



Cooperative Research Centre for Sustainable Rice Production



RICE WATER USE EFFICIENCY WORKSHOP PROCEEDINGS

Edited by Dr E. Humphreys

Program 1: Sustainability of Natural Resources
in Rice-Based Cropping Systems



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INTRODUCTION

The Board of the CRC for Sustainable Rice Production identified the need for a workshop to review what is known about rice water use efficiency, and to determine future research needs. Dr Graham Harris, Chief of CSIRO Land and Water, played a key role in instigating and facilitating the workshop, which was organised by Dr Liz Humphreys.

OBJECTIVES

The overall objective was to review what's known about rice crop water use efficiency in the southern Murray-Darling Basin, to assist the Board in deciding whether there is a need to expand the research effort in this area, and if so, what should be the foci of any future R, D & E.

More specific objectives were:

1. To review what's known (and knowledge gaps) about rice crop water use (crop requirement to meet evaporative demand) and water use efficiency (amount applied/amount evaporated) – for ponded rice in the southern MDB
2. To review current and potential methods for identifying inefficient rice crop water use, and procedures and policies for dealing with inefficient rice crop water use
3. To review current and potential methods for predicting unsuitable soils for rice, including recent and current research
4. To review methods for increasing rice crop water use efficiency, including recent and current research
5. To identify research gaps and/or actions where greatest progress can be made in increasing rice crop water use efficiency (*e.g.* research, education, adoption, monitoring, instrumentation, policy)
6. To assess the potential for summarising available information on rice water use and water use efficiency into a readily available form.

This report provides compiled papers written by many of the workshop presenters. It provides a comprehensive summary of the available information for the southern MDB, and reference to sources of more detailed information.

Liz Humphreys

14 April, 2000

RICE CROP WATER USE EFFICIENCY IN THE SOUTHERN MURRAY-DARLING BASIN

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ABSTRACT

For rice grown under ponded conditions in the southern Murray Darling Basin, total evapotranspiration from the paddock during the ponded period can be estimated from $E_{pd} = 0.9 \times E_{pan} = 1 \times E_{To}$, where E_{To} is calculated using a locally calibrated Penman equation (Meyer 2000). The long term average E_{To} at Griffith is 1160 mm (11.6 ML/ha) over the rice season (Oct...Feb), while rainfall averages 160 mm. Therefore rice requires 1000 mm, on average, to meet net evaporative demand.

There is less certainty in weekly or monthly estimates of evapotranspiration from E_{To} or pan evaporation. The available data suggest that the crop factor increases during the season, reaching a maximum around anthesis, but the data are too variable and too few to assign monthly (or weekly) crop factors with confidence. Further refinement of monthly crop factors would assist in water budgeting during the irrigation season, especially in years of lower water availability. There is also little information on evapotranspiration from draining until harvest and after harvest, and its relationship with E_{To} or pan evaporation.

Total E_{To} over the rice season (Oct...Feb) at Griffith, Finley and Tullakool is similar, but it is about 10% higher for Hay. The same is true for net evaporation (E_{To} -rain).

Seasonal variations in E_{To} , rain and net evaporation are large. Therefore a rice paddock water use target based on seasonal conditions was adopted by the Rice Environmental Policy Advisory Group, commencing in the 1996/97 season. This target is calculated to be equal to E_{To} -rain+400, where all units are in millimetres. Rice paddock water use is routinely monitored by the irrigation companies, and the purpose of the target is to detect paddocks with excessive deep drainage ("leaky" paddocks) by identifying paddocks with high water use.

The biggest gains to be made in improving rice water use efficiency are by identification of leaky paddocks and their amelioration or elimination from rice growing. Accurate identification of leaky paddocks requires knowledge of the period of ponding and the pre-rice soil water content – simple information which would be easy for farmers to provide. More accurate measurement of applied irrigation water is also needed, and substantial improvement could be made by increased on-farm recording of water deliveries – however, this would require additional effort from farmers which some (many?) may be reluctant to apply for a range of reasons including pressures on time and lack of desire for this type of information.

Once the technology and systems are in place for more accurate identification of leaky paddocks, then the next gains in the drive towards higher rice water use efficiency would be firstly through implementation of the policy of restricting rice to areas that meet the water use targets, and secondly to progressively lower the rice water use target to E_{To} -

rain+ Δ SWC+100, where Δ SWC is the increase in soil water content over the rice season in the rootzone (0-1 m).

Socioeconomic factors are at present a major barrier to the adoption of all of these technically simple methods for improving rice water use efficiency. Furthermore, they consider the rice enterprise in isolation from other activities on the farm. Therefore alternative approaches examining whole farm water balances are being developed such as the SWAGMAN Farm model.

INTRODUCTION

Since the mid 1940s, rice growing has been subjected to many and varied “environmental” restrictions determining how much and where it can be grown (Humphreys *et al.* 1994). These restrictions are aimed at minimising the amount of water percolating into the groundwater, to reduce the development of high watertables and secondary salinisation. Past restrictions included the phasing in of a rice paddock water use (RPWU) target of 1600 mm (16 ML/ha), derived from the fact that approximately 1200 mm are evaporated from rice fields during the season, and from the principle that neither surface runoff nor deep percolation should exceed 200 mm. Since 1993/94 the target has been adjusted up or down to allow for variation in seasonal conditions. In 1995/96 Murray Irrigation Ltd adopted a new method for calculating the target, using the formula RPWU target = ETo-rain+400, where ETo is reference evapotranspiration calculated using a locally calibrated form of the Penman combination equation (Meyer 2000). This formula effectively lowered the target by 200 mm (2 ML/ha), mainly because it rightly included rain in the determination of the irrigation requirement for rice. This method of calculating the target was adopted by the Rice Environmental Policy Advisory Group (REPAG), commencing in the 1996/97 season.

The purpose of this paper is to review what is known about predicting evapotranspiration from rice in the southern Murray-Darling Basin, and to explore where the biggest gains can be made in increasing rice paddock water use efficiency.

Definitions and components of the rice paddock water balance

Rice crop water use (Erice) is defined here as the water evaporated directly from the rice plants (i.e. transpiration). In a rice paddock, evaporation may occur via the plants (Erice), directly from the floodwater (Efw), or directly from the soil surface (Es) if the soil is not flooded. Thus the total evaporative loss from a rice paddock (Epdk) is

$$E_{pdk} = E_{rice} + E_{fw} + E_s$$

Reference evapotranspiration (ETo), estimated using a locally calibrated form of the Penman equation, has been shown to be a good estimate of rice paddock evapotranspiration for ponded rice over the entire season (Humphreys *et al.* 1994). Thus

$$E_{pdk} = E_{To}$$

The amount of irrigation water (I) used for rice growing has been monitored on a farm scale for many years in southern Australia. The total amount of water applied to a rice paddock also includes rainfall (R), and the rice paddock water balance may be written as:

$$I + R = \text{Epdk} + \Delta\text{SW} + \text{SD} + \text{DD} \quad \text{rearranged as } I = \text{ETo} - R + \Delta\text{SW} + \text{SD} + \text{DD}$$

where ΔSW is the increase in soil water content in the upper profile (0-1 m). This water will ultimately drain below 1 m and contribute to deep drainage unless it is lost to the atmosphere by soil evaporation and transpiration via other crops after rice harvest. ΔSW typically ranges from 20-200 mm depending on seasonal conditions and cropping history prior to rice sowing.

SD is surface drainage (typically 0-50 mm)

DD is deep drainage – drainage below 1 m, considered to be unavailable to crops, and which will ultimately recharge the groundwater. This component does not include the additional deep drainage derived from water stored in the upper metre of the soil profile at the time of rice harvest.

The purpose of monitoring I is to identify paddocks where DD is unacceptably high (say > 100 mm). At present the rice paddock water use target is determined by the Rice Environmental Policy Advisory Group as:

$$\text{rice paddock water use target (mm)} = \text{ETo} - R + 400$$

In an average season, for an average crop ponded for 5 months, $\text{ETo} = 1,160$ mm and $R = 160$ mm. Thus the average net evaporative loss ($\text{ETo}-R$) is 1,000 mm, but it can vary greatly from 650 to 1,300 mm. The rice water use target automatically adjusts for seasonal variation in net evaporation.

The constant (400 mm) is to allow for soil wetting, surface drainage, deep drainage and error in measurement of paddock water use and/or in the estimate of Epdk. With current monitoring systems, deep drainage of up to 400 mm will not be detected in situations where ΔSW is close to zero (such as rice after rice and/or after wet winters). Furthermore, there is no allowance for crops where the duration of ponding varies significantly from 5 months. For example, for a shorter duration variety with a 4-month ponding period, $\text{ETo}-R$ in an average season is reduced from 1,000 to 880 mm. Thus deep drainage of up to 500 mm could go undetected at present when growing shorter duration varieties.

Finally, there is the problem of accuracy of the measurement of irrigation water supplied to the rice paddocks. In some situations one Dethridge meter supplies one or more paddocks either simultaneously or alternately, and the recording of water use against each crop relies on the farmer's record keeping or estimates.

Methods for estimating Erice and Epdk in ponded rice

Erice

Simpson *et al.* (1992) used isotope discrimination to separate evaporation via the plants (transpiration) and evaporation from the water. This technique relies on the fact that lighter isotopes (^1H and ^{16}O) are preferentially evaporated over heavier isotopes (^2H and ^{18}O), leading to enrichment in heavier isotopes in the floodwater, whereas transpiration through the plant leads to little net enrichment of the heavier isotopes in the residual water. They found that about 40% of the total evaporative loss was from the water and 60% was via the plants. Early in the season all of the evaporative loss was from the water. In mid-December two thirds was via the plants, increasing to 90% in mid-January.

Suppression of evaporation from the water (*e.g.* using synthetic floating beads) has also been used to directly measure transpiration in ponded rice.

Epdk

A range of direct and indirect methods have been used to estimate evaporation from ponded rice. These are summarised in Table 1, together with an indication of the relative strengths and weaknesses of each method. Local and large scale edge effects are an important consideration in all methods where the determination is done on small plots within a paddock (Lang *et al.* 1974, Humphreys *et al.* 1994).

TABLE 1.

METHODS FOR ESTIMATING EPDK IN PONDED RICE (✓ = GOOD, X=BAD)

	Accuracy	Cost	Complexity	Portability	Edge effects	
					Small scale	Large scale
DIRECT						
Weighing lysimeter	✓✓	XX	XX	XX	care needed	fetch > 100 m
Non-weighing lysimeter (“pan”)	✓	X	✓✓	✓	care needed	fetch > 100 m
Energy balance Bowen ratio	✓	X	X	✓	✓✓	fetch > 200 m
Isotope discrimination plus seepage estimation	✓	X	sampling ✓✓ analysis XX	✓	✓✓	care needed
<i>INDIRECT</i>						
<i>By difference</i> E=I+R+SD+Infiltr whole paddock	✓	X	✓	✓	✓✓	✓✓
Climate-based formulae	✓	✓✓	✓✓	✓✓	✓✓	✓✓

Relationships between Epdk, Epan and ETo

The results of comparisons between determinations of *Epdk*, *Epan* and *ETo* are summarised in Table 2. Some of these studies were done using whole paddock determinations of flow on and off the paddock, and point scale measurements of infiltration (Talsma and van der Lelij 1976, Humphreys 1997, Humphreys *et al.* 1998). These determinations were carried out over a wide range of locations across the major Australian rice growing regions - in the Murrumbidgee, Murray and Goulburn Valleys. The monthly data were derived from the average of the weekly determinations (not presented). The data suggest that the “crop” factor (*Epdk*/*ETo*) increases during the season, reaching a maximum around anthesis, but the data are too few and too variable to assign weekly or monthly crop factors with confidence. The crop factor over the

entire ponded period ranged from 0.9 to 1.2 (mean 1.0, std 0.1). There is no information on evapotranspiration from draining until harvest and after harvest.

Seasonal variation in ETo and rainfall

Humphreys and Meyer (1996) showed that variation between seasons in total ETo, rainfall and net evaporation is very large. Over the 32 years from 1962/63 to 1993/94 ETo ranged from 920 to 1360 mm (mean 1160 mm), and rain varied from 30 to 340 mm (mean 160 mm). Over the same period net evaporative demand (ETo-rain) ranged from 650 to 1300 mm. Therefore the rice water use limit must be based on seasonal conditions to identify paddocks where water use is excessive. In average years rainfall is a small component of the water balance (14% of ETo), but in extreme wet years it can be as much as one third of ETo.

TABLE 2.

RESULTS OF COMPARISONS OF EPDK, EPAN AND ETO

Researcher	Method	Epdk/Epan						Epdk/ETo Meyer		
		Oct	Nov	Dec	Jan	Feb	Mean			
Evans (1971)	Lysim. 1 x 7.3 m ²				daily 0.8-1.5		1.0	1.1^A	MIA	
Talsma and van der Lely (1976)	Pdk water balance E=I+R-SD-ΔFW-Inf INF IN 4-7RINGS X 0.4-0.6 m ² across the pdk		0.8 0.9	0.8 1.1 1.0	1.0 1.2 1.0	1.1 1.1 1.0	0.9 1.1 1.0	1.0^A 1.2^A 1.1^A	MIA MIA CIA	
Meyer <i>et al.</i> in Humphreys <i>et al.</i> (1994)	lys. 1? x 1.1 m ²	weekly 0.6-1.5 Oct...Feb						0.9	1.0	MIA
Humphreys (1997)	Pdk water balance E=I+R-SD-ΔFW-Inf Inf in 12-20 rings x 1.1 m ² across the pdk	(0.8) 0.8-0.8	0.8 0.8-0.8	0.8 0.7-0.8	0.9 0.8-1.0	0.7 0.5-1.0	0.8^A weekly	0.9 0.9	WMV (Tull) WMV (Deniboota)	
Humphreys <i>et al.</i> (1998)	Pdk water balance E=I+R-SD-Inf Inf = 0.5 ML/ha est. Whole season from start fill to draining						0.8^A 0.8^A 0.8^A 0.9^A	0.9 0.9 0.9 1.0	CIA CIA CIA CIA	
Bethune and Wang (1999) Bethune <i>et al.</i> (2000???)	Lysim. 6 x 1 m ²						1.0 0.9	1.1^A 1.0^A	N.Vic N.Vic	

Derived from ETo (Meyer) = 0.93 Epan n = 1,081, r² = 0.86

Geographical variation in ETo and rainfall

Total ETo over the five months from October to February is generally similar at the meteorological stations located at Griffith, Finley and Tullakool (Humphreys *et al.* 1994, Fig. 1). Over the past few years there has been a consistent trend for ETo at Hay to be about 10% higher than at Griffith, in contrast to the findings reported in Humphreys *et al.* (1994). The ETo data determined for Hay prior to 1994 are believed to underestimate actual ETo due to the positioning of the wet sleeve to far away from the temperature sensor on the “wet bulb” (Shell, pers. comm.). The relatively low ETo at Tullakool in 1998/99 was due to the fact that a farmer installed a channel and established irrigated pasture immediately adjacent to the meteorological station. (The station was shifted to a more suitable site in 1999). Over the past 12 years ETo at Finley has always been less than or similar to that at Griffith, except in 1997/98. The relatively high value at Finley in 97/98 was largely due to a significantly lower dew point during the months of January and February compared with at Griffith and Tullakool. Again there had been major changes at the site over the past few years and the station was relocated to a more suitable site and a wet bulb was included to provide similar instrumentation at all four stations.

Rainfall was more variable between locations, but was a much smaller component of the water balance than evaporation (Fig. 2). Therefore trends in net evaporation (Fig. 3) were similar to trends in reference evaporation, with higher values at Hay, and similar values at the other three locations. The relatively high value at Finley in 97/98 and the relatively lower value at Tullakool reflect the degraded site conditions mentioned above, and which has been addressed by relocation the weather stations. Fig.1 Reference evapotranspiration (ETo) compared at locations across the NSW Riverina

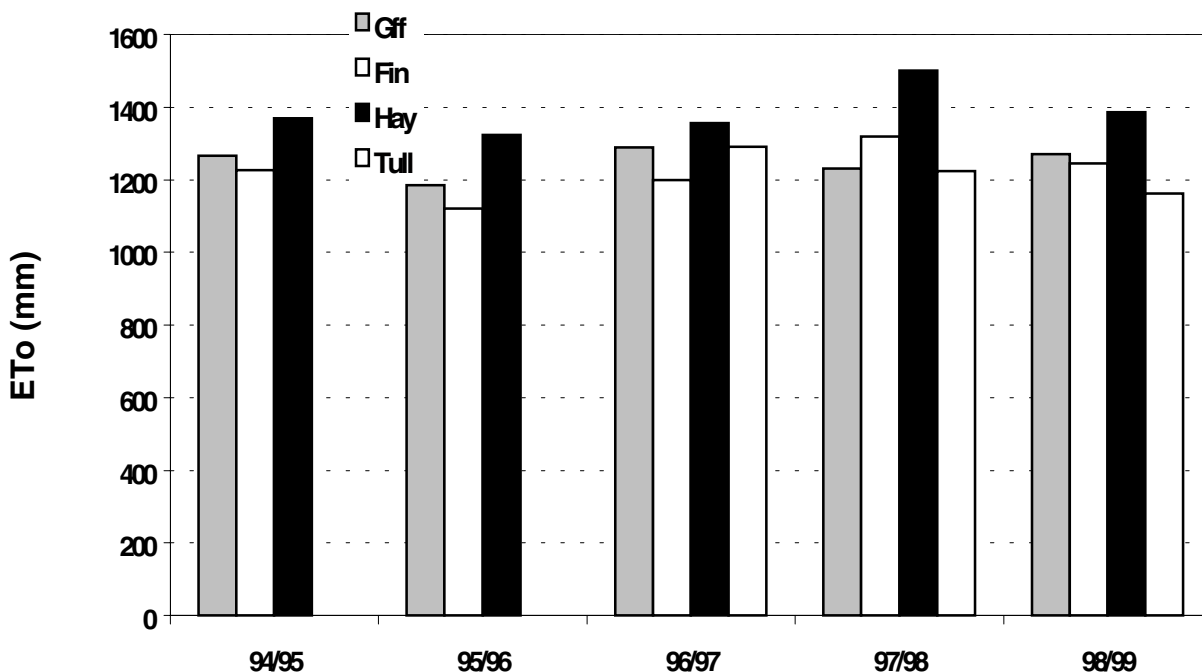


Fig. 2 Rainfall compared at locations across the NSW Riverina

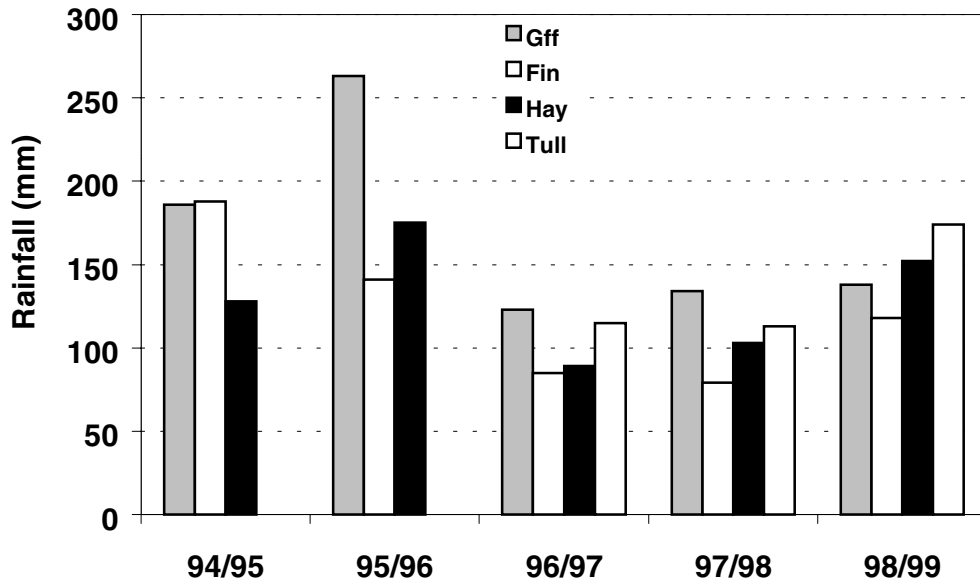
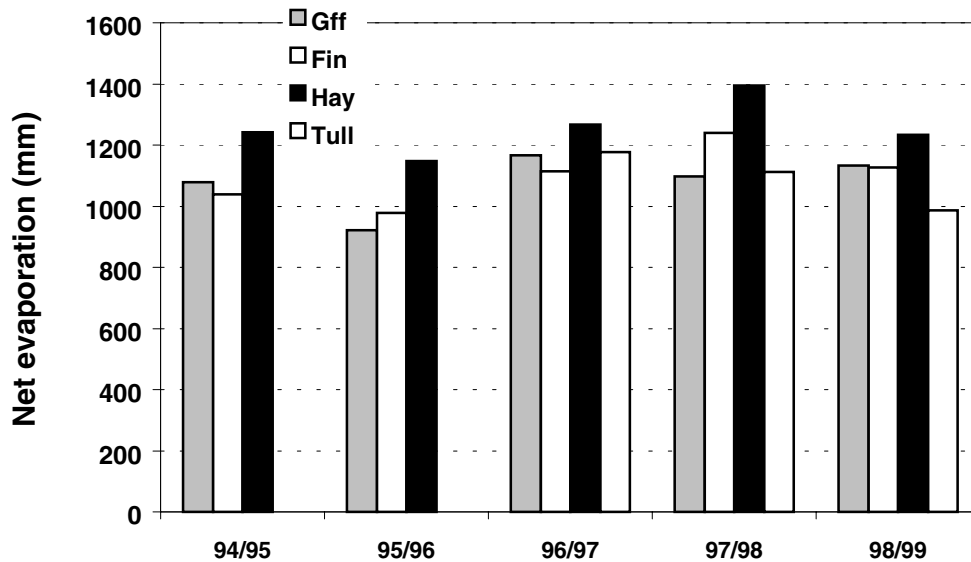


Fig. 3 Net evaporation (ETo-rain) compared at locations across the NSW Riverina



CONCLUSIONS

For rice grown under ponded conditions in the southern Murray Darling Basin, total evapotranspiration from the paddock during the ponded period can be estimated from $Epdk = 0.9 \times Epan = 1 \times ETo$, where ETo is calculated using a locally calibrated Penman equation (Meyer 2000). The long term average ETo at Griffith is 1160 mm (11.6 ML/ha) over the rice season (Oct...Feb), while rain averages 160 mm. Therefore rice requires 1000 mm, on average, to meet net evaporative demand.

There is less certainty in weekly or monthly estimates of evapotranspiration from ETo or pan evaporation. The available data suggest that the crop factor increases during the season, reaching a maximum around anthesis, but the data are too variable and too few to assign monthly (or weekly) crop factors with confidence. Further refinement of monthly crop factors would assist in water budgeting during the irrigation season, especially in years of lower water availability. There is also little information on evapotranspiration from draining until harvest and after harvest, and its relationship with ETo or pan evaporation.

Total ETo over the rice season (Oct...Feb) at Griffith, Finley and Tullakool is similar, but it is about 10% higher for Hay. The same is true for net evaporation (ETo -rain).

Seasonal variations in ETo , rain and net evaporation are large. Therefore a rice paddock water use target based on seasonal conditions was adopted by the Rice Environmental Policy Advisory Group, commencing in the 1996/97 season. This target is calculated to be equal to ETo -rain+400, where all units are in millimetres. Rice paddock water use is routinely monitored by the irrigation companies, and the purpose of the target is to detect paddocks with excessive deep drainage ("leaky" paddocks) by identifying paddocks with high water use.

The greatest gains in improving the detection of rice paddocks with excessive deep drainage will be made by: 1) more accurate monitoring of the irrigation water applied to (and drained from) individual paddocks, 2) monitoring the period of ponding (to determine period for calculation of ETo -rain), 3) monitoring recent paddock history (to estimate antecedent soil water content), 4) using these data to calculate $Epdk = ETo$ -rain+ Δ SWC, and 5) comparing $Epdk$ with the amount of irrigation water delivered to the paddock.

The period of ponding could be provided by the farmer or estimated from the dates of the first and last orders of water for rice. The pre-rice soil water content could be estimated from recent paddock history (also provided by the farmer, or from remote sensing) and winter/spring rainfall prior to irrigating for rice.

Better on-farm records of how much water is going to each paddock are theoretically possible, but would require additional effort from farmers which some (many?) may be reluctant to apply for a range of reasons including pressures on time and lack of desire for this type of information. Uncertainty over the reliability of the information reported by farmers is also a major impediment to this approach. Further improvement in measurement accuracy would require additional meters – for example in the measurement of recycled water. The accuracy of current metering is also questionable and needs to be determined and improved where it is shown to be outside the desired standards.

Once the technology and systems are in place for more accurate identification of leaky paddocks, then the next gains in the drive towards higher rice water use efficiency would be

firstly through implementation of the policy of restricting rice to areas that meet the water use targets, and secondly to progressively lower the rice water use target to $ET_{\text{rain}} + \Delta SWC + 100$, where ΔSWC is the increase in soil water content over the rice season in the rootzone (0-1 m).

Socioeconomic factors are a major barrier to the adoption of all of these technically simple methods for providing the information needed to more accurately evaluate rice water use efficiency. Furthermore, they consider the rice enterprise in isolation from other activities on the farm. Therefore alternative approaches examining whole farm water balances are being developed such as the SWAGMAN Farm model (Madden and Prathapar 1999) and the “Net Recharge Management” approach (Madden 1999).

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EVAPOTRANSPIRATION FROM AN IRRIGATED RICE CROP IN NORTHERN VICTORIA

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SUMMARY

Evapotranspiration (ET) of rice was measured directly using lysimeters and Bowen ratio instrumentation over a 20-day period. Climatic data measured at the site were used to calculate daily reference crop ET (ET_{ref}). ET_{ref} was linearly correlated with Bowen ET (ET_{β}) on a daily time step. Daily ET_{β} exceeded ET_{ref} by $(18 \pm 7 \%)$. Cumulated ET_{β} was 10 % less than lysimeter ET and 18 % greater than ET_{ref} over the 20 days.

INTRODUCTION

Rice growing was introduced to Victoria, Australia, on a commercial scale in 1992. Data on rice evapotranspiration (ET) requirements are needed to develop water policy. Historically, ET requirements are estimated from reference crop ET (ET_{ref}) and suitable crop coefficients [1]. Documented crop coefficients vary considerably. Differences in methods of computing ET_{ref} partly account for the variation in crop coefficients reported in the literature [2]. A standard method for calculating ET_{ref} has been developed [3]. This method has been adopted by the United Nations Food and Agricultural Organisation (FAO). The crop coefficient is also affected by local climatic conditions, crop characteristics, length of growing season, and the time of planting [1]. Existing crop coefficients for rice require testing before they are applied to Victoria.

In-situ lysimeters are widely used to measure ET. A lysimeter needs to contain an undisturbed sample of soil and vegetation if it is to provide estimates of evaporation that are representative of the surrounding field [4]. Installation of a lysimeter in a ponded rice field requires that the lysimeter wall extends above the water surface to prevent water splashing into the lysimeter. The higher lysimeter wall may result in local distortions of climate and potentially influence ET measurements.

The Bowen ratio (β) method allows measurement of actual ET with minimal disturbance of the crop and surrounds. The energy balance at the water surface is calculated by summing the incoming and outgoing energy fluxes (1). Net radiation (R_n) and soil heat flux (G) are directly measured.

$$R_n = H + \lambda E + G \quad (1)$$

The Bowen ratio (β) is the ratio of sensible heat flux (H) to latent heat flux (λE), (2).

$$\beta = \frac{H}{\lambda E} \quad (2)$$

$$H = \beta \cdot \lambda E \quad (3)$$

Expressing H in terms of β and λE (3), allows λE to be calculated from measurements of R_n , G and β (4).

$$\lambda E = \frac{R_n - G}{1 + \beta} \quad (4)$$

β is calculated from measurements of the temperature gradient ($T_L - T_U$) and vapour pressure gradient ($V_L - V_U$) above the soil surface (5).

$$\beta = \gamma \frac{T_L - T_U}{V_L - V_U} \quad (5)$$

γ psychrometric constant (kPa/°C)

T_L temperature at lower level (°C)

T_U temperature at upper level (°C)

V_L vapour pressure at lower level (kPa)

V_U vapour pressure measured at upper level (kPa)

λ latent heat of vaporisation (kJ/kg)

Lysimeter and Bowen ratio measurements of ET of a ponded rice field near Echuca, Victoria, are presented in this paper. The techniques are compared with the reference crop technique over a period of 20 days.

METHODS

Bowen Ratio

Campbell Scientific Bowen ratio instrumentation was used in this project [6]. The instrumentation was located in the centre of a large rice field that extended for at least 500 m in all directions.

Air temperature and dew point were measured at one and two metres above the soil surface. Vapour pressure was calculated from the dew point [7]. G equalled the rate of heat transfer across the air-interface and was calculated by summing the water-soil heat flux and change in water heat storage. Two heat flux plates were installed at the interface between the water and soil to calculate the heat flux from the water to soil. Water heat storage was calculated from the change in water temperature and the depth of water in the field.

The Bowen ratio was calculated from vapour pressure and temperature measurements averaged over a 20 minute time interval. ET was calculated on a 20 minute time step.

Lysimeter

Six lysimeter rings of 1.14 m diameter were installed within 20 metres of the Bowen ratio instrumentation. The lysimeters were pushed into the soil to a depth of 0.3 m using an excavator. They were then extracted containing an intact soil core. Bases were welded onto

these lysimeters and then they were lowered back into the hole from which they were previously extracted.

Water was added to the lysimeters twice weekly to maintain internal and external water depths at a similar level. ET was calculated twice weekly from the change in water height within the lysimeters. Water was measured in the lysimeter to an accuracy of 1 mm using a steel ruler. Rice plant densities were similar inside and outside the lysimeters.

Reference crop ET

Climatic data were measured over the rice field by an automatic weather station located 20 metres from the Bowen ratio instrumentation. Daily maximum and minimum temperature and relative humidity, daily wind run, and daily incoming short wave radiation were measured. ET_{ref} was calculated using FAO recommended standard methods [3].

RESULTS AND DISCUSSION

Bowen ratio

Temperature and vapor pressure gradients measured above the rice crop, and calculated β are presented for a typical 24-hour period (Fig 1a). The vapor pressure gradient was positive when there was evaporation. This occurred between 9 (9.00 am) and 21 (9.00 pm) hours on the day presented. At night and early morning there was a negative vapor pressure gradient, indicative of downwards water vapor movement or condensation. β was undefined for a small period when the vapor pressure gradient was zero (9 and 21 hrs). However, this did not introduce errors into the calculation of ET as evaporation was zero when the vapor pressure gradient was zero.

The temperature gradient was negative late afternoon because heat was extracted from the air to evaporate water as it moved over the rice field. β was negative when this occurred. ET could not be calculated when β was close to -1. This occurred twice in the example given, both times being close to 9:00 pm when evaporation was small.

The calculated λE closely follows the net radiation during daylight hours, and is close to zero at night (Fig 1b). G was of similar magnitude to the net radiation at night, when λE and H were small. G was an important component of the energy balance during the day, although smaller in magnitude than λE and R_n . In the evening, λE was greater than the energy available through R_n . This resulted from G being negative at this time and supplying energy for evaporation.

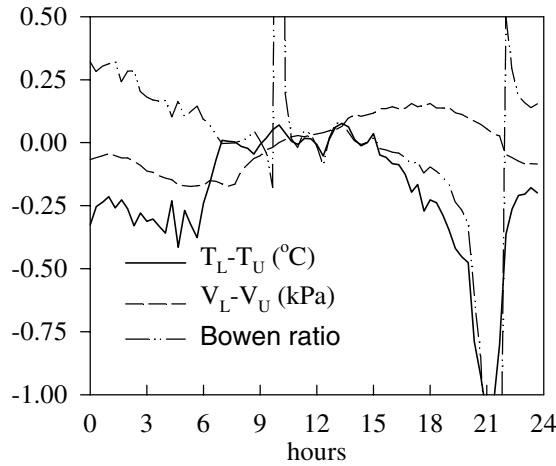


Fig 1a. Bowen ratio and temperature and vapour pressure gradients for 23/12/1997

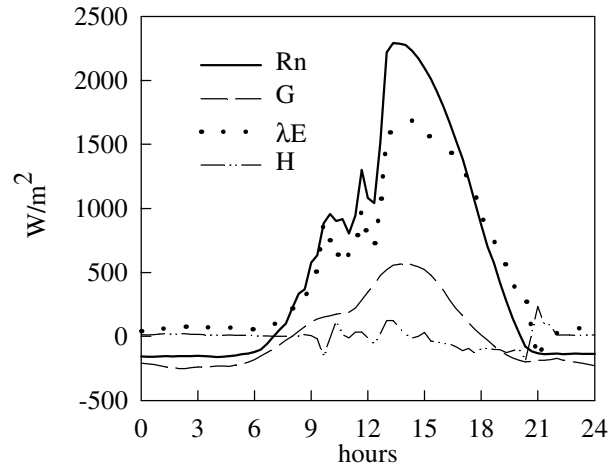


Fig 1b. Components of the energy balance for 23/12/1997

The 20 day time series of hourly data illustrates the dependence of λE on R_n (Fig. 2). λE peaks at a greater value than net radiation on days 355 and 356, and was of similar magnitude to R_n on some other days, such as day 361. During these days there was a negative β which indicates that regional advection may be significant in supplying energy for evaporation. Winds on these days were stronger than on average, wind runs were 440 (day 355), 300 (day 356) and 350 (day 360) km, compared to the average wind run over the twenty day period of 240 km. Insufficient fetch under these windy conditions may have caused errors in calculating λE . Strong winds may result in dry hot air being sampled by the upper arm which was not representative of the surrounding rice field. This may have caused errors in the calculation of β and λE .

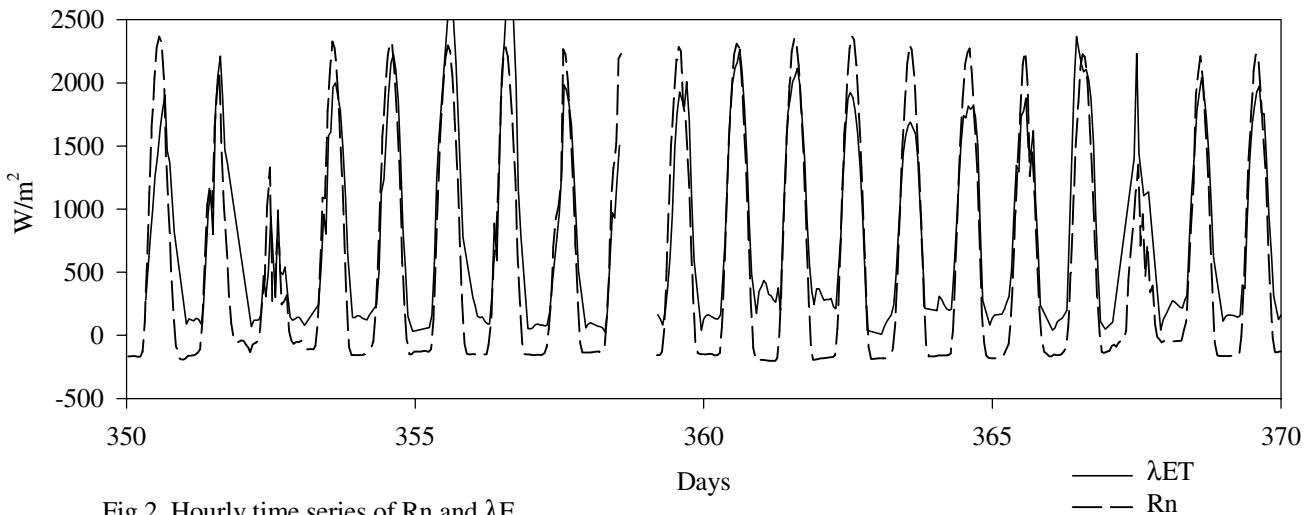


Fig 2. Hourly time series of R_n and λE .

Daily ET

ET_β was linearly related ($p < 0.001$) to ET_{ref} at a daily time step (Fig. 3). The line, forced through zero, accounted for 56 % of the variation in the data. The low level of variability described by the model results from the observations all being of similar magnitude. The crop coefficient is equal to the slope of the linear model (1.18 ± 0.07 , 95 % confidence interval).

This crop factor is only valid when climatic data used in the calculation of ET_{ref} are measured above a ponded rice field.

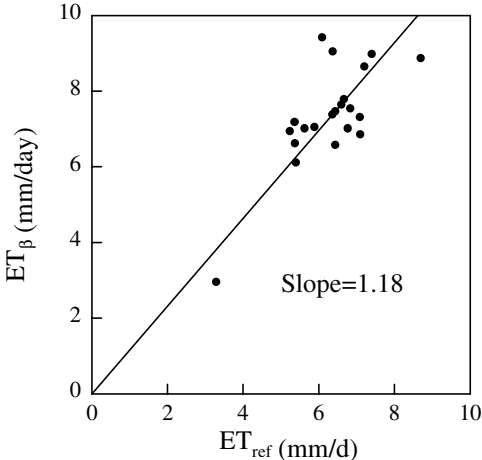


Fig 3. Comparison between ET_{ref} and ET_{β} at a daily time step.



Fig 4. comparison of ET measurements averaged between lysimeter readings.

Average ET per lysimeter reading.

Water depths in the lysimeters were measured irregularly, typically twice a week. Total lysimeter ET was calculated from the change in water depth since the last measurement. This total ET was divided by the number of days since the last reading to produce a daily average lysimeter ET (ET_{lys}). Daily ET_{β} and ET_{ref} were averaged for the dates between lysimeter measurements. All methods of estimating rice ET show similar behaviour over the 20 day period (Fig 4). ET_{lys} was always greater than ET_{β} and ET_{ref} . As on the daily time step, average ET_{β} occurred at a faster rate than average ET_{ref} .

ET cumulated over 20 day measuring period.

There was a good correlation between cumulated ET_{β} , ET_{lys} and ET_{ref} . Total cumulated ET_{β} was 18% greater than ET_{ref} (Fig. 5a) and 10% less than ET_{lys} (Fig. 5b). The crop coefficient calculated from the ratio of total cumulated ET_{β} to ET_{ref} was 1.18. The cause of the difference between ET_{lys} and ET_{β} was not clear. A longer period of data collection would have been required to determine the cause of this difference.

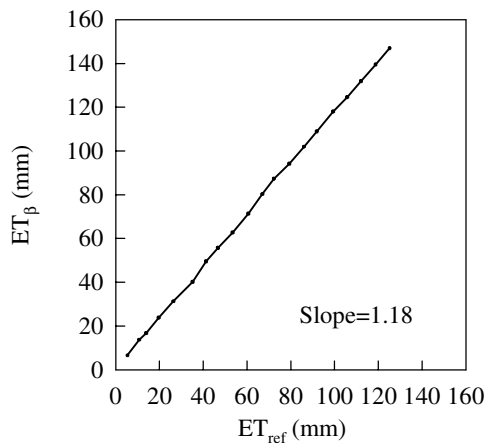


Fig 5a. Comparison of cumulated ET_{β} and ET_{ref} over 20 days of measurement.

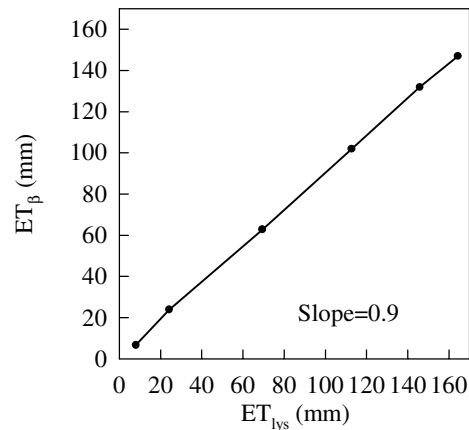


Fig 5b. Comparison of cumulated ET_{β} and ET_{lys} over 20 days of measurement.

CONCLUSIONS

- A crop coefficient of (1.18 ± 0.07) was derived from analysis of daily measured ET_{β} and ET_{ref} . This crop factor is only valid when climatic data used in the calculation of ET_{ref} is measured above a ponded rice field.
- Analysis of cumulated ET_{β} and cumulated ET_{ref} resulted in a crop coefficient of 1.18, which was comparable to ET values calculated on a daily time step.
- Measured ET_{β} was 10 % less than ET_{ref} measured in the lysimeters. The cause of this difference in measured ET were not clear.

ACKNOWLEDGEMENTS

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PREDICTING UNSUITABLE RICE SOILS

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INTRODUCTION

Groundwater recharge from irrigation has a major impact on regional groundwater levels and soil salinisation in irrigation areas of Southern New South Wales. Ricegrowing is undertaken on more than 130 000 ha annually, using about 2000 GL (2 million megalitres), being about 60-70 percent of all water diverted annually for irrigation in southern NSW. During the ricegrowing season, rice fields are inundated continuously for as long as 150 days, to a depth of up to 300 mm. Over the growing season 11.5-12.0 ML (1.15-1.2m) of water / ha are used to meet the evapo-transpiration demands of the rice crop. The remainder of irrigation water supplied to the rice crop is accounted for in surface drainage, soil storage and deep percolation.

Significant deep percolation to the groundwater system can potentially occur under ricegrowing, with resultant rising groundwaters and increased risks of soil and water salinisation. The rate of groundwater recharge from ricegrowing varies widely. It has been estimated that up to 35% of applied rice water bypasses the crop (GHD 1985). This excessive infiltration has been identified to account for 40-50 % of groundwater accessions in some irrigation areas.

For the context of this discussion, unsuitable rice soils are taken to be those which have excessive deep percolation under ponded ricegrowing conditions. Infiltration and subsequent groundwater recharge are affected by a multitude of factors including: antecedent moisture content, soil particle size distribution, % clay, clay type, water quality- EC, SAR, turbidity, soil quality - SAR, ESP, bulk density - compaction, swelling, structure, duration of ponding, entrapped air, physical location, puddling/ smearing, temperature, restricting layers, water table/ pressure, piston vs preferential flow, porosity- magnitude, continuity, changes.

Humphreys *et. al.* (1994) reviewed on-farm restrictions to minimize groundwater recharge these have included soil based criteria, paddock rice water use limits, exclusion of land from rice growing, and limits on the intensity of rice growing.

Until recently, rice soil suitability assessment was based upon Rice Environmental Policy Advisory Group (REPAG) criteria, grid sampling and soil type groups. Rice soil suitability is currently estimated from the proportion of heavy/medium clay textured material in the surface 2-3 metres of the soil, as determined by hand texturing (described by McDonald 1984; Table 1).

Grid sampling: One soil profile per four hectares (ie. 200m grid) is generally assessed. These profiles may be located on a grid basis or located subjectively following air photo interpretation.

Soil type groups: In some areas, the soil's suitability to grow rice has been assessed on the basis of soil type mapped regionally at a scale of 1:250,000.

Hallsworth *et al.* (1952) working on the grey and brown gilgai soils of the Murrumbidgee Irrigation Area, recorded a leaching effect due to ricegrowing which was more marked in areas overlying sand-drifts than in other areas. Hallsworth *et al.* (1952) concluded that it appears the shallower the sand-drift from the surface, the higher the water usage. Van der Lelij and Talsma (1977) found that cumulative infiltration during rice growing varied significantly over four broad soil categories : self-mulching soils, non self - mulching clay soils, near levee soils and transitional red brown earths. They also found large differences in the quantity of infiltration within these soil categories.

TABLE 1

CURRENT REPAG RICE SOIL CLASSIFICATION CRITERIA

Soil Classification	Murray Valley	Murrumbidgee Valley
Unsuitable	Less than 2 metres of continuous medium and heavy clay	Less than 2 metres of continuous medium and heavy clay if heavy clay sodic B horizon present Less than 3 metres of medium clay if no sodic B horizon.
Marginal (1:4 rotation)	Between 2 and 3 metres of heavy or medium clay	No new lands classified as marginal
Unrestricted	More than 3 metres of continuous medium or heavy clay	More than 2 metres of continuous medium or heavy clay if sodic heavy clay B horizon present More than 3 metres of medium clay if no sodic B horizon.

Limitations to this approach

The rice soil classification approach (Table 1) is based upon a general rule of relating clay content to likely infiltration characteristics of the soil. As indicated above there are many factors which can influence soil infiltration capacity. So in the field there are many exceptions to the existing clay content rule. This approach does not always identify difference in soils spatially across a rice field and does not allow effective delineation of problem areas within rice fields. Localised sites, allowing high levels of groundwater recharge, may exist within rice fields and their delineation is an important aspect of riceland management.

The direct measurement of infiltration is laborious and complicated by the highly variable spatial nature of infiltration. Indirect assays of recharge are therefore needed but current land assessment techniques will often not identify and define small areas of leaky soils.

Electromagnetic surveys

Electromagnetic induction techniques can be used to rapidly assess within field variability due to textural discontinuities within a landscape (McNeill 1980, Williams and Hoey 1987). The utility of subsurface assessment by electromagnetic methods lies in the greater volume of potential information, faster speed, lower costs, smaller logistical requirements and less environmental impact than the existing drilling program. The disadvantage of these techniques is that they do not have universal application and generally lead to a unique interpretation for each area surveyed. Extra information such as watertable depth, cropping history or surface soil texture may be needed to interpret the EM response within a field.

Oster *et al.* (1986) suggested using soil electromagnetic induction variability to estimate soil infiltration variability. Williams (1988) commented that “in the ricegrowing areas of NSW, groundwater recharge is a major problem due to the soil heterogeneity and the requirement of permanent flooding of the soil for periods of up to 130-150 days. Relatively new irrigation areas such as Coleambally Irrigation Area have seen watertables rise from an original depth of greater than 20 metres to less than 5 metres over the space of 20 years (GHD 1985). Survey techniques are obviously still not good enough to provide the level of detail necessary to prevent the use of some unsuitable soils for long term flooding”. Williams (1988) suggested that geophysical techniques, like EM, would improve the level of detail in soil surveys and may prevent rice from being grown on unsuitable soil.

Instrumentation including global positioning systems, which allow mobile collection of position and in situ ECa values has been demonstrated by Carter *et al.* (1993).

Knowledge of the likely soil conditions comes from a variety of sources including experience with similar conditions and from studies of vegetation, drainage patterns, surface soil conditions and available information from existing boreholes. Relative values from within field measurements will provide an indication as to the location of preferential recharge areas within rice fields.

The Geonics EM-31 instrument senses the apparent electrical conductivity (ECa) to a depth of 6 m from the soil surface. The ECa is related to the soil's salt content, clay content, moisture and bulk density. Field surveys with this instrument offer the potential of delineating rice fields into areas of distinctly different ECa. Targeted soil sampling and rice land assessment allowing for field variability can then be made on the basis of ECa measurements to infer the likely level of groundwater recharge.

McNeill (1992) concluded that ground conductivity meters will find increasing use for "...location of suitable sites for evaporation basins and subsequent monitoring for leakage, classification of land for irrigation suitability, and mapping of recharge and discharge areas in addition to a range of potential uses".

Beecher and Hume (1996) showed the potential for using EM-31 instruments combined with GPS to provide spatial detail on variation in soil properties across rice fields, and a methodology on where to investigate to provide assessment of rice soil using the current REPAG criteria.

Bulk electrical conductivity (ECa), as measured by the EM-31, responds to a number of soil properties including: water content, clay content, soil salinity, bulk density and temperature. The instrument, when mounted on a 4 WD motor bike, can gather information from 5 metres

depth. The density of data collection gathered by the EM-31 used in this fashion is significantly increased from 1 site per 4 hectares, to (depending on transect spacings and within transect intervals) about 100 points per hectare. Such data density, when combined with computer mapping packages, can significantly increase the precision and definition of areas within a rice field that respond differently.

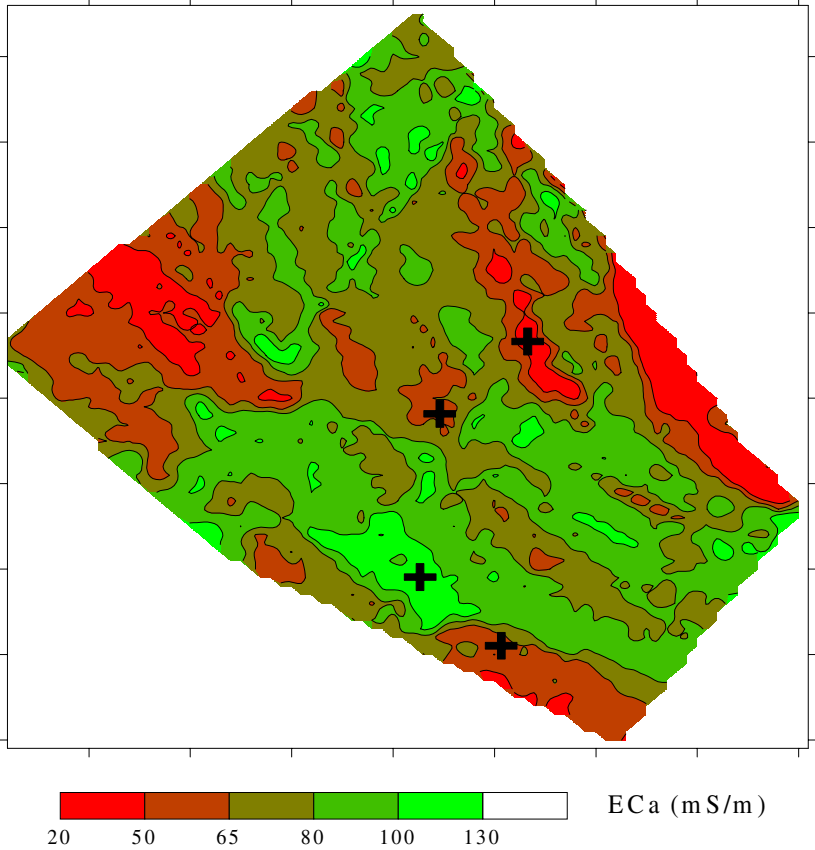


Figure 1 - ECa contour map of a rice field with a history of high rice water use

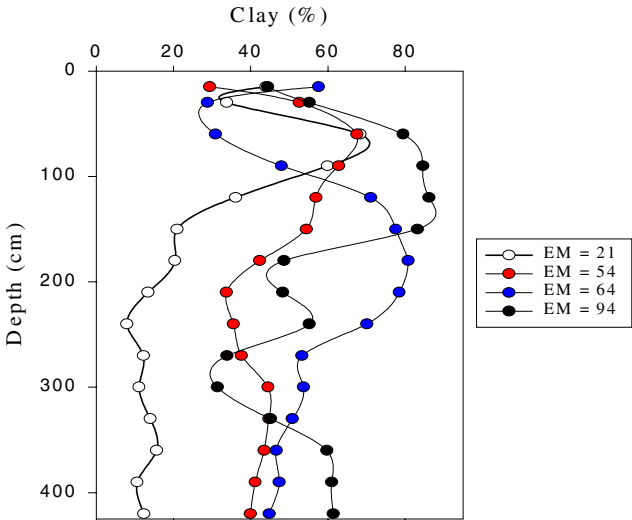


Figure 2 - Clay percentage with depth for selected sites in figure 1.

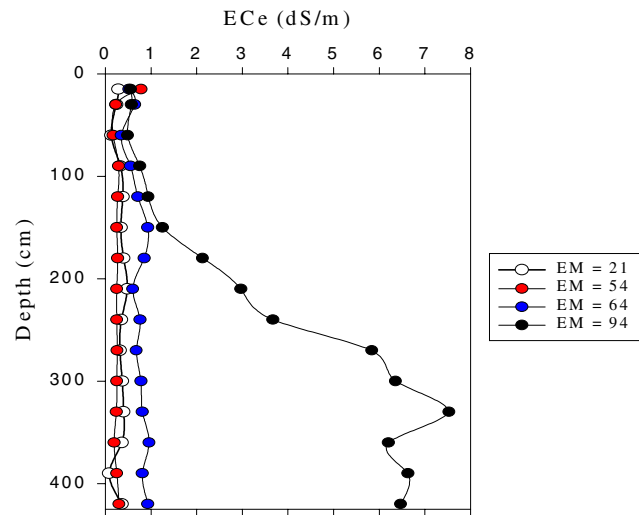


Figure 3 - Soil electrical conductivity with depth for selected sites in figure 1

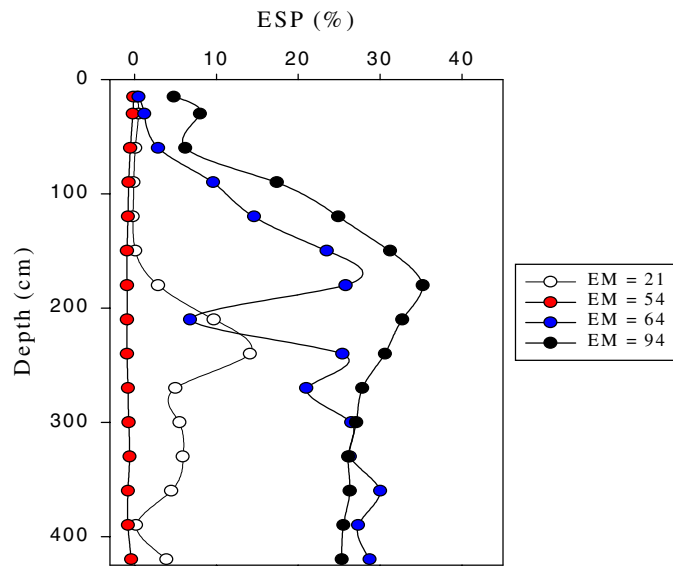


Figure 4 - Soil sodium adsorption ratio with depth for selected sites in figure 1.

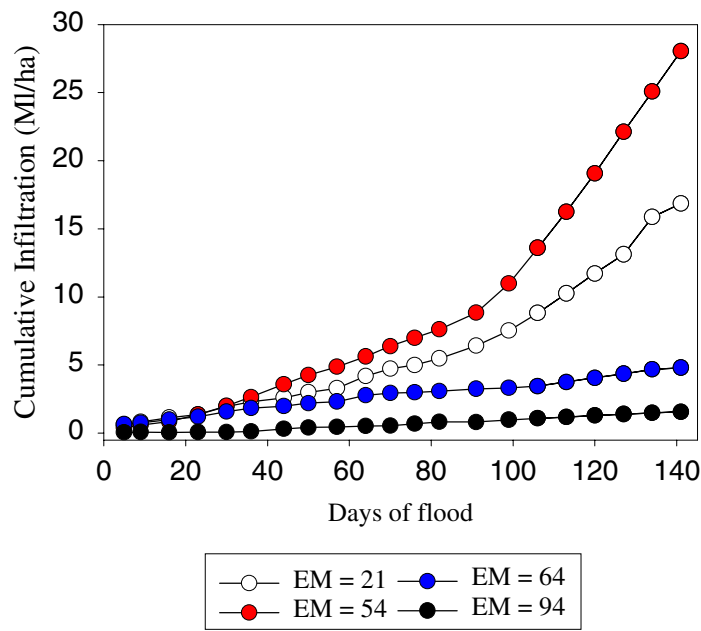


Figure 5 - Season-long cumulative infiltration for selected sites in figure 1.

EM implications

By using EM-31 combined with GPS technology, the survey intensity possible within a field increases from 1 site per 4 ha, to up to 100 sites per ha. The use of GPS technology with sub-metre accuracy allows for accurate site location, with the opportunity to accurately revisit sites in a cost effective manner. Having accurate GPS locations makes it possible to map on basis of EM values using computer based mapping software. Maps thus produced allow the delineation of differences in what superficially appears a “uniform” field or landscape. The degree and extent of spatial variability within a rice field is indicated. There is a reduced number of sites to be investigated based on EM values

However, problems are still experienced when using this technology in association with the existing REPAG criteria. Within specific soil types, sites with shallow sand can be identified which, on current soil textural criteria, would exclude the land from rice growing. Nevertheless, in many cases the soil has a high sodicity and such areas have rice water use which is claimed to be low and within acceptable limits. Conversely, many self mulching soils easily meet the existing soil textural criteria but have a stable soil structure which results in high water use on many occasions.

Using infiltration and soil data gathered within RIRDC projects DAN95A and DAN145A an attempt has been made to define an improved rice soil classification system. These projects provided 128 recharge assessments on 30 farms within the Murray, Coleambally and Murrumbidgee irrigation areas.

Field measurements were made pre- and post- rice growing, based on EM-31 targeted sites and covered soil water content, clay content, soil salinity, sodicity, and chloride content. Season long infiltration measurements were made at each location. The data collected were

used to develop estimates of groundwater recharge past 90 cm depth based on chloride mass balance models where chloride levels in the soils were adequate, or on water balance models where the chloride was inadequate.

Field measurements were undertaken on a range of soil and watertable conditions (Table 2).

TABLE 2

SITES ASSESSED DURING THE PROJECTS DAN145-A AND DAN95-A

Soil	Watertable			Total
	<1 m	1 – 2 m	> 3 m	
Red Brown Earth	27	9	16	52
Transitional Red Brown Earth	2	4	19	25
Non Self Mulching Clay	26	12	17	55
Self Mulching Clay	5	5	12	22
Total	60	30	64	154

TABLE 3

NUMBER OF SITES WHICH HAVE COMPLETE DATA SETS AND WERE USED TO DEVELOP CLASSIFICATION SCHEME

Soil	Watertable			Total
	<1 m	1 - 2 m	> 3 m	
Red Brown Earth	22	8	17	47
Transitional Red Brown Earth	2	2	10	14
Non Self Mulching Clay	24	12	9	45
Self Mulching Clay	5	5	12	22
Total	53	27	48	128

Recharge

The recharge estimates for the soil type and watertable categories are shown in Table 4.

TABLE 4

THE IMPACT OF SOIL TYPE AND WATERTABLE DEPTH ON RECHARGE (ML/HA)

Soil	Watertable			All Watertable
	<1 m	1 - 2 m	> 3 m	
Red Brown Earth	0.4 ^a	0.8	6.5 ^{ab}	2.6
Transitional Red Brown Earth	3.2	0.9	2.2	2.1 ^c
Non Self Mulching Clay	1.1	0.5	0.2 ^b	0.8 ^d
Self Mulching Clay	2.7	5.7	6.3	5.4 ^{cd}
All soils	1.0 ^e	1.6 ^f	4.3 ^{ef}	2.4

Categories marked with the same letter are significantly different at the 5% level of probability.

In general terms it appears that recharge increases with increasing watertable depth . It can also be seen that soil type does appear to influence the level of estimated recharge in a similar fashion to that observed by Van der Lelij and Talsma (1977).

Initially, we plotted recharge against EM-31 values (Figure 6). Adopting an allowable point recharge of 2MI/ha , we suggest that EM values greater than 150 will probably identify soil sites having acceptable recharge. However, at sites with EM -31 values of less than 150, a significant range of recharge values were observed and no relationship between recharge and EM-31 values occurs.

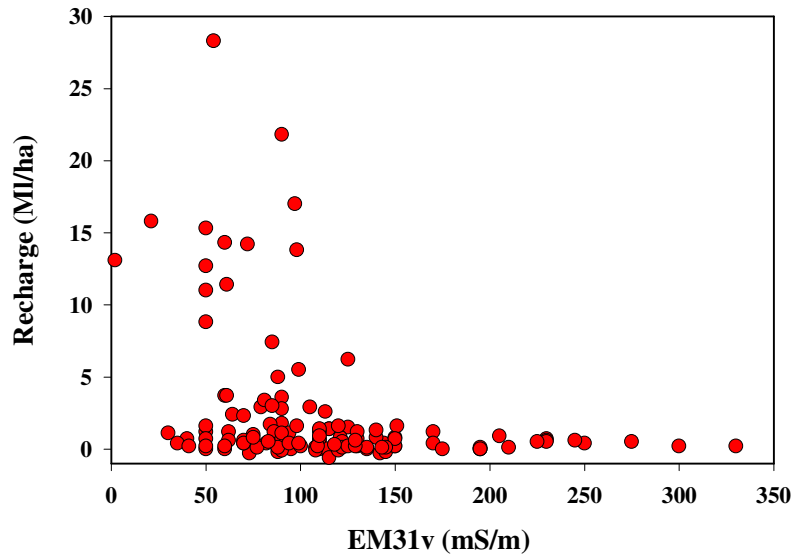


Figure 6 - EM-31 reading as a universal indicator of recharge

An analysis of the data with EM-31 values below 150 mS/m was then undertaken to evaluate relationships between the estimated recharge and measured soil parameters. The approach adopted was to examine correlations between the recharge estimates and depth weight mean values for ESP, clay percentage and ECe (soil salinity) (Table 5).

TABLE 5

PEARSON CORRELATION COEFFICIENTS BETWEEN DEPTH WEIGHTED SOIL PROPERTIES AND RECHARGE

a. All assessment sites

	ESP		Clay (%)		ECe (dS/m)		
	Recharg 0-60	60-150	0-60	60-150	0-60	60-150	
Recharge	1.00	-0.50	-0.43	0.10	0.07	-0.27	-0.33
ESP 0-30		1.00	0.72	0.03	-0.08	0.54	0.71
ESP 60-150			1.00	-0.06	0.11	0.18	0.47
Clay 0-60				1.00	0.70	0.13	0.07
Clay 60-150					1.00	0.04	-0.33
ECe 0-60						1.00	0.55
ECe 60-150							1.00

b. For assessment sites where EMv < 150

	ESP		Clay (%)		ECe (dS/m)		
	Recharg	0-60	60-150	0-60	60-150	0-60	60-150
Recharge	1.00	-0.50	-0.4205	0.11	0.04	-0.26	-0.33
ESP 0-30		1.00	0.67	-0.03	-0.08	0.59	0.67
ESP 60-150			1.00	-0.04	0.22	0.20	0.38
Clay 0-60				1.00	0.71	0.08	-0.01
Clay 60-150					1.00	0.00	-0.33
ECe 0-60						1.00	0.61
ECe 60-150							1.00

The correlation matrix indicates that the best relationships (but not highly significant correlations) were between recharge and ESP within the 0-60 and 60-150 cm intervals.

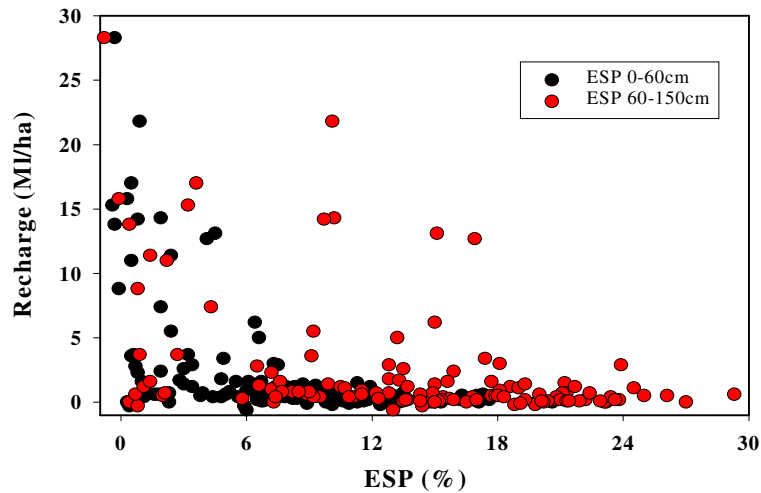


Figure 7 - The effect of ESP for two depth intervals on estimated recharge past 90cm.

Based on these data a new classification system is proposed for rice soil suitability which would result in reduced net recharge from rice growing.

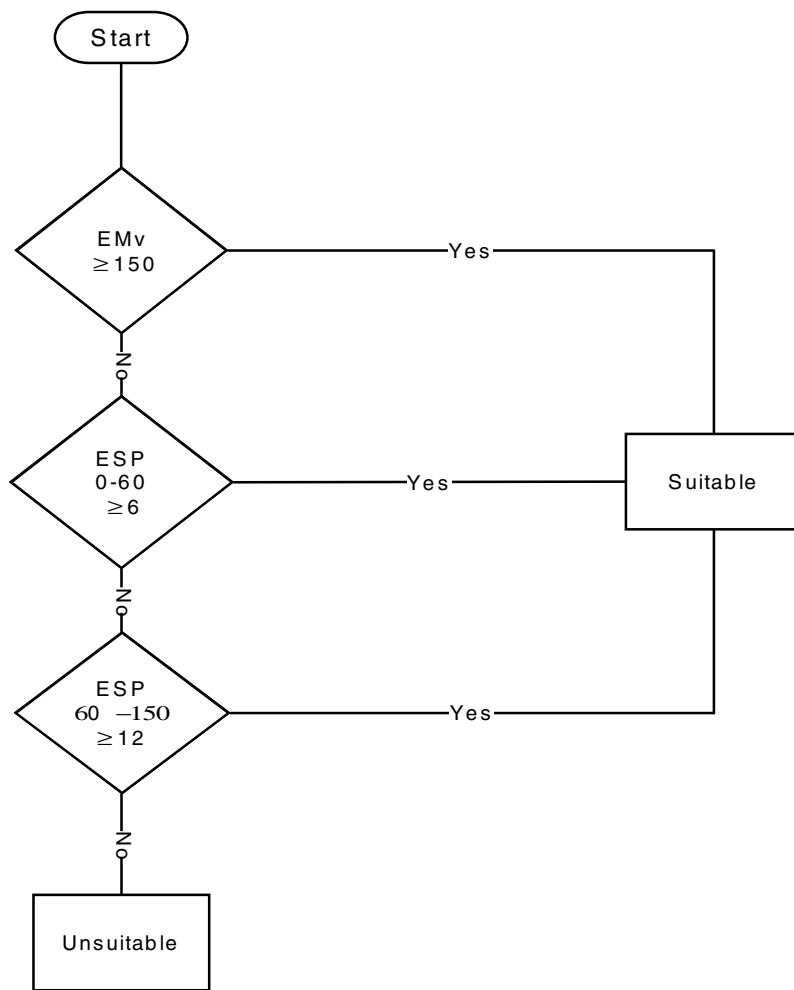


Figure 8 - A possible flowchart for rice land approvals

The following table shows the estimated recharge (mean, median and various percentile) for the total data set and for the current and proposed classification schemes. It shows that the adoption of the proposed scheme would allow for significant mean reductions in recharge.

TABLE 6

COMPARING THE NEW CURRENT SOIL SUITABILITY CLASSIFICATION SYSTEMS.

Statistic	Recharge (Ml/ha)		
	None	New	Current
Average	2.41	1.03	3.04
5th Percentile	-0.05	-0.09	0.14
25th Percentile	0.20	0.14	0.44
50th Percentile	0.59	0.44	1.15
75th Percentile	1.61	1.16	1.94
95th Percentile	14.08	3.15	15.72

A comparison of the sites examined under different classification schemes was undertaken. For comparison of the classification schemes the following should be noted. All sites used for this work were within existing rice fields - that is, all the land is currently approved for rice growing under the existing REPAG criteria.

Using the laboratory data to estimate clay percentage (with 45% clay being the minimum for a medium clay soil) and strictly applying the criteria of a minimum of 2 m continuous medium or heavy clay, the sites investigated were classified as to their suitability for rice growing. The sites were then classified for their suitability using the criteria developed as part of this project. From Figure 9 it can be seen that strict application of existing criteria results in about only 30 of the 128 sites (all currently growing rice) being considered suitable for rice growing. The suggested system results in over 90 of the sites being considered suitable for rice growing.

Figure 9 below indicates the groundwater recharge occurring at those sites considered suitable for rice growing under the two classification schemes and for the complete data set collected. It can be seen that compared to the complete data set the REPAG criteria removed about 75% of sites from rice growing and that the proposed system removes about 25% of sites. It can also be seen that both of the classification systems still allow sites with high levels of recharge to be approved however the current system does allow sites with higher recharge to be approved than the proposed system.

Application of improved land selection criteria will reduce groundwater recharge from ricegrowing. Land "retirement" from ricegrowing will be minimised through the identification of areas of high recharge within existing rice fields. This will allow the application of ameliorative techniques to these areas (Humphreys *et al.* 1995, Humphreys *et al.* 1998). Better assessment of new ricegrowing areas will enable the sustainable development and expansion of the rice industry.

This more refined and objective method of targeting soil assessment integrates the parameters changed by leaching processes. However, rice soil suitability at the point scale is still classified using the current criterion, soil texture.

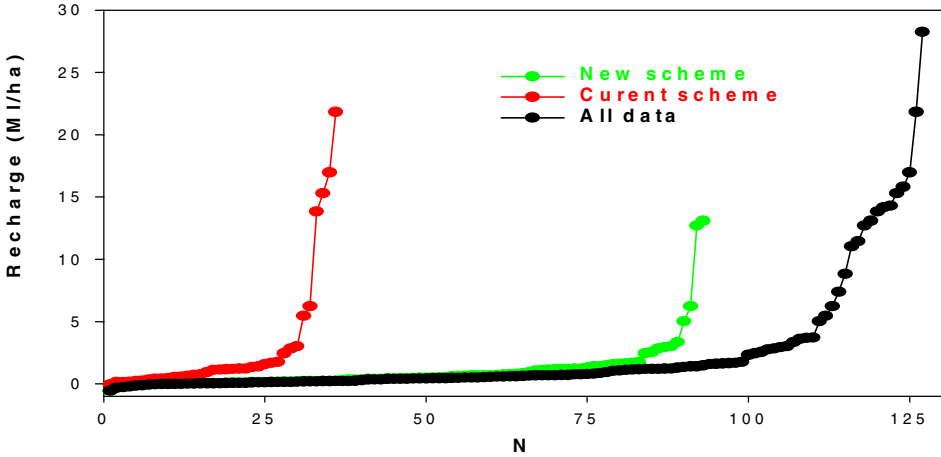


Figure 9 - The recharge ranked for all sites, and for sites which pass the strict application of current criteria (current scheme) and for sites which passed the suggested criteria (new scheme).

CONCLUSIONS

Riceland classification to reduce groundwater accessions and improve water use efficiency could be improved by explicitly including sodicity indices within the classification scheme. From data produced within these two projects it can be seen that the classification of rice soil suitability by clay content can be erroneous and potentially results in increased net recharge.

The proposed system reduces net recharge, works at farm and regional scales and is sensitive to changes in classification.

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LEAKYPAD - AN OPTIMISATION MODEL FOR IDENTIFYING LEAKY RICE PADDOCKS WITHIN A FARM

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INTRODUCTION

Rice is an attractive crop for many irrigators. However, recharge of groundwater from ponded rice is a problem as rice is ponded for around 5 months, and rice culture uses 50-70% of the irrigation water on 6-25% of the landscape. Rice environmental policy to reduce recharge from rice includes: soil must be assessed as suitable for rice culture (2-3 m of medium to heavy clay in the top 4 m are required), the area of rice that may be grown on each farm each year is limited in the MIA and CIA (maximum is ~33% of the rice suitable soils), and rice crop water use must not exceed a limit, calculated for each season, based on the theoretical crop water use requirement.

Until now, the estimation of recharge under rice paddocks cannot be done directly and has to be inferred indirectly from the measurement of other variables. The amount of water supplied to rice farms is measured using a Dethridge meter, and farmers are required to tell the irrigation water suppliers what proportion of the water is going to rice versus other uses. This information, together with crop areas measured from aerial photographs, is used to calculate farm average rice water use (ML/ha). Where possible, water use is also calculated for individual rice paddocks to identify which are the leaky (high water use) rice paddocks. Most farms have 1-3 Dethridge wheels and many paddocks. In some situations a single wheel may only supply a single paddock, and therefore rice paddock water use can be measured directly. But in many situations a single wheel supplies more than one rice paddock and it is not possible to directly apportion water use to individual paddocks and to identify if any of them are too leaky.

LeakyPad is an optimisation program designed to estimate recharge under individual rice paddocks based on identity and area of each rice paddock, annual farm rice water use (and paddock water use where available) and theoretical rice water use. To achieve a solution LeakyPad requires several years of data. The objective function minimises the sum of positive and negative errors over several years induced by the difference between rice water use in excess of evaporative demand (WEX) subject to the constraint that recharge is always positive.

THEORY

To determine the rice paddock water use (RPWU) in any year, a linear programming model was developed by Dr S.A. Prathapar (pers. comm.) as follows:

The data requirement consists of

- 1) $Area_{ij}$: area of rice in paddock j during year i (ha)

- 2) ET_i : crop evaporative demand during year i (MI/ha)
- 3) $Rain_i$: rainfall during year i (MI/ha)
- 4) Irr_i : amount of irrigation water supplied to rice during year i (MI)

The total area ($Tarea_i$) in a given year i is given by:

$$Tarea_i = \sum_j Area_{ij} \quad (1)$$

Total evaporative demand (TET_i) in year i is given by:

$$TET_i = Tarea_i \times ET_i \quad (2)$$

Total rainfall ($TRain_i$) during year i is given by:

$$TRain_i = TArea_i \times Rain_i \quad (3)$$

Farm rice water ($fwuse_i$) use in year i is given by:

$$fwuse_i = irr_i + TRain_i \quad (4)$$

Water in excess of evaporative demand (WEX_i) is given by:

$$WEX_i = fwuse_i - TET_i \quad (5)$$

Average farm rice water use ($Afwuse_i$) is given by:

$$Afwuse_i = fwuse_i / Tarea_i \quad (6)$$

The objective function is to minimise total positive and negative errors:

$$Total = \sum_i (error_i^+ + error_i^-) \quad (7)$$

subject to

$$WEX_i - \sum_j Area_{ij} \times Re ch_j - error_i^+ + error_i^- = 0 \quad (8)$$

$$Re ch_j \geq 1 \quad (9)$$

where

$error_i^+$ and $error_i^-$ = positive and negative errors in year i

$Area_{ij}$ = area of paddock j in year i (Ha)

$Re ch_j$ = Recharge in paddock j (MI/ha)

The rice paddock water use in each year ($RPWU_{ij}$) and the estimated error ratios are calculated as follows:

$$RPWU_{ij} = ET_i + Rain_i + Re ch_j \quad (10)$$

$$Err_i = \frac{error_i^+}{irr_i} \times 100 \quad (11)$$

or

$$Err_i = -\left(\frac{error_i^-}{irr_i}\right) \times 100 \quad (12)$$

The above equations were solved using the GAMS optimisation package (GAMS 1996).

LEAKYPAD APPLICATION

Data required

The following data are required for several years for individual farms:

- Annual farm rice water use
- Identification of which paddocks are grown to rice each year
- Area of each rice paddock
- Annual rice ET
- Annual rainfall.

Table 1 represents a farm with 8 rice paddocks, some of which are sown to rice each year over a period of eight years. The table shows the area sown to rice in each paddock in each year, the amount of irrigation water applied to rice, the total rice area, the theoretical rice crop water use (ET) and rainfall. The objective is to estimate the recharge and rice paddock water use for each paddock.

TABLE 1

HYPOTHETICAL FARM PADDOCK DATA

Year	Area sown to rice (ha)									Total rice irr (ML)	ET (ML/ha)	Rain (ML/ha)
	<i>Pad1</i>	<i>Pad2</i>	<i>Pad3</i>	<i>Pad4</i>	<i>Pad5</i>	<i>Pad6</i>	<i>Pad7</i>	<i>Pad8</i>	Total			
85/86				24.9	24.0	19.5			68.4	863.4	11.3	2.57
86/87						30.8	13.9	29.9	74.6	1280.3	12.2	1.07
87/88	8.4	24.6		24.9					57.9	926.4	13.6	0.62
88/89			24.2		24.0	30.8	9.2		88.2	1195.8	12.1	0.99
89/90	23.5	24.6		24.9			7.4	29.9	110.3	1420.8	13.1	1.16
90/91		24.6	24.2		24.0	30.8	9.2		112.8	1638.5	13.6	1.10
91/92				24.9	24.0		9.2	29.9	88.0	1308.7	12.1	1.62
92/93	23.5	24.6	24.2				7.4		79.7	1216.0	11.3	1.99

RESULTS

Using the hypothetical farm data given in Table 1, the linear programming solution indicates a total minimum error of 777 MI over the eight years. The optimised farm rice water use, recharge and relative errors are shown in Figures 1, 2 and 3.

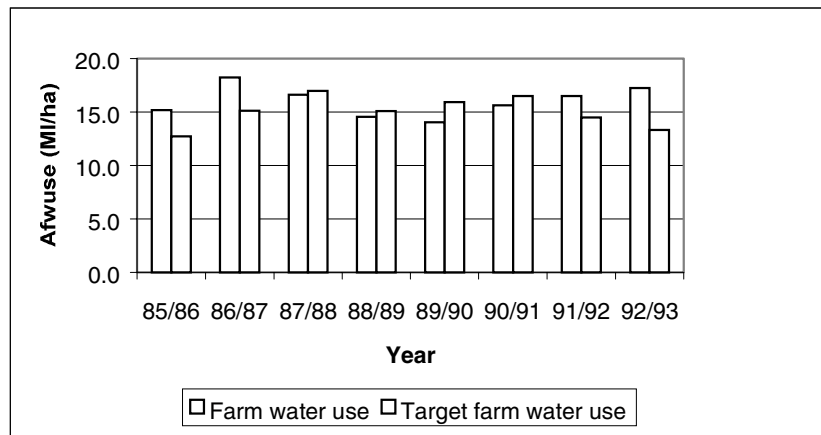


Figure 1 - Average farm water use per season

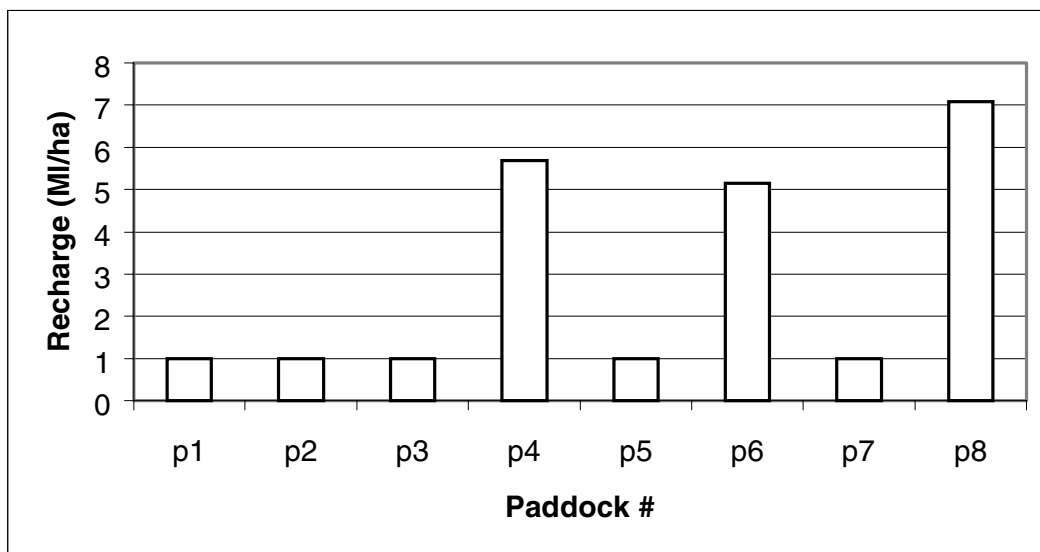


Figure 2 - Average Recharge per paddock

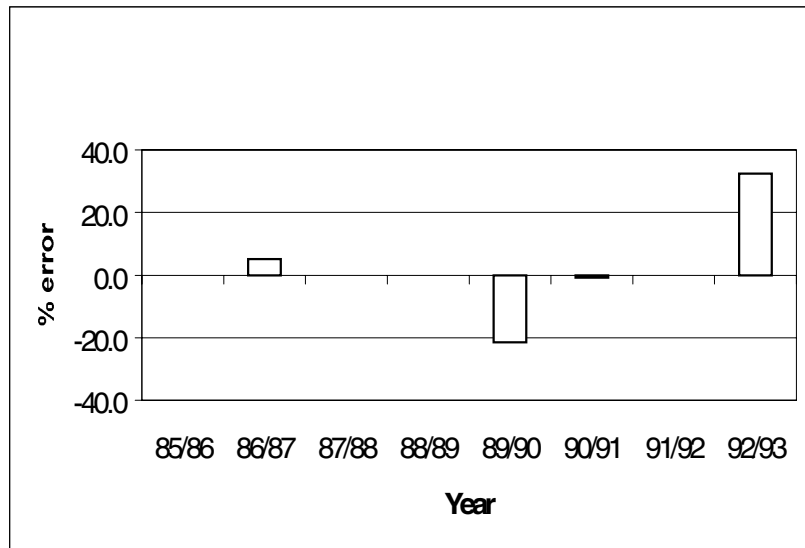


Figure 3 - Percent error of applied irrigation water occurring as over or under-irrigation. (See Eqn. 11 and 12)

Figure 2 shows the average recharge under each paddock. Paddocks p4, p6 and p8 appear to be extremely leaky, well above the nominal rate of 1MI/ha allowed for in the model formulation, and require further investigation to determine their suitability for rice. These paddocks have been consistently cropped to rice with relatively high areas over the years considered in the model (see Table 1).

The average farm rice water use fluctuates around 15MI/ha (Figure 1). The rice water use target each year is currently calculated as $ET_0 - \text{Rain} + 4$ (MI/ha) and is also shown in Figure 1. In 4 of the 8 years farm average rice water use exceeded the target.

Figure 3 shows that in 86/87 and 92/93 more water was applied than is needed for crop evaporative demand while in 89/90 less water was applied than is required. In all other years crop evaporation needs were just about right.

Further model improvements:

The current model formulation could be improved considerably by incorporating the following into the model:

- Effects of shallow water tables on recharge rates
- Effects of surface and sub-surface soil water storage and drainage.
- Effects of soil physical properties.

A beta version of user-friendly interface for the model is currently under being developed and example screens are shown in Figures 4 and 5.

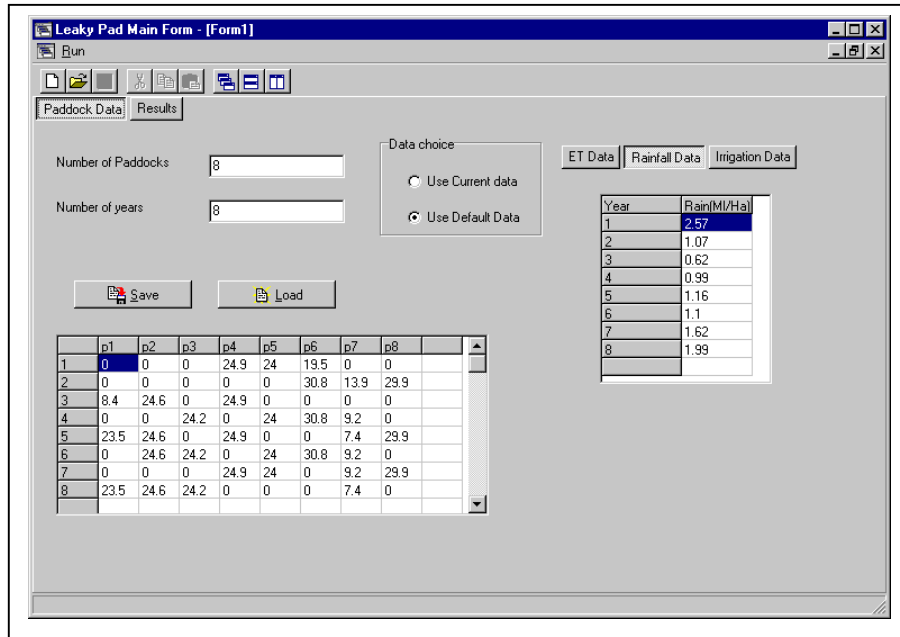


Figure 4 - Input Screen

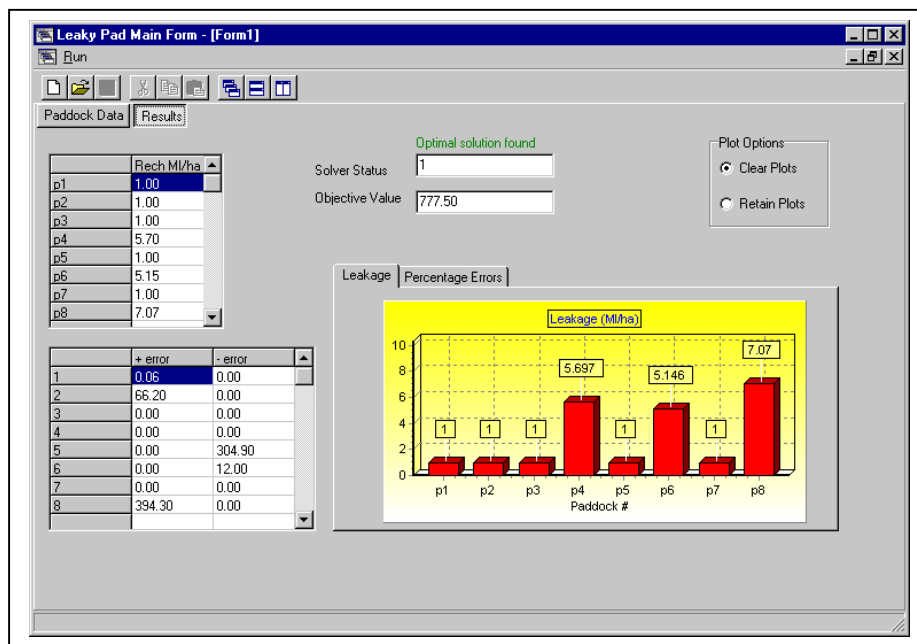


Figure 5 - Output screen

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FARMER METHODS FOR IDENTIFYING HIGH WATER USE RICE PADDOCKS AND BAYS

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INTRODUCTION

Rice paddock water use has been routinely calculated for every farm in the Irrigation Areas and Districts of southern NSW for many years (Humphreys *et al.* 1994). When water use exceeds the nominated target the farmer is required to discuss it with the relevant irrigation authority, and if a satisfactory explanation does not exist, the paddock is subjected to further investigations and/or banned for use for ponded rice culture. Therefore rice growers are usually aware of which paddocks have higher water use, although sometimes this is not so clear where more than one paddock is supplied via the same wheel, and the water diverted to each paddock is not measured and/or recorded separately.

Rice growers are also generally aware of which are the higher water use bays within each paddock. This becomes apparent when they “lockup“ (prevent water flowing between the bays) for herbicide applications – the water level drops much faster in the higher water use (more leaky) bays. However, they may not be aware of the significance of this in terms of the amount of additional recharge being contributed by these leaky bays. Humphreys *et al.* (1998a) gave an example of a 30 ha paddock in which two leaky bays (total area 2 ha) doubled the total recharge from the whole paddock.

There are a couple of simple techniques which farmers can use to become better informed about rice paddock water use, and leaky bays within paddocks.

LOCKUP BAY TESTS

A lockup bay test involves preventing water flow between the bays and recording the change in water depth each day over a period of several days, and was developed by staff of the former Water Resources and Irrigation Commission in their investigations of high water use paddocks. The only equipment needed is a peg with a millimetre scale attached and installed in each bay. The technique is described in Humphreys (1992), and has been used successfully by many farmers in co-operative research, including the study reported in Humphreys *et al.* (1998), and also in comparisons of water use in puddled and non-puddled bays. There is no evidence that farmers use this technique to improve their knowledge of the fate of water in their rice paddocks except in joint activities with researchers.

IMPROVED RECORDING OF IRRIGATIONS

There is scope for farmers to improve their determinations of irrigation water applied to each paddock by simply recording the wheel readings every time they change the destination of the water supply. This exercise was successfully carried out by several farmers over one season in

co-operation with Hope *et al.* (1997), and the current MIA Water Use Efficiency Improvement Scheme relies on farmers keeping good records and estimates of supply and drainage waters. It is currently not normal practice for most rice farmers to keep such detailed records of water transactions (Humphreys *et al.* 1998) as it is extra work for little perceived value, and in some cases farmers probably feel threatened by the data.

FLOWMETERS

One of the impediments to accurate determinations of supply to and drainage from paddocks is the lack of user friendly, portable, inexpensive and robust devices for measuring flows. A range of devices has been used in rice, row crops, pastures and winter cereals (Humphreys *et al.* 1998); they all have their deficiencies and advantages as summarised in Table 1. A more detailed summary of their advantages and disadvantages is presented in the Australian Irrigation Technology Centre (AITC 1999).

TABLE 1.

FEATURES OF FLOW MEASUREMENT DEVICES SUITABLE FOR USE ON RICE FARMS – SUPPLY AND DRAINAGE

N.B. the accuracy of all meters depends on correct installation and operating conditions
X = unsuitable, **✓** = suitable

	Dethridge wheel	Propeller meter	Ultrasonic meter
Portability	X	X✓	✓
Accuracy	✓	✓	✓
Robustness	✓	X	✓
OH&S	X	✓	✓
User friendly	✓	✓	X
Approx. price	\$5 k (includes installation)	\$1.5-4.5 k (varies depending on size of the meter and type of installation)	\$2.5-3.5 k (cost of installation negligible if installed in existing structure; meter price varies depending on features required e.g. digital display, depth measurement, logging capability)

Dethridge meters are relatively robust, easy to read and quite accurate (within 5% or better) provided they are installed correctly and operated with the correct heads (Long 1989). However they are expensive, not portable, and accuracy is reduced due to wear and incorrect operating heads.

Propeller meters are very user friendly with a large display of instantaneous flow rate (e.g. ML/day) and total flow (e.g. ML). If installed and managed correctly, then can be quite accurate. They are relatively portable except for the fact that they must be installed in a pipe that runs full at all times. Temporary installations can be constructed using a PVC or polythene pipe and strap-on meters, or open flow meters can be installed at the end of more permanent concrete pipe installations. In many situations the pipes may need to be partially

buried, or supplied with an end wall, to ensure that they run full. Propeller meters are very sensitive to interference from debris in the water, and require screens (which must be cleaned regularly). Even with screens problems with blockage of the meters has been observed in drainage installations.

Ultrasonic flow meters are very portable, and can be installed in many structures (pipes, channels) provided the geometry of the cross section can be described and is within the range of meter specifications. The simplest method is to install them inside a pipe. All ultrasonic flow meters measure velocity, and many also measure depth. If installed in a pipe, it is not necessary for the pipe to run full if the meter also measures depth. Some makes of ultrasonic flow meters have a digital display which indicates instantaneous flow rate and total flow. Logging the data is an option on some brands, and a normal feature on others. They are very robust – no moving parts or blockages, and because of their small size interference with flow is minimal. Their main disadvantage for farmers is that they must be set up using a computer, and meters without a digital display also require computer interrogation to get the data.

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WATER USE EFFICIENCY AT A FARM SCALE - SWAGMAN FARM APPROACH

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ABSTRACT

The SWAGMAN (Salt Water and Groundwater Management) Farm model has been developed by CSIRO Land and Water as a tool for simulating water and salt processes and economics on a farm scale. The model integrates physical and economic factors to help investigate the water use efficiency of different irrigation practices and cropping systems and corresponding impacts on groundwater levels and root zone soil salinity. This paper provides a general description of the model, and its application to date in irrigated areas of the southern Murray-Darling Basin. Future development of the model is also discussed.

INTRODUCTION

Demands are being placed on irrigated agriculture to become more efficient in the use of water and to minimise the adverse impacts of over-irrigation on watertables. Waterlogging and soil salinity pose major threats to agricultural production and environmental sustainability. Management of these issues requires an understanding of the balance between the excess irrigation water passing through the root zone (required to leach salts), and the ability of underlying aquifers to carry away this excess water.

In the Murray Valley, district hydrogeological studies suggested that the farm is the most important place where improvements can be made to minimise accessions to the groundwater (Bogoda *et al.* 1994; Bogoda & Kulatunga 1995; Bogoda *et al.* 1995a; Bogoda *et al.* 1995b). Modelling at a paddock-scale by CSIRO Land and Water (Prathapar *et al.* 1997) also resolved that, from a financial perspective, the farm is a more appropriate management unit.

Thus the key to managing waterlogging and salinity is to reduce net recharge to the groundwater and root zone salinisation whilst maintaining the economic viability of farms. CSIRO Land and Water has developed an optimisation model, SWAGMAN Farm, which provides a useful tool for analysing management decisions aimed at improving irrigation efficiency, and managing net recharge and root zone salinisation in irrigated areas.

MODEL DESCRIPTION

SWAGMAN Farm is a simple farm-scale water and salt balance model which integrates the hydrological analysis with economic returns from different crops. The physical processes represented in the model include irrigation, rainfall, evapotranspiration, surface runoff, recharge, capillary upflows, leakage to deeper aquifers and associated salt fluxes as shown in Figure 1. The salt and water balances are calculated for the cropping and non-cropping periods and lumped for individual crops to give results for one year for a farm. SWAGMAN

Farm has been written in GAMS to enable optimisation using mixed integer and non-linear routines Madden & Prathapar (1999).

SWAGMAN Farm estimates the change in salinity within the root zone, and recharge to the groundwater below the root zone, under a range of land management scenarios, whilst maximising economic returns. SWAGMAN Farm can be used in either a simulation or optimisation mode. During simulation mode environmental impacts and economic returns can be determined for given crops on a farm. In optimisation mode, the model can determine the best combination of crops that results in maximum profit within given constraints of water allocation, soil salinity and watertable rise.

The model can also be used to estimate pumping requirements to maintain watertables below given limits. The overall framework of the model provides an opportunity to understand water use efficiency in terms of profits/ML of irrigation water, recharge/ML of irrigation water, root zone salinity/ML of irrigation water and profits/ML of recharge etc.

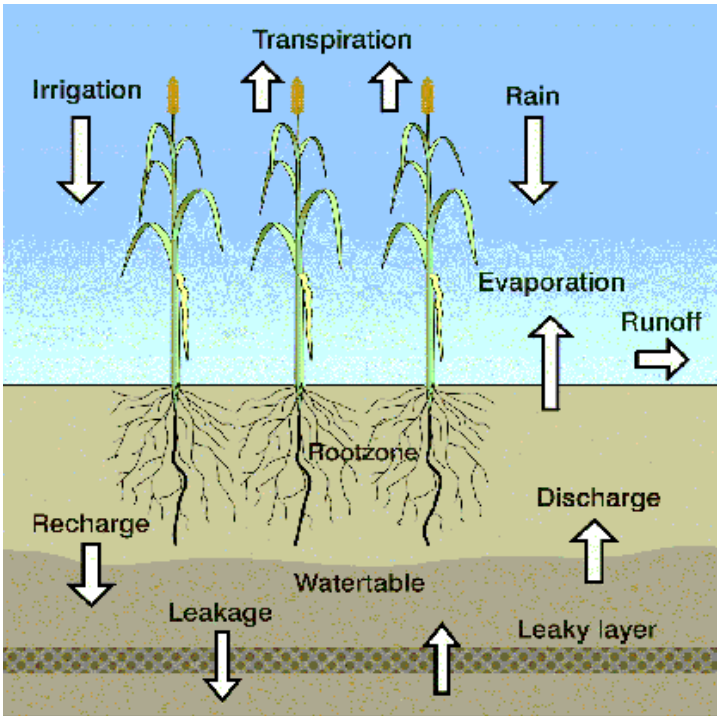


Figure 1. Water and salt balance processes represented in SWAGMAN Farm.

MODEL INPUTS

The data requirements of SWAGMAN Farm are summarised in Table 1. These input parameters cover agronomy, soils, economics, water quality, hydrogeology and model constraints.

TABLE 1.

DATA INPUT REQUIREMENTS FOR SWAGMAN FARM

Category	Parameters and units
Climate & Agronomy	<ul style="list-style-type: none"> ◆ Monthly evaporation and rainfall for dry, median and wet years (mm) ◆ Seasonal crop factors for various crops ◆ Growing period and duration for various crops (days) ◆ Irrigation water requirements for each crop on each soil type (MI/ha)
Soils	<ul style="list-style-type: none"> ◆ The area of each soil type (ha) ◆ Leaching fraction for each soil type ◆ Saturated water content for each soil type ◆ Average water content at the start of the season for each soil type
Economics	<ul style="list-style-type: none"> ◆ Gross margin for each crop (\$/ha) ◆ Yield for each crop (tonnes/ha) ◆ Price for each crop (\$/ha) ◆ Variable costs for each crop (\$/ha)
Water Quality	<ul style="list-style-type: none"> ◆ Salt concentration of irrigation water (dS/m) ◆ Salt concentration of rain water (dS/m) ◆ Salt concentration of groundwater (dS/m)
Hydrogeology	<ul style="list-style-type: none"> ◆ Depth to the watertable (m) ◆ Leakage rate to deep aquifers (MI/ha)
Model constraints	<ul style="list-style-type: none"> ◆ Allowable rise in the watertable (m) ◆ Allowable rise in the root zone salt concentration (dS/m) ◆ Maximum volume of water allocated to the farm (MI/ha) ◆ Upper and lower bounds on crop areas (ha)

MODEL OUTPUTS

The principle outputs of SWAGMAN Farm are the farm gross margin, crop areas and various components of both the water balance and salt balance. These outputs are listed in Table 2. The water balance components refer to recharge and discharge to the groundwater. The salt balance components refer to the processes that result in salt being transported in and out of the root zone.

TABLE 2.

DATA OUTPUTS FROM SWAGMAN FARM

Category	Parameters and units
Economics	<ul style="list-style-type: none"> ◆ Total farm gross margin (\$)
Agronomy	<ul style="list-style-type: none"> ◆ Area of each crop (ha)
Water Balance	<ul style="list-style-type: none"> ◆ Leakage to deep aquifers (MI) ◆ Recharge to the groundwater during the cropping period (MI) ◆ Capillary upflow from the watertable during the cropping period (MI) ◆ Recharge to the groundwater during the bare period (MI)

	<ul style="list-style-type: none"> ◆ Capillary upflow from the watertable during the bare period (MI) ◆ Net farm recharge (MI) ◆ Net recharge per crop (MI) ◆ Change in watertable level (m) ◆ *Volume of water pumped to maintain watertable level (MI)
Salt Balance	<ul style="list-style-type: none"> ◆ Salt brought in by rainfall (tonnes) ◆ Salt brought in by irrigation water during the cropping period (tonnes) ◆ #Salt lost by surface run-off in the cropping period (tonnes) ◆ Salt lost to recharge to the groundwater during the cropping period (tonnes) ◆ Salt brought in by capillary upflow from the watertable during the cropping period (tonnes) ◆ Salt lost to recharge to the groundwater during the bare period (tonnes) ◆ Salt brought in by capillary upflow from the watertable during the bare period (tonnes) ◆ Net salt change in the root zone (tonnes) ◆ Change in the salinity (concentration) of the root zone (dS/m)

* if pumping option is selected

if run-off water is not recycled on the farm

MODEL APPLICATION

SWAGMAN Farm was initially applied to the Murray Valley in 1995 as a tool to guide policy decisions (Prathapar & Madden 1995). It is now being further developed and applied to this area under the MIL/CSIRO/LWRRDC “Determining Optimal Irrigation Intensity” project. In the Coleambally Irrigation Area, SWAGMAN Farm has been incorporated into a formal education program and development of farm based recharge targets as part of the Land and Water Management Plan (Madden 1999). The Rice CRC “Net Recharge Management” project links these activities across the irrigation areas and provides resources for further model development.

FUTURE DEVELOPMENT

Currently the water and salt process of SWAGMAN Farm are being validated and refined by the following:

1. Sensitivity analysis of various model parameters by applying it to a range of situations;
2. Field validation and calibration of model inputs, processes and outputs.

The reliability of any model rests in its ability to adequately represent field situations. Collection of water and salt balance data is the key to understanding the surface-groundwater interactions and water and salt movements at the farm scale. Murray Irrigation Limited (MIL) and CSIRO have recently commenced detailed monitoring in 4 paddocks with funding support from LWRRDC. These field data will be used for refining SWAGMAN Farm;

3. The use of more detailed point-scale models (e.g. SWAGMAN Destiny), in combination with the field data, to provide a better understanding of processes under particular crop and soil situations;
4. Enhancements to the model's capability (e.g. improved definitions of weather parameters, double cropping); and
5. The development of a user interface and ability to link model inputs and outputs with GIS.

CONCLUSIONS

SWAGMAN Farm provides a useful tool for farmers, irrigation companies and regulators to understand water use efficiency, waterlogging and salinity issues in a quantitative manner. This model can be customised for different hydro-climatic and economic conditions and therefore can be easily applied to different regions. Its present applications in the Coleambally and Murray Irrigation areas have clearly demonstrated its ability to serve both as a policy development and educational tool for complex and important sustainability issues such as water use efficiency and net recharge management.

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SHORT DURATION RICE: IMPLICATIONS FOR WATER USE EFFICIENCY IN THE NEW SOUTH WALES RICE INDUSTRY

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ABSTRACT

A reduction in growth duration is an ongoing objective of the New South Wales (NSW) rice breeding program. One of its benefits is a reduction in the period of ponding, and hence in water use. This is important in light of current water restrictions and the increasing cost of irrigation water. The effect of growth duration on water use efficiency (WUE), here defined as yield divided by total water use (t/Ml), had until now not been quantified.

This effect has now been estimated using the rice crop model TRYM, which was used to simulate rice yield and total water use for 3 crop durations and 3 sowing dates over 42 seasons of weather data.

As duration from sowing to flowering decreased, yield declined by 0.12 t/ha/day and water use declined by 0.078 Ml/ha/day. Thus, in response to a 20 day reduction in time to anthesis, WUE declined from 0.80 t/Ml to 0.71 t/Ml. A similar reduction in yield in response to growth duration was observed in two replicated trials of advanced breeding lines in the 1997/98 season (0.11 t/ha/day). To ensure that WUE does not decline, the yield of new short-season cultivars should not decline by more than 0.062 t/ha for each day's reduction in growth duration.

INTRODUCTION

Rice is a major user of irrigation water in southern NSW irrigation schemes, accounting for 60% of total water diversion. Increased competition for the limited water supply is focusing attention on the water use efficiency of the NSW rice production system.

In response to this, the rice improvement program at YAI has aimed to produce short duration

rices, that would reduce total water use. Unfortunately these rices also have a lower yield.

Another reason for developing short duration rices (which take 10 to 20 days less to flower than the full season standard variety Amaroo) is that they increase on-farm flexibility of planting or harvesting time. Short duration rices can either be planted at the same time as full duration rices and harvested earlier, or be planted later and harvested at the traditional time. Late planting allows previous pastures to have an extra cut, and earlier harvest allows a greater chance of harvesting in dry and favourable conditions, before winter rains. The rice variety Jarrah was released in 1993 and has a 20 day shorter growth duration than the standard variety Amaroo. It is grown for the benefits of its short season, especially to resow medium grain crops where the first planting failed. Millin (which takes 10 days less to flower than Amaroo) was released in 1995, and its shorter duration, when combined with an early planting date, allows it to be sold to niche markets.

There is general agreement that these short duration varieties have a lower water use requirement and a lower yield than full season varieties, but little has been done to investigate the possible implications for water use efficiency in using such varieties. This paper utilises a rice model used in the NSW rice industry to investigate the water use efficiency of shorter season rice types, and concludes that it is lower than that of standard full season types. This conclusion has been supported by results of field trials.

MATERIALS AND METHODS

Simulating yield

The rice crop model TRYM (Williams et al 1994) was used to simulate crop development, growth and yield for 3 sowing dates (5, 15 and 25 October) and a range of pre-flood N application rates for each of the 42 growing seasons from 1955 to 1996. The N rates used were in increments of 25 kg N/ha, for the range from 0 up to 150 kg N/ha. The simulations used daily solar radiation and maximum and minimum temperatures for each of these seasons. Deep water at early pollen microspore was assumed, as this is the recommended practice to reduce low temperature damage.

Parameters for the model were based on the full season variety Amaroo, except that the simulations were run not only for the full duration of Amaroo, but also for two reduced durations. Duration was reduced only by reducing the number of days to panicle initiation (PI). PI was set to occur 90, 80 and 70 days after planting for what are defined as the full, medium and short duration rice types. This range in days to PI is similar to that observed in current available NSW rice cultivars. PI dates were input into the model for all simulations, while flowering and maturity were estimated by TRYM.

The simulation set the initial soil fertility so that 75 kg N/ha was taken into the full season crop during the 90 days from planting to PI. Yield was simulated with pre-flood N rates ranging from 0 to 150 kg N/ha. The optimal N application rate for each simulation was defined as the highest rate for which the addition of the last 25 kg N/ha increased yield by 0.5 t/ha. The optimal rate for most simulations was 100 or 125 kg N/ha.

Simulating water use

Water use was estimated for each of the 3 sowing dates for each crop, by adding estimates of

the amount of water required to fill the profile (a total of 1 MI/ha), deep percolation (1 mm/day) and daily evapo-transpiration (ET). Daily ET was estimated by multiplying a crop factor of 1.0 by the estimated evaporation from a class A pan at the meteorological station at Griffith NSW.

RESULTS

Grain yield

Grain yield declined with growth duration for all sowing dates. As there was no interaction between crop duration and planting date, the average yields of the 3 planting dates are presented (Table 1). Average simulated yields of almost 12 t/ha were achieved with the full season variety when 125 kg N/ha was applied pre-flood. The full season variety had a yield advantage of 1.2 and 2.5 t/ha over the medium and short duration types respectively. The reduction in yield was entirely due to a reduction in total biomass accumulation, and not due to changes in harvest index. The simulation took no account of the possible increase in harvest index with a reduced growing season, and may thus over-estimate the yield loss with a reduction in growing season.

The simulated yield potential gap of over 2 t/ha between the full and short duration types is similar to that observed by Reinke et al (1994). They found that in the absence of cold damage, a short duration cultivar M101 yielded 1.8 t/ha less than the full season cultivar M7, which has a similar phenology to Amaroo. The field trial also showed, as in the simulation, that the lower yield of the short duration variety could not be increased by increasing the application of N.

TABLE 1.

AVERAGE GRAIN YIELD, WATER USE AND WATER USE EFFICIENCY FOR FULL, MEDIUM AND SHORT DURATION RICE SIMULATED OVER 42 YEARS.

Results are averaged over 3 sowing dates (5, 15 and 25 October) with 125 kg N/ha applied pre-flood.

	Full 90	Medium 80	Short 70
Days to PI			
Grain yield (t/ha)	11.9	10.7	9.4
Water use (MI/ha)	14.7	13.9	13.2
Water use efficiency (t/MI)	0.80	0.76	0.71
Yield loss due to 10 day reduction		1.2	1.3
Water saved by 10 day reduction		0.78	0.78

Water use

Average water use decreased with crop duration. The reduction of crop duration by 10 or 20 days reduced water use by 0.78 MI/ha/10days. This is a combination of deep drainage (1 mm/day) and the extra reference evaporation (6.6 mm per day) for the additional period during which a full season rice still requires water.

This study compares crops which were sown on the same date. If one instead compares crops harvested on the same date, the savings in water use would be similar to or less than those estimated here, as ET is at least as high in March (at the end of the season) as it is in October.

The saving of water is therefore not commensurate with the decline in grain yield. Consequently, water use efficiency declines from 0.80t/MI to 0.71 as duration is decreased by 20 days (Table 1).

Target yield loss with reducing duration

Based on the figures in table 1, a target yield decline for shorter duration varieties can be estimated. The minimum target yield decline is the product of water use efficiency of the full duration crop and the water savings of the short season variety. i.e.

$$\text{Target yield decline (t/ha)} = \text{Water use efficiency (t/MI)} * \text{water saved (MI/ha)}$$

The minimum target yield decline estimated by this study is 0.062 t/ha/day.

Field validation

The effect of growth duration on yield was further investigated within the high yielding 1998 rice breeding population. This population was a set of advanced rice lines at the F5 stage which was grown for yield and quality testing. The trial had 2 rates of applied N at pre-flood. As there was no effect of applied N, the results were pooled for the following analysis.

Yield of the lines ranged from 10.3 to 16.1 t/ha, and the days to flowering ranged from 87 to 111 days after flooding. The linear effect of crop duration on yield accounted for 26% of the variation in yield. The slope of the regression shows yield was reduced by 0.11 t/ha/day reduction in duration (Figure 1). This field estimate of yield loss with shorter season rice varieties confirms the modelled value in the absence of cold damage. Unfortunately this value is almost twice the target yield reduction required to maintain water use efficiency in the shorter duration types.

Physiological basis

During March, when the full season crops are still growing but the short season types have finished, the full season crops are each day intercepting 0.9% (21.1MJ/m²) of the total radiation intercepted during the season. However they are only using 0.56% (7.8mm/day) of the total water used during the season. It is this which accounts for the fact that grain yield (which is a function of radiation interception) declines more rapidly than does water use.

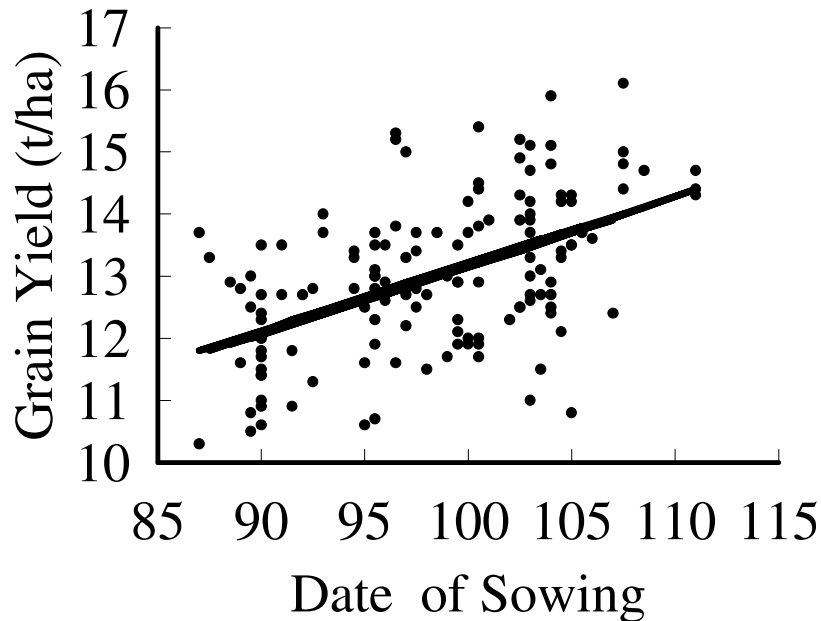


Figure 1 - Grain yield versus days to flowering for a NSW rice breeding population.

CONCLUSION

Short season rices are a valuable asset to the NSW rice industry in providing on-farm flexibility in terms of planting and harvest times. They give the possibility of sowing as late as November, allowing extra pasture to be grown. Alternatively, they allow an earlier harvest, increasing the chances of a winter crop being established.

However, this paper shows that that this flexibility comes at a cost. Short season rices in the NSW environment can not maintain, let alone increase, the water use efficiency of the rice component of the overall cropping system, as the yield advantage of full season varieties outweighs the water savings of the shorter duration types.

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METHODS FOR INCREASING RICE WATER USE EFFICIENCY

(Intermittent flooding, saturated soil culture, sowing method)

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INTRODUCTION

Rice grown in NSW consumes large amounts of water, the cost of which accounts for 20-30% of the total variable costs of rice production. The cost of the water will increase in the future and its availability will inevitably decrease due to more landholders activating their entitlements, provision for “environmental flows” etc. The potential to reduce water requirements and thereby increase water use efficiency should be explored.

RESEARCH RESULTS AND DISCUSSION

Intermittent flooding

An experiment at Yanco in 1981-82 examined the performance of the medium grain variety Calrose under different irrigation techniques (Heenan and Thompson 1984a). The work showed that flood irrigation at 7 day intervals throughout the season produced low yields and rice of unacceptable grain quality. However, when permanent flood was applied at panicle initiation both yield and quality compared well with a conventionally managed crop which had permanent flood at the 3 leaf stage. Using the technique of “delayed flooding” it was possible to reduce total water use by 23%.

Further work in 1982-83 and 1983-84, confirmed that water savings of 22-26% can be obtained by using intermittent flood irrigation during the vegetative phase followed by permanent water at panicle initiation (Heenan and Thompson 1984b). Results from 1983-84 indicated that flooding should commence approximately 2 weeks before panicle initiation. Intermittent flooding will present challenges for weed control and fertiliser management. This work was carried out on a relatively free-draining soil, and delayed flooding should be evaluated on heavier more typical rice soils (Humphreys *et al.* 2000)

Saturated soil culture

Research in the Burdekin River Irrigation Area in Queensland indicated that crop water use of rice grown on raised beds was 32% less than when grown using conventional permanent flood (Borrell *et al.* 1997). In the raised bed layout, irrigation water is maintained in the furrows between the beds rather than ponded over the entire soil surface. A comparison of water used and the potential evapotranspiration suggests that there was considerable drainage below the rootzone. There was no reduction in crop yield, however potential evapotranspiration was only 5-6 mm/day. (January and February in the Riverina can average 9-10 mm/day).

Whilst recognising that there are likely to be agronomic constraints to rice production on raised beds in southern Australia, especially with weed control and cold temperature damage, investigation of potential water savings is being evaluated. Field experiments were conducted in 1997-98 and 1998-99 on a transitional red-brown earth at Deniliquin. "Subbing" from the furrow to the middle of the beds was not complete and the rice growing in the centre of the bed suffered some "drought" stress. The most extreme treatment, where the crop was combine sown and water maintained in the furrows, reduced water use by 11%. However, a similar reduction in grain yield resulted in no improvement in water use efficiency.

In 1997-98, where rice was aerial sown and the water maintained in the furrows following establishment, there was a difference in maturity between the rice on the bed and that in the furrows. This is likely to reduce the quality of the harvested grain. The same effect was not apparent in 1998-99.

In 1999-2000, a field experiment will be conducted on a self-mulching heavy grey clay soil type. It is on this soil type, which historically exhibits "high" water use and where subbing will be satisfactory that the greatest opportunity to lower crop water use exists.

Sowing method

The 1997-98 experiment at Deniliquin also compared a conventional combine sown crop with a conventional aerial sown crop. Water use and grain yields were similar. The combine sown treatment was sown 12 days earlier than the aerial sown but flowered 6 days later. Any savings in water use from not ponding water until the 3 leaf stage are likely to be negated by the slightly longer growing season of the combine sown crop.

CONCLUSIONS

It is apparent that the current Australian varieties, when grown under the high evaporative demand experienced in the Riverina, are most productive under ponded conditions. This suggests that, when grown on the appropriate (low accessions) soil type, potential water savings are limited. Thus it is important that all other aspects of rice agronomy are optimised to ensure the highest possible yield is achieved, if water use efficiency is to be maximised.

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EFFECT OF SOIL AMELIORATION ON RECHARGE FROM PONDED RICE

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INTRODUCTION

Rice culture is one of the major causes of the rise in watertables in the major irrigation areas of southern NSW. Reducing additions to the groundwater from rice involves a range of approaches including the identification of paddocks (or sites within paddocks) with excessive recharge followed by their elimination from rice growing or amelioration to reduce recharge. Technologies with the potential to reduce recharge from rice include puddling and compaction. However, there are other technologies routinely adopted in rice-based cropping which have the potential to significantly increase recharge if not used with care.

Puddling

The majority of the southern Australian rice crop is aerial sown into the flooded bays, and land preparation typically involves 1-2 shallow (5-10 cm) cultivations, banding of urea below the soil surface using a combine seed drill, followed by ridge rolling or some other operation to break down any large clods which would otherwise protrude through the water surface. The cultivated soil is generally fairly dry when these operations take place. Numerous studies overseas have shown that puddling and compaction can significantly reduce deep percolation of water, and puddling is routinely practised throughout Asia for a range of reasons including to reduce loss of water by deep percolation.

In the early 1990s puddling and compaction technologies were developed for the highly mechanised rice cultural systems of southern NSW. These technologies were evaluated for their effects on infiltration, rice crop performance, soil properties, the performance of crops sown after rice and the economics of these techniques (Blunden *et al.* 1993, Humphreys *et al.* 1994, 1995, 1996, Humphreys and Muirhead 1996, Ringrose-voase *et al.* 1996). The results showed that puddling reduced infiltration and thereby rice paddock water use, although in some situations the reduction was not large enough to meet the rice water use limit. Rice yields with puddling were generally comparable to those without puddling, provided water management was optimal at the time of puddling to avoid creating a muddy water problem. Puddling appeared to be economic as the value of the water saved exceeded the additional cost of puddling instead of ridge rolling. The effect of puddling on infiltration did not carry over to the next rice crop, thus puddling needs to be repeated before each crop. Yields of wheat and canola direct drilled after rice harvest were not impaired, and there was no evidence of long term soil structural decline, consistent with the observation of no carryover effect on infiltration for consecutive rice crops. However, very few farmers adopted puddling.

Impact compaction

Major constraints to puddling probably included the slowness of the operation at a busy time of year, turbidity problems where water management was not optimal, reluctance to operate

machinery in the mud and water, and mixed results at the paddock scale. This led to some farmer-driven research to evaluate impact compaction for its use in rice culture. Impact compaction has the advantage of being able to be applied well in advance of preparation for rice sowing, whereas puddling is a “last minute” operation. The machines consist of massive cam-shaped drums which may be 3-, 4- or 5-sided which may be self-propelled or trailed, and are driven across the ground at speeds of 12-16 km/hr. Research was carried out over 2 seasons to evaluate the effect of impact compaction on infiltration, rice performance, soil physical properties and the economics of the process (Clark and Humphreys 1997, Humphreys *et al.* 1998a&b).

Soil water content at the time of compaction is critical to achieving the desired reduction in infiltration - a minimum of 20 g water/100 g soil in the heavy clay soils used for rice culture. At two very high water use sites with marginal soil water content down the profile at the time of compaction, three passes of the Landpac 3- and 5-sided rollers reduced infiltration from 1,600 to 300-400 mm and from 2,400 to 700-800 mm. At three low water use sites with higher soil water content, three passes of the Landpac machines reduced infiltration from around 300 mm to less than 150 mm. Crop growth throughout the season, grain yield and yield components were not impaired by any of the compaction treatments applied.

The effect of compaction on infiltration appeared to last throughout the second rice crop after treatment application, at the one site where this could be tested. For impact compaction to be economic, the effect needs to last for at least two seasons on highly leaky soils, or for three seasons on soils where the reduction in water use is of the order of 2 ML/ha, at the current cost of treatment (around \$330/ha).

The effects of impact compaction on soil structure were transmitted to depths below the soil surface of at least 0.4-0.5 m at some sites. These effects at depth included visible shearing, higher soil strength and possibly reduced hydraulic conductivity. However, there was no evidence of reduced hydraulic conductivity at a depth of about 1 m. The depth, nature and extent of changes in soil structure as a result of impact compaction are not known.

The results showed that impact compaction has the potential to seal highly leaky areas in rice paddocks, and this is a sensible use of this technology. Small areas of extremely leaky soil within otherwise sound rice paddocks can significantly increase (e.g. by a factor of 2) total recharge from the paddock, hence the importance of detecting and dealing with these areas (Humphreys *et al.* 1998c). Widespread application of impact compaction has the potential to significantly reduce recharge from ponded rice culture. However, widespread application is not recommended due to lack of knowledge of what happens to the soil structure during compaction, whether the changes that occur are reversible, and if so, how to restore the soil to its original state or better and the cost of doing this.

At present there is some farmer interest in the technology – in 1999 impact compaction was applied in 6 rice paddocks in the CIA, treating a total of about 120 ha (Clark, pers. comm.).

Soil management practices that increase infiltration

While much attention has focussed on soil amelioration to reduce recharge, recommended management practices such as landforming and gypsum application have the potential to increase recharge in some situations.

Landforming

Soils with a dense, dispersive clay subsoil are usually good rice soils because water moves through the soil only very slowly. However, for some soils, if the top of the sodic clay subsoil is removed to the depth where naturally occurring lime occurs, the soil becomes self-mulching, with high infiltration rates (e.g. 30 ML/ha Humphreys *et al.* 1998c). On these soils, deep cuts should be avoided if they are to be used for rice growing. Deep cuts can be avoided by terracing, or by changing grades or angles through the paddock.

Gypsum application

Highly sodic surface soils can create serious rice establishment problems, especially the development of muddy water due to dispersion. In recent years there has been increasing use of gypsum, broadcast on the soil surface before flooding, and this method is generally successful in controlling turbidity. Gypsum is also used to improve the establishment of crops grown in rotation with rice. However, it is well-known that gypsum improves soil structure and infiltration rate, and high rates applied immediately before ponding can significantly increase deep drainage (Loveday *et al.* 1979, McIntyre *et al.* 1982). Slavich *et al.* (1993) showed that up to 7.5 t/ha of gypsum applied for wheat 18 months prior to rice sowing had no effect on deep drainage during the rice season, however as little as 2.5 t/ha increased deep drainage from rice when applied only 6 months prior to rice sowing. A series of experiments with gypsum broadcast immediately before flooding confirmed that even the low rates of gypsum (1.25-2.5 t/ha) typically used to prevent muddy water increased infiltration rate, and that the effect increases with gypsum rate (Humphreys and Barrs. 1998a&b). However, this research also showed that these highly sodic soils have very low natural infiltration rates, and while the effect of gypsum on potential recharge is undesirable, total recharge remains low and within current limits.

Because of its effect on infiltration, gypsum should not be relied on as the panacea for muddy water problems. Reduced cultivation, improved layout, shallow water management, retention of residues and pasture rotations are all key parts of the solution.

Groundwater use

Groundwater is an important source of water for some irrigators, however the salinity of groundwaters in the rice growing areas is generally higher than that of fresh (surface) water supplies (0.06-0.2 dS/m). Therefore groundwater is often mixed with surface water to lower the salinity of groundwater used for irrigation. Rice yields of over 8 t/ha have been achieved using groundwater with salinities of 0.8-1.4 dS/m (MacDonald and Beale 1995). Beecher (1991) also showed no effect on yield for irrigation water salinities ranging from 0.25 to 2 dS/m on a red clay loam soil. However, total water use progressively increased by about 6 ML/ha as the salinity of the irrigation water increased from 0.25 to 2 dS/m. The increase in water use was attributed to an increase in infiltration. Thompson *et al.* (1998) also found significantly higher infiltration rates in two out of three red clay loam sites for supply salinities exceeding 1 dS/m, but no effect on three clay soils. They recommended that the salinity of the supply water used for rice growing should not exceed 0.5-0.6 dS/m to avoid substantially increasing recharge.

CONCLUSIONS

Puddling and impact compaction have the potential to reduce recharge from leaky rice soils, while impact compaction also has a significant effect on infiltration in soils with relatively low infiltration rates. Puddling needs to be repeated before each rice crop, and the low adoption rates observed to date indicate that it is not attractive to most rice growers. There is currently some grower interest in impact compaction despite the high cost of treatment. To be economic, the treatment must last for three seasons, but there is little information available on the longevity of the effect on infiltration. Impact compaction has been shown to affect the soil to depths of half a metre or more, and the consequences of this for longer term productivity of rice and other crops is unknown. Therefore, impact compaction is not recommended for widespread application, but may be an appropriate method for treating small leaky areas.

Landforming, gypsum application and the use of groundwater for irrigation are all standard irrigation farming practices, however each of these techniques has the potential to cause greatly increased recharge from rice growing with inappropriate use. Avoidance of heavy cuts exposing lime, restriction of gypsum use to highly sodic soils at rates of less than 2.5 t/ha and irrigating with water with salinities of less than 0.5 dS/m will minimise the effect of these technologies on recharge from ponded rice.

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RICE CROP WATER USE AND WATER USE EFFICIENCY IN THE SOUTHERN MURRAY DARLING BASIN - MURRUMBIDGEE IRRIGATION AREAS AND DISTRICTS

Lilian Parker

Murrumbidgee Irrigation

INTRODUCTION

Since July 1997 Murrumbidgee Irrigation has been responsible for monitoring and implementing the Rice Environmental Policy developed by the Rice Environmental Policy Advisory Group in the MIA&Ds.

METHODS

Presently rice areas within the MIA&Ds are aerially photographed in late December each year. The resulting photos are digitised and geo-referenced. ArcView software is used to calculate rice areas and produce farm maps. Each farm's rice area is compared to that allowed under the application of hydraulic loading and any subsequent subdivisions, rotations, paybacks etc. Penalties can be incurred for growing rice on unsuitable soils or on areas larger than that determined by the REPAG process. At the end of the irrigation season, crop water use is calculated for the area determined above from the water delivery records kept by Murrumbidgee Irrigation based on water orders by landholders.

The method used to calculate the rice crop water use target is $(ET_o - \text{rain} + 4)$ ML/ha. ET_o is provided from Griffith and Hay by CSIRO and the seasonal target calculated. Wah Wah Irrigation District rice crop target has been based on the average ET_o of Griffith and Hay.

RESULTS

Comparison with previous years of the average rice crop water use for the MIA shows a reduction regionally

Year	Hectares	Megalitres	ML/ha	ET-rain
83/84	41175.50	504582	12.25	9.80
84/85	41481.30	611492	14.74	12.52
85/86	38318.00	499733	13.04	11.01
86/87	34266.90	439821	12.83	12.46
87/88	36308.00	515879	14.21	14.23
93/94	33122.90	396318	11.97	10.17
94/95	31508.90	439341	13.94	12.82
95/96	35187.99	406818	11.56	10.70
96/97	35557.10	464959	13.08	11.70
97/98	33757.69	422949.06	12.53	11.00

However, there are still a proportion of landholders which show rice crop water use higher than the target. Properties with water use above 18ML/ha are targeted for EM surveys and rice land reassessment. A significant number of calculated high crop water use come from incorrect water ordering procedures and are reassessed.

The development of the Water Use Efficiency Improvement Scheme will provide comparisons of water use between all crops on each farm and may allow the determination of a farm water balance.

The trends in watertable levels over the last few years has seen a significant reduction in the area affected by watertables less than 2m from the surface - from a high of 70% in the early 1990's to 52% in 1998.

CONCLUSIONS

Direction and R&D requirements for water use efficiency in the MIA will focus on LWMP principles:

- soil suitability, based on EM surveys and correlation with soil permeability
- accurate crop area identification and measurements for rice and other crops by remote sensing methods
- farm water balance comparisons and benchmarking

RICE WATER USE EFFICIENCY IN THE COLEAMBALLY IRRIGATION AREA

Arun Tiwari

Coleambally Irrigation

INTRODUCTION

Coleambally Irrigation is the youngest of the three Irrigation Companies in southern NSW. Irrigation started in early - mid sixties. Irrigation water is supplied to the CIA Land and Water Management Plan Area (80,000 ha), the Kerarbury LWMP Area (15,000 ha to the north west of the CIA) and the Outfall Drain LWMP Area (220,000 ha to the west of the CIA).

Average crop water use and area in the CIA for 1997/8 are shown in the following table.

Average crop water usage and area

Water usage (ML/ha)	Crop	Area of Crop (ha)
13.18	Rice	24,624
2.27	Wheat	14,943
2.82	Winter Pasture	9,964
6.77	Soybean	4,998
1.54	Summer Pasture	3,937
1.34	Fallow	2,733
1.31	Oats	2,680
.094	Barley	1,970
7.32	Maize	1,917
5.00	Misc. and Other	1,649
1.40	Canola	1,469
2.50	Summer Vegetables	161
5.36	Lucerne	117
1.34	Vines	100
18.27	Citrus	10

COLEAMBALLY RICE MONITORING

Objectives

- To calculate rice water use (ML/ha) for every farm (for every supply point).
- To ensure all rice is grown on permissible land.
- To ensure rice planted area per farm does not exceed environmental limit.

Determination of rice water use efficiency (ML/ha)

Water measurement

- 5-year plan to replace all (640) Dethridge Outlets
- 70 already replaced
- 100 planned for this winter
- Project costing over \$3 million.
- Distribution within farm provided by landholders information.

Area measurement

- Aerial Photography
- Photography
- Scanning
- Georeferencing

RICE WATER USE IN THE CIA

Year	Rice water ML	Rice are ha	ML/ha	Rain mm Oct-Feb
1985/85	333990	21129	15.8	326
1986/87	300350	19799	15.2	196
1987/88	383922	23148	16.6	114
1988/89	342486	24046	14.2	168
1989/90	326938	23189	14.1	268
1990/91	265527	17582	15.1	106
1991/92	329930	23169	14.2	106
1992/93	219740	22673	9.7	361
1993/94	260261	22609	11.5	252
1994/95	297169	21215	14.0	146
1995/96	266272	21377	12.5	246
1996/97	270447	21327	12.7	83
1997/98	324507	24624	13.2	114

EXCESS WATER USAGE ON RICE CROPS

Year	Number of farms	% of all rice farms
1994/95	65	20
1995/96	28	9
1996/97	18	6
1997/98	37	11

Estimation of rice water use requirement from meteorological data

COMPARISON OF GRIFFITH AND COLEAMBALLY DAILY WIND VELOCITY (KM/DAY) 1 OCT 1998 TO 28 FEB 1999

Statistical Parameters	Griffith	Coleambally
Mean km/day	207.7	223.1
Median km/day	198.0	209.2
Mode km/day	172.0	197.3
Range km/day	390.0	412.3
Minimum km/day	88.0	51.9
Maximum km/day	478.0	464.2
Sum km	31362.0	33686.2
Count	151.0	151.0
Largest (1) km/day	478.0	464.2
Smallest (1) km/day	88.0	51.9

Coleambally mean daily wind velocity is 8% higher than Griffith, suggesting that potential evapotranspiration at Coleambally may be higher than at Griffith.

FUTURE DIRECTIONS

- Identification of potentially leaky areas within the paddock.
- Farm recharge targets instead of Regional rice water use target
- Establishment of weather stations to overcome variability in weather parameters.
- Improved Et calculations and crop factors.

ENVIRONMENTAL IMPACT OF RICE GROWING - TECHNICAL ISSUES

D. Poulton & A. Lavis

Goulburn-Murray Water, Tatura

BACKGROUND

Rice has been grown on a wide scale in southern New South Wales for many years, to the extent that rice is the major user of irrigation water there.

For marketing reasons, rice was not grown seriously in Victoria until 1992. Since then, the Madowla Park property (between Echuca and Nathalia) has expanded its rice cropping to 600ha in 1996/97. In 1996/97, four additional landholders between Swan Hill and Cobram grew some 80ha of rice, and further landholders have indicated that they intend to grow rice in 1997/98.

Because rice is grown in water ponded for a long period (up to 150 days), there is potential for excessive amounts of water to seep through the soil profile, and accede to groundwater. This may cause the development of shallow water tables and associated salinity problems, or aggravate existing problems. This risk can be minimised by restricting the crop to the more impermeable soils.

Drainage is an issue where the disposal of the volume, or its quality can impact upon the downstream environment or users. Of particular concern is the possibility that pesticide residues may impact upon the riverine environment.

Seepage and associated environmental impact

There is a widespread perception that irrigated rice results in excessive accession to groundwater compared to border check irrigation. This perception arises from the experience of rice growing in NSW where rice in the past has been grown on inappropriate soil types and there are clearly some areas where water use is far in excess of the crop water requirement, and the accession to groundwater excessive.

Establishing a maximum desirable seepage rate

Some accession to groundwater is inevitable when irrigating any crop, and a minimal leaching requirement is required to maintain a salt balance. The accession to groundwater will result in seepage to an adjacent area and may result in an increase in the regional water table and/or groundwater discharge and salination in adjacent areas.

The question in relation to rice growing is whether groundwater accession and seepage is excessive and greater than that which would have occurred using say border check irrigation of perennial pasture. The principal governing the target water use limit for rice (11.5ML/Ha) established in Victoria during the 1996/97 irrigation season is that seepage should not exceed 100mm. The TWE salinity guidelines adopted for permanent pasture allow for a leaching

fraction of 10% of the crop water requirement or 1 ML/Ha. This suggests a reasonable target for net accession to groundwater during a rice crop is 1ML/Ha or 100mm over the rice crop. In comparison the NSW target water use for rice growing is 16ML/Ha and water use has been reported up to 20 ML/Ha. It is considered the higher water use experienced in NSW is the result of excessive seepage due to rice growing on inappropriate soil types.

The accession to groundwater and resultant seepage to adjacent areas will be affected by several factors, including the presence or absence of an aquifer, the thickness and permeability of any clay layer over the aquifer, the regional water table level, and the size of the area flooded. The guidelines developed in NSW for rice culture assume the dominant influence affecting seepage is the influence of restricting clay layers within the top 3m of the surface.

It is convenient to divide the soil type found in the GMID into four broad soil groups on the basis of soil characteristics and groundwater conditions. Specifically :-

1. Prior stream formation - sand and sandy loam surface texture
2. Prior stream formation - clay loam/clay surface texture
3. uniform cracking clay soil types - low groundwater salinity
4. uniform cracking clay soil types - high groundwater salinity

These soil groups are similar to those recognised in NSW, with the addition of the soil group 4, which relates to conditions found in the northern part of the Kerang Region.

Approximate estimates of seepage for each soil group are based on the solution by Mazure for seepage from/to a circular area through a semi-confined aquifer(1). In each case it is assumed the area ponded is 20 ha. Seepage to/from the deeper aquifer system is only 5-10% of seepage flow through the shallow aquifer between 0-20m and is therefore disregarded for the purpose of this analysis. The regional water table in the area where rice is being grown is assumed to be 4 m except in the case of group 4 where it is assumed to be 1.5 m. Hydraulic conductivity values are typical for the soil groups and are based on paper by A van der Lelij (2). For group 4 soils hydraulic conductivity values are based on hydraulic conductivity values measured in lysimeter studies and on the tile drainage experimental area at Kerang. For each estimate of seepage the assumed aquifer thickness multiplied by the aquifer hydraulic conductivity (e.g. $KD = 20m^2d$) is shown as well as the assumed hydraulic conductivity of clay layers that restrict seepage and the assumed depth interval of this layer shown as a subscript(e.g. $K_{0.2-3m} = 0.25mm/day$).

Group 1 - Prior stream formation - sand and sandy loam surface texture

These soils are typically associated with the upper levee and ridges associated with prior streams (this soil group constitutes about 5-10% of the irrigated area in the Shepparton Irrigation Region and the southern part of the Kerang region.. The soils have high infiltration rates and are often underlain by permeable aquifers. These soils have excellent drainage characteristics, and for this reason are highly regarded for horticulture and dairying. The seepage rate ($KD = 40m^2day$, $K_{0-3m}=12mm/d$) is 6.2mm/day. Clearly this is an unacceptable seepage rate and rice should not be grown on these soils due to the high accession to water table that would occur.

Group 2 - Prior stream formation - clay loam clay surface texture

These soils are typically duplex soil types (light clay or clay loam A horizon overlying heavy clay at 20 cm depth) and is found in the mid levee situations and the plains associated with prior stream formations. This soil group represents about 60% of the irrigated area in the Shepparton Region and Southern part of the Kerang Region. The dense B horizon substantially limits infiltration and crop root development and these soils are considered to be inferior for cropping or horticulture, but suitable for pastures. The lower infiltration rate is consistent with land use for rice growing. The aquifer characteristics are variable, due to the presence of underlying relict prior stream aquifers, but generally $KD=10-30 \text{ m}^2\text{day}$. The B horizon and underlying subsoil is of low permeability ($K_{0.2-3\text{m}} = 0.1-0.5 \text{ mm/day}$), and it is not uncommon for the subsoil to remain unsaturated even though water is ponded on the surface. The seepage rate ($KD= 20 \text{ m}^2\text{day}$, $K= 0.25\text{mm/day}$) is 0.3 mm/day , well below the target rate of 0.8mm/day . In short, these soils are ideal soil conditions for growing rice.

However, the thickness and soil texture of the B horizon tends to be spatially variable which results in areas where the B Horizon is less effective. For instance if the B horizon is more permeable and only present between 0.2-1m ($K_{0.2-1 \text{ m}} = 0.5\text{mm/day}$), the seepage rate will be to 1.4mm/day , 50% above the target of 0.8mm/day .

The policy adopted in NSW of soil boring prior to rice growing is to demonstrate the presence of a clay subsoil to a depth of at least 3m. More recently electromagnetic survey techniques have been developed to determine the characteristics of the subsoil in conjunction with soil boring. The EM31 techniques also allow identification of areas with a low subsoil salinity thought to be associated with higher recharge under the current land use or following rice growing.

Group 3 Uniform cracking clay soil types - low groundwater salinity

These soil types are associated with the Flood Plain of existing river systems, such as the Murray, Goulburn and Loddon. These soils constitute about 20% of the GMID. The clay tends to shrink and swell more than in group soils, and gilgai features are common. Aquifers conditions are variable and may be completely absent. The distinct B horizon characteristic of group 2 soils is not present, however the depth of clay is often greater, and a 'throttle' to infiltration may develop after prolonged flooding. Despite the higher clay content the hydraulic conductivity tends to be higher than for group 2 soils. Seepage ($KD = 10$, $K_{0-3\text{m}}= 1.1\text{mm/day}$) is estimated to be 0.79mm/d about equal to the target. However, the thickness of clay is more likely to extend to depth and this will substantially reduce the seepage. For instance the seepage where there is ten metres of clay ($KD = 10$, $K_{0-10\text{m}}= 1.1\text{mm/day}$) is estimated to be 0.32mm/d .

Soil boring and EM31 survey can be used to select suitable soils for rice growing, together with subsequent measurement of actual water use and bay seepage tests.

Group 4 Uniform cracking clay soil types - high groundwater salinity.

Soils in this group are similar to group 3 and are found extensively in the northern part of the Kerang Region. About 70% of the soils north of a line drawn between Pyramid Hill and Boort are in this soil group. The subsoil hydraulic conductivity is generally far higher than found in

group 3 soils (typically $K_{1-3m} = 100-500$ mm/day) because the groundwater is highly saline and stabilises the soil structure and biopores. The shallow aquifer is comprised of layered clay silt and sand, and although not highly permeable is a sufficiently high to be a significant feature in seepage analysis. Shoestring sand aquifers are found in some areas.

The soils typically have a high infiltration rate in the absence of a high water table. High water table conditions developed very quickly in the Kerang Region, and practically all of the area has a water table within 2 m of the surface. Seepage will be limited by lateral movement through poor aquifers rather than by a restriction in the clay subsoil alone. For example, experiments by Sampson in 1972, showed the water table rose virtually immediately to the surface after 51mm was applied in an irrigation over a 1ha area. The water table 20 m from the area adjacent to the area irrigated rose by 30mm (13mm at 40m from the irrigated area). These values are consistent with seepage flow analysis given a high soil infiltration rate and a poor aquifer. In practice, rises in water table level of this magnitude are difficult to separate from changes in the regional water table level that occur over summer. However, as shown in Sampson's experiments, even a small increases in water table level will be associated with a significant increase in salinity adjacent to the area irrigated. This is consistent with solute transport models, which show a small amount of groundwater seepage (10-20mm/year) is sufficient to cause salination when the groundwater is highly saline.

The observed rapid rise in water table level in Sampson's experiments is frequently observed in the Kerang region. Water is thought to enter surface cracks and connect directly with water table level. Within 20 minutes of the soil swells and infiltration is substantially reduced. Under continuous flooding infiltration would be much lower than the infiltration rates observed. Further, a throttle similar to that found in the group 3 soils will tend to form and restrict infiltration. There are likely to be substantial increases in soil salinity within 50m of the area irrigated. Salt plumes may extend to 100-150m from the ponded area in discrete areas underlain by shoe-string aquifers. Seepage (estimated with a regional water table 1.5m deep, $KD = 5m^2/d$, $K_{0-1m} = 2.5mm/d$) was estimated to be 0.65mm/d, well within the 0.8mm/d target.

Some further points:-

- Permanent pasture irrigation in the district usually results in a fluctuating water table between 0- 0.8m during the irrigation season. This will also result in a seepage flow to adjacent land, perhaps about half that which would occur from areas ponded for rice. From a regional perspective, it is arguable that concentration of water on discrete areas with adequate and well managed buffer areas may be less detrimental than the use of the same quantity of water for autumn irrigation of annual pasture over the whole area.
- While the community groups have determined irrigation water should not be used on saline land (C and D class soils) rice irrigation on these soils will flush salt out of the surface soil at the expense of increasing salination in the adjacent area. Alternate irrigation of rice and other cereal crops may be a sustainable irrigation practice, particularly if the adjacent saline buffer area is well managed. This strategy for saline land management is worthy of further research but should not be advocated as a salinity control strategy until such research has demonstrated results. However, there may be situations where subsurface drainage has been installed, and growing a rice crop is seen as means of reclamation, for instance in the lower lying areas of the Tresco district.
- There is potential for increased discharge to the regional drainage system as a result of rice growing, and adequate buffer areas between rice growing and drains need to be

established. Controls on drainage of water from the buffer area into the regional drainage system may also be appropriate.

- The interim guidelines applied in 1996/97 recommended an environmental impact statement if the water table was within 2m of the surface. This prompted potential rice growers to seek out higher elevation sites within the region - probably the worst place to grow rice from a regional salinity management perspective. Guidelines have been modified accordingly.
- Soil boring and/or EM31 survey is unlikely to be useful in assessment for rice growing for group 4 soils. Careful monitoring of groundwater levels and salinity in the buffer area adjacent to the area where rice is being grown are more important. Notwithstanding, soil boring to 3.6m should be required for consistency and EM31 survey may be useful to determine areas of preferential seepage after rice has been grown on an area.
- A buffer area of 150 m with respect to environmentally sensitive areas, neighbouring boundaries, and surface drains should be required at least until some first hand experience is gained of the environmental impacts at several locations typical of the group 4 soils.
- Experience gained at Matthew's property in 1996/97 has been useful and demonstrates that suitable areas for rice growing can be found in the Kerang Region. However, the soil type and results this season suggest this site may be more representative of the group 3 soils described above, and may be atypical of other sites in the Kerang Region.

SUMMARY AND RECOMMENDATIONS

Experience in NSW would suggest Group 2 and Group 3 soils are suitable for rice growing with the adequate controls in place, while rice should not be grown on Group 1 soils. There is little or no experience of growing rice on the Group 4 soils typical of the Kerang Region. Clearly the high groundwater salinity and absence of clay layers that will restrict seepage present some environmental risks. On the balance of evidence rice growing should proceed with the wider buffer areas recommended. Early experience with rice growing should be closely monitored so that policy can be modified based on experience.

Assessment of Land Suitability for Rice Growing

Soil boring

The standard method of assessing soil permeability has been to bore to 3.6 m on a 200 m grid, with hand texturing of the profile. New South Wales have some variation in criteria in different areas, with a "marginal" classification and allowance for a heavy sodic B-horizon where it is present. The criterion adopted here is that land is suitable if there is 3 m of medium to heavy clay present in the top 3.6 m of the profile.

However, the boring and hand texturing are not ideal. The 200 m grid can miss shoe-string sands which can allow significant seepage, and even heavy clays can seep significantly, particularly where they are of the cracking, self mulching type.

EM surveying

New South Wales Agriculture has done considerable work over recent years using electromagnetic induction technology (EM 31), together with GPS technology to map inferred soil permeability values. The plans so produced are used to target a smaller number of holes than the conventional grid. Suitability of a field for rice growing is determined from the combined EM values and soil texturing.

Very good correlations have been found with the amount of clay in soil profiles, and with ponded infiltration rates. The EM equipment measures electrical conductivity in the top 6 m of the profile. Soil salinity is the main parameter influencing the conductivity, but clay content, moisture content, bulk density and temperature also affect the values obtained.

Murray Irrigation Limited has used the technology to evaluate rice fields found to have high previous water use. Particularly permeable areas of such fields have been identified and isolated, allowing the remainder of the fields to be used for rice growing. The Rice Growing Guidelines in Victoria have been modified to allow use of EM31 survey techniques where appropriate.

Management of drainage water from rice irrigation

The volume of rice runoff is not likely to be a problem where a property has off farm drainage. However, rice water often contains contaminants. Residues from pesticides such as Molinate and Saturn are of concern. Salinity and nutrient levels are not usually high.

In New South Wales, storage of rice drainage is considered desirable because of the potential for pesticide contamination of water bodies, and 0.25 ML/ha of rice is considered best management practice.

Consistent with the NSW guidelines, the Rice Growing Guidelines adopted by Goulburn-Murray Water for the 1996/97 season, and those proposed for 1997/98, require all rice water to be retained on the farm, "except in exceptional circumstances". A drainage reuse system with minimum storage capacity of 0.25 ML/ha of rice crop, a permanent pump and motor and a disposal area of at least 0.5 ha per ha of rice crop is specified.

The capacity of 0.25 ML/ha of rice crop specified is greater than the 0.075 ML/ha of perennial pasture specified in the Transferable Water Entitlements Salinity Guidelines. Both figures are based on the likely runoff after a 50 mm summer rainfall event. The average runoff from perennial pasture is assumed to be 15% of the 50 mm event, where 50% of that falling on the flooded rice field is assumed to run off. Theoretically, it is possible for the rice farmer to close his stops, and retain all of the water in the bays. In practice, this does not happen and 50% runoff from a 50 mm storm is quite likely.

While the most common cause of drainage from a rice field is the need to drain at the end of the season, the capacity of the storage is based upon the likely runoff from a summer storm, when there is more likelihood of there being pesticide residues in the water. Drainage at the end of the season can usually be managed at the farmer's convenience by pumping directly onto annual pasture (or other) at a suitable rate.

Buffer areas

Buffer areas are required primarily to protect neighbours and waterways from the impact of any raised water tables, but also to minimise the effect of any overspray from aerial spraying operations. It also provides some buffer for overtopping or breaking of banks.

Effect on waterways and drains

While the issue of drainage has been discussed above, the potential impact on drains and waterways also needs to be considered. Given the amount and types of pesticides used, and the standard of drainage reuse specified, what is the risk to downstream users and the environment? The Environmental Management Officer has recommended that an environmental risk assessment should be carried out.

Water use measurement

Measurement of water use provides a check on the seepage rate from areas ponded for rice growing. While metering is generally regarded as reasonably accurate across Goulburn-Murray Water, there are problems in attributing water use to a particular crop where more than one culture is irrigated from one metering point. The only way of achieving this is to rely on the farmer to read the meter before and after irrigating the particular crop. Considerable inaccuracies may arise if rice and other crop(s) are irrigated simultaneously.

The problem is compounded where rice is supplied at a low flow rate from a Detheridge meter outlet, as is quite common. At low flow rates (less than 3 ML/d for large meter outlets), Detheridge meters can be inaccurate (3). The problem has been long recognised in New South Wales rice growing areas, with limited alternatives being developed. Coleambally is progressively installing propeller actuated flow meters and ultrasonic flow meters may also be an option.

During the growing season evaporation from the flooded crop is typically in the range 8-10mm/d, compared to the target seepage rate of about 0.8mm/day. Because of uncertainty in the way we should use the available meteorological data, the error in measurement of seepage will often be greater than the seepage rate we are trying to measure. However, seepage tests on individual bays do offer a direct measure of seepage, and identification of parts of the rice growing area with very high seepage rates.

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2. A van der Lelij - Infiltration and Water Movement in Riverine Plain Soils used for Rice Growing. In : Proceedings 'The Hydrogeology of the Riverine Plain of SE Australia' ASSS 1977.
3. A Noonan - 1997 , Internal memo 'Accuracy of Large Meter Outlets at low flows.

GROWING RICE IN VICTORIA

Anon.

Goulburn-Murray Water

Rice can be a profitable crop and may be attractive to many irrigation farmers in northern Victoria. However, there is potential for environmental damage as a result of growing rice in inappropriate situations. In consultation with the rice industry representatives, Water Services Committees and Salinity Groups, guidelines for best management practices have been developed to minimise the environmental impact of rice growing. Goulburn-Murray Water is responsible for monitoring compliance to the guidelines by individual growers. The guidelines for best management practices are as follows:

- Soil boring should confirm that the land has a minimum of 3 m of medium or heavy clay in the upper 3.6 m of the profile.
- Groundwater observation bores should be installed and monitored to Goulburn-Murray Water specifications.
- Crop water applied should not exceed 11.5 ML/ha, allowing for seasonal conditions and geographic location.
- The maximum area grown on a property in a given season should not exceed 30% of the property area suitable for rice growing.
- Water meters should be operated within recommended operating conditions.
- All water should be held and reused on the property. The area to be planted to rice should be served by a drainage reuse storage with a minimum capacity of 0.25 ML/ha, a permanent pump and motor and a disposal area of at least 0.5 hectare for each hectare of rice crop.
- Where applicable, the rice growing development should have a local government planning permit or certified whole farm plan. The municipality may require a permit or certification of a whole farm plan for the earthworks required for rice growing.
- Growers should contact the Department of Natural Resources and Environment to determine their options for controlling wildlife.
- A buffer zone around the rice crop should be provided as follows:
- 150 m from a watercourse or Goulburn-Murray Water or community drain. However, where it is demonstrated that the watertable will remain more than 2 m below the bed of the watercourse or drain, rice can be planted to within 50 m.
- 150m from the property boundary in those areas West of the Campaspe River, or otherwise where the watertable is within 2m of the surface at the time of assessment.
- 50 metres from the property boundary in those areas East of the Campaspe River, or otherwise where the watertable is deeper than 2m of the surface at the time of assessment.
- A similar buffer should be considered for significant remnant vegetation. Further, it is recommended that a check bank be placed around any remnant paddock trees at a distance of 3 metres outside the tree drip line to protect those remnant trees (particularly box trees).
- Growers utilising aerial sprays need to avoid spray drift and this should be considered in the siting and design of rice bays.

COMPLIANCE MONITORING

Registration of rice growing areas should be made to the Area Manager Goulburn-Murray Water, or the Manager Diversions at the address shown under 'Further Information'.

A registration form is available from your Area Manager or the Irrigation Services Unit. Prospective growers should register prior to planting the crop and should include a plan of the property showing details of the area where rice will be grown, including the proposed layout and drainage reuse system.

Soil boring and observation bore installation will normally only be required for first the first time rice is grown.

The prospective grower will need to engage an accredited contractor to carry out the boring and observation bore installation, and forward details of the boring and initial watertable depth and groundwater salinity measurements to Goulburn-Murray Water. The soil boring sites will normally number approximately one hole per four hectares (200m grid). However, if an electromagnetic survey is carried out, fewer but targeted holes may be specified. The soil samples should be retained for two weeks to allow for inspection by a G-MW officer.

Groundwater observation bores should be installed to Goulburn-Murray Water specifications in the vicinity of the crop to monitor groundwater levels. Goulburn-Murray Water will recommend the location of soil boring sites and details of the groundwater observation bores required.

Where water use on land previously assessed as suitable has exceeded the water use target, a rice crop should not be grown on that area again unless the reason for the excessive usage has been adequately addressed. Where excessive seepage losses are evident additional testing such as EM 31 surveying and boring may identify and isolate areas with excessive seepage.

Goulburn-Murray Water will measure the area assessed as suitable. If the area planted is inconsistent with the area registered, additional boring and observation bores may be recommended. Where the unassessed area is considered to be unsuitable, the grower may be requested to abandon all or part of that area.

FURTHER INFORMATION

For further information on compliance monitoring contact the Irrigation Services Unit at Tatura :-

03 58335691 (or free call 1800 013 357)

Facsimile (03) 5833 5479

Registration should be made at the following addresses :-

SHEPPARTON

21 Wheeler Street

Shepparton Victoria 3630

Telephone (03) 5832 9900

Facsimile (03) 5832 9988

CENTRAL GOULBURN

PO Box 165 Tatura

Victoria 3616

Telephone (03) 5833 5460

Facsimile (03) 5833 5505

ROCHESTER

PO Box 165 Rochester

Victoria 3561

Telephone (03) 5484 0400

Facsimile (03) 5484 0450

PYRAMID-BOORT

PO Box 4 Pyramid Hill

Victoria 3644

Telephone (03) 5455 7100

Facsimile (03) 5455 7102

MURRAY VALLEY

PO Box 183 Cobram

Victoria 3579

Telephone (03) 5871 0100

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DLWC Griffith
Charles Sturt Univeristy
CSIRO Land & Water
DLWC Deniliquin
Goulburn-Murray Water Tatura
Murrumbidgee Irrigation
CSIRO Land & Water
CSIRO Land & Water
NSW Agriculture
Murray Irrigation
CSIRO Land & Water
Chairman of the Rice CRC Board
DLWC Deniliquin
NSW Agriculture
Coleambally Irrigation
Director of the Rice CRC
Murrumbidgee Irrigation
DLWC Deniliquin
CSIRO Land & Water
Ricegrowers' Association of Aust
ISIA Tatura
CSIRO Land & Water
CSIRO Land & Water
Charles Sturt Univeristy
Charles Sturt Univeristy
NSW Agriculture
Coleambally Irrigation
Irrigation Research & Extension
Committee (IREC)
Charles Sturt Univeristy
CSIRO Land & Water
Coleambally Irrigation
NSW Agriculture
CSIRO Land & Water*

PROGRAM

Chair

Graham Harris

Rice water use efficiency

1000-1030

Liz Humphreys

Review of methods; determinations for southern MDB

1030-1050

Nick Austin/Matthew Bethune

Rice crop water use determinations in northern Victoria

General Discussion

1050-1100

Rice water use issues, policies, implementation in the regions

1100-1145

Alan Lavis

Goulburn-Murray Water

Geoff McLeod

Murray Irrigation Limited

Arun Tiwari

Coleambally Irrigation Corporation

Lilian Parker

Murrumbidgee Irrigation

Ary van der Lely

Murrumbidgee DLWC

Ken Falahey

Murray DLWC

1145-1200

Natalie O'Connell

SWAGMAN Farm

12:00-12:10

Emmanuel Xevi

LEAKYPAD

Farmer self-monitoring

1210-1215

Liz Humphreys

Bay tests and paddock water use monitoring

Planned CRC research

1215-1220

John Blackwell

Determination of crop type and area using satellite data

General Discussion

1220-1230

Lunch

1230-1300

Predicting unsuitable soils for rice

1300-1330

Geoff Beecher

EM31, soil sodicity, texture

1330-1340

Derek Poulton

Environmental impacts of rice growing on saline soils

General Discussion

1340-1350

Methods for increasing rice water use efficiency

1350-1400

Lewin

Short season varieties

1400-1420

Thompson

Intermittent flooding, saturated soil culture, sowing method

1420-1430

Humphreys

Puddling and compaction

Discussion

1500-1600

Rice CRC ... of growing importance

About the Rice CRC

The Rice CRC is strengthening the rice industry's research and development (R&D) effort through its focus on sustainability.

Its mission is to increase the environmental, economic and social sustainability of the Australian Rice Industry and enhance its international competitiveness through both strategic and tactical research and the implementation of practical, cost-effective programs.

The Centre uses the intellectual resources of some of Australia's peak R&D organisations to target five main program areas:

1. Sustainability of Natural Resources in Rice-Based Cropping Systems
2. Sustainable Production Systems
3. Genetic Improvement for Sustainable Production
4. Product and Process Development
5. Education, Skills Development and Technology Transfer

Rice CRC core participants are Charles Sturt University, NSW Agriculture, CSIRO, Department of Land and Water Conservation, University of Sydney, Ricegrowers' Co-operative Ltd and the Rural Industries Research and Development Corporation.



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