Rigorously determined water balance benchmarks for irrigated crops and pastures

FINAL REPORT

January 2003

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CSIRO Land and Water, Griffith

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Land and Water Australia Project CLW21

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ABSTRACT

Strategic planning and policy development in the major irrigation areas will increasingly rely on assessment of management options using water balance models. Considerable investment has gone into the development of recharge management strategies in southern NSW, including the Coleambally Net Recharge Management Strategy, the Murrumbidgee Water Use Efficiency Improvement Scheme and the Murray Optimal Irrigation Intensity project (CWN13). However, adoption is hindered by the fact that there has been insufficient model validation to provide the required level of confidence for irrigation communities and their policy makers. This project seeks to supply rigorously determined data to assist in the calibration, refinement and validation of the SWAGMAN® Farm and Destiny Models.

A database of studies of the water balance and irrigation management for irrigated pastures and annual field crops in Australia was developed, with 222 entries as of 25 January 2003. Production of the REFIRR (pronounced "refer": REF=reference, IRR=irrigation) database was a joint effort between colleagues from Vic. DPI Institute of Sustainable Irrigated Agriculture (Tatura) and CSIRO Land and Water (Griffith). The possibility of making this database publicly available via the National Program for Sustainable Irrigation website, for both retrieving data and updating, is currently being explored.

The review of water balance studies found that there are very few comprehensive determinations of the components of the water balance for irrigated crops and pastures in Australia, and that there is great variability in deep drainage determinations for similar landuse and irrigation management on the same soil types. The findings reinforce the conclusions of Lyle (2002) and Bethune (2001) that there is a need for a systematic and comprehensive approach to understanding deep drainage for a range of soil types, landuses and management practices – and for its quantification in relation to a defined set of measured soil/site parameters, and for determination of what levels of recharge are acceptable taking into account the local and regional hydrogeological conditions.

The review of deep drainage determinations reveals that the most comprehensive work has been done in ponded rice, and that this is the best understood system in terms of the influence of soil chemical and physical properties, soil management and watertable depth on deep drainage. The work in rice perhaps best illustrates that deep drainage can be extremely variable within the one soil type and within the one field, and that irrigation with saline water and gypsum application increase deep drainage. All of these effects have been observed with other landuses in the few studies reported.

Components of the water balance were monitored in four fields with varying soil types and landuses including lucerne, annual pasture, maize and winter cereals. The main purpose of the monitoring was to generate input and validation data for the water balance models.

Despite frequent irrigation and application rates of 960-1,000 mm each season, there was no evidence of net recharge under the lucerne, and during the last season, which coincided with drought, there was evidence of significant crop water use from depth. The maize received 632 mm in irrigations and 83 mm rain in the first year following rice, and approximately 27% of crop water use was from upflow from the watertable, resulting in the watertable falling to about 1.75 m during the irrigation season. Thus the maize acted as a discharge crop following rice, despite

frequent irrigation. The second maize crop followed two winter cereal crops and a winter fallow. Consequently the soil profile was relatively dry prior to the first irrigation, and this crop received 184 mm more irrigation water (total 816 mm) and a similar amount of rain as the first crop (97 mm). There was a rapid rise in the watertable (from 3.5 to 1 m associated with the first two irrigations), but by the end of the season the watertable had declined to 2 m. Thus there was net recharge of 46 mm associated with the maize for initially deep watertable conditions, demonstrating that furrow irrigated crops can generate significant net recharge, although much less than what is generally observed in rice. The annual pasture and winter crops on bordercheck were infrequently irrigated, and the watertables seemed to be in equilibrium in these fields.

A large amount of model input and validation data was generated. There was generally very good agreement between model predictions and observed values. The model simulations also highlighted the importance of good knowledge of the regional hydrology (deep and lateral leakage) for rational application of the farm and crop models. The simulations also highlighted the need to modify Destiny to enable lucerne to be simulated over many years using actual irrigation amounts. Together with the findings of validations undertaken in other projects (especially in relation to wheat and maize), it is concluded that the SWAGMAN® Farm and SWAGMAN® Destiny water balance models are reliable predictors of watertable behaviour and crop performance in the irrigated areas of southern NSW, provided appropriate model inputs are used.

INTRODUCTION

Strategic planning and policy development in the major irrigation areas will increasingly rely on assessment of management options using water balance models. Considerable investment has gone into the development of recharge management strategies in southern NSW, including the Coleambally Net Recharge Management Strategy, the Murrumbidgee Water Use Efficiency Improvement Scheme and the Murray Optimal Irrigation Intensity project (CWN13). However, adoption is hindered by the fact that there has been insufficient model validation to provide the required level of confidence for irrigation communities and their policy makers. This project seeks to supply rigorously determined data to assist in the calibration, refinement and validation of the SWAGMAN® Farm and Destiny Models.

OBJECTIVES

1. to obtain and review data in the grey and published literature for determinations of deep drainage, crop water use and paddock water use for the range of irrigated crops, management practices, soils and climatic conditions experienced in Australia, and to collate those data considered to be derived from rigorous determinations

2. to carry out rigorous paddock scale water balance determinations for maize, winter cereal, annual pasture, lucerne and canola grown under good management practices

3. to use the data to validate and refine models used for determining optimal irrigation intensity and net recharge management in the irrigation areas of the southern Murray-Darling Basin

METHODS

Literature review

The objectives of the review were to:

- obtain data in the grey and published literature for determinations of deep drainage, crop water use and paddock water use for the range of irrigated crops and pastures, management practices, soils and climatic conditions experienced in Australia
- collate those data considered to be derived from rigorous determination.

The literature search included searching electronic databases and discussions with researchers in a range of Australian irrigation regions. A database of literature relevant to water balance studies and irrigation management for annual broadacre crops was developed and information uncovered in the literature search was entered. This was combined with a database of studies for irrigated pastures developed by staff of the Institute for Sustainable Irrigated Agriculture (Vic. DPI) to form the **REFIRR** irrigation database. Key findings relevant to determinations of components of the water balance were summarised in the report "A review of determinations of components of the water balance for irrigated crops and pastures" (Attachment 1).

Paddock water use monitoring

Components of the paddock water balance were monitored in the Murray Valley in four fields growing a range of pastures, summer and winter crops. Landuses included maize, wheat and barley growing on beds (field B), and lucerne (field L), wheat and canola (field W) and annual pasture (field P) on border check layouts. Sites and farmers were chosen to represent good layouts and management practices. Soil types included three red brown earths (with lighter and heavier textures) and a cracking clay soil. Information on all four sites is summarised in Attachment 2 with further details for individual sites in attachments 4-6.

All fields were surveyed using EM31 to identify soil variability, and one low and one high EM31 site was selected in each field for installation of soil water monitoring equipment with the objective of monitoring components of the water balance at sites covering the likely extremes of soil permeability. Thus a total of eight sites (four fields x two EM sites) was monitored.

Soil properties

Soil particle size analysis, saturation paste water content, chloride and EC were determined at all sites from samples collected at the time of installation of the monitoring equipment. Further pre and post "crop" soil samples for chloride analysis and EC were collected from the high EM sites in fields P and W.

Unsaturated hydraulic conductivity was measured in the 3 major profile layers in fields B and L at both EM sites using disk permeameters. Saturated hydraulic conductivity was measured in piezometers at all 8 sites using slug tests. The methods are described in Attachment 3.

Water flows

Starflow® ultrasonic flow meters were installed to measure irrigation applications and drainage flows on and off each field, and compared with Dethridge meter flows when possible (at fields B, L and W). Surface drainage at field L was not measured and was recycled back into the irrigation supply (downstream of the irrigation flowmeter).

Piezometric levels

"Shallow" (0.75 m) and "deep" piezometers (4 m) were installed at all EM sites and initially read manually, and later monitored using pressure sensors and Dataflow® loggers. Deeper (10 m) piezometers were also installed at site P to monitor the hydraulic gradient.

Soil water status

Soil water content was logged with Enviroscan® systems installed at all EM sites. The sensors were calibrated against volumetric water content of soil cores down the profile at each site. The results of two of the calibrations are presented in attachments 4 and 5.

Manually read tube tensiometers were installed adjacent to the Enviroscan® installations, at the same depths as the sensors, to determine the soil water characteristic at each site.

Watermark® (granular matrix) sensors were installed to 2.5 m at the high EM site in the lucerne and logged using a Campbell® logger. Logging tensiometers and Watermark® sensors were installed at depths of 1.2 and 1.35 m at both EM sites in the pasture paddock to determine potential gradients.

Evapotranspiration
Bowen ratio equipment was installed in the annual pasture in early 2001 for more direct determination of ET. For the other fields, ET was estimated from crop factors and reference evaporation (ETo). ETo was calculated from meteorological data at the CSIRO Finley and Tullakool weather stations, using a locally calibrated Penman equation and associated crop factors (Meyer 1999; Meyer *et al.* 1999).
Crop monitoring

Crop/pasture management details were provided by the collaborating farmers, and crop growth development and yield were monitored for the maize and winter crops. Lucerne growth was monitored in the first year, and harvest yields were provided by the farmer. The annual pasture was frequently grazed, and pasture growth was monitored in cages that were harvested periodically to coincide with the presence of sheep in the field.

Model validation and refinement

Results of the field monitoring were used to validate the SWAGMAN® Farm and SWAGMAN® Destiny models. SWAGMAN Farm (Khan *et al*. 2000) is a lumped water balance model which predicts net recharge, changes in the depth to the watertable and rootzone salinity, and gross margin for individual farms, taking into account landuse area according to soil type, seasonal weather conditions, irrigation water use, initial soil water content and groundwater conditions (depth, salinity), deep leakage rates and shallow groundwater pumping (where this occurs). The model runs on one-year timesteps, and is currently being used as an educational tool to help irrigation farmers achieve net recharge targets in the Coleambally Irrigation Area. In the forseeable future farmers in the CIA are likely to enter into formal net recharge target agreements with Coleambally Irrigation Cooperative Ltd, and the model will also be used in the Murray Irrigation Districts in the near future to help identify sustainable management for different groundwater management zones.

SWAGMAN Destiny (Godwin *et al*. 2003) is a more detailed daily timestep crop model which can be used to determine net recharge and changes in watertable and rootzone salinity and crop productivity, for a range of crops and pastures at a point in the landscape, as they are affected by management (e.g. sowing date, irrigation management), soil properties, groundwater conditions and weather. Outputs from SWAGMAN Destiny can be used to generate inputs for SWAGMAN Farm such as crop water use as affected by groundwater and seasonal conditions and irrigation management, and as a check against outputs of SWAGMAN Farm such as impacts on watertables and rootzone salinity for individual landuse/site conditions.

Both models have data requirements for reference files such as soil properties for different soil types - especially hydraulic properties such as soil water content at saturation (SAT), field capacity or drained upper limit (DUL) and lower limit or wilting point (LL) and hydraulic conductivity in different layers in the profile – and typical irrigation application rates (breakdowns over time for Destiny, and seasonal totals for Farm). Both models rely on crop factors to estimate ET, although Farm uses monthly average crop factors whereas the crop factor in Destiny is influenced by the rate of leaf area development.

Therefore the objectives of the field monitoring were:

1. to develop data sets for a range of model input parameters such as typical soil water content and hydraulic properties, irrigation and surface drainage quantities, crop coefficients
2. to compare model predictions with observed values.

The findings would be used to help identify strengths and weaknesses in the ability of the models and associated input data sets to predict observations in the field.

RESULTS

Literature review of water balance studies for irrigated crops and pastures

More than 200 reports and publications relevant to water balance and irrigation management studies in irrigated crops and pastures were identified, and we decided early on that a database would be useful for collating, organising and summarising the material in a readily accessible format. In the process of seeking information on irrigated pastures from colleagues at Vic DPI's Institute of Sustainable Irrigated Agriculture, Tatura, we learnt that they were doing a review of irrigated pastures and also developing a database. Therefore we combined the Tatura database with our database to form the REFIRR (pronounced "refer" – REF=reference, IRR=irrigation) database for irrigated annual field crops and pastures. On 25 January 2003 the database contained 222 records including 76 for irrigated crops, and 75 for pastures.

It should be noted that the focus of the REFIRR database is reports in which components of the water balance have been determined for irrigated crops and pastures across Australia, and it was developed to assist us meet the objectives of the review of water balance data. However some more general irrigation management and related studies have also been included. It is acknowledged that the list of records is not exhaustive and that the REFIRR database has some inbuilt redundancy and inconsistencies as a result of combining two independently developed databases which were designed for slightly different purposes. Furthermore, the database has limited search capabilities (currently by landuse, first author or full bibliography in alphabetical order). However, we consider that there may be merit in making the database, or an improved version, readily publicly available for use and for updating by others. We have previously suggested that the REFIRR database be made publicly available on the National Irrigation Science Network (NISN) website, with NISN providing maintenance and a mechanism for ready updating by workers in the field. NISN had previously expressed willingness to undertake this, however, before this is progressed further we recommend that:

1. the database be reviewed to assess its potential usefulness, and to identify desired improvements taking into account target endusers, and if the database is worth pursuing with
2. NPSI develop a strategy for further development, updating and maintenance of the database, and explore the possibility of doing this in collaboration with NISN

A CD containing a copy of the REFIRR database is provided with this report.

The review (Attachment 1) found that there are very few comprehensive determinations of the components of the water balance for irrigated crops and pastures in Australia, and that there is great variability in deep drainage determinations for similar landuse and irrigation management on the same soil types. The findings reinforce the conclusions of Lyle (2002) and Bethune (2001) that there is a need for a systematic and comprehensive approach to understanding deep drainage for a range of soil types, landuses and management practices – and for it's quantification in relation to a defined set of measured soil/site parameters, and for determination of what levels of recharge are acceptable taking into account the local and regional hydrogeological conditions.

The most accurate method for determining components of the water balance is using lysimeters, however great care is required to avoid artefacts due to edge effects and to provide realistic rootzone conditions. Lysimeters are expensive to construct and not transportable, therefore there are only few studies from lysimeters for irrigated crops in Australia. Most reports come from the drainage and weighing lysimeters at CSIRO Griffith, where Meyer and team demonstrated that even for well-watered crops, crop water use from capillary upflow from shallow watertables (0.6-1.3 m) can be significant (up to 29% for maize and 55% for lucerne on a well structured Hanwood loam).

Meyer and colleagues used the data from a comprehensive series of weighing lysimeter experiments to evaluate methods for predicting crop water use, including US Class A pan, the Penman combination equation, and the standardized FAO Penman-Monteith (Allen *et al*. 1998), and found that all methods were strongly correlated with measured ET. Meyer (1999) developed a locally calibrated Penman equation (Penman-Meyer) which predicted crop water use much more closely than Penman-Monteith, and this equation is now used for calculation of reference evaporation at a range of weather stations across the southern Murray-Darling Basin, including Griffith, Finley, Hay and Tullakool. Meyer *et al.* (1999) also published comprehensive data on crop factors to enable the development of generalized crop factors. However Bethune *et al*. (2001) found that the Penman-Monteith equation, used with the FAO recommended crop factors for rice in Australia, predicted rice crop water use accurately. Reference evaporation is calculated using a range of approaches across Australia, and the desirability of a national (uniform) approach for predicting crop water use has been discussed a number of times in the past, and is again under review (Anon 2002). US Class A Pan evaporation was the most common method of reporting potential evaporation in the literature, sometimes in combination with crop factors determined as a proportion of ground cover.

The review of deep drainage determinations reveals that the most comprehensive work has been done in ponded rice, and that this is the best understood system in terms of the influence of soil chemical and physical properties, soil management and watertable depth on deep drainage. The work in rice perhaps best illustrates that deep drainage can be extremely variable within the one soil type and within the one field, and that irrigation with saline water and gypsum application increase deep drainage. All of these effects have been observed with other landuses in the few studies reported.

Paddock water use monitoring

Water balance and crop/pasture monitoring was carried out over 3 to 4 irrigation seasons in four fields. An enormous amount of data was generated, and more detailed results are presented in attachments 3 to 6. The main purpose of the monitoring was to generate data for model inputs and validation, and to determine components of the water balance for fields where best management practices were being used.

Despite frequent irrigation and application rates of 960 to 1,000 mm each season, there was no evidence of net recharge under the lucerne, and during the last season, which coincided with drought, there was evidence of significant crop water use from depth. The maize received 632 mm in irrigations and 83 mm rain in the first year following rice, and the watertable was lowered from about 0.5 to 1 m during the irrigation season. The second maize crop received 816 mm in irrigations and a similar amount of rain as the first crop (97 mm), and there was a rapid rise in the watertable (from 3.5 to 1 m associated with the first 2 irrigations). By the end of the season the watertable had declined to 2 m. Thus there was significant net recharge (46 mm) associated with the maize for initially deep watertable conditions, demonstrating that furrow irrigated crops can have a significant impact on net recharge.

The annual pasture and winter crops on bordercheck were infrequently irrigated, and the watertables seemed to be in equilibrium in these fields.

Model validation and refinement

A large amount of model input data was acquired including wettest (SAT), drained (DUL), driest and initial volumetric soil water content for 6 depths to 1.5 m, and saturated hydraulic conductivity at piezometer depth (4 m, also 10 m at field P) at each of the 8 EM sites. Unsaturated hydraulic conductivity was also determined in the 3 soil horizons at the 2 EM sites in fields B and L. Electronic files of irrigation applications, soil water content (total and by depth), rain, surface drainage and piezometer level were prepared at daily and monthly time steps. Details of the input data sets and results of the model calibrations are presented in Attachment 7.

There was generally very good agreement between model prediction and observed values for all models, which is briefly summarised below.

The SWAGMAN Farm model was run for each field (annual time steps) and the predicted depth to the watertable was compared with field observations. There was generally good agreement between observed and predicted depth to the watertable at all four fields over the 3 to 4 years of observations.

The results highlighted the importance of understanding the local groundwater hydrology in model applications. For example, at field B, reasonably good agreement was obtained between Farm predictions and observed depths to the watertable with an initial leakage rate of 0.9 ML/ha/yr where the watertable was initially shallow following rice, but once the mound had dissipated a rate of 0.3 ML/ha/yr gave a better fit, consistent with results of earlier groundwater investigations.

SWAGMAN Destiny was tested against the 1998-9 maize silage crop (Hycorn 75) at field B – the crop growth model was calibrated using the observed phenological stages, and model predictions of observed crop growth, soil water content and watertable depth were compared with observed values. While the validation was not done with a completely independent data set, the close match between the observed and predicted values give good confidence in the model processes. Attempts to test Destiny for lucerne identified some problems in inputting information on irrigation dates when the model is run for more than one year, and inability to input lucerne cuts in the Windows version of Destiny, which needs to be rectified.

SWAGMAN® Destiny has also been calibrated for several wheat varieties and validated against independent field and weighing lysimeters data sets for a range of parameters including biomass, leaf area index, root length density, evapotranspiration, volumetric soil water content and depth to the watertables. The results generally demonstrate good agreement between predicted and observed values for all parameters (Smith and Humphreys 2003).

The MaizeMan model is a detailed maize growth model with Destiny salt and water balance routines including interaction with the groundwater. It has been calibrated and tested for a range of varieties grown under irrigation in southern NSW, with generally good agreement between predicted and observed values (Xevi *et al.* 2003). The 2001-2 silage maize crop (DK689) grown in field B was calibrated for MaizeMan using observed phenological stages, and predicted crop growth, soil water content and depth to the watertable were compared with observed values. Again there was good agreement between predicted and observed values for crop growth and volumetric soil water content, however there is currently a problem with the watertable simulation which is under investigation.

HOW THE OUTPUTS CAN BE ADOPTED

The outputs of this project need to be adopted at two levels. At one level the results are being used in the development or refinement of inputs for water balance models and in model validation. At another level they are being used to increase confidence of land and water managers that the model predictions are reliable and can be used to aid formulation of guidelines and policy.

Adoption and communication activities

The most important mechanisms for communication of project findings and technology transfer and adoption were the steering committee meetings (a total of six over the life of the project). Participants included direct endusers of the findings i.e. the researchers developing, evaluating and applying the SWAGMAN Farm and Destiny models, employee representatives of the 4 major irrigation companies in the southern MDB involved in the formulation of guidelines and policy for land and water management, and irrigators who would be directly impacted by policy implications. This mix of membership ensured that the informed by the findings of both the biophysical research and the results of model simulations were practical and reflected best practice.

Ongoing interaction between staff involved in this project and the model development application project (Khan and O'Connell for SWAGMAN Farm, Xevi and Smith for SWAGMAN Destiny) was aided by the fact that all are working for the same organisation (CLW) based at Griffith, and by the fact that the project officers for the modeling (O'Connell) and monitoring (Edraki) projects shared the same office at MIL.

Other communication activities included:

- Regular interaction by the project officer with the collaborating farmers by phone and face-to-face on-farm
- Reporting to the MIL LWMP staff meetings (held monthly – participation by the project officer in about half of these)
- Article/photo in the Pastoral Times (Feb 2000)
- Presentations at the Murray Land and Water Management Plan Research and Development Workshops (June 2000, July 2001)
- Presentation at CSIRO Land and Water sector meeting
- Article in issue 13 of Water Wheel
- Presentations to Australian Soil Science Society Riverina Branch meetings in Deniliquin in March 2001 and March 2002

COMMERCIAL POTENTIAL

None - the results of this work are publicly available.

PROJECT PUBLICATIONS

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