Validation of the SWAGMAN® Farm and SWAGMAN® Destiny models

M. Edraki, D. Smith, E. Humphreys, S. Khan, N. O'Connell, and E. Xevi

CSIRO Land and Water, Griffith

August 2003

Murray Irrigation Limited
A.C.N. 067 197 933

Coleambally IRRIGATION

NATIONAL PROGRAM FOR Sustainable Irrigation

CSIRO Land and Water Technical Report 44/03

Acknowledgements

The model input data and validations presented in this report were undertaken as an activity under the project "Rigorously determined water balance benchmarks for irrigated crops and pastures". This project is a collaborative project between CSIRO Land and Water and Murray Irrigation Ltd, with supplementary funding from the Land and Water Australia National Program for Irrigation Research and Development (LWA-NPIRD) and Coleambally Irrigation Cooperative Ltd.

We thank:

- Keith Steele, Phil Snowden, Ray Zanatta and Paul Gorey for the opportunity to undertake monitoring in their fields, and for their assistance in many ways

- Roy Zandona of CSIRO Land and Water for much assistance in the design, acquisition and installation of electronic logging equipment, and Brad Fawcett for assistance in installation of soil water monitoring equipment and particle size analyses

- Nadja Meister, a work experience student from the University of Kassel, Germany, who contributed to the determination of soil hydraulic properties

- NSW Agriculture staff for advice and assistance, especially Vivien Naimo, John Thompson, Sam North and Lindsay Evans

- Steve Langman of Deniliquin for casual assistance

- the members of the steering committee for initiating the work and for participation in meetings and for their suggestions and feedback, in particular Max Goudie, Ian Gillett, Geoff McLeod, Derek Poulton, Geoff Beecher, John Thompson

- Dr Helen Cleugh and Chris Drury of CSIRO Land and Water, Canberra, for assistance in the installation of Bowen ratio equipment, and instruction in its use and analysis of the data

Table of contents

Summary

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.

A paddock monitoring project was undertaken in the Murray Irrigation Districts of southern NSW from late 1998 to early 2002 to determine a range of input parameters required for the SWAGMAN® Farm and SWAGMAN® Destiny models. SWAGMAN® Farm 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 across soil types, seasonal weather conditions, irrigation water use, initial soil water content and groundwater conditions (depth, salinity), groundwater outflow rates and shallow groundwater pumping (where this occurs). SWAGMAN® Destiny is a more detailed daily time step 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.

Monitoring was undertaken in four fields with a range of representative soil types and landuses, including lucerne, annual pasture, maize and winter cereals. Input parameters determined for the models included soil water content at saturation, field capacity and the lowest values observed, and irrigation applications and surface drainage. Model predictions were compared with observed data for a range of parameters including watertable depth, crop growth and volumetric soil water content at different layers in the profile.

There was generally good agreement between model predictions and observed data. The model simulations also highlighted the importance of good knowledge of the regional hydrology (deep and lateral groundwater flow) for rational application of the SWAGMAN® Farm and SWAGMAN® Destiny models. The results presented here, together with the findings from two complementary projects, suggest that the SWAGMAN® Farm and SWAGMAN® Destiny models are reliable predictors of watertable behaviour and crop performance in the irrigated areas of southern NSW, provided appropriate model inputs are used. The project has generated datasets which can also be used for testing of other commonly used point scale water balance models.

While this work has generated data sets that are useful for refining inputs and for validating water balance models, it is limited in the range of parameters measured, and to a small range of situations. More comprehensive investigations are needed on a range of soil types and salinity, crops and watertable (depth and salinity) situations. In particular, data sets are required for a range of salinity situations, as are data sets to enable three dimensional representation of the interaction between a paddock and its neighbours, and other activities on the farm that influence the salt and water balance of a paddock, such as seepage from channels or groundwater pumping.

Model input data have a critical influence on predictions of deep drainage, especially the soil hydraulic properties. A major limitation to reliable application of salt and water balance models is the lack of knowledge of soil hydraulic properties, including hydraulic conductivity functions, as well as upper and lower limits of available soil water and saturation soil water content. These properties need to be determined for a wide range of irrigated soils. Building on this, a major effort is needed to generate pedotransfer functions to predict soil hydraulic properties from more readily

measurable soil attributes, taking advantage of recent developments in mathematical analysis (such as the application of genetic algorithms) and modern computing technology.

Water balance models such as SWAGMAN® Farm currently rely on estimating evapotranspiration (ETc) from reference evaporation and crop factors determined from limited investigations in the environment of the major irrigation areas. Crop factors were developed under conditions of non-limiting crop growth and a limited range of seasonal conditions. Evapotranspiration is usually the largest component of the water balance, and small errors in estimating ETc can lead to large errors in deep drainage estimates and its impact on watertables and leaching of salts. Actual ETc needs to be determined for a range of landuses using techniques such as Bowen ratio to evaluate and, if necessary, improve current methods for estimating ETc in water balance models such as SWAGMAN® Farm.

Watertables fluctuate under paddocks in response to management and landuse, and landuse varies in space and time on a farm. Therefore it is very difficult for a land manager to know what is really happening to the watertable on average across the farm. There is a need for investigations at the paddock and farm scales to develop monitoring guidelines to determine a reasonable representation of the average watertable change under a farm. This will be critical to the successful implementation of net recharge credit and trading strategies.

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 (NPIRD project CWN13 – Khan et al. 2000). 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. Therefore a field monitoring project was initiated by Murray Irrigation Ltd, and expanded with financial support from the Land and Water Australia National Program for Irrigation Research and Development (NPIRD) and Coleambally Irrigation Cooperative Ltd. The project (NPIRD project CLW21) sought to supply rigorously determined data to assist in the calibration, refinement and validation of the SWAGMAN® Farm and Destiny water and salt balance models (Humphreys and Edraki 2003).

SWAGMAN® Farm 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 paddocks and farms, taking into account landuse area across soil types, seasonal weather conditions, irrigation water use, initial soil water content and groundwater conditions (depth, salinity), groundwater outflow, and shallow groundwater pumping where applicable (Khan et al. 2001). The model performs a one-year or seasonal balance, and is currently being used as an educational tool to help irrigation farmers achieve net recharge targets in the Coleambally Irrigation Area. In the foreseeable future farmers in the Coleambally Irrigation Area are likely to enter into formal net recharge target/credit agreements with Coleambally Irrigation Cooperative Ltd, and the model will be used in the Murray Irrigation Districts to help identify sustainable management for different groundwater management zones. A user friendly web-based version of SWAGMAN® Farm has been developed and is currently hosted on the Coleambally Irrigation Cooperative Ltd website at http://www.colyirr.com.au/swagmanfarm/Default.aspx. Through the web-based version farmers can access information about their farm held on the irrigation company database, and run the model to evaluate the sustainability and profitability of landuse options on their farm in a secure environment.

SWAGMAN® Destiny is a point scale daily time step 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 (Godwin et al. 2003). 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 to validate outputs of SWAGMAN® Farm such as impacts on watertables and rootzone salinity for individual landuse/site conditions.

MaizeMan is a user friendly decision support system for water, nitrogen and sowing management for maize which combines the water and salt balance routines of SWAGMAN® Destiny with the CERES Maize model (Humphreys et al. 2003). CERES Maize is a more detailed crop model that enables aspects of sowing and nitrogen fertiliser management to be examined in addition to irrigation management, but it does not consider salinity or groundwater interactions. It's combination with SWAGMAN® Destiny provides the opportunity to investigate in greater detail the interactions between management, weather, soil and watertables on crop performance and the salt and water balances.

All three models have data requirements for soil properties - especially hydraulic properties such as soil water content at saturation (SAT), field capacity or drained upper limit (FC or DUL) and lower limit or wilting point (LL), and hydraulic conductivity, in different layers in the profile. All models also require management data such as typical or actual irrigation application rates (breakdowns over time for SWAGMAN® Destiny, and seasonal totals for SWAGMAN® Farm), and initial soil water and watertable conditions (depth, salinity). All models rely on crop factors to estimate actual evapotranspiration from reference evapotranspiration (ETo), although SWAGMAN® Farm uses monthly average crop factors whereas the crop factors in SWAGMAN® Destiny and MaizeMan are derived using leaf area development. SWAGMAN® Destiny and MaizeMan require more detailed daily weather (at least temperature, radiation, and preferably dew point temperature and wind run) and more detailed information about sowing and irrigation management. MaizeMan also requires information on nitrogen fertilizer management and soil chemical properties such as organic carbon and nitrogen, and pH.

Therefore the objectives of the field monitoring undertaken in project CLW21 were:

(i) to develop data sets for a range of model input parameters such as typical soil hydraulic properties, irrigation and surface drainage application rates, crop factors, and

(ii) to compare model predictions with observed values for a range of parameters including watertable levels, soil water content and various measures of crop performance

Methods

Results of the field monitoring undertaken in NPIRD project CLW21 *"Rigorously determined water balance benchmarks for irrigated crops and pastures"* were used to develop input data sets and to validate the SWAGMAN® Farm, SWAGMAN® Destiny and MaizeMan models.

Components of the 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 raised 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. The locations of the sites and associated landuses are shown in Figure 1.

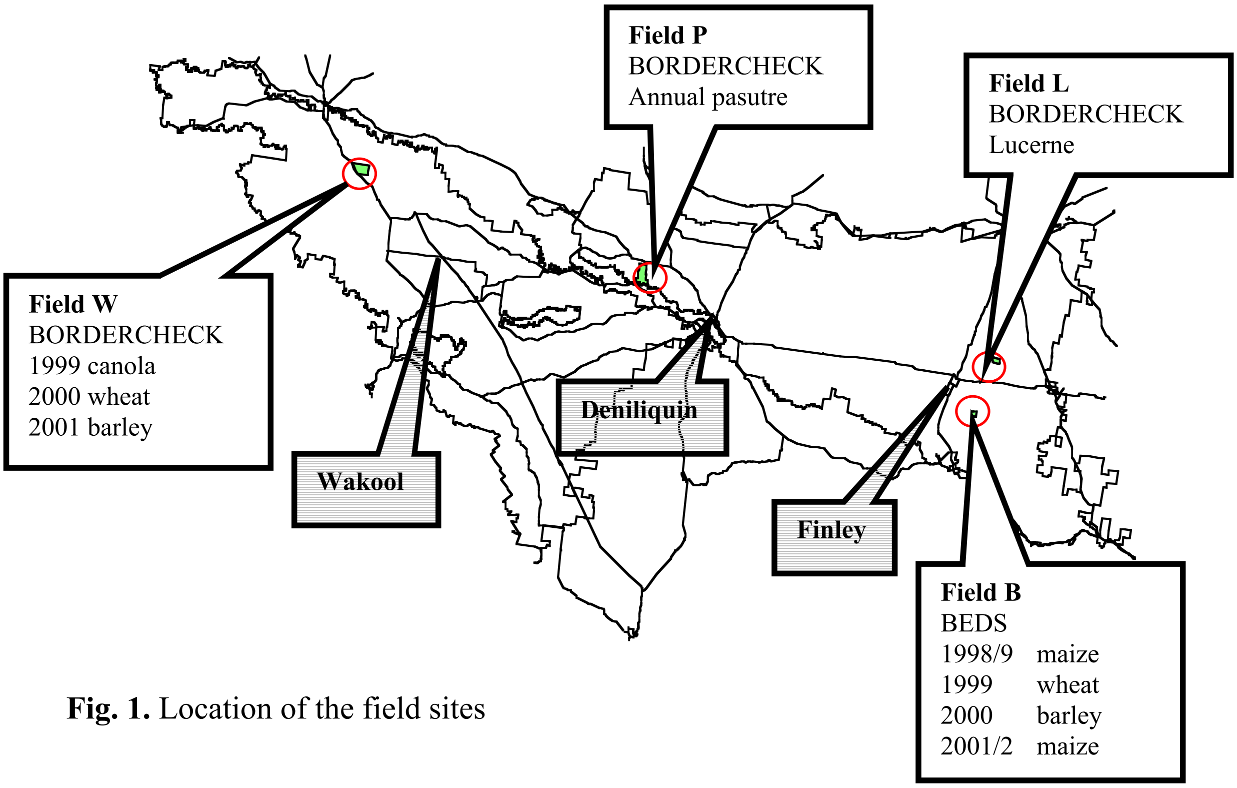


Fig. 1. Location of the field sites

All fields were surveyed using EM31 to identify soil variability, and one low and one high EM31 site were 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 (Beecher et al. 2002). Thus a total of 8 sites (4 fields x 2 EM sites) was monitored. The monitoring that was undertaken is briefly described below, and further detail on fields B and L is available in Edraki et al. 2003a,b. The fields and monitoring installations are shown in Photos 1-4.

Soil characterisation

Soil particle size analysis and electrical conductivity were determined at all sites from samples collected at the time of installation of the soil water monitoring equipment, and bulk density was determined from undisturbed cores at the time of sampling for calibration of the soil water monitoring equipment. Pits were dug at the high and low EM sites in fields B, P and L to help identify the soil type.

Hydraulic conductivity

Unsaturated hydraulic conductivity was measured in the 3 major profile layers in fields B and L at both EM sites using disk permeameters (Anon 1988). Saturated hydraulic conductivity was measured in piezometers at all 8 sites using a slug test (Smith and Mullins 1991). The methods used are described in greater detail in Meister (2002).

Photo 1. Field L - Lucerne paddock near Finley after cutting

Photo 2. Field W - Winter cereal site near Wakool

Photo 3. Field B – with maize on beds near Finley during furrow irrigation

Photo 4. Field P - annual pasture near Deniliquin during irrigation

Irrigation and drainage volumes

Starflow®[1] 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 taken down the profile at each site.

Tube tensiometers were installed adjacent to the Enviroscan® installations, at the same depths as the sensors, and read manually using a Loktronic® vacuum gauge. The data were used to determine the soil water characteristic at each site.

Watermark® (granular matrix) sensors were installed to 1.8 m at the high EM site in the lucerne and logged using a Campbell® logger. Logging Jetfill® 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 (ET)

Bowen ratio equipment was installed in the annual pasture in early 2001 for more direct determination of ET from the energy balance. "Crop factors" during the winter growing and summer fallow periods were determined from ET/ETo, where ETo is reference evaporation calculated from weather data at the CSIRO Finley weather station using a locally calibrated Penman equation (Meyer 1999; Meyer et al. 1999).

For the other fields, ET was estimated from crop factors and ETo calculated from meteorological data collected at the CSIRO Finley and Tullakool weather stations, using the locally calibrated Penman equation and associated crop factors (Meyer 1999; Meyer et al. 1999).

Evaporation (E) from fallow soil was also determined on two red brown earth soils near Griffith, using PVC cylinders (diameter 15 cm, depth 30 cm) installed in the field near Griffith in 1999. The cylinders were installed in May and periodically dug out, capped at the base, weighed, reinstalled in the field and weighed (usually daily) to determine moisture loss. Each cylinder was only monitored for a period of a one to four days (less when significant rain occurred) prior to discarding, because of the discontinuity with soil beneath the cylinder once capped at the base, preventing vertical fluxes. Fallow crop factors were calculated from E/ETo.

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

[1] Use of a registered trade name does not imply endorsement.

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.

Results

Site characterization

The soils at sites B and W were red brown earths (Stace et al. 1972) with a shallow clay loam topsoil and a heavy subsoil. The local description at site B was a Tuppal/Moira loam (Smith 1945). At site L the soil was lighter red brown earth with a deeper loam topsoil and a medium clay subsoil, rapidly changing to about 90% sand below 2 m, locally known as a Cobram loam (Smith 1945). Site P had a heavy black cracking clay soil (Stace et al. 1972) locally known as Wunnamurra clay (Smith 1945). Soil properties at the four sites are summarized in Tables 1-4.

Table 1. Soil properties at the two monitoring sites (low, high) [A] at field B – beds with maize, wheat and barley
Red-brown earth – Tuppal/Moira loam at low EM site, clay loam at high EM site

Depth interval (cm)	Bulk density (g/cm^3)		% clay		% silt		% sand		Hydraulic con (mm/h) at spec	
									4 cm tension	
	Low	High	Low	High	Low	High	Low	High	Low	High
0-15	1.40 (0.37)[C] 5-15cm	1.46 (0.13) 5-15 cm	24	31	17	22	59	47		0.96 5 cm
15-30	1.44 (0.08) 15-25 cm	1.47 (0.23) 15-25 cm	35	32	13	22	52	46		
30-45	1.54 (0.09) 35-45 cm	1.53 (0.15) 35-45 cm	62	49	9	15	29	36		
45-60	1.67 (0.10) 55-65 cm	1.68 (0.15) 55-65 cm	61	71	10	12	29	17	1.08 (0.16) 50 cm	
60-90	1.76 (0.07) 86-95 cm	1.72 (0.10) 86-95 cm	59	64	11	13	29	24		4.06 (0.62) 60 cm
90-120	1.66 (0.04) 115-125 cm	1.71 (0.10) 115-125 cm	54	58	13	14	33	28	1.77 (0.53) 100 cm	0.56 (0.28) 100 cm
120-150			53	57	15	15	33	28		
150-180			47	52	17	21	37	27		
180-210			49	50	18	22	34	28		
210-240			54	43	13	31	33	26		
240-270			59	41	14	27	28	32		
270-300			61	58	13	11	27	31		
300-330			62	61	13	10	26	29		
330-360			62	61	15	10	23	29		
360-390			55	60	16	12	29	28		

[A] low and high refer to apparent electrical conductivity as determined by EM31 survey.
[B] determined using disk permeametry
[C] standard deviation (n=3) in brackets

Table 2. Soil properties at the two monitoring sites (low, high) [A] at field L – lucerne on border check

Red brown earth – Cobram loam at both EM sites

Depth interval (cm)	Bulk density (g/cm^3)		% clay		% silt		% sand		Hydraulic con (mm/h at specified		
									4 cm tension		
	Low	High	Low	High	Low	High	Low	High	Low	High	
0-15	1.48 (0.06)	1.44 (0.07)	20	16	18	20	63	64	9.0 (2.9) 5 cm	13.6 (8.5) 5 cm	6
15-30	1.59 (0.02)	1.60 (0.07)	22	20	17	18	51	62			
30-45	1.74 (0.04)	1.65 (0.17)	32	26	13	16	55	58			
45-60	1.70 (0.09)	1.69 (0.05)	42	46	11	16	48	39	0.6 (1.01) 50 cm	0.4 (0.03) 60 cm	0.
60-90	1.72 (0.07)	1.70 (0.03)	32	44	23	21	45	35			
90-120	1.86 (0.23)	1.86 (0.26)	32	45	26	22	41	34	2.1 (1.2) 100 cm	0.9 (0.51) 100 cm	0
120-150	1.72	1.76 (0.16)	34	44	28	24	38	33			
150-180			30	43	31	33	38	25			
180-210			24	39	28	38	48	24			
210-240			19	31	19	27	62	42			
240-270			15	15	11	8	74	78			
270-300			8	15	1	8	92	78			
300-330			4	8	3	2	93	91			

[A] low and high refer to apparent electrical conductivity as determined by EM31 survey.
[B] determined using disk permeametry (Meister 2002)
[C] standard deviation in brackets (n=3)

Table 3. Soil properties at the two monitoring sites (low, high) [A] at field P – annual pasture on border check

Black cracking clay at both EM sites

Depth interval (cm)	Bulk density (g/cm^3)		% clay		% silt		% sand		EC (dS/m) (saturation extract)		Saturated hyd conductivity (	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	H
0-15	1.49	1.30	38	45	12	14	50	40	0.36	0.61		
15-30	1.58	1.51	46	52	13	13	41	35	0.39	0.95		
30-45	1.57	1.69	47	55	13	16	40	30	0.48	1.47		
45-60	1.63	1.66	39	56	15	14	47	29	0.54	2.46		
60-90	1.69	1.69	31	56	15	14	53	30	0.53	5.19		
90-120			29	56	22	21	49	23	0.52	7.22		
120-150			27	55	21	18	52	27	0.57	7.37		
150-180			26	56	21	17	53	27	0.58	5.54		
180-210			32	55	23	15	45	30	0.51	4.07		
210-240			50	54	18	16	32	30	0.50	4.45		
240-270			58	53	16	22	26	25	0.78	4.39		
270-300			60	53	19	20	21	28	1.02	5.14		
300-330			60	51	20	17	19	32	1.13	5.95		
330-360			62	52	22	19	15	29				
360-390			62	51	21	19	17	30			0.04	
950-1,000											0.20	0

[A] low and high refer to apparent electrical conductivity as determined by EM31 survey.
[B] determined using disk permeametry (Meister 2002)
[C] standard deviation in brackets (n=3)

Table 4. Soil properties at the two monitoring sites (low, high) [A] at field W – winter crops (canola, wheat, barley) on border check

Red brown earth at both EM sites

Depth interval (cm)	Bulk density (g/cm^3)		% clay		% silt		% sand		EC (dS/m) (saturation extract)		Saturated hydraulic conductivity (mm/d)
	Low	High	Low	High	Low	High	Low	High	Low	High	Low
0-15	1.37	1.39	16	22	25	21	59	58	1.25	0.60	
15-30	1.61	1.63	16	32	24	20	60	48	0.67	0.40	
30-45	1.68	1.87	24	36	20	20	55	44	1.38	0.53	
45-60	1.72	1.78	28	34	18	19	54	47	1.40	0.93	
60-90	1.67	1.70	16	33	10	18	74	49	0.68	2.12	
90-120	1.62	1.67	29	38	6	26	65	36	0.58	3.56	
120-150			45	54	33	23	22	23	0.51	6.06	
150-180			44	58	30	20	26	22	0.48	10.41	
180-210			45	56	29	23	25	21	0.50	13.13	
210-240			42	52	26	28	32	25	0.64	13.09	
240-270			41	63	24	21	35	16	0.65	12.52	
270-300			40	62	23	20	37	18	0.54	12.52	
300-330			34	58	19	20	47	22	0.55	13.96	
330-360			32	59	21	19	47	22			
360-390			29	57	20	24	51	19			0.002

[A] low and high refer to apparent electrical conductivity as determined by EM31 survey.
[B]determined using disk permeametry (Meister 2002)

Model input data

Soil water content

The highest and lowest soil water contents observed over the three years of monitoring were identified for each layer in the soil profile at all 8 EM sites (Table 5). Ideally these values should represent the soil water content at saturation (SAT) and at the lower limit (LL), an approximation of wilting point. However whether the soil is dried down to the lower limit depends on the seasonal conditions and crop growth (affects crop water use requirement) and root distribution and depth. In shallow watertable situations the lower limit will never be reached in the subsoil. The drained upper limit (DUL) or field capacity was determined after 1-2 days of drainage from the saturated condition, guided by observations of soil matric potential where available, with field capacity considered to be around – 0 kPa.

Initial soil water content can have a large effect on deep drainage calculated from the water balance. Therefore observations of soil water content at the time of sowing (or pre-irrigation where this occurred) were compiled for each annual crop (Table 6). Soil water content on the first of July each year was also noted (Table 7), as SWAGMAN® Farm has a computational period of one year, starting in July.

Monthly and daily data sets

Files of monthly totals of rain, irrigation applications and surface runoff and the change in profile soil water content were prepared (Tables 8-11). Files of profile (0-1.2 m) soil water content and depth to the watertable on the first day of each month were also prepared (not presented). More detailed files of daily irrigation applications and runoff, rain, volumetric soil water content at each depth and depth to the watertable were also prepared (not presented) and for use in validation of the SWAGMAN® Destiny and MaizeMan models.

Soil hydraulic conductivity

Unsaturated hydraulic conductivities, determined at low tensions (high soil water content) using disc permeameters, are summarised in Table 12. Hydraulic conductivity was always lower at –0.8 kPa than at –0.4 kPa, consistent with the exclusion of larger macropores at higher suctions. The values in field B are surprisingly high for a field classified as suitable for rice on the basis of rice crop water use and clay content. To meet the rice water use limit saturated conductivity needs to be less than ~0.08 mm/h (2 mm/d), compared with the minimum observed values of 0.4-0.5 mm/h at near saturation (-0.4 kPa). It is possible that in the process of digging pits to do the disc permeameter measurements at different depths, removal of the overburden and confining pressures allows the soil micropores to expand, increasing hydraulic conductivity.

Saturated conductivity in the layer into which the piezometers were installed (bottom half meter of the piezometer was slotted and screened) was determined using pump tests, and the results are summarised in Table 13. Conductivity at 4 m in field L was very high, consistent with the sandy material at this depth.

Crop factors for evapotranspiration

Crop factors for the annual pasture calculated using Bowen ratio energy balance and ETo at Finley are shown in Figures 2a,b. During the fallow period there was a thick mulch of dead pasture on the soil surface, and the crop factor fluctuated around 0.2 (Figure 2a). Following irrigation in early autumn, the pasture germinated and developed green leaf area, and the crop factor gradually increased in a reasonably linear fashion to around 1 in winter in 2001(Figure 2b). The crop factor tended to be lower in June in 2002, when conditions were exceptionally dry, compared with 2001.

Crop factors determined from microlysimeters during late winter and spring in a fallow field in the second year after rice fluctuated around 0.1 (Figures 3a,b). Soil water content in 10 cm layers to 30 cm was relatively constant during this period.

Table 5. Field saturation, field capacity (two days after irrigation) and driest recorded volumetric soil water contents (%) at the low and high EM31 sites in the four fields

Field L
Watertable – deep (>3.3 m)
Landuse - lucerne

	Cobram loam – red brown earth						
Depth	**Low EM31**				**High EM31**		
(cm)	**SAT**	**FC**	**Driest**		**Sat**	**FC**	**Driest**
20	32.4	26.9	13.7		28.0	24.7	11.1
30	34.5	30.5	13.3		27.7	25.6	13.2
40	38.7	34.5	13.3		33.4	31.3	15.1
60	38.4	33.3	23.9		42.5	40.6	16.1
120	30.9	30.0	25.1		42.0	42.0	32.8
180	22.1	21.5	17.8		37.1	36.8	30.9

Field B
Watertable – variable (0.75-3.5 m)
Landuse – maize, wheat, barley, maize

	Tuppal/Moira loam				**Clay loam**		
Depth	**Low EM31**				**High EM31**		
(cm)	**Sat**	**FC**	**Driest**		**Sat**	**FC**	**Driest**
10	35.5		18.8		37.9		18.0
20	39.8		21.6		39.8		23.5
40	44.9		20.5		42.1		21.0
60	44.7		23.6		42.5		22.8
90	45.4		36.1		42.5		28.7
150	44.9		37.0		44.2		35.0

Field P
Watertable – deep (>4 m)
Landuse – annual pasture

	black cracking clay						
Depth	**Low EM31**				**High EM31**		
(cm)	**Sat**	**FC**	**Driest**		**Sat**	**FC**	**Driest**
10	28.5	26.0	16.0		28.4	25.0	17.9
20	29.7	27.3	16.6		30.2	28.9	19.3
40	30.4	29.1	17.1		30.7	29.3	21.3
60	31.3	30.1	21.0		31.1	29.7	23.7
90	30.2	29.5	21.9		29.4	28.0	25.4
150	30.5	30.2	18.9		30.1	29.4	22.8

Field W
Watertable – intermediate (~ 2 m)
Landuse – winter crops (canola, wheat, barley)

	Red brown earth						
Depth	**Low EM31**				**High EM31**		
(cm)	**Sat**	**FC**	**Driest**		**Sat**	**FC**	**Driest**
10	28.2	26.1	11.6		30.6	28.9	11.3
20	25.0	25.0	12.8		30.2	29.3	11.3
40	26.0	25.9	10.8		33.9	30.5	18.5
60	27.9	27.8	12.9		33.5	30.6	21.2
90	26.8	26.7	12.2		40.1	39.4	10.1
150	34.0	33.0	22.8		48.6	48.4	36.2

Table 6. Volumetric soil water content (%) at the time of sowing (or pre-irrigation) at the low and high EM31 sites in 4 fields

Field B
Watertable – variable (0.75-3.5 m)
Landuse – maize, wheat, barley, maize

	Tuppal/Moira loam				**Clay loam**			
Depth	**High EM31**				**Low EM31**			
(cm)	**Maize**	**Wheat**	**Barley**	**Maize**	**Maize**	**Wheat**	**Barley**	**Maize**
	28/10/98	**28/05/99**	**19/06/00**	**15/11/01**	**28/10/98**	**28/05/99**	**19/06/00**	**15/11/01**
10	20.24	21.90	24.83	23.3	23.83	24.18	22.12	24.15
20	22.70	24.83	26.79	27.4	29.74	29.54	28.20	30.14
40	32.85	25.22	28.77	26.6	30.95	32.69	30.06	33.45
60	35.71	28.74	37.10	29.9	35.28	38.23	35.48	31.40
90	38.49	42.57	43.54	40.0	37.49	38.18	37.73	33.52
150	37.03	44.45	43.84	43.3	43.03	43.38	43.28	41.93
Profile (mm)	**512**	**529**	**565**	**524**	**538**	**553**	**535**	**512**

Field W
Watertable – intermediate (~ 2 m)
Landuse – winter crops (canola, wheat, barley)

	black cracking clay						
Depth	**Low EM31**				**High EM31**		
(cm)	**Canola**	**Wheat**	**Barley**		**Canola**	**Wheat**	**Barley**
	20/3/99	**17/3/00**	**16/3/01**		**20/3/99**	**17/3/00**	**16/3/01**
10	19.3	17.5	19.4		27.4	26.7	
20	20.2	15.2	16.8		28.0	28.0	
40	23.3	18.6	19.0		29.4	33.9	
60	27.3	26.0	24.9		29.4	33.4	
90	25.4	23.3	18.9		31.4	39.9	
150	30.2	32.1	29.6		36.7	48.4	
Profile (mm)	**408**	**359**	**351**		**498**	**569**	

Table 7. Volumetric soil water contents (%) on 1 July each year at the low and high EM31 sites in the four fields

Field L **Watertable**	**Lucerne – deep (>3.3 m)**						
	Cobram loam – red brown earth						
Depth	**Low EM31**				**High EM31**		
cm	**1/07/99**	**1/07/00**	**1/07/01**		**1/07/99**	**1/07/00**	**1/07/01**
20	26.7	24.6	14.4		15.6	24.7	11.5
30	29.6	25.2	13.7		21.9	27.2	13.4
40	29.7	23.9	13.6		22.4	28.2	15.3
60	28.6	26.1	23.9		28.3	28.8	16.8
120	24.0	23.8	25.5		26.4	28.8	33.8
180	19.7	18.8	18.0		27.9	29.5	31.4
Profile (mm)	**326**	**298**	**248**		**292**	**335**	**245**

Field B **Watertable**	**Beds with maize, wheat, barley, maize – variable (0.75-3.5 m)**						
	Tuppal/Moira loam				**Clay loam**		
Depth	**Low EM31**				**High EM31**		
cm	**1/07/99**	**1/07/00**	**1/07/01**		**1/07/99**	**1/07/00**	**1/07/01**
20	23.6	26.8	22.0		23.8	26.3	21.6
30	25.6	27.5	24.9		29.7	32.1	28.0
40	26.1	29.0	23.1		31.0	34.0	31.6
60	30.8	37.1	29.6		35.9	31.5	29.7
120	42.6	43.6	40.8		37.5	33.7	33.1
180	44.0	43.8	42.6		43.0	41.9	35.3
Profile **(mm)**	**537**	**568**	**512**		**538**	**519**	**474**

Field P **Watertable**	**annual Pasture – deep (>4 m)**						
	black cracking clay						
Depth	**Low EM31**				**High EM31**		
cm	**1/07/99**	**1/07/00**	**1/07/01**		**1/07/99**	**1/07/00**	**1/07/01**
20	17.4	18.2	20.3		19.9	19.8	22.8
30	19.3	18.6	22.5		24.4	24.0	24.5
40	26.6	21.2	25.7		26.7	25.5	26.2
60	29.6	22.7	28.1		27.9	25.5	27.4
120	23.0	25.7	29.2		27.7	26.0	26.5
180	19.0	29.9	30.0		23.2	27.6	27.5
Profile (mm)	**344**	**366**	**412**		**386**	**384**	**396**

Field W **Watertable**	**Winter crops (canola, wheat, barley) – intermediate (~ 2 m)**						
	Red brown earth						
Depth	**Low EM31**				**High EM31**		
cm	**1/07/99**	**1/07/00**	**1/07/01**		**1/07/99**	**1/07/00**	**1/07/01**
20			13.6		22.6	17.2	17.4
30			13.6		22.6	20.1	20.8
40	14.6	13.4	15.6		29.4	25.9	25.8
60	24.6	22.1	22.9		29.4	25.0	24.4
120	21.6	19.3	19.3		35.0	34.9	34.9
180	32.1	30.7	30.7		47.1	47.3	47.2
Profile (mm)	**325**	**313**	**329**		**511**	**485**	**484**

Table 8. Monthly water balance for field B – maize and winter cereals on beds (DD = deep drainage below 1.2 m, UF = upflow)

Date	Rain mm	Irrig I mm	Surface drainage SD mm	ΔSWC (0-1m) mm	Finley ETo mm	Kc	ET= ET_0*Kc mm	Deep drainage , +ve (upflow , –ve) mm	I
Oct-98	25	97	119	59	158.9	0.20	55.6	43	F
Nov-98	48	0		-19	215.2	0.27	107.6	9	
Dec-98	16	136	257	-5	306.9	0.58	214.8	45	
Jan-99	15	182	263	-21	319.3	0.83	271.4	-23	
Feb-99	2	127	165	15	243.0	0.75	206.6	-78	
Mar-99	19	0		-3	180.9	0.2	36.2	-15	F
Apr-99	4	0		1	114.5	0.3	34.4	-32	F
May-99	26	0		6	65.4	0.4	26.2	-6	F
Jun-99	51	0		-1	30.0	0.6	18.0	34	
Jul-99	8	0		-6	36.9	0.9	33.2	-19	
Aug-99	45	0		2	62.5	1.1	68.8	-23	
Sep-99	24	42	51	70	103.8	1.1	114.2	-115	
Oct-99	42	0	0	-64	155.6	0.8	124.5	-19	
Nov-99	38	0	0	-68	209.2	0.5	104.6	1	
Dec-99	40	0	0	26	283.0	0.2	56.6	-42	
Jan-00	11	0	0	-10	295.1	0.2	59.0	-38	F
Feb-00	31	0	0	14	238.1	0.2	47.6	-31	F
Mar-00	61	0	0	30	197.2	0.2	39.4	-8	F
Apr-00	30	0	0	-5	118.6	0.3	35.6	-1	F
May-00	61	0	0	12	54.8	0.3	16.4	33	F
Jun-00	35	0	0	1	29.8	0.5	14.9	20	
Jul-00	35	0	0	5	43.3	0.8	34.6	-5	
Aug-00	63	0	0	17	53.2	1.0	53.2	-8	
Sep-00	47	38	45	26	89.8	1.0	89.8	-68	
Oct-00	35	0	0	-78	152.8	0.9	137.5	-25	
Nov-00	47	0	0	-33	211.9	0.5	106.0	-26	
Dec-00	0	0	0	-2	322.1	0.2	64.4	-62	F
Jan-01	26	0	0	4	332.7	0.2	66.5	-45	F
Feb-01	0	0	0	-6	242.5	0.2	48.5	-42	F
Mar-01	22	0	0	2	204.1	0.2	40.8	-21	F
Apr-01		0	0	-65	130.9	0.2	26.2	65	F
May-01	4	0	0	-27	67.1	0.2	13.4	31	F
Jun-01	18	0	0	8	43.7	0.2	8.7		F
Jul-01	28	0	0	15	40.6	0.2	8.1		F
Aug-01	30	0	0	-5	96.6	0.2	19.3		F
Sep-01	15	0	0	25	141.8	0.2	28.4		F
Oct-01	56	0	0	93	155.6	0.2	31.1		F

Nov-01	0	105	0	54	167	0.20	33		
Dec-01	8	101	?	29	303	0.36	109		
Jan-02	6	213	?	-4	328	0.70	230		
Feb-02	81	159	?	-4	225	0.85	192		
Mar-02	0	69	?	-42	179	0.69	123		

Table 9. Monthly water balance for field L – lucerne (DD = deep drainage below 1.2 m, UF = upflow)

	Irrigation I mm	Rain R mm	ΔSWC (0-1.2 m) mm	Finley ET_0 mm	Kc	ETc (ET_0*Kc) mm	DD+ve (UF-ve) mm	Use	Yield t/ha
Nov-98	133	48	16	215	0.75	161	3	hay	3.8
Dec-98	200	9	21	307	0.84	259	-70	hay	4.4
Jan-99	198	27	11	319	0.84	267	-53	hay	4.1
Feb-99	135	6	0	243	0.79	192	-52	hay	3.8
Mar-99	58	31	-15	181	1.02	185	-81	hay	3.2
Apr-99	0	13	-32	115	0.61	70	-26		
May-99	0	30	-14	65	0.91	60	-17		
Jun-99	0	54	19	30	0.68	20	14		
Jul-99	0	7	-14	37	0.65	27	-7		
Aug-99	0	44	4	63	0.70	44	-3		
Sep-99	83	42	46	104	0.50	52	27	silage	2
Oct-99	0	66	-27	156	0.84	137	-44		
Nov-99	98	55	-6.7	209	0.75	171	-11	hay	3.4
Dec-99	156	58	21	283	0.76	202	-9	hay	4.6
Jan-00	170	11	-5	295	0.79	234	-49	hay	3.9
Feb-00	199	35	11	238	0.8	190	33	hay	2.8
Mar-00	65	39	-35	197	0.84	162	-23	hay	3.5
Apr-00	38	24	-18	119	0.77	90	-9		
May-00	0	60	-4	55	0.81	44	19	silage	2
Jun-00	0	42	10	30	0.59	18	15		
Jul-00	0	34	0	43	0.65	28	5		
Aug-00	0	82	27	53	0.50	27	28	silage	2
Sep-00	0	58	-10	90	0.86	80	-12		
Oct-00	0	57	-12	153	1.18	180	-112		
Nov-00	98	66	32	212	0.93	202	-70	hay	4.5
Dec-00	201	4	29	322	0.78	251	-75	hay	3.9
Jan-01	182	61	7	333	0.77	255	-19	hay	3.8
Feb-01	135	28	2	243	0.82	199	-39	hay	2.8
Mar-01	77	22	-43	204	0.87	178	-37	hay	2.1
Apr-01	0	19	-52	131	0.96	125	-55		
May-01	0	3	-29	67	0.82	55	-22	silage	2
Jun-01	0	23	-1	44	0.58	25	-2		
Jul-01	0	28	-2	41	0.65	26	3		
Aug-01	0	24	-2	97	0.69	66	-40		
Sep-01	106	35	113	142	0.91	129	-101		
Oct-01	0	27	-23	156	1.18	184	-135		
Nov-01	98	16	29	250	0.90	226	-141	hay	4.6
Dec-01	238	9	-1	303	0.78	237	11	hay	4.7
Jan-02	248	4	61	328	0.79	258	-66	hay	4.5
Feb-02	125	60	-20	225	0.86	193	12	hay	3.5
Mar-02	171	29	-7	231	0.83	193	14		
Apr-02	0	12	-42	124	0.98	122	-68	hay	2.5

Table 10. Monthly water balance for field P – annual pasture (DD = deep drainage below 1.2 m, UF = upflow)

Date	Rain R mm	Irrig I mm	Surface drainage SD mm	ΔSWC (0-1.2 m) mm	R+I-SD-ΔSWC mm	Bowen ratio ET mm
Nov-98	63.4	0.0	0.0	1.5	61.9	
Dec-98	7.2	0.0	0.0	-0.5	7.7	
Jan-99	35.5	0.0	0.0	16.3	19.2	
Feb-99	0.0	0.0	0.0	-1.0	1.0	
Mar-99	143.5	0.0	48.7	56.4	38.4	
Apr-99	0.0	0.0	0.0	-29.0	29.0	
May-99	55.0	0.0	0.0	-2.5	57.5	
Jun-99	37.5	0.0	0.0	1.6	35.9	
Jul-99	9.0	0.0	0.0	-12.3	21.3	
Aug-99	36.5	0.0	0.0	0.6	35.9	
Sep-99	35.5	0.0	0.0	-26.1	61.6	
Oct-99	73.5	0.0	0.0	-6.7	80.2	
Nov-99	48.0	0.0	0.0	7.1	41.0	
Dec-99	26.5	0.0	0.0	3.6	22.9	
Jan-00	11.0	0.0	0.0	2.9	8.1	
Feb-00	53.0	0.0	0.0	16.2	36.9	
Mar-00	22.0	65.9	11.8	38.5	37.6	
Apr-00	16.5	0.5	8.2	-21.4	30.2	
May-00	16.0	0.0	0.0	-13.7	29.7	
Jun-00	2.5	0.0	0.0	8.9	-6.4	
Jul-00	43.9	0.0	0.0	-10.4	54.3	
Aug-00	0.0	0.0	0.0	-9.6	9.6	
Sep-00	24.5	80.2	26.5	28.2	49.9	
Oct-00	9.2	33.4		14.8	27.8	
Nov-00	109.5	0	16.4	-12.0	105.1	
Dec-00	0	0	0	-2.6	2.6	
Jan-01	10	0	0	1.0	9.0	
Feb-01	38	0	0	4.4	33.6	
Mar-01	13	60.9	18.2	-2.9	58.6	77.9
Apr-01	41	57.1	22.4	-3.4	79.2	96.6
May-01	0			-18.95	18.9	59.3
Jun-01	14.5					43.2
Jul-01	29.5			-0.70	30.2	
Aug-01	67.0					
Sep-01	25.0	75.0				
Oct-01	40					
Nov-01	21.5			-29.58	51.1	
Dec-01	0			-0.04		60.5
Jan-02	15.5			3.78	11.7	
Feb-02	49			17.98	31.0	
Mar-02	35.00	73.51	15.26	40.33	52.9	
Apr-02	18					
May-02	17.5					54.7
Jun-02	12	13.75		-0.97	26.7	38.7

Table 11. Monthly water balance for field W – winter crops on bordercheck

Landuse	Date	Rain R mm	Irrig I mm	Surface drainage SD mm	ΔSWC (0-1.2 m) mm	R+I-SD-ΔSWC mm	Events
Canola 1999	**Mar-99**	144.4	48.2	59.19	97.0	36.4	pre-sowing irrigation
	Apr-99		3.20	0.00	-9.0	12.2	
	May-99		41.60	0.00	-15.5	57.1	sowing canola
	Jun-99		21.60	0.00	-8.0	29.6	
	Jul-99		23.00	0.00	-6.9	29.9	
	Aug-99		58.50	0.00	0.9	57.6	
	Sep-99	111.1	33.00	39.43	12.4	92.3	irrigation
	Oct-99		79.50	0.00	-19.3	98.8	
	Nov-99		54.00	0.00	9.4	44.6	windrowing
	Dec-99		29.50	0.00	-0.5	30.0	
	Jan-00		16.00	0.00	7.3	8.7	
	Feb-00		27.80	0.00	7.4	20.4	
Wheat 2000	**Mar-00**	113.9	10.00	55.85	11.9	56.2	pre-sowing irrigation.
	Apr-00		40.00	0.00	-10.3	50.3	
	May-00		25.50	0.00	-25.54	51.0	grazed by sheep
	Jun-00		3.00	0.00	-2.14	5.1	grazed by sheep
	Jul-00		0.00	0.00	-11.14	11.1	
	Aug-00	125.0	3.50	26.60	32.62	69.3	irrigation
	Sep-00		28.50	0.00	-41.55	70.1	
	Oct-00		75.00	0.00	5.84	69.2	
	Nov-00		74.50	0.00	-13.54	88.0	
	Dec-00		1.50	0.00	5.21	-3.7	harvested
	Jan-01		34.0	0.0	7.66	26.3	
	Feb-01		27.00	0.00	-13.00	40.0	
Barley 2001	**Mar-01**	129.7	33.0	23.8	61.15	77.8	pre-sowing irrigation
	Apr-01		10.50	0.00	-32.54	43.0	
	May-01		29		-27.44	56.4	
	Jun-01		19		7.02	12.0	
	Jul-01		54.5		16.75	37.8	
	Aug-01		38.5		-4.24	42.7	
	Sep-01	93.90	21.5	11.0	24.50	79.9	irrigation
	Oct-01		33		-27.01	60.0	
	Nov-01		2.5		-22.48	25.0	
	Dec-01		0		-22.70	22.7	

Table 12. Unsaturated soil hydraulic conductivity (mm/h) determined using disc permeameters

Depth (cm)	Field B				Field L			
	Clay loam		Tuppal/Moira loam		Cobram loam			
	Low EM31		High EM31		Low EM31		High EM31	
	0.8 kPa	0.4 kPa	0.8 kPa	0.4 kPa	0.8 kPa	0.4 kPa	0.8 kPa	0.4 kPa
5	0.76	0.96	7.0.		4.01	13.6	6.91	9.01
50	0.4		0.56	1.08			0.33	0.65
60	2.19	4.06	2.74		0.31	0.37		
100	0.22	0.56	1.17	1.77	0.6	0.92	0.85	2.13

Table 13. Saturated hydraulic conductivity (mm/h) determined using slug tests in piezometers

Field	EM31 site	Soil name	Soil type at piezo depth	Piezometer depth	
				4 m	10 m
B	Low	Tuppal/Moira loam	Heavy clay	0.25	
B	High	Clay loam	Heavy clay	0.42	
L	Low	Cobram loam	Sand		
L	High	Cobram loam	Sand	17.8	
P	Low	Black cracking clay	Heavy clay	0.25	0.20
P	High	Black cracking clay	Heavy clay		0.22
W	Low	Red brown earth	Light clay	0.0001	
W	High	Red brown earth	Heavy clay	0.0088	

Figure 2a. Crop factor (Kc) for annual pasture during summer soil is covered by thick mulch of dead pasture – Kc calculated from Bowen ratio determinations of ET and ETo at Finley and Tullakool (the thin straight lines are trendlines)

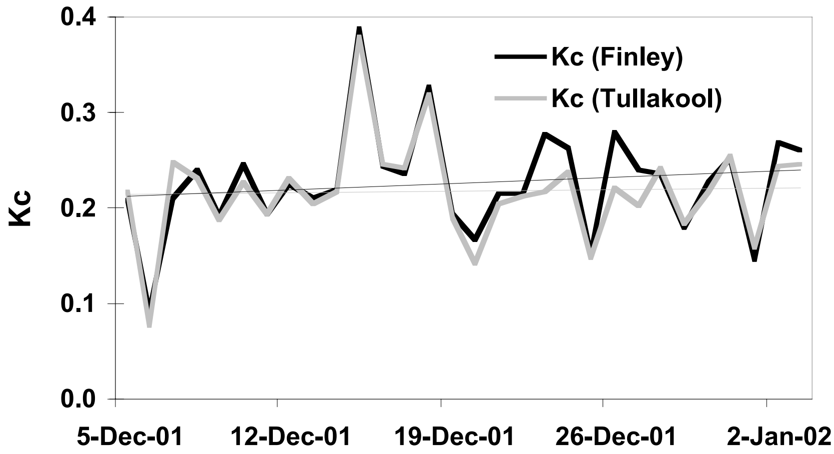
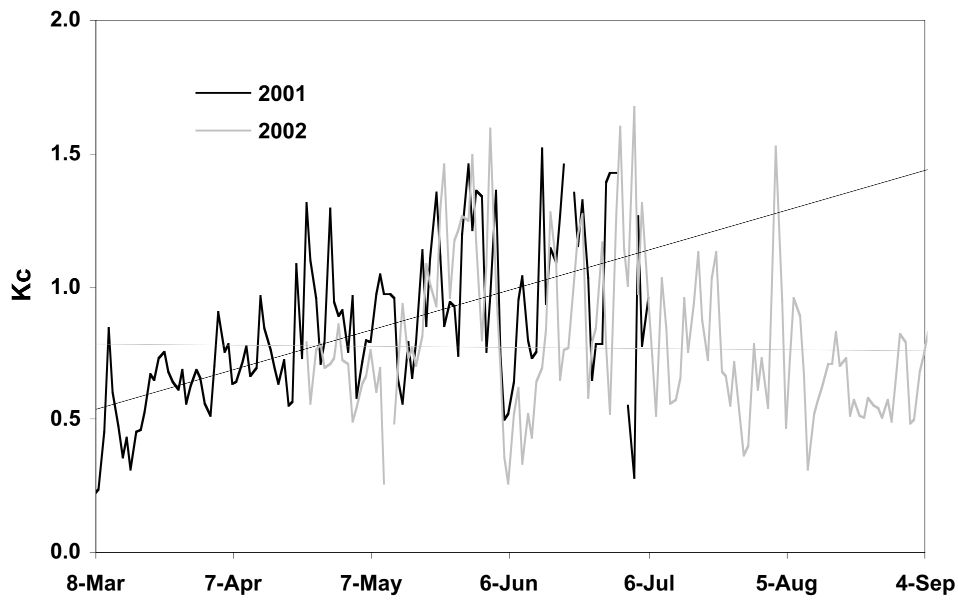
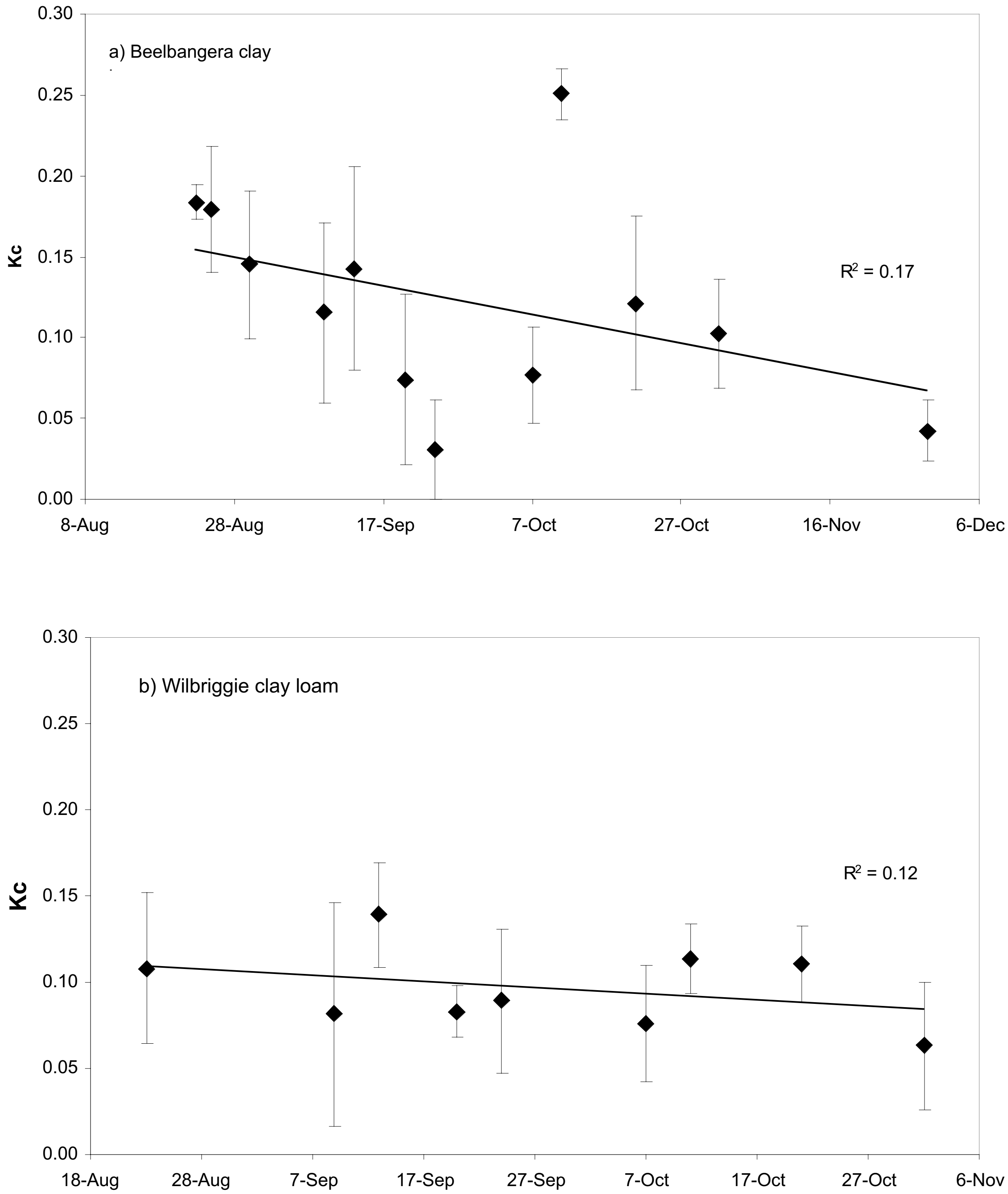


Figure 2b. Crop factor (Kc) for annual pasture during the growing season - Kc calculated from Bowen ration determinations of ET and ETo at Finley (the thin straight lines are trendlines)



Figures 3a,b "Crop factors" during the fallow period in the second winter/spring following rice on two soil types near Griffith in 1999



Model validation

SWAGMAN® Farm

The SWAGMAN® Farm model was run for each field (annual time steps) and the predicted depth to the watertable was compared with field observations (Figures 4-7). The initial conditions were adjusted to match the observed initial conditions at the start of each year. Figure 4 shows the effect of the rate of groundwater outflow used in the model on the final depth to the watertable, and highlights the importance of understanding the local groundwater hydrology in model applications. Reasonably good agreement was obtained between SWAGMAN® Farm predictions and observed depths to the watertable with an initial leakage rate of 0.9 ML/ha/yr when 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 regional groundwater investigations (Khan 2003).

There was little movement in the watertable under the lucerne, which remained deep at around 3.5 m (Figure 5), and the model predictions matched these observations fairly closely. The watertable level in the annual pasture fluctuated considerably (range 1.5-4 m) from mid 2000 to mid 2002 in response to irrigation and rain (Figure 6). There was good agreement between predicted and observed values (4 m piezometer) for the first and third years of annual pasture, but the model predictions were lower at the end of the second year of pasture. Agreement between observed and predicted values was also good for the winter crops grown on border check (Figure 7).

Khan et al. (2003) undertook detailed sensitivity analyses of SWAGMAN® Farm for initial soil water content, area (%) of rice (on suitable soils), groundwater outflow rate and rice paddock water use. The results showed that the model provides sensible results under a range of situations.

SWAGMAN® Destiny

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 for a range of parameters not used in the calibration give good confidence in the model processes (Figures 8a-i). These parameters were biomass production, volumetric soil water content at different depths and depth to the watertable, over the duration of the crop.

SWAGMAN® Destiny has also been calibrated for several wheat varieties and validated against independent 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 (Godwin et al. 2002, Smith et al. 2003, Xevi et al. 2003b). This work was undertaken in the Cooperative Research Centre for Sustainable Rice Production project 1205 *Quantifying and maximizing the benefits of crops after rice*. The results of this Rice CRC project also influenced refinements to the soil water accounting processes in SWAGMAN® Farm (Khan et al. 2001).

MaizeMan

The MaizeMan model is a detailed maize growth model with the Destiny salt and water balance routines including interaction with the groundwater. It has been calibrated for and tested against a range of varieties grown under irrigation in southern NSW, with generally good agreement between predicted and observed values (Humphreys et al. 2003, Xevi et al. 2003a). The 2001/2 silage maize crop (DK689) grown in field B was calibrated for MaizeMan using observed phenological stages.

Time course observations of 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 (Figures 9a,b) and volumetric soil water content (Figures 9c-e).

General discussion

The results above indicate generally good agreement between model predictions and observed values. The model simulations also highlighted the importance of good knowledge of the regional hydrology (especially groundwater outflow rates) for rational application of the SWAGMAN® Farm and SWAGMAN® Destiny models. The results presented here, together with the findings from two complementary projects, suggest that the SWAGMAN® Farm and SWAGMAN® Destiny models are reliable predictors of watertable behaviour and crop performance in the irrigated areas of southern NSW. The project has generated datasets which can also be used for testing of other commonly used point scale water balance models which use numerical solutions of Richard's equation to investigate deep drainage/upflow responses, such as Hydrus and SWAP (Soil Water Atmosphere Plant).

While this work has generated data sets that are useful for refining inputs and for validating water balance models, it is limited in the range of parameters measured, and to a small range of situations. The validity of the models outside the measured range of parameters needs to be supported by sensitivity analysis and sensibility checks. More comprehensive investigations are needed on a range of soil types and salinity, crops and watertable (depth and salinity) situations. In particular:

(i) there are few, if any, suitable data sets available for validating salt and water balance models, from predictions of salinity fluxes to crop response to salinity, for the range of saline or potentially saline situations and landuses in the irrigation areas of the southern Murray-Darling Basin

(ii) model input data have a critical influence on predictions of deep drainage and identification of improved management/landuse. Rigorous characterization of soil hydraulic properties is required for a range of soil types, including hydraulic conductivity functions, as well as upper and lower limits of available soil water and saturation soil water content. Building on this, a major effort is needed to generate pedotransfer functions to predict soil hydraulic properties from more readily measurable soil attributes, taking advantage of recent developments in mathematical analysis (such as the application of neural networks) and modern computing technology.

(iii) there are very few quantitative determinations of actual crop evapotranspiration (ETc), usually the largest component of the water balance. Small errors in estimating ETc can lead to large errors in deep drainage estimates and its impact on watertables and leaching. Water balance models rely on estimating ETc from reference evaporation and crop factors, and the crop factors were developed under conditions of non-limiting crop growth in a lysimeters environment. Actual ETc needs to be determined for a range of landuses using techniques such as Bowen ratio to evaluate and improve current methods for estimating ETc in water balance models such as SWAGMAN® Farm

(iv) the monitoring to date has focussed on the water balance at the point and paddock scales, whereas the situation is often much more complex than this. Three dimensional approaches are also required to simulate the interaction between paddocks and neighbouring influences such as channel seepage, and lateral flow between paddocks in addition to the unsaturated hydrology. Data sets to support such three dimensional approaches are almost totally lacking

(v) watertables go up and down under paddocks in response to management and landuse, and landuse varies in space and time on a farm. Therefore it is very difficult for a land manager to know what is really happening to the watertable on average across the farm. There is a need for investigations at the paddock and farm scales to develop monitoring guidelines to determine a reasonable representation of the average watertable change under a farm. This will be critical to the successful implementation of net recharge credit and trading strategies.

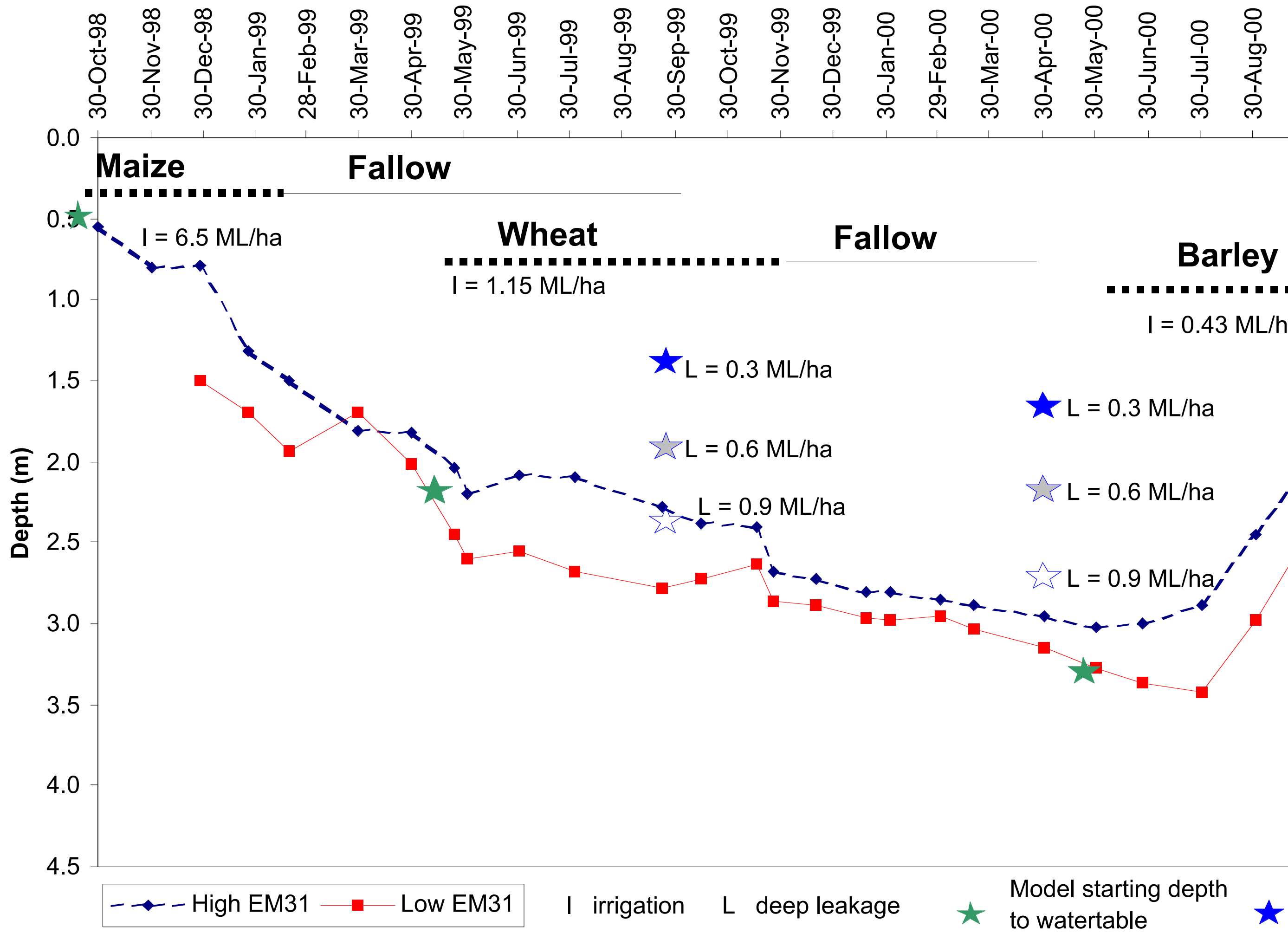


Figure 4. Field B depth to the watertable - observed and predicted using SWAGMAN® Farm with deep/lateral leakage rates of 0.3, 0.6 and 0.9 Mlha/yr

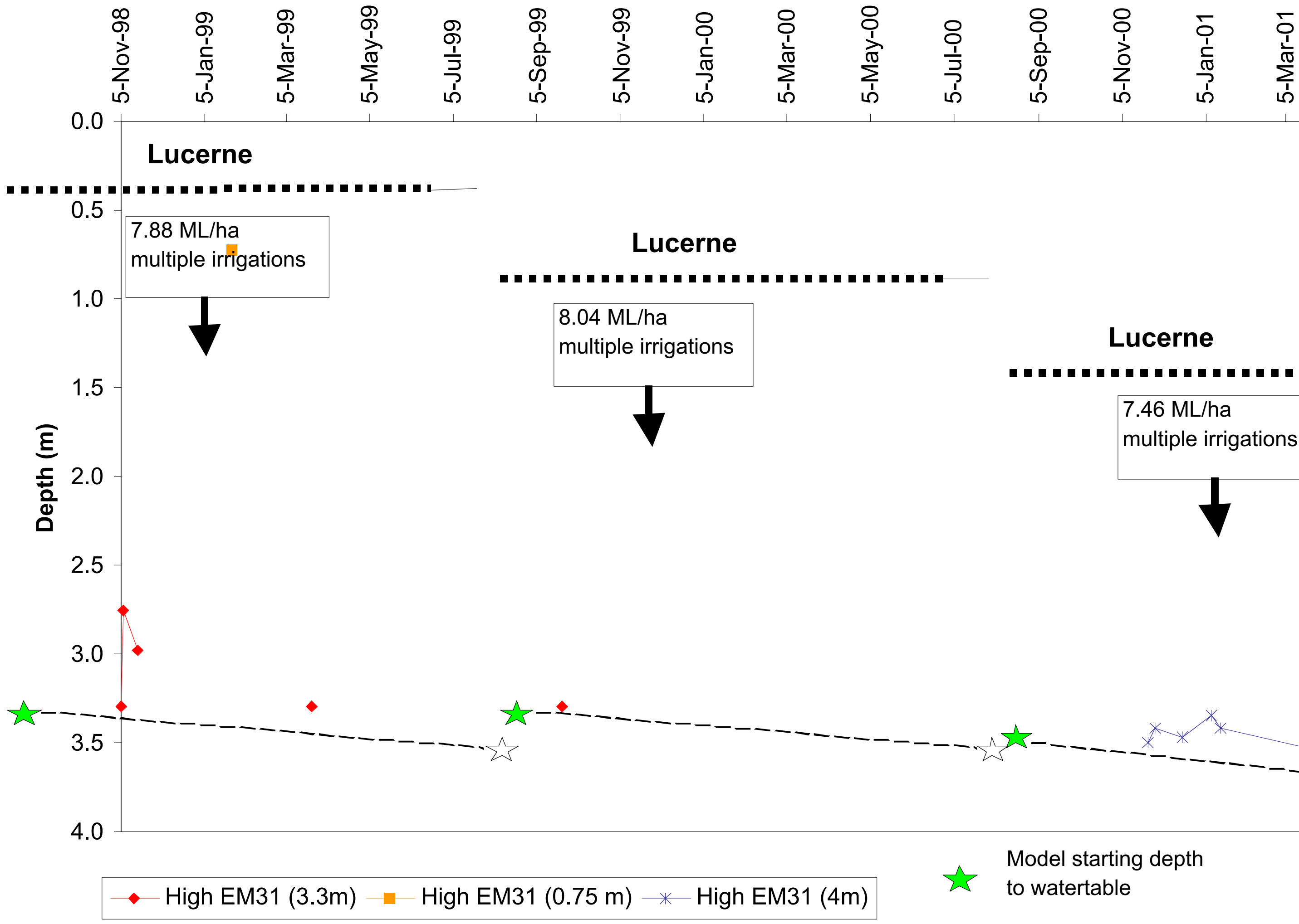


Figure 5. Field L depth to the watertable - observed and predicted using SWAGMAN® Farm

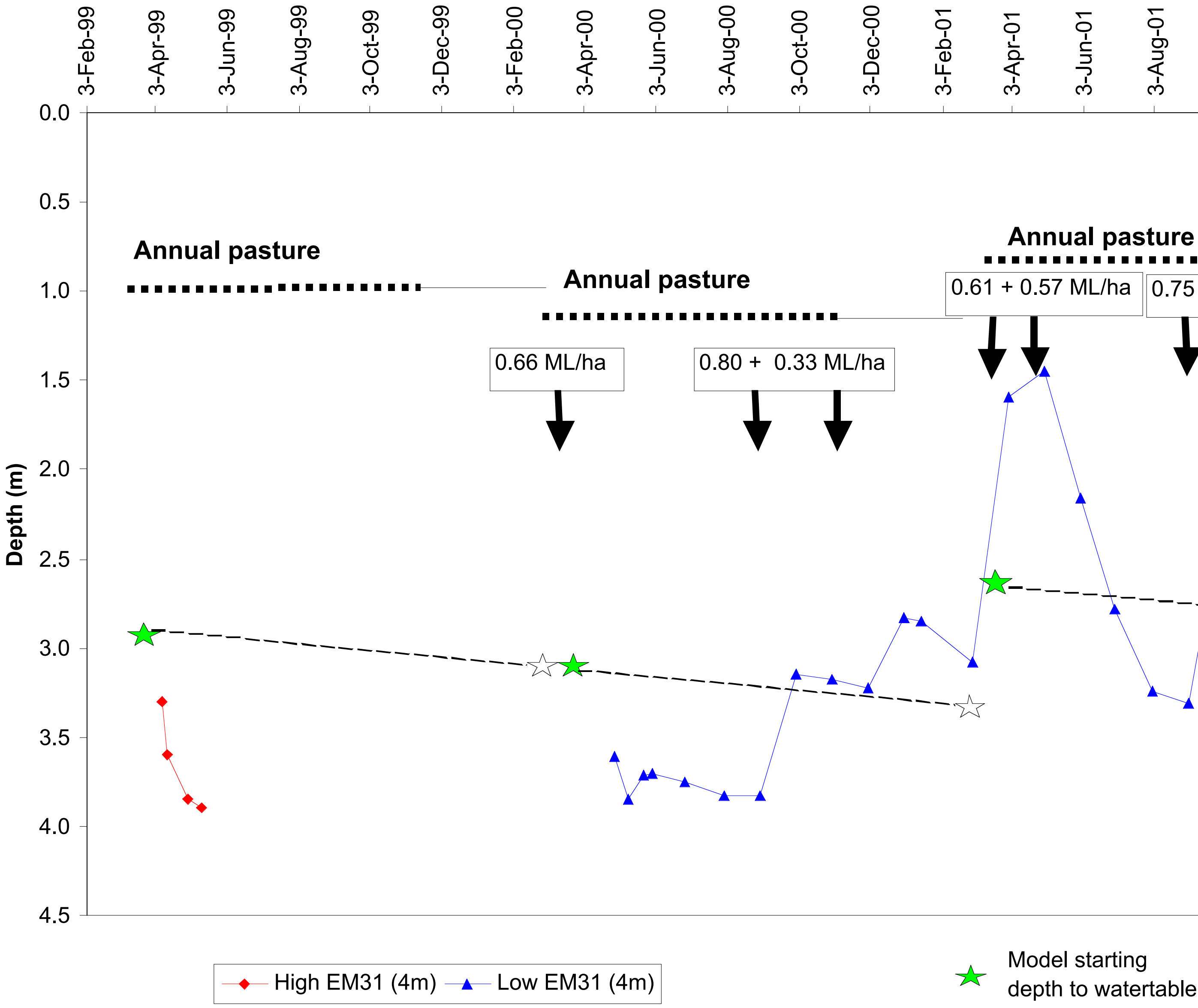


Figure 6. Field P depth to the watertable - observed and predicted using SWAGMAN® Farm

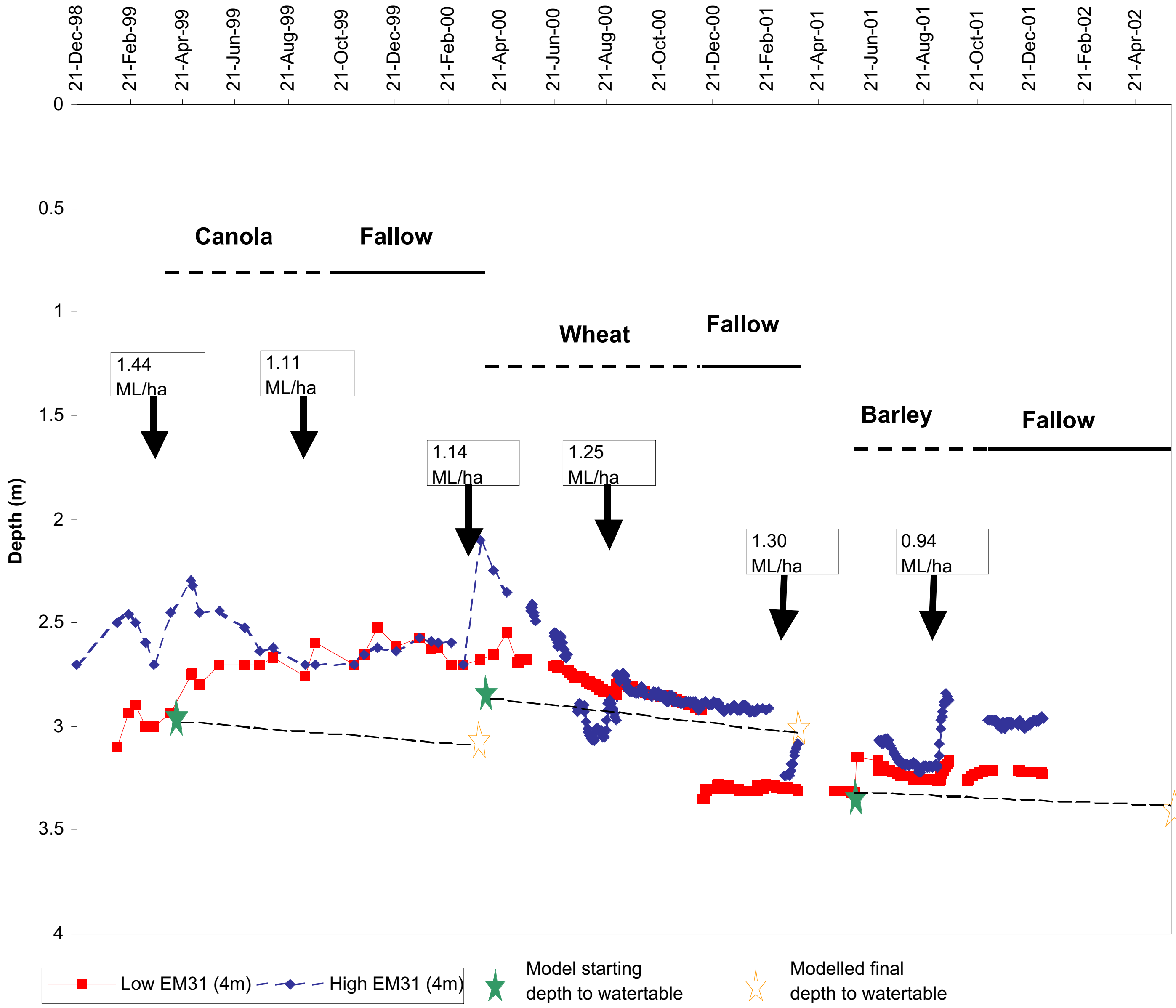


Figure 7. Field W depth to the watertable - observed and predicted using SWAGMAN® Farm

**Fig. 8a. Maize leaf area index (Field B) - comparison of observ
and predicted values using SWAGMAN Destiny**

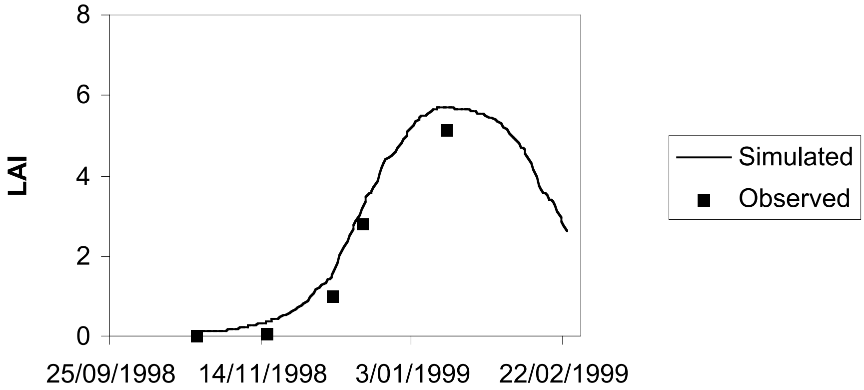


**Fig. 8b. Maize biomass (Field B) - comparison of observed a
predicted values using SWAGMAN Destiny**

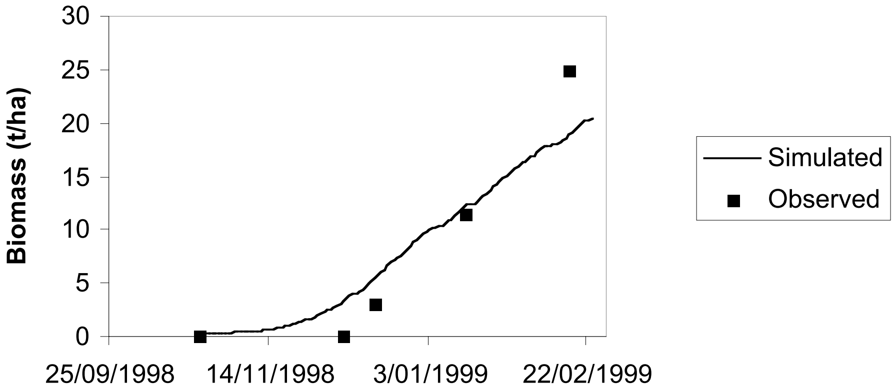


**Fig. 8c. Depth to the watertable in irrigated maize (Field B) -
comparison of observed and predicted values using SWAGMA
Destiny**

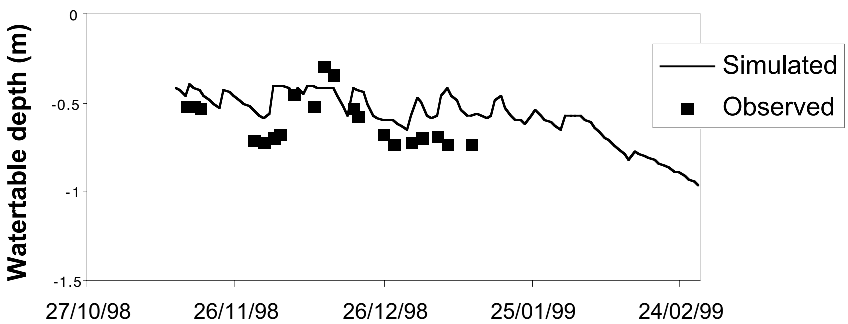


Fig. 8d. Volumetric soil water content at 10 cm in maize field B comparison of observed and predicted values using SWAGMA Destiny

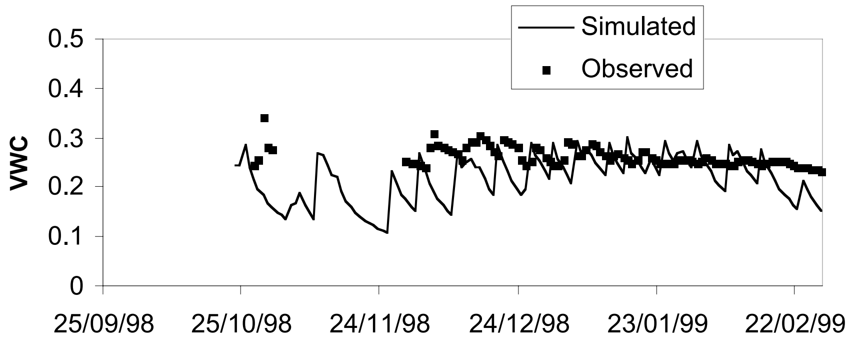


Fig. 8e Volumetric soil water content at 20 cm in maize field B - comparison of observed and predicted values using SWAGMAN Destiny

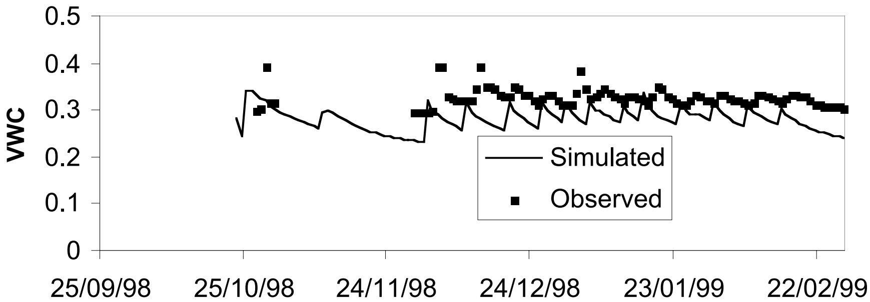


Fig. 8f. Volumetric soil water content at 40 cm in maize field B - comparison of observed and predicted values using SWAGMAN Destiny

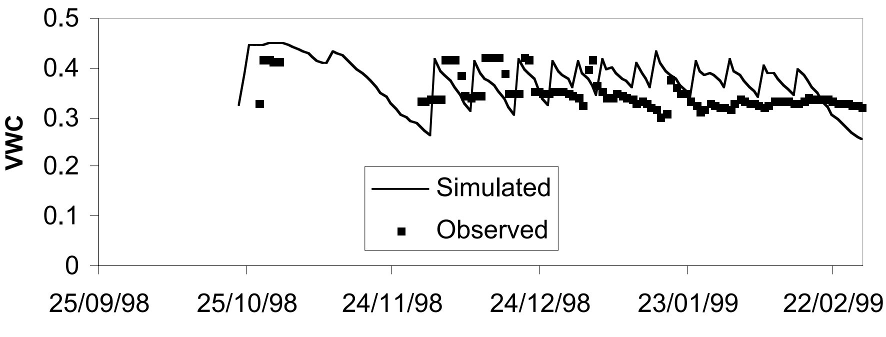


Fig. 8g Volumetric soil water content at 60 cm in maize field B comparison of observed and predicted values using SWAGMA Destiny

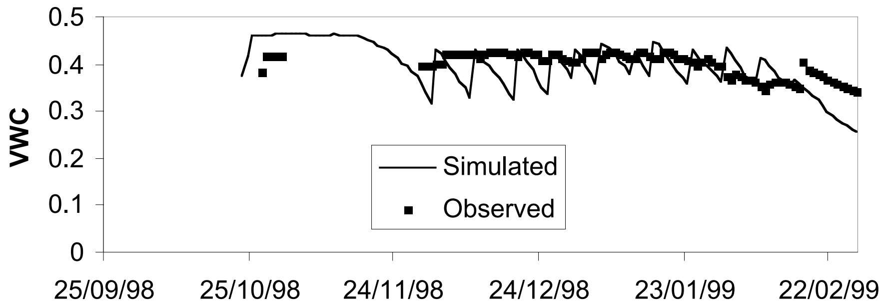


Fig. 8h. Volumetric soil water content at 90 cm in maize field B - comparison of observed and predicted values using SWAGMAN Desti

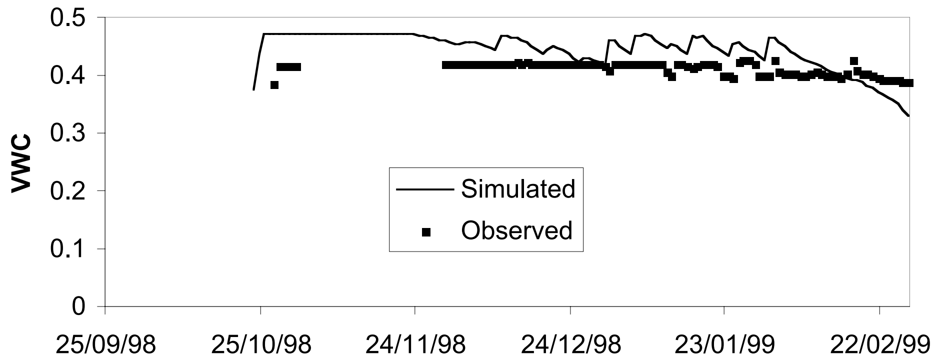


Fig. 8i. Volumetric soil water content at 120 cm in maize field B - comparison of observed and predicted values using SWAGMAN Destiny

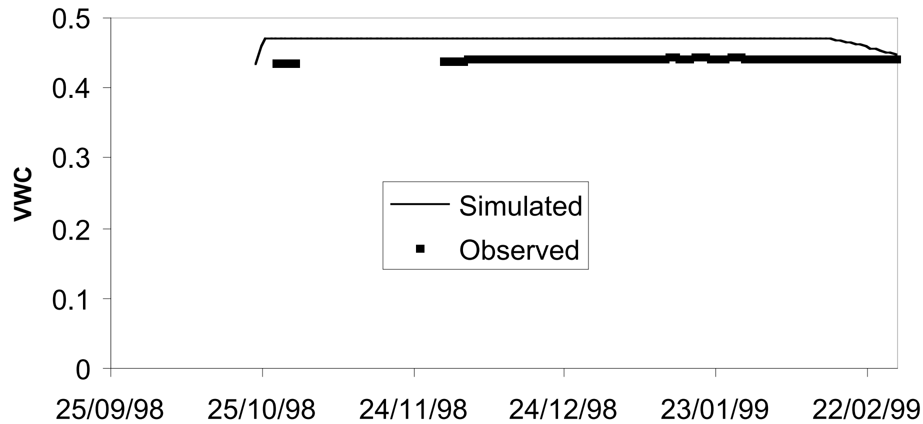


**Fig. 9a. Maize biomass (field B 2000/1) - comparison of observed and predicted values usi
MaizeMan**

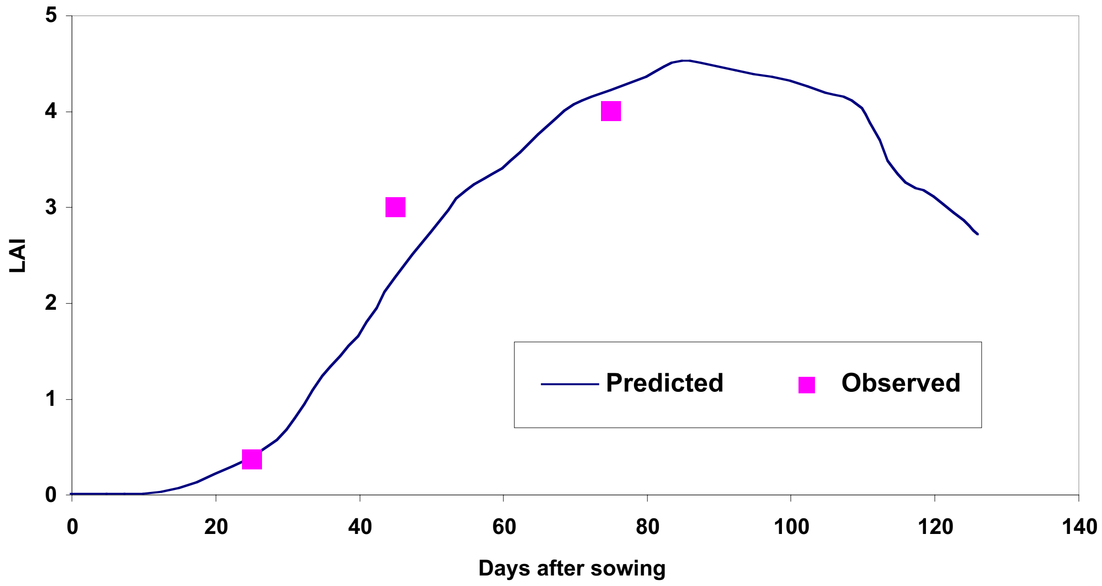


Fig. 9b. Maize biomass (field B 2000/1) - comparison of observed and predicted values using MaizeMan

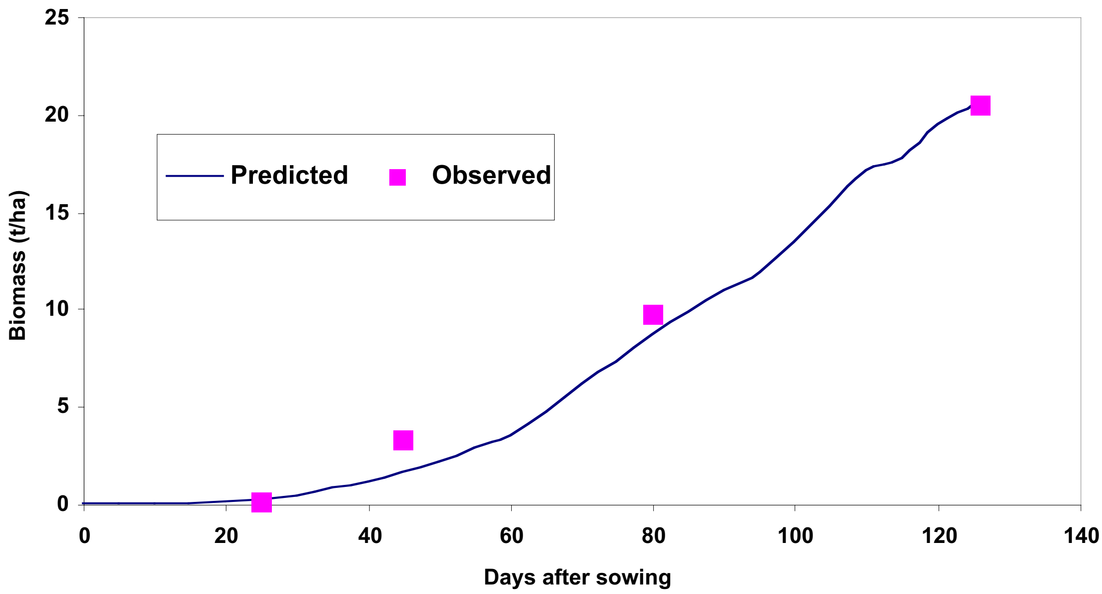


Fig. 9c. Volumetric soil water content at 10 cm in maize in field B - comparison of observed and predicted using MaizeMan

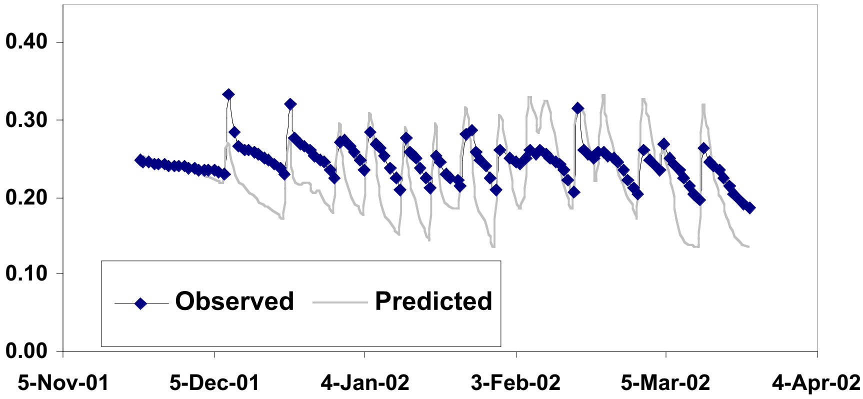


Fig. 9d. Volumetric soil water content at 10 cm in maize in field B - comparison of observed and predicted using MaizeMan

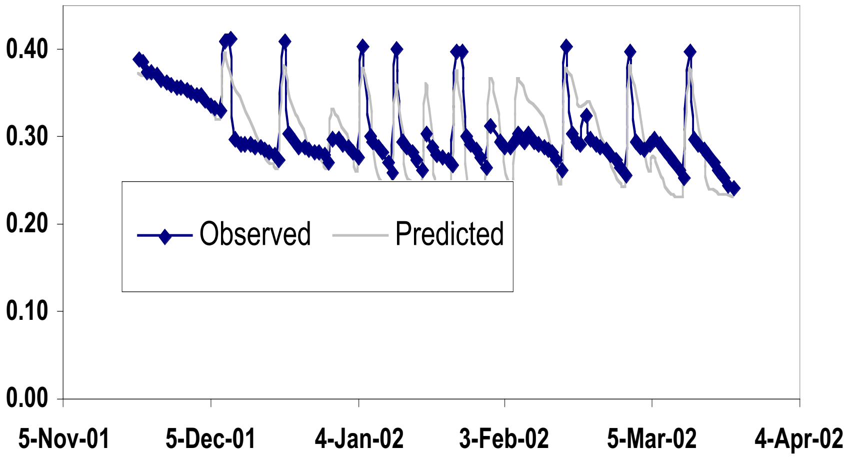
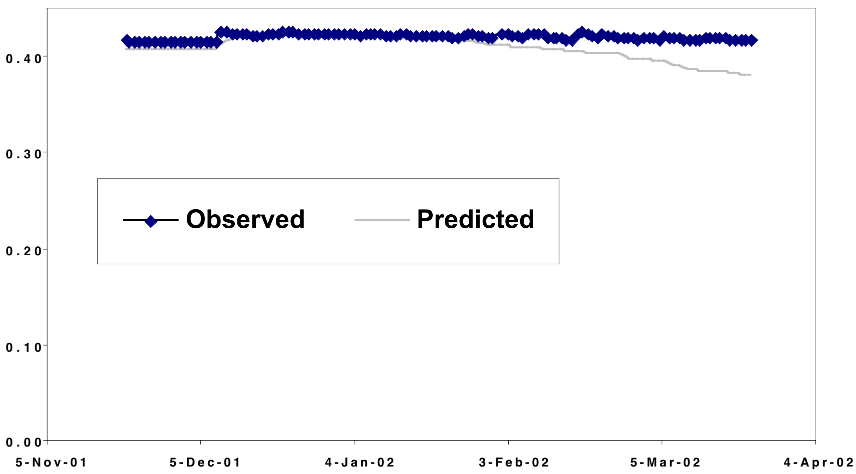


Fig. 9e. Volumetric soil water content at 10 cm in maize in field I - comparison of observed and predicted using MaizeMan



References

Anon. (1988). CSIRO Disc Permeameter Instruction Manual. CSIRO Centre for Environmental Mechanics, Canberra, ACT.

Beecher, H.G., Hume, I.H., Dunn, B.W. (2002). Improved method for assessing rice soil suitability to restrict recharge. Australian Journal of Experimental Agriculture 42: 297-307.

Edraki, M., Humphreys, E. and O'Connell, N. (2003a). Soil water dynamics and components of the water balance for irrigated lucerne in southern NSW. CSIRO Land and Water Technical Report 41/03.

Edraki, M., Humphreys, E., O'Connell, N. and Smith, D.J. (2003b). Determination of irrigation efficiency and deep drainage for irrigated maize with a shallow watertable. CSIRO Land and Water Technical Report 30/03.

Godwin, D., Humphreys, E., Smith, D.J., Timsina, J., Xevi, E. and Meyer, W.S. (2002). Application of SWAGMAN® Destiny to rice-wheat cropping systems. In 'Modelling irrigated cropping systems, with special attention to rice-wheat sequences and raised bed planting. Eds E. Humphreys and J. Timsina. CSIRO Land and Water Technical Report 25/02.

Godwin, D.C., Meyer, W.S., Xevi, E. and White, R.G.J. (2003). SWAGMAN Destiny: A simulation model of irrigated crops as affected by irrigation practice, water tables and salinity. 1. Model description. Under Review.

Humphreys, E. and Edraki, M. (2003). Rigorously determined water balance benchmarks for irrigated crops and pastures. Project CLW21 Final Report to NPIRD. CSIRO Land and Water Consultancy Report.

Humphreys, E., Smith, D.J., White, R.J.G., Xevi, E. and Godwin, D.C. (2003). MaizeMan – a decision support system for water and nitrogen management. In: Proceedings of the 5th Australian Maize Conference, 18-20 February 2003, Toowoomba.

Khan, S. (2003). Regional groundwater hydrology of Murray Irrigation Area (in preparation).

Khan, S., O'Connell, N., Xevi, E., McLeod, G., Madden, J., Zhou, F., Robinson, D. and Humphreys, E. (2000). Determination of optimal irrigation intensity for irrigation areas. NPIRD Project CWN13 Final Report. CSIRO Land and Water Consultancy Report.

Khan, S., Robinson, D., Xevi, E., O'Connell, N. (2001) Integrated hydrologic economic modeling techniques to develop local and regional policies for sustainable rice farming systems. 1st Asian Regional Conference on Agriculture, Water and Environment, ICID, September 2001, Seoul, Korea.

Khan, S., Xevi, E., O'Connell, N. (2003). Better management of rice-based farming system: advances in mathematical modeling. Natural Resource Management. Special Issue June 2003. pp. 55-62.

Meister, N. 2002. Saturated and Unsaturated Hydraulic Conductivity of Soils in the Murray Irrigation Area. CSIRO Land and Water Studentship Report. Griffith, NSW.

Meyer, W.S. (1999). Standard reference evaporation calculation for inland, south eastern Australia. CSIRO Land and Water Technical Report 35/98.

Meyer, W.S., Smith, D.J. and Shell, G. (1999). Estimating reference evaporation and crop evapotranspiration from weather data and crop coefficients. CSIRO Land and Water Technical Report 34/98.

Smith, R. 1945. Soils of the Berriquin Irrigation District, N.S.W. Council for Scientific and Industrial Research Bulletin No. 189. CSIR, Melbourne, Vic.

Smith, D.J., Humphreys, E. and Godwin, D.C. (2003) Effect of management, site and seasonal conditions on net recharge and yield of wheat sown after rice. Rice CRC/CSIRO Land and Water Technical Report (draft)

Smith, K.A. and Mullins, C.E. (eds) (1991). Soil Analysis, Physical Methods. Marcel Dekker Inc.

Soil Survey Staff (1975). Soil Taxonomy: A Basic system of Soil Classification fro Making and Interpreting Soil Surveys. USDA Handbook 436. Washington, USA

Stace, H.C.T., Hubble, G.D., Brewer, R., Northcote, K.H., Sleeman, J.R., Mulcahy, M.J. and Hallsworth, E.G. (1972). A Handbook of Australian Soils. Rellim Technical Publications, Glenside, SA, Australia.

Xevi, E., Smith, D.J., Humphreys, E., Godwin, D.C. and White, R.J.G. (2003a). The MaizeMan Model – description, calibration and validation. CSIRO Land and Water Technical Report (draft).

Xevi,E., Godwin, D., Meyer, W.S. and White, R.G.J. (2003b). SWAGMAN Destiny: A simulation model of irrigated crops as affected by irrigation practice, water tables and salinity. 2: Model testing and evaluation. Under Review