The management of groundwater-induced river salinity due to land clearing in the Murray Basin, southeastern Australia

S. R. BARNETT
South Australian Department of Mines and Energy, PO Box 151, Eastwood, South Australia 5063

Abstract Widespread clearing of native vegetation and extensive irrigation in the Murray Basin has dramatically increased recharge and caused a major change to the hydrodynamic equilibrium of the basin. The resultant rising water tables have caused widespread salinization with an estimated annual cost of $100 million. Computer modelling has been used to estimate the effects on the salinity of the River Murray of the increase of saline groundwater discharge which will result from the rising water table. Selective broadscale revegetation in critical areas adjacent to the river will reduce groundwater inflows by reducing recharge, but may prove uneconomic.

Contrôle de la salinité résultant d’apports supplémentaires d’eau souterraine provoqués par la suppression des phréatophytes

Résumé Le nettoyage largement répandu de la végétation naturelle et l’irrigation extensive dans le bassin du Murray ont dramatiquement augmenté la recharge et ont causé de grands changements à l’équilibre hydrodynamique du bassin. La remontée résultante des niveaux d’eau de la nappe phréatique a causé des problèmes de salinisation sur de grandes surfaces avec un coût estimé à $100 million par an. La mise en modèle (sur ordinateur) a été employée pour estimer les effets sur la salinité de la River Murray par suite de l’augmentation des apports d’eau souterraine salée qui résultera de l’élévation des niveaux d’eau. La reconstitution selective de la végétation dans les régions critiques voisines de la rivière va réduire ces apports d’eau souterraines par réduction de la recharge, mais ces mesures peuvent s’avérer non économiques.

INTRODUCTION

Groundwater is a very important resource in Australia with large areas dependent on it for agricultural, industrial and domestic purposes. Australia is a very dry country with 80% of its area receiving less than 250 mm annual rainfall. Australia is also a young country in terms of European settlement which occurred only 200 years ago. The combination of these circumstances resulted in some early decisions on water resources being based on ignorance and misguided enthusiasm
and having a profound effect on the quality of both surface and groundwater. This paper describes a computer modelling exercise which was carried out to assist decision-making in developing management strategies to overcome problems caused by earlier inappropriate decisions.

THE MURRAY BASIN

This exercise took place in the Murray Basin in southeastern Australia (Fig. 1). It covers some 300,000 km² and contains some of the nation's most important farming land which generates several billion dollars in agricultural income, both from dryland farming and irrigation. The climate is mostly semi-arid with annual rainfall in the range 200–400 mm and annual evaporation over 2000 mm.

The basin consists of a thin veneer of Tertiary sediments up to 600 m thick which contain a multi-layered series of aquifers of limited storage capacity in a closed groundwater basin. Recharge occurs mainly in the higher rainfall areas around the basin margins with diffuse recharge from the infiltration of rainfall occurring over the basin as a whole.

Discharge occurs by evaporation from areas of shallow groundwater, and more significantly, by discharge into the River Murray (Fig. 1). This is the dominant river whose drainage basin includes almost the entire sedimentary basin. It is a vital resource which supplies water for irrigation and domestic supplies for over one million people.

The basin can be divided into two broad geomorphic units — the very flat and extensive Riverine Plain, which is dominated by fluvial processes and is transversed by numerous westerly-flowing rivers and tributaries, and the Mallee region which is flat to undulating and is dominated by aeolian landforms such as dunefields (Fig. 1).

Early land management practices in the Murray Basin sowed the seeds of a bitter harvest which we are now beginning to reap. These are the ill-conceived establishment of irrigation, and more importantly, the widespread clearing of the native vegetation to establish cropping and grazing.

Irrigation

Large irrigation areas were established early this century on the Riverine Plain for the cultivation of rice, dairy pasture and horticulture. Fears of water logging and soil salinization were dismissed by the experts at the time ... "the quantity of water necessary to raise the water table to the surface is so great that it almost baffles the imagination"; and "it is felt that there is a reasonable chance of the underground water getting away towards the sea or the river sufficiently fast to prevent the raising of the groundwater level unduly, no matter what amount of irrigation water is applied to the surface" (Irrigation Record, 1916).

However, because of the combined effects of the leaching fraction required to remove salt from the root zone, leaking irrigation channels and poor irrigation practices, the water table inevitably rose (Fig. 2(a)) until, at
The management of groundwater-induced river salinity

DARLING BASIN

Mallee regional groundwater model

Irrigation areas

Fig. 1 Location diagram of the Murray basin.

the present time, some 560 000 ha have been affected by the water table being within two metres of ground surface and the resultant salinization. Over the next 30 years, an additional 300 000 ha are expected to be affected.

Further downstream in the Mallee region, large horticultural irrigation areas adjacent to the River Murray have similarly formed water table mounds which displace naturally occurring saline groundwater into the river.

Vegetation clearance

The native vegetation is well adapted to the semiarid environment, particularly
a species of eucalypt called mallee which is dominant in the Mallee region. It is a deep rooted species and an excellent scavenger of water. Point estimates of diffuse recharge using the chloride concentration of soil water in the unsaturated zone obtained consistent results of 0.1 mm year$^{-1}$ beneath uncleared areas of this mallee vegetation (Allison & Hughes, 1983).

However, beneath cleared areas which are now used for cropping and grazing, recharge rates are much higher, in the range of 5–30 mm year$^{-1}$ (Cook et al., in press). This dramatic increase in recharge by up to two orders of magnitude has resulted in a major change to the hydrodynamic equilibrium of the basin with disastrous consequences. Rising water tables (Fig. 2(b)) are bringing salt previously stored in the aquifer to the surface where it is concentrated by evaporation and adversely affects soils, streams and vegetation. This process is occurring not only within the basin but in the highland recharge areas bordering the southern and eastern margins of the basin. Aquifer water levels are rising at the rate of 0.1–0.2 m year$^{-1}$ (Macumber & Dyson, 1988) and have salinized thousands of hectares. As regional water tables rise, especially in the Mallee region, discharge of saline groundwater to the River Murray will also increase which is of great concern to the downstream users in South Australia where an increase of 1 EC unit (1 microSiemen cm$^{-1}$) results in a total cost to industrial, agricultural and domestic consumers of $67 000 per year.

The total cost to Australia of rising water tables and the resultant salinization in the Murray Basin is of the order of $100 million a year through the loss in agricultural production and land values as well as the costs to the domestic and industrial users. It is becoming the nation's most critical environmental problem.
The management of groundwater-induced river salinity

THE MALLEE REGIONAL MODEL

Because of the concern for the increase in salinity in the River Murray, an investigation into the regional hydrogeology of the South Australian portion of the Murray Basin has been carried out over the past eight years and a good understanding of the groundwater systems and their interactions with the River Murray has been obtained (Barnett, 1989). The aquifer in question is the Murray Group limestone which is in hydraulic connection with the River Murray. It is mainly recharged in southwest Victoria and groundwater moves under low gradients along flow paths of up to 350 km before it drains into the river. Salinities increase downgradient from below 1000 mg l⁻¹ at the margin of the basin, to over 20 000 mg l⁻¹ adjacent to the river. The limestone aquifer is overlain by a blanket of Pliocene sands up to 50 m thick with the depth to water table varying from 30 to 60 m which is much deeper than the Riverine Plain where salinization has already occurred.

A groundwater computer model of the Mallee region was established to assist in developing management strategies to overcome probable increases in river salinity as a result of land clearing. This three-layer finite element model calculates groundwater flow rates and pressure distribution of the major aquifer systems on a 25 km grid over the area shown in Fig. 1. Recharge to the model can be varied, depending on the distribution of Mallee vegetation. Groundwater outflow from the model is calculated and, knowing groundwater salinities adjacent to the river (which is a discharge boundary), salt inflows to the river can be determined. Predictive runs have been made with various scenarios of vegetation cover, ranging from completely cleared to completely revegetated, and these are presented in Table 1.

### Table 1 Scenarios modelled and effects on river salinity after 50 years of increased recharge

<table>
<thead>
<tr>
<th>SCENARIOS</th>
<th>INCREASE IN TONNES/DAY AT TAILLEM BEND</th>
<th>INCREASE IN EC AT MORGAN</th>
<th>AVERAGE ANNUAL COST ($ MILLION, 1983)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A PRESENT VEGETATION PATTERN, 5mm RECHARGE OVER CLEARED AREAS</td>
<td>355</td>
<td>70</td>
<td>4.7</td>
</tr>
<tr>
<td>B PRESENT VEGETATION PATTERN, 10mm RECHARGE OVER CLEARED AREAS</td>
<td>722</td>
<td>145</td>
<td>9.7</td>
</tr>
<tr>
<td>C ALL VEGETATION CLEARED, 5mm RECHARGE OVER WHOLE AREA</td>
<td>367</td>
<td>72</td>
<td>4.9</td>
</tr>
<tr>
<td>D PRESENT VEGETATION PATTERN, ASSUMES 40km STRIP ADJACENT TO RIVER</td>
<td>67</td>
<td>16</td>
<td>1.0</td>
</tr>
<tr>
<td>D_{25} ASSUMES 25 YEARS OF HIGHER RECHARGE RATES (10mm/YEAR), THEN 40km STRIP IS REVEGETATED</td>
<td>167</td>
<td>37</td>
<td>2.3</td>
</tr>
<tr>
<td>E WHOLE AREA REVEGETATED AFTER 50 YEARS OF HIGHER RECHARGE RATES (VICTORIA EXCLUDED)</td>
<td>197</td>
<td>35</td>
<td>2.6</td>
</tr>
</tbody>
</table>

The model calculated only inflows from the groundwater system to the River Murray from south and east of the river. Upstream of Morgan, saline inflows are not expected to increase markedly from the north because of the limited amount of clearing in the area, which receives marginal rainfall for cropping. Downstream of Morgan, a geological fault to the west of the river
acts as a barrier to groundwater flow toward the river and will restrict any increase in saline inflows. Also, clearing is restricted in this area because of the shallow stony soils which are unsuitable for cropping.

Using known aquifer geometry and hydraulic parameters, a good steady-state calibration with the present water table configuration was achieved using the pre-clearing recharge rate of 0.1 mm year\(^{-1}\) (Fig. 3(a)). The present situation is essentially a pre-clearing scenario as the pressure front of the increased recharge resulting from clearing, which began some 50 to 80 years ago, has not yet reached the water table over most of the Mallee area and will probably not do so for another 30 to 50 years (Jolly et al., in press). When it does so, the water table will rise over a period of 500–1000 years to reach a new steady state position close to the ground surface (Fig. 3(b)).

The results of the modelling exercise are shown in Fig. 4 where the time intervals are taken from when the increased recharge first reaches the water table, not the present time. Because of the regional nature of the model and its coarse grid, the actual values of salt inflows presented as tonnes day\(^{-1}\) may not be exact. However the increases in inflows from present values are more meaningful.

Table 1 shows the effect of these increased salt inflows on River Murray salinity after a period of 50 years of increased recharge. This was calculated using the MURKEY model which simulates flow, water levels and salinity for the river. The cost to the community of these salinity increases is calculated by SACOST, a salinity economic impact model which considers damages to horticultural and pastoral crops and to domestic and industrial users.

![Fig. 3 Water table contours (steady state): (a) before clearing, (b) after clearing.](image)

**RESULTS**

Scenario A includes the present vegetation distribution with 0.1 mm year\(^{-1}\) recharge and a conservative 5 mm year\(^{-1}\) recharge over all cleared
areas. As expected, salt inflows will steadily increase by about 30% over the total river length resulting in a mean salinity increase at Morgan of 70 EC after 50 years at an average annual cost of $4.7 million.

Scenario B assumes the same conditions as Scenario A but with a value of 10 mm year\(^{-1}\) recharge over the cleared areas which represents the lower range of recharge values obtained. Increases in salt inflows are approximately double those due to a 5 mm year\(^{-1}\) recharge rate, especially up to 50 years with 145 EC increase at Morgan and an average annual cost of $9.7 million.

Scenario C assumes complete clearance of all vegetation and 5 mm year\(^{-1}\) recharge over the whole area. Increases in salt inflows above Scenario A are not great up to 50 years and even after 500 years, the total increase is only 9% resulting in an increase of 72 EC at a cost of $4.9 million.

Scenario D maintains vegetation in the 40 km zone adjacent to the river. This will reduce saline inflows to the river because the vegetated zone will act as an umbrella to reduce recharge and hence the rate of rise of the water table beneath that zone as shown in Fig. 5. Gradients toward the river are reduced and so are the saline groundwater inflows. Table 1 shows that salt inflows would have been significantly reduced had this area remained vegetated. An increase of only 16 EC would have been recorded at Morgan at an annual cost of $1.0 million.

Scenario D_{25} assumes that strong political will and community support occurred for a revegetation of the 40 km zone after the high recharge rates had occurred for 25 years. Although not as effective as Scenario D, it still results in a significant reduction of 50% in the Morgan salinity increase compared with the "do nothing" scenario A, with an increase of 37 EC costing $2.3 million.

Fig. 4 Result of modelling exercise.
Scenario E is a somewhat idealistic frame of reference for revegetation strategies and requires that after 50 years of the higher recharge rates, the whole of the Mallee in South Australia is revegetated. After the initial increase in saline inflows due to clearing, this scenario allows only a small increase thereafter. However, for the first several hundred years, the more selective revegetation strategies under Scenario D obtain greater reductions in inflows (Fig. 4).

It is anticipated that further work will provide an improved understanding of recharge rates and their areal distribution and also an estimate of when the increased recharge will reach the water table. This will allow refinement of the model which will incorporate a finer mesh and will take into account more recent drilling information. The sensitivity of saline inflows to the location and area of strategic revegetated zones will also be tested. Needless to say, the economic aspects of broadscale revegetation need to be investigated.

CONCLUSIONS

The clearing of native vegetation and extensive irrigation has changed the hydrodynamic equilibrium of the Murray Basin by increasing recharge by up to two orders of magnitude. Rising water tables have caused widespread salinization and will raise the salinity of the River Murray by increasing saline groundwater discharge.

Computer modelling has indicated that an increase of at least 70 EC units could occur 50 years after the water table begins to respond to the increased recharge. Broadscale revegetation in strategic areas adjacent to the river may reduce saline groundwater inflows by reducing recharge. However, the economic and social impacts need to be investigated.

REFERENCES


