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Root Zone Salinity Management Using Fractional Skimming Wells with Pressurized Irrigation

Inception Report

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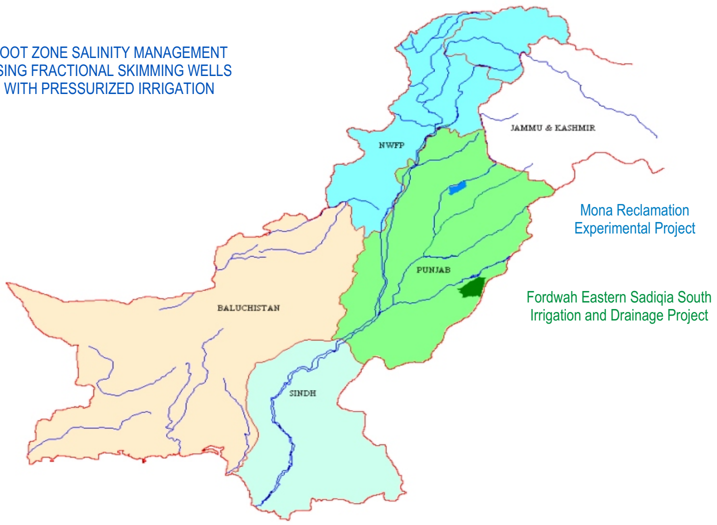

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In the short water supply environment of Pakistan, farmers try to minimize the gap between demand and supply of canal water extracting groundwater for irrigation purposes. However, saline groundwater upconing may occur in response to fresh groundwater 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 application systems use small discharge effectively, but the cost and availability of equipment in the local market is a significant constraint. 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) of National Agricultural Research Centre (NARC), and Mona Reclamation Experimental Project (MREP) of Water and Power Development Authority (WAPDA) are collaborating to undertake an applied research Project on *Root Zone Salinity Management Using Fractional Skimming Wells with Pressurized Irrigation*. This project is funded by the World Bank through WAPDA under the Research Sub-Component of the National Drainage Program (NDP). The duration of the project is three years March 1999 – February 2002.

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1 INTRODUCTION

This Inception Report provides information and progress of the activities of the project entitled, "Root Zone Salinity Management Using Fractional Skimming Wells With Pressurized Irrigation". Details of the implementation plan covering methodology, technical interventions and field research studies are included in this report.

1.1 BACKGROUND

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 (Wirojanagud and Charbeneau, 1985; Gupta and Gaikwad, 1987; Sarma et al., 1987 and Motz, 1992). Examples of brackish groundwater intrusion are most numerous in coastal aquifers, but are sometimes present in inland aquifers as well (Dagan and Bear, 1968**;** Schmorak and Mercado, 1969; Reilly and Goodman, 1980; and Rushton, 1980). Probably, the most important example of the latter case exists in the Indus Basin (Wang, 1965; and McWhorter, 1980).

The Indus basin irrigation system has caused the disruption of the hydraulic regime due to seepage from the 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 was salty because of the underlying geologic formation being of marine origin. Now, this native salty groundwater is overlain by fresh groundwater due to seepage from rivers and canals of the Indus basin irrigation system. Thus, shallow fresh groundwater zone occurs between the native pre-irrigation and the present day water tables (Sufi and Javed, 1988; and Sufi, et al., 1992 and 1997).

Near the rivers and canals, the fresh surface water seepage has improved the quality of the native groundwater to 120 to 150 meters depth. However, in some areas, the thickness of the shallow groundwater zone ranges from less than 60 meters along the margins of *Doabs* (area enclosed between two rivers) to 30 meters or more in the lower or central parts of *Doabs* (Zuberi and McWhorter, 1973; and Sufi and Javed, 1988). Figure 1 shows the groundwater salinity to a depth of 110 meters in the Upper Indus Basin (Ghassemi et al., 1995 and Qureshi and Barrett-Lennard, 1998).

Recently, it has been estimated by NESPAK (1983); Sufi (1987) and Sufi et al., (1992) that nearly 200 billion cubic meters of fresh groundwater (mostly in the form of a thin layer) is lying on salty groundwater. Obviously, if proper technology is applied, the referred thin fresh groundwater layer can be skimmed from the aquifer with minimum disturbance of the salty groundwater zone. In the short water supply environment of Pakistan, such extractions would become a significant part of supplemental irrigation.

1.2 FRACTIONAL SKIMMING WELL TERMINOLOGY

The terminology of the fractional skimming well have been adapted from Wang (1965); Sahni (1972); Kemper, et al., (1976); McWhorter (1980); Sufi and Javed (1988); Chandio, and Chandio, (1992); Joginder, et al., (1992); and Mirbahar, et al., (1997) and presented as under:

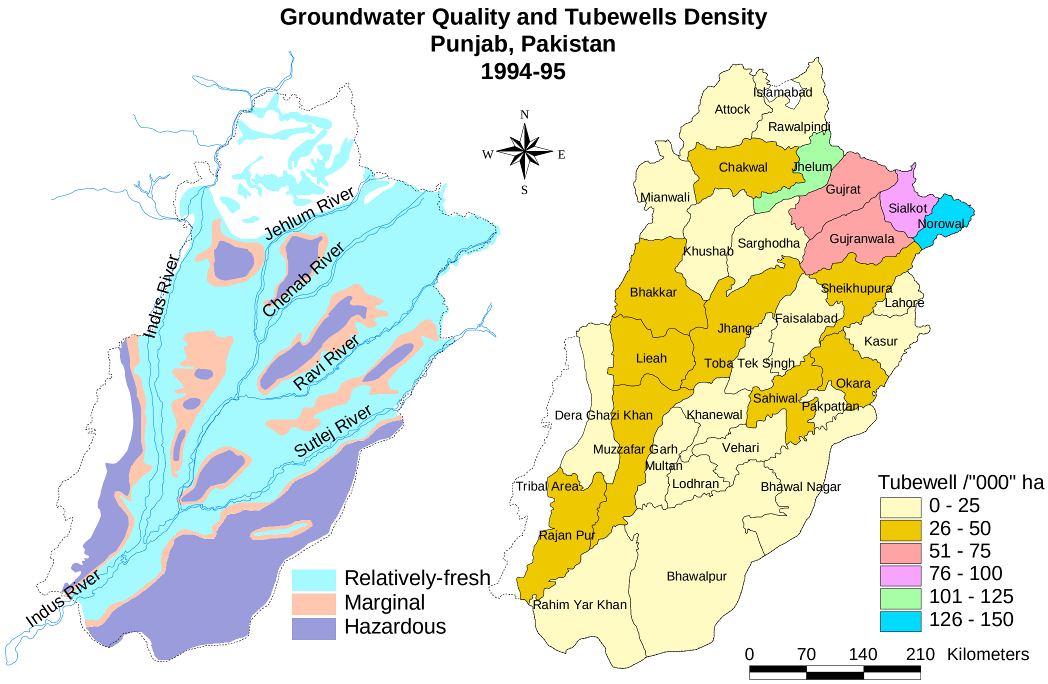

Figure 1. Shallow groundwater quality and tubewell density in the Upper Indus Basin.

Skimming: The recovery of fresh water overlying salty groundwater from the aquifer with effective designs if well.

Fresh and salty groundwater interface: There is no specific definition available for the interface between the fresh and the salty groundwater. However, this interface may be defined by using the irrigation water quality criteria proposed by USDA (1954) and WAPDA (Table 1). Thus, in this study, fresh and salty groundwater interface is defined while considering the salinity and sodicity of the groundwater and the criteria defined by USDA and WAPDA (Table 2).

Table 1. Irrigation water quality criteria.

United State Salinity Laboratory Staff, USA (USDA, 1954)			
	Fit	Marginally Fit	Unfit
ECe (dS/m)	< 1.0	1 - 1.25	> 1.25
RSC (meq/l)	< 1.25	1.25 - 2.25	> 2.25
SAR $(mmol/l)^{0.5}$	< 6.0	6 - 10	> 10
WAPDA, Pakistan			
ECe (dS/m)	< 1.5	1.5 - 2.7	> 2.7
RSC (meq/l)	< 2.5	2.5 - 5.0	> 5.0
SAR $(mmol/l)^{0.5}$	< 10	10 - 18	> 18

Table 2. Groundwater quality definitions used in this project.

	Fresh Groundwater	Fresh and Salty Groundwater Interface	Salty Groundwater
ECe (dS/m)	< 1.0	1.0 - 2.7	> 2.7
RSC (meq/l)	< 1.25	1.25 - 5.0	> 5.0
SAR $(mmol/l)^{0.5}$	< 6.0	6.0 - 18	> 18

Upconing: The salty groundwater rises in the shape of a cone due to the reduced head near the well when a partially penetrating well pumps fresh groundwater overlying salty groundwater. This rising of salty groundwater in the shape of a cone is called upconing.

Optimum penetration depth of a fractional skimming well: This is a designed penetration depth of a well into the fresh groundwater layer that permits maximum discharge without intrusion of the salty groundwater.

Fractional skimming well arrangement: This is a pumping facility designed to exploit the relatively fresh groundwater layer overlying salty groundwater. This arrangement might have four options: i) multi-strainers fractional well; ii) scavenger well (very similar to compound wells tested by Kemper et al., 1976 at the Mona Reclamation Experimental Project with limited success); iii) radial collector well using suction or gravity; and iv) dugwell using seepage.

- **Multi-strainers fractional skimming well**: This is one of the most commonly used fractional skimming well technique that comprises of multi-strainers penetrated to an optimal depth above interface of the fresh and salty groundwater. For the skimming of thin fresh groundwater underlain by salty groundwater, a low capacity (6 to 9 liters per second) fractional skimming well was tried in the MREP AREA. The effect of groundwater pumping by using a single strainer fractional well on the salty groundwater upconing phenomenon was studied. Based on the preliminary findings, the researchers were encouraged to increase the number of strainers on the fractional skimming wells to skim relatively fresh groundwater with higher discharge rates (as much as 28 liter per second). In this way, the multi-strainers fractional skimming wells can serve more than one farmer and hence, the setup has a good potential to replace the existing tubewells in the private sector.
- **Scavenger well**: Another fractional skimming well arrangement used for simultaneous pumping of fresh and salty groundwater from the relevant layers of an aquifer. This well has a single bore hole with separate intakes (or bore hole located very near to each other) for fresh and salty groundwater but the pumps are usually connected with one power source. This technique aims at maintaining the original position of the fresh and salty groundwater interface. Already, several Scavenger wells have been installed in the Sindh province, but their impact on the fresh and salty groundwater interface is yet to be documented.
- **Radial well**: This technique is considered suitable for exploiting a thin fresh groundwater layer that otherwise is difficult by means of vertical wells as they cause upconing of salty groundwater. Under such conditions, the thin fresh groundwater layer groundwater can be recovered by radial

collector wells using suction or gravity. The idea of radial wells for skimming fresh groundwater seems an attractive option, but its costs and the efforts required to have such a facility in place may not be very helpful. An agro-economic evaluation for the tile drainage project conducted by Gaffar et al., (1993) reveals that the estimated benefits are lower than the estimated costs of 0.276 million rupees. However, the project becomes economically feasible if surplus water from the tile drainage system is utilized to irrigate an additional 4.5 hectares. Thus, if the implementation of radial wells is coupled with existing or future tile drainage programs along with the pressurized irrigation application systems, its success could augment surface supplies for almost 30 percent of the irrigated area of Pakistan.

- **Dugwell**: This technique is also considered particularly suitable for exploiting a thin fresh groundwater layer that otherwise cannot be done by means of vertical wells. Under such conditions, the thin layer of the fresh groundwater can be recovered by dugwells using seepage. Furthermore, dugwell provides a cost-effective option for skimming of fresh water.

1.3 NEED OF THE STUDY

The explosion of pumping technology in the private sector, high capacity tubewells of more than 28 liter per second discharge are being installed even in the thin fresh groundwater zones (Table 3). In such zones, these tubewells are likely to draw a substantial portion of their discharge from the salty 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 Punjab, Pakistan. The exception would be tubewells located adjacent to rivers and large canals where large quantities of seepage are recharging the groundwater reservoir.

Table 3. Tubewell capacity definitions based on the discharge rates.

Discharge capacity	Discharge Rates (liters per second)
Low	< 9
Medium	9 - 28
High	> 28

Thus, if such tubewells are not replaced with fractional skimming wells, there is a serious concern that the pumped groundwater will become increasingly salty 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 salty (saline, saline-sodic or sodic) with time (Hafees et al., 1986). 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 technology to address these future concerns.

1.4 THE PROBLEM

In the above given context, the main issues which come to surface are as follows:

- Saline water upconing in the middle of *Doabs* in the Indus Basin is a serious concern because of uncontrolled groundwater exploitation in both the private and public sectors;

- Fractional skimming well and dugwell technologies can help to skim the shallow fresh groundwater but, in most cases, the small discharges (6-9 l/s) of such wells cannot be efficiently applied on surface irrigated croplands;
- Pressurized irrigation application systems can use such small discharges effectively, but their cost and availability of the needed equipment in the local market is a significant constraint; and
- Irrigation with skimmed groundwater, the root zone salinity is expected to increase in the absence of proper salinity management.

1.5 RESEARCH QUESTIONS

The research questions that can be addressed in this project are:

- What are the design and management parameters of the fractional skimming well technology that affect the upconing of fresh and salty groundwater interface?
- How does the pressurized irrigation application systems help in uniform and efficient irrigation water application for root zone salinity management?
- How to manage root zone salinity for commonly grown crops, creeper-type vegetables and orchards?
- How irrigation scheduling advisory services can help farmers in managing root zone salinity?

1.6 OBJECTIVES

To address the selected research questions, the specific objectives of the project are:

1. Identify and test a limited number of promising technologies of fractional skimming well in the shallow fresh groundwater aquifers, which could control the salty groundwater upconing phenomenon as a consequence of pumping;
2. Encourage and support in-country manufacturers to develop low-cost pressurized irrigation application systems adaptable within the local setting of Pakistan, and;
3. Implement irrigation scheduling program aimed at root zone salinity management with skimmed fresh (in a relative sense) water applied by pressurized irrigation application systems.

2 THE PROJECT

For future exploitation and application of groundwater in irrigated agriculture of Pakistan, the Mona Reclamation Experimental Project (MREP), Water Resources Research Institute (WRRI) of the National Agricultural Research Center (NARC), and International Water Management Institute (IWMI) collaborated in launching the subject project. The main focus of this project will be to introduce packages of technology and management for addressing serious concerns related to the quantity and quality of groundwater in order to use fresh water resource on sustainable basis.

This research project is funded by the Water and Power Development Authority (WAPDA) of Pakistan through the Research Sub-Component of the National Drainage Program (NDP). This project aims at root zone salinity management with the participation of farmers by using technology and management packages. These technological and management packages will comprise the following components:

- Fractional skimming wells;
- Dugwells;
- Pressurized irrigation application systems; and
- Irrigation scheduling advisory services by using skimming source pressurized irrigation application systems.

2.1 PROJECT SITES

The project sites will be selected within the Fordwah Eastern Sadiqia (South) Irrigation and Drainage Project (FESS) and the Mona Experimental Reclamation Project (MREP) areas (Figure 2). These project areas have certain zones with fresh groundwater layer within 30 to 60 meters.

2.2 PROJECT JUSTIFICATION

The project aims at the management of root zone salinity for the field conditions that are mainly associated with the *center and lower part of Doabs* and other pockets of irrigated lands where similar conditions exist in the Indus Basin. These are the locations where ***exploitation*** and ***application*** of groundwater by using the traditional means is either not feasible or there is a serious concern that the ongoing practices will render the thin-layered fresh groundwater unusable in the very near future. But, with the application of appropriate skimming well technology, the fresh groundwater layer can be skimmed effectively from the aquifer. Furthermore, if this skimmed fresh (in a relative sense) water is applied by pressurized irrigation application systems, the root zone salinity can also be managed with the adoption of carefully designed irrigation scheduling program.

Thus, the proposed project will test a limited number of promising groundwater pumping, water application technologies and salinity management packages that will become increasingly more valuable over time as an alternative to conventional groundwater pumping, water application technologies and salinity management practices.

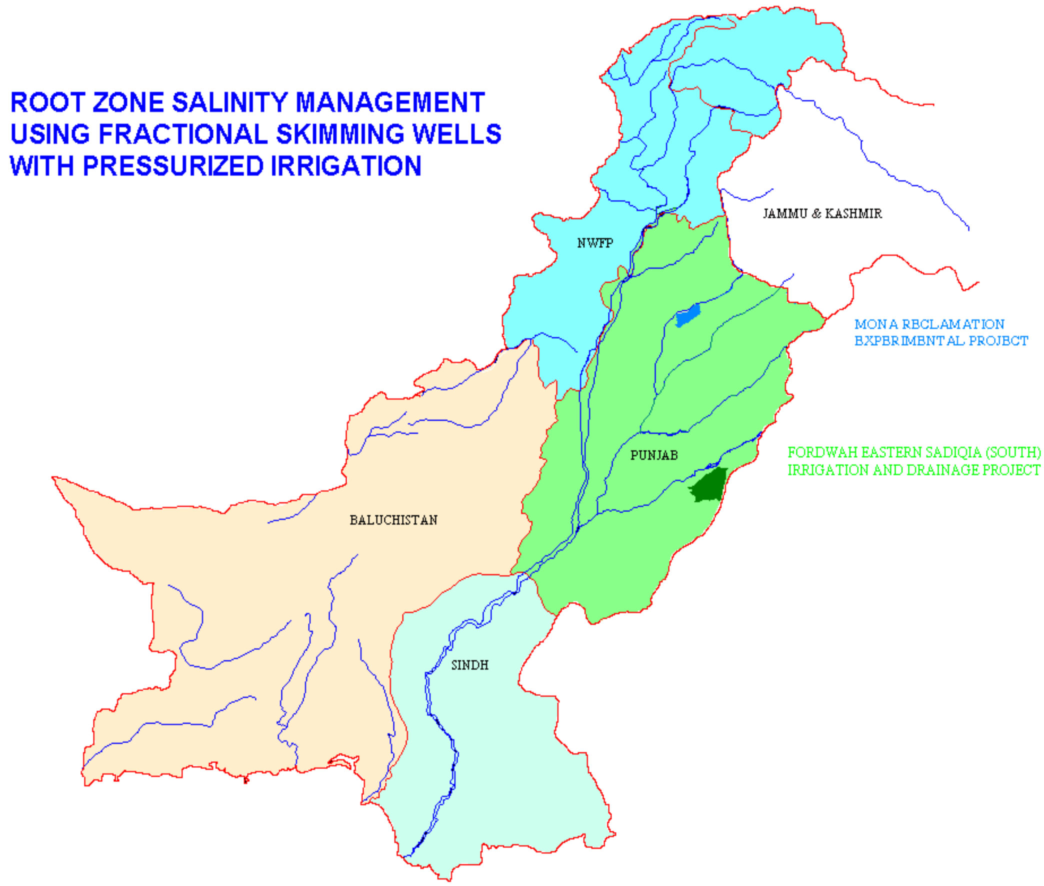

Figure 2. Location map of project sites.

2.3 THE INVOLVEMENT OF SELECTED IMPLEMENTING AGENCIES

The collaborating institutions include the MREP, WRRI and IWMI in undertaking the project. In the following given context, the tripartite arrangement would enable these institutions to develop practical and cost-effective technology for skimming well and application systems with a main focus being salinity management in the root zone.

The MREP has already developed initial methodology for skimming well technology and having a mandate to further refine the technology. The WRRI is the pioneering institution in the country that has commercialized the pressurized irrigation application system in collaboration with the local industry and worked with dugwells. Furthermore, WRRI is now actively engaged in other areas of groundwater research including energy efficiency. The IWMI has considerable research experience in the field and testing of irrigation scheduling, hydraulic and salinity simulations for managing root zone salinity under the irrigated agriculture areas in the Indus basin of Pakistan.

<u>Thus, the importance of this undertaking is enormous.</u>

2.4 RESEARCH STUDIES

The research studies designed in the project and other innovations/activities are presented in Table 4.

Table 4. Project management activities.

Activities
Project Management
Year 1: MREP AREA
Planning
Reconnaissance Survey
PRA
Selection of Site(s) and Farmer(s)
Diagnostic Analysis
Supportive Survey and Information Collection
Skimming well Installation and Development
Dugwell Development
Pressurized Irrigation system Installation and Development
Irrigation Advisory Services -Preliminary Framework
Farmers' Training
Software Activities
Monthly Progress Report
Quarterly Progress Report
Year-end Progress Report
Year-end Seminar
Year 2: MREP AREA
Research Studies
Supportive Survey and Information Collection
Skimming well Refinement and Installation
Dugwell Development
Pressurized Irrigation System Refinement and Installation
Irrigation Advisory Services Refinement
Farmers' Training
Software Activities
Monthly Progress Report
Quarterly Progress Report
Year-end Progress Report
Year-end Seminar
Year 3: FESS and/or MREP AREA(S)
Research Studies
Planning
Reconnaissance Survey
PRA
Selection of Site(s) and Farmer(s)
Diagnostic Analysis
Supportive Survey and Information Collection
Skimming well Installation
Dugwell Development
Pressurized Irrigation system Installation
Irrigation Advisory Services
Farmers' Training
Software Activities
Monthly Progress Report
Quarterly Progress Report
End-of-Project Final Report
End-of-Project Seminar

The year-by-year details of the interventions/activities are given later in this report. However, the details of research studies are as under:

2.4.1 Fractional skimming wells

Different scenarios will be simulated based on hypothetical and ground-truth data for designing fractional skimming wells with reference to fresh and salty groundwater interface movement while considering the following physical aspects:

- Spacing, diameter, penetration depth, configuration of perforated portion and number of strainer(s) for fractional skimming wells;
- Site specific hydraulic parameters of aquifer. This will help in generalizing the experience gained from different aquifer hydraulic characteristic sites regarding the performance of various fractional skimming well configurations; and
- Aquifer physiography. Depth of thick clay layer may affect in designing the penetration depth and position of the perforated portion of the strainer(s).

Different scenarios will be simulated based on the hypothetical and ground-truth data for evaluating various operational strategies for fractional skimming wells with reference to fresh and salty groundwater interface movement while considering the following aspects:

- Operational hours, and
- Equal/unequal discharge rates from different strainers. Different discharge rates combinations from different strainers will affect differently on the fresh and salty groundwater interface movement.

2.4.2 Pressurized irrigation application systems

Monitoring and evaluation of pressurized irrigation application systems based on:

- Hydraulic performance, and
- Water use efficiency.

Comparative performance of pressurized irrigation application systems based on the root zone salinity levels during the whole cropping season.

2.4.3 Root zone salinity management

Framework for preliminary irrigation scheduling advisory services will be prepared to manage root zone salinity by adopting pressurized irrigation application systems with fractional skimming well technology, based on the existing knowledge while considering the following:

- Quality of surface irrigation water;
- Variations in the root zone depth with time;
- Uniformity coefficient of irrigation application;

- Crop salts tolerance levels of root zone salinity during different growth stages for crops , creeper-type vegetables and orchards; and
- Quantity and quality of capillary groundwater contribution to the crop water requirements with different root zone and groundwater table depths.

This exercise of preparing framework for preliminary irrigation scheduling advisory services would guide in defining practical ways and means for managing root zone salinity under the field conditions.

- Irrigation scheduling advisory services will be redefined based on the monitoring, evaluation, comparative performance and computer simulation results of various tested pressurized irrigation application systems while using irrigation water of different qualities (with/without considering the quantity and quality of capillary groundwater contribution).

3 METHODOLOGY

3.1 SELECTION OF TARGET AREA

Three locations will be selected around the MREP area for initial reconnaissance survey. The criteria for selection of these locations during the initial reconnaissance survey would include:

- Proximity to the field area and accessibility for demonstration and dissemination of results;
- Farmers are in need of groundwater;
- Canal supplies and SCARP tubewell water are not sufficient to achieve the potential cropping intensity; and
- Groundwater table is not below 5m depth.

The joint team of MREP, WRRI and IWMI will conduct a reconnaissance survey to select three locations. Afterwards, two villages at each location would be selected for conducting a participatory rural appraisal (PRA). The methodology of rapid rural appraisal as proposed by Chamber et al., (1993) will be used. This would include interactive dialogue with the community at selected villages by the joint team of MREP, WRRI and IWMI. The tools like transect walk, Venn diagram, timeline, flow diagram in addition to visualization would be used.

At each location two villages will be selected in a way that they represent head and tail situations. Efforts will be made to avoid areas with extremes--too big landholdings and too small landholdings or areas having notables. For the conduct of the PRA, a checklist will be developed considering the following main elements:

- Households system (family size, landholding, livestock, livelihood sources, education, decision making, etc.);
- Resource availability (number of households; land owners, minimum, maximum and average land holdings; land tenure system; salt-affected land; cultivated land; number of tubewells; type of wells; groundwater quality; groundwater table depths; etc.);
- Agricultural productivity (crops, livestock, fisheries, cropping intensity, cropping pattern, crop yields, etc.);
- Resource use (water availability: canal water only, canal and tubewell water, only tubewell water--indicate number of farmers or area under each category; present use of waterlogged and salt-affected lands; etc.);
- Resource degradation (historical trends for rise in groundwater table; salt-build up; land salinization and sodification effects of SCARP; deterioration of groundwater; etc.);
- Constraints and problems faced by farmers and ranking of problems; and
- Farmers' perceptions regarding solutions and interventions.

The results of PRA and secondary data available from MREP and other sources will be used for final selection of the location. The selection criteria would include:

- Farmers' willingness to use groundwater to increase their cropping intensity and/or productivity;
- Farmers' urge to pump fresh groundwater to maintain soil health on long-term basis;
- Farmers' willingness to participate in the project activities and ready for O&M of the system;
- Availability of fresh groundwater layer preferably upper layers which are underlain by groundwater of marginal to brackish in quality; and
- Potential for technology transfer outside the nucleus of the Target Area.

3.2 DESIGN OF INTERVENTIONS

The results of the PRA for the selected locations will be used to list the interventions as stated by the community and its ranking. The joint survey team will re-visit the area for final presentation of the PRA results and finalizing the selection of the target area. Farmers of the two villages will be informed for the final selection of the Target Area.

The detailed diagnostic analysis will be conducted for the two selected villages for assessment of the state of land and water resources, their utilization and information for design of interventions. The elements of the diagnostic analysis are:

- Land holding;
- Cropping intensity;
- Availability of canal water (discharge, turn, volume);
- Groundwater use;
- Groundwater quality profile;
- Water table depth;
- Waterlogged and salt-affected area;
- If tubewell is not installed, farmers' willingness to install and sharing of cost;
- Farmers' perceptions about quality of groundwater, profile variability and willingness to use fractional skimming well;
- Farmers' interest in use of pressurized irrigation application systems;
- Farmers' interest for use of fractional skimming well or dugwell;
- Farmers' interest or perceptions for using irrigation for cooling and control of frost for citrus orchards using sprinkler irrigation in April-June and December to February, respectively.
- The results of PRA and diagnostic surveys in conjunction with secondary data will be used for the design of selected interventions.

3.3 SELECTION OF TARGET FARMERS

Based on the results of the PRA and diagnostic survey, one village will be selected and two farmers will be identified to initiate the project activities. More farmers will be added later. The MREP and WRRI in collaboration with IWMI will initiate the research activities selecting one farm each. MREP would take a lead on fractional skimming tubewell, whereas WRRI would take lead on a dugwell.

3.4 LAYOUT OF SELECTED FARMS

MREP and WRRI will initiate the topographic and *bunded* units maps of the selected farm. The survey would include the development of a base map. The *bunded* units maps will be used to document the Kharif 1998 and Rabi 1998-99 seasons crops, crop yields and cropping pattern.

3.5 SUPPORTIVE SURVEY AND INFORMATION COLLECTION

3.5.1 Soil and water sampling

After the development of the base map, composite soil samples from each field will be taken for analysis of pH, ECe, cations, anions, SAR and ESP. This will provide the baseline information for 0-15cm, and 15-30cm soil depths. Information on soil physical conditions covering texture, bulk density and infiltration would be collected. One observation well will be installed at each farm to collect groundwater samples. These samples will be analyzed for pH, ECe, cations, anions, SAR, RSC and ESP to document the groundwater quality profile. The design of the observation well is given in Figure 3.

3.5.2 Hydraulic properties determination

Hydraulic properties of soil (surface and subsurface) by point and composite measurements, and of the aquifer by pumping test analysis will be determined at the selected fields. The data needed for pumping test analysis include tubewell discharge (constant) and time-drawdown data (i.e., temporal and spatial data of the fall of water level in the observation wells). This analysis will also help in designing fractional skimming wells spacing while considering radius of influence of the well. Soil well logs will also be prepared at the selected fields.

3.5.3 Hydraulic and salinity behaviors estimation

The hydraulic and salinity behaviors of the aquifer against the induced discharges will be estimated. For this purpose, the aquifer’s inflows and outflows will be monitored with the help of piezometers and observation wells installed along the boundary of the study area. Furthermore, a network of piezometers and observation wells also be installed within the study area.

3.5.4 Supportive information collection

Inventory of the secondary data, review of the existing knowledge and collection of required information related to various components of the study; and general survey related to social, technical, and economic information in the project area.

3.6 SOFTWARE ACTIVITIES

Different scenarios will be simulated based on hypothetical and ground-truth data for designing and evaluating various operational strategies for fractional skimming wells with reference to fresh and salty groundwater interface movement.

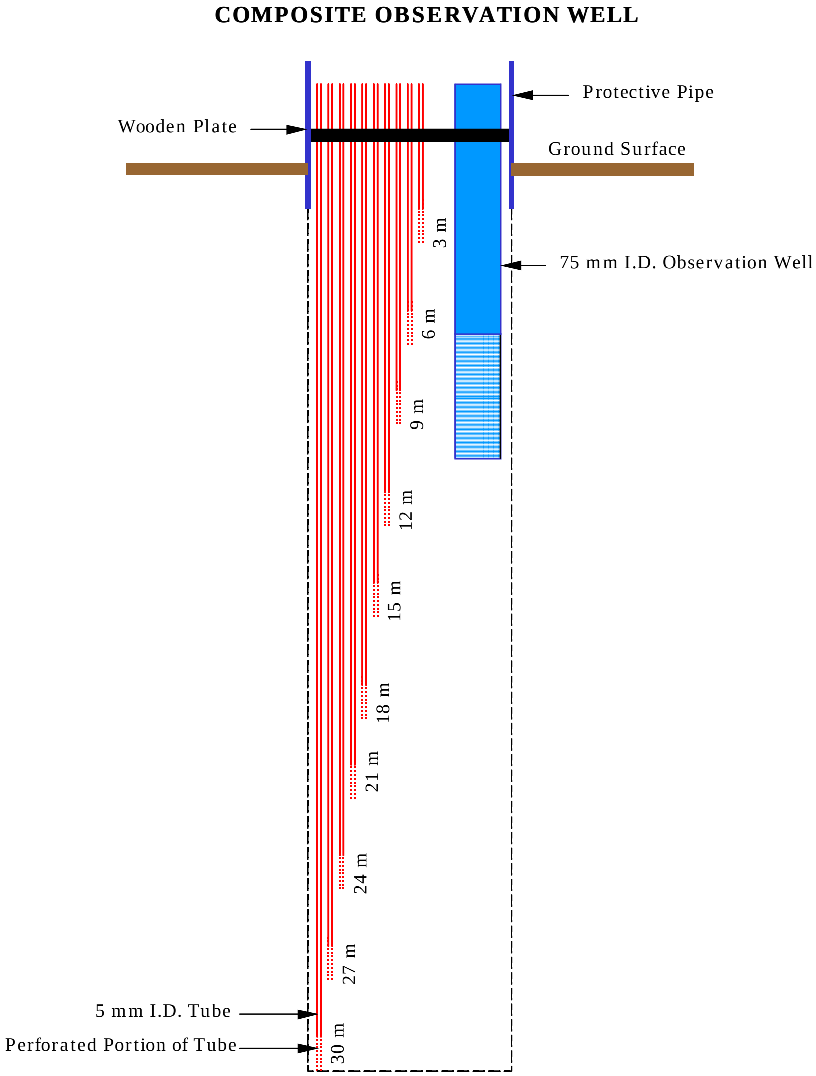

Figure 3. Design of an observation well.

4 YEAR-BY-YEAR INTERVENTIONS/ACTIVITIES

4.1 YEAR 1

I. Reconnaissance survey for selection of three locations having good accessibility, demonstrability, and potential for transfer of technology.

II. Select two villages at each location representing farmers interested in project activities.

III. PRA of six selected villages by joint interdisciplinary team for identification of ranked problems, ranked interventions as farmers' perceptions.

IV. Select two potential villages as Nucleus Target Area based on PRA results and secondary information available.

V. Diagnostic surveys to document type and extent of problem in relation to groundwater and root zone salinity.

VI. Select one village with higher potential based on PRA and diagnostic surveys.

VII. Select two most promising farmers as Nucleus Farmers to initiate the studies.

VIII. Supportive survey and information collection.

IX. Establishes field facility for fractional skimming tubewell with required options.

X. Establishes field facilities for dugwell with required options.

XI. Installation of pressurized irrigation application systems (For example, sprinkler irrigation for crops; and drip for orchards and creeper-type vegetables).

XII. Preparation of preliminary framework for irrigation scheduling advisory services.

XIII. Farmers' training in use of pressurized irrigation application systems, irrigation scheduling for these systems, etc.

XIV. Software activities using hypothetical data for simulation and management of fresh and salty groundwater interface under various fractional skimming well configurations.

XV. Year-end seminar.

4.2 YEAR 2

I. Field research studies related to fractional skimming well, pressurized irrigation application system, and root zone salinity management.

II. Refinements in the fractional skimming well; dugwell; and pressurized irrigation application system technology (techno-economic aspects), and management using available models and practical field experiences.

III. Further installation of systems on additional farms.

IV. Supportive survey and information collection.

V. Refinement in irrigation scheduling advisory services using available models and practical management strategies.

VI. On job training of farmers in O&M of systems and document problems faced in the use of systems for further fine tunings.

VII. Proposal for final tunings of systems and technology for introduction in FESS area.

VIII. Software activities by using hypothetical and ground-truth data for simulation and management of fresh and salty groundwater interface under various fractional skimming well configurations.

IX. Year-end seminar.

4.3 YEAR 3

I. Repeat Step I to XI and XIII, as laid down for year 1, for FESS and/or MREP area(s).

II. Field research studies related to fractional skimming well, dugwell, pressurized irrigation application system, and root zone salinity management.

III. Software activities by using hypothetical and ground-truth data for simulation and management of fresh and salty groundwater interface under various fractional skimming well configurations.

IV. Final workshop and reporting.

V. Proposal for follow-up actions and extension of activities.

4.4 PERFORMANCE INDICATORS

The project duration is not sufficiently enough to document the effects and impacts of skimming water on productivity and sustainability of selected farms. However, data would be collected for indirect analysis of addition of salts to the soil under skimming well and dugwell options. Furthermore, analysis will be made based on research data regarding the sustainability of groundwater quality profile. The performance indicators selected for the project are as under:

- Reduction in root zone salinity.
- Increased cropping intensity.
- Higher yields and increased quality of produce like *Kino*.
- Sustainability of groundwater quality profile.

5 PROJECT IMPLEMENTATION

The MREP, WRRI and IWMI will collaborate for the management and implementation of the activities under the present project. The roles of the three organizations and farmers are depicted in Table 5.

5.1 ROLE OF MREP

The Mona Reclamation Experimental Project (PREP) will provide development, monitoring, evaluation and dissemination support regarding fractional skimming well technology. The MREP will also give training to the farmers in efficiently and effectively using various fractional skimming well configurations. The project site during the first two years is located at the MREP, Bhalwal. Hence, the MREP has an additional responsibility to provide all necessary field support to other collaborating units. In general, the multi-disciplinary staff of all units of MREP will be involved in implementation of this project. However, more active and day-to-day support will be provided form the following four sections of MREP:

- Hydrology and Water Management;
- Soils and Reclamation;
- Agricultural Extension; and
- The field station of MREP in FESS (during the third and last year of the project).

5.2 ROLE OF WRRI

The Water Resources Research Institute (WRRI) of Pakistan's National Agricultural Research Center (NARC) of Islamabad will provide development, monitoring, evaluation and dissemination support regarding the dugwells and pressurized irrigation application systems. The WRRI will also give training to the farmers in the use of the dugwells and pressurized irrigation application systems. Thus, for an efficient and effective implementation of the project, the WRRI will establish a field office at the MREP, Bhalwal. The field team will consist of:

- One senior agricultural engineer;
- Two assistant agricultural engineers;
- One social organizer;
- One survey assistant; and
- Two technicians.

The same Field Team will work in the FESS area during the 3rd year. The staff involved at the head office of WRRI at Islamabad will be:

- One part-time Design Engineer;
- One part-time Computer Assistant; and
- Full time Administrative/Account Assistant.

Table 5. The roles and responsibilities of the collaborating units under the project.

Activities	MREP	WRRI	IWMI	Farmers
Project management	Leading Agency	Leading Agency	Leading Agency	
Year 1: MREP AREA				
Planning	Active Role	Active Role	Active Role	Participant
Reconnaissance Survey	Participant	Participant	Participant	Participant
PRA	Participant	Participant	Participant	Participant
Selection of Site(s) and Farmer(s)	Participant	Participant	Participant	Participant
Diagnostic Analysis	Participant	Participant	Participant	Participant
Supportive Survey and Information Collection	Leading Role	Supporting Role	Technical Guidance	Supporting
Skimming well Installation and Development	Leading Role	Active Role	Technical Support	Advisory Role
Dugwell Development	Active Role	Leading Role	Technical Support	Advisory Role
Pressurized Irrigation system Installation and Development	Active Role	Leading Role	Technical Support	Advisory Role
Irrigation Advisory Services -Preliminary Framework	On-site Support	Active Support	Leading Role	Participation
Farmers' Training	Leading Role	Leading Role	Technical Support	Participant
Software Activities	Active Support	Active Support	Leading Role	Active Involvement
Monthly Progress Report	Active Role	Active Role	Leading Role	
Quarterly Progress Report	Active Role	Active Role	Leading Role	
Year-end Progress Report	Active Role	Active Role	Leading Role	
Year-end Seminar	Active Role	Active Role	Active Role	
Year 2: MREP AREA				
Research Studies	Active Support	Active Support	Leading Role	Discussion
Supportive Survey and Information Collection	Leading Role	Supporting Role	Technical Guidance	Supporting
Skimming well Refinement and Installation	Leading Role	Active Support	Technical Support	Advisory Role
Dugwell Development	Active Role	Leading Role	Technical Support	Advisory Role
Pressurized Irrigation System Refinement and Installation	Active Support	Leading Role	Technical Support	Advisory Role
Irrigation Advisory Services Refinement	On-site Support	Active Support	Leading Role	Participation
Farmers' Training	Leading Role	Leading Role	Technical Support	Participant
Software Activities	Active Support	Active Support	Leading Role	Active Involvement
Monthly Progress Report	Active Role	Active Role	Leading Role	
Quarterly Progress Report	Active Role	Active Role	Leading Role	
Year-end Progress Report	Active Role	Active Role	Leading Role	
Year-end Seminar	Active Role	Active Role	Active Role	
Year 3: FESS and/or MREP AREA(S)				
Research Studies	Active Support	Active Support	Leading Role	Discussion
Planning	Active Role	Active Role	Active Role	Participant
Reconnaissance Survey	Participant	Participant	Participant	Participant
PRA	Participant	Participant	Participant	Participant
Selection of Site(s) and Farmer(s)	Participant	Participant	Participant	Participant
Diagnostic Analysis	Participant	Participant	Participant	Participant
Supportive Survey and Information Collection	Leading Role	Supporting Role	Technical Guidance	Supporting
Skimming well Installation	Leading Role	Active Role	Technical Support	Advisory Role
Dugwell Development	Active Role	Leading Role	Technical Support	Advisory Role
Pressurized Irrigation system Installation	Active Role	Leading Role	Technical Support	Advisory Role
Irrigation Advisory Services	On-site Support	Active Support	Leading Role	Participation
Farmers' Training	Leading Role	Leading Role	Technical Support	Participant
Software Activities	Active Support	Active Support	Leading Role	Active Involvement
Monthly Progress Report	Active Role	Active Role	Leading Role	
Quarterly Progress Report	Active Role	Active Role	Leading Role	
End-of-Project Final Report	Active Role	Active Role	Leading Role	
End-of-Project Seminar	Active Role	Active Role	Active Role	

5.3 ROLE OF IWMI

Of the three collaborative partners, the International Irrigation Management Institute (IWMI) is responsible for field research, software activities and report(s) writing. Based on the field research, IWMI will provide irrigation scheduling advisory services to manage root zone salinity by adopting pressurized irrigation application systems with fractional skimming well technology. Based on the software activities, IWMI will also give technical support to the MREP and WRRI for the development of fractional skimming well technology, dugwells and pressurized irrigation application systems. Furthermore, regarding the design and operational management of the dugwells and fractional skimming wells, IWMI will provide a computer modeling expertise too.

The IWMI will provide technical support to the MREP for conducting the individual and comparative performances of fractional skimming wells. The IWMI will also provide technical support to the WRRI for conducting the individual and comparative performances of dugwell and pressurized irrigation application systems. The IWMI will give training with the help of MREP and WRRI to the farmers regarding the irrigation scheduling. Regarding the supportive survey(s) and information(s) collection, IWMI will guide MREP and WRRI too.

For these purposes, IWMI will provide services of the two national staff members and one international staff member located in head office, Lahore. These staff members will be visiting the MREP, Bhalwal, on regular basis. They will stay in the project area for short time periods to guide the field staff on the project activities. From the inception of this project, informal consultation with Mr. A.B Sufi, a fractional skimming well expert of the International Waterlogging and Salinity Research Institute (IWASRI), will take place from time to time. IWMI has requested to the Government of Punjab to get the services of a person for this project from the Agricultural Department. If the Government accepted the request, then this national person will also join IWMI's team to give on-site support to the field staff during the data collection and their preliminary analyses. This person will be based at the MREP, Bhalwal.

5.4 PROJECT ACTIVITIES

This applied research project will be completed in three years after releasing first installment of the project funding by the NDP management. Table 6 gives a set of broadly defined project activities, distributed within the project duration of three years.

Table 6. The year-by-year plan of work[1].

Activities	J	F	M	A	M	J	J	A	S	O	N	D
Project management	■	■	■	■	■	■	■	■	■	■	■	■
Year 1: MREP AREA												
Planning	■											
Reconnaissance Survey	■											
PRA		■	■									
Selection of Site(s) and Farmer(s)				■	■	■						
Diagnostic Analysis				■	■	■						
Supportive Survey and Information Collection							■	■	■	■	■	■
Skimming well Installation and Development							■	■	■	■	■	■
Dugwell Development							■	■	■	■	■	■
Pressurized Irrigation system Installation and Development							■	■	■	■	■	■
Irrigation Advisory Services -Preliminary Framework	■	■	■	■	■	■	■	■	■	■	■	
Farmers' Training												■
Software Activities	■	■	■	■	■	■	■	■	■	■	■	■
Monthly Progress Report	■	■		■	■		■	■		■	■	
Quarterly Progress Report			■			■			■			
Year-end Progress Report												■
Year-end Seminar												■
Year 2: MREP AREA												
Research Studies	■	■	■	■	■	■	■	■	■	■	■	■
Supportive Survey and Information Collection	■	■	■	■	■	■	■	■	■	■	■	■
Skimming well Refinement and Installation	■	■	■	■	■	■						
Pressurized Irrigation System Refinement and Installation	■	■	■	■	■	■						
Irrigation Advisory Services Refinement	■	■	■	■	■	■						
Farmers' Training							■					
Software Activities	■	■	■	■	■	■	■	■	■	■	■	■
Monthly Progress Report	■	■		■	■		■	■		■	■	
Quarterly Progress Report			■			■			■			
Year-end Progress Report												■
Year-end Seminar												■
Year 3: FESS and/or MREP AREA(S)												
Research Studies	■	■	■	■	■	■	■	■	■	■	■	■
Planning	■											
Reconnaissance Survey	■											
PRA		■										
Selection of Site(s) and Farmer(s)			■									
Diagnostic Analysis				■								
Supportive Survey and Information Collection	■	■	■	■	■	■	■	■	■	■	■	■
Skimming well Refinement and Installation	■	■	■	■	■	■						
Pressurized Irrigation system Refinement and Installation	■	■	■	■	■	■						
Irrigation Advisory Services	■	■	■	■	■	■						
Farmers' Training							■					
Software Activities	■	■	■	■	■	■	■	■	■	■	■	■
Monthly Progress Report	■	■		■	■		■	■		■	■	
Quarterly Progress Report			■			■			■			
End-of-Project Final Report												■
End-of-Project Seminar												■

[1] Minor adjustments would be required based on delays in transfer of funds to the project collaborators. The plan will be adjusted accordingly without sacrificing any activities.

6 OUTPUTS

Every written output/publication will be jointly authored by all the three collaborating units and ranking (senior, junior authorship) would be in accordance with the roles and responsibilities defined in Table 4. The main outputs of the collaborative research will be:

6.1 YEAR 1

a) Methodology for the selection of sites, options for fresh water skimming facilities, types of pressurized irrigation application method and techniques for sustainable operation and maintenance of the *skimming source pressurized irrigation application system* aimed at root zone salinity management by participating individual farmers.

b) Fractional skimming wells, pressurized systems and dugwells installed, tested and refined.

c) Site specific reports about installation of the skimming facility and the low-cost pressurized irrigation application system (*skimming source pressurized irrigation application system)*.

d) Seminar to report results to research and irrigation management agencies.

6.2 YEAR 2

a) One research paper on the comparison of salty water upconing characteristics under various tested fractional skimming well arrangements.

b) One research paper on the performance of the low-cost *adapted* pressurized irrigation application methods installed at various locations in the MREP area.

c) One research paper about the irrigation scheduling methodology adopted and the results obtained for root zone salinity management under different conditions within the project area.

d) A seminar to report annual progress to research and irrigation management agencies.

6.3 YEAR 3

a) Site specific reports about the installation of field-tested and improved skimming source pressurized irrigation application systems in the Fordwah Eastern Sadiqia (South) Irrigation and Drainage Project and/or MREP area(s).

b) One research paper on management of the fresh and salty groundwater interface in the FESS and/or MREP area(s).

c) One report comparing actual and simulation results regarding the movement of the salty water upconing phenomenon.

d) One report about design methodology for skimming source pressurized irrigation application system for root zone salinity management.

e) A workshop to present the research findings of the project.

6.4 DISSEMINATION

Different means will be used to disseminate the technology and management packages comprising of fractional skimming well techniques coupled with low-cost pressurized irrigation application systems to manage root zone salinity. Some of the options that will be considered are as follows:

- As the package of technology and management is planned to refine and test in most cases on farmers' fields, the applied nature of the research work will provide a built-in advantage of fast dissemination of its findings. Moreover, the extension section of the MREP will be responsible for conducting field days to demonstrate the innovative techniques to manage root zone salinity.
- After perfecting the technology and management package during the first two years at the MREP area, the site for the applied research will be the command area of FESS. Again, field demonstration days will be organized to introduce the package to the farmers of the area. At this stage, information about well-tested techniques will be provided to the extension directorate of the provincial agriculture department (PAD) for its dissemination to a wider audience.
- At the end of each year, a seminar will be held to report progress and information generated to the researchers and managers of all relevant agencies in the country. In addition, three papers will be produced to present at national or international conferences.
- Efforts will be made by MREP and WRRI to develop multi-media training and demonstration modules including output on CD for the use of development agencies.

7 PROCUREMENT AND ADMINISTRATION ISSUES

7.1 MREP

MREP does not need additional staff to support the proposed activity. However, staff time spent in the implementation, and required research equipment including computers, will be charged to the project funds. In order to facilitate field activities, there will be 2 vehicles needed: one for the actively involved sections and one for the FESS field station of MREP.

7.2 WRRI

The research equipment, computer hardware/software, 2 field vehicles, 2 motorbikes and drafting/reproduction equipment will be purchased with project funds. The WRRI's *High Efficiency Irrigation Systems* Research *Program* will be strengthened to provide overall technical backstop support for the designing and manufacturing of appropriate irrigation equipment. This strengthening will include provision of research equipment, computer, operational funds, and one vehicle (out of above 2 vehicles).

7.3 IWMI

The Institute will purchase two motorbikes and two computers to provide the required support in the field, data analyses, mathematical modeling in the choice area and report writing.

8 PRE-IMPLEMENTATION INCEPTION ARRANGEMENTS

8.1 MOU BETWEEN MREP, WRRI AND IWMI

A formal joint Memorandum of Understanding (MOU) was signed between MREP, WRRI and IWMI on November 25, 1998. This MOU defines specifically the respective roles and responsibilities of each party in undertaking various components of this research project. The MOU provides the required basis for proper coordination among the three parties (MREP, WRRI and IWMI) responsible for the implementation of the project.

8.2 MOU BETWEEN PARC AND IWMI

A formal joint MOU was signed between PARC and IWMI on December 7, 1998. This MOU allows WRRI to formally enter into an agreement between IWMI and PARC.

8.3 SET UP OF STUDY COORDINATION COMMITTEE

In order to further improve communications and smooth functioning among the three parties concerned, a Study Coordination Committee (SCC) was also set up on November 25, 1998. This committee comprises of the following officials: (i) Project Director, MREP; (ii) Director WRRI (iii) Director, IWMI. It was decided during the first SCC meeting that the project activities during the first and second year(s) would be focused within the MREP area. Whereas, the MREP and/or FESS area(s) would be targeted during the third year while considering technical, social and financial situations.

8.4 CONTACT(S) WITH THE IDENTIFIED PANEL OF EXPERTS

In order to ensure the quality of the research work, a panel of 2-3 experts was planned for the review of research methodologies, implementation of activities and outputs in the project proposal. The following persons were identified while considering the nature of the project:

- Dr. David McWhorter (USA);
- Dr. Brij Sahni (India); and
- Dr. Nazir Ahmed (Pakistan).

8.5 SELECTION OF RESEARCH AREAS AT MREP, BHALWAL

Pre-reconnaissance survey for the selection of three project sites at MREP, Bhalwal having good accessibility, demonstrability, and potential for transfer of technology was carried out during December 28-29, 1998. During that visit, it was also decided that for design, planning, and testing purposes, the basic experiments would be carried out at Phullarwan Research Farm of MREP, Bhalwal. These experiments will also help in exploring data requirements for farmers fields experiments. The existing dugwell and multi-strainer fractional skimming well will be used for these controlled experiments.

8.6 ESTABLISHING FIELD STATION AT MREP, BHALWAL

The field station was established at MREP, Bhalwal on December 28, 1998.

9 DESCRIPTION OF THE MREP AREA

9.1 LOCATION

The MREP area constitutes a part of SCARP-II, and lies in the north-central part of the Chaj Doab. The project area is located at a distance of 144km north of Faisalabad, and about 90% of the area is situated in the Bhalwal Tehsil of the Sargodha District, whereas about one-tenth lies in the Phalia Tehsil of the Gujrat District. The project area is bounded on the north by the Shahpur Branch Canal, and on the east by the Lower Jhelum Canal (Figure 4). The southern boundary is formed by the northern branch of the Lower Jhelum Canal as well as by the Sargodha-Gujrat Road. No significant boundary line demarcates the project area on the western side. The area is connected with the rest of the province with road and rail. The Sargodha-Gujrat Road touches the project area at several points, and runs parallel to the project area for a length of 30km. The railway line passes through the eastern part, and there are four railway stations within the project area. The Motorway (M2) passes through the center of the project area. The Salam interchange is at about 12km from the Mona colony.

The project area covers 71772 hectares, spread over 83 villages. It is 48km long from east to west, and 13km wide from north to south. Bhalwal lies towards the south at a distance of 3km outside the project area. Phularwan, a small market town, is situated within 3km of the project boundary at its southern edge. Small towns of Bhera and Miani are situated in the project area and Malakwal is located at a distance of 10km from the Project area towards north.

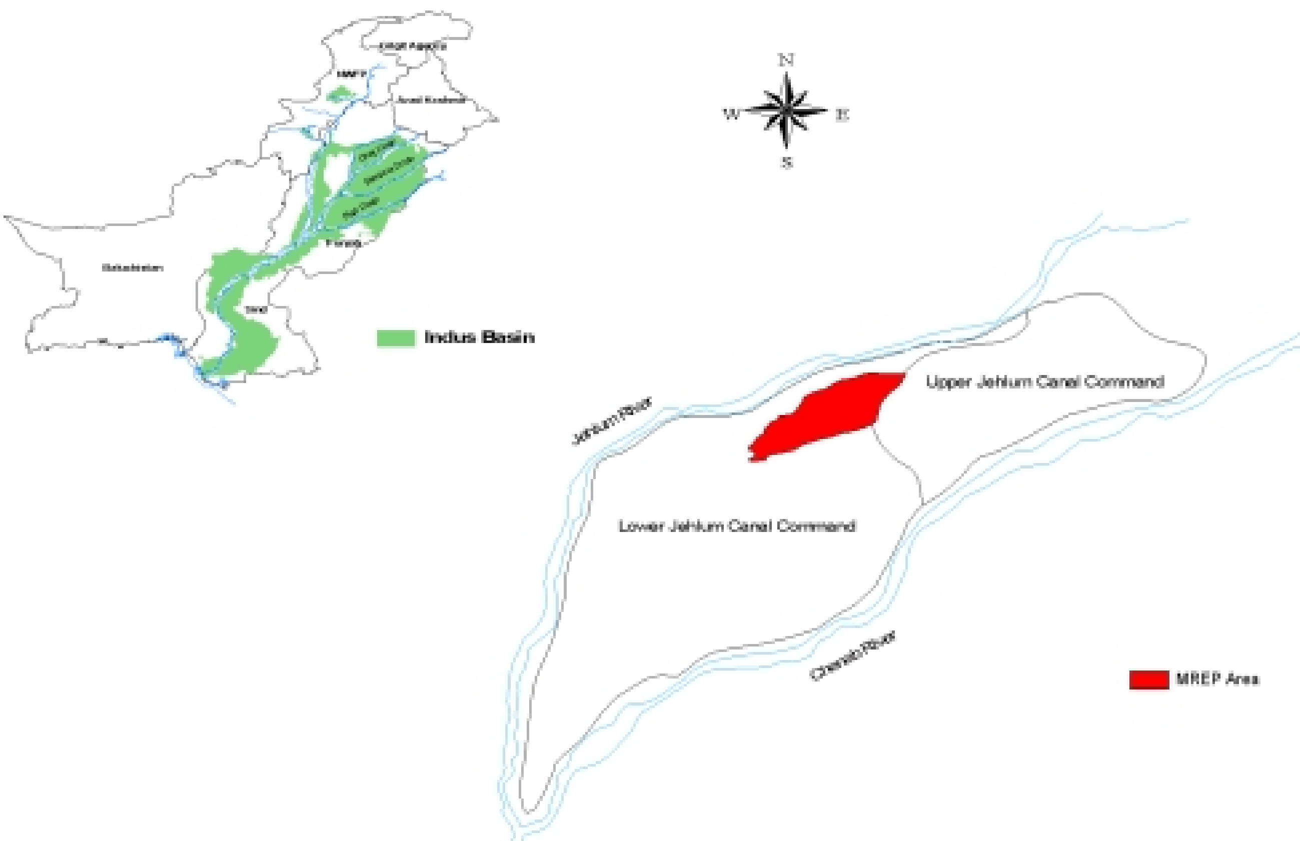

Figure 4. Mona Reclamation Experimental Project area map.

9.2 CLIMATE

The climate of the MREP area is characterized by large seasonal variations in temperature and rainfall. From December to February the temperature falls considerably and the weather becomes cold. Usually the temperature during winter ranges between 7°C to 20°C. In summer from May-July, the weather is extremely hot with 20-40°C and extends to August. Mean annual rainfall lies around 600mm at the Phularwan Weather Station (Kahlown et al., 1998).

9.3 IRRIGATION

The command area of the MREP is irrigated by 36 distributaries and minors that off-take from Shahpur branch (non-perennial) as well as from northern branch of Lower Jhelum Canal (perennial). The entire project command area is augmented by 308 SCARP tubewells of the Mona and Shahpur units. The operation and maintenance of SCARP tubewells in the project area is the responsibility of the MREP. Farmers of the area, generally irrigate their fields by flooding. At some places basin irrigation is practiced for orchards.

Irrigation supplies usually remain surplus during the monsoon period, and over irrigation is commonly practiced. The distributaries, minors and watercourses in the project area are unlined and poorly maintained. The water loss measurements conducted by the Colorado State University and the MREP engineers showed that about 45% of the diverted water lost before reaching the farmer's fields. This state of affairs is depriving the farmers from the precious irrigation water on the one hand, and causing the problem of waterlogging on the other hand (Kahlown et al., 1998).

9.4 WATERLOGGING

The MREP is bounded by the Lower Jhelum Canal as well as by the River Chenab. In spite of the availability of drainage infrastructure, about 25% of the project area have groundwater level in the range of 0-1.5m (Table 7). The problem of waterlogging is impairing the agriculture productivity on one hand and causing the damage to buildings, road network and airfields (Kahlown et al., 1998).

Table 7. Groundwater table depth distribution in the MREP area.

Sr. No.	Groundwater table depth (m)	Mona unit area (%)	Shahpur unit area (%)
1	0-1.5	23.84	25.39
2	1.5-3.0	52.80	74.61
3	< 3.0	23.36	-

9.5 DRAINAGE

In the project area, both surface drains and SCARP tubewells are in operation. The operational pumping data of these SCARP tubewells at Mona and Shahpur units is given in Figure(s) 5 and 6, respectively. The present utilization of the Mona and Shahpur units varies from 21 to 67 percent and 20 to 55 percent, respectively. This reduced percent utilization of SCARP tubewells is a point of concern. Surface drains are not being regularly cleaned and as such they have lost their effectiveness (Kahlown et al., 1998).

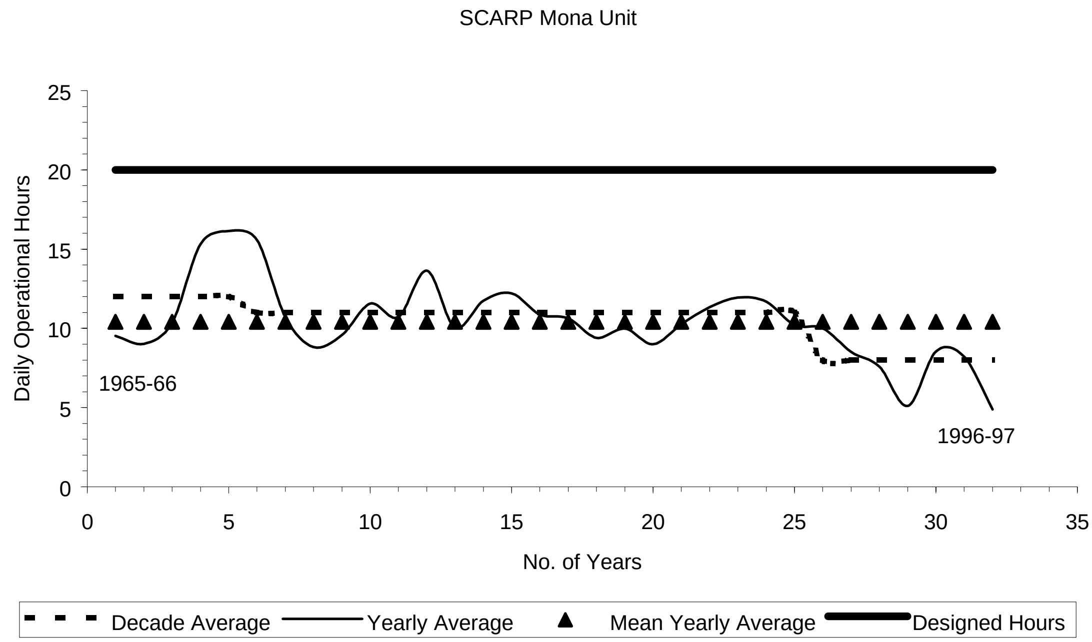

Figure 5. Year-wise pumping data of SCARP tubewells at Mona unit.

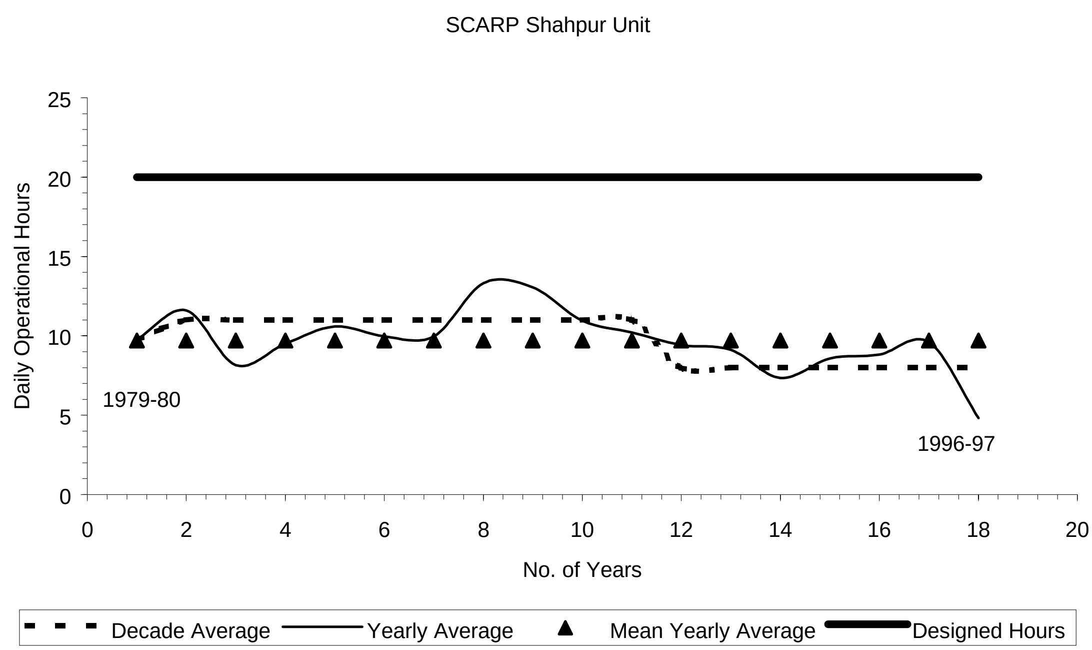

Figure 6. Year-wise pumping data of SCARP tubewells at Shahpur unit.

9.5.1 Surface drainage

To provide drainage relief to command area of the MREP, an extensive drainage system comprising eight surface drains with total length of 170km is being maintained by the Irrigation & Power Department, Government of Punjab. Out of these eight drains, Mona Drain is the biggest, which is designed to carry a discharge of 45000 liters per second (l/s). The other bigger drain is Bhakar Drain, with a discharge of 4500 l/s. Drains of this size require heavy machinery for cleaning and maintenance. It is highly unlikely for the individual farmers to maintain such drains unless a collective mechanism is put in place. Presently, most of the surface drains are non-functional and require large-scale cleaning and maintenance.

9.5.2 Vertical drainage

For vertical drainage, 308 SCARP tubewells of the Mona and Shahpur units are operating in the project area to provide the drainage relief. In the salty groundwater zone, tubewells discharge water into the surface drains for further disposal, whereas in the fresh groundwater zones, tubewell water is used to supplement the canal supplies.

9.6 PRESENT AGRICULTURE

9.6.1 Soils

The soils texture of the MREP area range from coarse to moderately fine, with the pre-dominance of moderately coarse texture soils. According to the survey conducted by MREP in 1990, about 78% of soils were non-saline, and non-sodic. About 14% soils were classified as saline-sodic, 6% sodic and 2% as saline soil (Kahlown et al., 1998).

9.6.2 Land use

Land utilization is affected by a number of factors; such as irrigation, cultural practices, agricultural credit system, size of holdings and soil characteristics. Out of the total project area of 71772 hectares, about 68067 hectares are cultivated. The remaining 3705 hectares are uncultivated due to waterlogging, salinity, sodicity and shortage of irrigation water. Some of the uncultivated area is out of cultivation, while the rest of the area is partially out of cultivation for the last several years (Kahlown et al., 1998).

9.6.3 Farm holdings

Land holdings form an economic base for productivity. Small size holdings are relatively less profitable to operate and manage. Usually, productivity of small land holdings is low. On the other hand, the large land holdings provide better opportunity for adoption of improved techniques for higher yields and increased incomes. In the Project area, there are 73 % small farmers with small land holdings (less than 5 hectares), 18% are with medium land holdings (5 to 10 hectares) and 9% are large farmers with land holdings of more than 10 hectares (Kahlown et al., 1998).

9.6.4 Cropping pattern

Land holdings, irrigation supplies, weather, labor, and market mechanisms, etc. effect the cropping pattern. The cropping patterns in the project area are rice-wheat, maize-wheat, and cotton-wheat with sugarcane as a cash crop in all the cropping patterns. Citrus occupies an important position in the cropping pattern and considered as most profitable crop of the area (Kahlown et al., 1998).

9.6.5 Cropping intensity

The cropping intensity is defined as the ratio of cropped area to cultivated area. It is always expressed in percentage. The project cropped and cultivated area amounts to 103985.43 and 68360.73 hectares, respectively. This gives a cropping intensity of 152 % (Kahlown et al., 1998).

9.6.6 Farm inputs and management practices

About 10-15% of the progressive farmers uses seed of promising varieties of wheat, sugarcane and rice. The rest of farmers generally use their own retained seed at their farms. Fertilizer is a strategic input and plays an important role in increasing agricultural production. Level of fertilizer use in the project area is shown in Table 8. Weeds are a major constraint in achieving the higher per hectare crop yields. Generally, broad and narrow spectrum weeds compete with plants for air, light, moisture, fertilizer, and other plant micro- and macro- nutrients. These weeds ultimately causing about 15-20% reduction in yield in the project area. Chemical weed control is cheaper and economical as compared to manual weed control. Insect pest attack is also important in reducing crop yields. According to a recent survey about 20-25% yield is reduced due to improper use of insecticide/pesticide (Kahlown et al., 1998).

9.6.7 Crop yields

The crop yields are usually low on small land holdings (Table 9) and at the tail end farms (Table 10). The source of these information is "Causes of Variability in Crop Production Within an Irrigated System, 1998". The Farmers with small land holdings have higher per unit cost of production with less return. While the farms at the tail end of the distributary usually have the shortage of irrigation water. These results in low input use and consequently low farm produce (Kahlown et al., 1998).

9.6.8 Farm income

The gross farm income is a monetary measure of the total production. However, a high gross income resulting from a high cost of production may be no better than a low gross income with low expenditure. A high portion of the income may be affected by a corresponding high cost of production. Therefore, it is the net income that is the final important attribute. Net income per hectare was computed by subtracting production costs from gross income. Farm cost included the cost of land, labor, seed, cultural practices, irrigation, fertilizers, chemicals, etc. Per hectare farm cost and net income in the project area is shown in Table 11 (Kahlown et al., 1998).

Table 8. Fertilizer use in the MREP area.

Crops	Fertilizer application (bags per hectare)		
	Urea	DAP	SOP
Wheat	2.5	2.5	-
Rice	2.5	2.5	-
Sugarcane	5.0	2.5	-
Maize (Fodder)	2.5	-	-
Cotton	2.5	2.5	Negligible

Table 9. Yields of major crops as affected by farm size in the MREP area (kg/hectare).

Crops	Small Farm	Medium Farm	Large Farm
Wheat	2218.06	2334.15	2487.29
Sugarcane	50783.20	57896.80	62935.60
Rice	2074.80	2173.60	2371.20
Cotton	592.80	494.00	296.40

Table 10. Yields of major crops as affected by farm locations in the MREP area (kg/hectare).

Crop	Head	Middle	Tail
Wheat	2371.20	2272.40	2173.60
Sugarcane	57402.80	53055.60	50684.40
Rice	2272.40	2074.80	1976.00
Cotton	543.40	484.12	296.40

Table 11. Farm cost, gross income and net income per hectare in the MREP area.

Item	Head	Middle	Tail	Overall
Annual cost/hectare	11371.88	11006.32	10665.46	11011.26
Annual benefits/hectare	24299.86	23551.45	22644.96	23492.17
Annual net benefits/hectare	12927.98	12545.13	11979.50	12480.91

10 DESCRIPTION OF THE FESS AREA

10.1 LOCATION

The FESS area constitutes a part of SCARP-VIII and is located at a distance of about 300km from Lahore in the south-eastern part of the Punjab province. The project area lies in the Bahawalnagar district and partially covers the Bahawalnagar, Haroonabad and Chistian thesils. This area is located between longitudes 72° 40′ and 73° 25′ East and latitude 29° 25′ and 30° 00′ North. The area is bounded by the Malik Barnch Canal and Murad distriburory in the north-west, by the Hakra 6-R distriburoty of the Hakra Branch Canal in the south, by the Haran minor in the west, and by the Indian boundary in the east (Figure 7). The area is connected with the rest of the province with road and rail.

The gross command area of the project is 126117.41 hectares of which 120573.68 hectares are culturable and 109936.44 hectares are canal commanded. Haroonabad is the only major town situated in the project area while other small towns are Dunga Bunga and Dahranwala. Approximately 242000 inhabitants live in the rural areas comprising many villages (WAPDA, 1988; and Kahlown and Iqbal, 1998).

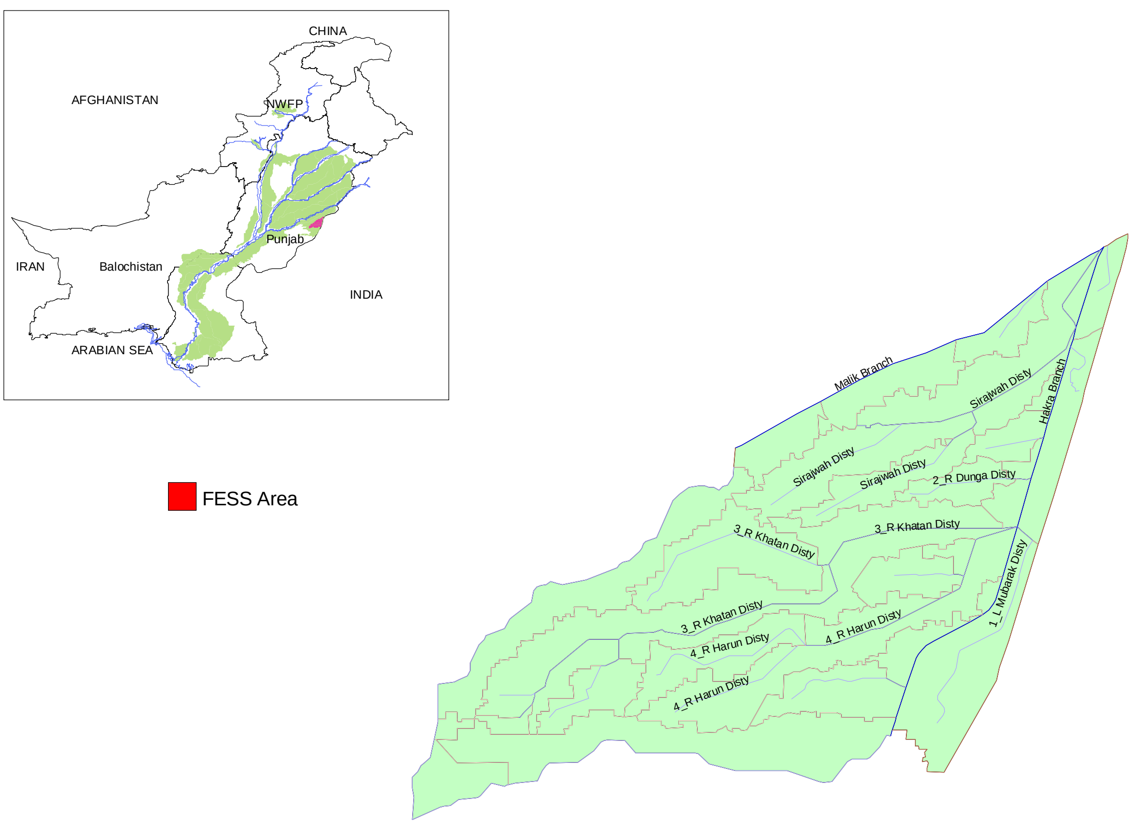

Figure 7. Fordwah Eastern Sadiqia (South) Irrigation and Drainage Project area map.

10.2 CLIMATE

The project area is in the Cotton-Wheat agro-climatic zone of the Punjab province. The project area has large seasonal variations in temperature and rainfall. The average annual rainfall is about 246mm of which 84 percent occurs during monsoon (in July-August) in the Kharif season. The potential evaporation exceeds 737mm annually, thereby necessitating irrigation for agriculture. In summer, May and June are the hottest months. Daily mean maximum temperature varies between 32 to 48°C during the summer season. The winter season is mild with short duration and extends from December to February. January is the coldest month. Daily mean minimum temperature varies between 12 to 24°C during the winter season (Kahlown and Iqbal, 1998).

10.3 IRRIGATION

The project area is irrigated through Eastern Sadiquia Canal off-taking from Sulemanki Headworks from the Sutlej river (Figure 8).

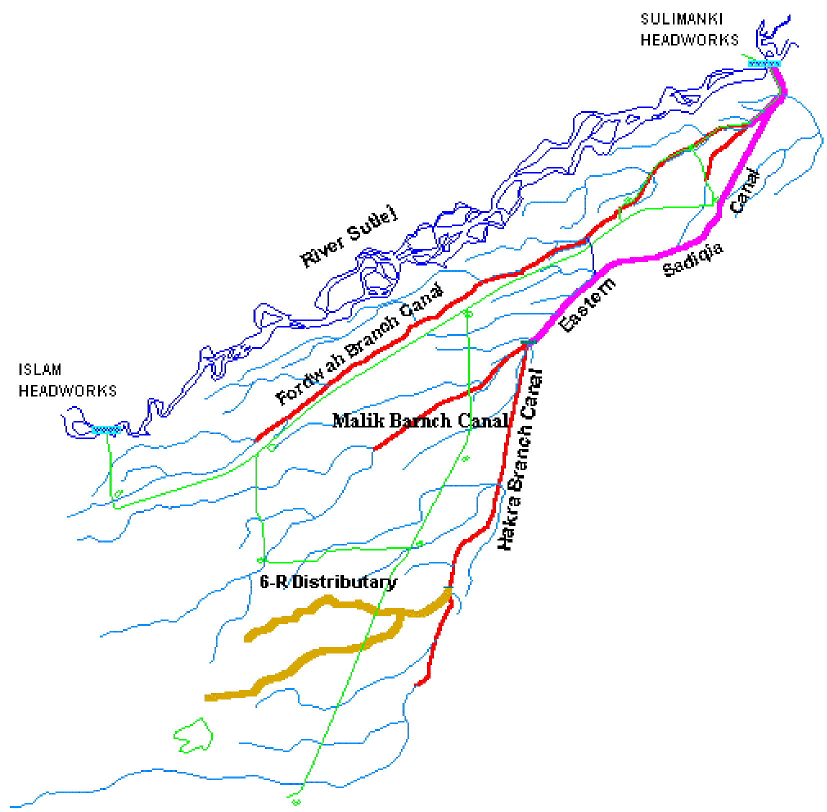

Figure 8. Irrigation system for the Fordwah Eastern Sadiqia (South) Irrigation and Drainage Project area.

This Eastern Sadiqia Canal runs for a distance of about 74km before bifurcating into the the Hakra and Malik Branch Canals at the beginning of the project area. From each of the canals, there are distributaries, minors, sub-minors and watercourses. The design of the canal system is based on the water allowance of

0.085 cumec per 400 hectares, which permits a cropping intensity of about 80 percent. Water supply has increased significantly after the completion of Mangla Dam under the Indus Basin Treaty. The supplies were made available at Sulemanki from Mangla Reservoir through Rasul-Qadirabad, Qadirabad-Balloki and Balloki-Sulemanki Link Canals. Since 1970, the Eastern Sadiqia Canal has been receiving entire irrigation supplies from the western rivers. Because of the increased water supply, the cropping intensity is now about 129.3 percent, with 55.3 percent in the kharif and 74 percent in the rabi seasons. In short canal water supply environment, these cropping intensities are quite high. The main reason is sub-irrigation from the shallow groundwater table.

Farmers irrigate their fields by flooding and thus over irrigation is commonly practiced. The distributaries, minors, sub-minors and watercourses in the project area are mostly unlined and poorly maintained. This state of affairs is depriving the farmers from the precious irrigation water on the one hand, and causing the problem of waterlogging on the other hand (Kahlown and Iqbal, 1998).

10.4 WATERLOGGING

The project area falls on the left side of Sutlej valley. Before the introduction of weir controlled irrigation, the groundwater table was very deep and at certain places about 30m below the soil surface. It remained at the same level for quite a long time due to the natural equilibrium conditions. However, the current situation states that, in spite of the availability of drainage infrastructure, about 75% of the project area have groundwater level in the range of 0-1.5m (Table 12). The problem of waterlogging is impairing the agriculture productivity on one hand and causing the damage to buildings, and road network (WAPDA, 1988).

Table 12. Groundwater table depth distribution in the FESS area.

Sr. No.	Groundwater table depth (m)	Area (hectares)	Area (%)
1	under water	899.60	1.00
2	0-1.5	71748.99	57.00
3	1.5-3.0	43322.27	34.00
4	< 3.0	10146.56	8.00
Total		126117.41	100.00

10.5 DRAINAGE

In the project area, both surface drains and SCARP tubewells are planned under the Fordwah Eastern Sadiqia (South) irrigation and drainage project. For the surface drainage measures, the project would consist of two zones: the Northern and Southern Zones. An independent network of surface drains has been planned for each part. The surface drains in the Northern Zone will discharge into the Sutlej River below the Islam Headworks. The surface drains in the Southern Zone will discharge into a series of evaporation ponds situated at the end of the natural slope in the south-west of the project area in the Cholistan Desert. At the moment, surface drains are not properly functional and as such they have lost their effectiveness.

The project area has private tubewells too, but most of them are of small capacity. Thus, these tubewells are not providing any relief from waterlogging and salinity to the area.

10.6 GROUNDWATER QUALITY

Actual damage done to the plant or soil depends on the concentration of salts in the soil solution rather than the irrigation water. Thus, the use of the water from the same source might lead to a severe salt problem in the soil where drainage is poor, whereas, in good drainage conditions, crops can be grown without any evidence of salt damage. Thus, the effect of irrigation water on different soils depends on a number of factors, like the amount and nature of soluble salts, the depth of irrigation water applied, physio-chemical characteristics of soils, drainage facilities, climate, and the management practices. The deep (35-80m) and shallow (15-35m) groundwater quality analyses results indicate that the average EC in the project area is 19 and 12.9 dS/m, respectively. Water quality at very shallow depths tapped by hand-pumps and tubewells located along the canals indicate that water from these sources can be used for irrigation purposes (Kahlown and Iqbal, 1998).

10.7 PRESENT AGRICULTURE

10.7.1 Soils

The soils texture of the FESS area range from moderately coarse to moderately fine. However, moderately coarse textured soils covers about 91.5% of the project area, while medium textured soils, moderately fine textured soils and non-agricultural soils cover 6.3, 1.2 and 1.0 percent of the project area, respectively. The majority of the soils are non-saline and non-sodic (90.6%). About 1.6% soils were classified as saline-sodic, 0.4% sodic and 6% as saline soils, whereas, non-agricultural soils cover 1.4 percent of the project area (WAPDA, 1988).

10.7.2 Land use

Land utilization is affected by a number of factors; such as irrigation, cultural practices, agricultural credit system, size of holdings and soil characteristics. Out of the total project area of 126117.41 hectares, about 109936.44 hectares are cultivated. The remaining 16189.97 hectares are uncultivated due to waterlogging, salinity, sodicity and shortage of irrigation water. Some of the uncultivated area is out of cultivation, while the rest of the area is partially out of cultivation for the last several years (WAPDA, 1988).

10.7.3 Cropping pattern

Land holdings, irrigation supplies, weather, labor, and market mechanisms, etc. effect the cropping pattern. The cropping pattern in the project area is mainly cotton-wheat with sugarcane as a cash crop (Kahlown et al., 1998).

10.7.4 Cropping intensity

The cropping intensity is defined as the ratio of cropped area to cultivated area. It is always expressed in percentage. The project cropped and cultivated area amounts to 142147.81 and 109936.44 hectares, respectively. This gives a cropping intensity of 129.3% (Kahlown et al., 1998).

10.7.5 Crop yields

The crop yields are usually low on salt-affected areas (Table 13) and the average yields for the areas having groundwater table depths more than 1.5m were higher than those of 0-1.5m groundwater table depth areas (Table 14) (WADPA, 1988).

Table 13. Yields of major crops as affected by soil salinity in the FESS area (kg/hectare).

Crops	Normal Soils	Salt-Affected Soils	Project Average
Wheat	1956.24	1432.60	1877.20
Sugarcane	22328.80	16203.20	21834.80
Rice	1689.48	1047.28	1590.68
Cotton	978.12	503.88	918.84

Table 14. Yields of major crops as affected by depth of groundwater table in the FESS area (kg/hectare).

Crop	Depth to Groundwater Table		Project Average
	0-1.5m	> 1.5m	
Wheat	1788.28	2124.20	1877.20
Sugarcane	19364.80	31616.00	21834.80
Rice	1551.16	2153.84	1590.68
Cotton	622.44	1482.00	918.84

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