Optimisation of agricultural drainage to manage irrigation salinity in Australia – an example from the Murray irrigation area, Australia

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INTRODUCTION

The environmentally sustainable productivity of irrigated agriculture areas in the semi-arid and arid regions of the world is being challenged by the waterlogging and secondary salinisation of landscapes (Ghassemi *et al*., 1995). About one-third of the world's irrigated lands have reduced productivity as a consequence of poorly managed irrigation that has caused water logging and salinity (FAO, 1998). In a 1990 study (Gutteridge *et al*., 1990) it was estimated that areas of high water tables (i.e. water tables within 2 m of the land surface) in the Murray-Darling Basin of Australia would increase to 95% of the total area irrigated within 50 years if no actions were taken. This situation coupled with dry land and urban salinity and consequent rising salinity levels of rivers resulted in the development of a range of land and water management schemes (Blackmore, 1995) under a basin wide Salinity and Drainage Strategy. In order to achieve the salinity targets a number of actions such as adoption of engineering options to manage irrigation salinity and best management practices, on-farm and regional management activities, and education and extension endeavours are being implemented. Wakool Tullakool Subsurface Drainage Scheme (WTSSDS) is an example of engineering options to manage irrigation salinity in the Murray Irrigation Area of New South Wales, Australia.

The Wakool Tullakool Subsurface Drainage Scheme (WTSSDS) is located in the Wakool and Tullakool Irrigation Districts of New South Wales, Australia. The total area of these irrigation districts is 2080 km^2 (208 000 ha) which includes 357 holdings. Rice, winter pasture, summer pasture, dairying and winter crops are the major irrigated enterprises. During 1981, WTSSDS was installed to drain shallow saline groundwater into evaporation basins for "disposal".

WICKED WATER PROBLEM

Wakool and Tullakool irrigation districts are being irrigated by water from the Murray River through irrigation supply channels. Extensive clearing of land combined with inefficient irrigation practices resulted in recharge greater than aquifer storage capacity and regional groundwater flow, leading to a gradual rise of the water tables. In 1944, 8 years after irrigation commenced in the area, the average depth to the water table was 8 m. From 1945 to 1981 the water table rose 0.08 m per year, bringing the average water table depth to around 5 m. In 1981, 323 km^2 (32 300 ha) had a water table within 1.5 m of the ground surface in the Wakool District. Waterlogging combined with secondary salinisation caused over 20 km^2 (2000 ha) of land to go out of production and crop yields declined by around 50% in the remaining areas (Rana, 2008).

The waterlogging and salinisation situation is very complex if low quality water exits in the superficial aquifers consisting of low-permeability materials such as medium- high plasticity clays. In such aquifers shallow groundwater pumping is possible only in limited locations and re-use or disposal of saline groundwater poses a major problem (Beltran, 1999). Once a shallow groundwater pumping regime is put in place to service a waterlogged area, changing temporal conditions (rainfall, flooding and irrigation practices) necessitate a dynamic management approach based on a comprehensive understanding of the underlying groundwater dynamics. Over a period

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of time some tubewells may prove to be ineffective while others may be drawing more water than their design discharges (Khan, 2005).

To achieve effective water table and salinity control in an irrigated area the drainage scheme should serve to keep the water levels between 2 and 3 m below the natural surface. However, in many locations in the WTSSDS the water table has been much deeper than 3 m, while at other locations the water tables have been closer to the surface. Therefore the current operation of the scheme is not hydro-economically efficient and needs to be optimised according to the changing groundwater dynamics, both in terms of space and time to achieve the hydro-economic efficiency.

TOOL TO SOLVE THE PROBLEM

For the optimal operation of the WTSSDS scheme a 3-D dynamic surface water–groundwater interaction modelling approach (Fig. 1) coupled with an optimisation model based on Generic Algorithms was developed to optimise the pumping operation of the Wakool Tullakool Subsurface Drainage Scheme (WTSSDS) to achieve hydro-economic viability. The calibrated surface water–groundwater interaction model of WTSSDS was used to optimise the pumping operation of current tubewells using Modular Groundwater Optimizer (MGO). This program was used in this study to determine the optimal well pumping rates at pumping wells in order to achieve a specific objective: minimizing the pumping rate at one or more pumping wells while maintaining the same or better water table control performance of the scheme, i.e. maintaining a minimum of 2 m groundwater depth below the natural surface in the shallower aquifer.

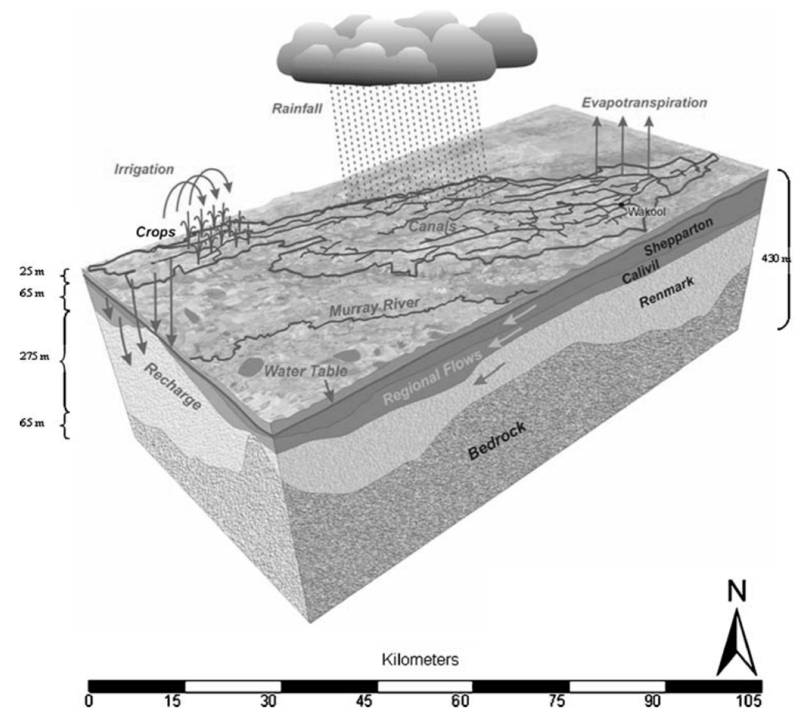

Fig. 1 Schematic of the 3-D dynamic surface–groundwater interaction conceptual model of WTTSSDS, illustrating the hydrogeological features, flows in, through and out of the model.

An assessment of the predictive capability (validation) of this optimisation model was carried out. Spatial groundwater level comparison between the water levels with actual pumping and with optimised pumping shows very less discrepancy in the whole WTSSDS (Fig. 2). Since the optimisation model reproduces closely approximated water levels in most of the study area, there was no systematic over- or under-prediction of heads in most parts of the WTSSDS area.

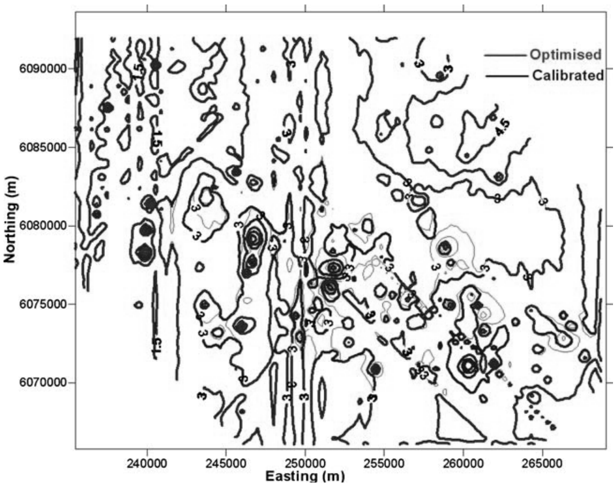

Fig. 2 Validation of the optimisation model performance using depth to water table (m) contours comparison.

KEY LESSONS

Genetic Algorithm (GA) was applied to simultaneously find the optimal well location and pumping rate in the defined problem domain. The advantage was a significant reduction in model runs, which consequently reduces the computational time and cost. After defining objective function and constraints the solution was obtained in less than 30 min of simulation time, including a MODFLOW run as well as for an entire GA simulation on an Intel Pentium processor of 2 GHz with 1 GB of RAM.

The optimal management strategy, as determined by the simulation-optimization analyses, suggests the same or even better pumping performance of the scheme could be achieved using 42 wells (rather than 53) and a maximum pumping rate of 1000 m^3 day^{-1} for an individual pump. The groundwater pumping can be reduced by around 1 MCM $year^{-1}$, which is approx. 20% less than the existing rate. This will lead to substantial cost savings by reducing the number of wells needed, and less pumping. Preliminary cost estimates indicated that $4000 MCM $year^{-1}$ pumping cost could be saved.

This study has also shown that a MODFLOW based surface–groundwater interaction model, using hydrogeology, soils, groundwater levels, groundwater pumping, channel network and net recharge information can be a useful tool for developing understanding of groundwater dynamics. The simulation–optimization analyses can effectively be used to plan an optimal operation of the subsurface drainage scheme to control water logging and salinisation in a hydro-economically viable way.

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