

Methodology Development for Selection of Sites for Skimming Wells and Pressurized Irrigation Systems

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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 m³ 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).

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

- 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);
- Participatory Rural Appraisal of selected thirteen villages of the Target Area of the project (referred as PRA Study);
- Diagnostic Analysis Study of seven villages out of thirteen selected under the Target Area (referred as DAS Study).

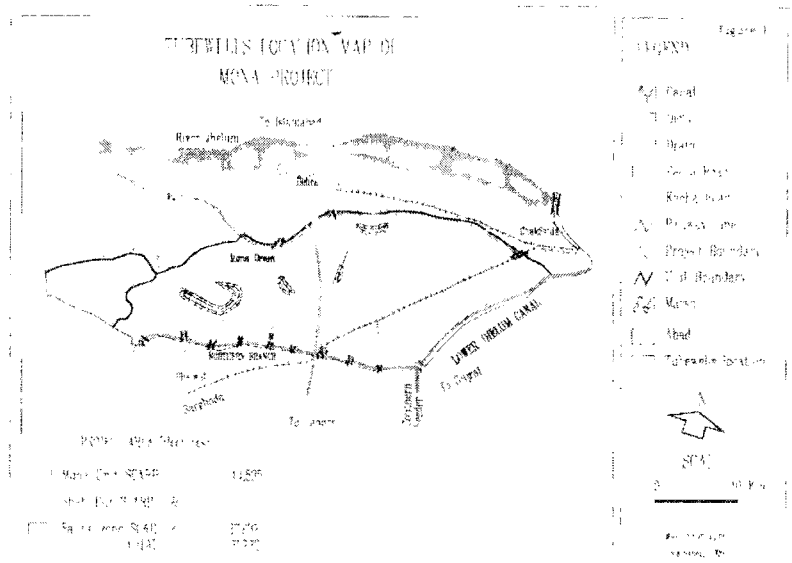


Figure 1. Tubewells location map of Mona project.

The specific objectives of the methodology development are as under:

- 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.
- 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.
- 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:

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

FINDINGS OF STUDIES

GIS study

Classification of deep groundwater of SCARP tubewells in the Target Area

According to the GIS study, the thirteen potential villages were selected which represent freshwater, marginally saline, marginally saline-sodic and hazardous quality of deep groundwater. The freshwater villages were selected to validate whether the SCARP tubewells represent the overall picture of the area or not (Table 1).

Table 1. Classification of SCARP Tubewells in selected villages based on spatial analysis of deep groundwater in the Mona Unit, MREP, Bhalwal.

Sr. No.	Name of Village	Number of SCARP Tubewells Installed	Classification of Tubewells Based on Deep Groundwater Quality
1	Ratho Kala	33 34, 37	Marginally saline-sodic Hazardous saline marginally sodic
2	Thathi Noor	39, 40, 41, 44	Marginally saline hazardous sodic
3	Jalar Waraichan	30, 31, 32	Marginally saline-sodic
4	Head Fagerian	26, 28, 29	Marginally sodic
5	Chak No. 6 ML	45	Marginally saline hazardous sodic
6	Nabi Shah Bala	39, 94	Marginally saline-sodic
7	Dhera Ranjha	80	Marginally sodic
8	Chak No. 15 NB	81, 82	Marginally sodic
9	Chak No. 17 NB	84	Marginally sodic
10	Banga Minhas		Saline Zone
11	Sakacar (Jurra)		Saline Zone
12	Moza Dohri	27, 68	Freshwater (Very Good)
13	Chak No. 1 (Phularwan)	69	Freshwater (Very Good)

Groundwater quality zonation

Maps of three parameters of TDS, SAR and RSC were overlapped to characterize and classify groundwater zones (Figures 2 and 3). The classification of groundwater quality zonation indicated that around 12% and 5% area of the very good quality freshwater and marginally saline-sodic zones have been shifted to other zones. There was increase in the area under marginal and hazardous groundwater zones (Table 2 and Figure 4). The areas having freshwater zone have to be given priority so that further deterioration should not occur in these areas. The target for the NDP Project in the Mona Unit should be the marginal and hazardous deep groundwater zones so that the thin layer of freshwater over the marginal or hazardous quality deep groundwater can be pumped.

This zonation exercise represents all levels of salinity and sodicity, as it represents all the four classes of salinity and sodicity in terms of very good, good, marginal and hazardous and combinations. In total there were 8 groundwater quality zones prevailing in the Mona Unit. The criteria for

characterization of TDS, SAR and RSC was defined for four classes of very good, good, marginal and hazardous groundwater. Therefore, this zonation methodology represents more practical criteria for selection of potential locations for installation of skimming wells and pressurized irrigation systems.

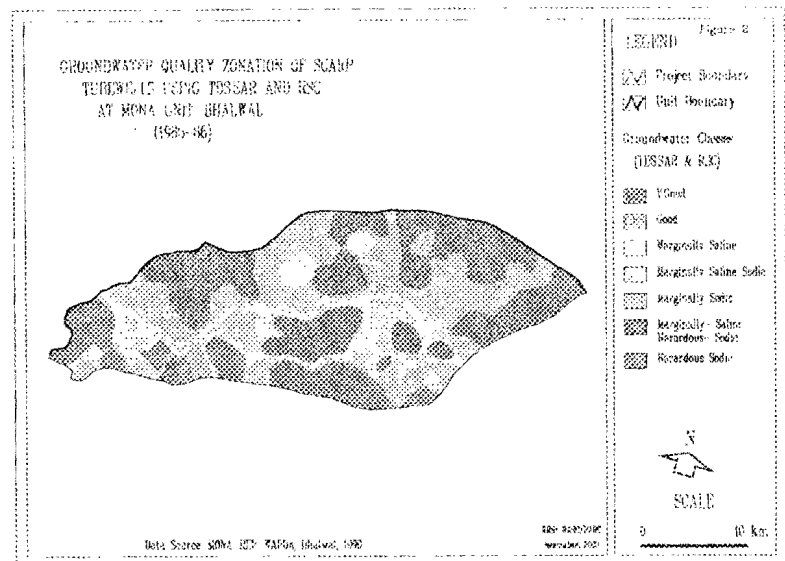


Figure 2. Groundwater quality zonation using TDS, SAR AND RSC (1965-66).

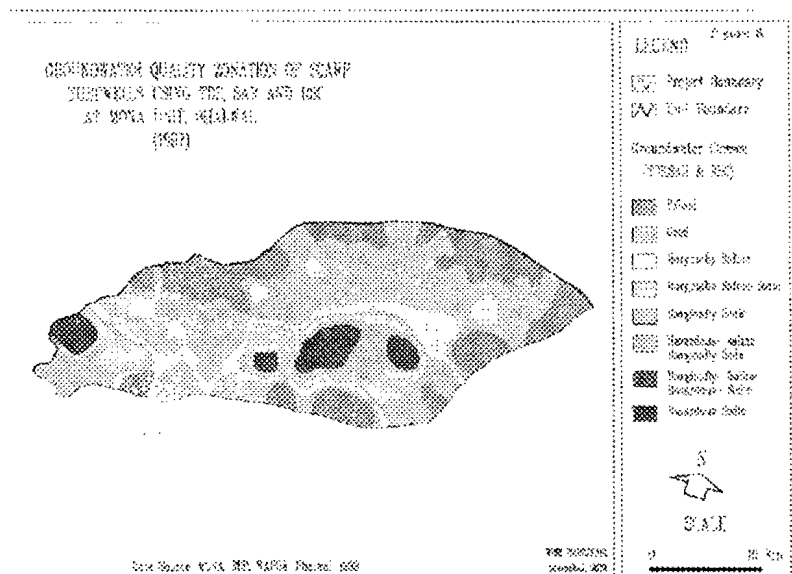


Figure 3. Groundwater quality zonation using TDS, SAR AND RSC (1997-98).

Table 2. Classification of project area considering groundwater quality zones of SCARP Tubewells during 1965-66 and 1997 at Mona Unit of MREP, Bhalwal.

Groundwater Zone (TDS in ppm, SAR, RSC in meq/l)	Project Area (%)		Change in Project Area (+ or -) (%)
	1965-66	1997	
V. Good (<500, <5, <2.5)	35.76	23.87	- 11.81
Good (500-1000, 5-10, <2.5)	24.49	35.82	+ 11.33
Marginally Saline (1000-2000, <10, <2.5)	4.69	10.15	+ 5.46
Marginally Saline-Sodic (1000-2000, <15, <5)	12.45	7.27	- 5.18
Marginally Sodic (<1000, <15, <5)	8.83	12.0	+ 3.17
Hazardous-Saline Marginally-Sodic (>2000, <15, <5)	0.0	4.18	+ 4.18
Marginally Saline Hazardous Sodic (1000-2000, >15, >5)	13.25	3.63	- 9.62
Hazardous Sodic (<1000, >15, >5)	0.53	3.08	+ 2.55
Total	100.00	100.00	0.00

Figure 4 Temporal changes in groundwater quality at Mona, Bhalwal.

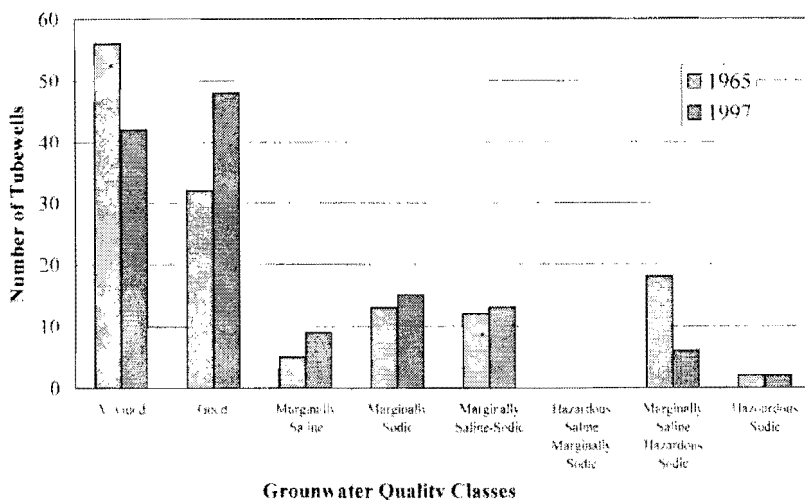


Figure 4. Temporal changes in groundwater quality.

Distribution of tubewells under groundwater quality zones and potential locations for skimming wells and pressurized irrigation

Distribution of tubewells under different groundwater quality zones for the period 1997 is presented in Tables 3. The distribution pattern for 1997 indicated that 90 tubewells out of 138 are located in freshwater zones (very good and good), which is around 65% of the tubewells in the Mona Unit. The marginal zones include 37 tubewells out of 138, which represents around 27% of the tubewells in the Mona Unit. There are only 11 tubewells in the hazardous zones, which represents 8% of the tubewells in the Mona Unit.

The 8% tubewells of the hazardous zone constitute the high potential area, whereas 27% tubewells of the marginal zone also fall in the potential area. The potential locations alongwith distribution of tubewells is presented in Figure 5.

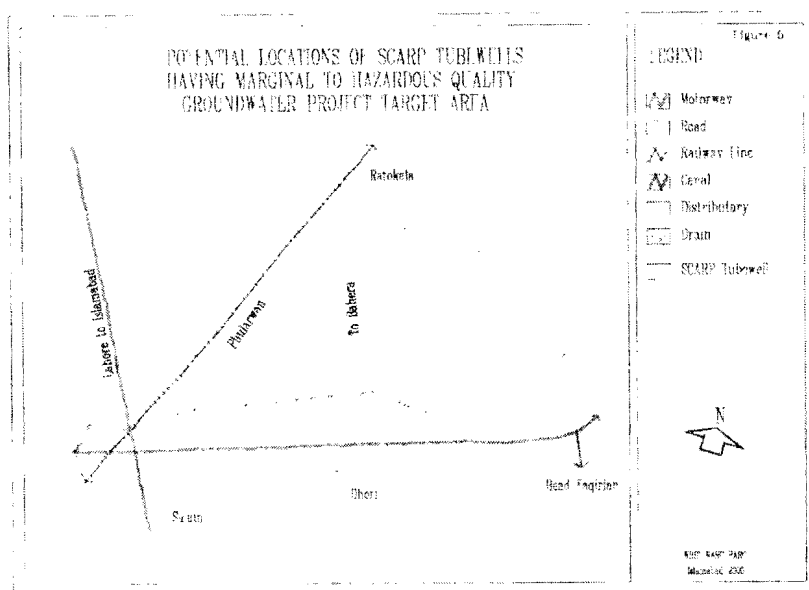


Figure 5. Potential locations of SCARP tubewells having marginal to hazardous quality groundwater – project target area.

Table 3. Classification of tubewells under different groundwater quality zones during 1997 at Mona Unit of MREP, Bhalwal.

Groundwater Quality Zones	Limits	No. of Tubewells	List of Tubewells
V. Good	TDS < 500 SAR < 5 RSC < 2.5	42	1, 5, 6, 7, 8, 9, 10, 11, 12, 14, 24, 27, 54, 67, 68, 69, 70, 77, 78, 96, 97, 99, 104, 105, 106, 108, 109, 113, 114, 117, 118, 119, 120, 123, 124, 125, 126, 127, 128, 129, 131, 132
Good	TDS 500 – 1000 SAR 5 – 10 RSC < 2.5	48	2, 3, 4, 19, 20, 21, 22, 42, 53, 55, 56, 57, 60, 62, 63, 64, 65, 66, 71, 73, 98, 100, 101, 103, 107, 110, 111, 112, 115, 116, 121, 122, 130, 133, 134, 135, 136, 137, 138, 140, 141, 142, 143, 144, 145, 146, 147, 148
Marginally Saline	TDS 1000 – 2000 SAR < 10 RSC < 2.5	9	15, 16, 17, 18, 47, 59, 61, 102, 139
Marginally Sodic	TDS < 1000 SAR < 15 RSC < 5	15	13, 23, 26, 28, 29, 48, 72, 74, 75, 76, 79, 80, 81, 82, 84
Marginally Saline-Sodic	TDS 1000 – 2000 SAR < 15 RSC < 5	13	30, 31, 32, 33, 46, 49, 51, 52, 91, 92, 93, 94, 95
Hazardous Saline Marginally Sodic	TDS > 2000 SAR < 15 RSC < 5	3	34, 36, 37
Marginally Saline Hazardous Sodic	TDS 1000 – 2000 SAR > 15 RSC > 5	6	39, 40, 41, 44, 45, 50
Hazardous Sodic	TDS < 1000 SAR > 15 RSC > 5	2	25, 83

Groundwater depth fluctuations and zonation

Maps of water-table depths were prepared for the pre- and post-project periods. The comparison of the temporal data indicated that there was an increase of around 19% in area having water table of less than 2 m (Table 4). Area having water table of less than 3 m is classified as waterlogged. Therefore, there was an increase of around 16.9% in the waterlogged area. This increase is mainly due to the reduced pumping of groundwater because of increased energy prices and abandoning of the tubewells having brackish groundwater. This is a serious concern and an indication of the poor performance of the reclamation projects.

Table 4. Classification of project area considering water table depth during 1964 and 1999 at Mona Unit of MREP, Bhalwal.

Water Table Depth (m)	Project Area (%)		Change in Project Area (+ or -) (%)
	1964	1999	
< 1	1.07	1.92	+ 0.85
1 – 2	7.32	25.52	+ 18.20
2 – 3	34.31	32.12	- 2.19
> 3	57.30	40.44	- 16.86
Total	100.00	100.00	0.00

Application of groundwater spatial and temporal analyses

Temporal and spatial groundwater analyses indicated that there was an increase in groundwater salinity and waterlogging in the project area. This information is useful for planning of future projects to control waterlogging and salinity.

Groundwater quality zonation exercise provided information of potential locations and methodology for conducting research to develop skimming wells to pump shallow freshwater. This will be having higher impact on the control of water-table depth and management of root zone salinity rather than pumping brackish water from deeper depths. In addition to this, increase in energy prices requires development of energy efficient pumping systems to maintain water table below the root-zone depth. The smaller discharges of skimming wells can be applied efficiently using pressurized and innovative irrigation systems.

The criteria of water table of more than 3 m need reconsideration in the freshwater zone. Because water table of more than 1m depth in the freshwater zone is suitable for field crops, except cotton. However, water table should be more than 3 m deep to grow fruit orchards. As farmers are growing quality citrus in the project area, therefore, they want water table sufficiently deep enough to grow good quality citrus.

Farmers should be encouraged to grow forest plants having higher water requirements especially in areas having marginal to hazardous quality groundwater.

PRA study

Potential locations for project interventions

Based on the PRA, the villages were categorized based on the depth of thin layer of fresh groundwater overlain by the brackish groundwater. Five villages out of thirteen included in the PRA study were found slightly suitable for skimming dugwells (Table 5). However, the thickness of the layer of freshwater was less than 7.5 m. Therefore, design of dugwell should be based on the recharge to the well and the drawdown pattern in a given location. These villages thus have low potential for dugwells and discharge has to be limited to avoid intrusion of poor quality groundwater.

Two villages out of thirteen included in the PRA study were found highly suitable for skimming dugwells (Table 5). The thickness of the layer of freshwater was less than 15 m. Therefore, design of dugwell should be based on the recharge to the well based on the drawdown pattern in a given location. These villages thus have high potential for dugwells and discharge has to be limited to avoid intrusion of poor quality groundwater.

Six villages out of thirteen included in the PRA study were found suitable for skimming tubewells (Table 5). The thickness of the layer of freshwater was less than 30 m. Therefore, design of tubewell should be based on the recharge to the well based on the drawdown pattern in a given location. These villages thus had medium potential for tubewells and discharge had to be limited to avoid intrusion of poor quality groundwater.

Table 5. Villages having potential for skimming wells based on PRA at MONA Unit, MREP, Bhalwal.

Villages with Potential for Installation of Dugwells		Villages with Potential for Installation of Tubewells
Low Potential	High Potential	
Thathi Noor	Chak No. 15NB	Ratho Kala
Jalar Waraichan	Chak No. 17NB	Head Fagerian
Chak No. 6ML		Nabi Shah Bala
Bonnga Minhas		Dhera Ranjha
Sakacer (jurra)		Moza Dohri
		Chak No. 1 (Phularwan)

Problems and constraints

The farmers' groups in selected thirteen villages of the Target Area identified thirteen problems and constraints (Table 6). The problems and constraints as perceived by the farming community are described as under:

1. Shortage of canal water supplies;
2. Waterlogging and salinity;
3. Non-availability and high price of seed, fertilizers and pesticides;
4. Lack of credit availability;
5. In-effective surface drainage and closure of SCARP tubewells;
6. Limited availability and high cost of labour;
7. Low output prices, insufficient support prices of commodities and delayed payment especially from sugar factories;
8. Water conveyance losses;
9. In-appropriate Mogha size and location;
10. Higher rates of diesel fuel;
11. Unskilled tenants and other related issues;
12. Non-availability of government subsidy; and
13. Non-availability of services from input delivery and other service channels and insufficient infrastructure.

The farmers' groups in different villages identified two to six problems and constraints related to agricultural productivity and production system. Each group was asked to rank the problems. The ranking of problems by different farmers' groups can also be presented for each village. As the objective of the PRA was to identify and select suitable locations for the field research of skimming well and pressurised irrigation technology, therefore ranking of problems per village basis was not provided in this report. However, the percentage of respondents will help to describe weight of different problems and constraints

The problems identified by the farmers' groups of the selected thirteen villages cover a wide range. The thirteen problems identified in total can be described in the following seven broad areas.

- Mogha size and location;
- Water conveyance losses and canal water supplies;
- Waterlogging and salinity;
- Drainage and SCARP tubewells;
- Input availability and high prices (seed, fertiliser, pesticides, diesel fuel, credit and labour);

- Output prices (support price and payments), provision of services and subsidy;
- Infrastructure.

Table 6. Constraints and problems faced by farmers in selected villages at the Mona Unit, MREP, Bhalwal.

Village	Problems and Constraints												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Ratho Kala		-	✓	-	-	-	-	✓	✓	-			
Thathi Noor	✓	✓			-		-	✓				✓	✓
Jalar Waraichan	✓	-	✓	✓	-	-	-	✓		-			
Head Faqerian	✓	-	✓	✓	-	-	✓						
Chak No. 6ML	✓	-	✓	✓	-	✓	-				✓		✓
Nabi Shah Bala	✓	✓	✓	✓	✓	-	-			-			
Dhera Ranjha	✓	-	✓	-	-	-	✓			✓			
Chak No. 15NB	✓	-	✓	-	-	-	✓		✓				
Chak No. 17NB	✓	-	✓	-	-	-	-			-			
Bonga Minhas	✓	✓	✓	✓	✓	-	-						
Sakacar (Jurra)		-	✓	-	✓	-	-		✓	-			
Moza Dohri		✓	✓	✓	-		-		✓	-	✓		
Chak No. 1 (Phularwan)	✓	-	✓	✓	-	-	-			✓		✓	✓
Percent Responded	77	31	92	46	23	8	23	23	31	16	16	16	23
	✓	Problem identified; -					Problem not identified						

Some of these problem areas are not directly related to the project objectives. Therefore, these have to be further ranked considering the project objectives.

Priority issues

Farmers' perceptions were very clear regarding problems and constraints they faced in farming. About 92% farmers groups indicated that non-availability and high price of inputs like seed, fertilizer and pesticides was a major problem. In addition farmers' groups of 46% villages surveyed indicated that lack of credit availability was another concern for the use of improved inputs. Farmers' groups of 23% villages indicated that low output prices, insufficient support price of commodities and delayed payment from sugar factories were also issues related to the farming. Some of the farmers' groups also highlighted the problem of high price of diesel fuel. Therefore, profitability of irrigated agriculture was a major concern being faced by the farming community and all the above stated problems and constraints are related to profitability.

The second major issue relates to the shortage of canal water supplies. Around 77% villages were facing this problem. In addition 23% farmers' groups of selected villages stated that water conveyance losses was a major factor in contributing towards shortage of canal supplies and waterlogging. This is an indicator for the need of additional water supplies from tubewells to meet crop water requirements. The appraisal also indicated that 10 and 67% villages are dependent on tubewells and tubewells plus canal water supplies, respectively. Therefore, tubewell irrigation is an essential element to have reliable and timely supply of water to meet peak irrigation water requirement of crops. Normally, the canal supplies in the peak demand periods of March and September is limited.

Farmers' groups of around 31% villages of the surveyed area indicated that waterlogging and salinity were concerns for agricultural productivity. This figure is very much in line with the national average figure of saline and waterlogged area in the IBIS.

The three main issues faced by the community based on the participatory appraisal are stated as under:

- Profitability of irrigated agriculture as the input prices were higher and farmers were not getting right prices of their produce. The situation becomes critical when they have to face problem in availability of inputs and delayed payment of their marketable products especially the payment by the sugar mills.
- Shortage of canal water supplies and water conveyance losses resulted into reduced surface water supplies at the farm level. Therefore, farmers were forced to use groundwater for supplemental purposes. The use of poor quality groundwater further added to the secondary salinization and sodification of soils. The cost of per m³ of tubewell water was almost twenty times of the canal water, thus it further adds toward high cost of production and reduced profitability.

Waterlogging and salinity was a serious concern in certain areas, where productivity and profitability of irrigated agriculture was being affected drastically.

The above mentioned three issues seem logical. The first issue is beyond the scope of the project. However, the project can address indirectly the other two issues. The analysis by farmers and their perceptions support the research hypothesis to develop technology for skimming fresh groundwater and efficient utilization.

Farmers' perceptions for interventions

Farmers' perceptions for problems and interventions were analyzed (Table 7).

Table 7. Farmers' perceptions regarding interventions in selected villages at the Mona Unit, MREP, Bhalwal.

Village	Interventions				
	1	2	3	4	5
Ratho Kala	95	85	80	90	95
Thathi Noor	100	90	75	90	100
Jalar Waraichan	100	90	100	80	100
Head Fagerian	100	50	80	25	25
Chak No. 6ML	100	100	80	100	90
Nabi Shah Bala	100	100	85	100	90
Dhera Ranjha	100	100	0	100	100
Chak No. 15NB	100	100	80	80	50
Chak No. 17NB	100	85	50	80	90
Bonga Minhas	100	100	80	90	95
Sakacar (Jurra)	100	100	75	100	95
Moza Dohri	100	80	25	70	75
Chak No. 1 (Phularwan)	100	90	60	80	80
Average	100	90	67	83	83

The five major aspects described by the farmers' groups were compared in the thirteen selected villages and are stated as under:

1. Need for increasing cropping intensity and productivity;
2. Willingness of farmers' groups to use groundwater for increased cropping intensity and enhanced productivity;

3. Knowledge on presence of fresh groundwater layer underlain by marginal to brackish groundwater;
4. Need for pumping of fresh groundwater; and
5. Willingness to participate in the project activities.

All the farmers' groups supported the need for increasing cropping intensity and productivity. Around 90% farmers' groups were willing to use groundwater to accomplish the task of enhanced productivity and production. About 67% farmers' groups were having the knowledge of presence of fresh groundwater layer underlain by brackish groundwater. Around 83% farmers' groups identified the need for pumping freshwater and had shown their willingness to participate in project activities.

DAS study

Farmers' awareness on research issues and interventions

Eleven research issues were presented to farmers' groups in seven villages of the Target Area. These eleven issues can be grouped into following five major areas:

- Thin layer of freshwater overlain by the brackish groundwater;
- Intrusion of brackish groundwater into thin fresh layer;
- Concept of skimming well and problem of low discharge associated with this concept;
- Acceptance of dugwell as a skimming well; and
- Advantage of innovative and pressurized irrigation systems for application using smaller discharges.

Farmers were aware reasonably well regarding all the first four areas. For innovative and pressurized irrigation systems, farmers were well aware about furrow irrigation and its benefits from that of basin irrigation. However, most of the farmers were not aware about sprinkler and trickle irrigation systems. Awareness about sprinkler irrigation (21%) system was relatively higher than trickle irrigation (4%).

In general, farmers were aware about research issues as they had access to media (radio and television). The dialogues with farmers' groups indicated that project had addressed some of the real issues faced by the farming community.

Farmers' willingness regarding interventions

Project interventions were presented to farmers' groups to document their willingness regarding these interventions. These interventions include skimming wells, sprinkler irrigation and trickle irrigation. The overall percent of willing respondents was 86, 95 and 32 for

skimming wells, sprinkler irrigation and trickle irrigation systems, respectively.

The higher percent of willing respondents for skimming wells and sprinkler irrigation was mainly due to the issues faced by farmers in relation to secondary salinization and reduced productivity. The lower percent of willing respondents for trickle irrigation was mainly due to less awareness of the system and less area of orchard due to waterlogging. The water-table in the Target Area was high.

In general, farmers were willing to participate in the project interventions as they already had long association with the Mona Project. The Mona Project was able to develop rapport with the farming community, therefore they are willing to collaborate in the project activities. Furthermore, project has addressed some of the real-issues faced by the farming community.

Probability of variation in groundwater quality of handpumps

The overall average of 56 handpumps in terms of total dissolved solids varied between 242 to 2176 ppm with an average of 778. The pH of shallow groundwater varied between 7.1 to 7.8 with an average of 7.3. Therefore, the shallow groundwater was non-sodic, whereas salinity varied considerably in the Target Area.

Probability analysis of total dissolved solids and pH was made for the selected 56 handpumps in the Target Area. There was a wide variability in groundwater quality (Table 8).

Table 8. Variability of shallow groundwater quality of handpumps in selected villages at Mona Unit, MREP, Bhalwal.

Probability (%)	TDS (ppm)	pH
Minimum	242	7.1
5	262	7.1
10	323	7.1
25	435	7.2
50	656	7.3
75	881	7.4
80	957	7.5
90	1083	7.5
95	2016	7.6
Maximum	2349	7.8

The probability analysis indicated that there was only 10% chance that total dissolved solids were higher than 1083 ppm. Thus at 90% probability the total dissolved solids were less than marginal quality. There was 25% probability that the total dissolved solid were less than 435 ppm.

Therefore, the probability was very high for having good quality of shallow thin layer of groundwater.

The probability analysis of pH indicated that there was hardly 10% chance of having pH of more than 7.5. Therefore, there was hardly any chance of having sodic water in the shallow depths (Table 8).

Probability of groundwater quality of private tubewells

The total dissolved solids of private tubewells varied between 155 to 3040 ppm with an overall average of 862. Except one village (Chak #6 ML) the quality of private tubewells in terms of salinity was very good. The pH of these tubewells varied between 7.1 to 7.9 with overall average of 7.4 for the selected 35 tubewells (Table 9).

Table 9. Variability of shallow groundwater quality of private tubewells in selected villages at Mona Unit, MREP, Bhalwal.

Probability (%)	TDS (ppm)	pH
Minimum	155	7.1
5	205	7.1
10	303	7.1
25	443	7.2
50	634	7.3
75	879	7.4
80	905	7.5
90	2227	7.5
95	2233	7.6
Maximum	3040	7.9

The probability analysis of total dissolved solids and pH was conducted for the 35 selected private tubewells. The probability analysis was required to have assessment of variability in quality of groundwater (Table 9).

There was 80% probability that the total dissolved solids were less than 905 ppm. Thus there was hardly 20% chance of having marginal to brackish quality groundwater. In addition, there was 90% probability that pH was less than 7.5. This showed that there was 80% chance of having non-saline and non-sodic water.

Suitability of potential locations for project interventions

Handpumps

The average total dissolved solids of shallow groundwater of handpumps in five selected villages were 426, 773, 690, 661 and 415 ppm for Head Fagerian, Jalar Waraichan, Ratho Kala, Chak #1 (Phularwan) and Thathi Noor villages, respectively. All the selected handpumps in these villages were having total dissolved solids of less than 1000 ppm. The pH of shallow groundwater varied between 7.1 to 7.8. Therefore, these villages are suitable for the installation of skimming wells, especially the dugwells. The quality of deep groundwater in these villages as per SCARP tubewells was marginal to brackish.

The low level of total dissolved solids and low pH confirmed that thin layer of freshwater was non-saline and non-sodic. Thus if this fresh layer is pumped without disturbing the brackish layer underlain by the freshwater, root zone salinity can be sustained on longer-term basis.

Private tubewells

The average total dissolved solids of shallow groundwater of private tubewells in four selected villages were 568, 600, 747 and 683 ppm for Ratho Kala, Chak #1 (Phularwan), Thathi Noor and Moza Dohri, respectively (Table 13). All the selected farmers' tubewells in these villages were having total dissolved solids of less than 1000 ppm and only two tubewells of Moza Dohri were having total dissolved solids of more than 1000 ppm. There was 80% probability of having less than 1000 ppm of total dissolved solids and pH of around 7.5 or less. Thus there were 80% chances of having good quality groundwater if tubewells are placed in less than 50 m depth. In the saline water zone, the quality was brackish even in very thin layers of upto 30 m.

Thus if the fresh layer of groundwater is pumped without disturbing the brackish layer underlain by the freshwater, rootzone salinity can be sustained on longer term basis. This concept is new and emerging and most of the scientists have difficulty in visualizing the concept, which is almost reverse of the traditional approaches, where we are treating the effect rather than the cause. The real cause of secondary salinization is the use of poor quality groundwater. Actually the concepts of land reclamation, soil management and saline agriculture address the effect. Thus there is a need to have awareness among different stakeholders.

Project interventions

The following interventions were identified based on the priority issues and interventions as stated by the farmers' groups and the project objectives:

- Installation of dugwells one each in very thin, thin and medium thickness zones of fresh groundwater;

- Installation of tubewells in medium thickness zone of fresh groundwater;
- Installation of raingun sprinklers systems for crops, vegetables and orchards;
- Installation of trickle irrigation system for young orchards; and
- Furrow irrigation on permanent furrow-bed system.

RECOMMENDATIONS

The DAS results provided sufficient information for the selection of potential locations for the project interventions related to skimming wells and innovative irrigation systems. However, there is a need to conduct detailed survey and design for selected farms to implement the interventions:

- Final selection of farmers (for dugwells and tubewells) in the villages selected under the DAS.
- Detailed engineering surveys to design and layout the skimming wells and pressurized irrigation systems interventions.
- The results of GIS, PRA and DAS will be presented in the workshop to a wider group of scientists/engineers/farmers to finalize the methodology.

REFERENCES

MREP, 1997. Project profile. Mona Reclamation Experimental Project, Bhalwal, WAPDA.