WORKING PAPER 65

Growing More Rice with Less Water: Increasing Water Productivity in Rice-Based Cropping Systems

Progress of Research
1 July 2002 to 30 June 2003

International Water Management Institute

FUTURE HARVEST
IWMI is a Future Harvest Center supported by the CGIAR

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IWMI receives its principal funding from 58 governments, private foundations and international and regional organizations known as the Consultative Group on International Agricultural Research (CGIAR). Support is also given by the Governments of Ghana, Pakistan, South Africa, Sri Lanka and Thailand.

This project is supported by funds from the Australian Centre for International Agriculture Research (ACIAR).

International Water Management Institute (IWMI). 2004. *Growing more rice with less water: Increasing water productivity in rice-based cropping systems.* Progress of research, 1 July 2002 to 30 June 2003. Working Paper 65. Colombo, Sri Lanka: International Water Management Institute.

/agricultural research / irrigation programs / water management / water conservation / fertilizers/ farmers/soils/productivity/ groundwater / irrigation water / water resources / rice / rain / land / yields / irrigation management / water balance / hydrology / soybean / cotton / crop-based irrigation / irrigation systems / environment / training / conferences / projects / China / Australia/

ISBN 9290-90-531-X

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Contents

Acronyms Used

ABARE	Australian Bureau of Agricultural and Resource Economics
ACIAR	Australian Centre for International Agricultural Research
ASNS	Alternately submerged/non-submerged regime
AWD	Alternate wetting and drying irrigation technique
BHE	Bureau of Hydraulic Engineering
BIM	Bureau of Irrigation Management
CAU	Chinese Agricultural University, Beijing
CCAP	Center for Chinese Agricultural Policy
CF	Continuous flooding
CGIAR	Consultative Group on International Agricultural Research
CIMMYT	Centro Internacional de Mejoramiento de Maize y Trigo, Mexico
CS	Continuously submerged
CSIRO	Commonwealth Scientific and Industrial Research Organization
DAT	Days after transplanting
DSR	Direct seeded rice
EHWPMB	East Henan Water Projects Management Bureau
EMC	East main canal
ET	Evapotranspiration
FI	Flush irrigation
FIA	Farmer Irrigation Association
GCRPS	The ground cover rice production system
GIS	Geographic information systems
GMC	General main canal
GPS	Global positioning system
HD	Han Dao
HELP	Hydrology for the Environment, Life and Policy
HPWCRI	Henan Provincial Water Conservancy Research Institute
HZAU	Huazhong Agricultural University
IARI	Indian Agricultural Research Institute
IGP	Indo-Gangetic Plain
IPS WAR	International Platform for Saving Water in Rice
IRRI	International Rice Research Institute, Philippines
IWMI	International Water Management Institute, Sri Lanka
LAI	Leaf area index
LID	Liuyuankou irrigation district
LIS	Liuyuankou irrigation system
MC	Main canal
MIA	Murrumbidgee irrigation area
MODFLOW	MODular three-dimensional finite-difference groundwater FLOW model
MWR	Ministry of Water Resources
NARS	National agricultural research system
NCIDD	National Center of Irrigation and Drainage Development, China
NMC	North main canal
NSW	New South Wales
OFC	Other field crops

O&M	Operation and maintenance
ORYZA	Crop growth model
PAU	Punjab Agricultural University
P1	Panicle initiation
PRF	Partially rain-fed
RB	Raised beds
RF	Rain-fed
RS	Remote sensing
RW	Rice-Wheat
RWC	Rice-Wheat Consortium
RWS	Relative water supply
SEBAL	Surface Energy Balance Algorithm for Land
SMC	South main canal
S&P	Seepage and percolation
SRI	System for rice intensification
SSC	Saturated soil culture irrigation technique
SSC-RB	Saturated soil culture on raised beds
SWAGMAN	Farm-scale hydrologic economic model
TPR	Transplanting of rice seedlings
TTWS	Technology Transfer for Water Savings
UPLB	University of the Philippines at Los Baños
UPRIIS	Upper Pampanga River Integrated Irrigation System
WHU	Wuhan University
WJX	Wenjiaxiang
WOTRO	Netherlands Foundation for the Advancement of Tropical Research
WRB	Water Resources Bureau
WSI	Water-saving irrigation
WUE	Water-use efficiency
YR	Yellow river
YRDMD	Kaifeng Yellow River Diversion Management Section
ZAU	Zhejiang Agricultural University, China
ZIAB	Zhanghe Irrigation Administration Bureau
ZTD	Zhanghe Irrigation District
ZIS	Zhanghe Irrigation System, Hubei, China

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Executive Summary

Work continues at two sites in China, the Zhanghe irrigation system (ZIS) in Hubei and the Liuyuankuo irrigation system (LIS) in Henan, and at the Murrumbidgee irrigation area (MIA) in Australia. Progress this year is reported by subproject. However, as we move into the modeling phase of the study, a major focus this coming year will be on integrating activities between subprojects.

Subproject 1: Field Scale

Field-level activities included: a) field experiments at Tuanlin (ZIS) and Huibei (LIS) (pp. 5, 32) to compare the effects of WSI methods on yield and water productivity, both under deep water-table conditions, b) participatory testing by farmers (p. 32) to assess the performance of aerobic rice at LIS, and c) modeling at field level (p. 36) to facilitate the extension of water-saving methods to other locations at LIS.

The most important finding is that *flush irrigation and partially rain-fed irrigation* can reduce irrigation requirements over farmer's practices by 50 percent or more without significant loss in yield if the soil moisture potential is kept at a relatively high level (-30kPa measured at 20 cm soil depth).

The performance of *aerobic varieties* was compared *with conventional varieties.* The aerobic variety gave low yields in Tuanlin due to low tillering and high spiklet sterility caused by high temperature. In Huibei on the other hand, yields of the *aerobic variety* ranged from 4 to 5 tons depending on irrigation treatment compared to 5 to 7 tons for the *inbred variety.*

Work progressed on upgrading the ORYZA2000 model in order to quantify the components of water balance under the alternate wetting and drying (AWD) irrigation technique and to simulate aerobic rice. With experimental data from the Tuanlin and Hubei sites, the model is being calibrated and validated.

Subproject 2: Scaling Up

Activities included in subproject 2 are a) early stage development of modeling in ZIS, b) water accounting and development and calibration of MODFLOW in LIS, and c) development of a three-dimensional surface water and groundwater interaction model for MIA.

At ZIS, water-balance studies at system level indicate that only 10 percent of the water input leaves the system and that there is not much scope for further water savings over the whole system. Modeling work is being initiated to identify the impact of small farm-level irrigation reservoirs on water savings and increased water productivity.

The spatial modeling (MODFLOW) at LIS showed a dramatic and large cone of groundwater depression under the Kaifeng city indicating that the growing demand for water in Kaifeng will affect water-table levels and overall water availability in LIS.

At MIA the surface water and groundwater model was calibrated on a monthly basis for the period 1995-2000. A number of future land- and water-management scenarios are being modeled. The objective is to achieve an appropriate mix of crops that will provide an optimum level of groundwater pumping and appropriate allocation of water for irrigation and the environment.

A remote-sensing (RS) analysis was carried out at ZIS and LIS. At ZIS, the RS was used to estimate land use cover and evapotranspiration for the rice season. This was used to estimate the water balance and accounting. At LIS, work continued on the RS analysis, which will be used to derive a similar estimate of ET for the season.

Subproject 3: Policy, Institutions and Management

Activities included in subproject 3 are a) the development of survey questionnaires to quantify the effects of water resources (ponds in ZIS and groundwater in LIS) outside the control of irrigation-systems managers on the adoption of water-saving irrigation practices, and b) preliminary analysis of long-term trends in cropping patterns and water use at Kaifeng and LIS.

Draft questionnaires on pumps in LIS and ponds in ZIS have been developed with input from several project staff, and surveys will be conducted and analyzed in the coming year. The surveys are being developed specifically to complement the modeling studies in subproject 2.

A preliminary analysis of the long-term trends in cropping patterns and water use was conducted. In terms of water use, two trends are clear. First, since the 1970s, water for irrigation has been declining while water for domestic and industrial use has been rising and now accounts for over one-third of the water used in the four Kaifeng city districts. Second, industrial and municipal needs are met by groundwater while diversions from the Yellow river continue to provide the major source of water for irrigation.

Subproject 4. Extension of Research Results

Extension of research results to date has occurred largely through research publications many of which are in Chinese language (see section 6) workshops, and seminars targeted at national and international audiences. Last September, seven members of our research team attended the International Rice Symposium in Beijing and presented papers on topics related to our research. An even larger representation was planned for the Yellow River Forum in May with four papers dealing directly with our research in LIS. Due to SARS the Yellow River Forum has now been postponed until October.

In the future, we plan to give more emphasis to presentation of results and dialogue at the system and farm level on issues related to potentials for improved management and potential for further water savings.

PROGRESS OF RESEARCH WORK

This section reports details in the progress of research in subprojects 1 and 2.

Subproject 1: Field Scale

In the reported period, we have completed a) field experiments in Kaifeng and Tuanlin to compare effects of water managements on performance of hybrid (at Tuanlin), inbred (Kaifeng) and aerobic rice varieties; b) participatory testing to determine the performance, and farmer's acceptance of, aerobic rice in Kaifing; c) modeling at field level; and d) a list of publications for dissemination of our results (p. 30).

A. Field Experiments in Kaifeng and Tuanlin

In 2002, we conducted experiments in Tuanlin, Hubei Province and in Huibei, Kaifeng, Hennan Province under subproject 1. In Kaifeng, the experiment was conducted south of the railway in Pan Lou village, Xin Long township, where upland crops are often grown because of deep water-table conditions. In Tuanlin, the experiment was moved to an area near the eastern wall of the Tuanlin experiment station in the second and third terraces from the wall of the station. We also constructed 1-m deep drainage canals to ensure a deep water table.

The purpose of the experiments was to compare the effects of WSI methods on yield, water input and water productivity of aerobic and conventional rice varieties at two sites with deep water table conditions. The soil in Tuanlin was clay loam while Huibei has loam soil. Three water-saving irrigation methods were tested. In alternate wetting and drying (AWD) in puddled soil, the field was kept dry for several days after the disappearance of ponded water before irrigation was reapplied. It included a period of mid-season drainage by withholding irrigation water for 10-15 days around mid-tillering (no active drainage). Flush irrigation (FI) in non-puddled, aerobic soil involves irrigation of the field with a layer of 40-80 mm of water which quickly infiltrated into the soil. Flush irrigation (FI-x) was reapplied when the soil water potential at 20-cm soil depth reached a threshold soil water potential, x. Partially rain-fed (PRF) treatment in puddled soil involves no application of irrigation water from 10 days after transplanting (DAT) onwards.

The experiment in Tuanlin, was laid out in split-split plot design in three replications while in Huibei, a split plot design in four replications was followed. The main plots were water treatments in which fields were kept flooded with 2 to 5-cm water depth during the transplanting recovery period, for about 10 DAT, followed by water treatments as follows:

In Tuanlin, water treatments were AWD, PRF, and FI-50 while in Huibei, main plots included, FI-10, FI-30, FI-70 and PRF. In the subplots, hybrid rice variety 2you-725 (V1) was compared with aerobic rice variety HD502 (V2) at Tuanlin; and inbred variety 90247 (V1) with aerobic rice variety HD502 (V2) at Huibei. The experiment in Tuanlin included two N-fertilizer treatments (zero N fertilizer [N_0] and 180 kg N ha^{-1} [N_{180}]) in the sub-subplots. N fertilizer was applied in 4 splits as 30% basal, 30% at 10 DAT, 30% at panicle initiation (PI) and 10% at heading. All treatments received 70 kg P ha^{-1} in Tuanlin and 50 kg P ha^{-1} in Huibei as basal application. At both sites, 70 kg K ha^{-1} were also used as basal application.

Daily meteorological parameters (rainfall, pan evaporation, sunshine hours, temperature and wind speed) were collected from meteorological stations at the Tuanlin and Huibei experiment stations. Measurements included irrigation water input using flow meters at each irrigation, daily standing water depth using meter gauges, daily percolation rate using percolation rings and groundwater depth. In Tuanlin, irrigation water and surface drainage were measured in individual sub-subplots while in Huibei these were measured in the subplots. The amount of surface drainage was calculated from the difference in the ponded water depth before and after drainage events. The seasonal amount of percolation was computed as the sum of measured daily percolation rates. It was assumed that there was no percolation during days without standing water. The seasonal seepage was estimated as the closure term in the water balance over the whole season: seepage = rainfall + irrigation - percolation - surface drainage - evapotranspiration. Evapotranspiration was computed from the weather data using the Penman equation. At 15 DAT, PI, flowering and maturity, 12-hill samples were collected to measure biomass tiller number and LAI. At maturity, we also measured grain yield and yield components. Water productivity was calculated as the grain yield per unit of irrigation water used (WPI) from transplanting to harvest and grain yield per unit of total water used by irrigation and rainfall (WP_{I+R}) also from transplanting to harvest.

The groundwater table changed from 200-cm depth at transplanting to about 350-cm depth at harvest in Huibei (figure 1) and between 20 and 90 cm depth in Tuanlin (figure 2). In Tuanlin, the groundwater table depth fluctuated with rainfall or irrigation event. Groundwater table depth was deeper in the higher toposequence (rep 1, figure 2a) than in the lower toposequence (rep 3, figure 2b).

In Tuanlin, there were higher field water depths in AWD compared to FI-50 and PRF until about 1 month after transplanting. At later stages, only a few days had ponded water and there were no clear differences in perched water depth among the water treatments. In Huibei, it was not possible to maintain ponded water in the field, except for a few hours after the flush irrigations. Thus, the number of days with standing water refers also to the number of irrigations. In table 1, the number of days with standing water during the crop season declined as the threshold soil water potential decreased. Except for the FI-10 treatment, a large number of days with ponded water occurred during the transplanting recovery period.

In Tuanlin, the yield of the hybrid rice variety was significantly higher than that of the aerobic rice variety, in all water treatments and at both N levels (figure 3a). The low yields of the aerobic variety were caused by low tillering and high spikelet sterility due to higher temperature. Rice yield in N_{180} treatment was generally higher than in N_0 plots in both varieties. There were no significant differences among the three water treatments. In Huibei, the local inbred variety (6 tons ha^{-1}) had significantly higher yields than the aerobic variety (4.7 tons ha^{-1}) as shown in figure 3b. This may be attributed to a lower tillering ability and a shorter duration (107 d of the aerobic variety versus 115 d of the inbred variety) of the aerobic variety compared with the inbred variety. The deep water table in 2002 allowed different water treatments to impose different stress levels on the rice plants. In the inbred variety, FI-10 and FI-30 (about 7 tons ha^{-1}) had significantly higher yields compared to FI-70 (5.8 tons ha^{-1}) and PRF (4.8 tons ha^{-1}). In the aerobic variety, FI-10 had higher but not significantly different yields (4.8 tons ha^{-1}) compared to FI-30 (4.4 tons ha^{-1}) but significantly higher compared to FI-70 and PRF (about 4.1 tons ha^{-1}). There was no significant difference in yields among FI-30, FI-70 and PRF.

The differences between treatment FI-10 and FI-30 in both varieties were small. This indicates that reducing the soil-water potential down to -30 kPa will not result in yield reduction in both varieties. However, if the soil water potential is reduced from -30 kPa to -70 kPa, there will be a significant decrease in yield in the inbred but not in the aerobic variety, which indicates that water stress might result in a yield penalty in the inbred variety, but not in the aerobic variety. This shows that the inbred variety was more sensitive to water stress than the aerobic variety.

In Tuanlin, the total water input (rainfall + irrigation) ranged from 800 to 1,600 mm, of which 350 mm constituted rainfall. The irrigation water input in AWD was significantly higher in of all treatments, while FI-50 and PRF had no significant difference in irrigation water input (figure 3a). The mean daily percolation rate was 1.4 mm d^{-1}. Summed over the whole season, the percolation loss was 35 mm in AWD and about 25 mm in the other two treatments (statistically all the same). There was no drainage outflow because rainfall was low during the season. The calculated seasonal seepage loss was highest in AWD compared to PRF and FI-50.

In Huibei, the total water input (rainfall + irrigation) ranged from 1,000 to 3,300 mm, of which 270 mm constituted rainfall. The differences in irrigation water inputs among the treatments were statistically significant. Irrigation water input was highest in FI-10, followed by FI-30, FI-70, and RF. A similar level of significance was found in the S&P values. No drainage occurred in 2002 (figure 3b) because rainfall was very low during the crop season.

The high water inputs were attributed to the high S&P losses, because of lighter soil and a deeper groundwater table. Most (about 1,300 mm) of the S&P in 2002 occurred during the transplanting recovery period, when irrigation had to be applied daily to keep the field flooded (though only a part of the day) to help plants recover from the transplanting shock. This period was longer in the aerobic rice variety than in the inbred rice variety (17 vs. 10 d, table 1), indicating that the former suffered more severe transplanting shock than the latter. The irrigation amount supplied during transplanting recovery to the aerobic variety was higher than that supplied to the inbred variety.

In Tuanlin, the total water productivity, WP_{I+R} (for hybrid rice), ranged from 0.1 to 0.8 kg m^{-3}, while the irrigation water productivity, WP_I, ranged from 0.6 to 1.6 kg m^{-3}. The WP_{I+R} values are relatively low due to the combination of relatively high water inputs and low yields (figure 5a). The low values of WP_I in aerobic rice were caused by the extremely low yields in these treatments. In Huibei, the mean WP_{I+R} (total water productivity) ranged from 0.15 to 0.33 kg m-3, whereas mean WP_I ranged from 0.17 to 0.41 kg m^{-3} (figure 5b). The WP_{I+R} values are relatively low compared with previous studies and are explained by the combination of relatively lower yields (of aerobic rice) and extremely high water inputs, especially in the FI-10 treatment (figure 4b). Among the four water treatments, FI-10 had the significantly lowest WP_{I+R} and WP_I. The differences among FI-30, FI-70, and PRF were not significant.

The aerobic rice variety HD502 used in our experiments was primarily bred for, and tested in, temperate zones of China. The relatively high yields (around 5 t ha^{-1}) we obtained in Huibei are an indication that aerobic rice varieties can also be grown in subtropical environments. Aerobic rice has a distinct advantage over the inbred variety in that it is less sensitive to the level of water stress.

The lower yield of the aerobic variety compared with that of the inbred variety was related to its shorter duration and lower tillering capacity. In contrast, a shorter duration may have other advantages compensating for the lower yield, such as allowing earlier establishment of a post-rice crop thereby increasing its yield, and perhaps increasing total system productivity and/or water productivity. Increasing plant density may compensate for the lower tillering capacity of aerobic rice.

Aerobic rice was bred and selected for direct seeding. This could explain the severer transplanting shock (as reflected by the longer period of transplanting recovery) than with the inbred variety. Transplanting shock can be avoided by establishing the crop by direct-seeding methods. This may further increase the yield of the aerobic rice. More importantly, direct seeding removes the need for maintaining standing water in the field during the transplanting recovery period (of the transplanted rice), which would reduce the amount of irrigation substantially, especially when the soil is permeable and the groundwater is deep. Direct seeding is thus very important for increasing the water productivity of aerobic rice.

WSI, especially flush irrigation and partially rain-fed systems, can significantly reduce the amount of irrigation compared with farmers' practices, without affecting rice yield if the soil-water potential is not allowed to drop below -30 kPa. This implies that there is a possibility for irrigation-system managers to reduce the amount of water diverted to rice at the study sites. These findings and their implications, however, are site-specific and care must be taken in extrapolating them. Our results were obtained in relatively small subplots in farmers' fields, which allowed us to keep irrigation time short and the irrigation application efficient. In larger fields, the irrigation time is longer, which may result in larger seepage and deep-percolation losses. Our results also confirmed that yield responses to irrigation management are highly dependent on groundwater depth. Data on the effect of irrigation management were useful only when groundwater depth and soil conditions were specified. More study is needed on the interaction between irrigation and groundwater table depths before recommendations for the large-scale application of water-saving irrigation techniques can be made. Furthermore, seepage from unlined irrigation canals in our study areas may also recharge the groundwater. With the wide-scale adoption of water-saving irrigation techniques, the groundwater tables may go down because of less groundwater recharge from the rice fields and the effect of irrigation management on yield may become more prominent. Systems approaches, using models, may be useful in analyzing the complex interactive effect of groundwater, canals, irrigation management on rice yield and water productivity.

Table 1. Number of days with standing water in the field during the crop season and transplanting recovery period in Huibei, Kaifeng, 2002.

Treatment	Days with standing water			
	Crop season		Transplanting recovery	
	V1[a]	V2[b]	V1	V2
Flush irrigation at				
-10 kPa	44±1	40±1	14±1	17±1
Flush irrigation at -30 kPa	24 ± 1	27± 1	13 ±1	17± 1
Flush irrigation at -70 kPa	21±1	22±1	14±1	17±0
Rain-fed	16±1	20±1	14±0	17±1

[a]V1 = Inbred rice.
[b]V2 = Aerobic rice.

Note: The standing water in the field lasted only a few hours after irrigation; the number of days with standing water thus equaled the number of irrigation events.

Figure 1. Mean groundwater table depth and rainfall in Huibei, Kaifeng, 2002.

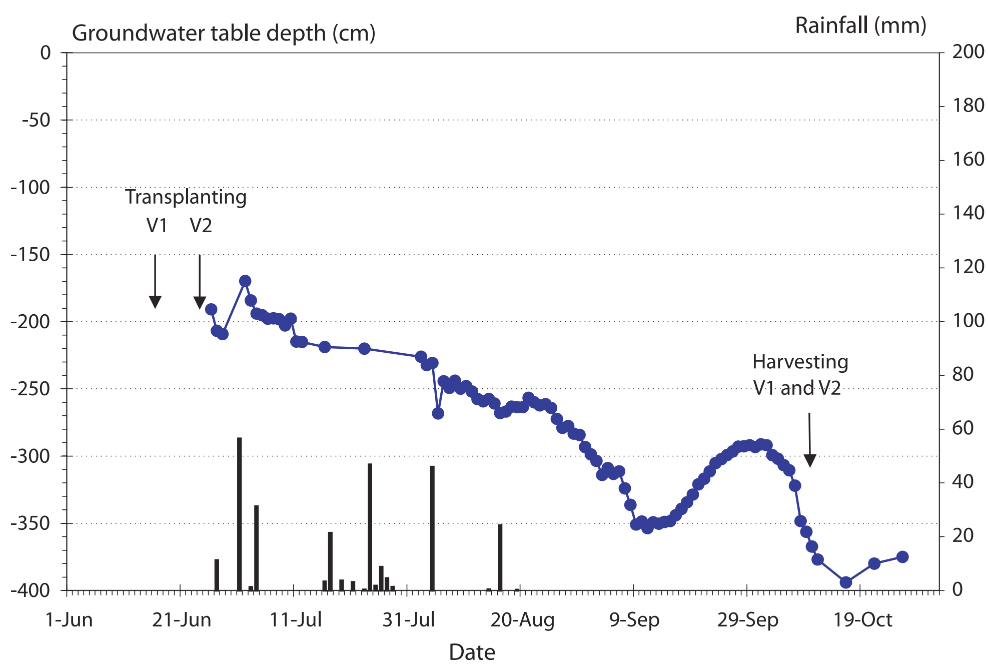
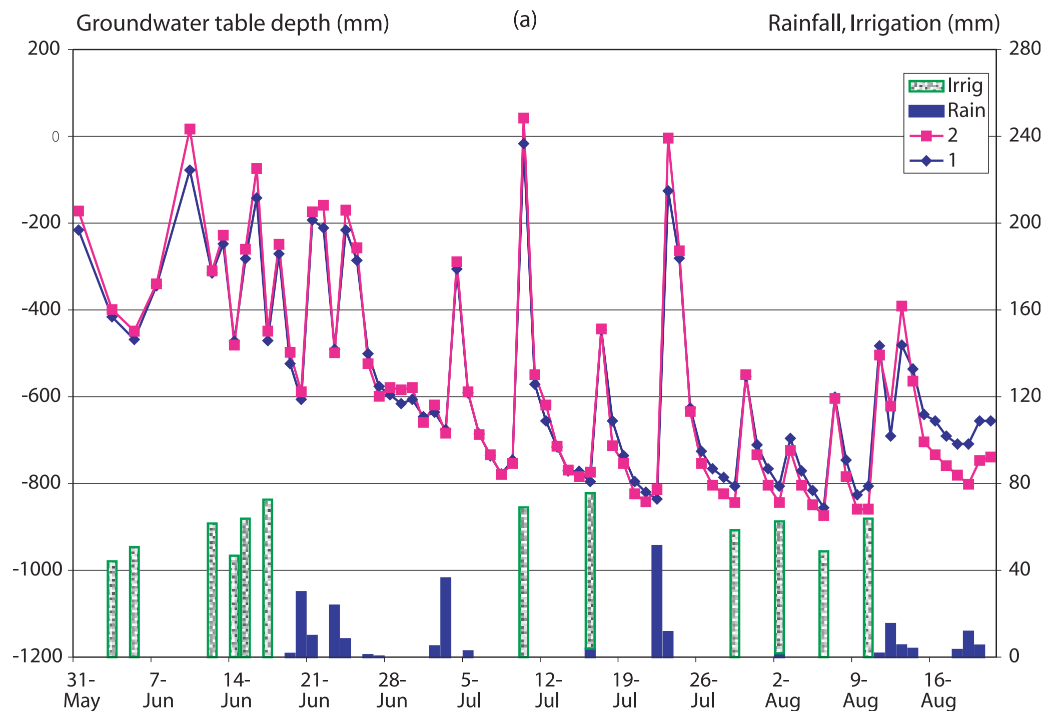


Figure 2. Groundwater table depth, rainfall and irrigation in (a) upper terrace in rep 1 and (b) lower terrace in rep 3 at Tuanlin, 2002.



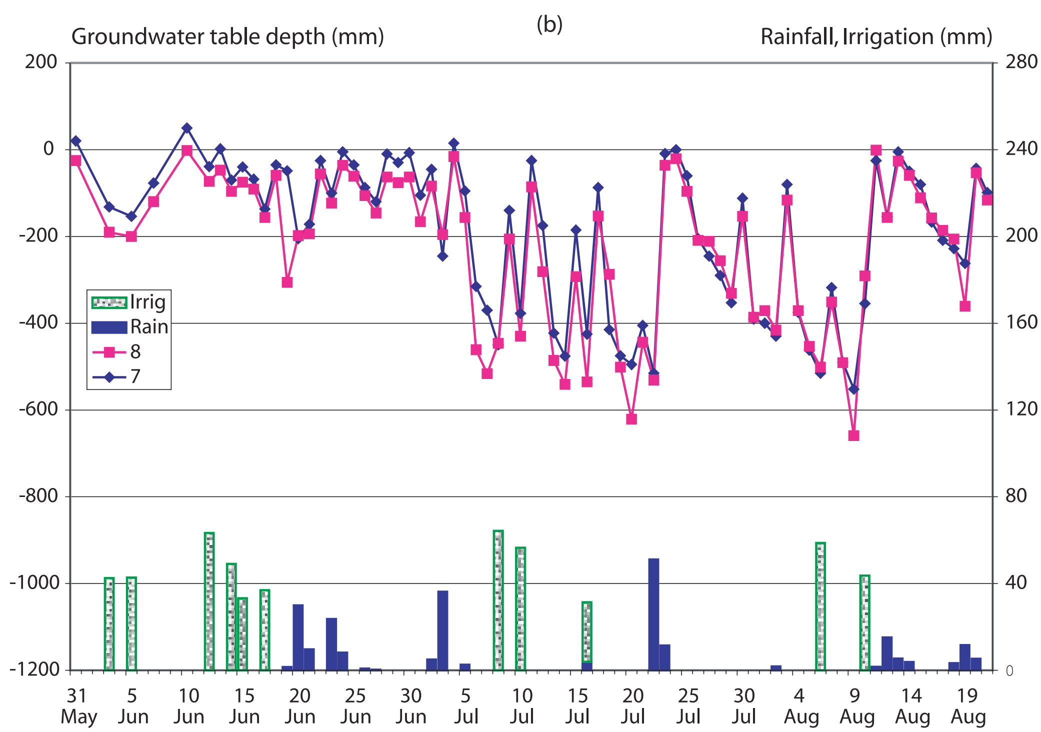
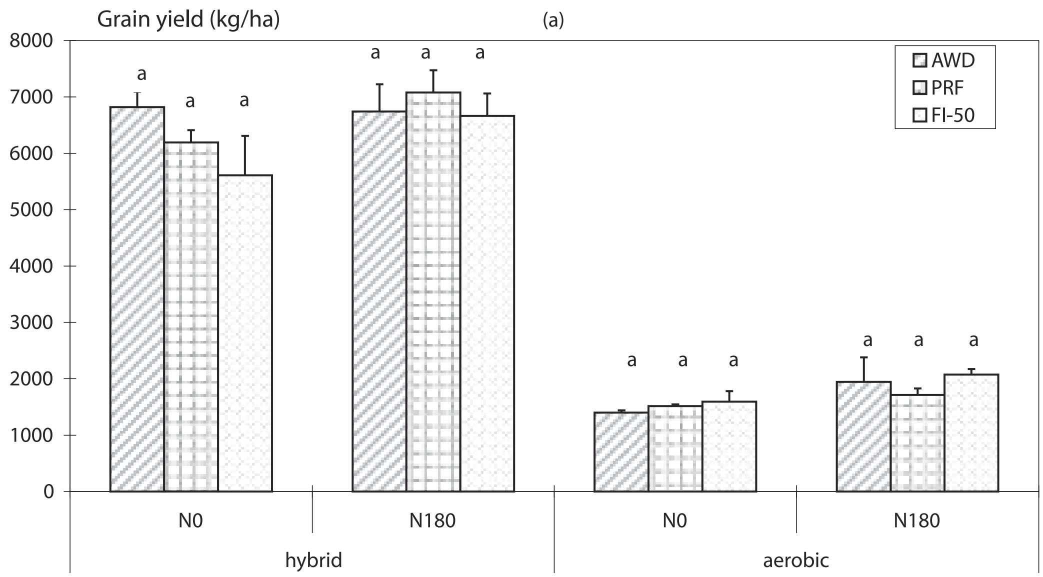
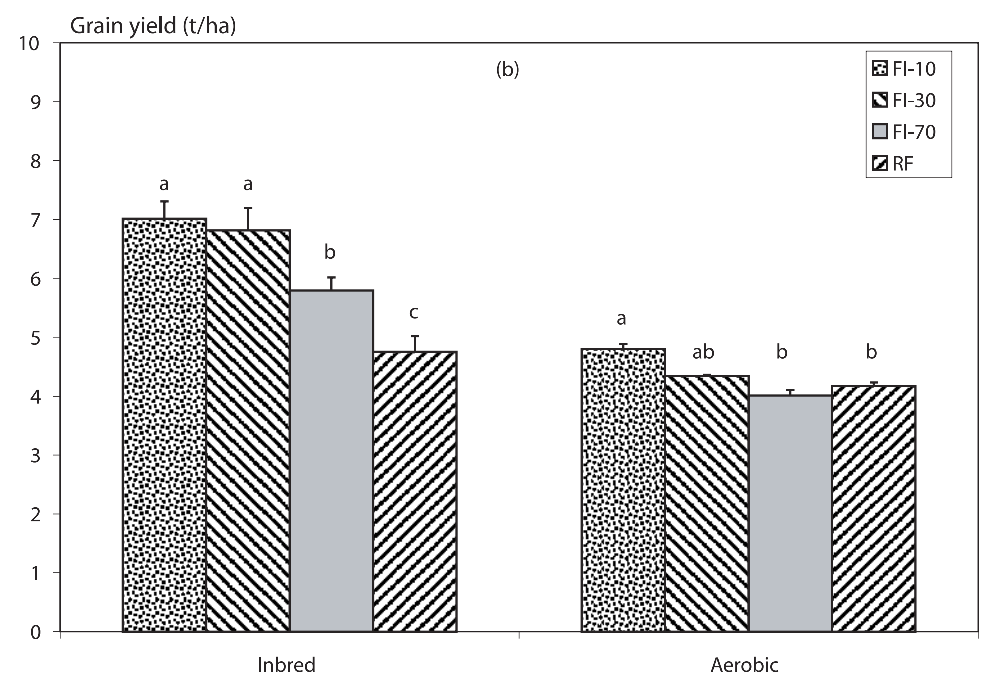


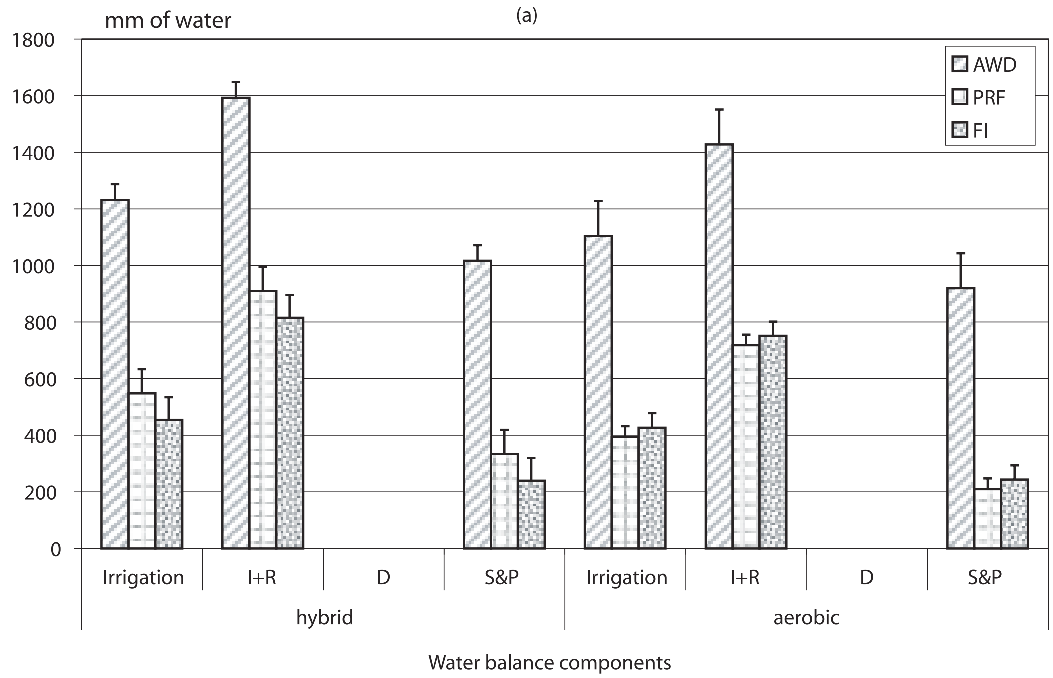
Figure 3. Mean grain yields in (a) Tuanlin and (b) Huibei.

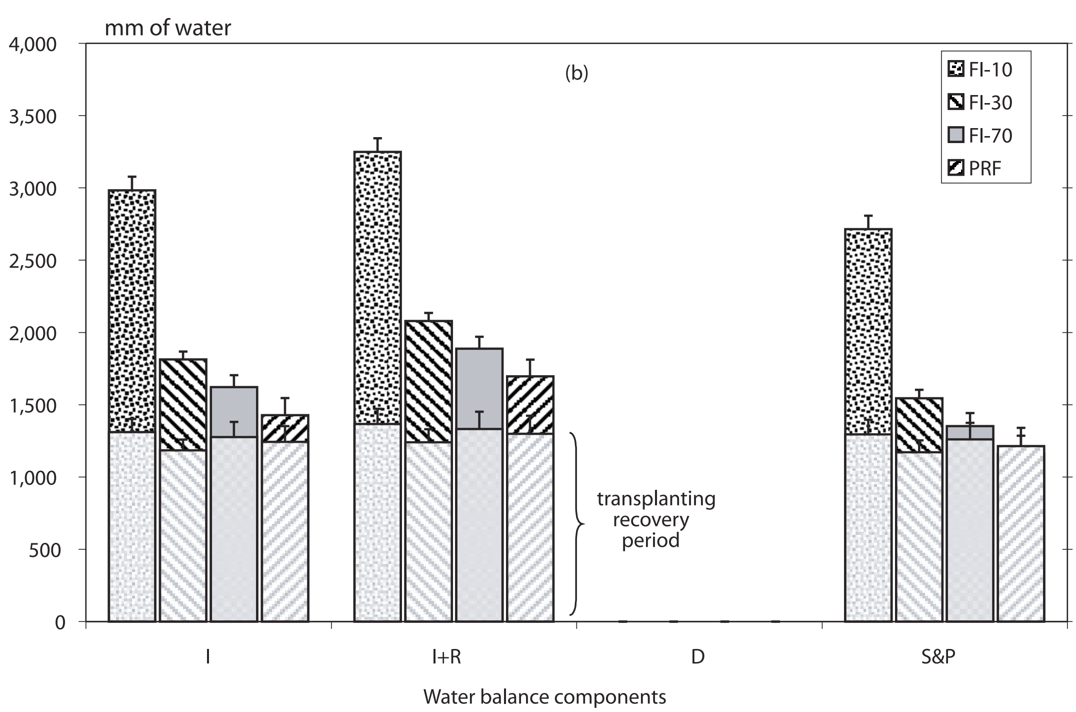




Notes: AWD = alternate wetting and drying; PRF + partially rain-fed; FI-10 = flush irrigation at -10kPa; FI-30 = flush irrigation at -30kPa; FI-50 = flush irrigation at -50kPa; FI-70 = flush irrigation at -70kPa; N0 = zero nitrogen; N180 = 180 kg N ha -1. In each variety and N treatments in (a) and each variety in (b), columns with the same letters are not significantly different at 5% level.

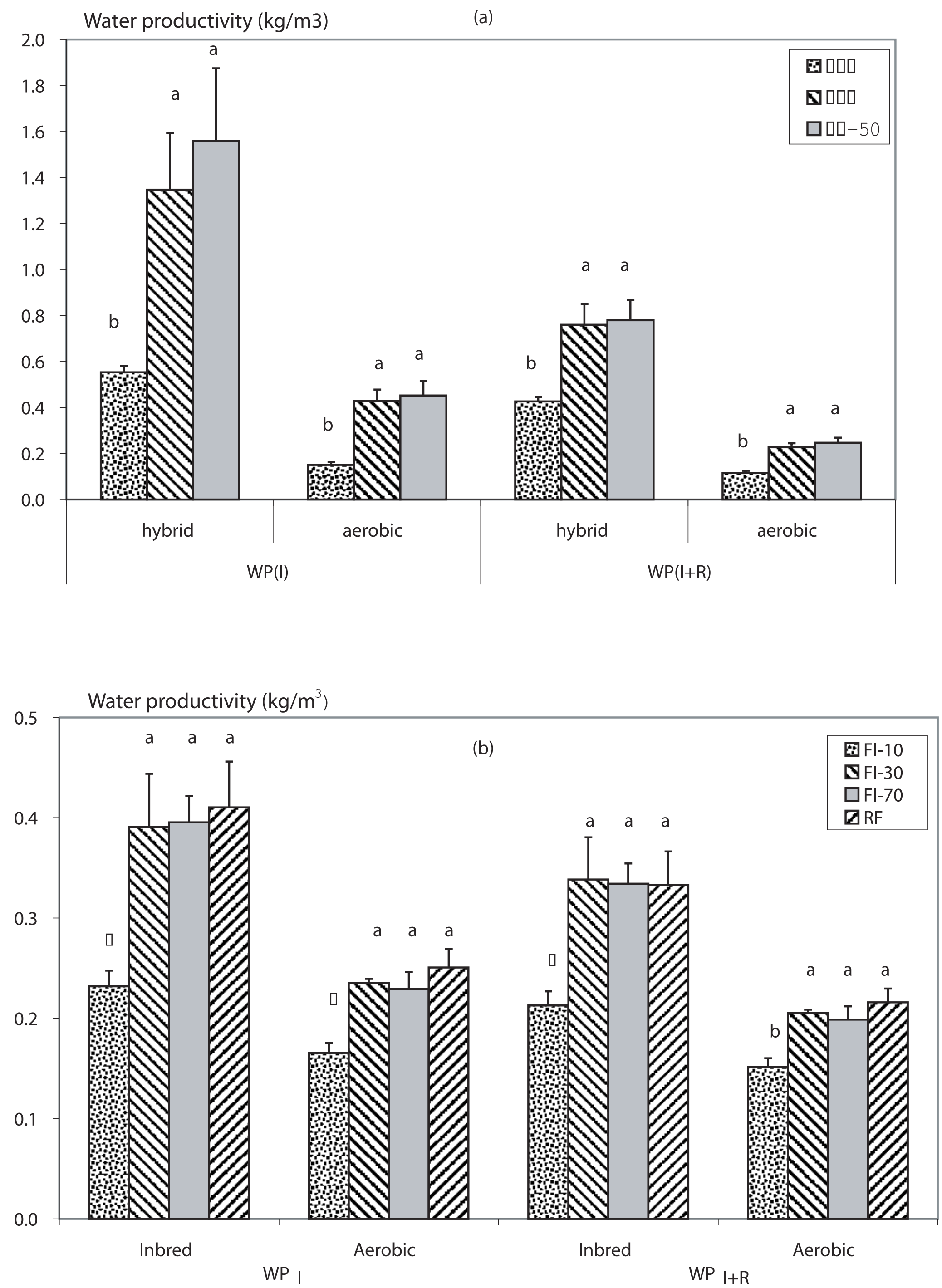
Figure 4. Mean water balance components in the period from transplanting to harvest in Tuanlin (a) (N=6, in hybrid rice, from 2 N treatments and 3 replicates), and in Huibei, and (b) (N=6, from 2 varieties and 3 replicates).





Note: AWD = alternate wetting and drying, PRF= partially rain-fed, FI-10 = flush irrigation at-10 kPa, FI-30 = flush irrigation at -30 kPa, FI-50 = flush irrigation at -50 kPa, and FI-70 = flush irrigation at -70 kPa.

Figure 5. Water productivities with respect to irrigation (WPI) and to total water input (WPI+R) in (a) different water and nitrogen treatments in Tuanlin and (b) in different water treatments and varieties in Huibei.



Note: AWD = alternate wetting and drying, PRF= partially rain-fed, FI-10 = flush irrigation at-10 kPa, FI-30 = flush irrigation at -30 kPa, FI-50 = flush irrigation at -50 kPa, and FI-70 = flush irrigation at -70 kPa. In each variety in (a) and (b), columns with the same letters are not significantly different at 5% level.

Subproject 2: Scaling up from Farm to Irrigation System, and Subbasin Levels

Activity 2.1 Mathematical Modeling of Surface Water and Groundwater Interactions at LIS

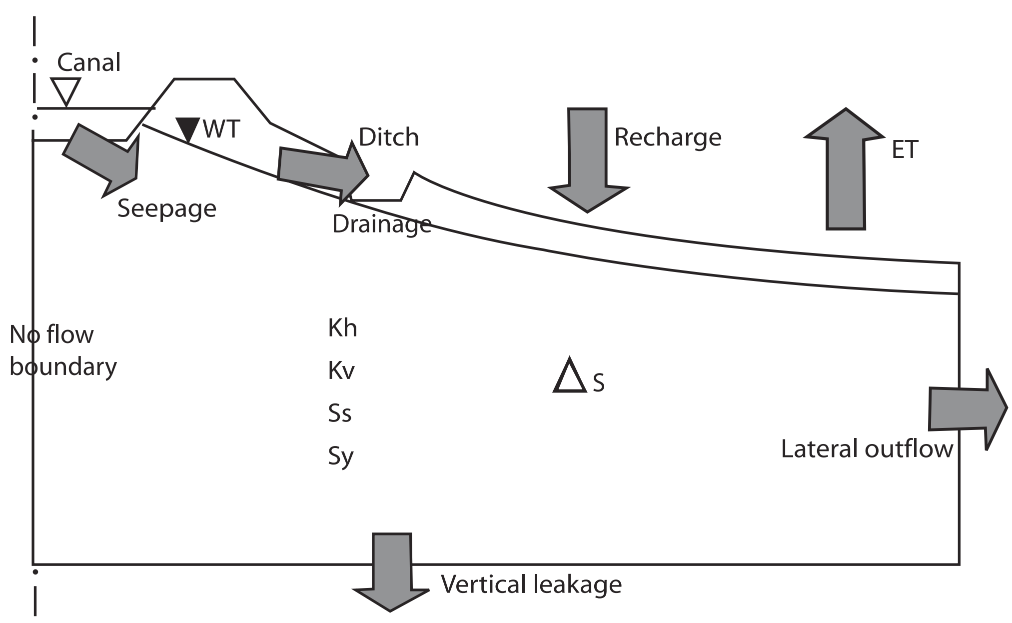
Objective: To assess whether on-farm water savings practices—AWD, SSC, and aerobic—lead to real water savings at the irrigation-system level enabling more water to be available for other uses in a manner that sustains existing production and is not detrimental to the environment.

Progress at the Irrigation Channel Level

A two-dimensional cross-sectional groundwater flow model based on Processing MODFLOW was developed to simulate the interaction between the East Main Canal in the LIS and the aquifer system beneath it. Processing MODFLOW for Windows (PMWIN) was used as it provides a fully integrated simulation system for modeling groundwater flow and automated calibration and sensitivity analysis using UCODE.

A cross-sectional model was used assuming relative horizontal homogeneity of the aquifer characteristics and uniformity of flow conditions along the canal. Figure 6 shows a schematic diagram of the conceptual model, where Kh is horizontal hydraulic conductivity, Kv is vertical hydraulic conductivity, Ss is specific storage and Sy is specific yield.

Figure 6. Schematic diagram of the conceptual model.



The model was calibrated with both automated inverse modeling software UCODE and manual trial-and-error iterations. Basic aquifer parameters were calibrated with UCODE and inflow and outflow fluxes in the MODFLOW packages were calibrated using the trial-and-error procedure. The monthly calibrated water balance components are shown in table 2. Details of calibrated aquifer parameters are given in Luo et al. 2003.

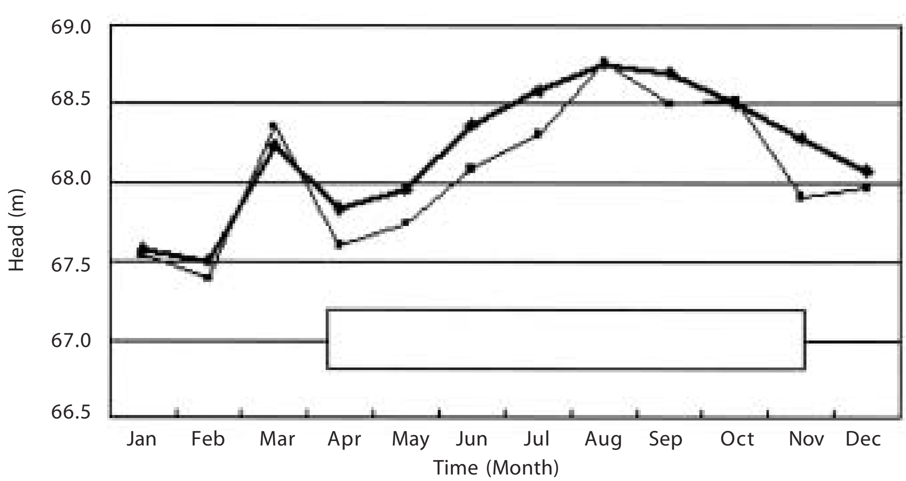
Table 2. Calibration results.

Date	Maximum ET rates (m/day)	Recharge flux (m/day)	Heads in the canal (m)	Recharge rate of wells-lateral (m^3/day)	Leakage rates (m^3/day)
Jan.	0.0004	0.0002	70.13	-158	-68.5
Feb.	0.0009	0.0008	70.13	-147	-68.5
Mar	0.0022	0.0083	70.13	-154	-137
Apr.	0.006	0.0011	70.17	-206	-68.5
May	0.0078	0.001	70.22	-408	-34.3
June	0.0033	0.0067	70.3	-373	-68.5
July	0.0057	0.0074	70.5	-233	-137
Aug.	0.0054	0.0063	70.4	-200	-205.5
Sept.	0.0045	0.004	70.3	-199	-205.5
Oct.	0.002	0.0009	70.16	-196	-205.5
Nov.	0.0014	0.0005	70.17	-245	-137
Dec.	0.0014	0.0001	70.15	-241	-102.8

The calibration performance was measured as follows:

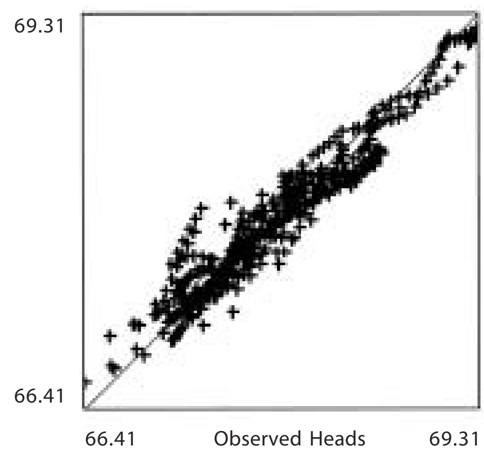
- Simulated piezometric hydrographs were compared with the observed hydrographs at a number of observation boreholes along a transect line. Figure 7 shows an example of the simulated and observed hydrographs for a borehole, 621 m from the canal.

Figure 7. Comparison between simulated heads and observed heads.



- Figure 8 shows the scatter diagram of measured versus modeled heads. From figure 8, it is obvious that some modeled heads are higher than the observed but some are lower, which indicates that there is no systematic error in the model. The variance is 2.87E-02. Scaled Root Mean Square (SRMS) and Scaled Root Mean Fraction Square (SRMFS) are 4.85% and 4.84%, respectively, which are both less than 5% indicating that the ratio of error to total head differential is small, and hence errors are only a small part of the overall model response. According to the Australian modeling standards calibration errors are within acceptable limits and correspond to a high fidelity model.
- Simulated levels are compared with observed levels at those boreholes that are not used for determination of boundary conditions. The difference between the simulated and observed values was generally less than 0.15 m. In most instances, the calculated value is higher than the measured.

Figure 8. Scatter diagram of measured versus modeled heads.



A key finding of this work is the transient nature of losses from channels as show in table 3, which shows losses computed for a 100 m width of the East Main Canal. Further details of this work are given in Luo et al. 2003.

Table 3. Losses from the East Main Canal.

Date	Groundwater table increase (m)	Seepage rate (m^3/day)	Recharge rate (m^3/day)
Jan.	-0.05	60.0	18
Feb.	-0.1	60.0	89.8
Mar.	0.66	60.0	935.7
Apr.	0.65	300.0	118.9
May	1.03	552.0	112.2
June	0.1	470.7	751.7
July	0.19	459.8	830.3
Aug.	-0.09	399.8	706.9
Sept.	-0.1	401.6	448.8
Oct.	-0.78	240.0	103.2
Nov.	0.01	300.0	56.1
Dec.	-0.56	180.0	7.9

Progress at the System Level

A range of lumped water balance and mathematical studies were carried out. The following methodology was used to develop a monthly water balance for the whole of LIS from 1981 to 2001.

- computation of crop water requirements using ET, crop factors and crop areas
- estimation of surface water availability to crops from surface water supplies in the areas after accounting for losses
- estimation of groundwater requirements to meet crop demands

For major crops in the LIS, crop development stages are given below in table 4. Crop coefficients of the 5 major types of crops (rice, wheat, cotton, maize, soybean) are shown in table 5.

Table 4. Plant date and lengths of crop development stages for different crops in the LIS.

No.	Crop	Plant & harvest date	Initial (days)	Development (days)	Middle (days)	Late (days)	Total (days)
1	Winter Wheat	11/10-31/5	140	50	20	30	240
2	Summer Maize	10/6-30/9	5	20	55	30	110
3	Cotton	15/4-10/11	40	45	80	70	235
4	Rice	16/6-10/10	20	30	25	40	115
5	Soybean	10/6-30/9	15	20	25	30	90

Table 5. Monthly crop coefficients: Kc.

No.	Crop.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aub.	Sep.	Oct.	Nov.	Dec.	Aver.
1	Winter Wheat	0.31	1.04	0.96	1.43	1.33	0.65				0.60	0.90	0.97	1.0
2	Summer Maize						0.47	1.13	1.67	1.32				0.99
3	Cotton				0.60	0.69	0.72	1.23	1.23	0.55	0.50			0.87
4	Rice*						1.22	1.29	1.41	1.29	1.1			1.30
5	Soybean*						0.538	0.904	1.119	0.93				0.864

*Kc for rice and soybean are from Anhui province (near Kaifeng).

Crop water requirements were obtained by multiplying the respective crop coefficient by the reference crop evapotranspiration value for each corresponding month. The value of crop water requirement for each crop in different years. Crop water requirements for wheat are shown in table 6.

Table 6. Monthly crop water requirement of winter wheat (mm).

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1981	9.99	36.69	77.67	159.59	263.05	108.23	0.00	0.00	0.00	59.52	40.23	38.49	793.46
1982	10.96	33.78	69.34	178.46	240.37	106.67	0.00	0.00	0.00	48.73	41.85	44.80	774.96
1983	11.15	49.21	66.36	152.72	178.11	93.99	0.00	0.00	0.00	39.62	44.55	36.99	672.71
1984	11.53	36.69	78.86	143.72	176.46	89.12	0.00	0.00	0.00	44.08	40.77	26.46	647.70
1985	8.17	32.03	54.76	160.88	158.32	96.33	0.00	0.00	0.00	38.69	42.66	28.87	620.70
1986	10.86	42.81	65.77	136.85	177.70	84.83	0.00	0.00	0.00	48.17	41.58	30.37	638.94
1987	9.71	42.52	57.14	143.72	156.67	85.02	0.00	0.00	0.00	54.87	44.82	35.18	629.64
1988	11.63	50.09	57.44	156.59	164.92	106.86	0.00	0.00	0.00	39.06	53.19	36.99	676.75
1989	7.21	32.32	70.83	142.43	178.11	86.97	0.00	0.00	0.00	49.48	38.88	24.96	631.19
1990	7.02	29.99	62.79	139.00	147.60	85.41	0.00	0.00	0.00	45.57	57.24	33.08	607.70
1991	8.84	35.24	48.81	114.11	138.53	75.66	0.00	0.00	0.00	48.55	50.22	29.47	549.42
1992	8.55	44.55	51.78	161.73	155.85	87.3	0.00	0.00	0.00	43.90	38.07	22.55	614.35
1993	6.53	32.61	63.09	134.28	136.88	80.54	0.00	0.00	0.00	41.85	34.83	27.06	557.68
1994	9.80	41.64	65.77	147.58	189.66	95.16	0.00	0.00	0.00	48.73	35.64	24.36	658.34
1995	9.23	41.93	64.88	133.85	169.04	84.83	0.00	0.00	0.00	41.11	47.52	26.46	618.84
1996	6.82	32.03	41.37	98.24	130.70	71.18	0.00	0.00	0.00	33.67	35.10	26.76	475.86
1997	7.78	33.49	57.14	118.40	159.97	87.95	0.00	0.00	0.00	49.48	33.75	27.97	575.92
1998	8.07	43.97	60.12	115.83	128.23	85.41	0.00	0.00	0.00	44.45	48.33	30.67	565.08
1999	10.09	48.63	49.70	123.55	156.67	78.59	0.00	0.00	0.00	36.27	41.58	38.19	583.27
2000	6.34	32.61	76.48	163.45	176.88	82.49	0.00	0.00	0.00	37.01	36.45	26.76	638.48
2001	6.44	26.50	76.78	136.42	164.10	80.15	0.00	0.00	0.00	34.22	38.07	23.45	586.13
Aver.	8.89	38.06	62.71	141.02	168.94	88.22	0.00	0.00	0.00	44.14	42.16	30.47	624.62

The surface water and groundwater balance obtained from this study is currently being refined on the basis of lysimetery studies in the area and crop areas determined from survey and GIS data.

Digital Elevation Map of the Study Area

A digital elevation map of the study area was developed by digitising more than 9,000 data points from 39 maps as shown in figure 9. According to the digital elevation model the Yellow river is higher than the surrounding irrigation area due to deposition of sediments over the geological times.

Figure 9. Digital elevation map of LIS - 39 maps, 9,288 data points.

Using aquifer, channel geometry, groundwater pumping and recharge-analysis data a three-aquifer layers surface water and groundwater interaction model of the LIS has been developed. The model consists of 6,468 cells for each aquifer layer. The area of each cell is 500 m^2. The result of an initial steady state simulation overlaid on a false cover image of the study area is given in figure 10. The preliminary results show that the Yellow river is a major source of recharge and there is a major cone of depression under the Kaifeng city, which causes some of the Yellow river seepage and irrigation losses to be captured by the urban pumping. The recharge due to surface irrigation from the north of the railway line is being captured by groundwater pumping on the south of the railway line. Incorporation of time-dependent recharge and discharge, and refining river and channel geometry will help further improve this model during 2003-2004.

Figure 10. Steady piezometric levels under the LIS area.

Activity 2.2: System Scale Studies for the Murrumbidgee Irrigation Area

Objective: To identify optimal options for improving river water flows while minimizing adverse economic and environmental impacts within the irrigation areas of the Murrumbidgee basin.

Progress

A three-dimensional surface water and groundwater interaction model of the MIA region has been developed. Figure 11 shows the tertiary bedrock formation under the MIA using deep bore logs in the region. There is a major impact of bedrock geometry on the surface water and groundwater interactions in the region since the presence of unconnected "local alluvial pockets" impedes regional flow. The surface water and groundwater model has been calibrated on a monthly basis for the 1995-2000 period. Currently, a number of future land- and water-management scenarios are being modeled in close collaboration with the project steering committee. Figure 12 shows an estimate of vertical and lateral groundwater outflow capacity of the aquifers, which will be used to determine net recharge limits for the seven management zones.

Figure 11. Bedrock configuration for the MIA (x and y axes show UTM coordinated and z axis AHD elevation; all units are in m)

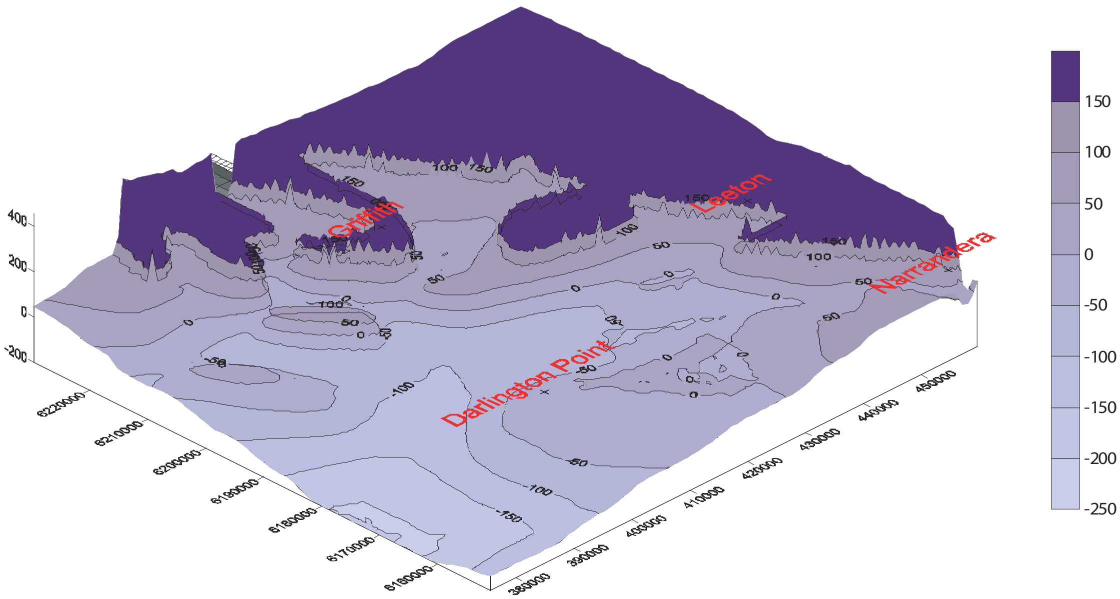
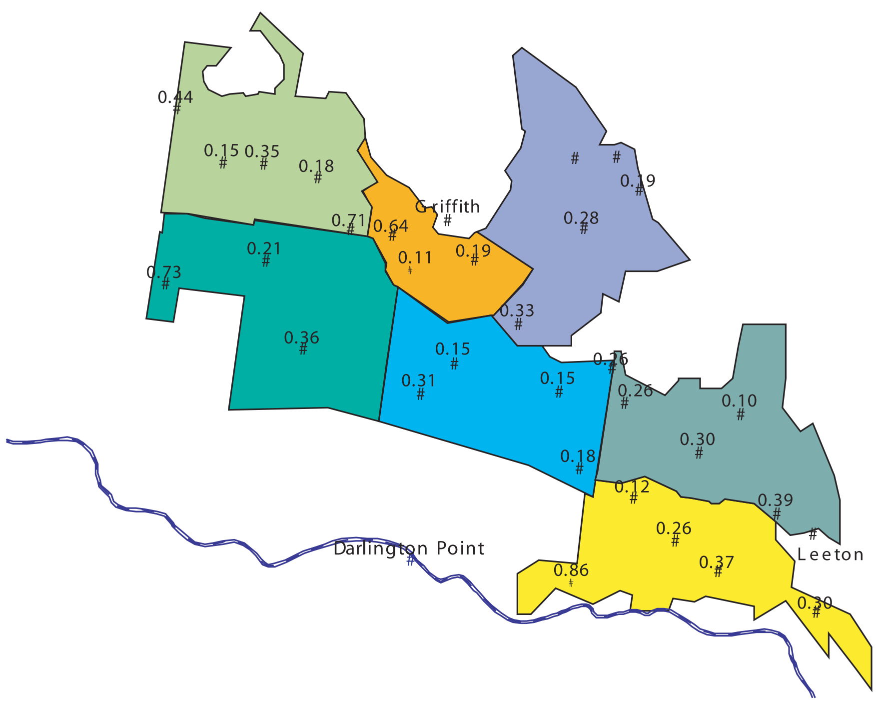


Figure 12. Groundwater outflow rates in ML/ha for the MIA.



A multi-objective nodal network optimization model for the MIA region has been developed using GAMS modeling environment. It simultaneously optimizes three objective functions:

- maximizing net returns (NR)
- minimizing variable cost (VC)
- minimizing total supplementary groundwater pumping requirements to meet crop demand

The three objective functions are formulated as follows:

$$Max \quad NR = \sum_{c} CGM(c) \times X(c) - \sum_{c}\sum_{m} (WREQ(c,m) \times X(c) \times C_w) - C_p \times \sum_{c}\sum_{m} P(c,m)$$

$$Min \ VC = \sum_{c}\sum_{m} \left(X(c) \times WREQ(c,m) \times C_w \right) + \sum_{c} X(c) \times Vcost(c)$$

$$Min \ TP = \sum_{c}\sum_{m} P(c,m)$$

where *X(c)* = area of crop *c* (ha); CGM(c) = gross margin for crop c (\$); *WREQ(c,m)* = water requirement for crop c in month m (ML); C_w = total cost of water per unit volume (\$/ML); C_p = cost of groundwater pumping and delivery (\$/ML); Vcost = variable cost (such as fertilizer and pesticides applications) per hectare other than water cost for crop c; and P*(c,m)* = volume of groundwater pumped from irrigation areas for crop c in month m (ML). The model consists of a network of nodes that connect supply nodes to irrigation or urban areas (demand nodes). The links connecting the nodes include river reaches that may carry environmental flows as well as irrigation canals. The physical and environmental constraints imposed on the model are given in Xevi and Khan 2003.

Conceptually, NR and VC may represent the view of resource economists while minimizing total pumping may be the desired goal to avoid groundwater mining and aquifer pollution. The management options to achieve the above objectives consist of the selection of an appropriate mix of crops, optimum level of groundwater pumping and appropriate allocation of water for irrigation and environment. Constraints imposed on the system include seasonal environmental flows targets. In addition, water allocation rules and pumping targets for each month are constraints imposed on the system. A customized user-interface for this model has also been developed as shown in figures 13 and 14. Details of this model are given in Xevi and Khan 2003.

Figure 13. User-interface of the Nodal Network Model.

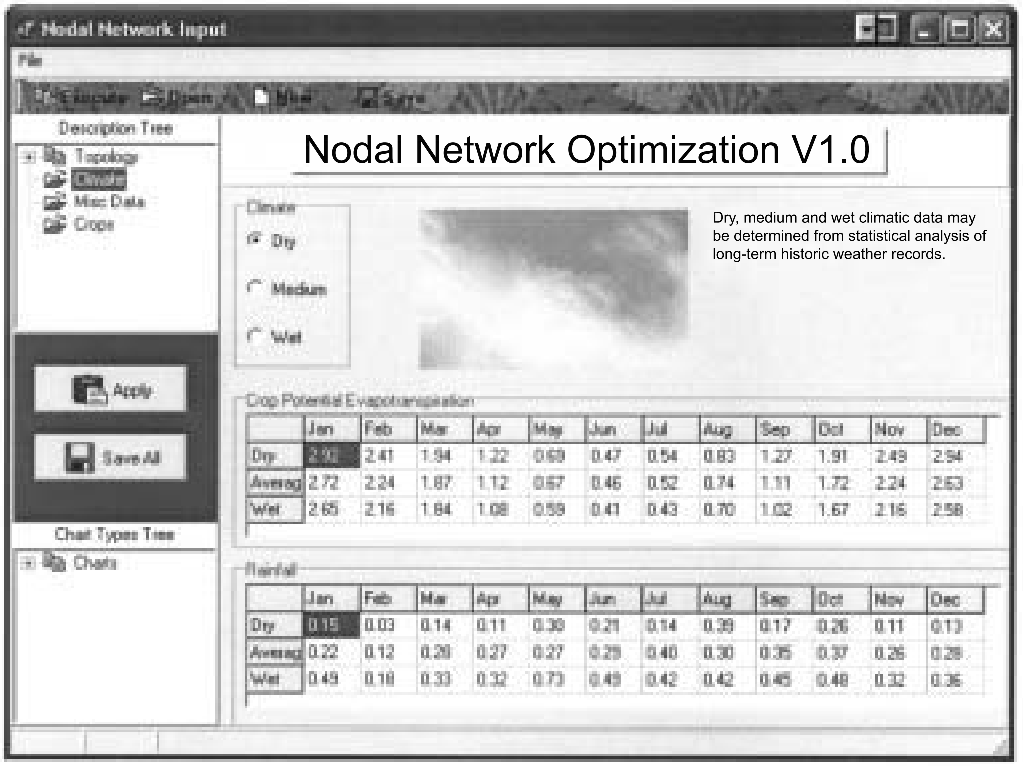
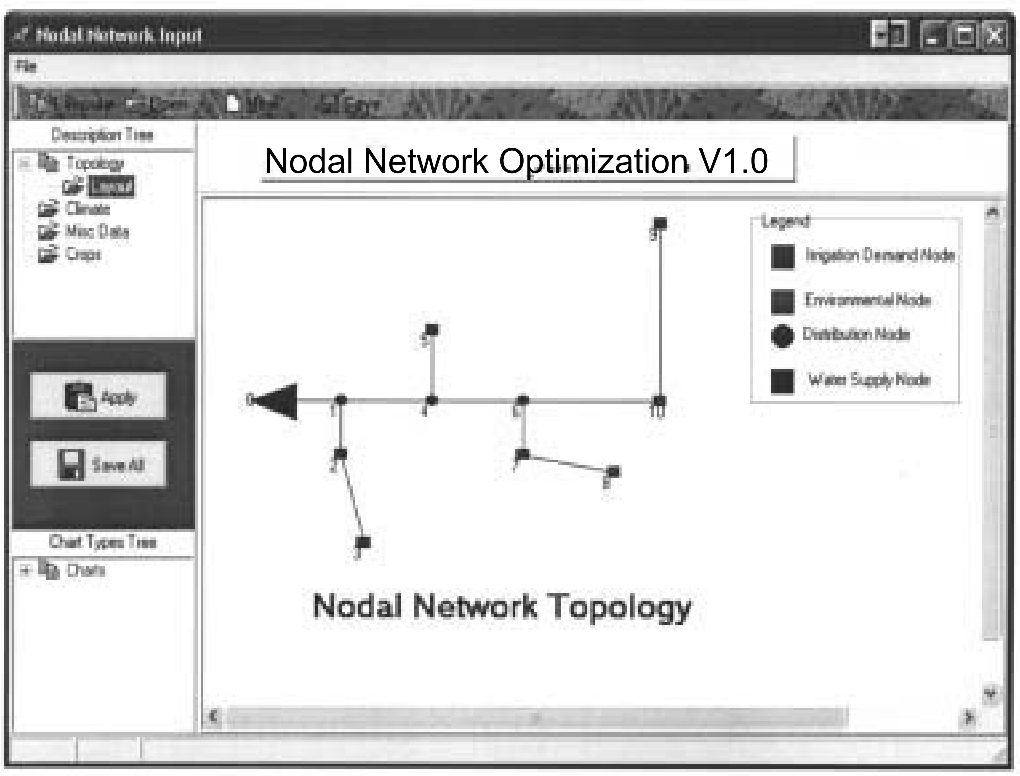


Figure 14. Schematic of the Nodal Network Model.



Other Activities

CSIRO Land and Water hosted a project-related delegation from the Provincial Water Bureaus in Henan, Hubei and the Ministry of Water Resources.

Cui Yuanlai and Luo Yufeng visited Australia to work with CSIRO Land and Water Griffith team on the LIS surface water and groundwater balance and East Main Canal Seepage Model.

Khan organized a dialogue on water and climate with key participants from a number of Australian national, state government and research organizations at the Brisbane River Symposium, September 2002. The Murrumbidgee component of the ACIAR project was well represented by a number of stakeholders from the region.

Khan gave a presentation on modeling developments of the ACIAR project at the Australian National Committee on Irrigation and Drainage Conference, Griffith, 1-4 September 2002.

He presented the Murrumbidgee project and MDB UNESCO's HELP perspectives at the "Synthesis Workshop of the Dialogue on Water and Climate" in Dhaka, Bangladesh on 17 and 18 December 2002.

He attended the 3rd World Forum on invitation from Swedish IHP, HELP and Dialogue on Climate and Water. He represented ACIAR-related research in the Murrumbidgee catchment in the sessions on Dialogue on Water and Climate and Basin dialogues - scientists,' policymakers' and stakeholders' perspectives, March 2003.

PROJECT IMPACTS

The following is a statement on impacts prepared by our Chinese colleagues that refer to more than just the time period covered by this report.

Community (Social, Economic, Environmental)

(1) At national level, the AWD irrigation technique has been accepted, and its application in the whole of China has been suggested in the National Water Saving Irrigation Development Planning and the National Programme for Efficient Agricultural Water Use issued by the Ministry of Water Resources of China. Water Productivity has been selected as an indicator for evaluation of the modernization and rehabilitation of irrigation schemes in China and for assessment of all water-saving projects that are funded by the government.

(2) At Tuanlin, study results confirmed that farmers could reduce water input without affecting yield by using AWD. This gave confidence to system managers who encourage farmers to accept this technique on a wider scale and this, in turn, will help them with their plan to divert more water from agriculture to other users.

(3) In early studies of water saving for rice in China, most of the studies focused only on improving water use efficiency without considering fertilizer use efficiency. This study investigated the interactions between irrigation practices and fertilizer supply. Results show the need to integrate the management of water and fertilizer to obtain optimum yields of paddy rice.

(4) In Huibei, the water-saving technique was not used before our project. After the demonstration of this project, farmers as well as the management agency are thinking of adopting AWD in LIS as one of the main strategies to cope with the water shortage in the Yellow river. Also, aerobic rice demonstration in Huibei showed that there could be a possibility to plant aerobic rice instead of paddy rice to cope with water shortage in LIS. In fact, some local partners are very interested in increasing the demonstrated area of aerobic rice.

(5) Because of water-saving irrigation for paddy or using aerobic rice, seepage from paddy fields decreased much; this also decreases the loss of fertilizer and improves the environments in rice-cropping area.

Capacity-Building Impacts

(1) In the past 2 years, Prof. Li Yuanhua gave lectures about AWD for paddy rice to more than 200 senior researchers and managers from all over China. Based on the research on water productivity on different scales, he also gave lectures on the methodology for increasing return-flow use and strategies for water-resource planning to more than 300 senior researchers and managers from all over China.

(2) Trainings that have been offered to Chinese colleagues (these are already in the project annual report.

(3) Master and Ph.D. dissertations, which were based on the projects:
One Ph.D. student graduated from WHU in 2002. Six M.Sc. students graduated from 2000 to 2003 from WHU, and four M.Sc. students graduated from 2002 to 2003 from HAU. Three Ph.D. candidates and three postgraduate students (M.Sc.) from WHU and two postgraduate students (M.Sc.) from HAU are engaged in the project. One student from the Wageningen University (co-advised by IRRI scientists) also works on the data from the Tuanlin experiments.

(4) Wuhan University and Huazhong Agricultural University are known more by overseas institutions. WHU is collaborating with IWMI and CSIRO in applying for CP projects in the Yellow river basin.

(5) Tuanlin and Huibei station improvement.

Due to the project, Tuanlin became a “training center” for irrigation experiments and water management (especially in the aspect of water-saving techniques). Two training courses have been given to irrigation managers from all experimental stations in Hubei Province in 2001 and 2002 in collaboration with experts from WHU and HAU. In June 2003, Tuanlin was approved by the Ministry of Water Resources of China as one of the 30 Central Experiment Stations in China, and Huibei was approved by the same Ministry as one of the 85 Key Irrigation Experimental Stations in China.

Science Impacts

(1) Improving the understanding of water by nutrient interaction in AWD and its "flexibility." These will be related to the application of the techniques elsewhere.

(2) Chinese partners are the pioneers to have contributed to the methodology of water accounting at different scales in China based on experimental data. More and more people agree with the concept that "paper water saving" is not equal to "true water saving" due to the project.

(3) Chinese scientists have paid less attention to the socioeconomic aspects in the field of water saving. This project has improved the understanding that water saving can be economical or uneconomical. Economic analysis is very important in the application of WSI techniques.

PROJECT MANAGEMENT

Revision in Project Objectives

The objective of activity 3.1 has been revised in light of changed circumstances surrounding the project staff. At a meeting of all subproject leaders held at IRRI in May 2002, a decision was made to focus on two key surveys, one in the Zhanghe Irrigation System (ZIS) and another in the Liuyuankuo Irrigation System (LIS). The agreed-upon new objectives, outputs, and potential applications are as follows:

Objective: To quantify the effects of water resources outside the direct control of irrigation system managers (ponds in ZIS and groundwater in LIS) on farmer adoption of water-saving practices.

Scientific output: a) A detailed description of the pond system in ZIS including ownership structure, patterns of multiple uses (e.g., fisheries) mitigation of risks, and an econometric assessment of its effects on the adoption of WSI practices. b) Improved understanding of the changing role of groundwater extraction over time in optimizing the use of available water resources within LIS, including the quantification of pumping costs and the effects of pumping on farm profitability and reliability of water supplies.

Potential application: a) Will be crucial in assessing the potential for application of WSI techniques in other countries where alternative sources of water are not always available. b) Will provide information for understanding the long-term trends in water productivity in LIS and how canal lining or reduced diversions from the Yellow river may affect pumping costs by reducing groundwater recharge.

Progress toward Prescribed Outputs in Project Document (See Table 1.16 in Project Document)

Subproject 1

Activity 1.1 Raised bed (SSC) has been discontinued. Experiments have been successfully completed in ZIS with AWD, partially rain-fed, and flush irrigation treatments and in LIS with partially rain-fed and flush irrigation treatments. In both sites trials include the comparison of the yield and water saving performance of aerobic with conventional rice varieties. The water balance work is OK but data on transpiration will be obtained from other sources.

Activity 1.2 The modeling work is on track. With experimental data from ZIS and LIS the ORYZA model is being calibrated and validated. The model is being modified to accommodate aerobic rice. Discussions are underway to link the output from this model to the modeling in subproject 2. We developed a common work plan for both subproject 1 and 2 to a) find the effects of WSI on the groundwater level and the general subsurface hydrology of Kaifeng and b) to determine how these in turn will influence water input, yield, and water productivity of WSI.

Activity 1.3 The analysis of input use and profitability of AWD has been completed in ZIS. There has been almost no adoption of WSI practices in LIS to date. Cost and return comparisons were conducted for aerobic vs. conventional rice on a small number of farms testing aerobic varieties.

Subproject 2

Activity 2.1 Water-balance studies scaling up from the farm to the meso-site have been completed for ZIS and are in progress in LIS. The water-balance results at ZIS show that there is very limited potential for further water-saving at the system-basin level.

At LIS the groundwater modeling (MODFLOW) is on track and is already providing useful insights in understanding the surface water-groundwater linkages crucial to the proper management of LIS water resources.

The data base for GIS format will be available for LIS but not for ZIS.

Separating the impact on water savings of various management practices at the farm and system level (e.g., AWD, volumetric pricing, small reservoirs) is proving to be a difficult task. In ZIS, survey and modeling work is in the planning stage to identify more clearly the impact of small reservoirs.

The modeling work in China is on track but still in the formative stage. There is a need for greater communication across subprojects to link the modeling activities in stage 2 with activities 1.2 and 3.1 in order to relate physical to institutional analysis. We need to be able to use the modeling results to assess the physical and socioeconomic consequences of water-allocation decisions.

Although we are further ahead in our thinking at ZIS than at LIS, we are not ready as yet to recommend a set of management practices that would meet the objectives of water savings and increasing water productivity.

Activity 2.2 A three-dimensional surface water and groundwater interaction model of the MIA has been developed and calibrated on a monthly basis for the period 1995-2000. A multi-objective nodal network optimization model for the MIA region has also been developed. Supply nodes are connected to irrigation- or urban-area demand nodes. A number of land- and water-management scenarios are being simulated with the models. The objective is to provide an appropriate mix of crops that will provide zero net recharge, optimum use of surface water and groundwater, and appropriate allocation of water for irrigation and the environment.

Subproject 3

Activity 3.1 The activity was revised in light of changed circumstances surrounding the project staff (see section 1). A questionnaire on water management and costs and returns for the summer crops in LIS was developed and implemented. However, due to problems with the implementation most of the key data are unusable. In line with the new objectives, draft questionnaires have been developed for pumps in LIS and small reservoirs in ZIS and they will be implemented in the coming year.

Activity 3.2 The data on long-term trends in water use and crop production in LIS are almost complete, although some work continues to check discrepancies in the data. Data on long term-trends in ZIS have been updated. Both sites reflect the continuing growth in demand for water for nonagricultural uses and, hence, the need to increase the productivity of water for irrigation. In ZIS, the demand is being met by a reduction in the diversion of canal water for irrigation, but in Kaifeng this demand is being met by groundwater extraction which is lowering the water table.

Subproject 4

Dissemination of findings to date have largely targeted national and international audiences (see sections 2 and 4.4). The links that can promote the use of these findings to farmers need to be strengthened. More importantly, the message to be conveyed with respect to improved management for water savings needs to be clearly defined.

Thus far, training activities have been mostly "on-the-job" training (section 4.5). IRRI has developed a special training workshop for crop water modeling - ORYZA (not yet given to Chinese colleagues due to SARS). CSIRO has developed training materials for groundwater modeling - MODFLOW, and IWMI has training materials for water balance.

See annex 1: Minutes of the May ACIAR Project Meeting, and annex 2: Willett Report on a Visit to the Philippines for more details.

Describe Any Variations in Activities in the Flow Chart (See Table 1.15 in Project Document)

While the various activities are generally on track, the timetable has been set back to some degree because of SARS. As a consequence of SARS we were unable to hold our annual review and planning workshop in China, but held the workshop at IRRI instead, without our Chinese colleagues who could not attend it.

See annex 1: Minutes of the May ACIAR Project Meeting, and annex 2: Willett Report on Visit to the Philippines for more details.

Project Personnel Changes

There were three personnel changes at IWMI mostly affecting subproject 2.

(i) Ronald Loeve left IWMI in February to return to the Netherlands to do a Ph.D. However, he plans to do his Ph.D. thesis research on the work he started at the LIS sight.

(ii) Peter Droogers, who was to be involved with the modeling, resigned from the Institute in July 2002 and returned to the Netherlands. Nicolas Roost has been added to the team with some backup support from Chu Thai Hoanh. Roost is currently developing a model to test the impact of farm-level reservoirs on water savings.

(iii) Jinxia Wang, a postdoctoral economist, was stationed in Beijing and completed her postdoctoral assignment in December. She was never actively involved in the project.

TRAINING ACTIVITIES

In addition to field visits by the staff to China, four of our Chinese colleagues received training during the year at research centers outside of China.

Hong Lin spent a month at IRRI from August 6 to September 10 where she worked under the guidance of Piedad Moya and David Dawe in analyzing a) the data from questionnaires, b) the long-term trends in water use and agricultural production in Kaifeng city, and c) participating in an IRRI team survey of farmers in Central Luzon.

Lu Guoan has been a frequent visitor to IRRI consulting with To Tuong and Romy Cabangon on design and analysis of field experiments. This past year, he was there from December 11 to Jan 22 at IRRI.

Lu Yufeng completed his M.Sc. at Wuhan University on modeling channel seepage at CSIRO Land and Water, Griffith. He passed the entrance examination for Ph.D. and will continue to work on up-scaling irrigation efficiencies and water management in the LIS area.

Dong Bin received his Ph.D. from Wuhan University in March. The title of his thesis is: “Study on the scale effect of water-saving irrigation for rice.” Bin was at IWMI from late February to early May working under the direction of David Molden. He did water accounting at different scales in LIS and analyzed the long-term historical data in Kaifeng city and LIS. He prepared a draft IWMI research report on “Issues of scales and water productivity” and worked with Nicolas Roost and Cui Hoanh for the ZIS modeling.

A training course was developed by IRRI to familiarize students with the use of ORYZA2000. The model simulates the growth, development and water balance of rice under conditions of water and nitrogen limitations. The course was given at IRRI from April 28 to May 2 for IRRI (Cabangon, Castillo and support staff) and Philippine NARES researchers. The course for the Chinese ACIAR project staff was scheduled for June 2003 but had to be postponed because of SARS.

D. List of Publications

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1st International Yellow River Forum (Postponed from May to October)

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Annex 1

Minutes of Project Meeting, IRRI, Philippines, May 20-22, 2003

Project Leader's Foreword

We held a very successful meeting, and appreciated, in particular, the participation of Ian Willett, but missed the presence of our Chinese colleagues.

The minutes below were prepared by Romy Cabangon, who took notes during the meeting, and Randy Barker, who prepared daily summaries. We are nearing the end of the project but are committed to a good deal of analytical work involving the integration of subprojects 1, 2 and 3. This will require frequent exchange of e-mails among principals (with copies to all members of our research team, the Swimming Ducks), a periodic (every 3-4 months or so) updated report on progress prepared by Randy Barker and small group meetings when necessary.

Normally, this project would have an external mid-term review. However, it was decided that this meeting would take the place of the mid-term review. Willett's objectives are to review the objectives and milestones of the project as set forth in the original proposal and to see what changes needed to be made. We systematically reviewed the objectives and scientific output of the project as listed in the log frame on pages 11-15 of the original proposal. Ian Willett is preparing a separate report covering the progress in each project activity in which he gives detailed comments on the log frame.

We hope that some of us can meet in China in September-October possibly still in connection with the postponed Yellow River Forum.

Participants

ACIAR
Dr. Ian Willet

IWMI
Dr. Randy Barker
Dr. David Molden
Dr. Nicolas Roost

CSIRO
Dr. Shahbaz Khan

IRRI
Dr. To Phuc Tuong
Dr. Bas Bouman
Dr. David Dawe
Ms. Pie Moya
Mr. Paul Belder
Mr. Romy Cabangon

May 20, 2003 (Day 1)

Most of Day 1 was taken up in a discussion of the findings of subprojects 1 and 2.

Subproject 1: Summary

Subproject 1 reported on results from Tuanlin and Kaifeng. In Tuanlin, PRF (no water after crop establishment) and AWD gave the same yield but with higher water productivity for PRF. The data on economic analysis of AWD and conventional irrigation are close to completion for ZIS. In the coming year, subproject 1 will drop SSC but will focus on AWD and aerobic rice in LIS and AWD plus PRF in ZIS.

In a related project Bas Bouman reported on costs and returns from a small group of farmers practicing aerobic rice in LIS in order to begin to determine the conditions under which aerobic rice might be suitable.

The recently started modeling work with ORYZA is progressing.

A. Station Experiments at Tuanlin and Kaifeng in 2002 (R. Cabangon)

In 2002, the experiments at both sites on groundwater table conditions were deeper than in 2001.

In the Kaifeng main plot water treatments were flush irrigation when soil water potential reached (1)-10 kPa, FI-10 (2) -30 kPa, FI-30 (3) -70 kPa, FI-70, and (4) PRF treatment. In the subplots the varieties were inbred and aerobic rice.

In the Tuanlin main plot, water treatments were (1) AWD, (2) PRF and (3) flush irrigation at -50 kPa, FI. In the subplots the varieties were hybrid and aerobic rice. In sub-subplots the N rates were 0-N and 180 kg N/ha.

In both sites, water treatments were imposed after the transplanting recovery period.

The results confirmed that yield responses to water management are highly dependent on groundwater table conditions.

In Kaifeng, -30 kPa at 15 cm depth seemed to be the threshold to maintain high yield.

In Tuanlin, PRF rice seemed to do as well as AWD. More study is needed on the interaction of irrigation and groundwater table depths before recommendations for the large-scale application of WSI can be made.

The high water table may be related to maintaining field water in surrounding rice fields. In the wide-scale adoption of WSI, the water table may go down and the effects of water management on yield may be more prominent. Systems approaches (models) may be used to analyze the effect of groundwater and irrigation water management on rice yield and water productivity.

Seepage was the main component of outflows, much larger than percolation. The role of seepage in “regional water balance” must be further investigated. This may depend on the location of the field in the toposequence.

Further work on aerobic rice in Tuanlin should focus on variety selection and that in Kaifeng on management to increase yield by:

- Better nutrient management.
- Increased plant density.
- Direct seeding to avoid transplanting shock (does not require standing water during the transplanting recovery=>less irrigation).

These will increase water productivity of aerobic rice.

B. Participatory Testing of Aerobic Rice in Kaifeng in 2002 (Bas Bouman)

The small number of farmers who participated in the aerobic trial were from south of the railway and immediately above the north of the railway line. There were also a couple of “secret farmers” who were not originally in the list but who were able to secure the seeds and grow the aerobic rice in their fields. Farmers who grew other crops like maize and cotton were selected. Some lowland rice farmers were also selected.

In general, aerobic rice (4-5.5 t/ha) had lower yields than lowland rice (6-8 t/ha). However, the "secret farmers" who planted aerobic rice were able to obtain yields of 5 tons/ha, which were comparable to yields of aerobic rice obtained in the station-managed experiment.

The total water input was three times higher in lowland rice than in aerobic rice. Water productivity in aerobic rice was higher than in lowland rice and cotton but was lower than in maize. Net income of aerobic rice was lower than that in other crops.

ORYZA 2000 Presentation (Bas Bouman)

Bas presented a brief description of the ORYZA 2000 model and how it may link to the hydrology models in subproject 2 in LIS (Shabbaz Khan) and LIS (Nicolas Roost).

C. Modeling at Field Level (Paul Belder)

Paul calibrated the crop parameters for Tuanlin for hybrid rice. Paul ran the ORYZA model at different scenarios, e.g., at Continuous Submergence (CS) and Alternate Submergence Nonsubmergence (ASNS) at different levels of nitrogen rates, e.g., 0-N and 180 kg N/ha. The ORYZA model simulated observed values reasonably well. He showed outputs of different crop variables such as LAI, biomass, etc., and soil and water variables, e.g., water depth and soil tension.

Work Plan of Subproject 1 for 2003 (T. P. Tuong)

Presentation of the work plan for 2003
The model part for Kaifeng is subjected to what may happen to SARS.

1. Field experiment to increase yield and optimize water productivity of direct- seeded aerobic rice (Kaifeng).
2. Comparing rain-fed and irrigated rice (Tuanlin).
3. Modeling at field level.
4. Farmer's trial of aerobic rice (associated activities, not funded by the ACIAR project).
5. Publication.

Subproject 2: LIS—Summary

Molden indicated that work on the LIS mezzo sites would continue but that we needed data on the outflow from LIS and that this would be obtained in the coming year. Would it be possible to get this in the coming year?

Khan reported on the groundwater modeling and illustrated how the drawdown of water for municipal use in Kaefeng city was competing with water use for agriculture in LIS. He has been in touch with Yuanlai regarding additional data needs. We discussed simulating the impact of canal lining and other water-saving practices and looking at comparative costs.

Water Accounting at Different Scales at LIS (David Molden)

Decreasing irrigation duty with time from 1974-1998.

Modeling at LIS (Shabbaz Khan)

Shabbaz presented the lump analysis and cross section model at LIS. Water balance components were shown together with mapping to show the movement of groundwater in LIS toward Kaefeng city and to the south of the railway tracks. In linking ORYZA and the groundwater model, fluxes will be used from ORYZA as recharge.

Future work in LIS groundwater modeling

Refine lump analysis

Include surface water features

Calibrate for 10-year data and validate for the next 10-year data

Build water quality aspects—not a high priority for this project

Link model with ORYZA model from subproject 1

Upscale from field to subsystem level

At the moment the model is of steady state; eventually it will become dynamic.

In the list of different scenarios, Randy Barker stressed that objectives of Chinese colleagues must be addressed.

May 21, 2003 (Day 2)

Subproject 2: ZIS—Summary

David Molden synthesized the findings in a forthcoming research report by Dong Bin, Molden, Loeve, Li Yuanhua and Chen Chongde on "Issues of Scales in Water Productivity: A Case Study of the Zanghe Irrigation System in China." Molden noted that it has been difficult to isolate the factors contributing to the increase in water productivity over time.

Nicolas Roost presented his plans for modeling to isolate the impact of small reservoirs or ponds. There was discussion about the need to visit ZIS in order to be able to properly develop the model. It is hoped that such a visit could take place by October, as going beyond this date would push the work back too far toward the end of the project.

Water Accounting at ZIS (D. Molden)

Water productivity per unit of gross inflow increases significantly as one moves from farm to system or basin level. The analysis of data from both time series and remote sensing indicates an increase in water savings and water productivity over time. There is only a 10% loss in the system. Hence, the question is how to reallocate the water.

Remote sensing work has been carried out for land use classification and for estimating yields through measurements of ET.

OASIS Framework (Nicolas Roost)

Presentation of OASIS

Investigate the role of reservoirs and small ponds by running the model with and without reservoirs to see impact on water savings.

Work Plan for OASIS in 2003

1. Build info base, system-level modeling
   a. Field data collection
   b. Base map development
   c. Remote sensing analysis
2. Model conceptualization
3. Model testing and validation
4. Scenario analysis

Need to know what the minimum data requirement is and if the data are available.

Subproject 3: LIS—Summary

In subproject 3, we first discussed the work on long-term trends in Kaefeng and LIS. Ronald, Dong Bin, David Dawe and Hong Lin have all been involved in collecting and summarizing data. There are some problems with some of the data, and David Dawe agreed to take the lead in contacting everyone, assembling and checking the data. We can then produce a good paper on long-term trends in Kaefang and LIS.

We also discussed the priorities for survey work in the coming year. It was agreed that the first priority was on ponds in ZIS and the work on farmer organizations would probably not be pursued. The survey results should provide important information and input into the Roost development of the OASIS model.

The priority in LIS would be on a survey and economic analysis of pumps. This would complement the subproject 2 model simulations allowing us to estimate the economic cost of pumping from lower depths due to reduced water releases from the Yellow river or reduced groundwater recharge due to canal lining. The main change in LIS was the decision not to pursue the economic analysis of returns for different crops.

Long-Term Trends in Water Utilization, Cropping Patterns, and Crop and Water Productivity (David Dawe)

A good deal of data have been collected for both Kaefeng city and LIS, covering the period 1968 to 2000. However, there are some gaps and inconsistencies in the data that need to be corrected where possible. Dawe will be circulating more details on this.

Trends for Kaefeng City show an increase in water for nonagricultural vs. agricultural purposes and an increase in groundwater vs. Yellow river diversion water.

Economic Analysis and Data Needs in LIS and ZIS (David Dawe)

Difficulties in carrying out the planned surveys in LIS and ZIS were discussed. It was agreed, in the case of LIS, that the focus would be on surveys to identify costs associated with pumps in order to complement the model scenarios being run and assess the impact in terms of costs in LIS resulting from reduced diversions from the Yellow river, canal lining, or other interventions.

It was agreed to research on the economics of pumps in LIS and small ponds or reservoirs in ZIS.

May 22, 2003 (Day 3)

Discussion on linking models and subproject research (P. Belder, R. Cabangon, N. Roost, B. Bouman, S. Khan, T. Tuong and D. Dawe).

Summary

The first part of the morning was taken up with a discussion on the integration of modeling in LIS in subproject 1 (Bouman) and subproject 2 (Khan). The distinction was drawn between physical integration and integration with the objective of informing and influencing management. We see the latter as the principal objective of the modeling work. This led to a discussion of the role of subproject 3. That is to say, what were the implications of the modeling different scenarios on the cost of pump operations?

LIS Modeling Time Table

March/April, 2003	Prototype available already
April, 2003	Workshop (all)
After April, 2003	Li Ping Feng and Cui Yuan Lai in Griffith (1 month)
October, 2004	Refined model, Scenario run and analysis (training)

ZIS Modeling Time Table

October, 2003	Field visit (all)
December, 2003*	Prototype model
March/April, 2004*	Initial scenarios, meeting with stakeholders

*Depending on the decision in October

Integrating Subprojects 1, 2 and 3 (All Staff)—Summary

At LIS, the integration of subproject 3 with other subprojects will focus on the economic analysis of the costs associated with canal lining, adoption of water-saving technologies, and pumping for the Khan model scenarios assuming different levels of irrigation water intake from the Yellow river. For example, given the interest in the impact of canal lining, we would run the model scenarios for a given Yellow river water intake, with and without canal lining and then compare the costs associated with pumping and canal lining.

At ZIS, subproject 3 will focus on the impact of small reservoirs. The effort will be to determine how small reservoirs are managed in conjunction with ZIS and with farm-level decisions regarding water use. Subproject 3 (Dawe) will work closely with subproject 2 (Roost) in designing a questionnaire that will provide information on small ponds useful in developing subproject 2 model to examine the impact of small reservoirs.

LIS

1. Effect of lining.
2. Decrease in diversion/adoption of WSI.
3. Effect of pumping in the north/surface irrigation in the south.

Hydrologic effects	*Economics*
Groundwater deepens in some areas and increases in other areas	Water costs Pumping cost Initial investment for pumps

ZIS

Hydrologic effects	*Economics*
Reservoir/ponds	Management and institutions
Alternative use of water	Economic trade-offs (???)

Subproject 4 (Barker)–Summary

In Subproject 4 we discussed various means of informing stakeholders and the message to be delivered regarding results. Five levels of stakeholders were defined: international, national, irrigation districts, water users' association, and farm level. Reaching the international stakeholders through meetings and workshops such as the Yellow River Forum or ICID, and research publications presented a relatively easy task. At the national level, we should encourage publication of our results in Chinese and look for an opportunity for presentation of findings and dialogue at a workshop involving policymakers, water-resources managers, etc. At the system level we will have recommendations for improving management and increasing water savings. The farm-level dialogue was seen as most difficult in part because our research was devoted to encouraging farm-level practices for saving water to be productively used elsewhere. The best approach may influence the irrigation managers on the "management of the system," and, therefore, creating conditions for farmers to adapt water-saving technologies. What are the benefits for the farmer? Both the message to be delivered and the presentation of findings will depend on the timing of our results. The subproject can easily report on findings from experiments and farm-level analyses, while findings from subprojects 2 and 3 will depend to a larger degree on modeling results to be obtained over the next several months.

Notes

Communication.
Integrating research.
Needs paper that links the work together (link models, cross-cutting paper).
To promote the project, ICID meeting in Taiwan is a good venue. One abstract from IRRI and one from IWMI.
There is a need to outline the communication between subproject 3 and subprojects 1 and 2.
Communication/dissemination of findings at different levels.

International - ICID, Yellow River Forum	
Workshops IPSWAR	Subproject 4
National - Chinese Language materials, Workshop	Li Yuan Hua, Subproject 2

Irrigation District - meetings	Subprojects 2, 3
User Groups - meetings and dialogues	Subprojects 1, 2 and 3
Farmers - discussion	Subproject 1

Ian Willett emphasized the need to specify concrete impacts.

Closing Comments

Willett indicated that if SARS prevails the project might be extended somewhat in time.

There will be an external review 3 months before the end of the project.

- Achievement of objectives
- Potential impacts
- Recommend on future work

Annual Report will be completed by July in the given new ACIAR format.

Submit to Randy Barker Progress reports in the same format as last year (see IWMI Working Paper 54) by June 10 and he will put in the ACIAR format.

The attached appendix shows the revision of the flow chart and outputs table (tables 1.15 and 1.16 of the original proposal) based on our discussions. In Appendix II, Ian Willett's report presents a somewhat different revision of 1.16).

Appendix: Revision of Outputs Table

[Words in italics on Pp. 42–46 are modifications made during the mid-term review, 20–*22* May 2003.]

Subproject 1: Field scale. Compare yields, profitability and on-farm water-balance components of three different systems of water-saving irrigation: AWD, SSC and aerobic rice, and continuously flooded rice.

Mid-term review: SSC will not be continued in year 2004. Replaced by "partially rain-fed" in Tuanlin; focusing more on aerobic rice in Kaifeng.

	Objectives	Scientific Output	Potential Application
Activity 1.1	To quantify and compare yield and water-balance components of three water-saving irrigation systems and continuously flooded rice in two contrasting soil-hydrological environments.	Methods of determining water-balance components under three water-saving irrigation systems. Mid-term review: we do not measure ET in China, but we do it at IRRI, backed up by work at IRRI. Crop growth, yield response and water-balance components under three water-saving irrigation systems and continuously flooded rice.	Determine water balance and water saving in other locations. Adaption and validation of crop model.
		Mid-term review: OK	Introduction of water-saving irrigation with acceptable rice yields.
Activity 1.2	To adapt and validate crop growth and water-balance simulation models for AWD, SSC and aerobic rice system.	Rice-crop growth and water-balance models refined and validated for two contrasting sites in China. Mid-term review: On track, will deliver. *Add aerobic rice module.* Water balance and estimation of return flow refined and validated for two contrasting sites in China. Mid-term review: OK	Predict optimal water management for WSI technologies for each study site taking into account seasonal and site variability. Application to other environments.
Activity 1.3	To quantify effects of AWD on input use and profitability at the farm level. *Mid-term review: will include aerobic rice in LIS.*	Cost and return balance sheet constructed showing the effect of AWD on yield, input use and profitability: (i) between farmers at different locations within each irrigation system (ZIS and LIS); and (ii) between farmers in the two irrigation systems.	Introduction of AWD that is profitable for farmers.

Subproject 2: Scaling up. Impact of alternative water saving and management practices at farm, irrigation system, and subbasin levels.

	Objectives	Scientific Output	Potential Application
Activity 2.1	To assess whether on-farm water-savings practices—AWD, SSC and aerobic—lead to real water savings at the irrigation-system level, enabling more water to be available for other uses in a manner that sustains existing production and is not detrimental to the environment.	Quantified water accounts at field, meso (intermediate scale) and irrigation-system scales to better understand existing physical and institutional processes. Mid-term review: Water accounting OK. Will not continue with institutional process in LIS; will document this. Better understanding of physical processes and knowledge of how farm-level intervention scales up to system and subbasin. *Mid-term review: on track.*	Water-resources management planning at a range of scales from farm to irrigator group to irrigation-system level.
		Database in GIS format for the three sites (ZIS, LIS, Murrumbidgee). *Mid-term review: LIS is on track. Difficulty at ZIS due lack of base maps.* *What we should do is to transfer the data to the System Manager in China.*	Readily accessible data for this study and future activities such as benchmarking or performance monitoring.
		Quantification of the impact of farm-level and other water-management practices at irrigation-area and subbasin scales in terms of water-savings production, productivity, and environmental sustainability. *Mid-term review: on track at ZIS. Will be supported by modeling. Quantifying the "environmental sustainability" will be outside the scale of the study.*	Knowledge on the determinants of water-savings in rice areas that are useful in design, management and policy interventions at the study sites and elsewhere.

	Objectives	Scientific Output	Potential Application
Activity 2.2		Improved methodologies including models for each of the three sites, water accounting, and multi-scale analysis integrated with institutional analysis. *Mid-term review: Good progress; paper will be written on the "lessons learnt" on water-accounting procedures. "Will integrate the institutional" at the project level (probably in subproject 4?).*	Tools and models useful for enhancing understanding and providing decision support for design, management and policy interventions for application at study sites and other areas.
		Recommendations for improved management at the study sites. *Mid-term review.*	Investments, policies and management practices that are better targeted at meeting objectives of water savings, productivity, and environmental sustainability.
	To identify optimal options for improving river water flows while minimizing adverse economic and environmental impacts within the irrigation areas of Murrumbidgee basin. *Mid-term review: everything is on track.*	A spatial hydrologic-economic model for the Mid-Lower Murrumbidgee (MLM) in Australia. Results of application of the model for selected scenarios.	Application of the methodology to other regions to assist in optimizing the use of land and water to achieve environmental sustainability while maximizing financial returns.
		A nodal network optimization model (NNOM) for MLM derived from surface-groundwater interaction model. Investment decision making, and design, e.g., storages.	Investment decision making and design. e.g., storages.
		Assessment of options for simultaneously improving reliability of water supply to irrigators and environmental flows including on- and off-stream water storages, and on-farm water-management options.	Policy development, e.g., reservoir operation and river-regulation flow rules; intervalley and intra-valley water transfers.
			Land & Water Management Planning-options and incentives.

Subproject 3: Effect of policies, institutions, management practices and infrastructure on the allocation and utilization of water and on the incentive to adopt water-saving practices at farm and system level.

The revised objectives and outputs of subproject 3 written up later on by D. Dawe and passed directly to Ian, have not been included in this table.

	Objectives	Scientific Output	Potential Application
Activity 3.1	Quantify the effects of water costs, water-pricing mechanisms, irrigation group size, and mode of group organization on group-level water diversion at ZIS and LIS.	System of cross-section multivariate regression equations estimated to measure the effects of group size, organizational type and water costs on surface-water diversion.	Improvement of irrigation group organizational structure to facilitate water savings at farm level, including application to other irrigation systems.
Activity 3.2	Identify institutions, infrastructure, and decision-making practices that encourage on-farm and off-farm water saving and reuse at ZIS and LIS.	Long-term trends in water productivity estimated at ZIS and LIS. Assessment of the role played by new technologies, improvements to system infrastructure, changes in institution and management policies, and exogenous economic development in explaining these trends. Undertaking of the practical means employed in China to collect money and deliver water.	Improvement of irrigation-system management to increase system-level water productivity, including application to other irrigation systems.

Subproject 4: Extension of research results.

	Objectives	Scientific Output	Potential Application
	Quantify the effects of water costs, water-pricing mechanisms, irrigation group size, and mode of group organization on group-level water diversion at ZIS and LIS.	Findings and results on potentials of farm-level water-saving technologies widely disseminated *Mid-term review:* *Publication: journals, ICID,* *Communication:* *International: ICDI, Journals, etc.* *National: Via Li Yuanhua, Chinese language publication. Need input from Yuanhua.* *Irrigation level user group.* *Farmers: already started in subproject 1.*	Improvement of irrigation group organizational structure to facilitate water savings at farm level, including application to other irrigation systems.
		Training of researchers in China on methodologies for assessing water-saving potential of selected farm-level practices at farm, system and basin level.	

Annex 2

Willett Report on a Visit to the Philippines

LWR1/2000/030
LWR1/2001/003

(19 to 24 May 2003)

I. R. Willett

The main purpose of this travel was to participate in the second annual meeting of LWR1/2000/030 "Growing more rice with less water" (China-IWMI-IRRI-CSIRO). The project is at its midway mark. Most of the work is done at two sites in China but the meeting was switched to IRRI because of travel restrictions due to SARS. Although it was hoped that some Chinese participants could attend this meeting they could not do so. I also visited the Bureau of Soils and Water Management at Quezon City to monitor the establishment of LWR1/2001/003 "Inabanga Watershed, Bohol."

———————————————————————————

Project Meeting for LWR1/2000/030

Growing More Rice with Less Water: Increasing Water Productivity in Rice-Based Cropping Systems (20 to 22 May 2003)

The meeting was hosted by IRRI, Los Baños, as travel to and from China was curtailed due to SARS. It was run in a productive informal style. There were between 12 and 15 participants at most times. They included the key senior project staff (Barker, Molden, Tuong, Bouman, Dawe, Khan). Inputs of less senior staff from IWMI were not so evident considering Droogers, Jinxia Wang and Loeve were meant to be contributed by IWMI.

Below are some key points from the presentations, followed by a brief systematic summary of progress to date. The meeting was focused on the Chinese rather than on the Australian work.

Subproject 1: Water-saving irrigation at field scale (mostly IRRI)

In 2001, there was little difference in the rice yield between reduced irrigation treatments and continuous flood irrigation at the two sites (LIS near Kaifeng, Yellow river basin, and ZIS at Tuanlin, Yangtze basin) because of very shallow groundwater tables. In 2002, the Tuanlin experiment was run at a site with deeper groundwater, with comparisons of water regimes (flush irrigation), varieties and N rates (0 and 180 kg N/ha). The varieties included aerobic rice (provided in conjunction with China Agricultural University) but these were bred for northern China and are not suited to the (warmer) Tuanlin site. At Kaifeng, the deeper groundwater site with light soils only permitted ponding for a matter of hours. The rice was an aerobic variety suited for dry seeding and it suffered from being transplanted. Reduced watering (to -30 kPa at 15 cm depth) decreased yields from 7 to 4.7 t/ha with conventional varieties. Yields of aerobic rice varieties were not so markedly reduced but were generally lower (4 - 5 t/ha) than local practices. From the perspective of water use, the results are not so discouraging because producing 5 t/ha on 500 mm of water (200 mm rain, 300 mm irrigation) is a remarkable achievement. There are obvious questions relating to acceptability by farmers but the difference could be reduced if rice varieties were better matched to the reduced watering conditions (which may be imposed in any case by water suppliers), establishment method and climates.

Bas Bouman (IRRI) has made a connection between the ACIAR project and his work with the Irrigated Rice Research Consortium (IRRC) which emphasizes farmer inputs into experimental work, and between the CAU aerobic rice work and the ACIAR work. At first, it was difficult to get CAU on board and they had no interest in the Kaifeng (LIS) area. In addition, the farmers of this area had no experience of aerobic rice. The project has looked at water use and the financial aspects of aerobic rice in comparison with lowland (fully irrigated) rice at LIS. Aerobic rice yields are lower than lowland irrigated rice, around 4 to 5.5 t/ha. Some local farmers had (without approval or support) implemented aerobic rice with variable results depending on their skills as rice growers in general. It was thought that the yields of aerobic rice will need to be around 6 t/ha to make it attractive to farmers (yield potential of the aerobic varieties is 6 to 7 t/ha). The attractions of aerobic rice are that it is less labor-intensive than lowland (transplanted) rice and is amenable to mechanization (dry seeding).

SARS has stopped Beijing- and overseas-based staff from visiting the LIS field site. Though the experimental work will continue there is concern that the quality of the field work could suffer without visits by external scientists.

Bas outlined work in Brazil and the Philippines on aerobic rice. There is evidence from Brazil that yields suddenly and markedly dropped after a few years. This problem may be related to nematode buildup, and he has some preliminary data to support this explanation. I informed him of the LWR2 "biofumigation" work at UPLB (in vegetable systems and maybe different nematode species, but the aerobic rice work is likely to have to consider rotations to break nematode life cycles).

Subproject 2: Scaling up from farm to irrigation system, and subbasin levels (mostly IWMI)

David Molden set the context for the LIS Kaifeng site. The city is dependent on groundwater for domestic and industrial supplies, and has excessive overdraft of groundwater. The groundwater is also subject to pollution by nitrate. It seems to be a good example of the northern Chinese problem of competition for water between urban and agricultural users.

Shahbaz (who works at LIS, not ZIS) outlined his work on hydrogeology of the district, described in terms of three main aquifers (0-70, 70-170, and >170 m), an area with deep alluvial aquifers. The deep aquifer is of good quality (40 m/day and low salt). The spatial work showed a dramatic and large cone of depression under the city. The Digital Elevation Map showed that the river is raised above the plain. The water is flowing away from the river, so in effect it is replenishing the city and groundwater by underground flow. The models are now ready for application to scenarios including assessing the groundwater impacts of introducing aerobic rice, and modernization of infrastructure (including canal lining which is of particular interest).

David Molden outlined the work at ZIS. Farmers' WSI practices are not ideal AWD but intermittent AWD and all of them include mid-season drainage. Water savings at the field scale are clear but at the middle scale "saved" water is intimately connected with the management of the numerous small reservoirs and ponds within the system. It seems to be the flexibility associated with local water storages that gives the farmers the means to adopt WSI practices; they have less dependence on supplies from the system channels. As only about 10 percent of the water leaves the system there is probably no scope for reducing water discharge (that is no, or very little, scope for more water savings at the whole system scale).

Subproject 3: Effect of policies, institutions, management practices, and infrastructure on the allocation and utilization of water and on the incentive to adopt WSI practices at farm and at system level.

This subproject was presented by David Dawe. The details were not presented at the meeting. The subproject has serious problems with getting questionnaires implemented in the field at ZIS, and changes to the Chinese staff are needed. I will make enquiries about a possible replacement from ACIAR's network of projects, but I am not too hopeful of finding a suitable person. It is not likely the project can train a new person with travel restrictions because of SARS. As a result of staff changes, the May meeting of subproject leaders, and the discussions at this meeting, the following amendment to activity 3.1 was agreed:

Activity 3.1

Objective: Quantify the effects of water sources outside the direct control of the irrigation system managers (ponds in ZIS, groundwater in LIS) on farmer adoption of WSI practices.

Output (1): A detailed description of the pond system in ZIS, including ownership, patterns of multiple use (e.g., fisheries), mitigation of risk, and an econometric assessment of their effects on the adoption of WSI practices.

Output (2): Improved understanding of the changing role of pumps over time in optimizing the use of available water resources within LIS, including quantification of pumping costs and the effects of pumping on farm profitability and reliability of water supplies.

Potential application (1): Crucial in assessing the potential for application of WSI practices in other irrigated areas where alternative sources of water are not available.

Potential application (2): Provide information for understanding long-term trends in water productivity in LIS and how long canal lining might affect the water-management options available to farmers if it reduces aquifer recharge.

Subproject 4: Extension of research results

This was mostly scheduled for the latter half of the project and to date largely involves awareness raising at scientist and policymaker level. The project work will be included with others in IWMI's Comprehensive Assessment. It is certainly too early to promote a WSI-aerobic rice package to farmers, though there is some promotion of AWD in China. Nevertheless, I emphasized the need for some clarity in identifying "next users" of the research findings. The next users can be considered in terms of international, national, irrigation-system level (mostly subproject 2), and agricultural-bureau, water-user-group and farmer level (mostly related to subproject 1).

Integration of the results of the first couple of years is needed now. The November ICID meeting in Taiwan presents an opportunity to bring this about (again SARS permitting, but this should not stop the integration efforts). I think it is important that a series of international meetings of senior managers at different spots around the globe does not substitute for communication of the project's findings to those who can use them.

Additional Notes

- David Molden proposes a joint visit by himself, Hugh Turrel (now IWMI, ex- LWR1/1998/034) and Hector Malano (LWR1/1998/034 and, in China, LWR1/2001/001), which is a good idea (after SARS).

- The ICID meeting planned for China in 2005 could be linked to the final workshop for this project (perhaps involving other ACIAR projects). To be decided later if timing works out.

- The Yellow River Forum (postponed because of SARS) could still be used as an opportunity to bring together the group of ACIAR water-related projects situated in the Yellow river basin.

- SARS is likely to cause delays in the project. The lack of visits may also reduce the quality of the field work. I informed Randy that my approach will be to conserve funds not spent because of delays, with a view to using them for an extension of the project's termination date (as far as existing funding commitments allow).

- It appears that the Chinese participants are very well funded by the project, much more so than in our bilateral projects where I directly negotiated inputs from the Chinese side.

- Shahbaz noted that ACIAR's LWR2 had recently increased salary inputs into a bilateral project because of pay rises. I do not think that this is appropriate for this project as CSIRO will get a large payment in the 2003-4 financial year.

Notes on Progress in Each Project Activity

Subproject 1: Field scale. Compare yields, profitability and on-farm water balance components of three different systems of WSI: AWD, SSC and aerobic rice, and continuously flooded rice.

	Objectives	Scientific Output	Progress notes
Activity 1.1	To quantify and compare yield and water-balance components of three WSI systems and continuously flooded rice in two contrasting soil-hydrological environments.	Methods of determining water balance components under three water-saving irrigation systems.	(a) Water balance work OK but transpiration not measured directly. Will rely on other data for its calculation.
		Crop growth, yield response and water-balance components under three WSI systems and continuously flooded rice.	(b) SSC was discontinued in China; work being continued by IRRI elsewhere. Focus now on AWD and rain-fed rice at ZIS. Focus on aerobic rice at LIS.
Activity 1.2	To adapt and validate crop growth and water balance simulation models for AWD, SSC and aerobic rice system.	Rice crop growth and water-balance models refined and validated for two contrasting sites in China.	(c) Modelling work in on-track, Paul Belder will complete it. Focus is on AWD and aerobic rice systems.
		Water balance and estimation of return flow refined and validated for two contrasting sites in China.	(d) Should be achieved, to be done after validation of models (above). (not SSC).
Activity 1.3	To quantify effects of AWD on input use and profitability at the farm level.	Cost and return balance sheet constructed showing the effect of AWD on yield, input use and profitability: (i) between farmers at different locations within each irrigation system (ZIS and LIS); and (ii) between farmers in the two irrigation systems.	(e) ZIS is close to being finished. No real adoption of WSI at LIS. There are data on finances for small numbers of farmers at LIS.

Subproject 2: Scaling up-impact of alternative water-saving and -management practices at farm, irrigation system and subbasin levels.

	Objectives	Scientific Output	Potential Application
Activity 2.1	To assess whether on-farm water-savings practices—AWD, SSC, and aerobic—lead to real water savings at the irrigation-system level enabling more water to be available for other uses in a manner that sustains existing production and is not detrimental to the environment.	Quantified water accounts at field, meso (intermediate scale) and irrigation system scales to better understand existing physical and institutional processes.	(f) Done for ZIS. Is being done for LIS; different data sources are being assessed.
		Better understanding of physical processes and knowledge of how farm-level intervention scales up to system and subbasin level.	(g) Khan's models of LIS will be applicable. At ZIS, Molden not using SLURP but RS approaches.
		Database in GIS format for the three sites (ZIS, LIS, Murrumbidgee).	(h) LIS is OK but delivery to the Chinese needs more thought. GIS not likely for ZIS.
		Quantification of the impact of farm level and other water-management practices at irrigation area and subbasin scales in terms of water-savings production, productivity and environmental sustainability.	(i) At ZIS the use of small reservoirs is the key factor for improved water use rather than WSI. *Note:* Detailed assessment of environmental sustainability is not expected from this project!
		Improved methodologies including models for each of the three sites, water accounting, and multi-scale analysis integrated with institutional analysis.	(j) Technical side is on track, but institutional side needs more work at LIS, especially on water-allocation decisions. Work needs integrating in relation to communications (under subproject 4).
		Recommendations for improved management at the study sites.	(k) Investments, policies and management practices that are better targeted at meeting objectives of water savings, productivity, and environmental sustainability.

	Objectives	Scientific Output	Progress notes
Activity 2.2	To identify optimal options for improving river water flows while minimizing adverse economic and environmental impacts within the irrigation areas of Murrumbidgee basin.	A spatial hydrologic-economic model for the Mid-Lower Murrumbidgee (MLM) in Australia.	(l) This has been achieved (not discussed in detail here).
		Results of application of the model for selected scenarios.	(m) Not presented.
		A nodal network optimization model (NNOM) for MLM derived from surface-groundwater interaction model.	(n) Nodal network work is being developed. *Note:* NPIRD project foreshadowed in project document did not happen. CSIRO activities to be supported from other sources.
		Assessment of options for simultaneously improving reliability of water supply to irrigators and environmental flows including on- and off-stream water storages, and on-farm water-management options.	(o) Scenarios to be developed.

Subproject 3: Effect of policies, institutions, management practices and infrastructure on the allocation and utilization of water and on the incentive to adopt WSI practices at farm and system level.

	Objectives	Scientific Output	Progress notes
Activity 3.1	Quantify the effects of water costs, water-pricing mechanisms, irrigation group size, and mode of group organization on group level water diversion at ZIS and LIS.	System of cross-section multivariate regression equations estimated to measure the effects of group size, organizational type and water costs on surface water diversion.	(p) *Note:* Already agreed that statistical multivariate approach not appropriate (after First Progress Report). See notes above on amendment. Information of farmer organizations has been collected. Problems with executing questionnaires at LIS. Replacement of Chinese field enumerator is required.
Activity 3.2	Identify institutions, infrastructure, and decision-making practices that encourage on-farm and off-farm water saving and reuse at ZIS and LIS.	Long-term trends in water productivity estimated at ZIS and LIS. Assessment of the role played by new technologies, improvements to system infrastructure, changes in institution and management policies, and exogenous economic development in explaining these trends. Undertaking of the practical means employed in China to collect money and deliver water.	(r) Should be OK?

Subproject 4: Extension of research results.

	Objectives	Scientific Output	Progress notes
	To begin to identify those regions where the potential to save water and increase water productivity appears greatest, and to promote WSI practices and policies in those regions.	Findings and results on potentials of farm-level water-saving technologies widely disseminated.	(s) Integration of the first couple of years' results is needed now. Premature for aerobic rice; appropriate to promote AWD in ZIS. Links to those who can promote finding to farmers' needs to be strengthened.
		Training of researchers in China on methodologies for assessing water-savings potential of selected farm-level practices at farm, system and basin level.	(t) Training is mostly "on-the-job."

In general, the project is making good progress but with weaknesses in subprojects 3 and 4. In addition to the specific need to find someone to execute the surveys, I gained the impression that the project needs more inputs from less-senior "workhorses" of IWMI to support the inputs of the senior managers. Subproject 4 needs more thought (especially in terms of identifying "next users") so that some concrete examples can be achieved within the time frame of the project.

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FUTURE HARVEST
IWMI is a Future Harvest Center supported by the CGIAR

ISBN: 92-9090-536-0