CONSTRAINTS AND OPPORTUNITIES FOR INTEGRATED WATER MANAGEMENT TOOLS

J. Boonstra

International Institute for Land Reclamation and Improvement (ILRI), P.O. Box 45, 6700 AA Wageningen, The Netherlands

Introduction

The water management problems in semi-arid regions can be summarized as follows. Due to an overall shortage of water to irrigate all the agricultural lands, the farmers in the fresh-water zones use groundwater as a supplementary source of irrigation water, quite often resulting in a groundwater decline as a consequence of the mining of this resource. On the other hand, the irrigation losses from the conveyance system and in the fields are resulting in a rapid rise of the watertables in the saline groundwater belt. The poor quality of the groundwater in those areas reduces the possibilities of its beneficial use and pollution problems may be created when the excess saline groundwater is drained to the river systems or is disposed in another way. It is clear that there is not a single simple way to solve these problems. A combination of measures has to be taken to attain technically and economically feasible solutions.

Optimal management of the available surface and subsurface water resources with respect to quantity and quality will be urgently needed in view of increasing demands, limited resources, rising watertables, and salinization. The complexity of the groundwater-surface water system is caused by the multiple interactions of the various components of the system. For managing this system, integrated water management tools are a prerequisite. In this paper, applications of this type of tools are presented with field examples from Pakistan and India and their constraints and opportunities discussed. To avoid duplication, relevant aspects of the application of this type of tools are spread over the three presented case studies.

Integrated water management models

The water balance is defined by the general hydrological equation, which is basically a statement of the law of conservation of mass as applied to the hydrological cycle. In its simplest form, this equation reads:

Inflow - Outflow = Change in Storage

Irrigation areas and areas in need of drainage usually cover only part of a river catchment or a physical groundwater reservoir. We therefore have to take into account any surface and subsurface inflow and outflow across the vertical planes of the boundaries of these areas. If we determine all their inflow, outflow, and water-storage components, we can assess the overall water balance. This is how water-balance studies are usually done (de Ridder and Boonstra 1994).

In overall water balances, we consider the flow domain vertically - from the soil surface to the impermeable base of the groundwater reservoir. The impermeable base may consist of massive hard rock or of a clay layer whose permeability for vertical flow is so low that it can be regarded as impermeable. Three reservoirs occur in this flow domain: at the surface itself, in the zone between the surface and the watertable, and in the zone between the watertable and the impermeable base. Because the reservoirs are hydraulically connected, partial water balances often have to be assessed for each of them in order to specify the drainable surplus. These water balances are referred to here as: the surface water balance, the water balance of the unsaturated zone, and the groundwater balance.

In the first two presented studies, ILRI's numerical groundwater simulation model SGMP (Boonstra and de Ridder 1990) was linked with different water distribution/unsaturated zone models. For the Schedule I-B of the Fourth Drainage Project in Pakistan, SGMP was linked with a spread-sheet model which calculates the flow components at the land surface and in the unsaturated zone. At a later stage, SGMP was linked with ILRI's SALTMOD model which calculates the flow components in the unsaturated zone. This integrated model, also known as the Regional-Agro-Hydro-Salinity Model (Rao et al. 1996) was also applied to the same area. For the Sirsa District Project in Haryana in India, SGMP was linked with the Winand Staring Centre's SIWARE model which is a combination of a surface-water distribution simulation model and an unsaturated-zone model. All the above unsaturated-zone models are based on a volume-balance approach. For the Fordwah Eastern Sadiqia (South) Project in Pakistan, SGMP version 2.8 was used as a stand-alone model. Here, an inverse-modelling approach was applied.

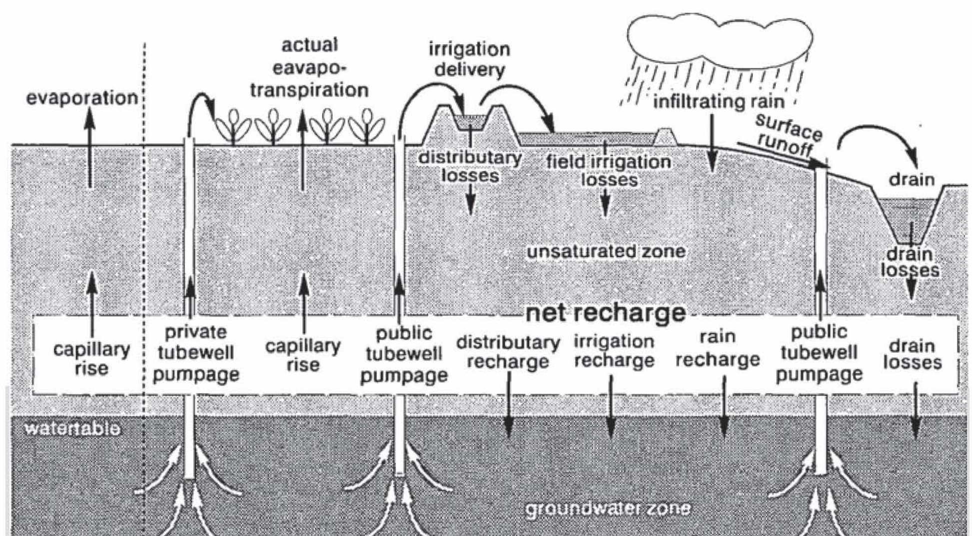

Figure 1. Water balance components resulting in net recharge to the aquifer

The linking mechanism between saturated and unsaturated flow in the above integrated water management models is the net recharge (Figure 1). This net recharge to the groundwater system is the algebraic sum of the following recharge and discharge components: rainfall; seepage from main canals, distributaries, minors, and water courses; field irrigation losses; capillary rise from watertables; and pumping by tubewells. Based on values of reported rainfall, irrigation water supplies, irrigation efficiencies, land use data, crop water requirements, capillary rise and evaporation data, and pumping by tubewells, the various unsaturated-zone models calculate the corresponding net recharge rates to the underlying aquifer system. Based on these net recharge values, the numerical groundwater simulation model SGMP then calculates the corresponding watertables; SGMP then returns its calculated watertables to the particular unsaturated zone model. When watertables are within critical depth, an iterative procedure follows till all the partial water balances are stabilized, before the calculations are continued for the next time step.

Schedule I-B of Fourth Drainage Project

To improve drainage design criteria, the Netherlands Research Assistance Project/NRAP, in collaboration with the International Waterlogging and Salinity Research Institute/IWASRI in Lahore, Pakistan, executed field research at the Fourth Drainage Project near Faisalabad in Pakistan. The Fourth Drainage Project is located in the south-western part of the Rechna Doab. The Rechna Doab consists of the area between the Rivers Ravi and Chenab and comprises about 28,000 km^2. The Fourth Drainage Project includes two separate areas, Schedule I and II, covering a total of 55,000 ha. In an area of 31,000 ha, horizontal subsurface drainage systems have been installed. Various research activities were initiated to provide answers to problems occurring during the pre- and post-periods of installing the various subsurface drainage systems. One of the objectives of the research in this Project was to use a groundwater approach to refine the calculation of the drainable surplus of an irrigated area.

Schedule I-B was selected as the study area; Table 1 summarizes the relevant information on this area. Schedule I-B belongs to the Samundri Unit II. It borders on the Lower Gugera Branch Canal in the north, on the Burala Branch Canal in the south, on the town of Satiana in the east, and on the Maduana Branch Drain in the west. To alleviate waterlogging and salinity in this area, eleven sump units with collectors and field drains have been installed (see Figure 2); their design capacity, also called drainable surplus, was calculated by the USBR as 2.44 mm/d.

Table 1. General project area information

area	:	9,000 ha
altitude	:	175 m a.m.s.l.
mean annual rainfall	:	250 - 400 mm
mean annual evaporation	:	1500 mm
irrigation water delivery	:	2 mm/d
transmissivity aquifer	:	6000 - 8500 m^2/d
specific yield aquifer	:	5 - 15 %

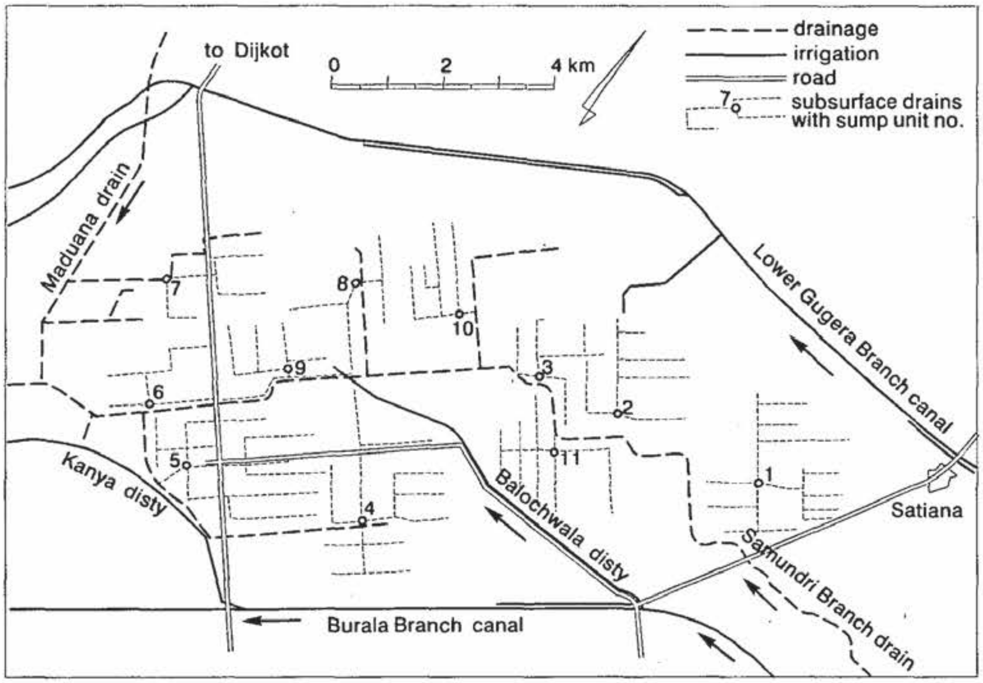

Figure 2. Schedule I-B of the Fourth Drainage Project with the location of the 11 sump units

In Pakistan, the depth-to-watertable has been monitored twice a year from the beginning of this century onwards. To this end, a primary observation network covers all of Pakistan. The spacing of these wells in the Rechna Doab area is some 15 km. In 1985, to be able to study the watertable behaviour in the Fourth Drainage Project in more detail, the SCARP Monitoring Organization/SMO installed about 300 observation wells throughout the area. Some 40 wells were installed in Schedule I-B; since that time, they have been monitored twice a year, in June and in October. These data were regarded as being representative of the pre-monsoon and post-monsoon conditions.

The model was run for the period June 1985 - June 1990 with a variable time step of 4 and 8 months, respectively. This yielded ten sets of seasonal net recharges: five sets for monsoon periods and five for non-monsoon periods. After calibration of the model, the five-year average contributions of the various water-balance components to groundwater recharge were assessed (Table 2).

Table 2. Water-balance components contributing to net recharge (in mm/d)

Water-balance components	five-year average
rainfall	0.28
distributaries	0.05
water courses & fields	0.29
capillary rise	0.38
private tubewells	0.03
Net recharge	0.21

In drainage design in Pakistan it is common to take a one-in-5-year wet monsoon to represent the design rainfall. A frequency analysis of the rainfall records of Faisalabad for the period 1930 to 1989 showed that the total rainfall in such a design monsoon would equal 347 mm (Boonstra et al. 1991). The historical monsoon season of 1975 yielded the value closest to the design rainfall of 342 mm. This historical monsoon of 1975 was taken as being representative of a design monsoon. The wettest monsoon in the study period occurred in 1986, with 282 mm of rainfall and a return period of 2.8 years; its rainfall data were replaced by those of 1975. The model was rerun with the design monsoon data and Table 3, Column 2 shows the corresponding water balance components and the resulting design net recharge.

Table 3. Water-balance components contributing to net recharge (in mm/d)

Water-balance components	Design Monsoon	Design Month
(1)	(2)	(3)
rainfall	0.93	2.30
distributaries	0.07	0.05
water courses & fields	0.39	0.42
capillary rise	0.55	0.46
private tubewells	0.04	0.14
Design net recharge	0.8	2.17

Comparison of Columns 2 of Tables 2 and 3 shows that the contribution of rainfall to the overall net recharge significantly increased as was to be expected. The reason that the contribution of the irrigation components also increased, can be explained by the canal closure period which was only accounted for in the five-year average values. The increase in capillary rise can be explained by the shallower depth-to-watertables during a design monsoon.

The same model was applied to the same area, but now on a monthly basis with more consistent field data. The objective was to study the effect of monthly rainfall compared to that of monsoon rainfall and to verify the previous results. The model was run for the period June 1994 - October 1994 with a fixed time step of one month. This yielded four sets of monthly net recharges. After calibration, the model was rerun with the design monsoon data of 1975 and Table 3, Column 3 shows the corresponding water balance components and the resulting design net recharge. Table 3 shows that the increase in design net recharge is mainly due to the higher design rainfall.

The above assessments of the design net recharge are very similar to what is usually done in traditional drainage design. The relevant components are considered and appropriate values are adopted. Such a drainable surplus is actually the design net recharge to the aquifer system. It is often assumed that its value is representative of the drainage coefficient, i.e. the discharge capacity of a subsurface drainage system. The model was used to test the validity of this assumption. In SGMP, there is a provision to prescribe upper levels of the water table, which may not be exceeded in a simulation run. If during a particular period the calculated watertable elevations exceed an upper level, SGMP introduces an artificial drainage component to keep the calculated watertable elevation just below that level. These upper levels represent the minimum permissible depth to watertable to be controlled by a subsurface drainage system, and the artificial drainage rate represents the drainage coefficient. In reality, the watertable depth between two drains will be less than the actual drain depth. This can be accounted for by taking the average of the minimum permissible watertable depth midway between the drains and the actual drain depth.

The areas where the 11 sump units in Schedule I-B are located were selected as potential areas in need of drainage. In other words, the drainage strategy of USBR was again adopted in this study. To these areas, upper levels of the watertable were assigned. The levels were calculated as follows: Average natural surface elevation in the area in question minus average permissible depth to watertable (being 1.5 m below land surface). With these data, the groundwater model was run for the period June 1985 to June 1990 and for the monsoon 1994 data with various permissible depths to watertable. The model introduced artificial drainage rates whenever the calculated watertable exceeded the prescribed upper limit in a certain area. Figure 3 shows the areas in need of drainage when the permissible depth to watertable was taken as 1.5 m below land surface. This critical depth was also used in the original design of the 11 sump units.

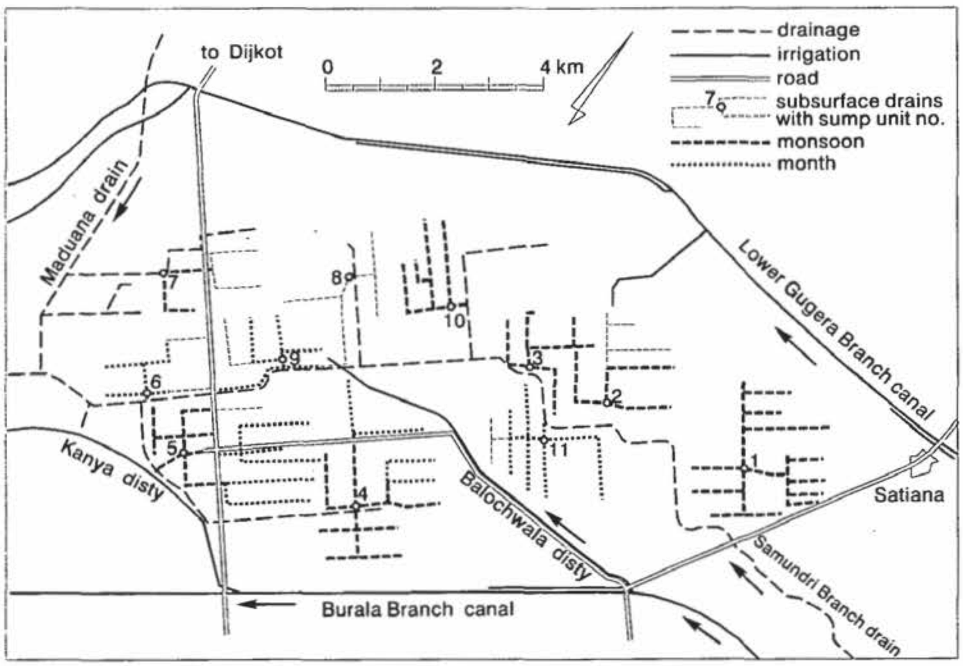

Figure 3. Results of the model study with respect to the areas in need of drainage in Schedule I-B (bold dashed lines based on monsoon period and bold dotted lines based on monthly period)

For a design monsoon rainfall, the results can be summarized as follows: (1) of the 11 sump units, only half of them are actually needed, and (2) an average value of 1.3 mm.d^{-1} for the drainage rate was found whereas, in the original USBR design, it was taken as 2.4 mm.d^{-1}. For a design monthly rainfall, Figure 3 shows that all the sump units except sump unit 8 are needed; their average drainage rate was calculated by SGMP as 1.7 mm/d. From the results of both studies, it is clear that, although the introduction of large scale irrigation in Pakistan in the beginning of this century is the main cause of the rise of the regional watertable close to the land surface at present, drainage is now required to cope with the monsoon rainstorms. The watertable is at present so shallow that a few high intensity rainfall results in a rise of the watertable within the so-called critical depth. A field drainage system should not be designed on these short-duration high intensity rainfalls; the costs would simply be prohibitive. It is therefore proposed that a design monsoon rainfall is used for the design of field drainage systems. Such an approach was also followed by the USBR in their design; the contributing rainfall was representative for a period of approximately 2.5 months. It should be noted that taking the average design monsoon rainfall as component in the drainage coefficient will result in watertables within critical depth during monsoon periods.

Finally, this study clearly demonstrated the dynamic relationship between the drainable surplus, i.e. design net recharge, the permissible depth-to-watertable, the areas in actual need of drainage, and their required drainage rate. Such relationships can only be studied when this type of models are used.

Sirsa District Project

The application of an integrated water management model was one aspect of the research carried out within the framework of the Operational Research Project for Hydrological Studies. This project was implemented at the CCS Haryana Agricultural University in Hisar in collaboration with ILRI and the Winand Staring Centre for Integrated Land, Soil and Water Research from The Netherlands. The main objective of the research in this Project was to make forecasts of the effects of alternative water management scenario's on both the regional rising and falling watertables using this type of models. Sirsa District was selected as the study area; Table 4 summarizes the relevant information on this area.

Table 4. General project area information

area	:	420,000 ha
altitude	:	175 - 210 m.a.m.s.l.
mean annual rainfall	:	300 - 550 mm
mean annual evaporation	:	1600 mm
irrigation water delivery	:	1.6 mm/d
transmissivity aquifer	:	100 - 1300 m^2/d
specific yield aquifer	:	8 - 16 %

Sirsa district is situated in the north-west of Haryana State (see Figure 4); it borders on the state of Punjab in the north and Rajasthan in the west and south. Here, the same phenomena are encountered as can be found in the whole state of Haryana, i.e. rising watertables in the saline belt and falling watertables in the fresh groundwater zone along the Ghaggar river.

The depth-to-watertable are also monitored in India twice a year: in June and October. In Sirsa district a network of 91 observation wells is located. These data were obtained from the

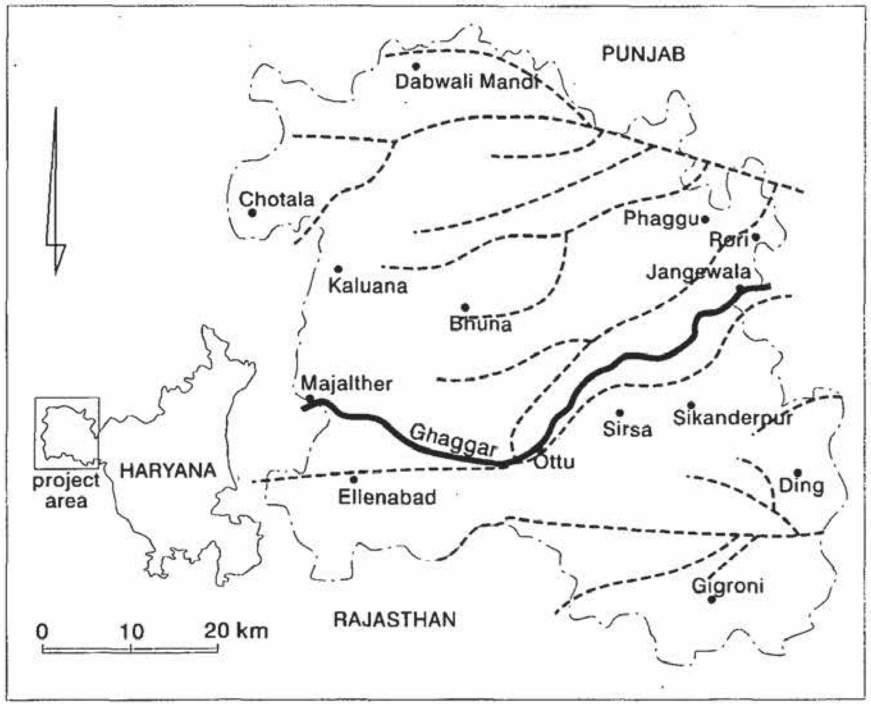

Figure 4. Sirsa District showing the location of the primary irrigation network

Haryana State Minor Irrigation Tubewell Corporation for the period 1976 to 1992, together with the reduced levels of the observation sites.

The model was run for the period January 1977 - January 1992. The time interval within a calendar year was dictated by the irrigation interval, irrigation being the major component in the overall net recharge. A calendar year was therefore subdivided in 15 intervals of 24 days - the common irrigation interval in Sirsa district - and one interval of 5 days to have exactly a calendar year. So, the complete simulation period of 15 years comprised 240 different time intervals and resulted in 15 yearly water budgets.

The period for which historical records are available, is usually split up in two parts. The first part is used to make certain adjustments in the uncertain model input parameters to obtain a good agreement between the calculated and observed watertable behaviour (calibration). The second part is used to check the accuracy of the calibration results; in this period the calibrated input parameters remain unchanged (validation). The model was calibrated using the data of the first five years and subsequently validated using the remaining ten-year period. Figure 5 shows the comparison between calculated and observed watertables in the north-western part of Sirsa district, where the watertables were rising monotonously during the period 1977-1991; here the validation results were very successful. In the central part of Sirsa district the watertable behaviour was quite different. Close to the Ghaggar river, the tendency of rising watertables was reversed after the first two years due to increased tubewell pumping by farmers. Further away from the river, the watertable stabilized either after an initial rise or after an initial rise followed by a decline. In this central part, the validation results were less successful. Figure 6 shows the comparison between calculated and observed watertables for two nodes in this area. Finally, in the south-eastern part of

Sirsa district, where the watertables were also rising monotonously during the period 1977-1991, the validation results were again successful.

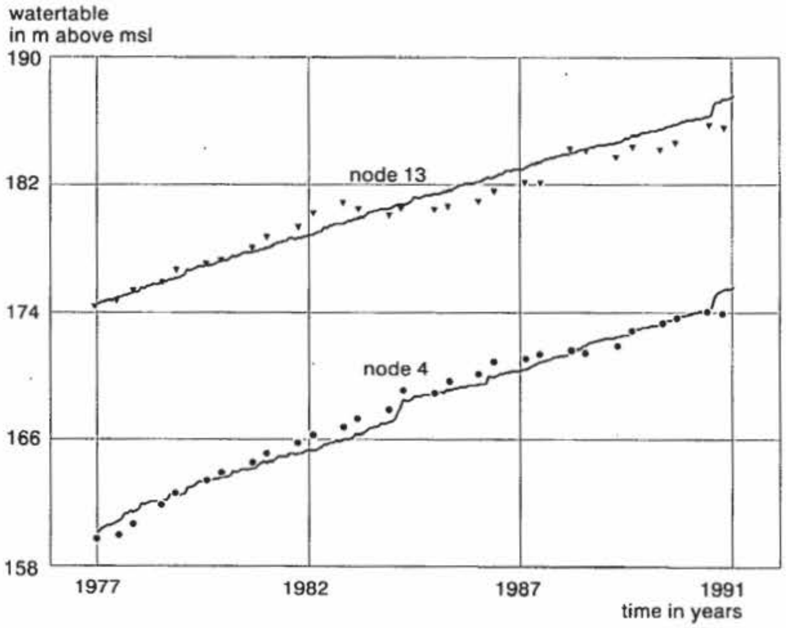

Figure 5. Comparison between simulated (continuous lines) and observed (discrete points) watertable elevations in the north-western part of Sirsa district

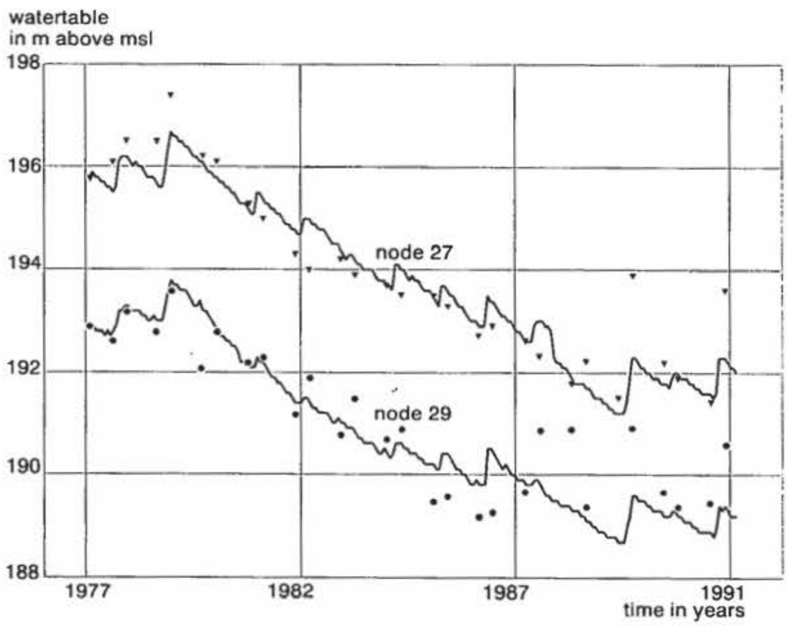

Figure 6. Comparison between simulated (continuous lines) and observed (discrete points) watertable elevations in the central part of Sirsa district around the river Ghaggar

It is standard procedure to make predictions on future watertable behaviour on the assumption that the present water management practices remain unchanged. In these prediction runs, two issues generally need to be addressed: (1) which recharge rates need to be prescribed to the model and (2) how to deal with the boundary conditions. In the calibration and validation periods, the various recharge and discharge components to the overall net recharge were more or less constant, except for rainfall, Ghaggar river recharge, and tubewell pumping; the latter increased significantly over the period 1977-1991. Instead of extrapolating this tendency in tubewell pumping, the overall net recharge was assumed to be constant in the prediction run, being the average of the historical recharges in the period 1982-1991.

The boundary conditions to the groundwater model were treated in the calibration and validation phases as head-controlled boundaries. In stead of extrapolating the tendencies in watertable elevations at the boundary nodes, the average flux over these boundaries of the groundwater model was determined over the period 1982-1991 and assumed to be constant in the prediction run. The groundwater model was subsequently run for the period 1985-2010. Figure 7 shows the results of this prediction run in terms of waterlogging conditions, i.e watertable depths less than 3 m below land surface. It can be seen from Figure 7 that waterlogging conditions will develop in the year 2000 in the central-eastern part and in the south-eastern part of Sirsa district and that especially in the central part north of the Ghaggar river, these waterlogging conditions will expand rapidly in the succeeding ten-year period. Although these predictions should be treated with some caution due to the above-mentioned assumptions, it will be clear that a considerable part of Sirsa district will face serious problems in the near future unless changes will be made in the present water management practices.

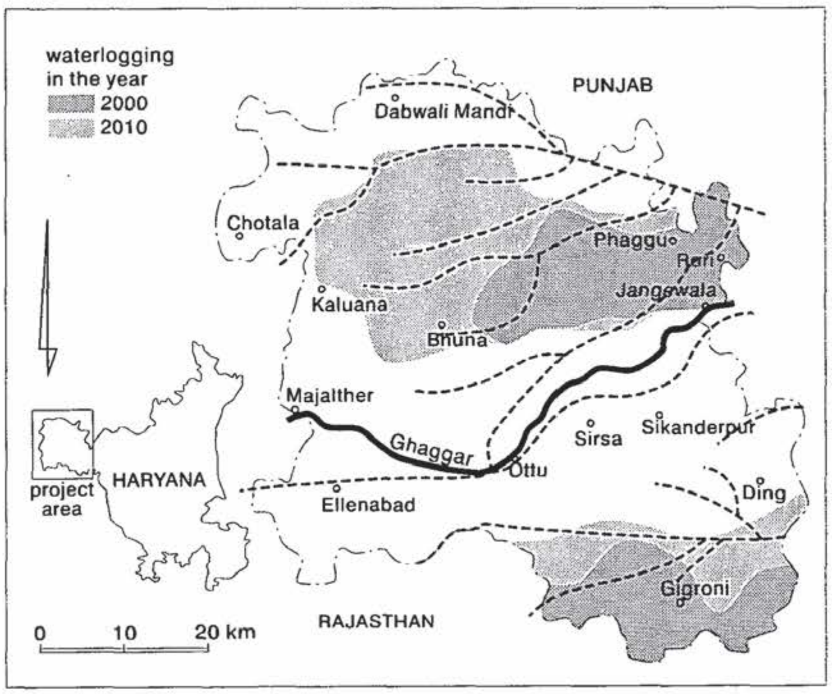

Figure 7. Results of the model study with respect to predicted waterlogging conditions (depth-to-watertable less than 3 m below land surface) in Sirsa district

Finally, two different water management scenario's were simulated with the integrated model: scenario 1 was based on water pricing, i.e. water charges to the farmers are based on the amount of water rather than on the irrigated area, and scenario 2 was based on water supply according to demand (Boels et al. 1996). Table 5 shows the results of future waterlogging conditions for scenario b compared to that with the without case, i.e. present water management will remain unchanged in the future.

Table 5. Predicted waterlogging conditions as percentage of total area

Period	Without case	Scenario 2
1995 - 2000	10 %	5 %
2000 - 2010	45 %	20 %
2010 - 2040	50 %	45 %

For both scenario's, the tendency of rising watertables in the northern and southern part of the Sirsa district could only be attenuated, but not stabilized. This attenuation will be only prominent in the first coming 15 years as can be seen from Table 5.

Fordwah Eastern Sadiqia (South) Project

The main objectives of the FESS project can be summarized as follows: (i) increase agricultural productivity and income; (ii) reduce the need for expensive subsurface drainage and avert environmentally harmful effects; and (iii) improve the equity of water distribution. Within this project, it is the intention to install interceptor drains along unlined branch canals and distributaries, to line 180 km of minors and distributaries with a geomembrane covered with soil and then concrete slabs, to improve another 340 water courses, and to construct another 159 km of surface drains giving a total length of 352 km of surface drains.

One of the objectives of the research in this Project was to use a groundwater model to study the effects of the above anti-seepage measures on the regional watertable and to what extent these measures would reduce the areas in need of drainage. Table 6 summarizes the relevant information on the FESS area.

Table 6. General project area information

area	:	120,000 ha
altitude	:	140 - 160 m.a.m.s.l.
mean annual rainfall	:	170 - 190 mm
mean annual evaporation	:	> 2000 mm
irrigation water delivery	:	2 mm/d
transmissivity aquifer	:	800 - 1600 m^2/d
specific yield aquifer	:	10 %

In 1993/1994, to be able to study the watertable behaviour in the FESS Project in sufficient detail, the SCARP Monitoring Organization/SMO installed about 125 observation wells throughout the area (see Figure 8); since June 1994, they have been monitored on a monthly basis.

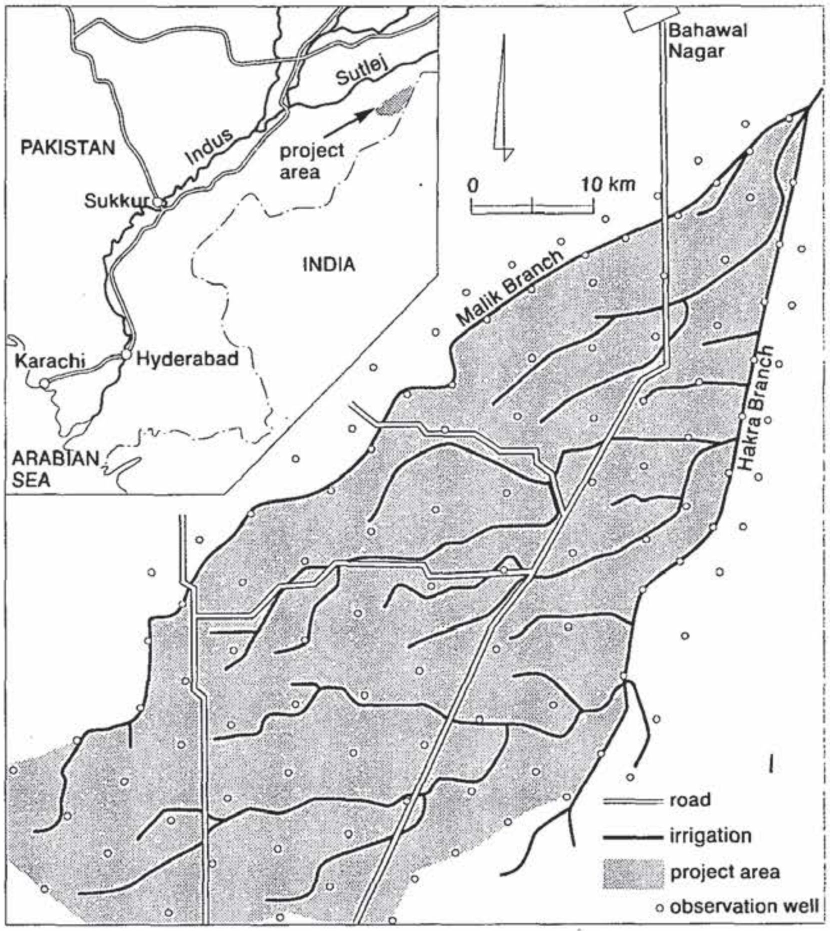

Figure 8. Fordwah Eastern Sadiqia (South) Project with the location of the 125 observation wells for depth-to-watertable measurements

The data base of the collected watertable data presently consists of monthly absolute watertable elevations for the period June 1994 up to August 1996; groundwater hydrographs and watertable contour maps were prepared to analyze the regional watertable behaviour. At present, five additional aquifer tests are made which will be analyzed with software (Boonstra 1989). The model will initially be run in the inverse mode; its principles were discussed by Boonstra and Bhutta (1996).

The advantage of assessing the net recharge with SGMP in inverse mode is that far fewer data are required. For instance, to assess the same net recharge by integrating the water balance for the unsaturated zone with the water balance at the land surface would require considerably more data (e.g. data on rainfall, irrigation, seepage from open water bodies, cropping pattern, crop-water requirements, soils, and tubewells).

The historical net recharges thus obtained will be prescribed to SGMP to make forecasts for future depth-to-watertables. Figure 9 shows the expansion of areas with depth-to-watertable less than 1.5 m (critical depth) between now and the next five to ten years. This figure clearly shows that the area in need of drainage will significantly expand unless changes will be made in the present water management practices.

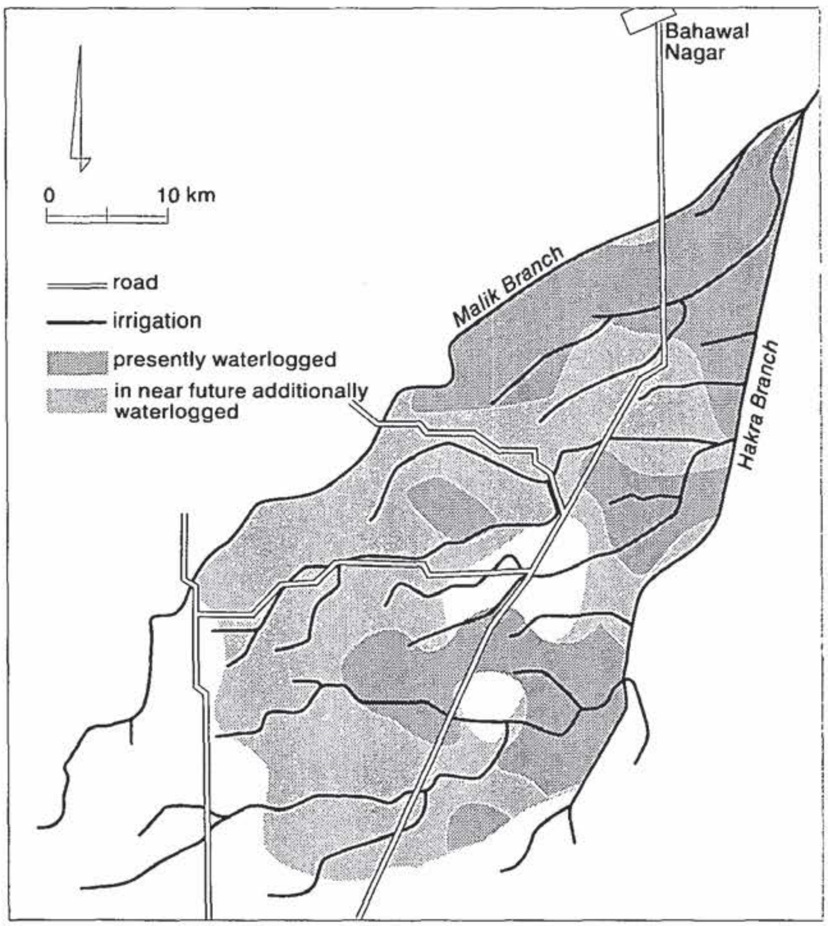

Figure 9. Results of the model study with respect to present and predicted waterlogging conditions (depth-to-watertable less than 1.5 m below land surface) in FESS area

At present, IWASRI is doing considerable field research; it comprises (i) field measurements to determine how much surface water is being lost in distributaries to the groundwater; (ii) the construction of test sites with interceptor drainage along the two main branch canals to study to what extent these interceptor drains will reduce the seepage losses to the groundwater; and (iii) the installation of subsurface drainage systems at three sites to test design specifications. Once these data are available, prediction runs will be made with the numerical groundwater model to make forecasts to what extent the anti-seepage measures will reduce the actual areas in need of drainage.

Concluding Remarks

With integrated management models, the magnitude of the various recharge and discharge components contributing to the overall net recharge to the underlying aquifer system can be systematically accounted for and evaluated. This is an important aspect of this type of tools because it significantly contributes to a proper understanding of past and present water management practices. Another aspect of these tools is that the effects of alternative water management scenario's can be tested on the regional watertable behaviour before they are implemented.

A major constraint of these models is that they require many input data that are often not readily available. This implies that a good monitoring network is necessary, with proper screening procedures to minimize field measurement errors. Finally, it is stressed that GIS pre-processors are a prerequisite when this type of models is applied on a provincial or state level, due to the inherent large spatial variability of the relevant data.

References

Boels, D., Smit, A.A.M.F.R., Jhorar, R.K., Kumar, R. and Singh, J. 1996. *Analysis of Water Management in Sirsa district in Haryana: Model Testing and Application.* Indo-Dutch Operational Research Project on Hydrological Studies. Wageningen. DLO Winand Staring Centre.

Boonstra, J. 1989. *SATEM: Selected Aquifer Test Evaluation Methods.* A Microcomputer Program. ILRI-Publication 48, Wageningen, The Netherlands.

Boonstra, J. and Bhutta, M.N. 1996. Groundwater Recharge in Irrigated Agriculture: The Theory and Practice of Inverse Modelling. *J. Hydrol.*, 174: 357-374.

Boonstra, J., Moghal, M.A., Ali, H.S., Ahmad, M.I. and Vlotman, W.F. 1991. *Collection, Processing, and Screening of Data for the Water Balance Study of Schedule I-B of the Fourth Drainage Project.* Netherlands Research Assistance Project/NRAP, Report 30, Lahore. 104 pp.

Boonstra, J. and de Ridder, N.A. 1990. *Numerical Modelling of Groundwater Basins* (2nd ed.). International Institute for Land Reclamation and Improvement/ILRI, Publication 16, Wageningen.

Boonstra, J., Rizvi, S.A., Moghal, M.A., Ilyas, M. and Bhutta, M.N. 1994. *Assessment of Drainable Surplus S-I-B Area Fourth Drainage Project. The Groundwater Approach.* Netherlands Research Assistance Project/NRAP, IWASRI-Publication 142, Lahore. 159 pp.

Boonstra, J., Singh, J. and Kumar, R. 1996. *Groundwater model study for Sirsa district, Haryana.* Indo-Dutch Operational Research Project on Hydrological Studies. ILRI, Wageningen.

Rao, K.V.G.K., Boonstra, J., Oosterbaan, R.J. and Ramnandanlal, H. 1996. *RAHYSMOD: Regional Agro-Hydro-Salinity Model. Description of Principles.* Central Soil Salinity Research Institute, Karnal.

Ridder, N.A. de, and Boonstra, J. 1994. Analyses of Water Balances. In: *Drainage Principles and Applications* (2nd Ed.). H.P. Ritzema (Editor). International Institute for Land Reclamation and Improvement/ILRI, Publication 16, Wageningen. pp. 601-635.

Rizvi, S.A., Boonstra, J. and Bhutta, M.N. 1996. *Application of Groundwater Approach to Drainage design for the Monsoon 1994 at S-I-B Area of Fourth Drainage Project.* Netherlands Research Assistance Project/NRAP, IWASRI-Publication 163, Lahore. 76 pp.

Discussion

Asked whether the model gave consistent results, the author replied that the approach in this model application was based on unsteady-state conditions and that results were consistent. Another participant asked about the surface drainage system in Fordwah Eastern Sadiqia South and whether the effect of surface drainage was incorporated in the model. The author replied that surface drains were not included in the model and that in Fordwah Eastern Sadiqia South construction of the surface drainage system had not yet been completed. At this point in time it was not yet possible to calculate the effects of surface drainage on the model output, but the author offered the following observations on the effect of a functioning surface drainage system: (1) During monsoon surface drains would evacuate overland flow from the project area, thus reducing the groundwater recharge. (2) Although on the upstream side surface drains would be shallow and may not cut into the watertable, this would not be the case at the downstream end where large surface drains, like the Harunabad Drain, would not only remove overland flow but would also remove groundwater and so lower the watertable. (3) During harvesting periods, when irrigation supplies continue but farmers cannot use this water, it can be expected that this excess irrigation water will be discharged in the surface drains and leave the project area towards the evaporation ponds. This would also reduce groundwater recharge in the project area. The above three effects indicate that surface drains would reduce groundwater recharge and lower the watertable, provided these drains would be properly maintained. In case maintenance would not be good, this would mean more water would remain in the area, would recharge groundwater and result in more shallow watertables.

From the audience the remark was made that maintenance of surface drains is a government responsibility. Even if privatization programs would be introduced and become effective and the farmers themselves would accept responsibility for drainage, maintenance of main drains would always remain with the government.