitoring has been employed to determine contaminate leak detection along specific transport pathways (Kramer et al., 1992), and to monitor land disposal of effluent with the NP technique (Johnson & Borough, 1992).

Time Domain Reflectometry (TDR)

Determines the apparent dielectric (K_a) of the soil matrix and this is empirically related to the volumetric soil moisture content as shown by Topp et al., (1980). The method is quick, is relatively independent of soil type, non destructive, is suited for surface and profile measurements, and allows repeatable *in situ* measurement. The TDR is a portable unit that can be carried allowing point soil moisture measurements or as reported by Heimovaara & Bouten (1990), linked to a multiplexer to measure an array of buried waveguides. The moisture content determined by the TDR is the average moisture along the length of the waveguides. Therefore, to measure at depth of 20 cm, waveguides are placed in the soil horizontally at that depth. If 30 cm waveguides are placed vertically into the soil, the moisture content determined by the TDR will be the integrated moisture content from the soil surface to a depth of 30 cm.

The technique is based upon cable testing technology, with a broad-band Electromagnetic (EM) step pulse generated and propagated along a coaxial cable (Figure 2). At the end of the cable stainless steel rods (waveguides) are inserted into the ground. The time of travel of the EM wave is determined by the apparent dielectric (K_a) of the medium (in this case soil). Water with a high dielectric ($K_a \approx 80$), compared to soil ($K_a \approx$ 3 to 5) and air ($K_a = 1$), dominates the measured K_a. Thus, if the soil is saturated the K_a is high (due to the presence of increased water) and the travel time of the EM wave along the waveguides is long. If the soil is dry the travel time along the waveguides is short and the K_a is therefore low. Equation (1) shows the relationship of K_a to travel time (Δt) in one direction along the length of the waveguides.

$$K_a = (c\Delta t/L)^2 \qquad (1)$$

Where c is the velocity of light (3×10^8 ms^{-1}) and L is the length of the wave guide (m). Topp et al. (1980) empirically related K_a to θ_v via third order polynomial and this equation (2) is the basis for soil moisture measurements at present.

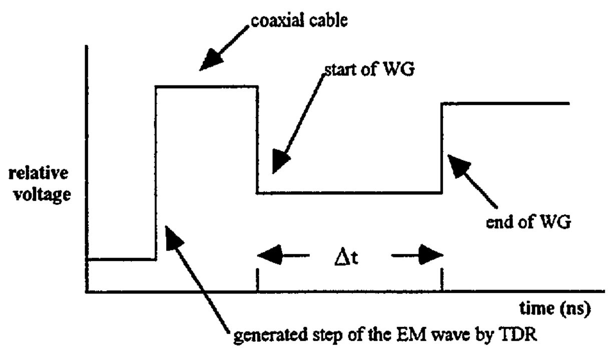

Figure 2. Schematic diagram of an EM wave generated by a step pulse TDR system as it travels along the coaxial cable and down the waveguides in the soil.

$$\theta_v = -5.3 \times 10^{-2} + 2.92 \times 10^{-2} K_a - 5.5 \times 10^{-4} K_a^2 + 4.3 \times 10^{-6} K_a^3 \qquad (2)$$

Further calibration is required for soil high in organic matter and other materials such as grain. In the field waveguides (stainless steel) are of two forms being either balanced (two-wire) or unbalanced (three-wire) and may be positioned vertically or horizontally.

Effective length of waveguides (and therefore the depth of measurement) will be determined by the power of the step pulse generated by the TDR, the soil type (heavy clay attenuates the wave more so than lighter soil types) and the moisture content of the soil. Zegelin et al. (1992) have successfully used waveguides of length 2 m to measure moisture content in Australian soil. However, in wet heavy clay soil effective waveguide length has been reduced due to attenuation of the EM wave. Importantly, the attenuation of the EM wave in conducting soil (soil with a high electrical conductivity) will allow the TDR technique to independently measure moisture content and bulk soil electrical conductivity. This is important for the measurement of solute travel (e.g. applied fertiliser) as shown by Kachanoski et al., (1992) and Vanclooster et al. (1993).

Tensiometers

Portable and stationary tensiometers measure the soil moisture content as a tension or pressure ranging from 0 to -100 kPa. Tensiometers fundamentally act in a similar fashion to a plant root measuring the force that plants have to exert to obtain moisture from the soil. As the soil dries the water is lost from the tensiometer via a porous ceramic cup. The loss of water creates a vacuum in the tensiometer and is reported as a pressure reading, the drier the soil the higher the pressure reading.

Tensiometers may be placed permanently in the soil giving an analogue or digital output. Logging of tensiometers is possible via transducers and a communication cable back to a computer or datalogger. Tensiometers can take time to equilibrate especially in heavier soil types and this should be accounted for in determining an irrigation scheduling regime. Tensiometers must be installed correctly and well maintained to operate accurately and the practical limit for reliable readings generally -80 kPa.

Frequency Domain (Capacitance)

The capacitance technique is similar to that of TDR in that the apparent (K_a) dielectric of the soil is measured and empirically related to the moisture content (θ_v). A high frequency transistor oscillator (generally ≈150 Mhz) operates with the soil (dielectric) forming part of an ideal capacitor as shown in equation (3).

$$C = K\varepsilon_0 A/s \qquad (3)$$

where the dielectric (K) is related to the capacitance (C) via the relationship of the total electrode area (A) and spacing of the electrodes (s), noting that (ε_0) the permittivity of free space is constant (White and Zegelin, 1995).

In a field situation the design of the capacitance probe is not ideal with two annular rings (electrodes) placed in a plastic access tube in the soil. The measured area is now removed from between the electrodes to outside the access tube. The measurement area is considered a "fringe field" as the main influence on the oscillating wave is the uniform interior of the access tube.

Measurement is undertaken by either lowering a sensor into the access tube (Bell et al., 1987), portable meters or placing an array of sensors into the soil and logging the output frequency. The measured (angular) frequency is related to the soil moisture content via a non-linear calibration. Measurement of absolute (and perhaps relative) moisture content is dependant on soil type and bulk density.

Electrical Resistance (Gypsum) Blocks

Electrodes are embedded in a porous (gypsum) block and placed in the soil at different depths in the root zone. The water in the soil will reach an equilibrium with the water in the gypsum block and the electrical resistance is then determined and related to moisture content as a tension (kPa). Gypsum blocks do not measure the moisture content at low potential (from 0 to -100 kPa) well. The operating range is suited from about -60 kPa to -700 kPa (as the soil dries). Gypsum blocks will dissolve over a period of time (with the rate of dissolution increasing in sodic soil) generally lasting for two to three seasons in good conditions (Gardener, 1986).

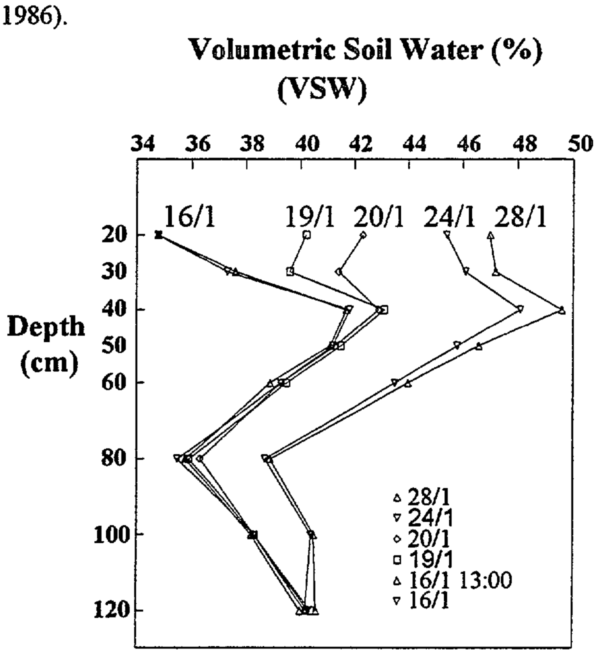

Figure 3. Soil moisture profiles after application of effluent

Large errors, up to 100%, can occur due to: slow equilibrium of blocks with the actual soil potential; the dependence of resistance on the block temperature; contact with the soil; and, blocked pores by fine material such as silt or clay particles (White and Zegelin, 1995). Electrical resistance is a useful indicator of the soil moisture content in respect to root conditions such as: plentiful water; good growing conditions; approaching water stress; and water stressed plants.

Land Disposal of Effluent - A Case Study

The city of Dubbo, NSW, has established a waste water re-use woodlot, with the water applications being monitored with various soil moisture sensors. Initially, the automatic irrigation system was set to apply water for 1 hour per day.

From Figure 3 note the two readings on 16/1 were taken before and after the 1 hour irrigation. There is almost no change in the profile indicating an ineffective application of effluent. The applied effluent was evaporated before entering the soil profile The irrigation time was increased to 3 hours per day and the water profiles started to increase, with infiltration down to 40 cm by 19/1 and by the 24/1 an increase in water content at 120 cm. There is a possibility that effluent may be draining through the profile. The same data can be plotted as a time graph (Figure 4), with the through-drainage showing as an increase in water content at 100cm on 22/1.

Quantitative measurement of soil moisture, combined with appropriate software, allows for routine monitoring of the woodlot. The irrigation schedule can now be adjusted to optimise tree production, while at the same time ensuring that effluent does not contaminate the aquifer.

Solid waste disposal using landfill can also result in through-drainage of contaminants. California environmental protection regulations are now calling for environmental monitoring to *guarantee* that through-drainage is not occurring. This results in a very different design problem, as the assumption that isolated monitoring is indicative of overall behavior is no longer appropriate. Some landfill sites have had impervious liners installed, with several horizontal access tubes below the liners for neutron probe monitoring of possible leaks as shown by Kramer et al., (1992).

Conclusions

In monitoring effluent for irrigation purposes there are three aspects to consider:

entry of water into the soil;
quality of water in the soil;
quantity of water in the soil.

Use of field instruments such as permeameters before irrigation systems are designed will reduce potential pollution control problems such as surface ponding and runoff. Suction lysimeters allow continued sampling of soil water quality in the zone (unsaturated) above the water table.

Correct irrigation scheduling can control the soil moisture status reducing through-drainage and maintaining optimum levels of soil water for maximum plant growth. To implement a reliable and accurate irrigation scheduling regime regular, objective soil moisture readings are essential. The choice of instrumentation will be determined by the form of information required by the operator, the soil type, relative cost, reliability and ease of use in the field. With the information collected from various techniques it is essential that it is presented in a uniform and concise fashion to justify management practices and satisfy regulatory requirements.

Acknowledgments

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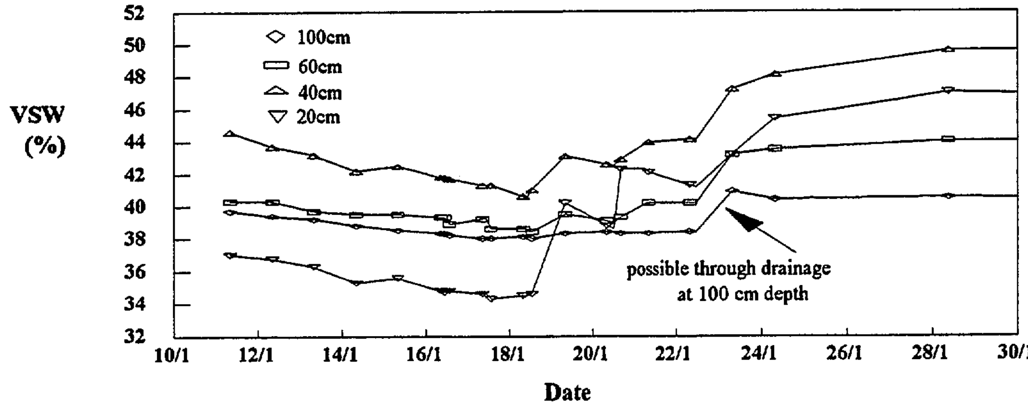

Figure 4. Changes in soil moisture with time (days) at different depths

the National Teaching Company Scheme (agreement number 12234).

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Towards quantitative irrigation water quality guidelines for sustainable cotton production

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Introduction

The widespread use of surface water for irrigation of cotton is resulting in rising water tables through increased recharge to groundwater. One strategy to manage shallow water tables is the conjunctive use of surface and groundwater for irrigation. As salinity and sodicity are the key water quality parameters determining the suitability of groundwater for irrigation of cotton (Shaw and Gordon, 1994), an accurate prediction of the likely impact of altering irrigation water quality on soil leaching, soil salinity and thus crop yield is required.

Leaching controls salt accumulation in the root zone and the extent of downward salt mobilisation. As the salinity of irrigation water increases the greater the leaching required to maintain root zone salinity at levels not toxic to cotton. The addition of saline water will also increase the exchangeable sodium percentage (ESP) of the soil surface. As ESP increases, the rate of water infiltration into the soil surface will decrease, hence reducing the amount of leaching.

Therefore it is important to have good predictions of salt leaching in soils, particularly the slowly permeable Vertisols on which cotton production is concentrated, for reliable irrigation suitability assessments. A knowledge of the potential salt accumulation under irrigation is also important in determining the likely impact on crop production and long term sustainability of irrigation and management practices.

One of the earliest models developed to quantify irrigation water quality with prediction of leaching flux under "steady state" conditions, is the USSL (United States Salinity Laboratory, 1954) model of mass balance. The USSL is also the steady state solution to the SODICS model (Thorburn et al., 1990). The SODICS model is a transient salt mass balance model developed specifically for slowly permeable soils and provides information on predicted steady state chloride profiles and the estimated time for the profile to reach equilibrium under the current management practices and water quality. A weighted salinity model was used by Shaw and Thorburn (1985) to predict the leaching fraction (flux out relative to the flux in) under irrigation. The underlying assumption of this model (SaLF) was that, "if the ESP-EC-rainfall equilibrium established for the non-irrigated sites is below the threshold level for maximum hydraulic conductivity (K), there will be a linear increase in leaching for an increase in electrolyte concentration above this level".

More recent research has developed a non-linear relationship between increasing electrolyte concentration and leaching fraction. This project is utilising the model of Suarez (1981) to account for irrigation water compositions where the ESP of the soil will be changed and incorporating this effect into the steady state predictions of the Shaw and Thorburn (1985) model. The model of Suarez allows the sodium adsorption ratio (SAR) of drainage water, hence the ESP of the soil, to be simply and accurately calculated from a derived equation and a table accounting for the ionic strength and HCO_3/Ca ratio in the irrigation water.

Historically water quality criteria for irrigation have been developed for a specific region where local soils, environmental conditions and management practices have been influential in developing suitability limits. These guidelines tend to be overly conservative and cannot be satisfactorily extrapolated to different regions.

This paper presents results from data collected from the Lockyer Valley and Darling Downs and makes initial comparison between SODICS, USSL and SaLF models in the development of a quantitative approach to irrigation water assessment. This work is part of a research project sponsored by the CRC for Sustainable Cotton Production.

Preliminary results are presented for soil and water samples collected from the Darling Downs and Lockyer Valley in southern Queensland.

Methodology

Soil and water sampling was undertaken on key sites selected within cotton growing regions in southern Queensland (Figure 1). Sites were selected where groundwater provided a significant proportion of the irrigation supply to allow monitoring of the impact of marginal quality waters on soil properties, salinity and sodium levels. Samples were collected from non-irrigated, short-term and long-term irrigation paddocks from each site. A detailed history of irrigation and management practices on each of the paddocks was collected from farmers, consultants and regional agronomists. This information was collated to provide data on the total amount of water (hence sodium and total salts) applied to each paddock that was sampled as part of the project.

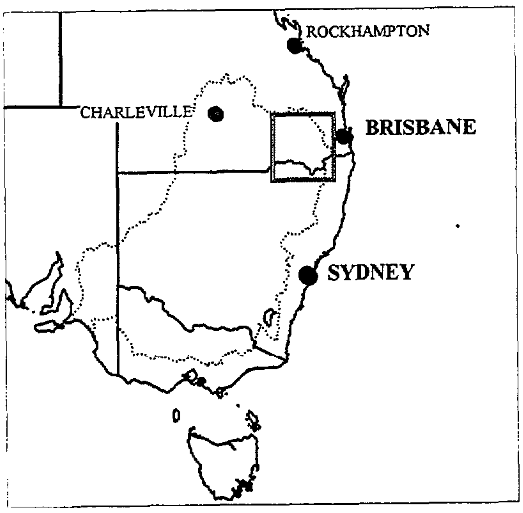

Figure 1. Location of soil and water sampling

Laboratory analysis of samples provided the data to run SaLF, SODICS and the USSL models. These models were selected as they can be applied to data routinely collected during soil surveys and water testing and require no detailed soil physical measurements. The minimum data set required to run all models includes, for soils, soil chloride, particle size analysis, cation exchange capacity, sodium and 15 bar moisture content and for irrigation water, salinity, chloride concentration, sodium, magnesium and bi-carbonate levels.

The USSL model requires chloride %, SODICS requires chloride and 15 bar information and SaLF uses clay, CEC, and ESP to predict leaching flux from soil properties.

From the models calculations of leaching flux at the bottom of the root zone, the average root zone salinity was then calculated using a relationship derived by Rhoades (1983) as follows:

$$EC_{se,\,avg.} = EC_{iw} * LF_{avg.} \,/\, 2.2 \qquad \text{Eq. 1}$$

where:
$EC_{se,\,avg}$ is the averaged root zone electrical conductivity of soil saturation extract, EC_{iw} is the electrical conductivity of irrigation water and $LF_{avg.}$ is the average leaching fraction of the root zone.

and,

$$LF_{avg.} = (\,0.976\, LF_{bottom} + 0.022\,)^{0.625} \qquad \text{Eq. 2}$$

where LF_{bottom} is the leaching flux at the bottom of the root zone.

Results & Discussion

The soil chloride profiles indicate that long term irrigation with saline water increases root zone chloride levels in the Lockyer Valley (Figure 2a) and "steady state" chloride levels are exceeding the critical concentration for cotton yield reduction for some depths within the profile. Chloride profiles for three sites on the Darling Downs (Figures 2b, 2c and 2d) also indicate an increase in chloride levels with irrigation using bore water, but under long term irrigation the "steady state" chloride levels should be having minimal effect on cotton production. Steady state is assumed when the salt concentration down the soil profile doesn't change over time under current conditions of water quality input. Steady state in the SODICS model is assumed when the average root zone chloride concentration value is within 5% of the calculated final chloride concentration value.

Data collected from field sites was used to estimate the leaching flux under the various irrigation treatments. These leaching flux estimates were then used to calculate the average root zone salinity for each treatment using equations 1 and 2. Leaching flux and average root zone salinity estimates from the three models tested are presented in Table 1.

Under steady state conditions there is a general agreement of estimated leaching fluxes between the SODICS and the USSL model (Table 1). This is to be expected as the USSL model can be shown to be a special case of the SODICS model when steady state chloride levels have been reached. Therefore, under conditions where steady state exists, the USSL provides similar accuracy compared to SODICS but requiring less input parameters. The SODICS model has indicated that steady state has not been reached for those sites on the Darling Downs where irrigation has only been applied for a few years. This would contribute to the difference in estimated leaching fluxes between the SODICS and the USSL models. For the highly saline waters in the Lockyer Valley the SaLF model gave a similar estimate of leaching flux to the SODICS and USSL models, however with the saline, sodic irrigation waters from the Darling Downs, the

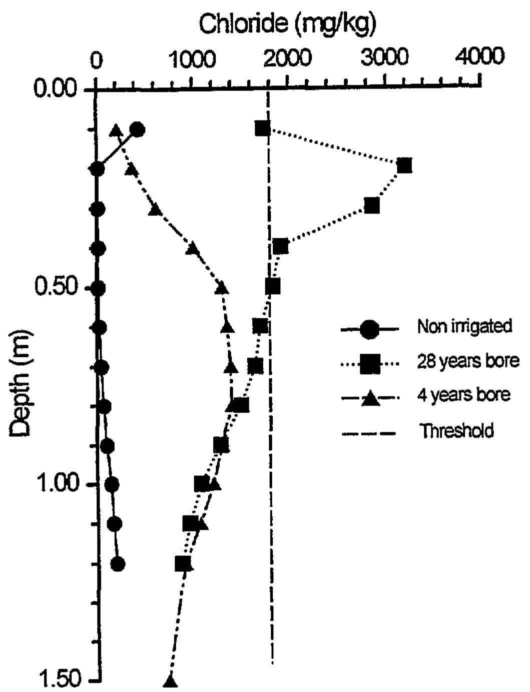

Figure 2a. Soil chloride profiles measured on a cotton property in the Lockyer Valley. Sites included a non-irrigated (——), 28 years bore water (·····), and 4 years bore water /dam water blend (–··–) where water salinity was 7.19 dS/m.

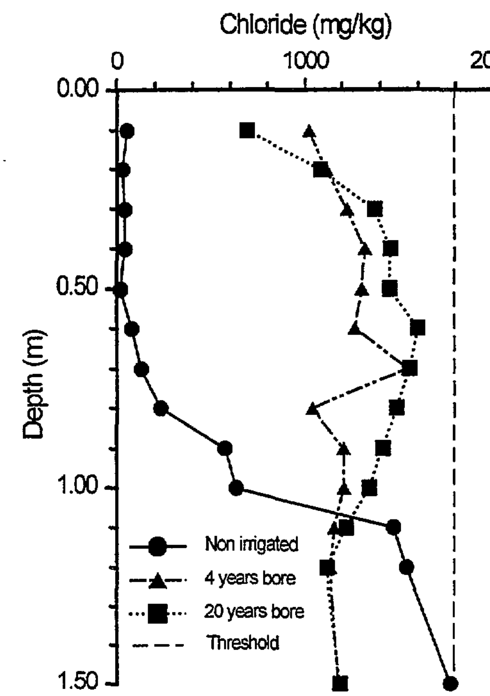

Figure 2c. Soil chloride profiles measured on a cotton property on the Darling Downs. Sites included a non-irrigated (——), 4 years bore water (–·–·), and 20 years bore water (·····) where water salinity was 4.06 dS/m.

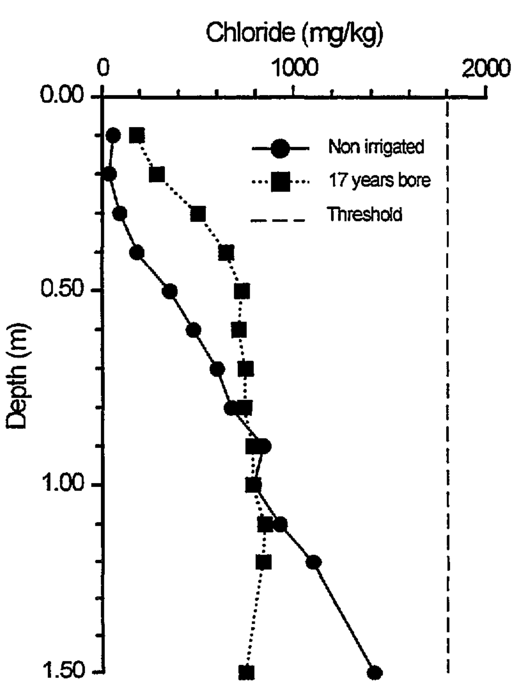

Figure 2b. Soil chloride profiles measured on a cotton property on the Darling Downs. Sites included a non-irrigated (——), and 17 years bore water/ dam water blend (·····) where water salinity was 2.25 dS/m.

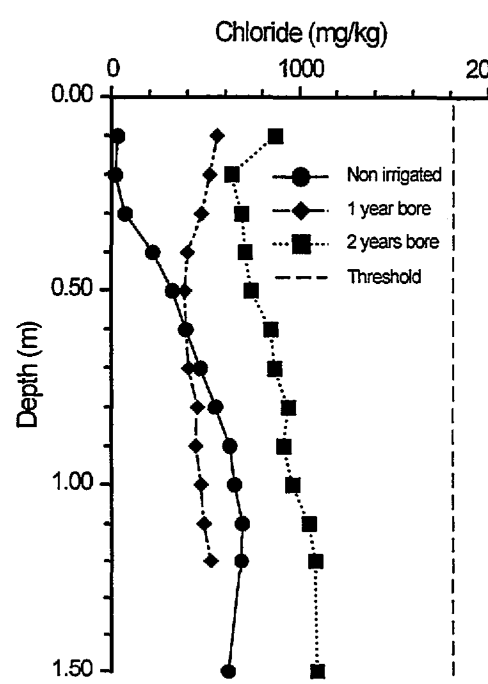

Figure 2d. Soil chloride profiles measured on a cotton property on the Darling Downs. Sites included a non-irrigated (——), 1 year bore water (·····), and 2 years bore water (–·–) where water salinity was 4.1 dS/m.

Table 1. Predicted leaching fluxes and average root zone salinity from soil and water data collected from sites in the Lockyer Valley and the Darling Downs.

Site	Irrigation (years)	Bore water quality		Steady-state (*)	Estimated Leaching Flux (mm)			Estimated salinity (dS/m)			Measured (dS/m)
		EC (dS/m)	SAR		SODICS	USSL	SaLF	SODICS	USSL	SaLF	
Lockyer Valley											
Site 1	0			Yes		21	10		0.2	0.3	1.1
Site 2	28	7.2	2.2	Yes	327	346	311	6.7	6.5	6.9	6.9
Site 3	4	3.8	1.1	No (12)	73	79	113	7.9	7.6	4.4	5.0
Darling Downs											
Site 1	0			Yes		1	1		0.2	0.2	3.6
Site 2	17	1.5	5.8	Yes	35	38	10	6.7	6.5	9.6	4.3
Darling Downs											
Site 1	0			Yes		5	1		0.2	0.2	2.0
Site 2	4	4.1	15.0	No (14)	106	117	29	7.3	6.9	12.0	6.0
Site 3	20	4.1	15.0	Yes	79	85	29	8.4	8.1	12.0	5.9
Darling Downs											
Site 1	0			Yes		2	2		0.2	0.2	2.1
Site 2	1	2.6	15.0	No (7)	126	151	57	6.9	6.2	10.1	4.1
Site 3	2	3.0	15.2	No (4)	355	398	57	3.8	3.6	10.1	2.5

* Predicted number of years to reach steady-state from the SODICS model.

SaLF model gave lower estimates of leaching flux than the other models under steady state conditions. These differences could be due to the use of existing ESP of the non-irrigated soil in model calculations rather than the final ESP under irrigation.

Cotton growth is considered to be affected by salinity once a threshold of electrical conductivity of the soil saturation extract (EC_{se}) of 7.7 dS/m has been exceeded. Estimates of average root zone salinity (Table 1) show a strong agreement between calculated and measured salinity for the SODICS and USSL models, particularly under steady state conditions. The slight overestimation of root zone salinity as compared to measured values from these two models could be contributed to assumptions used in the Rhoades (1983) methodology for estimating average leaching flux from bottom of the profile leaching flux values. In deriving this methodology Rhoades assumed that there was a linear pattern of water uptake from within the root zone. The estimated root zone salinity from SaLF match measured salinity levels in the Lockyer Valley well, but tend to overestimate the salinity levels for site on the Darling Downs. These differences appear to be related to the variation in leaching flux estimates from the SaLF model, although the conversion from leaching flux to root zone salinity could also be contributing to the observed differences in estimated and measured root zone salinity.

The Australian Water Quality Guidelines (1992) provide general criteria which suggest that waters with salinity levels (EC) greater than 2.3 dS/m are "not suitable for irrigation water under ordinary conditions". Results presented in Table 1 indicate that long term cotton production is feasible with irrigation water salinity levels in excess of commonly accepted criteria. Water salinity and sodicity are currently the only parameters considered when the impact of irrigation water on leaching flux is calculated in the SaLF model. New approaches under development are to incorporate the impact of water chemistry on leaching flux estimates and hence develop an approach which takes into account both soil properties and water properties when estimating leaching fluxes and soil salinity.

Full statistical analysis has not been completed for data presented in this paper, but results highlight the relativity between the various approaches to estimation of leaching flux under irrigation. The SODICS model provides our closest estimate of "reality" as it has been developed specifically for slowly permeable soils and is not reliant on steady state assumptions. The USSL model has been widely applied in irrigation studies due to its simplicity but is limited due to the assumption of steady state conditions. The SaLF model provides a simple empirical model based on rainfall, irrigation water and easily measured soil properties related to hydraulic conductivity. This approach allows prediction of future values of leaching flux and root zone salinity that will occur under irrigation, hence provides a useful tool for water quality assessment.

Conclusions:

Results from this project highlight the fact that irrigation of cotton can be sustained with water quality considered to be unsuitable under "traditional" water quality criteria. A more logical approach would be an assessment of water quality for a particular soil type. A soil properties based approach such as the SaLF model could provide a mechanism to rapidly assess the suitability of any water source for irrigation on a particular soil type. Further improvements to the SaLF model as indicated in this paper would make a more robust methodology for assessing water quality impacts on soil leaching and soil salinity. This approach also has important ramifications for assessing the viability of salinity management options such as conjunctive use strategies.

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Urban Salinity Investigations in Wagga Wagga

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Introduction

Salinity has been recognised in a number of towns within the Murray Darling Basin. The magnitude of this problem due to the intensity of urban infrastructure is just being realised. At a community level these include the threat to underground utilities such as water, gas, electricity, telephone and sewer; deterioration of the foundations of buildings, roads and other structures; and the loss of public recreation areas and sporting facilities. For individual residents within salt affected areas they are maintaining their home and garden in a saline and sometimes water logged environment as well as realising the economic loss of their property's value.

An urban salinity action plan is being developed for the city of Wagga Wagga which is located on the south west slopes of New South Wales (NSW). This is a pilot project looking at the options available for urban salinity management and control. It is a joint project involving state and local government agencies, Charles Sturt University and community groups. It includes investigations into the recharge processes, strategies to reduce recharge as well as considering the management options available for rehabilitation of urban discharge areas.

This paper looks at urban salinity issues and presents some of the preliminary findings of the investigations undertaken in Wagga Wagga.

Recharge in Urban Areas

As with salinity problems that have developed in agricultural areas, salinity in urban areas is a result of excess recharge reaching the underlying groundwater system causing the water table to rise. Evaporation from the shallow water tables concentrates the naturally occurring salts, in the groundwater and soils, leading to salinisation.

In an undisturbed catchment the primary source of recharge is rainfall. The clearing of deep rooted vegetation has resulted in an increase in the volume of rain water infiltrating through to the underlying groundwater. This additional rain water recharge has been sufficient to cause groundwater levels to rise causing land salinisation throughout southern Australia.

Most urban development is occurring on cleared rural land on the fringes of existing settlement. The increase in paved and rooved areas on this cleared land decreases the available infiltration area. This initially suggests that groundwater recharge is reduced in an urban area. However this needs to be put into context with all aspects of the urban water cycle.

Urbanisation generally results in a net increase of groundwater recharge as a result of contributions from pipe leakage, waste water disposal, drainage soakaways and over irrigation of recreation areas (Foster et al 1994, Lerner 1986). Foster et al (1994) suggests that although the relative contributions of each of these recharge sources will vary, they almost always exceed the reduction in rainfall recharge resulting from the increase in hard surfaces in the urban area.

The 1993 NSW Water Supply and Sewerage Performance suggests that leakage from town water supplies is generally underestimated by Councils. A study of 40 water supply schemes in NSW were found to have leakages ranging from 7% to 35% of the total supply with an average of 17% (Sarma et al, 1994.)

Leakage from sewerage and storm water pipes also add to the groundwater recharge under urban areas. Leakage from these sources is harder to quantify than that from water mains which are metered.

Urban Salinity in Wagga Wagga

Wagga Wagga has a population of 56,000 and is located 450 km south west of Sydney. The city was originally sited on the floodplain on the southern bank of the Murrumbidgee River. The urban area now encompasses some 44km^2 with 60% situated on the hill slopes south of the floodplain. Urban development has also recently taken place on the slopes north of the floodplain.

Salinisation has occurred predominantly on the lower slopes adjacent to the southern floodplain which also corresponds to the earlier developed areas of Wagga Wagga. Other sites higher in the catchments have also shown signs of water logging and salinity which are most likely due to local perched water tables.

The overall cost of urban salinity to the Wagga Wagga community has been estimated at $442,500 per year with the projected total costs ranging from $4.4 million and $5.1 million over the next ten years (Christiansen, 1995). There are an estimated 600 residential houses at risk of being affected by salinity with 50 to 100 of these already requiring some form of remedial work. The main infrastructure expenditure is on maintenance of urban roads with some $226,600 being spent each year to repair damage resulting from high water tables (Christiansen, 1995).

Hydrogeology

The alluvial sediments of the Murrumbidgee River are up to 80 metres (m) thick in the Wagga Wagga area. Transmissivity values from 900 m^2/day to 1,200 m^2/day have been determined from pumping tests (Malebe, 1970 cited in Woolley 1972). High yields of up to 200 litres/second (L/s) are obtained providing low salinity irrigation and town water supplies (Lawson, pers comm 1995). Sixty percent of the Wagga Wagga city water supply is obtained from bore fields on the floodplain.

Ordovician metasediments and Silurian granites of the Lachlan Fold Belt forms bedrock and outcrops on the adjacent hills. The contact between these two rock units is a prominent north south ridge, Willans Hill, which runs through the southern suburbs of Wagga Wagga. To the west of this ridge the city is underlain by the metasediments and to the east by granite which also outcrops north of the floodplain.

The metasediments are mostly comprised of phyllite and shale although some quartzite and schist is also present. They are generally well fractured in outcrop. Drilling data indicates that both the granite and metasediments have a thick weathered zone overlying them.

There are few bores completed in the bedrock within close proximity to Wagga Wagga. However yields from bores in the metasediments in the area are typically small falling in the range of 0.3 - 0.5 L/s. Some higher yields have been experienced in the metasediments where well fractured zones have been intersected (Britten, 1994).

A transmissivity of 1.5m^2/day was calculated from a pumping test undertaken on a test bore drilled into the metasediments as part of the urban salinity investigations.

Bores into the granite have generally been unsuccessful although some bores have obtained yields up to 0.3 L/s.

Groundwater Levels

A regional groundwater reconnaissance survey of groundwater levels in the Wagga Wagga - Narrandera area was undertaken by the Department of Water Resources in 1991. The survey showed that the median rate of groundwater level rise in the granite was 0.24 m/year and 0.34 m/year in the metasediments (Lytton et al, 1993).

Thirty three monitoring bores have been drilled within Wagga Wagga as part of the urban salinity program. The majority of these have been installed into the colluvium overlying the metasediments in the western areas of Wagga Wagga where salinisation is presently occurring. Depth to groundwater varies from 15 metres in the mid catchment to near surface on the lower slopes.

Groundwater contours indicate that groundwater movement is down catchment towards the Murrumbidgee River floodplain. Groundwater levels become progressively shallower down catchment as a thick clay sequence at the base of the slope adjacent to the floodplain is approached. Once onto the floodplain alluvium the depth to water increases again responding to the more permeable sand and gravel sequences.

Salinisation within the metasediments has resulted from the water table backing up behind the low permeability clay preventing it from sub surface discharge into the highly transmissive alluvium.

Localised water logging has occurred in the granite catchment underlying the eastern half of Wagga Wagga. Monitoring bores drilled in this catchment struck water from 30 m to 15 m below ground level.

Drought conditions have been experienced since the monitoring began and groundwater levels have been falling during this period with the greatest falls, 1.5 - 2 m, being in the mid to upper catchment (Farrugia, 1995).

Groundwater Quality

Electrical conductivity in the metasediments varies from 1,100 μS/cm from a deep (61m) bore completed into fresh shale to 22,000 μS/cm from a shallow bore in a saline discharge zone. Most are in the range from 4,000 to 7,000 μS/cm.

Bores located in the granite catchment tended to have lower salinity water with conductivities from 500 to 1,200 μS/cm on the valley slopes. However further down gradient where the catchment opens out the salinity is significantly higher at 16,000 μS/cm. These bores were all completed within the clay colluvium overlying the granite.

Recharge in Wagga Wagga

Preliminary work on the relative contribution of the various recharge sources has been undertaken in an 425 ha area of Wagga Wagga. It includes 1,800 residences, a commercial area and a number of education and government institutions. Water usage and rainfall for a 12 month period from August 1993 to July 1994 were used to estimate recharge contributions which are summarised in Table 1.

The recharge sources can be divided into three categories, rainfall (which includes both diffuse rainfall and roof run off into rubble pits), leakage from pipes and irrigation.

Table 1. Contribution of Recharge

Recharge Source	Estimated Volume for 93/94 year (kL)
Rainfall - diffuse (1-3%) - rubble pits	 29,750 - 89,250 53,120
Pipe Leakage - water supply (5-17%) - sewer (5-15%)	 46,400 - 190,130 16,430 - 49,280
Irrigation (1-5%)	4,120 - 20,600

In some of the earlier developed urban areas of Wagga Wagga houses on the low side of the street which were unable to discharge their roof run off to the street had their roof water directed into rubble pits in the back yard. These rubble pits provide direct recharge to groundwater. Twenty three percent of houses in this area use rubble pits to dispose their roof run off. Using rainfall data and an average roof area of 186m² the volume of water directed into these pits was calculated.

Potential recharge from rainfall infiltration has not been measured. Urbanization in this area has resulted in 30% of the land being made impermeable. (Hamilton, 1995). Level contour banks constructed on Willans Hill to prevent erosion enhances rain recharge as run off is retained behind these banks and its only escape is to infiltrate or evaporate. A range of 1 - 3% of rainfall was used for diffuse rainfall recharge.

Leakage from water supply pipes can be divided into two components, losses from the main distribution system and the losses on the consumers' properties. Estimates of losses from the mains system is in the order of 5 - 10 % (Nash, pers comm, 1995). Leakage from the meter to the consumer is often the leakiest part of the system (Lerner et al, 1990). For the purposes of comparison to other recharge sources the average estimated leakage for town water supply leakage of 17% has been calculated.

Leakage from sewer pipes and storm water drains cannot be measured and would depend on their construction, maintenance and the properties of surrounding soils. The inflows and outflows of these systems are not metered. Using a sewerage volume of 200L/day/person (Earnshaw, pers comm 1995) and a range of leakage values from 5 - 15% a broad estimate of potential leakage from sewers has been made.

Combining the water usage on domestic gardens, irrigation of public recreation areas, schools, TAFE, university and the grounds of other public authorities, an estimated 44% of the total area's water supply is applied as irrigation (Hamilton, 1995).

These figures are first estimates only and are provided to illustrate the various sources of recharge in an urban area and the potential relative contribution of these sources.

Options for Management in an Urban Area

As with irrigation and rural dryland salinity, urban salinity is a water balance problem. It's management within the urban environment will require a unique set of management strategies due to the vastly different land use and urban community expectations.

The long term management of urban salinity will rest with the reduction of recharge. To achieve this, local authorities and the urban community as a whole will need to understand and accept the limitations of the natural catchment in accommodating urbanization.

Opportunities for recharge reduction by revegetation are often limited in established urban areas due to the density of housing and the lack of suitable areas. However as urban areas expand the need for vegetation management for recharge control should be considered at the planning phase.

Rubble pits act as numerous point sources of recharge. Their disconnection would provide immediate recharge relief.

In practice however this is difficult. In Wagga Wagga for example there is no record of their existence and each house has to be individually surveyed. The installation of rear of block drainage to take this roof water is expensive. It is also difficult logistically as there is usually no drainage easement and the works need to be installed through established gardens dodging such things as sheds, pools and trees.

The willingness of residents to participate in such a program is also an issue. Those not directly impacted by salinity will not be inclined to contribute financially nor be inconvenienced by the installation of rear of block drainage. The education of the community and their adoption of the salinity action plan's recommendations will be crucial for its successful implementation.

Strategies to reduce recharge address the cause of salinity and form the basis of long term management. However this does little to provide relief to homes which are currently deteriorating in saline discharge areas.

Investigations in Wagga Wagga are exploring the feasibility of potential drainage options to alleviate high water tables as a means of short term relief. The disposal of saline water, whether by evaporation or river discharge, are issues that need to be investigated in terms of off site impacts and the constraints of the existing urban development.

An outcome of the Wagga Wagga urban salinity program will be to develop a set of management strategies for local government and community groups for the treatment of saline urban land. This will include education programs, management options for urban recharge control and remediation of discharge areas.

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Salt Kit
A "Do It Yourself" Salinity Identification Kit For Farmers

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Introduction

The Salt Kit is a "do it yourself" soil and water salinity assessment kit for farmers and Landcare groups. The Salt Kit arose from the increasing interest of the irrigation farming community in northern Victoria, wanting to understand more technical information related to salinity. With expanding Landcare activity, there was a need to develop and document standardised methods for collecting, monitoring and interpreting information on the status of watertables and soil salinity. The Salt Kit will help farmers work with advisory people to develop options for their farm or catchment. It also endeavours to promote the uniform use of units and terminology between Government Departments, Landcare groups and landholders.

The Salt Kit consists of three sections:

- a reference manual,
- a waterproof liftout of the field procedures contained in the manual,
- a box containing a set of jars, plastic bags and a texta for soil and water sampling.

This paper summarises the individual chapters in the Salt Kit. Initial background chapters are mentioned only briefly. More emphasis is placed on the testing, monitoring and interpreting of watertables and soil salinity.

Chapter 1 Setting the Scene

This chapter describes why it is important to measure watertable and salinity levels. Often the early signs of salinity, sodicity and waterlogging are confused with other problems such as lack of fertiliser or water. Decreased yields often occur before visible indications of problems including salinity arise. It is important that resources such as water, seed and fertilisers are used more efficiently by concentrating them on the non-saline soils. Table 1 demonstrates that losses in productivity from soil salinity can be very high, even on moderately saline soils, and highlights the requirement for monitoring.

Chapter 2 Defining Terms and Salinity Units

A glossary of terms is provided in this chapter which simply describes the terminology or "jargon" often used when discussing salinity. The salinity of a soil or water sample is measured by determining the capacity of the sample to carry an electric current and is expressed as electrical conductivity. This is often referred to as EC units and the following conversions apply;

$$1000\ EC = 1000\ \mu S/cm = 1\ dS/m.$$

The Salt Kit proposes that the following units be used uniformly for water and soil salinity measurements:

- microSiemens per centimetre (µS/cm) for <u>Water</u>,

Soil Salinity	Class	Dairying	Mixed Farming
Little or no salinity	(Class A+)	$ 170	$ 50
Low salinity	(Class A)	$ 120	$ 30
Moderate salinity	(Class B)	$ 55	$ 10
High salinity	(Class C)	$ 5	$ 0
Extreme salinity	(Class D)	$ -15	$ -15

Table 1: Estimated returns from applying 1 ML of irrigation water to different classes of saline land for Northern Victoria (modified from Branson, 1992).

It can also be expressed as total dissolved salts (TDS) in milligrams per litre (or parts per million) by the following conversion: *TDS (mg/l) = Water Salinity* ($\mu S/cm$) *x 0.6* (approximately).

- deciSiemens per metre (dS/m) for Soil,

This can also be expressed as total soluble salts (TSS) in milligrams per litre (or parts per million) using the following conversion: *TSS (mg/kg)* = $EC_{1:5}$ *(dS/m) x 3000* (approximately), when measured as a one part soil to five parts water extract and referred to as $EC_{1:5}$.

Chapter 3 Looking for the signs

This chapter defines the processes of salinity, describing local (perched) and regional watertables, capillary rise and how salinity is identified in plants, the landscape and the natural environment. This chapter aims to provide some background knowledge on salinity and to enable farmers to recognise the visual indicators of salinity. Other inter-related factors such as waterlogging and sodicity are briefly discussed in terms of their effects and means of identification.

Chapter 4 What is happening to the watertable under your farm ?

Simple tests can be undertaken to measure watertable levels and water salinity through the installation of "testwells". A testwell consists of a PVC pipe installed to a depth of two to three metres having slots over most of its length, thereby allowing groundwater free movement into it. This chapter provides guidelines on locating, installing and the monitoring of testwells and a basic interpretation of the results.

Locating and Installing Testwells

Watertables in any area can be highly variable because they are affected by soil type, rainfall, topography, land use and irrigation. When installing testwells, it is suggested to work from areas of low topography up. Watertables are generally closest to the surface in low lying areas (depressions) with heavy soils. These areas will normally show the first signs of salinity. Higher areas on the farm have typically light soils and are less prone to salinity because they have deeper watertables. If a range of land uses exist on a property (eg. permanent summer pasture, sub-clover, cropping, tomatoes etc.), it is a good idea to install testwells in all of these areas.

It is important to install the testwells in areas of easy access (fencelines or permanent checkbanks are ideal) and where they will not be damaged by stock or farm machinery. It may also be valuable to install testwells at varying distances away from areas influenced by watertable control measures, such as groundwater pumps, tile drains, or large tree plantings. By monitoring these testwells, it will be possible to gauge the effectiveness of these strategies over time and assess their area of influence. If possible, it is also worthwhile locating a testwell next to a piezometer (PVC pipe installed to greater depth, usually into an aquifer, with slotting only at the bottom of the pipe) to compare the watertable level with the groundwater pressure.

Testwells should be located more than 30 m from the following;

- Permanent or semi-permanent bodies of water (ie. dams, reuse systems, supply or local channels, blocked roadside table drains).
- Dairy or other buildings.
- Mature tree(s).
- The spears of a spear point groundwater pump.
- Areas subject to long periods of inundation.

When installing testwells it is important to backfill the hole with coarse sand around the slotted pipe section. Above the slotted section, the hole should be backfilled with clay to form a seal preventing water moving down the side of the pipe. A dome of soil formed around the top of the testwell will help to prevent water from ponding there. Once installed, it may be important to record the location of the testwell on a district map. Many northern Victorian Landcare groups are using a Global Positioning System to accurately locate their testwells for monitoring purposes and the production of watertable maps. General information relating to site position provides a useful reference for interpreting testwell readings. A data sheet is provided at the back of the Salt Kit folder which lists the main information that needs to be recorded for this purpose.

Monitoring Testwells

Watertable depths in irrigation areas normally fall over summer and rise during wet autumn, winter and spring periods. To appreciate changes in watertable depths over a year, it is important to take monthly measurements. During the irrigation season, measurements in irrigated pastures should be taken just before an irrigation cycle commences. This will reduce the risk of irrigation water seeping into the testwell and distorting the reading. It is recommended, if water samples are being collected to measure salinity, that the testwells are bailed beforehand. Irrigation water and rainfall, along with groundwater that has concentrated in the testwell, can significantly alter the salinity level of the groundwater.

Watertable salinity µS/cm (EC units)	Soil salinity risk where;	
	Low Evaporation & Watertable deeper than 1 metre	High Evaporation & Watertable shallower than 1 metre
less than 2,000	Very low	Low
2,000 - 3,999	Low	Medium
4,000 - 8,999	Medium	High
9,000 - 14,999	High	Very high
15,000 - 23,999	Very high	Extreme
greater than 24,000	Extreme	Extreme

Table 2: Potential soil salinity risk associated with watertable salinity.

Four days is the suggested standard time needed to allow the water in the testwell to return to its static level after bailing, before measuring the depth of the watertable and taking a water sample.

Interpreting Testwell Readings

Shallow saline watertables increase the likelihood of capillary rise and are closely linked to the soil salinity in the plant rootzone. Table 2 summarises the hazard associated with different watertable levels. This information is based on average levels over a number of years. As shown, higher groundwater salinities greatly increase the risk of soil salinisation and the rate at which it will develop.

Chapter 5 What is happening to the soils on your farm ?

Two techniques are commonly used to assess soil salinity; soil sampling with chemical analysis, and electromagnetic induction (EM38) surveying. This chapter describes how the Salt Kit can be used by farmers and Landcare groups to do their own soil sampling and monitoring when access to EM38 surveys is not available.

Two methods of soil sampling are described in this section. Firstly, a quick appraisal method where just topsoil samples are collected and mixed together for analysis. This is suggested for small areas suspected to be suffering from salinity. The second is a more extensive survey recommended prior to development work being carried out on the farm such as laser grading. A number of soil samples are collected from zones of similar soil type, topography and land use across the farm and from different depths in the profile.

In the laboratory, there are two methods used for measuring soil salinity; $EC_{1:5}$ and EC_e. The first is the most commonly used, as it is simple and cheap. The electrical conductivity is measured on a solution of 10 g of soil mixed with 50 ml of distilled water. However, this method does not give a true representation of the salinity experienced by the plants and does not take into account the influence of soil texture. The second method, (EC_e), which measures the electrical conductivity of a soil saturation extract, partially overcomes these problems and is commonly used to relate soil salinity directly to plant growth. An extract is prepared by wetting a dry soil sample to saturation and then extracting the soil water under a vacuum. This method is more expensive, time consuming and can only be done in the laboratory.

The Salt Kit describes, through using the containers provided in the box, how soil samples can be measured for salinity in the field, with a modified $EC_{1:5}$ method. One lid of crushed soil is mixed with five lids of rainwater, shaken and then allowed to stand before being measured by an electrical conductivity meter. To provide a more accurate representation of what the soil salinity readings mean, it is necessary to convert the $EC_{1:5}$ reading to an EC_e by taking into account soil type identified through hand texturing. A soil sample is prepared for hand texturing by moistening it, but not saturating it so it becomes sticky. Table 3 gives general multiplication factors for the conversion between the two methods and describes how the soil types are classified. This method of predicting EC_e is not as accurate as a laboratory analysis; however, the expected error is only around 10-15%.

Interpreting Soil Salinity Results

In northern Victoria, saline soils are defined as those having an EC_e reading greater than 3.8 dS/m (ie. Class B, C or D), as described in Table 1. However, different types of crops and pastures have different levels of tolerance to the effects of salt and some salt

Soil Texture Group	Multiplication Factor
Sandy loams have some coherence and can be rolled into a stable ball, but not to a thread. Sand grains can be felt between your fingers.	14
Loam to clay loams can be rolled into a thick thread, but this will break or crack before it is 3-4 mm thick. The soil ball is easy to roll and has a smooth spongy feel with no obvious sandiness.	10
Light clays can be rolled into a thread 3-4 mm thick without cracking. It bends easily (ie. is flexible), feels smooth with some resistance to rolling out. Ribbons to about 70 mm between your thumb and forefinger.	8
Heavy clays can be rolled to a thread 3-4 mm thick and formed into a ring in the palm of the hand without cracking. These soils are smooth and very flexible with a moderate to strong resistance to rolling out.	6

Table 3: Soil texture groups and associated multiplication factors for converting $EC_{1:5}$ readings to EC_e readings. For example, if the soil you are working with is a light clay with an $EC_{1:5}$ reading of 0.5 dS/m, multiply the 0.5 by 8. The resulting figure of 4 is the EC_e reading for the soil sample.

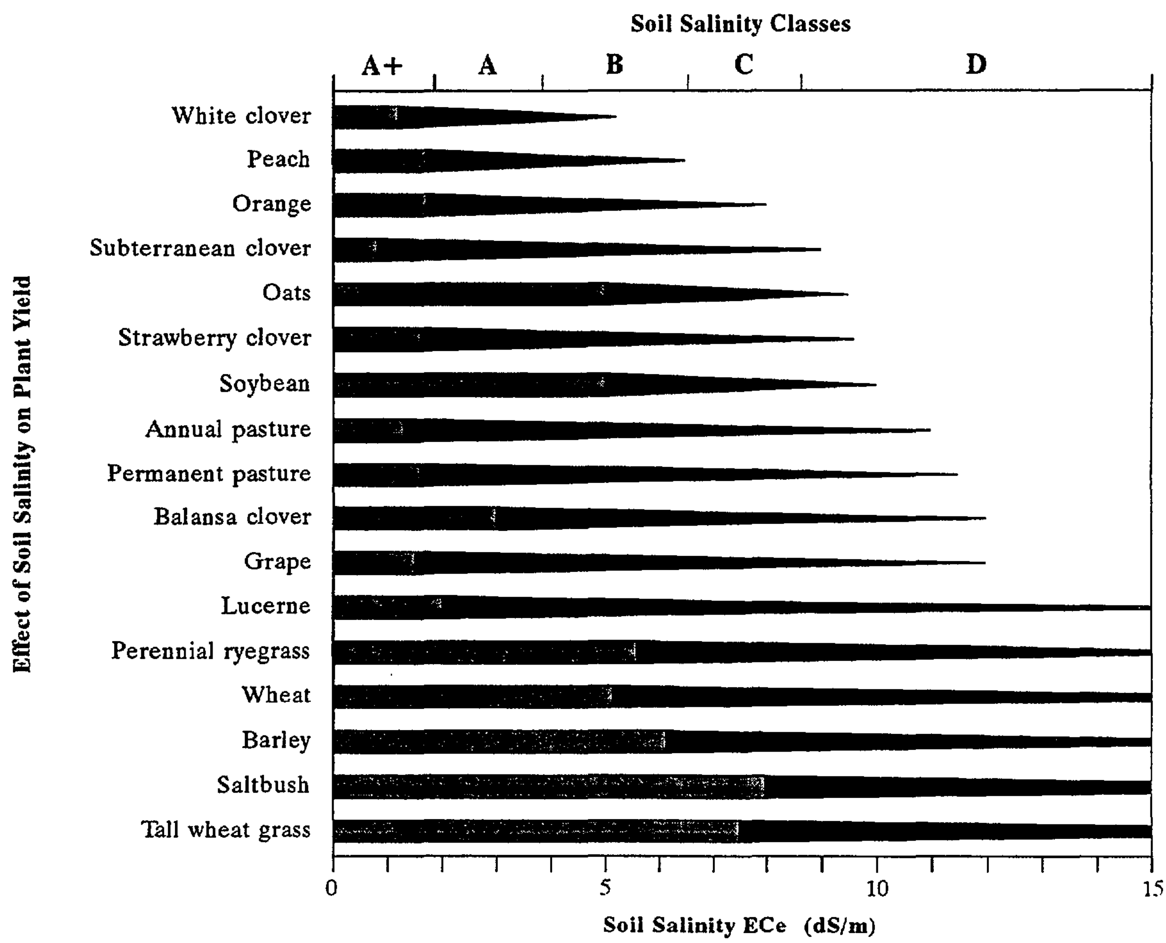

Figure 1: Effects of increasing salinity on the productivity of a range of plants. 100% growth is represented by the grey area in each bar. A loss in yield is represented by the decreasing width of the bar. The yields shown above are based on non-waterlogged conditions. If soils are waterlogged, yields will decrease more rapidly.

sensitive plants are affected at EC_e levels well below 3.8 dS/m (ie. Class A+ and A).

Figure 1 shows the effects of soil salinity on the growth of a range of plants. Note that the figures in this diagram are only an indication. and many other factors (such as waterlogging, climate and soil conditions) can influence actual plant growth.

Chapter 6 Where do you go from here ?

The final chapter describes how the information collected in previous chapters can be used to develop whole farm plans in consultation with Government agency staff. It also details the background and strategies of the various Salinity Management Plans in northern Victoria and the incentives available to landholders for salinity mitigation.

Adoption of the Salt Kit

The Salt Kit was officially launched at a meeting of the Goulburn-Murray Landcare Network at the Institute of Sustainable Irrigated Agriculture, Tatura on the 8th of May, 1995.

The distribution of the Salt Kit is being closely regulated to ensure that people receiving one are first trained in its use. Across northern Victoria training schools have been conducted for extension staff from the various Government agencies and the Goulburn Murray Landcare Network. Training schools will also be conducted for individual Landcare groups in association with the relevant Departmental "contact officer" for the group. The training schools work through the kit and involve "hands on" collection of soil samples, measuring the $EC_{1:5}$ of samples, and hand texturing. Although the Salt Kit is targeted towards the northern irrigation regions, some of the material is also applicable to dryland areas.

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Tracing disposal water leakage from Lake Tutchewop, Vic. using hydrochemistry and isotopes

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Introduction

Lake Tutchewop, and the smaller lakes William and Kelly, comprise a saline disposal basin complex located halfway between Kerang and Swan Hill (see Simmons and Narayan, this volume for location). The lakes receive about 12,000 ML of water per annum via diversions from Barr Creek. Lake Tutchewop is now a terminal basin after abandonment of the Mineral Reserves Basin scheme. This work is part of a larger program involving several organisations, and partly funded by the Murray-Darling basin Commission, to assess the longevity and overall performance in disposing of saline water at this, and other disposal basins. the overall aim is to increase the lifetime of irrigation areas as well as short-circuit discharge of saline groundwater to the River Murray.

This paper presents chemical and isotopic data from groundwaters collected from shallow piezometers installed near the lake margins, regional groundwaters and extracted pore waters from drillholes near the lakes. These data are used to establish the horizontal and vertical extent of water movement from the lakes over the past 30 years, as well as provide better constraints for input parameters to solute-transport models. Through improved understanding of the mechanisms of salt movement within this complex, we hope to better manage other existing and planned disposal basins within the Murray basin.

Other studies using hydrogeochemical techniques to investigate surface water - groundwater interactions in the Murray basin include that by Chambers et al., (1992), Herczeg et al, (1992) and Plumb and Herczeg, (1991). This is the first to use these techniques for a system that has been operating for more than 30 years, and has developed relatively high salinities (>100,000 mg/L) over that time.

A major field campaign of drilling and installation of piezometers was undertaken during April, 1993 to 1994. Several deep stratigraphic holes were drilled and cored as well as more than 30 shallow piezometers installed (also cored and logged) adjacent to each of the three lakes (Tutchewop, William, Kelly). Installation of about seven shallow 'mini-piezometers' at the north-east margin provided some information about relatively recent vertical movement of water. Collection of a time-series of surface waters of all lakes was conducted from from Oct 1994 through to early 1995. A constant-feed evaporation pan experiment at the northern margin (located on a farmers property).as a 'control' for the time series of lake water isotope data was also conducted from Sept '94 to Feb '95. .

Sampling of the piezometers took place at various times during July and September 1994. Sampling of many deeper regional bores was done by Hydrotechnology in October '94. Analysis for major and minor ions was done by AGSO, and stable isotopes of water and some ^{14}C samples were subsequently undertaken at CSIRO.

Results and Discussion

There is a large range in salinity for groundwaters within a 10km radius of Lake Tutchewop. Very high salinity waters (up to 120,000 mg/L) were measured at shallow piezometers very close to Lakes William and Tutchewop. Regional groundwater salinities are between 45,000 and 65,000 mg/L. Lower salinity waters (~15,000 mg/L) were detected north of Lake Tutchewop within the vicinity of irrigation channels.

Higher salinity disposal basin water has a similar chemical composition to that of the regional groundwater, therefore using ion ratios are not sufficient to trace lateral and vertical movement of disposal water. Although higher salinity waters may be indicative of water movement from the disposal basin, it remains equivocal on that data alone whether it is the result of surface water evaporation, or through evaporative concentration through groundwater discharge processes. The lake water salinity has increased from about 70,000 mg/L in Oct '93 to the current salinity of ~110,000 mg/L. Major ion ratios relative to conservative Br do not vary between lake and regional groundwaters.

Groundwaters that are not affected by irrigation or channel leakage, or located within 50m of the lakes, have salinities about 40 - 45,000 mg/L. These 'native' groundwaters have δ^2H composition of -25 to -32‰ and $\delta^{18}O$ between -3.5 and -4.1‰ relative to V-SMOW. Plumb and Herczeg (1991) reported a similar range of values for groundwaters from the Shepparton and Parilla Sand aquifers just 10 km east of this study area.

Stable isotope ratios for most regional groundwaters plot close to, but to the right of, the Meteoric Water Line (Fig. 1). Waters at the bottom left end of the continuum of data correspond to 'native' groundwaters, while those circled are those identified as having been recharged by irrigation drainage, or from irrigation channel leakage. Other waters that plot between ~-22‰ and 10‰ (deuterium) are from piezometers near the Tutchewop lake margin and have some component of lake water signature (+25 to +30‰).

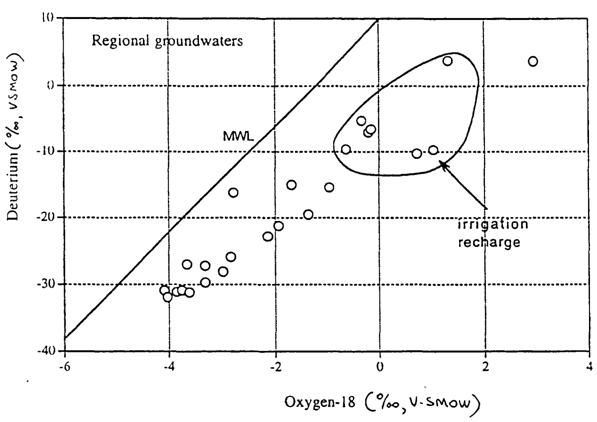

Fig. 1. Deuterium versus oxygen-18 for regional groundwaters near the Lake Tutchewop complex.

Distribution of deuterium concentrations as a function of Electrical Conductivity (EC) for the above data set (Fig. 2) shows the a group of groundwaters derived from irrigation recharge with an enriched deuterium concentration and relatively low salinity. Other groundwaters show a very large variation in salinity, however only a weak correlation with deuterium concentration. .

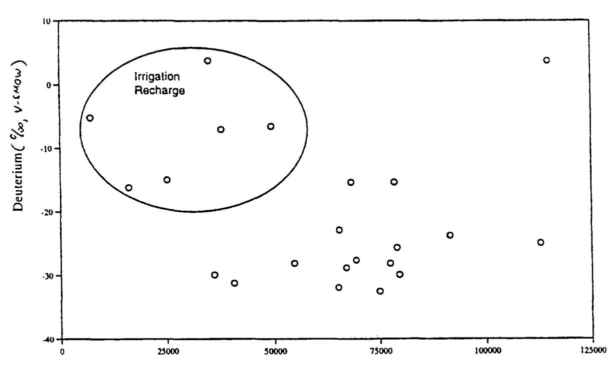

Fig. 2 Deuterium versus Electrical Conductivity for regional groundwaters

A more detailed look at the isotopic composition of waters collected from nested piezometers installed near the lake margins (Fig. 3) shows a quasi-linear trend that plots to the right of the meteoric water line. The group of waters circled refers to regional groundwaters that are unaffected by lake water or irrigation leakage. Current lake water deuterium composition is approximately +35‰ at the end of April 94 when salinity was highest. most waters plot on a line with a slope of 5.7 indicative of surface water evaporation. A few waters from the southern and western margin plot almost on a horizontal line from the regional groundwaters.

If we assume that waters on the line are the result of mixing between lake water (δ^2H = +30‰) and groundwater of δ^2H = -30‰ then it is clear that the waters even very close to the lake is dominated by a regional groundwater isotopic signature. Therefore, movement of water from the lake appears to have been less than 50 metres laterally, and less than 2 m vertically, since the time that the lake has been used for disposal of saline water.

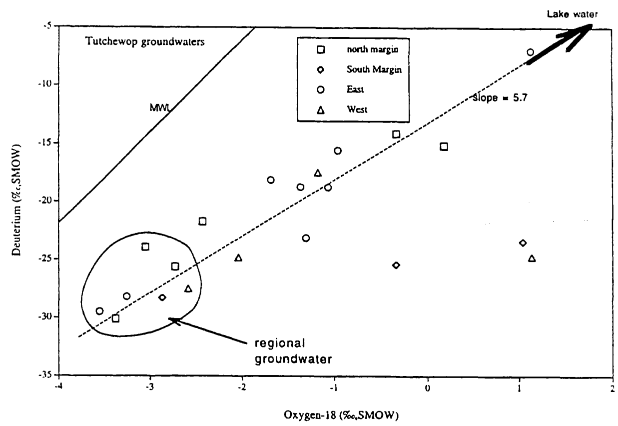

Fig 3. Isotopic composition of waters from shallow nested piezometers installed near the Lake Tutchewop margin.

A plot of deuterium versus chloride concentration (Fig. 4) depicts several groups of data:

1) Regional groundwater with the most depleted isotopic signatures and chloride concentrations between 15,000 and 20,000 mg/L.
2) A series of 'mini-piezometers' installed within the lake, near the northern lake margin at 0.5 and 1m depth
3) Samples from a time series of the lake water

Waters that are just below the lake are isotopically 'lighter' than present day lake waters, even those measured at a relatively dilute phase of lake evolution (i.e., during disposal of Barr Creek water). they are also slightly less saline, but at the same time do not lie on a mixing line between lake water and regional groundwater. They may be a remnant of a previous phase of lake isotopic enrichment that has descended to at least 1.5m below the present lake surface, but maintain high salinity possibly due to solute movement to that depth. this need to be checked with solute transport modelling.

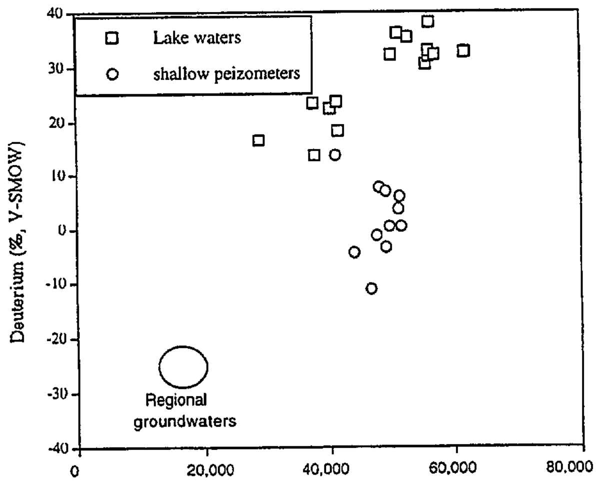

Fig. 4. deuterium versus chloride for lake waters, shallow 'mini-piezometers' and regional groundwater.

Conclusions

Isotopic and chemical data at lake Tutchewop demonstrate relatively little (<50m) movement of water and salt from the lake since disposal of saline water over the past 30 years. based on a preliminary isotopic mass balance calculation, even within 20m of the lake, less than 50% of groundwater at the water table is derived from lake leakage. There is some evidence of vertical leakage to at least 1.5m from a previous phase of lake evolution.

An additional component of solute transport modelling necessitates a better estimate of recharge to the local groundwater system. In the Lake Tutchewop region, there is a significant fraction of irrigation recharge (recognised by enriched δ^2H signatures and low salinity groundwater).

Acknowledgements

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Psyche Bend Lagoon
A Community Story

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Summary

The community group which drives the Sunraysia Salinity Management Plan has a story to tell about the complex issues facing their endeavours to implement their first drainage diversion works at Psyche Bend Lagoon near Mildura.

The project was developed as part of the Sunraysia Salinity Management Plan and the Murray Darling Basin Commission were to undertake the works as part of their Irrigation and Drainage Strategy.

However, no implementation date for the works had been set and the likelihood of any construction works set back by the need for major repairs to weirs along the river.

In 1994 Sunraysia was selected as a pilot project to implement the regional program for the Irrigation Management Strategy of the MDBC. The project was called SunRISE 21.

SunRISE 21 saw benefits in joining forces with the Sunraysia Salinity Implementation Group to fund the Psyche Bend works as the first in a range of sustainable projects for Sunraysia.

The community's view was that the new funding arrangements placed the project in a regional context - not just one of salinity mitigation, but as part of a broad regional development initiative focussed on the long term sustainability of the Sunraysia Region.

The Steering Committee's struggle to get the project up and running is a reflection of the divergent views of the community and Government, both State and Federal.

The Sunraysia Region

The region comprises the community irrigation districts of Merbein, Red Cliffs, Mildura and Robinvale.

Sunraysia horticulture began in the 1880s with the establishment of Mildura and was entirely dependent on the River Murray for all freshwater.

For the first fifty years the early settlers suffered severe waterlogging and salinity problems as salt leached from the soil profile and watertables formed as a result of impeding clay layers.

However, in the 1930s sub-surface drainage was installed across most of Sunraysia. Waterlogging problems were overcome and on-farm salinity problems virtually eliminated. Horticultural plantings remain productive to this day.

The region now comprises 17.4 thousand hectares of productive irrigated horticulture mostly yielding dried sultanas and wine grapes, with some table grapes and citrus.

However, irrigation has continued to have considerable impact on the River Murray through salinity and some nutrient pollution.

The Groundwater System

Sunraysia is in the centre of the Murray Basin. The irrigation districts overlay the Parilla sands, an aquifer with highly saline groundwater (as salty as seawater).

The less permeable soils underlying the irrigated areas have led to perched watertables and subsequent installation of sub-surface drainage reticulation. Much of the drainage water is fed back to the river adding salt loads equivalent to 9 EC at Morgan, and also nutrients, principally nitrogen.

There is still sufficient percolation of surplus irrigation water into the underlying Parilla sands to cause a water mound surmounting highly saline (50 000 EC) groundwater.

There are no aquitards isolating the river from the groundwater, so the groundwater mound pressure is transmitted through to the river bed causing extra highly saline groundwater to seep into the river, causing an estimated extra 12 EC at Morgan.

The Sunraysia Salinity Management Plan

The Salinity Management Plan was developed by the community, with ample technical resources supplied by Government.

The Plan evaluated options for salinity mitigation. It proposed both improved irrigation management to reduce causes of pollution at the source - and modification of the drainage system that fed onto the Murray floodplain and then into the river.

Drainage systems and implementation

When the Plan reached implementation, it was decided to cede responsibility for implementing drainage diversion works to the Murray Darling Basin Commission under provision of the MDB Irrigation & Drainage Strategy.

However no implementation date was set and likelihood of any construction works set back further by the need for major repair to weirs elsewhere on the Murray.

Partnership with SunRISE 21 *(Sunraysia's Regional Initiative for a Sustainable Economy - 21st Century)*

In 1994 Sunraysia was selected as one of two pilot projects to implement the regional program for the Irrigation Management Strategy of the MDBC.

The project explores ways to achieve economic sustainability, taking into account the relationship between horticultural production and environmental issues. The project aims for a long term improvement in the sustainable management of the Basin's land and water resources and prosperous regional communities.

The initiative was designed to build on and complement regional projects already in place - such as the Sunraysia Salinity Management Plan.

SunRISE 21 saw benefits in joining forces with the Sunraysia Salinity Implementation Group and offered to undertake a partnership arrangement to fund the Psyche Bend Lagoon drainage diversion project as the first in a range of sustainable projects which would encompass irrigation, drainage, water quality and salinity issues.

Psyche Bend Lagoon - project description

Psyche Bend Lagoon is both a discharge area for highly saline regional groundwater (as salty as seawater) and a disposal point for much fresher irrigation drainage water *(approximately 2000 ECs)* immediately upstream of the pumps serving the First Mildura Irrigation Trust (FMIT).

The proposal has three aspects ...

Firstly - increased diversion away from the river. Some drainage water is currently pumped inland to Cardross evaporation basins. The proposed diversion works will use the existing infrastructure to divert a greater amount of drainage water away from the river to the Cardross Basins, rather than through the Psyche Bend Lagoon system and into the River Murray.

Secondly - isolation of regional groundwater. Under current arrangements, relatively fresh drainage water flows through the lagoon, and displaces highly saline groundwater which discharges, uncontrolled, into the River Murray. The drainage diversion works will isolate the lagoon from the drainage system. Instead, primary drainage water (2000 EC) will be transported, via a pipeline, around the lagoon and into the river downstream of the First Mildura Irrigation Trust's pumps.

The continuous, uncontrolled flows of highly saline groundwater into the river from the lagoon will cease.

Thirdly - alteration of floodwater flushing of Psyche Lagoon. Under current arrangements, as high rivers recede the river is contaminated by highly saline flows from Psyche Lagoon. The drainage diversion works propose flushing the lagoon on a rising river. This will result in less salinity impact, both locally and downstream.

Benefits to the Region

Currently, 6 540 tonnes of salt annually enter the River Murray from the Psyche Bend Lagoon.

These drainage diversion works will reduce salt export from the region by approximately 2 240 tonnes per year. This will achieve a salinity benefit of 1.74 EC at Morgan and have the following benefits to the region ...

i. Improved river water quality by :

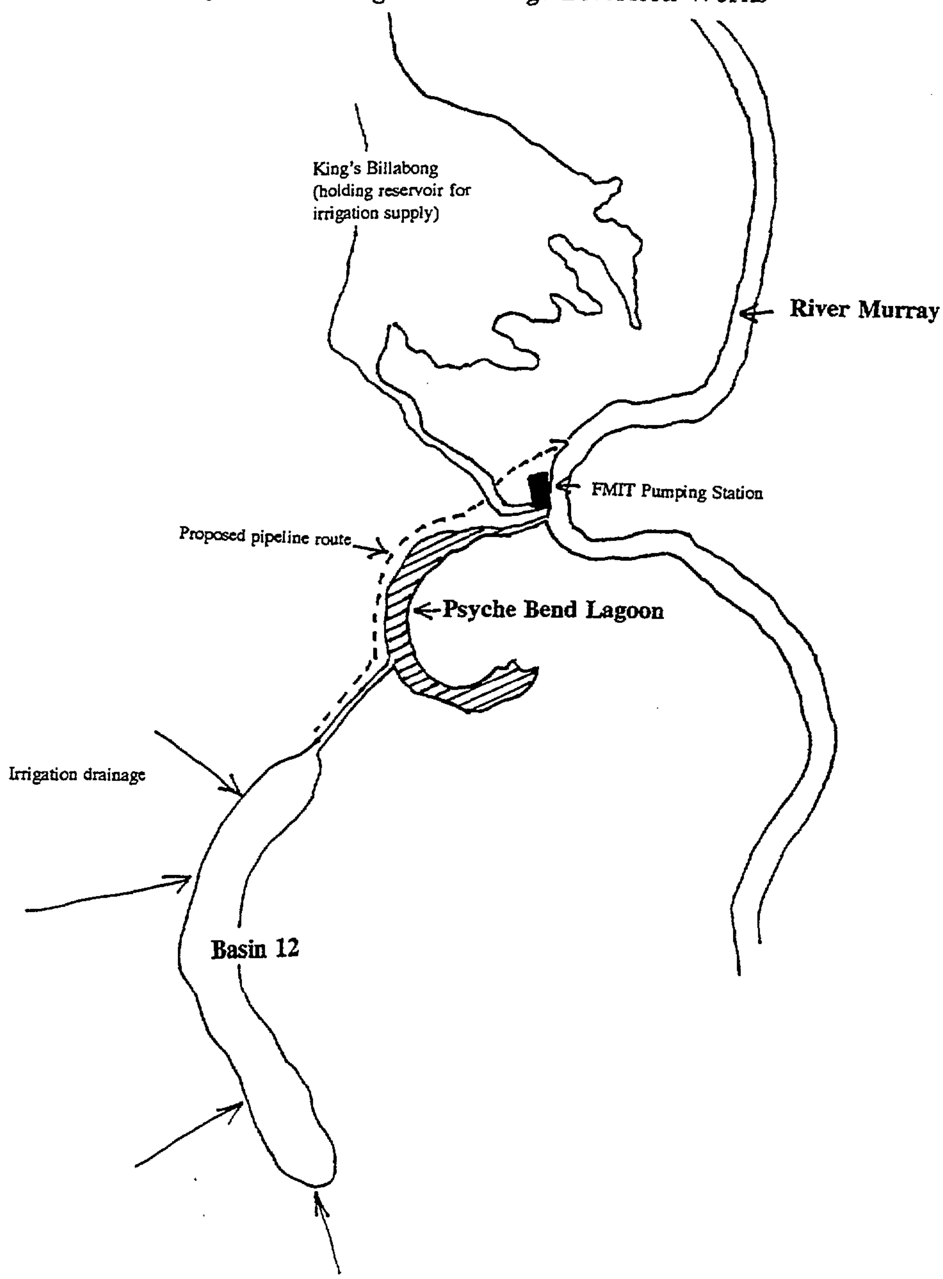
- *Isolation of highly saline regional groundwater (salty as seawater) from drainage water and controlled release to coincide with river flush.*

- *Reduced nutrient loads to the river and likelihood of toxic blue green algal outbreaks.*

ii. Demonstration to other Basin communities of Sunraysia's commitment to improved water quality and management. It will benefit downstream water users including some in Victoria and NSW Sunraysia, as well as all South Australian users.

iii. Incorporation into future ecological and heritage tourism initiatives which will demonstrate the interrelationship of the region's history, economic development and long-term sustainability.

Psyche Bend Lagoon Drainage Diversion Works



Managing the project - from initial concept through to construction

The Psyche Bend Steering Committee was formed to drive the project. The authors were members of the committee which was made up of community members from both the Salinity Group and SunRISE 21, with minimal support from Government agencies.

The Psyche Bend project had only been developed to a conceptual level in the Salinity Management Plan. The preliminary conclusions developed as part of the concept needed verification by the engineering consultant who would ultimately develop the detailed design.

The committee thought, perhaps naively, that its role in seeing the project through to construction would be reasonably straightforward.

SunRISE 21 were keen to get this, the first of its on-ground works, up and running as a visible demonstration to the community of its commitment - so time was of the essence.

The project was community driven, but the funding was channelled through government. The Federal Government had agreed to provide matching funding with State funds from Victoria. Agriculture Victoria was the vehicle to manage the funds.

The first task was to develop the project from what we assumed was a feasible concept, to detailed design phase. The group needed to employ a project manager and/or design consultant to verify the assumptions which formed part of the design brief, and ultimately see the project through to construction.

We placed our first advertisement in the papers for expressions of interest in the project management and/or design phase. We were on the move ... or so we thought.

But our frustrations were about to commence ...

Expressions of interest had been received, and we realised we needed to write up additional information - terms of reference, a brief for the project manager, tender documentation ..... We needed this information prepared before we could get started with the project design works.

It was becoming clear that the process was more complex than we could have realised - and none of us had previous experience in this area. We did have technical representation on our group from the various agencies, but their representation did not include the time required to carry out these specialised tasks on our behalf.

We needed an experienced project manager on deck - and quickly! But to employ a project manager we had to employ one as a consultant.

Because funding was channelled through Agriculture Victoria, we had to comply with their bureaucratic process. Consultancies are closely regulated and require a lengthy, time consuming approval process. It could delay the process by a couple of months! We were at a stalemate again ... and it was going to take too much time! Time the group could ill afford if we were to achieve our timeline.

We later discovered that we would have made life much simpler for ourselves if we had undertaken a Government Services Contract with Sunraysia Rural Water Authority (SRWA), which would have incorporated project management and financial responsibility. *(Although Agriculture Victoria was the lead agency for the project, this type of construction work is not the normal business of Agriculture Victoria, and there were no precedents for us to follow.)*

However SRWA were not interested in the total management of the project including the financial responsibility, but were prepared to supply (for a fee) an experienced engineer to manage the project.

We could relax at last - we had an experienced project manager at our disposal who knew the ropes! His first responsibility to the Steering Committee was to write his own brief - then to assess the expressions of interest, arrange tender documentation and develop a works program including timelines. He was also able to arrange the design consultancy through the more simplified SRWA process - and that would save us much time.

So detailed design was proceeding well under the direction of our new Project Manager ... but while this scene had been playing out, an even more complex saga was unfolding.

As far as the community had been aware, funding provided to SunRISE 21 was new money to the region - Federal money supplied for projects which fitted in with the regional sustainability ethos - and matched by State funding.

So we considered that the new funding arrangements placed the project in a regional context - not just one of salinity mitigation, but as part of the broad regional development initiative focussed on the long term sustainability of the Sunraysia region.

... Or that was the community's perception of the process - and herein lay a problem which caused the Steering Committee (and probably both State and Federal players) many a headache.

The Psyche Bend project generated salinity credits of 1.74 EC at Morgan which are estimated to be worth approximately $1M per EC.

If the original arrangements had remained in place and the project had been undertaken and funded through the MDBC, the salinity credits would have been managed as part of the Salinity & Drainage Strategy. *(But this could have been to our detriment. It would have enabled more salt disposal to enter the River Murray upstream of Sunraysia.)*

However as we saw it, that process had now been superseded by the new management arrangements under SunRISE 21. *(SunRISE had originally been sourced through the Murray Darling Basin's Irrigation Management Strategy, and received some initial funding from the Commonwealth Government's "Working Nation" Industry Statement to match contributions from Victoria.)* In our view, it was SunRISE 21's responsibility to allocate their funding to projects of their choice within the Region. So the salinity credits had been earned by SunRISE who planned to use them to provide for future potential river disposal given the likelihood of expansion of the irrigation districts in the future.

Very divergent views between the Sunraysia community and government were evident.

Government had failed to be explicit to the community with the conditions which applied to the funding. The Psyche Lagoon project did not fit neatly in any particular pigeon hole and a number of negotiating positions were developed.

Confusion and misunderstanding were rife between government and the community.

From government's perspective, the Psyche Bend project did indeed remain a salinity funded project. The funds were not sourced through the Sunraysia Salinity Plan's base budget, but they were sourced from within the Salinity Program *(we later discovered)*. And from the State's point of view the same conditions applied to this project as any other salinity funded project. This related to ownership of EC credits, ownership of the infrastructure, and responsibility for ongoing operations and maintenance of the project.

Unresolved issues still to be finalised

At the time of writing this paper, the question still remains unanswered - whose project is this? Does it belong to the Murray Darling Basin, to the State government, to the Salinity Plan, or to SunRISE 21?

The saga of ownership of the salinity credits and responsibility for on-going operations and maintenance costs appears to be nearing completion. By the time this paper is presented at Wagga Wagga, we hope to have resolved these issues - to the satisfaction of all players.

Conclusion

The process has been one of learning, gaining experience ... and knowing how to approach a new game plan next time.

The crucial, and missing element, in our saga has been communication.

From day one, the process would have been very much simplified if all players had got together and developed a plan of action, instead of all operating under a different premise.

Instead, our action evolved through trial and error, and much frustration - probably by all players concerned - both community members and Government.

What it has demonstrated is the Sunraysia community's commitment (despite the difficulties), and its dedication to ensuring the future of Sunraysia as a viable community, well placed for a prosperous future!

Landscape Processes and Stream Water Salinity, Mn and Dissolved Organic Carbon.

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Stream water quality is reduced by background contamination of salt, from groundwater, and dissolved organic carbon (DOC) and manganese (Mn), from interflow, in a reservoir catchment in the Adelaide Hills. Land use in the catchment is a mixture of plantation forestry, native woodland and unimproved pastures.

Stream order is identified as a factor in groundwater-related land management decisions in sub-catchments. The saline groundwater discharge problem contributes to the levels of the other two stream water contaminants. This problem may be resolved by forest plantation development in some first order stream sub-catchments that are currently under pasture.

The potential for, and occurrence of, saline groundwater discharge in high order catchments can be assessed from the gradient of higher order streams and soil indicators observed in the field. Plantation forestry can be focussed to reverse the stream water quality problem in an upland Mediterranean environment, and also make a profit, using routine soil and land survey information.

Episodic Recharge Under Crops and Shrubs in the Mallee Zone

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INTRODUCTION

The prediction of groundwater recharge rates is crucial to the development of ways to reduce dryland and river salinisation. An important step is to model how economically viable land-use options affect recharge. Accurate modelling of groundwater systems requires knowledge of rates of recharge beneath current and proposed landuses (Kennett-Smith *et al.* 1992). Within the Mallee zone recharge has been estimated mainly by studies which evaluated average rates of recharge over long time periods (c. 10-100) years since the clearing of native vegetation (Walker *et al.* 1991). The chloride tracer techniques used in these studies require knowledge or estimation of the soil chloride profile prior to clearing, which is then used as the baseline from which recharge is calculated. This approach is useful to estimate long term average recharge rates, but can be confounded by seasonal variations in soil moisture and landuse.

Groundwater recharge is influenced by both landuse and rainfall. The variable and discrete nature of rainfall will result in event based recharge. The amount of recharge depends on the size of the rainfall event and the potential for use of stored soil water by crops. Water use varies with the phases of the rotational cropping practices of the Mallee, and winter fallowing has been identified as a potential cause of significant recharge in Mallee soils (O'Connell *et al* 1992).

The elimination of fallow from cropping rotations or a change of landuse to productive perennial species offers opportunities to optimise water use by plants which can dampen peak recharge events. In recognising that the recharge process is episodic it suggests a modelling approach that represents faithfully the recharge process under a wide range of land-use options and rainfall conditions be applied. A modelling framework is being developed to accomplish this which needs testing in the field (Halton 1993). Field data from sites throughout the Mallee zone are needed to test and apply the model.

Here the focus is on evaluating land-use options to minimise episodic recharge in the Mallee areas of the Murray-Darling Basin at two locations in the Mallee zone.

METHODS

An integrated program of field experimentation was established on the Mallee Research Station, Walpeup (Vic) and on a farm property, Hillston (NSW). A common experimental methodology was used at both locations although the cropping treatments differ to reflect local practice.

Common experimental methodology

Experimental design

The rotational treatments were established as cyclical rotational experiments (Patterson 1963). This design has each phase of each rotation expressed in each year of the experiment and provides an efficient means of replication in both time and space which will encompass inter phase interaction. Experimental treatments were allocated to minimise spatial variability of soil properties which were assessed by electromagnetic surveys (EM38).

Climate data

Daily records of radiation, temperature, rainfall, and relative humidity were collected by automatic weather stations.

Crop data

Germination , establishment, growth (biomass and LAI) and yield of all traditional crops and pastures was measured using standard methods. Oil yield of blue mallee was assessed by steam distillation (Millthorpe and Hillan, 1994).

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Rotational details and local variants of methodology

Experimental layout

Hillston. The layout has 25 plots ,each plot 40 m x 40 m. Experimental measurements are made within the central 25 m^2 area surrounded by a 15 m buffer. In the centre of the plot is one aluminium neutron probe access tube.

Traditional Rotation - Oats, 2 x Wheat, 4 x Medic Pasture, Fallow (8 years) Modified Rotation - Oats, 2 x Wheat, 4 x Lucerne, Fallow (8 years) Perennial shrubs - Blue Mallee, Jojoba, established in September 1991.

Walpeup. An annual crop rotation was established comprising 18 plots 20 m x 21 m. Each plot contains a drainage lysimeter (0.75 m x 1.4 m) and contains two PVC neutron probe access tubes 10 m apart in the central portion. Each plot has 10 m buffer . A second component comprises 8 perennial shrubs plots in a replicated design with a plot area of 900 m^2 with a central 100 ^{m2} for sampling. This area contains one PVC access tube in the centre of each plot .

Traditional Rotation Peas, Fallow, Wheat (3 years). Modified Rotation - Peas, Mustard, Wheat (3 years). Perennial Shrubs - Blue Mallee, Broom Bush established in September 1993. Drainage beneath each rotation treatments was measured at 1.5 m by drainage lysimeters.

Soil data

Hillston. For each soil horizon the soil water holding capacity, and saturated hydraulic conductivity were defined by the Broadbridge and White (1988) model. The parameters were estimated by trial and error inverse modelling, the soil moisture profiles predicted by an eco hydrological model (WaVES) were matched to those measured in the field under fallow conditions.

Walpeup. For each soil horizon the upper limit (water potential at air entry) and lower limit as defined by the Campbell (1974) were estimated from observed soil moisture values which were used to define the parameters Ψ_e and b of the Campbell model of soil water potential. Saturated hydraulic conductivity was estimated using a disc permeameter.

Recharge monitoring

Hillston. Temporal changes in soil moisture content beneath each treatment was measured to a depth of 3 m by neutron moisture meter on a fortnightly basis. These data were used in the Broadbridge and White (1988) soil equation to predict profiles of soil matric potential (Ψ) and unsaturated hydraulic conductivity (k_θ)which were in turn used to estimate vertical soil water flux using the Darcy Buckingham equation:

$$q(z,t)=-k_\theta(d\Psi/dz) \quad (1)$$

where:
$q(z,t)$= flow of soil water solution (mm)
k_θ = unsaturated hydraulic conductivity at depth z and time t (mm/day)
Ψ= total pressure head of soil water at depth z and time t

Walpeup. Temporal changes in soil moisture content beneath each treatment was measured to a depth of 4 m by Neutron Moisture meter on a monthly basis. Groundwater recharge was estimated by soil moisture mass balance. Changes in storage below 1.5 m was assumed to be owing to drainage and considered recharge.

RESULTS AND DISCUSSION

Rainfall

Hillston. During the first two years of experimental measurements rainfall was high (>75th centile) in most months before the onset of drought in 1994/5 (Table 1).

Table 1: Rainfall (mm) at Hillston

	J	F	M	A	M	J	J	A	S	O	N	D	Tot
1991	32	0	2	10	16	33	21	29	31	3	8	36	44
1992	24	16	1	18	29	15	42	61	28	107	45	114	500
1993	54	37	64	3	41	2	110	12	95	84	22	60	584
1994	2	83	26	2	0	23	7	1	20	15	21	17	217
1995	82	3	0	2	57	53	21						210
Median	16	14	15	16	22	30	26	30	22	29	18	19	345

Walpeup. Rainfall during 1993 was considered average whilst 1994 growing season experienced drought conditions.

Table 2: Rainfall (mm) at Walpeup

	J	F	M	A	M	J	J	A	S	O	N	D	Tot
1993	46	28	9	1	6	18	36	36	69	37	23	38	349
1994	4	23	0	1	14	46	17	4	16	11	15	2	152
1995	52	22	0	36	63	57							
Median	20	25	22	21	33	31	32	35	34	36	25	23	337

Soil hydraulic properties

A sandy clay B horizon was present at both experimental sites, which possessed soil saturated hydraulic conductivity an order of magnitude lower than the A horizon and a broader pore size distribution , and water holding capacity. (Table 3).

Table 3: Mean of the parameters of the Broadbridge and White soil model defined by inverse modelling at Hillston and the Campbell soil potential model estimated from field soil moisture at Walpeup

Site	Parameters	A horizon	B horizon
Hillston	K_{sat}(m/day)	0.0379	0.0021
	θ_{sat}	0.3	0.355
	θ_{res}	0.05	0.1
	C	1.32	1.09
	λ_C	0.36	0.44
Walpeup	K_{sat}(m/day)	0.7	0.15
	θ_{sat}	0.27	0.35
	Ψ_A	-0.1	-0.03
	b	5	16

Soil moisture

The soil moisture content of the A horizons at both sites was much more dynamic then the B horizon in response to rainfall and evapotranspiration events.

Hillston. Beneath the Mallee the soil became significantly drier than beneath all other treatments after only one year of growth (Figure 1).
A similar pattern of soil drying is now becoming evident beneath three year old Jojoba shrubs. A considerable volume of water was stored beneath the cropping rotations at Hillston since the commencement of the experiment. Entering the spring of 1993 the soil profile was still wet below a depth of 30 cm. This water remained untapped owing to the failure of the crops sown in the autumn of 1994. Despite active spring and summer growth, lucerne, sown at Hillston has not actively used the considerable amount of water stored in the soil during the winter months. The total amount of water stored in the soil profile has been greatly reduced by growing shrubs or including perennial lucerne as the pasture phase of cropping rotations (Figure 1).

Walpeup. The immature shrubs at Walpeup have had minimal effect on the total soil water stored in the profile. As the shrubs mature the amount of stored soil water in the root zone is expected to dramatically reduce, as observed at Hillston.
At Walpeup above average September 1993 rainfall, led to increases in soil moisture to 1 m under both the traditional and modified cropping treatments.

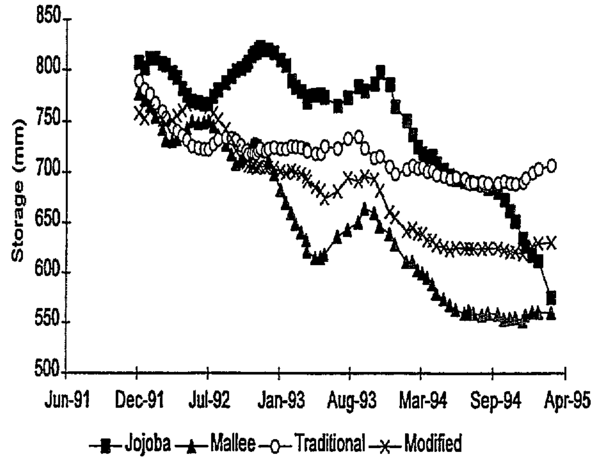

Figure 1: Total soil water stored to a depth of 3.5 m beneath four landuses at Hillston

Recharge

Hillston. The time (fortnightly) and depth (between 10 and 50 cm) increments used in soil water flux calculations are quite wide and may invalidate the assumptions of the Darcy Buckingham equation. However, the estimates of soil water flux and recharge are indicative of the relative rates of recharge beneath each of the treatments (Table 4). Recharge beyond 3 m occurred continuously beneath all landuses, even during the drought of 1994/5. The soil hydraulic properties of the B horizon dominate the recharge process. The A horizon readily accepts high rates of rainfall and the soil water store of the A horizon fills quickly. Owing to the low permeability of the B horizon soil water perches on top of the B horizon and redistributes only slowly within the B horizon.

Table 4: Recharge (mm/year) measured at a depth of three meters beneath traditional and modified crop rotations and perennial shrubs at Hillston

Year	Traditional Rotation	Modified Rotation	Jojoba	Blue Mallee
1992	16	10	15	11
1993	18	11	18	7
1994	13	5	12	4

Recharge was highest beneath the traditional cropping rotation which included only annual crops or pastures. Including perennial lucerne as the pasture phase of the rotation (modified rotation) reduced recharge in all years. Recharge beneath Jojoba was less than under traditional rotation but greater than beneath the modified rotation, however, there is a trend to decreasing recharge as the shrubs mature. Blue Mallee was the landuse under which recharge was least and the rate of recharge declined in all three years.

These data suggest that there is a significant lag between the time rain falls and that rain becoming recharge.

Walpeup. Recharge measured by drainage lysimeters was less than that estimated by soil moisture mass balance. A number of individual recharge events were recorded by the lysimeters, each less than 1 mm .

The recharge was highest beneath the immature shrubs. It is anticipated that recharge beneath the shrubs will decline as they mature and exploit more of the soil water resource. Excluding fallow from the cropping rotation reduced recharge (Table 5).

Table 5: Recharge (mm/ year) estimated at 4 m under traditional and modified cropping regimes at Walpeup during 1993-94

Traditional rotation	Modified Rotation	Broom bush	Blue Mallee
17	14	20	27

These data suggests that the drainage lysimeters are not sensitive enough to monitor low soil water fluxes. Recharge is estimated best by soil water flux , but the accuracy of these estimates is limited by that of soil hydraulic properties.

CONCLUSION

Recharge can be reduced by :

- Changing landuse from rotational cropping to perennial shrubs.
- Including lucerne in a rotation
- Eliminating the fallow phase of a rotation

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The LIGULE[1] Project - Meeting the Dryland Salinity Challenge.

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Introduction.

Dryland salinity is estimated to directly affect some 243,000 ha of once-productive lands in the Murray-Darling Basin (Murray-Darling Ministerial Council 1993, with updated estimates for Victoria provided by Allen 1994). Salinisation is estimated to be increasing at a rate of between 2 - 5% per year within the Basin and more than 1M ha considered to be land at risk.

Salinity is evidence of reduced or incomplete water use by the agricultural crops and pastures which have displaced much of the original vegetation throughout the Basin (Johnston 1993). This has resulted in increased rates of deep drainage of water to local and regional groundwater systems, and concurrent increases in water table levels of the order of 4 - 11% of the annual rainfall (Gates and Williams 1988; Chiew and McMahon 1991; Kevin 1993).

Shallow upland soils with a low water holding capacity, and which are generally impoverished and of low pH, contribute disproportionally more deep drainage than deeper more productive soils which are at greater risk of salinisation (Dyson 1993). Perennial pastures are difficult to establish on such sites and species such as *Phalaris aquatica*, *Dactylis glomerata* and *Medicago sativa*, which are recommended for controlling recharge lack long-term persistence. Low persistence and the costs associated with sowing, managing and maintaining these species is a strong disincentive to their widespread use.

In Australia, most new cultivars of temperate perennial grasses have been developed from a narrow range of "mainstream" species, namely *P. aquatica*, *D. glomerata*, *Festuca arundinaceae*, and species of *Lolium* (Oram 1990). These species are all cool season C3 plants, their adaptive range is largely dictated by the extent to which they are capable of summer dormancy.

This situation contrases to that in north America where cultivars have been developed from a wide range of species, with a correspondingly wide adaptive range. In Australia, the consequence for high rainfall (> 500 mm average annual rainfall) areas is that available cultivars are poorly suited to large tracts of landscape, especially soils which are acid and infertile, sites which are more arid, and where establishment and management of pastures is difficult. Such situations are typical of many upland areas in the Murray-Darling Basin.

Two other issues are important in addressing dryland salinity. The first is that any "sustainable" solution must be economically viable and be capable in the longer term of providing a positive benefit/cost outcome (Robertson 1990). Low input grasses may offer substantial cost savings and therefore provide the basis for a more favourable economic outcome compared with currently available cultivars. The second issue is that the problem of dryland salinity is underpinned by the way people think about using land, including the land they use, how they use it and what they use it for (Bawden and Sriskandarajah 1990). Without a change in attitude towards the land a sustainable solution to salinity will remain evasive.

Sowing adapted,. persistent perennial native grasses would be compatable with the conversion of present-day grazing lands to woodlands or forest.

The thrust of agricultural development in Australia has been to replace the indigenous plant communities with species and cultural systems from other lands. According to Alexandra (1995) the rate of land clearing in Australia exceeds that of any other industrialised country and since European settlement some 18 billion trees have been cleared in the Murray-Darling Basin. Until there is some intervention to reconcile the cause of the salinity problem with the extent of the resulting havoc, there is unlikely to be any real inroads into controlling the problem.

[1] Low Input Grasses Useful in Limiting Environments.

The remainder of this paper presents an overview of the LIGULE project which is an innovative research project specifically directed to developing a wider range of agriculturally useful perennial grasses for recharge control on the uplands of the Murray-Darling Basin.

Discussion.

Australian native grasses offer adaptive advantages compared to non-indigenous species. However the agricultural potential of most species has not seriously been investigated. The LIGULE project has sought to collect and evaluate a large number of accessions, of a wide range of potentially useful species over an extensive geographical area of south-eastern Australia.

Although Johnston (1993) believed that summer active C4 grasses may impact on recharge to a greater extent than summer dormant C3 species, all species of perennial grasses listed by Cunningham *et al.* (1981) were considered as potentially useful except those which possessed awns or barbs likely to cause injury to livestock or those known to be of little agronomic value.

A total of 33 species were nominated as potentially useful. In order to keep the project within manageable limits, the target list was arbitrarily divided into two groups. The first contained species which were considered to hold greatest promise, while the second group contained the remainder. Six individual plants of the species in the first group were collected in the field, while three plants were collected of species in the second group. At most collection locations, surface (0 - 10 cm) soil samples were also collected for analysis for soil $pH_{(CaCl2)}$, phosphorus (Olsen), particle sized distribution, electrical conductivity and where $pH_{(CaCl2)} < 5$, exchangeable aluminium. Account was taken of these attributes in the selection process.

Species which were difficult to identify in the field, (mainly *Danthonia*, *Digitaria*, and *Bothriochloa*) were collected on the basis of genera. A total of 825 Accessions were collected from 210 locations (Figure 1). The numbers of Accessions collected for species and genera are listed in Table 1.

Plants collected in the field were taken to Wagga Wagga and Rutherglen where they were established in nurseries and evaluated over a 2-year period. The following attributes were noted for each accession at about 6-weekly intervals using a specifically designed rating form:

* number of plants alive (persistence)
* morphology (growth habit, stemminess, culm height)
* inflorescence characteristics and seed retention
* growth - increase in diameter and leaf height
* vigour
* responses to drought and frost; leaf senescence
* phenology and stage of growth
* insect and disease prevalence and damage
* seedling recruitment and palatability

For all attributes, pattern analysis was used to create groups of accessions having similar responses over time. A number of selection criteria were than applied to these groupings which resulted in the nomination of 8 genera with superior attributes, and within these genera, 20 Accessions worthy of further evaluation.

The 20 selected Accessions have been established as spaced plants at four upland sites at Cowra and Wagga Wagga N.S.W. and near Rutherglen and Bendigo, Vic. together with the following commercially available cultivars: Consol lovegrass, Taranna wallaby grass, Porto cocksfoot and Sirosa phalaris. All species will be intensively evaluated over the next two years. The following attributes will be measured each month:

* survival
* dry matter production
* herbage digestibility and protein content
* phenology, drought and frost responses, insect and disease damage
* palatability
* changes in plant size.

Gypsum blocks are being used to monitor soil moisture status to determine if Accessions show marked differences is soil water use to a depth of 120 cm. Ventilated chambers are being used at one site (Bendigo) to measure differences in evapotranspiration between a subset of Accessions.

The research which is continuing is expected to lead to the commercial release of a range of native grass cultivars for recharge control and agricultural use on the uplands of the Murray-Darling Basin.

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Figure 1. The location of sites where native grasses were collected for the LIGULE project.

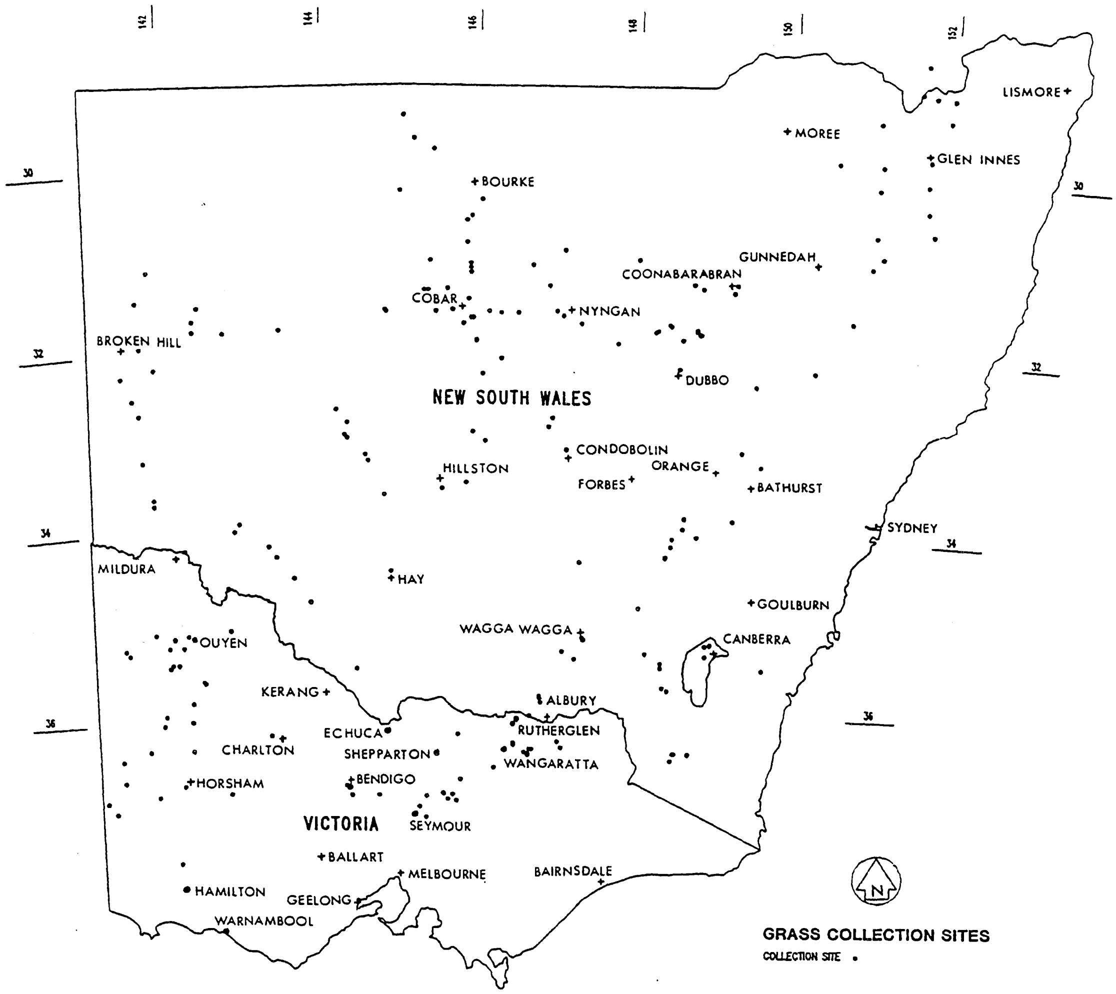

Table 1. Target species, the number of Accessions collected and the nurseries where they where planted out for evaluation.

Target species		Nursery location	
		Wagga Wagga	Rutherglen
Danthonia caespitosa Gaudich.			
Danthonia eriantha Lindl.			
Danthonia linkii. Kunth var. *linkii*			
Danthonia richardsonii Cashmore			
Danthonia setacea R. Br.	*Danthonia* total:	123	115
Elymus scaber (R. Br.) A. Love var. *scaber*		62	55
Enteropogon acicularis (Lindl.) Lazarides		53	43
Microlaena stipoides (Labill.) R. Br.		43	35
Themeda australis (R. Br.) Stapf		64	48
Group 2.			
Amphigogon caricinus F. Muell. var. *caricinus*		-	3
Bothriochloa decipiens (Hack.) C.E. Hubb.			
Bothriochloa macra (Steud.) S.T. Blake	*Bothriochloa* total:	37	3
Cymbopogon ambiguus A. Camus			
Cymbopogon obtectus S.T. Blake			
Cymbopogon refractus (R. Br.) A. Camus	*Cymbopogon* total:	-	17
Cynodon dactylon (L.) Pers.		8	1
Digitaria ammophila Hughes			
Digitaria brownii (Roem. & Schult.) Hughes	*Digitaria* total:	39	2
Paspalidium constrictum (Domin) C.E. Hubb.			
Paspalidium gracile (R. Br.) Huges	*Paspalidium* total:	-	7
Setaria gracilis[A] Kunth		-	2
Chloris truncata R. Br.			
Chloris ventricosa R. Br.	*Chloris* total:	65	2
Dichanthium sericeum S.T. Blake Subsp. *sericeum*		1	17
Ehrharta calycina[A] Sm.		3	2
Enneapogon nigrticans (R. Br.) P. Beauv.		15	-
Eragrostis brownii (Kunth) Nees			
Eragrostis setifolia Nees			
Eragrostis xerophila Domin		26	-
Hyparrhenia hirta[A] (L.) Stapf		1	-
Monachather paradoxa Steud.		13	-
Panicum colaratum[A] L.		3	-
Thyridolepis mitchelliana (Nees) S.T. Blake		26	-
Total numbers of Accessions		579	352
Control species			
Dactylis glomerata[A] L. cv. Porto		83	31
Eragrostis curvula Complex[A] (Schrad.) Nees cv. Consol 83		83	31
[A] These species occur naturalised in the collection area or are recognised herbage plant cultivars.			

Floodplain Salinisation in the Chowilla Anabranch and its Impact on River Salinity and Native Riparian Forests

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Introduction

Floodplain salinisation caused by discharge of shallow groundwater is a worsening problem throughout the Murray-Darling Basin. Increased salt accessions to floodplain streams (and hence the Murray-Darling system) and wetlands, and vegetation dieback are often observed consequences of salinisation. Notable examples include Lindsay River (Vic), Chowilla (SA), Lake Victoria (NSW), the Menindie Lakes (NSW) and the Macquarie Marshes (NSW). Groundwater interception schemes have been proposed for reducing salt loads from some of these areas but they may not be financially justified on this basis alone. The considerable community concern over the salinity impacts on native riparian forests and wetlands has led to the increasing use of environmental factors in the justification for such schemes. In this paper we summarise research carried out in the Chowilla region over the last few years by CSIRO Division of Water Resources (in collaboration with the South Australian Engineering and Water Supply Department and the Department of Mines and Energy) on the salinisation of the floodplain and its impact. This study has provided necessary background for the formulation of a groundwater interception scheme for this floodplain which attempts to address both the water resource and ecological impacts of flooplain salinisation.

Regional setting

In the lower reaches of the River Murray, groundwaters of the regional unconfined aquifer (Pliocene Sands) discharge into the River Murray via the alluvial Monoman Formation which underlies the often wide (up to 10 km) floodplains. The floodplain streams act as "interception drains" for the saline (up to 50,000 mg L^{-1}) regional groundwater and in doing so provide continuous transport of salt to the River Murray. Prior to river regulation (which commenced in the 1920's) the watertables in non-flood times were generally below the base of the ephemeral creeks and so salt transport to the river probably differed greatly in both space and time to that observed under current conditions.

The Chowilla Anabranch is a 200 km^2 floodplain on the SA/NSW border and is the source of ~10% of the salt added to the river in the South Australian reach. Moreover, wide-scale soil salinisation has resulted in the dieback of ~40% of the native riparian forests which are comprised predominantly of *Eucalyptus largiflorens* (black box). This is of considerable concern as the Chowilla floodplain has been classified under the UNESCO Ramsar Convention (Section 14.5) as a Wetland of International Importance (NEC, 1988).

Why is salt accumulating in floodplain soils and why does this lead to vegetation dieback?

River regulation since the 1920's has led to rises in the watertable beneath the floodplain and reduced the frequency of medium to large floods by a factor of three (Ohlmeyer, 1991). Under present conditions the watertable in non-flood times is usually within ~4 m of the soil surface and resides within the Monoman Formation or, as is often now the case, within the overlying Coonambidgal Clay. Prior to regulation the watertable was 1-2 m deeper and generally located within the Monoman Formation.

The increase in "average" watertable height has resulted in higher rates of groundwater discharge and caused increased transport of salt up into the soil profile. The reduction in flooding frequency has resulted in less leaching of the stored salt downwards, a process which previously counter-balanced the salinisation caused by groundwater discharge. Prior to regulation a "balance" between these two processes ensured that, over the long-term, an adequate low salinity zone was maintained in the soil from which vegetation could extract water. Under current conditions, this "balance" has been disturbed, resulting in the movement of a "salt front" from the water table up through the soil profile. As the "salt front" moves towards the surface over a number of years, the depth of low salinity soil water available to the vegetation decreases resulting in osmotic drought and subsequent dieback (Fig. 1).

Shown in Fig. 2 is a soil chloride profile which shows the "salt front" at the surface, and with salt accumulating at concentrations much greater than that of the groundwater (the source). Not surprisingly, the *E. largiflorens* community at this site is now dead. Jolly et al. (1993) predicted that at this site it would have taken ~17 years for the "salt front" to reach the surface and a further ~20 years for the additional salt to accumulate in the top 1.8 m. This site was last flooded in 1956 and if it is assumed that complete leaching of the profile took place at this time, it can be seen that there has been adequate time for the observed accumulation to occur.

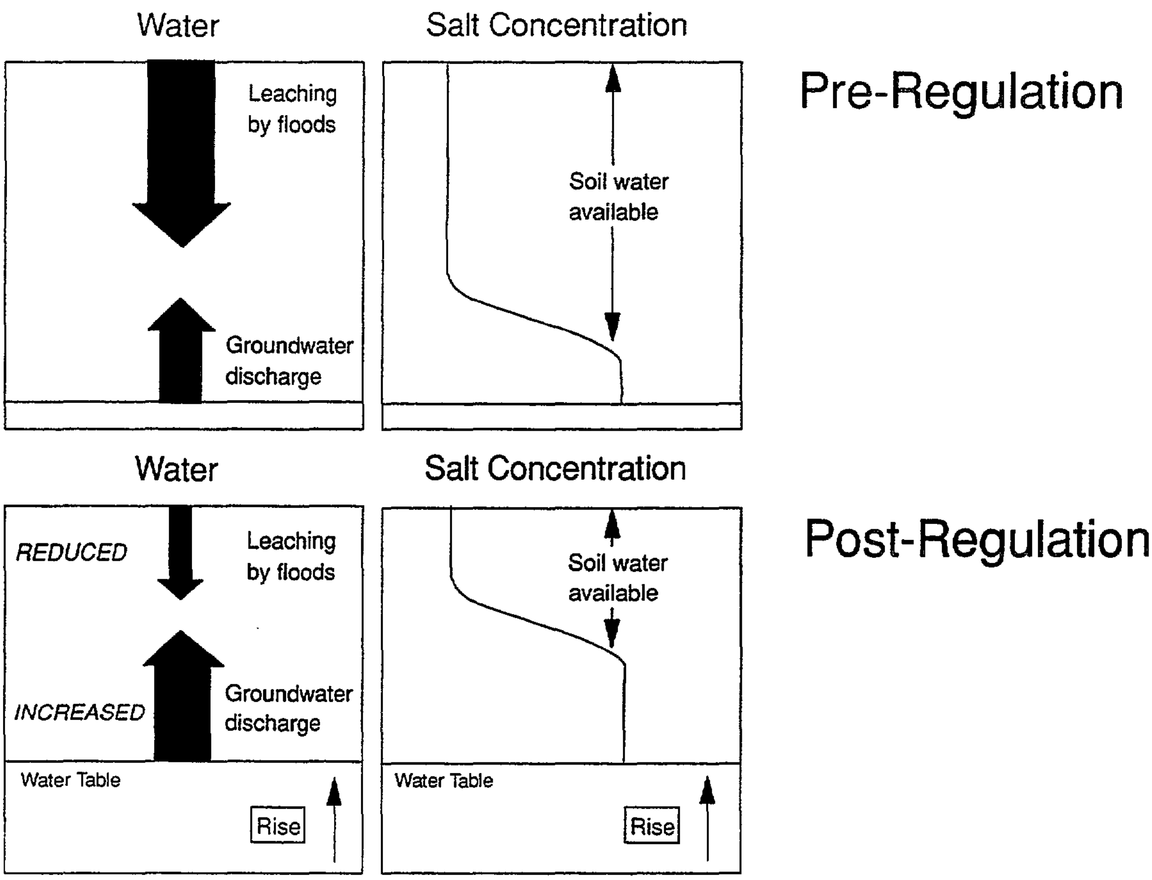

Figure 1: Salt accumulation mechanisms in floodplain soils.

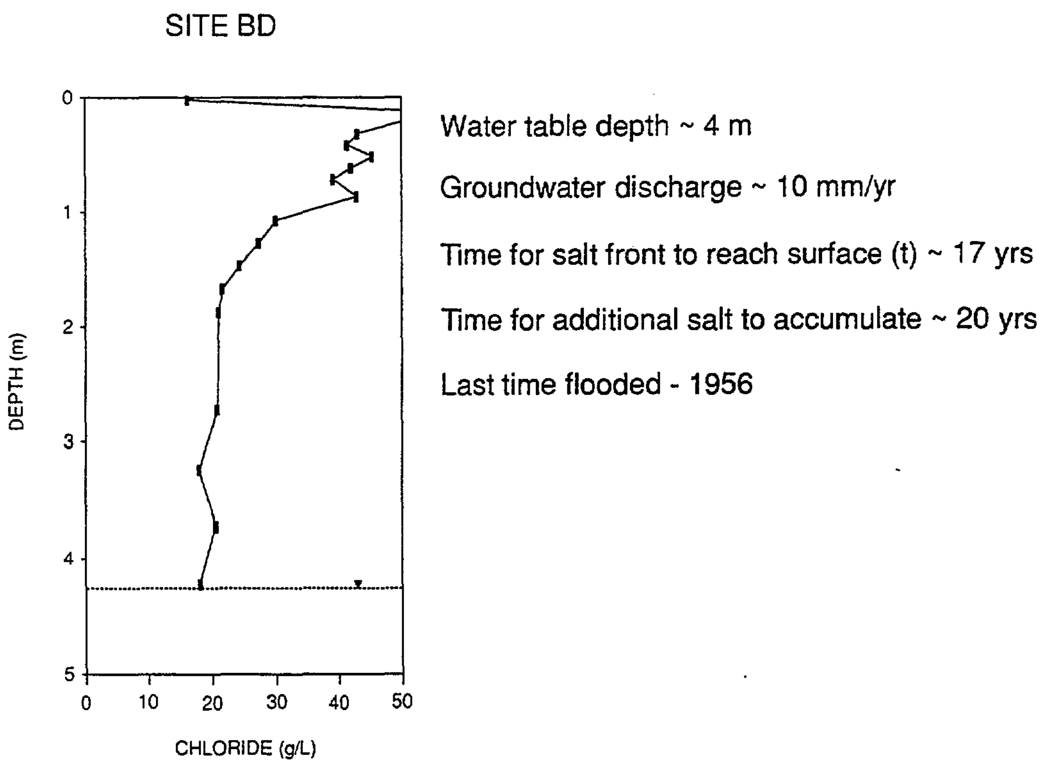

Figure 2: Soil chloride profile from a site where *E. largiflorens* has died as a result of soil salinisation.

It is interesting to note that if the non-flood watertable depth was 5 m prior to regulation then it would have taken ~50 years for the "salt front" to reach the surface. Conversely, if the water table depth had been 3 m then it would have taken only ~6 years for the "salt front" to rise to the surface. This example illustrates how sensitive salt accumulation on the floodplain is to small changes in water table depth and flooding regime.

The proposed Chowilla management scheme

The Chowilla Working Group (1992) have proposed a scheme which attempts to address both floodplain stream (and hence river) salinisation and riparian vegetation dieback. It involves the installation of 15 tubewells on the outer northern portion of the floodplain and the pumping of saline groundwater to a remote evaporation basin. It is predicted that within 10 years the watertable in the immediate vicinity of the pumping bores will be lowered by up to 1.5 m, reducing the flow of saline groundwater to the streams to negligible amounts (Charlesworth et al., 1994). The lower watertable will also lower the rates of groundwater discharge and hence reduce the movement of salt up into the soils. The second component of the plan is the enhancement of flood flows by controlled releases from a nearby upstream storage (Lake Victoria) at or near the peak of floods. This will provide some increases in the frequency of medium to large floods, although not enough to return to pre-regulation conditions.

Threshold and GIS models of vegetation health

To identify further areas at risk, and to predict the success of the proposed management scheme, it is necessary to have a good understanding of the current health conditions and the major factors which influence this. Jolly et al. (1992) found that the health of E. largiflorens was mostly controlled by groundwater salinity, flooding frequency and groundwater depth and that there were threshold values of each which separated communities of different health. Taylor et al. (1995) applied these threshold values to data from 80 sites to disaggregate the floodplain into 6 classes and found that the health was good in four of the classes and poor in the remaining two (Table 1; Fig. 3). A GIS of the Chowilla Anabranch was used to spatially scale the classes over the entire floodplain and health predictions from the GIS model were compared with those derived from aerial photography. It was found that the GIS classes predicted 85% of the observed health accurately.

Overton et al. (1994) further showed that in the river flow range of 70-100 GL day^{-1} (where most of the *E. largiflorens* communities are found) a 7 GL day^{-1} release of water from the nearby upstream storage (Lake Victoria) at the peak of a flood would result in an 10-20% increase in the area of *E largiflorens* flooded and convert some of the areas contained within GIS class 3 (poor health) to GIS class 4 (good health).

While this simple GIS model is useful in understanding the current distributions of *E. largiflorens* health, it is of limited value in determining the benefits from management options such as increased flooding and watertable lowering. It is limited by its discretisation of the floodplain into large "homogeneous" areas and its inability to model the actual mechanisms which lead to the observed health patterns. For example, lowering the watertable by groundwater pumping will probably reduce the rate of salt transport up into the profiles, however it is uncertain as to how long it would take under an improved flooding regime for large amounts of the stored salt to be leached downwards. Furthermore, it is uncertain as to how a given degraded vegetation community will respond to the greater availability of floodwater and it is unclear whether releases of water from upstream storages should be optimised for maximum flood height (to cover greater areas) or length (to provide more water and leaching to areas which would have been flooded anyway).

Table 1: Parameters, thresholds, areas and predicted *E. largiflorens* health of GIS classes.

GIS Class	Groundwater Salinity (dS m^{-1})	Flooding Frequency (years)	Groundwater Depth (m)	Area (ha)	Predicted Vegetation Health
1	>40	>1 in 13	<4	1046	Poor
2	>40	>1 in 13	>4	764	Good
3	>40	1 in 10-13	-	1724	Poor
4	>40	<1 in 10	-	2038	Good
5	<40	<1 in 10	-	377	Good
6	<40	>1 in 10	-	564	Good

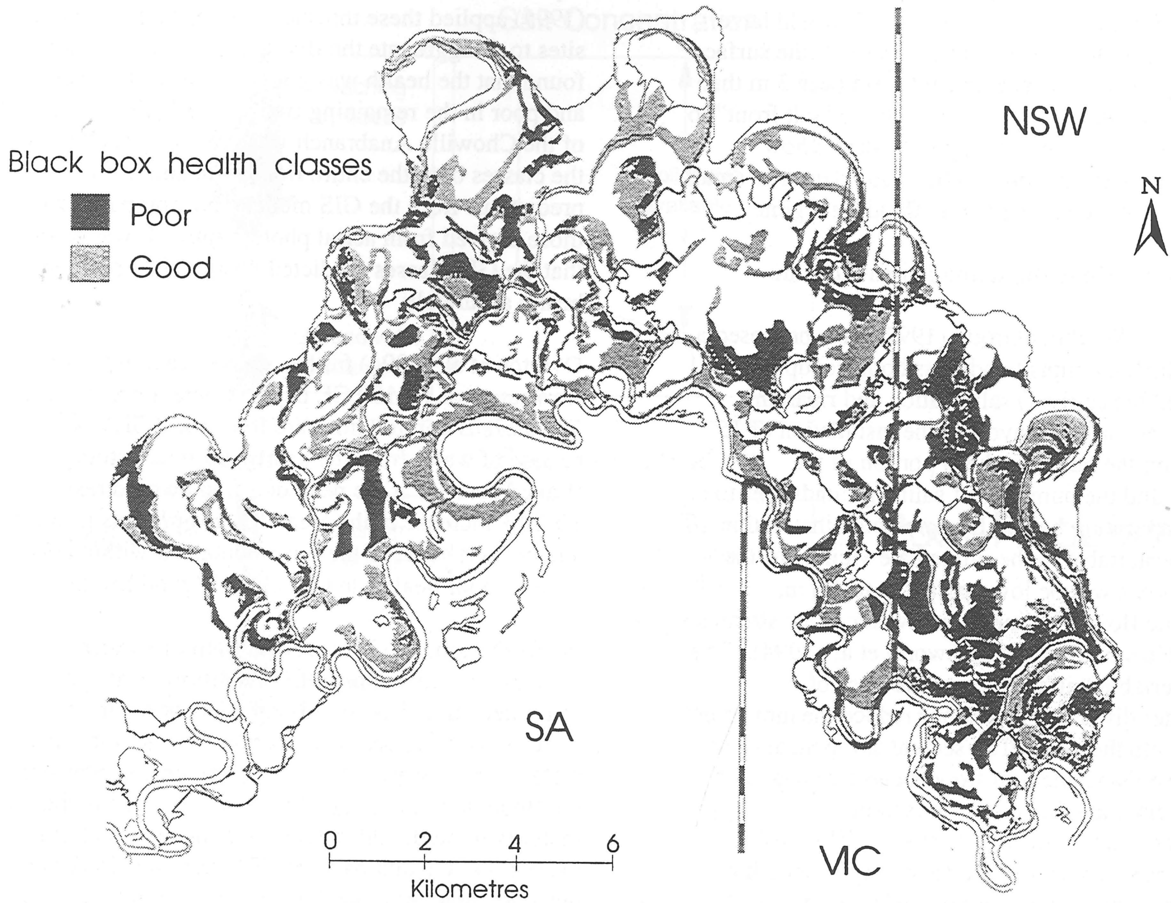

Figure 3: Spatial extent of GIS classes showing areas of predicted poor and good health *E. largiflorens* (after Overton et al., 1994).

Response of *E. largiflorens* to water availability

Because lack of water caused by high salinity was found to be the primary cause of dieback, several studies on the water sources of *E. largiflorens* and how they respond to flooding were carried out. These were mostly conducted at detailed study sites in each of the 6 GIS classes and involved measurements of soil moisture and salinity, groundwater elevation, transpiration rate and associated physiological measurements, leaf death and growth, flowering, fruiting and leaf chemistry.

Transpiration during non-flood times was found to be very low (<1 mm day^{-1}; Thorburn et al., 1993; Streeter et al., 1995) and was consistent with low stomatal conductance and low xylem water potential due to the saline and semi-arid conditions. A range of water use strategies were observed (ie. trees at the more saline sites used from water from near the soil surface, while those at less saline sites used groundwater-derived soil water) with the locations of extraction consistent with the zones of highest plant water availability. Flooding appeared to have a beneficial effect on the water use of *E. largiflorens* although transpiration rates were still low compared with potential evaporation. The degree of impact varied from site to site with the surface Coonambidgal Clay controlling the infiltration of flood water and the consequent leaching of salt. Following a flood, the water used by the trees was mostly extracted from near the soil surface and then as the surface soil dried, extraction occurred from the capillary fringe (Jolly and Walker, 1995). At non-flooded sites, this change occurred earlier. Low surface root mass after a flood appeared to limit the ability of the trees to quickly use the water (Richter et al., 1995).

Modelling the impacts of proposed management options

The above studies have formed the basis of a number of modelling approaches to predict the long-term *E. largiflorens* health (Jolly et al., 1994), predict rates of groundwater uptake by *E. largiflorens* (Thorburn et al., 1995), and to develop and validate a generalised soil-vegetation model of *E. largiflorens* water use and growth (Slavich and Walker, 1995). These models, while useful in assessing various scenarios, are essentially site based and do not provide the spatial predictions required for operational management. Our present work is aimed at combining river flow models such as the River Murray Model (Water Studies, 1992) with GIS models of vegetation response so that the spatial impacts of various water release strategies can be tested objectively.

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Predicting the Likely Impact of Land Management Changes on Land Salinisation in the Upper South East of South Australia

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Introduction

The Upper South East is an important agricultural region in South Australia. However, over more than 50% of the region the shallow saline water table has risen to within 2 m of the soil surface (USEDSFMPSC, 1993). This is causing significant soil salinisation. Given its importance and unique features, an area comprising some 680 000 ha has been chosen as one of 5 focus catchments as part of the National Dryland Salinity Research, Development and Extension program. About 250 000 ha of this is currently salinised, with a further 180 000 ha potentially salinised (~$^2/_3$ in total).

A management plan and environmental impact statement have been prepared for the region (USEDSFMPSC, 1993). Key components of the management plan are surface water and wetland management, a co-ordinated groundwater drainage scheme, revegetation and agricultural production and on farm measures. Revegetation of recharge areas was considered to provide a means of controlling the rise in groundwater. The on-farm measures suggested for the region included improved pasture management using a combination of salt tolerant pasture species on saline areas and deep rooted perennials elsewhere (to decrease recharge). However, no assessment of the potential of the salt tolerant vegetation to assist in controlling water table levels and salinity on the inter-dunal flats had been conducted. The long-term sustainability of salt tolerant vegetation had also not been assessed. This was due primarily to the paucity of information regarding recharge and discharge (water use, salt tolerance and productivity) of the various conventional and salt tolerant species used in the region. There was also little information available on the water use characteristics of the native vegetation in the region.

Consequently, a modelling approach was used to assess the potential impact of the vegetation based management options by calculating the water balance for the region. The models were based on a groundwater model for the region developed by Armstrong and Stadter (1992). A number of field studies were implemented to obtain some of the information required for the modelling exercise. The field studies encompassed both native and agricultural species.

Regional Description

The Upper South East region is in the temperate zone of Australia (Fig. 1) and forms part of the western extremity of the Murray Geological Basin. The mean annual rainfall ranges between 400 and 600 mm. Class "A" pan evaporation is about 1600 mm yr^{-1}. The surface geology comprises mainly Quaternary (recent-Pleistocene) marine sedimentary deposits (sediments and limestone) from the last oceanic transgression, Rochow (1969). The sedimentary deposits form a series of north-west trending calcarenite dune strandlines with intervening wide inter-dunal flats. The flats are underlain by secondary limestone deposits overlying unconsolidated sands. Beneath this lie Tertiary limestone deposits.

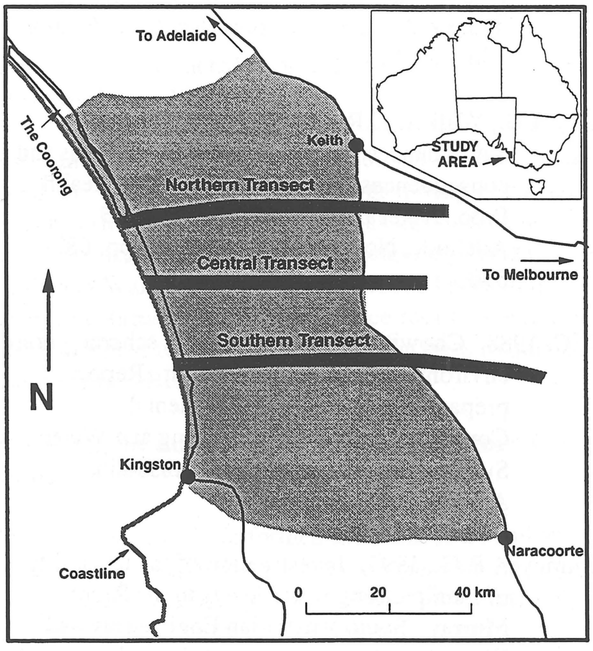

Figure 1: Map of study region showing model transect.

The water table aquifer in the study region lies within the Tertiary limestones, and overlying Quaternary deposits. Regional groundwater flow is to the west away from recharge areas in western Victoria. Over much of the region water tables are rising at a rate of between 5 and 10 cm yr^{-1} (MacKenzie and Stadter, 1992). This is particularly so under higher areas *eg.* dune systems, and is due to increased recharge as a result of clearing of the land for agriculture. In areas with shallow water tables, for example the inter-dunal flats, the water table is essentially in steady state apart from seasonal fluctuations. A comprehensive observation well network has been established in the region. The groundwater salinity varies from less than 1 dS m^{-1} near recharge areas under dunes, to greater than 60 dS m^{-1} toward the north of the region under discharge areas on the inter-dunal flats.

Most of the region has no natural outlets for surface water flow and no permanent streams, although near the coast surface water can enter the southern end of an estuarine lagoon during periods of high flow (MacKenzie and Stadter, 1992). However, there are extensive natural drainage lines and wetlands, mainly along the western side of the inter-dunal flats. Water flows each year when the shallow groundwater rises to the surface due to winter rainfall. Surface water flows to the north-west (approximately perpendicular to the direction of groundwater flow) where it is eventually prevented from flowing further by a continuous dune complex. Extensive surface water drainage channels and diversion banks have been constructed throughout the study region in an effort to remove water from agricultural land. However, this has increased the volume of water able to reach the northern part of the study area, increasing the incidence of water logging.

Most of the study region was cleared about 40 years ago, although pockets were cleared as early as 120 years ago, USEDSFMPSC (1993). Agricultural enterprise in the region comprises mostly sheep and cattle grazing.

Field Studies

The field studies examined the water relations of the main vegetation types on each of the main land forms in the region. For native vegetation these are mallee woodlands on the sand rises and dune systems, and Melaleuca heathlands (which comprise a large proportion of the ecologically important ephemeral wetlands) on the inter-dunal flats. The management plan has suggested that for improved agricultural production and salinity management, lucerne should be considered for the sand dunes and rises, while salt tolerant 'Puccinellia' and Tall Wheat Grass are proposed for use on the inter-dunal flats.

A brief description of results for each vegetation type is given below.

Mallee Woodlands - Recharge under mallee woodlands has been shown to be less than 1 mm yr^{-1}, but under typical annual pastures to be potentially of the order of 50-70 mm yr^{-1} (Walker *et al.*, 1992).

Melaleuca Heath (Ephemeral Wetlands) - We studied the ephemeral wetlands which are most likely to be affected by salinisation and the predominant native wetland tree species, *Melaleuca halmaturorum* (Mensforth, pers. comm.). This species is adapted to the original groundwater discharge conditions of wetlands in the region. Our research has shown that central to this adaptation is:

(i) its ability to lower plant water potentials to ranges typical of xerophytes (< -5 MPa compared to -1.5 MPa, the usual wilting point of agricultural crops);
(ii) its ability to be able to extract groundwater even at high salinities (this follows from (i));
(iii) its dynamic root system that enables it to operate in a fluctuating groundwater system with contrasting salinities; and
(iv) its stomatal control that limits transpiration rates, even at high potential evapotranspiration rates (PET).

Lucerne Pastures - Lucerne pastures were shown to have the potential to reduce recharge rates under sand dunes to the same order as under the native mallee vegetation (Walker *et al.*, 1992).

Salt Tolerant Pastures - There has been quite varied opinion within the literature on the sustainability of these pastures and the impact of these pastures on long term groundwater levels. Preliminary work on the salt tolerant species Puccinellia (*Puccinellia cilliata*) and Tall Wheat Grass (*Agropyron elongatum*) suggests that in the Upper South East:

(a) Puccinellia is dormant and Tall Wheat Grass effectively dormant over summer;
(b) biomass production peaks in July and August as fresher rainfall derived water becomes available, but before water logging and surface flooding occur; and
(c) from preliminary water use studies and from (a) and (b) it is clear that these pastures would not discharge significant amounts of groundwater over and above that discharged by direct evaporation.

Model Description

The groundwater flow model MODFLOW (McDonald and Harbaugh, 1987) was used to model the region. Data from 3 east-west transects (70-90 km in length) was discretised to form the basis of 3, 1 km wide, two layer, cross section models (Fig. 1). These were based on a model developed by Armstrong and Stadter (1992). The models were run using monthly time steps (stress periods). Rainfall, pan evaporation and hydrograph data for a 13 year period up to Dec. 1993 was used in the simulations. Recharge was assumed to be equal to the monthly rainfall where the water table was generally less than 1 m deep and $^{1}/_{12}$ of the average yearly recharge elsewhere. The maximum possible evaporation for each month was assumed to be 0.8 x pan evaporation for that month. Recharge and vegetation water use data from field studies in the area were used in the model (McKewan and Kennett-Smith, 1995; Walker *et al.*, 1992).

Table 1: Annual recharge and extinction depth used for the 4 management options modelled.

	Management Option							
	High Recharge		Moderate Recharge		Low Recharge		Deep Extraction Depth	
	Annual Recharge	Extinction Depth	Annual Recharge	Extinction Depth	Annual Recharge	Extinction Depth	Annual Recharge	Extinction Depth
Dune	40 mm	2 m	20 mm	2 m	2 mm	2 m	40 mm	2 m
Inter-dunal Flat	Rainfall	1 m	Rainfall	1 m	Rainfall	1 m	Rainfall	2 m

The main difficulties in the modelling of groundwater discharge areas include the impact of surface water inundation, dealing with the large area of shallow water tables (and hence sensitivity to topography) and modelling groundwater gradients. These were all considered in the discretisation of the modelled transects. A description of the discretisation and calibration of the models is presented in Kennett-Smith *et al.* (1995).

The models were run for 4 different recharge-extinction depth combinations, representing 4 land management options (Table 1). Water budgets were calculated for zones within each transect using the MODFLOW Utility ZONEBUD. The zones were chosen through consideration of recharge-elevation-extinction depth characteristics across the model.

Modelling Results

The main results of the modelling are that:

(i) nett water fluxes through the flats are much smaller than the total fluxes, but these nett fluxes are comparable to those through the dune systems. However, a very large reduction in recharge on the dune ranges will be needed to reverse the rising groundwater trends under the dune ranges (Fig. 2)

(ii) reduction of recharge on the dune ranges will decrease the salinisation rate of the inter-dunal flats, although there would be no discernible fall in water table levels (Figs 3,4). However, reducing recharge to achievable rates on the dune ranges is unlikely to change significantly the area of the inter-dunal flats potentially salinised

(iii) increasing the extinction (plant water extraction) depth will lead to a lowering of the water table under both the flats and the dune systems depth. However, it does not change the total salt accumulation but does dramatically change the distribution (Figs 3,4)

(iii) on the time and spatial scales of the model, the details of the groundwater discharge areas are not well modelled and the impact of different land uses is not distinguished. It is necessary to look at a smaller scale to do this.

Discussion

The models allow us to do some preliminary assessment of the management options. Sustainability of any management system depends on the prevention of water logging and salt accumulation. Supposing that hydrologic equilibrium is attained the recharge discharge fluxes will become stable. If a salt equilibrium is not reached the discharge areas will become progressively more saline, and hence any production will not be sustainable. Under the current management system ~40% of the region is salt affected and will continue to accumulate salt. The degree of water logging can be assessed from the predicted groundwater levels. The average rate of salt accumulation can be predicted from the modelled water balances.

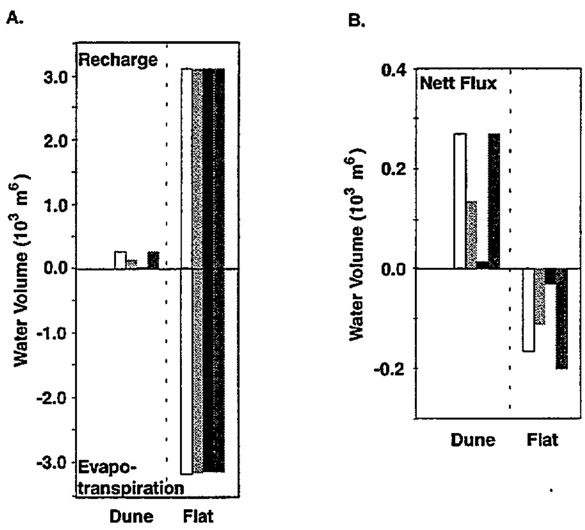

Figure 2: A. The recharge and evapotranspiration budgets and B. the difference between recharge and evapotranspiration (nett flux) for a dune and an inter-dunal flat for a 10 year period. The 4 management options are represented by ☐ - high recharge, ▒ - moderate recharge, ■ - low recharge and ■ - deep extraction depth.

Groundwater levels under the dune systems are continuing to rise and hence the groundwater discharge will increase. The reduction of recharge under the dune systems by half is predicted to lead to declining groundwater levels. In practice it may be difficult to achieve recharge reduction of more than an order of magnitude due to levels of uptake of planting and plant water use. This is partly due to the presence of non-wetting sands. However, if the recharge can be reduced by a substantial amount then groundwater levels beneath the dune systems will drop and the rate of salt accumulation on the flats will decrease.

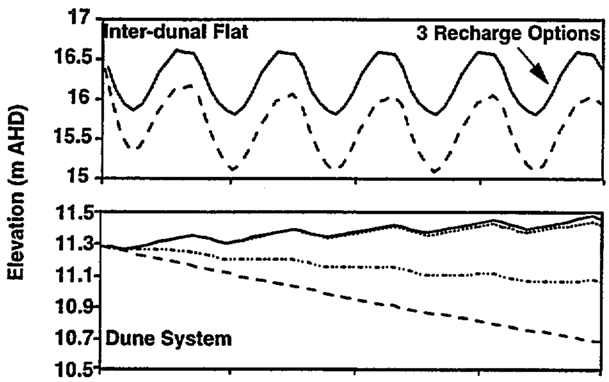

Figure 3: Predicted water table levels over a 5 year period from for a flat and a dune cell, for each of the 4 management options (— high recharge ······ moderate recharge; ····· low recharge; - - deep extraction depth).

While increasing the extinction (extraction) depth was predicted to lower the water table, it does not change the average salinity of the flats but focuses it on the western side. However, given that even the locally adapted Melaleuca species does not have significant root mass below about 60 cm (Mensforth, pers. comm.) it is unlikely that such a plant could be found. If such a plant could be found high water use is unlikely to be sustainable in the long term given the high salinities that will result in the 'focus' area.

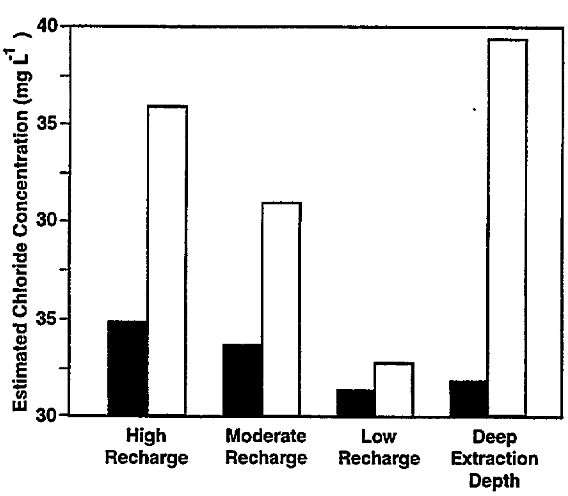

Figure 4: Estimated chloride concentration in the top 1 m of the soil profile based on the water balances generated by the model for a 10 year period. This is used as an indication of the average salinity in the top 1 m of the soil profile (including the top of the water table). Estimates for the four managment options for an inter-dunal flat - ☐ and a dune - ■ are presented. The initial chloride concentration was 20 mg L^{-1}.

The primary aim of surface water drains is to remove water to reduce water logging to allow pasture establishment. However, unless sufficient salt is removed by the drains, the pasture will not be sustainable due to salinisation. This would certainly be the case with the salt tolerant species mooted for the area as they appear to synchronise their growing season with relatively low salinity and non-logged conditions. Groundwater drainage provides a mode of both lowering water tables and removing salt, although this is not assessed here.

During the course of this work it has become obvious that the micro-topography and salinisation processes are strongly related. Due to the very low water table and topographic gradients small changes in surface elevation (order of 30 cm) make a considerable difference to the degree of salinisation and to the ability of salt tolerant species to persist. This may be due as much to water logging tolerance as to salinity tolerance. These changes occur over distances of metres, very small scale models are required to model these effects. In the modelling exercise reported here the scales were of the order of 100's of metres. Thus the average salinity for the average surface elevation has been modelled. The degree of salinisation found at any site can be much greater or much less than those predicted here. Managing land at this scale may not be economically justifiable. Also, modelling and managing land at this scale presents difficulties which is not addressed here.

Conclusions

Groundwater modelling has been used to assess the likely effect of different management options in a salinised area of South Australia. The main outcomes are

1. reduction of recharge in nett recharge areas has been predicted to have a significant effect on salt accumulation in the discharge areas, although not on groundwater levels.
2. increasing the water extraction depth will not change the overall salt accumulation but will change the spatial distribution.
3. sustainability of agriculture in discharge areas needs to be thought of in terms of salt as well as water. Therefore nett fluxes must be considered to allow assessment of the salinisation processes.

The sustainability of agriculture on the inter-dunal flats in the region depends on the ability of the vegetation to cope with salinity and water logging. It would appear unlikely that salt tolerant vegetation will provide a means of controlling or managing water table levels or salinisation. Some form of drainage would be necessary to lower water tables in order to reduce salinisation. This was not addressed here.

In this study where topographic and water table gradients are low, salinisation processes are dominated by the micro-topography. Thus modelling at greater scales will not show the range of salinisation actually present. Land management and modelling at this scale were not addressed here.

ACKNOWLEDGEMENTS

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DRYLAND SALINITY AND RELATED MANAGEMENT PRACTICES IN YAHOO PEAKS AND BARNEYS REEF CATCHMENTS, NSW

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This paper reports on the progress of a research project currently being implemented by the Orange Agricultural College in collaboration with the Department of Land and Water Conservation and the local Landcare Groups. The study will evaluate the salinity control measures in the Yahoo Peaks and Barneys Reef Catchments in terms of their efficiency and sustainability and to identify the preferred management options on farm and catchment levels.

The rise of watertables and associated dryland salinity have been identified as major land degradation problems in the slopes and tablelands of the Macquarie Region New South Wales (Central West Total Catchment Management Committee, 1994). Within the Upper Macquarie River Catchment, outbreaks of dryland salinity now affect 3 850 ha of land. The most affected catchments include Barneys Reef, Yahoo Peaks, Suntop, Berrenjoy, Rylstone and Cook Mayall's (Taylor, 1994). A range of biological and engineering mitigation schemes and management options have been adopted to control the dryland salinity problem in these catchments.

To date there has been very little, if any, effort to evaluate the effectiveness of the adopted solutions since their establishment. Furthermore the availability of relevant information and data on the different schemes are patchy and not readily accessible to researchers, extension officers and Landcare Groups (Al Bakri, 1994). The lack of monitoring and evaluation of salinity management practices has also been noted by several studies (e.g. Policy Development Planning (PDP), 1992 and Webb and Price 1994). It is obvious that there is an urgent need to acquire data and information about the efficiency and sustainability of the various options in place to control dryland salinity in this region. In order to meet this need, the proposed study is designed to conduct a comprehensive assesment of the processes causing the salinity in order to determine the impacts and limitations of such management practices in two sub-catchments within the Macquarie Region, namely: Yahoo Peaks and Barneys Reef. These two catchments were chosen because they offer well established salinity management schemes, and provide interesting contrasts in terms of the approaches used to determine their salinity management practices (Al Bakri, 1994). The study's objectives include evaluating the effectiveness and sustainability of the mitigation schemes in terms of lowering the watertable levels and reducing the salinity and to investigate the nature of the groundwater systems and the impact of the geology and geomorphology on rising watertables. The influence of the chemical compositions of the rocks and soils of the two catchments on the chemistry of the ground and surface waters as they relate to the origin of the salts will also be investigated. Recommendations on the appropriate "best bet" dryland salinity management schemes for both catchments will be formulated.

To achieve the above objectives the following tasks are being carried out at both catchments. Monthly monitoring of the piezometer networks for a period of 12 months to record waterlevels, salinity and pH. Additional monitoring will be undertaken after events such as heavy rains. This monitoring program will complement and update the historical data recorded since establishing the piezometers. Flow velocity of the creeks will be measured to determine the discharge rates and to estimate the salt loads in both catchments. Rainfall gauging stations will be placed on both sites for the purpose of monitoring rainfall and sampling for cation and anion compositions, specifically Chlorine. Supplementary geological mapping of the sites will be carried out and rock samples will be collected from each lithological type for laboratory analyses. Soil samples will be collected using an auger from depths of approximately 2-4 m. Sampling will occur along transects over the salted areas specifically, but also in areas of possible recharge.

Surface and ground water samples are being collected to be analysed for alkalinity, hardness, calcium, magnesium, sodium, potassium, chlorine, bicarbonate, sulphate, electrical conductivity (EC) and pH. These samples will be prepared and analysed according to the procedures outlined in HACH, 1992. The soil samples will be analysed to determine their cation exchange capacity, exchangeable sodium percentages (ESP), calcium, magnesium, sodium, potassium, chlorine, bicarbonate, sulphate, electrical conductivity (EC) and pH. These samples will be prepared and analysed according to the procedures outlined in HACH, 1993. X-Ray Fluorescence techniques (Hutchinson, 1974) will be used to analyse the soil and rock samples to determine their elemental compositions.

Statistical techniques such as Pearson correlation coefficient (r), simple and multiple regression and the multivariate analysis of variance (MANOVA), (Shott, 1991 and Gay & Diehl, 1992) will be used to investigate the correlation between the chemical compositions of the waters, soils and rocks as they relate to the salinity problem and the related management schemes.

A survey of the local landholders, extension officers and Landcare Groups will be conducted to gauge their views on the effectiveness and limitations of the current management practices in place. This survey will be carried out prior to the development of the "best bet" management options for dryland salinity control in the two catchments being studied.

Yahoo Peaks catchment covers an area of 3000 ha and is located at Baldry, 39 km NE of Parkes in New South Wales. The Yahoo Peaks catchment drains north into Baldrudgery Creek which then meets Little River a further 10km north. Rainfall is approximately 400 mm per annum and throughout the entire catchment, annual evaporation exceeds annual precipitation in the drier and warmer months (Taylor, 1994). At Yahoo Peaks mixed farming operations are dominant, principally cattle grazing and cereal cropping for wheat and oats. A small proportion of land in the Baldry/Little River Catchment incorporating Yahoo Peaks is used for mining (Nicholson, 1990).

The development of management practices at Yahoo Peaks was preceded by investigating the processes causing the salting. Terrain and geological mapping, soil mapping, contour survey, electro-magnetic induction survey and T.O.P.O.G. modelling were carried out (Nicholson, 1990). The information obtained from the above tasks was used to understand the hydrologic processes within the catchment and the land features which control them. It was then possible to design management strategies suited to the specific catchment. The main management strategies included tree plantings and the use of deep rooted perennial pasture species for recharge and discharge areas (Nicholson, 1990). Other management strategies developed to combat the salinity problem include, the establishment of a network of piezometers and a program of structural works including earthworks and fencing off affected areas. Property plans incorporating the salinity management practices have been developed for those properties.

Barneys Reef is a low range of hills 20km north of Gulgong, and the catchment drains to the Talbragar River 6km to the north. The demonstration of salinity control measures and strategies lies principally on the property "Winona", a 810 ha property which runs a self replacing merino stud for wool production (Nicholson and Seis, 1993). The catchment has an average annual rainfall of 650 mm per annum (Nicholson and Seis, 1993).

In comparison to Yahoo Peaks very little detailed investigation has been carried out over Barneys Reef Catchment prior to the development of the management practices. The approach used was by correlation and analogy whereby land attributes associated with known occurrences are determined and used to predict potentially saline sites. Management strategies which have been found to be appropriate in similar areas of dryland salting were then applied. A demonstration program for remedial action has been established (since early 1990) under Salt Action and the National Resource Management Strategies funding to combat the widespread salinity outbreaks at Barneys Reef Catchment. A program of land management initiatives including property planning, soil survey, tree and pasture establishment in both recharge and discharge situations, a co-ordinated program of structural works (earthworks and fencing) and a monitoring and investigatory network of piezometers have been established (Nicholson and Seis, 1993). The network of piezometers have been monitored regularly over the past three years. Monitoring has involved recording watertable levels, salinity and pH. As part of this project an electro-magnetic survey has been completed over Barneys Reef Catchment. This survey has indicated the need for additional piezometers in areas previously thought not at "risk" to salinisation.

This study will provide the opportunity to carry out detailed investigations of the geology, water and soil chemistry, climate and landuse activities in two small catchments to enable a better understanding of the processes causing the salting problems. This approach will help assess the effectiveness and sustainability of the management schemes in place. Based on the findings from the above activities, a comparative assessment of the two catchments will be carried out to determine the best way to approach a dryland salinity problem in terms of developing the management options. The detailed assessment of the salinity management practices and related factors and processes in the two catchments will enhance the ability to extrapolate the findings to similar catchments. This study will thus contribute significantly towards extablishing a regional perspective to assist in developing dryland salinity management strategies in the slopes region of the

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Increasing Groundwater Usage and its Effect on Groundwater Level Trends in the Lower Murrumbidgee Valley

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Introduction and Location

The Lower Murrumbidgee valley occupies a large part of the eastern Riverine Plains of the Murray Geological Basin. It extends from Narrandera, on the Basin's eastern margin, westwards to Balranald and includes the Murrumbidgee and Coleambally Irrigation Areas (MIA and CIA). This area is shown in the locality plan in Figure 1.

The bulk of the area is underlain by unconsolidated Murray Basin sediments comprising the Shepparton Formation, Calivil Formation and Renmark Group. Low salinity, high yielding aquifers of the Calivil Formation and Renmark Group underlie the eastern end within an area surrounded by the towns of Narrandera, Griffith, Carrathool and Jerilderie. This area is often referred to as the Murrumbidgee alluvial fan and is designated as Groundwater Management Area 002 (GWMA 002).

Hydrogeology

The alluvial fan sediments have a maximum thickness of about 250 m. The Shepparton Formation is the upper layer and is characterised by yellow and brown polymictic sands and variegated clays. It is generally about 60 m thick, with sand and gravel lenses mainly concentrated in the upper 20 to 30 m.

The Calivil Formation lies directly beneath the Shepparton Formation and is generally about 60 m thick. It is dominated by grey, quartzose coarse sand and fine gravel deposits which are the main productive aquifers within the area, and typically comprise 50 to 70 % of the Formation. Lenses of pale grey to white kaolinitic clay are also common.

The Renmark Group is the basal unit and therefore has a highly varying thickness which reaches a maximum of about 150 m in an area to the west of Darlington Point. It is characterised by dark coloured clays and lignite deposits but also contains thick sequences of medium-grained quartzose sand which are often tapped by the deeper irrigation bores.

The deep aquifers of the Murrumbidgee alluvial fan are recharged mainly from leakage beneath the Murrumbidgee River. The groundwater quality is generally very good with EC's as low as 200 uS/cm close to the recharge source, and 500 to 600 uS/cm throughout much of the rest of the area.

Land Use

Land and water usage is dominated by irrigation of orchards, rice, row crops and pasture with surface water within the Irrigation Areas and along the river, and irrigation of rice, row crops and pasture with groundwater in some of the remaining area. There are also large areas of dryland grazing, mainly in the west. Annual volumes of water diverted or pumped from the river in this area are generally about 2 000 000 ML. Irrigation has not been without side effects, and currently at least 3/4 of the MIA and 2/3 of the CIA are underlain by shallow watertables.

Groundwater Usage

Groundwater usage data for the Murrumbidgee alluvial fan is available from 1982/83, at which time bore licences in NSW were being converted from having an authorised area of irrigation to an annual volumetric entitlement. However, the most reliable data occurs after 1985/86 when meters became compulsory for high yielding bores and a metering inspector was employed for this area.

Annual groundwater usage is shown in Figure 2. It displays an increasing trend with a maximum of about 120 000 ML pumped in 1991/92. The 1994/95 figures are not available yet but are expected to be higher still due to the drought.

Further increases in usage are expected in the future due to:

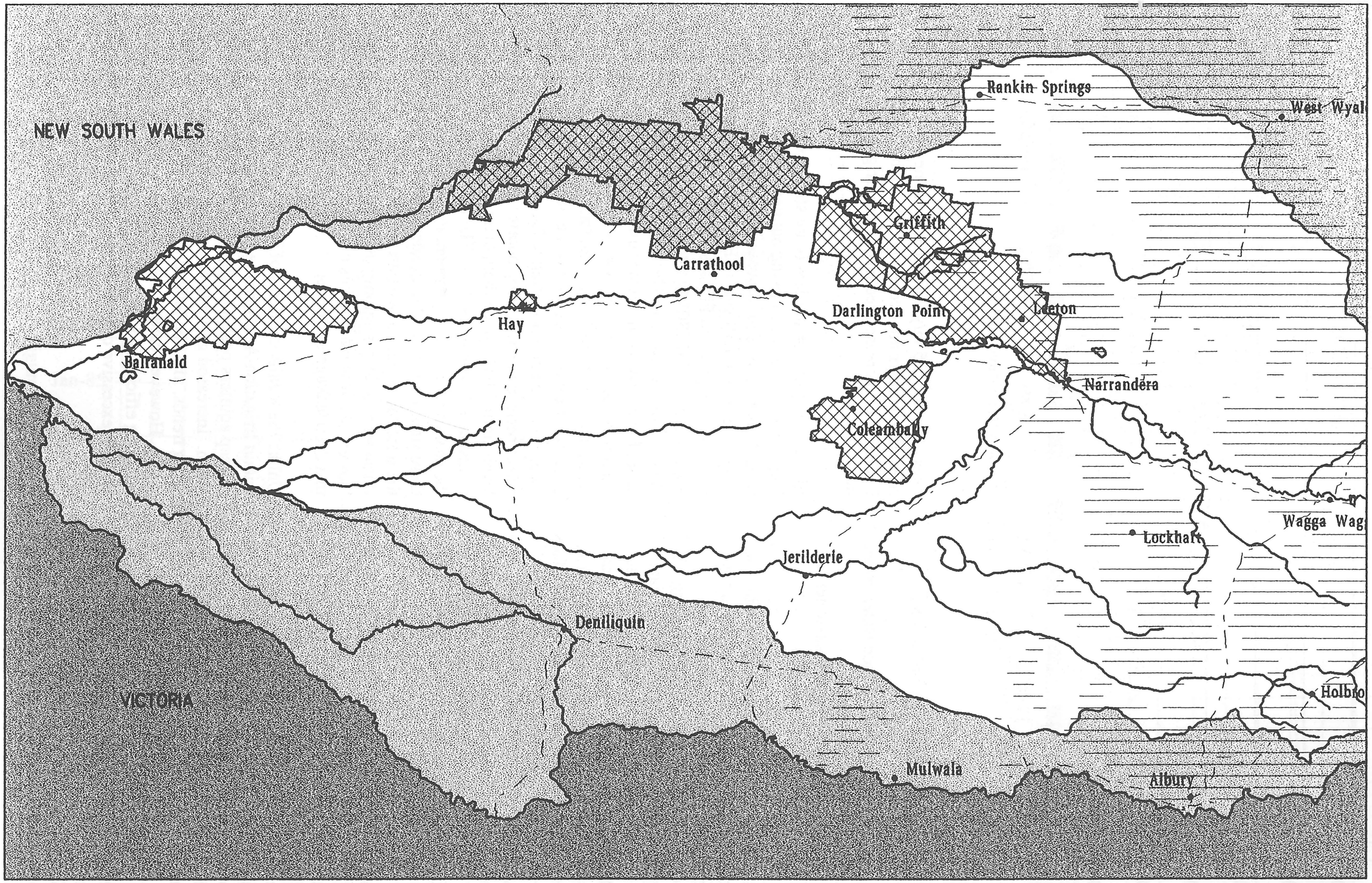

FIGURE 1. LOCALITY PLAN

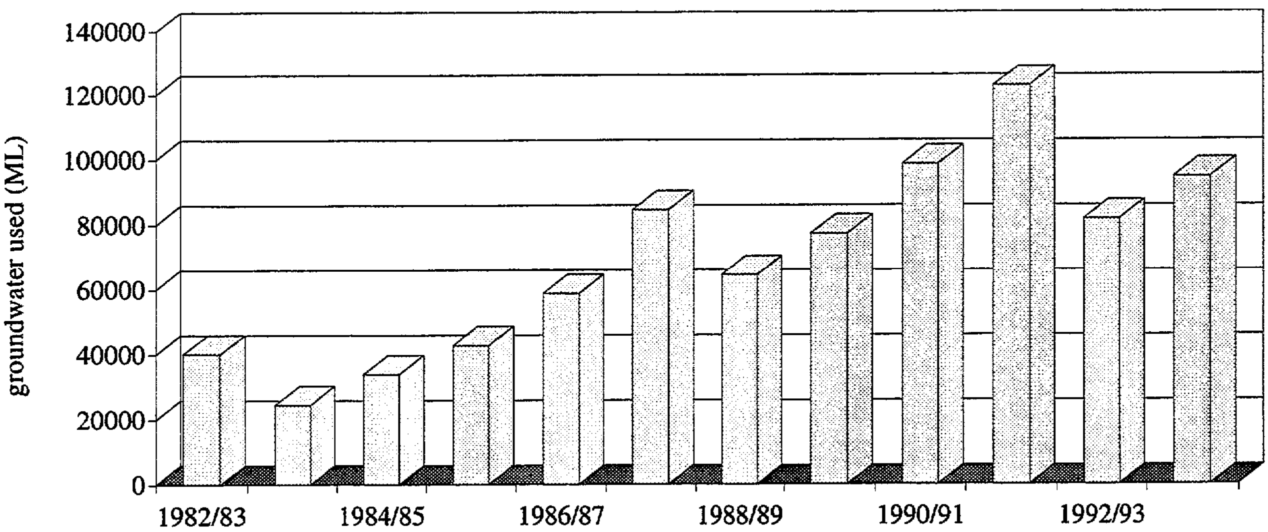

Figure 2. Annual Groundwater Usage (ML)

- a large number of new bores sunk during the drought;
- expected increasing surface water costs, and
- limited availability of surface water for expansion of irrigation.

Almost all groundwater usage occurs outside the Irrigation Areas, with intensive pumping in the Darlington Point area - particularly to the southwest of the town. The lack of pumping within the Irrigation Areas is due to both surface water availability and a conjunctive use policy which limits the use of groundwater by Irrigation Area farmers. Groundwater pumping within Irrigation Areas is desirable to enhance deep leakage and, as an alternative to increased usage in areas where intensive pumping already occurs, enable a more even spread of drawdown throughout the alluvial fan. Within the CIA an experimental bore, sunk to assess deep leakage, pumps about 6000 ML annually into the surface supply system.

Groundwater Level Trends

The deep aquifers are fairly detached from surface processes and are not influenced significantly by seasonal climatic effects and short term events such as floods. Rather, they are influenced more by land management practices affecting recharge over the long term, and by pumping.

Rising groundwater levels occur in the deep aquifers in the northwestern part of the alluvial fan. An example is provided in Figure 3. Piezometer site 36267 is just outside the Benerembah Irrigation District, to the west of Griffith, and groundwater levels are rising in all aquifers at rates of up to 0.35 m/yr. Further west, near Hay, rises of 0.07 m/yr are occurring. The rising trend is a result of increased recharge from irrigation to the east.

Elsewhere, groundwater levels are stable over the long term, or were once rising but have declined recently in response to increased groundwater usage over the last 10 years. Examples of these situations are given in Figures 4 and 5. Piezometers 40582, 30342 and 30341 are located about 7 km southwest of Darlington Point in an area of intensive groundwater use. The deep aquifer groundwater experiences extreme fluctuations of 10 to 15 m/yr and has recently begun to decline. Piezometer site 36040 is located on the central western edge of the CIA and experienced rising deep aquifer groundwater levels until 1990. Since then, these groundwater levels have begun to decline. The rising trends in the shallow aquifers (equivalent to watertable) at these sites are mainly due to lateral migration of the watertable mound beneath the CIA, and illustrate that deep pumping does not actually "lower" shallow watertables but merely ensures that deep leakage can occur.

Unlike the localised effects of shallow watertables within Irrigation Areas, rising groundwater levels in deep aquifers pose a threat to the entire Murray Basin. Increased groundwater usage, to reverse rising trends, must be looked upon as a positive move. However, care is needed to ensure that pumping efficiency is not unfairly compromised through excessive drawdown in areas of intensive use.

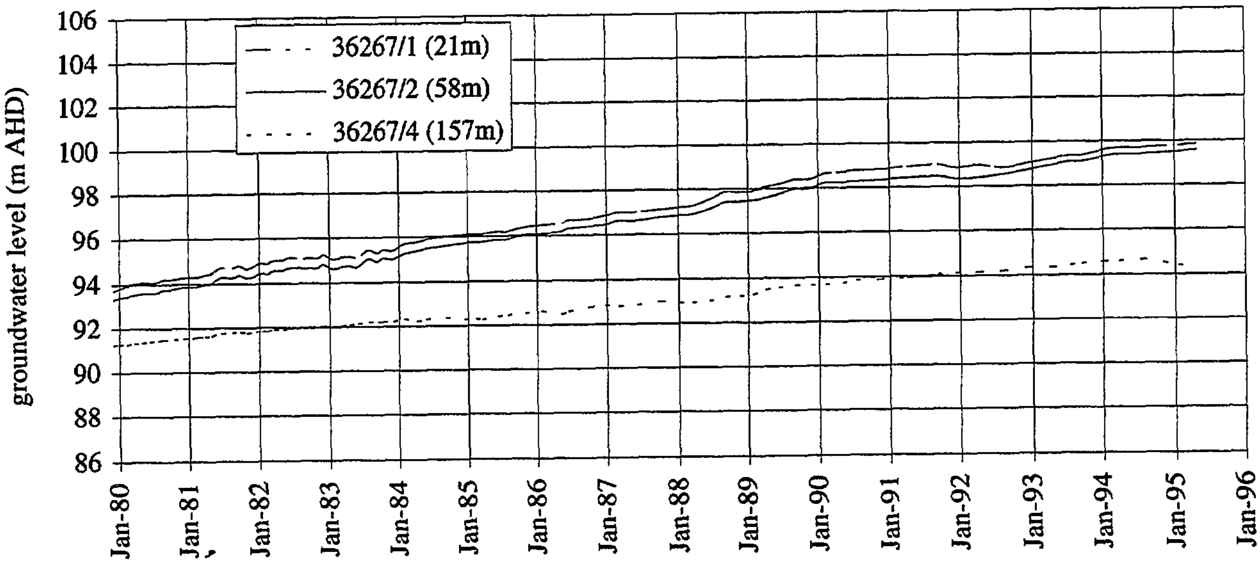

Figure 3. Groundwater Hydrographs - Bore 36267

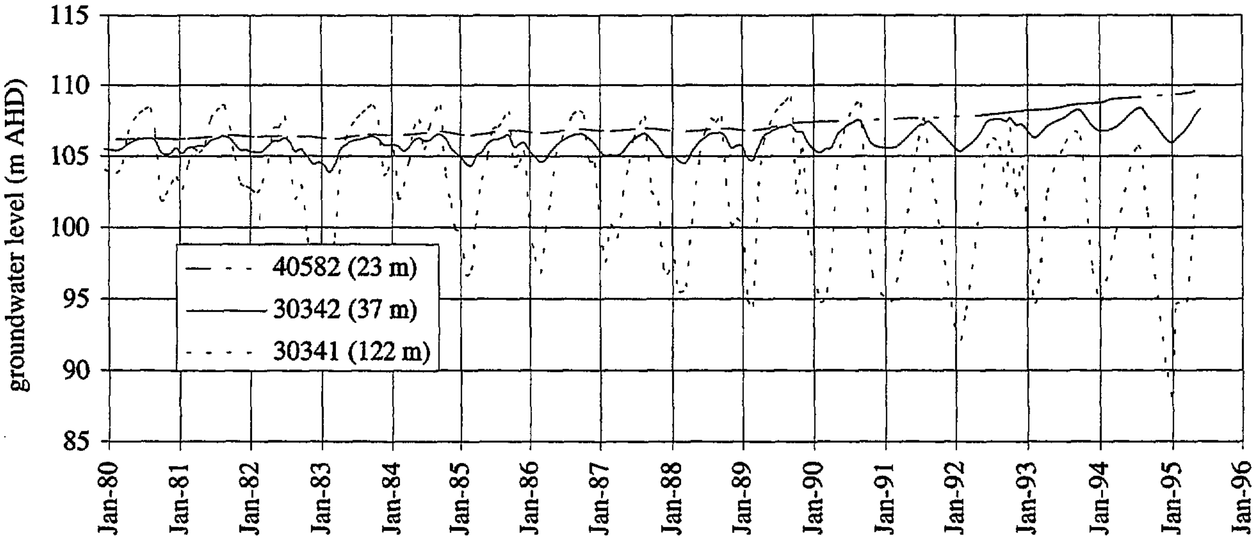

Figure 4. Groundwater Hydrographs - Bores 40582, 30341 and 30342

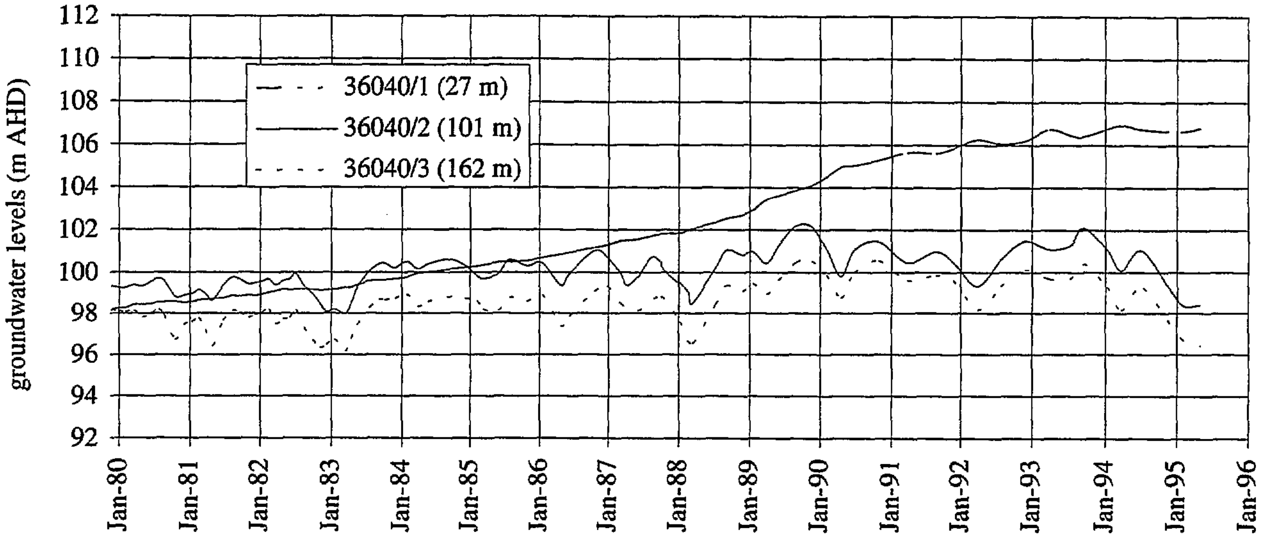

Figure 5. Groundwater Hydrographs - Bore 36040

Current Groundwater Allocation Policy

The current groundwater allocation policy has been in place since July, 1991. It refers to all GWMA's in the NSW part of the Murray Basin, and therefore includes the Lower Lachlan and Lower Murray valleys as well as the Lower Murrumbidgee. Some important components of the policy are:

- an announced 150% allocation until July 1996;
- whole property entitlements on a tapered scale, beginning with 4 ML/ha for properties of less than 250 ha;
- a property ceiling of 6000 ML (which applies to all properties of more than 8000 ha)
- conjunctive use provisions which allow surface water irrigators a base allocation in some cases, and makeup of surface water with groundwater in years of reduced surface water allocation;
- a total applied water intensity ceiling of 6 ML/ha for conjunctive irrigators, and
- unrestricted entitlements for spearpoint batteries and tubewells less than 20 m deep within Irrigation Areas and Districts.

A major point of controversy with the current policy is that it unnecessarily restricts the use of groundwater within Irrigation Areas. This goes against recommendations for deep pumping and flexibility of water use which are emerging from Land and Water Management Plans.

The conjunctive use regulations have evolved from experiences in more restricted upland valleys where the productive aquifers have more direct connection with the river. In such cases, overall valley water use can be optimised by treating the groundwater system as a "bank", which can be drawn upon during dry times and, in doing so, creating room for recharge during periods of high flow. The Lower Murrumbidgee, with a huge storage and less direct connection between the river and deep aquifers, should not necessarily be treated in this way.

The Future

Groundwater usage should continue to expand in the Lower Murrumbidgee. It's encouragement no longer appears necessary as once thought. Rather, management must aim to optimise the usage that will occur.

A revised groundwater allocation policy is planned to be in place by July 1996. The revised policy is considered essential to:

- confirm the future of the current 150% announced allocation;
- clarify conjunctive use regulations, and make them consistent with the directions provided by Land and Water Management Plans and roles of newly corporatised Irrigation Areas and Districts;
- provide a suitable playing field to allow groundwater usage to expand evenly throughout the valley to it's full potential.
- reflect physical constraints of aquifer yield and recharge as well as land management.

The first phase of policy revision will involve a detailed Status Report describing groundwater usage patterns and groundwater level trends in detail. It should also provide updated estimates of "safe" or "sustainable" yield type figures for the area. This will be followed by community consultation then a draft and final policy.

Policy development should be aided considerably by the Lower Murrumbidgee Regional Groundwater Model (part of the Murray Basin groundwater modelling program) and Land and Water Management Plans for the MIA and CIA - three large tasks approaching completion from which results were not available to feed into the current policy. The need to put the results of these projects into practice, combined with the pending increase in groundwater usage in the area, suggest that the time is right to set some direction for groundwater usage that could benefit the entire Murray Basin.

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Fresh Groundwater in the S-W Murray Basin Resulting From Recharge During Wet Climatic Periods

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Summary

The fresh groundwater in the S-W Murray Basin has been shown to originate from recharge during wet climatic periods, the most recent of which occurred 4,000 -8,000 years ago. Palaeo-recharge occurred in both the Big and Little Deserts but was greater in the Little Desert as a result of slightly higher rainfall and sandier. soils. Under the present arid climatological phase, only the Little Desert shows significant recharge occurring

Introduction

A 20,000 km^2 area of low salinity groundwater, elongated north -south along present day flow lines, exists in the S-W Murray Basin (Fig. 1). This fresher groundwater is present in both the upper predominantly unconfined Murray Group aquifer and the lower confined Renmark aquifer. Groundwater salinity, as low as 500 mg/L in some areas below the Big and Little Deserts, increases gradually to about 3,000 mg/L radially from these areas and then rapidly to 7,000 mg/L (Fig. 1).

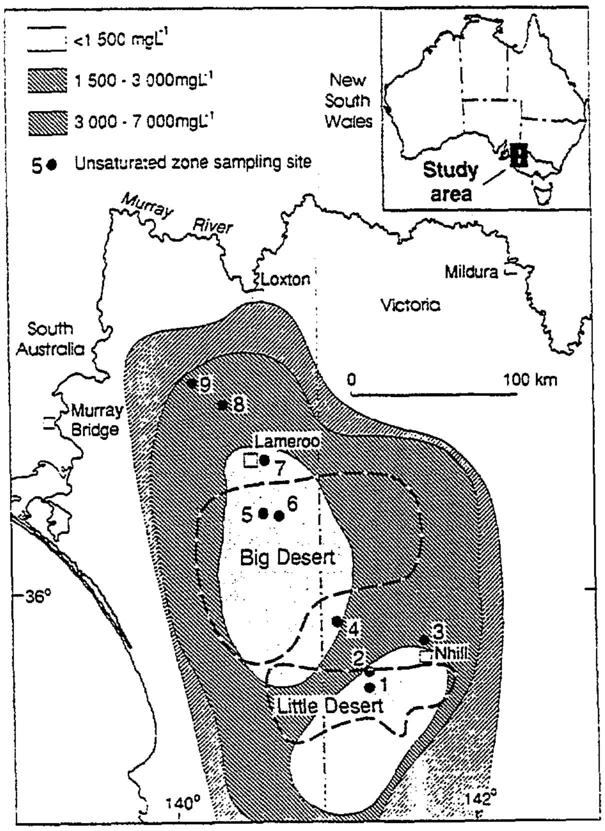

Fig. 1 Location of low salinity groundwater and unsaturated zone sites in the S-W Murray Basin

Annual precipitation ranges from ~550 mm just south of the Little Desert to ~300 mm near the River Murray. Groundwater flow is generally South-southeast to North-northwest with isopotentiometric gradients ranging from ~2 $m.km^{-1}$ near the Dundas Plateau to ~0.3 $m.km^{-1}$ closer to the River Murray. Surface soil types range from clays in the flatter areas and interdunal swales to deep unconsolidated sands in the Big and Little Deserts. Results from chloride and isotopic (carbon-14 and stable isotopes) analyses for samples collected during drilling through the Big, Little and Sunset Deserts showed considerable variations in the amount of salt accumulation (presented as soilwater chloride) in the unsaturated zone (Leaney et al. 1994). These profiles are included with the results of more recent sampling later in this paper (Fig. 2).The amount of salt stored in the unsaturated zone at these sites records different rates of recharge; higher salt concentrations reflecting a lower rate of recharge. Hence, recharge in the Little Desert was considerably greater than recharge at the other two sites. In addition to this, for the Big and Little Deserts, soilwater chloride concentrations were considerably less for the bottom of the unsaturated zone when compared to the top. These differences reflect temporal changes in the rates of recharge for these two sites with the lower soilwater chloride resulting from recharge during a wetter climatic period. Furthermore, by assuming a constant chloride flux equal to that measured today, they suggested this wetter phase occurred 4,000 to 8,000 years ago.

In this paper, we present an extension of the results from the unsaturated zone sampling program considering, in addition to the sandy sites, several areas with clay surface soils. In addition, we present results showing indicators of wet (higher recharge) and arid (lower recharge) climates preserved in the chemistry and isotopic signature of soilwater from the unsaturated zone.

What Determines Recharge Rate

During the last decade, considerable effort has been extended in identifying and evaluating the parameters that effect recharge in the Murray Basin.(Kennett-Smith et al. 1994). The major factors are rainfall, vegetation and surface soil type with the rate of recharge being a function of all of these. Clearly, higher rainfall tends to produce higher rates of recharge but how the rainfall is distributed spatially and the duration and intensity of rainfall events is of equal or greater importance to recharge.

Surface soil types are important as they dictate the depth to which rainfall infiltrates. When water infiltrates beyond the zones of evaporation and transpiration it recharges the groundwater unless it is forced laterally by a barrier of low permeability. Vegetation differs greatly in its ability to remove water from the soil both with regard to its salinity and also soilwater potential. Furthermore, variations in the rooting depth for different types of vegetation determine the maximum depth from which plants can remove water from soil. In addition to affecting recharge, these factors also determine the salinity of the recharging water where, in general, factors reducing recharge also result in more saline recharge. Results of studies illustrating this in the Murray Basin are well documented (Allison et al, 1990; Barnett, 1990; Kennett-Smith et al, 1994).

It is now generally accepted that recharge in the Murray Basin ·

- has been low in most areas as a result of a semi-arid environment and the presence of water use efficient, deep-rooting vegetation (mallee). ·
- has generally resulted in moderately to highly saline groundwater.·
- has increased greatly in areas cleared for pasture or grazing, particularly if these areas have sandy surface soils. This has resulted in the potential for further groundwater salinisation as saline soilwater is flushed into the groundwater.

The areas of the Little and Big Desert do not conform to these generalisations and, in order to understand why, it is important to consider the impact of palaeo-climate on factors affecting recharge.

Palaeoclimatic Changes During the Middle to Late Holocene

Palaeoclimatic reconstruction for a particular area relies predominantly on dating material from lakes in that area. Material found at higher levels on the lake bank is assumed to have been deposited during periods where lake levels were high and are associated with wetter periods (high ratio of precipitation : evapotranspiration). Conversely, material deposited lower in the profile is assumed to represent more arid climates. Changes in vegetation during this time are likewise suggested by relating pollen associated with different vegetation type to the dated material. As more data becomes available, regional changes in climate and vegetation are reconstructed from this proxy data. A palaeoclimatic summary using Australian data was made by Wasson and Donnelly ,(1991) presenting four time series of climate proxies for S-E Australia (2 from sites with extensive records in the Murray Basin and 2 summaries from a total of 33 sites in South Australia and Victoria) have been reproduced in this paper. Combining the results from these time series, two consistent temporal changes are seen·

- The predominant wet phase occurred prior to 25,000-30,000 years ago.·
- The last 20,000 years has been predominantly arid; except there is evidence for a shorter wet phase 4,000-8,000 years ago.

Humidity changes are often reflected by changes in vegetation . Little data is available for the period prior to 10,000 years ago but pollen data since then is available from studies at Lake Tyrell (Luly ,1990) This data suggested the area around Lake Tyrell was open woodland dominated by Casuarina and Cypress Pine from about 10,000 -6,500 years ago. The presence of Cypress Pine also supports rainfall considerably higher than present for this area as this species is found in 700+ mm/y rainfall areas. A strong Eucalypt signal was only found associated with material less than 4,000 years old. Hence, there is evidence for the presence of less water-use efficient vegetation during periods when rainfall is higher and the introduction of mallee type vegetation during arid times. If this vegetation/rainfall association is true for all of the S-E Murray Basin, then changes in climate would result in changes in vegetation. It is therefore imperative, when trying to manage groundwater in the S-E Murray Basin that we not only understand the recharge process now but also how it has varied over time.

Results

Chloride Data

All sites were cored through the entire unsaturated zone to the groundwater, the depth of which ranged considerably from 33 metres at site 9 to 68 metres at site 4. High chloride concentrations (up to 10,000-18,000 mg/L) can be seen throughout the unsaturated zone (Fig. 2) at most sites. Diffusion of soilwater chloride from the bottom 10 m of the unsaturated zone to the groundwater ($[Cl]_{gw}$ = 100-2,000 mg/L) can be seen at these sites. At sites 1, 2 and 4, however, the chloride concentrations are considerably less reaching maximum concentrations of 3,000-9,000 mg/L.

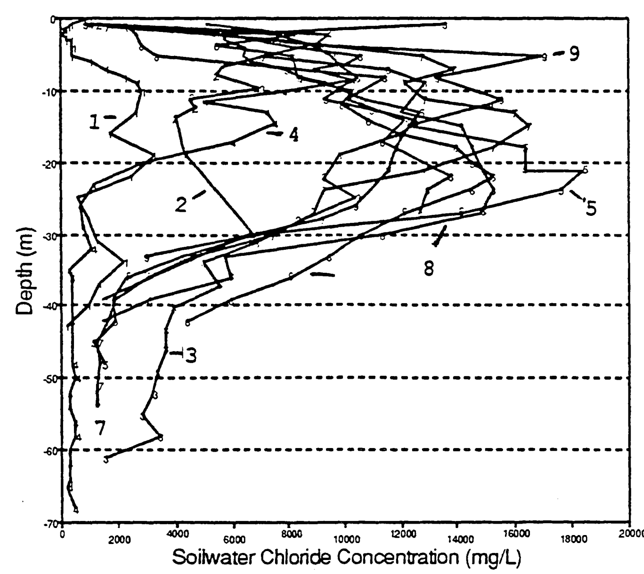

Fig. 2 Chloride Concentration of Soilwater vs Depth

At site 4 and to a lesser extent site 3, a large part of the unsaturated zone above the groundwater shows much lower salinities than the rest of the unsaturated zone. The zone of lower chloride zone is too extensive to be explained by diffusion with the groundwater and hence another explanation is necessary.

Another method of presenting this data is to plot cumulative water CW (mm) against cumulative chloride CC ($g.dm^{-2}$) for each site (Fig. 3). Cumulative water represents a parameter closely related to the total amount of recharge (to a particular depth) and is independent of water content and soil type. Cumulative chloride may be considered as an approximate proxy for time if one assumes a constant chloride flux in precipitation over time. Hence, steeper slopes for cumulative water plotted against cumulative chloride are indicative of high recharge while lower slopes represent periods when recharge rates were low. If climatological changes resulted in changes to recharge, the slope of cumulative water to cumulative recharge would also change.

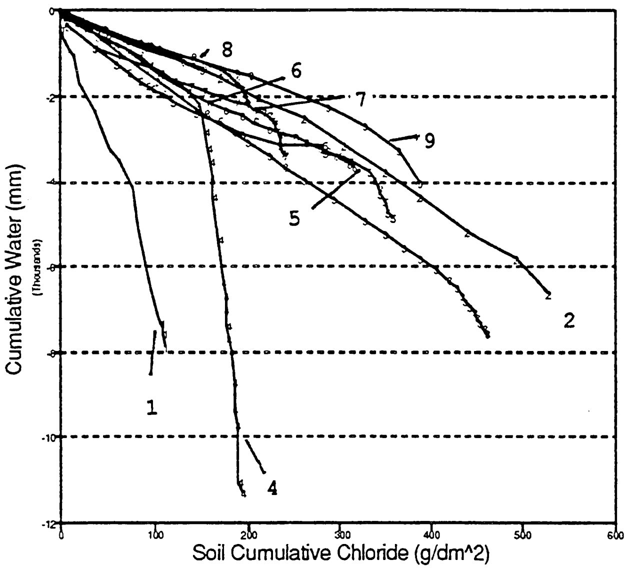

Fig. 3 Cumulative Water vs Cumulative Depth for Soilwater (All Sites)

For all sites except site 1 and the bottom of site 4, cumulative water vs cumulative chloride profiles display similar slopes with no break of slope to the water table. However, at site 1, the slope is much steeper and at site 4, there is a distinct break of slope. Interpretation of this data with respect to recharge is given in the discussion section.

Stable Isotope Data

Profiles for the deuterium and oxygen-18 composition of soilwater for the 2 sites indicate enriched composition of soilwater at site 2 compared to site 4 (Fig. 4 and 5). The deuterium composition of soilwater at site 2 is reasonably consistent except for the interval CW = 5,000-6,000 mm where an enriched peak can be seen. At site 4, the most depleted values are at CW > 7,000 mm. Deuterium compositions are similar at both sites near the surface although there is a lot of scatter for this data at site 4.

Profiles for oxygen-18 are similar to deuterium at both sites with the following exceptions: there are local minima values for oxygen-18 at CW = 4,900 and 8,000 mm and there is a tendency for oxygen-18 composition to decrease throughout the complete profile rather than just near the bottom as seen for the deuterium profile.

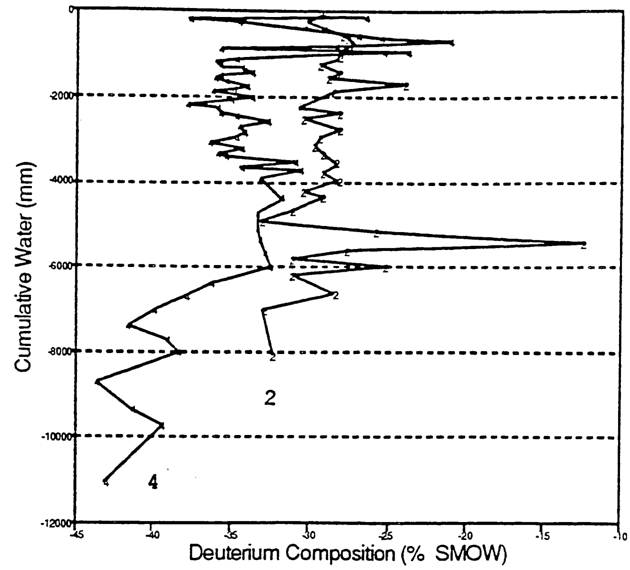

Fig. 4 Cumulative Water vs Deuterium Composition of Soilwater (Sites 2 and 4)

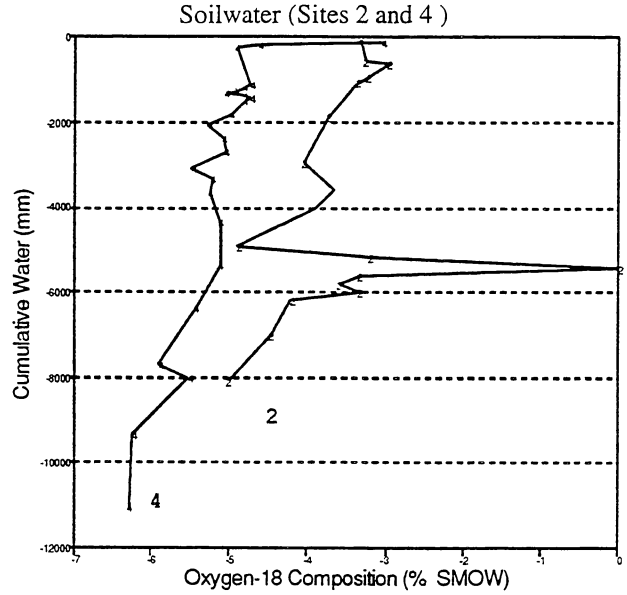

Fig. 5 Cumulative Water vs Oxygen-18 Composition of Soilwater (Sites 2 and 4)

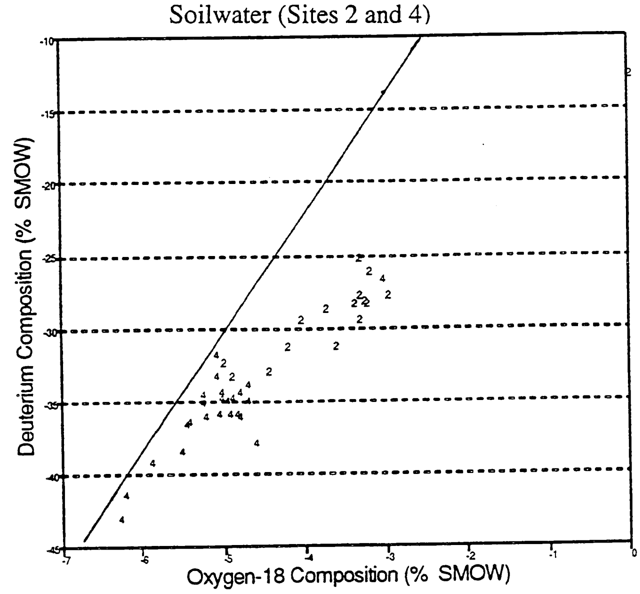

Fig. 6 Deuterium vs Oxygen-18 Composition for Soilwater (Sites 2 and 4).

When plotted in deuterium vs oxygen-18 space, it is clear that the isotopic composition of soilwater at site 4 is depleted in both isotopes and closer to the World Meteoric Water Line (WMWL) compared to that for site 4 (Fig. 6).

Percentage Clay Content

Analyses for clay content were made for the top 2-3 m as the relationship between clay content for that interval and recharge has been shown to give the best correlation (Kennett-Smith et al. 1994). Clay contents range from 1-67 % (Fig. 7). Only sites 1 and 8 have clay contents <10% for that depth interval despite many of the sites being chosen in desert areas

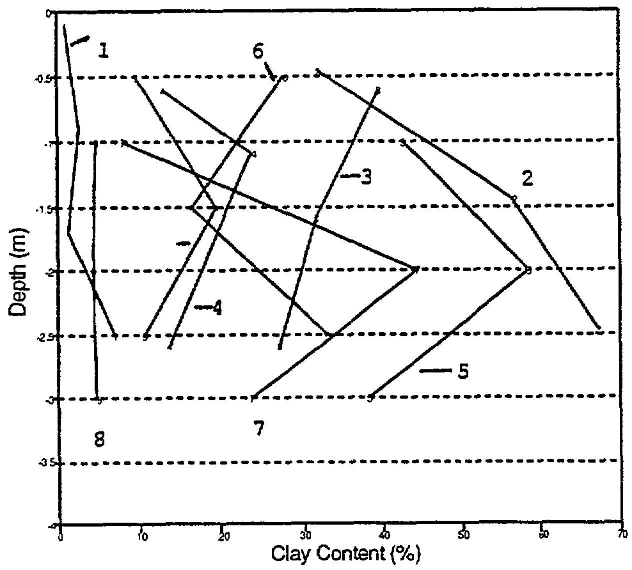

Fig. 7 Clay Content for the Top Three Metres of Soil (All Sites)

Discussion

Factors Affecting Recharge; Past and Present

Estimates of recharge rate can be made at each site by multiplying the slope of the CW vs CC profile (mm.dm^2.g(Cl)$^{-1}$) by the mean chloride input (g.(Cl).dm^{-2}.y^{-1}). Where there is a change in slope, estimates of recharge rate can be made for different CW intervals corresponding to different time periods and inferring different climatological conditions. As no data is available for temporal changes in chloride, we have used present day values for chloride input.

The greatest limitation to this method of recharge estimation results when salt concentration build up in the unsaturated zone during a period of low recharge and are then leached to greater depths in the profile when climate changes result in much higher recharge. It is necessary to flush several pore volumes of water through the soil before the chloride concentration of the soilwater is an accurate proxy for recharge. Hence, where slopes are high (site 1 and bottom of site 4) recharge estimations using this method should be considered minimum values and recharge rates may be considerably higher (Cook 1992).

Current recharge rate estimates for the S-W Murray Basin are < 0.3 mm/y for most sites except site 1 where higher precipitation and sandy surface soils have increased this at least 5 fold (Fig 8). The highest recharge rate is seen at site 4 and corresponds to the most recent wet period 4,000-8,000 years ago (Leaney et al. 1994). Recharge at site 1 would presumably been extremely high during this time but recharge water from this period has already recharged the aquifer and hence is not evident in the unsaturated zone profile. Rainfall greater than 500 mm/y, and sandy surface soils with mean clay content < 5%, are required before significant recharge is likely under mallee-type vegetation.

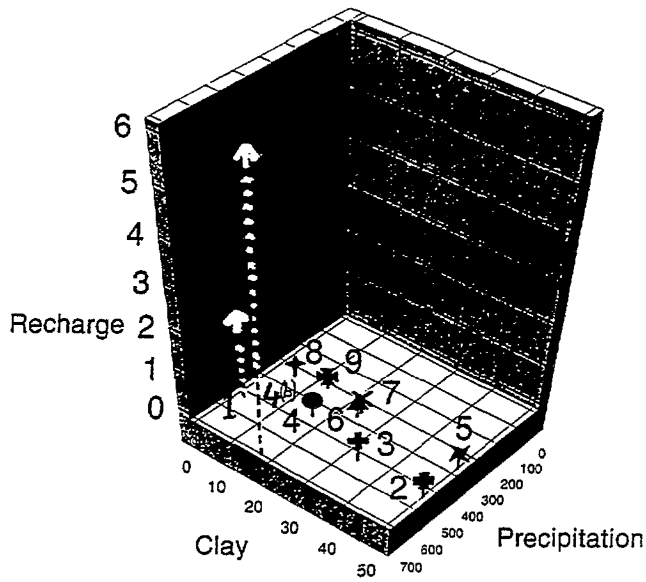

Fig. 8 Recharge Rate Estimates as a Function of Rainfall and Surface Clay Content (All Sites).

It is difficult to determine whether the increase in recharge during the most recent wet phase at site 4 is the result of increased rainfall or a change to shallower rooting vegetation. There is little evidence for higher palaeo-recharge for sites further north despite sites 8 and 9 having very sandy surface soils. Perhaps, this suggests that vegetation type may be the greatest determinant to recharge and that, during wetter climatological periods, the boundary for mallee-type vegetation may have migrated northward. The replacement of mallee-type vegetation with grassland, Casuarina and Cypress Pine in areas where rainfall exceeds 700 mm/y and the association of this shallower rooting vegetation in the Lake Tyrell environs during the most recent wet (Luly 1990) gives support to this hypothesis. Further evidence can be found with studies showing increased recharge after clearing of natural vegetation (Allison et al. 1990, Barnett 1990).

Evidence for palaeoclimatological wet and dry periods from changes in the isotopic composition of soilwater.

Soilwater isotopic data is available at sites 2 and 4. Assuming present day chloride input of 0.024 and 0.022 at sites 2 and 4 respectively, the accumulated chloride in the unsaturated zone would have taken 22,000 years at site 2 and about 9,000 years at site 4. There is clearly evidence of a faster rate of recharge at site 4 prior to about 6,000-7,000 years ago and a much slower recharge rate since then. The isotopic data for the 2 profiles reflect a greater recharge rate at site 4 with the isotopic composition of the soilwater depleted and nearer the WMWL compared to site 2. The isotopic composition of rainfall plots close to the WMWL and is enriched to the right as a result of evaporation during or prior to recharge.

When plotted against CW, the deuterium and oxygen-18 compositions are enriched only in the top 1,000 mm (4,000-5,000 years) reflecting only minimal recharge and an arid climate similar to the present. Below that point, the soilwater maintains a depleted signature indicating recharge during a wetter phase. There is evidence for even higher recharge rates for CW > 6,000 mm from the even more depleted signature of the soilwater.

The isotopic composition of the soilwater at site 2 shows little evidence of periods where recharge rates may have been higher but does show an enriched isotopic signal at about CW = 5,000 -6,000 mm (~20,000 years ago). This time period lies between the 2 most recent wet periods and may represent a time of extreme aridity. For much of Australia, this time was seen to be the driest period in the Holocene with rainfall in many areas 30-50 % of current mean annual precipitation (Wasson and Donelly 1991).

It should be noted that diffusion within the unsaturated zone is likely to dampen many of the chloride and stable isotope peaks and alter the profiles. As the diffusion constants for chloride and the stable isotopes of water are different, it is unlikely that the results from these will be entirely consistent (Wang et al. 1952). .However, interpretation of trends using both chloride and stable isotopes should help substantiate the interpretation using either of these independently.

Conclusions

Recharge rate for the S-W Murray Basin is correlated to rainfall rate, surface soil and type of vegetation cover. Under the current climatical conditions and where mallee-type vegetation dominates, significant amounts of recharge are only possible in limited areas where rainfall is greater than 500 mm/y and surface soils have less than 10 % clay content.

However, it is likely that, under previous wetter phases, recharge rates were high for much of the Big and Little Deserts. Recharge during wetter phases in these areas has resulted in the fresher groundwater resource in the S-W Murray Basin. It is not possible to determine with the available data, whether changes in vegetation type as a result of a wetter climate or merely the wetter climate itself had the greatest impact on recharge rates in this area.

Results from the isotopic composition of soilwater supports different rates of recharge at sites with similar rainfall but different surface soil types and also provide evidence of temporal changes in the aridity and recharge at each site.

Recharge to groundwater in the S-W Murray Basin is characterised by large changes over time scales 10^3 to 10^5 years. Lengthy periods of steady-state where little or no recharge occurs are established by deep-rooted vegetation in a semi-arid environment. These "equilibria" are punctuated by limited periods in time and space where, as a result of climate change and the response of vegetation to that change, recharge in some parts of the Basin increases considerably.

Recently, as a result of land clearing, man has induced a further change in the recharge regime of the Basin. We can envisage similar changes to the groundwater salinity as seen for palaeoclimatic change and eventually a fresher groundwater resource will result. However, the more immediate phase when groundwater in fact becomes more saline is of concern to managers who do not have the luxury of planning on a geological time frame.

Acknowledgements

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Groundwater Interception from a Multi Well Point Scheme Using Air Lift Pumping

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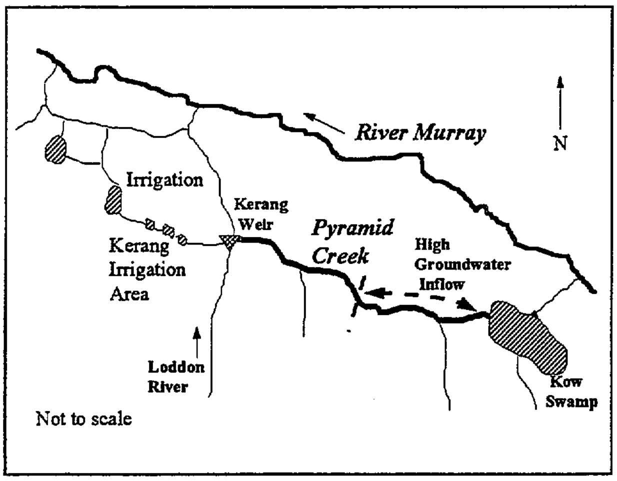
1. INTRODUCTION

The Pyramid Creek Groundwater Interception Scheme will intercept highly saline groundwater inflows along 13 km of the creek. Pyramid Creek is an enlarged natural stream that is now used as a major irrigation carrier from Kow Swamp to the Kerang and Swan Hill Irrigation Districts, a distance of approximately 60 km. Typical flows in the creek are 1,200 ML/day during the irrigation season reducing to 100 ML/day in the winter months. Some of the water that passes down the creek that is not diverted for irrigation eventually outfalls to the River Murray.

Figure 1: Locality plan of the study area.



Approximately 50,000 tonnes of salt enters Pyramid Creek each year from highly saline regional groundwater discharge. The distribution of groundwater inflow is non uniform, with approximately 50% of the salt inflow occurring in the upper 13 km of the creek. This is a result of the creek bed being more deeply incised and thus having higher hydraulic gradients, combined with higher permeability soils than those in downstream areas.

The aim of the interception scheme is to reduce the groundwater inflow in the upper section of the creek, reducing the salt input by 20,000 tonnes of salt per year. It is proposed to intercept the saline groundwater along both sides of the upper 13 km reach of the creek, using groundwater pumping to lower the groundwater levels and reduce or eliminate the hydraulic gradient into the creek.

Agricultural productivity and the high environmental value associated with many of the wetlands in the area, some of which have international significance, are suffering severely from the effects of salinity. Reducing the groundwater induced salt load along Pyramid Creek by 20,000 tonnes per year would result in an increase in the gross margin for the Kerang and Swan Hill areas of $390,000 per year.

There would also be significant benefits to the salinity in the River Murray. The salt load passing through the Kerang system would be reduced by 16,000 tonnes per year. This would generate an economic benefit to the users of River Murray water, in particular the urban population of Adelaide, of approximately $340,000 per year.

Taking into account these benefits, and first order estimates of capital and ongoing costs of interception and disposal, the scheme is estimated to have a benefit cost ratio of 2.6 and a Net Present Value of $8.64 Million.

2. GROUNDWATER INFLOW

The aquifer of interest in the study area is known as the Shepparton Formation. In this region it is approximately 80 metres thick and consists of clay and silts and thin fluvial beds of sand. These sand layers take the form of discontinuous sand lenses, commonly referred to as shoestring sands formed from prior streams. The variable nature of the sand lenses results in an aquifer system that is neither isotropic or homogeneous. From groundwater pumping tests the hydraulic conductivity of the Shepparton Formation is estimated to be in the order of 0.5 m/day, while the transmissivity over a 1 km reach determined from short term pumping tests varied between 20 and 200 m^3/day.

Pyramid Creek is approximately 3 metres deep and 15 metres across. Being incised into a landscape with high watertables, the creek acts as a drain for groundwater, resulting in a lowering of the watertable in the vicinity of the creek. Groundwater inflow to the creek occurs on both sides of the creek.

However, the general groundwater response, particularly back from the creek, is not greatly tied to the creek level. Creek levels vary by about 1.5 metres between the irrigation and non irrigation seasons. In general the watertable in the area adjacent to the upper reaches of the creek is between 1.5 to 2 metres below natural surface. A seasonal fluctuation in general groundwater level occurs away from the creek, rising in winter and falling in summer, in general, in response to evaporative potential. This seasonal fluctuation is in the order of 0.5 metres.

Monitoring of observation bores has shown that groundwater levels remain 0.5 to 2.5 metres above creek level, creating a permanent hydraulic gradient towards the creek.

The factors that drive the high watertables and the seasonal fluctuations in this area include both local and distant changes to the water balance. In particular, recharge to the groundwater systems at both local and regional scales has increased due to a combination of land clearing and hence less plant water use in up-basin dryland areas and the application of irrigation water, which is generally in excess of crop requirements, in the Kerang area. While these processes can be addressed by looking at the causes, they are occurring on such a large scale that solutions which involve reducing recharge are not technically feasible or economically viable options for reducing salt loads to Pyramid Creek.

The variable nature of the aquifer system suggests it is highly likely that groundwater inflow is not uniform either in length along the creek or vertically through any cross section. Salinity traverses along the creek have identified several point sources of very high salt inflows, suggesting considerable variability in the degree of direct intersection with saline sand lenses. There is also some evidence that during dredging of the creek in the late 1960's some major sand aquifers were intersected. On this basis it can be assumed that both horizontal and vertical groundwater flow paths to the creek exist.

3. GROUNDWATER CONTROL OPTIONS

There are a number of possible options to reduce the problems associated with the salt inflow to Pyramid Creek.

These involve reducing the volume of groundwater that reaches the creek while maintaining it as an irrigation supply channel. Two broad mechanisms exist for reducing groundwater induced salt loads to the creek:

(i) Provide a barrier to groundwater inflow to the creek.

This can be achieved by:

- raising the water level in the creek, by constructing a series of weirs along the creek to raise the creek water level to above the maximum groundwater level, or at least to the average groundwater level, or,
- by using impermeable lining on the bed of the creek.

(ii) Lower the groundwater level near the creek.

Some form of sub-surface drainage can be utilised to induce hydraulic gradients away from the creek by lowering the groundwater near the creek (eg. tile drainage or groundwater pumping).

There are a number of critical factors to be considered in the evaluation of the interception options. They are the capital and operating costs; magnitude of downstream benefits; technical feasibility; and environmental impacts.

Impermeable lining was discounted due to two factors:

- the prevention of lateral groundwater flow would induce increased groundwater levels behind the barrier, resulting in salinisation of the surrounding land.
- Clay lining costs in the order of $\$10/m^2$, equivalent to \$200,000 per km of the creek, would be prohibitive.

The use of **weirs along the creek**, by raising the water level in the creek would reduce the groundwater inflow gradients. While the costs are relatively low, the weirs could not be used in the high flow irrigation season as any significant increase in creek water levels during this period would result in flows overtopping the banks.

The **sub-surface drainage** option involves removal of groundwater along a line parallel and close to the creek. This would lower groundwater levels and reduce or eliminate the hydraulic gradient into the creek. It is possible this option would be beneficial to the land adjacent to the creek.

While possibly benefiting the surrounding land, this option involves the generation of water and an associated salt load requiring disposal. As the groundwater is extremely saline, disposal options are limited to use of basins, possibly combined with dumping to the River Murray at times of very high river flow. Disposal basins primarily rely on evaporation for ongoing removal of water, although often include seepage back to the groundwater system for further removal of water as well as salt. In any disposal option involving basin seepage, either naturally or by design, the impacts of seepage require comprehensive assessment to ensure control of any off site effects. Several basin disposal options exist for the Pyramid Creek scheme, including local basins, a more remote but existing basin with spare capacity, and combinations of holding basins with River Murray dumping. Detailed groundwater modelling for potential disposal sites is proposed.

There are two main forms of sub-surface drainage: shallow tile drainage and groundwater pumping.

While shallow tile drains would lower groundwater levels, it is likely these drains would not fully intercept groundwater due the presence of deeper groundwater flow paths, in particular at sections where the creek bed intersects a major sand layer which is connected directly to the creek via upward hydraulic gradients. Also the shallow stratigraphy is dominated by clays and silty clays of low hydraulic conductivity. Hence low interception volumes may result, reducing the effectiveness of the drains.

The second form of sub-surface drainage is groundwater pumping. Pumping of deep bores to 30 metres on both sides of the creek would create a line of groundwater interception. The volumes pumped and the spacing between the bores are designed using aquifer properties related to groundwater flow and the criteria of maintaining a upper limit on groundwater level between the bores which is close to creek water level.

While a pumping scheme can be operated all year round, the drawdowns required in winter, for much smaller downstream benefits, are much greater than in the summer irrigation season. Greater drawdown equates to increased pumping and cost. Hence a system combining both groundwater pumping and low level weirs may be cost effective.

The relatively low aquifer transmissivities at Pyramid Creek eliminate tubewells or single bore pumping systems due to low aquifer yields and hence limited extent of significant groundwater control, in this case less than 200 metres. The high cost per installation generally limits single bore pumps to areas where effective watertable control can be established with spacings extending to greater than say, 1000 metres.

Optimum bore spacing at Pyramid Creek is generally 200 metres. The spacings were established using the Theis equation for confined, non steady state groundwater flow (Kruseman et. al., 1983). A simple model was used to incorporate the interference effects of pumping from neighbouring bores.

There are also high costs and risks associated with conventional well point systems. Groundwater pumping based on suction is limited by the suction capacity of the pump, usually about 7 metres on a sustainable basis, and by the length of the suction line, which often can experience air entrapment resulting in loss of prime. This leads to a need for a greater number of individual well point systems to obtain effective groundwater control, increasing the cost substantially.

Airlift pumping eliminates these concerns and offers further cost and operational advantages. The airlift system is based on:

- compressors located close to the power source,
- use of low cost air lines to each pumping bore,
- individual air flow control mechanisms for each bore to optimise the interaction between air flow, groundwater flow and drawdown for the total system, and
- discharge pipelines.

Airlift pumping is specifically suited to sites where power is remote from the site, eliminating the very high costs of extending electricity lines, where flow is likely to be low, where flow control is required at each bore, and in corrosive and erosive groundwater environments. All of these conditions exist at Pyramid Creek.

4. AIR LIFT DESIGN FEATURES

4.1 Design features

Airlift pumping has been in use in a variety of applications for almost 200 years, but until relatively recently was not favoured because of its generally low efficiency compared to conventional pumps. The method is currently enjoying an increase in popularity for many of the reasons that it was proposed for the Pyramid Creek Interception Scheme.

The particular features of airlift pumping which support its use in this case are its simplicity, low capital cost, resistance to corrosive and erosive fluids, easy restart after power failure, and control of flow from each bore. In other industries it is being chosen for pumping of corrosive, erosive, toxic or radioactive fluids and slurries, because of the absence of moving parts in the fluid and the ability to construct the exposed parts of virtually any material capable of resisting the particular fluid.

As the groundwater in this area is highly saline and contains substantial concentrations of iron - both factors which significantly increase both the capital and the operating costs of conventional pumps - airlift pumping is an appropriate choice. The higher operating costs resulting from the lower efficiency is the price which must be paid for the other advantages of airlift pumps.

In addition to its simplicity of construction and its resistance to corrosion and wear, as described above, the airlift system also has other strengths. It requires no priming or other special starting method and so will resume pumping as soon as power is restored after an interruption. The compressor - typically electric powered - can be located remote from the well or wells and the air conveyed to the pump sites via relatively inexpensive air lines. This is much cheaper than supplying electric power to every site in a system.

4.2 Design basics.

The basic design parameters for an airlift pump are not dissimilar to those for a conventional well pump design. It is necessary to define the flow rate, the static aquifer level and the drawdown level at rated flow, the total lift required, the size of the bore casing and the elevation of the bore screens.

The design water flow is the prime determinant of the air quantity required, although the actual air flow required can be optimised by correct setting of the air diffuser below the drawdown level in the bore. This setting is called the submergence, and can adversely affect the efficiency of an airlift pump when installed into an existing bore. The inability of setting the diffuser deeply enough in proportion to the total lift in an existing bore will mean that, while the airlift pump will still function, more air is required to lift the same quantity of water. In the case of Pyramid Creek, the aquifer is quite shallow, and optimum submergence can be achieved with bores of less than 30 metres depth. In high lift bores the extra depth of bores to allow optimum airlift pumping may affect the economic viability of the system.

In established literature, a ratio of air flow to water flow of approximately 1.8 to 1 has been considered good for a low lift airlift pump, with the ratio increasing with increasing lift and decreasing submergence. However, tests carried out by the State Rivers and Water Supply Commission on a typical groundwater control bore in 1981 produced ratios better than that, averaging 1.24 with a low of 0.98 in one series of ten trials. Better design and setting of the diffuser and air controls is expected to improve on these figures, thus improving system energy efficiency.

The mechanism by which the introduction of air lifts the water has been the subject of several researchers. Laboratory evidence suggests that best efficiency is obtained by creating a mass of fine bubbles which 'froth' the water and cause it to rise uniformly due to the reduced density of the mixture. Larger bubbles tend to coalesce into slugs of air which tend to act as pistons, completely blocking the riser pipe and lifting the water in slugs. This mode of operation tends to be less efficient, partly due to the tendency of water to slip back past the air 'piston' as the large bubbles rise. This leads to a diffuser design which uses a large number of small diameter holes to generate a fine bubble froth of air in the water.

In detail design and construction there needs to be a recognition of the presence of water vapour in the air and on condensation, its potential to block air lines or valves.

4.3 System control.

As the air required at a given bore will vary with the bore yield and - to a lesser extent - with the lift required and submergence available, it is necessary to control the air flow at the bore. This is essential when several bores are being pumped from a single compressor station, as is the case at the Pyramid Creek Scheme. The air control system consists of an isolating valve to allow a bore to be turned off without disabling the rest of the system, a pressure regulator to allow the pressure to be limited to the minimum necessary to deliver air to the diffuser, and a control valve to allow adjusting of the air flow rate to optimise the efficiency. Control at the compressor station is limited to maintaining the system pressure above the minimum needed to supply the required flow rate throughout the system. This is usually achieved by using the pressure switches supplied with the compressor, although it may be necessary to stagger the starting of multiple compressors to reduce starting loads on the electrical supply system.

Hence, there are three critical pressure settings: at each bore the pressure is regulated to enable the air to get to the bottom of the bore, flow through the diffuser and overcome the back pressure from the water column above: at the air storage tank at the compressor the minimum pressure is set to meet the maximum pressure required at the bores, plus an allowance for losses along the air line: at the compressor the maximum pressure is limited by the design and construction of the compressor.

4.4 Compressor selection.

Correct compressor selection is particularly important, as it can affect the reliability of the pumping system as well as the operating costs - both energy and maintenance. Two types of compressors are generally used for the airlift application, reciprocating air (piston) compressors and rotary (helical) screw compressors. Reciprocating air compressors are not designed to run under load continuously, particularly the smaller units which may seem attractive for use on small 'low-cost' schemes. Long term high duty cycle operation of reciprocating air compressors will significantly shorten their life, requiring excessive maintenance and replacement of parts to keep them operational. The compressor capacity and air receiver volume should be selected together in relation to the total system air demand, to optimise the duty cycle, motor starting frequency and system cost.

At Pyramid Creek, cheap (short life-span) reciprocating compressors are being used for the initial pilot scheme to prove the value of the interception principle in this application. In the full scheme the compressor station or stations will be much larger and probably located elsewhere, at which time industrial quality rotary screw compressors will be selected.

5. PILOT SCHEME

As an input to the investigation and design process, a pilot groundwater interception system has been constructed over a 1.2 km reach. A total of 13 bores have been constructed, 6 on the northern side of the creek and 7 on the southern side. The bores are 200 metres apart, with bores on one side of the creek offset by 100 metres from those on the other side.

The pilot scheme has been run for two periods of three months, providing valuable information to increase the understanding of salt interception, the volumes of water generated for disposal, and the total project costs and benefits.

The pilot scheme has been constructed with air supply from one side of the creek only, with air lines running across the bed of the creek.

The discharge per bore to achieve drawdown in groundwater level to below the summer creek running levels is approximately 0.5 L/s. The corresponding flows in winter are significantly higher at approximately 1 L/s. The total summer and winter system flows over the 1.2 km pilot scheme are 7 L/s and 14 L/s respectively, or 0.6 ML/day and 1.2 ML/day.

The set up costs for the pilot scheme, including bore construction, airlift components, temporary disposal line, and monitoring requirements, were $80,000. The major proportion of the works for the pilot scheme will be used in the full scheme.

The typical air:water ratio achieved for the pilot scheme was 1.8:1 which corresponded to an electric power running cost of $21/ML for 24 hour, 7 day pumping.

Total flow generated for the full scheme is expected to be in the order of 1,000 ML per year. While the final form of groundwater control along the full length of the scheme and the disposal system is uncertain, capital costs are likely to be in the order of $4.5 million.

6. CONCLUSIONS

Highly saline groundwater inflows to Pyramid Creek result in considerable economic losses in downstream irrigation areas and urban and industrial centres. An assessment of salinity control schemes has been carried out, identifying groundwater interception as the likely preferred option. Inputs to this assessment include local and regional hydrogeological conditions, technical feasibility, environmental impacts, particularly from changes to local groundwater conditions, and costs and benefits.

The local hydrogeology points to a need for groundwater pumping as against shallow sub-surface drainage. However, the relatively low yielding aquifers, together with the requirement for a very long line of interception, 13 km, parallel to and on both sides of the creek, limits the application of conventional pumping systems, primarily due to very high costs.

Airlift pumping eliminates a number of the concerns with conventional pumping for this project. In particular, its simplicity, low capital cost, resistance to corrosive and erosive fluids and easy restart after power failure support its use at Pyramid Creek.

The compressor - typically electric powered - can be located remote from the wells and the air conveyed to the pump sites via relatively inexpensive air lines. This is much cheaper than supplying electric power to every site in a system. In a multiple well system such as Pyramid Creek, pressure regulation and air flow control at each bore allows for optimisation of water flow and drawdown to match the variable aquifer characteristics.

7. ACKNOWLEDGMENTS

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Valuable technical inputs to the study have been provided by the following staff within Sinclair Knight Merz: G. Foley, M. Budahazy, M. Kenna.

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Effect of Reafforestation on Stream Flows, Salinities and Groundwater levels in the Pine Creek Catchment

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1. INTRODUCTION

Pine Creek, a tributary of Sunday Creek and part of the Goulburn River system, lies between Kilmore and Broadford in southern central Victoria. Pine Creek drains a catchment area of 3.2 km^2 (320 ha), virtually all of which is contained within "Glenburnie", a property owned and managed by Smorgon Forests, part of the Smorgon group of companies.

Pine Creek has been monitored by the Rural Water Corporation (RWC) since 1988, with the aim of detecting and quantifying significant changes to the hydrological process within the catchment, resulting from a program of reforestation across Glenburnie, initiated by Smorgon Forests in 1986. This paper presents the findings of analysis of flow, salinity and groundwater data for the Pine Creek Catchment

2. DESCRIPTION OF THE CATCHMENT

The Pine Creek catchment is defined by a series of hills surrounding the small valley. There is significant change in elevation across the catchment, from a maximum of approximately 400 m in the south to around 250 m at the creek's northern outlet over a straight-line distance of almost 3000 m. The catchment originally consisted of open grassland and was subject to severe degradation (eg. soil erosion). Land salinisation was not a significant problem.

The program to reforest Glenburnie (and the Pine Creek catchment) commenced in 1986, with the planting of 202.6 ha of *pinus radiata,* predominantly on the eastern half of the property. The program continued through 1987 and 1988, with a further planting of 250.9 ha and 6.1 ha of *pinus radiata*, respectively. The plantations have been successful, with the majority of pines becoming established and growing to heights of 3-5 m. In December 1987, it was observed that approximately 2.5 ha of plantation had failed and these were predominantly on hill sides to the south of the property. The pine plantations are surrounded by grassland, and are joined by native vegetation such as eucalypts along major waterways.

The main stream line of Pine Creek flows northward along the central corridor of the catchment. It is approximately 3-5 m wide, and generally 1.2 m below natural surface level, but this varies along its length. Various reaches of the creek have been subject to quite severe erosion, and areas of alternate scour and deposition can be observed. The channel bed is typically formed from exposed shale, and consists of gravel and clay deposits in several locations. There is evidence of groundwater intrusions to the creek close to the catchment outfall.

Pine Creek has two main tributary branches to the main stem. Each branch is lined by native forest growth. Some flow towards Pine Creek passes through three small dams, estimated to have capacity of approximately 1 ML, 1 ML and 5 ML, respectively. None of the dams are thought to cause significant impedance to runoff entering Pine Creek, with each having little usage apart from stock and wildlife watering and firefighting purposes.

3. DATA AVAILABILITY

A monitoring site for the catchment was established approximately 15 m south of the northern boundary of Glenburnie, and has been identified as Station 405290A, Pine Creek at Broadford. The monitoring equipment employed at Pine Creek consists of a float for measurement of stage, a probe to record electrical conductivity as a measure of stream salinity, and an automatic rain gauge, with the continuously recorded data stored on an electronic logger. Flow at the monitoring site is controlled by a V-notch weir, which is used to calculate discharge in collaboration with ratings provided by the Hydrographic staff that maintain the measurement equipment.

The continuous monitoring equipment used at Pine Creek was installed during the second half of 1988, commencing operation on 20 September. The equipment has been used to provide a continuous record of stream flow, salinity (in terms of electrical conductivity (EC) units in µS/cm at 25°C) and rainfall.

A chart recorder is installed at the monitoring site as a back-up to the electronic recorder. Information provided by the chart recorder has been used to infill missing flow records, and apart from a twelve day missing period, a complete data record is available for flow.

Groundwater data for the Pine Creek catchment is available for two bores maintained by the Department of Conservation and Natural Resources, Broadford. One bore (D1) is located at the groundwater discharge area of the lower catchment and the second bore (D2) is located within the recharge area of the upper catchment.

Bore readings measuring groundwater level and groundwater salinity were taken infrequently until early 1990. Since then readings have become more frequent, improving the accuracy of interpreting changing trends in groundwater and salinity levels. Approximately 15 m difference in groundwater levels exists between D1 and D2 and there is approximately 1000-3000 EC difference in salinity levels between the bores. The bore which is located in the upper catchment (D2) has the higher groundwater level and the lower salinity.

4. DISCUSSION OF RESULTS

4.1 Stream Flow

Pine Creek displays a distinct seasonal pattern, with much of its annual flow occurring through the wetter months of winter and early spring. Conversely, the creek has extremely low flows during summer and autumn months, and has ceased to flow on several occasions.

Comparison of flow data with rainfall events, reveals that flow in Pine Creek is predominantly influenced by rainfall events, with most larger flows and flushes occurring shortly after significant rainfall. However, there is some evidence that the magnitude of the flushes diminishes over the period of record. This trend is supported by the annual flow volumes shown in Table 1, which indicates that the flows have decreased considerably from approximately 690 ML in 1989 to 240 ML in 1993. The data also shows that this decrease in flow occurs with little change in the annual rainfall which varies from 865 mm/yr in 1989 to 914 mm/yr in 1993.

Table 1: Annual Stream Flow, Rainfall and Salt load - Pine Creek (405290A)

	1989	1990	1991	1992	1993
Flow (ML/yr)	687	263	163	308	239
Salt Load (t/yr)	153	119	92	93	41
Rainfall (mm/yr)	865	643	647	857	914

Note: Catchment Area = 3.2 km^2

The downward trend in outflows from the Pine Creek catchment is not evident in flows at two nearby catchments; Sunday Creek at Tallarook (Table 2) and Mollison Creek at Pyalong (Table 3). The preliminary analysis of these adjacent catchments indicates that flow, rainfall and salt load have varied only with seasonal influences rather than catchment changes.

Table 2: Annual Stream Flow, Rainfall and Salt load - Sunday Creek (405212D)

	1989	1990	1991	1992	1993
Flow (ML/yr)	73264	35034	25080	63110	66262
Salt Load (t/yr)	12822	9871	7979	14395	16685
Rainfall (mm/yr)	591	479	560	804	839

Note: Catchment Area = 337 km^2

Table 3: Annual Stream Flow, Rainfall and Salt load - Mollison Creek (405238A)

	1989	1990	1991	1992	1993
Flow (ML/yr)	33052	16376	18567	43507	39496
Salt Load (t/yr)	4588	2818	2872	5522	5024
Rainfall (mm/yr)	852	525	604	793	785

Note: Catchment Area = 163 km^2

It has been hypothesised that the flow reductions in Pine Creek have resulted from the continued growth of the pine plantations across Glenburnie. This hypothesis gains added support from an inspection of cumulative flow plotted against cumulative rainfall (see figure 1). The curve displays a stepped nature related to Pine Creek's seasonal flow characteristics, however the amount of flow volume resulting from rainfall has steadily decreased.

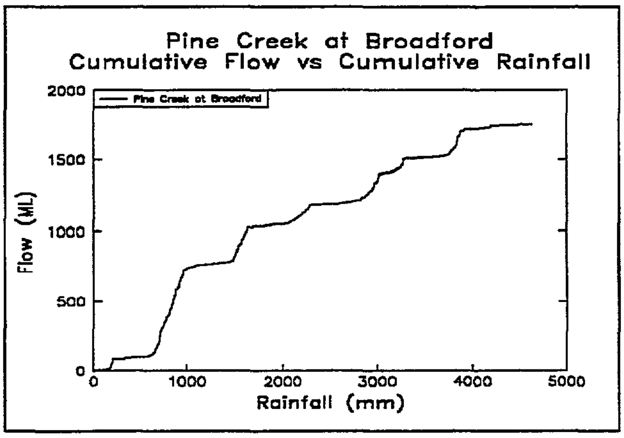

Figure 1 Pine Creek Cumulative Flow vs Cumulative rainfall

A comparison of the cumulative flow per unit catchment area between Pine Creek, Sunday Creek and Mollison Creek (Figure 2), reinforces the idea that the flow in Pine Creek is changing in response to the growth of the pine plantations and not due to some regional factor. Both Sunday Creek and Mollison Creek are much larger catchments than Pine Creek (337 km^2 and 163 km^2 compared with 3.2 km^2) with a stable mixture of land use (forest and grazing). The cumulative flow curves for Station 405212 (Sunday Creek at Tallarook) and Station 405238 (Mollison Creek at Pyalong) show a similar increase in the flow from one year to the next, while the yield from Pine Creek gradually decreases.

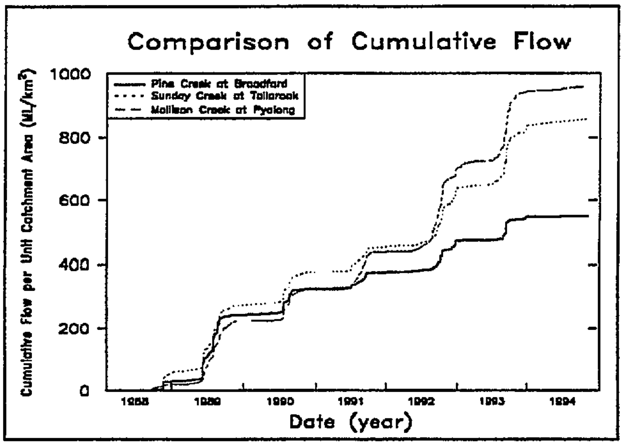

Figure 2 Comparison of Cumulative flow per Unit Catchment Area For Pine, Sunday and Mollison Creeks

Further assessment of the trends in flows in Pine Creek has been carried out using Double Mass Curves between Pine Creek and adjacent monitoring sites on Sunday, and Mollison Creek. The Double Mass Curve for flow is a plot of cumulative flow at one site against cumulative flow at another site.

From the Double Mass Curve between Pine and Sunday Creek, it is evident that approximately half way along the curve (representing the period of 1991), accumulated flow in Pine Creek catchment begins to decrease, evidenced by the change in slope of the curve. This deviation in slope can also be identified in the Double Mass Curve for Pine Creek versus Mollison Creek (see Figure 3). The flow in Mollison Creek is more representative of the rainfall-runoff process than Sunday Creek as there are no major diversions occurring upstream of the Mollison Creek gauging station as there are for Sunday Creek. Any significant trends in Pine Creek flow will therefore be more easily identified on the Mollison Creek versus Pine Creek plot.

The change in slope in the cumulative flow for Pine Creek occurs approximately a third of the way into the study period which is between 1990 and 1991. This suggests that it has taken the pine plantation approximately 4-5 years to reach a level of maturity where it can have a significant impact on the amount of stream flow.

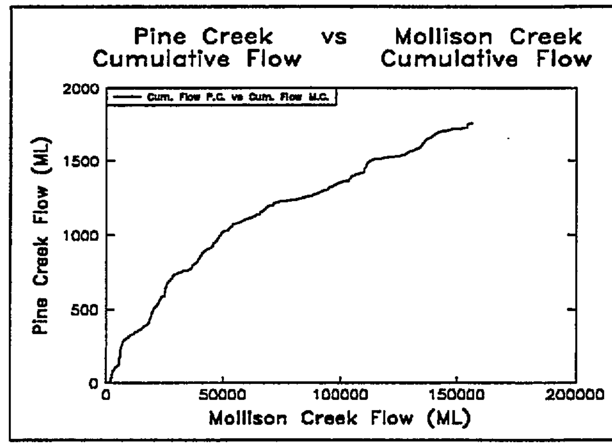

Figure 3 Double Mass Curve - Pine Creek vs Mollison Creek

4.2 Salinity and Salt Load

From the data available for salinity in Pine Creek, it is apparent that salinity levels experience seasonal variation. Stream salinities increase during the drier summer months as flow recedes, but fall considerably during the increased flows of winter and spring. Salinity levels exceed 10,000 EC at times through summer, and may fall to levels as low as 20 EC following flushing flows. Salinity levels also appear to be highly responsive to changes in flow regimes, with the rising arm of a flush frequently producing a sudden drop in salinity.

It appears that long term salinity levels are decreasing with time, with all seasonal readings decreasing irrespective of the diminishing flow. A comparison of a frequency plot of salinity levels in Pine Creek for the years 1989 and 1992 (years of similar rainfall) showed that the 1989 salinity levels were greater than 1992 salinity levels. In 1989, 90% of all salinity readings were less than approximately 8000 EC compared to 1992, where 90% of all salinity readings are less than approximately 3500 EC.

Similarly, salt load (obtained from the infilled salinity data) shows a decline over the study period. The results in Table 1 show that the yield of salt is decreasing consistently, with annual totals measuring 153t, 119t, 92t, 93t and 41t for the five years from 1989 to 1993, respectively. The annual salt load yield for 1992 shows a small increase in the otherwise decreasing trend but this can easily be accounted for due to the increase in yearly flow for 1992 in comparison to the other years (see Table 1).

A plot of cumulative salt load against cumulative rainfall (Figure 4), unlike flow versus cumulative rainfall, does not have a stepped nature, because the discharge of groundwater to the stream contributes to the salt load, resulting in a more even rate of salt generation. Similar to flow however, there is a reduction in the rate of salt generation from the catchment. This reduction in salt can be linked to the reduction in surface and groundwater flows entering Pine Creek.

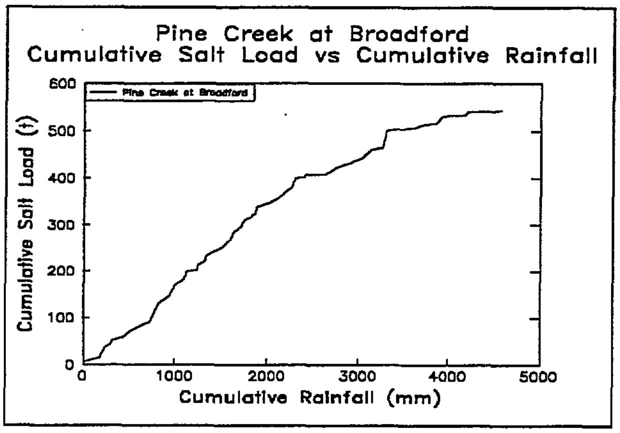

Figure 4 Pine creek - Cumulative salt load vs cumulative Rainfall

The salt load from Pine Creek has been compared to the loads from Sunday Creek and Mollison Creek. A plot of cumulative salt load per unit area for Pine Creek, Sunday Creek and Mollison Creek (Figure 5), supports the idea that the salt yield in Pine Creek is declining due to the growth of the pine plantations. The different appearance of the curve in comparison to that generated for flow together with the relatively high salt loads in the early part of the monitoring period is evidence of significant saline baseflow intrusions. These baseflows are most likely declining as recharge to groundwater reduces with time.

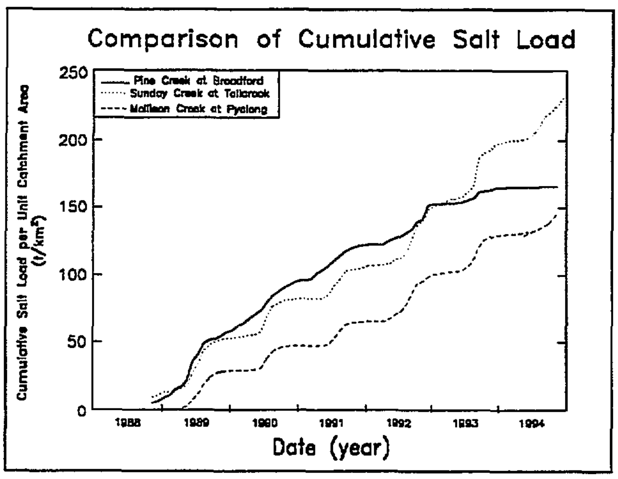

Figure 5 Comparison of Pine Creek's, Sunday Creek's and Mollison Creek's Cumulative Salt Load per unit area

4.3 Groundwater

Inspection of the data retrieved from the two Department of Conservation and Natural Resources bores reveals a significant change in characteristics since 1988. A plot of bore hydrographs indicates that the continued plantation growth has lowered the groundwater levels by approximately 2-3 m. The groundwater level in the bore in the upper catchment (D2) was approximately 5 m below the natural surface in 1988 and has fallen to nearly 8 m in 1994. The bore lower down in the catchment recorded a lesser decline in levels, with the level being approximately 21 m below natural surface in 1988 and 23 m below natural surface in 1994. The decline indicates reduced groundwater recharge, most likely due to the implementation and establishment of the pine plantation.

Groundwater salinities experienced some variation in both bores during the early records, but do not seem to have developed a definite trend. The bore in the upper catchment (D2) is currently showing salinities of about 1000 EC after initial readings in the vicinity of 2000 EC. The bore in the lower catchment (D1) shows a marginally smaller variation between maximum and minimum salinity readings, with the salinity ranging between 4000 and 3000 EC.

5. CONCLUSIONS

Stream flows from the Pine Creek catchment have reduced significantly over the period from late 1988 to 1994, while the annual rainfall on the catchment has remained relatively constant. The much larger Sunday Creek catchment and adjacent Mollison Creek catchment, do not exhibit similar trends, demonstrating that the observed decline in the Pine Creek's flow is most likely due to a change in local catchment land use.

Salt loads from the Pine Creek catchment have decreased over the study period from approximately 0.45 to 0.13 tonnes/hectare/year. The magnitude of salt inflows to the stream are not solely related to flow, demonstrating that groundwater intrusion to the creek bed is also contributing a proportion of the inflow. Over the last six years, groundwater levels have declined by approximately 2 m, which is consistent with the decreasing salt inflows to the creek over time.

Both the flow and the salt load from the catchment have significantly diminished due to the change in land use from open grassland/bare land to Pine plantation. Due to increased uptake of water by the pine plantation (interception, evapotranspiration etc.), the amount of rainfall, runoff and groundwater recharge has reduced and hence so has the salt load being discharged to the stream.

6. ACKNOWLEDGMENTS

Sinclair Knight Merz extends its thanks to Mr Burnie Mack of Smorgon Forests for his support of the establishment and monitoring of the Pine Creek catchment and Department of Conservation and Natural Resources, Broadford for the provision of bore data.

Shepparton Irrigation Region Land Water Salinity Management Plan - Community Involvement

Athol McDonald - Chairman Irrigation Committee
Ken Sampson - Irrigation Plan Co-ordinator

Background

The Shepparton Irrigation Region comprises:-

* 500,000 hectares of which 280,000 hectares are irrigated
* 7000 farms
* a population of 100,000 people
* all or part of 3 municipalities and,
* an annual economic output of $2.6 billion (1988)

Implementation of the Shepparton Irrigation Region Land and Water Salinity Management Plan (SIRLWSMP) will

* maintain the productivity base of the region
* protect the environment from further degradation
* prevent the social costs which will occur if high watertables and salinity are allowed to continue to develop.

Both during preparation of the Plan and subsequently during the implementation phase particular emphasis has been placed on ensuring broad community input into its development and on-going refinement, and ensuring community support for its implantation.

SIRLWSMP Development

The SIRLWSMP was developed under the control of the community-based Salinity Pilot Program Advisory Council (SPPAC) within guidelines provided by the Victorian Government. SPPAC comprised fifteen members with, collectively, landholder, local government, education and industry background. SPPAC was appointed on the basis of recommendations from the catchment community. Community input to Plan development was facilitated/encouraged through

* encouraging and assisting the formation of landholder groups
* close interaction with the 13 municipalities in the region at that time
* regular information meetings with special interest groups (bankers, service groups, accountants, business people, farm management consultants), school teachers, and industry groups (eg VFF)
* SPPAC CHATS - Key issues were raised in community issue papers - "SPPAC CHATS" - which were widely distributed via landholder groups, local government, VFF branches and news media. Community feedback was considered in addressing these issues in the Plan.
* Representatives of the Rural Water Corporation (RWC) Water User Groups were co-opted on to the SPPAC Irrigation Sub Committee.

A major community education program was mounted at the same time to raise community awareness of the issues. University of Melbourne surveys indicated the number of landholders in the region who believed salinity was likely to affect their farm increased from 38.9% in 1987 to 60.7% in 1989. This period corresponded to the time of Plan preparation. The increase in awareness was linked very much with the Underground Flood campaign - a series of maps of the region showing the inexorable rise of watertables such that by 2020 65% of the area would have watertables within 2m of the surface.

Response to Draft Plan

The Draft SIRLWSMP was discussed with the community at six public meeting attended by around 1000 people. Written comments received from the community in response to these meetings were taken into account when SPPAC finalised the SIRLWSMP for presentation to Government.

Eighty-one written submissions were received in response to the draft Plan.

11 Local government
29 Community groups and organisations
28 Individuals
7 Government Agencies.

SIRLWSMP Implementation

The Plan has been in the implementation phase since June 1990 under the direction of the community-based Salinity Program Advisory Council (SPAC). SPAC comprises 12 members appointed from people nominated by individuals or groups in the region with an additional 3 members nominated to represent each of Municipal Association of Victoria, Victoria Farmers Federation and the Conservation Council of Victoria.

SPAC

* develops annual implementation budget within Government guidelines
* sets annual works program priorities
* develops operational guidelines and policies for Plan implementation
* approves any movement of funds between SIRLWSMP projects in Government agencies.
* approves payment of RWC expenditure on the SIRLWSMP through the Government Services Contract
* coordinates the operational programs of Government agencies.
* reports directly to the Salinity Committee of Cabinet
* is recognised as the Community of Common Concern for the Irrigation Region under the MDBC Natural Resources Management Strategy.

The Shepparton Irrigation Plan has the goal to "manage the salinity of land and water resources in the catchment in order to maintain and where feasible improve the social well-being, environmental quality and productive capacity of the region".

The plan is an integrated salinity management plan with the sub-surface drainage program one of the four major action programs. The others are farm, surface drainage and environmental.

All the programs are very much linked and this is a feature of this plan. The plan directed 26% of its budget of over $10M towards the sub-surface drainage program in 1994/95.

All the programs are aimed to prevent accessions to the groundwater or to manage the groundwater such that the region has a sustainable future.

The sub-surface drainage program was developed as part of this plan.

A number of sub-surface drainage packages ranging from do nothing to full watertable control were evaluated against SPAC's social, economic and environmental goals. SPAC's preferred option was to serve some 213,000 ha of the estimated 274, 000 ha with potential high watertables by means of:

(i) implementing management arrangements for 395 existing and 365 new private pumps to serve 85,000 ha:

(ii) 426 public pumps and some 50 disposal basins to serve a further 85,000 ha in areas where private pumping and farm reuse was not feasible; and

(iii) tile drainage and small capacity pumps beneath 11,200 ha to protect the productive capacity of 43,000 ha of irrigated land where prospects for large scale pumping were limited.

The above mix of works for salinity and partial watertable control with managed salt disposal would ultimately require an estimated 16.7 SDE.

The Government response in June 1990 strongly endorsed the proposal for private and public pumping with managed reuse and disposal. However, the response requested that public scale basins be justified and that tile drainage and private scale basins be limited to pilot trials in the short term. It also limited the allocation of SDE's to the Plan as a whole to 10 EC, on the basis of current expectations for Northern Victoria.

A review of the sub-surface drainage program was undertaken during 1993/94. Main areas addressed were works progress to date, basic technical assumptions, works targets and cost sharing arrangements. It was agreed that the original work target should be maintained for all works except small pumps and tile drains despite the limited availability of SDE's, and that additional SDE's should be investigated, together with alternative methods for local reuse of saline groundwater.

The primary aim of measures to 1993/94 were to support SPAC'S policy favouring private in preference to public works. Consequently, progress with the private component of the program was satisfactory and ahead of target.

The current basic technical assumptions underlying SPAC policies were reviewed and endorsed. The issue of winter salt disposal by private pumps to achieve local or sub-regional salt balance was identified as needing further technical assessment at the conclusion of current research projects.

A revised 30 year works program was prepared in light of activities to date, the Government response and potentially limited SDE's.

The revised program retained the original overall Plan targets for the larger capacity private and public pumps. Targets for tile drains and small pumps were restricted to horticulture until a cost effective solution for pasture can be demonstrated.

The original plan cost sharing arrangements were reviewed and endorsed with some minor amendments to the proposed level of capital grant for private pumps. The level of grants is to be reduced from 80% to 65% over 3 years. It was agreed that the Groundwater Pumping Incentive Scheme should be terminated after 1994/95 and alternative methods of encouraging consistent pumping of groundwater be explored.

A key outcome of the Review was the development of a Groundwater Management Plan for private pumps within the Region. The declaration process under the Water Act commenced early in 1995. This planning process will be used to develop groundwater licence conditions which include a commitment to consistent pumping of groundwater.

To ensure SPAC remains fully responsive to community needs and views it has established an administrative structure to facilitate the appropriate interactions.

These administrative arrangements include:

* A communications Committee with a charter- to ensure effective communication between SPAC and the community, and- to implement an active community education program which includes among other things Watertable Watch and a Saltwatch Program involving 78 regional schools and 2,500 students
* appointing representatives from each of the four RWC Water Services Committees (WSC) to the SPAC Irrigation Committee (Members of the WSCs are elected by irrigators)
* establishing Working Groups with community representatives for each of the SIRLWSMP Action Programs to develop operational policies and guidelines for implementing the SIRLWSMP
* Support for Community Action Groups. There are now 56 landholder action groups actively involved in implementing the Plan. A number of these have now joined together as far as Goulburn-Murray Landcare Network. A regular Landholder Link Newsletter is distributed to all these groups. The program also employs a facilitator to assist the functioning of these groups.

Other factors which demonstrate community support for implementation of the SIRLWSMP include the following:-

Local Government

The 13 municipalities in the Shepparton Irrigation Region

- have formed a regional body - the Municipalities Against Salinity in the Northern Victoria (MANSNV) - and appointed a Municipal Salinity Liaison Officer to coordinate local government participation in the Plan.
- have developed uniform planning regulations for implementation of drainage works under the Plan
- pay 17% of the annual costs of public salinity works constructed under the Plan
- Have used provisions of the local Government Act, 1989, to support community salinity control projects (surface and sub surface drainage).

For example, Shepparton Shire, accepted a proposal to establish the 'Orvale Central Community Groundwater Pumping Scheme'. The Council provided the legal basis to construct and commission the works and struck a special rating on behalf of the landholder group, for ongoing operation and maintenance.

This relationship has continued with the newly amalgamated local government bodies.

Community Financial Contribution

In 1993/94 the community contributed directly $571,000 to capital projects requiring the sharing of costs between the community and government, and a total of $21 million on activities recognised to be components of the Plan. The overall uptake of Plan incentives matched the budget allocations. There is a waiting list for assistance to install private groundwater pumps.

Major Works

Major capital works projects only proceed if at least 67% of the direct beneficiaries vote in favour. Major work programs are generally meeting Plan targets indicating community support for these works.

This includes public Groundwater Pumping Schemes.

Annual Report

Irrigators in the Shepparton Irrigation Region participate in an annual Farm Survey to collect data for the SIRLWSMP Annual Report.

Conflict Resolution

SPAC has established a tribunal process to consider complaints from within the community relating to the implementation of SIRLWSMP operational policies and guidelines. The tribunal has addressed several complaints, resolving some in favour of the

General

Public meetings convened by SPAC are invariably well attended, the program receives wide and regular cover in all sectors of the media, and SPAC regularly hosts visits to the region from community organisations, senior politicians both State and Federal and overseas visitors.

Challenges for the Future

* Restructuring of Local Government, Urban Water Authorities and Rural Water Authorities means that the close links with the SIRL&WSMP and these key organisations will have to be re-established quickly.

* The establishment of the new Catchment and Land Protection Boards and their involvement in natural resource management will need to be integrated into our implementation program.

* The number of technical issues particularly in relation to regional groundwater reuse and disposal are still to be resolved.

* The establishment of the SIR as a groundwater supply protection zone and then the development of a groundwater management plan.

* Most importantly, maintaining the community knowledge and understanding of groundwater issues as they evolve.

Summary

Implementation of the SIRLWSMP is now generally achieving its targets. This can only occur with widespread support throughout the community.

Groundwater Monitoring Network Rationalisation in the Eastern Murray Basin

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Abstract

The Department of Land and Water Conservation has an extensive groundwater monitoring network in the Eastern Murray Geological Basin. Because much of the drilling was originally designed for stratigraphic information, the network is not an optimal configuration for routine monitoring. Considerable savings could be made if the monitoring network were reduced in size.

A geostatistics based methodology has been developed for network rationalisation. This study has deliberately kept statistics to a minimum, so that the methodology will be more palatable to a wider range of users, and has posed the problem in optimisation terms wherever possible. The optimisation is achieved with a commercial software package (GAMS). The final output of the process is a bore deletion list which indicates the order in which bores should be removed from the network.

Based on systematic rationalisation and subsequent verification, it appears that about 50% of the network could be removed. The developed methodology has potential application to other monitoring networks.

Introduction

The Department of Land and Water Conservation monitors about 224 bores, three to four times per year, outside the irrigation areas of the Eastern Murray Geological Basin. Considerable savings could be made if either the monitoring network were reduced in size, or the frequency of monitoring were decreased. This study is restricted in scope to assessing the adequacy of the monitoring network for providing information on groundwater level *spatially*. Time considerations and water quality performance are beyond the scope of this study. This work is part of a broader study which aims to maximise the value of monitoring by minimising the number of bores in time and space, without information loss.

The specific aims of this study are to systematically rationalise the groundwater monitoring network by providing a bore deletion list which indicates the order in which bores should be removed from the network.

The area of study is shown in Figure 1. It is a large area of almost 80,000 km^2, with one bore to each 350 km^2. However, bores are not evenly spaced but tend to cluster around Hillston (in the north), Darlington Point (in the south, 30 km south of Griffith), and near Corowa (in the south-east corner). The centres of concentration correlate with three major rivers: Lachlan River (north), Murrumbidgee River (centre), Murray River (south). The Lachlan area in particular is characterised by close-spaced line drilling. There are large expanses with no bores.

Methodology

The approach followed in this study has been guided by the methodology developed by Dillon (1987) and in particular its practical application to the rationalisation of the Namoi Valley monitoring network in New South Wales (Dillon & Knight, 1992). The lessons learned from that study have allowed a more pragmatic approach to be followed here.

The Namoi methodology was based on a series of FORTRAN programs and expected a good knowledge of statistics on the part of the user. This study has deliberately kept statistics to a minimum, so that the methodology will be more palatable to a wider range of users, and has posed the problem in optimisation terms wherever possible with minimal dependence on FORTRAN programming. The optimisation is achieved with GAMS software (Brooke *et al.*, 1988). GAMS is a high-level programming language designed for solving general optimisation problems.

Data for the years 1985 and 1990 have been chosen to allow the investigation of short-term effects (about 6 months) and long-term effects (about 5 years). This subset of the database includes data for 188 bores, which is 84% of the entire network.

A constraint on the study is that 46 vital bores are to be retained in the network. This constraint is particularly easy to impose when the rationalisation problem is expressed as an optimisation problem. These bores have been used as

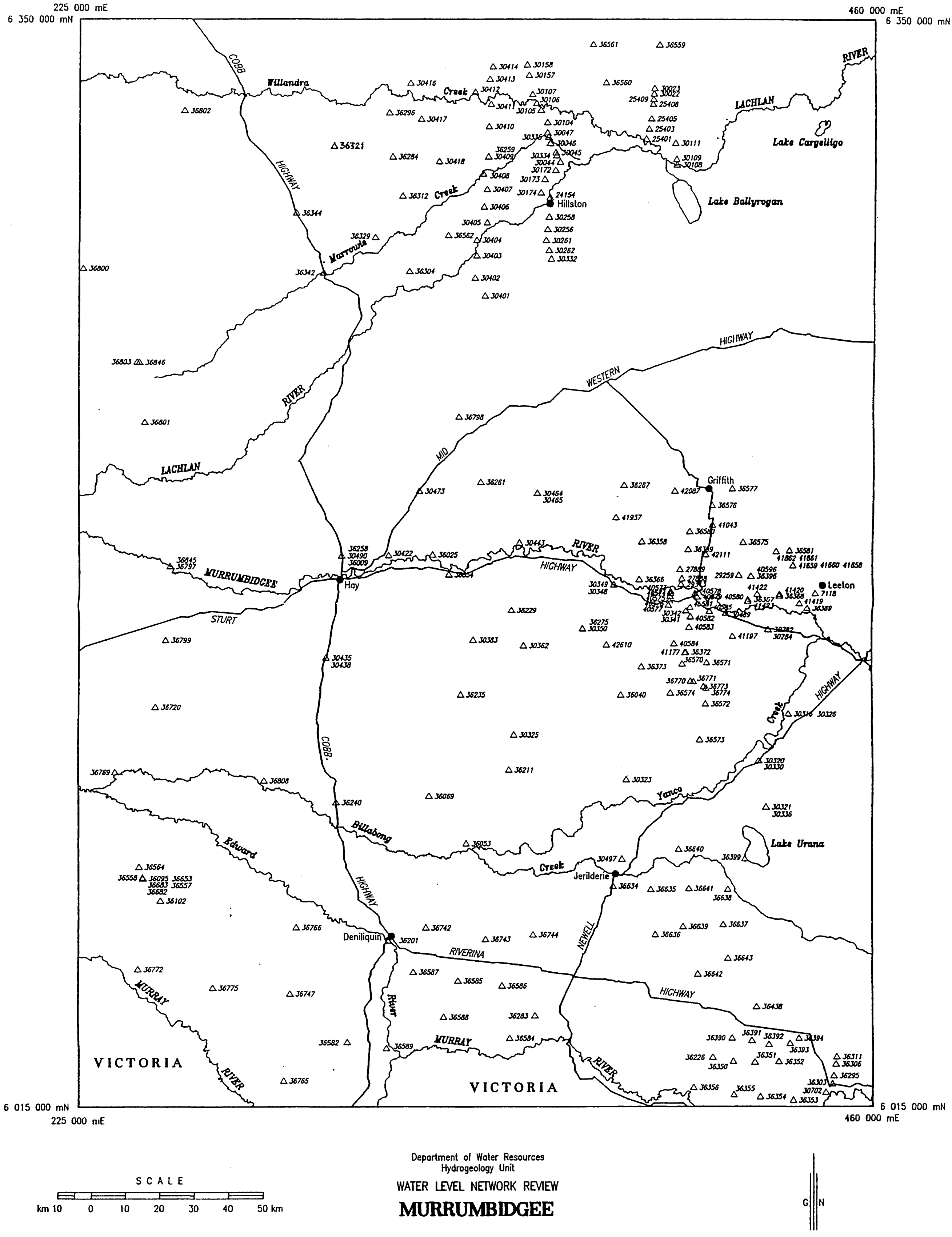

Figure 1. Groundwater Monitoring Bore Network

key bores for Status Reports, hydrogeological maps, model calibration or have been sited strategically since 1985.

The adopted methodology requires a number of stages:-
(1) Data selection;
(2) Analysis of frequency distributions;
(3) Semivariogram analysis and model fitting;
(4) Universal kriging;
(5) Semivariogram model verification;
(6) Network rationalisation by iterative elimination of insignificant bores;
(7) Plots of the variation in network statistics as network size is decreased;
(8) Composite deletion list for multiple datasets.

FORTRAN programs have been written for the first two stages and GAMS programs have been developed for stages 3 to 6.

Data Selection

A frequency analysis conducted on water level measurements from the Calivil/Renmark aquifer showed that the most populous datasets are February 1985, April 1985, September 1985, February 1990 and April 1990. The number of samples in the five datasets ranges from 66 to 104. Three drawdown datasets were also selected for study: February 1985 - September 1985, February 1985 - February 1990 and April 1985 - April 1990; the number of samples ranges from 28 to 79.

Water level contours for February 1985, generated by the SURFER (ver.4) kriging algorithm (with 12 nearest points) applied to a 42x30 grid, are shown in Figure 2.

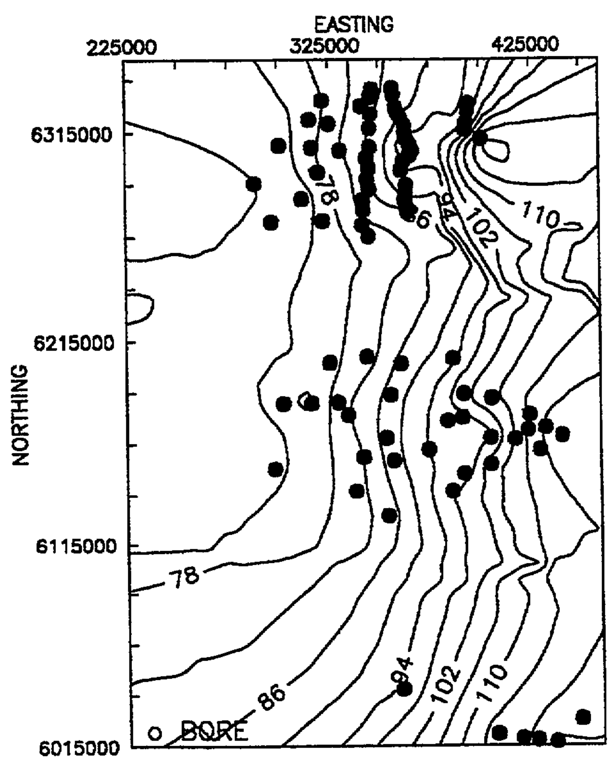

Figure 2. February 1985 Water Level (m AHD)

The February 1985 data capture the recharge bulges associated with the Lachlan and Murrumbidgee Rivers, but the Billabong Creek and Murray River systems are poorly defined. In contrast, the February 1990 data (not shown here) have no resolution in the Lachlan area, but the Murrumbidgee and Murray Rivers and Billabong Creek are well defined; there is a substantial low in the vicinity of Jerilderie which is believed to be a natural groundwater closure trapped between growing mounds produced by irrigation in the Coleambally and Murray areas.

Classical statistics were calculated for each dataset and for log-transformed water level data to check if they followed a normal distribution, a premise of geostatistics. The only datasets which complied were: February 1985 (raw and log), September 1985 (raw and log), and April 1985-1990.

Because log-transformation did not have an appreciable effect on all datasets, and the procedure was impossible for drawdown data, the decision was made to work with raw data with emphasis on February 1985 data as the primary dataset.

Variography

Geostatistics (Davis, 1986) deals with *regionalised variables* which, when sampled, display non-random spatial correlation. Groundwater level is a good example, because samples taken close together will have a distinct correlation, governed by gravity and the local hydraulic gradient. Furthermore, groundwater level is a *nonstationary* regionalised variable because it has a definite spatial trend.

The *semivariance* is a measure of the degree of spatial dependence between samples. Its variation with distance between samples is a *semivariogram.* Because a semivariogram is a *statistic* derived from sampling, an experimental semivariogram is an *estimate* of the true underlying semivariogram. To uncover the true semivariogram, it is standard practice to fit one or more functions to the data, and then use the best-fitting function as a model for subsequent processing.

A GAMS program (SVFIT) was written to compute a semivariogram and automatically fit a number of functions to it. The optimisation facility in GAMS is ideal for this purpose, because the asymptotic behaviour of functions can be constrained to match the general variance (the *sill*). The functions modelled are (Dillon, 1987): Linear, Linear with Sill, Exponential, Gaussian and Spherical.

The water level semivariograms show good structure, but the drawdown semivariograms are poorly defined. For most datasets the Gaussian model gave the best fit, but the linear with sill model was not much inferior. Figure 3 shows the best-fitting models for February 1985 water level data.

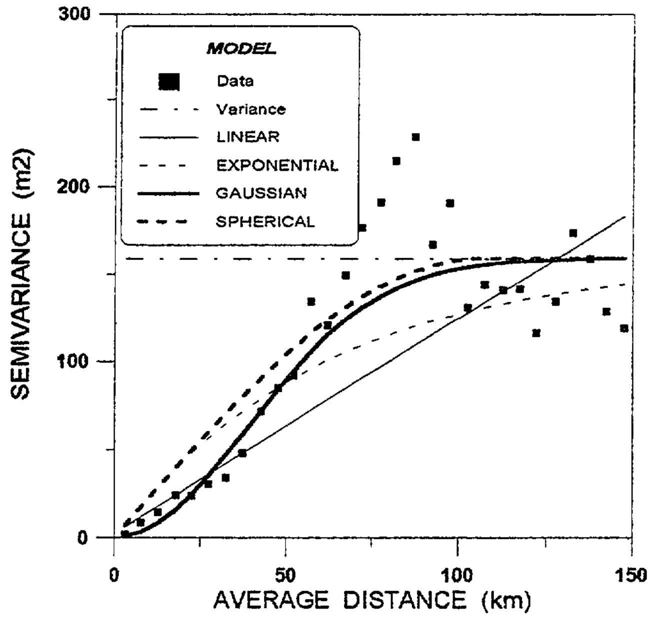

Figure 3. Semivariogram Models for February 1985 Water Level (Class Size 5 km)

Interpolation

Kriging is a method of interpolation between scattered sampling points which takes into account the spatial correlation that exists between points. The *kriged* value at a point is estimated as a weighted average of the values at neighbouring points. The weights are determined by the spacing between points, which is quantified by the semivariogram. Kriging not only provides an estimate of the value at a point, but also provides a measure of the uncertainty of the estimate (in the form of variance or standard error). Universal kriging is appropriate for nonstationary regionalised variables.

The estimate of a variable Z at an unsampled point P can be expressed as a weighted average of known values at sampled locations *i* :

$$Z_P^* = \sum_{i=1}^{n} W_i^P Z_i$$

The estimation variance at *P* is:

$$s_\varepsilon^2(P) = \sum_{i=1}^{n} W_i^P \gamma_{iP} + \lambda_P + \alpha_1^P x_P + \alpha_2^P y_P$$

where γ is semivariance, λ is a Lagrange multiplier, α_1 and α_2 are unknown linear drift coefficients. The kriging weights W_i are found by solving a system of linear equations which guarantee that the estimation variance will be minimised (de Marsily, 1986):

$$A \bullet \underline{W} = \underline{B}$$

The semivariance values in A and $\underline{B}$ are computed from the chosen semivariogram model.

In this study, a *linear with sill* model has been used to represent each dataset's semivariogram. The system of kriging equations has been formulated as an optimisation problem by allowing some residual between left and right sides of the semivariance equations, and then minimising the sum of residuals for all grid points. A GAMS program (NETKRIGD) has been written to solve the simultaneous equations and provide estimates over a grid.

The most important output from NETKRIGD is a file of accumulated kriging weights. The kriging weight associated with a bore varies from grid point to grid point. It has been reasoned by Dillon and Knight (1992) that the sum of a bore's weights for all grid points provides a measure of the importance of that bore in the network. The accumulated weights for all bores provides a means of ranking bores in order of importance.

Another GAMS program (NETVALID) verifies that the chosen semivariogram model produces reliable kriged estimates at sampled locations.

Network Rationalisation

The approach adopted for network rationalisation has been to eliminate one bore at a time from the network, up to the maximum number of bores available for deletion. At each step, global values for mean estimate, mean variance and mean standard error of estimate are calculated. Plots of the global means against the number of deleted bores show the sensitivity of the network statistics to network size. One would expect the standard error curve to be flat at first, and then to increase sharply as the network size reaches a critical level.

The key question is: *In what order should bores be eliminated from the network?* The most rigorous approach would be to compute the global variance resulting from the deletion of each bore in turn, and to select that bore which causes the least change in variance. Having found the first bore to be deleted, the process would then be repeated to find the second least significant bore; and so on. However, this proves to be so computationally excessive that a more pragmatic approach is needed. At each step in the elimination process, we choose that bore which has the minimum accumulated kriging weight. After each bore is deleted, the kriging weights must be re-computed. The result of this compromise will be that the precise deletion order of bores will not be significant. It is more sensible to consider a bore as a member of a group (for example: 1st, 2nd, 3rd or 4th quartile) in assessing its importance, rather than ranking bores individually.

A GAMS program (NETKILL) has been written to perform the rationalisation and produce a monitoring network deletion list. The performance of the network as it is reduced in size is illustrated in Figure 4 for February 1985 data. The standard error is quite stable as network size is reduced, until about the 60th bore is deleted. This suggests that a network of only 33 bores would have been sufficient to describe the water level distribution for February 1985.

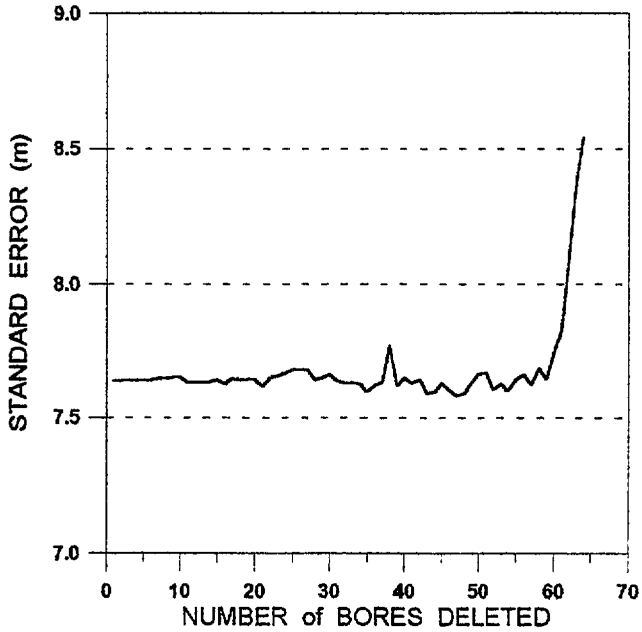

Figure 4. Network Performance for February 1985 Water Level

Not all monitoring bores are present in the February 1985 dataset; in fact, only 41% of bores are represented. So the deletion list based on one dataset does not tell the whole story. The most reliable deletion list is obtained by a weighted average of the ranks derived for the February 1985 and September 1985 datasets. There are 81 bores in this list; when coupled with the 46 bores which must be retained, the degree of coverage of the entire network is 57%. The group which contains the least significant bores has 11 bores in the northern (Lachlan) area, only 2 bores in the central (Murrumbidgee) area, and 7 bores in the southern (Murray) area. A less reliable deletion list can be composed by calculating an overall weighted ranking based on all five datasets.

If it is possible to eliminate a substantial percentage of the network, without information loss, then one should be able to generate equivalent water level contour maps *ad hoc* with different network sizes. Figure 5 shows the result when the network has been reduced to 48% (44 samples). Comparison with Figure 2 suggests that some slight changes are beginning to show, with the recharge bulges along the Lachlan and Murrumbidgee Rivers being less pronounced. The average error is 1.6 %RMS. There is a definite deterioration in the response in the northern area when the network is reduced to 35% (32 samples). However, the average error is only 2.7 %RMS. In contrast, deletion of the 13 most significant bores causes 4.4 %RMS error for a network size of 86%.

Conclusion

Geostatistics has been applied successfully to rationalising the groundwater monitoring network for the Eastern Murray Basin. Considerable cost savings can be made with minimal information loss by reducing the monitoring effort in the basin. Based on systematic rationalisation and subsequent verification, it appears that about 50% of the network could be removed. This figure is consistent with that derived by Dillon and Knight (1992), who found that about 50% of bores could be removed from the Lower Namoi Valley monitoring network.

A simplified methodology has been developed for application to other networks. The procedure relies heavily on GAMS optimisation software to accomplish the major tasks of semivariogram model fitting, semivariogram verification, universal kriging and network rationalisation.

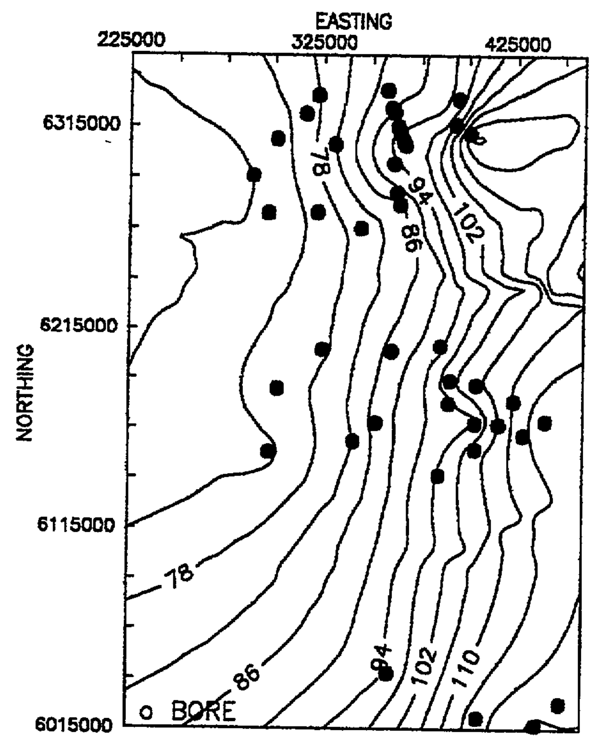

Figure 5. February 1985 Water Level (m AHD) Based on 48% of the Bore Network

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Landholder perceptions of the impact of tree planting on dryland salinity

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Introduction

A National Tree Survey was initiated in mid-1994 to document the extent and success of tree plantings by landholders for the management or control of land degradation. The survey was distributed through the Landcare network to landholders in dryland agricultural areas of all States. More than 1100 responses were received, amounting to a high response rate of approximately 9%. The spatial distribution of responses is shown in Figure 1. The area covered corresponds closely to the 400-700 mm rainfall p.a. zone within the dry temperate and mediterranian areas of Australia.

Survey aims

In the past, it has been demonstrated that trees can be used to combat wind erosion, gully erosion and salinity (Bicknell 1991; Bird et al. 1991; Prinsley 1991). These issues have been targeted by the survey. While other forms of land degradation, such as landslip, are of regional importance, they are less significant at a national scale in terms of tree planting effort.

Survey questions sought three main groups of information:

- the age and area of tree lots on farms, planted for land degradation control and other reasons;
- the success or otherwise of trees in addressing land degradation problems;
- the kinds of indicators or criteria used by landholders to assess changes in land degradation.

Information about other factors which might have influenced tree planting effort and/or success was also sought. Examples include: species used, extent of remnant vegetation and the level of management effort. This survey was conducted at the end of a prolonged drought and it is expected that the results will be affected by this. These factors, however, are not further discussed in this paper.

This paper presents a preliminary analysis of a subset of responses to survey questions about the impact of trees on dryland salinity or waterlogging control on farms.

Reasons for planting trees

Landholders responding to this survey usually planted trees for more than one purpose, leading to multiple responses to this part of the survey. Consequently we present the reasons for planting trees in two ways in Table 1. Column (1) shows the reasons given by landholders for planting trees, expressed as a proportion of the total number of respondents to the survey, so 53% of landholders have planted trees to address salinity/waterlogging (see Figure 2 for the spatial distribution of these responses). The middle column (2) shows the results of this survey as calculated after the method of Prinsley (1991), for which proportions were calculated using the total number of reasons given as the total. This is provided to allow direct comparison between this survey and the results of the RIRDC agroforestry survey shown in column (3) (Prinsley 1991).

Table 1. Reasons for farm tree plantings (respondents often stated more than one purpose for planting trees).
(1) % of all landholders replying to survey
(2) % response using the method of Prinsley (1991)
(3) Results for dry zone from Prinsley (1991)

Purpose of tree planting	Response Rate		
	(1)	(2)	(3)
Salinity/waterlogging	53%	23%	20%
Wind erosion	40%	18%	
Gully erosion	34%	15%	13% (Wind, Gully and Streambank erosion combined)
Streambank erosion	3%	1%	
Stock shelter and shade	40%	18%	29%
Windbreak	16%	7%	17%
Aesthetics	11%	5%	-
Ecology	11%	5%	7%
Revegetation	5%	2%	-
Commercial uses	3%	1%	-
Other	9%	4%	15%
Totals	1100 land-holders	100%	100%

National Tree Survey – Total Responses

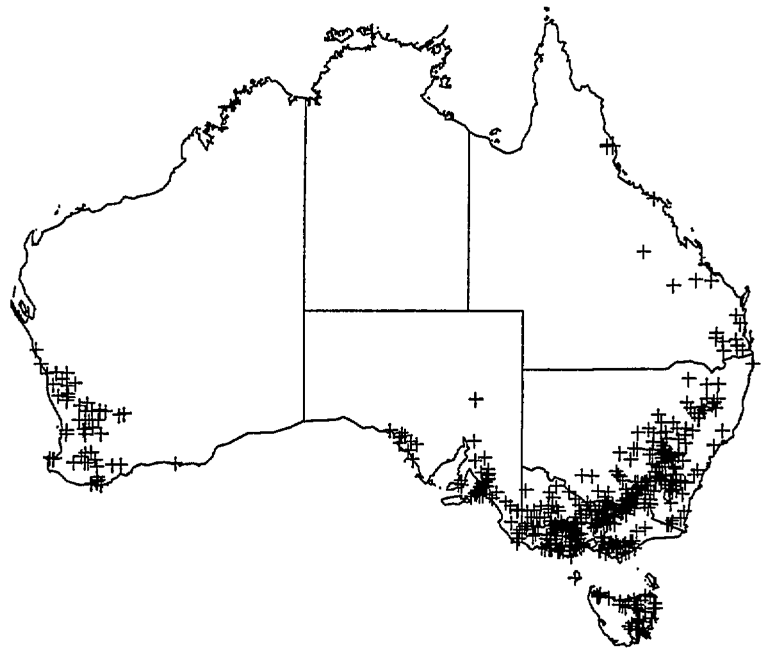

Figure 1 : Distribution of all survey responses (by nearest town).

National Tree Survey – Salinity Responses

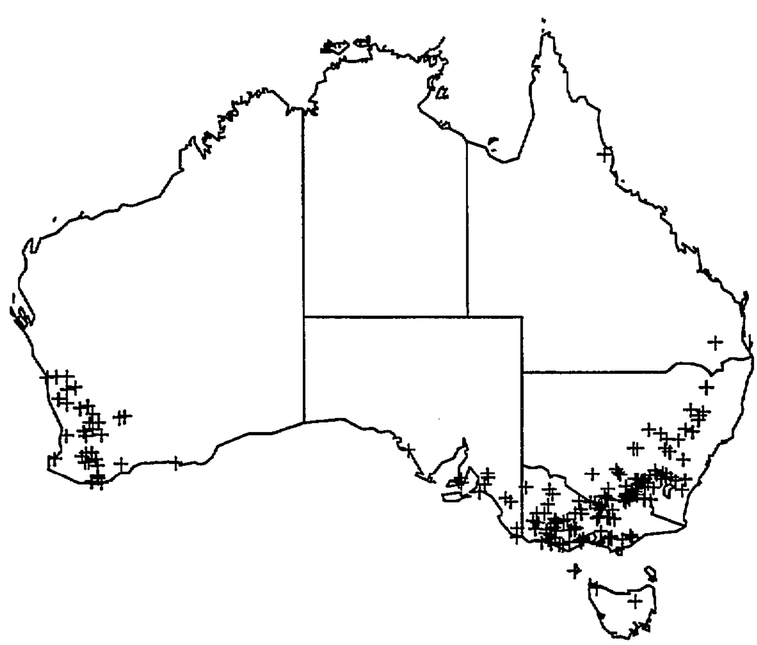

Figure 2 : Areas in which trees have been planted to address dryland salinity (by nearest town).

This survey showed that very few landholders planted trees for one purpose (22%), with only 8% of respondents having planted trees to address salinity/waterlogging alone. Most tree plantings for salinity management also served other farm production purposes, particularly stock shelter (including shade) and windbreaks.

Landholders' perceptions of improvement

Trees are often established in conjunction with other salinity management strategies, for example, pasture improvement. Separating the effects may not always be easy. To achieve some separation the question of improvement in salinity was addressed in two parts: (1) whether landholders thought the salinity/waterlogging had improved generally; and (2) to what degree they thought trees had improved the salinity/waterlogging problem (Table 2).

Table 2. Stated changes in salinity/waterlogging

Improvement categories	Responses
1. An improvement in the salinity problem:	
• "yes" - an improvement	49%
• "too early to tell"	30%
• "no"	21%
Total	100%
2. The effect of tree plantings on the salinity problem:	
• full recovery	2%
• much better	33%
• slightly better	41%
• no change	24%
Total	100%

The results in Table 2 suggest that in 40-50% of cases a positive improvement was recorded.

There is a strong association between responses to the two questions ($p<0.0001$). This is illustrated by the fact that of the 49% who stated an improvement in the salinity/waterlogging problem, 92% stated the result was due, at least in part, to their tree lots.

The next phase of the project is to check a subset of these results in the field to determine whether ground measurements can substantiate the landholder observations.

It is worth noting that the category "too early to tell" was not included in the survey questions, but it was instead proffered by respondents, often with an explanation that their salinity treatments were only recently initiated. Inclusion or otherwise of this category in later analyses of the results made no difference to their significance.

Indicators of salinity used by landholders

Landholders were subsequently asked to list what they used to recognise or indicate the change in salinity and/or waterlogging. No predefined options were given from which landholders could select, so these responses represent respondents own observations. 63% of those who stated a change or otherwise in salinity and/or waterlogging on their farm listed at least one factor they used to recognise that change. The indicators used by landholders are given in Table 3.

The category "other" in Table 3 includes responses such as the use of EM or EC meters, the presence of salt patches, crop growth and tree health/growth (each scored less than 1% of the total responses).

Discussion

In terms of the purpose for planting trees, the results of this survey differ from the results of other, broader surveys, such as the RIRDC agroforestry survey (Prinsley 1991) although the general pattern of responses is similar to that obtained from the Kondinan Group's National Agricultural Survey (Kondinan Group 1993) .

In regards to the RIRDC survey, although the results were similar for salinity control, a higher proportion of respondents to this survey indicated they planted trees for other land degradation problems (wind and gully erosion), and substantially fewer planted trees for the purposes of stock shelter/shade and windbreaks.

There are several possible reasons for this. Firstly, we asked a different question to that of Prinsley (1991). This survey requested information about all tree lots on a farm, and Prinsely's (1991) survey requested information about current (at the time of the survey) tree planting activities in a district. One consequence of this is that purposes for which trees were historically planted, eg the gully control schemes of the 1970's, may not appear as important in a "snapshot" survey.

Secondly, we intended to survey only those who planted trees for land degradation control. An indirect result was that landholders who did not plant trees for land degradation control, but who did plant trees for other purposes (eg "agroforestry", timber production or stock shelter) were not as inclined to participate in the survey. Evidence for this lies in the fact that only 2.1% of respondents planted trees for shelter or windbreaks alone.

While this survey also could be considered to have predominantly sampled a relatively select group (Landcare members), Landcare membership is not necessarily associated with an increase in the level of tree planting on farms (Cary, et al. 1993).

The use of specific criteria or indicators (Table 3) did affect landholders' perceptions of improvement in their salinity/waterlogging problem. Of those who used indicators to identify changes in salinity, 61% observed an improvement, 21% stated "too early" and 18% had observed no improvement. That is, more respondents were prepared to state an improvement in a salinity problem if they had observed their landscape in some detail.

Of interest is the high proportion of landholders who nominated indicators which reflect surface conditions, eg visual, groundcover, surface waterlogging, pasture growth and species compositions, and etc.. Only two groundwater indicators were nominated by a significant number of respondents: bore monitoring and groundwater salinity. This is not an unreasonable result, given the focus of extension literature on the use of vegetative indicators of salinity (Vanclay and Cary 1989).

There appears to be a good case to develop a set of indicators based on the landholders' suggestions and to help landholders interpret the indicators by outlining limitations and advantages of specific indicators. This aspect will be investigated as part of the field verification studies.

Table 3. Indicators used to recognise a change or otherwise in salinity or waterlogging problems (many landholders listed more than one indicator).

Indicator	% of landholders
bore monitoring	30%
visual	27%
groundcover	21%
surface waterlogging	16%
pasture growth	12%
species composition	10%
groundwater salinity	5%
size of area affected	4%
photography	3%
changed productivity	2%
erosion levels	1%
other	13%
Total listing indicators of salinity:	329 landholders

Conclusions

There are three main conclusions suggested by the preliminary analysis.

1. Salinity control is the predominant reason given by landholders addressing land degradation problems using trees in dryland agricultural Australia.
2. About 40% to 50% of those who have planted trees for salinity control believe that an improvement has occurred.
3. A wider use of indicators based on those used by landholders would help landholders evaluate improvement in their fight against salinisation.

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Deep drainage from conservation tillage

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Introduction

The adoption of conservation tillage systems is currently been advocated in recent years to reduce soil erosion, runoff and improve productivity in much of the dryland cropping areas of the Murray Darling Basin. Conservation tillage practices such as stubble retention, reduced or zero tillage are all able to increase soil water infiltration rate, soil water storage and as a consequence, increase grain yield (Cantero-Martinez, 1995; O'Leary, 1994).

It is likely, however, that the improvement in soil structure from conservation tillage practices may lead to problems of increased water loss to drainage and subsequent rises in saline groundwater, if the water conserved is not fully utilised by the subsequent crop (van Rees et al., 1990). This would be particularly important on those soils which respond positively to conservation tillage in terms of water conservation (e.g. McGuinness et al., 1993). This paper examines the extent of deep drainage, and by implication potential recharge to groundwater, after ten years of conservation tillage practices on a clay soil in the Wimmera region of Victoria.

Methods

A long-term fallow-wheat rotation experiment in the Wimmera district of Victoria was used to examine the effects of conservation tillage on deep drainage. The experiment had been established for 10 years to study soil water, mineral nitrogen accumulation, and crop productivity (Cantero-Martinez et al., 1995).

The experiment was located at the Wimmera Research Station, Dooen, Victoria on a friable grey cracking clay (Ug 5.2; Northcote, 1979). Zero-tilled (Weed control by herbicides) (SRZT) and sub-surface tilled fallows (blade plough) (SRST), both with retained stubble residues, were compared to conventionally cultivated bare fallows in which the stubble had been removed by burning (NSCT). Weed control in the 18-month fallow phase of the fallow-wheat rotation commenced between July and September for a period of 9-10 months. The experimental layout utilised a randomised design with each treatment replicated 4 times. In order to have each phase of the rotation present each year the first phase commenced in 1980 (Field 1) and the second phase commenced in 1981 in a different, but nearby, field (Field 2).

Calculations of deep drainage were made using volumetric water and chloride measurements from soil sampling to 2 m, the limit of root growth at this site. Sampling was conducted after harvest of the fifth crop in the fallow-wheat rotation in each field at the end of the ten-year experiment. Four 43 mm diameter soil core samples were taken at each sampling from each plot and divided into 25 cm intervals to examine profile patterns. The top 25 cm layer was further sub-divided into 0-10 and 10-25 cm segments. Plot samples were composited within depths and sub-sampled for laboratory analyses.

The combined mass balance of chloride and water technique of Walker et al. (1991), as applied by O'Connell et al. (1995) to crop rotations, was used to determine differences in drainage below the root zone and by implication, potential recharge to groundwater between two tillage systems. An important assumption of this approach is that no upward movement of water from below the root zone in the vapour phase occurs. Hence, the estimates may slightly overestimate the true potential recharge, but it is considered small because of the usual high relative humidity of soil minimising strong gradients to induce significant vapour flow. A more important assumption, however, is that the downward flux occurs as diffuse flow through the soil matrix. Hence the method provides conservative estimates of the change in potential recharge (O'Connell et al., 1995). The maximum depth of rooting was assumed to be 1.75 m for these calculations (i.e. one layer above the deepest layer (2 m) sampled). Accumulated water differences between 1.75 and 2 m were very small (< 1 mm) and so the assumption of a maximum rooting depth as deep as 2 m (Incerti & O'Leary, 1990) would not significantly alter potential recharge.

Analyses of variance was used to determine tillage effects on water content and triplicate chloride measurements from each composite plot sample.

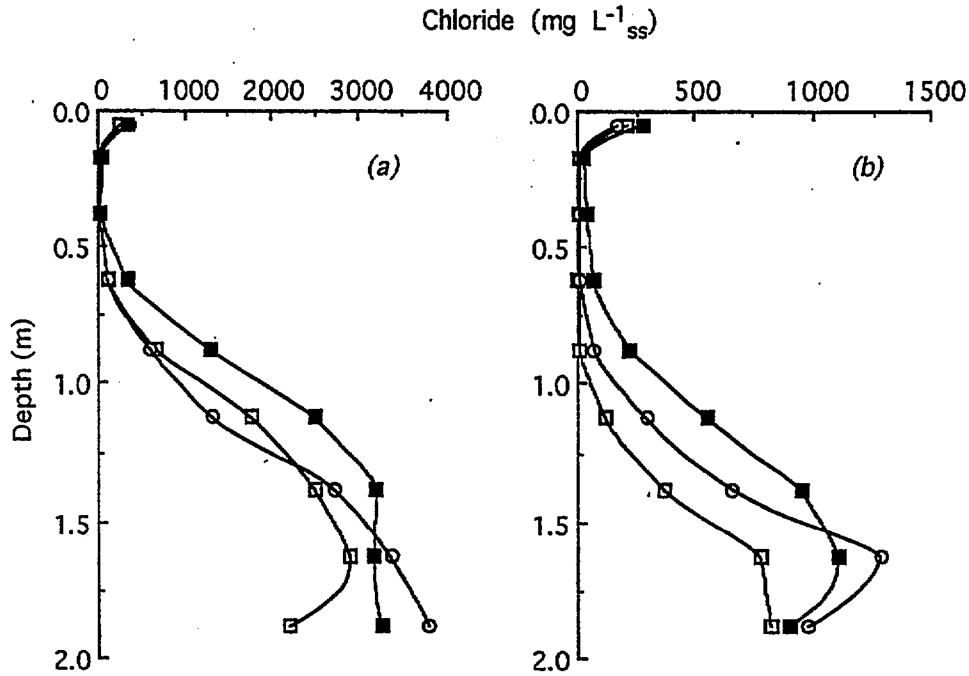

Figure 1. Soil solution chloride concentration (backtransformed data) for the stubble-retained, zero-tilled fallow (SRZT; □), sub-surface tilled fallow (SRST; ○) and fully-tilled conventional fallow (NSCT; ■) systems for Field 1 (a) and Field 2 (b).

Natural logarithmic transformations were applied to the chloride data to avoid violations to the assumptions of normally distributed residuals in the analysis of variance.

Results and discussion

The SRZT fallow leached more chloride than the SRST fallow compared to the NSCT fallow as indicated by the resultant Cl concentration in soil solution in both fields (Figure 1). In Field 1, there was no statistical difference ($P>0.10$) in leaching between SRST and NSCT, however, in Field 2 SRST fallow leached a significant ($P<0.05$) quantity of chloride, but not as much as SRZT. Whilst each fallow system had leached almost all of the Cl to 0.5 m the differential leaching was very evident between 0.75 and 1.5 m.

The greater leaching of chloride in SRZT compared to NSCT corresponded to an additional 18.5 and 18.6 mm yr^{-1} deep drainage for Field 1 and 2, respectively. Similarly, SRST fallow showed significantly less deep drainage ranging between 2.2 and 3.8 mm yr^{-1} compared to NSCT fallow.

The relatively high drainage rates under SRZT (18 mm yr^{-1} greater than NSCT) highlights the dilemma facing farmers trying to employ tillage systems that conserve soil and water resources, yet risk increased drainage and off-site environmental hazards with a potential rise in saline groundwater. The estimates of differential drainage are worrying, since estimates of the difference between NSCT fallow and non-fallow rotations is 6 mm yr^{-1} on a nearby (<300 m) site on this soil type (O'Connell et al., 1995). This work provides evidence that the practice of stubble retention and zero tillage fallowing is a potential hazard to rising saline watertables, not previously available despite strong suspicions.

Fortunately, there are productive gains in yield from increased water use (O'Leary, 1994) that is not a regular feature of conservation tillage on other soil types. On the heavy textured soils at Dooen, SRZT fallowing has been advantageous in years of low rainfall where a yield improvement over both NSCT (up to 0.8 t ha^{-1}) and SRST (up to 0.6 t ha^{-1}) was reported (Cantero-Martinez et al., 1995). However, in wet years there is an increased risk of drainage occurring under crops sown on SRZT fallows and thus the beneficial role of increased soil water content resulting from these fallows must be questioned on the soils in this environment. The observed loss here, however, is not as great as has been assumed when no yield gains are observed (van Rees et al., 1990).

On the heavy textured soils at Dooen there are, however, alternative conservation tillage systems that offer markedly less drainage (e.g. sub-surface tillage with residue retention), but they are not as higher yielding as the more extreme system of maximising residue retention with zero tillage (Cantero-Martinez et al., 1995). Measurements of infiltration rate on the surface in this experiment corroborate the greater drainage in SRZT, with an 8-fold increase in saturated hydraulic conductivity (K_s) from 12-33 to 145-206 mm hr^{-1} in SRZT compared to NSCT (Bissett & O'Leary, 1992). It is not unexpected that a significant proportion of water escapes the root zone, but sub-surface tillage whilst exhibiting intermediate K_s (44-76 mm hr^{-1}), it did not display a proportional increase in drainage.

It is therefore, likely that some tillage is advantageous, not only for agronomic purposes such as weed control, but also to minimise drainage rates whilst largely maintaining the more important component of conservation tillage systems in this environment; surface residues (O'Leary, 1994). Further work on the regional implications of these drainage rates is warranted, particularly the extent and frequency of the extreme conservation tillage system of stubble retention and zero tillage.

Acknowledgments

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Depletion of the Aquifers along the Irrigation Areas of the Namoi River

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I want to give a broad overview of the area, the cause and the prognosis of the problem of the depletion of aquifers along the Namoi River.

I am a Councillor on a Shire Council that has a unique responsibility of providing domestic water to three towns situated on the Namoi River and drawing its water from the alluvial aquifer beneath each town.

These water supplies are reasonably cheap to administer and are very reliable. The fact that there has never been a need to construct a weir or a dam to supply town water is testimony of the reliability of these underground streams.

The fact that Narrabri, Boggabri and Wee Waa have been built on or near the river is simply a testimony also to the pioneers who knew of the reliability of the streams. Wee Waa and Narrabri have been known in the past as towns of windmills and spear point watering systems. The position of Boggabri is on the edge of the aquifer but still draws on the same.

Irrigation in the past dated back to the post and pre-war period of World War I when large inefficient old crude oil engines lifted water from the river and simply spilled it over the bank into an immediate field.

The change to the draw-down on the water supply started in the early sixties when cotton production took off and brought with it high tech methods and very large and efficient pumps and engines. The water instead of being pumped from the river over the banks often travelled 20 kilometres to its destination to water the irrigation area.

It soon became obvious that the river could not keep up with the supply for the expanding cotton, soya bean, maize and other crops. The people then turned to technology and better screen bores, larger capacity deep well pumps and more efficient engines were designed to lift the waters from the underground aquifer system.

Bores of up to 300,000 gallons per hour are not common but do exist in this valley. East of Gunnedah there are two bores in close proximity delivering about 300,000 gallons per hour. Bores of 100,000 are common place.

In 1993 when I was Mayor I attended an underground water meeting called by the Lower Namoi Water Users Association. Senior Engineers speak at these seminars each year as guest speakers from the W.R.C.

I became very concerned at a statement made by the senior hydrologist with the Water Resources when he said that the area was licensed to pump 156,000 megalitres per year by licensed users and the recharge rate in any normal year is about 82,500 megalitres only (1981 - 1986 period). In 1994 I went along to the same annual meeting and the similar figures were quoted. About 138,000 usage and 82,000 recharge.

As this area is sitting over a bedrock strata and as the water can only come from the river itself, I soon became aware that eventually given less than average years, it is possible to pump those aquifers dry.

The question was asked in 1993 "how much is held in the large area" and we were told 19 million megalitres. In 1994 the same question was asked and the answer was there had been a re-estimate and it was about 16 million megalitres. Given room for variance in the calculations it is quite obvious that the supply or reservoir will and is depleting.

My property is at the base of the hills and possibly 20 kilometres from the edge of this large aquifer. In 1993 1 asked could the depletion of the river aquifer effect my supply. The answer was definitely "no". I asked the same question in 1994 and the answer was eventually "yes".

Another question I asked in 1993 was what could we do if the town water supplies dried up at the shallow level we were pumping from and the answer I received was, "you will have to go deeper."

The immediate evidence of a change taking place in the system is that shallow stock watering bores, called "stock and domestic" have been effected. We think close to 45 have had to be deepened or gone dry East of Gunnedah and 80-100 in our Shire mostly North West of Narrabri. The admission that this has been due to extraction contrary to normal depletion is the subsidy scheme whereby the State Government, Water Users and stock owners jointly subsidise the deepening of the stock and domestic bores.

Another feature of serious concern is the subsidence in this North-West area of the irrigation belt where actual measurements have measured a drop of up to 9 inches.

The summary must then be made that we are drawing off more water than is being recharged in to the reservoir.

The prognosis is that it is inevitable that the system cannot be sustained. The economic fact is that irrigation is a wonderful stabiliser in times of irregular rainfall.

If sustainability is agreed upon as a good management practice of our ecology, at what point in time should we seriously look at the over extraction of water if the equation of water in and water out is the simple criteria.

Good news as of the first week of July in this year of 1995, is that two large areas in our aquifer system have been shut down due to the fact that no measurable water has inflowed into Keepit dam which is at 3% only of capacity. The two large areas that have been shut down are to the North West of the alluvial aquifer system. The eastern edge of this system is alarmingly only about 28 km from Narrabri town water supply.

I will go on record saying that I believe this action by the department is a step in the right direction and they should be complimented for one, realising the recharge rate in this area is low, and secondly admitting that the bore licences have been over committed .

Due to large irrigation banks and channels there is a theory that the recharge has gone up from the 82,500 but at present the current allocation are 156,000 megalitres. in a normal year and 208,000 megalitres per year in a dry year. In 1994 138,000 megalitres were used.

The decision to halt some pumping must be a responsible one, even is a little late.

An anomaly I believe that has to be addressed is the "conjunctive use" clause.

Conjunctive use in this area means that anyone with a surface water supply, can in times of nil allocation from the river, pump about 60% of their river allocation from a bore on their property if they have one to use. This conjunctive use clause must surely be also a doubtful practice in good management. It simply means that someone with a surface water licence can use the reservoir of stored water under the ground if the river dries up. Rivers usually dry up when it doesn't rain and when it doesn't rain there is no natural recharge. The conjunction use clause is counter productive to the law of sustainability.

It is also worthy to note that the present policy allows groundwater users to extract a certain amount of water depending on their 1) historical usage, 2) the size of their property and 3) the hydrogeological zone.

If we go back in history and look at the basis for the 1992 Water Act it doesn't add up to the fact that the Water Act was principally designed to try and drought proof Australia and about 400 megalitres per year was thought adequate to help sustain a mixed farm. Historical use and the size of the farm must subscribe to the theory that big is better and the need for large areas are the only ones that can be termed viable. Surely this bears little resemblance to the intent of the old Water Act or whether or not the area is in drought or having a good season. It is only my personal opinion that somewhere along the way the size of the farm in relation to underground allocations have been influenced by what is viable in today's socio-economic climate.

Having accepted these and other facts, even if the viability of the farming area changes in relationship to the water allocating, it is certain that in an average rainfall of some 150 years, one can assume that the amount of water to be pumped will not change. It must then be assumed that the pumping rate should not alter if sustainability is to be maintained. Finally on land subsidence, even though the area does not resemble any areas such as the Gippsland area of the Latrobe Valley where up to 1.7 metres has taken place, or areas in the San Joaquin and Santa Clara Valleys in California where 8.5 metres have been measured over 13,000 square kilometres, only small areas by comparison have been measured in the Namoi Valley.

A small amount of subsidence has been measured, (about 70mm) in the area now known as zone (5) where the amount of storage in the aquifer is diminishing and has now a moratorium on pumping. It can be assumed that ground subsidence and overpumping are related.

If I can summarise my paper to this meeting I will simply say, man has in a very short space of time affected a once considered endless supply of water.

What I am saying is that anything less than an extraction rate equal to normal recharge will and should not be tolerated. To take the large aquifer under our flood plain as a gift of nature, to remove this must be considered as immoral as removing a mountain range rising above the land.

Finally as Shire mayor I consider it my duty as Local Government Leader to respect any asset within the Shire whether or not that asset be administered by State or

Federal agencies. In the case of water section 100 of our commonwealth constitution precludes the Commonwealth from interference with our rivers, so the onus of managing the underground aquifers must surely rest with the State.

It is hoped good sense will prevail. I believe the shut down of two irrigation zones in our Shire is a positive and sensible step.

Local Government can and will continue to take a keen interest in the future use of underground water extraction. Our Council has too much to lose of any of our ratepayers are disadvantaged by over indulgence by a minority of our people.

Stratigraphic settings of Mallee salinas - Indicators of disposal basin performance

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Approximately 150 saline water disposal basins are presently operative as a major component of the salt interception strategy for the Murray River. These basins are sited in a diverse range of stratigraphic and geomorphic settings and offer the full hydrodynamic spectrum from almost complete isolation to open connection with the underlying host aquifer. Unfortunately, little is known of most basins (Hostetler & Radke, 1995) and their performance is poorly understood.

Reliable information on permeabilities of the enclosing host aquitard and underlying aquifer does not exist for most basins; k_v is available for only 7% of basins and k_h for 20% (Brodie *et al.*,1995). Consequently for an assessment of performance from permeability characteristics, the default is to use 'regional' values or indirect methods for prediction. Regional aquitards are found under closer scrutiny, to have variable permeabilities. In areas where fluvial channels were more prevalent, such as close to the existing river trench, and in areas of greater paleomorphologic relief, such as near Parilla strandline dunes or faulting, sandier sediments accumulate within lacustral aquitard deposits. This challenges the casual application of regional stratigraphy for such purposes.

Lithostratigraphic criteria are calibrated with hydrodynamic research and are used to predict relative permeability and salt movement in Mallee salinas which were chosen for their range of lithostratigraphic settings; from sand-dominant (Scotia Discharge Complex) (Figure 1), through mixed (Mourquong Discharge Complex/Disposal Basin) (Figure 2) to clay-dominant (Nulla Discharge Complex) (Figure 3). Generalisation of these stratigraphic settings (Figure 4) elucidates the range of hydrodynamics possible.

Field investigations (Ferguson & Radke, 1994) generally support theoretical predictions that high-permeability sand-dominant conditions favour rapid advective reflux of salt, in contrast to low-permeability clay-dominant conditions which favour the much slower process of diffusion to the underlying aquifer (Barnes *et al.*,1991; Ferguson *et al.*, 1992) under conditions of predominantly vertical migration. The natural situation is more complex and discharge complexes individually display a high degree of heterogeneity in both lithostratigraphy and consequent permeability. Lateral fluid migration can be significant or dominant and the proportionality between lateral and vertical fluid movement can change seasonally, as well as during re-equilibration after natural systems have been modified with the addition of disposal waters.

All discharge complexes studied have evidence of at least three major phases of deflation and subsequent lake sediment accumulation. These events have contributed a stratigraphic complexity and heterogeneity to each system. This heterogeneity can be a major qualifier to the general rule, and necessitates an iterative assessment of disposal basin sites to determine whether there are heterogeneities present, and of a type which significantly influences the basin hydrodynamics.

Classification

Accepting the inevitable complexities, there is still a requirement to compare disposal basins throughout the Murray Basin on a standard basis. By expanding the generalisations of the lithostratigraphic settings of the three salinas studied (Figure 4) a basin-wide classification is possible.

Permeability characteristics of a basin are controlled by the enclosing host sequence, and the distribution and type of lining on the basin floor and margins.

The host may have uniform character, be stratified, or have irregular heterogeneities. Sand and sand-dominant units approximate high permeability, while clay and clay-dominant units approximate low permeability. Heterogeneity may also be prevalent in these lining deposits. A first-order lithostratigraphic classification of basins has been developed (Figure 5; Radke & Hostetler, in prep.) that categorizes characteristics of both the host units and the basin lining deposits, in dominant sediment type, stratigraphic geometry and uniformity. Reliability of the categorisation is also included.

We advocate the use of this lithostratigraphic classification, even though it only offers a first-order approximation of what we know to be complex systems. All basins are categorized in 26 of the 51 possible classes, and 58% of basins comprise 4 classes (Brodie *et al.*, 1995).

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Basin function and performance

Assessment of basin performance hinges on the function expected of the basin to the overall salt interception strategy. Basins can have the function of disposal via leakage, or storage. Permanent storage utilizes evaporation for brine concentration. Temporary storage in holding basins can accumulate disposal water within the floodplain until the next flushing by river flood, or be used to transfer disposal water to more distant leakage disposal basins. The ideal basin for this storage function would have an impermeable host and/or an impermeable basin lining of clay or clay-dominant sequence.

Leakage has been recognized as a positive characteristic in basins which are remote from environmentally sensitive areas and where brine is returned to underlying saline aquifers. The ideal basin types for this function would have a laterally impermeable host but permeable bottom such as clay over sand. Basin linings with sand=clay or sand > clay would be preferable. At Nulla Discharge Complex, fracture porosity in carbonate strata enhance the permeability of an otherwise tight clay.

Most basins are used for **evaporative** concentration of salt. This function is obviously dependant on substrate factors so that leakage rates should be low enough to allow evaporative reduction to be significant. The key question becomes what level of leakage is required or is acceptable for particular basin location and function. Again this requires assessment of permeability.

Ironically, the types of host substrates for basins appear to clash with their location and function. Basins within the river trench, and especially those with higher frequency of flooding, tend to be in fluvial-dominant sediments with characteristically high permeabilities and potentially high leakage rates. Solutions to this problem have required assistance from bore interception, or by keeping operating levels lower than surrounding groundwater heads to maintain hydrodynamic closure.

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In basins further removed and relatively hydrodynamically isolated from the trench, the aquitard substrate generally has a minimal fluvial component and is consequently less permeable, with lower leakage characteristics. Such basins may require enhanced connection with underlying aquifers to improve their leakage function.

It is theoretically feasible to induce leakage to form stable brine pools in the underlying aquifer as an engineering solution to the salt disposal issue.

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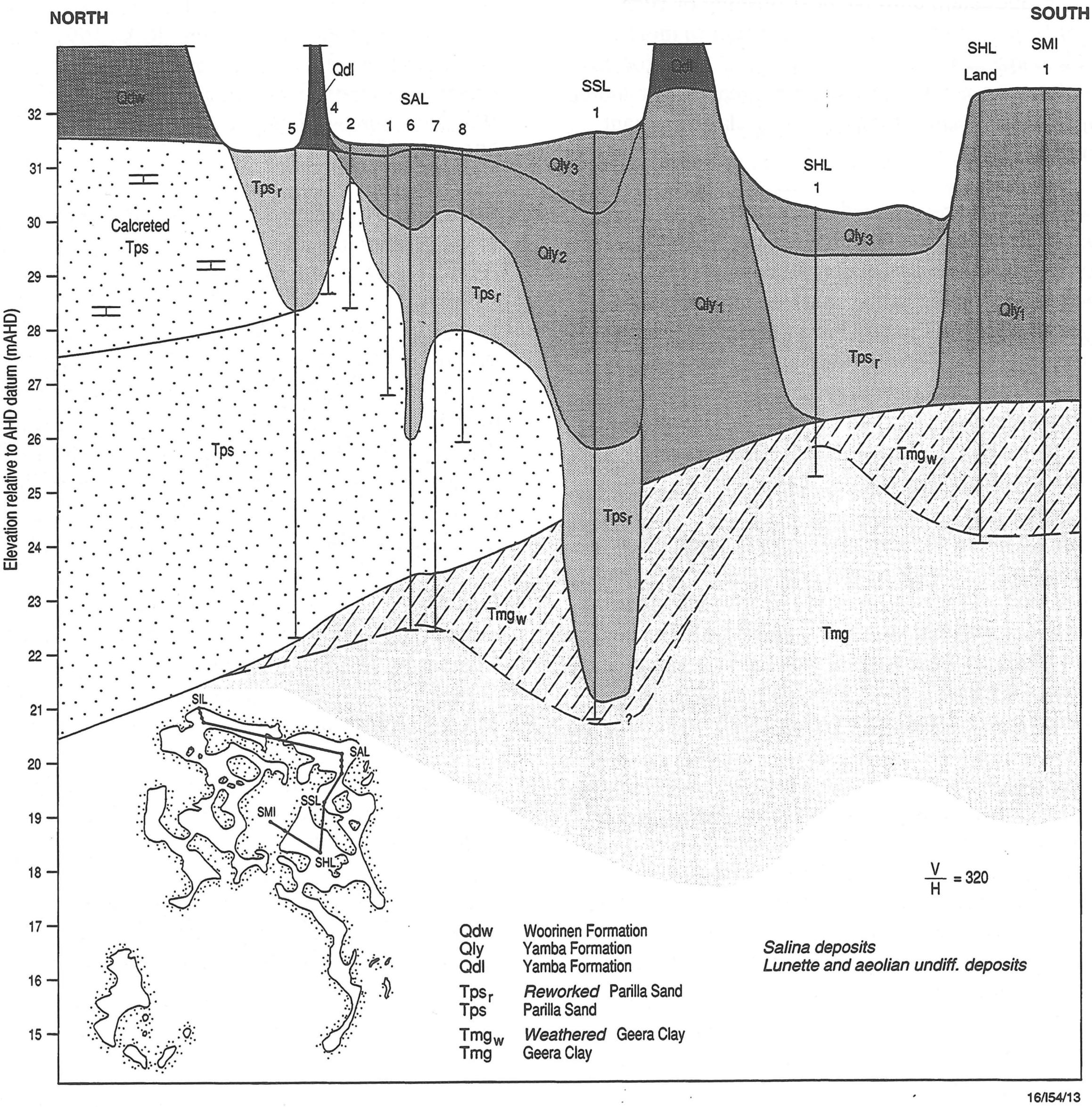

Figure 1. Stratigraphy, north-south section of Scotia Discharge Complex (from Ferguson and Radke; 1994).

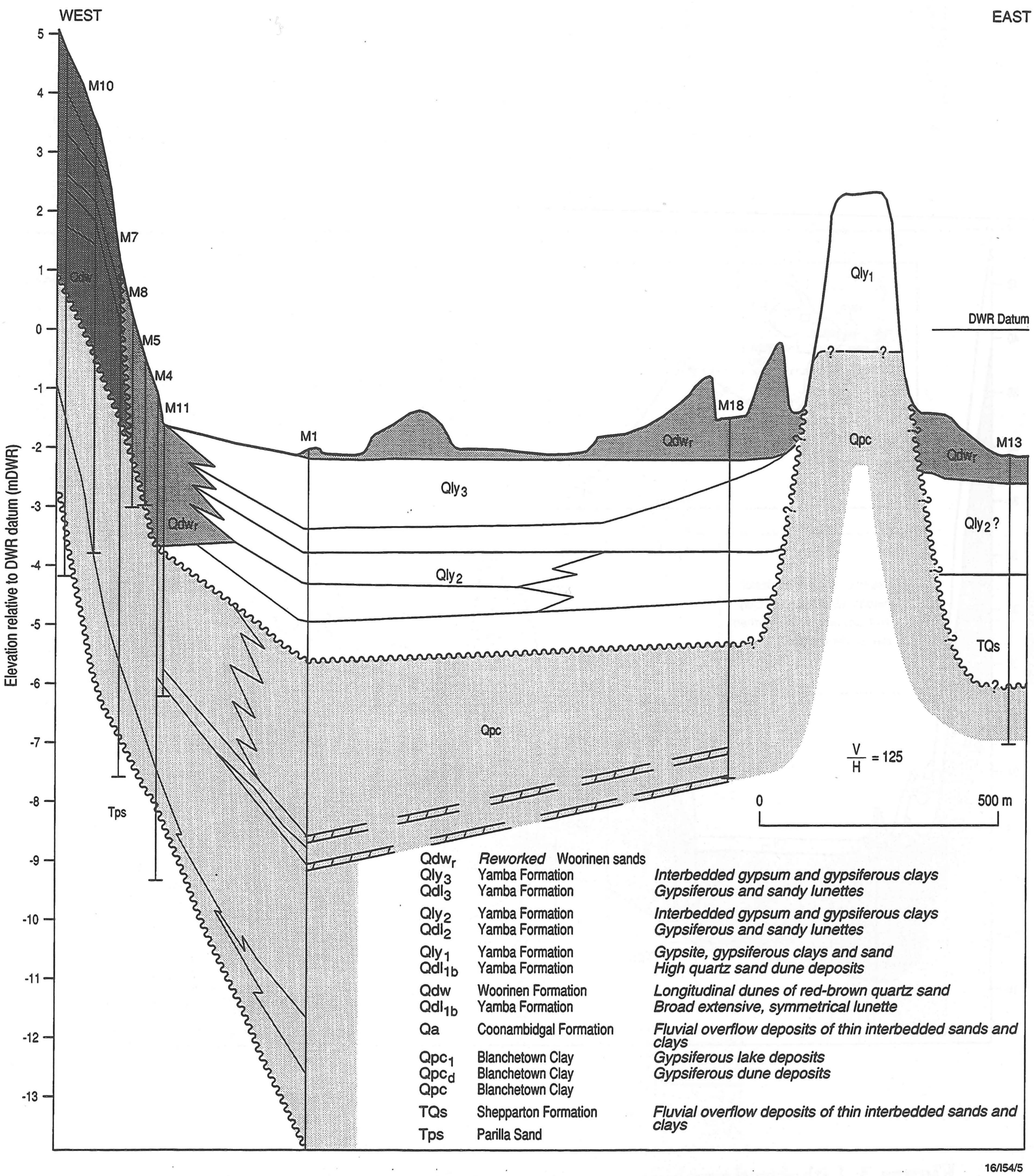

Figure 2. Stratigraphy of the Mourquong Disposal Basin; E-W section (from Ferguson and Radke; 1994).

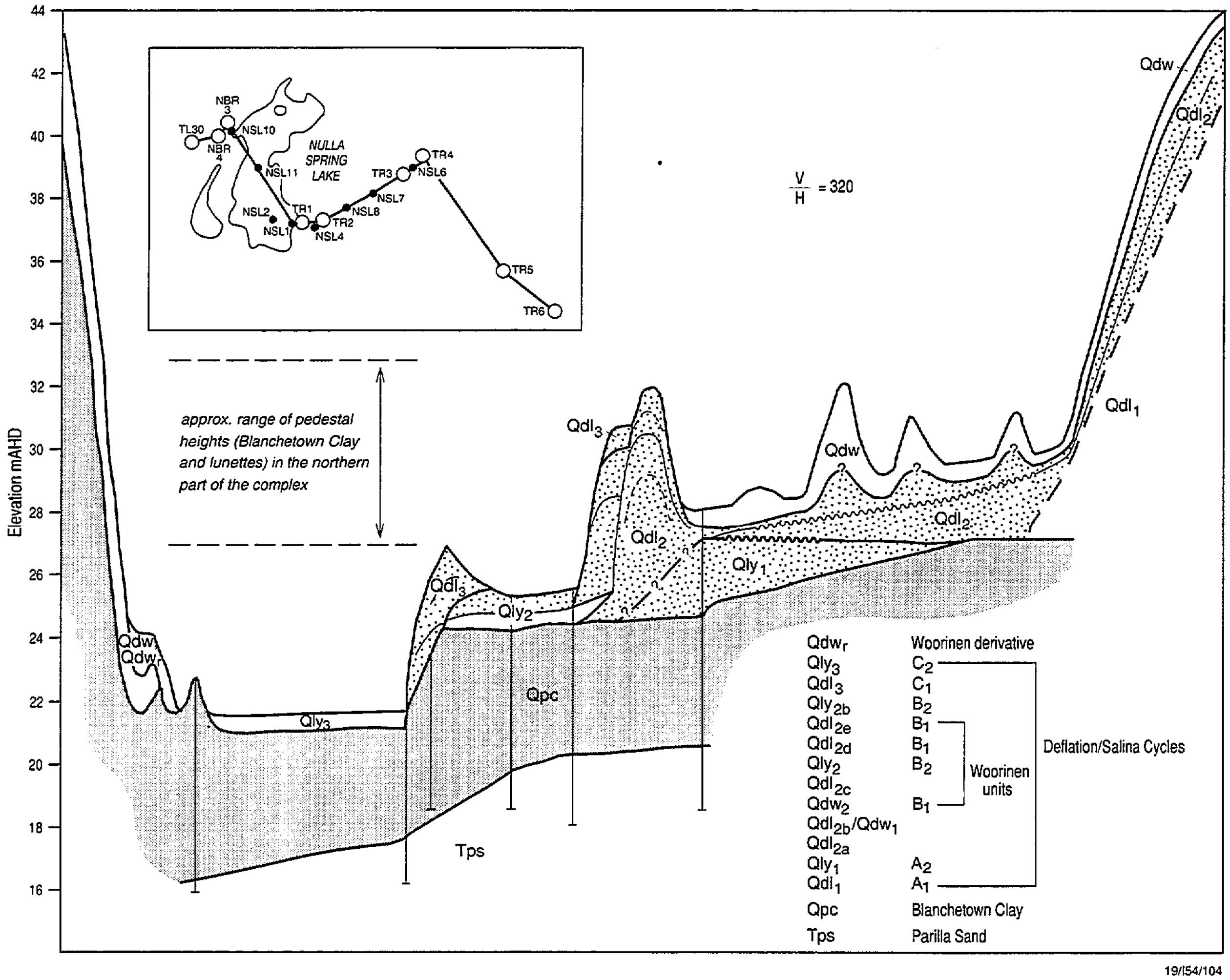

Figure 3. Lithostratigraphic units of the Nulla Discharge Complex in a section through Nulla Spring Lake (from Ferguson and Radke; 1994).

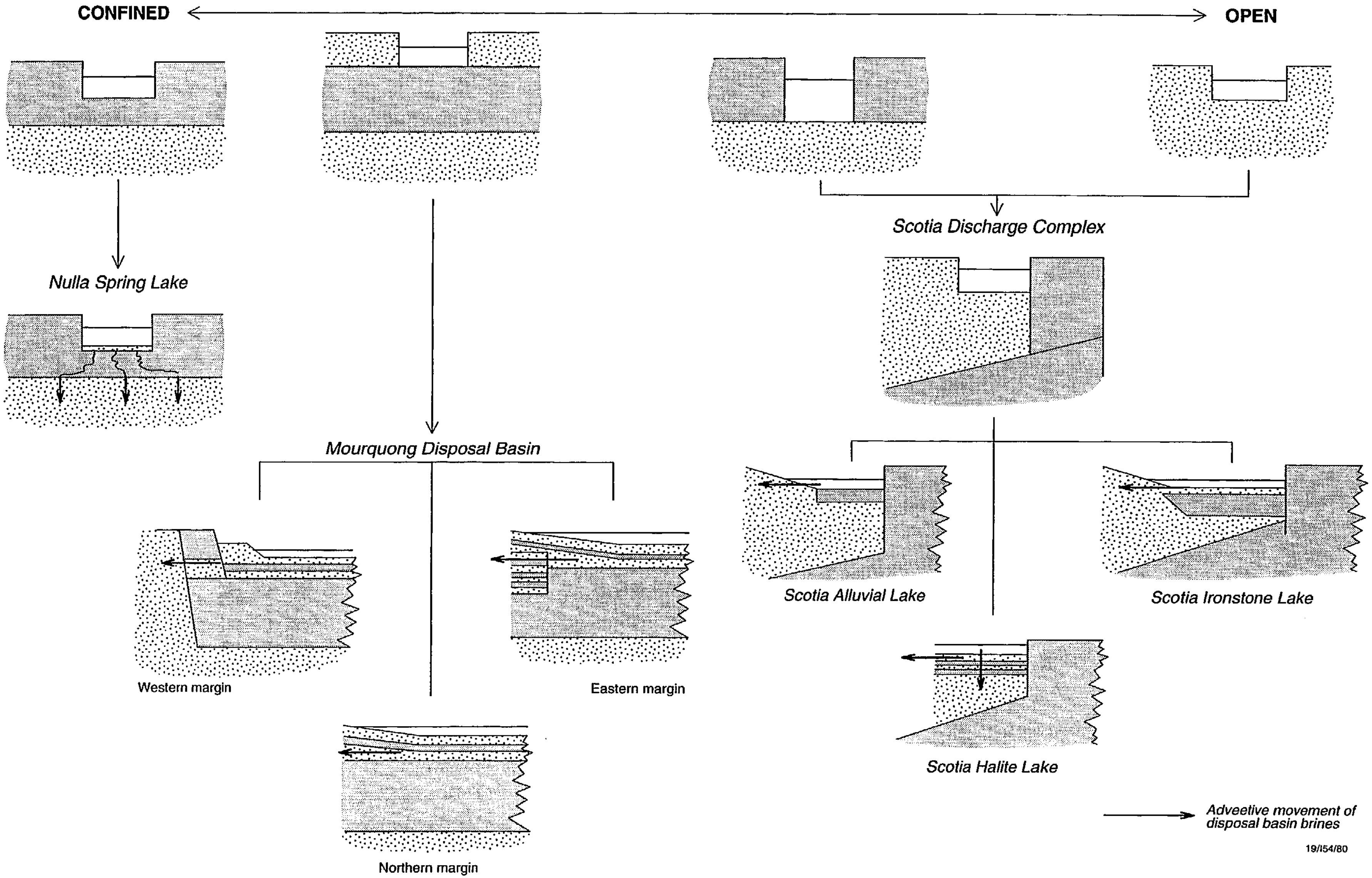

Figure 4. Relationship of hydrodynamics to permeability distribution in disposal basins (from Ferguson and Radke; 1994).

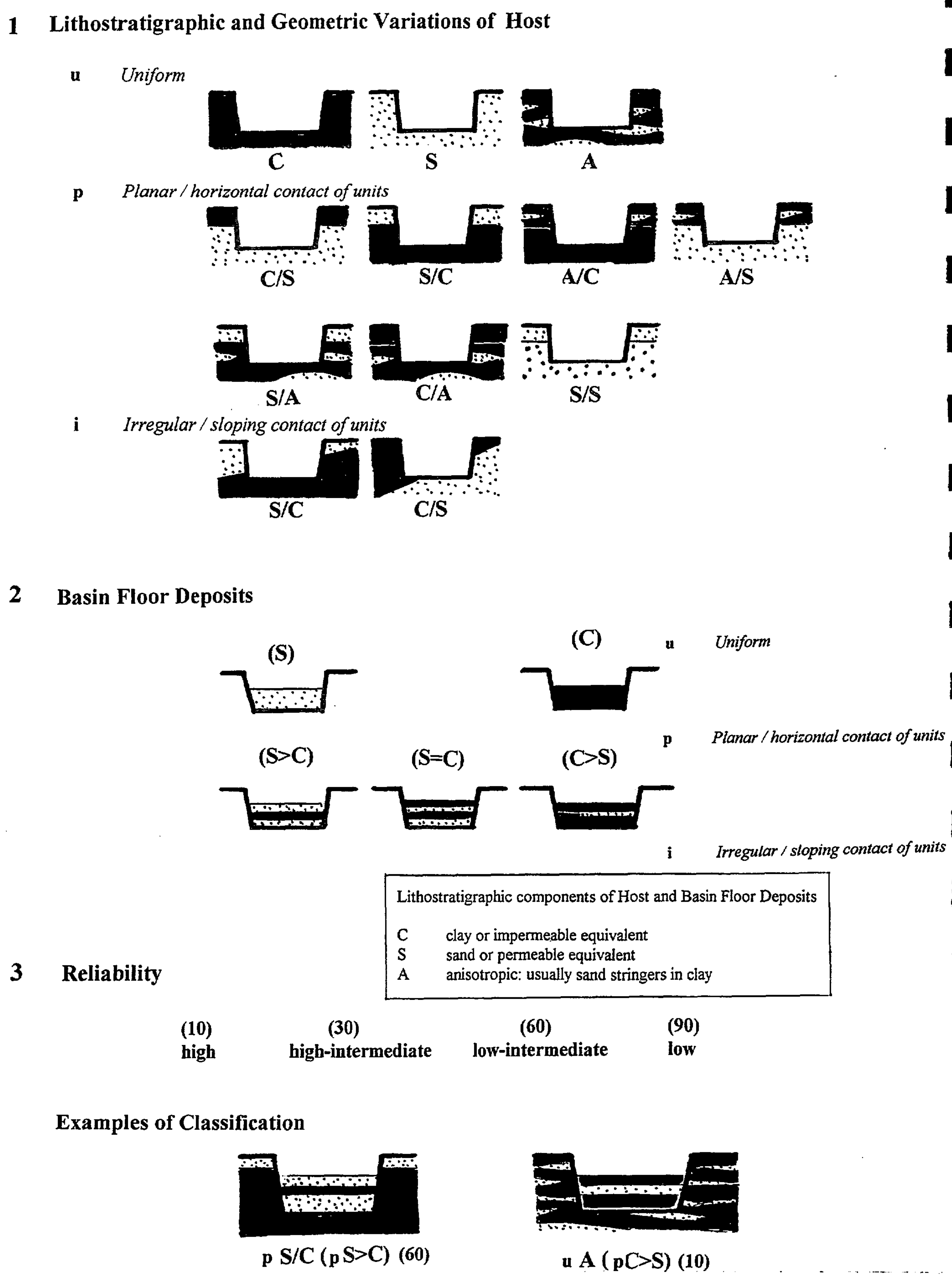

Figure 5. Lithostratigraphic classification of evaporation basins (from Radke and Hostetler; in preparation).

Burkes Flat - A Salinity Treatment Success Story

by
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Introduction

A 900 hectare catchment at Burkes Flat, near St. Arnaud, (Figure 1) was chosen for investigation and treatment of salinity in the rolling sedimentary rises country of Central Victoria. Salinity was first recognised as a problem at Burkes Flat in the 1930s. Aerial photographs confirm the development of severe salinity at breaks of slope and within drainage lines between 1947 and 1963. By the mid 1980s, the salt affected areas occupied 12% of the catchment, causing substantial losses to farm production and exporting 700 tonnes of salt to the Avoca River each year (CLPR, 1993).

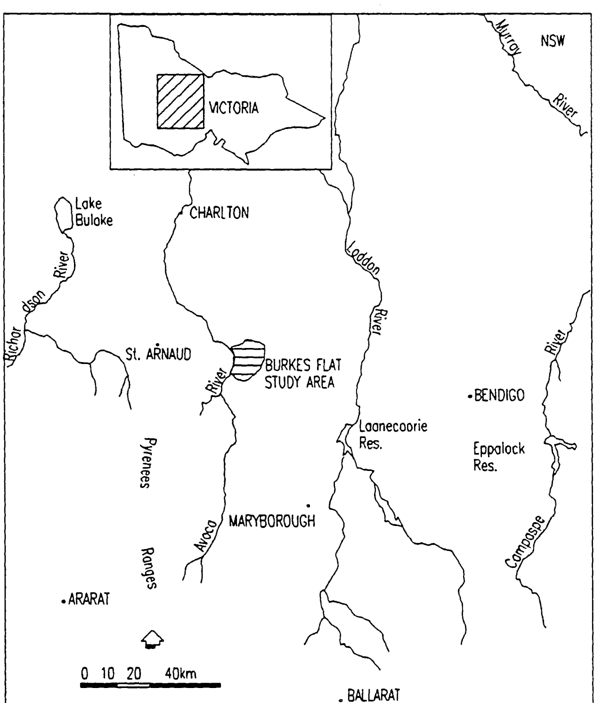


FIGURE 1. LOCALITY PLAN

The Burkes Flat Group Conservation Area was declared in November, 1968. In early 1983, a pilot project in this area was funded by the National Soil Conservation Program for investigation, treatment and monitoring of dryland salinity. With the support and assistance of the four landholders in the selected project area (J.Gallacher, B.Scollary, B.Rinaldi and W.Roger) and other members of the local community, a catchment treatment plan was developed. Investigations carried out by Day (1985), including recharge mapping, provided the hydrogeological framework upon which the treatment plan was based and assisted greatly in targetting the treatment. The plan covered the whole catchment, its aim being to establish a farming system which would increase the uptake of annual rainfall, thereby lowering, or at least stabilizing, groundwater levels (CLPR, 1993).

Between 1983 and 1986, native trees were planted on the mapped high recharge areas and lucerne and phalaris-based perennial pastures were established on the low to moderate recharge country between the tree plantations and the discharge area. The discharge area was fenced off and planted to salt tolerant grasses, primarily tall wheat grass. By August, 1986, 90% of the catchment had been treated. Financial assistance was provided for tree and pasture seed with labour provided by each of the four participating landholders.

Twenty-six (26) observation bores have been established within and adjacent to the catchment (Figure 2) and monitored consistently at monthly intervals. By 1992, the watertable monitoring results were quite clear for most of the catchment. Watertables had dropped by between 1 and 4m in the middle to upper parts of the catchment and by up to 1m in the lower parts. In the discharge areas, the effect was not so apparent with watertables remaining stable, allowing for seasonal variability (Day et al, 1993).

This paper presents updated information and interpretation on groundwater trends and effects of salinity treatment at Burkes Flat. It describes and demonstrates the considerable benefits achieved through well managed perennial pastures and trees. These benefits include reductions in groundwater discharge with resultant improvement in the condition of the discharge areas.

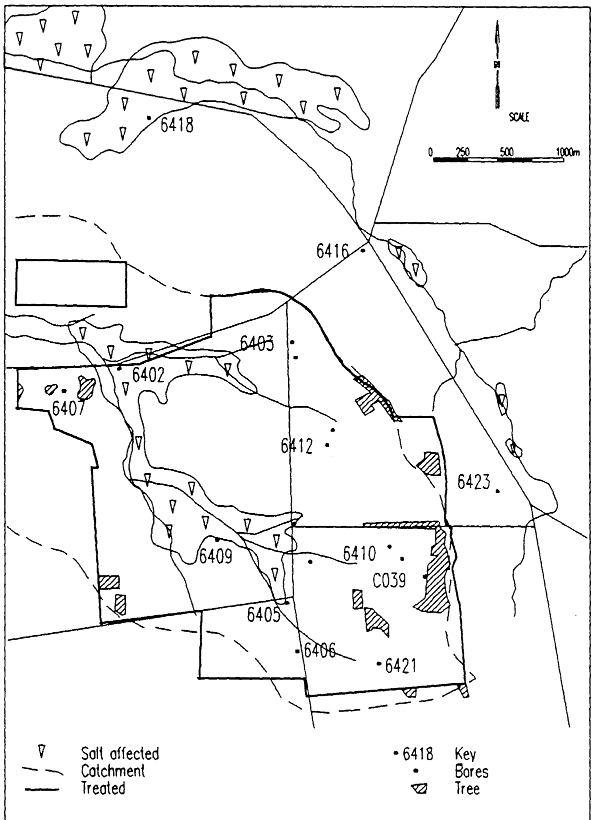


FIGURE 2. PILOT CATCHMENT & BORE LOCATION

Hydrogeology

The geology at Burkes Flat primarily comprises thinly bedded Ordovician (450 million years old) sandstones, siltstones and mudstones which form a landscape of rolling hills with slopes up to 15% (Day, 1985; CLPR, 1993 and Day et al, 1993). Weathered to depths of up to 70m, these rocks hold naturally high salt storages. Soils are typically shallow with rock outcrop common along the eastern and southern catchment divides.

Groundwater flow at Burkes Flat occurs within a network of connected fractures in the Ordovician bedrock. The low permeability of the weathered bedrock zone has given rise to relatively steep hydraulic gradients between the catchment divide and discharge areas. Day (1985), and Day and Dyson (1990) have shown that the groundwater flow system controlling the occurrence of salinity in the pilot catchment is localised and confined within the catchment boundary. The ramification of local flow conditions is that the recharge areas exist immediately adjacent to the discharge zones and complete treatment can be more easily devised and managed than for larger scale flow systems.

The work by Day (1985) also revealed that high recharge areas exist along the eastern and southern rims of the catchment on rocky ridges. Middle and lower slopes, with their deeper duplex soils, were mapped as moderate to low recharge.

Groundwater salinities in the weathered bedrock are typically high (>10,000mg/L TDS; CLPR,1993) and show a tendency to increase down the flow path. Values range from as low as about 300mg/L TDS in the upper parts of the catchment to as high as about 15000mg/L TDS in the salted areas (Day, 1985).

Groundwater Trends

Based on regional data, Day and Ryan (1992) estimated that the watertable in the Burkes Flat pilot catchment would have risen by an average of 10cm per year if it was untreated. This would broadly translate to an increase in salt affected land of about 1 or 2% per year.

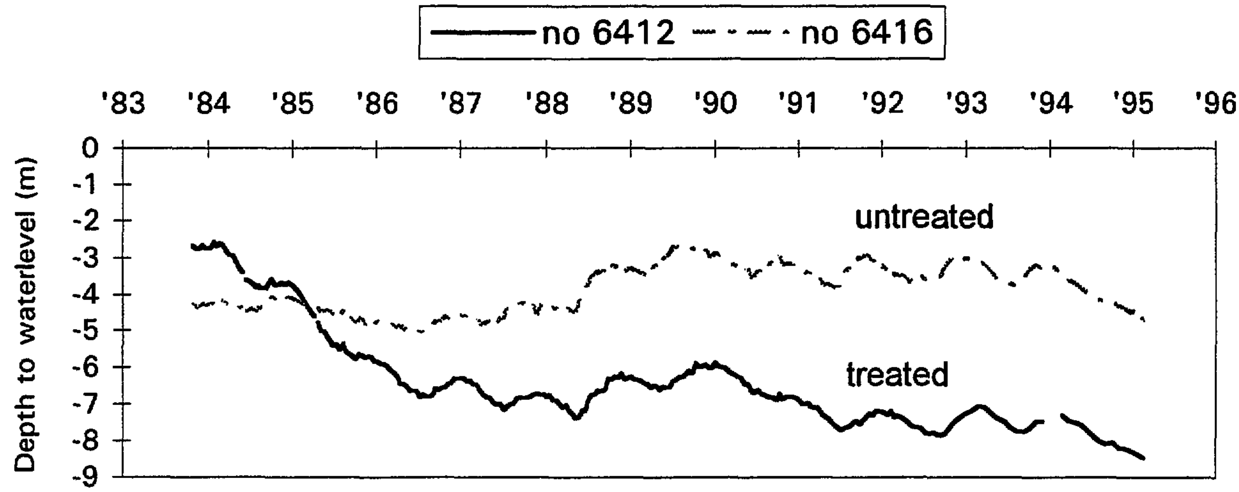
Monthly measurement of groundwater levels at the pilot catchment commenced in 1983, the year that treatment commenced. In the middle to upper parts of the catchment, substantial drops in levels of up to 4m were recorded as early as 1987, with the most significant decline occurring during 1985 and 1986. Despite wet years in 1988, 1989 and 1992, a general downward trend has continued in these areas (e.g, Bore 6412, Figure 3). Recorded total drops since 1983 are now up to 6m.

The actual impact of the treatment becomes more apparent when comparing groundwater trends in the pilot catchment with those in untreated areas outside the catchment. Figure 3 shows, as an example, the comparitive hydrographs of Bores 6412 and 6416 for the period, 1983 to 1995. Bore 6412 is situated within the upper reaches of the treated catchment in a lower to mid-slope position, while Bore 6416 is located amongst annual pasture in a lower slope position, approximately 500m outside the catchment.

In terms of general trend, the two hydrographs in Figure 3 can be subdivided into two periods, namely, 1983 to 1986 and 1986 to 1995. The first period records the steepest and largest drop in the 6412 level (approx. 4m) and the largest relative change between the two bores. The second period shows much less relative change but, nevertheless, a steadily increasing separation in the respective water levels until 1992. Since 1992, the separation has remained consistently around 3.8 to 4m and represents a turnaround of some 5.4 to 5.6m.

The most significant seasonal response differences between 6412 and 6416 have mainly occurred between late summer and early winter. This is particularly the case for the years 1984 to 1988, and 1991, where 6412 records substantial drops while 6416 is stable to slightly dropping during the same periods. This indicates that the perennial pastures were using much more water than the annual pastures during the dry summer/autumn seasons of these years.

Figure 3. Burkes Flat Bore Hydrographs



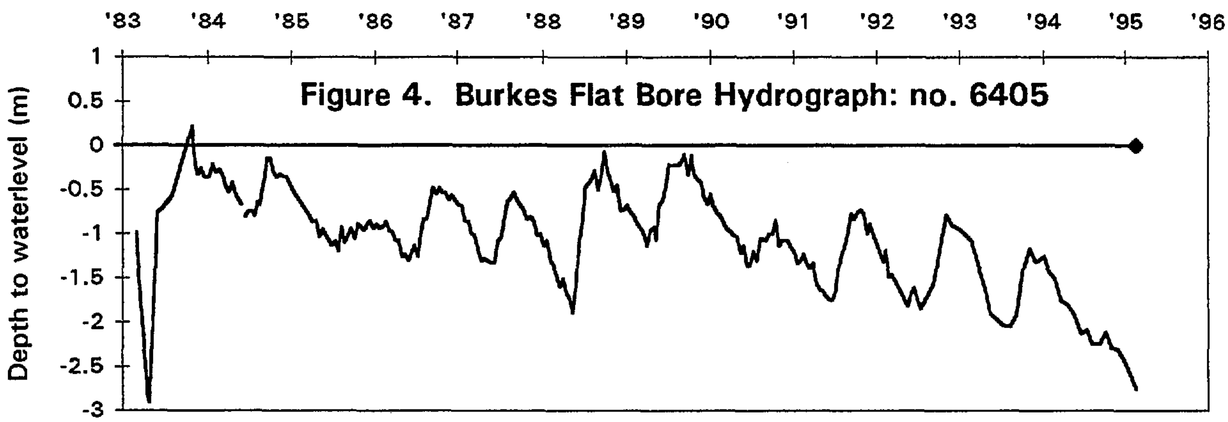


Figure 4. Burkes Flat Bore Hydrograph: no. 6405

Another very interesting feature of Figure 3 is the comparitive responses during the period from 1988 to 1991. The years 1988 and 1989 were wetter than average and the responses of the two bores are very similar in shape and magnitude, somewhat dispelling the "reducing recharge" reasoning in the strict sense. However, following these wet years, Bore 6412 recorded a fairly steep decline to a level which, by winter 1991, was actually about 35cm lower than the 1988 low, completely reversing the effect of the 1988/89 recharge. This contrasts strongly with 6416 which recorded only a relatively slight drop to a level about 65cm above the equivalent 1988 low. The 1990 winter/spring peak of 6416 is virtually absent in the 6412 hydrograph, suggesting that perennial pastures were using up more of the excess soil water store during the drier conditions which followed 1988/89.

The above observations reveal two important points regarding the effect of perennial pastures on groundwater levels at Burkes Flat, particularly in the middle to upper parts of the catchment. One is that, in the early, formative phase, the pastures had a telling impact on groundwater levels, either by just depleting the soil moisture store or by also directly tapping into the watertable where it was sufficiently shallow. The other point is that, later, when mature, they were successful in totally negating the initial effect of the wet 1988/89 period by presumably using up most of the high soil moisture store and possibly also tapping from the watertable during the following drier period of 1990/91.

Further corroboration of the above observations is provided by hydrographs of other bores within and outside the middle to upper catchment. Within the catchment, similar downward trends and behaviour to Bore 6412 are observed in bores such as 6403, 6406 and 6410 which occupy lower to upper slope positions (Figure 2). Outside the catchment, to the east, another control bore, 6423, has record going back to 1987 which shows a slightly rising trend and behaviour similar to that of 6416.

Bore C039 is located in a rocky crest area planted to trees (Figure 2), and has recorded an overall drop in groundwater level of about 1m since early 1984. This appears to be a reasonable result given that the trees are not yet fully mature and the area is regarded as high recharge. Downslope influence of the trees is not certain but the nature and larger magnitude of the drops recorded in bores further down strongly suggests that the perennial pastures have been providing the main controlling influence on groundwater levels.

It is now clear from the hydrograph record that seasonal groundwater levels under the pilot catchment's upper discharge area have been steadily becoming lower. Dropping trends of 5 to 11cm/year have been recorded at three sites in this area (e.g, Bore 6405, Figure 4). In early 1995, the level in 6405 was approximately 2.5m lower than it was in early 1984.

At the lower end of the pilot catchment discharge area, the trend is not so clear. Allowing for the strong seasonal fluctuations, the Bore 6402 hydrograph seems to show a slight rising trend from 1983 to 1989 (approx. 3.5cm/year) and perhaps a slightly dropping to flat trend since 1989. It is probably reasonable to expect that changes at this end of the catchment will be more subtle and gradual than at the upper end of the catchment. The nearby lower slope bore, 6407 (Figure 2), seems to support this argument with its subdued and slightly dropping trend. Although the results from these bores are somewhat inconclusive at this stage, the condition of the lower discharge area has markedly improved in the opinion of landholder, James Gallacher (pers. comm.).

Further substantiation of the beneficial effects of the salinity treatment is provided in two ways by results from another control bore, No. 6418, which is situated in a large discharge area to the north of the pilot catchment (Figure 2). Firstly, the bore shows a steadily rising watertable trend of about 8cm/year from late 1983 to 1989. This contrasts greatly to the dropping trends of discharge site bores in the upper pilot catchment (e,g, Bore 6405) during the same period and is greater than the rising trend of Bore 6402 at the lower end of the pilot catchment discharge area. Secondly, since 1990, Bore 6418 has recorded a fairly strong declining trend of about 11cm/year despite wet springs in 1991 and 1992. Further enquiries (James Gallacher, pers. comm; Matthew McCarthy, Department of Agriculture, Energy and Minerals, pers.comm.) suggest that this could be explained, partially at least, by effects caused by significant land management changes in the adjacent area from 1990 to 1992. These changes include the establishment of lucerne and phalaris in a number of paddocks between Bore 6418 and the pilot catchment's northern boundary.

Figure 5 shows a schematic profile of ground and watertable elevations along a transect of bores in the pilot catchment (see Figure 2 for bore locations). The watertable elevations have been plotted, where known, for January 1984, January 1988 and January 1995. It can be seen that the watertable surface along the whole profile has dropped at each stage, and by a substantial amount overall. As is typical for the pilot catchment, the greatest magnitude of change has occurred in the upper reaches, leading to a general "flattening" of the watertable surface and, hence, a reduction in hydraulic gradient. From the available information, the reduction in watertables and hydraulic gradients appears to have occurred over the majority of the pilot catchment. If so, then this must mean there are now mostly lower horizontal groundwater fluxes and, therefore, significantly reduced groundwater discharge.

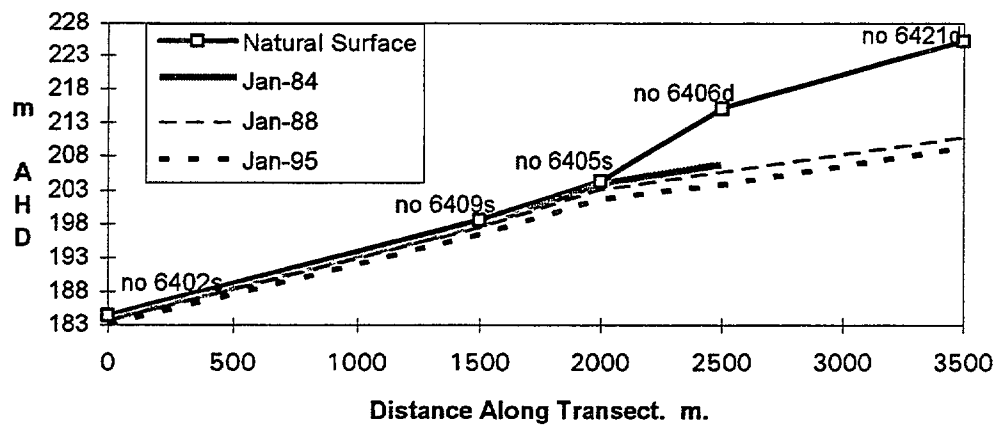


Figure 5. Time Series Watertable Profile.

Pilot Catchment Condition and Production

Most of the ridgetop tree planting has now been established for ten years and the success of the establishment is reflected by the generally good health, density and growth of the trees. It is expected that the trees will achieve maximum water uptake during the next five years. Lucerne and phalaris pastures have consistently achieved good strikes and flourish on the middle and lower slopes. The pastures have outperformed annual pastures in adjacent catchments and their condition has been generally better during dry spells.

Records kept by James Gallacher for his property, which is 729ha in area and occupies the majority of the pilot catchment, show an almost 100% increase in wool production between 1983 and 1990 (from about 12kg/ha to 24kg/ha). Production levels since 1990 have been maintained at around 23 to 26kg/ha (James Gallacher, pers. comm.).

Recent inspections and discussions with James Gallacher strongly point to a considerable improvement in the condition of the pilot catchment discharge area since 1983. The improvement has been qualitatively gauged from observations of the following:-

a) general appearance;

b) plant cover;

c) soil stability;

d) extent of bare soil; and

e) overall extent of the degraded area.

Improvements have been observed in the first three of these criteria and a significant reduction has been observed in (d). It could be inferred from this that some improvement in the productive value of the catchment discharge area has also occurred.

In regard to (e), there is not yet clear evidence on change, one way or the other. Despite this, common opinion (anecdotal) seems to be that so far there has been little, if any, change in the actual area affected by salt (originally estimated to be approx. 100 ha). If true, this in itself should be regarded favourably because, based on the local and regional evidence, a further significant expansion of salt affected land was highly probable if the treatment was unsuccessful. If the groundwater levels had continued to rise at an average rate of 10 cm per year (estimated for untreated conditions by Day and Ryan, 1992; see **Groundwater Trends**), a noticeable expansion would have been expected by now (possibly up to 25% expansion). That apparently little or no expansion has occurred is a good sign, particularly considering the number of wet years that have occurred since treatment began.

In contrast to the pilot catchment discharge area, the condition of some untreated discharge areas (i.e, no recognised effective treatment to control the recharge) in similar, neighbouring catchments to the west and south, has noticeably deteriorated in the last five or so years, according to local landholders. An inspection of these catchments has shown that their discharge areas are currently in much worse condition than that of the pilot catchment.

Accurate, quantitative assessment of changes to salt affected land in the Burkes Flat area will be possible in the future with the recent establishment of a treated and untreated pair of monitored discharge sites. The treated site is within the pilot catchment and the untreated site is within a catchment to the south, mentioned above. Both catchments are similar in terms of climate, topography, geology and groundwater systems. The monitored discharge sites have been established as part of a Statewide initiative to measure the effectiveness of salinity management plans.

Conclusions

Success in terms of a significant decline of groundwater levels in the upper part of the pilot catchment and an improvement in agricultural production has been previously documented (Day and Dyson, 1990; Day and Ryan, 1992; CLPR, 1993 and Day et al, 1993), though the effect on the catchment discharge area was not clear. This paper has presented updated evidence to show that the groundwater declines have continued to occur, are more widespread than previously documented, and are occurring in the discharge area.

The main conclusions drawn from the updated evidence are, (i) that the salinity treatment has been effective in reducing watertables and providing productivity benefits over most of the catchment, including the discharge area, and (ii) that the perennial pastures have had the greatest controlling influence on watertables in the catchment over the past eleven years.

Virtually all observation bores in the pilot catchment, including most of the discharge site bores, have shown declining groundwater level trends. Many of the bores, particularly in the upper part of the catchment, now have substantially lower levels (by up to 6m) than when first measured during or following the salinity treatment in the eighties. In contrast, two control bores located in untreated areas outside the pilot catchment (Bores 6416 and 6423) show rising trends with current levels higher than or similar to original levels. A third control bore in a discharge area to the north (Bore 6418) has displayed a marked dropping trend since 1990. However, it could be argued that this is in response, partially at least, to salinity treatment and improved land management in the adjacent area between 1990 and 1992. Prior to 1990, this bore recorded a consistent rising trend.

It is concluded from the reduced groundwater levels across the catchment, combined with the generally lower hydraulic gradients, that the amount of groundwater discharge has reduced. While retraction of the pilot catchment's discharge area is not obvious from the information available at this stage, it can be concluded that there has been considerable overall improvement in its condition and little, if any, expansion. This has happened despite several years of above average rainfall during the period from 1988 to

1993 and is attributed partly to the actual discharge area treatment and partly to the recharge treatment. By comparison, the conditions of discharge areas in a couple of neighbouring untreated catchments are noticeably worse, and deteriorating.

The evidence presented and discussed in this paper provides compelling confirmation of the salinity control and productivity benefits of well managed perennial pastures and trees on ridges in a localised sedimentary bedrock groundwater system in undulating rising country. The Burkes Flat pilot catchment project has proven to be an excellent example of salinity control through community involvement in catchment planning and productive land management. Its success should provide strong encouragement for the adoption of similar strategies in this commonly occurring type of area.

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Groundwater Monitoring And The Community - Improving Data Collection And Feedback In Victorian Dryland Salinity Regions.

by
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Introduction

Community involvement is integral to the successful implementation of salinity management plans. Because of the well established links between groundwater processes and dryland salinity, groundwater monitoring has been recognised as a vital tool in helping to prioritise areas for treatment and in measuring the effectiveness of treatment and, ultimately, the plans.

Regional offices of DCNR and CLPR have over the last fifteen or so years, developed an extensive and detailed network of more than 5000 bores across the dryland regions of Victoria. Data collected from these bores is currently stored in a groundwater database managed by CLPR. Monitoring of the bores has, historically, been carried out in a loosely coordinated fashion by a combination of staff from DCNR regional centres, staff from CLPR and some landholders. With recent changes to DCNR structure and operations and an increased emphasis on community involvement, the number of community people monitoring bores is steadily increasing.

In the latter part of 1994, CLPR completed a review of groundwater monitoring procedures to address deficiencies identified in the monitoring network, existing monitoring practices, transfer of collected data and feedback of results to the community. The deficiencies had led to a loss of effective communication between landholders and DCNR on groundwater trends and some inconsistencies in the quality and frequency of collected groundwater data.

As a result of the review, a number of changes are being progressively implemented to improve the way groundwater data is collected, stored, processed and transferred. These changes will eventually lead to a significant increase in community participation in the monitoring process and interpretation and distribution of results. This in turn will, hopefully, generate a much better general community awareness of and interest in groundwater trends as indicators of salinity risk and effectiveness of salinity treatment strategies. Important in all of this will be the communication links between DCNR, CLPR and the community, and the use of DCNR's Information Technology.

The Need For Review of Monitoring

The need for review of DCNR groundwater monitoring procedures has been necessitated for a number of reasons alluded to above and covered in Heislers and Reid (1995). They can be categorised as follows:

- lack of feedback to the community on groundwater trends
- lack of coordination of and communication with groundwater monitors
- incorrect groundwater monitoring practices
- inadequate groundwater data transfer procedures
- bore identification and maintenance problems

The kinds of problems caused by the above include:

- lapses or irregularities in monitoring
- innaccurate or dubious groundwater data
- lost or strayed data
- inefficient monitoring networks
- lack of groundwater salinity data
- poor bore condition, sometimes preventing measurement or resulting in spurious data
- lack of community awareness and loss of interest
- results (good or bad) not readily getting out to the community

The review looked particularly closely at the development of more effective links between CLPR, which manages the DCNR groundwater database, and the DCNR regional offices. This was seen as critical in enabling provision of useful groundwater information to the community, both on a regular basis and on demand.

Groundwater data integrity depends, among other things, upon consistency and regularity of monitoring. With the movement now more towards community based monitoring, quite a number of areas are being monitored by groups of unpaid landholders, each landholder responsible for one to several bores within or close to their property. It is therefore important to have a reliable and effective communication and data transfer network in place (see below). However, with complete and faithful adoption of the framework for improved monitoring, outlined below, this seemingly complicated type of monitoring arrangement should prove to be reliable and successful. Nevertheless, in some cases, where agency monitoring is being transferred over to the community, adoption of paid community groundwater monitoring will be a more appropriate option. Already, in some areas, the community has been contracted to monitor bore networks and supply groundwater data.

Framework for Improved Monitoring and Information Transfer

To improve groundwater monitoring and the transfer of groundwater information between CLPR, DCNR Regions, monitors and the community, the following framework, in five parts, and based on Heislers and Reid (1995), has been established.

1. Communication and Data Transfer

Each of the DCNR offices in salinity regions now have clearly identified contact officers responsible for the reception and transfer of groundwater data from community monitors in their respective areas. These officers are the important link between the community and the CLPR.

The DCNR regional offices have been provided with a software routine and user manual enabling the contact officers to plot groundwater hydrographs on demand. CLPR will provide any necessary continuing support in software installation and training in analysis and interpretation of hydrograph trends.

Simplified technical information on groundwater monitoring has been disseminated via the regional offices and landholder groups. The information is in the form of a couple of easy-to-read CLPR leaflets, entitled as follows:

- "The importance of groundwater monitoring" (CLPR, 1994); and
- "The way to better groundwater monitoring" (CLPR, 1994a).

CLPR has produced specially designed groundwater data recording booklets for issue to each community monitor. In addition to entry of groundwater level readings, the enclosed duplicate data recording sheets provide for entry of monthly rainfall and electrical conductivity readings of groundwater, along with any comments on things affecting the bore or the readings. The booklets have already been widely distributed and are designed so that monitors can send in data to their respective contact officers on a six monthly basis (April and October). The monitors have been instructed on the correct use of the booklets and told to follow this six monthly routine. Once collated at the relevant regional office and entered into that office's database, the new groundwater data will be forwarded to CLPR for entry into DCNR's groundwater database.

Meetings or field days are being arranged with various groups of community monitors to convey the revised data collection and transfer arrangements, issue recording booklets, check/supply monitoring equipment and instruct on correct bore monitoring technique and data recording. Further meetings/field days will be arranged for new groups and on an 'as needed' basis for existing groups to keep them informed of results and to ensure that good monitoring standards are maintained.

CLPR has undertaken to provide regular community reports (annual or biennial as required) on the groundwater trends for each region it is responsible for investigating. These will include simplified appraisals of the trends and behaviour of key bores selected in each region as well as an overview of trends in the catchment. Their will be close reference to the land management units (LMUs) and any salinity treatment where good groundwater record exists.

In parallel with the community monitoring reporting will be technical reporting of groundwater trends. The aim is to carry out a detailed appraisal of groundwater trends and behaviour for a third of the LMUs in each catchment, each year, over a three year cycle.

The community monitoring reports will be mainly targetted at monitors and landholder groups. They will be disseminated via the various regional DCNR offices and community salinity forums. The technical monitoring reports will be aimed more at the technical working groups. However, the pertinent results will be relayed to the community through the salinity forums, field days and seminars.

2. Monitoring Efficiency and Data Reliability

Regular frequency of monitoring is important for accurate seasonal correlation of water levels from year to year. Accordingly, it has been impressed upon the monitors in each region to take readings at the same time of each month when a reading is due. The timing will be consistent across each area, usually the first week of the month.

To alleviate the inconsistencies caused by varying equipment standards, CLPR is producing 'fox whistles' (measuring tape devices for water level measurement in bores) and bailers (for collecting bore water samples) that are constructed to a common standard. These are available to all monitors.

To further improve monitoring efficiency, DCNR bore networks are currently being reviewed by CLPR hydrogeologists in terms of monitoring frequency. For example, where five or more years of continuous monthly record has been obtained, it may be decided, depending on the nature of the trend and other factors, to reduce the frequency to, say, twice yearly. It is planned to repeat the review process every one or two years.

Collection of groundwater salinity data is an important component of the groundwater monitoring program but has tended to be lacking or infrequent in many areas. To address this, CLPR are selecting key bores in each dryland salinity region for measurement of electrical conductivity on an annual (April) or twice yearly (April and October) basis.

3. Bore Maintenance and Numbering

Long term collection of quality groundwater data is also dependent upon regular and appropriate bore maintenance. To gauge the condition status of the DCNR bore network, CLPR are undertaking a census of all bores in each DCNR region. Much of the State has already been covered. It is envisaged that this census will only be necessary once, because, thereafter, the monitors will have the knowledge and the mechanisms to report on bore condition. The information collected in the census will be used to develop a bore maintenance program.

Bore maintenance will be an ongoing, combined DCNR Region and CLPR activity. Strict standards have been set for bore construction and adherance to these should minimize maintenance problems.

All DCNR bores now have a unique DCNR groundwater database number. However, a lot of the older bores are still not clearly or properly identified, many still showing the old local numbers. Relabelling of these bores is now being carried out as a priority activity in conjunction with the bore maintenance program. In future, all new bores will be clearly labelled on completion with their unique DCNR groundwater database number.

4. Bore Site Classification

As a part of the above bore census, the LMU, the landscape position of the bore (e.g, discharge; lower slope; crest, etc.) and observations of land cover in the immediate area are also being noted so as to aid later in the interpretation of groundwater trends.

5. Information Technology

The use of the DCNR Wide Area Network (WAN) to access statewide groundwater information has significantly improved the availability of that information to DCNR regional catchment management officers and the community. Data collected under the Victorian Government Services Contract and the State Salinity Program has been imported to a relational groundwater database which can be directly linked to the DCNR Geographic Information System (GIS). The GIS Corporate Library holds information such as LMUs, land systems, topography, remnant tree cover, agricultural land use and climate.

CLPR will be making extensive use of the GIS and groundwater database to synthesize groundwater data and present findings to the communities. The combination of the geographic information base with the time series information held in the groundwater database will enable the findings on groundwater trends to be more effectively related to other relevant natural resource and land management information.

Longer term aims include the establishment of facilities via Email (World Wide Web) to access groundwater information.

Summary

With the main aims of achieving a high level of community awareness of groundwater trends (and effectiveness of salinity treatments) and a high quality of useful groundwater information in the Victorian Dryland Salinity Regions, the following important changes and innovations have recently been introduced by CLPR:

- A policy of progressively increasing the level of community based groundwater monitoring.
- Provision of guidelines and standards for community based groundwater data collection (including provision of specially designed groundwater data recording booklets).

- The establishment of a formalised network of agency based contacts and data entry and access points across the State.

- Coordinated entry of groundwater level and salinity data into a central groundwater database at CLPR (the database will be linked to the GIS in order to improve the quality and usefulness of groundwater information).

- A program of annual or biennial reporting of groundwater trends to the community for each dryland salinity region.

For Victorian dryland areas in general, the above changes and innovations will eventually lead to a substantial increase in the participation of the community in the data collecting and transfer processes. This in turn will greatly improve community awareness of groundwater trends, priority salinity areas and effectiveness of salinity treatment strategies, thereby increasing the adoption rates of recommended treatment and also allowing well informed refinement of salinity plans.

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Hydrogeological Characterisation of the Axe Creek Sub Catchment - Victoria

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Recent significant developments in geographical information systems have been used to develop new methods for hydrogeomorphic classification of large catchments. This classification has been used as a surrogate for hydrogeological characterisation of catchments.

Hydrogeomorphic maps for the Axe Creek subcatchment in the Campaspe region in north-central Victoria have been prepared using a 20 m DEM. The hydrogeomorphic units showed very good correlation with detailed traditional geomorphic mapping done previously for the subcatchment.

The hydrogeomorphic units reflected most of the major geological features of the area. These include the Whitelaw fault (reverse thrust slip fault) extending in an NW-SE direction and the N-S strike of the steeply dipping Ordovician rocks, which form sharp steep ridges southwest of the fault and less steep ridges where softer rocks occur in the northeast were identified in the hydrogeomorphic map. The major drainage lines which follow a NE direction were also clearly picked by the HGU classification.

Groundwater level maps were prepared for the catchment (using regression between the water levels and the surface elevation and controlled by the hydrogeomorphic classification and vegetation cover). Broadscale and detailed flownets were also constructed and fluxes calculated.

Salt loads from two gauging stations were used to calibrate the fluxes. Detailed downhole electromagnetic surveys were used to estimate the salt contribution from the different hydrogeomorphic units.

Recharge was calculated from borehole hydrographs and separated into two major components. These are seasonal recharge to the top aquifers which eventually discharges to the streams or leaves the catchment as underflow and a residual (annual cumulative) recharge which causes an annual rise of water level of 0.01 - 0.2 m yr^{-1}.

Minimising Water Transfer Effects on the Murray - A Community Group's Role

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Summary

The Nyah to SA Border Salinity Plan was developed by a group of community irrigators. The plan, based on firm technology including a comprehensive hydrotechnological study, encourages the most efficient use of water (through water entitlement transfers for new irrigation development) while minimising the impact of irrigation on the River Murray and its environs.

Introduction

North West Victoria was chosen as the site for one of the first major irrigation settlements in the 1890s. A lack of understanding of the land/water relationship led to major drainage problems causing nutrient and saline pollution. In addition the geology of the area leads to considerably increased saline groundwater inflows into the River Murray. The entire area was tile drained during the 1920s and 1930s due to the rising saline watertables threatening crop production. Further development in the 1960s, particularly at Nangiloc and Colignan upstream of Mildura, led to similar groundwater and drainage problems. Today expensive drainage works are being installed in this area.
A better understanding of the hydrogeological systems of the riparian zones and the expected consequences of water reform identified the need for a strategy to cope with further development of irrigation properties along the Murray and so minimise any further degradation of the local environment (particularly the wetlands) and pollution of the river.

As a consequence a community group was formed to determine future development policy in the Nyah to SA Border area. Their brief was to provide guidelines for development that :

- was compatible with the MDBC Irrigation and Drainage Strategy.
- encouraged the most efficient use of water in economic terms.
- minimised impact on the environment.
- was socially fair to existing irrigators.

The Nyah to SA Border Salinity Planning Group were well resourced by the Victorian Government with funds for administrative and technical support.

Water right in the Nyah to SA Border area

Originally water licences were granted for specific areas of land. This was done deliberately to ensure development of that land took place. However this eventually led to an inflexible system where many properties did not fully utilise their water entitlement. This led to underutilisation of the water resource. Other properties had fully developed their entitlement and were relying on unsecured sales water to irrigate permanent plantings. Some flexibility was introduced in 1987 when the irrigator had the option of purchasing extra land with water right and transferring the water to their original holding. The likely advent of new water from Dartmouth Dam and new water legislation in 1989 that would free the link between irrigation water licences and the land, made it timely to introduce new policy.

Hydrogeological Methods

Prior to the Nyah to the SA Border Hydrogeological Study, which was undertaken for the development of the Salinity Management Plan, very little was known of the shallow hydrogeology in the Mallee tract of the Murray River. A field based hydrogeological investigation was undertaken which involved the drilling and construction of 275 monitoring bores in 25 section lines along the Murray River between Nyah to the SA Border. Groundwater data was collected from these bores over a number of years, including groundwater level and water chemistry. Based on this data, numerical groundwater models of eight "type case" situations were developed. These models were used to predict the effect of additional irrigation within the eight areas, on this reach of the Murray River. The detailed methodology, results of drilling and modelling results are presented in Thorne *et al.* (1988).

Results from the hydrogeological investigation

From the numerical modelling it was found that the salinity impact of irrigation on the Murray River varied greatly. The main factor on which it depended was the hydrogeology of the underlying sediments. Areas that had a high conductivity aquifer, in close connection to the River and also had high natural groundwater salinity, seeped large amounts of salt into the Murray River.

In some cases the existing irrigation impacts are delicately balanced, so that any increased irrigation would lead to marked increases in saline inflows. From the field modelling and monitoring it was possible to predict which areas in the Nyah to SA Border region would be particularly susceptible to high saline inflows if new irrigation development took place.

Development of Irrigation Hazard Zones

From the results of the numerical modelling, it was possible to convert the amount of salt expected to be displaced to the Murray River per ML of irrigation water applied. At this stage of the Plan development, internal Government discussions led to the tentative establishment of three "Hazard Zones" based on the likely salt load to be displaced, and the expected economic cost of the salt in the Murray River. This economic cost is usually expressed in terms of EC in the River at Morgan (in South Australia). The hydrogeological study commissioned by the Nyah to the SA Border group estimated that unrestricted development was likely to result in an 11 EC increase in salinity at Morgan.

The zone boundaries were initially set at 0.2, 0.5 and 1.0 tonne of salt displaced to the river per ML of irrigation water applied. These were converted to lines on a map using both the existing hydrogeological understanding and the results of the eight "type-case" models. The map with these zones was then passed to the Community Working Group for comment.

Community Modification of the Zones

The Nyah to the SA Border Salinity Management Plan Community Working Group considered the hazard zones in draft form, with the three zones and also evaluated the likely impact of their use on irrigators. After much discussion and consultation, it was agreed that the administration of three separate zones would be difficult and would not yield significant improvements in river water quality over a two zone system. From this, the two lower hazard zones were amalgamated to form the "Low Impact Zone" (LIZ) and the "High Impact Zone" (HIZ), differentiated by whether more or less than 1 tonne of salt would be displaced by 1 Ml of irrigation.

Two areas of HIZ were identified. One occurs immediately upstream of Robinvale and included the private diverters of Tol Tol. The second larger area starts upstream of Red Cliffs and covers land through to Lindsay Point near the South Australian Border.

The Salinity Plan

The Nyah to SA Border Salinity Planning Group developed the following recommendations for government consideration:

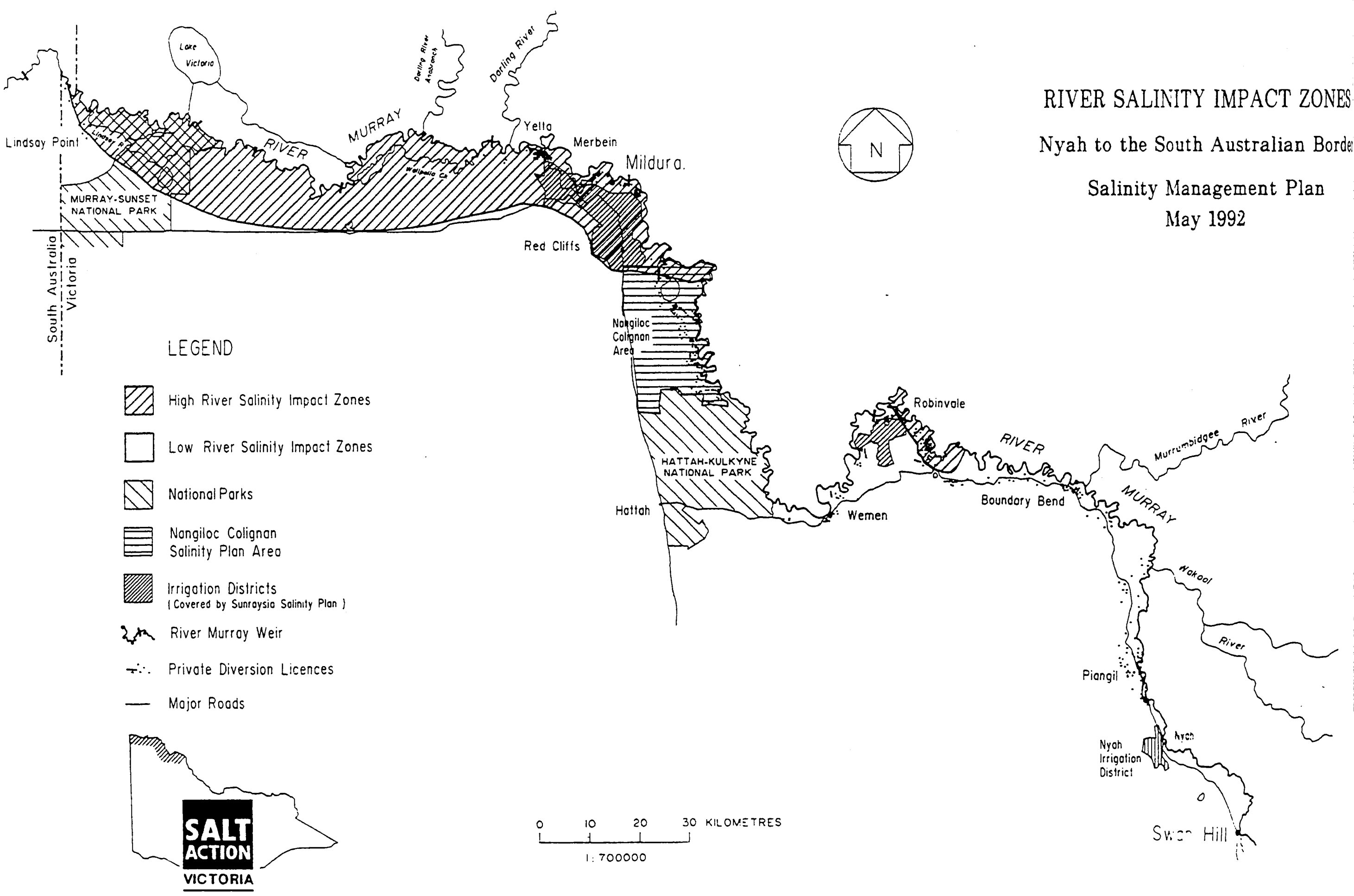
- Irrigators of existing land would not be penalised by withdrawal of water right.
- Licensed water was categorised into two types - water that was used for irrigation prior to August 1993 (used water) and water that has never been used for irrigation - (sleeper or unused water).
- Any new irrigation development would be required to meet strict specifications prior to the licence being granted.
- They also developed guidelines for Transferable Water Entitlements (TWE) (see Table 1).
- All water can be bought or sold in the Nyah to SA Border area.
- Water that is currently used or has been used in the HIZ between 1989-1993 may be transferred to either the HIZ or LIZ. This effectively limits the area of irrigation in the HIZ. To encourage water transfer to LIZ, the government will pay a $50/Ml bonus for HIZ used to LIZ transfer.
- All other water (HIZ unused and LIZ) may only be transferred to LIZ. There is no bonus attached to this transfer.
- Irrigators with unused entitlements (even those presently tied to HIZ land) will be able to develop irrigation on that land provided they meet the planning requirements set for TWEs.

Table 1. Eligibility of water entitlement transfers

Water entitlement transfer	Permitted
HIZ used to HIZ	✓
HIZ used to LIZ	✓ +$50
HIZ unused to HIZ	X
HIZ unused to LIZ	✓
LIZ to HIZ	X
LIZ to LIZ	✓

As well as meeting the zoning regulations for water transfer, growers who wish to develop new land in the Nyah to the Border area also have to meet stringent guidelines before a licence to irrigate is granted. These include:

- An environmental impact statement that demonstrates that the environment will not be damaged by the proposed irrigation.
- A land use capability study including soil survey, drainage hazards and potential readily


RIVER SALINITY IMPACT ZONES
Nyah to the South Australian Border
Salinity Management Plan
May 1992
LEGEND
High River Salinity Impact Zones
Low River Salinity Impact Zones
National Parks
Nangiloc Colignan Salinity Plan Area
Irrigation Districts (Covered by Sunraysia Salinity Plan)
River Murray Weir
Private Diversion Licences
Major Roads
Lake Victoria
Lindsay Point
MURRAY-SUNSET NATIONAL PARK
South Australia
Victoria
RIVER
MURRAY
Darling River
Yelta
Merbein
Mildura
Red Cliffs
Nangiloc Colignan Area
HATTAH-KULKYNE NATIONAL PARK
Hattah
Wemen
Robinvale
RIVER
Boundary Bend
MURRAY
Murrumbidgee River
Wakool River
Piangil
Nyah Irrigation District
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available water holding capacity of the land must be completed.

- An irrigation design of acceptable standard and irrigation shifts that match soil water holding capabilities in the variable and patchy Mallee Soils.
- Plans are in place for good irrigation management including a recognised scheduling technique.

A kit identifying all of the requirements that have to be fulfilled prior to the transfer of water taking place has been produced. Any grower who shows interest in water transfers is given the kit.

The requirements are attached to the water licence of the new development. Failure to comply with the conditions could result in the water licence being revoked. Rehabilitation of areas of environmental degradation caused by irrigation are to be at the irrigator's expense.

Outcomes

At June 1995, previously unused water was selling for as much as $400/Ml while HIZ used water was fetching $700/Ml.

A total of 42 water transfers has taken place using the TWE scheme to move 6717 Ml of water in the Nyah to SA Border region in 18 months. This has included transferring 360 Ml of used water from the HIZ to the LIZ.

Completion of the requirements for TWEs has led many irrigators to better understand their land's potential and now willingly employ means to make optimum use of the land in a sustainable manner. Some irrigators have recognised the benefits of the irrigation and drainage management plans (compulsory for TWEs) to maximise their knowledge of their land and its potential and now undertake them, even when not carrying out a TWE.

Conclusions

The Nyah to SA Border Community group has developed guidelines that minimise the effects of water transfers on an intra-regional basis.

The Nyah to SA Border Salinity Plan provides a good model for irrigation development. The Plan is based on sound technology but the guidelines have been crafted with due cognisance of the social and economic aspects and with regard for environmental heritage.

With inter-regional and interstate water transfers currently under consideration, now is the time to develop guidelines to ensure that the environmental effects of water transfers are not ignored in the chase for financial rewards.

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Precipitation Intensity and Duration Models Derived from a Critical Analysis of Historical Rainfall Data

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Between December 1994 and January 1995, CSIRO undertook processing of climate data required by a complex land-atmosphere interaction model intended for use in addressing dryland salinity (WaVES model). Source data was supplied by the National Climate Centre of the Bureau of Meteorology (BOM).

Data were used to reproduce values for daily precipitation (sourced from BOM daily climate records) and to develop an index of daily precipitation duration (based on BOM 3-hourly climate records).

It was intended that 3-hourly precipitation records be analysed in the context of total daily precipitation to obtain a relative rainfall duration index for each day of a period of approximately 30 years for one BOM station at Wagga Wagga, NSW. The 3-hourly surface climate data set contains 141,494 records covering the period between 18/08/41 and 31/10/93, although the precipitation record is not complete for all this period. The daily surface climate data set contains 14,972 records covering the period 01/01/53 to 31/12/93.

A number of issues arose from this investigation concerning data quality and the quality of models and indices derived from these data.

Issues of data quality and error rectification were addressed. A simple model for the estimation of precipitation intensity based on findings in the course of critically analysing these data was derived. This model is explained in conjunction with a precipitation duration model developed jointly with Dr Ray Leuning.

These findings are based on analysis of records from only one BOM station. However, it is the authors' understanding that practices discussed herein with regard to the Wagga Wagga AMO (station no. 72150, located at Longitude 147.46°E Latitude 35.16°S) are typical of other weather stations in Australia.

BOM precipitation data
Comparison of 3-hourly records with daily precipitation totals showed substantial discrepancies, particularly after 1988. The discrepancy is most obvious in 1989, where the annual totals are 970 mm and 705 mm, respectively. Comparisons with data sourced from non-BOM stations show that daily climate record values should be considered more reliable than 3-hourly records.

After discussions with the BOM; critical analysis of subsets of the data in question; comparison with original log books used by BOM observers; reference to BOM procedural documentation and use of alternative sources of precipitation data, a list was compiled of the major contributing factors to the discrepancy between the 3-hourly and daily data sets. These are discussed in the order of their importance - that is, in the order in which they contribute in magnitude to the discrepancy.

Installation of the Automatic Weather Station
An Automatic Weather Station (AWS) was installed at the Wagga AMO station in 1987. The AWS, apart from having its own limitations, unintentionally exposed the deficiencies of 'pre-automated' BOM precipitation data recording practices. Most notable of the AWS current practice limitations are weaknesses due to human-machine interfacing in the 'post-automation' period.

The AWS at Wagga records sub-daily precipitation with the use of a Tipping-Bucket Rain Gauge (TBRG). As the TBRG bucket tips, the instrument makes contact with an element which registers 'one tip', representing an accumulation of 0.2 mm of precipitation to a remote digital readout in the station.

The weakness in the system appears to be that observers are required to manually record the information supplied by the digital readout. When no personnel are available to make this notation, the AWS will continue to register bucket tips without automatically logging the time of registration. The correct cumulative number of tips will register but staff will not know the correct time of registration. This forces staff to use discretion when logging precipitation retrospectively

Daily precipitation is recorded using a standard 200 mm rain gauge which is read by an observer at 9:00 am EST each morning. This reading, being the source of Wagga's 'official' rainfall, is observed and recorded with diligence.

BOM manual precipitation recording practices

It would have been convenient to assume that the installation of the AWS, plus some data processing errors or erratic practices in manual recording of output from the AWS, have caused the discrepancy from 1988 onwards. However, an investigation of 'pre-automated' precipitation recording practices has revealed that they can provide no more assurance of accuracy than the present system.

Prior to the installation of the AWS, a BOM observer made a manual observation of the precipitation accumulated in a standard rain gauge since the last observation, usually 3-hourly, and record the value in a log book. The values in the log book are reviewed and/or altered by the same observer prior to dispatch of the log books to the National Climate Centre.

Many 3-hourly observations are absent from the electronic data record of that time in places where, based on alternative sources of data, some rainfall must have occurred. In addition, there are a large number of days where total precipitation may equal the daily reading but many observation windows have no value logged. Some personnel within the BOM have suggested that there may have been occasions when observers were unable to read the gauge for reasons including bad weather and staff shortages.

These and other anomalies in procedure have led to incomplete logging of 3-hourly observations. At the end of the precipitation day (9:00 am), the observer would review whatever 3-hourly observations were collected and compare the sum of these to the daily (9:00 am) precipitation total. If the 3-hourly total did not equal the daily reading, the observer would 'rub-out' the 3-hourly values entered in the log book and replace these with new values. A BOM Surface Observations Handbook directs observers to proportionally adjust all 3-hourly observation for the 24-hour period to meet the daily total. However, this practice is not widely acknowledged by BOM officers. The official explanation is that observers 'use their own discretion' to adjust observations when 3-hourly and daily totals differ. Due to the lack of standards being applied, it is virtually impossible to construct any reliable adjustment reversal algorithm for the data based on proportional adjustment alone.

It is illogical that given discretion, adjustment practices will have been freely coordinated. Equally, it would be prudent to assume that errors have been made in log book adjustment, as is the case in any repetitive task.

On 27-28/04/60, where total 3-hourly value is 7.4mm and total daily value is 4.8mm, the 3-hourly observation recorded for 09:00 is curiously equal to the total daily precipitation.

There is no doubt that manual logging combined with AWS-observer interfacing, are the major contributors to data discrepancy. Knowledge of recording practices prior to the AWS must motivate users of these data to a degree of scepticism (and reprocessing) when data are applied to sensitive models or other decision platforms.

Instrumentation error

The TBRG is not an infallible instrument. An example of a significant error is when the TBRG malfunctions by failing to tip completely. If the instrument tipping mechanism is obstructed near the element which registers the tip, many registrations can be generated erroneously as the bucket rattles along the contact point.

In the days of manual adjustment, an observer would compensate for errors (supposedly by using their discretion). However, since the installation of the AWS, it appears that current quality control practices do not correct alleged instrument errors.

On 30-31/03/89, where the total 3-hourly value is 98.8mm and the total daily value is 1.6mm, there is one 3-hourly observation window with 98.0mm recorded. Over-registration due to possible instrument failure, while not large in comparative number of individual occurrences, has a substantial impact on the overall record and notably on statistics (such as means and standard deviations) for these data.

This type of error may prompt users of these data to erroneously assume 1989 to have been the wettest year on record for Wagga Wagga.

Electronic error due to rounding

Another issue arising directly from the installation of the AWS is that of rounding. The data transfer specifications of the computer system used by the BOM to transmit logged 3-hourly data to the National Climate Centre force 3-hourly precipitation observation values greater than 1.0 mm to be rounded to the nearest 1 mm. Observations less than 1.0 mm are not rounded.

Conversely to the instrument failure error discussed above, error due to rounding is small in individual record magnitude and large in terms of the total number of records affected.

On 20-21/08/91, where the total 3-hourly value is 6.8mm and the total daily value is 7.4mm, it could be suggested that the 'missing' 0.6 mm can be accounted for within two blank observation windows on that day. There are, in fact, cases within the precipitation record where this seems to have happened, but in the example above the loss of 0.6 mm can be accounted for through rounding.

Note that this example, albeit conservative in comparative magnitude of error, illustrates that rounding error can easily account for a reduction or increase of 10% in the archived observation values.

Recording of traces and null precipitation
The BOM has stated that precipitation traces of less than 0.2 mm during an observation period (ie. 0.1 mm) are not recorded by BOM staff, transferred or archived. However, it is clear from examination of the 3-hourly climate record that there are 430 individual instances of trace recording appearing between 01/01/88 and 20/10/93. Although it has been suggested by the BOM that these are a product of quality control measures exercised by the Bureau, it is certainly unclear as to whether any precipitation occurred in the observation windows accounting for those 43.0 mm of rainfall. trace recordings can also be found prior to the installation of the AWS.

As for trace recordings, the BOM also states that null precipitation observations are not made by the AWS system, nor are they archived or recorded. However, from 01/10/87 there are 524 instances of null precipitation in the record. These are distinct from records where no observation is recorded. Whereas these instances of null precipitation may not represent any error in the context of precipitation totals and models, the issue, nonetheless, still requires consideration if not explanation.

Addressing the problem of poor data quality
Algorithms were developed to correct for sources of error. A decision was made to retain the official daily precipitation record as the reference point for future analyses, on the basis of supporting precipitation records from a non-BOM weather station near Wagga, as well as analysis of daily climate records for at least a dozen BOM stations nearest to the Wagga AMO.

A number of algorithms, primarily in the form of original code, were used to repeatedly process and reprocess the 3-hourly data set, each process being followed by an analysis of the results. In many cases, code was utilised to interface between machine and the analyst who made the final decision with regard to individual records where it was 'unclear to the computer' which category of error to delineate. This approach was necessitated by the fact that 100,000 records had to be reviewed and corrected in two weeks, precluding the possibility of subjective assessment of each record.

Initially, this prototyping approach was used to assess the significance of each of the error types, and later to analyse the effect of a variety of corrective approaches to each problem.

It was important to find a benchmark, in addition to the daily record, with which to judge the performance of the trialed correction procedures. The daily record will only indicate what the sum of 3-hourly records should be. It will not assist in the comparative assessment of correction procedures.

Post-automation error correction was given highest priority as these are the records with the greatest discrepancy to the daily record.

Instrument failure errors, human recording errors, trace and null recordings and errors due to rounding were identified and classified. Each type of error was given a priority value that was calculated based on its overall significance to data discrepancy and on the presence of other error types in the same recording day. Pre-automation errors, though not substantial as the former, are nonetheless present in the data sets. These errors consisted mainly of human error types. Some other anomalies of unknown origin existed and these were corrected subjectively.

The result of many corrective process trials was a new 3-hourly data set containing a number of fields representing the values derived from selected algorithms. From these 'versions' of the 3-hourly registrations one data set was selected to represent the final corrected 3-hourly record.

Justification for the corrected 3-hourly record
Statistical procedures were applied to the derived data sets to test for any noticeable anomalies and to compare means, standard deviations and correlations with the original data set. It is clear that we will never know with certainty what the actual precipitation values were. Therefore, it is a matter of utilising comparative processes and models to justify the use of one data set over another.

One benchmark used in this process was a principle derived from E. Linacre and J. Hobbs (1977) stating that a fourfold decrease of duration raises the maximum total precipitation by 60% to 100%. An analogy to this principle is that a fourfold decrease in averaging duration will result in an increased maximum precipitation intensity of 60% to 100%. The maximum precipitation intensity principal strongly supports the validity of the corrected 3-hourly data set, while simultaneously supporting the rejection of the originally supplied data set.

Developing a precipitation duration model

Each 3-hourly observation window was treated as 1/8 of a 24-hour period and assigned a binary value (ie. 1=some precipitation, 0=no precipitation). A majority of the 3-hourly data set contained only 7 valid observations per day. The 1/8 window was therefore amended to a 1/7 window. This type of model was useful particularly for applications that required a precipitation duration index with minima of 0 and maxima of 1. The model's use of a binary measure of precipitation was also useful in circumventing the problem of some data errors.

Seven observation windows were plotted, and a regression analysis was carried out which produced a function that can be used to calculate fractional daily precipitation duration based on total daily precipitation.

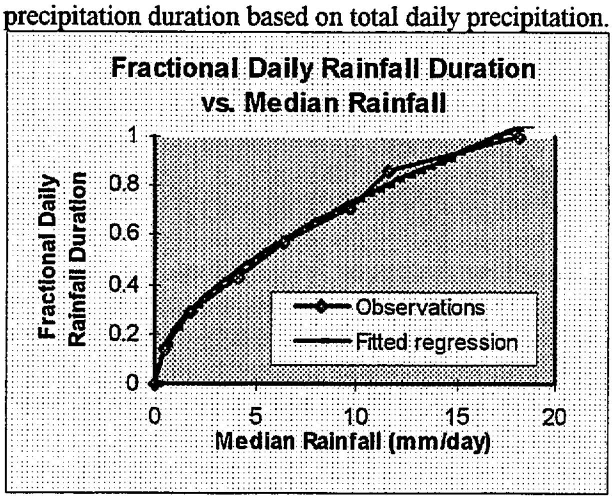

Figure 1: Fractional daily precipitation duration vs. median precipitation

The equation for this function is:

$$f(p) = 0.214144\,p^{\frac{1}{2}} + 0.006729\,p$$

where: $f(p)$ is the fractional daily precipitation duration; p is the total daily precipitation.

The process utilised to arrive at this function is relatively simple and can be applied to other data sets.

Developing a precipitation intensity model

The duration model above, whilst fulfilling the immediate requirements of the WaVES model, left the question of estimating precipitation intensity. The values derived from the duration model could not be used to calculate intensity due to their binary origin.

Developing a precipitation intensity model was complicated by two factors. Firstly, it is doubtful that the 3-hourly observations are a reliable primary source of intensity data. Experience suggests that observed intensity of rainfall can fluctuate greatly within a 3-hour period. Secondly, preliminary analyses of the adjusted 3-hourly precipitation values were marked by wide variation in precipitation pattern and relative magnitude.

Finding pattern by regrouping the data set

Analysis of the adjusted precipitation record did not yield reasonable results that would allow modelling of rainfall intensity. Plots of calculated intensity against many other variables (including time) yielded scatter with no pattern whatsoever. However, this was only the case so long as data was analysed in the two contexts in which it had been utilised thus far. The first of these is in the context of a precipitation day of 09:00 to 09:00, and the second in a normal 24-hour day of 0:00 am to 23:59 (in which the data is supplied).

Data was reprocessed so as to form precipitation 'blocks'. These blocks I defined as 'sets of contiguous non-zero precipitation observations that are delimited by observations of no precipitation'. The regrouped observations yielded a scatter that showed a sine wave-shaped envelope. Frequency distributions and class means were calculated. The pattern of the scatter and the precipitation mean time series suggested further investigation was worthwhile.

Similar reprocessing (blocking) of the daily precipitation record yielded similar result. The mean precipitation (%) plots in both instances suggested a single cycle sine wave with a peak at 0.5 and a slight skewness to the left (included in 2).

Analysis of these curves showed that various equal interval values produced total precipitation (%) values of approximately 1.3 (ie. 130%) for both daily and 3-hourly record. This was a substantial improvement over the original 3-hourly data set which produced mean totals of 140% after blocking. Recalling my assertion that 3 hours is too long a period from which to obtain valid precipitation intensity values, the goal was now to derive a function that will calculate precipitation (%) for a time series, which will total 1.0 (ie. 100%) for the equal interval value sum.

Deriving an equation for precipitation vs. time

No regression equation was found to be appropriate to describe this function. By prototyping, combined with analysis of the 3-hourly and daily mean plots, I derived the following equation, calibrated for a time series with a variable number of time segments.

$$p_{i,x} = \left[(0.2\delta t_{i,x}{}^{2} - 0.1\delta t_{i,x}) + \frac{\sin(\delta t_{i,x}\pi)}{\pi\sqrt{\left|t_{i,x} - \theta\right|} + \pi} \right] \left(\frac{6}{x}\right)$$

where: $p_{i,x}$ is the precipitation proportion for time; $t_{i,x}$.; i is the time segment of interest; x is the total number of time segments; $t_{i,x}$ is the time proportion expressed as $\frac{i}{x}$;

θ is the peak precipitation segment (ratio 'time:total period'); $\delta t_{i,x}$ is the value $Z_{(t_{i,x}+0.5-\theta)}$ (with Z being a rational finite number system defined as $Z\frac{x}{x}$) expressed in radians.

This equation is not meant to describe rainfall generally, but rather a mean precipitation event. The equation models the relationship between time and mean precipitation. A plot of this equation is illustrated below, for a precipitation block of 10 segments (ie. x=10) and peak precipitation at θ=0.5. The figure also includes plots for daily and 3-hourly means for comparison.

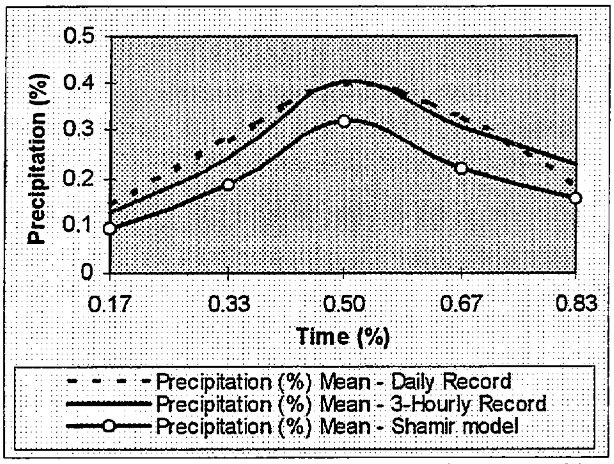

Figure 2: Time x 100 (%) vs. Precipitation x 100 (%) (daily, 3-hourly record - all years & model)

Use of the model to generate a time series for a specific number of time segments will yield a time sum of 1.0 approximately. The curve shows a peak at t=0.5 and a slight left skew with values slightly greater on the right side of the curve than the corresponding values to the left of t=0.5. The model satisfies all observed mean precipitation intensity phenomena for the Wagga data set.

Supporting the model with data

The motivation behind developing the model was to reduce the error generated by too few precipitation observations (ie. 3-hourly or daily). It seemed logical, therefore, to test the model against precipitation data collected at frequent time intervals.

A CaLM weather station near Wagga supplied a data set collected by pluviograph for 18/09/91 to 09/03/93. Registrations of precipitation totals are made over 1 minute intervals providing a far greater accuracy than 3-hour records. These data were blocked, and class mean values superimposed. Substantial support was gained for the model when mean 1-minute data were plotted alongside the model.

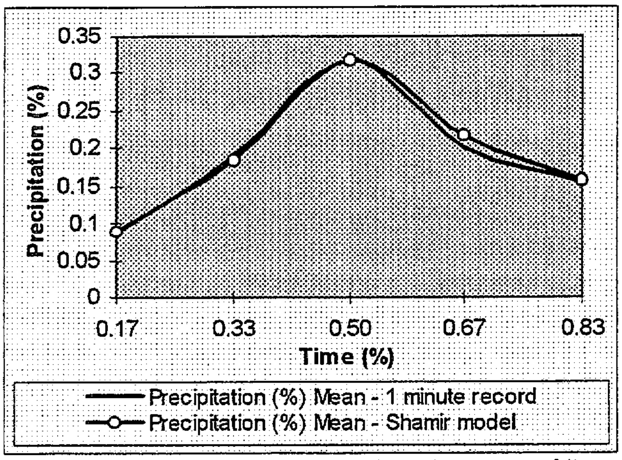

Figure 3: Time x 100 (%) vs. Precipitation x 100 (%) (1 Minute record mean & Model)

Use of the model

The precipitation intensity model is used to approximate proportional precipitation based on a given set of variables. The model is flexible in that more input data yields a more accurate result.

As a minimum, the model requires the user to specify how many time segments (x) to partition the precipitation block into. If no precipitation peak segment (θ) is known, the user will set θ=0.5 (as is the case with mean curves derived from the data). Finally, the user will specify which time segment ($t_{i,x}$) they are interested in deriving a $p_{i,x}$ value for.

$\sum p_{i,x}$ will equal a value between 0.99 and 1.00.

The model requires no change in order to vary the position of peak precipitation. The user is required to furnish a value for θ.

<u>Example:</u>

What will be the proportional mean precipitation at minute 22, during a 32 minute precipitation block with peak precipitation occurring at minute 20 ?

$$p_{22,32} = \left[(0.2\delta t_{22,32}^{\ 2} - 0.1\delta t_{22,32}) + \frac{\sin(\delta t_{22,32}\pi)}{\pi\sqrt{|t_{22,32} - 0.6250|} + \pi} \right] \left(\frac{6}{32} \right)$$

$p_{22,32}$ = 0.048, therefore approximately 4.8% of the total precipitation for that block fell during minute 22.

The model is adjustable for approximations of precipitation blocks with more than one precipitation peak. In general, the term $\delta t_{i,x}$ is redistributed across the $p_{i,x}$ terms for secondary, tertiary and other peaks (if present), reflecting the order of relative peak magnitude. The model has the capacity to reflect multiple peaks of equal magnitude, as well as multiple peaks of varying magnitude.

Modelling density induced flow and solute transport in regions containing saline disposal basins: Lake Tutchewop case study

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1. Introduction

In the Murray-Darling Basin, large volumes of saline water are produced as a consequence of rising water tables and drainage effluent from irrigation. A major engineering approach adopted to reduce salt accessions to streams and rivers is the diversion of irrigation returns into saline disposal basins. In the past, almost all of these basins have been natural depressions, saline lakes, salinas or River Murray billabongs but in recent years, constructed basins have become more common.

The continued use of saline disposal basins requires a detailed understanding of their groundwater and solute transport dynamics. Evidence shows (Allison and Barnes, 1985) that salt loss in such basins may be due to slow downward convection of the dense saline waters.

Continual evaporation of saline brines results in a layer of dense saline water overlying less dense groundwater. Under certain conditions these dense brines may become unstable causing them to mix with groundwater over distances several orders of magnitude greater than due to diffusion alone. Density contrasts may therefore lead to enhanced solute transport to the underlying aquifer system. See work by Simmons and Narayan (1995) for further details.

In Victoria, one of the larger basins is Lake Tutchewop, which is located midway between the townships of Kerang and Swan Hill. Since 1968, saline water has been pumped from Barr Creek into Lake Tutchewop and two surrounding basins, Lake William and Lake Kelly, via a number of artificial channels. It was necessary to pump this water into these lakes to reduce the salinity input of Barr Creek into the River Murray. Initially, it was intended that this three lake system be an intermediate storage only, with the final disposal area being the Mineral Reserves Basin, located about 6 kilometres south-west of Lake Tutchewop. However, this plan never eventuated. At present, the groundwater and salinity dynamics below Lake Tutchewop are poorly understood and the long term stability, sustainability and leakage rates from this basin are unknown. It is therefore necessary to characterise the current and future impacts of pumping saline water into Lake Tutchewop. It is also important that the potential for groundwater/lake interaction be clearly understood. Salt and water budgets should also be quantified for the system.

A number of investigations are reported on Lake Tutchewop (eg. HydroTechnology, 1994; Fergusson, 1993) which deal with the hydrogeology, hydrodynamics and hydrogeochemistry of the lakes. The possibility of land salinisation to neighbouring regions by Lake Tutchewop was also investigated by Dimos (1992).

A study by Narayan and Armstrong (1995) showed some qualitative support for the existence of strong convection below Lake Ranfurly, a saline disposal basin also located in Victoria, but did not quantify the instability development and physical processes that occur below such basins. Work by Simmons and Narayan (1995), showed that the onset of gravitational instabilities and the formation of free convective cells below a saline disposal basin occurred when the magnitude of a nondimensional parameter combining a Rayleigh and modified Peclet number exceeded a certain critical value. These nondimensional numbers are defined in terms of basin scale hydrogeologic parameters.

In this work, a U.S.G.S. model SUTRA (Saturated-Unsaturated TRAnsport) developed by Voss(1984) is employed to simulate variable density flow and solute transport processes in the Lake Tutchewop region. This work will attempt to answer existing questions about the stability, sustainability and lifetime of the Lake Tutchewop disposal basin system, using numerical modelling techniques and by considering salt budgets for the lake system.

2. Site Description

2.1 Barr Creek Salinity Management Plan

Located mid-way between the townships of Kerang and Swan Hill in north-central Victoria, Lakes Tutchewop, William and Kelly form part of the Kerang Lakes system of natural depressions (Fig. 1). The Barr Creek catchment covers over 66,000 hectares and comprises about 450 landholders. East of the catchment, high density dairying is the predominant land use whereas in the west, grazing is more common.

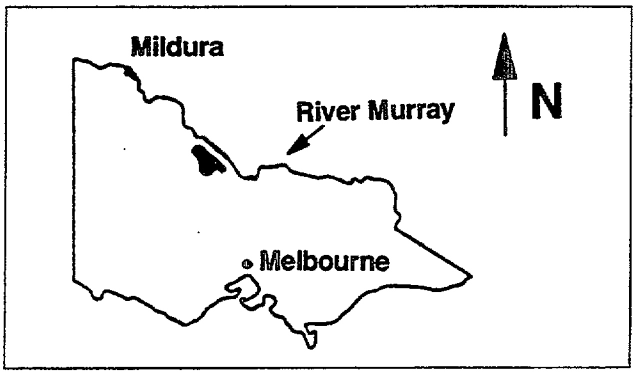

Figure 1: Locality map of Lake Tutchewop and the Barr Creek Salinity Management Plan.

Barr Creek is now the trunk stream for a comprehensive deep drainage network in the Cohuna and Kerang Irrigation districts. Prior to 1968, Barr Creek delivered on average 180,000 tonnes of salt to the River Murray each year. It is estimated that Barr Creek carries over 11,000 ML of disposal water each year at an average salinity of 4,000 mgL^{-1}.

To reduce the amount of salt entering the River Murray, water has been pumped from Barr Creek via a number of artificial channels into Lakes Tutchewop, Kelly, and William which act as evaporative disposal basins.

2.2 General Hydrostratigraphy

A brief summary of the hydrostratigraphy of the Lake Tutchewop area is presented here. A more detailed investigation is documented in a report by HydroTechnology (1994).

The stratigraphy of the Lake Tutchewop area consists of a thick sequence of Tertiary aged sediments deposited in the Kerang Lakes Trough bedrock valley which runs roughly north-west from the township of Kerang. In the vicinity of Lake Tutchewop, the Tertiary sequence is about 250 metres thick and is divided into 3 major stratigraphic units. The deepest of the units is the Renmark Group which generally consists of interlayered sand, gravel, carbonaceous clay, silt and coal. It is about 120 metres thick and is overlain by the Parilla Sand unit. This consists of interlayered beds of sand, silty clay and minor clay and is about 50 metres thick. The Shepparton Formation overlies the Parilla Sands. It is approximately 40 metres thick and consists of clay and silty clay with intermittent shoe string lenses of silt, clayey silt and sand. An analysis of the Shepparton Formation stratigraphy by HydroTechnology (1994) showed that there was no consistent aquitard or aquifer which could be traced across the local area. To simulate the Shepparton Formation heterogeneity, this study uses a division of 5 metres below the surface to divide the Upper Shepparton Formation containing the water table from the Lower Shepparton Formation containing deeper sub-aquifers.

3. Numerical Modelling

3.1 Conceptual Model

In order to model Lake Tutchewop, a vertical slice taken along a north westerly transect A-A' through the lake was used (Fig. 2). This cross section was 7100m long, 90 m deep and 100m thick and is illustrated in Fig. 3. Several bores which lie along this transect were used in model calibration (Bore numbers 6016, 26826, 49558, 49569). Only the Shepparton Formation and Parilla Sand layers were simulated in this model. It was not considered necessary to model the Renmark group as this would not effect the solute transport processes directly below the basin. In doing so further computational complexity was also avoided.

The boundary conditions for simulation of flow and transport are also shown in Fig. 3. A no flow boundary condition is specified along the bottom of the mesh at depth 90m where the base of the Parilla Sand is considered to be impervious. Time-dependent heads $h_1(t)$ and $h_2(t)$ were used along the left and right hand vertical boundaries respectively and were extracted from piezometer readings taken in the field.

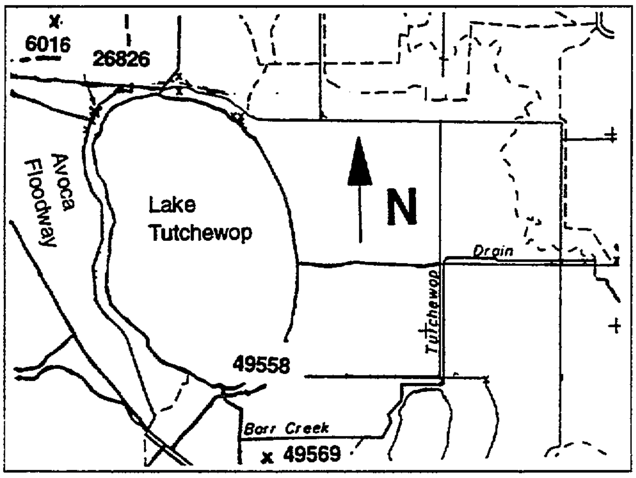

Figure 2: Lake Tutchewop basin. Bores along transect are 6016, 26826, 49558 and 49569.

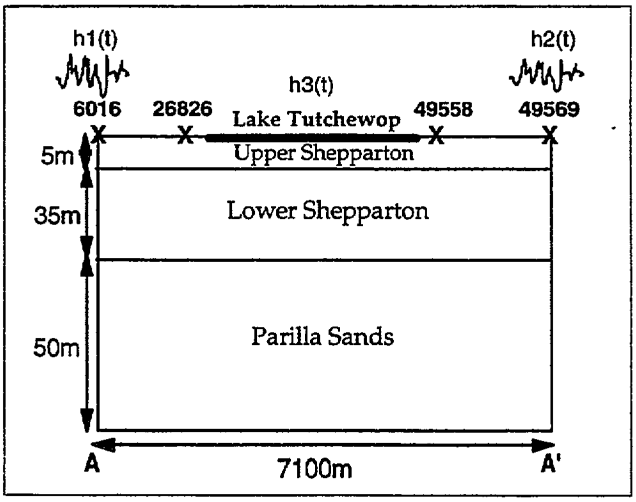

Figure 3: 2-D cross sectional view of Lake Tutchewop model, indicating boundary conditions.

Lake Tutchewop was represented as a time-dependent concentration source C(t), 3800m long, located on the surface of the model with position described mathematically by 1500m<x<5300m where x is the coordinate variable for the horizontal direction. A fluctuating time-dependent lake head $h_3(t)$ extracted from field data was also employed on the lake surface.

To represent initial conditions for the system, a steady state run was made with pressures along both vertical sides being defined by the hydrostatic equation $p=\rho_{gw}gh$ where p is the hydrostatic pressure, ρ_{gw} is the density of groundwater which initially occupies the aquifer and h is the depth below the system surface. Groundwater concentrations of 70,000mgL^{-1} were used throughout the model and for the purpose of obtaining initial conditions, the effects of Lake Tutchewop were not included in this run.

3.2 SUTRA Model

Due to the high salinity contrast between the lake and the underlying groundwater system, the use of a model capable of simulating density dependent solute transport was considered necessary. SUTRA (Voss, 1984) is commonly used for this purpose.

3.3 Spatial and Temporal Discretisation

Voss (1984) has provided some general guidelines for proper discretisation. In most cases, a rule of thumb which guarantees spatial stability is defined by $\Delta_L \leq 4\alpha_L$, where Δ_L is the local distance between sides of an element measured in the direction parallel to local flow and α_L is the longitudinal dispersivity. The cross sectional vertical slice, 7100 m long and 90 m deep was discretized to form 2736 rectangular elements and 2842 (48x49) nodes. The horizontal spacing varied from coarser elements (Δx=200m) near model boundaries to finer elements (Δx=100m) under Lake Tutchewop. The vertical spacing was determined by trial and error in an attempt to account for non-uniform vertical conditions such as the sub-aquifers in the Shepparton formation and the Parilla Sands group below Lake Tutchewop. Stable solutions were obtained with vertical spacings of Δy=1m and Δy=2m in the Upper and Lower Shepparton formations respectively, and with Δy=2m in the Parilla Sands group. In this modelling exercise, all transient simulations were run with 300 time steps to cover a simulation time of 25 years. The time step size was held constant at one month intervals throughout all simulations.

3.3 Model Calibration

The salinity of Lake Tutchewop measured during 1984-1994 is shown in Fig. 4. Salinity was initially measured in terms of electrical conductivity (EC in µS/cm) but for the purpose of this modelling exercise, values were converted to total dissolved solids (TDS in mgL^{-1}) based on the estimated correlation between EC and TDS. Linear regression techniques were applied to the data given to find a time dependent salinity function C(t) for Lake Tutchewop. Neglecting seasonal and diurnal fluctuations, a straight line approximation for this data was reasonable. The model was calibrated over a five year period January 1989 - December 1993 using a lake salinity equation given by:

$$C(IT) = [73{,}440 + (IT-1)\,569.1]\ mgL^{-1} \qquad (1)$$

where IT is a month number index or time step counter.

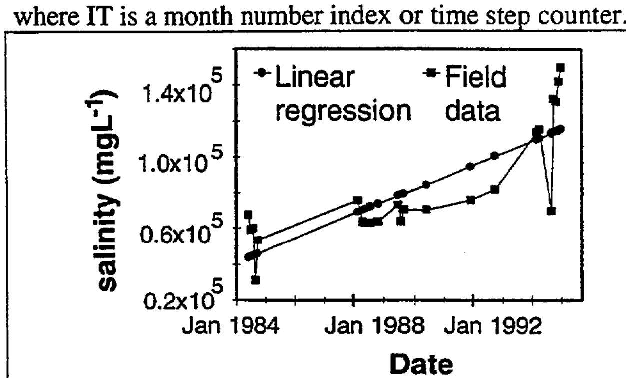

Figure 4: Lake Tutchewop salinity

The model calibration was checked by extracting model results for hydraulic head at points corresponding to bores 26826 and 49558 and comparing them to corresponding field measurements. The results of model calibration are given in Fig. 5. The parameters determined from this model calibration are given in Table 1 and are consistent with field observations made

Freshwater density (ρ) = 1000 kgm^{-3}	
Groundwater salinity= 70,000 mgL^{-1}	
Lake salinity (C_L) = C(t) mgL^{-1}	
Fluid dynamic viscosity (μ) = 10^{-3} kgm^{-1}s^{-1}	
Coefficient of fluid density change($\partial\rho/\partial C$)=700 kgm^{-3}	
Water compressibility = 4.5 x 10^{-10} Pa^{-1}	
Soil compressibility = 1x10^{-8} Pa^{-1}	
Hyd. cond. of Upper Shepparton	K_{HUS} = 10^{-1} md^{-1}
	K_{VUS}= 10^{-2} md^{-1}
Hyd. cond. of Lower Shepparton	K_{HLS}= 6x10^{-1} md^{-1}
	K_{VLS}= 10^{-3} md^{-1}
Hyd. cond. of Parilla Sands	K_{HPS}= 1 md^{-1}
	K_{VPS}= 10^{-2} md^{-1}
Porosity of Upper Shepparton (ε_{US})= 0.35	
Porosity of Lower Shepparton (ε_{LS})= 0.35	
Porosity of Parilla Sands (ε_{PS})= 0.25	
Longitudinal dispersivity (α_L) = 50 m	
Transverse dispersivity (α_T) = 5 m	
Molecular diffusivity (D_0) = 2.8 x 10^{-9} m^{2}s^{-1}	
Acceleration due to gravity (g) = 9.81 ms^{-2}	
Aquifer depth (H) = 90 m	
Aquifer length (L) = 7100 m	
Lake dimension along the slice = 3800 m	
Upper Shepparton thickness = 5 m	
Lower Shepparton thickness = 35 m	
Parilla Sands thickness = 50 m	

Table 1: Model Parameters

at Lake Tutchewop (HydroTechnology, 1994). In order to simulate the transport process within the 7100m of slice length and given the limitations on mesh size, a longitudinal dispersivity of α_L=50m and a transverse dispersivity of α_T=5m were considered appropriate.

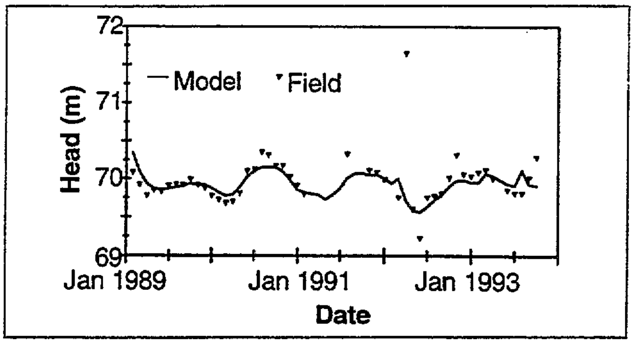

Figure 5: Model calibration results for the period January 1989 - December 1993 at Bore 49558.

4. Results and Discussion

In order to use the calibrated model, the boundary conditions $h_1(t)$, $h_2(t)$ and $h_3(t)$ were repeated every five years for 25 years. The lake salinity function C(IT) given in (1) was assumed to hold for the entire 25 year simulation. The simulation was run to cover the period January 1989 - December 2014.

4.1 Concentration and Hydraulic Head Profiles

Cross sectional concentration profiles corresponding to Jan 1994 and Jan 2014 are given in Fig 6. In January 1994, model results show that leakage from the current disposal regime is confined to within 2m of the lake bottom which is consistent with measured field observations (HydroTechnology, 1994). After 25 years, results for January 2014 suggest that leakage is confined to within 10m of the lake bottom. This suggests that the lake system is inherently stable with very little vertical movement of salt from Lake Tutchewop to the underlying aquifer system. This is in response to the small vertical hydraulic conductivities of the Shepparton formation (~10^{-2} - 10^{-3} md^{-1}). Lateral leakage to neighbouring regions is also minimal owing to the very small horizontal hydraulic gradients in the area below Lake Tutchewop (head gradients as small as 200mm in lateral distances of 1km).

A computed hydraulic head contour of the aquifer system for January 1994 is given in Fig. 7 and shows the groundwater hydraulics below Lake Tutchewop. These results show that flow is radial into Lake Tutchewop around its periphery and that the regional groundwater flow is in a north-westerly direction. Both of these modelling results are consistent with field observations (HydroTechnology, 1994). A groundwater mound corresponding to the Avoca River Floodway is also observed north-west of Lake Tutchewop.

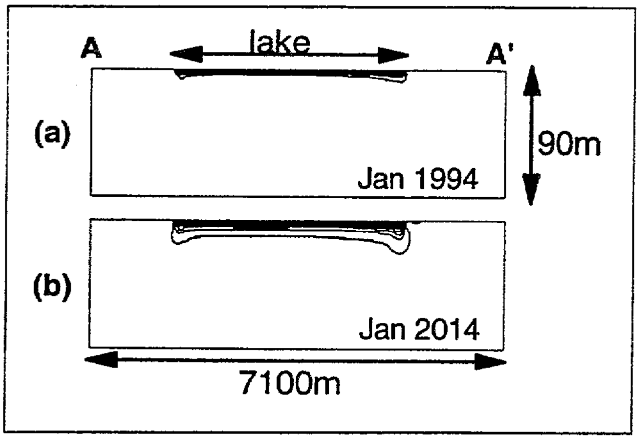

Figure 6: Computed concentration profiles for aquifer at (a) January 1994 and (b) January 2014.

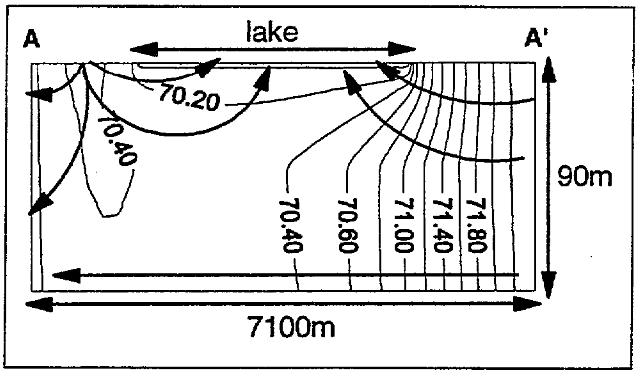

Figure 7: Hydraulic head profile (in metres) for aquifer system extracted from model for January 1994

4.2 Lake Tutchewop Stability

Simmons and Narayan (1995) showed that the stability of a saline disposal basin is related to a nondimensional parameter called the Rayleigh number defined as

$$R_a = \frac{gk_v\beta(C_{max} - C_{min})H}{\varepsilon\nu_0(D_0+\alpha_T V_{amb})} = \frac{Buoyancy\ forces}{Resistance\ forces} \quad (2)$$

where g is acceleration due to gravity, L/T^2 ; k_v is the vertical Darcy intrinsic permeability, L^2; $\beta=\rho_o^{-1}(\partial\rho/\partial C)$ is the linear expansion coefficient; C_O, C_L are the minimum and maximum values of concentration, expressed as solute mass relative to fluid mass, M_s/M; ε is aquifer porosity; $\nu_o=\mu_o/\rho_o$ is the kinematic viscosity of the fluid, L^2/T; D_o is the molecular diffusivity, L^2/T; α_T is the transverse dispersivity, L; V_{amb} is the ambient velocity due to external head gradients, L/T.

In their work, Simmons and Narayan (1995) showed that when the Rayleigh number exceeded some critical Rayleigh number Ra_{crit}, basin behaviour became unstable and vast amounts of salt, much greater than due to diffusion alone, were delivered to the underlying aquifer through the process of free convection. Neglecting ambient groundwater flow in the region below Lake Tutchewop, (2) is evaluated to be Ra~1 (at the start of the simulation) for the Upper Shepparton formation. This is well below the critical Rayleigh number of Ra_{crit}=1250 (Simmons and Narayan, 1995) for the case of free convection alone. Lake Tutchewop is therefore inherently stable owing to both the low vertical permeability and low concentration gradients below its lake bed. A preliminary analysis also shows that saturation salinity levels of about C_{sat}=290,000 mgL^{-1} in Lake Tutchewop may be reached in about 40-50 years but would also result in stable basin operation. Therefore it is unlikely that Lake Tutchewop will exhibit unstable behaviour.

4.3 Salt Budgets

The components of the solute budget are: (a) Barr Creek inflows, (b) regional groundwater input and (c) leakage through the lake bed. Presently, Lake Tutchewop leakage rates are small and most of the input from Barr Creek feeds the increase in salinity of Lake Tutchewop. However, as salinity levels rise, the amount of salt lost from Lake Tutchewop due to vertical leakage also increases. Model results show that under present conditions, the approximate leakage rate from the basin is 30,000 $tonnesyr^{-1}$. Predictions estimate that leakage rates may rise to above 60,000 $tonnesyr^{-1}$ as lake salinity levels begin to exceed 220,000 mgL^{-1}. It is worth noting that lake salinity is assumed to be a linear function of time with salt accumulating at 44,000 $tonnesyr^{-1}$. This is based on salt input from Barr Creek. A sensitivity analysis showed that leakage rates were dependent upon the vertical intrinsic permeability of the Upper Shepparton formation. By the year 2014, it is estimated that vertical leakage will have accounted for over one million tonnes of salt being delivered to the aquifer (in total) under the current disposal regime. The effective volume for storage of this salt below the lake can be calculated by taking porosity (ε)=0.35, the total surface area of Lake Tutchewop to be A_{LT}=6.5km^2 and an average salinity of say Cav=100,000 mgL^{-1}. To store just over one million tonnes of salt below Lake Tutchewop would require salt storage to a depth of about 6m below the lake bed. This is consistent with the concentration profile presented for January 2014 shown in Fig. 6(b). Model predictions also estimate that saturation levels in Lake Tutchewop will be reached in about 40-50 years.

5. Conclusions

The SUTRA model has been used to simulate variable density flow and salt transport in the vicinity of the Lake Tutchewop saline disposal basin. Results show that the present effect of the current disposal regime is felt at depths no greater than about 2-3 m, and that even 25 years from present time, the effects of leakage will not be felt at depths greater than 10m below the lake bed. Simulations have also shown that if present salinity trends in the lake are to continue, the amount of leakage from Lake Tutchewop to the underlying groundwater system will at least double in the next 25 years.

Rayleigh number calculations showed that Lake Tutchewop exhibits stable behaviour in the Upper Shepparton formation. This means that leakage is predominantly caused by mechanical dispersion in the aquifer and not by free convective instabilities. Therefore, under the stable regime, the amount of leakage expected from Lake Tutchewop is considerably less than would be expected for an unstable lake situation. It is unlikely that this lake will become unstable owing to the very low permeability of the basin lining and it is expected that precipitation will occur in the next 40-50 years, well before the onset of potentially unstable behaviour. The governing parameters which determine basin stability are the intrinsic permeability of the aquifer material underlying the basin and the density contrast between the lake and ambient groundwater.

Further work is still required to test a number of other management options for the control of this basin. This modelling exercise has provided significant insight into the behaviour of the Lake Tutchewop disposal basin complex.

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Interactions Between Groundwater and Vegetation in Saline Discharge Areas.

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Introduction

There has been little research into understanding the interrelationships between groundwater discharge, soil salinisation processes and vegetation growth, despite pressing economic and environmental needs. This is because research into the causes of water balance problems has been considered as having greater benefits than that into the symptoms ie land salinisation and vegetation loss. Consequently, very weak criteria are currently being used to guide large investments aimed at salinity control and vegetation management. The depth of the watertable is still the most widely reported, and often only, criteria used to define the risk of land salinisation. However, we know that for a given watertable depth soil salinisation rates vary widely and are influenced by factors associated with soil, vegetation, climate and groundwater properties. There is a need to develop system models which integrate a range of factors to predict salinisation rates and critical conditions which result in surface soil salinisation and vegetation loss.

This paper outlines the need for a better understanding of salinisation processes in groundwater discharge areas so that improved criteria can be established to guide salinity management programs. The need for this understanding should be considered in view of the wide range of issues related to the management of groundwater discharge and the very large cost of groundwater control programs.

Groundwater discharge-vegetation management issues

Each of the following issues requires a common understanding of soil salinisation processes affecting vegetation in groundwater discharge zones.

(i) Conservation of wetlands and remnant native vegetation

Groundwater rise and soil salinisation is affecting increasing areas of native vegetation which have high conservation values. The vegetation systems in decline include floodplain and wetland environments such as Chowilla floodplain, wetlands in the Upper South East of SA, Macquarie Marshes, NSW, Kerang Lakes, Vic. Remnants of native terrestrial vegetation are also dying. Communities are demanding that these native vegetation remnants be managed such that their survival and growth is ensured. These demands will affect the way river flows and drainage systems are managed. Large expenditure programs for drainage and groundwater pumping have been proposed. For example, a $40M surface drainage program has been outlined for the Upper South East, SA (Anon, 1993); a $15M groundwater interception scheme was proposed for the Chowilla Floodplain.

(ii) Groundwater pumping schemes in irrigation districts

Large areas of irrigated crops and pastures are underlain by permanent shallow groundwater of highly variable salinity. It is clear that the present pattern of land and water use cannot be sustained without provision of surface and sub-surface drainage. As land and water management plans have been prepared there has been a very large increase in requests to fund groundwater pumping schemes. Optimal management of groundwater pumping schemes is important because the capacity to dispose saline groundwater is limited. It must depend on the criteria used to define the critical conditions for soil salinisation and production loss and not simply water table depth.

(iii) Agroforestry systems

Plantation forests and agroforestry systems are also being proposed for development on farms with shallow saline watertables. In dryland catchments these may be designed as groundwater interception belts above the discharge zone, whilst in flat irrigated landscapes they may occur in recharge-discharge zones. These systems usually require a large initial investment with a long period before income is generated. They are managed for high production, and hence high leaf area and water use. However, rootzone salt accumulation has been observed within the expected harvest cycles of 15-30 yrs (Bolger 1991; Bennett and George, 1995). There is concern that the salt accumulation may affect the sustainability of these systems.

(iv) Revegetation of saline land

Revegetation of saline agricultural land with salt tolerant trees, shrubs and grasses is increasing along side the wider strategy of reducing recharge through changes in land management. Establishment costs for this work may vary from $33/ha for sown pastures to $590/ha for transplanted seedlings with deep ripping, excluding fencing (Branson and Shaw, 1994). The M$40 cost for drainage in the Upper South East, SA has been justified by the productivity increases which are expected to be obtained by establishing salt tolerant pastures on the interdunal flats. Revegetation of discharge areas is perceived as having a wide range of benefits which include soil conservation, habitat construction, reductions in stream salinity, lowering of shallow watertables, improved grazing, provision of shelter and wood production. We do not know how many of these benefits can be realised or sustained, nor their relation to whole catchment recharge control measures.

Critical limits for soil salinisation and vegetation decline

The watertable depth has become the most widely used criteria for managing soil salinisation in both rainfed and irrigated systems. Talsma (1963) found that the maximum groundwater discharge rate, and hence soil salinisation rate, of the Riverine Plain clay soils decreased only very slowly below 1 mm/day if the watertable was lowered beyond 1.2 m for bare soil; or 1.2 m below the rootzone for vegetated land. Talsma (1963) concluded there were diminishing returns in providing drainage to lower the watertable to depths beyond 2 m. This led to the general adoption that engineering works should aim to lower the watertable to 2 m. However, this doses not mean that 2 m also represents a critical watertable depth for salinity control for irrigated agriculture.

Peck (1978) suggested that the critical watertable depth for dryland agriculture should limit the maximum upward steady flux to 0.1 mm/day. This recognised that dryland agriculture in southern Australia has a long dry period and hence greater potential for groundwater discharge than irrigated agriculture. This means the critical watertable depth for dryland agriculture usually varies from 1.5 to 6m.

Clearly, the concept of a critical watertable depth is only *very generally indicative* and should at least be defined in relation to a soil-vegetation-climate system. As a single criteria it is *meaningless* in terms of quantifying the salinisation process. The effects of watertable and soil water salinity, soil hydraulic properties, vegetation characteristics, climate and flooding can each have major influences on the salinisation rate. Peck (1978) concluded that a detailed dynamic analysis is required to define critical conditions, or *combinations of critical factors*, that result in land salinisation and vegetation loss. The range of factors need to be combined using system models to develop more useful criteria.

Some progress towards defining more useful salinity control criteria for the native forests of the Chowilla floodplain was recently presented by Jolly *et. al.*(1993). This work used a simple model which accounts for limits on watertable depth, the maximum groundwater salinity that can be transpired by the vegetation, soil hydraulic properties and flooding frequency. The model allows the effect of the above factors on the salinisation rate, represented by the rate of movement of a solute front, to be evaluated. This approach has been useful for estimating the potential time scale for salinisation and for identifying classes for use in a geographic information system.

A more detailed analysis of salinisation processes requires dynamic modelling of water and solute movement coupled to vegetation growth. These site scale models can be used to evaluate the sensitivity of a range of processes to changes in management.

Modelling the Soil-Vegetation-Atmosphere Continuum (SVAC)

An extensive experimental knowledge base gained from field and laboratory studies of water and carbon transfer now exists. The major transfer processes and are described well enough to establish reasonable mathematical representations. This has lead to the development of numerous SVAC models, each with its own strengths and weaknesses for particular applications.

Whilst SVAC models have been improving, their application has been limited by large data requirements for calibration. SVAC models may be used to obtain virtually any result unless they are appropriately calibrated for the questions being asked. However, recent developments in field instrumentation for plant water use, cheap data logging equipment and indirect parameter estimation methods now enables such models to be calibrated with greater confidence. Transpiration rates for woody species can be measured directly using heat pulse. The soil hydraulic conductivity determines the rate of water and solute movement. Hence, temporal observations of both water content and salinity profiles need to be considered when establishing this parameter. Soil moisture characteristic parameters affect mainly the soil water storage and shape of the drying profile and can be guided by texture information. Also, the use of natural isotopes to identify the sources of water taken up by the root system can provide indirect information on root functioning. Complex SVAC models can only be applied with confidence after they have been tested against data from contrasting environments and time scales.

Regional vs site scale modelling

Regional scale models are used to answer different questions than point or site scale models. Regional scale salinisation rates have been estimated by comparing the average salinity of different districts which have different histories of shallow watertables. This has shown that the average soil salinity increases with the time shallow watertable has been present and has been used to evaluate the regional scale costs of salinisation. However, individual landholders with particular problem sites require site specific information on the degree and rate of soil salinisation.

Regional scale groundwater flow models provide essential information on the total quantity of discharge which must occur on different parts of the landscape. However, the spacial discretisation used by these models is usually too coarse to be useful in terms of management at a paddock scale. These models average out the small scale variation in topographic elevation that usually exists within cells. However, microrelief has a large effect on salinisation processes and vegetation growth. Hence, site scale models should be used to see how this discharge might be distributed within cells and how this may affect the vegetation.

Water use strategies in saline groundwater discharge areas

Water use studies have been conducted in South Australia on the Chowilla floodplain of the lower River Murray and in a saline ephemeral swamp near Keith in the Upper South East. These studies measured seasonal changes in a broad range of vegetation, soil, groundwater and climate factors ie transpiration rates using the heat pulse technique, soil water content, matric soil water potential, soil water chloride concentration, stable isotope (^{2}H and ^{18}O) composition of plant water and plant water sources, minimum xylem water potentials, root growth, leaf area, groundwater depth and salinity, local climatic variables.

The species studied were *Eucalyptus camaldulensis* (red gum) and *Eucalyptus largiforens* (black box) on the Chowilla floodplain, and *Melaleuca halmaturorum* (swamp paper bark) in the Upper SE wetlands. Similar studies are also in progress on *Atriplex nummularia* (old man saltbush) near Deniliquin NSW and on *Puccinellia cilliata - Agropyron elongatum* (tall wheat grass) in the Upper SE, SA.

The studies of native vegetation systems have identified a number of common strategies that different species employ to sustain their water use and growth in saline areas. The most important of these are

(a) Low areal transpiration rates due to maintenance of low stomatal conductance and low leaf area.
(b) Ability to decrease leaf xylem water potential to very low values as soil water potentials also decrease with increasing salinity.
(c) Development of an adaptive and dynamic root system that increases its growth and water uptake at depths where the total soil water potential (matric plus osmotic) is highest.
(d) Reliance on periodic flooding which locally recharges the groundwater and leaches salts from the upper rootzone.
(e) Maintenance of water uptake under temporarily flooded conditions.
(f) Use of groundwater for survival during dry periods.

These water use strategies will have limits at which they breakdown and tend to be strongly seasonal in their operation. Because the vegetation is growing in the presence of continual stress it is likely to be much more prone to unfavourable seasonal climatic conditions. We know that the salt accumulation process is usually very slow and many years or decades may be required before vegetation decline becomes apparent. However, rapid vegetation loss and surface soil salting can occur after a wetter than average season. We do not have a good understanding of the preconditions that are associated with these dieback events.

Other questions that are commonly asked and SVAC models may assist to answer include - What will happen to the salinisation rate if the watertable is lowered? How much groundwater is transpired by the vegetation and what is the effect on the depth of the watertable? How much growth can be expected at a particular soil salinity? These are questions of direct importance to land management that general groundwater models cannot answer.

A relatively complex SVAC model called WaVES (Water and Vegetation Energy with Solute movement; Dawes and Hatton, 1993) is being adapted so that it can describe the water use strategies of vegetation growing under saline conditions. The model is being used to develop a better understanding of soil salinisation process for vegetated land and the critical conditions which lead to vegetation loss. Its application to black box on the Chowilla floodplain is illustrated.

WaVES simulation of Black Box water use on Chowilla floodplain

The soil hydraulic and vegetation parameters required by the model were calibrated using field data collected before and after a major flood in 1993-94. This involved matching observed rates of profile drying, leaching and transpiration with simulated values.

A simulation was conducted to predict the rate of soil salinisation and leaf area decline between flood periods. The simulation used daily climatic data for Renmark (1969-1994), whilst soil properties and a watertable depth of 4 metres were set similar to a field site where vegetation decline had been observed. The initial soil water chloride concentration was set to 5 g/L and that of the groundwater was set at 20 g/L. This groundwater salinity was estimated to be the maximum for water uptake.

The simulation shows black box leaf mass (Fig. 1) declining over 5-10 year periods as the soil salinity increases (Fig. 2). The growth temporarily recovered after a recharge event in year 6. The root density profiles which also reflect the long term water availability , had maxima near the soil surface as well as at 0.8 m (Fig.3). The upper maxima mainly reflects the effects of rainfall whilst the lower maxima reflects higher matric potentials maintained by upward flow. There was a net discharge of groundwater and steady rootzone (0-4m) salinisation in most years (Fig 4).

Whilst the groundwater salinity itself was too saline for direct uptake it can still be transpired after mixing with less saline soil water as a consequence of capillary rise. This leads to the development of a shifting solute profile rather than a defined solute front which moves vertically. The discharge and salinisation rates would be larger if water table fluctuations, due to changes in the river level, had been imposed.

The simulation are consistent with field observations and show that the leaf mass is constrained by soil salinity in a groundwater discharge regime. Hence, in the long term vegetation die back is expected without periodic recharge events which partially leach solutes from the upper rootzone. Leaf growth, and hence dieback, appears to be most sensitive to salinity increases in the zone of maximum long term water availability.

Conclusions

Soil salinisation rates are determined by a combination of factors related to groundwater, soil, vegetation and climate characteristics. There is a need to develop salinity management criteria based on an understanding of these characteristics and predicted salinisation rates rather than on very broad criteria such a watertable depth. Dynamic modelling can increase understanding of the sensitivity of vegetation growth to changes in environmental conditions and how this may influence the salinisation process. Given the wide range of vegetation-groundwater issues and large investments being made in salinity control programs across the basin, there is a strong need to establish the limits on critical factors which affect vegetation growth in saline discharge areas.

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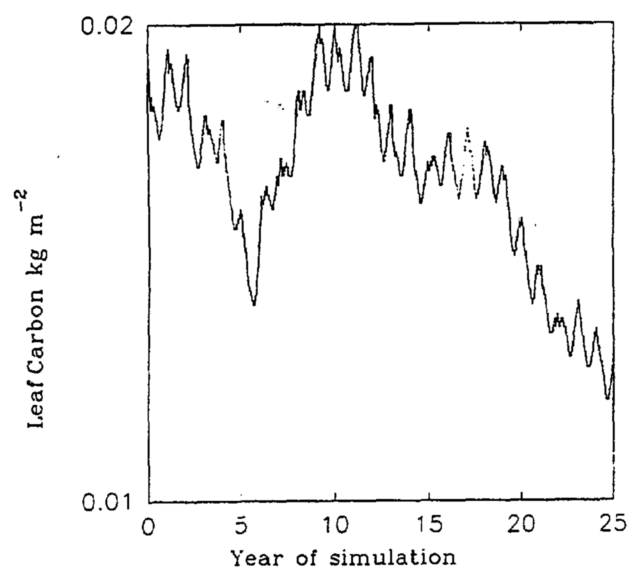

Figure 1 . WaVES simulation of changes in leaf mass of black box on Chowilla floodplain.

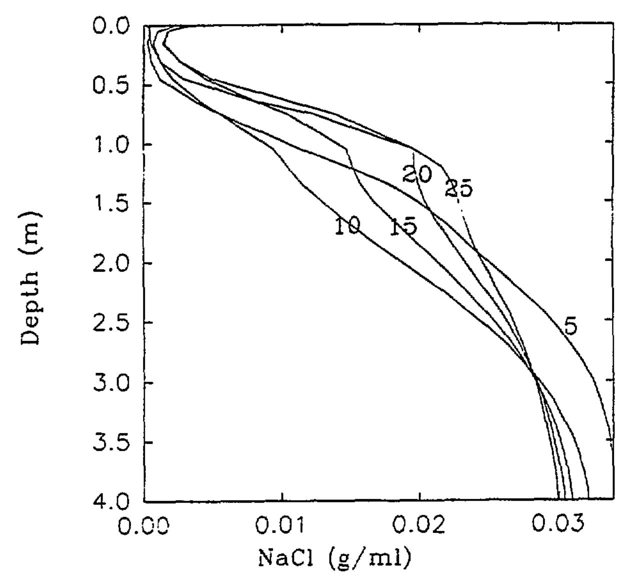

Figure 2. Simulated changes in soil water salinity (as NaCl). Numbers indicate year of simulation.

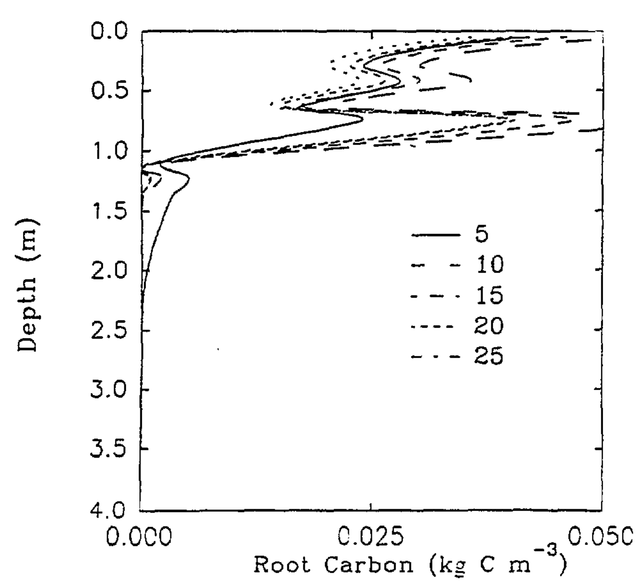

Figure 3. Simulated root density profiles for selected years.

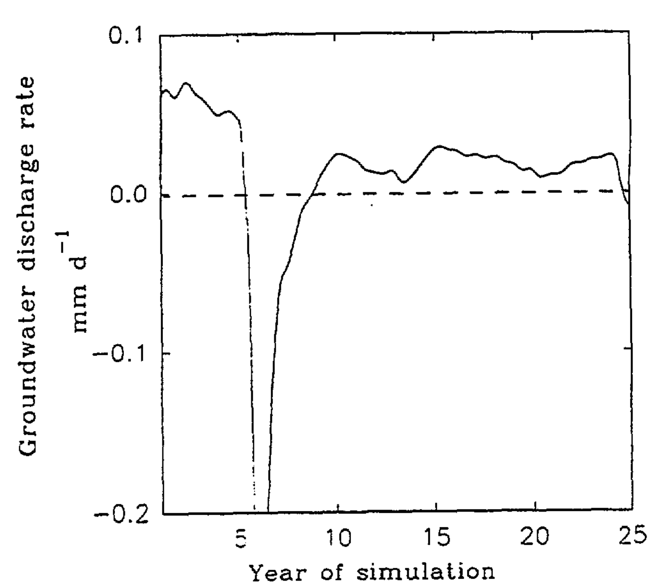

Figure 4. Simulated groundwater discharge or recharge (negative values) for a watertable at 4m.

Dryland Salinity and Flooding In the Upper South East of South Australia

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Introduction

The Upper South East of South Australia occurs on the south western margin of the Murray Basin and covers a large part of the Padthaway Ridge, which separates the Murray Basin from the Otway Basin to the south.

Dryland salinisation and related surface water inundation are causing extensive land degradation in the area with about 250 000 hectares of land experiencing moderate to severe salinisation.

Dryland salinity became evident in the area in the early 1980's following the loss of deep rooted perennial lucerne pastures due to aphid infestation in the late 1970's, significant flooding in 1981 and a drought in 1982.

Increased community awareness of the problems, assisted by further excessive inundation in 1988 and 1989, prompted the State Government to prepare a management plan to address the problems. This plan was incorporated in a draft Environmental Impact Statement (DEIS).

Background

The area addressed in the management plan covers about 700 000 ha of land to the west of the Keith to Naracoorte road as shown in Figure 1.

Topographically the area comprises a series of stranded coastal dune ranges, sub-parallel to the present coastline, and a series of broad inter-dunal flats. In the northern part of the area these dune systems merge and become less distinct.

The area has poorly developed natural surface water drainage with extensive parts of the inter-dunal flats becoming inundated over the winter months. Surface water accumulates on the western side of the flats against the dune ranges and moves slowly towards the northwest, forming a series of ephemeral swamps and wetlands. The surface water catchment areas extend eastwards across the South Australian border into western Victoria. The terminal discharge points for these surface water flows are the extensive wetlands in the northern part of the area or historically to the Southern Lagoon of the Coorong.

Extensive drainage schemes, constructed over the last century south of the area, have diverted some surface water from flowing northwards. These existing drainage schemes ultimately discharge the surface water to the sea.

The area is characterised by a regionally occurring unconfined aquifer occurring within the Tertiary and Quaternary limestones. There is general widespread use of the groundwater resource through the area for stock and some irrigation purposes, apart from northern parts of the area where groundwater salinities exceed 10 000 mg/L.

Groundwater movement is generally to the west or northwest with regional groundwater discharge occurring to either coastal ephemeral lakes or the Coorong.

There is rapid vertical recharge occurring to the aquifer over the winter months with seasonal groundwater level fluctuations in the lower lying parts of the area being in the order of 1 metre.

The depth to groundwater varies through the area being less than 2 metres below ground surface in the low lying inter-dunal flats, and ranging from 10 to 20 metres beneath the more elevated dune ranges.

Groundwater level monitoring through the area over the last 20 years has shown that there is clearly a non-equilibrium situation, with long term groundwater level rises occurring in the more elevated dune ranges and increasing groundwater evaporative discharge occurring along the eastern sides of the inter-dunal flats. This non-equilibrium is attributed to both the historic clearance of native vegetation over the last 20 to 30 years and the loss of the widely established lucerne pastures in the late 1970's, which have increased the vertical recharge rates to the unconfined aquifer. The rates of groundwater level rise generally range from 0.05 to 0.1 metre per year.

Impacts of Dryland Salinity and Flooding

The dryland salinity phenomenon is a result of the evaporative groundwater discharge during the summer period occurring in areas where the water table is two metres or less from the ground surface. This process causes waterlogging and salinisation of the soil profile with deposition of salt at the surface.

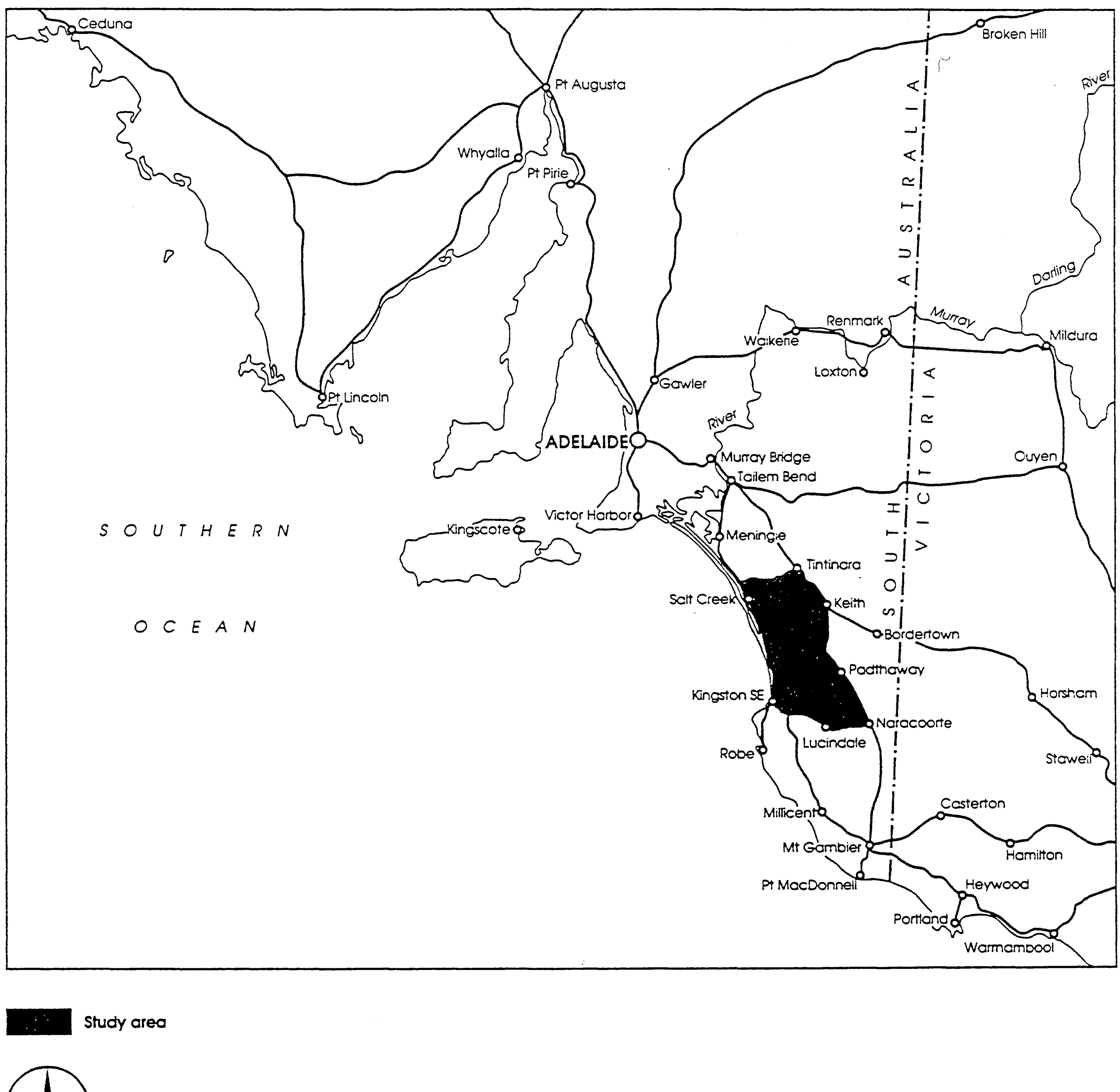

Figure 1: Locality Plan

Evaporative groundwater discharge has occurred historically at a number of localities throughout the study area.

The increasing salinisation now evident through the area is a direct result of rising groundwater levels caused by increases in the aquifer recharge rates and the diversions of surface water flows.

The increasing salinisation evident in areas with a historically occurring shallow water table, such as the inter-dunal flats, is a result of more elevated summer groundwater levels. These higher summer groundwater levels are due to a gradual reduction in the transpirative use of water by a changing vegetation cover, as salt sensitive species are replaced with more salt tolerant species. Higher summer groundwater levels are also being maintained locally by increased groundwater outflows from adjacent areas.

Initial evidence of salinisation is the presence of salt tolerant vegetation species such as sea-barley grass and salt-water couch. As groundwater levels rise further, the soil profile becomes more water-logged and salt deposition at the surface becomes more evident with the salt-tolerant vegetation species gradually being replaced by halophytic vegetation such as samphire. Ultimately the water table is exposed at the land surface, either as a free-standing permanent body of water or semi-permanently as a saline lake during the winter-spring period.

The areas experiencing or at risk of salinisation are obviously those where the water table is at very shallow depth, these being, the low lying land-locked depressions within the dune ranges and generally the eastern side of the broader inter-dunal flats.

As groundwater levels continue to rise within the more elevated areas, additional lower lying depressions within the dune ranges will experience salinisation problems. Also, groundwater outflow to the inter-dunal flats will increase with the eastern edges of the inter-dunal flats experiencing more water-logging and salinisation.

The increasing salt deposition at the land surface can result in either a gradual accumulation of salt within land-locked depressions, or the effect may not be as noticeable due to the removal of salt by overland surface water flow during the winter-spring period.

There will also be an impact on the quality of the surface water flow in the study area. The salinity of the surface water will increase as a result of the additional salt load being deposited at the land surface, and possibly by direct groundwater outflow from the dune ranges. Such increases in the surface water salinity will adversely impact any down-stream wetlands.

The groundwater level rises being observed through the study area indicate that dryland salinisation will increase until a new groundwater equilibrium is reached in the area. With the long term groundwater level responses evident, such a new equilibrium will not be achieved in the short term but rather will take some decades to become established.

If the problems of surface water inundation and dryland salinisation are not addressed, it it has been estimated that over 400 000 hectares of land will experience some degree of degradation.

The impacts of this land degradation, both currently and in the longer term, are significant. The long term loss in agricultural production is estimated to be about $9 Million per annum. The flow-on effects to rural service centres, such as Naracoorte and Keith, are likely to be severe.

Also at risk are a number of conservation parks, existing native vegetation and wetlands through the affected area.

The Management Plan

The management plan prepared to address the problems of dryland salinity and flooding comprises an integrated package of measures :

- revegetation to reduce aquifer recharge rates and to restore some of the previously cleared native vegetation
- improved agronomic practices, particularly establishment of salt tolerant pastures, to reduce recharge to the aquifer
- the construction of a network of major and minor drains. These drains are designed to remove excess surface water and also to remove groundwater to provide some control of shallow groundwater levels
- a program of restoring wetlands through the study area.

The total cost of implementing the management plan has been estimated to be $75 M, with the major cost of up to $36 M being associated with the drain construction. Costs of revegetation and on-farm measures have been estimated to be $13 M and $25 M respectively.

Obviously with such a broad embracing plan there has been, and continues to be, debate regarding the appropriateness of the plan. The main issues being :

- the overall cost and its funding
- the disposal of excess water to the Southern Lagoon of the Coorong , or to the ocean
- the construction of drains through some environmentally significant areas
- the nature of drains required to achieve control of groundwater levels.

Groundwater Pumping Systems for Water Table Control

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Introduction

The expression of salinity is not constrained by property boundaries. Land use and land management decisions by one land holder, may have adverse effects on another land holder. Therefore there is a need for an integrated catchment approach as the long term response of many landscapes necessitates a long lead time after treatment before the effects are evident. Salting involves a complex interaction between land use, hydrogeology, landscape features and historic salt loads. Such an interaction makes strategies for management and reclamation of salted lands difficult to produce and implement and often the land affected has less value than the cost of implementing a complete reclamation strategy.

This paper discusses the various options for groundwater pumping to control watertable levels, reports some preliminary results from air pumping and outlines the results to date of an irrigation strategy to manage dryland salinity.

Background

Landscapes can be considered as comprising of recharge, transmission and discharge areas (Shaw et al 1987). Within a landscape, there are three basic utilisation strategies for salted lands: manage water inputs in the recharge area, manage water and salt outputs in the discharge area, or manage water in the transmission zone.

Management of the water inputs is most commonly achieved by land use changes that reduce the proportion of rainfall passing through the root zone.

Trees have been widely promoted within recharge and/or discharge areas to reclaim salted areas. This can be very costly and invariable involves a long lead time. It can be ineffective due to an insufficient number of trees, trees not using enough water or low survival rates, especially in the discharge zones. Trees are aimed at controlling the problems caused by recharge whereas another approach is to consider the the excess water in the landscape as a resource rather than a problem. Generally, the excess water entering the catchment is a resource but may become a problem through the hydrologic process. Thus the water can still be a resource after recharge. So the resource only becomes a problem due to evaporation and capillary rise when the watertable is less than 2 metres below the ground surface. A deeper watertable allows the salt to be stored in the unsaturated zone at the bottom of the root zone where its effect is less significant.

Another option is to physically remove the water and/or salt out of the system. Discharge to streams is generally an unacceptable practice.

The removal of water and the reduction of shallow watertables by some interception methods in the transmission zone is promising where the geologic and soil conditions are favourable. This water may be of good quality but the transmissivity of this zone may restrict flows to low levels. Consequently, a number of bores across the transmission zone could be required to effectively intercept the excess water and prevent the water moving into the discharge zone.

Options

There is a number of ways to intercept excess water in a landscape. Engineering methods are generally pumping and drainage, both surface and subsurface. Drainage will not be considered further in this paper.

Pumping

There are many commercially available pumping systems for agricultural use. These systems are generally designed for a specific use and have narrow operating ranges. The specifications can usually be changed by removing or adding separate components e.g. this includes changing motor speed, changing pulley diameter and adding extra stages to the pump.

Commercially available pumps can be categorised into three types.

(1) *Low flow pumps.* Low flow pumps are generally intended for stock and domestic water. These are designed to be very low maintenance and essentially have zero running costs. Solar pumps and windmills mainly fill this category as they do not need to be located near a conventional long periods. Pumping starts and stops power source and can be left unattended for automatically, dependent on the system energy requirements. Some domestic pumps require conventional power but these systems are commonly located near to a house where power is available and maintenance inspections are not a problem due to the close proximity to a house. These systems generally pump up to one litre per second with the 0.7 litre/sec - 1 litre/sec range often requiring a large expensive system. Pump manufacturers are continually developing these systems to increase their output life and to reduce the capital cost, running and maintenance costs.

(2) *Low to medium flow pumps.* This group is of low to medium flow pumps in the range of 0.7 litre/sec - 5 litre/sec. They are generally fire fighting type pumps for surface pumping applications. Some small scale irrigation systems utilise small turbine and helical rotor pumps in this range but this is only where the irrigated crop has a high value as the irrigated area can only be small and the cost of the pump system will negate any profits from low value crops.

The market for these types of pumps is limited and efficiencies, maintenance and long life are not considered as important as ease of use. Consequently, pump manufacturers are not producing rapid developments for this group.

(3) *Medium to high flow pumps.* The third pump type is medium to high flow pumps and covers pumps operating at greater than 5 litres/sec. The majority of these pumps are used for large scale irrigation systems. Pump manufacturers are concentrating on improving these pump types due to their high value, high running costs and large market opportunities. These mainly include both diesel and electric driven turbine, and helical rotor pumps. These pumps can be used in the low-medium flow region in a reduced form but parallel requirements of drive systems and motors is where the majority of the cost lies with these systems. This causes the cost of these units to be excessive for their requirements.

Using pumps for salinity management in transmission zones requires low-medium flow pumps; approximately 0.7 litre/sec - 5 litre/sec, with the energy, maintenance and running characteristics of the low flow pumps but a reduced capital cost especially as multiple bore holes and pumping systems will be required to intercept the required amount of water moving in the transmission zone. Also landholders are not keen to invest in reclamation strategies if the cost is high and the return is low or uncertain.

Windmills

Windmills have been used extensively throughout Australia for many decades and have generally been used for stock water and domestic purposes. They are restricted to fairly low flows and the consistency of output varies greatly from day to day so water needs to be stored for days where there is little or no wind. The main problems encountered with windmills are that as the mill must be placed directly over the borehole. Good producing bores may not be located in the ideal wind site and not all areas have suitable wind characteristics to maintain the required water supply.

The cost of using windmills in multiple borehole systems is directly proportional to the number of bores as no parts of the system can be shared.

Solar

Solar pumps come in a large variety of configurations. Pumps can be 12v DC, 12v AC or inverted to 240v AC.

Solar systems can only operate during daylight hours or when a battery storage system is employed, but it is cheaper to store water than electricity and the system is not designed as an on demand pressure system. Solar systems are also relatively portable when compared to windmills and have a similar lifetime to that of both windmills and diesel pumps.

Pump output is reduced with the occurrence of cloud but overcast conditions are generally cooler and the water requirements would be less, obviously depending on the required use of the water. The solar panels can be located away from the water source so they can be placed in the most efficient power generating location.

Harrington et al (1984) conducted cost comparisons between solar, wind and diesel pumps. The cost comparisons took into account the initial cost of the system, running costs, maintenance costs, system life and time value of money. Other factors such as fuel price increases and tax concessions were not included together with the costs factors common to all three systems, e.g. tanks and reticulation systems. Comparisons were done for typical on farm pumping requirements. Figure 1 shows cost effective regimes for bore hole pumps.

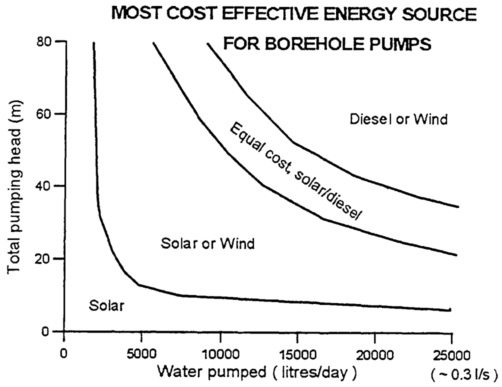

Figure 1: Cost effective regimes for bore hole pumps with different energy sources.

Figure 1 shows that solar pumping is economical in a variety of situations. The flows used in figure 1 are fairly low and where water table control is required, multiple pumping points would be required which would increase the cost greatly. Solar pumping also only operates during daylight hours and quoted pumping rates are often only for that period (commonly 8-10 hours/day effective) so the average daily rate would be less than half the amount quoted and this would need to be noted when running comparisons with other long term pumping systems. Where interception of water in a transmission zone is required, and the amount of water to be pumped is often increased due to the overcast and rainy conditions, the effectiveness of solar pumping is reduced.

Diesel and Electric Pumps

Diesel and electric pumps can share some common components and the energy source is often chosen due to site constraints. Common pump configurations include helical rotor and turbine pumps driven by a shaft leading to the top of the bore hole and either directly coupled to an electric motor or through a right angle drive to an electric or diesel motor. Submersible pumps are available in both turbine and helical rotor and offer similar characteristics to their shaft driven counterparts. They are only available in electric form and as the name implies, the motor is submerged below the water.

A study by Cross (1992), compared diesel to electric fuel costs (not maintenance or replacement costs) found that the differences were quite minimal depending on which tariff was used. The main difference when choosing between diesel and electric is the availability of a nearby electric power source. Table 1 shows the costs of a range of solar, wind and conventional pumping systems for different flow rates.

Table 1: Cost comparisons of different pumping systems for three flow rates, high flow rates have been used to provide a common basis for comparison.

	Average Weekly Flow Rate Litres/second		
PUMP SYSTEM	**up to 1**	**1 - 5**	**5 - 15**
Solar 240V submersible pump	$21,500	-	-
Solar borehole pump	$29,000	-	-
Helical rotor bore hole pump Diesel	$5,700	$6,000 - $6,500	$8,000 - $12,600
Helical rotor bore hole pump Electric	$2,500	$3,000 - $4,000	$4,000 - $7,500
Turbine bore hole pump	equivalent to helical rotor borehole pumps		
Turbine submersible pump	$800 - $2,500	$2,500 - $3,000	$3,000 - $6,000
Windmills	up to $29,000	-	

Source: Southern Cross Pump Price List 1994

This table suggests that the capital cost of wind and solar pumping systems is up to ten times that of diesel or electric systems.

The cost of a diesel or electric system, involving fuel, maintenance and capital cost can still be significantly less when comparing to an equivalent solar pump or windmill.

Third World Designs.

A lot of work has been done investigating simple low flow pumps for third world applications. These systems include rope/washer pumps, treadle pumps and helical coil tube pumps. The rope washer pump involves an endless rope with evenly spaced washers being rotated over a pulley. These systems have useful applications but human power and the general requirement of a large diameter well reduces their applicability for pumping to control salinity, especially where long term pumping and multiple extraction points are required.

Air

Another type of pump which is not widely used in agriculture is the air pump. There are two basic types of air pump: the first being a positive displacement type where there is a submersed vessel. When the vessel is full, a controller (either electronic or mechanical) allows compressed air to pressurise the vessel which forces water into the delivery pipe. When the vessel is emptied, the compressed air is shut off allowing the vessel to refill with water and the process is repeated. The second type of pump is where air is injected at the base of a submerged discharge pipe forming a mixture of water and air which is lighter than the head of water outside; consequently the mixture will rise to the surface.

The advantages of using air are; (a) the pump piece essentially has no moving parts so pumping dirty or corrosive water will have no effect on the pump; (b) a number of bores can be driven from the one compressor through a network of inexpensive piping with up to 7 km between the compressor and the water extraction point; (c) the pump foot piece used in the system where air is injected at the base of a discharge pipe is simple and inexpensive which reduces the cost of multiple borehole systems; and (d) only one compressor is required.

The pressure vessel method still requires control devices down the bore hole which may become unreliable in the long term. This device also contains two non-return valves which may reduce the performance of the pump when dirty water is encountered.

The air injection method into a submerged discharge pipe has considerable advantages for salinity control. An important aspect of the submerged air lift pump is the ratio of the head of water above the pump foot piece to the total lift of water required above the pump foot piece. The efficiency of air lift pumps is greatest when this ratio is above 70%. That is, for a total head of 10m, there is a 3m lift above the water surface and 7m submergence. Therefore these systems are most efficient where there are shallow water tables.

Considerable experimental and theoretical work performed on air lift pumps has found that although the pump is simple in construction and operation, the pump is not matched by simple theory. The pumps are generally treated as a particular example of two phase (gas-liquid) flow in a vertical tube. There has been some debate as to the importance of the method of air entry into the water at the base of the pump.

Figure 2 shows the results of an initial test indicating the importance of submergence ratios and showing difference between air entry methods.

Additional tests were conducted on a number of different pumps. Small diameter pumps with concentric delivery (internal) and discharge pipes were tested by adjusting the number, position and diameter of the air discharge holes. Figure 3 shows the outcome of these tests, indicating that there is little difference attributable to the different hole configurations in these smaller diameter pumps.

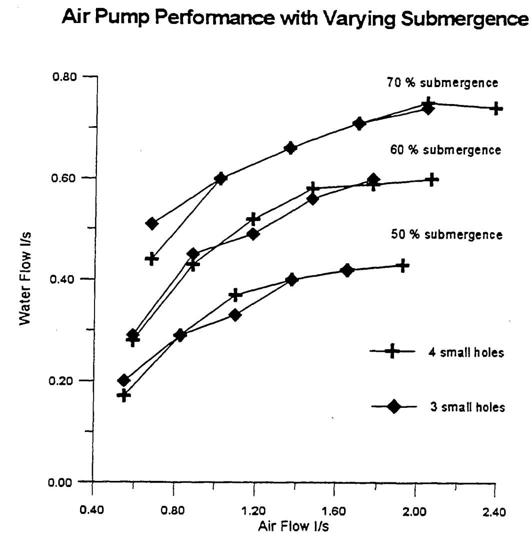

Figure 2 Water flow rates for different air flow rates with modified air entry systems and varying submergence ratios.

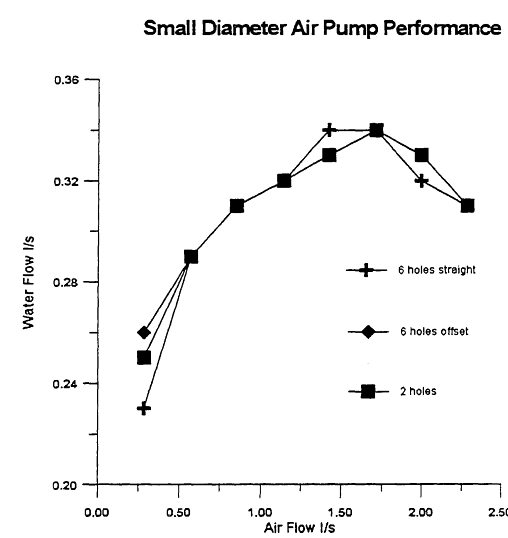

Figure 3 Small diameter air pump performance.

Other tests were conducted on larger diameter pumps, both using an external air delivery line. The inlet pipe for the air entering into the water was adjustable so as the cross-sectional area for the air entering the water stream could be modified. Figure 4 shows the performance characteristic for these pumps: concentric 2 being twice the cross-sectional area of concentric 1 and the single jet ejector.

The velocity of the air entering the water at the base of the discharge pipe and the consequent velocity of the air/water mix as it travels up the discharge pipe are important aspects for pump performance. Further investigations are planned to characterise these aspects and the construction of a suitable, inexpensive pump will enable the whole system to be easily constructed and operated by individual landholders.

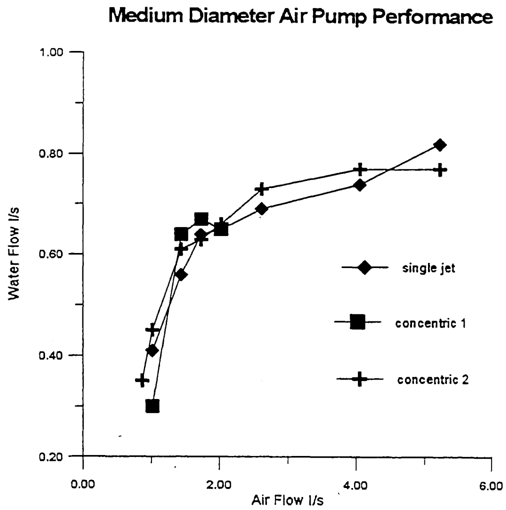

Figure 4 Medium diameter air pump performance

Brymaroo Catchment Case Study

To evaluate the potential for groundwater pumping to control salinity in Queensland, an area where interception of excess water in the transmission zone seemed possible was investigated. The Brymaroo catchment on the eastern Darling Downs has an area of 1,400 ha; of which about 60 ha are affected by severe water table salting and an adjacent 30 ha affected to some extent. An interface between the dominant formations of basalt in the upper catchment and Walloon coal measures in the lower catchment, has induced the salting as water moving through the more permeable basalt cores to the less permeable Walloon formation, dams up and rises to the surface. Trees had been planted within the catchment, but were generally restricted to non-cropping areas with survival and growth rates being affected. A drilling investigation within the transmission zone indicated flows of around 5 l/s and an electrical conductivity in the range 1.6 - 1.8 dS/m which was considered to be suitable for reuse in an irrigation system. The landholder installed a conventional diesel driven turbine pump, direct coupled to a travelling boom irrigator and is currently irrigating approximately 40 ha of rye grass and lucerne.

Figure 5 shows the water levels and rainfall for the period June 1994 to April 1995. It can be seen from this figure that the water level responds quickly to rainfall and this is due to the high permeability of the intake area. Little rain has fallen from the period March 1994 to November 1994 and consequently there has been a greater reduction in water level than expected. When there is rain, the water level will rise but due to the water deficit in the aquifer from pumping, the water table is unlikely to rise back close to the surface as it was before pumping began. This can be seen in figure 5 for the rainfall period in March 1995.

The aim is to control water table levels so that the salt currently stored in the discharge area can be stored beneath the tree and crop root zone. As salt-affected land like this is managed, it will further reduce any effect salinity has on downstream water quality.

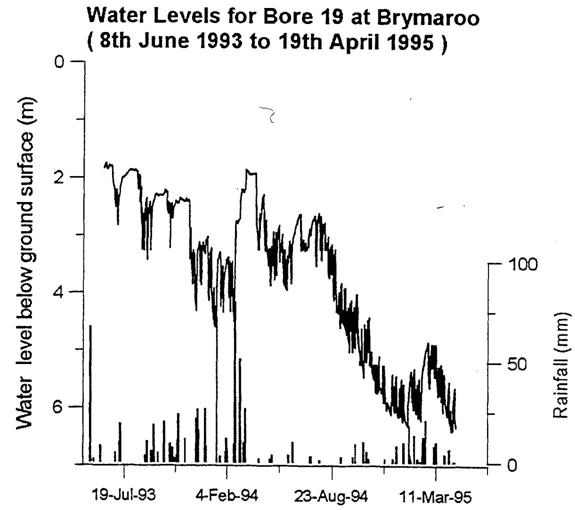

Figure 5 Water levels for the Brymaroo Catchment.

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Modelling Subsurface Transport of Microorganisms: A Brief Review

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Introduction

The transport and fate of microorganisms in porous media is of great importance in a number of study areas such as community health, bioremediation, and biological control of plant root diseases. Experimental studies in soils and other subsurface materials (e.g., Bitton et al, 1974; Gannon et al., 1991; Tan et al., 1991; Tan et al., 1992) have shown that many environmental factors affect the subsurface transport of microorganisms. Processes such as growth, decay, attachment, detachment, advection, motility, diffusion and dispersion are known to be involved in the transport and fate of microorganisms. Recent years have witnessed the development of a number of mathematical models to describe the subsurface transport and fate of microorganisms.

Vilker & Burge (1980) and Matthess & Pekdeger (1981) appear to have been among the first to apply a transport equation to describe the distribution of bacteria and viruses in time and space. They each presented equations for microbial transport based on the advection-dispersion equation for solutes, but simplified in different ways by omitting various processes. Corapcioglu & Haridas (1984) presented a more complete transport equation, also based on the advection-dispersion equation, in which all processes known to affect microbial transport were included.

Approaches other than those based on the conventional advection-dispersion equation have been proposed for microbial transport, adopting alternative models for solute transport suggested in recent years. These followed the apparent failure of the advection-dispersion equation to describe solute transport adequately under some field conditions, particularly highly variable fields and where flow was dominated by macropores. Jury (1982) introduced the transfer function approach, which was subsequently applied to the transport of bacteria by White et al. (1986). Another approach that has been introduced for transport through subsurface materials with macropores is the kinematic wave approach, which was applied to bacteria by Germann et al. (1987). Despite the introduction of alternative approaches, the advection-dispersion equation is widely accepted for most circumstances (Corapcioglu & Haridas, 1984; 1985; Taylor & Jaffe, 1990; Harvey & Garabedian, 1991; Hornberger et al., 1992; Tan et al., 1994a; Tan & Bond, 1995).

This paper presents a review of the recent work on the modelling of microbial transport in porous media. Transport equations developed for bacterial transport can be generally simplified for the description of virus transport. This paper focuses on bacterial transport.

General transport equation for microorganisms

The general transport equation for microorganisms in porous media is based on the continuity or mass balance equation. In three- dimensional space the continuity equation for a particular microorganism is therefore written as

$$\frac{\partial(\theta C)}{\partial t}+\frac{\partial(\rho_s C^a)}{\partial t}=-\nabla\cdot\left(v\theta C-\theta D\nabla C\right)+R_g-R_d \quad (1)$$

where θ is the water-filled porosity, C is the concentration of microorganisms in the water phase, C^a the concentration of microorganisms in the attached or immobile phase (mass of microorganisms per unit mass of solid material), t is time, ρ_s is the bulk density of the porous medium, v is the sum of water velocity and chemotactic velocity, and D is the sum of the diffusion-dispersion coefficient and the random motility coefficient, and R_g and R_d are the growth and decay rates of microorganisms respectively. Sedimentation is generally considered to be unimportant for bacteria and viruses and its contribution to their transport is neglected.

The rate of change of the attached biomass phase is

$$\frac{\partial(\rho_s C^a)}{\partial t}=R_a-R_y+R_g^a-R_d^a \quad (2)$$

where R_a and R_y are the rates of microbial attachment and detachment, and R_g^a and R_d^a are the growth and decay rates in the attached biomass phase.

Various formulations exist for growth and decay rates, and attachment and detachment rates, depending on the assumptions regarding the pore scale distribution of attached bacteria. Two major conceptual frameworks have emerged relating microbial activity to the pore scale spatial distribution of attached bacteria in porous media. The first approach assumes that the distribution of bacteria on the solid surfaces is unimportant and has no effect on their access to substrates for growth (Bazin et al., 1976; Corapcioglu & Haridas, 1984). This has be referred to as the strictly macroscopic approach (Baveye & Valocchi, 1989). The second approach assumes that collections of bacteria attached to solid surfaces have specific geometries, usually either biofilms or microcolonies (Rittmann et al., 1980; Molz et al., 1986; Chen et al., 1992).

Growth and decay rates

Bacterial growth occurs in the water phase and attached biomass phase. Corapcioglu & Haridas, (1984) expressed the growth rate as

$$R_g = R_g^w + R_g^a = \frac{\mu_m S}{K_s + S}\theta C + \frac{\mu_m S}{K_s + S}\rho_b \sigma \qquad (3)$$

where R_g^w is the microbial growth rate in the water phase, S is the substrate concentration, μ_m is the maximum specific growth rate of bacteria, K_s is the Monod half-velocity constant and σ is the volume of bacteria per unit volume of solid material. Note that $\rho_s C^a$ is equivalent to $\rho_b \sigma$. Taylor & Jaffe (1990) adopted the biofilm approach and expressed the rate of microbial growth in the attached phase (biofilm) as

$$R_g = \frac{\mu_m S}{K_s + S}\theta C + \frac{\eta \mu_m S}{K_s + S}\rho_b L_b M \qquad (4)$$

where M is the surface area of the water-biofilm phase boundary per unit volume of porous material, L_b is the biofilm thickness and η is an effectiveness factor introduced to correct for the diffusional resistance at the biofilm-water phase boundary. Equation (4) reduces to (3) if we assume that there is no diffusional resistance at the biofilm-water boundary (i.e., $\eta = 1$), and that ML_b is equal to σ. It is noted that the specific growth rate, μ is based on the Monod equation [$\mu = \mu_m S/(K_s + S)$]. More complex models exist (Tan et al., 1994b) and can be easily incorporated.

The decay of bacteria is usually described by an irreversible first-order process, expressed mathematically as

$$R_d = R_d^w + R_d^a = b\theta C + b\rho_b \sigma \qquad (5)$$

where R_d^w and R_d^a are the rates of decay in the water phase and in the attached or immobile phase, and b is the decay constant.

Attachment and detachment rates

Expressions from the filtration literature have been adopted to describe the attachment rate of microorganisms in porous media (Corapcioglu & Haridas, 1984):

$$R_a = k_a \theta C \qquad (6)$$

where k_a represents the attachment coefficient. The attachment coefficient can be treated either as an empirical parameter in its own right or calculated from more complex empirical expressions. Taylor & Jaffe (1990) obtained k_a using the empirical relationship of Deb (1969), who found that k_a was a linear function of σ ($k_a = \sigma c_1 + c_2$ with c_1 and c_2 as constants). Tan et al. (1994a) found experimentally that once the concentration of attached bacteria (C^a) reached a threshold value, the porous matrix did not retain bacteria as effectively. They therefore proposed the following equation to describe the retention of biomass in the porous medium:

$$R_a = k_a \left(1 - \frac{C^a}{C_m^a}\right)\theta C \qquad (7)$$

where C_m^a is the maximum mass of bacterial cells that can be retained by unit mass of solid material.

Similarly, a number of different expressions have been proposed for the detachment rate. Corapcioglu & Haridas (1984) expressed detachment rate as a power of the attached bacteria concentration, i.e.,

$$R_y = k_y \rho_b \sigma^h \qquad (8)$$

where k_y is the detachment coefficient and h is an empirical constant, often assumed to be unity (Tan et al., 1994a). Speitel & DiGiano (1987) proposed a two term equation with the first term similar to Eq. (6) and the second term describing the dependence of biomass shearing on microbial growth rate. Taylor & Jaffe (1990) simplified their equation to

$$R_y = b_1 \rho_b \sigma + b_2 L_b M \frac{\eta \mu_m S}{K_s + S}\rho_b \qquad (9)$$

where b_1 is the specific shear loss coefficient and b_2 is a dimensionless parameter describing the biological aspects of shearing. It is evident that a variety of mathematical expressions exist for attachment and detachment of bacteria to and from solid surfaces in porous media. None of these expressions are universally accepted.

Simultaneous transport of substrates with bacteria

The transport of growth-limiting substrates often occurs simultaneously with that of bacteria during soil and groundwater flow and therefore forms a natural part of a discussion of the transport of bacteria in porous media that includes growth. When transport of substrates occurs at the same time as transport of bacteria, the concentration of substrate is unlikely to remain constant. Thus, transport equations for the limiting substrates must be derived and solved simultaneously with that for bacteria transport in order to obtain the substrate concentration on which growth is based.

The main processes affecting solute transport include advection with the flowing water, diffusion and hydrodynamic dispersion, and sorption by the solid phase. Transport of a solute that is the limiting substrate for microbial growth is also affected by its consumption. Taking these processes into account and assuming that growth is controlled by a single rate-limiting substrate, the transport equation for a biologically reactive solute can be written as

$$\frac{\partial(\theta S)}{\partial t}+\frac{\partial(\rho_s S^a)}{\partial t}=-\nabla\cdot\left[-\theta D_s\nabla S+\theta v_w S\right]-R_b \quad (10)$$

where S^a is the mass of substrate adsorbed per unit mass of solid matrix, D_s is the diffusion-dispersion coefficient of the substrate, v_w is the velocity of water flow, and R_b is the rate of substrate consumption by bacteria combined for the water and attached biomass phases.

Different approaches for describing the spatial distribution of bacteria in the pore space result in different mathematical expressions for the substrate consumption rate. This is because the specific growth rate in the water phase may differ from that in the attached biomass phase. The specific growth rate of bacteria in the attached biomass phase has been variously assumed to be a function of the substrate concentration in the water phase, that in the attached biomass phase, or that in the "immobile water phase" that lies between the free water phase and "attached biomass phase" (Baveye & Valocchi, 1989). The assumption that the specific growth rate is related to substrate concentration in the attached biomass phase, or in the immobile water phase, is equivalent to assuming that the response of biomass is determined directly by the environment that it "sees" in its immediate vicinity. This approach introduces considerable complexity and extra equations need to be included to ensure mathematical closure. It is assumed here that any immobile water phase present is indistinguishable from the attached biomass phase.

The simplest approach is to assume that the substrate concentration throughout the attached biomass phase is equal to that in the external soil solution, i.e., that there is no impedance of access of the bacteria to the substrate as a result of their attachment to the surface. The specific growth rates for both phases are therefore dependent on the substrate concentration of the water phase only. This following expression for R_b results:

$$R_b=\frac{1}{Y}\frac{\mu_m S}{K_s+S}\left(\theta C+\rho_s C^a\right) \quad (11)$$

where Y is the maximum yield coefficient expressed as the amount of biomass produced per unit mass of substrate consumed.

The biofilm approach, on the other hand, assumes that the rate of substrate utilisation by biomass in the attached phase is controlled by the transfer of substrate from the water-phase to the biofilm phase as the biofilm grows, and from the water phase to the biofilm phase by diffusion across the water-biofilm phase boundary. Taylor & Jaffe (1990) expressed this as follows

$$R_b=\frac{1}{Y}\frac{\mu_m S}{K_s+S}\left(\theta C+\eta\rho_b L_b M\right) \quad (12)$$

Depending on the choice of model, either Eq. (11) or (12) is substituted into Eq. (10), which must then be solved simultaneously with the appropriate bacteria transport equation.

Model capabilities to represent experimental data

Few experimental studies have been carried out to test both specific mathematical models and the conceptual approaches for microbial transport. Of those studies reported, most have found that specific models provide a good description of experimental results, but very few models have been validated using independently measured parameters. Similarly, few models have been tested beyond their initial development or applied to other scenarios. Much experimental work remains to be done before models of microbial transport can be used with confidence to make *a priori* predictions. Nevertheless, existing experimental studies have advanced the modelling efforts of microbial transport during the last decade or so and have provided valuable information for the study and evaluation of microbial transport and fate in soil and ground water. The experimental data of Tan et al. (1994a) are included here as an illustration of the capability of mathematical models to represent experimental data.
Tan et al. (1994a) measured breakthrough curves of bacteria during steady-state water flow at three water flow velocities (0.05, 0.1 and 0.2 mm s^{-1}) in columns packed with a coarse aquifer sand. Three different

initial cell concentrations (10^7, 10^8, 10^9 cells mL^{-1}) were used. All experiments were conducted at a temperature of 3 ± 1.5°C and no substrates were added. For these conditions, bacterial growth and decay can be neglected and the appropriate equations are Eqs (1), (2), (7) and (8) with $R_g = 0$, $R_d = 0$, and $h=1$. These equations were solved using the finite difference Crank-Nicolson scheme combined with the Newton-Raphson iterations. Water flow velocity was calculated from the measured inflow and average water content, and the dispersion coefficient was estimated from chloride breakthrough curves. The remaining three parameters (i.e., k_a, k_y and C_m^a) were adjusted using the downhill simplex optimisation technique to minimise the sum of the squares of deviations between model simulations and experimental data to obtain the best fit. The model described the experimental data very well under all the experimental conditions tested. Figure 1a and 1b illustrate examples of these simulations together with observed bacterial breakthrough curves.

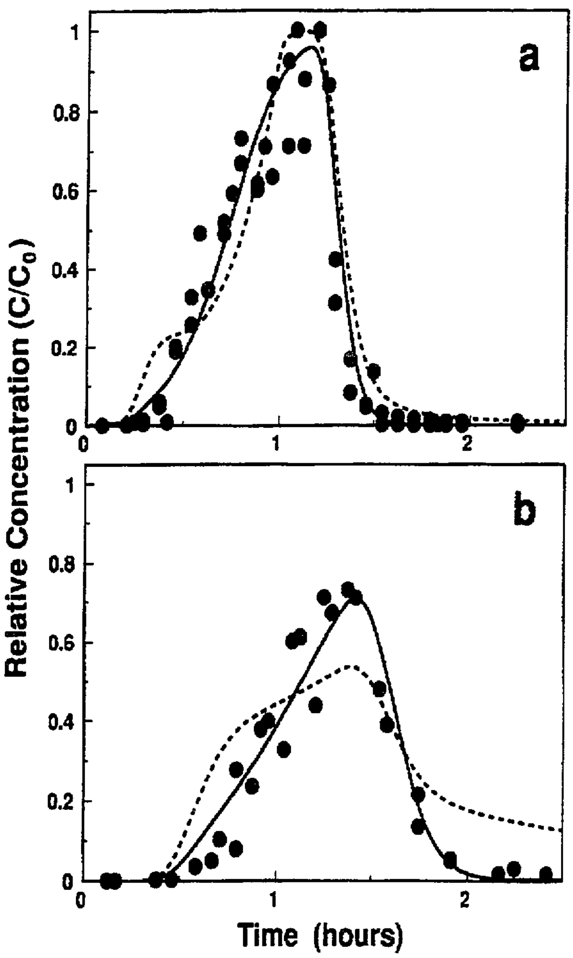

Fig. 1. Comparison of measured bacteria breakthrough curves (points) with simulations using the model of Tan et al. (1994a) (——) and Corapcioglu & Haridas (1984) (-----) following injection of a pulse with a concentration of 10^9 cells mL^{-1} (after Tan et al., 1994a). (a) $v_w = 0.1$ mm s^{-1} (b) $v_w = 0.05$ mm s^{-1}.

Tan et al. (1994a) also used their experimental data to test the alternative formulations for attachment and detachment proposed by Corapcioglu & Haridas (1984) [Eqs (6) and (8)]. Simulations obtained using Eqs (1) without the growth and decay terms, (2), (6) and (8) are also presented in Fig. 1. In this case the three parameters k_a, k_y and h were adjusted to obtain the best fit of simulations to experimental data. The model using the attachment/detachment expressions of Corapcioglu & Haridas (1984) did not represent the experimental data as well as the model proposed by Tan et al. (1994a). The better representation of the experimental data using the model of Tan et al. (1994a) was achieved by the inclusion of a maximum retention capacity, C_m^a, i.e., by assuming that once a finite number of attachment sites in a given volume of porous medium are saturated, bacteria can move through that volume without significant retention. It was found that C_m^a increased with cell concentration and ionic concentration of microbial suspension, but was unaffected by water flow velocity.

The experimental studies for a variety of experimental conditions appear to have all been well represented by the various models applied to them (Taylor & Jaffe, 1990; Bengtsson & Lindqvist, 1995). The models vary in conceptual approach and complexity and it is not possible to say that any one model is better than the others, particularly as different models have rarely been compared with each other. Furthermore, the ability of the models to match experimental data by no means proves that the models are based on correct descriptions of the chemical, physical, and biological processes occurring. Many processes are often lumped together and many parameters required are difficult to measure independently.

Conclusions

This paper provides an overview of the current state of progress with the development of models for the subsurface transport of microorganisms. Recent years have seen the development of a number of mathematical models which vary in conceptual approach and degree of complexity. Most models are based on the advection-dispersion equation, with terms added to account for processes such as growth, decay, attachment, and detachment.

The principal differences between models depend on which of these processes are included and how they are described. One of the key differences between bacteria transport models results from the assumption made concerning the pore-scale distribution of bacteria, viz. biofilm versus macroscopic approach. However, even when a biofilm approach is adopted in the theoretical development, simplifying assumptions are often made which reduce the model to the macroscopic approach.

These two different approaches for pore-scale bacteria distribution may not necessarily result in operationally significant differences in the capabilities of specific models to predict microbial transport.

Most models are able to describe experimental data adequately. However, few models have been tested for their ability to provide *a priori* prediction using independently measured parameters. Much work remains to be done to allow independently measured hydrological, physical and biological parameters to be used to predict the microbial transport in the subsurface environment. This, together with simplifying the models for use as management tools, are the challenges for future work in this field.

Acknowledgment

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Aquifer Storage and Recovery in the Murray Basin

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Abstract

Artificial aquifer recharge and subsequent recovery of the recharged water is an important new water management technique with a range of applications in the Murray Basin. Two projects are currently under way in South Australia.

Firstly the holiday shack community of Clayton on Lake Alexandrina has had its water supply cut off in recent years because of cyanobacteria blooms. The feasibility of storing lake water during winter for extraction during summer is being assessed.

Secondly, the Strathalbyn-Milang water supply network is also dependent on the lake for its supply, although an emergency groundwater supply is available. The feasibility of aquifer storage and retrieval along the pipeline is being assessed and if successful is anticipated to avoid the cost of duplicating a pipeline (ie more than one million dollars). It is currently planned to build a filtration plant, using activated carbon and ozonation, to remove toxins. Additional cost savings may accrue if a reliable storage can be developed and the aquifer storage and retrieval used to store water for pumping during blooms.

Aquifer storage and recovery has other potential uses.

Modelling capillary upflow under irrigated crops: Sensitivity to parameter-variations in a numerical model

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INTRODUCTION

Shallow water tables are common in most surface water-based irrigation areas. They can either cause problems, such as water logging and/or high soil salinity, or be a useful resource, supplying a proportion of the crops' water needs. Thus their presence must be taken into account when developing water management strategies in irrigation areas.

The long-term fate of different irrigation management practices can be assessed by simulating them with models of soil water flow. The models commonly used for this purpose are one dimensional and based on numerical solutions to Richards' equation,

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial z} K\left(\frac{\partial\psi}{\partial z} - 1\right) + S, \qquad (1)$$

where θ is soil water content, t is time, z is depth, K is hydraulic conductivity, ψ is soil matric potential and S is a source/sink term which can describe plant water uptake. Plant water uptake is commonly described by functions based on root length density (e.g. Campbell 1985).

While such modelling has been previously applied to irrigated soils (e.g. Prathapar et al. 1992, Schwamberger et al. 1994), little attention has been paid to the sensitivity of the model predictions to variations in the inputs. For example, K is highly variable in space (Nielsen et al. 1973), but it is an important parameter in simulating infiltration of water into soils without plants present (Bristow and Williams 1987). Also, root length density is difficult to measure or predict (Meyers and Barrs 1991).

This paper examines the sensitivity of simulated water movement upwards from a shallow water table to variations in model parameters. A readily available Richards' equation-based model was used and simulations conducted under hypothetical conditions using previously measured soil data. The study aimed to illustrate possible problems in applying this modelling approach to irrigation management problems.

METHODS

Model

The SWIM program of Ross (1990) was used. This program numerically solves Richards' equation under conditions (e.g. soil characteristics, vegetation, water inputs, evapotranspiration) set by the user. For the program the soil moisture characteristic, $\psi(\theta)$, is described by the function,

$$\psi = \psi_e\left(\frac{\theta}{\theta_s}\right)^{-\beta}, \qquad (2)$$

where ψ_e is the air entry potential, θ_s the saturated soil moisture content and β is the slope of the ln ψ *vs* ln θ curve. The soil hydraulic function is described by,

$$K = K_s\left(\frac{\theta}{\theta_s}\right)^{\left(2+\frac{3}{\beta}\right)}, \qquad (3)$$

where K_s = the saturated hydraulic conductivity.

Transpiration from plants is represented in the program. It is calculated as a proportion of potential evapotranspiration (ET_p), and water uptake any depth in the soil depends on the root length density and soil-plant water potential gradients at that depth. The proportion of ET_p is related to plant growth. Plant growth is described by a sigmoidal function which sets lower and upper limits on the proportion of ET_p transpired. The depth distribution of root length density, R, is describe by the exponential function,

$$R = R_0 \exp\left(\frac{z}{(C_d - 1)}\right), \qquad (4)$$

where R_0 is the root length density at the soil surface and C_d is the decay constant, being the depth at which $R = 0.37\ R_0$. Root growth is represented by increasing values of R_0, with a maximum value, R_m set by the user.

Table 1. Characteristic values of model input parameters used in the simulations (symbols are defined in the text).

Soil	θ_s ($m^3\ m^{-3}$)	K_s (m day^{-1})	β	ψ_e (kPa)	C_d (m)	R_m (m m^{-3} 10^{-4})
clay loam	0.35	8.8	8.7	-0.07	0.25	5
light clay	0.48	0.1	10	-0.34	0.25	5
clay	0.4	0.002	8.2	-0.39	0.25	5

Simulations

Simulations were performed for three different soil types with a fresh watertable at 1.2 m depth. The soils were; (1) a clay loam (red earth, Bristow and Williams 1987), (2) a light clay (typical MIA light clay, Schwamberger et al. 1994) and (3) a clay (Mundiwa clay loam B horizon, Prathapar et al. 1992). These soils were chosen from the literature as they had previously been used in Richards' equation-based simulations of water flow and represented a range of textures and hydraulic properties (Table 1).

For each soil, the profile was divided into 12 equal 0.1 m thick layers. The only parameter that varied between layers at the start of the simulation was the soil matric potential. This was set to -1500 kPa at the soil surface, and increased linearly to 0 kPa at 1.2 m depth (i.e the water table).

Simulations were run for 24 weeks over three periods, covering establishment and growth of a crop:

1. weeks 1 to 10 – no plants present,
2. weeks 11 to 17 – full plant growth achieved,
3. weeks 18 to 24 – plants remained at full growth.

Water additions were set at a constant amount, 14 mm $week^{-1}$, occurring on the first day of each week. Daily values of ET_p were set constant at 5.7 mm.

The parameters in the sigmoidal growth function were set so 0.1 % of maximum growth had occurred at the beginning of week 11 and 99.9 % had occurred at the beginning of week 18. Maximum possible transpiration from the plants was set to equal ET_p. For root growth, the characteristic values of R_m and C_d (Table 1) were chosen to be realistic value for a variety of plants in irrigated soils (e.g. Meyer and Barrs 1991).

Capillary upflow values were extracted from the SWIM output files after the simulations were run. Daily upflow values were summed over each week, giving 24 weekly values for each simulation. Results are not shown for the first week of the simulation, as they would have been more an artefact of the initial conditions (i.e. the soils "wetting" up) than an indication of the soil properties. This may also be the reason behind the decrease in upflow during the first period, prior to the growth of the plants.

Sensitivity analysis

To assess the sensitivity of upflow to parameter variations, the characteristic model input parameters (Table 1) were varied by ± 50 %. Relative sensitivity (σ) to the model parameters for each week of the simulations was then determined from the relative change in upflow (U), i.e.

$$\sigma = \left| \frac{U_h - U_l}{U_c} \right|, \qquad (5)$$

where the subscripts h, l and c refer to the high, low and characteristic parameter values. Since the input parameter values were varied by ± 50 %, their relative change was 1 and they were not included in eqn. 5. σ values were not calculated for the root parameters during the first period as there were no plants present.

RESULTS

Capillary upflow rates ranged from approximately 2 to 25 mm $week^{-1}$ (Fig. 1). These results are consistent with measured values in light (Kruse et al. 1993) and heavy (Dugas et al. 1990) textured soils under generally similar conditions, indicating that the processes represented in the model were relevant to the conditions being simulated.

Highest upflow rates occurred in the lighter textured soil, especially during the third period. Upflow rates also increased during the last period due to the proximity of the roots to the water table when the plants were at full growth.

The sensitivity of upflow rates to parameter variations (i.e. σ values) differed between the different simulation periods and different soil types (Fig. 2). In the first period, upflow was most sensitive to ψ_e in the clay loam, and θ_s (and β to a lesser extent) in the two heavier textured soils. When plants were introduced, σ values for the soil parameters generally decreased.

During the third period when plants had achieved full growth, upflow was most sensitive to C_d in all three soils. In fact σ values for C_d in the clay soil were the highest σ values in the study.

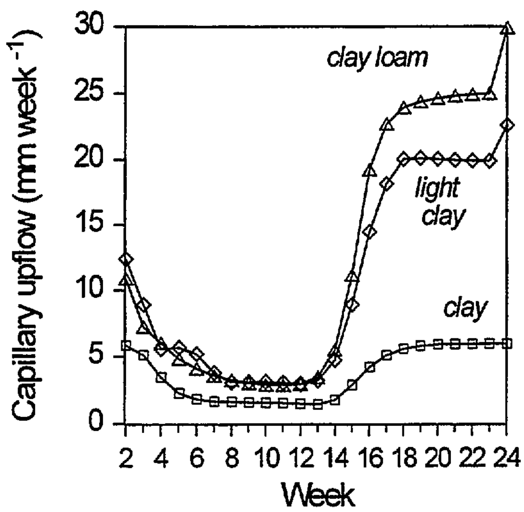

Figure 1. Weekly capillary upflow from a water table simulated for three soil types. Plants were included in the simulation from week 11. The plants reached full growth in week 18 and remained at that level of growth for the remaining time.

DISCUSSION

The sensitivity of upflow to ψ_e and θ_s in the bare soil conditions (i.e period 1) is due to the important role these parameters play in unsaturated flow. Capillary upflow is an unsaturated flow process, as water moves through the unsaturated soil above the water table. The sensitivity to ψ_e and θ_s found in this study (Fig. 2) contrasts the results of Bristow and Williams (1987) who simulated infiltration with a model similar to SWIM. They found infiltration into the same clay loam used in this study much more sensitive to K_s (i.e. $\sigma \sim 1$) than β and ψ_e ($\sigma \sim 0.1$ for both). However, infiltration is more dominated by saturated flow than is upflow.

The sensitivity to the root parameters during the third period (Fig. 2), when plants were fully developed, indicates the overriding effects plants can have on soil water flow. Root length density has a large impact on upflow because the distance over which water must flow through the soil from the water table is shorter when large numbers of root are present close to the water table. The impact of plants was greatest in the clay soil as this soil had lower K (Table 1), and hence higher resistance to flow, than the other two soils. Upflow was more sensitive to C_d than R_m , as C_d has a greater impact on root length density deeper in the soil profile (from eqn. 4).

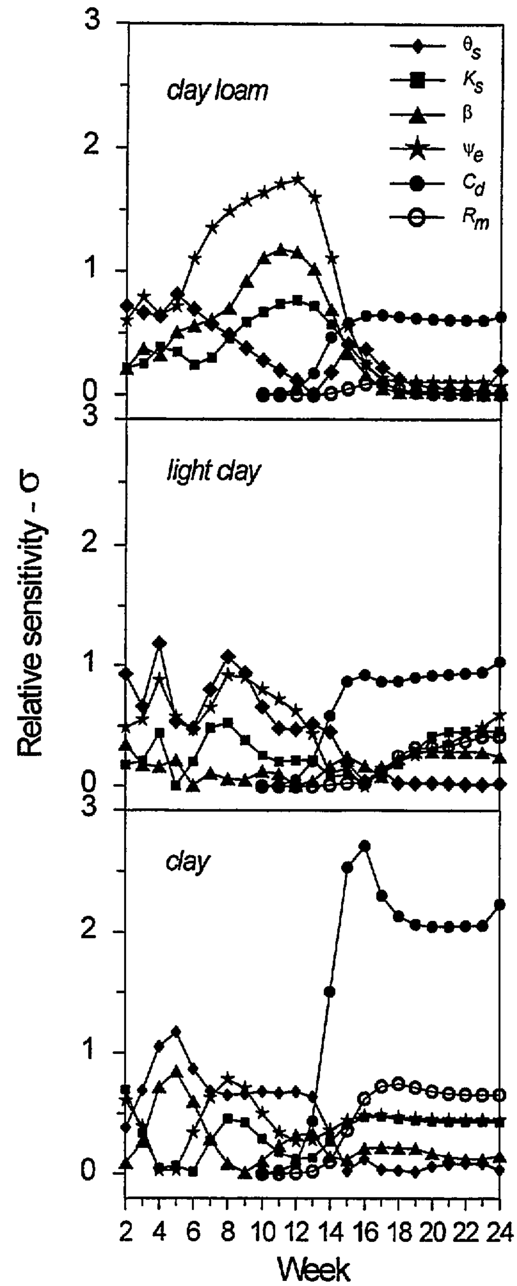

Figure 2. Relative sensitivity of capillary upflow to input parameter variations (symbols explained in the text) for three soils.

Doubts have been raised about the value of applying Richards' equation-based models to practical water management problems, because of the difficulty in measuring the model input parameters. Soil water flow parameters, e.g. K_s, are highly variable in space. The higher sensitivity of upflow to θ_s and ψ_e , which are capacity parameters and not as spatially variable as K (Nielsen et al. 1973), therefore suggest that Richards' equation-based models may be more relevant to modelling capillary upflow in bare soils than to situations dominated by infiltration.

When plants are present however, the outlook may not be as optimistic. Root length density data are difficult to measure. Rooting patterns are also sensitive to soil conditions, e.g. oxygen levels, salinity, soil strength, and variations in irrigation water management (Meyer and Barrs 1991). Therefore, application of Richard's equation-based models to modelling upflow under cropped conditions may result in predictions of poor accuracy. Other modelling approaches, such as those of Prathapar et al. (1992) or Thorburn et al. (1995) my be better in these circumstances.

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What if there was no River System

a paper by Robert Vincin
International Environmental Consultant

The world is a bank, a bank of resources! Man has, from time immemorial, withdrawn from that bank, never depositing, not even rolling over, those resources. Now, the management of those resources, Nature, is calling for the account to be addressed, failure to do so will see the receivers brought in.

It has come to rest upon this, our generation, with the young, "the historians of tomorrow", looking over our shoulders, to implement environmental restoration.

What if there was no River System? The following is data that is aimed to establish that Australian land management and that of some other nations, is based upon incorrect data.

If you were considering buying a business that was historically sustainable, however after a series of managers, changes of philosophes, it was in "an all but terminal state", **What would you do?**

1. Continue the motivation of the staff, branches and say, "keep up the good work, carry on", prepare an E.I.S.!
2. Buy it and write it off as a tax loss. OR
3. Go back through the company records and establish what made it successful, return to that position as a starting point, using modern business and technology principles to rebuild to a profit base.

When it comes to land/water vegetation management business fact is referring to:

1. the staff were trained by staff who (as the following shows), were working off erroneous data;
2. since it is the only business and home available and no buyer we can't write if off;
3. records show we were No.1 GNP in the world not so long ago (and now No.29+). God, sheep, beef and grain provide all, this was the promised land (like historically land elsewhere, before)...

So, what went wrong and when!

What proof is there of the sustainable land; is it expensive to repair and what resources are there to effect reparation and get the business running sustainably?

So to research ...

Look at the company's books of land management and sustainability.

The first company book to look at is that of the parent company, 'The Bible'. Not only is it a proven chronology of day to day millennium to millennium record, but spells out clearly the stock holdings the business originally had.

Some extracts from the parent operation; you will note from these examples that the holding known as Egypt for millenniums before landholders brought into the operation ran successfully and sustainably. From Journal entries we can establish that the timber holdings had at least 26[1] basic species[2]; 8 varieties of edible nuts[3], dates, several grape species, corn,[4]; wheat[5], abundance of meat[6] and vegetable varieties,[7] volumes of fresh water[8], air and water recycling plants.[9]

It is noted clearly in 387 specific and detailed references,[10] "there was no constant flowing river system"[11] through the holding according to the original accountants and auditors of the book. Only ponds-pools-brooks-springs. **There is no word in Hebrew for River, the closest reference being the Egyptian "loan-word" ye' or, closest translation (Brown-Driver-Briggs) is Watercourse**. There is even detailed references (after we took over, of how to maintain the holding).

The water was retained in the soil and in reed ponds. A sound and tested business plan, rested the plant in sections every seven years (R & R).

Let me show you at this point how future accountants fiddles the books forming an incorrect basis for future managers. In each "rewrite", the writer added his own interpretation and recent observation. Hebrew, **Ponds Reeds**; - *Isaiah 019-006;* Romanised, **Pond-Reeds;** *Isaiah 019-006;* - Romanised, **Pond-Reeds**; - King **James Brook-Reeds**; - Revised King James, **River-Papyrus**; - American, **Nile-Meadows**; - Living Bible, **River and green things**; This is one of 621 reference variations between records of Hebrew, Egyptian, Romanised versions and that of more recent versions.[12]

The example shows that, by accepting the data on face value, following environmental and business planners made decisions perpetuating the decline in the holding, all contrary to the holding creator's guidelines.

Today we read where archaeologists have found lost cities in these holdings, (RAMSES II), 50/100 feet below sand and eroded mountains with evidence of flood, driven silt, timber, vegetation, caught in the ceiling. There is equally well documented evidence of the collapse of other civilisations through land/water denigration i.e., Mayan civilisation demise through excessive land clearing. I personally have been down "wells" in China, the bottom of which is a tunnel for a "former river" with men lowered up and down 24 hours a day clearing silt and repairing cave-ins. The water supplies the cities.

So, how about this branch here in Australia, if we decided to invest, can we reverse damage, restore and maintain the holding and profit yield?

Inspection of the holding, the erosion, the recurring and increasing drought frequencies suggest, it is not a favourable investment.

Let's look at the branch account books! The first auditors taking stock of the holdings and assets, although somewhat damaged by previous mismanagement, they[13], Mr Oxley, Captain Sturt, W. Hume, Sir T. Mitchell, etc., reported to the C.E.O.'s[14], Governors Darling and Bourke in part, typical reports (from each), our progress is constantly stopped by massive reed barriers around lagoons (billabongs) and across the catchment, sometimes 50 miles wide, there are no rivers as we know them (U.K. France) ... the aborigines show us how to dig for fresh water scores of miles from the lagoons even in severe drought conditions ... excellent natural plains tall grasses ... It appears that in some morasses ... water flows from the lagoons not to them.

The Castlereagh, the Barwon, Macquarie, Lachlan, Morrumbidgee, Darling are series of ponds, mostly higher than the surrounding plain all with reeds.

The Macquarie flows into the marshes, circumnavigating these reeded ponds establishes there is no out-flow. Water appears to flow in and not out. The soil and clay consume the water, some morasses distribute water to surrounding ponds but no further.

'Oxley'[15] Called for Common, along the water courses, ponds and mountain streams and swamps.

(Sir) Thomas Mitchell[16] to Governor Bourke .... the Darling River at the point where it joins the Murray is 2 boat lengths wide, in full flood, from waters from the north country. The water all but surfaces flush! Mitchell's Map a consolidation of his previous trips and those of Sturt, Hume and Hume Cunningham, Oxley entitled Tropical Australia, Routes of 4 Explorations to accompany his report 47/2L dated 26 January 1847 shows all inland rivers as broken by 'non flowing/ponds and reeds.

Mitchell to Bourke[17] ... "and before following up Capt. Sturt's" assumption regarding the Darling joins the Murray and it joins the Morrumbidgee and to find its source Sir, I suggest I await the flood waters[C] that have been also reported as an annual event due in April. This delay will permit us to row and sail up the flow, the alternate will be, to use the horses and dray and again, dismantle the boat upon reaching the perimeters of the lagoons (as experienced in the Darling and Macquarie)."

From these early audit reports and over 150 years of ensuing management records show, massive erosion that were given the name of 'river', they evolved, draining the soil, vegetation of the water that it had depended upon for millenniums, "the sustained water-table gone". Mitchell as did Allan Cunningham, Colony Botanist, concluded "The lagoons (Billabongs) are the indicator (mirror) of the water table within the catchment's soil.

FACTS FOR CONSIDERATION IN YOUR DECISION TO INVEST, TO RE-STRUCTURE - TO REPAIR - REPLACE.

Reed Barriers:[18]

Reed barriers were natural dams digesting salt, excess nutrients, algae - collectors of silt - aerators of water, binder/collectors of the soil.

These original local auditors reported lagoons were higher ground than the surrounding plain/land. (TRAPPED SILT RAISING PROFILE).

Billabongs:[19]The water height was the mirror of the water-table across the catchment. "The reason the settlers took up their holding 150+ years ago".

The Secretary of S.A.[20] offered[F] a prize of £10,000 for the first boat to join the billabongs together up the Murray and reporting on the difficulty of crashing the weeds (the reeds). Hence, TODAY the aerial view of the Murray shows, the prior billabongs and indeed the prior annual flood route in parts (usually the high land side of the catchment).

Hill slopes and tops were treed, vegetated, stable and ongoing nutrient generators, for the lower catchment and flats as they were to supplying, "silt free water".

As each region of the inland were discovered, settlers followed, cleared land around "billabongs", removing weeds (reeds) for better access and trees off the flats near the water. During annual flood flow between billabongs, soil began permanently eroding deeper each season.[21] Across these "Rivers" new arrivals built bridges and causeways that acted as chokes and dams, floods evolved. They accepted that the "rivers" were always there. Silt losses, salt and drought appeared as a problem as indeed did waterloggings. Later landholders cleared the hills (the nutrient generators) and therefore increased the speed of water runoff.

What had been created, sustainable, evolved into the diminishing asset we see today.!

To-day we know;[22] UN data after Oceans Polar caps, **inground water** is (was) the largest storage. Open dams, rivers, lakes evaporate in sub-tropic regions average 8 ft. per annum.

Salt; Fresh water floats on salt water. Salt water on fresh water will invert (year 9), some trees, lower water levels in soil and therefore salt!

Reeds: (varies species) consume salt, algae - collect and filter silt - raise land profile, aerate water. Salt

Bush, Rhagodia parabolica 2oz salt per 1lb of: Edible after boiling - Allan Cunningham.

Salts; are a natural produce of all living matter.

Rabbit, foxes, all feral animal and weeds are out of control, adding to the demise of the land, its vegetation and water.

Desert - travel at 80 kilometres per annum. (U.N.E.P.).

River Bank - River Erosion. Note: Sr Thomas Mitchell sketch #27 his book Tropical Australia Crossing Darling near Murray (in flood 2 boat lengths wide and surface high, 1847. Sketch by H. Forde (1 of 20) Murray Darling Junction 1865; flow now 40 ft wide and eroded down 2 metres and under the surrounding plain. Large trees, some falling, also see (Footnote 21) in 20 years from there 'There was no River System' to gully erosion, called river.

Water; flowed in soil, inground to equilibrium and/or to lowest point. The gully erosion IS foreign, i.e., river erosion, they are the lowest points. Water pumped from "the River" 15 metres below the surface for irrigation returns carrying nutrient salts, fertilisers, contaminating the water and soil down catchment.[23]

Soil; CSIRO and U.N.E.P. advised that up to 90% of the land needs reparation. 50% bordering on irreversible loss.

A Billabong; is (was) the window of the water table in the catchment. The recent pumping of water from the Shoalhaven to Warragamba illustrated how rapidly the water table drops when the "river" is drained, (as does the marsh and the "swamp").

Ground water; is being pumped, fissures and historical entrance routes are closing. Hence where water flowed away now remains. Some waterlogging occurs in some regions. The regions originally dependant upon water supplied via fissures, morasses now starved.

Solutions:

1. According to printed data of C.A.L.M.-W.R.-L.C., C.S.I.R.O. etc.

   Dig out the bending in the rivers, improve the "flood flow" to escape. **All this is based on printed data 1901 and not 1810 - 50, that there were no Rivers.**
2. **More Weirs and Dams:** "evaporative ponds"
3. **Do nothing:** and continue rhetoric
4. or accept that the "new" Murray-Darling System associated "creeks/catchment erosion was not a system prior to the original and subsequent land users, whom, in dismantling (the asset) the vegetation - "pulled the plug" on sustainability.

The decision prior to investing then is....
... do nothing and watch the decline like that of the parent holding and China, Africa, America, etc.
Buy in with a small investment, (like landcare grants to 2000 branches - Greening Australia grants to Shire Councils etc.), make statement to the shareholders "things look promising".

OR

Look at how the holding was - prior to original "department" records, we re-establish it using modern know-how and utilise untapped resources to rebuild and, aim again for No. 1 G.N.P.

If it is the later, we have never had such an opportunity.

The one thing that has been clear after reading the voluminous original documents of the explorers and governors is that, for 150 years we have been working off incorrect data in forming plans to maintain or more specifically adding to the demise of land-water-vegetation. We are a people when, a problem and solutions clearly explained, historically rally in support. Yes!

There are properties[24] that have restored their catchment back to "pre-settlement conditions", incorporating, modern technology to assimilate inground water routes across catchments. These property's output today exceeds that of any previous period. They remained drought proof through 3 major droughts. Photographic evidence shows the profile increased as silt collected in the reed barriers.

(Water, when it flowed in catchments or ponds, often flowed **from** the billabong in ground and in shallow vegetated gullies not the reverse).

We can no longer treat symptoms by throwing ongoing money at "drought relief", dig the bend out, find water to flush the algae out, ask former Judges to adjudicate on water sharing water that's not necessarily there. We must effect the best solution, a solution to ensure sustainability for the entire "Catchment System". We cannot speak of Conservation until, we have the asset, the business restored to the original historically stable condition, incorporating modern know-how to assimilate those conditions.

There exists untapped trained and untrained resources[25] of people, utilities and detailed proven working plans in place ready to drought proof catchments, restore hillslopes generators, eliminate feral pests and all it needs is a "leader" in government to say "here are the resources for 7 trials, show me US results within the year", and (I) we will support "What if there were no River Systems". Launch "Revegetation, Land, Water, Stability back to No.1 G.N.P." and in so doing create fuller employment and a new national ethic of "we" together can be by the turn of the century the No.1 G.N.P. nation. History has shown that Australians are a people whom when called to serve the Nation, rally.

I would subscribe that restoration of **all** water-soil-vegetation-currently under a variety of services - overlapping of departments including qangos-various funding of work, demands a central agency administration. This is a responsibility of governments, and should by necessity be expedited and indeed be apolitical.

Assuming that such an agency existed I propose:

a. A series of 7 trial sites run simultaneously, each commencing at the first source of "erosion" and hill slopes, combining all the skills of the various government departmental experts in one endeavour.

b. Funding to cover the following:

   1. appropriate flows and control while and until restoration is effected.

   2. preplan appropriate vegetation supplies.

   3. fencing

   4. agreement with landholders, including Banks and Institutions, and upon the holding becoming viable, cost recovery, relative to income profit.

c. Legislation for "the Common" that region adjacent to the erosion, the watercourse, the river, the swamp, the marsh, the lake, the common dam. Included in such legislation will be appropriate compensation for reclaimed Common and unfertile production land or exchange. There must be included heaviest of penalties for clearing of vegetation, swamp, marshes. The laws must include restoration of historical marshes (including reclamation of canals, channels, trenches, dug to drain them). NB: NeverDry adjacent to the Macquarie Marshes is dry for the first time in 150 years.

It's important to recall Oxley, Sturt, Mitchell, Cunningham all reported water into the marshes and no evidence of surface outflow, but water below the surface 60 miles away. While restoration is being effected legislation is mandatory for a more equitable distribution of water, i.e. if water is stored in soil/groundwater and used on the property it is in essence being recycled. If on the other hand the now *15 metres deep eroded river/gully is the low point and a farm draws off with a pump to irrigate the surface, water then returns to the low point 15 metres down from the original historical water table, leaching contaminants and salts with it.

Conclusion

January 1994 the U.N. issued an urgent communique warning of impending food shortages in those countries unable to produce or procure food and whose soils are exhausted or consumed by deserts. In 1994 Australia previously a nett exporter of grain, imported because of the continuing drought. U.N.E.S.C.O.'s Man and Biosphere 1976 set out impact on hill and mountain stream bank clearing. The countries listed in 1976 are the same as '94 in the U.N. communique.

Erick P. Eckholm in his well researched and documented book 'Losing Ground' 1976, confirms U.N. and World Bank position that, **unless a nation as a people commit themselves to restoration, no amount of government regulation or rhetoric will help.**

Referring to restoration for the next generation by planting a tree (or 1 million trees) here and there without a detailed land/water/vegetation plan, will not do anything. Fact is if the young return to see their efforts die, then their response for the future involvement also dies. We cannot afford a P.R. once off "look at us", we will loose our most valuable resource, our fellow Australian's help.

While the Asian nations leave the fields for the dollars in the factories, and their unkept farms and deserts also encroach, do we not have a business opportunity to capitalise on truly faithful restoration of our best asset, and in turn produce for these immense markets?

If your input data is wrong and other nations Egypt/China/Africa/U.S.A. records showed they travelled the same path we are rapidly taking, shall we sit and divide up the water that's not there, or shall we carry out trials and putting back into the soil, the water for storage and use by those on top of it.

There was no river system; and now each year there is less and less a system or stable surface soil and vegetation.

Let's update the input data!

"There was No River System".

TREE SPECIES
EGYPT PRIOR TO 'NILE RIVER'

Species according to Hebrew, Roman, King James

Spikehard	Lotus	Fig	
Saffron	Mulbery	Olive	Hazel
Calamus	Cedar	Pomegranates	Chestnut
Almug	Cypress	Poplar	Box
Chinnamon	Juniper	Elm	Myrtle
Frankincense	(Broom)	Willow	Shittah
Fir	Sycamore	Oak	
	Almug	Terebinth	

"Tree of Life" & Tree of Knowledge
(See Endnote 2 for source).

[1] Footnote 1-11. Data extracts: Chronicles King's.
[2] 2 Kings, Leviticus, Genesis, Job, Psalms, Nunbers, Song of Solomon,
[3] Deuteronomy, Isaiah, Matthew, Luke, Ezekiel, Jeremiah, Ecclesiastes.

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12 Hebrew Bible; Egyptian manuscripts; King James, Revised King James, Romanised, International Version, American Standard, Living Bible Revised Standard, Revised American versions of the Bible. a) Rabbi Raymond Apple, The Great Synagogue, Sydney. b) D. Rom. Bible Versions, Dixon Library, Sydney. Hebrew Pond Reeds; - Isaiah 019-006; Romanised, Pond-Reeds; Isaiah 019-006; - Romanised, Pond-Reeds; - King James Brook-Reeds; - Revised King James, River-Papyrus; - American, Nile-Meadows; - Living Bible River and green things; This is one of 621 reference variations between records of Hebrew Romanised versions and that of more recent versions. The older detail hiding a City in the wilderness trees and ponds and the more recent working of accumulated error write of the burning sands and the desert wilderness.

13 John Oxley, Survey General NSW 1812-28. CY 542 - CY 815 - CY 1488 - Journals, papers, Mitchell Library, Rare Book Collection. Captain Charles Sturt of the 39th Regiment in company with Hamilton Hume. Followed route of John Oxley to Macquarie Marshes and circled the Marshes. No sign of outflow. Plus other discoveries. Mitchell Library Rare Book Manuscripts, see His Excellency Lieut. G. Ralph Darling Proclamation December 25, 1828. Ref. Q346-911/N. (Reader Ticket 382/75 Robert Vincin). Major (Sir) Thomas L. Mitchell. Explorer/artist/writer. See Mitchell Library Rare Books and Manuscripts. * see attached stack slip References.

14 Governor's Darling and Bourke - various Proclamations and dispatches/orders covering Oxley, Sturt, Hume, Cunningham, Mitchell reports. Mitchell Library Rare Books and Manuscripts.

15 Oxley witnessed clearing around ponds and burning of reeds called for Governor Darling to declare "a Common" and fees. Mitchell Library Rare Book and Manuscripts. A1191 CY 815.

16 Major (Sir.) Thomas Mitchell detailed pencil sketches, 27 Plates # 25 & 27. 27 with his hand written addition for Publisher of his Tropical Australia vividly illustrates "Crossing the Darling in flood", and "flood" down the Macquarie watercourse 3 ft wide, 1 ft high - see DG A6 DX PD 719.

17 DGA6 PXA3 Tropical Australia (CY1560). CY1099 981-6A1 Maps MT4/805, 1827.50/1, ZM2 806-1847/1, 981/6A1, CY 695, CY 419 CY 811.

18 Mitchell to Bourke CY811 Missing Dispatch (CY 695 Oct. 4 1835) 15/3/36.

19 Allan Cunningham, Colonial Botanist Mitchell Library Rare Book Collection FM4/.3578, FM 43089, CY 815, John Oxley CY 5452.

20 Oxley, Sturt, Mitchell, Cunningham, see above references.

21 Murray River 1853 Sir Henry Young: Captain Cadell Forced boat during flood between the ponds and reed beds. A381 CY 877.

22 See Mitchell Tropical Australia and sketches, see 16. for original status.

All - see DGA6 No.2 Morrumbidgee at Murray only a few feet wide 1846. see C.D. Rom. Photo Mitchell 03648 Bourke, A River forming Hay 1870, River forming trees under cut. Nyngan 1890 town fell into 20ft deep gouged river 47684 and Deniliquin 1902. Clearing the freshly gouged river banks of trees for fuel. Fort Bourke station 1865 now flowed 6 metres below. Sir Thomas Mitchell Pond above the surrounds. # 03648. Bourke S.S. Nile sat on the bottom of "the River for 3 years before it caught fire. Albury 1869 still No. 06235 town picnic on floor of "the river" 5 metres of fresh eroded bank and trees. 1880 Bathurst 1 metre diameter tree growing middle Macquarie River 04428, river then 12 feet wide eroded 1 metre from surface.

23 U.N.E.P., U.N.N.Y. and U.N.I.C. Sydney

24 See Bourke Wier, C.D. Rom 03669 in 1907 and surrounded eroded banks still fresh cut. 03658 vessel S.S. Andrea awaiting a river. 03626, 03627 "Barrington" Bourke bore a pump 1711 ft down, 170,000 gallons daily 1895, failed in 1897, salted: 05941 Shepparton 1905 irrigation channel: 06314 Lohama 1914. Pumping station built across dry Murray. 03689 Bourke 1937 Donkey Engine, Bore Pump looking for fresh water.

25 A Current Affair Restored drought proof properties January 5, 1991. T.C.N. Channel 9 Sydney.

See: a) M.P. Tony Abbott Member for Warringah releases of Robert Vincin's paper 5E Environment, Employment, Economy, Export, Education, detailed plan of Environ Employment based on 12 years of field trials. Israel and Roosevelt Civil Construction Corp.

Assessment of Salt Load Impacts on the River Murray Due to Irrigation Development in the Eastern Riverland District of South Australia

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INTRODUCTION

The eastern Riverland district is located between Overland Corner and the South Australian -Victorian border (figure 1). The district contains 20 801 ha of irrigated land, planted mainly to vines, citrus and vegetables. The annual diversion volume for this area is in excess of 205 000 ML.

In the past the potential for mobilisation of salt to the River Murray due to the use of river water for irrigation in a saline groundwater regime has not been used as a criterion for irrigation management. The River Murray Water Resources Commission (RMWRC) has undertaken to formulate a strategy to monitor and control irrigation transfers with the aim of controlling salt loads to the river. To facilitate this, RMWRC has developed a policy that requires the best use of the limited water resources available for the least impact. This involves best practice on-farm irrigation management and stringent monitoring of water allocations and transfers.

A finite difference, single-layer computer model of the eastern Riverland is currently being used to model various scenarios of increased irrigation up to the year 2045. The objective of the study has been to optimise the location of potential irrigation sites to provide the most effective control of irrigation induced salt loads to the river and floodplain. This will allow water resources managers to strategically plan future irrigation at sustainable levels within the eastern Riverland, thus avoiding environmental degradation and economic losses.

The assessment of salt load impacts of existing major new irrigation developments has been achieved with the groundwater model described in this paper.

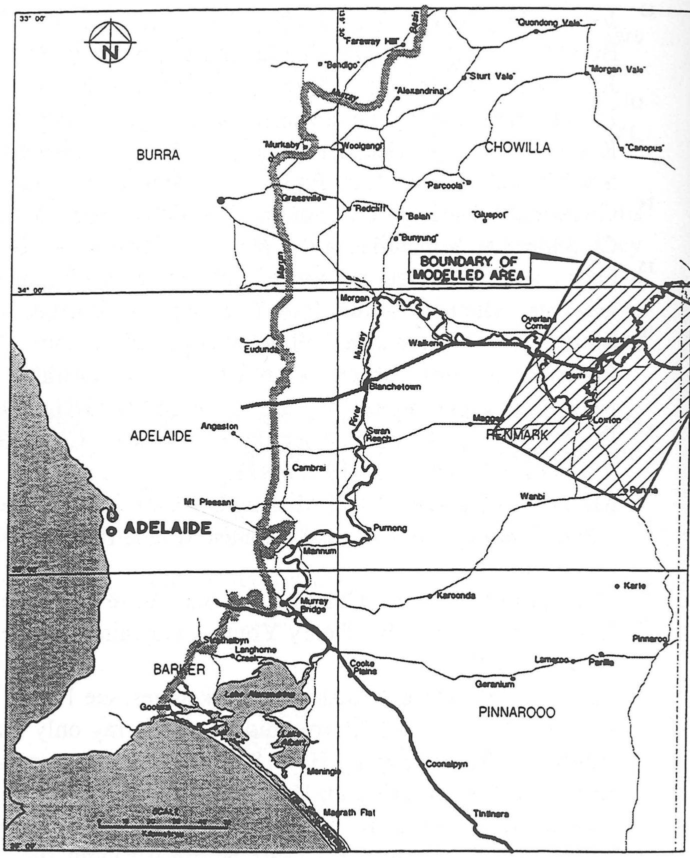

Figure 1: Location Plan

REGIONAL HYDROGEOLOGICAL SETTING

Surface Mallee sand deposits (Woorinen Sands) are ubiquitous in the eastern Riverland district. The sands are underlain by variable thicknesses of Blanchetown Clay, depending on surface elevations. Irrigation drainage percolates through these layers and recharges the unconfined Loxton Sands aquifer which comprises two units; an upper medium to coarse grained unit and a lower fine grained, silty unit. Significant watertable mounding has occurred within the Loxton Sands aquifer due to irrigation development (figure 2). The Bookpurnong Beds aquitard, which comprises sandy marls and fine silty sands directly underlies the Loxton Sands aquifer and separates it hydraulically from the confined Murray Group limestone aquifer. The river valley is infilled with medium to coarse alluvial sand deposits of the Monoman Formation which are in direct hydraulic contact with the River Murray.

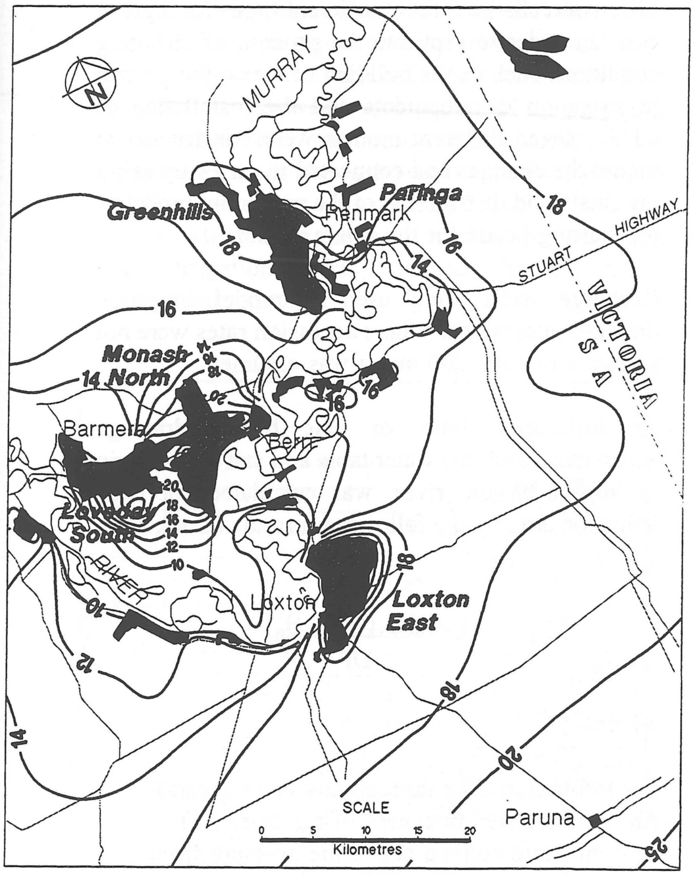

Figure 2: Current Water Table Contours, Observed

A list of hydraulic parameters adopted for the model are shown in table 1.

Monoman Formation:	k = 10 m/day
	$s_y = 0.15$
Woorinen Sands:	$\theta_1 = 0.14$
Blanchetown Clay:	$\theta_1 = 0.35$
Loxton Sands:	k = 2 m/day
	$s_y = 0.15$
	$\theta_1 = 0.07$

Note: θ_0 assumed to be 0.05 for all layers.

Table 1: Adopted Hydraulic Parameters

COMPUTER MODEL

General Description

The model (EASTMOD) was constructed using MODELCAD386, a computer aided design groundwater preprocessing package, and simulated using MODFLOW, a groundwater modelling program developed by the United States Geological Survey. It is a finite difference, single layer, regional groundwater model which simulates groundwater levels and flow within the Loxton Sands aquifer. The geographical extent of the model is shown in figure 1. It is 90 km long by 70 km wide and comprises 1189 square and rectangular elements forming an irregular grid with a minimum cell size of 400 ha. The model grid was designed irregularly in order to provide higher resolution within the areas of interest. General head boundaries were used at the edges of the model.

River levels were set using constant head cells and varied according to major historical changes in river levels. Pre-locking river levels were assigned by assuming lock lower pool elevations represented the average annual river level before locking. A gradient was calculated between these points and each river cell assigned the appropriate elevation.

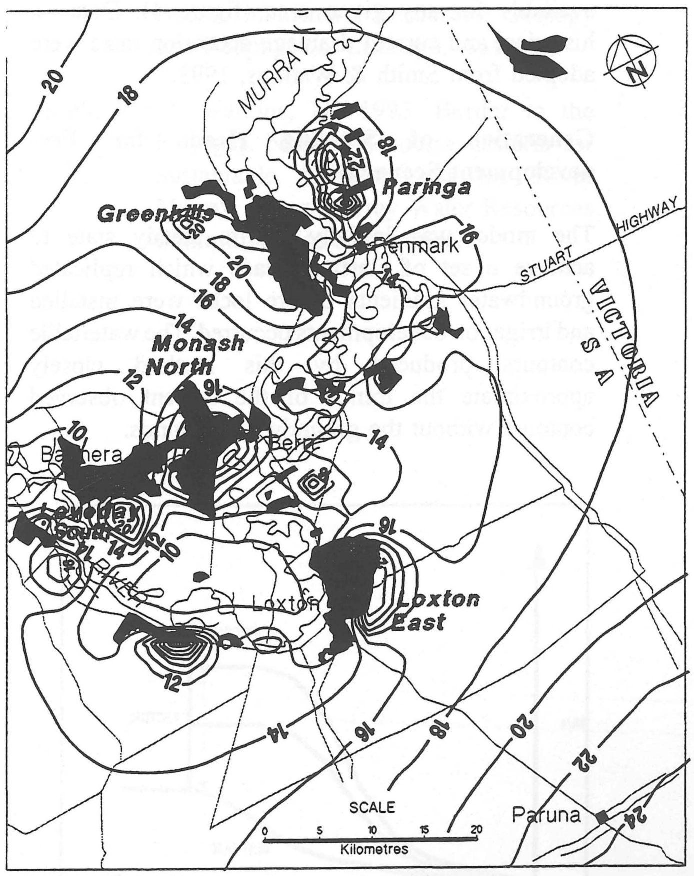

Figure 3: Current Water Table Contours, Modelled

Floodplain Storage

Floodplains of the River Murray store salt which is returned to the river as high salt loads during flood recessions. EASTMOD was not constructed to take account of these short term events. Floodplain processes have been ignored and the floodplain has been included as part of the river. Any reference to induced salt load in this paper therefore refers to induced salt loads to both the floodplain and the river.

Effects of Development

The development of irrigation areas in the Riverland has generally been ad hoc with many private irrigation areas beginning on a small scale early in the 1900's but failing, only to be restarted later as Government Irrigation Areas. The increases in size of irrigated areas is reflected in the increases in drainage accession volumes until the introduction of drains (figure 4). The drains remove water from the system leaving a fixed volume that passes through the root zone. Prior to drain installation, the available applied volume data is poor and hence a curve is assumed for application and accession volumes. In EASTMOD, a worst case scenario has been modelled by using the highest accession volume available for any given area (figure 4). Data on historical and current drainage accession rates were adopted from Smith & Watkins, 1993.

Generation of Starting Heads for Pre-development Scenario

The model was initially run to steady state to achieve a set of starting heads which replicated groundwater gradients before locks were installed and irrigation developments occurred. The watertable contours produced by this method closely approximate the trends of the current observed contours without the groundwater mounds.

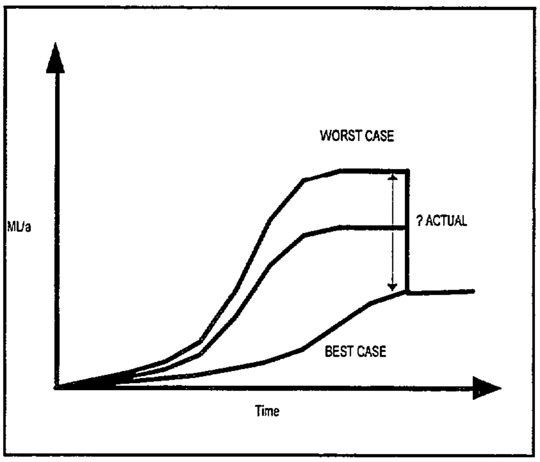

Figure 4: Diagrammatic Representation of Assumed Growth in Drainage Accession Volumes

Transient Calibration

The starting heads generated with the steady state model were then used in a transient calibration model that takes into account the development of irrigation in the region, the building of locks and the construction of Comprehensive Drainage Schemes (CDS's).

MODELCAD386 does not allow the input of different recharge rates at different times for a given area. In order to replicate the process of changing conditions such as the building of locks, the growth in irrigation developments and the installation of CDS's, seven different models were constructed to model the changes and connected in series by using the final head distribution of the preceding model as the starting heads for the active model.

Recharge wells were used to model irrigation drainage accessions. Where accession rates were not known a rate of 200 mm/a was assumed.

An infiltration time, or time before drainage accessions reach the water table and salt loads begin to impact on the river, was calculated for each irrigation area by the following formula (Cook et al, 1993);

$$t_i = \frac{\Delta b.(\theta_1 - \theta_0)}{DF}$$

where;

t_i = infiltration time through any layer (years)
Δb = unsaturated thickness of the layer (m)
θ_1 = moisture content above the pressure front
θ_0 = moisture content below the pressure front
DF = drainage flux (m/year)

EASTMOD was developed with the best available data for hydraulic conductivity (k), and hence transmissivity (T), as well as specific yield (s_y). Model sensitivity runs for combinations of k and s_y were carried out to obtain the best calibration to current groundwater levels.

The model was validated against groundwater level maps of the Murray-Darling Basin (Barnett, 1991 and 1993, RWC, 1991). The modelled groundwater levels on figure 3 compare well with the observed data shown on figure 2. It is concluded that the model represents the hydrogeology of the eastern Riverland sufficiently well to use it as a predictive tool.

Predictive Modelling

The aim of this work is to use the model to predict future groundwater level conditions and induced salt loads to the river and floodplain assuming the two scenarios of maintaining current irrigation or further expansion of irrigation in the region.

A baseline scenario was run maintaining irrigation areas at current sizes and accessions for a period of 50 years. Irrigation areas of 1000 ha were then added at proposed new development sites and their impacts compared to the baseline scenario. A final scenario was run which included all of the proposed sites to model the total impact. A comparison of the induced salt loads shows the relative impacts of 1000 ha of irrigation at these sites (figure 5). The flat curves, which have the least impact, are associated with irrigation areas situated behind major groundwater mounds.

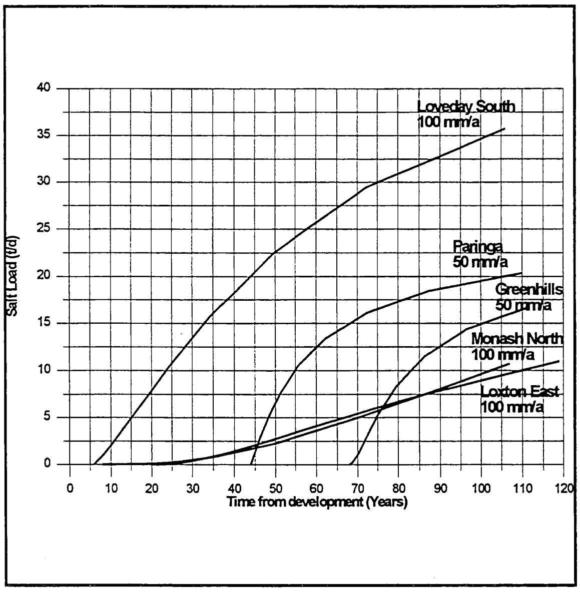

Figure 5: Salt Load Impacts of New Irrigation Developments

CONCLUSIONS

A regional groundwater model has been developed for the eastern Riverland district which effectively simulates current groundwater levels and flows in the Loxton Sands aquifer. The model has been used to quantify the salt load impacts of currently proposed irrigation developments in the district on the River Murray. It has shown that irrigation induced salt loads can be minimised by locating future irrigation developments away from the river behind existing groundwater mounds.

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Trend in salt concentration and salt load of stream flow in the Murray and Darling Drainage Basins - the historic picture.

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Introduction

In developing the Murray-Darling Basin Salinity and Drainage Strategy (MDBC 1987,1988) it was estimated from limited analyses that, for the period 1986-2006, salt loads from dryland areas would increase the River Murray salinity up to 40 EC units at Morgan, SA. The recent Murray-Darling Basin Commission (MDBC) estimates suggest that this figure may need to be revised upwards, following the quantification of increasing salt loads from Victorian dryland catchments. Based on the results for some Victorian catchments (eg Earl, 1988) and the increase in the estimates of non-irrigated land salinisation in many New South Wales catchments, it is expected that there has been a similar impact on the salinity of streams. The long term consequences of the magnitude and direction of salinity trend is a major factor in establishing where, which type and with what urgency remedial measures are required to control and reverse adverse trends. Using available historical data obtained since the mid-1970's for both stream water quality and flow it has been possible in this preliminary phase of a 3-year NRMS-CSIRO trend project to provide a basin-wide quantitative assessment of the historic trends. Factors which influence the salinity trend have been identified at the broad scale but need to be quantified to establish a rigorous predictive approach to salinity risk assessment and to prioritise catchments in the process of developing management of stream salinity in the Murray-Darling Division.

A significant input to the debate has been by Allison and Schonfeldt (1989) who, accepting that irrigation and dryland farming practice have increased recharge beyond pristine levels, concluded that these elevated recharge levels would be reflected in an increase in the saline groundwater accessions to streams. They estimated that increased recharge at 20mm yr^{-1} in the Riverine Plains Zone of Victoria would produce, after steady state was reached, an aquifer discharge of 2.5×10^6 tonne yr^{-1} either as baseflow or in seepage onto the soil surface. If, over the next 50 years, only 25% of this reached the River Murray, the impact would be an increase of 140 $\mu S\ cm^{-1}$ in the salinity at Morgan.

The determination of trend in both salt load and salt concentration of streams across the whole of the Murray-Darling Drainage Division (MDDD) has not been attempted until now. The overall objective for the NRMS-CSIRO project is to establish the historic, and estimate the future, trend in salt load and salt concentration in streamflow of catchments in the Basin. In addition the project aims to identify the type and significance of factors controlling the trends and their management, analyse for salinity risk in each catchment, and determine appropriate stream indicators for monitoring the status of dryland salinisation. The results given here are for the preliminary phase; the detailed results are in Williamson et.al. (1995).

Data Availability and Data Sources

Within the Murray and Darling Rivers system, responsibility for collection of stream flow and water quality data has been handled principally by state water agencies from whom the data examined has been obtained. Data are collected at hundreds of stream gauging stations within the 26 river basins which make up Division 4, the Murray Darling Drainage Division (MDDD). Records are of variable length and frequency, with the longest for stations on the River Murray with flow recorded since 1909 (Swan Hill) and water quality since 1938 (Morgan). Since the 1970's there has been an evaluation of the gauging station network. The consolidation and standardisation of the monitoring programme has seen the establishment of key stations for which specific data types and frequency are now maintained.

From the historical data sets available, 88 stations were selected based on location and the length of record for both electrical conductivity and flow. Record length varies generally from 15 to 25 years. The hope that the data would have a minimum frequency of one quality sample per month is realised for many stations in the last 5 to 10 years but rarely in the previous monitoring periods. It is obvious that, until the 1990's, the criteria for collection of water quality data did not consider the needs of statistical analysis. In contrast, the streamflow records have good continuity in general. The salinity data are given as electrical conductivity in µS cm^{-1} at 25^0C (the *EC unit*). The 26 river basins within the MDDD have been gathered into 9 groups based on climatic, hydrogeological and topographical association.

Data Analysis Methodology

Data collection prior to implementing the key monitoring sites program did not make adequate provision for statistical analyses nor calculation of load (salt, nutrient). Not only irregular sampling intervals, but limited length of record (<30 years) constrains the capacity to determine trends for the period (>50 years) since the development of extensive agricultural production. However, any reasonable attempt to use the available data is certainly preferable to applying conjecture, provided the assumptions are clearly identified as part of the interpretation. The approach for the analyses has been to include as much of the historical data as is retained by monitoring agencies for archival purposes on the assumption that the data will have passed through a reliability filter.

Salt load (the product of flow and salt concentration tonne day^{-1}) was calculated from the available data for flow and electrical conductivity applying a hierarchal preference of instantaneous flow, or if not available then measured daily flow. The salt concentration was calculated as the product of the electrical conductivity in µS cm^{-1} and the slope of the linear relationship of electrical conductivity and total soluble salts (TSS) standardised as 0.6 within the MDDD. No attempt has been made at this stage to determine annual salt loads except where the frequency of daily salt concentration data is adequate as is the case with a number of monitoring stations along the River Murray and some tributaries. For the stations in NSW (basin groups 2 to 6) median flow and EC were available, and their product was used as an initial estimate of "median" salt load. It was found that the true and estimated median values were within 10%.

The statistical methods used were those which are currently adopted by each of the Water Resource management agencies. A general examination of the data gave no doubt that trends would be non-linear and periodic (or cyclic) due to primarily to seasonality and exogenous variables such as streamflow. Consequently, the Seasonal Kendall-τ Test and the Lowess non-parametric smoothing approach were applied to the data without exclusion of data from the sets available. (The Kendall trend results for gauging stations in Queensland are flow adjusted). In statistical terms, trend analysis is a determination of whether the probability distribution for the random variable has changed over time. For the null hypothesis there is no trend at the probability level selected. Given the nature of the data and associated assumptions, a result of "no trend" is accepted as a statement that the available evidence is not sufficient to conclude that there is a trend. This is important in this study because most data sets are incomplete for years prior to the late 1980's. The fact that trends are computed by the Kendall method as a constant slope for the period commencing in the 1970's needs to be remembered when considering the relationship of trend to geo-environmental factors which affect salt load and/or concentration.

Results

The historic trend results have been prepared as two maps (EC and saltload) and a table in Williamson et al (1995). All values have been mapped although only about 32% are statistical significant at α=0.05. For the majority of sampled gauging stations the statistical analysis provides the conclusion that there is no significant trend but this could be primarily a consequence of the inadequacy of the data set.

Trend in Electrical Conductivity

A number of features have been identified in the results of historic trend:

- The statistically significant (at α=0.05) annual trends in electrical conductivity are in the range from a fall of 16µS cm^{-1} (at station 406202 Campaspe River at Rochester for 1976-1994) to a rise of 40µS cm^{-1} (at station 410091, Billabong Creek at Walbundrie for 1970-1992). However 85% of the significant values range between a rising trend of 6µS cm^{-1} and falling trend of 7µS cm^{-1}.
- The statistically significant (at α=0.05) annual trend in saltload (tonne day^{-1}) is better indicated by the % change rather than the absolute change. These are in the range from a falling trend of 6% to a rising trend of 19%. In the basin groups in Victoria all the significant trends are increasing.
- The Lachlan and Murrumbidgee Rivers, and the Billabong Creek, are all showing a rising trend for their entire length.
- There is a reasonable number of stream segments where the trend in EC is contrary to the trend in saltload. For streams in Basin Groups 7 and 8 (Goulburn-Upper Murray and the Loddon-Campaspe) there is a strong correlation between the trend in saltload and streamflow suggesting that the saltload trend is more dependant on the trend in streamflow than the EC trend.
- The trends in EC and saltload using either the Seasonal Kendall or the LOWESS methods are generally in agreement.
- The LOWESS trends show the non-linear nature of the basic unadjusted (for streamflow) data. While this was anticipated, it does confirm the need to take this non-linearity into account if useful trend information for salt is to be obtained from the historic data.
- Using the MDBC data for the River Murray and its immediate tributaries, normal or strongly skewed frequency distributions of EC and saltload have been observed. These distribution types can be exploited

for identifying the probable source type for salt in a stream segment. A comparison of median and mean values is a simple test of the nature of the distribution.. The EC and saltload show both skewed and normal distributions with some consistency within sub-catchments. In all cases the mean flow is exceedingly higher than the median flow, giving a skewed distribution.

Changes in Saltloads within River Systems.

- The changes in saltload along the major rivers and the associated input from tributaries has been determined using median saltloads for Darling, Lachlan, Murrumbidgee and Murray River systems. Between Walgett and Wilcannia in the Darling River system, saltload increase appears to be dominated by input (about 500 tonne day^{-1}) from groundwater. Williams (1994) found significant input of groundwater via the "Glen Villa" springs between Bourke and Louth estimated at 30 to 50 tonne day^{-1}. A convergence in the alluvial aquifers forced water at 23750 mg L^{-1} to the surface. Between Wilcannia and the confluence with the River Murray a decline in median load of about 700 tonne day^{-1} appears related to the Menindee Lakes scheme and recharge to the Murray Basin.
- The trends along the Condamine River in Basin Group 1 are of special interest hydrogeologically. The segment of falling EC (and presumably saltload) between Londoun Bridge and Chinchilla appears to be a direct result of the substantial drawdown of the hydraulic head in the valley aquifers due to groundwater extraction for the Condamine Groundwater Irrigation Area near Dalby.
- In the Lachlan River system salt enters the stream in the upland parts of the catchment but a salt export of about 230 tonne day^{-1} occurs in the plains, 80% of this between Forbes and Condobolin.
- The salt loads in the Murrumbidgee River system have similar magnitude to those in the Darling River system. Unidentified sources contribute about 200 tonne day^{-1} of salt as the river passes through the ACT and the southern highlands into Burrinjuck Dam, and a similar input enters near Gundagai from the Tumut River which contains inter-basin transfer. However, the median EC values differ by a factor of 4. Between Wagga Wagga and Hay about 650 tonne day^{-1} is diverted in irrigation and added to the Murray Basin aquifers. An increasing trend in saltload of about 15% occurs at both Hay and Balranald, compared to about 3% upstream of Gundagai.
- The median saltload in the River Murray increases progressively at each of the primary gauging stations downstream of Yarrawonga Weir. The saltload (median values) entering from New South Wales between Swan Hill and Euston Weir is about 290 tonne day^{-1}. The summation of mean saltload values is about 2600 tonne day^{-1} for tributaries entering the River Murray from Victoria upstream of Swan Hill. The estimated median saltload at Swan Hill is 1105 tonne day^{-1}. The difference may be due to comparing median and mean values and to loss of salt in diversions for irrigation. The data show that the Loddon Catchment is contributing 48% (1232 tonne day^{-1}) of the tributary input to the River Murray upstream of Swan Hill, with the notorious Barr Creek contributing less than half of that salt (530 tonne day^{-1}). The Goulburn River and the Upper Murray tributaries each contribute about 410 tonne day^{-1} with 320 and 350 tonne day^{-1} contributed from the Loddon River and Pyramid Creek respectively. With the exceptions of these latter two rivers, the tributaries each show a significant (α=0.05) increase in annual saltload of between 1% and 5%.

Predicting Trends and Potential Outcomes

The project will now move into a predictive phase. However, an interesting prediction is possible using data already analysed. The MDBC (1992) have predicted that, depending on assumptions used, an additional saltload of 1×10^5 tonne yr^{-1} (equivalent to doubling the present load) for each of the Darling, Murrumbidgee and Goulburn Rivers would raise the salinity at Morgan by 30 to 70 μS cm^{-1}. Allison and Schonfeldt (1989) have suggested that there is potential for more than this increase to occur based on simple numbers driven by increased recharge in the non-irrigated lands of the Victorian Riverine Plains alone. From the average trend values obtained, and accepting the current mean saltload of 1840 tonne day^{-1} for the tributaries draining the Victorian Riverine Plains, if the trend remains at 3% then the additional 1800 tonne day^{-1},(6.6×10^5 tonne yr^{-1}), equivalent to 140 μS cm^{-1} increase at Morgan, would be reached by the year 2020. If the saltload estimate is too large, and say is only 900 tonne day^{-1}, then the prediction of Allison and Schonfeldt (1989) of the increase taking 50 to 100 years would be met.

An example of the concerns expressed by hydrogeologists is given by Williams et al (1994) who present data indicating a significant lag time between the cause and effect for mobilising salt in the Darling Drainage Basin. Jolly (1989) concluded that stream salinity for the Darling Basin will generally develop more slowly than in the Murray Drainage Basin and other parts of southern Australia. There is opinion expressed in many hydrogeological reports for the Murray-Darling Drainage Basin that the impact of land use changes over the last 50 to 100 years is only beginning to be expressed in expanding discharge areas. The response time has been subjectively assessed as about 50 years in the southern part of the Basin and about 80 years in the northern half of the Basin. With this scenario, the current trends would be expected to continue into the foreseeable future.

Some Conclusions

It would not be acceptable to use the historic trends in salt load and salt concentration for linear extrapolation into the future. But there seems to be little evidence, and few exceptions, to suggest that the historic result will be reversed in the foreseeable future. The estimation of future trends depends on our ability to understand sufficiently the mechanisms which have produced the historic trends. The importance of groundwater flow into rivers is of major interest. It has been shown that saltload in some streams in Victoria has its dominant source in accumulated salt being washed off the surface or mobilised in sub-surface storm flow. Some characteristics useful for recognising the source of salt have been identified, and will be refined as more detailed work is done on the flow and quality data.

For 11 salinity mitigation schemes established since 1968, the accumulated annual total of salt prevented from entering the River Murray has been estimated as 266×10^3 tonne (16% of measured mean annual salt load of 1930×10^3 tonne) at Morgan. This exclusion of salt could be expected to show a clear response. The trend in annual saltload at Morgan has been rising, and the flow-adjusted EC falling, since the late 1970's.

There is a substantial redistribution of salt occurring through the diversion of water (and hence salt) for irrigation purposes. This regional imbalance may be producing a time bomb of salt, but equally may be providing a mechanism to retain more salt in storage while salt is released from other regions as the response to the changes in groundwater levels. The use of salt balance studies at the regional scale should assist in the management of salt within the MDDD.

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Community Involvement in the Rehabilitation of Gol Gol Wetlands

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Paul Lloyd: Project Officer NSW Murray Wetlands Working Group

Background

The Gol Gol wetlands lie 8km to the east of Mildura and cover over 1000ha (Figure 1). During times of flood under pre-regulation conditions, Gol Gol Swamp was filled from the Murray River via a short inlet creek. Higher floodwaters overflowed into Gol Gol Lake to the north.

With the establishment of irrigation in the area in the late 1950s, an irrigation supply channel was constructed along the eastern side of the Swamp and the southern side of the Lake. Several regulators were built on Gol Gol Creek to hold water supplies in the creek system. These structures also controlled flows into the wetlands.

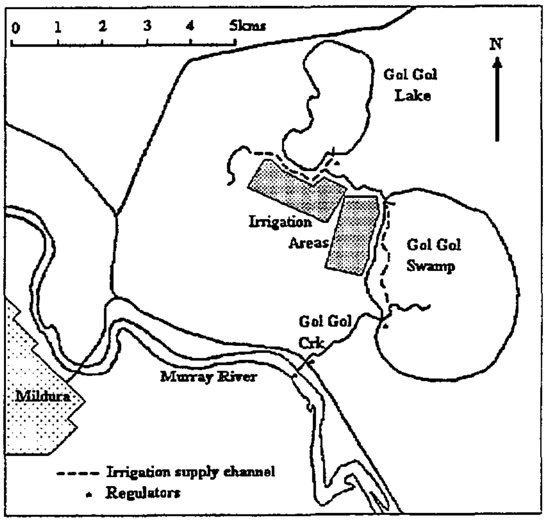

Figure 1: Location of Gol Gol wetlands

Wetland Values and Groundwater Impacts

The wetlands support a diverse range of vegetation communities and breeding habitat for wildlife. However, these ecological values have deteriorated over the past 30 years possibly due to the restriction of flood inflows and rising saline groundwater levels. The impact of shallow watertables has been particularly evident in the declining health of Lignum, River Red Gum, River Cooba and Black Box. Saline groundwater mounds (approximately 50,000 EC) underlie much of the Lake and Swamp bed at a depth of 1 to 4 metres below the surface. Monitoring of a series of piezometers in the area indicate that the watertable is rising slowly in most areas.

If unchecked, the rising watertables and progressive salinisation of the two basins would destroy the existing wetland habitat.

Community Involvement

At the instigation of the NSW Murray Wetlands Working Group, a Community Reference Group was formed in 1993 to promote a community-based and cooperative approach to the rehabilitation of the wetlands. The Reference Group comprises the current landowners of the wetlands, irrigators from adjacent areas, regional conservation groups and the NSW Murray River Management Board. Technical support is provided from the NSW Murray Wetland Working Group and government agencies.

The Reference Group is examining options for the rehabilitation and long term management of the wetlands and groundwater impacts, in particular. In the last year, it has obtained NRMS funding to assess the causes of groundwater accessions and to upgrade the regulators at the inlet to the Swamp.

The groundwater study will assess the contributions to groundwater accessions from:

- leakage from the irrigation supply channel;
- local irrigation; and
- the ponded water behind Mildura Weir (Lock 11).

Conclusions

The Community Reference Group has been critical in the development of a rehabilitation program for the wetlands. It has allowed a broad cross-section of the community to be involved, and this has lead to a focus on identifying practical and long term management options. The Reference Group has also raised the level of appreciation of the wetlands among the community.

The long term rehabilitation of the wetlands will not be straight forward. However, the initial planning and investigations have been undertaken to identify the most practical means of addressing the causes of the degradation.

Wastewater Irrigation, Hydraulic Conductivity and Wastewater Storage

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Introduction

Government policy currently favours wastewater storage and re-use in preference to treatment and off-site discharge. Most agencies implementing this policy recognise that the long term sustainability of wastewater irrigated land-use in the Murray Darling Basin still needs to be demonstrated. The risk of turning a water quality problem associated with nutrients in effluent, into a groundwater problem, is potentially quite high. The disposal of organic matter and salt, as well as nutrients, becomes a key factor in the application of wastewater to land. The land application of heavy metals and pathogens pose additional problems which are fortunately restricted to relatively few sites.

Research is currently underway at a number of sites in the Basin to study the impact of wastewater irrigation. Critical to most of these sites is the need to maintain a leaching fraction to export undesirable salts from the plant root zone. Salts exported from this zone are either removed by surface drainage systems and subsurface drainage systems or allowed to accumulate in soil profiles, ultimately some of this salt is likely to enter the groundwater. This resource is also under threat from nitrate.

Maintenance of adequate soil hydraulic conductivity is critical to facilitate plant growth and the leaching of salts from sites in receipt of wastewater. Hydraulic conductivity is modified by the organic matter content and physico-chemical influence of wastewater SAR and EC, hence this parameter changes with time and land management practices.

Storages are frequently associated with wastewater irrigation systems. The need for storage following treatment is associated with the provision of detention time for effluent polishing. In addition, storage reduces the need for land application of wastewater at times when the climate or weather conditions are not suited to irrigation. Research into the investigation, design, construction and operation of these earthen wastewater storages is unfortunately not keeping pace with developments in wastewater irrigation practice. Problems with seepage to groundwater are becoming more evident at a number of locations in the basin. Soils forming these storages are subject to the same physico-chemical effects as wastewater irrigation areas and prospects for ameliorating site conditions are restricted once storages are operational.

This paper provides very limited coverage of the results of a study on the determination of hydraulic conductivity from a saline-sodic soil site in northern Victoria in receipt of saline-sodic wastewater. This site was the subject of protracted legal action a few years ago. At the time it was claimed that seepage from a wastewater ponding system and associated elevated water tables was rendering surrounding land unviable for wastewater irrigation. In addition, off-site high water tables and salinity were being observed on neighbouring properties, and were being blamed on the lack of integrity of wastewater storages.

Interaction Of Soil And Wastewater

The natural pre-disposition of sodic soils to instability, and the influence of saline and sodic waters on soil structure has been under study for over 40 years. Richards (1954) served as the source book for much of soils data utilised by agronomists in irrigation practice. This influence was not widely reported in engineering practice until about 10 years later following research work by staff at the CSIRO (Aitchison, Ingles and Wood, 1963).

Soils used for wastewater impoundment are frequently saline and sodic as the land purchased for this purpose is often cheaper and undeveloped because it is of low quality for agriculture. Even non-saline and non-sodic soils can be modified given the appropriate application or impoundment of wastewater, becoming saline or sodic in character. In Australian practice, saline-sodic soils exhibit Exchangeable Sodium Percentage (ESP) values greater than 6% and the Electrical Conductivity (EC) of saturation extract values greater than 4 dS/m. The pH of saline sodic soils range from 8.2 to 8.5. Sodic soils have ESP values in excess of 4%, EC values less than 4 dS/m and pH values greater than 8.5.

The common field characteristics of these soils are:-

Sodic Soils

When wet, sodic soils are sticky and slippery. Infiltration of water is slow. In a sodic soil the individual particles disperse away from one another when the soil becomes wet. Structure is poor. On drying, the collection of individual particles at the surface forms a crust. The rest of the soil forms large, hard clods. Sodic soils on slopes erode easily, subsurface tunnels form, then huge gullies. Sodic subsoils are a common cause of poor drainage and earthworks failure in many parts of the Murray Darling Basin.

Saline-Sodic Soils

The high level of salts in a saline sodic soil allows the individual particles to aggregate. A simple example of this effect can be seen in small earthen dams. If the water in a dam remains turbid for an extended period, it is an indication that the level of salts in the water is low. Clear water means that there never were any colloids in the water, or that they have been precipitated out by salts in the water. Adding a solution of any salt to turbid water will cause the water to clear if the resulting salt concentration is high enough. The structure of a saline-sodic soil can be maintained, provided the salts remain in the soil. As soon as the salts are removed all the problems of a sodic soil appear. This is what happens when rain falls on a saline-sodic soil, when it is irrigated with non-saline water or when freshwater is stored upon it.

Saline and sodic soils are of major concern in dam engineering practice. Dam failure by post construction deflocculation (or dispersion) is a relatively common phenomena in Australia despite years of research and the availability of corrective measures (Ingles and Metcalf, 1972; Moore, Wrigley & Styles, 1985).

The chemical characteristics of the wastewater for irrigation or impoundment is critical to the performance of the soil. Infiltration rate and hydraulic conductivity are regarded by most practitioners as indices of the ease with which water can move into and through a soil. Both parameters are influenced by the salinity and sodicity of irrigation water or impounded water. A sodic water (high Sodium Adsorption Ratio water) tends to increase the Exchangeable Sodium Percentage (ESP) in the soil. An increase in the ESP is usually associated with a reduction in the hydraulic conductivity of most types of clay. A relationship between Sodium Adsorption Ration (SAR) and ESP has been established, although this relationship lacks precision. A correction for the influence of CaCO3 can be made to improve accuracy.

A reduction in the hydraulic conductivity of clay soil as ESP increases may be due to both increased clay swelling and clay dispersion which blocks pores. The relative significance of these mechanisms depends on factors such as clay content and mineralogy, ESP and electrolyte concentration. Even at high ESP levels, the hydraulic conductivity of clay soils can be maintained if the electrolyte concentration exceeds a critical threshold (Quirk and Schofield, 1955).

In the case of secondary treated municipal wastewater, the Total Dissolved Solids (TDS) can range from about 400 mg/L in primary ponds to in excess of 800 mg/L in winter storages. These TDS levels indicate that wastewater contains an elevated electrolyte concentration. Sodium in this wastewater can contribute to an increase in the ESP of soil forming the floor of the storages. In addition, the elevated electrolyte concentration serves to limit clay swelling and clay dispersion and could preclude both phenomena if wastewater was very saline.

In soil science parlance the high ESP of the saline sodic soils forming the bed and banks of storages, in association with a relatively high electrolyte concentration of the impounded water would contribute to the maintenance of a flocculated clay structure. In other words, the structure of the clay would be maintained in the absence of chemical or mechanical amendment leading to a higher hydraulic conductivity than would be the case if freshwater was impounded.

In the case of dam failure by soil dispersion, the loss of bank integrity is frequently associated with rainfall rilling on embankments, or earthen storages which fill quickly from rainfall runoff.

Hydraulic Conductivity Testing

Hydraulic conductivity is a major design parameter for wastewater storage and irrigation. The magnitude of groundwater accessions is influenced by this parameter which can be determined in-situ or by laboratory testing. In-situ testing is preferred by most agencies.

Various researchers have studied the impact of soil and water salinity and sodicity on hydraulic conductivity over the past 40 years (Agassi, Shainberg and Morin, 1981; Chang Seo Park and O'Connor, 1980; McIntyre, 1979; and Suarez, Rhoades and Lavado, 1984). There is some debate in these papers about the classification of soil types but little disagreement about the impact of electrolyte concentration on soil structure. Shainberg and Shalhevet (1984) and Tanji (1990) provide very detailed coverage of salinity, sodicity and soil responses and these publications should be consulted by practitioners.

In Australian Standard AS1289.F7.1-1984 "Determination of Permeability of a Soil-Constant Head Method", in the section entitled "Notes on Test", the following note is made:- "6. Preferably the water used in this test is the native water from the location in which the soil is to be used".

The Australian Standard AS1289.C8.1-1980 "Determination of Emerson Class Number of a Soil" is used to classify soils on the basis of their dispersive characteristics with chemical testing. In undertaking this test the following statement is made:- "C8.1.3 Water. The water used shall be either distilled water or water from the environment of the soil, eg. reservoir water or other water with which the soil will be in contact during use". Vickers (1978) is even more explicit, claiming:- "....that it is of little relevance to pass de-aired and/or distilled water through a sample in the laboratory if it differs from the water found on site".

Unfortunately there is no standard method for hydraulic conductivity determination in the field. Techniques depend on site conditions, the location of the water table being the most significant control on methodology.

Loveday (1974) was the standard reference for testing of irrigated soils. This publication provide details on standard procedures for laboratory testing of soils to determine their hydraulic conductivity. This publication states:- "Available field methods are laborious and time consuming and require either relatively large quantities of water or the presence of a water table. They are of very limited applicability on cracking clay soils, particularly during the survey of potential irrigation lands in subhumid areas where water supplies are limited.

In the field much of the water entry and redistribution takes place in unsaturated soil and/or at negative pressures (suctions). Laboratory measurements with such conditions imposed are slow and complex, and it is practically impossible to simulate field conditions directly, especially for swelling soils. Consequently, measurement of saturated hydraulic conductivity under a positive head is often made on cores or packed columns of ground soil, as being the best practical alternative. The data produced are useful in the comparative sense and, in particular, ground soil may perhaps be reasonably representative of the actual condition of tilled surface soils. For most soils finer in texture than sandy loam, the saturated hydraulic conductivities will rate in the same order as the unsaturated values at which significant movement of water occurs in the field".

It is very evident from this quote that Loveday is concerned about the applicability of tests to the determination of the properties of cracking clay soils (which are saline-sodic in character). In addition Loveday specifies the need for considering water quality. He further states:- "For assessment of irrigation soils the hydraulic conductivity should be measured with the proposed irrigation water and, in the case of a surface soil, with distilled water also. The latter is to find the effect of rain on dispersion of the soil and whether its hydraulic conductivity subsequently decreases. Whichever water is used, it needs to be de-aired sufficiently to prevent air coming out of solution, which can cause faulty head readings and, in the sample, block conducting paths".

The lack of a well defined process for testing soils using wastewater to determine hydraulic characteristics is lamentable. This lack of standardisation has contributed to the poor design and performance of wastewater treatment and re-use in the Basin.

Treatment And Storage

The need to maintain confidences precludes detailed coverage. Information provided herein is of a general nature only.

In wastewater treatment the raw wastewater entering ponds contains organic matter and chemicals that are determined by influent characteristics. Open water surface storage, biological action, and depositional processes associated with treatment usually lead to an increase in the salinity of the wastewater and a reduction in organic matter content of effluent. These characteristics usually mean that particulate matter resident in ponds helps to seal the bed and banks, and the physico-chemical action of relatively low salinity wastewater assists the process through soil dispersion. The accumulation of sludge and detritus usually contributes further to a reduction in the hydraulic conductivity of reservoir bed and banks.

Winter storages which are now becoming more common provide residence time for low organic matter wastewater. In addition, the salinity of wastewater in these open-water surface receptacles is prone to increase over most inland sites despite rainfall collection. During the summer months, storages north of the divide which are not well maintained can incur a two-fold increase in salt concentration. Extended storage can have a markedly deleterious influence. The author is aware of one particular site where the salinity of the winter storage is 10,000 mg/l.

Relatively high seepage losses from winter storages are more prevalent than losses from treatment ponds. The relatively high EC and low organic matter content of winter storage wastewater combined with the large open (and often shallow) storage designed for a 90th percentile wet year contribute to this phenomena.

Storage lining is now commonplace in order to meet EPA hydraulic conductivity guidelines of less than 10^{-9} m/sec. Many older storages are however not designed to achieve this maximum value, with seepage losses unmeasured.

Results Of Case Study

For the case study site intended for wastewater treatment and re-use, in-situ hydraulic conductivity tests were conducted in the 1980's. These yielded relatively low hydraulic conductivities for a saline sodic cracking clay site. Tests were conducted at least 5km from an effluent source hence fresh water was used for testing. Field staff were not aware of the potential problems associated with the use of an inappropriate fluid.

Based on hydraulic conductivities determined, the works proceeded. Within 5 years of the commissioning of works, water tables around the site were elevated and seepage was identified.

In order to gauge the likely impact of distilled water (or freshwater) on dispersion and sealing compared with saline effluent, in-situ tests were commissioned. The results of these tests are presented in Table 1.
The same testing processes were employed for both series of tests using different liquids. These results are derived from tests conducted in the unsaturated zone which confirm the influence of different water qualities on the magnitude of hydraulic conductivity.

The action of fresh water on this soil type was to help seal up the walls of the test hole and limit water movement, compared with saline effluent which maintains soil structure. Clearly the information derived initially from freshwater testing was of limited value given that storages were intended to store relatively saline wastewater.

Current Practices

Following the outcome of the legal case there has been enhanced use by practitioners of wastewater for hydraulic conductivity testing both in the laboratory and in the field.

Unfortunately there is still no standardisation in testing methods nor a strong recognition of the need to emulate operational conditions with tests.

For large scale projects the author advocates the use of excavator pits or slots for hydraulic conductivity testing. These at least enable the soil profile to be inspected and provide a relatively large surface area of soil for hydraulic conductivity testing. In addition, tests can take place over weeks rather than hours using on site labour for monitoring. Such testing may also emulate what is likely to occur in practice with the storage of wastewater.

Laboratory tests have marked utility for the determination of clay line hydraulic conductivity. In addition, the influence of organic matter clogging is best gauged by extended testing or an accelerated program of wetting up and rewetting to simulate the floor of a storage.

Site investigations should result in the determination of soil chemical characteristics from all parts of a soil catena. Whenever possible, both geotechnical and agronomic tests should serve to gauge the impact of wastewater on physical characteristics. Sites which already evidence saline-sodic soils or elevated water tables should be discounted in favour of sites where amelioration has greater utility. Topography and soil texture alone should not direct project planning.

Recommendations For Further Research

The influence on water quality on winter storage is important to gauge. In addition, the influence of water quality on the hydraulic conductivity of all ponding systems is essential, especially where liners are not proposed.

Standardised testing methods need to be adopted by industry in the determination of design parameters. This requirement is essential where testing is required in the unsatured zone. Research is warranted to determine the best methods and the match between method and soil type.

Monitoring systems need to be developed to assess the magnitude of seepage losses from existing and proposed storages.

Conclusion

This paper is limited in scope by legal circumstances. Despite this limitation it should be evident that the design of wastewater storages as well as irrigation systems warrant the detailed study of the interaction between wastewater and soil.

The need for standardised testing procedures and monitoring systems is critical to overcome problems from the past and cope with them in the future.

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TABLE 1: IN-SITU PERMEABILITY TEST RESULTS
1.5m Standpipes, De-ionised Water and Saline Effluent

Test Location	Standpipe Depth (m)	TEST 1		TEST 2		TEST 3	
		Saline *K (m/sec)*	De-ionised *K (m/sec)*	Saline *K (m/sec)*	De-ionised *K (m/sec)*	Saline *K (m/sec)*	De-ionised *K (m/sec)*
1	1.5	2.9×10^{-8}	4.1×10^{-8}	7.3×10^{-9}	2.6×10^{-9}	9.7×10^{-9}	N.M.F*
2	1.5	N.M.F	1.4×10^{-9}	N.M.F	N.M.F	N.M.F	N.M.F
3	1.5	3.1×10^{-7}	N.M.F	3.4×10^{-7}	N.M.F	5.0×10^{-7}	N.M.F
4	1.5	2.4×10^{-6}	N.M.F	8.5×10^{-7}	N.M.F	4.6×10^{-7}	N.M.F
5	1.5	3.3×10^{-9}	N.M.F	2.1×10^{-9}	N.M.F	2.5×10^{-9}	N.M.F
6	1.5	9.5×10^{-9}	1.8×10^{-9}	3.3×10^{-10}	2.3×10^{-9}	3.3×10^{-9}	2.3×10^{-9}
7	1.5	6.7×10^{-9}	N.M.F	9.6×10^{-9}	N.M.F	1.1×10^{-8}	N.M.F
8	1.5	3.6×10^{-9}	N.M.F	3.0×10^{-9}	N.M.F	1.3×10^{-9}	N.M.F
9	1.5	2.9×10^{-8}	N.M.F	1.3×10^{-8}	N.M.F	8.8×10^{-9}	N.M.F
10	1.5	Abandoned	N.M.F	3.2×10^{-8}	N.M.F	3.6×10^{-8}	N.M.F

N.M.F. No Measurable Flow

Testing Key Assumptions of the Tragowel Plains Salinity Management Plan

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Objective
To evaluate a number of key assumptions of the Tragowel Plains Salinity Management Plan. These assumptions are:

- that information from the soil salinity surveys will lead farmers to increase concentration of water on soil salinity classes A & B,
- that the benefits of transferring water will not redistribute soil salinity across the farm, and
- that the viability of Tragowel farms within the existing structure will improve.

This project will provide a unique and detailed view of the adjustment process in the northern Victorian irrigation districts of Tragowel Plains and Kerang over the last 7 years. It will allow for a revision of adjustment targets to be made, and a more accurate estimate of the benefits of the Plan.

The detailed implementation information will allow for better informed decisions about the implementation of Management Plans in neighboring mixed farming irrigation areas.

Methodology
The project is made up of four main components:

Stage 1: Adjustment Strategies

A sociological survey, carried out just prior to the implementation of the plan, is the basis for now identifying the adopters/ non-adopters of the Plan. This survey will be updated with personal farmer interviews, property and water records, and the Tragowel Plains project database. A report on the extent of adoption, and the predicted rate of future adoption, will be made. After linking with Stage 3, a comparison of the extent of adoption and the capacity for water transfer within and between properties will be made.

Stage 2: Soil Salt Transport

Stage 1 results will be used to identify where water has and has not been transferred from high salinity soils to low salinity soils during the first two years of the Plan. One hectare randomly selected sites will be resurveyed for root zone soil salinities based on the 1990 EM-38 survey program. Site histories for water application and landuse will be developed from personal interviews and farm records. These sites will be re-surveyed using the EM-38 technique, during two consecutive winters. Analysis will allow for seasonal variation by the use of control sites where no water redistribution has occurred.. Modelling of salt transport will only be made if the field work detects significant changes in salt distribution due to changed irrigation management.

Stage 3: Remote Sensing of Water Re-Distribution

Identifying historic changes in irrigated land cover will reveal to what extent water has moved onto or off land. Identifying those areas which have become more effectively managed will be possible by comparing pre-Plan landcover with current landcover. This comparison will be made on multitemporal Landsat TM satellite imagery for both pre-Plan and current imagery. The landcover will be linked to current and historic water use records to support the identified changes. This information will be used to modify the findings of the first stage of the project to report on the extent and nature of, and potential for further, structural adjustment.

Stage 4: Economic Evaluation of the Tragowel Strategy

An economic study of the implementation of the Plan will evaluate the effect water transfer has had on both adopters and non-adopters, at the farm and community level; the total benefits available to the community through water reallocation both within and across property boundaries; additional benefits captured by water and land transfer; and the contribution of the restructuring incentives available in the Plan. Finally, a comparison will be made with benefits gained in neighboring irrigation regions where soil survey methodologies have only recently been implemented.

Acknowledgement

The authors wish to acknowledge the financial support of the Murray-Darling Basin Natural Resources Management Strategy. This three year project began Oct. 1994.

Australian Groundwater Quality Assessment Project: Background and Current Status

John Bauld

Australian Geological Survey Organisation (AGSO), Canberra

Ground water is an important resource in rural and urban Australia where increasingly it is extracted for drinking, industrial, and agricultural purposes. About 20% of the nation's total water requirements are presently met by ground water, though this proportion may be as high as 50-100% in large areas of inland, arid-zone Australia. The already apparent degradation in the quality of our surface water resources emphasizes the need to manage our groundwater resources so as to ensure the sustainability of groundwater-dependent ecosystems and economic activities.

Groundwater quality, as judged by domestic, industrial, agricultural or environmental criteria, is determined by both natural processes and human activities. Groundwater quality may be assessed not only by factors such as salinity but also by nutrient, toxic chemical and microbiological loads. Despite the implementation of strategies such as integrated pest management, the application of pesticides and fertilisers continues to be extensive and widespread in agricultural production throughout the nation. Groundwater resources underlying these areas may be exploited for domestic and town water supplies, as tables threaten production ground water may be pumped to adjacent surface waters for disposal. Following two years of reconnaissance studies the national geoscience agency AGSO was granted increased support, through the Prime Minister's Statement on the Environment, to carry out a more intensive assessment of groundwater quality. Field study areas are selected in consultation with State (ground)water agencies and assessment is carried out in cooperation/collaboration with these agencies. The Project has as its operational objectives to establish base-line/benchmark conditions in key groundwater resource areas, to monitor them for subsequent trends in quality indicators, and to identify and understand those processes impacting on groundwater quality in areas investigated. Information obtained in the achievement of these operational objectives will assist water resource managers to assess the efficacy of catchment management strategies.

Thus far (July 1995) groundwater samples have been acquired from *ca* 470 bores within six catchments in five states during eleven field operations since August 1993. Two of these five catchments lie within the Murray-Darling Basin. Sample acquisition is now complete for the priority areas within the Goulburn-Broken Catchment (Victoria). Comprehensive written reports will follow completion of sample and data analysis, though some preliminary findings are presented at this conference (see poster by Ivkovic, Reid & Bauld). Sampling in the Border Rivers Catchment(NSW/QLD) will be completed later this month. Further sampling in the Murray-Darling Basin is scheduled during November in the Murray-Riverina Catchment (NSW).

Groundwater Quality in the Berriquin-Denimein Irrigation District: A Brief Reconnaissance

John Bauld[1], Greg Brereton[2]*, Mark W Sandstrom[3]

[1] AGSO - Canberra; [2] DWR - Deniliquin; [3] USGS - Arvada * Present Address, DWR - Dubbo

The Berriquin-Denimein Irrigation District (BDID) lies within the Murray Catchment on the Riverine Plain of the Murray Basin. Land use within the BDID is dominated by rice and pasture (ca 60% and 35% respectively). The Shepparton Formation, which hosts the unconfined aquifer in this area, comprises heterogeneous clays and silts containing discontinuous shoestring sands. Seventeen observation bores in the BDID were sampled in April-May 1991 during a reconnaissance assessment of groundwater quality. At the time of sampling median depth to water table was 2.7m (n=17; range 0.9-7.1m). Among the groundwater quality indicators analysed were faecal indicator bacteria (FIB), nutrients and pesticides.

Overall, 7/17 groundwater samples contained FIB but, except for two bores, population densities were only just above detection limits. Nutrients, including nitrate, were generally present at low concentrations. The maximum nitrate-N concentration found was 6.0 mg NO_3-N/L and only 2/17 samples exceeded 3.0 mg NO_3-N/L. Pesticide compounds were detected in 5/16 bores but were present at very low concentrations. Desethylatrazine (DEA), a metabolite of the triazine herbicide atrazine, was present in three samples although the parent compound was not detectable. Other compounds detected were the herbicides simetryn and trifluralin.

It seems probable that the shallow ground waters in the unconfined aquifer of the BDID are afforded a measure of protection by the clay-silt dominated soils and sediments. The presence of the atrazine degradation product DEA in the absence of the parent compound is consistent with slow leaching of solutes to the water table.

Groundwater quality in the Padthaway-Coonawarra area of SE South Australia

John Bauld[1], Mark W Sandstrom[2], and Fred Stadter[3]

[1] AGSO - Canberra; [2] USGS - Arvada; [3] SADME - Naracoorte

The Padthaway-Coonawarra area is located in the Upper South East of South Australia. It lies just outside the southwestern boundary of the Murray-Darling drainage basin but straddles the boundary between the Murray and Otway sedimentary basins. Land use is a mixture of sheep and cattle production with irrigated agricultural production of pastures, specialist seed crops, horticultural and viticultural crops. The area is characterised by sandy soils with underlying clays over the limestone sediments which comprise the unconfined aquifer. The unconfined aquifer occurs at relatively shallow depths (ca 1-5 m) and there is active vertical recharge over the winter months. Groundwater samples from 17 observation bores were acquired during October 1991 and analysed for a range of groundwater quality indicators including pesticides, nutrients and faecal indicator bacteria.

Pesticides, principally the triazine herbicides atrazine, simazine and propazine, were detectable in 15/17 samples. However, 62% (26/42) of all detects were at trace concentrations. Atrazine (trace-785 ng/L) and simazine (trace-1086 ng/L) were each found in ca 60% of samples, while propazine (trace concentrations only) was present in 40% of ground waters sampled. The atrazine degradation product desethylatrazine (DEA) was present (trace-1013 ng/L) in about 70% of atrazine-positive samples but was not found in the absence of the parent compound. Some DAR (DEA-to-Atrazine Ratio) values were > 1.0 (consistent with slow transport to the water table) while about two-thirds were < 1.0 (consistent with rapid transport), suggesting considerable spatial heterogeneity in the subsurface environment. Trace concentrations of the herbicide butachlor and the insecticides p,p'-methoxychlor, endrin (aldehyde and ketone) and carbofuran, were each found in one or two samples.

Nitrate-N concentrations exceeded the WHO drinking water guideline value of 10 mg NO_3-N/L in 4/17 groundwater samples and exceeded 3 mg/L in 11/17 samples. There was no obvious association of elevated nitrate-N with any particular land use. For example, about half of the samples from both viticulture and pasture sites had nitrate-N concentrations < 3 mg/L. In the Padthaway area there was some indication that low nitrate-N concentrations were more likely to be associated with low concentrations of dissolved oxygen indicating that microbial denitrification may be removing some of the nitrate input. Groundwater samples were infrequently contaminated by faecal indicator bacteria and usually at low population densities. The presence of *E gallinarum* together with *E faecalis* suggests birds as well as livestock as probable sources.

Project MUDBEEP:
Murray Darling Basin Environmental Education Project

Jim Bowler & Michelle Smith,
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The scientific stories that describe the mysteries of the Murray Basin provide a powerful stimulus to the scientific community. But what of their relevance to those people, old or young, of Koorie or European descent, who live in, and now must manage, this special region of Australia? The MUDBEEP program, with an emphasis on education, aims to make basic information on this region accessible to a wide range of people .

This land has an incredible history of its own. It is a history of human-land interaction spanning almost the entire period of the last ice age - more than 100,000 years. In that time, the combination of natural climate change along with human impacts have produced the landscape we seek to understand today. The search for that understanding takes us on a journey through the past with dramatic changes on a pattern that is both immense in its spatial scale and mind-stretching in time.

The project, supported by funding from the Murray-Darling Basin Commission, aims to make information accessible by digitising basic data then constructing the stories that both interpret and permit its interrogation. In the first instance, we focus on the Willandra Lakes World Heritage Area, a region of central importance to the Murray Darling Basin and one that has been selected for public education through the World Heritage declaration.

The second focus is the Murray River, again involving both its natural and cultural history.

Data sets involving text, diagrams, photographs, video and sound are being packaged for distribution to a range of users. The target groups include;

A. School users
B. Community groups
C. Peer group researchers

The availability of digital packaging now enables us to interpret the same basic data sets directed towards three different audiences.

The pilot program exhibited here represents an early attempt to demonstrate the type of educational package we aim to provide. This first stage has focussed on establishing the basic data set from the Willandra Lakes World Heritage Area. It is now being structured with assistance of graphic artists and design specialists for a product to be trialed by both teachers and community groups.

As a pilot program, we aim to show what can be done, rather than to demonstrate a finished product. That stage will require a further 6 months work. User feedback is essential to ensure the success of the product. We would appreciate comments and suggestions for further developments.

GIS Database of Murray Basin Hydrogeology

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Introduction

In December 1994, the Minister for Primary Industries and Energy, Senator Bob Collins launched the Murray Basin Hydrogeological Map Series. Since then, the Australian Geological Survey Organisation (AGSO) has completed a digital database from the mapping. This allows greater flexibility in how the information can be presented, queried and analysed.

The Hydrogeological Map Series

Systematic hydrogeological mapping of the Murray Basin commenced in 1987 in a six-year collaborative effort between the water agencies of New South Wales, South Australia and Victoria and AGSO. Twenty six mapsheets covering the Murray Basin at 1:250 000 scale are now available. The objectives of the mapping were to show the influence of groundwater on salinisation, highlight present and potential salinity hazard, delineate useable groundwater resources and enhance community awareness of prevailing groundwater systems (Evans, 1992).

Each map contains a wealth of information on the regional groundwater system. The main 1:250,000 scale map depicts the salinity and yield for the shallow aquifer, as well as surface contours and flow directions relating to the shallow watertable. Insets at 1:1,000,000 scale provide information on the deeper aquifers in terms of groundwater salinity, aquifer yields, water levels and structure contours of the top of these aquifers. The depth to the watertable and a map showing the potential vertical groundwater flow are mandatory insets.

Order forms and further information are available from NSW Department of Land & Water Conservation, Mines and Energy South Australia, Hydrotechnology Victoria and the AGSO Sales Centre.

The GIS Database

With funding from the Murray Darling Basin Commission (MDBC), AGSO has constructed a digital database from the map compilations using a Geographical Information System (GIS). Over 400 coverages were derived from the hydrogeological themes depicted on the maps. The relevant coverages were appended to create seamless basin-wide datasets in vector format.

Access to hydrogeological information is paramount for the Community to make informed decisions on salinity management strategies within the basin. The published maps are one method of achieving this; the GIS database is another. A number of options are being investigated for making the database accessible. The data needs to be widely available, simple to use and of low cost.

The principal mechanism for maintaining, documenting and administering the GIS datasets will be the World Wide Web. The current and projected growth of the Internet throughout the world provides an opportunity to reach many clients. AGSO is currently establishing the Australian National Geoscience Information System (@ngis) to facilitate access to geoscientific information over AARNet. Under the AGSO home page, an extended digital version of a 'user manual' for the maps and GIS datasets is currently being constructed. This consists of a series of hyperlinked text and images at;

http://www.agso.gov.au/information/structure/egg/mb

For the majority of users without access to the Internet it is planned that a 'snapshot' of the information package will be published on CD-ROM. This will not only include the GIS data files, attribute files, the hyperlinked 'user manual' and graphics but also cheap support software.

Even with the rapid growth of information technology, there will still be a need for hardcopy output. The GIS database gives a seamless basin-wide perspective of the groundwater features over the entire Murray Basin. There is potential to publish an atlas containing not only small-scale maps of the themes depicted on the printed maps, but also new themes derived by the GIS. The mapped datasets can be reclassified and combined to produce new output such as salinity hazard, stock water supplies or artesian conditions.

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Precipitation and River Discharge in the Headwaters of the River Murray in SE Australia Related to ENSO Forecasts of SST for the NINO-3 Region of the Pacific Ocean

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Annual precipitation and natural surface water runoff of the headwater catchments of the River Murray in SE Australia are often inversely related to observed anomalies in sea surface temperature (SST) in the eastern tropical Pacific Ocean. The physical processes causing these SST variations are part of planetary-scale variations in coupled transport of the low-latitude Pacific Ocean and atmosphere termed the El Nino-Southern Oscillation (ENSO). These processes are incorporated in model calculations by several groups that permit skillful forecasts about a year in advance of SST anomalies for a large, ENSO sensitive region of the Pacific Ocean: 90° - 150° W, 5°N - 5°S (NINO-3 region).

The forecasts of SST in the NINO-3 region from physical process models, based on inputs of observed wind fields and observed SST in the low latitude Pacific Ocean provide opportunities for making estimates approximately a year ahead of statistical probabilities of hydrologic cycle parameters in many regions. The surface water catchments supplying large storage reservoirs in SE Australia provide an attractive location for exploration of practical methods to incorporate SST forecasts into water management practice. This region of Australia has long been known to experience substantial excusions in precipitation and river discharge amount in response to large-scale ENSO processes. In addition, the physical infrastructure of water storage reservoirs and irrigation diversion systems plus a regional water management authority (Murray - Darling Basin Commission) are already in place to permit assimilation and potential alteration of current water management practices based on model forecasts of SST.

Historical data of monthly precipitation (P) at three locations in the upland headwaters of the River Murray with long records (Beechworth [1876+], Mitta Mitta [1909+], and Whitlands [1889+]), and natural surface water inflow (Q) to Hume Reservoir [1892+] have been organized into probability tables relating annual values of observed hydrological parameters to observed SST through 1985. Another set of tables were prepared relating observed NINO-3 SST and forecast SST (9 months in advance) for the period 1971- 1985. These two groups of tables were combined into contingency tables relating annual P or Q to forecast SST.

The statistical relationships for P and Q, based on SST forecasts from physical model calculation outputs, were grouped into either (a) two or (b) three categories: (a) Lower (< 50 percentile) or Upper (>50 percentile); and (b) Low (< 30 percentile), Medium (30 - 70 percentiles) and High (> 70 percentile). Thus for a year with a "warm" SST forecast (El Nino year) in the NINO-3 region (>0.5°C above mean SST), the probability of lower than median P during the coming year is about 2:1, based on approximately a century of observational data, and about a decade of SST forecasting experience. The probability for Q to be in the Low discharge category is about twice that for being in the High category, based on combined tables for observed Q and forecast SST of >0.5°C above the mean. Such contingency tables provide examples of simple approaches to incorporate some elements of recent advances in understanding of ENSO processes into planning of water resource allocations about one year in advance of scheduled reservoir releases.

Soil Sodicity and Groundwater Reuse

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Institute of Sustainable Irrigated Agriculture, Tatura.
Agriculture Victoria.

Introduction

Groundwater pumping and on-farm reuse is a major strategy for watertable and salinity control in the Shepparton Irrigation Region Land and Water Salinity Management Plan (SIRLWSMP). On farm reuse of saline groundwater represents the "least-cost" option to farmers for disposal, however it poses the risk of increasing the sodic nature of soils. Farmers within the Tongala Groundwater Pumping Project area have expressed concern over the possible development of sodicity arising from long-term reuse of groundwater. A soil sodicity survey was conducted to attempt to quantify a relationship between long term groundwater reuse and soil sodicity.

Background

The Tongala Groundwater Pumping Project has been operating since 1982. The project area covers 610 ha and is located east of the township of Tongala in the Shepparton Irrigation Region of Victoria. Privately installed groundwater pumps (currently 17) are used to extract groundwater from the existing shallow aquifer system. Groundwater is of moderate salinity (1500 - 4000 µS/cm) and is generally shandied with channel water prior to its use on perennial pasture. Groundwater pumping at the Tongala project area has been successful in gaining salinity control, but not watertable control, primarily due to the passive nature of pumping and the influence of rainfall events on local watertables.

Method

Prior to the initiation of the soil survey, all farmers within the project area were interviewed to determine irrigation management practices across their properties for the past five years and the salinity of applied water. Applied water salinity varied considerably depending upon the source of the water, location of irrigation paddocks, water demand and the shandy rate adopted by the farmer. Despite Agriculture Victoria recommending that perennial pasture be irrigated with water no higher than 800 µS/cm, many farmers regularly irrigated with water considerably more saline.

All paddocks (250) in the project area were soil sampled at their mid-point, at depth intervals of 0-15, 15-30 and 30-60cm. Samples were dried and crushed prior to analysis of the saturation extract for sodium adsorption ratio (SAR) and soil salinity (ECe).

Results and Discussion

In Australian soils, when the adsorption of sodium on the surface of clays exceeds 6% of the total exchange capacity (ie. the exchangeable sodium percentage, ESP=6), the soil is classified as sodic and subject to structural degradation (Rengasamy & Olsson, 1991). The SAR obtained from a saturation extract is approximately the same as ESP. At the Tongala project area, twenty five percent of soil sampling sites located on the lighter prior stream levee soils had topsoil (0-15 cm) SAR values greater than 6, with values as high as 19.9. Fifty nine percent of sites on the heavier flood-plain soils had topsoil SARs greater than 6, the highest value recorded being 22.0. As expected, highest SAR values were obtained at sites with high soil salinity and SAR was shown to increased with depth for both soil types.

Further data analysis is being conducted to examine the association between SAR and applied water salinity, soil salinity, distance to nearest pump, piezometric levels and soil type for the Tongala project area.

Acknowledgments

The authors wish to acknowledge the financial support of the Federal Water Resources Assistance Program and the Victorian State Salinity Program.

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Chlorofluorocarbon Dating of Groundwaters

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The release of chemicals into the atmosphere from anthropogenic sources has increased over the past 50 years. Consequently, concentrations of a range of atmospheric trace gases have been steadily increasing. In particular, chlorofluorocarbons (CFCs) CFC-11 ($CFCl_3$), CFC-12 (CF_2Cl_2) and CFC-113 ($C_2Cl_3F_3$) have relatively long atmospheric lifetimes, and their atmospheric concentrations have been documented at reference sites throughout the world (Fig. 1). They are thus able to be used as tracers both of air movement and, as they are soluble in water, as tracers of water movement.

Chlorofluorocarbons are now routinely used as tracers of oceanic circulation (e.g. Trumbore et al., 1991). The use of CFCs as natural groundwater tracers was first proposed by Thompson et al. (1974), although most early studies were at contaminated sites. Recently, chlorofluorocarbon concentrations have been used for groundwater dating over timescales of 0 - 50 years (Busenberg & Plummer, 1992; Dunkle et al., 1993). Estimates of groundwater age can be used to calculate recharge rates and groundwater flow velocities with much greater accuracy than traditional hydraulic-based methods.

Because the time frame for CFCs is limited to the last 50 years, the technique is unlikely to be useful in slow-moving groundwater systems. They will probably find best application in areas where recharge rates are greater than approximately 20 mm yr^{-1}. While CFC-11 may degrade in anaerobic groundwaters, and CFC-113 may partition to aquifer materials, CFC-12 appears to be conservative in most natural systems (Cook et al., 1995).

A chlorofluorocarbon analytical system has now been set up at CSIRO Division of Water Resources in Adelaide, partly through LWRRDC funding. Field investigations are underway at three sites: Howard East (NT), Eyre Peninsula (SA) and Lake Mourquong (NSW). At Lake Mourquong, nests of piezometers with short (15 cm) screens were installed beneath the lake, and sampled for chlorofluorocarbons. The observed age gradient beneath the lake should provide information on the vertical water flux (leakage). The age gradient between piezometers installed near the middle of the lake, and those near the lake margin should allow estimation of the rate of lateral water flow away from the basin.

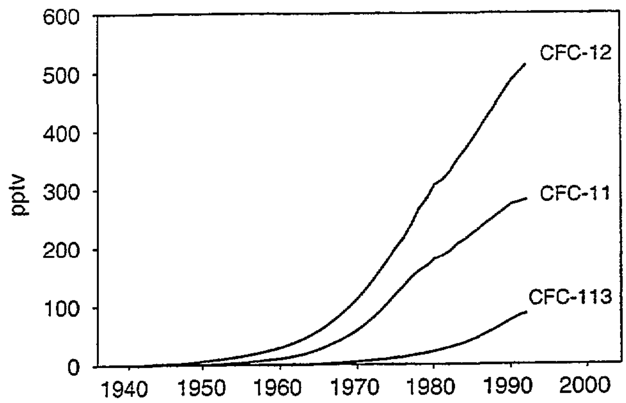

Figure 1: Atmospheric concentrations of CFC-11, CFC-12 and CFC-113 (parts per trillion, by volume).

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Salinity Recharge Mapping Kit

Cathryn Culley, Victorian Department of Conservation & Natural Resources, Broadford.

What is Recharge?

Recharge is water that enters the groundwater system. As recharge increases, groundwater systems fill up, discharging saline groundwater to lower areas in the landscape. Salts present in the soil and water cause the serious environmental and economic problems that we see today.

Recharge occurs across the whole landscape to varying degrees. Some areas have low recharge rates, eg. swampy areas. Other areas, such as shaly rocky outcrops, have high recharge rates. To reduce recharge, the whole landscape must be treated.

Why should recharge maps be drawn?

Identifying different recharge zones will enable short and long-term planning to control salinity and will improve land management and sustainability.

How can salinity recharge zones be identified?

A number of steps are taken to 'map' salinity recharge areas. These steps are outlined in an eighteen page booklet entitled "Salinity Recharge Mapping Kit - a guide to assessing the recharge capacity of soils on sedimentary country in Central Victoria." The booklet was produced through the Department of Conservation & Natural Resources with funding from the National Soil Conservation Program.

The booklet is designed to be used by landholders. The landholder can take the book out on their property and produce their own recharge map. This will enable better planning and management of the property for salinity and sustainability purposes. eg. After completing a recharge map for their property, land managers will know where they should concentrate their efforts to reduce recharge and help control the salinity problem.

The booklet has been aimed at the sedimentary country in Central Victoria but could quite easily be extrapolated to sedimentary country elsewhere in Australia.

Producing a Salinity Recharge Map!

The first step in identifying recharge zones is to look at obvious indicators of recharge across the landscape. eg. boggy and rocky areas. Higher rates of recharge generally occur in mid and upper slopes while low recharge areas lie in the lower areas of the landscape. This gives you a better picture of the recharge patterns across the landscape.

The next step is to take a closer look at the situation by looking at the depth and clay content of the soils. These soil features influence how permeable a soil will be. The deeper soils that contain more clay generally have lower recharge rates. This is due to the soil holding the water in its mass instead of allowing it to flow down the soil profile to the groundwater system. Shallow soils with little or no clay do not hold much water and thus allow water to flow freely to the watertable.

Soil testing is done across the landscape with an auger hole being dug down to the clay subsoil at each point. (In the Silurian and Ordovician sedimentary country in central Victoria, most soils are duplex and thus have a clay subsoil). The soil is tested for depth and texture (ie. clay content).

Measuring this rate of water movement into and down the soil profile gives a general guide to the recharge potential of the soil. This 'infiltration' testing' follows the soil testing and is completed using infiltration rings at a number of sites across the test area.

The soil and infiltration testing results are combined and classified to establish low, moderate or high recharge zones. This information is then put onto an overlay on an aerial photograph or property plan so the land classes can be determined. Each of these land units will require a different management strategy. By putting the information onto a property plan, short and long-term plans can be made for the future to use water where it falls, to control the salinity problem.

If you would like further information on this booklet, please contact Cate Culley on (057)841303.

Dryland Salinity Around North Star and Yallaroi in North-West NSW

Hemantha De Silva, Department of Land and Water Conservation, Muswellbrook.

Introduction

Salinisation of land and groundwater was examined thorough hydrogeological studies supported by interpretation of satellite images and construction of a observation bore network covering over 200,000 ha of land around North Star and Yallaroi. Two cases of interest in practice are considered; one is groundwater seepage to shallow geological formation from deeper confined aquifers of Great Artesian Basin; the other is the movement of moisture within the unsaturated zone near the surface.

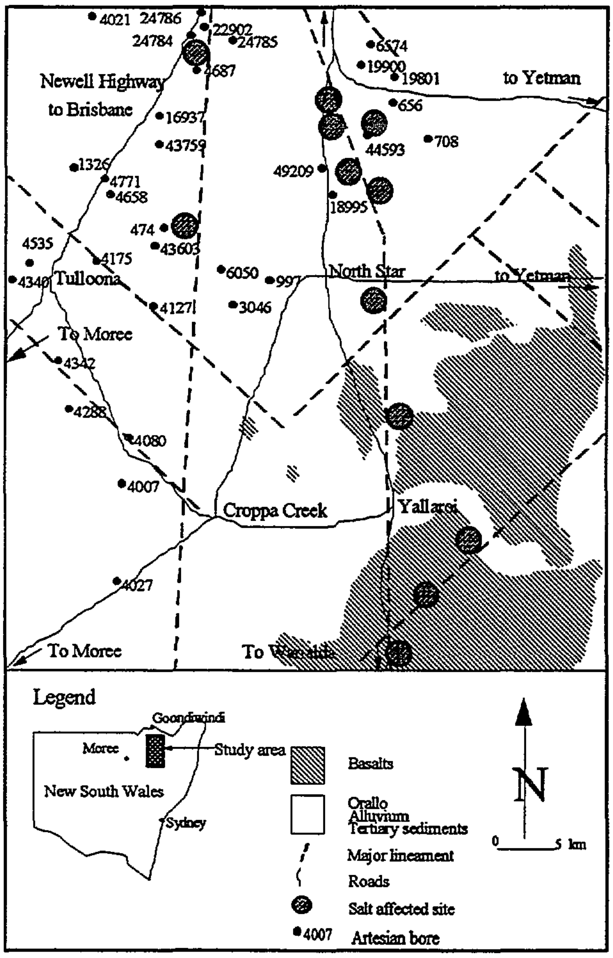

Figure 1. Map of the area showing main geological features, artesian bore locations and salt affected sites.

The area of study receives an average of 660mm of summer dominated rainfall, however above average winter rainfall has been observed in the last ten years. The southern part of the area consist of basaltic capped ridge and valley topography and the northern part is flat to undulating landforms of sandstones, siltstones and shales of Orallo formation (Stroud, 1990). The area is well covered by an ephemeral drainage network with streams flowing through large flood plains. Geophysical survey results show a series of lineaments trending along N-S, NE-SW and NW-SE directions as shown in Figure 1. (Tenison Woods 1988)

Most of the artesian bores (currently flowing or ceased to flow) are located in the northern, western and south-western parts of the area. Occurrence of salt outbreaks near major lineaments indicate these outbreaks are structurally controlled.

Four conceptual models were developed, each one corresponding to a particular occurrence of dryland salinity as shown in Figures 2, 3, 4 and 5.

Type 1: Salinisation due to seepage from bore drains

Bore drains are a common feature in grazing country in the western and north western part of the area. Most of the flowing artesian bores in NSW have unrestricted flow. Many of these have no head works, hence discharge large volumes of water into watercourses, swamps and bore drains where over 90 percent of water is wasted through evaporation and seepage. Naturally-flowing bores or water pumped by windmills carry water along these drains for long distances (hundreds of kilometres). As a result of stagnation and evaporation, salts build up along the banks of the drainage. Salt deposits along the drainage lines are visible during dry periods. (see Fig. 2)

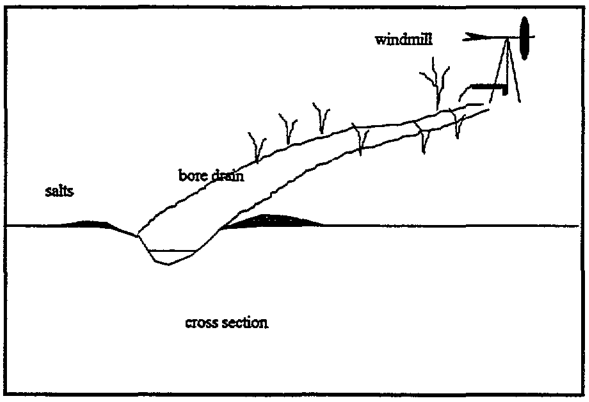

Figure 2. Sketch diagram showing salinisation due to seepage from bore drains

Type 2: Salinisation due to seepage of saline groundwater from artesian bores.

Artesian bores usually have large diameter steel casing pressure cemented into place around the inner supply casing to prevent shallow saline water from contaminating the deep, better quality groundwater. In many of the artesian bores drilled during the early part of this century, prolonged exposure to saline groundwater caused corrosion in the outer casing. This resulted in the release of saline groundwater to the upper rock/soil profile and ground surface. Evaporation of the groundwater results in localised salinisation around the bore. (see Fig. 3)

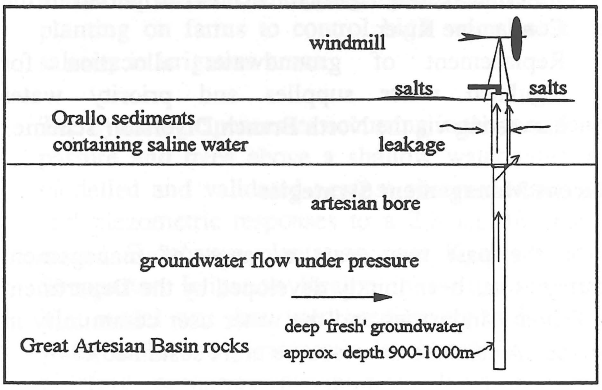

Figure 3. Sketch diagram showing salinisation due to seepage of saline groundwater from artesian bores

Type 3: Salinisation due to moisture movement in the soil profile.

Clearing of native vegetated land and replacement with crops and pasture has changed the natural balance of moisture in soil profile.

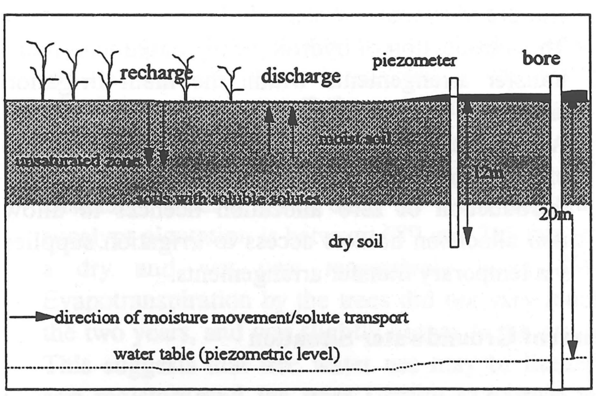

Figure 4. Sketch drawing showing the concept of salinisation due to moisture movement in the soil profile.

The amount of water penetrating the surface may sometimes be insufficient to reach the watertable, but will be retained within the unsaturated zone. Soluble salts in the soil will be dissolved by the moisture when the soil profile remains moist for a long time. During periods of high evaporation, salt laden soil moisture close to the surface evaporates, leaving the salt behind. If this process continues for a long period with only limited accession to the water table, wind-borne salts will accumulate within the profile, causing dryland salinisation. The unusual feature of this type of saline outbreak is that patches of saline soil moisture can spread over a wide area. (See Fig 4)

Type 4: Salinisation due to upward movement of groundwater

Groundwater in the Great Artesian Basin is under pressure and tends to seep towards the surface through fractured and weak zones which are highly permeable relative to the surrounding rock. The water seeping to the surface carries salts from shallow saline sediments. The process is similar to salinisation due to seepage from an artesian bore but the transport path for groundwater is natural fractures or high permeable zones.

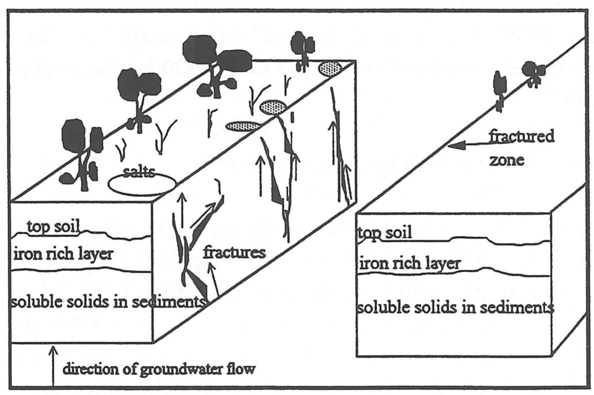

Figure 5. Sketch drawing showing the concept of salinisation due to upward movement of groundwater.

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Management Strategies of the Condamine Groundwater Management Area

Gregory James Embleton: Queensland Department of Primary Industries

The Condamine Groundwater Management Area is 360 000, hectares in total area and includes the towns of Millmerran, Cecil Plains, Brookstead, and Macalister. It contributes approximately 25 - 30 Million dollars to Queensland through agricultural produce and supplies water to the towns of Millmerran, Pittsworth, Cecil Plains and Dalby. The groundwater yield of the system is approximately 25 000 Megalitres per year.

Although the district was settled in the mid - 1800's, irrigation from the Condamine River Alluvium did not begin until the 1940's. Significant irrigation development occurred during the 1960's with the area of irrigation increasing from 790 to 20 000 hectares in the period between 1960 and 1970 (currently the total area under irrigation is 15 000 to 18 000 hectares per year).

Groundwater Management History

In early 1969, groundwater within the Condamine River Alluvium was found to be rapidly depleting. Restriction of groundwater use was required and a system of allocations commenced. In April 1970 an embargo was imposed on the issue of new allocation licences in an area surrounding the Condamine River. This area became known as the Condamine Restricted Licence Area (CRLA). By the late 1970's, in the central part of the CRLA, water levels had fallen by as much as 20 metres.

In an effort to remedy the situation, an area known as the Condamine Groundwater Management Area (which included the CRLA) was recognised in 1979. To reduce demand on the groundwater resource and collect data on water use, water meter installation (on all allocation facilities) commenced. In addition, from 1980 charges were levied on groundwater usage. Excess water use charges followed in 1982.

Various initiatives involving the 'exchange' of groundwater allocations for surface water have been introduced to reduce the over - exploitation of the groundwater system. These initiatives involve:

- The substitution of groundwater allocation with water harvesting rights for licensees riparian to the Condamine River.
- Replacement of groundwater allocation for regulated water supplies and priority water harvesting via the North Branch Diversion Scheme.

Recent Management Strategies

Over the past two years a range of management strategies has been jointly developed by the Department of Primary Industries and the water user community in an attempt to make the resource more sustainable.

These strategies include:

- Staged introduction of announced allocations as follows:

1995/96	80%
1995/96	70%
1997/98	to be announced.

- Changes to advance draw and carry over provisions to promote saving of water rather than borrowing.
- Formation of a groundwater advisory committee to liaise with the water user community and the Department of Primary Industries.
- Change of the water year to enable better planning and use of available water.
- The introduction of hydrologically based temporary transfer arrangements within the main irrigation area.
- An extension programme to promote more effective and efficient methods of water use.
- Introduction of zero allocation licences to allow non allocation holders access to irrigation supplies via temporary transfer arrangements.

Current Groundwater Situation

- Groundwater use has decreased from an estimated 75 000 megalitres per annum (prior to 1980) to an average current annual use of approximately 50 000 megalitres.
- Water levels, in some areas, are still declining but at an decreasing rate.

Shallow Groundwater Movement in Response to Eucalypt Plantation Water Use

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Abstract

The current lack of understanding of the response of shallow groundwater to water extraction by trees makes it difficult to appraise the potential of tree planting on farms to control high water tables and salinity in irrigation areas.

The hydrologic processes occurring in the root zone of pasture and trees above a shallow water table were modelled and validated against observed water table and piezometric responses to a 2.3 ha, 18 year old mixed *Eucalyptus* plantation near Kyabram, in the Shepparton Irrigation Region in northern Victoria. The model was then used predictively to investigate water table and piezometric level response to other planting scenarios of interest. Field work was undertaken to determine soil and aquifer hydraulic characteristics, and this, together with additional existing data, is used in the modelling approach.

Local recharge under irrigated perennial pasture and discharge under the plantation was simulated using SWIM (Ross, 1990), which uses a one-dimensional representation of Richard's equation in the unsaturated zone. Recharge to a shallow water table occurring under irrigated conditions in the surrounding pasture was estimated to be between 78 and 160 mm/yr in a dry and wet year respectively. Most recharge under irrigated pasture occurred during the winter months. Under non-irrigated conditions, net recharge (94 mm/yr) occurred in the wet year whereas net discharge (243 mm/yr) from the shallow water table occurred in the dry year.

Discharge from a water table (at 6 m) through the eucalypt plantation is between 689 and 215 mm/yr for a dry and wet year respectively using SWIM. Evapotranspiration by the trees did not vary much in the two years, and was slightly higher in the dry year. This suggests that tree water use may be limited by soil moisture and the trees' ability to extract water from the water table. During the dry year, trees obtained about 74 per cent of their water from groundwater, compared about 24 per cent in the wet year.

The spatial characteristics of groundwater drawdown were investigated with steady state simulations using MODFLOW (McDonald and Harbaugh, 1984), a widely used groundwater flow model. Additional tree planting designs were considered, and the response of shallow groundwater to each was determined.

A water table drawdown of over 2 m was simulated under the 84 m wide Kyabram plantation extending to 0.12 m at 90 m from the edge of the trees. Piezometric levels in the semi-confined aquifer below the plantation are lowered by about 0.63 m, causing the piezometric level to be higher than the water table and thereby inducing a groundwater discharge area. Such a situation is conducive to salt accumulation in the root zone of the trees.

The same block planting in a lighter soil type has less of an impact on groundwater with a maximum water table and piezometric level drawdown of 0.75 m and 0.21 m (36 per cent and 33 per cent of those under the Kyabram plantation) respectively. The extent of groundwater drawdown is greater in a lighter soil type. Checkbank plantings 40 m apart provide localised water table control with a maximum drawdown of 0.35 m extending to about 10 m from the trees, with a negligible effect on piezometric levels.

Alley plantings 10 m wide induced water table and piezometric level drawdowns of 1.5 m and 0.22 m respectively, extending to about 35 m from the trees. Smaller tree plantings, such as alley plantings, offer greater potential for localised water table and salinity control. Although an upward pressure gradient may still exist, there is greater chance for periodic leaching to prevent salt accumulation in the root zone.

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Design and Operational Considerations to Control Iron Bacteria Problems in Groundwater Pumping Systems

Peter Forward: South Australian Water Corporation, Berri, South Australia

INTRODUCTION

The fouling of groundwater pumping systems by iron bacteria is a world wide problem resulting in impaired hydraulic performance, increased pumping and maintenance costs, increased metal corrosion and decreased water quality. Since the occurrence of iron bacteria is due to a combination of physical, chemical and microbiological factors, successful control measures must address all of these.

BACKGROUND

The phenomenon of microbiological incrustation or biofouling (which includes "iron bacteria") is now well recognised but not fully understood. It is caused by the accumulation of microbes (bacteria), extracellular polymeric substances and inorganic precipitates (usually iron or manganese oxides). In the case of iron bacteria, they derive energy during their metabolism through oxidising soluble ferrous iron to its insoluble ferric form. The resultant biofilm is commonly found as a slimy or gelatinous deposit on bore screens, pump inlets and internal waterways and discharge components, sometimes extending well into the distribution pipe system.

In the absence of external contamination, aquifers were once assumed to be microbiologically clean. However, it is now known that bacteria are often endemic in aquifers throughout the world and that aquifers can allow the free transmission of bacteria under suitable conditions. Bores can also become contaminated from external sources such as infiltration of surface water or from drilling and maintenance equipment taken from bore to bore.

The microbiology of iron bacteria is very complex and a number of chemical and physical factors are considered to be critically involved in assessing the risk of fouling in a bore. These include; aquifer characteristics, total iron, dissolved oxygen, temperature, pH and Eh (redox potential), total nitrogen, total phosphorous, nitrate and organic carbon.

Unfortunately, given the variability of interaction between these factors, it has not yet been possible to derive some form of "iron fouling potential index" to predict with certainty whether iron bacteria problems will be encountered at any particular site. Likewise control measures used by operators vary widely in type and effectiveness and include a range of both physical and chemical techniques, often in combination. Their success is often dependent on the physical and operational aspects of the installation.

SA WATER EXPERIENCE WITH IRON BACTERIA

In the past six years SA Water, with funding from the Murray-Darling Basin Commission, has constructed and now operates the Woolpunda and Waikerie Salt Interception Schemes which prevent highly saline (30 000 EC) groundwater from entering the River Murray. Out of a total of 66 bores in the two schemes 57 developed biofouling problems, 50 of these having iron bacteria and the other 7 suffering severe corrosion problems due to the presence of hydrogen sulphide which is also caused by bacterial action. A number of other bores elsewhere in South Australia used for domestic water supplies also suffer from iron bacteria problems.

In the most severe cases in the Woolpunda Scheme, a newly installed pump would lose 45% of its flow within 50 days of installation due to clogging of the internal waterways with iron bacteria deposits. Techniques developed by SA Water have now totally overcome the iron deposition problem within the pumps such that some have now run continuously for over three years with no loss of output due to the effects of iron bacteria.

In researching solutions to the problems and based on SA Water and other operators' experience to date, there are many factors of both design and operation that will influence the extent to which a groundwater pumping system may suffer iron bacteria problems and the ease with which they can be dealt with by operators. These include:

Bore Construction

- Non corrosive casing, sealed against surface contamination
- As long a length of screen as possible
- Size of screen slots
- Provision for easy chemical dosing

Pump

- Corrosion resistance
- Ease of maintenance
- Flow rate, drawdown
- Dynamic water level above the pump
- Water velocities and turbulence in the bore, pump and pipework

Discharge pipework

- Diameter
- Ease of dismantling for cleaning
- Provision for insertion of foam rubber pigs (swabs) to clean pipelines

Pump and bore performance monitoring

- Pressure gauge and flowmeter
- Bore water level measurement
- Regular monitoring program

Salinity/Rising Watertable Surveys in the Murray-Darling Basin

Jay Gomboso
Australian Bureau of Agricultural & Resource Economics, Canberra ACT

This poster will present the results of two salinity/rising watertable surveys of all local government councils and selected state and federal government agencies located wholly (or partly) within the Murray-Darling Basin.

There are five main aims of the surveys. These are to:

- identify the extent of government awareness of dryland salinity problems;
- obtain information on the type and extent of the physical impacts of dryland salinity;
- obtain estimates (in dollar amounts) on the off-farm expenditure resulting from dryland salinity problems;
- identify the source of funds used to meet the off-farm costs of dryland salinity problems; and
- obtain information and expenditure on research and extension work being carried out by governments on off-farm dryland salinity.

Dryland Salinity Catchment Management in South Australia

C J Henschke
T N Herrmann
T D Evans

Primary Industries South Australia (PISA)
Sustainable Resources, Waite Campus, GPO Box 1671, Adelaide, SA, 5001

1. Whole Catchment Approach
In South Australia, it is recognised that improved understanding of salinity processes by land managers, together with community involvement and group ownership is necessary to implement whole catchment management strategies.

Management strategies aim to reduce the impact of salinity, improve catchment health and overall productivity.

Key principles being promoted include:

- High water use strategies (maximise crop and pasture productivity and establish perennial vegetation)
- Saltland agronomy
- Drainage options to reduce flooding/waterlogging

Catchment planning days are conducted with community, landcare and property planning groups where landholders gain an understanding of salinity management, identify recharge and discharge areas and develop a catchment management plan.

2. Catchment Planning
Groups are encouraged to develop a resource inventory of catchment characteristics (soils, geology, groundwater details, current land use etc).

Relevant background information often already exists and can be obtained from various agencies or from reconnaissance field investigations.

Supplementary information, where required, is obtained from drilling and installing monitoring bores along with field surveys (eg electromagnetics, soils).

Active participation by group members in both collecting and collating information is encouraged.

3. Technical Resources
Catchment groups are supported with relevant technical resources to assist in developing appropriate management plans.

- *Recharge area identification*: Key land units are characterised according to their groundwater recharge potential. This shows where high water use land management systems should be a priority in the planning process.

- *Saltland agronomy*: Investigations and demonstrations of saltland agronomy technology to assist farmers establish profitable salt tolerant pastures on their saline discharge areas. Demonstrations have been established in co-operation with a number of landcare groups across the State.

- *Groundwater modelling*: Conducted in focus catchments to predict the impact of management option scenarios.

- *Information packages*: Includes an information sheet series, technical documents, bulletins and manuals.

4. Implementation
For whole catchment methodology to be successful, it should be incorporated into a framework of property and wider district planning. This allows implementation of various components of a salinity control plan in an economically viable manner.

Property planning helps to prioritise the stages of on-farm development. Implementation usually occurs over a number of years.

Principles of whole catchment management are being highlighted at property management planning workshops to increase the adoption of salinity management practices.

MURDER: Murray Basin Disposal by Evaporation Resource

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Introduction

Evaporation-disposal basins have been used in the Murray Basin since 1917 to dispose of saline groundwater and irrigation excess. Despite this history, little is known about the effects of disposal water on the hydrodynamics and ecology of the individual basins and their surrounds. Proper management decisions on the use of disposal basins necessitates considering a combination of the needs of the community, with the long term effects of saline water disposal.

Hostetler and Radke (1995) published an inventory of all known disposal basins in the Murray Basin using as a base the criteria set forth in Evans (1989). The second phase of the project was to transfer the inventory into a GIS system to allow greater accessibility to the information contained in the inventory.

Format of MURDER

The information source consists of five parts an Oracle database, basins outlines, airphotography, geologic cross-sections through the basins, and on-line documentation.

Oracle database

The Oracle database is broken into 10 data tables (containing information on the administration, construction, geology, hydrodynamics, hydrostratigraphy, impacts, location, and operating conditions of each basin) and 15 authority tables that provide information on codes and abbreviations used in the database. Access is through a link in ArcView 2 which enables the location of the basins to be linked to queries of the database. Tables may be joined in any combination but included in the database are several preset options addressing the most important of Evans' (1989) criteria. The construction of the database has highlighted the paucity of information presently available on the disposal basins. Local hydrodynamic data and hydraulic conductivities of the host are especially scarce. However, because of the dynamic nature of the database, information can be updated and future basins can be added.

Basin outlines

Basins were digitised using the best available base. In the vicinity of the Murray River floodplain 1:25,000 scale River Murray Mapping rectified areal photography was used, while outside this area the largest scale topographic maps were used. Multiple polygons are used to represent the dynamic nature of the basins and the dramatic changes in areal extent with a slight change in water level. Polygons are graded with the *relev* code with values from 0 to 70 representing low to intermediate values, 80 equal to the maximum operating level, and 90 equal to the maximum inundation level.

Airphotography

MURDER contains two sets of airphotographs taken approximately 20-30 years apart. The first is from the Murray Mapping Series, which have been transferred to grid's and are available as background themes. The second is an older set of airphotographs consisting of scanned images of the basins and can be accessed via hotlinks.

Geologic cross-sections

Basin geology is demonstrated by selected geologic cross-sections generated in ARC/INFO. Cross-sections show bore lithology, interpreted geologic formations and structures, and reliability.

On-line documentation

Complete documentation of the database will be available in a hypertext format via an internal link with the Internet. This will be located under the AGSO homepage; http://www.agso.gov.au/information/structure/egg/mb.

Uses of MURDER

The primary use of MURDER will be as a management tool to assess the viability of present basins and as a guide to the placement of future basins. It is anticipated that MURDER will be of use to landmanagers, farmers, and scientists.

References

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Groundwater Quality In The Murray Valley Irrigation District, Northern Victoria

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Introduction

In August 1993 AGSO sampled 21 observation bores in the Murray Valley Irrigation District (MVID) as part of AGSO's Australian Groundwater Quality Assessment Project (see Bauld, this conference). The groundwater samples were analysed for physical characteristics, major and minor inorganic chemical constituents, some stable and radioactive isotopes, nutrients, pesticides and indigenous and contaminant microorganisms. Prior to this study, the only available water quality information related to salinity, which was found to be generally low.

Study Area-Land Use and Hydrogeology

The MVID is located in northern Victoria and sits within the Goulburn-Broken Catchment. The study area within the MVID comprised approximately 270 km^2 and was centred around the towns of Strathmerton, Yarroweyah and Cobram. The predominant land uses in the study area are improved irrigated pasture for dairy cattle, orchards, residential developments utilising septic tanks and some rural industry.

The study area is underlain by the Shepparton Formation which is primarily composed of silty to sandy clay. Within the clayey sediments there are discontinuous sand and gravel lenses which were deposited in the beds of prior streams. These infilled channel deposits form the unconfined through to confined Shepparton Formation aquifers.

The water table in the study area is relatively high and the groundwater flow paths are generally in a northerly direction towards the Murray River. The MVID is situated close to the Murray River and consequently there is the potential for contamination not only to the underlying aquifers, but also to the river through groundwater discharge.

Results and Discussion

Depths to water table were found to range from 1 to 4.5 metres with a median of 3.2 metres. The total depths of the bores ranged from 6.5 to 20 metres. The EC ranged from 365 to 7980 µS/cm with a median value of 1354 µS/cm.

Nitrate-N concentrations ranged from <0.01 to 29 mg/L with a median value of 0.73 mg/L. Three of the 21 bores sampled exceeded the WHO drinking water limit of 10 mg/L nitrate-N. About 29% of the samples contained nitrate-N concentrations higher than background concentrations (arbitrarily taken as 3 mg/L). The dissolved oxygen content of the groundwater ranged from 0 to 4.6 mg/L (median 0.1 mg/L) suggesting that the anaerobic aquifer conditions would generally tend to favor nitrate removal through microbial denitrification. Contamination by faecal indicator bacteria (FIB) was negligible (only in one case was FIB contamination associated with high nitrate-N) suggesting that nitrate contamination may not be caused by septic tanks or livestock manure. Total phosphate concentrations ranged from 0.02 to 0.24 mg/L with a median value of 0.06 mg/L.

Pesticides were detected in 48% of the groundwater samples. The triazine herbicides were found to be the dominant group of pesticides detected. Ten of the samples contained simazine at concentrations ranging from trace to 0.45 µg/L with a median value of 0.03µg/L. Two of the samples contained atrazine concentrations of 0.02 and 0.04 µg/L and one of the samples contained the herbicide bromacil (2.5 µg/L). Pesticide concentrations did not exceed the Draft 1994 NH&MRC Australian Drinking Water Guidelines of 0.02, 0.02 and 0.3 mg/L for simazine, atrazine and bromacil respectively. Triazine degradation products were not found suggesting rapid movement of pesticides to the aquifer, possibly through preferential flow paths within the overlying silts and clays. The widespread detection of herbicides in the groundwaters suggests that nitrogenous fertilisers are also likely to be transported to the shallow aquifers and that nitrate-N may be removed by denitrification.

There were no obvious associations between nutrient or pesticide contamination and EC or with depth to water table. The presence of elevated nitrate-N concentrations and traces of herbicides could not be correlated with land use and occurred with the same frequency of detection under both orchards and perennial irrigated pastures. Further studies need to be undertaken to determine whether any contamination to the Murray River is occurring through groundwater discharge.

Management of Waterlogged Soils for Dryland Agriculture

Tim Johnston, Research Officer
Agriculture Victoria, Rutherglen Research Institute

Background

Waterlogging is a major limitation to grain production and an increasing land degradation issue in many areas of SE Australia. In north-east Victoria the loss from crop and pasture averages about $10 million annually.

The problem of waterlogging in NE Victoria is principally due to the presence of hardpans or dense subsoils (approx 15 cm below the surface) which restrict the movement of water down through the soil profile. Perched water tables occur in the top soil following rain, as evidenced by shallow ponding on the soil surface.

Soil management techniques for these wet areas are required to increase the water holding capacity of the soil lower down the profile. Artificial drainage is also needed to remove excess water from the soil once the profile approaches saturation.

Drainage Systems

As a general rule, it is much cheaper to prevent water from running onto a paddock than it is to drain it off. Hence, open surface drains or spinner cuts should be the first option considered to alleviate waterlogging. If surface water run-on cannot be fully controlled, subsurface drainage may be required.

In the past, subsoil drainage systems have been reliant on expensive pipe drains. Research at Rutherglen is investigating the use of **conventional mole** and **gravel mole** systems to reduce the costs of conventional pipe drainage systems.

Conventional mole drains are unlined channels (diam. 10 cm) formed in the clay subsoil by a mole plough. The mole plough consists of a ripper blade with a cylindrical foot which trails an expander to compact the wall of the channel. The requirements for good channel formation are stable subsoils with a clay content >35% and moisture content at time of installation of about 25%. The development of cracks above the critical depth (figure 1) are essential for water to enter the channel. Gravel moles are similar to conventional moles but are filled with gravel for greater longevity in unstable soils.

Pipe drains are still required in most circumstances, but as the spacing of the pipes is greatly increased, costs of subsoil drainage systems are reduced.

Method

The benefits of subsoil drainage are being trialed through experimental work on three sites. Subsoil drainage options are being evaluated for their effect on production of a range of grain crops. The options (pipe, conventional mole and gravel mole) are being tested with and without deep ripping and gypsum. The research will determine the best mix of options, both in terms of productivity, sustainability and cost. Crops which are being used include wheat, barley, triticale, oats, lupins, field peas, faba beans and canola.

The problem of drain outflow has not been ignored. Regular monitoring of salinity and nutrient levels in drained water and quantity of drainage outflow is taking place.

Achievements

Drainage systems were installed in February 1994 and will be carried over three cropping phases.

Future analysis of these sites will enable us to gain a more complete picture of nutrient movements over the year in both surface and subsurface drains, enabling the prediction of the likely effect of drainage on catchment water yield and quality.

This project is funded by the Grains Research & Development Corporation.

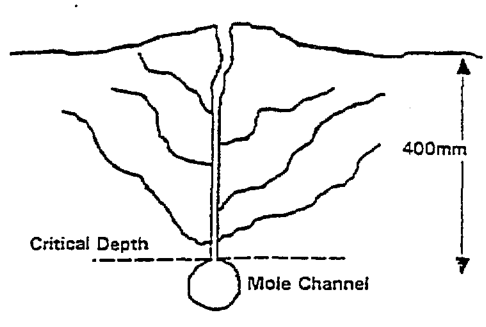

Figure 1: The mole channel.

Goulburn Murray Watertable Network
A Community Management Strategy

Ross Jones
Chairman, Goulburn Murray Landcare

Abstract

Test wells (or shallow observation wells) primarily have been used as a visual education tool for creating awareness of salinity amongst the community. Installation and monitoring of community test wells has now been done by the community in the Shepparton Irrigation Region. A unique network has now been established encompassing 16 Landcare groups representing over 1000 farm properties.

The Goulburn Murray Watertable network will be responsible for the accurate measurement of 1400 test wells on a monthly basis for watertable level and biannually for salinity. The network will be able to identify local areas at risk ("hotspots") and investigate appropriate management techniques in conjunction with relevant Government agencies.

Groundwater Quality Monitoring Requirements in the Irrigated Agricultural Areas of the Terai Belt, Nepal.

Mohan Singh Khadka

Senior Division Chemist, Department of Irrigation, Kathmandu, Nepal

Groundwater is used extensively for irrigated agriculture in the Main and Inner Terai regions of Nepal. Currently there are about 260 deep tube wells and about 46,000 shallow tube wells in use which irrigate 13,000 ha and 15,000 ha respectively. Priority development of additional irrigation schemes will bring the total to 700 deep tube wells (30,000 ha) and 90,000 shallow tube wells (360,000 ha). Thus, groundwaters in the Terai will play a vital role in upgrading living standards of the poorer sections of the Nepalese population and also in stimulating the national economy.

The increased intensity of agriculture resulting from the development of irrigation schemes will be accompanied by increasing usage of chemical fertilizers and pesticides. For example, in the Chitwan district (East Rapti Irrigation Project) the application rates are estimated to be 0.42 tonne/ha/yr for fertilizers and 3.3 kg/ha/yr for pesticides. Shallow wells, which would be the most vulnerable to contamination, provide the main source of drinking water in the Terai. While preventing or minimizing contamination of groundwater through improved or controlled agricultural practices is preferred, it is necessary to monitor groundwater quality in the shallow aquifer in order to give adequate warning of potential health dangers.

Preliminary analyses from a small number of shallow tube wells sampled pre-monsoon, in an area now moving to more intensively irrigated agriculture, show low nitrate-N concentrations (< 2.2 mg nitrate-N/L), though these are considerably higher than found in adjacent river waters. It is planned to commence pesticide analysis within the next few months.

A Direct Approach To Compute Groundwater Balance Using Observed Watertable Rise Rates In Shallow Watertable Aquifers

N. Kulatunga & K.R. Bogoda
Department of Land & Water Conservation, Deniliquin

The Murray Region is located in the eastern edge of the Murray geological basin which is filled with a sequence of sediments. The Shepparton Formation represents the most recent major phase of fluviatile sedimentation and consists of clay, silt and interbedded sand layers. The sediments in the Upper Shepparton Formation is related to a system of prior streams and the aquifers can be considered mainly as watertable aquifers. The land and water management practices in Irrigation Districts exert a direct impact on the hydrogeological regime of the Upper Shepparton Formation aquifers.

Rising Watertables in irrigated and dryland areas in the Murray Region indicates an 'imbalance' groundwater system. The flow into the Upper Shepparton aquifers (as rainfall/irrigation accessions, lateral inflow etc.) significantly exceeds the amount of outflow (evapotranspiration, run-off, leakage into deep aquifers etc.), causing the watertable rise. The quantification of excess groundwater added to the watertable each year was a key issue to develop options for watertable control in Land and Water Management Plans in the Murray Region.

The initial approach was to simulate the increase in groundwater storage in the shallow aquifer by using a simple model and identifying and estimating the various components involved.

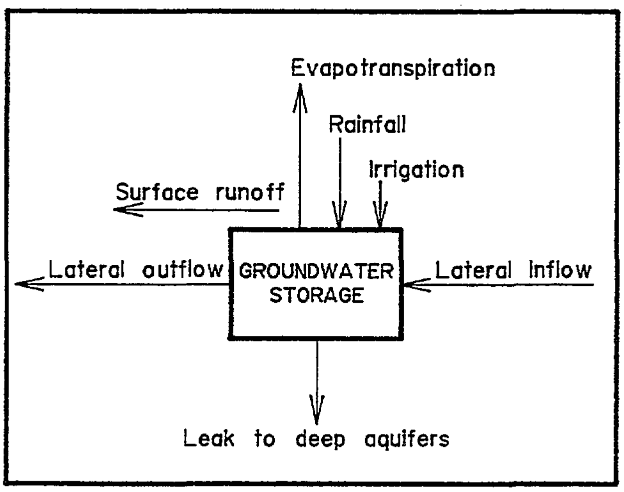

Figure 1 : Schematic model showing major components of the water balance

This simulation (Fig. 1) is open to significant errors because of the difficulty in estimating some of the components to a reasonable accuracy. Evapotranspiration for example, accounts for about 80% of the outflows in the water balance. 10% error in evapotranspiration estimation can change the water balance by order of 100,000 ML/yr.

Subsequently, a direct approach by using a spreadsheet model was developed to simulate Irrigation Districts in 2x2 km (400 ha) grids to compute groundwater balance (change in groundwater storage) by using observed water levels.

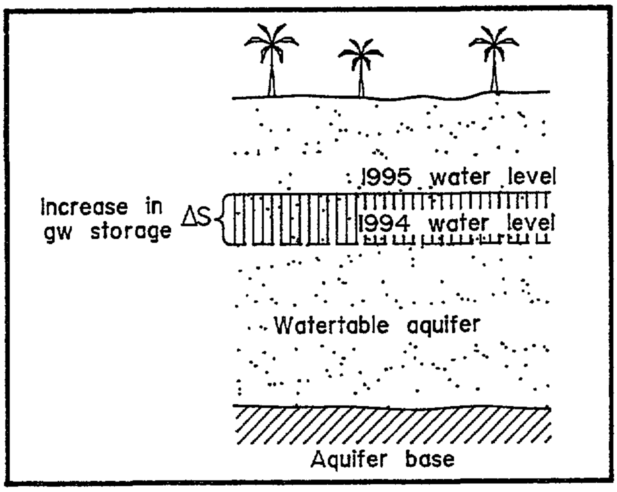

Figure 2 : Increase in groundwater storage for a given year

The observed groundwater level rise rates (cm/yr) for each cell was converted to a groundwater volume (Fig. 2) using the aquifer specific yield assigned to each cell which were estimated using borelog information (Johnson , 1966). This method seems to be more reliable than the conventional 'indirect approach' of estimating inflows and outflows. The water balance figures computed by this 'direct approach' for Cadell, Wakool and Denimein Irrigation Districts are 70,000, 50,000 and 18,000 ML/yr respectively. An example of computation of the waterbalance for Cadell area is shown in Figures 3a (watertable rise rates), 3b (specific yields) and 3c (change in groundwater storage).

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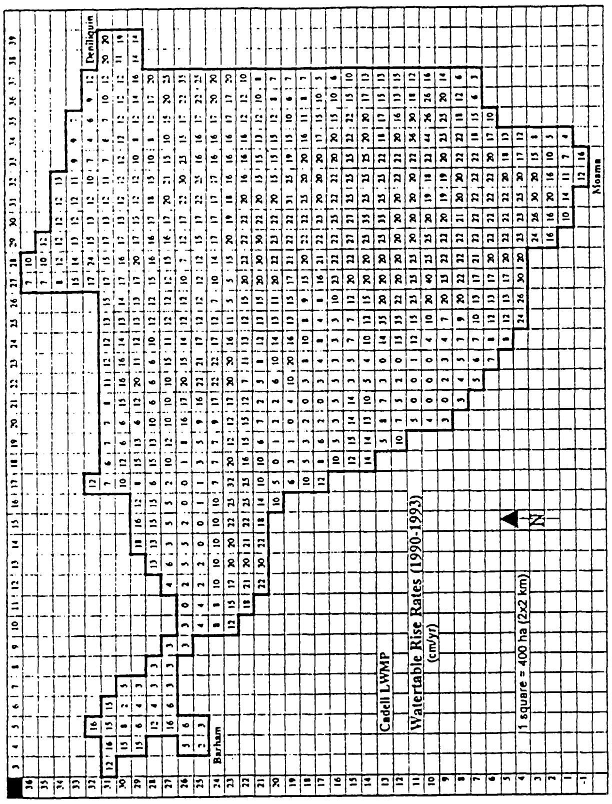

Fig. 3a : 2x2 km grid of the Cadell Area showing watertable rise rates

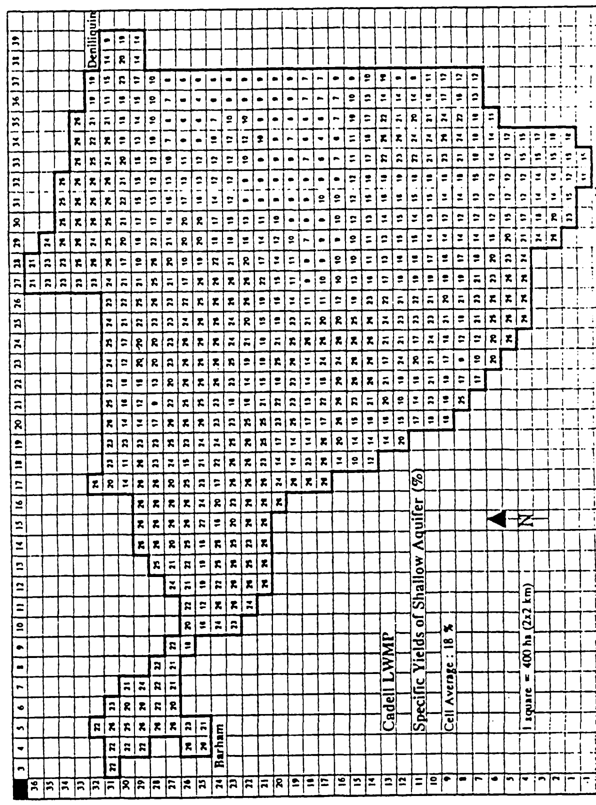

Fig 3b : Specific yield of the shallow aquifer

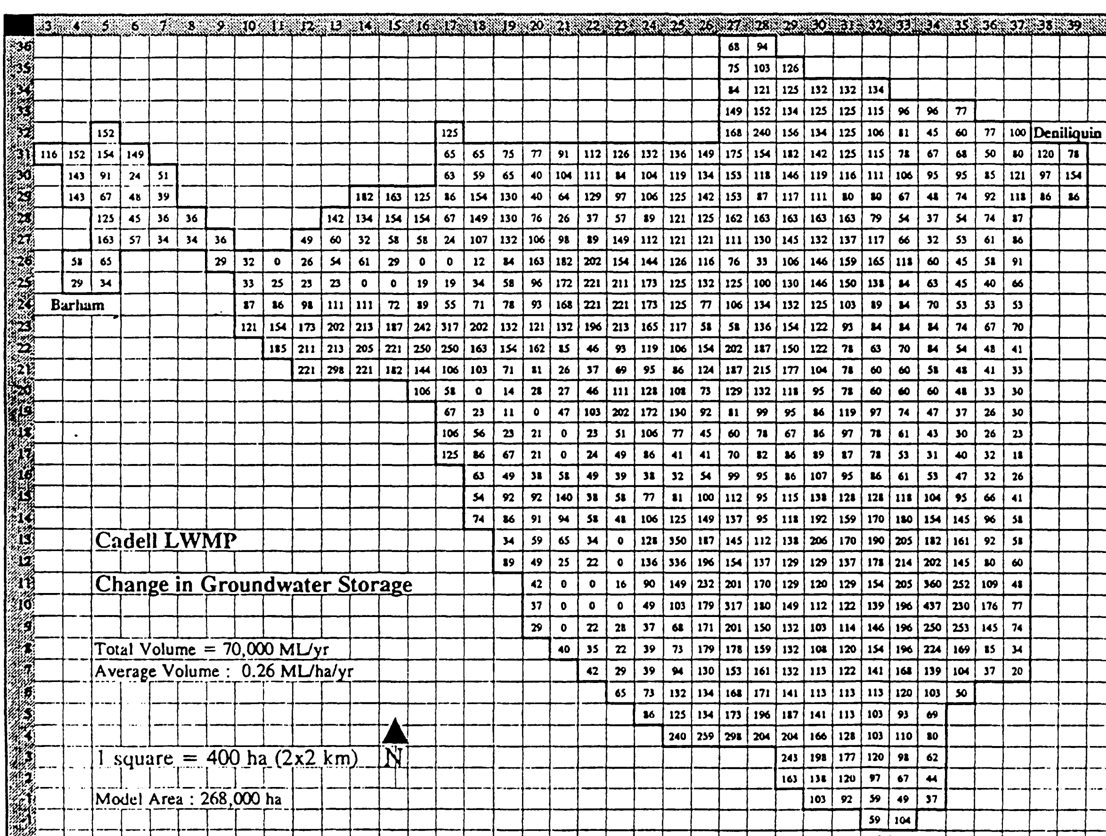

Fig. 3c : 2x2 km grid of the Cadell Area showing the yearly increase in groundwater storage

Air Lift Pumping System

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Using air power to lift water from the ground has been in existence for many centuries. Early Egyptians used bellows to produce compressed air which in turn lifted water out of wells. Today compressors are used to flush out water from tube wells during well development and to obtain samples from wells for analysis. Pumps worked by compressed air have been developed in all sizes to pump liquids and is used mainly in the oil industry.

Airline Pumping System as it is called today and marketed by "Salinity and Catchment Management ®)"Company, differs slightly from the conventional methods. This system uses compressed air which is released into the well via an "Air Pump". This pump is patented by Mr. S.M. West and is not available on the open market. The Department of Land and Water Conservation, Murray Region (formerly Water Resources) has the licence to design and install these pumps. The efficient working of this system will depend on the accurate design of the pipe and jet sizes and the proper air pressure taking into account the drawdown in the well. The quantity of water and the height through which it is lifted, depends on the well yield and the volume of air. A single air line from a compressor can service a multi-well points system spread over a few kilometres. This system is superior to the conventional system in areas of high salinity groundwater or low yielding aquifers.

This system is very versatile and can be used for dewatering, intercepting groundwater, channel seepage control, pumping groundwater for stock and agriculture and so on. The simplicity of the installation and the less expensive components makes this a very promising system in the future. The Air Line System does not require power at the site, instead air is carried through a small diameter poly-pipe to the well point, even if they are several kilometres away. The costs involved in this method of pumping is approximately two thirds of a conventional system using electric pumps.

The Department of Land & Water Conservation has the licence to design, construct and equip airlift pumping systems in the Murray Region.

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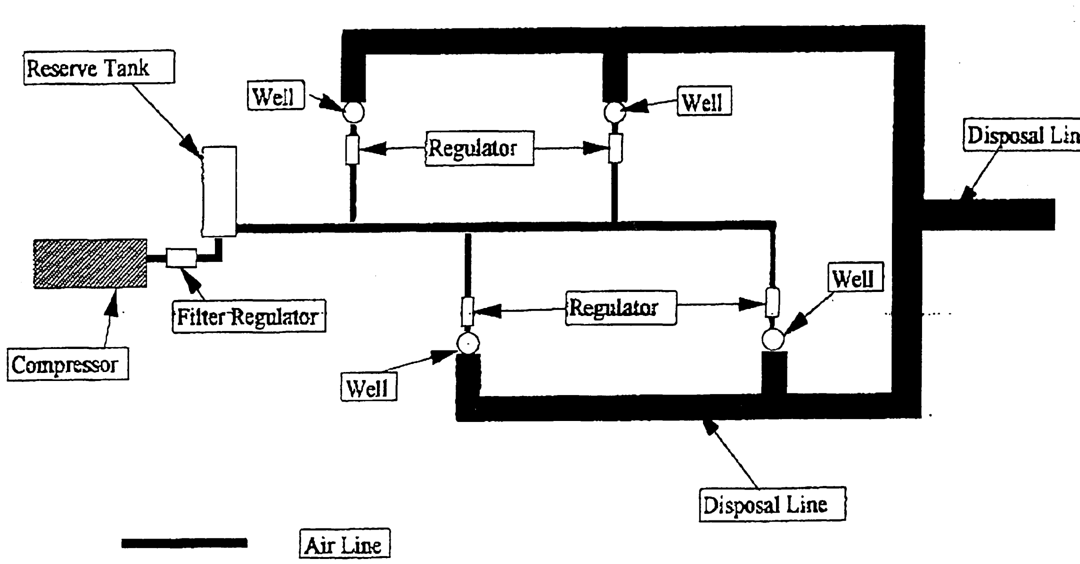
PROJECT COSTING

TYPICAL 4 WELL SITE

PIPES + FITTINGS	$ 4300
COMPRESSOR + FITTINGS	$ 1,500
50 mm TUBE WELLS (4)	$ 2,200
TOTAL	$ 8,000

AIRLINE PUMPING SYSTEM LAYOUT



Sources of Phosphorous in Rivers of the Namoi Basin, New South Wales: Nd-Sr Isotopic and Rare-Earth Element Constraints

Candace E. Martin & Malcolm T. McCulloch (both at: Research School of Earth Sciences, The Australian National University, Canberra ACT 0200)

Introduction

The supply of excess nutrients, in particular phosphorous, is cause of major concern in the Darling River and its tributaries. In an attempt to distinguish between natural versus anthropogenic sources of phosphorus in rivers, we report here the first application of neodymium (Nd) and strontium (Sr) isotopic variations in the Namoi River catchment. The geochemical characteristics of different rock, sediment and soil types can vary tremendously. It is possible to "trace" the sources and determine the processes of formation of Earth surface materials by measurement of naturally occurring elemental and isotopic abundances. These sorts of data are also fundamental inputs to hydrologic models.

The Namoi River has been chosen for this study as its catchment is made up of a number of diverse bedrock types and sediments. Along the Peel River in the vicinity of Chaffey Dam, the dominant bedrock types are Tertiary (less than 65 million years old) basaltic igneous rocks and Devonian-Carboniferous (approximately 300 to 400 million years old) metamorphosed sedimentary rocks. Soils have developed on both rock types.

Results

Isotopic results for the different rock and soil types are shown in Figure 1. There is a large variation in Nd and Sr isotopic ratios, which are inversely correlated. Nd isotopic ratios are usually reported as deviations (in parts per 10,000) from a standard; these values are referred to as ε_{Nd}. Sr isotopic compositions are reported as $^{87}Sr/^{86}Sr$ ratios. Analytical uncertainties are better than ± 0.2 in ε_{Nd} and ± 0.00001 in $^{87}Sr/^{86}Sr$. The Tertiary basalt we analysed has $\varepsilon_{Nd} = +6.2$ and $^{87}Sr/^{86}Sr = 0.70345$, which are expected values for rocks of this type and age. The sedimentary rock has $\varepsilon_{Nd} = +4.1$ and $^{87}Sr/^{86}Sr = 0.70537$. Soils developed on both sedimentary and basaltic rocks have ε_{Nd} which are lower and $^{87}Sr/^{86}Sr$ which are higher than the rocks, with ε_{Nd} of about -2 to +2. For comparison, phosphorite deposits located on Christmas and Nauru Islands, which may be similar to fertilizer phosphate sources, have $\varepsilon_{Nd} < -6$. Sediment sampled at Chaffey Dam has $\varepsilon_{Nd} = +4.1$ and $^{87}Sr/^{86}Sr = 0.70704$, similar to the results obtained for the local bedrock. These results provide constraints on the amount of material which could be derived from sources external to the drainage basin in the vicinity of Chaffey Dam. The cause of the measured isotopic differences between bedrock and soil is as yet undetermined. Ongoing measurements of both solid materials and the dissolved load in rivers will further constrain the sources of the sediments and ultimately phosphorous in the Namoi basin.

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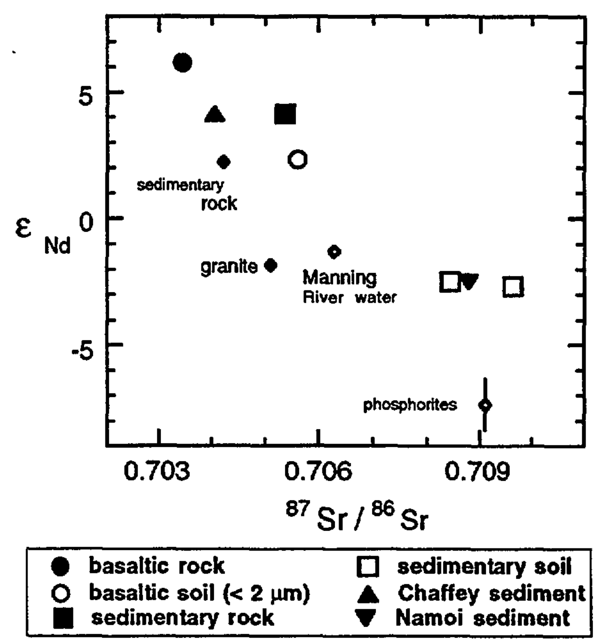

Figure 1. Plot of Nd vs. Sr isotopic variations in rocks, soils and sediments from the Namoi River basin. Rocks and sediments in solid symbols, soils and waters in open symbols. Other results for comparison are Manning River water (Goldstein & Jacobsen, 1987), the range in phosphorites from Nauru and Christmas Islands (H. Veeh, unpublished data) and other analyses of rock types from the Tamworth area (Hensel et al., 1985).

SWAGMAN® Destiny: Where to Watertables and Salinity Levels in Irrigated Areas

Wayne S. Meyer, Doug C. Godwin and Robert J.G. White. CSIRO Division of Water Resources.

SWAGMAN® Destiny

Identifying crop and land management strategies which minimise watertable rise and salinity development which are also economically viable in both the short and long term is a considerable challenge. SWAGMAN® Destiny is a computer simulation model which examines how management may impact future crop yields, groundwater levels and salinisation on a yearly basis for up to 30 years. The model is one dimensional (point scale) and estimates water and salt distributions and balances in a defined soil and crop situation. The program also has a basic economic component which enables the user to assess the economic viability of management options.

Inputs of weather data, crop type, soil type, watertable level, piezometric conditions, irrigation practice and production costs can be modified or added to the program. This allows the user to explore various management options by manipulating the crop and soil scenario and examining the trends over a maximum 30 year period in continuous mode.

In strategic mode the user can select a weather period or length, up to ten years, which remains fixed for each run. The user can then develop five runs or scenarios which are the same except for one variable. The variable can be either the watertable level, watertable EC, soil EC, irrigation water EC, irrigation effectiveness or soil type. The initial conditions at the start of each year are the same for each particular run, therefore each year is independent.

Output from SWAGMAN® Destiny is presented in graphical form which enables the user to easily identify trends. Output can be printed on most printers including Postscript printers.

Results from testing so far

The Destiny model has been validated using data collected from the weighing lysimeter facilities at the CSIRO Division of Water Resources Griffith laboratory. This data included multiple seasons of wheat, soybeans, maize and pasture crops. SWAGMAN® Destiny has also been tested and applied to a set of intensively monitored sites at Cohuna near Kerang, Vic. We are able to show that the model estimates observed fluctuations in the watertables reasonably well. It is also clearly demonstrates weaknesses and gaps in data and we suspect some artefacts induced by our measurement protocol.

Output from the model shows the dramatic interaction between watertable levels, irrigation practice and pasture growth. Clearly successful watertable management is greatly influenced by productive pastures which generate adequate leaf area.

In situations where the watertable is close to the soil surface and the soil profile is very wet, the model demonstrates the difficulty plants have in adapting to a shallow rapidly drying profile. In areas where the watertable is being lowered plant adaptation difficulties may have dire consequences for pasture productivity.

The upper root zone salt balance is closely linked to the EC of the irrigation water applied. Graphical output from the model shows that without net profile drainage upper root zone salt levels will double every 10 years if irrigation water quality and management practices remain the same.

Simulation of the effect of regional groundwater flux on the upper soil profile is still under development. However, from tests so far, the estimated rates of groundwater discharge cause estimated changes in root zone salinity which are much smaller than expected.

Where to now?

SWAGMAN® Destiny is currently in the development and testing stage. It is anticipated the model will continue to develop as it is applied to more areas and as our understanding of watertables and the salinisation process improves. The model has the potential to be a valuable decission support tool for managers of irrigation areas throughout Australia. For more information contact:

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The authors wish to acknowlege the programming efforts of Justin loughlin and Simone Dunn.

Pipe Overloads & Source Detections

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Abstract

The paper outlines an infiltration/inflow (I/I) investigation using a new source detection method involving hydrogeochemical assessment of lithologies surrounding the sewer, in association with flow monitoring within the pipes.

Correlation of hydrogeochemical and flow data enables source detection of leaking sewers at a significantly lower cost than conventional CCTV methods.

The method isolates branch lines with significant I/I by correlating sewer chemistry with wet and dry period flows. After data collation, each branch is graded in relation to the amount of groundwater infiltration into the sewer.

This source detection method can result in large savings in sewer maintenance, and enables the cost effective use of limited resources to achieve significant reductions in the volume of water requiring passage and treatment in a sewer system.

Stream Salinity Monitoring in the Goulburn Catchment

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Introduction

This poster paper describes the availability and reasons for collection of continuously monitored stream flow and salinity data in the Goulburn catchment, as part of the development and implementation of the Shepparton Dryland Irrigation Regions Land Water Salinity Management Plans.

The Rural Water Corporation (RWC) has been continuously monitoring stream flow and salinity in eleven sub-catchments and four sites in the main stem of the Goulburn River. Data will assist assessment of the effectiveness of implementation programs on dryland salinity problems, and quantify the long term trends in stream salinity, salt export from the region, and impacts on downstream water users.

Rising groundwater levels and salt affected dryland are resulting in a deterioration of stream water quality. This can have an effect on the stream's environment and on downstream water users. It is therefore important to understand how stream salinities are changing in response to rising groundwater levels and expanding areas of salinised land. Moreover there is also a clear need to develop a better understanding of processes affecting stream salinity and salt loads.

In addition surface water monitoring also provides valuable information to assess the effectiveness of individual salinity management plans (SMPs) in the Goulburn basin. Monitoring and evaluation are integral to the process of "learning to do things better". Monitoring results can be used to understand the impact of Plan implementation, in particular control of groundwater level.

Purpose of the Goulburn Stream Salinity Monitoring Project

- Monitor and assess long term changes in stream salinity and salt load.
- Accurately determine salt loads emanating from typical and problem area catchments.
- Define the processes affecting stream salinity and salt loads.
- Measure the effects of dryland salinity reduction measures and land use changes on stream salinity and salt loads. Provide feedback for revision of implementation strategies.
- Assess the effect of stream salinity on downstream water quality and water users, including the River Murray.
- Estimate future stream salinities in the light of projected changes in land use and the status of the salinity problem.

Glossary

Flow is recorded by continuous monitoring. This is performed by data loggers which are programmed to record stage and salinity at fixed time intervals, the stage is then converted to flow using the rating table for that station.

Salinity is the concentration of dissolved salts, or total dissolved salts (TDS, mg/L). It is measured in electrical conductivity (EC, µs/cm) and standardised to the value at 25 degrees Celsius. By multiplying EC by 0.6 a reasonable estimate of the TDS can be obtained.

Salt loads are a measure of the salt movement, and can be expressed in tonnes per day or tonnes per year and are calculated by multiplying the flow by the salinity. For example, the flow in ML/day can be multiplied by salinity in EC units and then by a factor of 0.0006 to convert the result to tonnes per day. The salt loads are therefore a reflection of the salinity and flow.

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Groundwater Irrigation Management in Nepal - Community Participation

Shree Krishna Shrestha

Project Chief, Groundwater Resources Development, Department of Irrigation, Kathmandu, Nepal.

The Terai Plain is characterised by numerous rivers and canals and is Nepal's main producer of food grains. As a consequence of seasonally high precipitation and deep alluvial sediments, which host multiple layers of aquifers, the Terai is rich in groundwater resources. Development of Terai groundwater is still in its initial phase with only a small fraction of the total developable resource so far extracted. Extraction/recharge ratios remain quite low (less than 10% in most parts of the Terai).

New irrigation policies emphasize sustainable utilization of irrigation water and a demand-driven approach to irrigation development. Farmers are encouraged to submit requests for tubewell facilities and water-user groups are involved in all stages of irrigation development. Government policy supports investment through capital subsidies as high as 85% for a community tube well.

The water-user groups assume full responsibility for operations and maintenance after completion of the system. Most of the shallow irrigation wells are driven by diesel pumps; some large scale groundwater irrigation project areas do have electrified pumping systems. Thus far, the operation of the systems by user groups is quite encouraging, though both management capability and sustainability are yet to be proven.

Herbicide and Pesticide Transport in the Soils of the Ardmona and Kyabram Irrigation Districts, Victoria.

David Wenig
School of Earth Sciences
University of Melbourne

Through NRMS funding provided by the Murray Darling Basin Commission, work is being carried out to investigate herbicide, pesticide and salt transport in the soils and the shallow sand aquifers of the Ardmona and Kyabram irrigation districts.

This work is investigating differences that varying land use practices may have on water quality in the region, particularly the use of a series of dewatering bores which are used for water table control. From these, extracted water is being reused by the landholders for irrigation purposes.

The application of pesticides and herbicides as a means of land management in orchard and grazing practices is of primary interest in this study. Preliminary results indicate that triazines and an organophosphorous pesticide are present in groundwater sampled. The same results indicate that organochlorine pesticide residues from historical use are also present in the groundwater.

Factors influencing the organophosphorous pesticide's transport in the unsaturated zone are being investigated, with characterisation of both chemical and physical soil characteristics. Ultimately, adsorption isotherms and dispersion characteristics will be determined by batch and undisturbed column experiments.

Both undisturbed cores and disturbed soil samples were taken at the Ardmona site during observation bore nest construction. These have allowed the characterisation of chemical (pH, electrical conductivity , chloride and organic carbon) and physical (soil texture, bulk density, porosity, matrix potential) properties of the unsaturated zone.

Results for 1:5 soil:water extracts, have shown that soils from the surface to O.5 m range between pH 5 and 7 while from 0.5m to the water table the pH generally ranges between 7 and 8.

EC values ranging between 0.15 to 1 dS m -1 per gram of soil at two sites were determined. At the other two sites, higher values of between 1 and 4.5 dS m ' per gram of soil were found.

The soil textures have been found to be between sandy clay loams and clay at three sites, while the fourth site has loamy sand to sandy clay loams, as defined by the USDA system. Particle sizes were defined according to the ISSS classification system

Preliminary results indicate that despite low hydraulic conductivity and the generally clayey nature of the unsaturated zone, pesticide transport to the water table occurs. This may be as a result of preferential flow paths, macroporosity effects, the existence of earthen channels which transport the aquifer water and relic streams which feature in the region. These are all thought to contribute to the transport of agrochemicals into the groundwater.

Modelling of the unsaturated zone in conjunction with this project is being carried out by David Lockington of the University of Queensland.

Diffuse Groundwater Pollution Hazard in Blue Lake Country

Mardi Whiting - Landcare Extension Officer, Department of Environment and Natural Resources
Kevin Mott - Water Quality Officer, Department of Environment and Natural Resources

Summary

The population of the South East lives above its drinking supply. The water supply for the Blue Lake Country, is drawn from the unconfined Gambier limestone aquifer, which feeds the Blue Lake. Due to the porosity of this limestone the groundwater is susceptible to contamination through infiltration. This paper outlines some activities the community is undertaking to minimise groundwater contamination.

Introduction

For the purpose of this paper, Blue Lake Country refers to the lower South East of South Australia, an area which is dependent on groundwater as its sole water source. The Blue Lake itself is located in Mount Gambier, in the south east corner of South Australia. The area around the Blue Lake has a population of 40000, all of whom live and work above their water supply.

Groundwater is contained in confined and unconfined aquifers. The majority of domestic and industrial water is drawn from the unconfined Gambier limestone aquifer. This is a highly permeable limestone which readily transmits pollutants from the surface into the aquifer. Caves and other karst features, which are common throughout the area, can provide a more direct route for contaminants to enter the unconfined aquifer.

Background

Groundwater quality is a major for the Blue Lake Country. Any deterioration in the quality of the groundwater will affect all people in the area, domestically, industrially and agriculturally. For this reason, the quality of groundwater needs to be maintained to ensure the future of primary industries in the Blue Lake Country.

This poster paper portrays active community involvement to ensure the future of the Blue Lake and therefore our water supply. The Dairy Industry is on active group who is working to effectively manage the dairy shed effluent to reduce nitrate contamination of the groundwater.

Potential sources of groundwater pollution

Our main concern with regard to groundwater quality is the level of nitrate. Excessive levels of nitrate in the groundwater affect its potability. Agricultural activities, namely fertiliser application and stocking rates, are a diffuse source of groundwater pollution. When the nitrate held in the soil profile is in excess of that required by vegetation, it is leached through the soil profile into the groundwater. Diffuse sources contribute about 89% of the total aquifer nitrogen load. (Dillon, 1977).

Stormwater run-off, chemical spills, industrial waste, and poorly managed waste disposal also contribute to groundwater contamination.

Community involvement

Previous attempts to control pollution using solely legislative measures, have had limited success. Community awareness and participation is now the main thrust with legislative measures used as a last resort.

The Dairy industry, Landcare, and school groups have all been involved in raising community awareness and addressing the issue of groundwater quality.

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