Trade-Offs Between Gross Farm Income, Groundwater and Salinity at Irrigation Sub-Divisional Level

Waqar A. Jehangir[1], Muhammad Ashfaq[2] and Kashif Majeed Salik[3]

ABSTRACT

This paper represents a part of study where the SWAGMAN Farm Model has been used to evaluate the financial and environmental trade-offs for effective conjunctive water management in the Rechna Doab. The data used in this study were collected from 544 sample farms located in twenty-eight irrigation sub-divisions of Rechna Doab. The SWAGMAN Farm Model was developed by CSIRO (Australia) and was adapted for 28 sub-divisions in the Rechna Doab. Among 28 sub-divisions this paper reports the results from three sub-division namely, Shahdra, Aminpur and Wer. The optimization results showed that it is possible to increase the total gross margins while keeping the salinity levels and the changes in depth to water table in the acceptable limits through conjunctive water management at the sub-division level. The model estimated an increment in the total gross margins to the tune of Rs. 25.41, 2.26 and 31.31 millions for Aminpur, Shahdra and Wer sub-divisions, respectively.

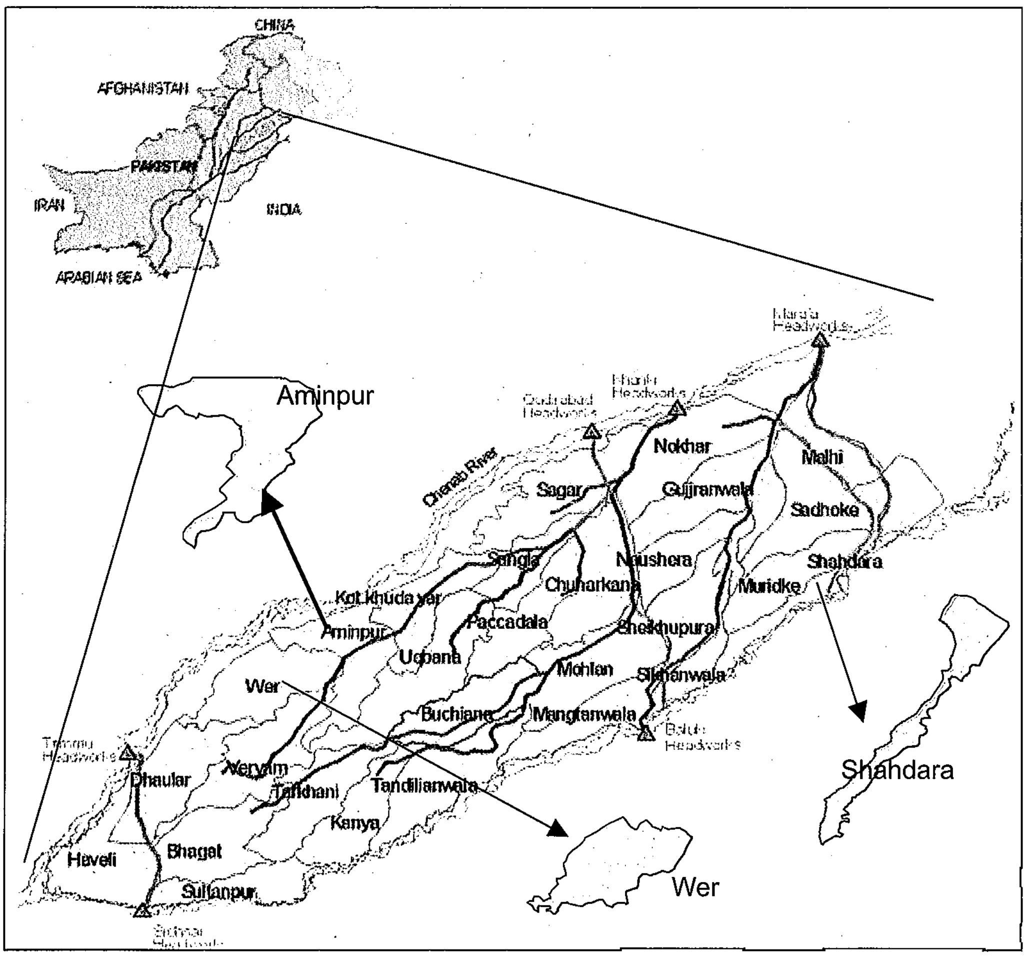
INTRODUCTION

The international literature is filled with the studies on conjunctive water management and its impact on crop productivity and related issues [O'Mara (1988); Bredehoeft and Young (1988); Shah (1988); Gangwar and Toorn (1987), Datta and Dayal (2000), Lingen (1988), Gorelick (1988), Brewer and Sharma (2000) and Raju and Brewer (2000)]. In Pakistan, the literature review shows that all of the previous studies conducted in the arena of water management reported the management problems leading to the inefficiencies in irrigation application and reduction in crop productivity, [Kijne and Velde (1991); Mustafa (1991) and Siddiq (1994)]. None of these studies have taken into consideration the trade offs between gross farm income, groundwater and salinity at irrigation subdivision level. To answer the issues of spatial differences in the trade offs between gross farm income, groundwater and salinity at irrigation subdivision level, this paper reports the results of the optimization modeling at the sub-divisional level in the Rechna Doab. The Rechna Doab is comprised of 2.98 million hectare (Mha) and is located between the rivers Ravi and the river Chenab (Figure 1). In arid and semi-arid climate of Rechna Doab, water availability plays an important role in determining the gross farm output/income along with other resources. Like other areas of Pakistan, the Rechna Doab is also facing the shortage of canal water supplies. About 57 percent of the farmers keep part of their lands fallow due to shortage of canal water. To meet the

[1] Senior Agricultural Economist, IWMI Regional Office, Lahore, Pakistan
[2] Agricultural Economist, IWMI Regional Office, Lahore, Pakistan
[3]Junior Researcher, IWMI Regional Office, Lahore, Pakistan

crop water requirement, farmers use groundwater along-with canal water. Therefore, where soils are suitable for specific crops, the presence of good quality groundwater helps in enhancing the productivity of crops. In Rechna Doab, out of the total surveyed area of 1.95 Mha, about 1.63 Mha of the area has fresh and useable groundwater supplies but 0.321 Mha has saline groundwater (Rehman et al. 1997). Thus the farmers with the area of saline groundwater have little opportunity to utilize groundwater alone in the critical periods of crop growth. The huge increase in population, low rainfall, and decreasing capacity of fresh water reservoirs, demands for devising the methods to fulfill the increasing demand of fresh water for the crops. Moreover, the presence of bad quality groundwater in the lower reaches of the Rechna Doab also calls for finding out the optimal solutions in conjunctive water management, which may help the farmers to raise the crops in a profitable way and at the same time also keep the hazards of salinity/sodicity to the lowest levels.

Figure 1: Locations of Aminpur, Shahdara and Wer Sub-divisions in Rechna Doab, Punjab Pakistan



The SWAGMAN Farm Model provides an opportunity to evaluate the financial and environmental trade-offs between gross farm income, groundwater level and salinity at the sub-division level. This paper describes the result of the Model for Shahdra, Aminpur and Wer irrigation sub-divisions. The objectives of this paper were to determine the possibilities of increasing total gross margins by taking optimal mix of crops; to determine the ways of best use of conjunctive water for irrigation and to estimate the impact on gross margins with respect to optimal crop mix, depth to water table and soil salinity. The paper is divided into five major sections. The section II explains the methodology, which is followed by results and discussion in section III. The conclusions are given in section IV and the model limitations and way forward are discussed in the final section of the paper.

METHODOLOGY

Study Area

The Shahdra, Aminpur and Wer sub-divisions are located in the upper, middle and the tail parts of the Rechna Doab (Figure 1). These sub-divisions had about 42.28, 77.27 and 63.67 thousand hectares of cultivated area, respectively. The water table depths were reported to be 3.42, 6.09 and 6.78 m in Shahdra, Aminpur and Wer sub-divisions respectively. Water allocation for the Shahdra, Aminpur and Wer sub-divisions was 0.73, 6.26 and 5.1 million mega liters (ML), respectively. The 25 years average of annual rainfall was reported to be 631, 325 and 314 mm in Shahdra, Aminpur and Wer sub-division, respectively.

Data Collection

The primary data sets were collected through a well-designed pre-tested questionnaire, which were used to collect the information from 544 sample farms located on 188 sample sites in the Rechna Doab. Physical and meteorological data were collected from secondary sources comprised of Punjab Irrigation and Power Department (PID), Salinity Monitoring Organization (SMO) and Meteorological Department. Physical data includes soil texture, area under different soils, textural classes and water quality. The meteorological data included information about rainfall, humidity, sunshine, wind speed and temperature. The data about irrigation, infrastructure and the designed discharges were collected from irrigation department.

Model Specification

The SWAGMAN Farm Model is an annual model that allocates land to different crops on annual basis, based on distribution of soils on farms within sub-divisions. Potential land uses, crop evaporative requirements, current irrigation practices, leaching requirements, annual rainfall, leakage to deep aquifer, depth to water table, capillary inflow from shallow water table, salt concentration of irrigation and groundwater and taking into consideration the economic returns from potential land uses, it maximize total gross margins for the sub-divisions subject to the given economic and environmental constraints. In the Rechna Doab, the crops sown during the Rabi and the Kharif seasons were taken in to account. The major crops during the Kharif season were Rice, Cotton and Kharif Fodder while in during the Rabi season the major crops were Wheat and Rabi Fodder. The sugarcane was an annual crop so it was treated as such in the Model. The specification of the model is given as follows

$$TGM = \sum_{C} \sum_{S} X_{C,S}(GMLW_C - IRRN_{C,S} \times WPRICE)$$

Where:

TGM	= Total gross margin (Rs.)
X	= Area under land use C and soil type S (ha.)
GMLW	= Gross margin of a land use less cost of irrigation water (Rs./ha.)
IRRN	= Irrigation water used for land C and across soil types S (ML/ha.)
WPRICE	= Price of water (Rs./ML)
C	= Land uses under various cropping patterns in the sub-division
S	= Soil types across the farms in the sub-division

The model was subjected to the constraints namely, area, salt balance, net water balance, pumping of groundwater and water allocation. As far as the area constraint was concerned the model specified that the rice crop could not be grown on sandy loam and loam soils and cotton was not allowed to grow on clay-loam and silt-clay soils. The second constraint considered in model was salt balance. The salt accumulation due to irrigation, rainfall and capillary up-flow within the root zone required to be removed by leaching and drainage practices, so that the amount of salt in the root zone should be less than the specified level of salinity. The third constraint considered in the model was net recharge. Net recharge or water balance level was defined as the allowable rise in the groundwater-table. Net recharge included both, recharge and discharge mechanisms. The fourth constraint in model was pumping of groundwater. If pumping was allowed in the model then the new depth to water table was determined by taking the difference between initial depth to water table and the change in the depth to water table after optimization. If there has been no pumping option then the model calculate the water required to maintain the water table at the present level. The last constraint taken in the model was water allocation. The total water requirements were not allowed to exceed the annual water allocation to the respective sub-divisions. The water allocation for a specific subdivision was calculated by multiplying area under specific crops on different soil types and irrigation requirements on farms. The objective function was solved by using the integer programming solver GAMS, subject to given constraints.

RESULTS AND DISCUSSIONS

Figures 2-13 provide the model results computed through SWAGMAN Farm Model for the optimal land use, total gross margins, impact on salinity and depth to water table with respect to Shahdra, Aminpur and Wer subdivisions in the Rechna Doab. With respect to the location of these sub-divisions the Shahdara subdivision was located in the Upper Rechna Doab and was comprised of a total culturable command area of 42279 hectares. Figure 2 shows that the optimized gross margins of Rs. 574.736 million could accrue through the changed cropping pattern as compared to the actual gross margins of Rs. 552.111 million calculated for existing cropping pattern in the Shahdra sub-division. It shows that there is a possibility to increase the gross margins by Rs. 22.625 million by adopting the cropping pattern proposed by the model. The model proposed to reduce the area under rice-wheat rotation from 32.22 thousand hectare (Tha) to 8.40 Tha and to increase the area under maize-wheat rotation from 0.03 Tha. to 28.38 Tha. Similarly, the model proposed not to grow any crop under Rabi fodder-rice rotation and under sugarcane, which currently was practiced on 4.41 and 2.07 Tha, respectively in the Shahdra sub-division. The major reason for this proposed change in the cropping pattern was due to the fact that the objective function of the model tried to maximize the total gross margin by taking into consideration the crop mix and soil mix which are suitable for specific cropping patterns. The decrease in area under rice-wheat cropping pattern was mainly due to soil limitation described in the model. As specified in the model, the rice crop cannot be grown in loam and sandy loam soils that constitute the major part (about 29 Tha) of the Shahdra subdivision, thus, led the model to propose the reduction in area under rice-wheat rotation. On the other hand, these soils were suitable for the cultivation of maize crop thus model has proposed a rise in area under maize-wheat cropping pattern to 28.38 Tha. This re-adjustment of area under proposed cropping pattern as compared to the current situation led to generate additional gross margins of Rs. 22.625 million in the Shahdra sub-division as already mentioned above. The proposed cropping pattern not only enhanced the gross margins but also had some positive impacts on environment in the Shahdra sub-division. The model results showed that the groundwater would go down by 10 cm from 3.42 meters to 3.42 meters (Figure 4) and the salinity would be reduced to about 0.66 dS/m (projected salinity level 0.90 dS/m salt as compared to the current salinity level of 1.56 dS/m) (Figure 5).

Figure 2. Total Gross Margin in Shahdara Subdivision

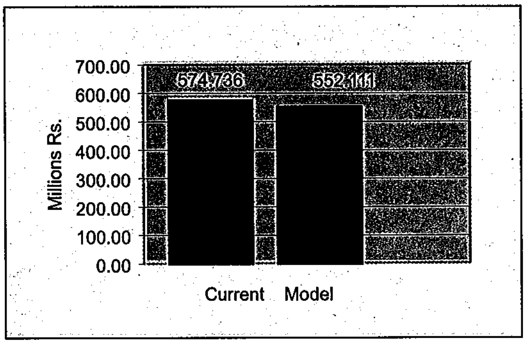


Figure 3. Land Use in Shahdara subdivision

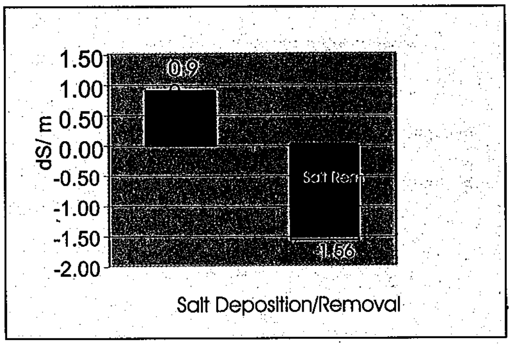


Figure 4: Depth to Watertable in Shahdara. subdivision

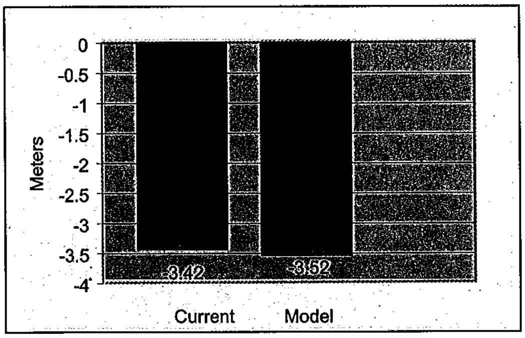
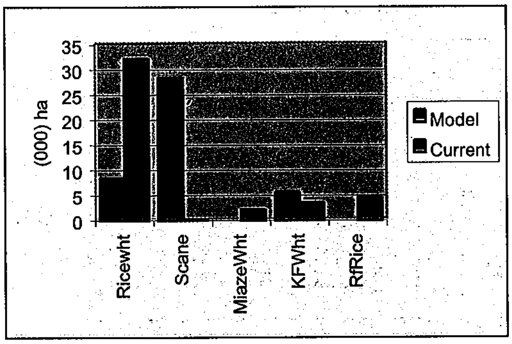


Figure 5: Impact on Salinity in Shahdara subdivision



The execution of the model for Aminpur sub-division led to the results indicating 11 percent increase in the gross margins from the proposed optimized cropping patterns in Aminpur sub-division as compared to the existing cropping patterns. The optimized cropping patterns raised the gross margins from Rs. 2050 million to Rs. 2304 million (Figure 6). The model proposed an increase in area under sugarcane and maize-wheat rotation from 22.97 to 46.38 and from 9.57 to 10.5 Tha, respectively. The model also proposed to reduce the area under cotton-wheat, kharif-fodder-wheat and rabi fodder-cotton rotation from 14.35 to 1.8, from 16.75 to 13.62 and from 13.64 to 4.98 Tha, respectively (Figure 7). This major shift was due to high gross margins in the sub-division from sugarcane crop as compared to the cotton but it increases the crop water requirement. The soils in Aminpur subdivision mainly comprised of moderately coarse soils (Rehman, G. *et al.*

1997). These soils are having mainly loam and sandy loam texture. Main crops in this subdivision are sugarcane, cotton, wheat and fodder. As the coarse texture of Aminpur soils do not allow the cultivation of rice therefore it remains invisible both in existing and proposed situation. The model results indicated that the groundwater table might rise by 9 cm and come up to surface from 6.09 meter to 6 meter (Figure 8). The model showed that salinity level in the Aminpur subdivision would rise from 1.28 to 1.41 dS/m (Figure 9) and this increase in soil salinity might be due to use of saline groundwater. The conjunctive use of saline groundwater with the canal water for production of high value crop might increase gross margins in the short run but increasing use of groundwater in the long run might result in the waterlogged conditions if high delta crops like sugarcane would be continuously grown in the Aminpur sub-division.

Figure6: Total Gross Margin in Aminpur subdivision.

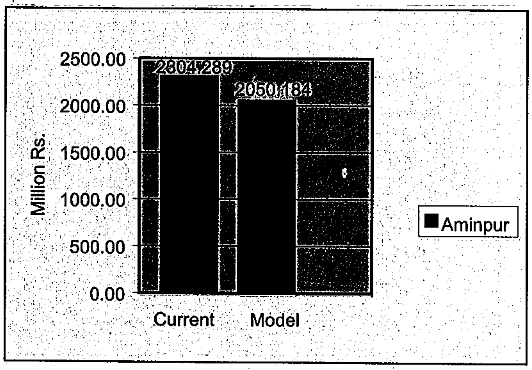


Figure 7 : Land Use in Aminpur subdivision

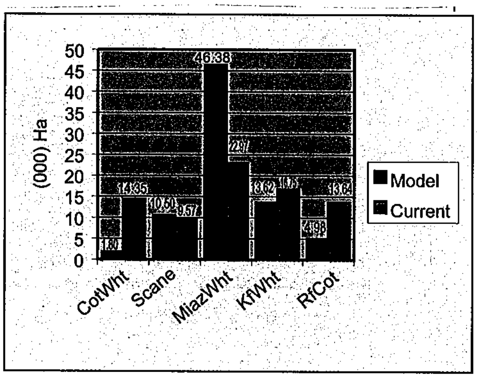


Figure 8 : Depth to Water Table in Aminpur Subdivision

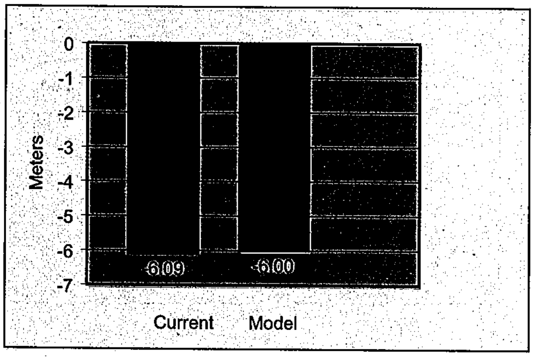
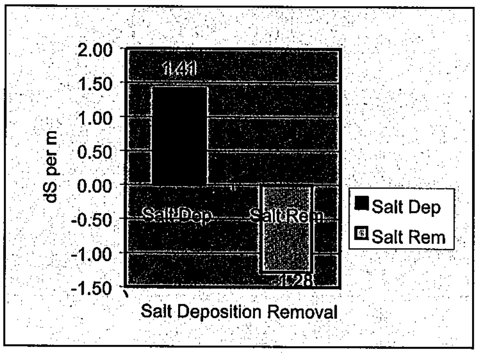


Figure9: Impact on Salinity in Aminpur Subdivision



In the Wer subdivision, where the soils have a balanced mix between moderately coarse sandy loam and fine sandy loam to medium textured loam, silt loam soils, the optimization of SWAGMAN Farm Model resulted in the changes for the cultivated areas under different crops being raised in the Wer sub-division. This redistribution of area under different cropping patterns provided 23.59 percent increase in gross margins; raising it from the current level of Rs.1013.92 millions to optimized level of Rs.1326.99 millions (Figure 10). The model allocated 30.5, 16.63 and 16.55 Tha of the cultivated areas to sugarcane, Kharif fodder-wheat, and Rabi fodder-cotton rotation respectively (Figure 11). The presence of the moderately coarse to medium textured soils in the Wer sub-division constrained the model to allow the cultivation of rice and thus the model proposed not to grow crops under Rabi-fodder-rice rotation; currently this rotation is being followed on 15.41 Tha. of land in the Wer sub-division. The model also reduced the area under Kharif fodder from 32.35 to 16.62 Tha in the Wer sub-division without considering its impacts on the livestock population in the area. Basically, this flaw was due to the fact that the model only considered the gross margins from the crops sector and then related them to the soils, water requirements and the other environmental conditions. It did not take into consideration the livestock sector as such because it was not included in the model. The excessive extraction of the groundwater for sugarcane might result in lowering of water table by 10 cm in the Wer subdivision as the new depth to water table was estimated to be 6.88 m as compared to the original water table depth of 6.78 meters in this sub-division (Figure 12). The model results showed that the proposed cropping pattern would not only increase the gross margins but it would also help to reduce the salinity levels to about 0.17 dS/m (Figure 13).

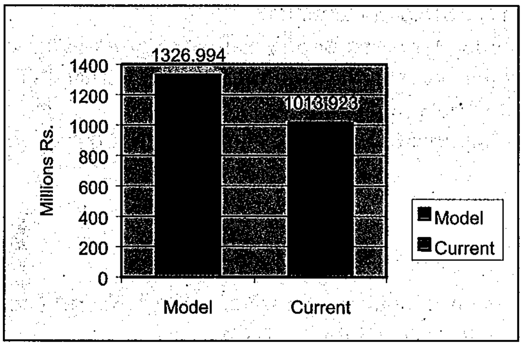


Figure 10: Total Gross Margin in Wer Subdivision.

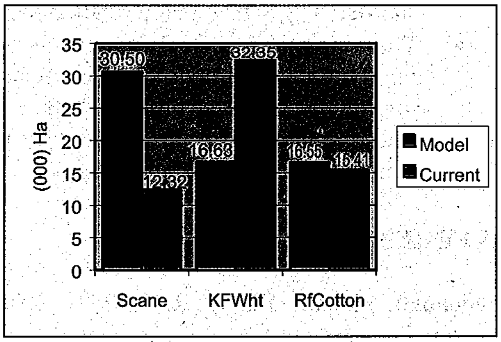


Figure 11: Land Use In Wer Subdivision.

Figure 12 Depth to Water Table in Wer Subdivision.

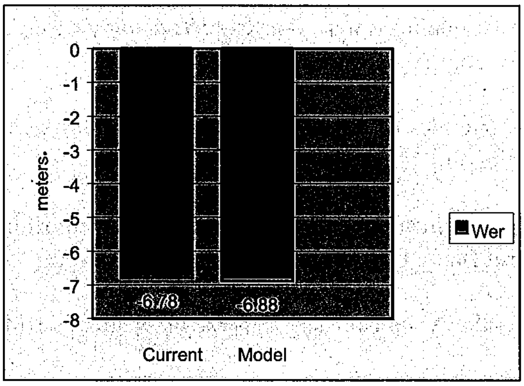
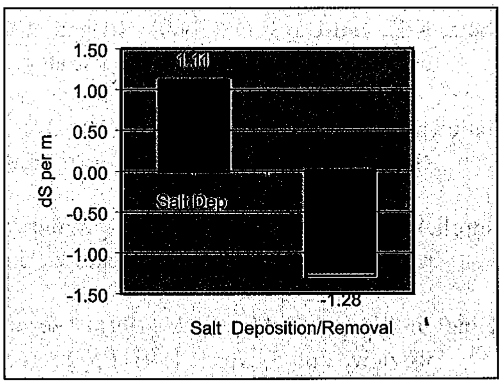


Figure13: Impact on Salinity in Wer



CONCLUSIONS

The paper revealed that it is possible to increase the gross margins to the tune of Rs. 25.41, 2.26 and 31.31 million in the case of Shahdra, Aminpur and Wer sub-divisions, respectively by changing the crop mix across farms in these sub-divisions. The model provided the estimates about the new depths to water table which show that in the case of Shahdra and Wer sub-divisions the use of tubewell would lead to increase the depth to water table by 10 cm while in the case of Aminpur sub-division the depth to water table would rise by 9 cm. With respect to the salinity conditions in these sub-divisions the salinity level would decrease in the Shahdra and Wer sub-divisions by 0.66 and 0.17 dS/m, respectively while the results showed an increase in the salinity level by 0.2 dS/m in the case of Aminpur sub-division. These results are constrained by the model limitations that are listed below.

LIMITATIONS OF THE MODEL AND WAY FORWARD

The limitations of the SWAGMAN Farm Model are enlisted below:

- The model takes into consideration the gross margins coming from different crop mix on the farms with in the sub-divisions.
- The model is annual and did not take into account the single crop grown on the farms in the sub-division, rather a crop rotation has been specified in the model.
- There was no live stock component and the model based on the estimated gross value of the fodder have proposed not to include fodder crops in the crop rotation but farmers have to grow the fodder in order to sustain their livestock population.
- These limitations in the model need to be improved to get better optimization out of the simulation results from the model.

REFERENCES

Bredehoeft, J.D. and Young, R.A.(1988), 'Risk aversion in conjunctive water use', A World bank Symposium on Efficiency in Irrigation, series 2, The World Bank, U.S.A

Brewer, J.D and Sharma, K.R. (2000), 'Conjunctive management in the Hardinath Irrigation System,, Nepal, International Water Management Institute, Nepal. Report No. R-94.

Datta, K.K. and Dayal,B. (2000), 'Irrigation with poor quality water : An empirical study of input use, economic loss, and coping strategies', Ind. Journal of Agri. Econ. Vol.55, No.1.

Gangwar, A.C. and Toorn, W.H.V.(1987), 'The economics of adverse groundwater conditions in Haryana state, Ind. Journal of Agri. Econnomics.Vol.42, No.2

Gorelick, S.M. (1988), 'A review of groundwater management models', A World Bank Symposium on Efficiency in Irrigation, Series 2, The World Bank, U.S.A.

Kijne, J. W. and Velde, E. J. (1991) 'Secondary salinity in Pakistan Harvest of Neglect'. IIMI Review, Vol. 5, No. 1. 1991. Pp. 15-16.

Lingen, C. (1988), 'Efficient conjunctive use of surface and groundwater in the People's Victory Canal, A World Bank Symposium on Efficiency in Irrigation, series 2,The World Bank, U.S.A.

Mustafa, U. (1991), 'Economic impact of land degradation (Waterlogging and salt effected soils) on rice production in Pakistan's Punjab'. Unpublished Ph.D. dissertation, University of Phillipines at Las Banos, (1991).

O'Mara, G.T. (1988), 'The efficient use of surface water and groundwater in irrigation: An overview of the issues', A World bank Symposium on Efficiency in Irrigation, series 2, The World Bank, U.S.A.

Raju, K.V. and Brewer, J.D. (2000), 'Conjunctive management in the North Bihar,, India, International Water Management Institute , India. Report, No. R-95.

Shah, T. (1988), 'Managing conjunctive water use in canal commands: Lessons from the analysis of the Mahi right bank canal,Gujrat' , Research paper 3, Institute of Rural Management, Anand, India.

Siddiq, A. (1994) 'Sustainability of Indus Basin: impact of tertiary salinity on wheat productivity, damage assessment and future public policy'. Ph.D. Dissertation, University of Illinois, Urbana-Champaign, U.S.A.