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ENVIRONMENTAL CONCEPTS AND MODELS FOR PARTICIPATIVE MANAGEMENT OF IRRIGATION AREAS – APPLICATIONS IN THE MURRAY DARLING BASIN

by
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Environmental Concepts and Models for Participative Management of Irrigation Areas – Applications in the Murray Darling Basin

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Innovative hydrologic research in partnership with growers and irrigation companies has shaped strategic planning and policy development for environmentally sustainable and economically viable management options in major irrigation areas of the Murray-Darling Basin. The participative research methodologies and tools developed are generic and can be applied to other irrigation areas across the nation and internationally. A range of unique mathematical models has been developed that integrate the biophysical processes of water and salt movement with economic implications at farm and irrigation district levels. These tools have successfully captured a wide range of groundwater, enterprise and soil conditions in the rice growing areas. The new software tools have helped promote rational land and water management options and provide a means to monitor change in water use efficiency and environmental conditions. One of the innovative tools is a state of the art farm level hydrological economic model, SWAGMAN Farm (Salt Water And Groundwater MANagement). SWAGMAN Farm can clearly show economic and environmental tradeoffs in adopting different land and water management options and help to decide sustainable irrigation intensities. This model is already being used both as an educational and management tool by environmental officers and farmers in the Coleambally Irrigation Area. Regional groundwater investigations, surface-groundwater interaction models of the irrigation regions and the SWAGMAN Farm model are strategic developments in natural resource management which are serving as the backbone for strategies such as improving water use efficiency, reducing net recharge to groundwater and monitoring changes in environmental conditions on a spatial basis. Coleambally Irrigation has structured its environmental management business around on-farm net recharge management using SWAGMAN Farm and groundwater management zones. This paper provides details of how these models are being used to increase farmer knowledge on the effect of biophysical impacts in response to farming decisions, building community confidence in modeling results and a tool to aid in improving water use efficiency within the region.

Introduction

The productivity of major irrigation areas in the semi arid and arid regions of the world is facing challenges of waterlogging and secondary salinisation of landscapes (Ghassemi et al., 1995). It is estimated that more than 60 million ha or 24% of the all the irrigated land is salinised (World Bank, 1992). A small fraction of deep percolation (leaching fraction) under crops is necessary to leach out excess salts from the root zone to maintain productivity (Hoffman, 1990). Excessive irrigation of crops, seepage losses from channels and storages result in groundwater recharge to the unconfined aquifers (Rushton, 1999). If the groundwater recharge is greater than the groundwater leakage to the deeper aquifers and lateral regional groundwater flow, the watertables will start rising. When the watertable is less than 2 m from the soil surface, the root zone of the plants becomes restricted and capillary flows from the watertable start accumulating salts in the root zone and at the soil surface causing reduction in crop yields (Kijne et al., 1998). In situations where the shallow groundwater is of good quality, it is possible to tap and re-use the groundwater recharge by using horizontal tile drains or vertical tube wells (Keller et al. 1996, Khan and Rushton 1997, Rushton 1999, Seckler 1996) or by adopting appropriate cropping and tree plantations. The waterlogging and salinisation situation is complex if low quality water exists in the superficial aquifers consisting of slowly permeable materials such as medium and heavy clays. In these aquifers shallow groundwater pumping is possible only in limited locations and re-use or disposal of saline groundwater poses a major problem. These are typical conditions that exist in the Murray Darling Basin irrigation areas.

In a 1990 study (Gutteridge, et al., 1990) it was estimated that areas of high watertables (i.e. watertables within two meters of the land surface) in the Murray Darling Basin (Fig. 1) would increase to 95 percent of the total area irrigated within 50 years if no remedial actions were taken. The historic groundwater rise trends in the Coleambally Irrigation Area are shown in Fig. 2 which show rapid rise in the 1970's and the early 1980's after the introduction of irrigation in the early 1960's. This situation coupled with dryland 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. Under this strategy greater emphasis was placed on the community based integrated resource management plans for irrigation areas. The plans are being supported by government funds for implementation of on-ground works and measures to control waterlogging and salinity. This approach provided an opportunity for community led action and ownership of the planning decisions, and coupled with education and training, has encouraged the community to implement the plans. These plans enlist specific sustainability targets for a 30 years period such as:

Sustainable productivity of farms
Achievement of on-farm water balance benchmarks
Extent of saline areas to be less than a certain proportion of total irrigation area by a certain number of years
Levels of salinity in the drainage waters at key locations

In order to achieve these targets a number of actions such as economic incentives, adoption of best management practices, on-farm and regional management activities and education and extension endeavors are planned. Due to the limited unconfined storage, discontinuous nature of underlying aquifers and limited regional groundwater discharge it was necessary to target LWMP actions. These are based on sound environmental concepts and models which are readily adoptable by the irrigation communities and can therefore effectively achieve targets in stipulated time scales. Realising these constraints, CSIRO Land and Water developed a suite of tools called the SWAGMAN (Salt WAter and Groundwater MANagement) series of models. In this paper some of the environmental management concepts, participative management models and their applications in the Murray Darling Basin are described.

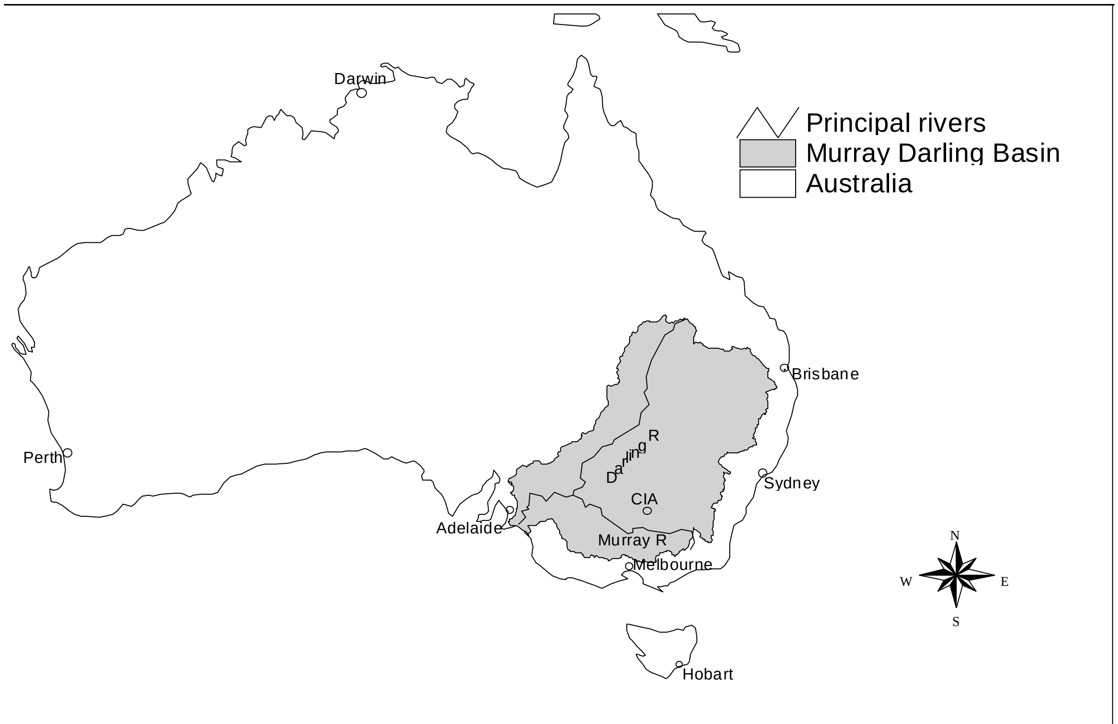

Figure 1 Location of the Murray Darling Basin and the Coleambally Irrigation Area

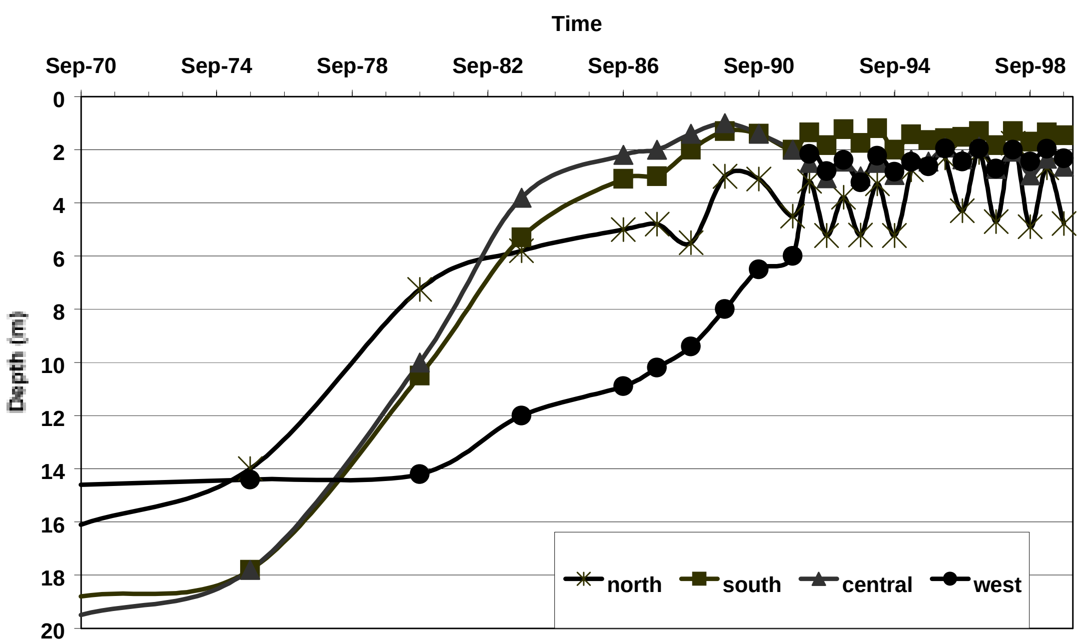

Figure 2 Historic Groundwater Level Changes in the Coleambally Irrigation Area

UNDERPINNING ENVIRONMENTAL MANAGEMENT CONCEPTS

In order to achieve sustainability targets it is important to introduce environmental management concepts, which are easily understood by the farming communities and therefore have a better chance of adoption. The irrigation management polices derived from readily adaptable environmental management concepts will result in better information and coordination of activities, which are essential for successful implementation of water management policies (Dinar, 1998). In this section environmental concepts such as benchmark irrigation levels, whole farm water balance, net recharge quotas, tradable cropping rights and groundwater management zones are introduced.

Benchmark Irrigation Levels

Irrigation water requirements include the amount of water required for crop evapotranspiration and the necessary excess drainage below the root zone to leach out excess salts. Achieving efficient levels of irrigation application rates can help reduce groundwater accessions to the watertables. Records of irrigation volumes used by better farmers can be used as yard sticks or benchmarks for the entire area. This is the traditional approach, which does not need support from any farm or regional water balance tools, however this concept fails to consider variability of soil, depth to watertable and regional groundwater discharge which may be responsible for differences in water use between different farms.

Whole Farm Water Balance

Crops such as rice cause excess groundwater recharge to the watertables due to ponded conditions during the growth period whereas other crops such as lucerne may reduce waterlogging by extracting water from shallow watertables. It is possible to devise a spatial mix of recharging and discharging crops to achieve an area wide water balance and to keep watertables at desired levels. In order to achieve whole farm water balance, a farm water model is required.

Net Recharge Quotas

In situations where recharge to groundwater is unavoidable, pricing of recharge above leaching requirements can be an option to formulate operational mechanisms to make inefficient users pay for the reduced system capacity and loss of production from a community's prospective. This may be an operational option in areas where the watertables are already shallow (<2 m) and effective porosity of soils are low (< 5 percent), therefore small fractions of excess irrigation and/or rainfall can cause the watertable to rise to the surface, resulting in waterlogging and salinity problems. Maximum allowable recharge quota or irrigation excess will depend on the regional groundwater discharge (through deep leakage and lateral groundwater flow). This policy option requires development of surface-groundwater interaction models of irrigation areas to identify hydrogeological connected zones and recharge quotas for individual farms located in these zones.

Tradable Cropping Areas

Depending on the hydrogeological conditions, crops such as rice may result in higher water requirements if the watertables are deep and or leakage to deeper aquifers is high. On the other hand the water requirements for the same crop may be low if the watertable is relatively shallow and leakage to deeper aquifers is either small or there is an upward groundwater flow due to artesian pressures in the deeper aquifers. In such situations allocation of cropping rights on the basis of presence of suitable soils may not result in desired environmental impacts on shallow watertables and soil salinity. Since crops such as rice have higher economic returns, the farmers in unsuitable areas may be given incentives to sell their cropping rights to other farmers with suitable hydrogeological conditions. Options such as tradable cropping areas require development of regional hydrologic economic models to help decide how cropping markets can be established and operated and how environmental impacts can be offset through competitive pricing.

Groundwater Management Zones

The shape of the watertable surface in an irrigation area depends on the spatial distribution of recharge and discharge. Regions where groundwater flow is directed downwards with respect to the watertable and away from a given farm are called recharge areas and regions where groundwater flow is directed upwards to the watertable or towards a given location are called discharge areas and the line separating the recharge and discharge areas are called hinge lines (Toth, 1963). An extreme environmental problem from the groundwater discharge zones may appear in the form of saline seeps as a result of saline groundwater flow to the soil surface (Rhoades et al. 1999) or waterlogging of adjoining landscapes. This concept is very important to decide which on-farm and regional actions are the most effective management options as recharge and discharge zones need to be considered together. This demarcation of groundwater recharge and discharge zones needs detailed spatial hydrogeological information. A typical groundwater flow map to describe groundwater management zones in the Coleambally Irrigation Area of the Murray Darling Basin is given in Fig. 3.

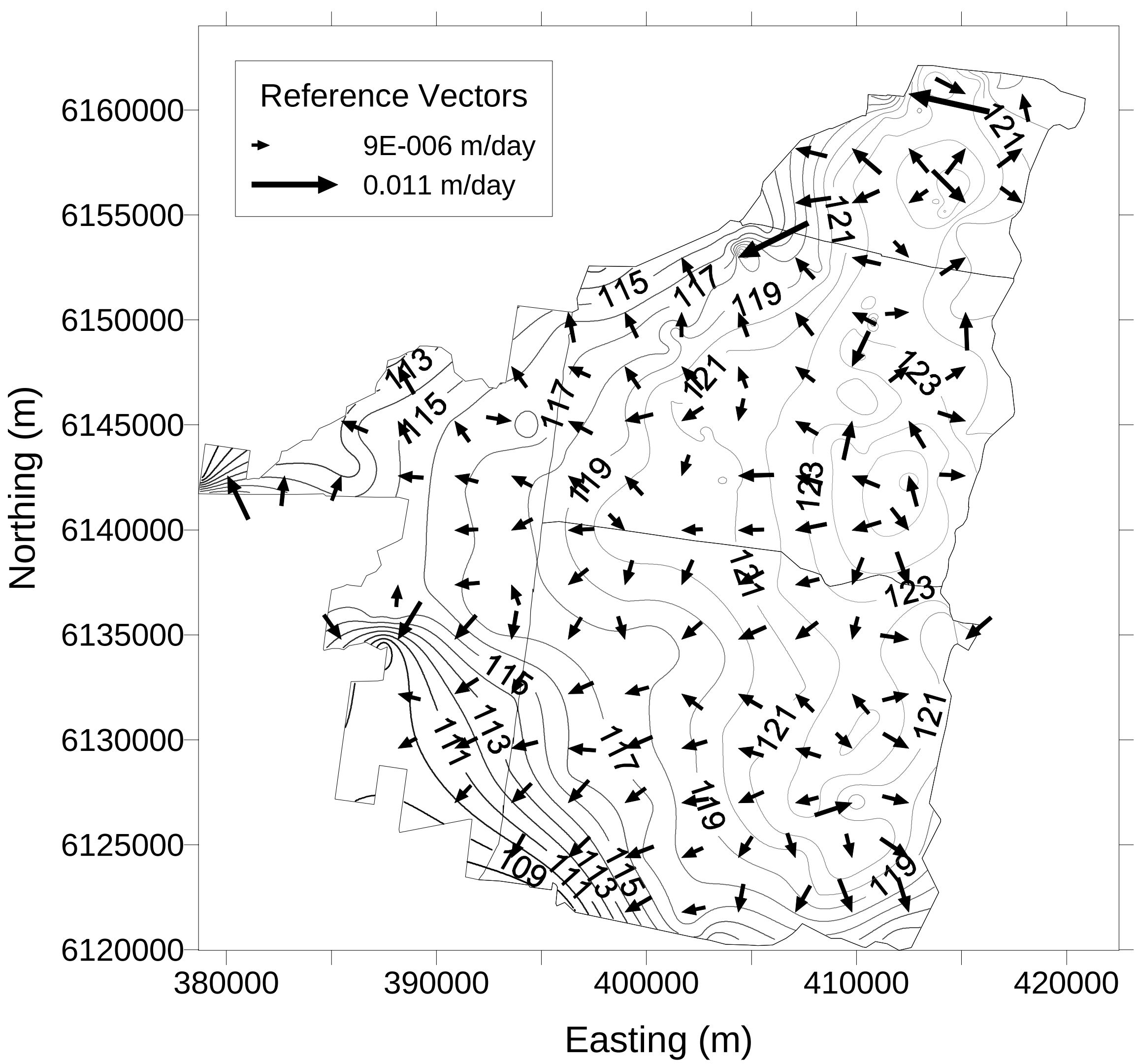

Figure 3 Groundwater dynamics in the Upper Shepparton aquifer (September, 1999)

SWAGMAN SERIES OF MODELS

CSIRO Land and Water developed a suite of models designed to investigate shallow saline groundwater conditions at a range of scales with varying degrees of complexity depending on the purpose and data availability. Models in this series include SWAGMAN Destiny (Meyer et al., 1996), SWAGMAN Whatif (Robbins et al., 1995), SWAGMAN Farm (Khan et al., 2000), SWAGMAN Options (Prathapar et al., 1995) and SWAGSIM (Prathapar et al., 1994). This section describes applications of a farm scale hydrologic economic framework SWAGMAN Farm to help guide whole farm water balance and net recharge options for environmental management.

SWAGMAN Farm is a lumped water and salt balance model which integrates agronomic, climatic, irrigation, hydrogeological and economic aspects of irrigated agriculture under shallow watertable conditions at a farm scale (Khan et al., 2000). This model has been used to develop management options such as net recharge management for control of shallow watertables which focuses on managing the net recharge beneath the root zone in relation to the vertical and lateral regional groundwater flow. In SWAGMAN Farm, the lumped estimates of the water and salt balance components (Fig. 4) for the cropping and fallow periods are computed for a range of irrigated crops such as rice, soybean, maize, sunflower, fababean, canola, wheat, barley, hay lucerne, grazed lucerne, annual pasture, perennial pasture as well as dryland wheat and uncropped areas, for different irrigation, soil, climatic and hydrogeological conditions. The water and salt balance computations for each of the crops are derived using the results of detailed monitoring (Meyer et al 1990, Prathapar and Meyer, 1992) and hydrological modeling (Prathapar and Madden 1995, Prathapar et al., 1992, 1994, 1995, 1996).

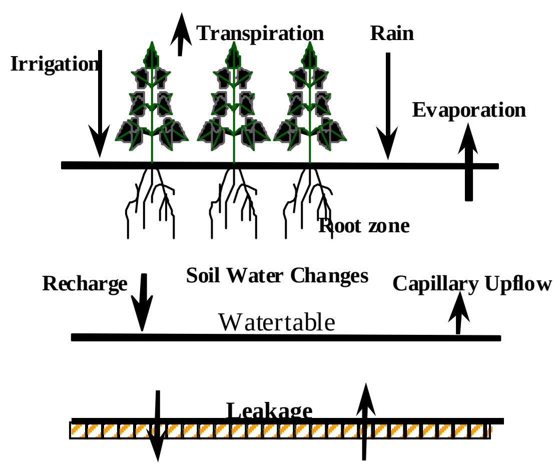

Figure 4. Schematic diagram showing biophysical processes under shallow watertable conditions

This model can simulate the effects of growing a certain crop mix on shallow watertable and soil salinity or it can compute an optimum mix of crops for which the watertable rise and soil salinity remain within the allowable constraints for given hydro-climatic conditions. The optimisation problem can be stated as:

> *"Selection of those land uses (crops) for which economic returns are maximised for watertable rise and root zone salinity changes within allowable limits."*

The total gross margin for a given farm is optimised subject to six constraints:

Constraint 1: Change in salt concentration in the root zone is less than or equal to allowable change.
Constraint 2: Change in watertable level is less than or equal to the allowable change.
Constraint 3: Area of a land use is constrained between maximum and minimum areas determined by physical limits and farmer preferences.
Constraint 4: Water allocation to the farm is greater than or equal to water used for irrigation.
Constraint 5: Sum of areas of all land use types is equal to the total area of the farm.
Constraint 6: Binary constraints to ensure a minimum land use area if crop area enters the solution vector.

This model was originally written in GAMS (General Algebraic Modeling Systems) (GAMS Corporation, 1999) and utilises Mixed Integer Non Linear Programming solvers such as DICOPT (DIscrete and Continuous OPTimser) to find optimum cropping patterns for given soil, climatic, irrigation and hydrogeological conditions. The convergence and appropriateness of optimisation routines was checked using the sensitivity analysis techniques for a range of shallow watertable situations (Pannell, 1997).

Recently a C++ based application has been developed with a customised user interface (Fig. 5) for ready distribution and application of model.

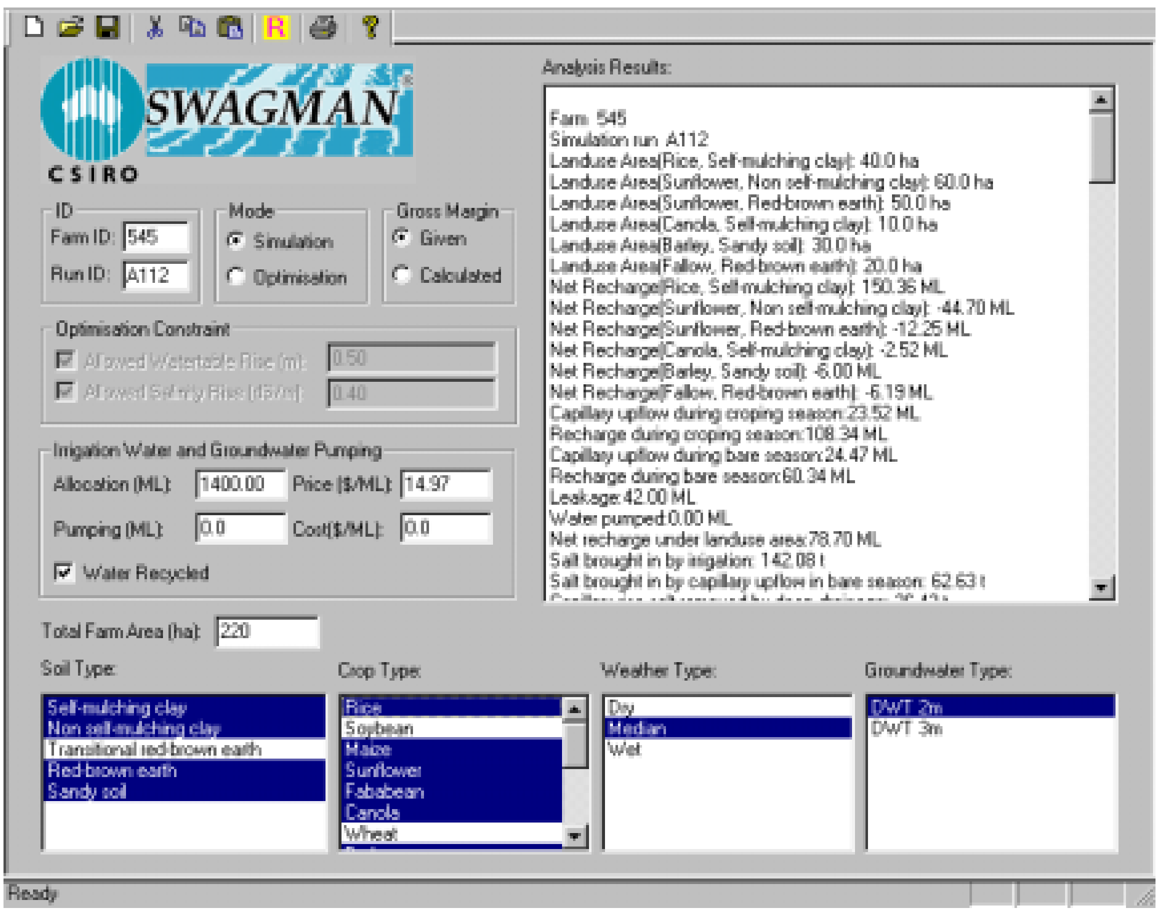

Figure 5 User Interface of SWAGMAN Farm Model

Special sensitivity and sequential analysis features have been added to compare scenarios across a range of values for variables such as depth to watertable, groundwater salinity, deep leakage, initial soil water content and rainfall. These can be done in the simulation mode i.e. for a given set of land uses. In the sensitivity analyses the model parameters are changed within the specified limits by a number of increments and the results are stored in a log file. This is an important feature enabling identification of the critical parameters influencing the model results, and highlighting where effort needs to be expended in determining those parameters that will improve confidence in the model results.

SWAGMAN Farm Example

A case study using the simulation mode for a hypothetical irrigated farm in the Southern Murray Darling Basin is presented here to show how a dialogue between a farmer and environmental office is started on the basis of existing practices. Examples of optimisation runs can be found in Khan et al. (2000). The total area of the farm is 220 ha with 50 ha of Self Mulching Clays (SMC), 60 ha of Non Self Mulching Clays (NSMC), 80 ha of Red Brown Earths (RBE), 30 ha of sands The depth to the watertable under the farm is 3.0 m and salinity of the groundwater is 4 dS/m. The total water allocation of the farm is 1400 ML (1 ML=100 mm/ha). The leakage rate under the farm is 0.2 ML/ha per year. The salinity of irrigation water is 0.15 dS/m and salinity of rainfall is 0.01 dS/m. Initial soil water content under the farm is assumed to be 0.3 for all soil types. Average climatic conditions with annual rainfall of 346 mm and 1779 mm of reference evapotranspiration are assumed. The land use annual gross margin is $90,556 for land used shown in Table-1.

Table-1. Distribution of land use (ha)

Land use	Soil Type			
	SMC	NSMC	RBE	Sands
Rice	30	30	-	-
Maize	-	10	10	-
Sunflower	-	-	50	-
Fababean	10	-	-	-
Canola	10	-	-	-
Barley			10	
Fallow		20	10	30

Due to higher gross margins, rice is the most financially attractive land use but its maximum area is restricted due to the constraint on watertable rise. The irrigation application for rice is assumed to be 12 ML/ha, 9 ML/ha for maize, 7 ML/ha for sunflower, 3.5 ML/ha for fababean, 4 ML/ha for canola and 2 ML/ha for barley. The farm rice area in this case is contributing an overall recharge of 37 ML and maize contributes 11 ML/ha whereas irrigated sunflower, canola, barley, and fallow are discharging land uses with individual discharges of 10 ML, 2 ML, 2 ML and 8 ML respectively. The capillary upflow under the farm is zero as the watertable is 3 m deep. The overall rise of watertable is 0.06 m. In this case the farmer is not causing excess recharge but if the farmer increases the area of rice or irrigation levels, corresponding recharge levels are identified and corrective actions such as improved irrigation efficiency or alternative cropping mixes are discussed with the farmer.

Table-2 shows a summary of the salt balance for the farm. The net increase in salts in the soil above the watertable is 87 tonnes. Recharge under the rice area during the irrigation and fallow periods partly remove (leach) the salt brought in by irrigation and capillary upflow.

Table-2. Salt balance for the example farm (all values in tonnes of salt).

Irrigation Salt	Rainfall Salt	Capillary Upflow Salts	Total Salt Removed	Salt change in the root zone
133	5	0	51	87

To date SWAGMAN Farm model has been applied to determine optimal irrigation intensities and develop net recharge management options in the shallow saline watertable areas (Prathapar and Madden, 1995, Khan et al, 2000).

APPLICATION OF SWAGMAN FARM IN THE MURRAY DARLING BASIN

The SWAGMAN Farm model is being used to apply the net recharge management concept in the Coleambally Irrigation Area .The Coleambally Irrigation Area (CIA) is located in the south eastern part of the Murray Darling Basin (Fig-1). Prior to irrigation, watertable levels were at depths of 15 to 20 m. During the 1960's, 333 farms were allocated 79,000 ha of land and irrigation rights from water diverted from the Murrumbidgee River with an average allocation of 500 Giga litres (500,000 ML). Post irrigation accessions to groundwater have lead to dramatic increases in the shallow watertable, and now a vast groundwater mound exists beneath the CIA. At present, 54% of the CIA has groundwater within 4m from the ground surface which necessitates improvement of irrigation efficiency and control of net recharge. Currently SWAGMAN Farm is being applied on a number of farms to change land use practices to match recharge with groundwater outflow according to the groundwater management zones.

Another user of SWAGMAN Farm in the Murray Darling Basin is Murray Irrigation Limited (MIL) which is the largest privately owned irrigation supply and drainage company in Australia, with an entitlement of 1445 Giga megalitres (1445,000 ML) which is 67% of the NSW share of Murray River irrigation entitlements. MIL provides irrigation water to over 2400 farms owned by 1800 family farm businesses in southern NSW. Murray Irrigation's area of operation is over 716,000 hectares of farmland north of the Murray River. In the Murray Valley, the threats of waterlogging and salinity are being addressed by improved farm management, district Land and Water Management Plans and environmental policies. MIL introduced the total farm water balance policy in 1997, which aims to minimise net recharge to the watertable. The SWAGMAN Farm model is being customized to account for different farm situations in the Murray Valley and to develop a rational irrigation management policy.

Confidence Building and Customisation

An educational approach is being taken in the Murray Irrigation Areas to build community confidence in SWAGMAN Farm's ability to represent water and salt movement processes on and underneath the individual farms, and to make it an acceptable tool for securing long term sustainability of the MIL region.

The SWAGMAN Farm model has been customised to conditions in the Murray Valley by modelling 14 farms for a range of enterprise, soil, climate, irrigation and groundwater conditions. Results for net watertable change compared well with water levels in nearby piezometers. During 2001 a consultation team, including a groundwater hydrologist and research officer took the model and results back to the individual farmers for discussion in the context of regional groundwater dynamics and on-farm practices. Feedback and responses from this exercise were very positive.

Model Validation

SWAGMAN Farm is being further refined from paddock monitoring data collected from a related project and regional groundwater research. Fig. 6 shows the results of SWAGMAN Farm validation for a winter cereal paddock in the Wakool Irrigation District. Paddock data on irrigation, runoff, rainfall, soil moisture and groundwater conditions were used in the model to predict the change in watertable over each year (1999, 2000, 2001). The results compare well with water levels in the piezometers in the paddock, but are dependent on a limited knowledge of the regional groundwater influences.

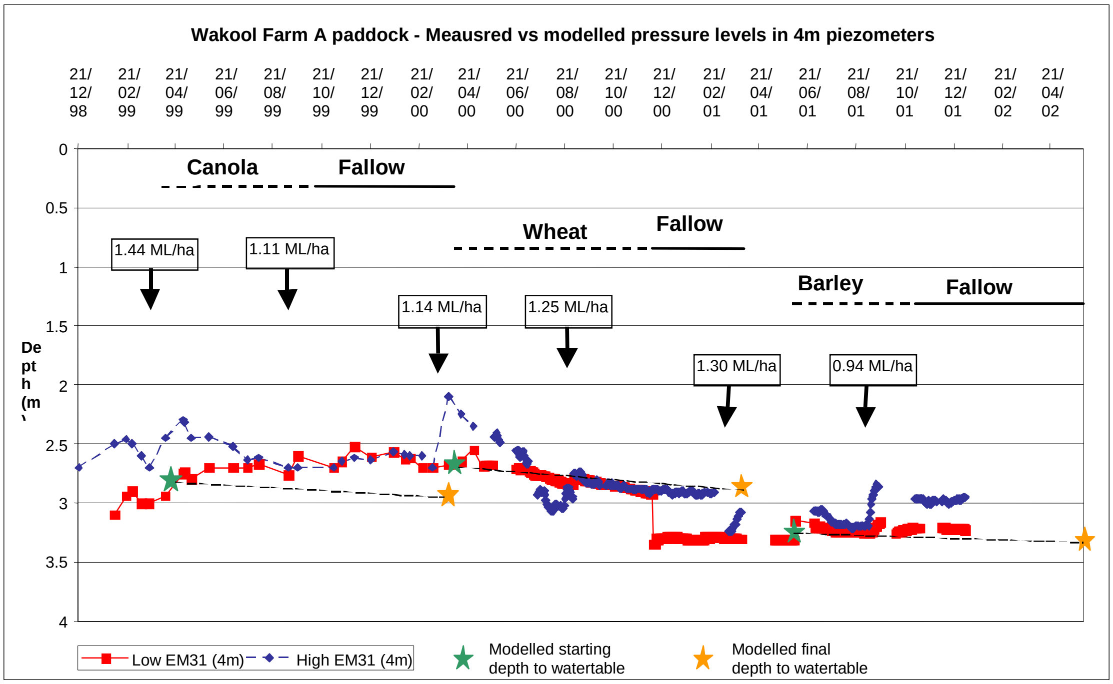

Figure 6 Validation of Lumped Model with Detailed Monitoring Data

Education of policy makers and senior irrigation company managers

Recognising the importance of educating the decision-makers, before introducing SWAGMAN Farm as a management tool, CSIRO have developed and delivered customised training material. Members of the Southern Riverina Irrigation Districts Council (SRIDC), Murray Irrigation Limited Board of Directors and MIL senior staff have attended these hands-on training sessions during the past couple of years. It is envisaged that a similar educational package could be run through the Land and Water Management Plan education program in the future. An educational program has been already in operation in the Coleambally Irrigation Area for the past five years.

Development of Policy Options

The current research project will develop policy options for different regions of the Murray Darling Basin through the refinement of SWAGMAN Farm, regional groundwater studies and a new GIS-based SWAGMAN Farm. Development of policy options in terms of allowable crops, irrigation intensity (ML/ha) and sub-regional net recharge targets is a very sensitive task which requires much input from irrigation companies and the community for wider acceptance.

A web based SWAGMAN model is currently being developed, which could enable wider access to the model through the irrigation company web page. Each user could be assigned a user identification and password to enable access to their own soils, crops, economics and other farm information to run the model for a given year, view results and make cropping decisions. This model could become operational once the MIL community is well informed about the model processes and is comfortable with the model results.

CONCLUSIONS

The following conclusions are drawn from application of modeling frameworks for participative irrigation management in the Murray Darling Basin.

Due to the limited unconfined storage capacity, the discontinuous nature of underlying aquifers and the limited regional groundwater discharge in the Murray Darling Basin, a sound set of environmental concepts and models which are readily adaptable by the irrigation communities were required to implement land and water management plans.

CSIRO Land and Water developed a suite of tools called the SWAGMAN (Salt WAter and Groundwater MANagement) series of models that can be easily customized to irrigated conditions in the Murray Darling Basin and can be used with appropriate environmental management concepts.

Irrigation management polices which are derived from readily adoptable environmental management concepts can result in better information and coordination activities which are essential for successful implementation of water management policies.

Sensitivity features included in SWAGMAN Farm have helped promote awareness of critical parameters influencing the model results, and have highlighted where effort needs to be expended in determining those parameters that will improve confidence in the model results.

- Educating the decision-makers and rigorous model validation before introducing SWAGMAN Farm as a management tool has helped win wider community trust.

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