Optimising the Location of Pump Sites for Improved Management of Groundwater Pumping Schemes

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Abstract: Irrigation areas in many parts of the world are affected by rising shallow watertables which result in soil salinity and reduced crop yields. Recharge from irrigated areas and inadequate drainage, have resulted in rising watertables and increased the potential for land salinisation in the Wakool Irrigation District in south-eastern Australia. To control the rising watertable a pumping scheme was established in the 1980's to pump saline groundwater for disposal to the Wakool Evaporation Basin. This study was undertaken in order to develop a series of optimisation tools for managing the existing groundwater pumping scheme and to develop a new model (PUMPSITE) which can be used to optimise the locations of new pump sites. The new pump sites are located to result in improved protection of the Wakool Irrigation District by minimising the impact of shallow watertables. Three models were developed: the first model is an optimisation model for estimating recharge; the second is a simulation model for predicting watertables at some future point in time; and the third model is used to predict optimised pumping rates for a given time period. The PUMPSITE model was used to determine the potential for siting new tube wells for any given location in the model domain. The results show that adequate protection from waterlogging and salinisation can be achieved when the pumps are operated at optimal levels. Optimising pumping rates using PUMPMAN results in a 25 percent reduction in disposable saline groundwater and a savings of AUD $80,000 in annual operating costs. PUMPSITE predicts the location of new pump sites where beneficial impacts are maximised, and optimises the pumping rate at which these new pumps should operate.

Keywords: Groundwater; Pumping; Watertable; Recharge; Optimisation;

1. INTRODUCTION

The Wakool Irrigation District in south-eastern NSW was established in 1936. Since then irrigation has expanded to the current level of 220,000 ha. Recharge from irrigated areas and inadequate drainage, have resulted in rising watertables and increased the potential for land salinisation in the Wakool Irrigation District (WID). By 1974 approximately 45,000 ha were affected by shallow water levels, within 2m from the surface. By 1983, losses in production up to 50 percent were being experienced in the rice growing areas within the district.

A pumping scheme was implemented for the Wakool Irrigation District (Figure 1) in two stages commencing in 1981 to minimise waterlogging and land salinisation. The scheme was used for dewatering the upper Shepparton aquifer in the Wakool Irrigation District. The near surface groundwater was pumped and disposed off in the Wakool Evaporation Basin which covers approximately 2000 ha. After commencement of the pumping scheme the approach taken by the Department of Water Resources was to monitor the rise in groundwater levels using an extensive piezometer network and then to recommend sites for new pumps as the problems appeared. The approach was simple and served the purpose of lowering the shallow watertable. However, several deficiencies were identified with this approach, the major ones being the inability to ascertain optimum pumping rates, over-pumping resulting in excess water for disposal, and the lack of a rigorous approach to siting tube wells.

This study arose from the need to manage the pumping scheme and to investigate the viability of shallow groundwater pumping for other irrigation districts in the Murray region. The Wakool Land and Water Management Plan has identified shallow groundwater pumping as one of several options for improving the sustainability of irrigated agriculture in the Murray region. Having a basis for accurately assessing this option against other options being proposed for the WID requires that a rigorous approach be used and to ensure that results meet with expectations.

This study will provide a means to accurately assess the benefits of shallow groundwater pumping against other options being proposed for the Wakool Irrigation District. A novel approach has been developed which involves a combination of optimisation and simulation models. Four models have been developed: the first model is a recharge optimisation model developed using Linear Programming; the second is a simulation model for predicting watertables at some future point in time; and the third model is used to predict optimised pumping rates for a given time period. The Pumpsite model was developed in order to determine the potential for siting new tube wells for any given location in the model domain. The model gives the Resource Manager several optimum locations for siting pumps. These results are then incorporated into a groundwater model to verify that the locations and the pumping rates specified in the option would produce the desired result.

2. DEVELOPMENT OF PUMPMAN AND PUMSITE

The study involved the development of four models. PUMPMAN was developed to optimise pumping rates for existing tubewells in the WID and to prepare a plan of operation for drainage tubewells to control water logging. PUMPSITE was developed to optimise the siting of new tubewells and rehabilitation of existing tubewells that are non-operational or operating at sub-optimal levels.

The method comprised four steps and was based on a 1000 m x 1000 m finite difference grid as shown in Figure 1. The model grid consists of 36 rows and 50 columns.

PUMPMAN and PUMSITE combine optimisation and simulation modelling and consist of:

- a model which optimises recharge rates;
- a simulation model for predicting watertables at some future point in time;
- a model which optimises pumping bores; and
- a model which optimises the siting of new tube wells.

2.1 Net Recharge Model

The net recharge model uses linear programming to determine the distributed recharge for a selected region of the Wakool Irrigation District.

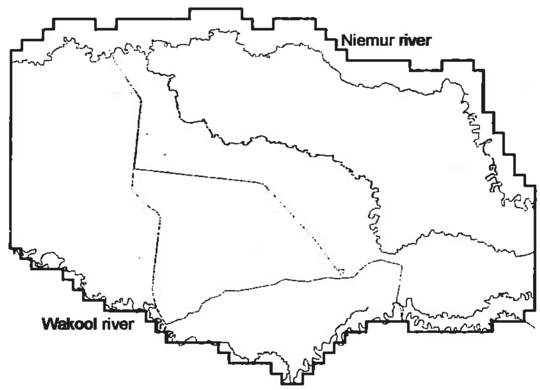

Figure 1. Model grid and pump site for the Wakool sub-surface drainage scheme.

The area is modelled using a 1000 m x 1000 m grid. The objective is to optimise recharge for the model domain given observed water levels for any two points in time and suitable aquifer characteristics. In this case we used observed water levels measured in February and July 1990 to obtain net recharge rates for each grid cell. Aquifer properties were estimated from the calibrated SHE model for Wakool [Storm and Punthakey, 1995; Demetriou and Punthakey, 1999].

The equation for flow in an unconfined aquifer was represented in a linearised form and embedded as the groundwater flow constraint in PUMPMAN and PUMPSITE.

$$T\frac{\partial^2 h}{\partial x^2} + T\frac{\partial^2 h}{\partial y^2} = S\frac{\partial h}{\partial t} + R(x,y,t) + Q(x,y,t)$$

where T is transmissivity ($m^2 d^{-1}$), h is piezometric head (m), S is the storage, x and y are cartesian coordinates (m), R is the net recharge rate ($m\ d^{-1}$) where positive values are recharge and negative values discharge, and t is time (d), and Q is groundwater pumping ($m^3\ d^{-1}$).

2.2 Groundwater Flow Model

The next step was to develop a groundwater simulation model for the same area using a 1000 m x 1000 m grid cells. Starting from initial observed water levels in February 1990 the model was run for 6 months till July 1990 with all pumps turned off. The simulated depth to watertable in July 90 is shown in Figure 2. The objective was to determine the maximum rise in water levels given zero pumping. The recharge rates used in this model were the optimised values obtained from the Recharge model described in section 2.1.

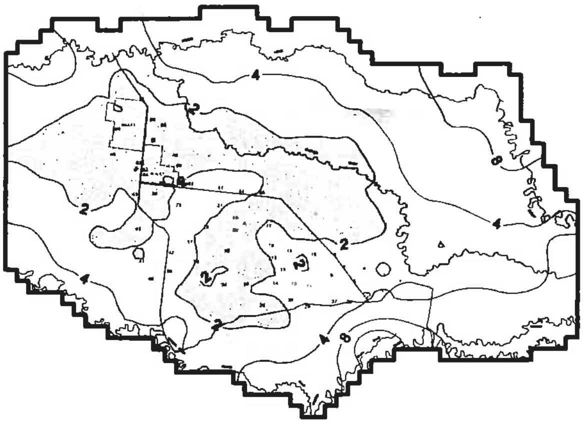

Figure 2. Depth to watertable (Jul 90) simulated by MODFLOW for the WID.

2.3 PUMPMAN Model

PUMPMAN was developed using linear programming to determine an optimum pumping schedule for the 6 month period under investigation [Punthakey et al 1994]. PUMPMAN utilises an embedded groundwater flow equation as a constraint and additional user specified constraints to determine optimum pumping rates given the watertable is constrained at a specified depth. The depth to the watertable was specified at 2.1 m below the ground surface. Provision is made in the model to allow the critical depth to vary spatially. The following additional constraints were used in PUMPMAN:

- Pumping was restricted to cells where a pump is present.
- All pumps must operate for at least 1 hour per day for maintenance purposes.
- Pumping rates must not exceed the operation capacity of the pump within a cell.

2.4 PUMPSITE Model

PUMPSITE was developed to optimise the location of new pump sites, to place pumps where beneficial impacts are maximised, and to determine the optimal rate at which these new pumps should operate. The basic features of the model are similar to PUMPMAN described in 2.3 above. PUMPSITE was developed using linear programming. The model constrains watertables to a specified depth and then identifies areas where the model over-achieves (target water levels are not met). The next step was to place imaginary tubewells in the target grid cells and to re-run PUMPSITE. The proposed strategy is to place imaginary pumps at various selected sites and to let the model decide which pumps need to be operated and at what rates.

Eight simulations were carried out over 6 monthly intervals from February 1987 to February 1991. Three periods representing dry, average and wet conditions were selected for February to July and similarly for July to February. In addition to optimising each pump the model also alerts the resource manager to areas where watertables are rising or are likely to rise and which cannot be controlled by the existing bore field.

3. RESULTS AND DISCUSSION

3.1 Analysis of Recharge

A series of runs were undertaken to estimate the spatial distribution of recharge using the recharge optimisation model described in 2.1. These runs were undertaken over a six month period from February to July 1987, 1989 and 1990 and are indicative of winter conditions with higher net recharge. The runs undertaken over the summer months from July 1987 to February 1988, July 1988 to February 1989 and February 1990 to July 1991 show lesser amount of net recharge. There were also large differences in the spatial distribution of recharge rates shown in Table 1. The runs are placed into three categories indicating low medium and high net recharge during winter and summer seasons. During the winter season the sum of recharging and discharging cells vary from 1.62 to 79.86 mm. During the summer season the sum of recharging and discharging cells vary from -17.36 mm to 9.99 mm.

3.2 Estimation of Future Water Level

Future water levels were predicted by MODFLOW using net recharge estimates from the Recharge model, with all pumping turned off. The simulated depth to watertable with all pumps turned off is shown in Figure 2. The forward modelling shows a large part of the district would be affected if the pumping scheme did not exist. The area with water levels within 2 m from the surface would have increased to 33,900 ha by July 1990 without pumping. The area with shallow watertables would probably have increased further if the model were simulated for a longer time period.

3.3 PUMPMAN Model Results - Optimising Pumping Rates

Pumping is about 15-16000 ML per year based on operating records of 60 pumps. Optimal pumping rates determined by PUMPMAN for selected stage 2 pumps are shown in Figure 3. The results show that optimising pumping rates can result in significant reduction in pumping rates as well as improve the performance of the scheme.

Table 1. Recharge and discharge rates estimated by the Recharge model (mm)

Run	Net Recharge	Recharge	Discharge	Recharge Category
Feb 87 – Jul 87	1.62	27.59	-25.97	Low
Feb 89 – Jul 89	42.63	65.06	-23.43	Med
Feb 90 – Jul 90	79.86	90.83	-10.96	High
Jul 88 – Feb 89	-17.36	31.43	-48.80	Low
Jul 90 – Feb 91	-5.83	37.31	-43.13	Med
Jul 87 – Feb 88	9.99	39.25	-29.26	High

Table 2. Optimised pumping rates estimated by the Recharge model

Run	Total Pumping ML/yr	Pumping Category	Area with water levels <1.5 m (ha)
Feb 87 – Jul 87	12000	Low	3000
Feb 89 – Jul 89	14000	Med	5200
Feb 90 – Jul 90	21000	High	6800
Jul 88 – Feb 89	9900	Low	700
Jul 90 – Feb 91	10000	Med	1500
Jul 87 – Feb 88	14000	High	2500

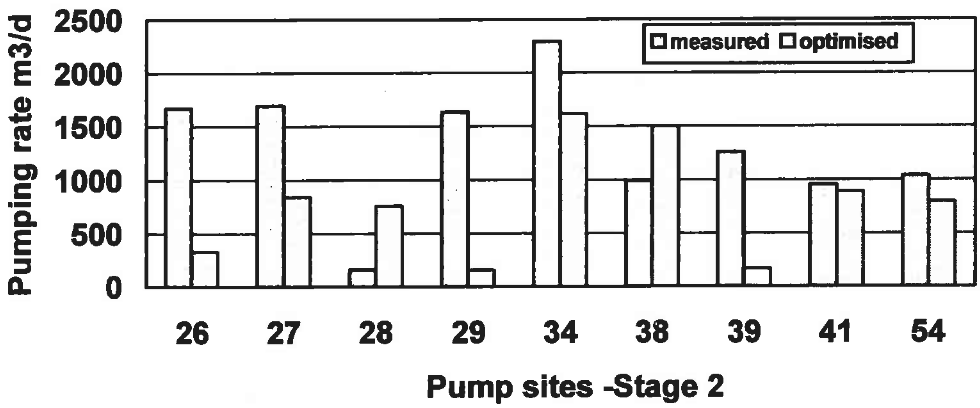

Figure 3. Comparison of measured (solid) and optimised (dash) pumping rates for selected Stage 2 pump sites, Feb 1990.

To lower the watertable to 2.1 m below the surface under various recharge scenarios would require continuous (dynamic) management of the existing pumping scheme to ensure target groundwater levels were met during each season. The major assumption that is involved in this estimate is that watertables need to be constrained at 2.1 m below the surface. Should this constraint be made less conservative say 1.5 m then this will result in much lower optimum pumping rates. To do so initially would be to introduce a level of risk which may not be acceptable. However, this figure could be fine tuned to perhaps 1.8 m as the management of the scheme was gradually improved with concurrent monitoring of water levels.

Overall we estimate that a probable savings of 20 to 25 percent could be achieved in operating costs by using this approach, with much higher savings if continuous or dynamic management of the scheme is adopted.

3.4 PUMPSITE Model Results - Siting New Pumps

In addition to optimising each pump the model also alerts the resource manager to areas where watertables are rising or are likely to rise and which cannot be controlled by the existing bore field. For instance the Feb to Jul 1990 run with average recharge identified 52 sites with watertable less then 1.5 m from the land surface. Imaginary pumps were placed at these sites with each pump having a pumping capacity of 1.5 ML/d, to let the model decide which pumps need to be operated and at what rates. The initial run identified a total of 41 sites for possible new pump sites (Figure 4). Eleven sites were discarded because optimal pumping rates were minimal.

Of the possible 41 new sites a further process of elimination needs to be undertaken. In order to improve results from PUMPSITE a set of practical constraints will be included. The initial set of rules which need to be embedded as constraints in the model are:

- ensure that existing pumps are not marginalised in order to minimise the number of new pump sites.
- include distance from spur lines and ability to determine costs of implementing new pumping sites
- embed the location of prior streams and water bearing areas to improve the likelihood of determining suitable sites for dewatering.
- identify sacrificial areas or areas where pumps will not be placed.
- define critical sites, and
- develop a strategy for staged implementation.

Finally a number of different simulations need to be undertaken with varying recharge and water level scenarios in order to identify and prioritise recurring pump sites for each simulation. These results can then be put in the simulation model for Wakool to verify that the locations and the pumping rates specified by the PUMPSITE model will produce desired results.

4. CONCLUSIONS

Simultaneous use of groundwater simulation and optimisation models to improve management of the Wakool pumping scheme is demonstrated in this study. The results show that adequate protection from waterlogging and salinisation can be achieved when the pumps are operated at optimal levels. Optimising pumping rates using PUMPMAN results in a 25 percent reduction in disposable saline groundwater and a savings of $80,000 in annual operating costs. PUMPSITE optimises the location of new pump sites allowing pumps to be placed where beneficial impacts are maximised, and also optimises pumping rates for new pumps. Preliminary runs have indicated the potential for 41 new pump sites. Inclusion of additional constraints outlined above will further refine the number and location of optimal sites.

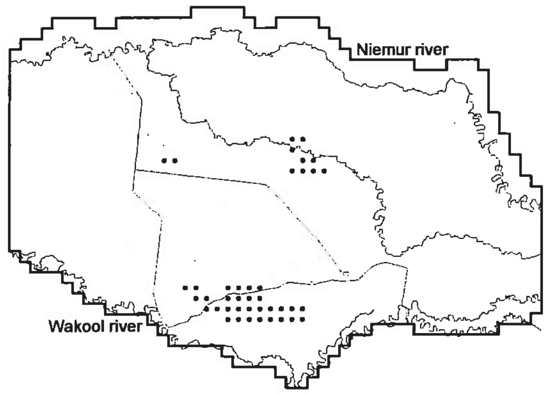

Figure 4. Optimised locations for new pump sites

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6. ACKNOWLEDGEMENTS

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