ROOT ZONE SALINITY MANAGEMENT USING FRACTIONAL SKIMMING WELLS WITH PRESSURIZED IRRIGATION

Proceedings of the Project-End Workshop 2003

Muhammad Nadeem Asghar, Muhammad Yasin, Muhammad Mehboob Alam and Asad Sarwar Qureshi, editors

International Water Management Institute
Mona Reclamation Experimental Project
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In the short water supply environment of Pakistan, farmers try to minimize the gap between demand and supply of canal water by extracting groundwater for irrigation purposes. However, saline groundwater upconing may occur in response to fresh groundwater withdrawals from unconfined aquifer underlain by salty groundwater. Skimming well technology can help in controlling this upconing phenomenon. However, in most cases, the small discharges of such wells cannot be efficiently applied on surface irrigated croplands. Pressurized irrigation systems use small discharge effectively, but the cost and availability of equipment in the local market are the constraints. Root zone salinity is also expected to increase if this skimmed groundwater is used for irrigation purposes, particularly in the absence of proper salinity management practices. To address these issues, International Water Management Institute (IWMI), Water Resource Research Institute (WRRI) and Mona Reclamation Experimental Project (MREP) collaborated to undertake an applied research project on *Root Zone Salinity Management Using Fractional Skimming Wells with Pressurized Irrigation*. This project was started in March 1999 and concluded in June 2003. The National Drainage Program (NDP), Research Component – WAPDA funded this project.

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Asghar, M.N., M. Yasin, M.M. Alam and A.S. Qureshi (Eds.), 2004. *Root zone salinity management using fractional skimming wells with pressurized irrigation: Proceedings of the project-end workshop 2003.* Lahore, Pakistan: International Water Management Institue (IWMI).

Keywords: Salinity / irrigation scheduling / groundwater / river basins / methodology / project planning / hydrology / geology / rain / tubewells / rivers / canals / seepage / irrigated farming / aquifers / crop water requirements / participatory rural appriasal / farmers / stakeholders / technology / sprinkler irrigation / water quality / hydraulics / field research / Pakistan

Special thanks are due to Ms. Ayesha Bhatti and Ms. Saiqa Batool for editing and formating this report, respectively.

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Methodology for Site Selection to Introduce Skimming Well Source Pressurized Irrigation Systems

M. Yasin, M.N. Asghar, M.M. Alam, G. Akbar and Z. Khan

Abstract

Detailed hydro-geological investigations were carried out while implementing SCARPs in the *Chaj Doab*. These investigations yielded a data set of groundwater quality at different depths of the aquifers (spatial) especially in the SCARP-II saline zone. In MREP area, 138 public tubewells, having strainers from 30-35 m till 60-75 m depth of the aquifer, were installed during the 1970s to help meet the irrigation water demand at farm level. The MREP, who was made responsible for operation and maintenance of these deep tubewells, continuously monitored the performance of these tubewells as well. Therefore, the pumped groundwater quality data (temporal) of these spatially distributed tubewells was also available. This data availability served as a basis for site selection using GIS analysis.

The GIS analysis, which was used in classifying different groundwater quality zones, helped in selecting fifteen villages (thirteen in MREP area and two in SCARP-II saline zone) that have hydro-geological potential for installing and operating skimming wells. In these selected villages, preliminary survey was carried out to get information on the farmers' willingness to use skimming well technology. Based on the GIS analysis and preliminary survey, different sites in six villages (two in SCARP-II saline zone, and four in SCARP-II non-saline zone) were selected to carry out the Diagnostic Analysis (DA) for investigating the hydro-salinity and hydro-geological conditions of the aquifer. Based on the DA results, four villages for the Participatory Rural Appraisal (PRA) to assess farmers' practices and perceptions in opting for skimming well technologies.

INTRODUCTION

Background of skimming wells and pressurized irrigation systems project

Exploitation of groundwater for agricultural, municipal and industrial uses is severely hampered in many parts of the world by the encroachment of brackish groundwater in response to fresh water withdrawals. Examples of brackish groundwater intrusion are common in coastal aquifers, but are sometimes present in inland aquifers as well. Probably, the most important example of the latter case exists in the Indus Basin Irrigation System (IBIS). The IBIS has caused disruption of hydraulic regime due to seepage from extensive water conveyance and distribution system, as well as deep percolation from irrigation and precipitation. The native groundwater that existed in the pre-irrigation period (early 19th century) was saline because of the underlying geologic formation being of marine origin. Now, this native saline groundwater is overlain by fresh groundwater due to seepage from rivers and canals of the IBIS. Thus, shallow fresh groundwater zone occurs between the native pre-irrigation and the present day water tables.

Near the rivers and canals, the fresh surface water seepage has improved the quality of the native groundwater to 120 to 150 m depths. However, in some areas, the thickness of the shallow groundwater zone ranges from less than 60 m along the margins of Doabs (area enclosed between two rivers) to 30 m or less in the lower or central parts of Doabs. Recently, it has been estimated that nearly 200 billion m^3 of fresh groundwater (mostly in the form of a thin layer) is lying on saline groundwater. Obviously, if proper technology is applied, the referred thin fresh groundwater layer can be skimmed from the aquifer with minimum disturbance of the saline groundwater zone. In the short irrigation water supply environment of Pakistan, such extractions would become a significant part of supplemental irrigation.

The explosion of pumping technology in the private sector, high capacity tubewells of more than 28 lps discharge are being installed even in the thin fresh groundwater zones. Framers are normally interested to install tubewells of higher discharges to have efficient basin irrigation by reducing the advance time of water front. This can be regarded as a psychological issue rather than based on techno-economics of tubewells or physical conditions of the aquifer. The discharge of skimming wells might be as low as 3 lps and thus pressurized irrigation technology is necessary for efficient application of smaller stream size.

In such zones, these tubewells are likely to draw a substantial portion of their discharge from the saline groundwater. The primary problem is that the tubewell discharges are too large for the given physical situation of the aquifer. This is particularly true for the tubewells located in the central regions of Doabs in the Punjab province of Pakistan. The exception would be tubewells located adjacent to rivers and large canals where large quantities of seepage are recharging the groundwater reservoir.

Thus, if such tubewells are not replaced with fractional skimming wells, there is a serious concern that the pumped groundwater will become increasingly saline with time. Already, many high capacity public tubewells are being shutdown at the request of farmers in these areas, as the pumped water has become saline with time. In addition, there is a high expectation that many private tubewells will have to be abandoned during the next coming years. Therefore, it is imperative to introduce fractional skimming well and pressurized irrigation technology to address these future concerns.

Taking into consideration the vital importance and urgent need for developing skimming wells and pressurized irrigation technology, a tripartite institutional arrangement (Water Resources Research Institute, NARC; Mona Reclamation Experimental Project, Bhalwal and the International

Water Management Institute) was developed to initiate a collaborative project entitled "Root-Zone Salinity Management using Skimming Wells and Pressurized Irrigation Systems". The project was financed by WAPDA under the National Drainage Program and initiated in the Target Area at the Mona Reclamation Experimental Project, Bhalwal during November 1998.

Location and purpose of the methodology development

In this study, Mona Unit area has been selected covering the gross command area of 44516 hectares with 138 tubewells (Figure 1). The pre-project water table was between 0 to 3.35 m during 1965, whereas it varies from 0.61 to 5 m during 1997. The pre-project cropping intensity was 99 %, whereas it is now 152 % during 1997 (MREP 1997).

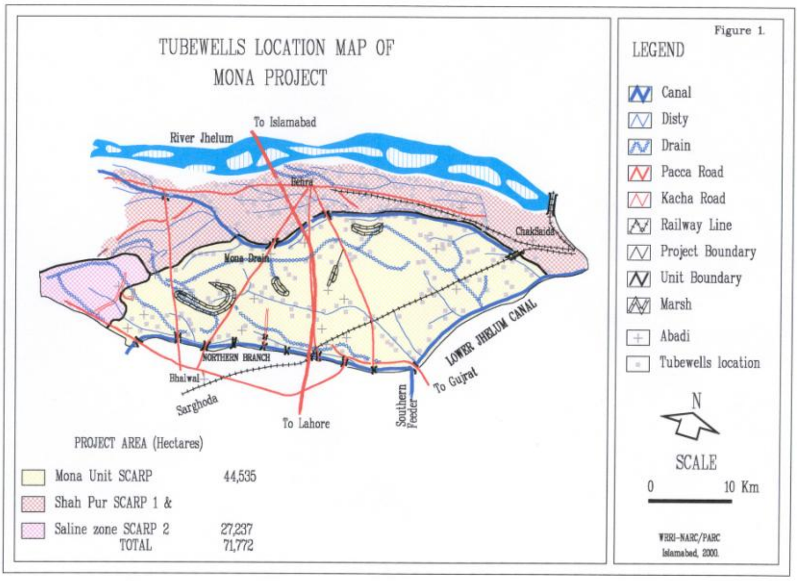

Figure 1. Tubewells location map of Mona project.

The following three studies were conducted in the Mona SCARP area to develop the methodology and are listed as under:

1. Spatial and Temporal Analysis of Deep Groundwater in the Mona SCARP area using the historical data of groundwater quality and the Geographic Information System (referred as GIS Study);
2. Participatory Rural Appraisal of selected thirteen villages of the Target Area of the project (referred as PRA Study);
3. Diagnostic Analysis Study of seven villages out of thirteen selected under the Target Area (referred as DAS Study).

The specific objectives of the methodology development are as under:

4. The GIS study was aimed to conduct spatial and temporal analysis of groundwater quality and water-table depth in the Mona Unit to evaluate changes occurred in the project area during the last 32 years. The long-term geo-referenced groundwater data collected by the MREP were used for GIS analysis. Salinity and sodicity data were used to characterize and classify groundwater quality zones. Methodology was developed to characterize potential locations for design and installation of skimming wells and pressurized irrigation systems. This methodology can be adopted for sustainable development of groundwater in marginal to hazardous zones.

5. The PRA Study was aimed to document perceptions of rural communities regarding problems and constraints using interactive processes of participation to prioritize real-issues including ranking of these real-issues as viewed by the community. Verification of potential villages considering the project interventions was based on the perceptions of the farming community. Criteria for installation of skimming dugwells and tubewells was fine-tuned based on the farmers perceptions regarding thin layer of freshwater and follow-up actions were proposed based on the PRA conclusions.

6. The DA Study was aimed to document farm level landuse, farming system, productivity and water table behaviour using interactive process of structured interviewing; and to collect samples of groundwater from selected farms representing shallow groundwater for quality analysis and document characteristics of private handpumps and tubewells. Similar process was used to document aspects of prime mover and fuel consumption of diesel operated pumping systems and farmers' awareness about research issues. Assessment of farmers' willingness in project interventions and finalization of methodology for the selection of potential villages considering the farmers' perceptions and findings about thin layer of freshwater was the ultimate objective of the study.

Criteria for selection of potential locations

The criteria for selection of potential locations was developed based on groundwater quality spatial analysis and PRA studies conducted in the Target Area. The criteria was based on the following elements:

1. The deep groundwater quality of tubewells beyond 30 m should be either saline, saline-sodic or sodic. This can be verified by the quality of SCARP tubewells for which sufficient data are available. In addition to this, hydrogeologic maps prepared by WAPDA and published by Survey of Pakistan can also be used.

2. The brackish groundwater is overlain by a layer of fresh groundwater having thickness either suitable for skimming dugwells (7.5-15 m) or tubewells (15-30 m).

3. The location is part of the Target Area (Mona Unit) and part of the cluster but meeting the above mentioned quality considerations.
4. Proximity to the Mona Field Office and accessibility especially during the rainy season to avoid problems associated with waterlogging.
5. Farmers' willingness to participate in project interventions based on their genuine needs in relation to skimming wells and pressurized irrigation systems.

GIS ANALYSIS

The GIS analysis was conducted for identifying areas having hydro-geologic potential for installing and operating skimming wells. Four classes of groundwater quality were defined for this analysis. The first class having quality of less than 1.0 dS/m represents the fresh groundwater zone, whereas the next class having quality ranging between 1.0-1.5 dS/m represent the relatively fresh groundwater zone. The third class having quality ranging between 1.5-2.7 dS/m represent the marginal groundwater zone. The quality class of more than 2.7 dS/m represents the hazardous groundwater zone. The marginal or hazardous groundwater quality zones were anticipated to have fresh groundwater lenses resulting from deep percolation of irrigation and rainfall waters.

The long-term geo-referenced pumped groundwater quality data collected from 1965 till 1997 by the MREP was used for GIS analysis. Figure 4 compares the changes in pumped water quality of deep tubewells installed in the MREP area. The distribution pattern for 1997 indicated that 90 tubewells out of 138 are located in fresh and relatively fresh groundwater zones, which is around 65% of the tubewells in the MREP area. The marginal groundwater zones include 37 tubewells out of 138, which represents around 27% of the tubewells in the MREP area. There are only 11 tubewells in the hazardous groundwater zones, which represents 8% of the tubewells in the MREP area. The comparison of temporal data indicated that groundwater quality of tubewells has changed from fresh to relatively fresh groundwater quality. Improvements were also observed in marginal groundwater quality tubewells. Pumping of groundwater from deeper depths has resulted into redistribution of salinity in the profile.

Figure 5 and 6 classify the deep groundwater quality zones in 1965 and 1997, respectively. During the 32 years of tubewells operations, the fresh groundwater area has reduced by 10.67 percent, whereas relatively fresh and marginal groundwater quality areas have increase by 9.43 and 1.29 percent. Figure 6 also indicates the location of thirteen selected villages that have potential for installing skimming wells in the MREP area. In case of SCARP-II saline zone, groundwater quality data at different aquifer depths was available (Figure 7 and 8). Figure 9 shows the groundwater quality zones across the SCARP-II saline zone. Two villages were selected in groundwater quality zone having fresh groundwater lenses underlain by hazardous groundwater quality layers.

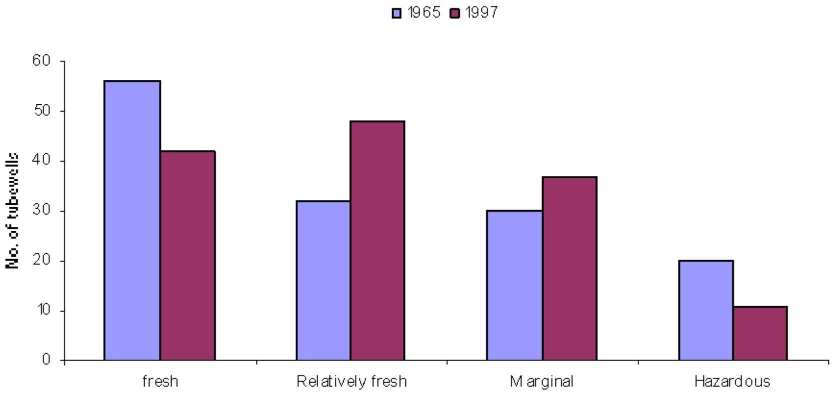

Figure 4. Changes in pumped water quality from 1965 to 1997 of deep tubewells installed in the MREP area.

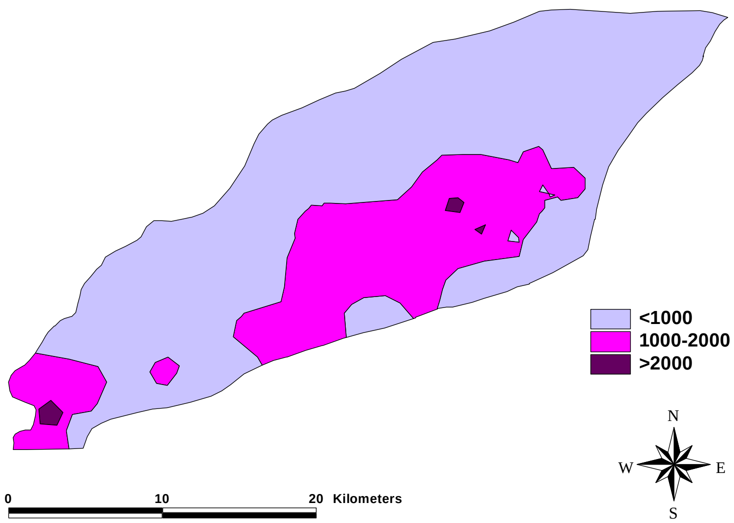

Figure 5. Deep groundwater quality zones in 1965.

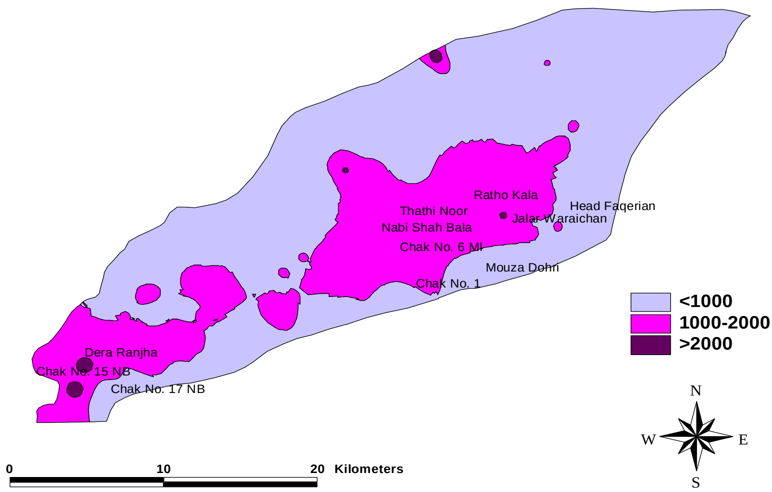

Figure 6. Deep groundwater quality zones in 1997.

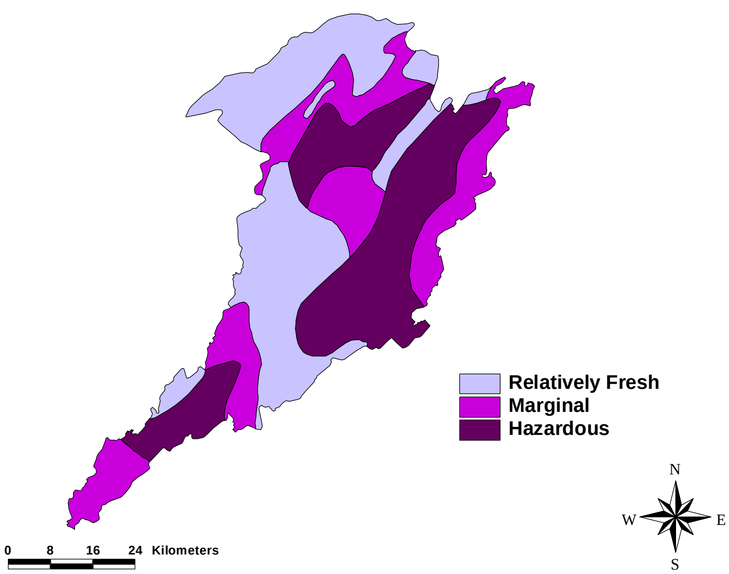

Figure 7. Groundwater quality of the 0-15m aquifer depths across the SCARP-II saline zone.

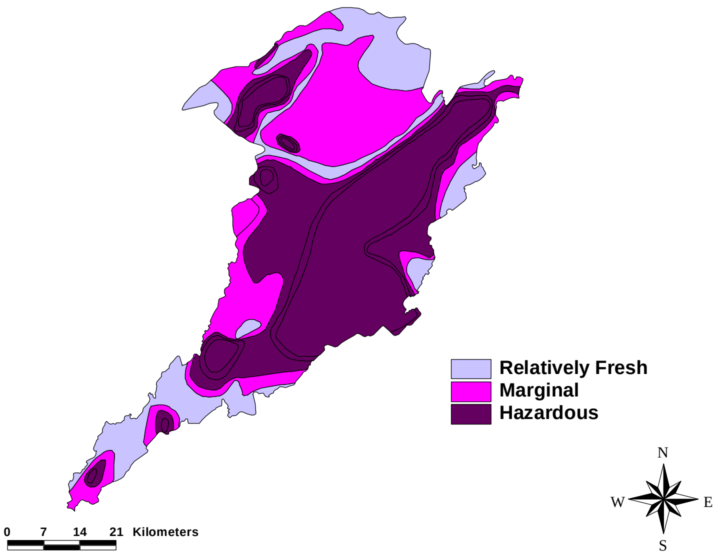

Figure 8. Groundwater quality of the 15-30m aquifer depths across the SCARP-II saline zone.

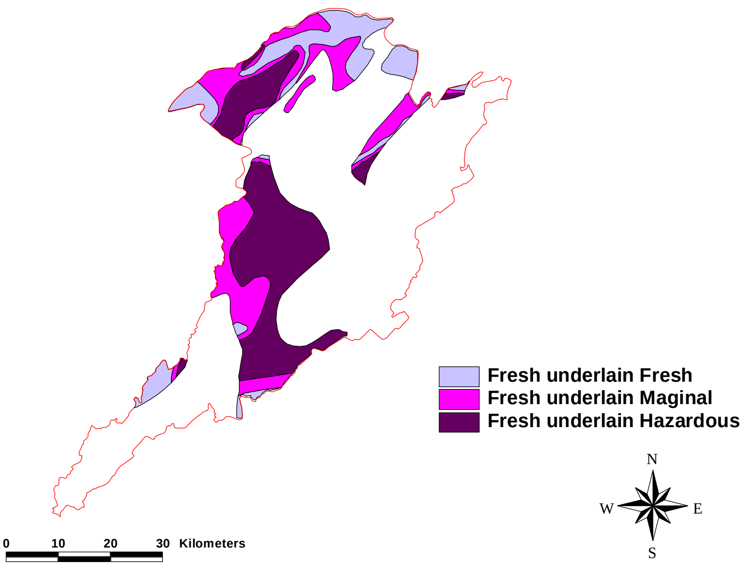

Figure 9. Groundwater quality zones across the SCARP-II saline zone.

PRELIMINARY SURVEY

In the selected fifteen villages based on the GIS analysis, preliminary survey was carried out to get information on the farmers' willingness to use skimming well technology. This survey involved open discussions with the farmers, and the results revealed that the main factors contributing to the popularity of skimming wells among farming community in the study area, would include:

1. Availability of locally manufactured material,
2. Availability of local expertise for drilling, installation and maintenance,
3. Shallower depths to water table that helps use centrifugal pumping units,
4. Technically simple as compared to other groundwater extractions technologies, and
5. Economics and affordability.

DIAGNOSTIC ANALYSIS

Based on the GIS analysis and preliminary survey, different sites in six villages (two in SCARP-II saline zone, and four in SCARP-II non-saline zone) were selected to carry out the Diagnostic Analysis (DA) for investigating the hydro-salinity and hydro-geological conditions of the aquifer. The DA used resistivity survey, bore logs (till the depth of 75m), and water quality samples from hand pumps and private tubewells to investigate hydro-salinity and hydro-geological conditions of the aquifer. These investigations did not only verified our hypothesis of anticipating the fresh groundwater lenses overlying the saline groundwater, but also helped in estimating the thicknesses of these fresh groundwater lenses, groundwater quality at different aquifer depths, and the aquifer composition.

Figure 10 shows the results of resistivity survey conducted at two representative sites in MREP area and SCARP-II saline zone. Thin lenses of fresh groundwater exist over the hazardous groundwater layer in the SCARP-II saline zone, whereas the situation of groundwater quality in the MREP area presents relatively fresh groundwater till 30 m aquifer depth.

Table 7 presents the results of probability analysis of groundwater quality in the six selected villages based of the hand pumps water quality samples. The depths of hand pumps in the project area varies from 6 to 12 m, and the pumped water quality results indicated that there is ninety percent probability for extracting groundwater of 1.62 dS/m. The maximum probability of groundwater quality till 12 m depth is 3.51 dS/m. Table 8 presents the results of probability analysis of groundwater quality in the six selected villages based of the private tubewells water quality samples. The depths of private tubewells ranges between 15 to 35 m, and there is ninety percent probability for extracting groundwater of 3.32 dS/m. However, there is eighty percent probability for extracting groundwater of 1.35 dS/m.

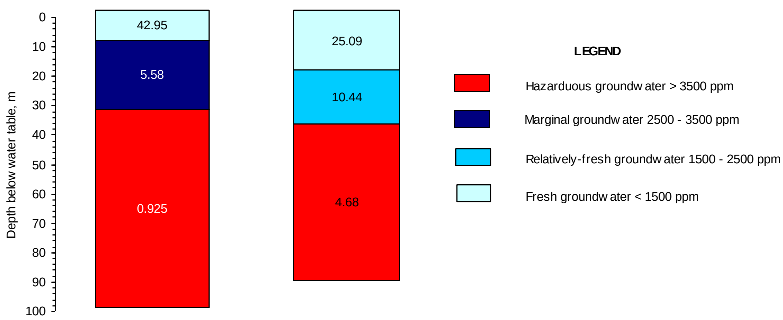

Figure 10. Resistivity survey results for two sites in the MREP area and SCARP-II saline zone.

Table 7. Probability of groundwater quality based on the hand pumps water quality analysis.

Probability (%)	Groundwater quality (dS/m)	pH
Minimum	0.36	7.1
5	0.39	7.1
10	0.48	7.1
25	0.65	7.2
50	0.98	7.3
75	1.31	7.4
80	1.43	7.5
90	1.62	7.5
95	3.01	7.6
Maximum	3.51	7.8

Table 8. Probability of groundwater quality based on the private tubewells water quality analysis.

Probability (%)	Groundwater quality (dS/m)	pH
Minimum	0.23	7.1
5	0.31	7.1
10	0.45	7.1
25	0.66	7.2
50	0.95	7.3

75	1.31	7.4
80	1.35	7.5
90	3.32	7.5
95	3.33	7.6
Maximum	4.54	7.9

PARTICIPATORY RURAL APPRAISAL

Based on the DA results, four villages were selected for the Participatory Rural Appraisal (PRA) to assess farmers' practices and perceptions in opting for skimming well technologies. A wide range of PRA techniques, including semi-structured interviews, trend lines, pie charts, field walks, flow charts, mapping and preference ranking, were used (Table 9). Group discussion with farmers helped to get information that they were, otherwise, reluctant to share during individual interviews. The main problems identified during PRA included deterioration in water quality and reduction in well discharge. The PRA results also showed that there was a wide variation in the design of skimming tubewells, which reflects the absence of design code for these wells:

1. Depth of well ranges from 9 to 27m (Figure 11),
2. Number of strainers varies from 2 to 26 (Figure 12) and
3. Horizontal distance of strainers from suction point (i.e., from Tee Joint as shown in Figure 13) varies from 1.5 to 4.6m.

Table 9. Techniques used for participatory rural appraisal.

PRA Technique	Purpose
Semi-structured interview	To obtain insights into farmers' perception, their constraints and possible improvements in skimming wells.
Trend line	To identify the months with high water table, peak water demand for crops and high skimming well operational hours.
Pie chart	To observe the change in cropping pattern after installation of skimming well and percentage contribution of well water.
Field walk	To have more insight into the problems mentioned by farmers and help to identify and locate additional problems with the skimming wells.
Flow chart	To visualize cause-effect relationship and identify solution to solve the problems with farmers' skimming wells.
Mapping	To understand the design of skimming wells, spatial distances between strainers and length of strainers and blind pipe.
Preference ranking	To identify and prioritize skimming well problems.

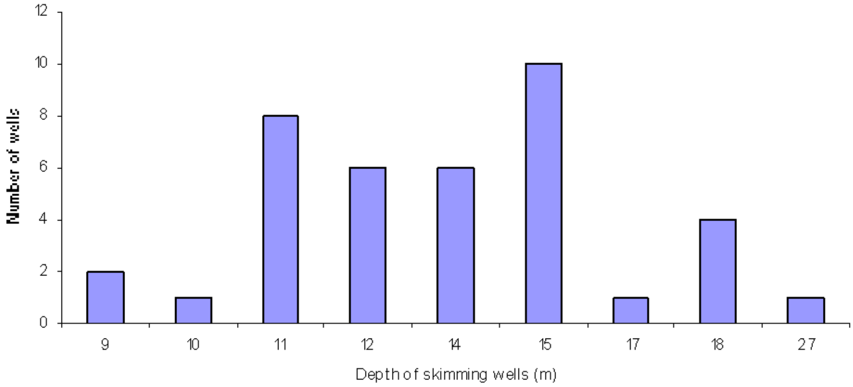

Figure 11. Variations in depth of farmers' skimmming wells.

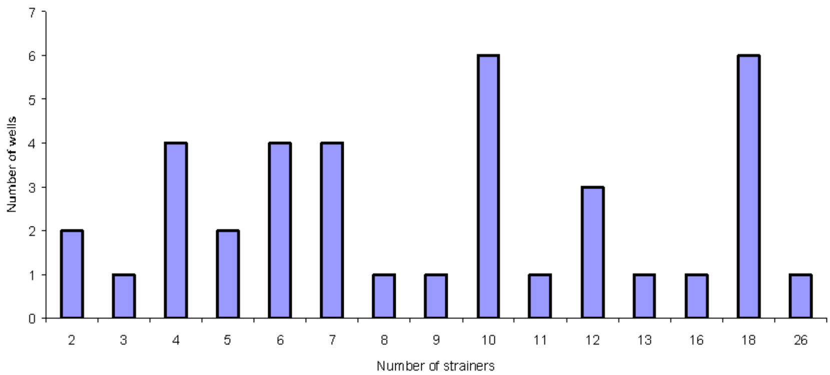

Figure 12. Variations in number of strainers in farmers' skimming wells.

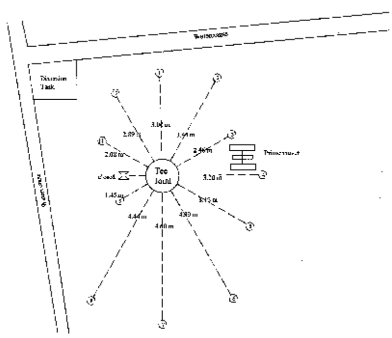

Figure 13. Variations in horizontal distance of strainers from suction point in farmers' skimming well.

Actually, local farmers are mainly concerned with quantity of pumped water and their well design is highly influenced by this factor. Local drillers had a common perception that the well discharge increases with the increase in number of strainers, and farmers have to choose one of the design options provided by the local drillers, which usually consider profitability rather than considering suitability of their design with the local hydro-geological conditions. It was also a common practice among local drillers to install the strainers at varying distances from the suction point. In their perception, if the strainers are installed at the same horizontal distances from suction point, they will take the water of each other thereby reducing the overall discharge of the tubewell. This was the reason of variable horizontal distance of strainers from suction point.

PROJECT SITES

On the basis of GIS analysis, preliminary survey, DA, and PRA results, several sites were selected, in the selected four villages (Figure 14), to carry out different field activities to achieve the project objectives:

1. One site for innovative surface irrigation systems in SCARP-II non-saline zone,
2. Three skimming well sites in SCARP-II non saline zone,
3. Three sites were selected for dugwell source raingun sprinkler systems –all in SCARP-II non-saline zone,
4. Three sites for round-basin irrigation system for orchards: two in SCARP-II non-saline zone, and one in SCARP-II saline zone,
5. Two sites for drip irrigation: one in SCARP-II non-saline zone, and the other one in SCARP-II saline zone, and
6. Two sites were selected for skimming well source raingun sprinkler systems: one in SCARP-II non-saline zone, and the other one in SCARP-II saline zone.

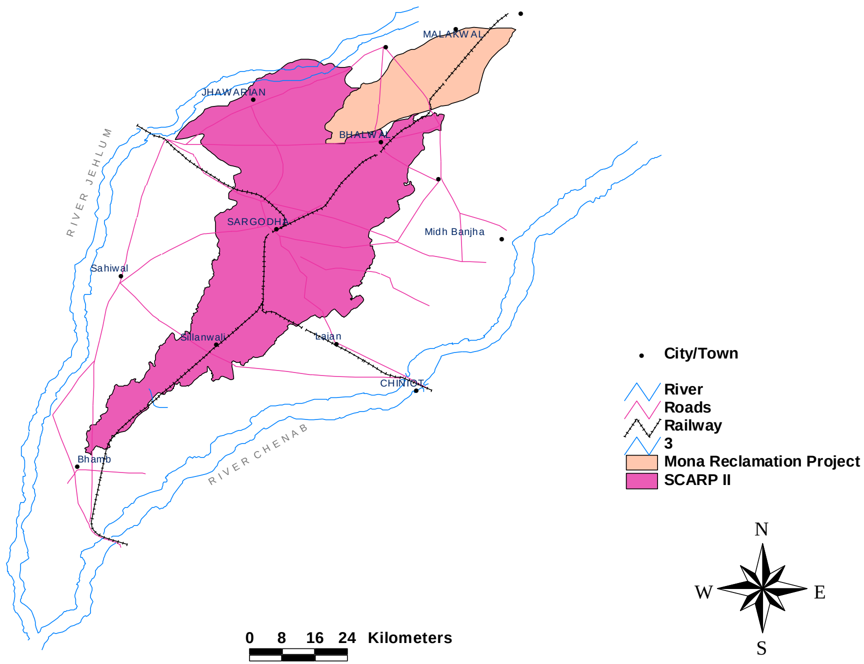

Figure 14 Location of the project sites in the *Chaj Doab*.

Design Methodology and Refined Guidelines for Managing Saline Groundwater Upconing

M.M. Alam, G. Murtaza, M. Hanif and S.H.M. Jaffery

Abstract

The groundwater resources have been extensively over-exploited because of limited canal water availability. Over exploitation of groundwater caused a number of environmental problems including salt water intrusion and increase in the soil and groundwater salinity. A large number of fresh water tubewells have started pumping saline groundwater in various parts of Pakistan indicating upconing of saline groundwater in the relatively fresh water aquifers. Use of poor quality groundwater for irrigation is considered as one of the major cause of salinity in the areas of irrigated agriculture. Indiscriminate pumping of the marginal and saline groundwater can add to the root zone salinity and ultimately reduce crop yield.

Hunt for more water to supplement existing irrigation supplies to meet the crop water requirement has compelled farmers to tap even thin fresh groundwater layers in areas of saline groundwater using fractional skimming wells. However, continuous pumping has resulted in saline water upconing and deterioration of fresh groundwater quality. Studies in such area indicated that farmers have done a considerable damage to their crops and soils before they realized that their well is pumping saline groundwater.

In this collaborative research project, MREP is responsible to specifically address the objective of the study which is to identify and test a limited number of promising skimming well techniques in the shallow fresh water aquifers which could control the saline water up-coning phenomenon as a consequence of groundwater pumping. Detailed investigations have been done at a number of locations in the central part of Punjab in the Chaj Doab at Bhalwal and Sargodha areas. Experimentation cover a range of various well point configurations to be tested at various intervals of skimming well operation. Watertable and water quality of various depths have been observed to study the saline-fresh water interface.

The study revealed that variable thickness of fresh groundwater exists in many parts of the region underlain by saline groundwater. The underlain saline groundwater qualities also vary from marginal to hazardous. Straightforward solution to exploitation to such fresh groundwater layers is not possible. Therefore management strategies for safe exploitation of such areas have been developed based on the field experimentation.

Continuous long term pumping proved to be dangerous which can cause saline water intrusion. Various guidelines have been developed to exploit fresh water and for the better management of saline-fresh water interface using fractional skimming wells.

INTRODUCTION

Intensive investigations revealed that groundwater quality is highly variable with respect to depth as well as spatial variability (Mohyuddin and Hanif 1995) . Seepage from the irrigation canals and river floods formed shallow fresh groundwater lenses in the top layers of aquifers underlain by saline groundwater. High capacity deep tubewells in the public sector often caused up-coning of saline groundwater. Similarly, dense scatter of private tubewell pumpage may produce a mixture of fresh and saline water. If the abstraction in such areas exceeds the recharge, the groundwater may tend to flow from the lower saline water layers as well as surrounding areas. Therefore, with the passage of time the quality of pumped water will further deteriorate. Examples of such phenomena can be found in various SCARPs (Ahmad et. al. 2000).

Data indicated that quality of a large number of useable water quality tubewells deteriorated with the passage of time. Useable water quality wells were decreasing whereas; the numbers of marginal and hazardous quality wells were increasing as a result of continuous groundwater pumpage. Examples of change in groundwater quality from the public tubewells of SCARP-II, SCARP-III and SCARP-VI Allahabad Pilot Projects can be found in literature (SMO, 1989). Similar examples can be quoted from other areas as well (Alam and Chaudhry, 1999). A number of simulation studies (Sufi, et. al. 1998, 1998b) and field studies (Kamper et. al. 1976, Hafeez et. al. 1986) have been conducted to test various options to exploit fresh water in saline areas.

Detailed review of the data indicated that deterioration in water quality has occurred generally in areas adjacent of saline zones. Smaller pockets of different quality of waters have also lost their identity and merged in the major water quality regions. Deterioration or improvement has also occurred in the form of isolated pockets quite wide apart indicating local changes in the water quality.

In this preview, it is imperative to carefully study the areas where saline water is underlain by fresh water and suggest proper management options to skim the upper fresh water layer without disturbing the saline water. Such management interventions are being tried at the Mona Reclamation Experimental Project (MREP) under the research component of National Drainage Program (NDP). Main objectives of the MREP collaborative work are: (i) to identify and test a limited number of promising skimming well techniques in the shallow fresh-water aquifers which could control the saline water upconing and (ii) to develop management strategies for safe exploitation of fresh groundwater overlain by saline groundwater.

DESCRIPTION OF THE STUDY AREA

This study was conducted in the north-central part of the Chaj Doab. The area is located between Jhelum and Chenab Rivers in the Indus Basin of Pakistan (Figure 1 and 2). The study area is bounded by the northern branch of Lower Jhelum Canal in the east and the Shahpur Branch Canal in the north. The soils of the area range from coarse to moderately fine, with the predominance of moderately coarse texture soil class. Most of the area is underlain by saline groundwater. However, upper water quality is useable. List of a few selected villages having research sites is given in Table 1.

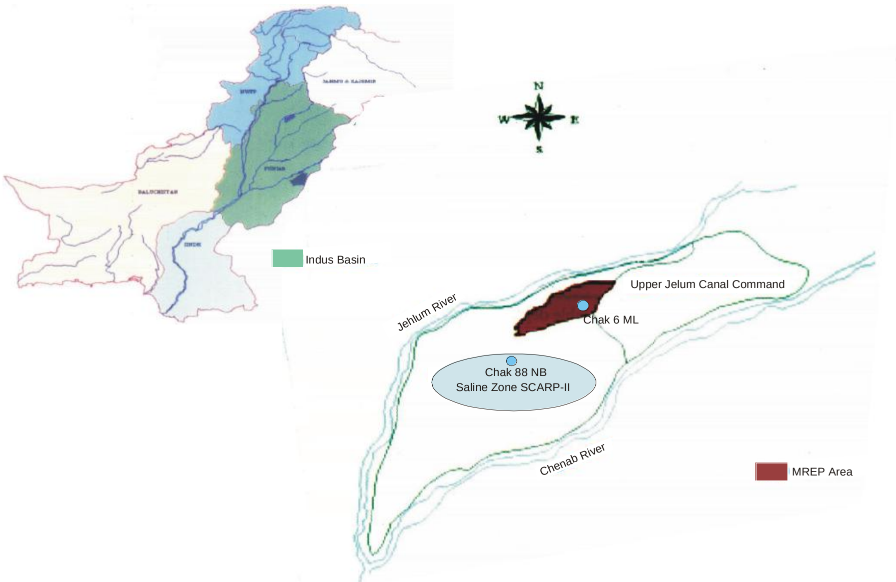

Figure 1. Location Map of Study Project Area.

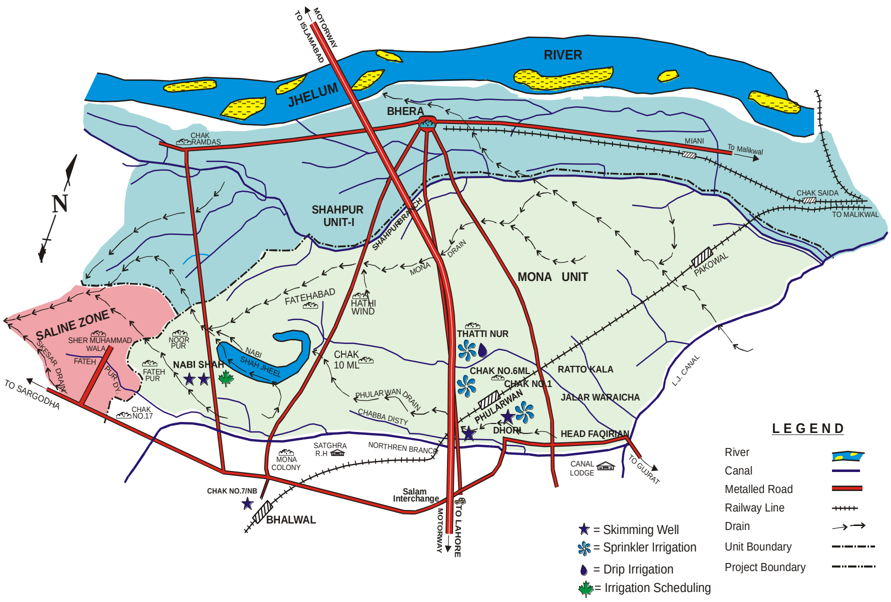

Figure 2. Location Map of Mona Project Area Research Sites

Table 1. **Selected villages based on the spatial analysis of deep groundwater quality in the study area.**

S/No.	Name of village	Deep groundwater quality
1	Ratto Kala	Marginal
2	Chak 1/NB	Marginal
3	Thathi Noor	Marginal
4	Jalar Waraichan	Marginal
5	Nabi Shah Bala	Marginal
6	Chak 6/ML	Saline
7.	Chak 88/NB	Hazardous

MATERIAL AND METHODS

Two phase strategy was adopted to conduct the field trials on the saline water upconing under various pumping regimes and designs of skimming wells. Four skimming wells varying from 1 to 16 strainers were selected for variety of interventions. Based on the experience grained under phase-I, two more skimming wells having 3 and 6 strainers were installed under phase-2 (Figure 3 and 4) to refine the results obtained under phase-I. Salient features of these skimming wells are given in Table 2.

Table 2. **Description of skimming wells installed or selected for the study.**

Well configurations	Discharge (lps)	Power modes	Irrigation methods
Phase-1			
3-strainers (Phularwan)	16-17	15 HP Electrical	Surface
4-strainers (Chak 7/NB)	20-22	18 HP Diesel	Innovative surface
6-strainers (Nabi Shah)	26-27	18 HP Diesel	Surface / innovative surface
16-strainers (Nabi Shah)	25-28	Tractor	Surface
Phase-2			
3-strainer (Chak 6/ML)	3	8 HP Diesel	Surface / innovative surface
6-strainer (installed) Jabbar Farm (Chak 88/NB)	8	20 HP Diesel	Surface / innovative surface

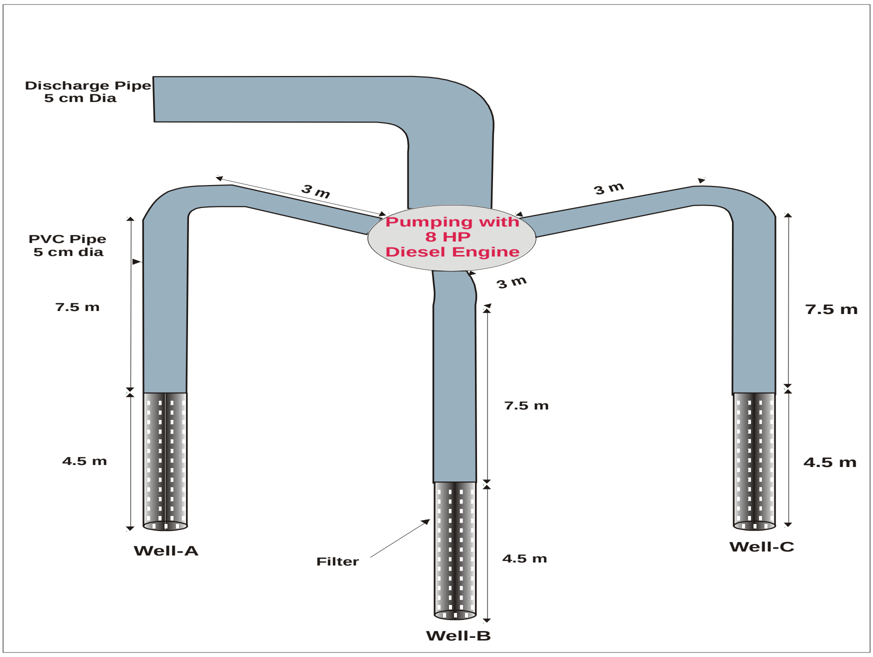

Figure 3. Layout of 3-strainers skimming wells (Chak 6/ML).

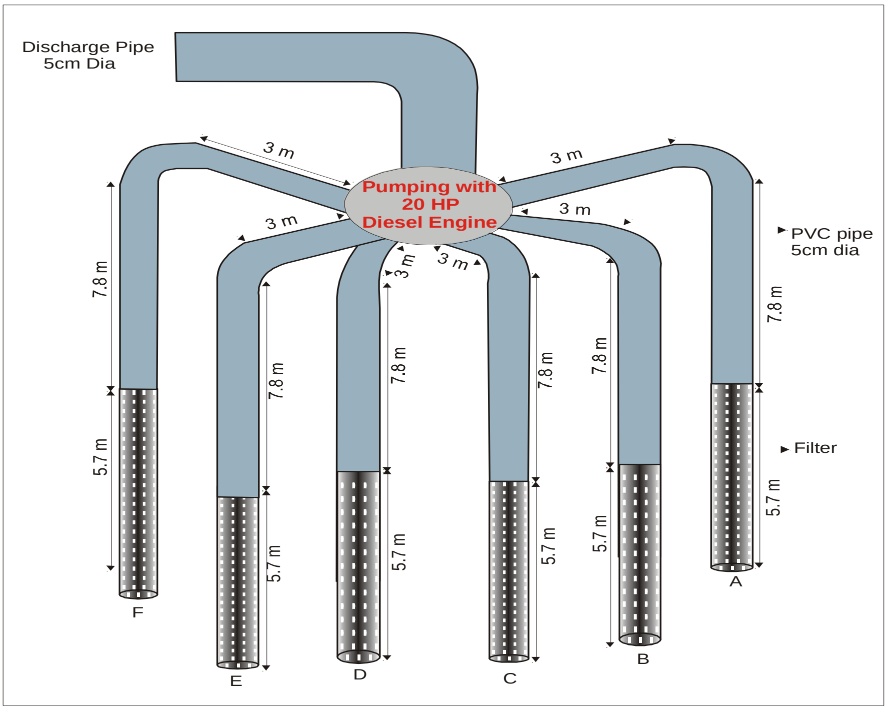

Figure 4. Layout of 6-strainers skimming wells (Chak 88/NB).

The following data was recorded regularly:

- Groundwater quality before and after pumping with respect to depth for monitoring of saline water upconing;
- Pumped water quality after starting and before shut off of well;
- Watertable draw down; and
- Discharge/volume of pumped water.

RESULTS AND DISCUSSIONS

Various design and operational parameters were studied such as:

1) Well penetration depth,
2) Impact of number of strainers on i) Discharge, and ii) Water quality,
3) Movement of saline fresh water interface, and
4) Impact of continuous pumping on i) Water quality, ii) Water quantity and iii) Watertable.

Pumped Water Quality due to Intermittent Pumping

Operational data on the effect of intermittent pumping on the quality and quantity of pumped groundwater of various wells is given in Table 3.

Table 3. Effect of intermittent pumping on the quality and quantity of pumped groundwater.

Skimming well	Duration (days)	Pumping days	Operational hrs/day	Discharge (lps)	Volume (m^3)
3-strainers well	97	71	5	17	21726
1-4-6 strainers well	304	180	5	22	71280
6-strainers well	304	180	5	27	87480
16-strainers well	70	41	6	28	24796
3-strainers well (6/ML)	502	15	4.25	3	789
6-strainers well	290	27	1.91	8	1485

The improvement in salinity level of the pumped water was most probably due to the pumping of salts from the shallow aquifer to the ground surface and the replenishment of the groundwater from (I) the recharge from the surrounding areas under the hydraulic gradient that developed due to pumping of water; (ii) seepage of water from the soil surface and from the nearby water sources, and (iii) rainfall that contributes to groundwater. However, if the penetration depth high and underlain groundwater layer has highly saline water, then there is chance to upconing of saline layer deteriorating fresh groundwater quality. Examples are shown in Figure 5 and 6.

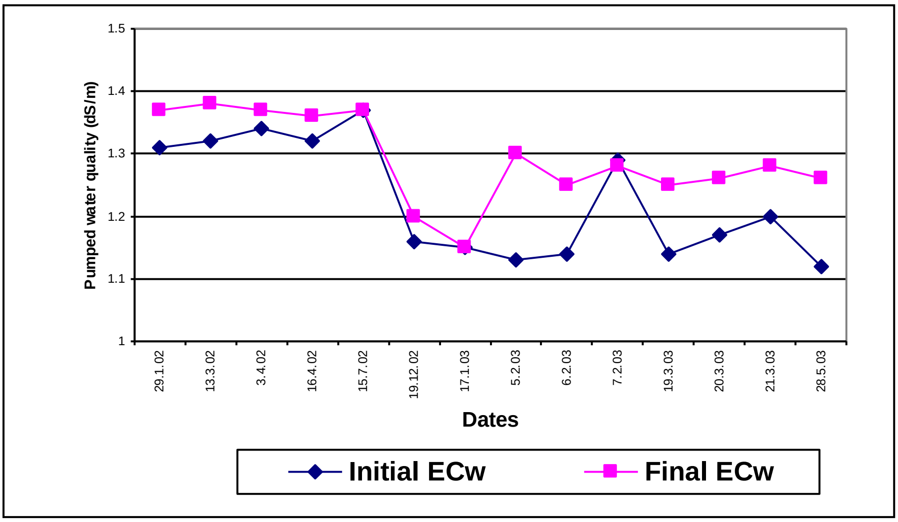

Figure 5. **Pumped water quality changes due to long terms pumping at Chak 6/ML.**

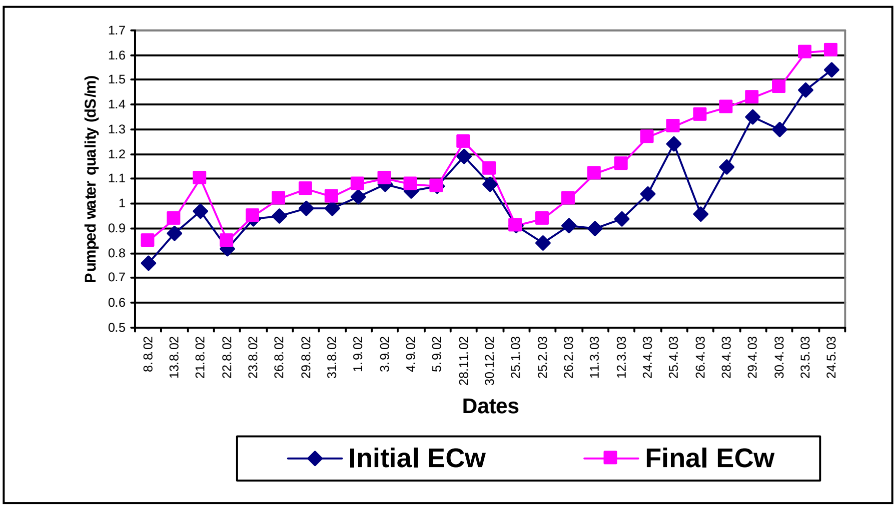

Figure 6. **Pumped water quality changes due to long terms pumping at Chak 88/NB.**

Groundwater Quality with Depth and Time

Two pumping tests having 4 and 8 hours operation of skimming wells for three consecutive days were conducted. Groundwater quality was observed during the course of tests from depths of 30, 50, 70, 85 and 105 feet from three deep observation wells located at a distance of 1.5, 4.5 and 10.5 meters away from the suction point of the skimming wells. This data was analyzed for study of the saline water upconing phenomenon.

The skimming well was installed at a depth of 40 feet. Groundwater quality at the time of installation of well was 1.20 dS/m at that depth. Whereas, deep bore groundwater quality data indicates that saline water interface having groundwater quality in the range of 4.6 dS/m existed at 105 feet depth. Keeping these parameters in mind the movement of saline water interface was studied. Figure 7 indicates results of 8 hours daily operation of skimming well for three consecutive days shown as before-pumping (BP), post-pumping day 1 (PP1), post-pumping day 2 (PP2) and post-pumping day 3 (PP3).

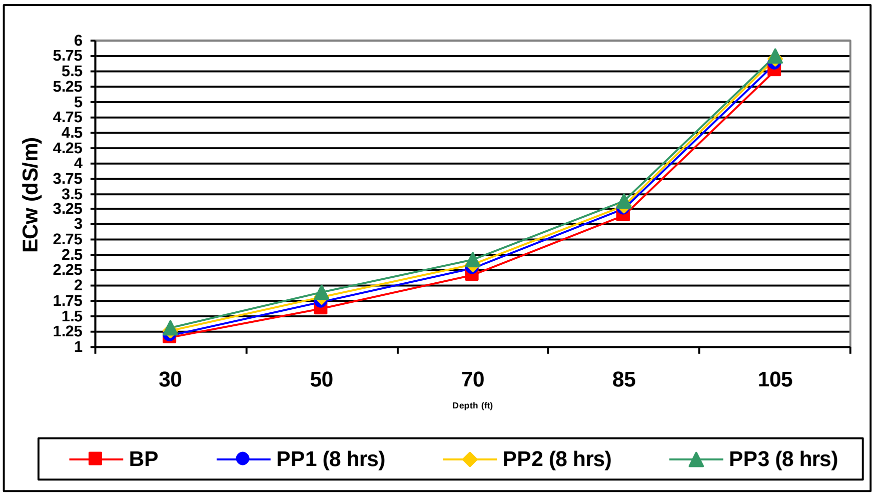

Figure 7. Effect of pumping on groundwater salinity observation well-A (Chak 6/ML)

Similarly, at check 88/NB, two pumping tests having 2 and 4 hours operation of skimming well for three consecutive days were conducted. Groundwater quality was observed during the course of tests from depths of 30, 50, 70, 75, 85 and 105 feet from three deep observation wells located at a distance of 1.5, 4.5 and 10.5 meters away from the suction point of the skimming well. This data was analyzed for study of the saline water upconing phenomenon. The skimming well was installed at a depth of 45 feet. Groundwater quality at the time of installation of well was 1.6 dS/m at that depth. Whereas, deep bore groundwater quality data indicates that saline water interface having groundwater quality in the range of 4.6 dS/m existed at 65 feet depth. Keeping this parameter in mind the movement of saline water interface was studied. Figure 8 indicates results of 4 hours daily operation of skimming well for three consecutive days. The data values indicated in figure are shown as before-pumping (BP), post-pumping day 1 (PP1), post-pumping day 2 (PP2) and post-pumping day 3 (PP3) to reflect the changes in EC_w.

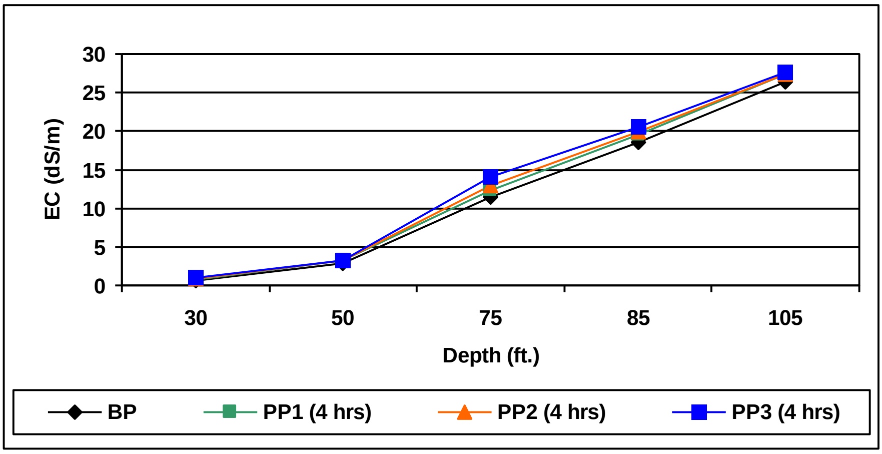

Figure 8. **Effect of pumping on groundwater salinity observation well-A (Chak 88/NB).**

Watertable Behaviour

The watertable behaviour in three piezometers of the 3-strainer skimming well was observed. Behaviour of watertable during pumping and recession of 8 hours pumping test is shown in Figure 9.

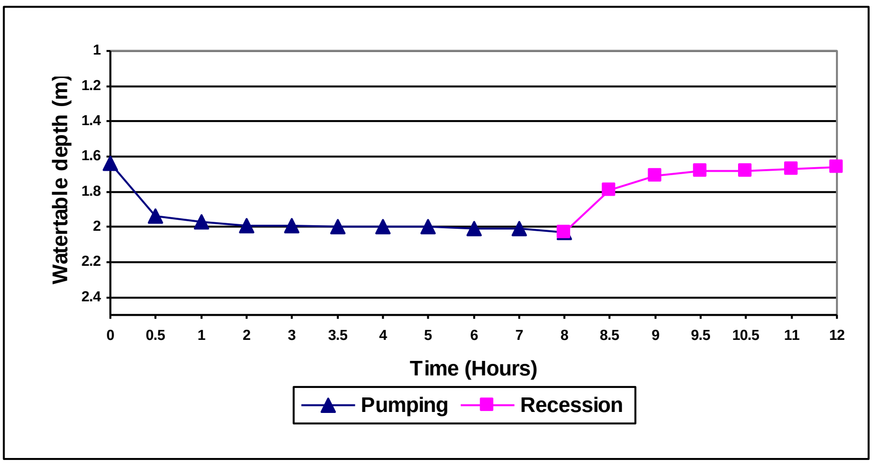

Figure 9. **Effect of pumping on watertable behaviour at Chak 6/ML.**

The watertable behaviour in the three piezometers of 6-strainers skimming well was observed in case of 4 hours pumping test. Behaviour of watertable during pumping and recession of 4 hours pumping test is shown in Figure 10.

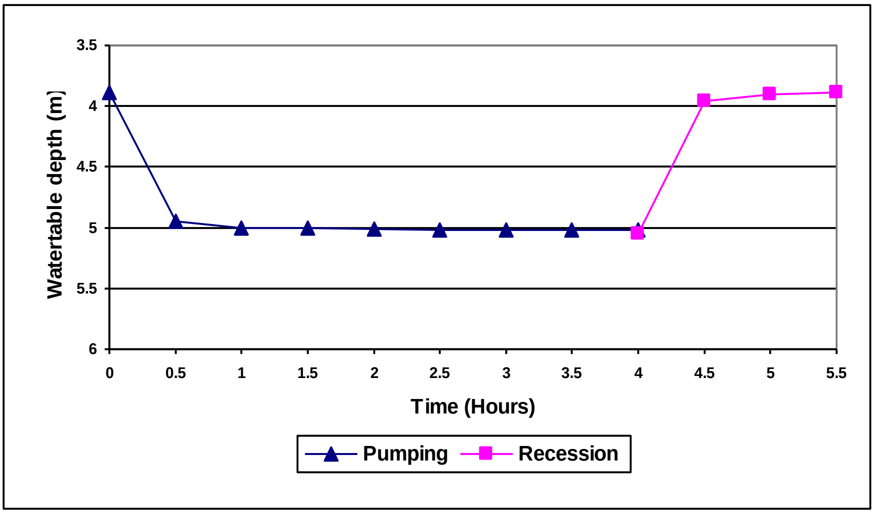

Figure 10. Effect of pumping on watertable behaviour at Chak 88/NB.

Impact on Discharge due to Skimming Well Operation

Two different interventions were tested to evaluate the impact on discharge of skimming wells, i.e. reduction in discharge due to continuous operation of skimming wells and impact of number of strainers on the discharge rate. Data on skimming wells at Chak 6/ML, Chak 88/NB and Akram Farm was taken. Results are shown in Figure 11.

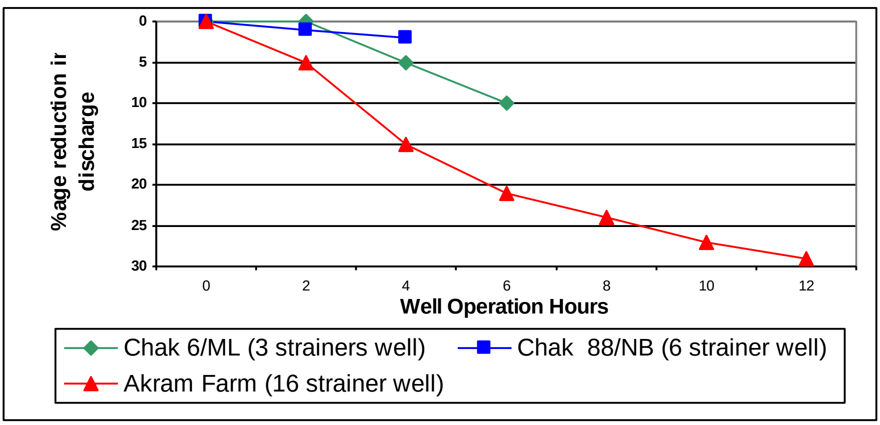

Figure 11. Reduction in discharge due to skimming well operation with various well configurations.

Impact of Number of Strainers on Discharge Rates

Data of a 6-strainers skimming well (Chak 88/NB) was analysed. Operating only one, two, three, four, five and six strainers one after the other made discharge measurements. Arrangement for operation of required number of strainers were made in the design by installing stop values in the individual strainers. Data pertaining to the variation in discharge due to number of strainers is shown in Figure 12. Analysis of data revealed that increase in discharge with increase of number of strainers is not linear. After 3 to 4 strainers, rate of increase in discharge reduced significantly. Therefore, increase in number of strainers beyond 3-6 merely adds to installation cost against a limited gain of discharge.

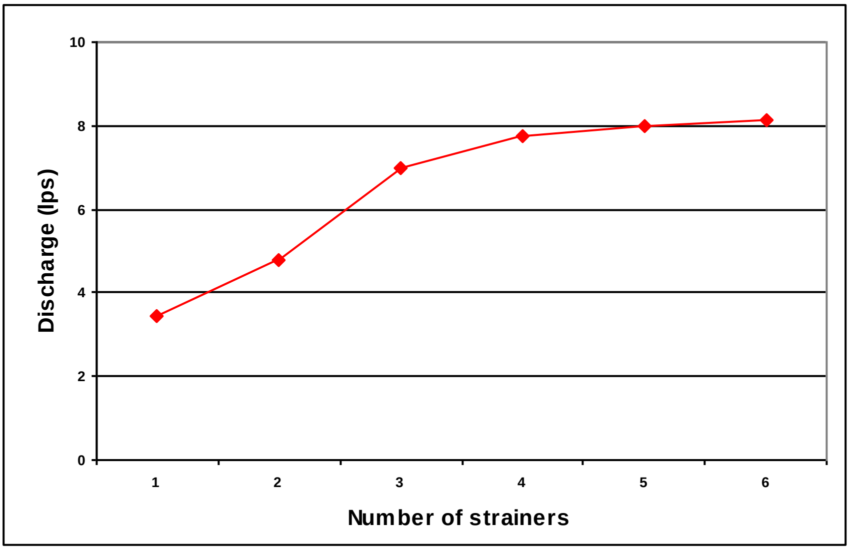

Figure 12. Variation in discharge due to number of strainers at Chak 88/NB.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following conclusions have been drawn from results of experimentation.

1. The multi-strainer skimming wells can be used efficiently to pump water of acceptable quality without disturbing brackish water interface.
2. Skimming wells with 3-6 strainers and 1.5 m horizontal distance of strainers from suction point may be more cost effective with less compromising on quantity and quality of groundwater.
3. The multi-strainer skimming wells could help in maintaining low salinity level and low movement of saline-fresh water interface for longer period as compared to single strainer deep well especially in the saline zones.

4. The rate of recharge is a key parameter that affects the operational management strategies of skimming wells installed in the shallow relatively fresh ground water aquifers underlain by saline ground water.
5. Continuous pumping deteriorates the pumped water quality.
6. Intermittent pumping can help in controlling the deterioration of groundwater quality.
7. Discharge of skimming well increased with increase of number of strainers to some extent. However, increase in discharge become minimal by further addition of strainers and add to cost of skimming well un-necessarily.
8. Discharge rate of skimming well reduces with time, therefore, long term pumping adds to additional operation cost.

Recommendations

The following guidelines are recommended based on the experience gained through skimming well testing.

1. Farmers should get their water samples analyzed before installation of skimming wells in their respective areas to avoid saline water pumping.
2. Regional groundwater database must be established to identify the potential area for exploitation of fresh groundwater through skimming wells.
3. Thorough investigations may be done before installation of skimming wells.
4. Proper dissemination to the end-users is required with respect to modern skimming well techniques.
5. Design discharge within 10 l/s is recommended in saline areas having thin fresh groundwater layer.
6. Well penetration depth of 60% of the fresh water aquifer is recommended to avoid suction break as well as saline groundwater upconing.
7. Pipe diameter of 5 cm and horizontal distance of strainers at 1.5 meter is recommended.
8. Three to six strainer skimming well is sufficient and cost effective to meet essential water requirement.
9. Design and operation of skimming well should based on the thickness of fresh water layer, quality of water to be pumped and underlying saline water quality depth.
10. Where shallow/thin layer of fresh water exists over the saline layer, continuous pumping should be avoided.

11. Long term pumping should be avoided for better quality and quantity of water and better efficiency of skimming well. Four to six hours intermittent pumping per day to meet the essential water requirement is recommended.

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Performance Evaluation of Locally Manufactured pressurized Irrigation

M. Yasin, M.M. Ahmed, G. Akbar and Z. Khan

Abstract

Rainguns are large rotary sprinklers similar in many ways to the small ones. They are usually mounted on three-leg stands, sledges or wheeled carriages, which can be adapted to suit the various furrow and row spacing and crop heights. They are of robust construction to withstand the large forces produced by the high discharge rates and operating pressures. They are of two types: a) swing-arm Raingun; and b) water-turbine Raingun.

Economics of locally manufactured Raingun sprinkler irrigation systems must be seen from two standpoints. Firstly, these systems and innovative adaptations must be cost-effective in the existing framework of the farmers' investment capacity in terms of the capital investments. Secondly, these systems and innovative adaptations must be cost-effective in terms of water and energy efficiency.

Two Raingun sprinkler irrigation systems were installed in the Mona SCARP area of Bhalwal, Sargodha having thin layer of fresh groundwater overlain by the brackish groundwater. There is shortage of fresh groundwater; therefore, farmers' are interested in conjunctive use of water (rainfall, canal water and groundwater). For this purpose, two farmers, in Chak #6ML and Thatti Noor villages were selected to install the skimming dugwells and Raingun sprinkler irrigation systems.

The unit cost can be reduced by 28% by changing the design from complete irrigation to supplemental irrigation. The pressure variations in the two systems installed in the Mona SCARP was 3-10%. The coefficient of uniformity of the Raingun varied between 78 to 91 % with pressure range of 30-40 m and nozzle sizes of 6 to 12 mm diameter. The evenness of water distribution under sprinkler irrigation can be seriously affected by wind and operating pressure. To reduce the effect of wind, the setting distance of Raingun sprinklers can be brought closer together. Thus reasonably high value of uniformity coefficient can be obtained through overlapping by adjusting the space between two Raingun sprinklers. Overlapping of 25% is essential to have better uniformity in water distribution.

Based on the performance evaluation of the Raingun sprinkler irrigation system it is necessary to develop standards for the manufacturers', so that they can use these standards as specifications for the manufacturing of Raingun sprinkler irrigation systems. Therefore, efforts should be made to minimize the pressure requirement to reduce the size of the pumping system leading to minimize the energy requirement. The layout of the Raingun sprinkler irrigation should be designed in such a way that the

coefficient of uniformity is optimised. This would help to improve the water use efficiency.

INTRODUCTION

Raingun Sprinkler Irrigation

Rainguns are large rotary sprinklers similar in many ways to the small ones. They are usually mounted on three-leg stands, sledges or wheeled carriages, which can be adapted to suit the various furrow and row spacings and crop heights. They are of robust construction to withstand the large forces produced by the high discharge rates and operating pressures. They are of two types: a) swing-arm Raingun; and b) water-turbine Raingun.

The swing-arm Raingun operates in a similar manner to the small rotary sprinkler. It rotates by means of a drive spoon on the end of a swing-arm, which is free to move up and down. The spoon is shaped so that water jet pushes the swing-arm downwards out of the flow. At the same time it is pushed sideways causing the Raingun to turn slightly. Once clear of the flow the swing arm is so balanced that it returns to interrupt the jet again. The Raingun then receives another sideways impulse. This action is repeated in a steady beating motion causing the Raingun to slowly rotate. The spoon also helps to breakup the water into fine droplets. The speed at which the Raingun rotates is controlled by the angle of the drive spoon and an adjustable friction brake. One complete revolution can take from 2 to 5 minutes (Kay 1983).

Rainguns can irrigate through a full circle but sector Rainguns that irrigate part of a circle are most common and preferred by farmers. When a sector Raingun reaches the end of its circular path it reverses rapidly again to the beginning. This is achieved by a series of smooth cams known as sector stops. When nearing the end of its path the cam roller rides on to the sector stop and engages the reversing arm from the jet. The Raingun is then set to start irrigation again. The positions of the sector stops are adjustable so that any size of circular arc can be irrigated (Kay 1983).

A rapid return of the Raingun at the end of a sector avoids un-necessary wastage of water but can create problems by over-riding the disengaging stop. In order to produce a sprinkler pattern, which is symmetrical, the disengaging stop is sometimes positioned to allow for the inertia for the Raingun. However, the speed of the gun reversing action is adjustable and should be checked and reset if seen to be very forceful (Kay 1983).

The water-turbine Raingun is similar in appearance to the swing-arm Raingun but moves in a smooth continuous manner rather than in a series of small jerks. This is because driven by small water turbine powered from the main jet or from a smaller nozzle close by. Rotation is achieved by means of a rack and pinion drive connected to the turbine through a small gearbox. The speed at which the Raingun rotates is controlled by the speed of the turbine wheel (Jensen 1981).

Locally Manufactured Raingun Sprinkler Irrigation Systems

Sprinkler irrigation is being introduced in several demonstration plots in the country. Furthermore, progressive farmers have imported sophisticated systems such as centre pivots and linear move sprinkler machines during 80s. The conventional sprinkler irrigation systems are capital intensive. Therefore, some modifications were needed to suit the socio-economic conditions and physical requirements in Pakistan (WRRI 1992).

The sprinkler system can be used with gravity flow where hydraulic head is available, which will reduce the initial cost. Such locations are available in Northern Areas, NWFP and Balochistan. Furthermore, these systems are suitable for areas where streamsize is very small and surface irrigation is not possible. Such locations are available in areas having limited well yields in mountainous and Barani regions and in the Indus basin having very thin layer of fresh groundwater overlain the brackish groundwater (Ahmad and Hussain 1987; Ahmad et al. 2000; WRRI 1992).

Most of the system components of solid-set, hand move and Raingun sprinklers have been successfully manufactured in Pakistan, except the cost effective aluminium pipes would need to be imported for specialized systems. The Water Resources Research Institute (WRRI), National Agricultural Research Centre (NARC), Islamabad in collaboration with MECO Pvt. Ltd., Lahore developed a complete range of Raingun sprinkler irrigation systems using locally available materials and technology. The high-pressure low-density polyethylene pipes with black carbon and UV stabilizers were produced in collaboration with Griffon Industrial Corporation, Lahore. These are now available in 13, 25, 50, 75 and 100 mm diameters, which can be used for pressures upto 84 m. Recently, the low-pressure systems are being designed and installed by farmers due to the rise in electricity tariff and diesel prices. The estimated installed cost of semi-solidset Raingun sprinkler irrigation systems is in the range of Rs. 25,000-40000 per ha for a system of atleast 4 ha using electric or diesel operated pumping systems.

Economics of Raingun Sprinkler Irrigation Systems

Economics of locally manufactured Raingun sprinkler irrigation systems must be seen from two standpoints. Firstly, these systems and innovative adaptations must be cost-effective in the existing framework of the farmers' investment capacity in terms of the capital investments. Secondly, these systems and innovative adaptations must be cost-effective in terms of water and energy efficiency (Irrigation Age 1977; Walker 1980).

These two elements were given due consideration while indigenizing the Raingun sprinkler irrigation system components in Pakistan. In fact there is a need to have trade-off between the two objectives of economics to have system fairly cost-effective in capital investment and fairly cost-effective in water and energy efficiency. A balance between the two is the approach, which will work in Pakistan.

Performance of Raingun Sprinkler Irrigation Systems

The evenness of water distribution can be seriously affected by wind and operating pressure. Spray from Raingun sprinklers is relatively of larger discharges compared to the standard sprinklers. However, it is easily blown by wind and this can distort wetting patterns and upset irrigation uniformity. To reduce the effect of wind, the setting distance of Raingun sprinklers can be brought closer together.

Although 5 m/s is only thought of as gentle breeze, it will seriously disrupt the operation of a Raingun. Rainguns need to operate very close together under these conditions to distribute water evenly. In prevailing wind conditions the designer will normally position the lateral at right angles to the wind direction and reduce the Raingun spacing along the lateral line (Kay 1983).

A Raingun sprinkler performs best at a given pressure, which is normally specified by the manufacturer. If the pressure is substantially above or below the recommended value then the distribution of water can be quite different from the normal distribution. If the pressure is substantially above and below the recommended pressure, then in both the cases the throw is reduced. Both these patterns are quite different from the normal triangular distribution and it is obvious that patterns such as these will not produce a uniform irrigation (Kay 1983).

Raingun Sprinkler Irrigation for Indus Basin

Raingun sprinkler irrigation systems can also be used in the Indus basin for efficient application of smaller stream size of even less than 3 lps pumped from the skimming wells. However, to minimise the input of groundwater and to maintain low cost of irrigation, it is necessary to integrate conjunctive use of rainfall, surface water and groundwater. The design and operation of irrigation systems will be based on the concept of management strategies considering the conjunctive water use. Therefore, design of pressurized irrigation systems should be made considering these concepts (Ahmad *et al*. 2000).

The present study is based on the concept of conjunctive use of rainfall, canal water and groundwater with a view to design Raingun sprinkler systems to evaluate the cost and performance of the systems under the concept of supplemental irrigation linked with the use of groundwater. Furthermore, this concept is in co-existence with the use of skimmed water, where discharges are much less than the traditional tubewells.

MATERIALS AND METHODS

Study Area

Two Raingun sprinkler irrigation systems were installed at farmers' fields in the Mona SCARP area of Bhalwal, Sargodha having thin layer of fresh groundwater overlain by the brackish groundwater. There is shortage of fresh groundwater; therefore, farmers are interested in conjunctive use of water (rainfall, canal water and groundwater). For this purpose, two farmers, in Chak #6ML and Thatti Noor villages, were selected to install the skimming dugwells and Raingun sprinkler irrigation systems.

Selection of Farmers and Design of Raingun Sprinkler Irrigation Systems

Two Raingun sprinkler irrigation systems were designed with an objective to test the concept of partial (supplemental) and complete irrigation concepts. The supplemental or partial irrigation system was designed to provide groundwater in addition to the rainfall and canal water availability. Therefore, the supplemental irrigation would help to reduce the unit cost of the Raingun sprinkler irrigation system.

Supplemental Irrigation System at Chak #6ML

In Chak #6ML, Ahmad Bakhsh Farm was selected for the installation of small-size Raingun sprinkler irrigation system on the dugwell. This system was designed to operate single-Raingun for small-size farms using a concept of supplemental irrigation. The designed operational time of 15 hours was used with overlapping of 25%. Peak designed supplemental water requirement of 3-mm was used.

Farmer’s abandoned dugwell was renovated, which was constructed in 1930s. The dugwell depth is 18.24 m and the inner diameter of the dugwell is around 1.52 m. A high pressure pumping system having discharge of 3 lps and pressure head of 60 m was installed at the renovated well. Diesel-operated prime mover of 8 hp was used to power the pumping system. Two manifolds each with 50 mm diameter were laid out having lengths of 176 m and 264 m. Raingun model PY_{1-30} with nozzle size of 12 mm diameter was used. The summary of design computations of Raingun sprinkler irrigation system installed on 5.3 ha area is presented in **Appendix I**. The command area can be increased to 7 ha if the peak operational time is increased to 20 hours. This is important to improve economics of the system.

Complete Irrigation System at Village Thatti Noor

In Thatti Noor village, Qadir Farm was selected for the installation of medium-size Raingun sprinkler irrigation system. This system was designed to operate 3 Rainguns for medium-size farms using a concept of complete irrigation. The designed operational time of 12 hours was used with overlapping of 25%. Peak designed water requirement of 5-mm was used.

A dug-bore well was constructed and lined using the pre-cast concrete rings. The technology of dug-bore well is attractive to reduce the digging cost and to induce higher recharge. Bore is needed in the saturated zone because the digging of dugwell in the saturated zone after a depth of 3 m is cumbersome and costly. The dugwell total depth is 5.63 m and the inner diameter of the dugwell is around 1.52 m. A bore of 3.52 m was made from a depth of 5.63 to 9.15 m. A high pressure pumping system having discharge of 8.2 lps and pressure head of 60 m was installed on the dug-bore well. Diesel operated prime mover of 18 hp was used to power the pumping system. Two manifolds were designed 1st having 75 mm inner diameter and 2nd with 50 mm inner diameter low-density polyethylene (LDPE) pipe. The lengths of 1st and 2nd manifolds are 250 and 364 m, respectively. The summary of design computations of Raingun sprinkler irrigation system installed on 5.7 ha area is presented in **Appendix II**. The command area can be increased to 9.5 ha if the peak operational time is increased to 20 hours.

Materials Used and Systems' Cost

Supplemental Irrigation System at Chak #6ML

Diesel operated pumping system was coupled with suction line of 63.75 mm inner diameter of galvanized iron pipe. The 51 mm inner diameter galvanized iron pipe was also used for delivery of water to the manifolds. The LDPE pipe of 50 mm inner diameter was used for manifolds. All the connections used were made of galvanized iron or metal alloys. The hydrants for water outlets were constructed using galvanized iron pipe of 51 mm diameter. The cost estimates of Raingun sprinkler irrigation system installed at the Ahmad Bakhsh Farm, Chak #6ML are presented in **Appendix III**.

Complete Irrigation System at Village Thatti Noor

Diesel operated pumping system was coupled with suction line of 63.75 mm inner diameter of galvanized iron pipe. The 51 mm inner diameter galvanized iron pipe was used for delivery of water to the manifolds. The LDPE pipe of 75 and 50 mm inner diameter were used for mainline and manifolds. All the connections used were made of galvanized iron or metal alloys. The hydrants for water outlets were constructed using galvanized iron pipe of 51 mm diameter. The cost estimates of Raingun sprinkler irrigation system installed at the Qadir Farm, Thatti Noor village are presented in **Appendix IV**.

Performance Evaluation

Performance Parameters

The performance parameters selected for evaluation of Raingun sprinkler irrigation system are as under:

1. Operating pressure of Raingun at various hydrants installed for connecting laterals and the Raingun;
2. Discharge of Raingun installed at various hydrants;
3. Uniformity coefficient.

Raingun with different sizes of nozzles was operated for one-hour duration under selected range of pressures. The sprinkled water was collected in the catch cans and depth of water was measured after the closure of the

Raingun. The coefficient of uniformity of the Raingun was estimated using the following relationship (Christiansen 1942):

$$C_u = [1 - \{(\left|\sum X_i - X_{av}\right|) / nX_{av}\}] * 100$$

where

C_u = Coefficient of uniformity, %;

X_i = Depth of water stored in the ith catch can, mm;

n = Total number of catch cans having water or number of observations; and

X_{av} = Average depth of water collected in catch cans, mm.

Supplemental Irrigation System at Chak #6ML

Performance of single-Raingun sprinkler irrigation system was evaluated at the Ahmad Bakhsh Farm of Chak #6ML. At this farm, the Raingun sprinkler irrigation system was evaluated by operating single Raingun with nozzle of 12 mm diameter. Evaluation was made at each hydrant to document the system's performance.

Complete Irrigation System at Village Thatti Noor

At Qadir's Farm in the Thathi Noor village, the system was evaluated at different hydrants. Discharge, pressure and covered area were measured at 60% engine throttle. Data of selected parameters were measured while operating two and three Rainguns with different sizes of Raingun nozzles.

RESULTS AND DISCUSSIONS

System Layout and Cost

Supplemental Irrigation System at Chak #6ML

In Chak #6ML Ahmad Bakhsh Farm was selected to install small-size Raingun sprinkler irrigation system, where discharge is sufficient to operate single Raingun. The system layout consisted of two manifolds of 50 mm inner diameter pipe of LDPE. Six double and two single hydrants were installed (Figure 1). The cost of pumping system with attachments for suction and delivery line was Rs. 21,133, which accounts for 29% of the total material cost. The cost of manifolds was Rs. 44,102, which accounts for 60% of the total material cost. The cost of other materials including hydrants, connections and gate valves was Rs. 8070, which accounts for 11% of the material cost. Thus the major cost is for manifolds and pumping system and related attachments. The cost of installation of Raingun sprinkler irrigation system was around Rs. 13,000. Thus the total cost of system and installation was Rs. 86,305. The average cost per ha was Rs. 16,284. Therefore, the unit cost would range between Rs.16,000 to 17,000 (Table 1).

The unit cost was reduced almost by 28% by changing the concept from complete irrigation to supplemental irrigation. This was a good achievement for the canal command areas, where the peak crop water requirement from Raingun sprinkler irrigation is reduced due to the conjunctive use of rainfall, canal water and groundwater.

Complete Irrigation System at Village Thatti Noor

In Thatti Noor village Qadir Farm was selected to install medium-size Raingun sprinkler irrigation system, where discharge was sufficient to operate 3 Rainguns depending on the availability of water from the dugwell. In fact the system was designed to operate three Rainguns, but due to shortage of water in the dugwell because of continued drought two Rainguns were appropriate to operate. The system layout consisted of two manifolds of 75 and 50 mm inner diameter of LDPE pipe. Six double and six single hydrants were installed (Figure 2). The cost of pumping system with attachments for suction and delivery line including foundation was Rs. 34,347, which accounts for 30% of the total material cost. The cost of manifolds was Rs. 67,615, which accounts for 59% of the total material cost. The cost of other materials including hydrants, connections and gate valves was Rs. 12,980, which accounts for 11% of the material cost. Thus the major cost is for manifolds and pumping system and related attachments. The cost of installation of Raingun sprinkler irrigation system was around Rs. 14,000. Thus the total cost of system and installation was Rs.1,28,942. The average cost per ha was Rs. 22,621. Therefore, the unit cost would range between Rs.22,000 to 23,000 (Table 1).

The unit cost was 39% more than the other farm, where system was designed for supplemental irrigation. This increase was due to the increase in the peak crop water requirement for the Raingun sprinkler irrigation system. However, the system size can be increased for conditions of supplemental irrigation.

System Performance

Discharge and Pressure Variations

Supplemental Irrigation System at Chak #6ML

The discharge and pressure of Raingun sprinkler measured at each hydrant of the system installed at Chak #6ML, Bhalwal is given in Table 2. The nozzle size of 12 mm diameter was used. The pressure at Raingun ranged between 39.9 m to 37.1 m with an average of 38.8 m. The pressure variations were $\pm$3.6 percent, which is extremely low and thus the system performance in terms of pressure variations was within the permissible limits. The discharge of Raingun ranged between 2.69 lps to 2.58 lps with an average of 2.65 lps. The discharge variations were $\pm$2.1 percent.

Complete Irrigation System at Village Thatti Noor

The performance evaluation of Raingun system at the Thatti Noor Farm was conducted under two sets of pressure conditions, when two Rainguns were used. In the first setting, the pressure at the pumping system was maintained at 35 m head, whereas in the second setting the pressure at pumping system was maintained at 28 m. The two sets of pressure conditions would help to evaluate the system in terms of pressure range instead of a fixed pressure.

For the first setting, the pressure at the pumping system was maintained at 35 m. The discharge and pressure of Raingun sprinkler measured at each hydrant of the system is given in Table 3. The nozzle size of 10 mm diameter was used. The pressure at Raingun ranged between 35.0 m to 30.8 m with an average of 33.8 m. The pressure variations were ±6.2 percent, which is reasonably low and thus the system performance in terms of pressure variations was within the permissible limits. The discharge of Raingun ranged between 1.92 lps to 1.80 lps with an average of 1.89 lps. The discharge variations were ±3.2 percent.

For the second setting, the pressure at the pumping system was maintained at 28 m. The discharge and pressure of Raingun sprinkler measured at each hydrant is given in Table 4. The nozzle size of 10 mm diameter was used. The pressure at Raingun ranged between 28.0 m to 22.4 m with an average of 26.1 m. The pressure variations were ±10.7 percent, which is reasonably low and thus the system performance in terms of pressure variations was within the permissible limits. The discharge of Raingun ranged between 1.73 lps to 1.58 lps with an average of 1.68 lps. The discharge variations were ±4.5 percent.

The pressure variations were ±3.6 and 6.2%, which is extremely low and thus the system performance in terms of discharge variations was within the permissible limits. This was mainly due to appropriate size of the Raingun nozzle, layout of the manifold, and the optimal range of Raingun pressure (30-40 m). The pressure variations increased to ±10.7%, when the pressure of the pump dropped to 28 m and pressure at Raingun was in the range of 22-28 m. Thus the Raingun pressure must be maintained between 30-40 m.

Radius of Coverage as Affected by Water Level in the Dugwell

Supplemental Irrigation System at Chak #6ML

Raingun sprinkler with 12 mm diameter nozzle size was used to estimate radius of coverage as affected by time and pressure. In fact there was lowering of water table in the dugwell up to 80 minutes from the start of the pumping. The depletion in dugwell water level was 1.38 m in 80 minutes and afterwards the water level in the dugwell got stabilized. The pressure at Raingun ranged between 39.9 m to 37.1 m with an average of 38.4 m. The pressure variations were ±3.6 percent, which is reasonably low and thus the system performance in terms of pressure variations was within the permissible limits. The radius of coverage of Raingun ranged between 24 m to 21 m with an average of 22.1 m (Table 5). The variations in radius of coverage were ±6.8 percent, which is reasonably low and thus the system performance in terms of area covered was within the permissible limits. The variations in Raingun radius of coverage were more than Raingun pressure, which is a good indication of the sensitivity of area of coverage as affected by pressure variations.

The radius of coverage is not the appropriate performance parameter; therefore this information must be used in estimating the area of coverage. The area of coverage at 24 m radius was 1810 m^2, whereas it was reduced to 1385 m^2 with reduction in radius of coverage to 21 m. The average area of coverage was 1534 m^2. Thus the variation in area of coverage from the average was ±13.8 percent, which is a concern. However, it will not affect the distribution of water except overlapping has to be adjusted accordingly.

Pressure Variations as Affected by Water Level in the Dugwell

For the Qadir Farm at Thatti Noor village, the evaluation was made under three settings in terms of Raingun positions at different hydrants. In all the three setting, three Rainguns were used to evaluate the performance in terms of water level in the dug-bore well and pressure variations.

First Setting of Rainguns

Three Rainguns were installed at hydrants # 1, 6 and 12 located at a distance of 20, 225 and 351 m from the pumping system, respectively. Raingun nozzle diameter of 8 mm was used. The water level in the dugwell stabilized at 5.62 m after 50 minutes of the operation of the pumping system. The pressure variation since the start of the pumping ranged between 40.6 m and 36.4 m at hydrants 1 and 12, respectively. The average pressure was 38.2 m. The pressure variation was ±5.5 percent (Table 6).

Second Setting of Rainguns

Three Rainguns were installed at hydrants # 1, 2 and 7 located at a distance of 20, 60 and 142 m from the pumping system, respectively. Raingun nozzle diameter of 8 mm was used. The water level in the dugwell stabilized at 5.61 m after 50 minutes of the operation of the pumping system. The pressure variation since the start of the pumping ranged between 40.6 m and 35.0 m at hydrants 1 and 7, respectively. The average pressure was 37.6 m. The pressure variation was ±7.4 percent (Table 7).

Third Setting of Rainguns

Three Rainguns were installed at hydrants # 3, 6 and 12 located at a distance of 100, 225 and 351 m from the pumping system, respectively. Raingun nozzle diameter of 8 mm was used. The water level in the dugwell stabilized at 5.61 m after 40-50 minutes of the operation of the pumping system. The pressure variation since the start of the pumping ranged between 40.6 m and 35.7 m at hydrants 3 and 12, respectively. The average pressure was 37.9 m. The pressure variation was ±6.5 percent (Table 8).

The evaluation of the three settings of the Raingun sprinklers indicated that the pressure variations varied between ± 5.5 to 7.4 %, which were within the permissible limits even during the transient state. The discharge variability would be in the order of ± 2.75 to 3.7%, which is also within the permissible range.

Performance of Raingun as affected by the Dugwell Yield

Supplemental Irrigation System at Chak #6ML

The operation of Raingun sprinkler at the dugwell installed at the Ahmad Bakhsh Farm at Chak #6ML indicated that dugwell could provide sustainable yield after 80 minutes. After stabilizing the water level in the dugwell, pressure and radius of coverage was also stabilized. Therefore, these pressures and radius of coverage should be used for the purpose of operation of the Raingun sprinkler. The constant pressure of 37 m can be maintained at the Raingun with constant radius of coverage of 21 m. Therefore, the constant area of coverage by the Raingun would be 1385 m^2 (Table 5). The system performed reasonably well as per design specifications primarily due to the sustained well yield at water depletion level of 1.38 m from surface of the well.

The field evaluation indicated that Raingun system installed on dugwells should be evaluated to find the appropriate levels for Raingun pressure, discharge, radius of coverage, and water level in the dugwell. If the water level in the dugwell drops more than 6 m, the discharge would be reduced tremendously. Thus draw down in the dugwell should be less than the permissible suction to attain the designed discharge.

Complete Irrigation System at Village Thatti Noor

The complete irrigation system was designed under two sets of Raingun settings. In the 1st set, two Rainguns were used with nozzle size of 10 mm diameter. The pressure variation was ±6.2% at pumping pressure of 35 m, whereas it was increased to ±10.7% with the reduced pumping pressure of 28 m. In the 2nd set, three Rainguns were used with nozzle size of 8 mm diameter. The pressure variation was ±5.5 to ±7.4 % under three settings of the Raingun positions. The stabilized pumping pressure with stabilized water level in the dugwell was around 40 m. The conclusion is that both sets of Rainguns (2 or 3) can be used with reasonable level of performance.

The details of three settings each with three Rainguns using 8 mm diameter nozzle are as under:

First Setting of Rainguns: Three Rainguns were installed at hydrants # 1, 6 and 12 located at a distance of 20, 225 and 351 m from the pumping system, respectively. Raingun nozzle diameter of 8 mm was used. The water level in the dugwell stabilized at 5.62 m after 50 minutes of the operation of the pumping system. The pressure variation at the start of the pumping ranged between 40.6 m and 37.8 m at hydrants #1 and 12, respectively. The average pressure was 39.2 m. The pressure variation was ±3.6. After stabilizing the water level in the dugwell, the pressure variation ranged between 38.5 and 36.4 m at hydrants #1 and 12, respectively. The average pressure was 37.6 m. The percent variation in pressure was ±2.8. The variation in Raingun pressure was reduced after the stabilization of the water level in the dugwell (Table 6).

Second Setting of Rainguns: Three Rainguns were installed at hydrants # 1, 2 and 7 located at a distance of 20, 60 and 142 m from the pumping system, respectively. Raingun nozzle diameter of 8 mm was used. The water level in the dugwell stabilized at 5.61 m after 50 minutes of the operation of the pumping system. The pressure variation at the start of the pumping ranged between 40.6 m and 38.5 m at hydrants # 1 and 7, respectively. The average pressure was 39.7 m. The pressure variation was ±2.6. After stabilizing the water level in the dugwell, the pressure variation ranged between 38.5 and 35.0 m at hydrants 1 and 7, respectively. The average pressure was 36.9 m. The percent variation in pressure was ±4.7 (Table 7).

Third Setting of Rainguns: Three Rainguns were installed at hydrants number of 3, 6 and 12 located at a distance of 100, 225 and 351 m from the pumping system, respectively. Raingun nozzle diameter of 8 mm was used. The water level in the dugwell stabilized at 5.61 m after 40-50 minutes of the operation of the pumping system. The pressure variation at the start of the pumping ranged between 40.6 m and 37.1 m at hydrants #3 and 12, respectively. The average pressure was 38.9 m. The pressure variation was ±4.5. After stabilizing the water level in the dugwell, the pressure variation ranged between 38.5 and 35.7 m at hydrants #3 and 12, respectively. The average pressure was 37.1 m. The percent variation in pressure was ±3.8 percent. The pressure variation was reduced after stabilization of the water level in the dugwell (Table 8).

Coefficient of Uniformity Under Various Pressure

For Raingun sprinkler irrigation system, the last quarter is overlapped to obtain better uniformity of water distribution. Therefore, the spacing between two sprinklers is kept equal to the effective diameter of coverage of the Raingun sprinkler. The coefficient of uniformity of the Raingun sprinklers was determined at the effective diameter of coverage i.e. up to third quarter. The coefficients of uniformity of the Raingun sprinkler as affected by effective diameter of coverage, nozzle sizes and pressure are presented in Table 9.

Nozzle Size of 6 mm Diameter

For the nozzle size of 6 mm diameter, the maximum coefficient of uniformity of 86.5% was observed at pressure head of 28 m. The effective diameter of coverage was 27 m, which represents the 75% of the potential diameter of coverage. However, with overlapping of 25% same level of uniformity can be achieved with potential diameter. Thus pressure head of 30 m is recommended with nozzle size of 6 mm diameter.

Nozzle Size of 8 mm Diameter

For the nozzle size of 8 mm diameter, the maximum coefficient of uniformity of 86.3% was observed at pressure head of 28 m. The effective diameter of coverage was 31 m, which represents the 75% of the potential diameter of coverage. However, with overlapping of 25% same level of uniformity can be achieved with potential diameter. Thus pressure head of 30 m is recommended with nozzle size of 8 mm diameter.

Nozzle Size of 10 mm Diameter

For the nozzle size of 10 mm diameter, the maximum coefficient of uniformity of 90.8% was observed at pressure head of 39 m. The effective diameter of coverage was 33 m, which represents the 75% of the potential diameter of coverage. However, with overlapping of 25% same level of uniformity can be achieved with potential diameter. Thus pressure head of 30-40 m is recommended with nozzle size of 10 mm diameter.

Nozzle Size of 12 mm Diameter

For the nozzle size of 12 mm diameter, the maximum coefficient of uniformity of 78.1% was observed at pressure head of 32 m. The effective diameter of coverage was 39 m, which represents the 75% of the potential diameter of coverage. However, with overlapping of 25% same level of uniformity can be achieved with potential diameter. Thus pressure head of 30-40 m is recommended with nozzle size of 12 mm diameter.

The coefficient of uniformity of the Raingun varied between 78 to 91 % with pressure range of 30-40 m and nozzle sizes of 6 to 12 mm diameter. Thus reasonably high value of uniformity coefficient can be obtained through overlapping by adjusting the space between two Raingun sprinklers. Walker (1980) recommended that uniformity coefficient should be in the range of 70 to 80 %. Jensen (1981) recommended that coefficient of uniformity should be more than 80% to justify the investments made in sprinkler irrigation. However, it is difficult to have higher uniformity coefficient without overlapping, as uniformity of Raingun sprinklers is always less than the smaller sprinklers.

Needed Modifications and Adaptations

The economics of Raingun sprinkler irrigation systems indicated that for the Indus basin, these systems must be designed considering the conjunctive use of rainfall, canal water and groundwater. Thus cost of the system can be reduced by 28% just by changing the concept of complete irrigation to supplemental irrigation. This demands that the peak demand water requirement must be changed from 5 mm/day to 3 mm/day or even less. Furthermore, the peak operational time should also be changed to 20 hours to reduce the size of the prime mover and the pump.

The Indus basin is also going to experience the water crises due to increase in demand among the competing water users' and the conflicting objectives. Therefore, sprinklers should be used for vegetables, fodders and field crops, whereas for orchards modified hose-fed system can be used. These systems have already been designed and installed at farmers fields in Khanpur and Haripur areas for the matured orchards, which were established originally under flood irrigation and the rooting pattern is extensive.

Needed Refinement in Design and Manufacturing of Systems' Hardware

Based on the performance evaluation of the Raingun sprinkler irrigation systems it is necessary to develop standards for the manufacturers, so that they can use these standards as specifications for the manufacturing of Raingun sprinkler irrigation systems. There are two major objectives of manufacturing and designing any Raingun sprinkler irrigation system. These include water and energy efficiency and cost-effectivity. Therefore, efforts should be made to minimize the pressure requirement to reduce the size of the pumping system and to minimize the energy requirement. The layout of the Raingun sprinkler irrigation should be designed in such a way that the coefficient of uniformity is optimized. This would help to improve the water use efficiency.

The recommended manufacturers' specifications and design parameters are presented in Table 10. This table provides specifications for the whole range of Rainguns suitable for very small to large farms.

CONCLUSIONS

1. The design and performance evaluation of the Raingun sprinkler irrigation system installed at Bhalwal, Sargodha indicated that the system cost can be reduced by 28% just by changing the design concept from complete irrigation to partial or supplemental irrigation. This is valid for the Indus basin, where concept of conjunctive use of water (rainfall, canal water and groundwater) is practiced.

2. The operational time of Raingun sprinkler irrigation system at peak demand was taken 12-15 hours, which can be increased to 20 hours for further reduction in cost. However, it would depend on the limitations of suction and lowering of water in the dugwell.

3. The level of water in the dugwell is an essential criterion for the design and performance of the system. Although the permissible limit for suction with centrifugal pumps is 6 m but the high-pressure pump performs better if the suction is less than 6 m. Therefore, extra care must be made while designing the pumping systems for Raingun sprinkler irrigation. Under conditions of extreme suction of around 6 m or more, the designed discharge of Raingun with 12 mm diameter nozzle was reduced to the point that either two

Rainguns of 10 mm diameter nozzle or three Rainguns of 8 mm diameter nozzle could be operated. The system was originally designed for three Rainguns with 12 mm diameter nozzle.

4. The important conclusion is that centrifugal pump based Raingun sprinkler irrigation systems should be designed for single Raingun with 12 mm diameter nozzle for sustained pumping and longer operational time for irrigation.

5. The pressure variations ranged between ±3 to ±10%, which is reasonable to have higher uniformity in water distribution (around 80% or more).

6. Another important conclusion is that the performance of locally made Raingun sprinkler irrigation systems is reasonably high at higher pressures of 30-40 m. However, it will reduce significantly if the pressure drops below 20 m.

7. Based on the limitations of the centrifugal pumps and the problem associated with lowering of water table in dugwells, there is a need to design and develop low-cost submersible pumps based Raingun sprinkler irrigation systems.

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Table 1 Cost of raingun sprinkler irrigation systems installed at two selected farms in Mona SCARP, Bhalwal, Sargodha Pakistan.

System Components	Cost (Rs.) (Percent of Total)	
	Allah Bakhsh Farm	Qadir Farm
Pumping System, Suction and Delivery lines and Foundation	21133 (29)	34347 (30)
Manifold #1	19311 (26)	33140 (29)
Manifold #2	24791 (34)	34475 (30)
Other Materials	8070 (11)	12980 (11)
Total Material Cost	73305	114942
Total Installation Cost	13,000	14,000
Total Cost	86,305	1,28,942
Average cost per ha	16,284	22,621
Cost Range (Rs./ha)	16,000-17,000	22,000-23,000

Table 2. Discharge and pressure of raingun sprinkler at various hydrants using 12 mm diameter nozzle at Chak #6ML, Bhalwal, Sargodha, Pakistan.

Position of Raingun	Distance from Pumping Station (m)	Pressure (m)		Discharge (lps)
		Pumping Station	Raingun	
Hydrant #1	48	41.3	39.9	2.69
Hydrant #2	40	41.3	39.9	2.69
Hydrant #3	142	41.3	39.2	2.66
Hydrant #4	176	41.3	39.2	2.66
Hydrant #5	75	41.3	38.5	2.64
Hydrant #6	150	41.3	38.5	2.64
Hydrant #7	208	41.3	37.8	2.61
Hydrant #8	286	41.3	37.1	2.58
Average			38.8	2.65
Percent Variation			±3.6	±2.1

Table 3. Discharge and pressure of Raingun sprinkler at various hydrants using 10 mm diameter nozzle at Thatti Noor village, Bhalwal, Sargodha, Pakistan.

Position of Raingun #1	Distance from Pumping Station (m)	Pressure (m)		Discharge at Raingun #1 (lps)	Position of Raingun #2
		Pumping Station	Raingun #1		
Manifold #1 (75 mm Diameter Pipe)					
Hydrant #1	20	35	35	1.92	Hydrant #6
Hydrant #2	60	35	35	1.92	Hydrant #6
Hydrant #3	100	35	35	1.92	Hydrant #6
Hydrant #4	140	35	35	1.92	Hydrant #6
Hydrant #5	180	35	35	1.92	Hydrant #6
Hydrant #6	225	35	33.6	1.88	Hydrant #5
Manifold #2 (50 mm Diameter Pipe)					
Hydrant #7	142	35	34.3	1.90	Hydrant #1
Hydrant #8	182	35	33.6	1.88	Hydrant #1
Hydrant #9	222	35	33.6	1.88	Hydrant #1
Hydrant #10	256	35	32.9	1.86	Hydrant #1
Hydrant #11	306	35	31.5	1.82	Hydrant #1
Hydrant #12	351	35	30.8	1.80	Hydrant #1
Average			33.8	1.89	
Percent Variation			±6.2	±3.2	

Table 4. Discharge and pressure of Raingun sprinkler at various hydrants using 10 mm diameter nozzle at Thatti Noor village, Bhalwal, Sargodha, Pakistan.

Position of Raingun #1	Distance from Pumping Station (m)	Pressure (m)		Discharge at Raingun #1 (lps)	Position of Raingun #2
		Pumping Station	Raingun #1		
Manifold #1 (75 mm Diameter Pipe)					
Hydrant #1	20	28	28	1.73	Hydrant #6
Hydrant #2	60	28	28	1.73	Hydrant #6
Hydrant #3	100	28	28	1.73	Hydrant #6

Hydrant #4	140	28	28	1.73	Hydrant #6
Hydrant #5	180	28	28	1.73	Hydrant #6
Hydrant #6	225	28	25.9	1.67	Hydrant #5
Manifold #2 (50 mm Diameter Pipe)					
Hydrant #7	142	28	25.2	1.65	Hydrant #1
Hydrant #8	182	28	25.9	1.67	Hydrant #1
Hydrant #9	222	28	25.9	1.67	Hydrant #1
Hydrant #10	256	28	25.2	1.65	Hydrant #1
Hydrant #11	306	28	23.1	1.60	Hydrant #1
Hydrant #12	351	28	22.4	1.58	Hydrant #1
Average			26.1	1.68	
Percent Variation			±10.7	±4.5	

Table 5. Radius of coverage of the Raingun sprinkler under various pressure heads using 12 mm diameter nozzle, Chak #6ML, Bhalwal, Sargodha, Pakistan.

Time (min)	Depth Depleted (m)	Pressure (m)	Radius of Coverage (m)
10	0.87	39.9	24
20	1.04	39.9	24
30	1.23	39.2	23
40	1.30	39.2	22
50	1.32	38.5	22
60	1.34	38.5	22
70	1.36	37.8	21
80	1.38	37.1	21
90	1.38	37.1	21
100	1.38	37.1	21
Average		38.4	22.1
Percent Variation		±3.6	±6.8

Table 6. Evaluation of first setting of three Raingun sprinklers with nozzle diameter of 8 mm at Qadir Farms, Thatti Noor, Bhalwal, Sargodha, Pakistan.

Time (min)	Depth to Water Table (m)	Pressure (m)		Remarks
		Pumping Station	Raingun	
Raingun at Hydrant #1 and at a distance of 20 m from the pumping system				
0	4.12	42	40.6	2nd and 3rd Rainguns at #6 & #12 hydrants
10	4.95	41.3	39.9	"
20	5.38	41.3	39.2	"
30	5.57	40.6	39.2	"
40	5.61	40.6	39.2	"
50	5.62	39.9	38.5	"
60	5.62	39.9	38.5	"
70	5.62	39.9	38.5	"
Raingun at Hydrant #6 and at a distance of 225 m from the pumping system				
0	4.12	42	39.2	2nd and 3rd Rainguns at #1 & #12 hydrants
10	4.98	42	39.2	"
20	5.46	41.3	38.5	"
30	5.59	41.3	38.5	"
40	5.60	41.3	38.5	"
50	5.61	40.6	37.8	"
60	5.62	40.6	37.8	"
70	5.62	40.6	37.8	"
80	5.62	40.6	37.8	"
Raingun at Hydrant #12 and at a distance of 351 m from the pumping system				
0	4.45	42	37.8	2nd and 3rd Rainguns at #1 & #6 hydrants
10	5.25	42	37.8	"
20	5.59	41.3	37.1	"
30	5.60	41.3	37.1	"

40	5.61	41.3	37.1	"
50	5.62	40.6	36.4	"
60	5.62	40.6	36.4	"
70	5.62	40.6	36.4	"
Average			38.2	
Percent Variation			±5.5	

Table 7. Evaluation of second setting of three Raingun sprinklers with nozzle diameter of 8 mm at Qadir Farms, Thatti Noor, Bhalwal, Sargodha, Pakistan.

Time (min)	Depth to Water Table (m)	Pressure (m)		Remarks
		Pumping Station	Raingun	
Raingun at Hydrant #1 and at a distance of 20 m from the pumping system				
0	3.94	42	40.6	2nd and 3rd Rainguns at #2 & #7 hydrants
10	4.87	41.3	39.9	"
20	5.38	40.6	39.2	"
30	5.58	39.9	39.2	"
40	5.59	39.2	38.5	"
50	5.61	39.2	38.5	"
60	5.61	39.2	38.5	"
70	5.61	39.2	38.5	"
80	5.61	39.2	38.5	"
Raingun at Hydrant #2 and at a distance of 60 m from the pumping system				
0	3.94	42	39.9	2nd and 3rd Rainguns at #1 & #7 hydrants
10	4.87	41.3	39.2	"
20	5.38	40.6	38.5	"
30	5.58	39.9	37.1	"
40	5.59	39.2	37.1	"
50	5.61	39.2	37.1	"
60	5.61	39.2	37.1	"
70	5.61	39.2	37.1	"

80	5.61	39.2	37.1	"
Raingun at Hydrant #7 and at a distance of 142 m from the pumping system				
0	3.94	42	38.5	2nd and 3rd Rainguns at #1 & #2 hydrants
10	4.87	41.3	37.8	"
20	5.38	40.6	37.1	"
30	5.58	39.9	36.4	"
40	5.59	39.2	35	"
50	5.61	39.2	35	"
60	5.61	39.2	35	"
70	5.61	39.2	35	"
80	5.61	39.2	35	"
Average			37.6	
Percent Variation			±7.4	

Table 8. Evaluation of third setting of three Raingun sprinklers with nozzle diameter of 8 mm at Qadir Farms, Thatti Noor, Bhalwal, Sargodha, Pakistan.

Time (min)	Depth to Water Table (m)	Pressure (m)		Remarks
		Pumping Station	Raingun	
Raingun at Hydrant #12 and at a distance of 351 m from the pumping system				
0	4.13	42	37.1	2nd and 3rd Rainguns at #3 & 6 hydrants
10	4.96	42	37.1	"
20	5.39	41.3	37.1	"
30	5.58	41.3	36.4	"
40	5.61	41.3	36.4	"
50	5.61	41.3	35.7	"
60	5.61	41.3	35.7	"
70	5.61	41.3	35.7	"
80	5.61	41.3	35.7	"
Raingun at Hydrant #3 and at a distance of 100 m from the pumping system				

0	4.25	42	40.6	2nd and 3rd Rainguns at #6 &12 hydrants
10	4.99	41.3	40.6	"
20	5.48	41.3	39.9	"
30	5.59	41.3	39.9	"
40	5.60	40.6	39.2	"
50	5.61	40.6	39.2	"
60	5.61	40.6	38.5	"
70	5.61	40.6	38.5	"
80	5.61	40.6	38.5	"
Average		41.2	37.9	
Percent Variation			±6.5	

Table 9. Coefficient of uniformity of Raingun sprinkler as affected by effective diameter of coverage, nozzle sizes and pressure, Bhalwal, Sargodha, Pakistan.

Pressure (m)	Nozzle Size (mm)							
	6 mm		8 mm		10 mm		12 mm	
	Diameter (m)	Cu (%)	Diameter (m)	Cu (%)	Diameter (m)	Cu (%)	Diameter (m)	Cu (%)
14	21	76.25	27	68.94	31	75.44	31	75.24
18	23	70.3	29	70.24	33	76.28	35	85.87
21	25	78.63	29	82.31	33	80.34	37	80.23
25	27	81.83	31	85.17	33	78.74	39	80.08
28	27	86.52	31	86.27	33	88.95	39	78.26
32	27	85.04	31	83.76	33	89.04	39	78.06
35	29	84.22	31	77.99	33	86.68	41	75.41
39	29	81.03	31	71.12	33	90.83	41	78.01
42	31	77.79	33	78.79	35	79.99	41	75.11
46	31	82.40	33	80.56	37	86.19	45	70.88
49	27	85.81	35	81.63	37	85.81	45	75.82
53	27	85.01	35	83.26	37	81.70	45	74.88
56	27	84.94	37	78.11	37	85.15	45	73.77

Table 10. Hydraulics of Raingun sprinklers recommended for local manufacturing and design for farmers in Pakistan.

Type of Raingun	Nozzle Diameter (mm)	Working Pressure (m)	Discharge of Sprinkler (lps)	Radius of Coverage (m)	Application Rate (mm/hr)
PY_{1-20}	6	30	0.66	19.0	2.09
		40	0.76	21.6	1.80
	7	30	0.85	20.8	2.24
		40	0.95	22.9	2.08
	8	30	1.11	22.4	2.54
		40	1.28	22.6	2.86
PY_{1-30}	9	30	1.38	24.2	2.70
		40	1.57	24.6	2.98
	10	30	1.67	25.6	2.94
		40	1.92	26.6	3.11
	11	30	2.03	27.6	3.06
		40	2.35	28.5	3.31
	12	30	2.35	27.2	3.65
		40	2.74	28.5	3.86
PY_{1-40}	12	30	2.64	27.7	3.94
		45	3.17	31.7	3.64
	13	30	2.94	28.6	4.13
		45	3.75	30.8	4.52
	14	35	3.58	31.9	4.03
		45	4.08	32.5	4.43
	15	35	4.36	34.0	4.34
		45	4.86	35.1	4.53
	16	35	4.83	34.9	4.55
		45	5.44	36.2	4.78
PY_{1-50}	16	40	4.97	37.2	4.11
		50	5.58	38.7	4.26
	18	40	6.28	38.9	4.75
		50	7.00	40.0	5.03
	20	40	7.56	41.1	5.10
		50	8.47	42.3	5.42

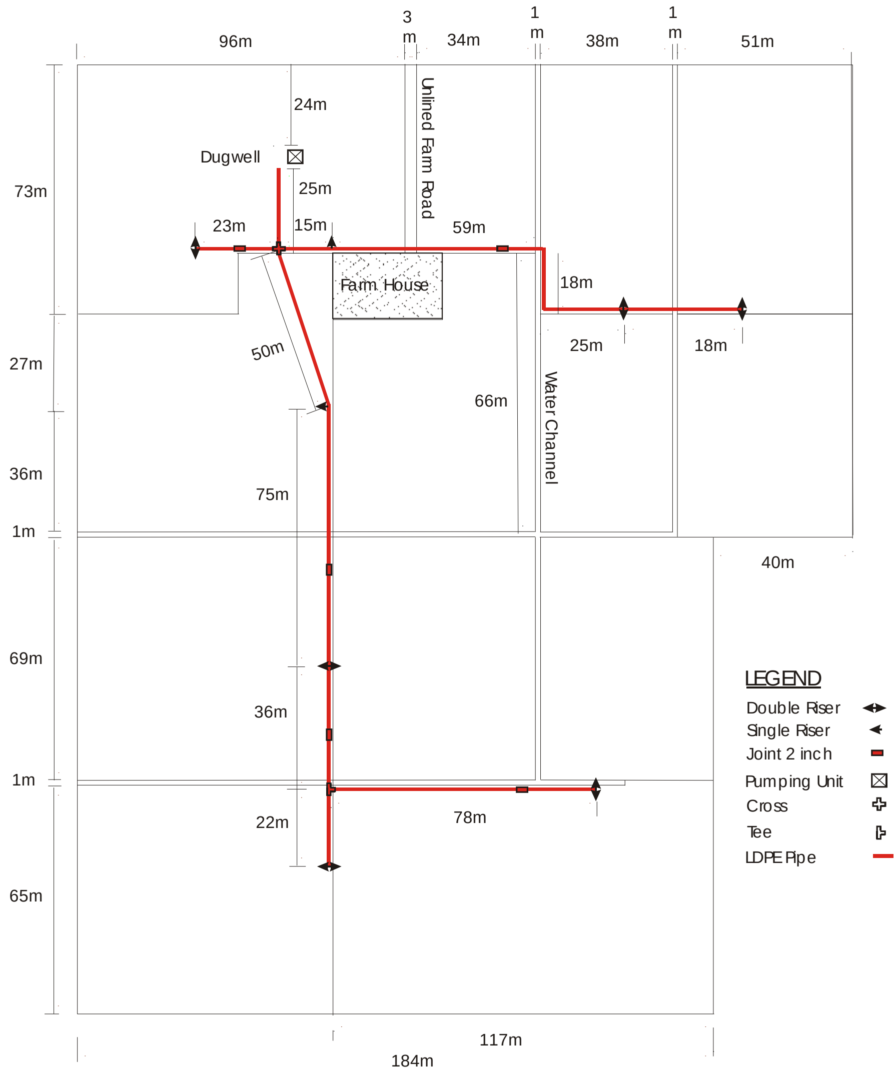

Figure 1: Line Diagram of Raingun Sprinkler Irrigation System
Ahmad Bukhsh Farm Chak 6ML Bhalwal

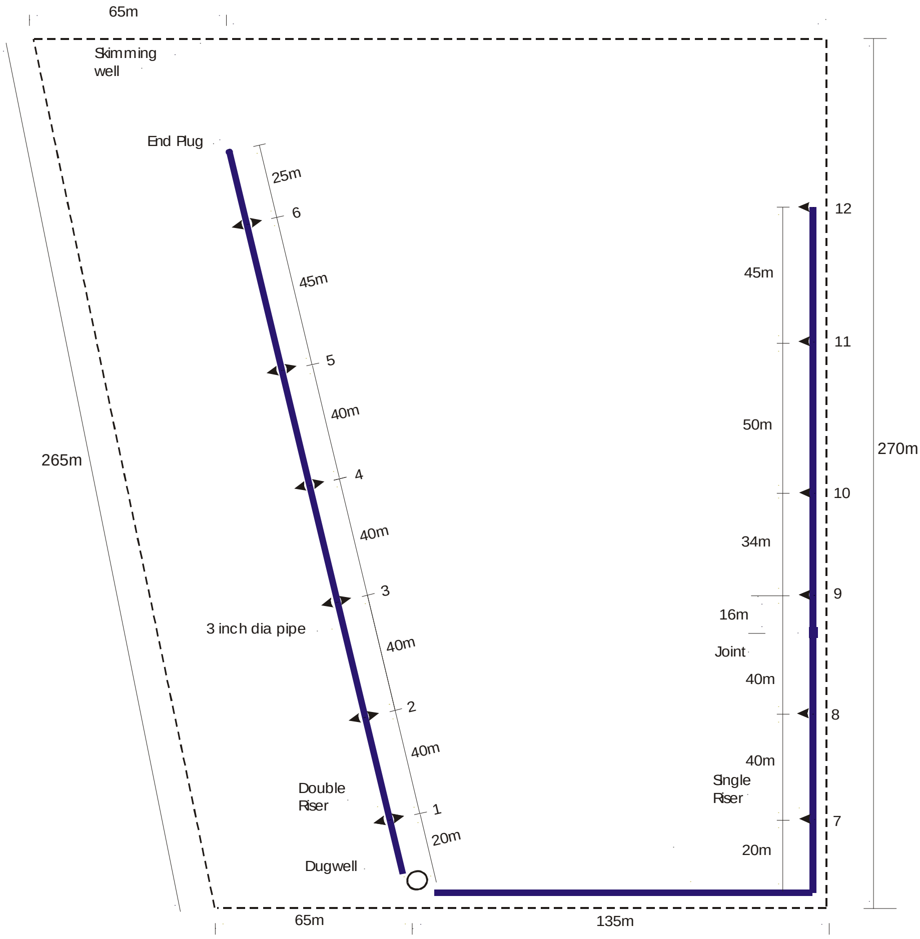

Figure 2: Line Diagram of Raingun Sprinkler Irrigation System
Qadir Farm Thathi Noor, Bhalwal

Appendix I. Design of Raingun Sprinkler Irrigation System of Ahmad Bakhsh Farm, Chak # 6 ML, Bhalwal, Sargodha, Pakistan.

PUMP

Engine Power	= 8 hp
Pump Discharge	= 3 lps
Pressure	= 60 m

Design of Manifold #1

Maximum length	= 176 m
Pipe Diameter	= 50 mm
Raingun Discharge	= 2.74 lps at 12 mm nozzle
Frictional Losses	= 7.8 m

Design of Manifold #2

Maximum Length	= 264 m
Pipe Diameter	= 50 mm
Raingun Discharge	= 2.74 lps
Friction Losses	= 11.7 m

Head Loss for Maximum Operational Line

Friction Losses in Manifolds	= 11.7 m
Suction	= 6 m
Friction Losses in Laterals	= 2.5 m
Connections and Valves	= 1 m
	===========
Total Head Loss	**21.2 m**
	===========

Total Head	= 60 m
Working head (Min.)	= 38.8 m
Working head (Max.)	= 48.7
Variation	=4.95m, ±11.5%

Appendix II. Design of Raingun Sprinkler Irrigation System of Qadir Farm, Thatti Noor, Bhalwal, Sargodha, Pakistan.

PUMP

Engine Power	= 18 hp
Pump Discharge	= 8.22 lps
Pressure	= 60 m

Design of Manifold #1

Maximum length	= 250 m
Pipe Diameter	= 75 mm
Raingun Discharge nozzles	= 5.5 lps [for 2 rainguns (PY_1-30) with 12 mm
Friction Losses	= 5.6 m

Design of Manifold #2

a)	Length	= 135 m
	Pipe Diameter	= 75 mm
	Raingun Discharge	= 2.74 lps for 12 mm dia nozzle
	Friction Losses	= 0.8 m
b)	Length	= 229 m
	Pipe Diameter	= 50 mm
	Raingun Discharge	= 2.74 lps for 12 mm dia nozzle
	Friction Losses	= 10.1
	Total Friction Losses in Manifold	= 0.8 + 10.1 = 10.9 m

Head Loss for Maximum Operational Line (Manifold #2)

Suction	= 6 m
Friction Losses in Lateral	= 2.5 m
Connections and Valves	= 1 m
	================
Total System Losses	**18.4 m**
	================
Total Head	= 60 m
Working head (Min.)	= 41.6 m
Working head (Max.)	= 50.1 m
Variation	= ± 9.3% ± 4.25 m

Appendix III. List of Materials Used for Raingun Sprinkler Irrigation System Installed at Chak #6ML, Bhalwal, Sargodha, Pakistan.

	Materials	Quantity	Amount (Rs.)

PUMPING STATION

a: Suction Line

	Materials	Quantity	Amount (Rs.)
i.	Foot valve 2½"	1 No	342
ii.	Suction pipe (GI) 2½"	20 ft	1320
iii.	Bend (GI) 2½"	1 No	130
iv.	Nippel (GI) 2½"	1 No	150
v.	Union (GI) 2½"	1 No	230
	Total		**Rs.2172**
	Percentage of Grand Total		**3**

b: Delivery Line

	Materials	Quantity	Amount (Rs.)
i.	GI Nippel 2"	4 No.	200
ii.	GI Tee Reducer 2"x2"x½	"2 No.	176
iii.	Pressure gauge	1 No.	450
iv.	Union 2"	1 No.	135
v.	Hose Nozzle ½"	1 No.	10
vi.	GI pipe 2"	8 ft.	544
vii.	Nippel ½"	1 No.	10
viii.	Handle valve ½"	1 No.	65
ix.	Elbow 2"	3 No.	195
x.	Hose Nozzle 2"	1 No.	40
	Total		**Rs.1625**
		Percentage of Grand Total	*2*

c: Foundation

	Materials	Quantity	Amount (Rs.)
i.	Bricks	50 No.	100
ii.	Cement	1 Bag	180
iii.	Sand	4 ft^3	36
iv.	Crush	2 ft^3	20
v.	Engine 8 hp (Chinese)	1 No	
vi.	Multistage pump	1 No.	17000
vii.	Iron Support for Engine & Pump	1 No.	
	Total		**Rs. 17,336**
	Percentage of Grand Total		**24**

MAINLINE NO. 1

i.	LDPE pipe φ 2"	200 m	13,000
ii.	GI pipe 2"	20 ft.	960
iii.	Tee 2"x2"x2"	4 No.	600
iv.	Hose Nozzle 2"	8 No.	320
v.	Nippel 2"	7 No.	350
vi.	Gate Valve 2"	7 No.	1715
vii.	Pipe Joints 2"	2 No.	26
viii.	Elbow 2"	4 No.	260
ix.	Couplers 2"	8 No.	2080
	Total		**Rs. 19,311**
	Percentage of Grand Total		**26**

MAINLINE NO. 2

i.	LDPE pipe φ 2"	300 m	19,500
ii.	Tee 2"x2"x2"	5 No.	750
iii.	Hose Nozzle 2"	8 No.	320
iv.	Nippel 2"	8 No.	400
v.	Gate Valve 2"	7 No.	1715
vi.	Pipe Joints 2"	2 No.	26
vii.	Coupler 2" in mainline No. 1 & 2	8 No.	2080
	Total		**Rs. 24,791**
	Percentage of Grand Total		**34**

OTHER MATERIALS

i.	Cross 2"x2"x2"	1 No.	150
ii.	Clamps 2"	30 No.	450
iii.	Samad Bond	1 kg.	200
iv.	Cloth	3 m	60
v.	Safeda	500 gms	50
vi.	Raingun with nozzle pegs	1 No.	3000
	Total		**Rs. 8,070**
		Percentage of Grand Total	*11*

Total Materials Cost for the System **Rs. 73,305**
Average Materials Cost per ha **Rs. 13831**

Appendix IV. Materials Used for Raingun Sprinkler Irrigation System Installed at Qadir Farm, Thatti Noor, Bhalwal, Sargodha, Pakistan.

	Materials	Quantity	Amount(Rs.)
1. Pumping Station			
a: Suction Line			
I.	Foot valve 2½"	1	342
ii.	Suction pipe (GI) 2½"	6 m	1320
iii.	Bend (GI) 2½"	1 No	130
iv.	Nippel (GI) 2½"	1 No	150
v.	Union (GI) 2½"	1 No	230
	Total		**2172**
	Percentage of Grand Total		**2**
b: Delivery Line			
i.	GI Nipple 2"	8 No.	400
ii.	GI Tee 2"x2"x½"	1 No.	176
iii.	GI Cross 2"x2"x2"x2"	1 No	150
iv.	GI Bush 2" x ½"	1 No.	25
v.	Pressure gauge	1 No.	450
vi.	Gate Valve 2"	2 No.	490
vii.	Union 2"	2 No.	270
viii.	Bends 2"	4 No.	320
ix.	Reducer 3" x 2"	2 No.	450
x.	Hose Nozzle 3"	2 No.	100
xi.	GI sockets 2"	2 No.	100
xii.	GI pipe 2"	14 ft.	672
xiii.	Nipple ½"	1 No.	7
xiv.	Handle valve ½"	1 No.	65
xv.	Pump size 2"x2½"	1 No.	28,500
xvi.	Prime Mover 18 hp Chinese Engine directly coupled with pump on Iron stand.		
	Total		**Rs.32,175**
	Percentage of Grand Total		**28**
2. Mainline No. 1			
i.	LDPE pipe φ 75 mm	240 m	21600
ii.	GI joints φ 75 mm	20 No.	600
iii.	Coupler	6 No.	1560
iv.	Clamps 3"	30 No.	750
v.	GI pipe 2"	15 ft.	720
vi.	Tee 2"x2"x2"	6 No.	900
vii.	Nipple 2"	12 No.	600
viii.	Gate valves 2"	12 No.	2940

ix.	Coupler 2"	12 No.	3120
x.	Reducer 3"x2"	1 No.	225
xi.	GI plug 2"	1 No.	15
xii.	Hose Nozzle 3"	1 No.	50
xiii.	Screws 3/4"	80 No.	60
	Total		**Rs. 33,140**
	Percentage		**29**

3. Mainline No. 2

i.	LDPE pipe φ 3"	126 m	11340
ii.	LDPE pipe φ 2"	250 m	16250
iii.	Reducer 3"x2"	1 No.	225
iv.	Hose Nozzle 3"	1 No.	50
v.	Clamps 3"	2 No.	50
vi.	GI 2" pipe	15 ft.	720
vii.	GI Tee 2"x2"x2"	06 No.	900
viii.	Hose Nozzle 2"	12 No.	480
ix.	GI Nipple 2"	12 No.	600
x.	Gate Valve 2"	06 No.	1470
xi.	Elbow 2"	07 No.	455
xii.	Clamps 2"	20 No.	300
xiii.	Coupler (one end) 2"	6 No.	1560
xiv.	GI joint 2"	1 No.	50
xv.	Screws 3/4"	50 No.	25
	Total		**Rs. 3,445**
	Percentage of Grand Total		**30**

Other Materials

i.	Samad Bond	2 kg.	400
ii.	Safeda	100 gms	50
iii.	Silver Wire	20 m	30
iv.	Raingun wire pegs & nozzles (PY_1-30)	2 No.	6000
v.	Extension Pipe (LDPE 2"100m		6500
	Total		**Rs.12,980**
	Percentage of Grand Total		**11**

Total Materials Cost for the System	**Rs. 1,14,942**
Average Materials Cost per ha	**Rs. 20,165**

Root Zone Salinity Management for Sustaining Crop Production in Saline Groundwater Areas

M.N. Asghar, A.S. Qureshi, S. Ahmad and I. Masih

Abstract

In the Indus Basin of Pakistan, multi-strainer shallow tubewells often called 'skimming wells' are used to extract groundwater from thin fresh lenses underlain by saline groundwater. Most of these wells face problems such as deteriorating water quality and reduction in discharge due to inadequate designs and poor operational and management strategies. This paper evaluates the current practices of farmers in the Chaj doab area of Pakistani Punjab and suggests improvements in design and operation of skimming wells to ensure long-term sustainability of irrigated agriculture in the area. The effect of existing design and operation of skimming wells on pumped groundwater quality was evaluated using MODFLOW. To study the long-term effects of skimmed groundwater use on crop production and soil salinity development, the soil water flow and solute transport model SWAP was applied. The results revealed that farmers could reduce the number of strainers from 16 to 6 without reducing the anticipated discharges. For the conditions considered, the maximum discharge of skimming wells should be 4-8 l/s and they should not be operated for more than 2–4 h per day. Increasing discharge rate or daily operational hours can disturb the interface between fresh and saline groundwater resulting in reduced quality pumped groundwater. Weekly operational schedules together with recommended discharge rate and operational hours will be the best strategy to use skimmed groundwater for achieving optimal crop yields while maintaining root zone salinity within acceptable limits. To avoid aquifer degradation, skimming wells should be used for supplemental irrigation rather than full irrigation of crops. Due to low discharge rates, skimming wells cannot be used to irrigate crop through surface irrigation methods. Therefore pressurised irrigation methods should be used. The results also suggest that continuation of present irrigation practices could lead to serious problems of land and aquifer degradation. Therefore, farmers need to adjust their irrigation and leaching requirements annually considering crop evapotranspiration, precipitation and salinity status of soils.

INTRODUCTION

In the Indus Basin, the natural groundwater is deep and saline because of the marine origin of the hydro-geologic formation. Percolation of irrigation and rainfall waters has formed fresh groundwater lenses in many locations above the underlying saline groundwater. The thickness of this fresh groundwater lens varies from a few meters to more than 150 m. In general the fresh groundwater lenses are found close to the rivers, and saline groundwater areas are present in the central and lower regions of the *doabs* –area enclosed between two rivers (Figure 1). In fresh groundwater areas, the fresh groundwater lenses are thick (> 38 m). In saline groundwater areas, the thickness of fresh groundwater lenses is thin (< 38 m).

According to Zuberi and McWhorter (1973), saline groundwater areas occupy more than 30 percent of the Indus Basin, mainly in Punjab and Sindh. In saline groundwater areas of the Indus Basin, about 200 Billion Cubic Meters (BCM) of fresh groundwater has accumulated (NESPAK, 1983), and over 20 BCM of fresh groundwater is being recharged annually to these saline groundwater areas (Sufi et al. 1998). Development of appropriate technology and adequate operational strategies for the safe abstraction of this valuable resource can contribute significantly in overcoming the scarcity of water in the Indus Basin (Mirbahar et al. 1997; Saeed et al. 2003). The use of 'skimming wells' can be an effective way of extracting fresh groundwater from thin lenses without disturbing the underlaying saline groundwater layers (Chandio and Larock, 1983; Sufi, 1999). A skimming well is a multi strainer tubewell penetrating partially, but vertically using small bores, into the unconfined aquifer underlain by saline groundwater layer.

The large-scale groundwater exploitation from the Indus Basin aquifer started about 40 years ago when about 1400 deep single-strainer tubewells with 30-75 m depth and discharge capacity of 80 l/s were constructed to combat waterlogging and salinity problems. Since then the utilization of groundwater for irrigation has grown rapidly. Farmers locally developed this technology as a single-strainer shallow tubewells in fresh groundwater areas, and small bore multi-strainer shallow tubewells, referred to as skimming wells, in saline groundwater areas of Punjab and Sindh provinces (Hafeez et al. 1986). The current rates of groundwater use in most of the areas are unsustainable. Rapidly falling water tables and increasing salinity of the pumped groundwater attest that more expensive and poor quality groundwater will have to be used for irrigation in future. This impairs the capacity of this region to feed its growing population.

In saline groundwater areas of Punjab and Sindh provinces, farmers have installed almost 10,000 skimming wells (ACE Halcrow JV Consultants, 2002). Most of these wells are not properly designed and are run with inadequate operational schedules (Saeed et al. 2002). As a result, saline groundwater upconing, i.e. upward movement of saline groundwater in an unconfined aquifer having fresh groundwater lens underlain by saline groundwater layer, occurs and the quality of pumped water is deteriorating and a large number of wells have already been abandoned. Moreover farmers do not have sufficient knowledge on the use of skimmed groundwater for maximizing crop yields and minimizing environmental degradation. Thus, salinity problems are emerging in large areas and salt-affected soils are becoming an important ecological problem with about 6 million ha already affected.

Due to relatively low discharge rates (3-8 l/s) the skimmed groundwater cannot be applied to the fields using surface irrigation methods. Therefore the effectiveness of alternative irrigation methods, such as pressurised irrigation systems, needs to be determined. Application of small volumes of water might trigger the salinity development in these soils due to less leaching of salts. Therefore long term effects of the skimmed groundwater use on crops and soils also need to be evaluated. This paper presents the results of a three year study conducted to develop cost-effective and technically feasible design and operational strategies of skimming wells and to prepare guidelines for managing root zone salinity in areas where skimmed groundwater was used with pressurised irrigation, either alone or intermittently with surface irrigation.

DESCRIPTION OF THE STUDY AREA

This study was conducted in the *Chaj Doab,* the area between Jhelum and Chenab Rivers, which is one of the intensively developed and significantly productive irrigated areas of the Indus Basin. The location map of the study area is shown in Figure 2. The Gross Command Area (GCA) of *Chaj Doab* is 0.95 Mha, and 87 percent forms the Culturable Command Area (CCA). The citrus orchards form the salient features of the landscape due to the suitability of agro-climatic and agro-hydrological conditions for citrus plantation. The percentages of CCA owned by the small, medium, and large landholders are 10, 37, and 53 percent, respectively. The majority of farmers have small and medium landholdings (around 80 percent with 1:1 ratio), however these two types of farmers have citrus orchards only on 6-8 percent of their CCA. In case of large landholders, such orchards occupy around 30 percent of their CCA. Annual cropping intensity is highest for small landholders (147 percent), and the lowest for the large farmers (115 percent).

The cropping seasons vary with individual crops but are generally defined as '*kharif'* from mid-April to mid-October, and '*rabi'* for the remaining year. Main crops of *kharif* season include sugarcane, maize, rice and *kharif* fodder, while wheat and *rabi* fodder are the main *rabi* crops. Two main canals, upper and lower Jhelum canals, irrigate this area. These two canals were designed to supply 4.4 BCM to the area. For the drainage purposes: this area is divided into two main zones: SCARP-II non-saline zone, and SCARP-II saline zone. Alluvial deposits underlie the *Chaj Doab,* the resulting aquifer is unconfined, and is mainly composed of medium to fine sand. Total thickness of the aquifer is more than 300 m, and the groundwater fluctuates between 1.5 and 4 m in a yearly hydrological cycle. The soils of the area range from coarse to moderately fine, with a predominance of moderately coarse texture soil classes.

The climate of the area is characterized by large seasonal variations in temperature and rainfall. During winter, the daytime high temperature ranges from 7°C to 20°C. In summer, from May to August, the weather is extremely hot with daytime high temperatures rising to 20-40°C. Although, the rainfall is markedly variable in magnitude, seasonality and its spatial distribution (Khan and Muhammad, 2000), it contributes significantly in meeting crop water requirements. The mean annual rainfall and reference evapotranspiration are 460 and 1625 mm, respectively. While comparing the cropping season with the climate season, it appears that the critical initial months of both the cropping season are practically devoid of rainfall. The supply of canal water is usually less than residual crop water requirements, which has prompted more and more farmers to groundwater to make up the remaining shortfall, and groundwater extractions are about 4.9 BCM in the study area.

Irrigation water use from different sources by types of landholders is presented in Table 1. Groundwater use (alone or conjunctively with canal water) is more than 50 percent in all types of landholders, however large landholders use more groundwater as compared to small and medium landholders since they can afford to have their own tubewells or purchase the services of tubewells from their neighbours. Thus, the distribution of benefits from groundwater irrigation in the society is not equitable. The current practices of groundwater extraction and its use have favoured the rich at the cost of poor. However, if well installation and operational costs are reduced, nearly all farmers will have their own tubewells. Skimming wells can offer such incentives. Therefore, developing cost-effective and technically feasible design and operational management strategies for skimming wells, is one way of ensuring equitable distribution of benefits from groundwater irrigation among the farming community.

MATERIALS AND METHODS

A GIS-based spatial analysis was carried out to classify deep groundwater quality zones in the study area. The marginal or hazardous groundwater quality zones, which cover around fifteen villages in the study area, were anticipated to have fresh groundwater lenses resulting from deep percolation of irrigation and rainfall waters. From these identified villages, six different sites (two in SCARP-II saline zone, and four in SCARP-II non-saline zone) were selected to carry out the Diagnostic Analysis (DA). The DA used resistivity survey, bore logs (to a depth of 75m), water quality sampling from hand pumps, and shallow wells to investigate salinity and hydro-geological conditions of the aquifer. These investigations confirm the presence of fresh groundwater lenses overlying the saline groundwater and in estimating the thicknesses of these fresh groundwater lenses, groundwater quality at different aquifer depths, and the aquifer composition.

A farmer owned sixteen-strainer skimming well was monitored from June 2000 till December 2001 to study its hydraulic performance and hydro-salinity behaviours under different pumping regimes. In this well, each strainer had 6.7m of screen length, and well penetration ratio was estimated to be equal to 60% of the fresh groundwater lens. The horizontal distance of strainers from suction point varies from 1.5 to 4.6m. For 74% of the times of observed tubewell operations, this well was operated between 2-8 h/d. A schematic diagram of the observed skimming well is shown in Figure 3.

The MODFLOW and MT3D models (Chiang and Kinzelbach, 1996) were calibrated for the Chaj doab conditions (Asghar et al. 2002) and used to study the effect of different penetration depths, operational hours and discharge rates on the quality of pumped groundwater. For model simulations a spatial domain 89m x 89m was divided into 23rows and 23 columns, with each cell of 3.9x3.9m. The vertical domain of 100m was divided into nine layers of variable thickness to accommodate groundwater quality profile, and to allow for simulation of the different well penetration ratios. No flow boundary condition was considered on the sides and the bottom boundaries. The top layer was considered unconfined while other layers were considered convertible between unconfined and confined depending upon the aquifer hydraulic conditions. The multi-strainer skimming well was represented as a single well point in the centre of the simulation network.

The values of horizontal hydraulic conductivity, vertical hydraulic conductivity, and specific yield of the aquifer were taken as 30 m/day, 20 m/day, and 0.4 (-), respectively. For the MT3D, the best-fitted values of the longitudinal, horizontal transverse, and vertical transverse dispersivity were taken as 1.89, 0.378, 0.378m, respectively. The value of the effective porosity of the aquifer was set equal to 0.4 Kemper *et al*. (1976). The initial depth to water table was taken as 1.5m. The initial thickness of fresh groundwater lens was 30m for relatively thick lenses, and 20m for thin lenses.

The operational strategies and resulting quality of skimmed groundwater optimized by MODFLOW simulations were tested for their long-term effects on crops and soil degradations. Soil-Water-Atmosphere-Plant relationship (SWAP) model (van Dam et al. 1997) calibrated by Sarwar et al. (2000) was used for this purpose. SWAP is a one-dimensional model to describe transient water flow and solute transport in a heterogeneous soil root system, which can be under the influence of groundwater. Root water extraction at various depths in the root zone is calculated from potential transpiration, root length density and reduction due to water and/or salinity stress in the root zone. Irrigation applications can be prescribed at fixed intervals or user may choose various irrigation timings, depth and water quality.

A farmer’s field measuring 0.4 ha was extensively monitored from July 2002 to April 2003 to gather information regarding irrigation applications, sowing and harvesting dates, groundwater pumpage and other agronomic parameters needed for model application. Maize-wheat cropping pattern was used for simulation, as these are the dominant crops of the study area. Maize is usually sown during the months of July-August to meet the fodder demands for their animals, while wheat is sown during October-November after the maize harvest. The groundwater table, which fluctuated in the range of 1.5 to 4.0m, was used as bottom boundary condition. The upper boundary condition was dependent on daily evapotranspiration rate, actual rainfall, and irrigation. The soil profile was taken as 480 cm and was divided into three soil layers for model application. The soil hydraulic properties of these three layers were defined by van Genuchten and Mualem (VGM) parameters (van Genuchten, 1980) and were adapted from Sarwar et al.

(2000). The details of input parameters used for model simulations are given in Table 2. Long-term simulations were performed for a period of 15 years, as daily rainfall, maximum & minimum temperatures, sunshine hours and wind speed were available from the study area.

RESULTS AND DISCUSSION

Evaluation of farmers' current practices regarding the design and operation of skimming wells

The results of Participatory Rural Appraisal (PRA) and field surveys conducted in the study area revealed that the major factors contributing to the popularity of skimming wells among farming community include: (i) availability of locally manufactured material, (ii) availability of local expertise for drilling, installation and maintenance, (iii) shallower depths to water table that helps use centrifugal pumping units, (iv) technically simple as compared to other groundwater extractions technologies, and (v) economics and affordability. The deterioration of water quality and reduction in well discharges over time were identified as major problems. Due to absence of any design code in the area, every skimming well in the area was different than the others in term of depth of skimming wells, number of strainers and horizontal distance of strainer from suction point. The depth of skimming well in the area ranges between 9 to 27 m and the number of strainers varying from 2 to 26. The results of modeling simulations revealed that initially discharge rate increased considerably with the increase in number of strainers. However, after 6 strainers the increase in the discharge rate was marginal (Figure 4). This shows that farmers could reduce number of strainers to a maximum of 4-6 without reducing the discharges. This will not only reduce the initial installation costs but will have a significant impact on the operational costs.

The horizontal distance of strainers from suction point was found to be between 1.5 to 4.5 m (Figure 3). The common perception of farmers and well drillers in the area was that well discharge increases with the number of strainers. It was also believed that putting all strainers at equal distance from suction point would reduce the well discharges. Therefore most of the skimming wells in the area are installed on the recommendations of local drillers rather than suitability of hydro geological conditions.

Evaluation of the performance of farmers' existing skimming wells

Figure 5 shows the changes in the quality of pumped groundwater as observed in the field during the period from October 2000 to July 2001. The water table tends to decline as the recharge due to rainfall and percolation from irrigation fields was minimal. As a result, quality of the pumped groundwater also deteriorated. From July onwards water table started rising and pumped groundwater quality was improved. This was mainly due to excessive recharge from the monsoon rains. This shows that percolation from rainfall is an important parameter that improves the quality of pumped water from skimming wells installed in the shallow fresh groundwater aquifers underlain by saline groundwater. Therefore restricting pumping from skimming wells during dry periods (April-July) when recharge is low and chances of water quality degradation are high could be a better management strategy for controlling saline groundwater upconing. This is practically feasible as after harvesting of wheat crop in April, fields are usually kept fellow till the sowing of maize in July-August. This intermitted pumping could be a good strategy to control groundwater quality and sustain crop production.

Pumping test were also carried out in the field using sixteen strainer skimming well to study the impact of daily operational hours on pumped water quality and discharge rate and the results are presented in Figure 6. The discharge rate of this skimming well was 28 l/s during the first hour of operation, which was reduced to 26.6 l/s after second hour of operation. With the increase in daily operational hours from 2-12, the pumped water quality deteriorated three fold, and the discharge rate reduced from 26.6 to 19 l/s. This equals to 30 percent reduction in discharge rate when compared with the first hour of operation. Figure 6 clearly demonstrates that in the conditions considered, operating skimming wells from 4-6 hour per day will keep the pumped water quality between 1.0 to 1.2 dS/m while reduction in well discharge will be 15-20%. Increased operational hours can cause drastic reductions in well discharges and a quantum drop in the quality of pumped water. Therefore operational hours of skimming wells installed in the thin fresh groundwater aquifer areas should be restricted to ensure long-term sustainability.

Evaluation of the impact of different operational strategies of skimming wells on aquifer behavior

The calibrated MODFLOW model was also used to study the effect of different discharge rates, daily operational hours and operational strategies on quality of pumped groundwater. The simulations were performed for the aquifers having thin layers (< 38 m) of fresh groundwater underlain by saline groundwater. The summary of simulation runs is given in Table 3.

Figure 7 shows the impact of different discharge rates on the salinity of pumped water. The simulations were performed for one year using calibrated MODFLOW model. The pump was operated for two hours after every week. Weekly irrigation schedule was preferred to comply with the 7-day fixed rotational canal water distribution system called 'warabandi'. This system is widely practiced in the study area to ensure equitable distribution of scarce canal water supplies to all farmers located in a specific canal comand area. This system allows each farmer to take an entire flow of the watercourse once in seven days and for a period proportional to the size of his land holding. As water duty is insufficient, groundwater is usually pumped to supplement canal water supplies.

The simulation results indicate that for the well discharges of 4-8 l/s, the increase in the salinity of the pumped water was marginal. The increase in salinity of pumped water was 1.5 to 1.8 dS/m after 1 year of well operation. However, discharges of 16-28 l/s increases the salinity of the pumped water to over 2.0 dS/m in just two months of well operation. Farmers in the area generally operate their well at 16-24 l/s discharges to generate sufficient flow to irrigate their fields using surface, irrigation methods. This has been one of the major seasons for the failure of most of the skimming wells in this area.

The effect of daily operational hours on the quality of pumped water is shown in Figure 8. In these simulations, each pump was operated after every week to extract 8.0 l/s. The results depicted that restricting well operation to a maximum of 4 h/d can control the saline groundwater upconing. The higher daily operational hours, even following the weekly operational schedule, could degrade the fresh groundwater resource resulting from saline groundwater upconing.

The effect of operational schedule on the quality of pumped water is shown in Figure 9. These results are based on 8 l/s well discharge with a maximum of two hours pumping every week. The results indicate that increasing the time between two consecutive pumping will have a positive impact on the quality of pumped water as it provides more time for aquifer stabilization. Although increasing the duration to 2-3 weeks can further help in maintaining the quality of pumped water, it might not be practically feasible for farmers due to continuous water demand of crops.

Based on the results of model simulations, two operational strategies were considered safe for skimming wells in this area as given in Table 4. In the first strategy the maximum irrigation application depth will be 15 mm while for the second strategy, it can increase to 30 mm. The average irrigation depth applied by farmers using surface irrigation method is about 40 mm. Therefore when skimmed groundwater will be used in isolation for irrigation, surface flooding method will not be suitable therefore pressurised irrigation systems should be preferred. For this study, a raingun system was used for irrigation with the skimming wells. However when skimmed water is used in conjunction with the canal water, surface irrigation methods can also be used for irrigating field crops.

Evaluation of long-term effects of skimmed groundwater use on crops and environment

The interactions of irrigation (skimmed groundwater and canal water) with crop production and soil salinity were studied under actual field conditions. Five irrigations were applied to a maize crop, out of which three irrigations were from canal water using basin irrigation system, and two irrigations were applied through raingun sprinkler system using skimmed groundwater. Wheat received a total of six irrigations: three irrigations from canal water , and three irrigations using skimmed groundwater. During these irrigations to maize and wheat crops, the average depth of canal water applied was around 40 mm; whereas an average depth of skimmed groundwater applied using raingun sprinkler system was 15 mm. The salinity of canal water and skimmed groundwater used for irrigations was around 0.3 and 1.3 dS/m, respectively. Irrigation schedules for wheat and maize together with the source of irrigation water followed by farmers and used for SWAP simulations are given in Table 5.

A set of simulations was carried out to evaluate the consequences of farmers' current irrigation practices on crops and soil salinity and the results are presented in Figure 10. The EC_e values represents the average root zone salinity calculated over a 1.0 m deep root zone. The root zone salinity during the maize season remained below 2.0 dS/m. This can be attributed to sufficient leaching during this period due to excessive monsoon rains. The relative transpiration (ratio of actual transpiration over potential transpiration: Ta/Tp) for maize was 0.96, which means that crop did not suffer from water or salt stress. However, this was not the case for the subsequent wheat crop where soil salinity remained below 2.0 dS/m for initial and middle stages of the crop but markedly increased to 6.0 dS/m in the late growing stage. This shows that the water applied through irrigation and rainfall to wheat was not enough to provide adequate leaching of salts from the root zone. As plants are constrained in their capacity to extract water from roots under highly saline conditions, the relative transpiration of wheat was reduced to 0.88 (12% yield reduction as compared to potential). This suggests that for sustainable crop production in these areas, farmers need to calculate their irrigation and leaching requirements more carefully.

Figure 11 shows the long-term effects of farmers' current irrigation practices on crops and soils. The results indicate that continuation of farmers' current irrigation practices could lead to serious land degradation and crop growth problems due to salinity build up particularly in below average rainfall years. Therefore farmers need to adjust their irrigation schedules every year on the basis of crop evapotranspitaions, precipitation and salinity situations of the soil profile. This is essential to sustain crop production in these areas where canal water supplies are not sufficient and availability of fresh groundwater is very limited.

A second set of simulations with the calibrated SWAP was carried out to evaluate the long-term effects of two operational strategies optimized by using MODFLOW (Table 3) on crop production and development of soil salinity. The modeling results reveal that the deviations in annual precipitations from an average year are critical to maintain equilibrium between different water and salt balance components. Figure 12 indicates the impacts of long-term use of skimmed groundwater through pressurised sprinkler system on crops and soil salinity. The results suggest that farmers could keep the salinity levels in the root zone below 4 dS/m if they apply 15 mm of sprinkler irrigation after every week to maize and wheat. The ratio of Ta/Tp based on 15 years average for this scenario was estimated to be 0.82 for maize and 0.96 for wheat. The reduction in maize yield was higher than wheat because maize starts facing salinity stress around 2 dS/m whereas wheat can tolerate salinity levels up to 6 dS/m.

Similar results were obtained for strategy II. This strategy also allows farmers to irrigate their fields using surface irrigation methods. Both of these scenarios showed good response to relatively dry years. The slight build up in salinity during dry years was compensated in the subsequent average and above average rainfall years. Therefore on long-term basis, crop production will be sustained due to availability of acceptable quality of groundwater for irrigation.

In the areas where periodic water shortages are experienced and access to groundwater is also limited as in the case of major parts of the Indus basin, the decision of which irrigation strategy to choose should not be a question of which schedule will maximize the crop production, but rather of which one will optimize crop production in a sustainable way within the available water supply and management capacity. The simulation results clearly indicate that in the present water deficient environment of the Indus basin, farmers need to do precise calculations of their irrigation and leaching requirements to halt environmental degradation and foster crop poroduction.

CONCLUSIONS

1. The farmer's present practices regarding design, operation and use of skimmed groundwater are not consistent with the hydro-geological conditions prevailing in the study area. The continuation of these practices could lead to serious land and aquifer degradation problems that can threaten the long-term sustainability of irrigated agriculture in this area.

2. Skimming wells should mainly be used for supplemented irrigation rather than full-scale irrigation with surface irrigation methods. Due to low discharges of skimming wells, pressurised irrigation methods are preferred for irrigating field crops with the skimmed water.

3. To sustain crop production, reduce soil salinity hazard and prevent aquifer degradation, well discharge of 8 l/s with 2 hours per day operation after every week will be the best management strategy for this area. By adopting this strategy long-term availability of groundwater of acceptable quality can be ensured, which is an essential element for sustaining crop production. Weekly operational schedule of skimming wells is in concurrence with the existing 7 days canal water distribution cycle therefore it will be much more practical for farmers.. This schedule can maintain near optimal crop yields without compromising on environmental sustainability.

4. Farmers need to adopt better management strategies for the use of available water resources (quantity and quality) to overcome problems of land degradation and consequent crop yield reductions. Relevant extension agencies should play a more active role in educating farmers by introducing the research results to the farming communities.

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Workshop Recommendations

A large research project, Root Zone Salinity Management Using Fractional Skimming Wells with Pressurized Irrigation, was conducted by the International Water Management Institute (IWMI) in the Punjab Province, and successfully completed in year 2003. A valuable conclusion from the project, as recommended by more than 100 participants at the project final workshop, was that the skimming wells technique as a tool for sustainable groundwater extraction would have a broad room to be extended in the country for better groundwater management.

To explore such application feasibility, the National Drainage Program (NDP) asked IWMI Pakistan to plan another project on 'Assessment of Hydro-Geological Potential of Skimming Wells In The Lower Indus Basin of Pakistan'.

In the Lower Indus Basin, groundwater aquifers are a mixture of fresh and saline water layers, given the marine aquifer origins, hydro-geologic formations, and limited rainwater but sizable irrigation percolation. Sustainable abstraction of valuable freshwater without disturbing the saline aquifer by using proper pumping technique represents a major challenge in Sindh water management. There are around 10,000 tubewells installed in Sindh. A large portion of them, however, is not in operation because of the saline quality of the water. Upward salt movement by groundwater pumping causes troubles for farmers in well water use. The skimming-well technique would find the best application in the province. However, do Sindh farmers welcome, and know, the technique, and what is needed guidance in field to extend the application? These questions were recommended for the project design on the Lower Indus Basin.

Based on the identified questions, the proposed project objectives were defined as:

1. To delineate (and map using GIS-RS) areas suitable for skimming wells while estimating (spatially and temporally) the thickness of fresh groundwater lenses above the underlying native saline groundwater layers; and

2. To understand farmers' perceptions regarding the social acceptability; economic viability; and potential for use of skimming wells in saline groundwater areas having different hydro-geological and hydro-salinity conditions.

Workshop Program

Thursday, June 26, 2003, Islamabad

09:30 – 09:35	Recitation from the Holy Quran
09:35 – 09:55	Welcome Address
	Dr. Asad Sarwar Qureshi, Acting Regional Director IWMI
09:55 – 10:10	Introduction of National Drainage Program (NDP)
	Mr. Hasnain Afzal, Chief Engineer, NDP
10:10 – 10:20	Introduction of Research Component of NDP
	Dr. Th. M. Boers, Chief Research Advisor, NDP
10:20 – 10:30	Inaugural Address by the Chief Guest
	Mir. Khalid Ahmad Khan Lund, State Minister for Water and Power
10:30 – 11:00	Tea Break
11:00 – 13:00	Session 1: Development of Skimming Well Technology
	Chair: Mr. Hasnain Afzal, Chief Engineer NDP
11:00 – 11:30	Conceptual Frame Work and Project Overview
	Dr. Asad Sarwar Qureshi, Acting Regional Director IWMI
11:30 – 12:00	Site Selection Methodology
	Mr. M. Yasin, Principal Scientific Officer, WRRI
12:00 – 12:30	Skimming Well Technology for Relatively Thick Groundwater Lenses
	Dr. M. Nadeem Asghar, Senior Agricultural Engineer, IWMI
12:30 – 13:00	Skimming Well Technology for Shallow Groundwater Lenses
	Dr. M. Mehboob Alam, Project Director, MREP
13:00 – 14:00	Lunch Break
14:00 – 16:00	Session 2: Management of Root Zone Salinity using Skimmed Water
	Chair: Dr. Zahid Hussain, Director WRRI
14:00 – 14:30	Sprinkler Irrigation System using Skimming Groundwater
	Mr. M. Yasin, Principal Scientific Officer, WRRI

14:30 – 15:00	Trickle Irrigation System using Skimmed Groundwater
	Dr. M. Munir Ahmad, Senior Engineer, WRRI
15:00 – 15:30	Irrigation Scheduling for Root Zone Salinity Management using Skimmed Groundwater with Pressurized Irrigation
	Dr. Asad Sarwar Qureshi, Acting Regional Director IWMI
15:30 – 16:00	Tea Break
16:00 – 17:20	Session 3: Lessons Learned & Way Forward
	Chair: Dr. Th. M. Boers, Chief Technical Advisor NDP
16:00 – 16:20	Discussion Agenda
	Dr. Asad Sarwar Qureshi, Acting Regional Director IWMI
16:20 – 17:20	General Discussion and Formation of Recommendations for Future Follow up of this Study

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89 Rainmakers

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90 Dr. M. Mehboob Alam

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94 Mr. Wali Ullah

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96 Dr. M. Nadeem Asghar

Senior Agricultural Engineer

97 Mr. Abdul Hakeem Khan

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IWMI-Field Officer

Gohati

Skimming Well Driller

98 Local Driller, Bhalwal

99 Local Driller, Sargodha

Farmers

15 Farmers