Water Saving in the Yellow River Basin, China.
1. Irrigation Demand Scheduling

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ABSTRACT

Water saving in irrigation is a main issue in the Yellow River basin. Field studies were conducted in two areas: The Huinong Irrigation District (HID), Ningxia Province, in the upper reaches, where excess irrigation water is applied giving rise to water-logging and salinity problems, and the Bojili Irrigation District (BID), Shandong Province, in the lower reaches of the river basin, where water availability is insufficient and salinity is related to drainage reuse. To control such problems, improved irrigation scheduling may play an important role. The irrigation scheduling simulation model ISAREG was used to evaluate the current schedules and to generate improved ones. It computes the capillary rise from the watertable and deep percolation when excess water is applied, and considers the effects of salinity in crop evapotranspiration, crop water stress and yields, as well as the leaching requirements. The model has been previously calibrated and validated for North China. The model has been explored interactively with surface irrigation simulation models to consider the limitations imposed by the field systems concerning depths to be applied and irrigation performances. For HID, improvements consist of reducing the number of irrigations and adopting new calendars according to the depth of watertable and the soil salinity conditions. Percolation could then be reduced from the current 60% of the applied depths to only the volumes required for leaching. Water saving would represent more than 33%, salinity could be controlled and drainage would be improved. For BID, current schedules are appropriate and the main issues concern deficit irrigation to cope with present water shortages. For both applications, it is concluded that effectiveness of irrigation scheduling improvements highly depend on required betterment in the basin irrigation systems mainly relative to land leveling, inflow discharges and field sizes.

Keywords. Irrigation demand management, simulation modeling, wheat and maize, percolation, leaching requirements, basin irrigation, salinity control

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A. Campos, L. Pereira, J. Gonclaves, M. Fabião, Y. Liu, Y. Li, Z. Mao, and B. Dong. "Water Saving in the Yellow River Basin, China. 1. Irrigation Demand Scheduling". Agricultural Engineering International: the CIGR Journal of Scientific Research and Development. Manuscript LW 02 007. July, 2003.

1. INTRODUCTION

The Yellow River (YR) is the second largest river in China and the main source of water in the Northwest and North China. It flows across nine Provinces and supplies water for about 130 million people, mostly farmers and rural people. The average water yield is 58 billion m^3/year, thus less than 500 m^3 per capita, clearly below the commonly assumed water scarcity threshold of 1000 m^3 per capita. Because irrigation is required through all the year in the arid Northwest and for the winter crops in North China, irrigated agriculture is the main water user in the basin, near 95% of total water use (Cai *et al.*, 2003). However, the demand is continuously increasing for domestic and industrial uses as well as hydroelectricity but this one does not correspond to a consumptive use. In drought years, the demand largely exceeds the supply and the river dries out for large periods before the monsoon rains. The very high charge of sediment during the high runoff periods makes difficult to increase reservoir storage that would increase the water availability in the dry season for the middle and lower basin regions.

The Yellow River is both suffering from high floods and water scarcity. The protection against floods in the North China plain is a main objective of the Yellow River Conservancy Commission (YRCC). Dikes and several hydraulic structures have been continuously built and upgraded to convert this large area into one of most productive regions in China. To cope with water scarcity, the YRCC manages the water in the whole basin in close cooperation with water management institutions of the nine Provinces. Competition for water is very strong among all Provinces and, inside these ones, among all users including the irrigation districts.

The water allocation process results from complex negotiations between the Provinces and the YRCC, and among counties and irrigation districts in each Province. In periods when water is scarcer, priority is given to non-agricultural uses, mainly municipal and industrial uses. However, the improvement and, for certain areas, the development of irrigated agriculture are being considered despite water scarcity. In fact irrigation is definitely required for food production in North China. Irrigated areas within the basin correspond to more than 4 million ha, and more 2 million ha outside the basin rely on YR water. An average 7 billion m^3/year is the estimated water deficit in the basin (Cai *et al.*, 2003). Water scarcity alleviation is expected from the South-North transfers whose canals will be built in the near future to bring water from the Yangtse River to the North China Plain. However, water conservation and saving have to be implemented in response to the need for sustainable use of water and land resources in the basin area.

With the objective of supporting further development of water conservation and saving policies, the research project “Policies for Water Savings in the Yellow River Basin: A DSS Applied to Ningxia and Shandong” funded by the European Union, and the Swiss Government, has been developed from 1998 to 2002 (Pereira *et al.*, 2003b). This project is essentially oriented for providing support to further implementing irrigation water saving policies by the Chinese Authorities and Institutions. The project was applied to only two case-study irrigation districts, one in the upper basin, the Huinong Irrigation District (HID), Ningxia, the other in the low plain region, near the river delta, the Bojili Irrigation District (BID), Shandong (Fig.1).

Figure 1. The Yellow River Basin and location of the case-study areas, The Huinong Irrigation District (HID) and the Bojili Irrigation District (BID).

The HID has 74 400 ha irrigated area and is part of the Qingtongxia Irrigation District, which covers more than 330 000 ha. It develops through 5 counties along the Yellow River. Climate in the HID is arid, with an average 190 mm rainfall during summer, and 5 months of dry and cold winter. Cropping systems are basically irrigated wheat x maize intercropped and paddy rice for the spring-summer season. The upland crops are often in rotation with rice and basin irrigation is used. Water diversion is regulated by the Qingtongxia dam and is available for the entire crop season. The intake volumes are extremely large, averaging 4460 million m3/year, i.e. 6 000 mm. This volume is much above crop irrigation requirements, which presently average 1400 mm for rice (Mao *et al.*, 2003) and 600 mm for upland crops (Campos *et al.*, 2003a). That excessive water diversion is due to poor regulation and control in the conveyance canal, which requires that high water levels be maintained in the canals to make it possible functioning the gates that supply the branch canals. Water is diverted into the branch canals and from there the water in excess flows to the drainage channels and ditches, and to low lands, and seeps to the groundwater. This produces the malfunctioning of the drainage system and causes extensive waterlogging and salinity problems. Soils are silty alluviums originated by sediments transported by the YR from the loess areas. They are naturally non-saline but induced salinity is observed in large areas where water management is poor.

The BID supplies water to three Counties - Huimin, Yangxin and Wudi – for about 110,000 ha total irrigated area. The average rainfall in the BID is 540 mm, mainly during the summer monsoon, from end June to early September. Main crops are the irrigated winter wheat, horticultural and tree crops, and rainfed summer crops such as maize, cotton and soybeans. No flow regulation exists upstream of the diversion from the YR into the irrigation supply canal and diverted water is often insufficient. The average volume diverted is 1703 million m^3, corresponding to 1548 mm, thus about one quarter of the total allocation to HID. The annual diverted volumes vary from 1005 to 2968 million m^3. This large variation relates to the inter-annual runoff variability of the Yellow River and to the management decisions to allocate water to the different users in the middle and downstream reaches of the YR. Water is often scarce for irrigation, thus water reuse is common. Farmers use the drainage system, ponds and every depression to store the canal water delivered in excess as well as runoff water due to rainfall in the monsoon season, or pump from the groundwater to satisfy the crop requirements when canal water is not available. As for HID, soils are silty alluviums deposited by the YR.

Problems are different in both case study areas because climate, cropping systems, water availability, irrigation systems, waterlogging and salinity as well as social and water management systems are different too. Developing the studies both in HID and BID provides for a large range of agricultural, water resources, irrigation, environmental and social conditions, Project results, despite oriented to selected areas where the project has been developed, are of wider application when appropriate adaptation for the prevalent social and environment conditions will be performed. Hopefully, this may provide to better support further developments of water saving and conservation policies in the YR basin.

The improvement of the farm irrigation scheduling as a mean to improve demand management to cope with water saving and salinity control is a part of the modernization required in the YR basin to achieve better irrigation performances, the effective application of water conservation and saving, improving water productivity, and increase farmers' incomes. This paper reports on field and simulation studies performed in both the HID and BID to assess crop water requirements, current irrigation practices, and formulate improved irrigation scheduling scenarios for demand management, i.e. irrigation demand scheduling. Studies were developed in combination with those aimed at improving basin irrigation, which are presented in a companion paper by Fabião *et al.*, 2003, Results of both studies were extensively used to build the demand hydrographs for selected years using an irrigation demand and delivery decision support system (DSS) where scenarios for the farm and distribution systems are evaluated using multicriteria analysis (Gonçalves *et al.*, 2002, 2003). These evaluations have shown that foreseen improvements are expected to positively influence the incomes of farmers.

The research reported herein was conducted in parallel with other studies (Pereira *et al.*, 2003a, 2003b), including those relative to paddy rice irrigation (Dong at al., 2000, Mao *et al.*, 2003), drainage and salinity control in HID (Hollanders *et al.*, 2003), surface drainage and water-table management in BID (Bouarfa *et al.*, 2003), water reuse in BID (Minhas *et al.*, 2003) and the improvement of the supply systems and management (Roost, 2003; Roost *et al.*, 2003). Hypothesis made about drainage improvements in HID are therefore based on assumptions developed through those complementary research findings.

The objectives of this paper are to present the methodology used to assess crop water requirements, the current irrigation scheduling practices and the potential for water saving and salinity control when implementing new approaches to irrigation demand scheduling in both case-study areas of the Yellow River basin. The approaches used to develop alternative scenarios by considering the constraints relative to basin irrigation improvement may contribute to upgrade research on crop irrigation scheduling and deficit irrigation because the integration between crop irrigation requirements and productivity with the irrigation system is often not considered. The results presented herein refer to selected locations and examples among those studied in both irrigation districts.

2. DEMAND MANAGEMENT, IRRIGATION SCHEDULING AND DEFICIT IRRIGATION

Demand management for irrigation under water scarcity includes practices and management decisions of multiple nature: agronomic, economic, and technical (Pereira *et al.*, 2002). The objectives concern a reduction of irrigation requirements, the adoption of practices leading to water conservation and savings in irrigation, both reducing the demand for water at the farm and increasing the yields and income per unit of water used, i.e. the water productivity.

Agronomic and economic decisions and farming practices are often dealt with in the literature. Several papers reviewed these issues for irrigated agriculture (e.g. Bucks *et al.*, 1990; Tarjuelo *et al.,* 1996; Tarjuelo and de Juan, 1999), including aspects relative to water allocation (Recca *et al.*, 2001; Shangguan *et al.*, 2002).

Often, issues for irrigation demand management refer mainly to irrigation scheduling (Endale and Fipps, 2001), therefore giving a minor role to the irrigation methods. Very often research on crop responses to irrigation and water productivity do not consider the constraints relative to the irrigation method, as it is the case for China (e.g. Liu et al, 2002; Wang *et al.*, 2001). However, a combined approach is required (Pereira, 1999; Pereira *et al.*, 2002). Irrigation scheduling (Heermann, 1996) requires knowledge on (a) the crop water requirements and yield responses to water (e.g. Allen *et al.*, 1998; Kang *et al.*, 2003), (b) the constraints specific to each irrigation method and irrigation equipment (e.g. Pereira and Trout, 1999; Liu *et al.*, 2000a, 2000b), (c) the crop sensitivity to salinity when water of inferior quality is used (e.g. Rhoades *et al.*, 1992; Minhas, 1996), (d) the limitations relative to the water supply system (e.g. Goussard, 1996; Hatcho, 1998), and (e) the financial and economic implications of the irrigation practice (e.g. El Amami *et al.*, 2001). The improvement of the irrigation method and the system performance requires the consideration of several factors as analyzed in the companion paper by Fabião *et al.*, (2003). However, in presence of shallow water tables as for HID, an integrated management of the irrigation and drainage system is required (Ayars *et al.*, 1999).

Deficit irrigation is commonly pointed out as the best solution to deal with water scarcity. It is an optimizing strategy under which crops are deliberately allowed to sustain some degree of water deficit and yield reduction (English and Raja, 1996). The adoption of deficit irrigation implies appropriate knowledge of crop ET, crop responses to water deficits, including the identification of critical crop growth periods, and the economic impacts of yield reduction strategies. The case for winter wheat is well studied in China (e.g. Kang *et al.*, 2002) and elsewhere, including for the economic effects of deficit irrigation when surface irrigation is applied (Zairi *et al.*, 2003). However there is insufficient information on the economic impacts of deficit irrigation, which are particularly important for farmers having limited land and economic resources as in China (Caldas and Mu, 2003).

In conditions where land availability is very limited as it is the case for the very densely populated Yellow River Basin, the general practice in irrigated agriculture is to maximize crop yield per unit land by applying full crop irrigation requirements and often over-irrigating. Therefore, in former studies for the North China Plain the approach has been to maximize yields and the irrigation performances by adopting the best irrigation scheduling, and improving the farm irrigation systems to limit the constraints these impose to crops water use, which result in improving both the land and the water productivity (Fernando *et al.*, 1998; Liu *et al.*, 2000a, 2000b). This strategy was also adopted in this research aimed at limiting the irrigation demand and controlling soil salinity. In this perspective, this paper is complemented by the companion paper in this Journal issue that deals with the potential for improving basin irrigation (Fabião *et al.*, 2003).

3. MODELING

Computer models have been widely utilized for irrigation scheduling because they allow development and evaluation of alternative strategies (Pereira *et al.*, 1995). However, models have to be calibrated/validated before being explored (e.g. Liu *et al.*, 1998; Panigrahi and Panda, 2003). A large number of models are available, performing either a simplified soil water balance or coupling water fluxes with crop growth simulation (Pereira *et al.,* 1992; 1995). They have different data requirements, those in the second group being of difficult use because they require much more detailed and difficult-to-obtain data (e.g. Kang *et al.*, 2001, applied to the middle YR basin). These two types of models were used in a study conducted in the North China Plain where it was demonstrated that soil water balance models' performance is adequate for field irrigation scheduling (Liu *et al.,* 1998, 2000a, 2000b).

The ISAREG model (Teixeira and Pereira, 1992) was selected to evaluate and support improved irrigation scheduling in both study areas, HID and BID, because its simplicity and accuracy were demonstrated in other applications in North China (Liu *et al.,* 1998, Liu and Fernando, 1998) and elsewhere (e.g. Rodrigues *et al.*, 2001). The soil water balance is simulated following the methodology proposed by Doorenbos and Pruitt (1977) and Martin *et al.* (1990), and the crop evapotranspiration is computed from ET_o with time averaged crop coefficients ($ET_c = K_c\, ET_o$). The yield-evapotranspiration relationship is that proposed by Stewart *et al.* (1977) and Doorenbos and Kassam (1979). The model was tested on the prediction of wheat yields decrease relative to water deficits (Teixeira *et al.*, 1995). Daily, 10-day and monthly data may be used for the simulations with ISAREG. Model descriptions are provided by Teixeira and Pereira (1992) and Liu *et al.* (1998). The new package for Windows (Pereira *et al.*, 2003c) includes the ISAREG model and two auxiliary computer programmes EVAP56 and KCISA that are used to provide input data for ISAREG simulations.

These models use the updated methodologies for computation of crop water requirements proposed in FAO 56 Manual (Allen *et al.,* 1998), which were verified for North China (Liu and Pereira, 2000; Pereira *et al.*, 2003a). The EVAP56 computes the reference evapotranspiration ET_o (mm/day). In this application, daily data on maximum and minimum temperatures, relative humidity, sunshine hours and wind speed were used to compute ET_o with the FAO Penman Monteith method. The KCISA program (Rodrigues *et al.*, 2000) computes the time averaged crop coefficients for the initial, mid season and end season, respectively $K_{c\ ini}$, $K_{c\ mid}$ and $K_{c\ end}$, the soil moisture depletion fraction for no stress (p), and the root depths (Z_r) for the crop development stages. The KCISA model includes computational options adapted to the cropping and irrigation conditions usual in the Ningxia and Shandong area, i.e. considering one irrigation before soil freezing and crop seeding before or after ice melting as it is practiced for the main crops in the area.

The ISAREG model has been improved to accurately compute the capillary rise into the root zone from a shallow groundwater table and to estimate the percolation water volumes (Liu and Fernando, 1998; Liu *et al.,* 2001). It was improved further to predict how evapotranspiration (ET) is affected by soil salinity and to compute leaching requirements (Campos *et al.*, 2003a). As described in the following sections, the model was used with locally collected meteorological, crop and soil data to simulate the actual irrigation schedules used for the main crops in the area and to search for improved irrigation schedules which could contribute to control the waterlogging and salinity problems occurring in the HID and BID. These improved schedules are considered in the analysis of actual performances of the farm irrigation systems and in the search for improved solutions for the basin irrigation systems as described in the companion paper by Fabião *et al.* (2003).

Simulations relative to irrigation demand scheduling and basin irrigation systems were performed for all management divisions of the HID and BID, soil types, and crop systems to create a database used as input to the simulation of the demand and delivery and to evaluate alternative scenarios with the SEDAM Decision Support System (Gonçalves *et al.*, 2002; 2003) as referred above. In a former study (Fernando *et al.*, 1998; Liu *et al.*, 2000a; 2000b) multiple seasons of simulation were used to produce robust results. In this research, considering those results obtained earlier, the model was first used to represent the observations performed in the field and then to simulate scenarios for present and for improved irrigation conditions.

These simulations were used with the referred model SEDAM to generate the demand with 10-day time steps at different space scales at both irrigation districts (Gonçalves *et al.*, 2002; 2003). The resulting demand hydrographs were later used as input to the supply simulation at the same time and space scales (Roost, 2003; Roost *et al.*, 2003). The years for simulation were selected on basis of the analysis of the supply data and are supposed to represent average supply conditions (Xie *et al.*, 2003): 1993-94 for HID and 1994-95 for BID. Calendar years were not adopted because hydrological and agricultural years are assumed to start after the monsoon, by October, when wheat is planted in the North China Plain (where BID is located), and to end by the harvest of maize (and rice in HID), by September.

4. BASE DATA

4.1. Climate

The application described in the following refers to the locations where more detailed field studies were developed: Pingluo (latitude: 38º55'N, longitude: 106º33'E, elevation: 1099 m) in HID, and Huimin (latitude: 37º30'N, longitude: 117º34'E, elevation: 12 m) and Wudi (latitude: 37º45'N, longitude: 117º37'E, elevation: 6.4 m) in BID.

For all locations, weather data were collected in standard meteorological stations of the Provincial Meteorological Bureaus. As for most of standard weather stations, they are located in courtyards in the limit of the county towns, with a reduced fetch, and measurements are generally performed above non-irrigated grass. A study performed in the North China Plain, comparing weather data collected in the Xiongxian standard meteorological station with those collected with a modern automatic station located inside an irrigated area, identified several sources of errors in standard data for reference evapotranspiration (ET_o) computations (Liu and Costa, 1998). Temperature differences were negligeable but relative humidity was overestimated in the standard station during the dry season. Wind speed measurements from the standard station have shown a trend to be smaller than those observed in the open field. The sunshine hours measured with the standard equipment show a very large variation that affects the estimation of the solar radiation mainly during periods of frequent cloud cover, i.e. the monsoon season. A trend to underestimate the sunshine hours was observed. These conditions lead to variable ET_o results when comparing data from a standard station with those from an automatic station located inside irrigated fields. The general trend is to slightly overestimate ET_o relative to the station site conditions proposed by Allen *et al.* (1998). It is expected that data available for this study could lead to similar trends. The homogeneity of the data sets was verified using the cumulative residuals method as described in FAO 56 (Allen *et al.*, 1998).

Climate in the HID area is arid, with hot summer and cold winter. The annual rainfall averages 190 mm (Fig. 2) but most of rain occurs during the summer, mainly in July and August. Precipitation is almost negligeable from October to April.

In the BID, the climate is semi-arid, characterized by a dry and cold winter and a hot summer that coincides with the monsoon rainy period (Fig. 2) and is concentrated during the monsoon period, from end June to early September. The annual average rainfall is near 500 mm. Rainfall is very low from November to April.

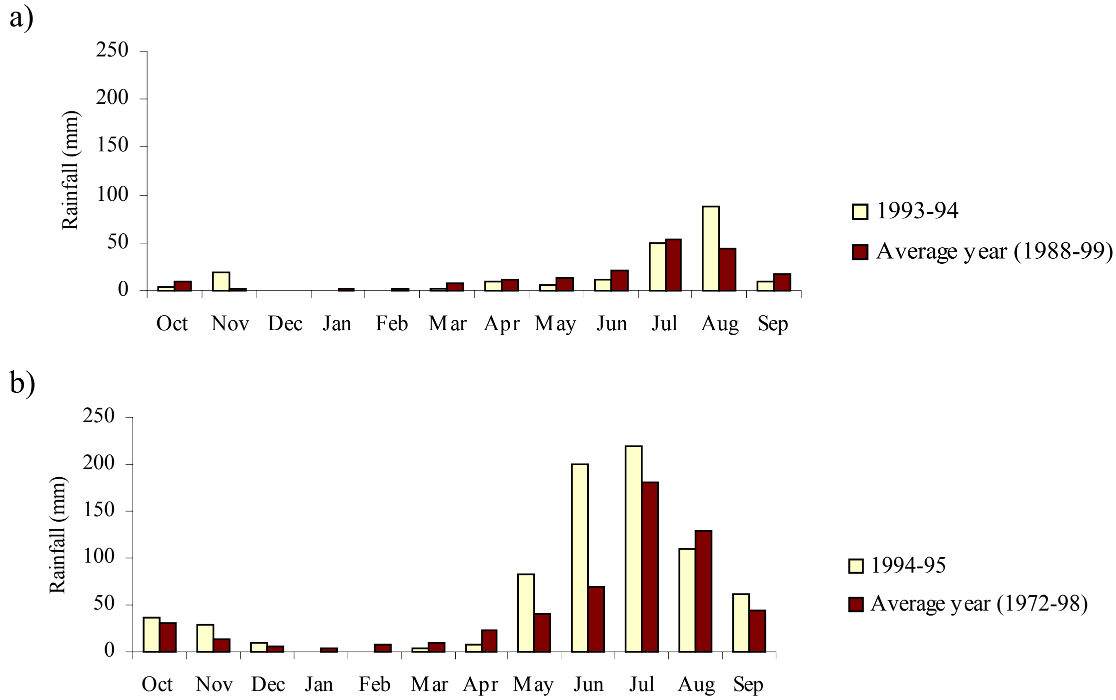

Figure 2. Monthly rainfall averages compared with the monthly totals for the reference years used in this study: a) HID (Pingluo) and b) BID (Huimin).

The analysis performed with monthly rainfall data shows very small spatial variation within both irrigation districts. Similar situation occurs with other weather data (Fig. 3). In HID the soil freezes from November to March and the climate allows for only one crop in the year, planted after soil water melting. In BID the soil freezes from December to February but a winter and a summer crop can be cultivated in the same land.

Maximum air temperatures exceed 30°C at both locations, but the Tmax-Tmin difference is greater at HID due to the aridity conditions there (Fig. 3). Minimum temperatures are lower at HID, which relates to elevation and aridity conditions due to the continental location of HID (Fig. 1). The relative humidity is generally higher at BID with larger differences during the summer monsoon. The ETo, tends to be greater at the BID.

4.2. Groundwater

In HID, the groundwater level has an important role concerning the contribution to crop water requirements, waterlogging and salinity problems. Detailed studies on the groundwater dynamics at local and regional scale, spatial and temporal variation of salinity in the soil and in the groundwater, as well as about the factors influencing the drainage performance were developed in parallel with the irrigation studies (Hollanders et al., 2003).

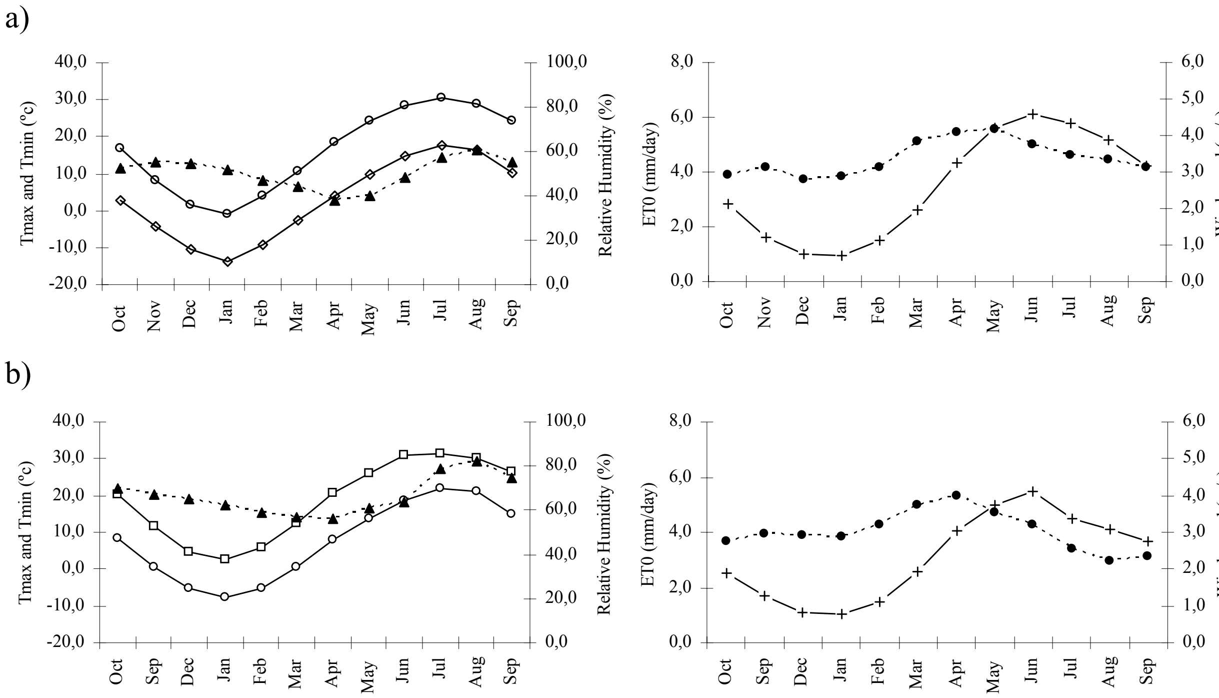

Figure 3. On the left the average minimum (−o−) and maximum temperature (−□−) and relative humidity (--▲--), and on right the average wind speed at 2 m (--●--) and reference evapotranspiration ET_0 (—+—) at a) HID (Pingluo, 1988-99) and b) BID (Huimin, 1972–98).

As pointed out in the introduction section, the diverted water volumes into the HID are nearly three times those required. Annually, almost half of that diverted water is drained back to the Yellow River, thus maintaining the drainage system full and unable to drain the agricultural land and to control the water table. Another part of the excess water flows to lower lands where it percolates to the groundwater and evaporates, bringing salts to the soil surface. Most of canals are non lined and are kept full, so seepage from canals is also important, corresponding to near 15.5% of the diverted volumes in case of main canals (Xie *et al.*, 2003), thus adding to the high water table. Percolation from the non-paddy irrigated fields represents only 10% to 15% of the excess water that is currently causing waterlogging and salinity problems (Hollanders *et al.*, 2003).

Modeling studies allowed concluding that reducing the water diverted into the system makes it possible to effectively lower the watertable and control the water level in the drainage system at about 1.5 m below the soil surface in upland crops areas and 0.8 m in paddy areas (Hollanders *et al.*, 2003). The reduction of the farm water application by 25% would only contribute to a reduction of 10% of the subsurface water flowing in the area. The target watertable depth of 1.0 m (Fig. 4) was selected after evaluating the feasibility for lowering it to that depth by considering how the drainage system would perform when the diversion to the area is reduced by about 50%. A reduction in the volumes diverted is already implemented for the 2003 irrigation season. However, this measure requires that the regulation and control structures of the main canal be modified, hopefully modernized to allow the appropriate functioning of the gates that supply the branch canals.

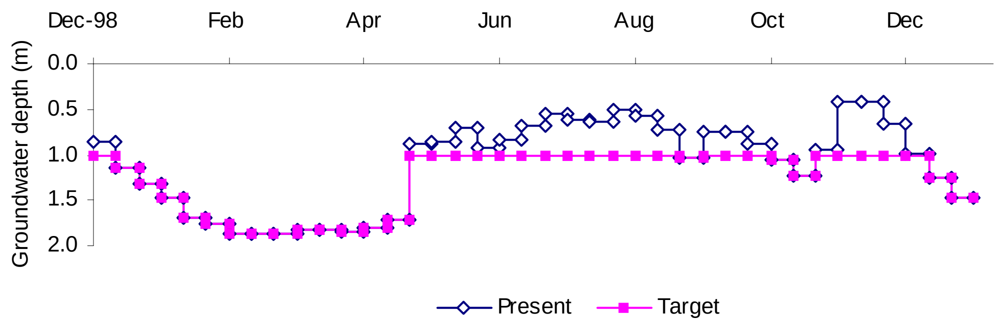

Figure 4. Scenarios of groundwater table depths in HID (observations at Pingluo).

The ISAREG model was used to evaluate different irrigation scenarios for wheat, maize and wheat intercropped with maize by considering different levels of capillary rise from the groundwater table, irrigation depths and TAW soil classes. Simulations led to formulate two scenarios for groundwater contribution in combination with the groundwater studies (Hollanders *et al.*, 2003) as presented in Figure 4:

- *The present scenario*, representing the present conditions, defined by the averaged observed watertable depths at Pingluo (1998 and 1999). Due to high watertable during the crop season, a maximal root depth of 0.5 m was considered.
- *The target scenario*, corresponding to the target depths for the groundwater table (maximum depth equal to 1 m), defined after soil simulations of the groundwater flow and the water balance, allowing 0.9 m root depth.

In Bojili Irrigation District, the simulation results have shown that the groundwater contribution is not as high as in HID because the measured watertable levels are lower, as shown in Figure 5 (Bouarfa *et al.,* 2001).

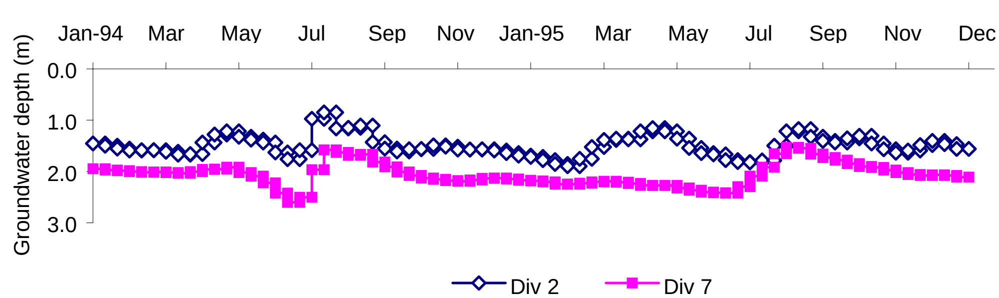

Figure 5. Groundwater table depths observed at BID, by upstream (Huimin) and downstream (Wudi).

For the ISAREG simulations, only one scenario for groundwater contribution was considered for each division, all allowing assuming root depths equal to 1 m. It can be observed (Fig. 5) that the high levels of groundwater table occur in the monsoon period, which lasts from June until the end of August.

4.3. Soils and salinity

The classes of the total available soil water (TAW) at HID were defined from the analysis of the observed soil hydraulic properties data. These were obtained from an appropriate survey and using laboratory methods for the full range of soil water tension Results of measurements indicate that the soil water properties have a small variation among the samples collected in the Huinong Irrigation District. Therefore, we considered that that the soil water reservoir could be characterized uniformly from the surface to the 1.0 m depth because the soils are formed by alluvial deposits of the same silt material transported by the Yellow River and the results for the soil hydraulic property determinations were not different through the soil profile. Water balance tests with ISAREG simulations have shown that it was appropriate to consider three soil classes for TAW (Table 1).

Table 1. Soil classes in HID relative to the total available soil water (TAW).

Classes	θ_{FC} (m^3 m^{-3})	θ_{WP} (m^3 m^{-3})	TAW (mm/m)
1	0.426	0.102	324
2	0.375	0.094	281
3	0.324	0.086	239

θ_{FC} -θ_{WP} soil water content at field capacity and the wilting point, respectively

For BID, eight locations were selected to take disturbed and undisturbed soil samples. Laboratory analysis included particle size distribution, particle density, bulk density and several points of the water retention curve. The wilting point values were estimated using pedotransfer functions and a scaling factor (Liu *et al*., 2003) based on former studies for the same type of silty soil in the North China Plain (Liu and Fernando, 1998). Table 2 presents a summary of the soil characteristics. Classes 1 and 2 are dominant in the upstream area (where Huimin is located) while class 3 is predominant by downstream (Wudi).

Large areas of HID are affected by salinity. Some low areas are not productive at all due to the very high salinity, in other areas maize and other non-tolerant crops are not cultivated, and in some less saline areas maize yields are affected. Salinity is man-induced due to the excess water diverted into the area that rises the groundwater to levels where evaporation from the soil is causing salts accumulation along the soil profile. Salinity is therefore associated with the poor groundwater and drainage management in HID.

Field and simulation studies in HID have shown that reducing the application depths by 25% and having the watertable depth between 0.7 and 1.0 m from the surface, as discussed in the precedent section, the upward salinity flux is controlled and the soil salinity will fluctuate around 3 – 3.5 dS/m in areas now saline (Hollanders *et al.*, 2003), which may become productive even for maize despite yields may be affected. However, appropriate irrigation management that reduces percolation but ensures appropriate salts leaching is required to maintain the watertable lower and keeping the soil at good production potential.

Table 2. Soil classes in BID relative to the total available soil water (TAW).

Classes	Depth (cm)	θ_{FC} ($m^3\ m^{-3}$)	θ_{WP} ($m^3\ m^{-3}$)	TAW (mm/m)
1	0-20	0.37	0.131	235
	20-40	0.34	0.121	
	40-100	0.37	0.131	
2	0-20	0.32	0.115	210
	20-40	0.34	0.121	
	40-60	0.28	0.102	
	60-100	0.35	0.125	
3	0-20	0.32	0.115	194
	20-40	0.34	0.121	
	40-60	0.32	0.115	
	60-100	0.35	0.179	

The salinity subroutine added to ISAREG should be only used when the relative crop yield loss (RYL=1-Ya/Ym) due to salinity does not exceed 50%. This value is generally assumed as the limit for the validity of the yield–water relationship (Doorenbos and Kassam, 1979). When the ratio between actual and potential yields Ya/Ym < 0.50, the crop is not allocated to such soil salinity class. The soil salinity classes and the respective crops allocation are shown in Table 3.

In BID salinity is generally not a problem because the watertable is enough lower to reduce upward fluxes by capillarity and the monsoon rains adequately leach the soils except in very dry years. However, drainage water reuse is common in the area. The ground water salinity increases from the upstream (~ 2-3 dSm^{-1}) to the middle (3-4 dSm^{-1}), and downstream areas (> 4 dSm^{-1}). Long term impacts were simulated which have shown that when irrigation was applied with waters having salt concentrations from 4.0 to 6.0 mg cm^{-3}, the maximum salinity build up at the time of wheat's harvesting was from 2.45, 2.96 and 3.44 mg cm^{-3}, respectively (Minhas *et al.*, 2003). However, much higher values have been found at several locations, which affect crop yields. There was a general increase in the content of salts in the soil profiles over the years of simulations. Higher amounts of salts were simulated in the surface soil at the time of planting of maize crop during a very dry year.

Table 3. Soil salinity classes and respective crops allocation.

Soil salinity classes ECe (dS/m)	Classification	Crops allocated to the classes			
0 – 2	Very low salinity	Wheat	Maize	Wheat × Maize	Rice
2 – 6	Low salinity	Wheat	Maize	Wheat × Maize	Rice
6 – 10	Moderate salinity	Wheat	-	-	Rice
10 – 14	High salinity	Wheat	-	-	-
>14	Very high salinity	Wheat	-	-	-

Simulations showed that yields of wheat and maize could be sustained with the reuse of drainage water having salt content up to 4 mg cm^{-3}. With climate at the site being monsoon type, this climatic situation favors leaching of accumulated salts, thus helping to maintain favorable salt balance (Minhas *et al.*, 2003). The reuse of drainage waters offers opportunities for improving irrigation water management in wheat for areas facing water shortage. Predictions indicate that drainage water reuse, if restricted to only up to < 3 mg cm^{-3} salts, may be sustained over long term basis. When salinity is higher, leaching may be considered necessary.

4.4. Crops and crop coefficients

In HID the main crops are rice, wheat and maize. These two are often intercropped to make better use of the land and energy available. Rice is not dealt in this paper. Other crops are pulses and horticultural crops but in a proportion negligible relative to the cereal crops. Winter irrigation is applied by November, before the soil freezes, to all crops. Wheat is planted after soil melting in the spring; maize is planted after wheat gets 2 to 3 leaves and attains full development only after wheat harvesting.

In the Bojili area, winter wheat is planted early October after the maize is harvested and crop residuals are exported or chopped. Maize and pulses are planted in June after wheat harvesting. Cotton is planted earlier, by April, when soil temperature is high enough in a bare fallow land. Other crops are deciduous tree orchards and berries, and horticultural crops, often in glasshouses. In this paper, only the cereal crops are considered. Studies included these crops (Liu *et al.*, 2003) but only wheat and maize are dealt herein.

The methodology proposed by FAO (Allen *et al.*, 1998), which has been earlier verified for North China (Liu and Fernando, 1998; Liu and Pereira, 2000), has been used to estimate the crop coefficients (K_c) and the water depletion fractions for no stress (p) for the main crops. These parameters were adjusted to the climate.

In HID the main crop is wheat intercropped with maize. The respective crop coefficients $K_{c\ (inter)}$ where the subscript inter stands for intercrop, are computed by weighing those for wheat and maize ($K_{c\ (wheat)}$ and $K_{c\ (maize)}$):

$$K_{c(inter)} = \frac{f_{(wheat)} h_{(wheat)} K_{c(wheat)} + f_{(maize)} h_{(maize)} K_{c(maize)}}{f_{(wheat)} h_{(wheat)} + f_{(maize)} h_{(maize)}} \qquad (1)$$

where h is the crop height and f is the fraction of soil surface cropped with each of the crops, generally $f_{(wheat)} = 0.6$, and $f_{(maize)} = 0.4$. A similar procedure is used to compute the soil water depletion fractions for no stress (p).

5. PRESENT IRRIGATION SCHEDULING

5.1. Huinong Irrigation District

Simulations for wheat, maize, and wheat intercropped with maize were performed with the ISAREG model for the available weather data sets with monthly data relative to five county weather stations in HID. Relatively small variations were observed both in time and space due to the climate features in the area, thus the year 1993-94 could be selected as reference for the modeling studies since it represents average supply conditions (Xie *et al*., 2003, Roost *et al*., 2003). Irrigation demand simulations were performed for the entire HID but only data for Pingluo are used in this paper because field investigations on irrigation and drainage systems were mainly performed in this county.

Using daily weather data for the selected year 1993-1994 and the current watertable depth, simulations were performed for all TAW soil classes (Table 1) and the main crops adopting the average irrigation depths and irrigation frequency typically used, as observed in farmer's fields. Due to the current high watertable, which influences crop development, computations were performed for a root zone limited to 0.5 m. Results for the soil class 2 (TAW = 281 mm/m) are shown in Table 4.

An irrigation before soil freezing, by November, is currently practiced to refill the soil profile. This pre-planting irrigation provides water to the early stages of the crops and improves the physical conditions of these silty soils because fine cracks are created along the soil profile due to successive freezing and melting of the soil water. However, this irrigation largely impacts on the watertable (Fig. 4). This pre-planting irrigation is not included in Table 4 but the available soil water (ASW) at planting is computed by simulating a bare soil condition from that winter irrigation to the planting date. The model does not simulate redistribution of moisture in frozen soils but has been appropriately validated to perform the water balance for such conditions (Liu and Fernando, 1998; Pereira *et al*., 2003a;).

The impacts due to the very high watertable, near 0.5 m during the growing season, are well evident in Table 4: near 51 to 61% of the applied irrigation depths result in percolation to the groundwater contributing to maintain current unfavorable conditions (Fig. 4). However, 51 to 58% of the crop water requirements are satisfied by the capillary rise fluxes. Due to this unbalanced situation, the actual ET ($ET_{c\ adj}$) does not attain the maximal crop ET (ET_c) and yields are adversely affected. The current irrigation scheduling is not appropriate for the existing soil water conditions and too much water is applied since the soil water is maintained always high, including at harvesting. This also results in non-using in full the limited rainfall.

Table 4. ISAREG simulation of the current average irrigation schedules at Pingluo (HID) with the present watertable and a soil TAW = 281 mm/m.

Crop	***Maize***		***Wheat***		***Intercrop***	
Irrigations after planting	**Dates**	**Irrigation (mm)**	**Dates**	**Irrigation (mm)**	**Dates**	**Irrigation (mm)**
	12/05	108	30/04	109	25/04	109
	05/06	95	12/05	108	12/05	108
	27/06	110	05/06	95	05/06	95
	25/07	92	27/06	110	27/06	110
	30/08	116			25/07	92
					25/08	116
Season irrigation (mm)	***521***		***422***		***630***	
Season rainfall (mm)	***168***		***79***		***168***	
ASW at soil freezing (mm)	138		138		138	
ASW at planting (mm)	35		91		91	
ASW at harvesting (mm)	141		141		141	
Percolation (mm)	266		213		386	
Capillary rise (mm)	383		297		471	
Non-used rainfall (mm)	55		36		69	
$ET_{c\ adj}$ (mm)	748		546		811	
ET_c (mm)	780		554		816	

ASW stands for available soil water; and $ET_{c\ adj}$ and ET_c are respectively actual and potential crop evapotranspiration

As referred above, ISAREG has an algorithm to compute the groundwater contribution and percolation fluxes. Because it has not been possible to perform field measurements of these fluxes but the soil hydraulic properties of the Huinong silt soils are similar to those of the Xiongxian silt soils where calibration was performed (Liu and Fernando, 1998; Fernando *et al.*, 2001), the same soil parameters were used. To test the assumption of similarity in soil behavior, results from ISAREG and from the surface irrigation simulation model SRFR were compared for percolation, which proved to be highly coherent (Gonçalves *et al.*, 2001), thus confirming the quality of simulations performed. The use of the SRFR model is described in the companion paper by Fabião *et al.* (2003).

The same irrigation schedule as that in Table 4 was simulated for the target watertable and an improved irrigation system, i.e. assuming a precision leveled basin with zero slope (Table 5). Under these conditions deep percolation could be reduced to 0 to 4% while the capillary rise fluxes would also decrease to 4 to 10% of the total applied depths. Despite the favorable results due to the watertable control and the improvements due to precision zero leveling of the basin surface, adopting the current schedules would produce excess water application, which can be observed through the high values for the soil water at harvesting. Results of simulations with the current non-leveled basins show high percolation. Changing the irrigation schedules is therefore required in combination with improvements in basin irrigation systems (cf. Fabião *et al*., 2003).

Table 5. ISAREG simulation of the current average irrigation schedules at Pingluo (HID) considering the target watertable depth and precision zero leveling basin for a soil with TAW = 281 mm/m.

Crop	*Maize*	*Wheat*	*Intercrop*
Season irrigation (mm)	***521***	***422***	***630***
Season rainfall (mm)	***168***	***79***	***168***
ASW at soil freezing (mm)	248	248	248
ASW at planting (mm)	141	202	201
ASW at harvesting (mm)	237	241	232
Percolation (mm)	0	0	22
Capillary rise (mm)	80	46	30
Non-used rainfall (mm)	0	0	6
$ET_{c\ adj}$ (mm)	780	554	816
ET_c (mm)	780	554	816

5.2. Bojili Irrigation District

The main crops in the BID are the wheat and maize cropped consecutively in the same land, thus consisting of a double crop sequence. Simulations for wheat, maize, and wheat intercropped with maize, as well as for other crops, were performed with the ISAREG model using 30 years weather data sets relative to three counties allowing to perform a detailed analysis of crop irrigation requirements for the average, high and very high demand conditions (Liu *et al*., 2003). Relatively large variations were observed in relation to the variability of monsoon rains from one year to another but the variations in space were small. However, supply data were available for a reduced period and the year 1994-95 has been selected as reference for the modeling studies because it represents average supply conditions (Xie *et al*., 2003, Roost *et al*., 2003). However, because water supply conditions reflect the water availability and allocation policies in the entire basin, that year do not represent average demand conditions in the BID.

Irrigation demand simulations were performed for that year covering the entire BID to produce data required for demand and supply simulations (Gonçalves et al., 2003, Roost et al., 2003) but only data for Huimin and Wudi counties are used in this paper because field investigations on irrigation and drainage systems were mainly performed there.

The present irrigation schedules are simulated using daily weather data for the selected year 1994-1995 considering three irrigations for wheat (at planting, before soil freezing and at spring, by the heading stage) and one irrigation for maize since the monsoon period coincides with its growth season. Selected results of simulations are presented in Table 6 for the upstream and downstream parts of the BID, Huimin and Wudi respectively. The groundwater conditions are those in Figure 5. The groundwater contribution and percolation were tested in field using the parameters computed in a former study (Liu and Fernando, 1998; Liu *et al*., 2003).

As referred above, results in Table 6 do not fully represent the existing conditions because the number of spring irrigations varies with water allocation policies to BID as decided by the Yellow River Conservancy Commission and the Shandong Water Conservancy Bureau. When more water is available, up to 4 or 5 irrigations may be applied to wheat in the upstream areas of BID, and 4 in downstream areas.

Table 6. ISAREG simulation for the current average irrigation schedules at BID.

Location	***Huimin***				***Wudi***			
Crop	**Wheat**		**Maize**		**Wheat**		**Maize**	
	Dates	Irrigation (mm)	Dates	Irrigation (mm)	Dates	Irrigation (mm)	Dates	Irrigation (mm)
Irrigations after planting	04/10	100	10/09	100	25/10	162	12/07	100
	01/12	135			17/12	186		
	20/04	150			03/05	170		
Season irrigation (mm)		**385**		**100**		**518**		**100**
Season rainfall (mm)		**177**		**583**		**231**		**336**
Results relative to the prevailing TAW soil classes								
TAW (mm/m)	***235***	***210***	***235***	***210***	***194***		***194***	
ASW at planting (mm)	189	160	73	55	64		109	
ASW at harvesting (mm)	73	55	206	181	109		64	
Percolation (mm)	142	191	61	63	227		20	
Capillary rise (mm)	13	29	3	5	12		15	
Non-used rainfall (mm)	27	11	64	77	0		134	
$ET_{c\,adj}$ (mm)	522	494	428	422	489		342	
ET_c (mm)	531	522	429	426	536		341	

However, data in Table 6 are considered representative for the year 1994-95 and reflect the delivery schedule adopted in BID as dictated by that allocation policy. Results evidence that water was scarce in BID, irrigations did not fully satisfy the crop water requirements, mainly in the downstream areas. Nevertheless, due to less appropriate field sizes and slopes, applied depths are excessive and originate high percolation fluxes, which vary with the field characteristics, as analyzed in the companion paper by Fabião *et al.* (2003).

There is evidence that improving the irrigation schedules depends upon improving the supply and delivery scheduling since farmers apply water when it is available and not when it would be required by the crops. However, when they have reusable drainage water available they supplement canal water for the critical crop stages and, mainly, for orchards, horticultural crops and cash crops such as cotton. To control the excess percolation due to non-uniform infiltration along the basins, mainly in case of the longer ones, the improvement of irrigation scheduling must go together with that of farm irrigation systems. Improved schedules were therefore studied assuming that both the farm and the delivery irrigation systems can be modernized to achieve higher performances that help better matching the crop demand and improve the timeliness of water applications.

6. IMPROVED IRRIGATION SCHEDULING

6.1. Huinong Irrigation District

Improved irrigation schedules are designed under three main objectives: water savings, control of percolation, and application of a leaching fraction according to the soil salinity. To develop the new irrigation schedules, simulations were performed interactively with the models ISAREG and SRFR (Fabião *et al.*, 2003). Both models have the capability to estimate deep percolation and are therefore used in combination to define the appropriate irrigation timings and depths under constraint of the irrigation method that provide for high irrigation performances including an uniform leaching fraction throughout the field. When searching for improved irrigation schedules, simulations for wheat, maize, and wheat intercropped with maize were performed assuming that the target watertable depth is implemented and the basin irrigation systems are improved such as by adopting precision zero leveling as discussed in the companion paper by Fabião *et al.* (2003).

For soils with low salinity, there is the need to control, and hopefully to avoid, percolation through the root zone boundary. Therefore, it is required to modify the irrigation scheduling by reducing the number of irrigations and changing the irrigation volumes applied. Leaching is assumed to be applied with the winter irrigation. Simulations were performed for the three TAW soil classes (Table 1) and for different number of irrigations. The schedules were simulated to maximize yields, thus producing $ET_{c\ adj} = ET_c$, i.e. without water stress. Simulation results when scheduling changes are minimal relative to present are summarized in Table 7. Results show that when improved irrigation depths and timings are selected and basins would be zero leveled, the season irrigation depth could be reduced relative to present by 80 mm for maize and the intercrop, and by 20 mm in case of the wheat crop. To be noticed that the ASW at harvesting are lower than at present (Table 4). Deep percolation could be avoided and the contribution of capillary rise fluxes to the crop water requirements keeps being high. Further reductions in the applied depths could be considered by delaying the irrigation events resulting in lower ASW at harvesting.

When saline soils are considered, then a leaching fraction up to 10 % is required. Two different scenarios are then considered. The first scenario corresponds to the expected improvement of present saline soils after implementation of improved drainage and watertable control, thus to a soil having ECe = 3 dS/m. Then ECe > $ECe_{threshold}$ for maize, which causes a yield decrease near 20%, but the wheat crop is not affected. The second scenario considers a soil ECe = 11 dS/m, which corresponds to the expected improvement for the presently very saline soils. For this scenario it is assumed an average yield decrease of 20% approximately for the wheat crop and a yield decrease is higher than 50% for maize, thus excluding both this crop and wheat intercropped with maize.

Table 7. ISAREG simulations of improved irrigation schedules at Pingluo (HID) for the target watertable depth, zero leveled basins and a soil TAW = 281 mm/m.

Crop	***Maize***		***Wheat***		***Intercrop***	
	Dates	**Irrigation (mm)**	**Dates**	**Irrigation (mm)**	**Dates**	**Irrigation (mm)**
Irrigations after planting	21/04	110	21/04	103	23/04	110
	08/06	110	12/05	100	20/05	110
	06/07	110	29/05	100	10/06	110
	28/07	110	13/06	100	09/07	110
					01/08	110
Season irrigation (mm)	***440***		***403***		***550***	
Season rainfall (mm)	***168***		***79***		***168***	
ASW at soil freezing (mm)	248		248		248	
ASW at planting (mm)	146		202		202	
ASW at harvesting (mm)	152		193		169	
Percolation (mm)	0		0		0	
Capillary rise (mm)	58		21		65	
Rainfall losses (mm)	7		4		45	
$ET_{c\ adj}$ (mm)	755		554		817	
ET_c (mm)	755		554		817	

Simulations results for saline soils with TAW = 281 mm/m, zero slope leveled basins aiming at maximizing yields, i.e. when $ET_{c\ adj} = ET_c$, are summarized in Table 8.

The results show that the number of irrigations and the applied season depth can be reduced relatively to the present situation (Table 4) despite they allow for the application of a leaching fraction of about 10% at every irrigation event in addition to an higher leaching fraction at the winter irrigation.

Table 8. Improved irrigation schedules for saline soils with zero slope leveled basins aiming at maximizing yields.

Crop	*Maize*	*Wheat*	*Intercrop*
ECe (dS/m)	3	11	3
Irrigations after planting	4	3	4
Season irrigation (mm)	***480***	***360***	***490***
Season rainfall (mm)	***168***	***79***	***168***
ASW at soil freezing (mm)	244	244	244
ASW at planting (mm)	142	197	198
ASW at harvesting (mm)	139	163	133
Percolation (mm)	41	31	39
Capillary rise (mm)	43	65	88
Rainfall losses (mm))	0	0	1
$ET_{c\ adj}$ (mm)	755	554	817
ET_c (mm)	755	554	817

Further reductions in applications depths and a reduced number of irrigation events are possible with a light decrease in crop ET as shown in Table 9. This schedule is modified from the former one by delaying the irrigation timings but adopting similar irrigation depths. It results in increasing the groundwater contribution (GW) and producing lower ASW at harvesting. Precise zero slope leveling was also considered.

Table 9. Improved irrigation schedules for wheat and maize in saline soils aiming at maximizing water savings (soil TAW = 281 mm/m).

Crop	*Maize*	*Wheat*	*Intercrop*
ECe (dS/m)	3	11	3
Irrigations after planting	3	2	3
Season irrigation (mm)	***370***	***260***	***390***
Season rainfall (mm)	***168***	***79***	***168***
ASW at soil freezing (mm)	241	238	244
ASW at planting (mm)	143	191	198
ASW at harvesting (mm)	133	166	129
Percolation (mm)	34	16	33
Capillary rise (mm)	107	118	1679
Rainfall losses (mm)	2	0	0
$ET_{c\ adj}$ (mm)	717	513	808
ET_c (mm)	755	554	817

Examples above show that large improvements in irrigation management are attainable when the following conditions are respected: lowering the watertable depth, improving basin land leveling and management, and timeliness for application of the large irrigation depths required for attaining high uniformity in basin irrigation.

6.2. Bojili Irrigation District

In the BID the improvements in irrigation scheduling were simulated considering two alternative strategies:

- adopting restrictions in water supply corresponding to several periods when water is not available in the canal system, as for the present situation, then irrigations were scheduled to minimize water stress impacts on yields, or
- without restrictions to the water delivery, thus allowing that irrigations be set to maximize yields.

In both cases the irrigation dates were set when the average soil water content falls to the soil water threshold for no stress defined by the depletion fraction p but the irrigation dates may be delayed when the first strategy referred above is considered. Irrigation depths are computed as those required to refill the soil to the field capacity. An irrigation before soil freezing, by the end of November, is considered. Simulations results for both strategies are presented in Tables 10 and 11.

Table 10. Improved irrigation schedules to maximize water savings when water delivery restrictions are considered (BID) with improved basin irrigation systems.

Location	***Huimin***				***Wudi***	
Crop	Wheat		Maize		Wheat	Maize
Irrigations after planting	2		0		3	0
Season rainfall (mm)	**177**		**583**		**231**	**336**
Results relative to the prevailing TAW soil classes						
TAW (mm/m)	***235***	***210***	***235***	***210***	***194***	***194***
Season irrigation (mm)	**230**	**220**	**0**	**0**	**335**	**0**
ASW at planting (mm)	153	137	69	56	64	109
ASW at harvesting (mm)	69	56	167	144	109	64
Percolation (mm)	7	24	0	0	2	0
Capillary rise (mm)	18	29	3	6	13	16
Rainfall losses (mm)	3	3	63	77	26	54
$ET_{c\ adj}$ (mm)	499	480	425	424	506	343
ET_c (mm)	512	503	429	426	536	343

Table 11. Improved irrigation schedules without restrictions on water delivery (BID) to maximize yields with improved basin irrigation systems.

Location	*Huimin*				*Wudi*	
Crop	Wheat		Maize		Wheat	Maize
Irrigations after planting	3		0		4	0
Season rainfall (mm)	**177**		**583**		**231**	**336**
Results relative to the prevailing TAW soil classes						
TAW (mm/m)	***235***	***210***	***235***	***210***	***194***	***194***
Season irrigation (mm)	**350**	**330**	**0**	**0**	**432**	**0**
ASW at planting (mm)	154	137	167	129	64	168
ASW at harvesting (mm)	167	129	167	144	168	64
Percolation (mm)	7	24	0	0	0	0
Capillary rise (mm)	8	16	0	4	4	13
Rainfall losses (mm)	3	4	155	145	27	104
$ET_{c\ adj}$ (mm)	512	503	428	427	536	349
ET_c (mm)	512	503	428	427	536	349

When water availability restrictions were considered (Table 10), only a small yield decrease, below 5%, was attainable for both wheat and maize. Water requirements for the latter are mostly satisfied by the monsoon rains and irrigation was not considered. However improvements in basin irrigation relative to basin sizes, field slopes, precision land leveling and inflow rates are required to minimize percolation and improve the irrigation performances including crop productivity, as discussed by Fabião *et al.* (2003). The resulting schedules are quite different from the present one because for the year under analysis the irrigation at planting was not required (despite it was effectively applied since water was available by then). Deep percolation is avoided except in the parts of the field receiving more water. The need for another irrigation to the wheat crop by late spring is however necessary, as for most years, due to the variable rainfall. Such reduced season irrigation depth produces a very low ASW at harvesting that originates an ASW at planting for the maize crop (Table 10), which may be insufficient for crop establishment when the monsoon rains are just a little delayed. Therefore a late irrigation in the spring is considered in Table 11 to decrease the risks for the maize crop.

Results in Table 11 refer to the optimal schedules when yield is maximized. The number of irrigations and the applied depths are close to those at present but the irrigation dates are different: the irrigation at planting is not considered and the number of spring irrigations is increased. Therefore, the ASW at harvesting, thus the ASW at maize planting is higher to control crop establishment risks. Crop water stress is avoided, so leading to $ET_{c\,adj} = ET_c$. Deep percolation is also negligible when the basin systems would be improved. Small increases in irrigation depths are feasible when a leaching fraction is required where low quality water reuse is considered (Minhas *et al.,* 2003).

As for HID, the results above for the simulated irrigation schedules are only attainable when basin irrigation systems are improved relative to land leveling, field lengths and inflow rates (cf. Fabião *et al.*, 2003) and when water allocation to BID would be more flexible to allow the delivery scheduling to be improved. However, further flexibility may result from drainage water reuse at critical crop growth periods when canal water is not available.

7. CONCLUSIONS

The ISAREG model has been successfully applied to simulate the current and foreseen irrigation schedules for the Huinong and Bojili irrigation districts. For HID, it was observed that the existing irrigation schedules are highly hampered by the very high level of the water table, which causes waterlogging and salinity, limits crop root development, and leads to excess percolation. The study shows that positive impacts from adopting improved irrigation scheduling definitely require that the watertable depth be controlled at 1.0 m below land surface. Lowering the watertable to this depth is feasible according groundwater and drainage studies performed in HID. Improved schedules with reduced number of irrigations and reduced seasonal volumes were also identified, as well as irrigation schedules applicable to saline soils. However the most effective results, with minimal percolation for the low salinity soils and with controlled leaching for the saline soils, are only achievable when basins would be precision leveled with zero slope. Significant water savings would then be produced while soil salinity could be controlled.

For BID, the actual irrigation schedules reflect that the existing restrictions in canal deliveries produce relatively high evapotranspiration deficits. However, due to adverse characteristics of the basins, a large fraction of the applied water percolates through the root zone boundary. Improved schedules were considered for improved basin sizes, field slopes and inflow rates considering two situations: non-restricted water deliveries and deliveries available at only given periods. The first allow maximizing yields and the second, despite insufficient satisfaction of the crop requirements, favors water savings and allow for the control of deep percolation. The need for a late spring irrigation, which favors the wheat crop and the establishment of the successive maize crop, was also identified.

ACKNOWLEDGEMENTS

This study was funded by a research contract on “Water Saving Policies for the Yellow River Basin” funded by the European Union, DG XII, Program STD-INCO, and the Swiss Government.

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