MURRAY BASIN 88

GEOLOGY, GROUNDWATER AND SALINITY MANAGEMENT

CONFERENCE SUMMARY REPORT

Sponsored by the Groundwater Working Group of the
Murray-Darling Basin Ministerial Council and
The Australian Geoscience Council

Bureau of Mineral Resources, Geology and Geophysics
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Division of Continental Geology Groundwater Series No. 16

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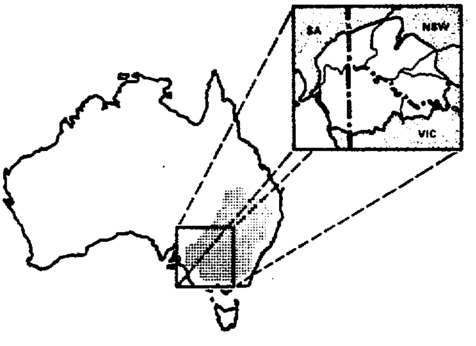

MURRAY BASIN 88
GEOLOGY, GROUNDWATER AND SALINITY MANAGEMENT

(CANBERRA, 23-26 MAY 1988)

CONFERENCE SUMMARY REPORT

SPONSORED BY THE GROUNDWATER WORKING GROUP OF THE
MURRAY-DARLING BASIN MINISTERIAL COUNCIL
&
THE AUSTRALIAN GEOSCIENCE COUNCIL

MURRAY BASIN 88 CONFERENCE
GEOLOGY, GROUNDWATER AND SALINITY MANAGEMENT
CANBERRA 23-26 MAY, 1988

SUMMARY REPORT compiled by

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BMR, Division of Continental Geology
on behalf of the Groundwater Working Group of the
Murray-Darling Basin Ministerial Council

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Sponsored by: Groundwater Working Group of the Murray Darling Basin Ministerial Council and the Australian Geoscience Council.

FOREWORD

Groundwater is one of Australia's most important natural resources, with large areas of the continent wholly or partly dependent on it for its water supplies. It is likely that agricultural, industrial and domestic use of groundwater will increase greatly in the future. Groundwater is also a source of some of the nation's most serious environmental problems, which have arisen because of modification of groundwater systems. Nowhere is this more evident than in the Murray Basin where a combination of groundwater-related land salinisation, associated soil erosion, and water logging is resulting in great cost to individual farmers and enormous cost to the community in general. The dual problems of salinisation and rising water tables are also having an adverse impact on the natural environment.

In recognition of the seriousness of these problems, the Commonwealth and the States have agreed to work closely together through the Murray-Darling Basin Ministerial Council and the recently established Murray-Darling Basin Commission. This need to work together in such areas is particularly critical for groundwater studies and it is therefore appropriate that the Groundwater Working Group is the first such group of the Murray-Darling Basin Commission to be established. The underlying philosophy adopted by this Group is to study the hydrogeology of the Basin unencumbered by State Boundaries

The Commonwealth has supported this approach through the direct involvement of BMR and the provision of funds through the Federal Water Resources Assistance Program (FWRAP) and the Australian Water Research Advisory Committee (AWRAC). At the same time, State Governments have funded many groundwater studies of their own.

Although co-operative Commonwealth-State groundwater studies are still at a relatively early stage there can be no doubt about their vital importance to the development of an overall salinity strategy for the basin. Already these studies have shown that there can be no "quick-fix" to the problems of the Murray Basin. Nor is there likely to be a single solution to the difficulties. What we can be certain of is that all considerations of the problems of the basin will have to include the fullest consideration of groundwater. This can only be done if we have a comprehensive understanding of groundwater throughout the Basin, not only because it is the source of many of the problems but because it may also provide some of the solutions.

As Chairman of the Murray-Darling Basin Ministerial Council I am particularly conscious of the need to communicate this new understanding of groundwater in the Murray Basin not just to the geoscientists, agriculturalists, engineers, environmentalists, and managers but to the community in general, if comprehensive and acceptable management options are to be developed for salinity and water logging problems. Therefore "Murray Basin 88 – Geology, Groundwater and Salinity Management" represents a milestone in raising community awareness of the importance of groundwater as a problem and yet a vital resource that must be managed carefully for the good of the community at large. I am sure that this volume will contribute to that aim and I commend it to all those concerned with the Murray Basin and its future.

Peter Cook
Minister for Resources
Chairman, Murray-Darling Basin Ministerial Council

MURRAY BASIN 88 CONFERENCE
GEOLOGY,GROUNDWATER AND SALINITY MANAGEMENT

(CANBERRA, 23-26 MAY 1988)

SUMMARY STATEMENT

The conference was aimed at identifying the nature and extent of groundwater-related problems of salinisation in the Murray Basin and canvassing issues concerned with the formulation of resource management options. A total of fifty papers by 92 authors were presented.

- The conference reinforced the fact that salinity problems in the Murray Basin are strongly groundwater-related. It revealed that many of the basic groundwater processes which result in salinity problems are reasonably well understood, but many aspects remain to be investigated. These include:
  - the timescales of salinisation and groundwater movement,
  - the mechanisms which control recharge and discharge.
- The conference highlighted the fact that recharge of groundwater systems, due to clearance of natural vegetation and leakage from irrigation areas, is a major cause of rising groundwater levels and hence salinity problems. Any further broadscale clearance should be discouraged. Revegetation is effective in solving local salinity problems, but broadscale revegetation is of uncertain economic or practical value as a salinity management tool. The groundwater systems must be fully understood before embarking on major revegetation programs. This will require the development of regional and basin-wide groundwater models.
- Broadscale resource management options for the Murray Basin must be developed, with the fullest consideration being given to hydrogeology and the role of groundwater in causing, and potentially in ameliorating salinity problems.
- The salinity regime of the Murray River is influenced by saline groundwater inflows. This inflow will increase with time. It is now clearly recognised that to manage the River effectively we now need to manage the land more effectively.
- Groundwater levels must be lowered in many parts of the basin – the alternative is reduced agricultural productivity and continuing environmental destruction. A variety of strategies involving reductions in recharge and/or lowering of the water table by pumping and other methods are currently being evaluated/implemented. The underlying problem in most salinity management strategies is the disposal of saline water in an economically and environmentally acceptable manner.
- The collection of data and investigation of systems/processes which cause salinisation needs to continue in key areas, but the emphasis of many current studies has now shifted to investigation of options for salinity management. Future emphasis should be placed on the development of predictive tools suitable for integrated management (e.g. hydrogeological maps, groundwater modelling and monitoring).
- High priority should be given to hydrogeological studies that will provide the basis for the development of an effective saline water disposal strategy.
- The joint use of surface water and groundwater requires investigation – involving a comprehensive assessment of the fresh groundwater resources of the basin.
- The development of community education programs is essential in order to raise the level of public awareness and provide support for government action.
- There is a need for co-ordination of groundwater actions by Commonwealth and State authorities, because groundwater systems operate basin-wide.
- Effective management of the Murray Basin depends on the development of appropriate institutional and consultative mechanisms, as well as a sound knowledge of the physical processes involved. These must be brought together at the earliest opportunity to avoid irreversible land degradation in the Murray Basin.

CONTENTS

CONFERENCE SUMMARY REPORT

INTRODUCTION

A major conference titled 'Murray Basin 88 - Geology, Groundwater and Salinity Management' was held in Canberra during May 1988. The conference was aimed at identifying the nature and extent of groundwater-related problems in the Murray Basin and canvassing issues in Murray Basin resource management. A particular aim of the Conference was to communicate the results of recent groundwater-related research to agriculturalists, soil scientists, engineers, environmentalists, managers and others interested in salinisation in the Murray Basin.

Proceedings were divided into a two day Overview Session followed by a two day Technical Session. The Overview Session was held at the Australian Academy of Science and consisted of a series of seventeen invited papers by a total of twenty seven authors, and addressed a wide range of topics chosen to provide broad perspectives of the salinity problems of the Murray Basin. Papers were grouped into four sessions, each of which was followed by a panel discussion. The Technical Session was held at University House, ANU, and provided a less formal forum for the presentation of results of groundwater-related research, including ongoing investigations. Thirty three papers by a total of sixty five authors were presented.

A total of one hundred and seventy registrants attended the Conference.

The Conference was sponsored by the:

- Groundwater Working Group of the Murray-Darling Basin Commission
- Australian Geoscience Council

BACKGROUND

Murray Basin

The Murray Basin contains some of the most important agricultural land in Australia and currently generates several billion dollars in agricultural income. It is also an area of great natural beauty – a special place for many Australians. Unfortunately clearance of natural vegetation and irrigation have been accompanied by both rising groundwater-levels and discharge of saline waters. In order to develop salinity management strategies an understanding of the systems in which these salinity problems have developed is essential. In particular, it is fundamental that the relationships between aquifer geometry, recharge, groundwater flow and distribution of surface discharge features be fully understood.

Geology

The Murray Basin forms a closed groundwater basin which consists of a thin veneer (200-600m) of sedimentary rocks containing a number of aquifer systems with limited storage capacity. A knowledge of the basin-wide subsurface stratigraphic framework is an essential prerequisite to understanding the factors controlling groundwater flow. Saline surface discharges can be related to aquifer thinning, either over basement structures or due to lateral changes in sediment type. The surface geology of the Basin provides a record of environmental change in the Basin, reflecting past fluctuations in climate and sea-level as well as interactions between surface geomorphic processes and fluctuating groundwater tables. Fossil (currently inactive) saline discharge sites can be recognised and are commonly areas where there is a particular risk of future salinity problems. The surface geology therefore helps us to define not only those changes which are 'natural' and those which are man-induced but also gives us insights into what the future may hold for the Basin as groundwater levels continue to rise. The surface geologic record shows us that at times the Basin has been even more saline than it is at the present day.

Groundwater

Groundwater is extensively used by irrigators and graziers and the future viability of many of the agricultural communities in the Murray Basin region is increasingly dependent on the controlled development and management of the water resources of the Basin. Rising saline groundwater has resulted in extensive areas of formerly productive agricultural land being turned into saline wastelands and trees have been killed by waterlogging of their roots. In some areas orchards have been damaged by the use of saline river water for irrigation. In addition, the quality of drinking water has deteriorated for many towns and cities (including Adelaide) which depend on water from the River Murray for their supplies. Against this background the Commonwealth and the States of New South Wales, Victoria and South Australia have been placing greater emphasis on the need to develop a better understanding of the groundwater regime of the Murray Basin.

Salinity Management

Salinity in the Murray Basin is Australia's most critical environmental problem. Costs of the order of $100 million per annum are incurred through urban and river salinity costs and the loss of agricultural production in the Basin. Some of these effects are cumulative and essentially irreversible. Consequently it is a matter of urgency to identify and understand the causes of salinity and develop a strategy for salinity management. As most salinity problems in the Murray Basin are related to groundwater it follows that salinity management and groundwater management must be pursued jointly. Salinity management must be pursued in a way that ensures the continuation of productive agricultural land and maintains river salinity at an acceptable level. It must also be done in a way which allows for the sustained and efficient use of groundwater and does not jeopardize the basin's groundwater resources in the shallow or deep aquifer systems. A full understanding of the groundwater mechanisms involved in salinisation will enable us to identify those areas under greatest threat from future increases in salinity, establish priorities and develop salinity management options. Inevitably there will be not one but several strategies brought to bear on the range of salinity problems within the Basin, but there can be little doubt that groundwater management will be pivotal to most if not all of them.

PUBLICATIONS AND PUBLICITY

A volume of Extended Abstracts was published in the BMR Division of Continental Geology Groundwater Series No.12 for distribution at the Conference (Bureau of Mineral Resources, Record 1988/7). A total of twenty papers presented at the Conference are currently being prepared for publication in a Special Murray Basin 88 issue of the BMR Journal of Australian Geology and Geophysics. Immediately prior to, and during, the conference a number of press releases were distributed to the media, and articles were printed in several newspapers. A number of radio and television interviews were given during the course of the Conference.

REFERENCE

Brown, C.M. & Evans, W.R., 1988 – Murray Basin 88: Abstracts, Geology, Groundwater and Salinity Management Conference, Canberra, May 1988. *Division of Continental Geology, Groundwater Series*, 12. *Bureau of Mineral Resources, Australia, Record* 1988/7.

CONCLUSIONS

Salinisation – investigation of occurrence and process

- The landscapes of the Murray Basin contain a record of Pleistocene episodes of natural salinisation over the past 0.5 million years. In just 100 years of intensive agriculture and rising groundwater levels we have caused the landscapes to revert to conditions more typical of those past Pleistocene periods. The lessons from the past, as recorded in the landscape must guide us into the future.

- Surface geological mapping of 'fossil' groundwater discharge features in the landscape can help to identify those 'natural' areas where there is a particular risk of future salinity problems as groundwater levels continue to rise.
- Some of the reasons why salinisation has developed lie in the subsurface geology, and a knowledge of the evolution of the subsurface structural and stratigraphic architecture of the basin over the past 60 Ma provides insights into why salinity problems have developed, and why specific 'natural' sites are particularly susceptible to salinisation. Groundwaters and salts are essentially trapped within a closed groundwater basin with thin sediments and limited groundwater storage capacity.
- Most of the salinity problems in the Murray Basin are groundwater related. To be able to adequately manage these problems, in both the long and short term, it is absolutely essential that the groundwater processes in the Murray are understood.
- If the observed pressure rises were to continue at present rates, it can be predicted that the entire Riverine Plain in Victoria – dryland and irrigation areas alike – will become a zone of regional groundwater discharge within 100 years. Similarly, in the dryland highland areas, and in the Mallee, under present land-use techniques the expansion in land and stream salinisation is inevitable and essentially irreversible. The ultimate effects will depend on the extent to which remedial action can be taken.
- Preliminary work suggests that in favourable circumstances, ^{36}Cl measurements can be used to distinguish between different possible sources of additional salt, and between the addition of salt versus evaporation or ion infiltration as a mechanism for increasing salinity.

Salinisation – discharge of saline waters to river systems

- A study of the aquifers flanking the River Murray in the Victorian Mallee indicated that for part of the year the River recharges the aquifer systems along its banks. On an annual basis, in most areas however, the situation is either near neutral or the aquifers have a net discharge to the river. There are exceptions, near Nyah for example, where the river recharges the aquifers for the entire year. An opposite example occurs near Merbein where groundwater discharges for the entire year into the river, hence, the need for the Mildura-Merbein Groundwater Interception Scheme.
- Saline groundwater intrusions are occurring in an extensive area of the Wimmera River, producing stable and long-lived vertical density gradients and stratification in pools in the bottom of the river bed. The major environmental problem associated with the groundwater intrusions arise not through the increased salinity itself, as most fish and other aquatic organisms can tolerate moderate salinities, but through the stable density stratifications produced by the conductivity gradients and subsequent deoxygenation of the saline pools.
- Investigations in the Woolpunda area S.A. have shown that the deepest sections of the River Murray are the focus for groundwater discharge to the river, and that plumes of salinised water flow along the bottom of the river until vertical mixing is forced by a shallowing of the river. The mechanism which causes the deep sections to be a focus for groundwater discharge is the density contrast between river water and groundwater. This mechanism in no way diminishes the efficiency of the Woolpunda Groundwater Interception Scheme.
- Preliminary sampling and testing indicates that some flocculation of clays in the River Murray seems to be occurring even at the low salinities presently experienced in the Murray. Low salinities also increase settling rates in a still column of water in the laboratory. More evidence is needed before the pattern of erosion and deposition in the Middle Murray can be attributed to rising salinities.

Groundwater resources

- Information about the volume of groundwater usage is incomplete, but only about half of the groundwater notionally available under allocations is actually used.
- Emerging groundwater problems include – the degradation of quality through

salt build-up and localised depletion of the resource.

Groundwater modelling

- No groundwater modelling simulations have so far been reported that use a stochastic approach. In view of the data uncertainties that still exist in the Basin, such an approach may be desirable
- Computer simulations of solute transport in a study area in the Ardmona-Toolamba area of the Victorian Riverine Plain indicate that within the study area salt transport is dominated by the vertical flow component. The simulations confirm that mass transport in groundwater is an extremely slow process.

Salinity management strategies — institutional and political

- Effective management of the Murray Darling Basin depends as much on institutional and political mechanisms as on sound technical knowledge of physical processes. We are entering a critical era of resource management where failure to act in time may mean losing the option of arresting and reversing the trend of degradation, and we are left with the sobering thought that decisions by this generation may determine the fate of the Basin irreversibly.
- An integrated approach to soil, water and vegetation management, strongly supported by land use planning at all levels, requires priority actions if salinity of the Basin and its land and water resources are not to become the environmental disaster of the third century of settlement in Australia.

Salinity management strategies — technical options

- Groundwater levels must be lowered — the alternative is the acceptance of permanent high water tables, saline areas, reduced agricultural productivity, and continuing environmental destruction.
- Pumping of both high and low salinity groundwater for distribution to existing users, dilution or disposal, is a potential method for the partial control of rising water tables and associated land management problems.
- To deal with salinity problems in irrigation areas there are only two basic sets of options available — to prevent water getting to the watertable, or to remove water from the watertable. A substantial proportion of land salinisation in irrigation areas of the Riverine Plains can be controlled by sub-surface drainage, the constraint being that salt disposal problems are kept within manageable limits. The principal technique is likely to be groundwater pumping from the shallow aquifer systems.
- The challenge in the future is to carry out the detailed hydrogeological assessments required in order to better quantify both the impact of rising water tables and the effects of the various proposed remedial actions.
- Groundwater re-use is an option for reduction in recharge to the aquifer systems, but eventually as the practice becomes more widely adopted, yield reductions are likely to increase over areas of higher groundwater salinities if current management practices for perennial pasture continue. Greater use of more salt tolerant species such as lucerne will have to be considered.
- Broadscale revegetation is of uncertain economic or practical value as a groundwater and salinity management tool; its use should be evaluated in terms of local conditions. On the other hand, vegetation management should be more widely interpreted to include all vegetation which may be utilised to effectively and efficiently control groundwater and salinity.

Salinity management strategies — options for disposal of saline waters

- The bottom line of almost all salinity and land management strategies is disposal. Outfall to the River Murray under controlled conditions and well sited evaporation basins should be encouraged; conversely the vast majority of shallow disposal bores have an unacceptable adverse impact on the River Murray and should be phased out. Pipelines/channels to the sea are uneconomic at the present.
- The Wakool/Tullakool Sub Surface Drainage Scheme has generated a benefit in

crop production of $750,000 over the period 1981-1987. From a hydrologic viewpoint the scheme has been successful. However the scheme has operation and maintenance costs of $300,000/year. Therefore a number of management strategies are being examined to minimise the cost, while at the same time maximising the area of land protected.

Salinity management strategies – community education

- A pilot community education program in the Goulburn Broken River region has played a major role in catalysing community response, in particular, facilitating the development of a co-operative group approach to salinity control. That is, where farmers join together with the aid of extension officers and the support of groups such as Conservation volunteers and the local Apex clubs to act to control salinity. The actions of such 'land care groups' has then been used to mobilize the media to facilitate public awareness and support for the government's action.

KEY ELEMENTS FOR FUTURE ACTION ARISING FROM THE CONFERENCE

- Broadscale management options for the Murray Basin must be developed, with the fullest consideration being given to the hydrogeology of the Basin, and the vital role of groundwater both in causing and potentially ameliorating salinity problems.
- Detailed hydrogeological assessments are required in order to better quantify the impact of both rising waterlevels and proposed remedial actions.
- Research should be conducted into the mechanisms controlling recharge to the unconfined aquifers of the entire Murray Basin and hence into ways of estimating changes in recharge.
- Research is required to investigate the timescales of salinisation and groundwater movement as these are not yet adequately understood.
- High priority should be given to the development of an effective saline water disposal strategy, covering the full range of disposal options, for the entire Murray Basin.
- More consideration should be given to management of the naturally occurring discharge areas for possible significant long term benefits.
- Evaporation basins should be reviewed, and if poorly sited, be phased out if considered to have unacceptable effects. Well sited evaporation basins should be encouraged.
- State authorities should adopt an integrated approach towards groundwater resource management, and should develop common databases which facilitate the exchange of data both within and between States.
- Future decision making should include the effective integration of surface water and groundwater resources.
- Comprehensive data on groundwater usage is surprisingly lacking and should be collected and collated as an aid to resource management.
- State authorities should continue the collection and analysis of groundwater data, including the monitoring of groundwater and salinity levels, and expansion of networks of observation bores. The groundwater data should be used to develop numerical modelling of groundwater systems and geochemical budgets.
- Future numerical modelling of groundwater in the Murray Basin should include solute transport simulation and surface water interaction models. It may also be desirable to use a stochastic approach to simulation in some circumstances to quantify resulting uncertainties in the model generated results. Both local and basin-wide predictive models should be developed.
- Further work should be undertaken to determine the extent of saline groundwater inflows to saline pools in rivers and streams.
- Impacts of large-scale vegetation clearance must be seen as a cause of rising

water tables and as an aggravation of salinity problems.

- Dryland agricultural practice should be modified, where practical, to maximise utilisation of soil moisture.
- Further research is required to improve plant-water use by existing species.
- The development of community education programs is viewed as essential in order to raise the level of public awareness and provide support for government action.
- The groundwater systems which result in salinisation operate basin-wide and in order to solve the salinity problem there is a definite need for future co-ordination of groundwater actions by Commonwealth and State authorities.

SUMMARY OF PRESENTATIONS

OVERVIEW SESSION PROGRAM

The Overview Session consisted of a series of invited papers which addressed a wide range of topics chosen to provide broad perspectives of the salinity problems of the Murray Basin. Papers were grouped into four sessions, each of which was followed by a panel discussion. A total of 17 papers were presented at the Overview Session.

I Setting the Scene

1. *Environmental and salinity history of the Murray Basin in the last 500,000 years*

J.M. Bowler
Museum of Victoria

The landscape of the Murray Basin contains a record of past episodes of natural salinity changes that were unknown to early European developers. Only now are we beginning to understand how the natural landscape of the Murray Basin has, in the past 500,000 years, been subjected to major episodes of salinisation, so severe as to make the present crisis appear more like a minor perturbation. For example, during the most intense phase of the last Ice Age, about 25-16,000 years ago in the Pleistocene, accelerated winds, hot summers and low rainfall, combined to produce episodes of intense droughts. Lakes became saline. The Aboriginal occupants, already occupying the Murray Basin for more than 10,000 years, saw their food resources turn into saline wastelands. Strong summer winds blew clouds of salt-laden dust; dunes spread across the face of the land.

About 15,000 years ago, the harsh glacial climates improved; trees returned to the landscape resulting in the gradual drawdown of previously high watertables, and for the next 10,000 years a general vegetation-groundwater equilibrium was sustained. No evidence is observed of major saline-erosional events.

Today, the situation has drastically changed. In just 100 years of intensive agriculture, the landscape has responded by reverting to conditions more typical of Pleistocene times. But now the watertable rise is a direct function of human rather than natural climatic changes. To reverse these trends requires even closer examination of just how the natural system operates. In this context, the lessons from the past must guide us into the future.

2. *Overview of the geology of the Murray Basin*

C.M. Brown
Bureau of Mineral Resources, Division of Continental Geology

Some of the reasons why salinisation has developed in the Murray Basin lie in the subsurface geology, and a knowledge of the evolution of the subsurface structural and stratigraphic architecture of the basin over the past 60 Ma provides insights into why salinity problems have developed, and why specific 'natural' sites are particularly susceptible to salinisation. The basin extends over 300,000 km^2 of inland southeast Australia, is almost entirely flanked by subdued mountain ranges, and forms a low-lying, saucer-shaped basin of internal surface and groundwater drainage. Groundwaters trapped within the basin can only escape by discharge to the River Murray or to the landscape, where evapotranspiration results in the accumulation of salts. Despite the great extent of the basin, it consists of only 200-600m of Cainozoic sediments, and therefore groundwater storage capacity is limited, and groundwater levels have risen rapidly during the past 100 years following the clearance of natural vegetation.

At the surface of the basin, active and 'fossil' (currently inactive) groundwater discharge complexes can be identified by a characteristic assemblage of sediments and landforms. In the subsurface, a basin-wide stratigraphic framework has been established by documenting the regional distribution, geometry and depositional environments of the Tertiary stratigraphic units and aquifer systems of the basin. The development of 'natural' groundwater discharge sites at the surface of the basin can be related to flow disruption, local high pressures and upward leakage created at permeability barriers formed where the underlying aquifer systems are significantly thinned by concealed basement barriers and/or by lateral changes in lithology.

3. *Overview of the hydrogeology of the Murray Basin*

W.R. Evans & J.R. Kellett (presented by W.R. Evans)
Bureau of Mineral Resources, Division of Continental Geology

The majority of the salinity problems of the Murray-Darling Basin are groundwater related. To be able to adequately manage these problems, in both the long and short term, it is necessary – if not mandatory – that the groundwater processes in the Murray-Darling Basin are understood. The Murray Basin is a closed groundwater basin consisting of a thin veneer (200-600 m. thick) of Cainozoic unconsolidated sediments and sedimentary rocks containing a number of regional aquifer systems: the *Renmark Group aquifer*; the *Murray Group aquifer*; the *Pliocene Sands aquifer*; and *Shepparton Formation aquifer*.

Recharge and Discharge: The deeper confined aquifers have recharge zones generally around the basin margins; the shallower unconfined aquifers receive water from both point source zones at the Basin margins and diffuse zones over the majority of the aquifer's surface. Due to clearance of natural vegetation, diffuse zone recharge dominates accessions to the watertable aquifers, resulting in large irreversible increases in groundwater levels. The majority of discharge from the watertable aquifer is either to the lower reaches of the Murray River and its tributaries, or by direct evaporation from the capillary zone. The aquifer systems of the basin show a layering of salinity, the most saline waters occurring toward the top of the sequence, the fresher water occurring at the bottom of the sequence. Natural salinity of groundwaters is variable, ranging up to 300,000 mg/L TDS. In general, the better-quality water is found around the basin margins. Very little connate salt (old seawater) is present in the aquifer systems. The primary source of salts is from atmospheric accessions over the recent geological past.

The groundwater system is undergoing a profound change. Aquifer water levels are increasing over most of the southern parts of the basin. This change has been brought about by an increase in regional recharge rates due to a reduction in evapotranspiration rates in recharge zones – a direct consequence of the changing land management practices since the late 19th century.

4. *Murray-Darling Basin land and water management policy and planning framework*

J. Paterson & P.D. Sutherland (presented by J. Paterson)
Victorian Department of Water Resources

Effective management of the Murray Darling Basin depends as much on institutional and political mechanisms as on sound technical knowledge of physical processes. Major developments in the evolution of resource management policy for the Basin have been: *1914 River Murray Waters Agreement (RMWA) and Subsequent Amendments*; *1985 Formation of the Murray Darling Basin Ministerial Council*; *1987 Council Adoption in Principle of a Draft Salinity and Drainage StrategY*; *1988 Formation of the Murray Darling Basin Commission*. Key features of the Salinity and Drainage Strategy are: (i) a program of works and measures to maximise net Basin benefits – striking an optimum balance between measures to reduce River salinity and to control land salinisation and waterlogging; (ii) a baseline for apportionment of rights and responsibilities of the respective States in relation to actions which influence the shared resource of the River; and (iii) Cost-sharing arrangements for joint funding of a program of salt interception schemes to reduce River salinity.

Lessons from the past: Historically, interstate initiatives for managing the resources of the Basin have been about resolving conflicts after problems have emerged rather than forward planning to maintain the amenity of the shared resources. Since formation of the Ministerial Council in 1985 substantial progress has been made in laying foundations for action on major problems of the Basin, although it would be naive to ignore the competing needs and priorities of States. However the heightened awareness of salinity problems is likely to maintain basin issues high on the political agenda. Enduring interstate agreement on management Strategies for the Basin will only occur where: (i) the perceived benefits to each State outweigh the costs; (ii) the entitlements and obligations of each State for actions which affect the shared resource are precisely defined; (iii) the instruments of co-ordination do not unduly interfere with institutional powers for internal resource management.

Future Challenge: We are entering a critical era of resource management where failure to act in time may mean losing the option of arresting and reversing the trend of degradation, and we are left with the sobering thought that decisions by this generation may determine the fate of the Basin irreversibly.

II Salinity

5. *The salinity problem in southern Australia — an overview*

P.G. Macumber* & P.R. Dyson+ (presented by P.R. Dyson)
***Victorian Department of Water Resources**
+Victorian Department of Conservation, Forests and Land

Throughout southern Australia we are today experiencing a wide ranging and fundamental readjustment in environmental equilibrium caused by the filling up of the regional aquifers in response to land use changes brought about by European settlement. Salinisation is occurring in almost every regional geographic and climatic setting, including the highlands, the Mallee and the inland and coastal plains. It effects virtually all major irrigation areas, and is now gradually affecting tributary systems feeding the major rivers of northern Victoria. If the observed pressure rises were to continue at present rates, it can be predicted that the entire Riverine Plain in Victoria — dryland and irrigation areas alike — will become a zone of regional groundwater discharge within 100 years. Similarly, in the dryland highland areas, and in the Mallee, under present land-use techniques the expansion in land and stream salinisation is inevitable and essentially irreversible. The ultimate effects will depend on the extent to which remedial action can be taken.

The Salinity Management Option Tree (SMOT) has been developed in Victoria to provide a conceptual and operational framework on which an overall salinity control strategy can be developed — based on a range of technically feasible control options and provides a framework for assessing outcomes of various combinations of options.

Salinity Control can be achieved by techniques which reduce accessions to the water table, or by sub-surface drainage which lowers water tables — the alternative is the 'living-with-salt' situation or saline agriculture, with its implied loss in productivity.

In irrigation areas, sub-surface drainage is essential — but it is likely that less than 40% of the Victorian irrigation areas can be protected by this means. High priority must therefore be given to the evaluation of different disposal options. In dryland regions the reduction of accessions to the groundwater is likely to be the most appropriate salinity control technique for most areas — agronomic and on-farm measures. Groundwater pumping is not a viable option for most dryland provinces. In the Mallee salinity control may take many generations to achieve and in some instances may be virtually unattainable. However, in a local flow system (highland), a limited number of deep rooted species are capable of controlling water tables — intensive research is now under way to improve plant-water use by existing species, and increase the number of additional deep rooted species.

6. *Recharge, salinity and land-use change in the Mallee region*

G.B. Allison, G.R. Walker, M.W. Hughes, P.G. Cook, & I.D.Jolly
(presented by G.R. Walker)
CSIRO Division of Water Resources

When the Mallee vegetation is replaced by shallow-rooted crops and/or pastures, there is a large increase (by about two orders of magnitude) in the recharge to the unconfined aquifers. This leads to higher water tables as well as mobilization of the salt stored in the soil. It is therefore important to understand the mechanisms operating in this environment and to be able to estimate changes in recharge. This problem has been addressed in the South Australian Mallee by the use of techniques involving chloride, carbon-14 and tritium. These show that the diffuse fluxes of water under Mallee vegetation are less than 0.3 mm yr^{-1} (approximately 0.1% of rainfall). After the Mallee is cleared the estimates of recharge are 5-30 mm yr^{-1} depending on soil type. Because of the depth to water table much of the effect of clearing is yet to be observed. This information is being used in a groundwater model of the South Australian portion of the Basin to estimate future trends of the piezometric heads and salinities of the groundwater.

7. *Irrigation Recharge*

W. Trewhella
Rural Water Commission of Victoria

Water table levels have risen throughout the irrigation areas in the Murray Basin as a result of the clearing of natural vegetation and introduction of intensive irrigation. In irrigated areas of the Mallee, recharge is dominated by direct irrigation recharge, and by channel seepage from unlined channels in places. Where tile drains have been in use for many years, leaching of the subsoils is often well advanced and an approximate salt balance exists. Where the subsoils are relatively light, major rises in regional water table levels result. As the underlying groundwater is almost universally very saline, large amounts of salt can be displaced to the land surface or the Murray. There is great potential to reduce these accessions by better irrigation scheduling or microjet or drip irrigation, and artificial lining or piping of irrigation supplies. Particular care is required in the siting of water storages or evaporation basins.

In the Riverine Plains a complex pattern of local recharge and discharge has developed, with the shallow aquifers linking the recharge and discharge areas. Part of the water entering the groundwater body continues downward as nett recharge to the Lower Shepparton Formation aquifer, and the 'deep leads', where present. However, the groundwater flow budget is commonly dominated by transfers occurring within the shallow aquifers at a local or subregional scale. Improved modelling of regional aquifers is needed to quantify the interaction between the irrigated and dryland areas. The Kerang Region clearly demonstrates the need to maintain both a regional and a local perspective of the recharge processes. Much of the region is a regional discharge zone but there are many local recharge areas which are profitably farmed. Options for reduction of recharge include: channel sealing/seepage interception; extending surface drainage to additional areas; improved irrigation management; farm restructuring and/or changes to agronomic practices. However, it seems inevitable that the combination of intensive irrigation and moderate rainfall on the Riverine Plains will continue to produce much higher recharge rates than the local and regional aquifer systems can safely accommodate. The alternatives are artificial subsurface drainage or the acceptance of permanent high water tables, saline areas, reduced agricultural productivity, and continuing environmental destruction.

8. *Impact of saline water discharge on soil degradation and erosion*

R.S. Junor
Soil Conservation Service of N.S.W.

In New South Wales, dryland salinisation has, to date, not been considered serious, compared with the situation in some other states. However, concern is spreading, and modern methods of detection and mapping are indicating that the potential exists for this form of land degradation to become very much more extensive. Whilst control methods are reasonably well understood, prevention of future degradation of the soil resource is an area requiring long term research and development of predictive technology combined with land use policies that may require some radical changes in concepts, attitudes and current land use practices. An integrated approach to soil, water and vegetation management, strongly supported by land use planning at all levels, requires priority actions if salinity of the Basin and its land and water resources are not to become the environmental disaster of the third century of settlement in Australia.

III Groundwater

9. *Groundwater use in the Murray Basin*

D.R. Woolley
New South Wales Department of Water Resources

Groundwater usage in the Murray Basin was not seriously contemplated until the 1950's when a number of factors arose to change this situation. Information about the volume of groundwater actually being used in the Basin is incomplete, and what is available is dealt with differently in each State. The major points that come from consideration of groundwater allocation and estimated usage data are the magnitude of the groundwater allocation, about 548,000 ML/year for the Basin, and the difference between allocation and actual usage, about half the volume allocated is used. The area of the Basin that has large quantities of usable groundwater is limited. Stock requirements are met from groundwater over about 60% of the Basin, whereas more intensive usage is restricted to specific areas, notably the Shepparton-Avoca region in Victoria, the Deniliquin-Corowa, Darlington Point and Hillston regions of NSW, and in a zone close to the Victorian border in South Australia.

10. *Overview of groundwater problems in the Murray Basin*

C.R. Lawrence
Victorian Department of Water Resources,

A number of technical problems associated with groundwater management, and organizational constraints to efficiently solve existing problems, as well as planning to minimise future problems, are evident. Two problem areas are emerging for groundwater – the degradation of quality through salt build-up and localised depletion of the resource. Areas prone to the former degradation are where applied water is of poor quality combined with recycling, the aquifer is unconfined to semi-confined, there is low natural recharge and low lateral groundwater movement. Management options applicable to this situation are to control the groundwater extraction rate with respect to the amount of lateral groundwater movement; use the best quality groundwater at a given location, regardless of depth, and irrigate downgradient of the pumped bore.

11. *Conjunctive use of surface water and groundwater in the Murray Basin: scope and problems*

R.C. Lakey* & R.M.Williams+ (presented by R.C. Lakey)
***Victorian Department of Water Resources**
+New South Wales Department of Water Resources

Pumping of both high and low salinity groundwater for distribution to existing users, dilution or disposal, is a potential method for the partial control of rising water tables and associated land management problems. Reserves of low salinity groundwater in terrestrial deposits located in the east and south-eastern areas of the Basin are being used for large scale irrigation to an increasing degree.

Significant groundwater development has also occurred in the south-western part of the Basin where extensive marine aquifers are being developed for irrigation. In 1983/84, a period of generally below average consumption, only about 6% of the water used for all purposes in the Basin was from groundwater sources.

12. *Modelling in the Murray Basin: an overview*

F.R. Kalf
Australian Groundwater Consultants

Modelling of aquifer systems has now become commonplace in groundwater hydrology. Modelling is both an art and a science. Analytical solutions remain a useful technique, but finite difference or finite element methods are generally used because of their greater flexibility. In the Murray Basin, models have been constructed of the entire Basin and also on a regional and site-specific scale. Most models so far reported are deterministic; isothermal; non-density dependent; two-dimensional; quasi or fully three dimensional. All deal with simulating groundwater flow, with only 2 reportedly using, in addition, a solute transport simulator and 1 a surface water process model. No simulations have so far been reported that use a stochastic approach. In view of the data uncertainties that still exist in the Basin, such an approach may be desirable in some circumstances to quantify resulting uncertainties in the generated results. These results could form important input to decision-making associated with salinity management of the Basin.

13. *Scenario modelling of aquifers in the Mallee region*

S.R. Barnett
South Australian Department of Mines and Energy

Recharge rates derived by the CSIRO Division of Water Resources beneath cleared and uncleared native Mallee vegetation were applied to a three layered finite element computer model of the Mallee region of South Australia and Victoria. A rate of 0.1 mm/yr was applied to vegetated areas, with values of 5 and 10 mm/yr being used for cleared areas in a variety of scenarios which included complete clearing and revegetation of certain zones.

The resultant rise in the water table from the increased recharge lead to higher inflows of saline groundwater to the River Murray. The model calculated the increase in these inflows at various times after the effects of the higher recharge had reached the water table (which lies at a depth of 30-40 m below ground level).

The calculated inflows were then used in MURKEY, a river flow and salinity model for the Murray River, to calculate the resultant increase in river salinity at Morgan. With the present vegetation distribution in the Mallee and a conservative value of 5 mm/yr for the increased recharge over cleared areas, an increase in salinity of 70EC at Morgan is predicted 50 years after the increased recharge reaches the water table. This would cost the state of SA $4.7 million annually.

IV Options for groundwater-related salinity management

14. *Salinity and drainage strategy – a groundwater perspective*

D.J. Blackmore
Murray-Darling Basin Commission

The advent, in November 1985, of the Murray-Darling Basin Ministerial Council with its objective, to 'promote effective planning and management for the equitable, efficient and sustainable use of water, land and environmental resources of the Basin', now provides the opportunity for co-ordinated and co-operative management policies to be developed and implemented.

It is estimated that over the next 30 years an additional 310,000 hectares of irrigated agriculture will be affected by high watertables. The consequent effect on productivity and environmental amenity depends on a range of factors related to each environment. The challenge in the future is to carry out the detailed hydrogeological assessments required so that these impacts can be better quantified as can the effects of the various remedial action proposed. This will require increased emphasis on regional hydrogeological investigations in the future.

The Draft Salinity and Drainage Strategy provides for a reduction in River Murray salinity and for the upper States to drain some of their high value irrigation land on the Riverine Plain. The key elements are: *Base Line Conditions*: current river salinity levels are to be adopted as the base line for evaluating responsibility for all future actions which affect river salinity; each State will be responsible for its future actions which affect River salinity. *Initial Program:* The three States and the Commonwealth will jointly fund cost effective salt interception schemes to reduce River salinity by 80 EC (median salinity at Morgan); Upper States may increase river salinity by up to 15 EC (median salinity at Morgan) as a consequence of joint funding of the salt interception program. *Future Program*: Beyond the joint program of works, States have the option of contributing to the costs of any further schemes that are identified, and will receive a salinity credit in proportion to their contribution to the cost; River salinity improvements obtained by any action in one of the States are to be credited to that State. *Administration*: The Strategy is to be embodied in a Salinity and Drainage Agreement and administered by the Murray-Darling Basin Commission.

Implementation of the Strategy: The Strategy provides for each State to be accountable for future actions. The future challenge that faces all resource managers is to obtain the necessary understanding of the longer term changes that are likely to occur to ensure that appropriate land and water management policies are implemented in the short to medium term. The Strategy is the starting point for action rather than an end point. It opens the way for States to tackle their high priority land salinisation problems and to initiate the necessary detailed regional planning. This is now occurring in Victoria and to a lesser extent in New South Wales and South Australia.

15. Options for salinity management in irrigation areas

D.G.Leslie
Dwyer Leslie Pty Ltd

The aspect being dealt with here is high and saline watertables in irrigation areas caused by a change in the hydrologic cycle following the advent of European farming some 150 years ago. Unfortunately the removal of European farming and restoration of prior conditions will not reverse the process. The increases in pressures in the major aquifer systems are irreversible except by pumping. The only means available in the short to medium term to completely deal with the salinity problem in irrigation areas is to treat the symptoms rather than the cause, and the only two options available are to prevent water getting into the watertable, or to remove water from the watertable. The only part of the soil profile of interest is the top couple of metres. Therefore, is an understanding of the geology and hydrogeology more important than an understanding of the soil physics or agricultural practices?

Watertable Accession Control at Public Scale – Surface Drainage: standard forms of constructed surface drainage are expensive, have low productivity benefits, do not greatly reduce accessions to the watertable and tend to mobilise salts to the detriment of downstream water users. The most economically attractive forms of surface drainage are likely to be the shallow forms such as improved natural drainage lines together with improved on farm drainage and re-use systems.

Reduction or Redistribution of Water Entitlements: even complete cessation of irrigation is unlikely to achieve a great deal. *Trees*: tree planting schemes may control watertables in recharge areas but are unlikely to do so in discharge areas (not efficient or cost effective).

Watertable Accession Control On-Farm includes: land-forming/re-layout; improved drainage; installation of re-use systems; improved water use management (e.g.'water on order' systems; adoption of appropriate pricing); groundwater pumping and re-use; tree planting along laneways and shelterbelts etc.

Unfortunately, even if universally adopted, above measures would still not have a great impact on watertables.

Sub-surface Drainage at Public Scale: The most cost-efficient method of controlling high watertables and salinity is undoubtedly sub-surface drainage (perhaps the only effective means). However, problems include: methods other than groundwater pumping are probably excessively expensive (e.g. tile) and likely to be restricted to areas with suitable aquifers; the principle problem is the disposal of the resulting saline effluent – particularly difficult whence sub-surface drainage is further restricted to areas with aquifers of reasonable quality. In the Shepparton irrigation region perhaps two thirds of the area likely to be at risk in the future can be reasonably be protected by sub-surface drainage methods. The balance of the area at risk has high salinity aquifers or no aquifers and is thus much more difficult to protect.

A substantial proportion of land salinisation in irrigation areas of the Riverine Plains can be controlled by sub-surface drainage, the constraint being that salt disposal problems are kept within manageable limits. The principal technique is likely to be groundwater pumping from the shallow aquifer systems. The economic, social and environmental benefits of such protection programs are likely to exceed the costs.

16. Is broadscale revegetation economic and practical as a groundwater and salinity management tool?

R.G. Dumsday*, R. Pegler[+] & D.A. Oram*

***La Trobe University**

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In the Murray-Darling Basin (MDB) agricultural production foregone from cropland and irrigated agriculture due to land degradation is estimated at $214.6 million per annum. Clearing and the replacement of deep-rooted native vegetation by shallow-rooted annuals has been identified as a major cause of increased groundwater recharge and land and water degradation. Improved vegetation management and revegetation of degraded and degrading lands will lead to significant improvements in surface water quality. Clearing controls can be useful in protecting remaining native vegetation of significance and can ensure that clearing is limited in aquifer recharge areas, on land having a particular degradation hazard and in areas of high conservation value. New assistance and incentive measures could improve implementation and effectiveness of vegetation management strategies. The utilization of education programs is also of major significance.

Proposed actions under the Murray-Darling Basin Ministerial Council draft Vegetation Management Strategy are: clearing and development controls, management of degraded and degrading lands, assistance and incentive measures, and community awareness.

The Economic and Practicalities of Controlling Groundwater and Salinity: Recharge strategies can basically be considered as preventative measures aimed at reducing deep percolation to the groundwater, over large areas of land, by the increased and more efficient use of soil water supplied by rainfall. These include reforestation and agroforestry, agronomic and engineering strategies. The economic benefits of agroforestry are frequently over-estimated (neglect of factors such as costs of area occupied by shelter belts and time taken for establishment); current arrangements for marketing commercial timber and setting prices are a cause of lack of private tree plantings, as are a lack of labour and management skills, the relative profitability of alternatives, and availability of capital. Though there appears to be benefits from forestry-based activities, which simultaneously control groundwater levels and dryland salinity, farmers need incentives to move to forestry-based systems.

Water Yield and the Benefits of Controlling Groundwater and Salinity: Most research predicts a net social gain from reduction in salinity problems, but the importance of water yield has been neglected – in the Campaspe Catchment if water yield was valued in excess of about $35 per ML the cost of stream flow foregone by reducing deep percolation would, in fact, outweigh the benefits from reduced salinity.

The substitution of short fallow for long fallow, and lucerne for annual pasture, dramatically reduces deep percolation suggesting that the wheat phase contributes little to groundwater recharge. Recommendations on the restriction of long fallow rather than on wheat cultivation would appear more appropriate.

Broadscale revegetation is not economic or practical as a groundwater and salinity management tool but its use should be evaluated in terms of local conditions. On the other hand, vegetation management should be more widely interpreted to include all vegetation which may be utilised to effectively and efficiently control groundwater and salinity.

17. Saline water disposal options

R.S. Evans
Rural Water Commission of Victoria

The bottom line of almost all salinity and land management strategies and plans is disposal. The preferred short term (10-50yrs) options are:

Reuse – may be the only option in some situations, but has a finite life (perhaps tens of years) before soil degradation occurs, and is not a long term sustainable option.

Outfall to the River Murray – benefits and disbenefits need to be assessed and any outfall needs to be undertaken under controlled conditions; limiting factors include salt load, time of outfall and frequency of floods; excessive reliance on small tributaries could have unacceptable environmental consequences. Disposal of irrigation waters to the lagoons and backwater of River Murray often leads to severe environmental disbenefits and the displacement of groundwaters (with higher salinities than the disposed waters) to the River.

Evaporation basins – well sited evaporation basins, where full engineering, hydrogeological and environmental investigations have been undertaken, should be encouraged; conversely poorly sited evaporation basins should be evaluated and phased out if considered to have unacceptable effects; all evaporation basins leak.

Disposal bores – 'out-of-sight and out-of-mind' but vast majority of shallow disposal bores have an unacceptable adverse impact on the River Murray and must be phased out with exception of some specific hydrogeological situations. Adoption of deep disposal bores should be investigated, but the extensive adoption of this technique is unlikely – the critical factor is a good understanding of the rate of transmission of the pressure and salt in the aquifer.

Pipelines/channels to the sea – grossly uneconomic at the present, but future analysis may favour this option.

Desalination – a very expensive concentrator, and is not recommended.

Social perceptions of feasible disposal options are often poor. The environmental disbenefits of salinity in general are enormous – with short term disbenefits on the ecosystems, and long term hydrogeological consequences. Investigation and evaluation of environmental effects of the major salt disposal options (principally evaporation basins) is currently underway and are becoming a key factor in the choice of the preferred option.

An effective saline water disposal strategy for the entire Murray Basin is one of, if not the, highest priority for dealing with salinity. Economic and environmentally acceptable options exist now, albeit politically difficult at the local scale. More consideration of how to manage the naturally occurring discharge areas of the Mallee may have significant long term benefits. Also we need to consider how best to maximise the use of all technically and environmentally feasible disposal sites. Hydrogeological processes at all scales will dominate these considerations.

SUMMARY OF PRESENTATIONS

TECHNICAL SESSION PROGRAM

The Technical Session provided an informal forum for the presentation of results of groundwater-related research, including ongoing research, which related to Murray Basin geology, groundwater and salinity management. A palynological working group was established to allow scientists in this discipline to discuss current research. Twenty-five papers were presented in four sessions over two days. Panel discussions were held at the end of each day.

Palynostratigraphy

Papers Presented:

Palynostratigraphy of the central west Murray Basin

M.K. MacPhail[1] & E.M. Truswell[2]

[1]Consultant, 29 Abbey St., Gladesville

[2]Bureau of Mineral Resources, Division of Continetal Geology

Palynology of the late Cainozoic in the Murray Basin and its bearing on the salinity problem

H.A. Martin & M.J. Knight

University of New South Wales

Palynological studies have provided a biostratigraphic framework to assist in the interpretation of the regional stratigraphy in the Murray Basin. Such a chronological framework is necessary to understand the geometry of economically important aquifers. In particular, aquifers within the continental sequence of the Renmark Group, in the eastern part of the basin, are lithologically similar, and Oligo-Miocene units are difficult to distinguish from those of the Eocene, although they contain waters of markedly different salinities. Palynology, by establishing time differences between the units, serves as a tool to differentiate the upper, middle and lower aquifers of the Renmark Group.

In addition, palynological investigations have permitted interpretation of palaeoenvironments. These environmental interpretations based on palynology show that the vegetation was predominantly forest throughout the Tertiary. In the late Pliocene-early Pleistocene, the vegetation became more open and woodlands and grasslands developed. Palynological and chemical analyses of core samples and groundwaters from bores in the southern Murray Basin margin area show that some aquifers in the Shepparton Formation which were initially saturated with freshwater were later (between 400,000-18,000 years B.P.) invaded by a series of concentrated NaCl water pulses. These originated from brine pools below salt playa lakes on the groundsurface above the aquifers. This saline invasion has significantly changed the chemical evolution of many of the basin's groundwaters, and a marine explanation for the observed salinity patterns is not plausible.

The Effect of Basement Structure and Geology on Hydrogeology

Papers Presented:

Pooncarie geological mapping — palaeohydrogeological indicators

R. Cameron

Geological Survey of New South Wales

Rifting and basement ridges in the Murray Basin region

V. Anfiloff

Bureau of Mineral Resources, Division of Geophysics

Towards a better understanding of the groundwater flow and chemistry on the Mallee/Riverine Plain boundary in the central Murray Basin

J.R. Kellett
Bureau of Mineral Resources, Division of Continental Geology

Under the Murray Basin, tectonism is controlled by a rectilinear system of crustal fractures. The framework is coherent and includes conjugate orthogonal belts. Mobile belts have developed along fractures by strike-slip movement producing compartmentalised rifts which have been individually converted to mobile belts by intrusion of granites and basic volcanics. Rifting is often polycyclic. Basement ridges form partitions in rifts and fan out across the basin. Narrow basement ridges protruding upwards into the Cainozoic sediments have been successfully mapped using gravity data, but are transparent to airborne magnetics.

Basement ridges represent the channelling of pervasive horizontal compression through the crust. When these forces were being balanced, strike-slip movements would have occurred, initiating rifting and igneous activity. At the same time, compression may have interfered with subsidence to produce flanking ridges. Ridges which partition mobile belts may represent the pivotal points of crustal blocks which have rotated slightly during strike-slip movements (e.g. Scopes Range ridge).

Major arcuate structures which flank and underlie the Murray Basin have a symmetrical and coherent relationship to orthogonal and possibly conjugate mobile belt systems. They are interpreted as the by-products of mobile belt development, possibly the gravity sliding of sediment cover in response to uplift along the mobile belts.

Basement ridges exert a profound influence on the hydrogeology and hydrogeochemistry of the overlying Tertiary aquifers, for example, the Ivanhoe Block in the central part of the basin. This is a composite structure consisting of two narrow northeasterly trending basement ridges with an intervening saddle. The western limb of the Ivanhoe Block, the Neckarboo Ridge, extends southwesterly towards the Murray River; 50 km above the river it splays into two major basement ridges – one ridge trends to the southwest and intersects the Murray River at Lambert Island. At this locality it forms an obstruction to lateral transmission of groundwaters in the Parilla Sands and is responsible for the discharge of saline waters to the river. The other ridge strikes southeast and represents the northerly extension of the Tyrrell Fault Block in Victoria.

The Neckarboo Ridge partitions the coarse-grained sediments of the Darling River provenance in the west from the much finer-grained sediments of the Lachlan-Willandra provenance in the east, and represents a true dividing groundwater flowline. The easterly limb of the Ivanhoe Block, the Iona Ridge, sharply delineates the boundary between the western Riverine Plain and the mallee country. There is a one-to-one correspondence between both limbs of the Ivanhoe Block and the elevated topography of the mallee country and both ridges appear to be fault-bounded with throws of up to 150 m.

The Willandra Trough occupies the intermediate ridge-basement depression and its aquifers are hydraulically connected to those of the Ivanhoe Trough in the northeast.

The top of the Renmark Group occurs at elevations up to 40m asl on the basement ridges and a mean elevation at sea level in the Willandra Trough. Channels filled with Calivil Formation sediments (and possibly younger sands) in the north and Geera Clay in the south are incised into the Renmark Group in the Willandra Trough at depths to -60m asl. Relict beach ridges of Parilla Sands outcrop at elevations up to 100m asl on the southern section of the Neckarboo Ridge.

There is significant vertical variation in groundwater salinity in the Renmark Group aquifers, and for this reason the Renmark Group has been subdivided into three units. To the east of the Neckarboo Ridge the lower Renmark Group aquifers always contain the best quality waters and the upper Renmark the worst. Discharge zones in the middle and upper Renmark Group aquifers occur near the boundary of the Geera Clay in the Willandra Trough, and these areas coincide with pronounced salinity gradients.

The Pliocene and Quaternary aquifers are generally unconfined on the basement ridges and are confined beneath the gypsum playas of the Willandra Trough and western Riverine Plain; in these environments groundwater salinities of the order of 35,000 to 50,000 mg/L TDS have been produced from evaporative concentration and refluxing.

Remote Sensing Techniques to Map Salinity

Paper Presented:

Application of LANDSAT thematic mapping to studies of geology and salinity in the Murray Basin

R.M. Johnston & J. Kamprad
Bureau of Mineral Resources, Australia

LANDSAT 4 and 5 provide spectral data in 7 bands in the visible and near infrared regions from an advanced multispectral scanner called the Thematic Mapper (TM). Distinctive spectral reflectance properties can be used to identify various types of vegetation, soils and other components of the land surface; however, spectral reflectance curves of the terrains studied can be used only as a general guide because of atmospheric attenuation and instrumental characteristics inherent in the uncorrected digital data. This paper described an investigation into the applicability of basic uncorrected LANDSAT TM data to the identification of active and relict salt lakes and groundwater discharge zones, and delineates the distribution of mineral salts within trial areas near Balranald and Lake Victoria.

Contrast enhanced composite images from the uncorrected LANDSAT TM data gave a quite detailed display of vegetation, geomorphology and landuse patterns. While images of data from each band showed slightly different features, a composite image of bands 1 (blue), 4 (red) and 5 (green) was found to give best definition of most features. Variation in vegetation was distinct, with changes across fence lines emphasizing the important control which grazing exercises over vegetation. Stands of mallee and casuarina were distinguished from saltbush, and some distinction was made between types of saltbush. Although changes in vegetation on the ground can be related to colour changes on the images, the reverse is not always true; very complex vegetation patterns displayed on the LANDSAT images are frequently not obvious on the ground. While it is not possible at this stage to unequivocally identify vegetation types on the images, depth of colour can be used as a rough guide to the density of cover.

Comparison of LANDSAT data with mapped geology, showed that TM data delineate both active salinas and ancient playas very well. Zonations within the active salinas are also well defined. Dunes within the lakes are easily distinguished by their vegetative cover, but those bordering the lakes are poorly defined since their vegetation merges with that of the surrounding plains. Vegetation differences between dune and swale emphasise the east-west trending dune sets of the Woorinen Formation, giving good definition of these areas compared to the aeolian sand plains.

Most TM bands indicate zonation in several of the active salinas, but patterns are not always coincident and assigning each zone to real phenomena is complicated by the seasonal variability of the salinas and the time difference between collection of field and TM data. Ground checking indicated that it is possible to use colours generated in false-colour composite TM images as a rough guide to the surface characteristics, rather than the exact mineralogy, of salt lakes. If corrected data are available, it may be possible to correlate TM data with laboratory spectral data for mineral species and identify mineralogical zonation within the lakes.

Recharge Studies in the Western Murray Basin

Papers Presented:

Localised recharge in the western Murray Basin

P.G. Cook, I.D.Jolly, G.R. Walker & C.D. Walker

CSIRO, Division of Water Resources

Diffuse discharge/recharge under native vegetation in the western Murray Basin

I.D. Jolly, G.R. Walker & P.G. Cook
CSIRO, Division of Water Resources

Studies of groundwater recharge in the western Murray Basin have provided estimates of diffuse recharge under native vegetation of the order 0.05-0.20 mm/yr. These rates were derived from point estimates using unsaturated zone profiles of environmental chloride, and from measurements of carbon-14 activity in the unconfined Murray Group aquifer in the South Australian mallee. Following clearing of native vegetation, recharge is enhanced several orders of magnitude with new rates in the range 3-40 mm/yr. Recent work in this part of the Basin has indicated that in some situations there can be a net discharge under native vegetation rather than recharge. This is thought to arise from the ability of the deep rooted (>20 m) mallee vegetation to extract water from deep (30-50 m) water tables during dry summer months. Although the fluxes involved are probably no greater than 0.05 mm/yr, this phenomena serves to highlight the importance of localized recharge under native vegetation in this part of the Basin.

In any case the most important aspect of groundwater recharge in this portion of the Basin is that it has increased several orders of magnitude since European settlement, resulting in a potential salinity problem of considerable magnitude.

Chloride profiles from a test site of a natural cleared depression in undisturbed mallee show enhanced rates of groundwater recharge through the base of the depression. Recharge rates obtained from the chloride mass balance are between 0.2 and 7.5 mm yr^{-1}. This technique, however, assumes one-dimensional, vertical flow. If runoff occurs from the calcreted areas around the depression, then the method may underestimate the actual recharge rate. It is likely that runoff contributes more water to the depression than direct rainfall, and so these calculated rates may be several times too small. Work is continuing in an effort to refine the estimates.

With this in mind, it is difficult at this stage to assess the hydrological importance of these natural clearings. Preliminary calculations have been carried out by assuming a mean recharge rate of 5 mm yr^{-1} over the whole of the depression. In the remaining mallee, natural clearings appear to have a density of one per 5 km^2, suggesting that 20% of all water recharging to the unconfined Murray Group aquifer may be occurring through these clearings. However the likelihood of runoff into the depression, and the possibility of diffuse discharge occurring under mallee mean that this figure may actually be as high as 50%.

Salinity Studies in the Basin Margin Areas of New South Wales

Papers Presented:

Geologically induced dryland salinity at Yelarbon, Border Rivers area, NSW

M.J. Knight[1], B.J. Saunders[2], R.M. Williams [3] & J. Hillier[4]
[1]**University of New South Wales**
[2]**Groundwater Technology Inc.**
[3]**New South Wales Department of Water Resources**
[4]**Queensland Water Resources Commission**

Changes in groundwater levels and water chemistry, Southeast NSW

G.W.B. Gates & R.M. Williams
New South Wales Department of Water Resources

The Yelarbon (near Goondiwindi) Salt Scald is one of the few examples of dryland salinity that is not directly attributable to environmental changes wrought by European settlement. The scald is located on the Peel Fault which has displaced the basement rocks and created artesian conditions in the fractured rock aquifers on the downthrown side of the fault zone. Vertical upwards flow of saline fluids from the deep artesian aquifers to the surface alluvium has resulted in transmission of these waters to the groundsurface giving rise to the scald.

Dryland salting is reported to be expanding in southeast New South Wales. There are in excess of 1000 sites in the study area (17,900 square kilometres in two trial catchments at Cootamundra and Yass in fractured and folded rocks of the Lachlan Fold Belt) averaging from 2 to 5 hectares in size. It is becoming generally accepted that a reduction in evapotranspiration and interception storage occurs when shallow rooted annual agricultural crops and pastures replace deep rooted perennial native forests. This in turn results in an increase in groundwater recharge and rising water levels. With a few minor exceptions there has been a significant increase in groundwater levels across the study area. Potentiometric levels have increased on average 4m over the 72 year period of record (1915-1972). Bores which recorded the largest groundwater level rises (greater than 10m) all had significant areas of their catchment under cropping. The relationship between water level rise and geology is a local one rather than regional, with fracture intensity of the catchment rocks being the dominant control that governs the location of recharge and recharge rates. Significantly, no relationship has been established between average rainfall and water level changes i.e. there are as many rises in the lower rainfall area in the west as in the higher rainfall areas in the southeast.

Impact on Surface Water: The salinity of water in all streams in the study areas is increasing with time. The salinity signal is diluted as water moves downstream because of the volume of inflow and the integration of different salting signatures.

The rise in groundwater levels causes an initial increase in stream baseflow and later as the seepage/evaporation processes become established on salinised areas, overland flow transports salts to streams after rainfall events. The data indicates that while the catchments are flushed by flood flows, the salt store available for mobilisation is quickly restored because the high water levels driving the salinity system are in place.

It is unclear if the increase in stream salinity which commenced many decades after clearing will be linear or if the rise to equilibrium will be exponential. Identifying the principal areas of recharge and reducing deep percolation is the key to success in reversing the observed rising stream salinity trends. This can be done by altering land management practices to hold existing salt in the catchment by lowering groundwater levels.

Remedial Measures to Deal With Salinity and Diminishing Groundwater Resources – A Case History From South Australia

Paper Presented:

Hydrogeological Investigations in the upper Southeast of South Australia

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S.A. Department of Mines and Energy

In 1984 the Tatiara Proclaimed Region (upper south east of S.A.) was promulgated under the S.A. Water Resources Act to manage groundwater withdrawals in the area because irrigation activities were expanding at an ever increasing rate and preliminary assessments of groundwater availability indicated that extraction had approached or exceeded replenishment in parts of the area; also there was evidence of a deterioration of groundwater quality in the western part of the region. This paper described the progress of subsequent hydrogeological investigations and resource management strategies, concentrated mainly on the Murray Group limestones.

The limestone aquifers have both a high primary permeability and an even higher secondary permeability in areas of solution activity. This dual permeability is reflected in the variation of transmissivity throughout the region from 500 to over 14,000 m^3/day/m. The main inflow into the system is through recharge from local rainfall and lateral throughflow. Lateral throughflow across the Victorian Border has been estimated to be 14,000 ML/yr. Recharge occurs via two mechanisms; diffuse and point recharge. Diffuse recharge has been estimated from chloride profiling and observed changes in groundwater storage to be of the order of 10-20 mm per year in the eastern portion of the region and up to 50 mm per year in the western sector. Point recharge occurs via surface discharge into numerous runaway holes in the Bordertown and Mundulla area. About 2 300 ML/yr is estimated to be recharged to the unconfined limestone aquifer via this point recharge. Total dissolved salts increase from about 1 500 mg/L in the eastern portion of the area to in excess of 9 000 mg/L in the west. Average annual increases in TDS values of 320 mg/L have been measured in the region since 1978 and it is considered that the increase has been caused by downwards leaching of salts which remain in the soil profile following irrigation. This leaching is enhanced in areas of higher recharge and where the water table occurs at relatively shallow depth i.e. the western portion of the region.

Groundwater Resource Assessment: The region was divided into 7 sub-areas, and a separate water balance was determined for each. Consideration was given to the hydraulic continuity of the unconfined aquifer across the region i.e. the groundwater outflow from one sub-area must balance the inflow into the sub-area which is immediately down-gradient. The results of this assessment indicate that to minimise the effects of any long term groundwater quality deterioration, particularly for irrigators located downgradient of areas with a high level of irrigation development, the maximum possible groundwater throughflow should be maintained. The management philosophy that has therefore been adopted for the next five years is to maintain groundwater allocations at the level of local recharge within each sub-area.

Progress Reports on Hydrogeological Investigations in the Victorian Mallee

Papers Presented:

Geological and hydrogeological assessment of the Victorian portion of the Mallee, with particular reference to the basal Tertiary Renmark Group

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*** Royal Melbourne Institute of Technology**

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Hydrogeology of the Victorian Mallee tract of the Murray River

R. Thorne & G. Hoxley

Rural Water Commission of Victoria

Until recently there was virtually no hydrogeological information for the basal Tertiary Renmark Group aquifer beneath the Victorian Mallee. Recent drilling in the far north west of Victoria has largely overcome this deficiency. The drilling sites were generally located from geophysical interpretation of pre-Tertiary basement structures, particularly where these structures were thought to influence the hydrodynamics of the Renmark Group aquifer, which in turn may significantly effect the hydrodynamics of the overlying aquifers, particularly with respect to groundwater discharge to the River Murray (e.g. Lambert Island). A follow up drilling program is being co-ordinated to establish a monitoring network for the Murray Group limestone and Pliocene Sand aquifers at all the recently drilled Renmark aquifer sites.

The hydrogeology of the Victorian Mallee Tract of the Murray River has been studied intensively during the Nyah to South Australian Border Hydrogeological Investigation, which concentrated on the shallower aquifers which may react to irrigation – in particular, the Parilla Sand and the Quaternary Channel Sands in direct hydraulic connection with the Murray River. It has been established that the Parilla Sand have been considerably affected by small-scale tectonism and a number of fault movements have truncated or warped the aquifer, disturbing the hydraulic flow in the region. This activity does not appear to have affected the Channel Sands unit directly but has controlled the extent of its deposition and the morphology of the Murray Trench. In general the Parilla Sand aquifer contains highly saline water (30,000-50,000 EC) while the Channel Sands aquifer is fresher with a wide range of values (1,000-30,000 EC).

The Channel Sands aquifer is in direct connection with the Murray River and the water levels nearer to the river respond to flood events in the river. This aquifer may become confined at the high flow stages because of the low permeability of the overlying floodplain material. No steady state level has been observed in the Channel Sands, it is perpetually rising and falling nearer the river. This effect has diminished to be imperceptible, in most cases, by 2 km from the river. Where the Parilla Sand is separated from the Channel Sands by the Blanchetown Clay aquitard, there is no hydraulic response to river floods in the Parilla Sand. There are cases where the Parilla Sand is in direct connection with the river (either via the Channel Sands with no intervening aquitard, or where the Parilla Sand is at surface) and in these situations a response to flood events is seen.

The responses in the aquifers indicate that for some time of the year the Murray River recharges the aquifer systems along its banks. On an annual basis, in most areas however, the situation is either near neutral or the aquifers have a net discharge to the river. There are exceptions, near Nyah for example, where the river recharges the aquifers for the entire year. An opposite example is near Merbein where there is groundwater discharge for the entire year into the river, hence, the need for the Mildura-Merbein Groundwater Interception Scheme.

A Study of the Effects of Saline Groundwaters on Aquatic Organisms

Paper Presented:

Primary and secondary environmental problems caused by saline groundwater intrusions into the Wimmera River, Victoria

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A recently completed study of the environmental flow requirements for the Wimmera River established that saline groundwater intrusions are occurring in an extensive area of the Wimmera River, producing stable and long-lived vertical density gradients and stratification. Saline water approaching seawater concentrations accumulates as stable saline pools in the bottom of the river bed. Saline pools were found in the Roseneath area upstream of Horsham, at Lower Norton downstream of Horsham and also in extensive areas from Polkemmet to Horseshoe Bend and between Antwerp and Jeparit. Significantly, the saline pools were absent from the Horsham and Dimboola Weir Pools and most of the deeper waters in the Little Desert National Park upstream of Dimboola. Some sites coincided with areas where the river bed intersected the uppermost portions of the regional Parilla Sands aquifer where the water table is uniformly 1-2 metres above river level and where extremely saline seepages are evident from the bank to the river. It is most likely that the saline pools are produced as a result of saline groundwater entering the river from above surface seeps or directly through the subsurface bed and banks.

The major environmental problems arise not through the increased salinity itself (most fish and other aquatic organisms can tolerate moderate salinities), but through the stable density stratifications produced by the conductivity gradients and subsequent deoxygenation of the saline pools. The deoxygenation either arises because the low dissolved oxygen levels of the groundwater intruding in the pools is retained and there is little or no replenishment of oxygen to the bottom of the pools, or it arises secondarily through the decomposition of organic matter in the saline pools once they form due to the low mixing and low rate of replenishment from the overlying surface layers. Because of the low oxygen levels the saline pools are uninhabitable for fish or other aerobic organisms. As a result there is a substantial reduction in the volume of water, and area of bed substrate which is available as habitat for fish and macroinvertebrates and a consequent lowering of the production of the river section affected. The saline pools are extremely stable. Major flow events remove the saline water but the saline pools quickly reform (less than two months).

Secondary effects of the saline groundwater intrusions: 1. Severe short-term changes in environmental conditions can occur when saline water (anoxic or hypoxic) which has accumulated in the channel bed during low flow periods or flow stoppages, passes as a 'slug' of water ahead of a flow front. Such first-flow events have caused fish-kills in the Wimmera River. 2. The total area degraded by the saline groundwater intrusions was shown to be considerably increased because of secondary salinity stratification which arose downstream of the site of the intrusion. Saline water which was moved downstream ahead of successive flow fronts produced three or more layers of water of different salinity which remained for long periods during low flow periods. Conductivity gradients of as little as 500 μS/cm were sufficient to produce a stable stratification which led to severe deoxygenation below the halocline. This led to severe deoxygenation problems and reduced the vertical mixing produced by subsequent flow events (occurred in the Little Desert National Park and Dimboola Weir pool areas in 1987. Consequently the area affected by the saline water intrusions can be secondarily increased by saline water being carried downstream into relatively deep and poorly mixed pools to form multiple layers.

The intrusions appeared to be localised rather than regional. Saline waters were not found in all deep pools within a major river section. Similarly saline pools were often found in a particular scour pool when a deeper scour pool on the next meander bend downstream was not saline. This offered some hope that there may be a localized solution to the problem. However, if groundwater levels continue to rise the problems in the Wimmera River would be expected to worsen. Similar saline groundwater intrusions are probably occurring in other rivers in Northern Victoria. Similar severe environmental problems associated with salinity stratification and hypoxia probably also occur in the downstream sections of other rivers below major off-stream diversion points. Many of these downstream river sections are highly regulated and have very little flow during the summer months. Severe environmental problems may be produced in areas which do not currently receive saline groundwater from natural drainage through the disposal of groundwater pumped to lower water tables.

Further work is required to determine the extent of the problem throughout Northern Victoria and to predict the future implications of a continuing trend for a rise in water table, and consequent natural and artificial drainage of saline groundwater into the rivers and streams.

Management of Salinity by Well Interception and Sub Surface Drainage

Papers Presented:

Woolpunda groundwater interception scheme — cause and effect

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South Australian Engineering and Water Supply Department

Groundwater management in the Wakool District, NSW

G.J. Brereton & D. Hoey

New South Wales Department of Water Resources

The Woolpunda Groundwater Interception Scheme (WGIS) is to be built along the River Murray in South Australia between Waikerie and Overland Corner to intercept saline groundwater discharges from the unconfined Murray Group limestones and Renmark Group confined aquifers into the River Murray. In the discharge zone the head difference between the two aquifers induces upward leakage of groundwater from the Renmark Group aquifer to the Murray Group aquifer. The upward leakage maintains a groundwater mound approximately 15 km south of the River and a similar though less well defined mound north of the River. These mounds control groundwater discharge into the River Murray in the Project Area.

The River Murray separates two distinct hydrochemical populations characterised by high Sulphate/Chloride ratios in both aquifers to the north of the river and corresponding low ratios to the south. Within each population the Murray Group groundwater is hydrochemically similar to or a dilute equivalent of Renmark Group groundwater; this, with the observed potential for upward leakage indicate that the Murray Group groundwater has been largely derived from the Renmark Group aquifer in this area. However at some sites the Murray Group groundwater appears to have been diluted by low salinity water from areas of internal drainage in the Murray Mallee with anomalously high rainfall recharge rates.

The existence of two distinct hydrochemical populations separated by the River Murray indicates that flow in all aquifers is toward the River. This flow pattern occurs because the River is the hydraulic boundary for the Murray Group aquifer and controls the shape of the water table, which in turn controls the potential for upward leakage from the Renmark Group aquifer.

The distribution of groundwater discharge into the River Murray is influenced by the bathymetry of the River and the density contrast between 450 mg/L river water salinity and 20,000 mg/L groundwater salinity. These two variables combine to generate a hydrostatic head which varies with river depth. The hydrostatic head differential at any datum beneath the River can vary by up to 0.26 m, assuming a River depth differential of 13 metres. River depth can vary from 2 metres to 15 metres in any River reach. Conceptual computer modelling has shown that this hydrostatic head difference is capable of redistributing regional groundwater flow over a radius of several hundred metres from the deepest sections of the River (trenches). Since the trenches are elongate parallel to River flow and are therefore well flushed, they are the focus for a large proportion of the groundwater discharge to the River. The density driven discharge mechanism has been observed and measured on the River. Water samples collected from the bottom of several trenches can be identified as deriving from either the north or south hydrochemical population.

The investigations have shown that the trenches are the focus for groundwater discharge to the Murray River around Woolpunda, and that plumes of salinised water flow along the bottom of the river until vertical mixing is forced by a shallowing of the river. The mechanism which causes the trenches to be a focus for groundwater discharge is the density contrast between river water and groundwater. This mechanism in no way diminishes the efficiency of the WGIS.

The Wakool Irrigation District in NSW covers over 200,000 hectares and uses an average 250,000 ML on 40,000 hectares of irrigated land each year.

Water tables in the Wakool/Tullakool area have historically been shallow; a survey in 1944 (8 years after irrigation commenced) indicated an average depth to the watertable of 9 m. Intensification of irrigation in 1949 when dairying and rice was introduced on a large scale, led to increased groundwater accessions. Heavy rain and flooding in 1956 accelerated watertable rises. Salinisation and waterlogging have become apparent from this time on.

In the 1960's experimental tubewell drainage was found to successfully control groundwater levels in the shallow 'shoe string' aquifers, (prior streams). Effluent was discharged to the Niemur river (and hence eventually to the Murray) though this caused problems downstream at low river flows, and pumping restrictions had to be enforced under low flow conditions.

The first plan for a drainage scheme, in 1973, was reinforced by wet conditions in 1974-75, when 45,000 ha were found to have watertables within 2 m of the ground surface. The present scheme was initiated in 1978 as a joint Commonwealth/State project and completed in early 1988.

The Wakool/Tullakool Sub Surface Drainage Scheme consists of 48 pump sites (predominately tubewells with a few spearpoints) pumping via a series of spur lines into two main collector lines. Each main line is approximately 25 kilometres long, discharging to separate evaporation basins where salt production can take place.

The scheme has pumped over 50,000 ML of groundwater with over 800,000 tonnes of salt being removed, over the period 1981-87. This has resulted in the lowering of watertables over 21,000 ha by more than half a metre. By comparison regional shallow watertables have risen by an average of 0.2 metres/year outside the protected area. Limited EM-38 soil salinity surveys have indicated that areas classed as salt affected have decreased from 72% of the sampled area in 1982 to 46% in 1984. This translates to a benefit in crop production of $750,000 over this period.

The principal aim of the sub surface drainage scheme was to lower watertables to below 2 metres, to prevent further salinisation and allow leaching of salts to below the root zone. From a hydrologic viewpoint the scheme has been successful. However the scheme has operation and maintenance costs of $300,000/year. Therefore a number of management strategies are being examined to minimise the cost, while at the same time maximising the area of land protected. Examples include intermittent operation of tubewells, discharge of pumped effluent to surface water supplies for re-use, and encouragement, with the N.S.W. Department of Agriculture, of better on-farm irrigation management to reduce groundwater accessions.

Numerical Modelling in the Victorian Riverine Plain

Solute transport modelling in the Shepparton region

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Rural Water Commission of Victoria

Accessions study on the Riverine Plain

D. Ife
Rural Water Commission of Victoria

In the Shepparton Irrigation region in northern Victoria (an area of approximately 500,000 ha) there are large areas with watertables within 2 m of the surface. In response to this rise, a number of private and government groundwater pumps have been installed. These pumps have been successful in locally maintaining watertable levels at a 'safe level', generally 2-3 m below surface. Much of the moderately saline (typically 1000 - 5000 EC) pumped groundwater is reused either directly on farms, typically diluted with good quality irrigation water, or reused within the region (via Rural Water Commission channels). As a consequence, little salt is being removed from the region with the existing salt within the system being recycled and further salt added with imported irrigation and rain water.

The 'Method of Characteristics' computer program for solute transport in groundwater has been applied to approximately 32,000ha of the Ardmona-Toolamba area, an area containing 30 RWC and several private groundwater pumps. The model is being used to: quantify time scales for aquifer salinisation in the absence of salt export; determine necessary salt export requirements to protect groundwater quality; quantify intrusion rates for the migration of poor quality water from adjacent areas to pumping zones; examine the local behaviour of pumps with high concentrations, particularly for the situation where a regional salt balance is being maintained;

The model treats the Shepparton Formation, to a depth of 30 m below surface, as 2 active layers with leakage to the underlying Calivil/Renmark aquifer system provided by the DITR regional model. This model has been calibrated for surface recharges/discharges for a five year period at a monthly time step given known pump rates. The leakage algorithms in the MOC model were modified to allow the upper Shepparton Formation aquifer to be treated as an active layer with leakage to the passive lower Shepparton Formation. A routine was added to calculate the salinity of the groundwater recharge as a function of the salt mass removed by pumps, the spatial distribution of pumps, the salinity of irrigation supply water and the relationship between irrigation application rates and groundwater accession rates.

The paper presented the results of the simulations to date and showed that within the study area salt transport is dominated by the vertical flow component. The simulations confirm that mass transport in groundwater is an extremely slow process.

The depth to watertable in the Shepparton Region of the Victorian Riverine Plain prior to agricultural development in the middle of the nineteenth century was at 30 - 50 m below surface, although areas close to the rivers, such as Echuca, had a higher watertable, possibly reflecting hydraulic connection between the surface watercourses and the shallow aquifers.

Two factors have contributed most to the high watertable problems: (a) the clearing of native vegetation and (b) irrigation.

Watertable Accession: The upper Shepparton Formation is composed of aquitards interspersed with alluvial channel sands. The piezometric levels in each aquifer determine the movement and magnitude of groundwater flow in a horizontal and vertical direction. The Calivil Formation which underlies the Shepparton Formation has a lower piezometric level over most of the Shepparton Region and under this condition acts as a drain for 'deep seepage'. There are two mechanisms by which vertical recharge can occur – piston flow or flow along preferential paths. Piston flow is a saturated front moving down through the sediments at a uniform rate, whereas flowing along preferential paths is selective and non-uniform, being controlled by the permeability of the medium and the degree of interconnection of permeable zones. It is likely that both mechanisms are valid, their applicability depending on scale and local conditions. Accession, or vertical recharge, is controlled by the vertical hydraulic conductivity of the conducting medium, which is usually unknown. In the Shepparton Region a combination of computer modelling, pumping tests and soil salinity studies are being used to gain a better understanding of this variable.

These studies are at various stages and our understanding of recharge and discharge processes is far from complete. The hydrogeological system is complex and problems of heterogeneity and scale make results extremely variable. A clear understanding of the physical conditions is a vital prerequisite for estimation of rates of accession.

An Example of the use of Pumped Groundwaters for Irrigation in Northern Victoria

Paper Presented:

Groundwater pumping/reuse in northern Victoria: recharge process, aquifer salinisation and farm productivity

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Shallow watertables and soil salinisation are causing agricultural productivity losses in the Shepparton Region of northern Victoria. Watertables must be controlled if irrigation is to remain viable because of inevitable economic losses and the high potential risk of environmental damage in areas where there is no drainage; salt disposal to the River Murray must also be minimised. Tile drainage is considered a less economical drainage option than groundwater pumping because pumpable aquifers exist under most of the region and pumped groundwater can be integrated into on-farm irrigation management with minimal disposal to the River Murray. This paper looks at the relationships between recharge, rootzone salinity and groundwater degradation which will ultimately determine the economic viability of the pumping/reuse strategy. Six years of data, collected on a 610 ha experimental area near Tongala, were used to look at problems encountered in the field application of this management system.

Irrigation salt inputs in the Tongala project area are about 300 tonnes per year. For salt balance to be obtained this would mean that about 220 ML per year would have to be exported out of the area. Failing to do this will result in an average increase in groundwater salinity of about 7 ppm TDS per year. The average shallow watertable closely follows the piezometric pressure levels in the shallow unconfined aquifer system. Pressure levels in the deeper aquifer system (Calivil Sands/Renmark Group) are generally lower, indicating that a potential exists for vertical leakage and salt leaching from the shallow aquifers. Heavy pumping of the shallow aquifer system during the 1982/83 drought brought the average piezometric levels in both aquifer systems close together creating a situation with potential saline water intrusion into the shallow aquifer. Since the 1982/83 drought, average watertable levels in the area fluctuated between one and two meters below the surface which is generally considered safe for perennial pasture.

Extraction rates in the area over the last 6 years ranged between 1.6 and 3.2 ML/ha/year. Analysis of chloride profiles in the area give Leaching Fractions from nearly zero on the heavier soils to 20% on the lighter soils under re-use. The high pumping rates indicate that some of the extracted water originated from outside the reuse area, resulting in higher rootzone salinities than is necessary to maintain watertables in the reuse area.

Aquifer salinities measured in the network of piezometers show a gradual upwards trend. Degradation can be expected to increase when present vertical downward gradients approach zero.

Consequences For the Future Management of the Region: Once groundwater re-use becomes more widely adopted, yield reductions are likely to increase over areas of higher groundwater salinities if current management practices for perennial pasture continue. Greater use of more salt tolerant species such as lucerne will have to be considered. Groundwater degradation is the principal environmental and economic problem associated with re-use. Disposal to maintain salt balance is unlikely to have a measurable short term effect on aquifer salinities.

In areas where good quality groundwater is surrounded or underlain by poorer quality water, low pumping rates and careful management will be essential to avoid accelerated groundwater degradation. If watertable control is aimed for, the irrigation shandy quality is determined by both the recharge and the aquifer salinity. Therefore in areas where watertable control results in poor quality shandies, the pumped groundwater should be distributed evenly over the farm to minimise overall rootzone salinity. Where high pump intensities exist, sub-regional salt redistribution should be considered.

A Research Proposal to Examine the Effects of Disturbance to Vegetation on Dryland Salinity

Paper Presented:

The effect of tree removal and afforestation on dryland salt distribution in the Murray Darling Basin

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This proposal seeks to examine what effects of various degrees of tree clearing and/or natural regeneration has had on salt redistribution in the landscapes of the Murray-Darling Basin. It is proposed to select sites with well-known land use histories and to derive 'salt flushing potentials' to describe the effectiveness and dynamics of the plant community/rainfall interaction in halting or reversing adverse salt redistribution. An integral part of the field methodology is the use of EM techniques to provide actual salt concentrations to depths of 15m in the experimental areas. The ultimate aim of the project is to provide a rational framework for decisions on future investments in reafforestation projects.

Isotope Methods to Investigate Velocities and Salinisation Processes in Murray Basin Groundwaters

Papers Presented:

The Application of ^{36}Cl Measurements to Groundwater Modelling

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Origins of Chloride Variation in the Murray Basin — Using Environmental Chlorine-36

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Chlorine-36 is a naturally occurring radioactive isotope with a half life of 301,000 thousand years. The high solubility of the chloride ion in water makes this an ideal isotope for the study of hydrological systems. The ratio of ^{36}Cl to stable chloride in typical environmental samples is of the order of a few parts in 10^{14}. It has only been due to the development of Accelerator Mass Spectrometry (AMS), over the last decade, that it has become possible to detect ^{36}Cl at typical environmental levels. Measurements of ^{36}Cl in environmental samples are presently being made using the 14UD accelerator at the Australian National University.

Chlorine-36 in the atmosphere is produced primarily by cosmic ray spallation reactions on atmospheric ^{40}Ar. The ^{36}Cl produced in this manner is mixed with atmospheric chlorine salts of a terrestrial origin which contain essentially no ^{36}Cl. This produces a variation in the $^{36}Cl/Cl$ ratio in atmospheric precipitation, from a few parts in 10^{15} on the coast to several hundred parts in 10^{15} in continental interiors. $^{36}Cl/Cl$ ratios of atmospheric precipitation in and around the Murray Basin have now been calculated; they vary by approximately one order of magnitude over the Basin. It is the modification of the ^{36}Cl signal that allows information on the movement of salt and water within an aquifer to be deduced. Factors that may affect the ^{36}Cl signal include: radioactive decay; subsurface production; dissolution of ancient salt evaporites; evapotranspiration and ion filtration; the mixing of two water bodies; and the addition of modern salt originating from atmospheric precipitation.

Radioactive decay and subsurface production of ^{36}Cl: Decay of ^{36}Cl is only important in systems which operate on time scales which are of the order of or greater than 300,000 years. In extreme cases, where aquifers flow over periods which are long compared with the half life, and where radioactive decay is the dominant process, the decay of the ^{36}Cl signal can be used as a dating tool, for example in the Great Artesian Basin.

Conversely, ^{36}Cl can be produced in subsurface chlorine as a result of neutron capture reactions on ^{35}Cl as a result of natural radioactivity in the aquifer matrix. If radioactive decay and subsurface production are the dominant processes affecting the ^{36}Cl signal, then the $^{36}Cl/Cl$ ratio will asymptotically approach the secular equilibrium value characteristic of the aquifer environment. This secular equilibrium ratio depends upon the local U and Th concentrations, and the chemical composition of the aquifer matrix. Typical secular equilibrium $^{36}Cl/Cl$ ratios range from $\sim 4 \times 10^{-15}$ in sandstones to $\sim 30 \times 10^{-15}$ in granites, while ratios in materials with unusually high U to Th content can be very much higher. As with radioactive decay, the time constant affecting the approach to secular equilibrium is the ^{36}Cl half life. Therefore, subsurface production will only be important in systems which operate on time scales which are of the order of or greater than this period, unless the secular equilibrium value is very high as a result of large U and Th concentrations. In situations where the $^{36}Cl/Cl$ ratio of the recharge water is very low relative to the secular equilibrium value, the residence time of salt in the system is long, and production of ^{36}Cl is the dominant process, then it would be possible to use subsurface production of ^{36}Cl as a dating tool. Such a situation may exist in confined aquifers which recharge near to the coast.

Evaporation and ion filtration: Evaporation or ion filtration will affect the ^{36}Cl concentration in the water, but leave the $^{36}Cl/Cl$ ratio in the water unaltered. Therefore, these processes have a distinct ^{36}Cl signature.

Incorporation of salt into the aquifer: The incorporation of salt into the aquifer will affect the ^{36}Cl signal in the manner that reflects the $^{36}Cl/Cl$ ratio of the added salt. For example, the effect of the dissolution of ancient salt evaporites, which will contain very little ^{36}Cl, would be quite different to the addition of relatively modern salt which has accumulated as a result of atmospheric precipitation.

Hence, in favourable circumstances, ^{36}Cl measurements can be used to distinguish between different possible sources of additional salt, and between the addition of salt versus evaporation or ion infiltration as a mechanism for increasing salinity.

The mixing of two water bodies: The mixing of two water bodies alters both the ^{36}Cl concentration and the $^{36}Cl/Cl$ ratio in the water to values intermediate between those of the two original water bodies. The extent of the effect depends in a linear fashion upon the degree of the mixing.

Lachlan Fan: Sixteen $^{36}Cl/Cl$ ratios have been measured for wells in the Pliocene and Renmark aquifers from the Lachlan Fan in NSW. In the recharge zone, the $^{36}Cl/Cl$ ratio is about 170×10^{-15} compared with 100×10^{-15} for the Great Artesian Basin and 20×10^{-15} in the Murray-Mallee recharge zone. Displacement of points downward and to the right in a plot of 36Cl/Cl versus 36Cl/L is observed between the recharge area and the farthest part of the flow-line studied. This indicates that solution of dead chloride and evaporation are important. If the change occurs uniformly down the flow-line, it can be calculated that evaporation increases the chloride concentration by about 8 mg/L per km while solution of dead chloride also increases the chloride concentration by about 9 mg/L per km. This model implies that from recharge to 250 km along the flow path, about 98% of the water in the Pliocene Sands is lost by evaporation. At the opposite limit of no evaporation, the dead chloride input must be doubled. Further measurements are needed to obtain more information on the progress of these processes through the aquifer.

Murray Mallee: Analyses of ^{36}Cl from 20 wells in the Murray Group limestone in the Victorian and South Australian mallee show an interesting contrast with results for the Lachlan Fan. The $^{36}Cl/Cl$ ratio in the recharge zone near Harrow is the smallest value observed. This is consistent with the proximity of the sea as a source of 'dead' chloride but the ratios tend to be lower than expected from reported chloride precipitation rates except nearest to the sea.

Values of $^{36}Cl/Cl$ increase systemically as the water moves along the flow line in a north-northwesterly direction from Harrow. This increase may be interpreted as being caused by underground production of ^{36}Cl and mobilisation of secular equilibrium chloride. However, the values of $^{36}Cl/L$ increase in a north-northeasterly direction which is consistent with an exponential decrease in sea spray Cl^- concentration with distance from the coast. It is therefore possible that recharge of the aquifer is occurring from rainwater infiltration over the whole area. If this is the case, the lower values of $^{36}Cl/Cl$ occurring near Mildura requires that there be some contribution from salt in the unsaturated zone or mixing with groundwaters from the east having lower ratios.

Further measurements are needed to quantify contributions from each of these processes. Assuming the change in chloride is uniform along the 230 km flow line between Harrow and Mercunda, it can be calculated that evaporation increases the chloride concentration by about 5 mg/L per km and causes about 87% of the water to be lost.

It should be emphasised that these results are only preliminary and further measurements are needed to characterise the various sources of chloride. There are also many gaps in the data. Sampling programs in wells separately tapping the Pliocene and Renmark aquifers in the Lachlan Fan need to be carried out so that detailed analysis of the chloride variations can be made. Further work in the Murray-Mallee area also seems warranted to clarify the origin and movement of chloride.

The Possible Effects of Salinity on the Channel Morphology and Sediment Load of the Murray River

Paper Presented:

Erosion and deposition along the middle Murray: is salt involved

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Salt can cause soils to either disperse, or flocculate. For a given soil the boundary between the flocculated and the dispersed states is dependant upon the sodium adsorption ratio (SAR), concentration of salts, pH and mineralogy This paper examined the possible influence of rising salinities in the Middle Murray (Torrumbarry to Lock 9) upon patterns of erosion and deposition since 1869.

Comparison of long profile surveys (published 1876, 1927, and 1981) shows that the bed of the Murray has generally aggraded since the 1920s with a significant zone of deposition below the Wakool Junction, across the Mallee. This zone corresponds with a dramatic drop in turbidity below the Wakool Junction – the assumption is made that suspended material is settling out in this reach of the river and contributing, to some degree, to the deposition across the Mallee. The salinity at Morgan is increasing at 1 - 3% per year. The mean gradient of the river bed increases to 14.5 x 10^{-5} between Nyah and the Wakool Junction, after which it drops suddenly to about 5 x 10^{-5}. Over the same reach salinity levels rise dramatically with the input from Barr Creek and the Loddon and Wakool Rivers. Perhaps a threshold has been passed where increasing salinity causes flocculation of suspended clays, and the drop in gradient across the Wakool Junction combined with the effect of the Euston Weir pool, may be enough to produce deposition.

There is also evidence of bank erosion between Albury and Wentworth with actively eroding banks and undermined River Red Gums, although there is no evidence that the rate of erosion has increased over the last century. It is possible that salty Murray water flowing past the banks, or hypersaline groundwater seeps, could be encouraging erosion, flocculating and depositing this material on the bed. In other words, increasing salinity may be producing a redistribution of material from the banks to the bed of the Murray River. If this scenario is true, rising water-tables across S.E. Australia may influence channel morphology in many streams. Further, the salinities involved may be lower than previously considered important.

Preliminary sampling and testing indicates that some flocculation seems to be occurring even at the low salinities presently experienced in the Murray. Low salinities also increase settling rates in a still column of water in the laboratory. More evidence is needed before the pattern of erosion and deposition in the Middle Murray can be attributed to rising salinities.

Groundwater Modelling

Paper Presented:

The nature of some ill-posed problems arising in aquifer modelling

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Quantitative modelling of hydrogeological systems will play a major role in future management of the Murray Basin. Increased data collection and computer power are allowing the development of complex groundwater models constructed to simulate management strategies. Firstly, however, the parameters and inputs must be identified. Some quantities are estimated – often an unstable process. This paper "examined the differences between the problems of identifying the parameters or inputs of a hydrogeological system from output observations, and the problem of simulating future outputs for given inputs and parameters". The implications for construction of algorithms for the solution of the above problems was discussed; the mathematics involved was also presented.

Social Issues

Paper Presented:

Community awareness for salinity control

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The Victorian State government has selected the Goulburn Broken Region as a pilot area for the development of effective strategies for the control of salinity. Part of this is the development of a community education program. This included an investigation of levels of community awareness and response to salinisation, and an evaluation of present community education strategies and mobilization. In response to a questionnaire 4,977 returns were obtained representing 3.6% of the regional population. Results revealed a high level of awareness of salinity (72.5%), although salinity was rated below social and economic issues facing the community. Tree clearing and planting were seen as the key cause and solution respectively, while responsibility for salinity control was believed by 73.0% to be that of government, farmers and the local community together. The results of interviews with key personnel revealed a varied level of awareness and concern.

The pilot management program has played a major role in catalysing community response, in particular, facilitating the development of a co-operative group approach to salinity control. That is, where farmers join together with the aid of extension officers and the support of groups such as Conservation volunteers and the local Apex clubs to act to control salinity. The actions of such 'land care groups' has then been used to mobilize the media to facilitate public awareness and support for the government's action.