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

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Abstract

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

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

INTRODUCTION

Background of skimming wells and pressurized irrigation systems project

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

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

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

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

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

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

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

Location and purpose of the methodology development

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

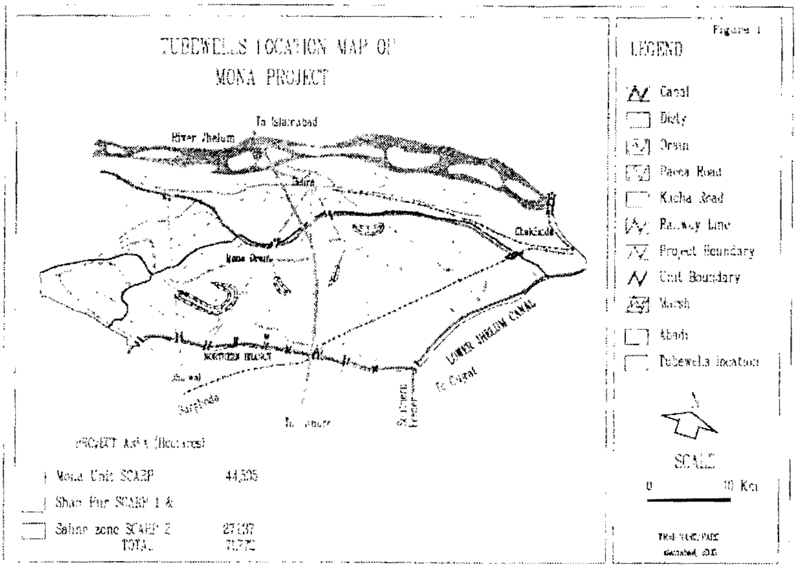

Figure 1. Tubewells location map of Mona project.

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

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

The specific objectives of the methodology development are as under:

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

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

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

Criteria for selection of potential locations

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

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

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

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

GIS ANALYSIS

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

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

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

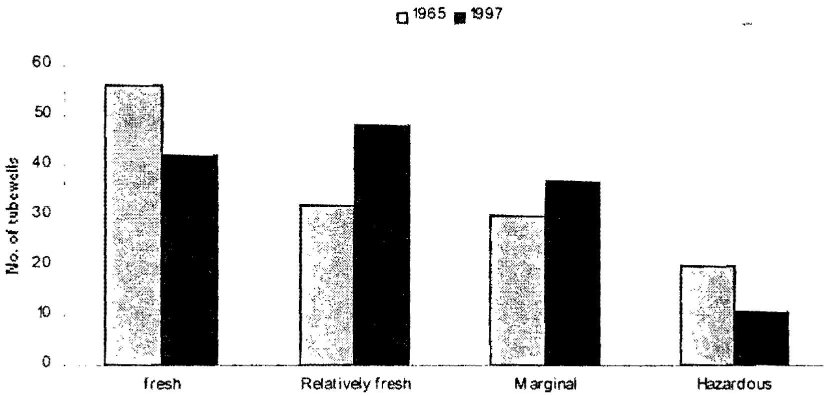

Figure 4. Changes in pumped water quality from 1965 to 1997 of deep tubewells installed in the MREP area.

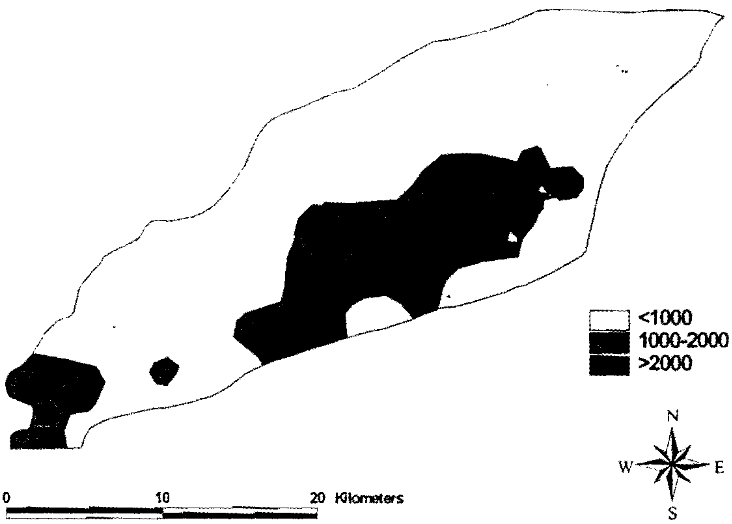

Figure 5. Deep groundwater quality zones in 1965.

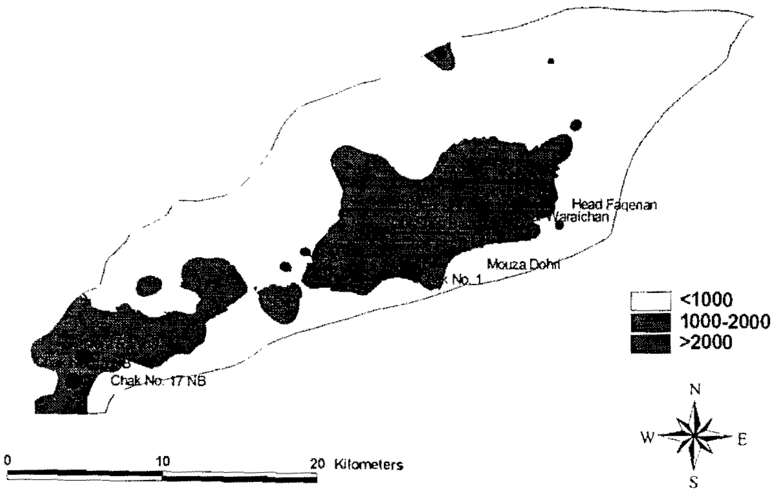

Figure 6. Deep groundwater quality zones in 1997.

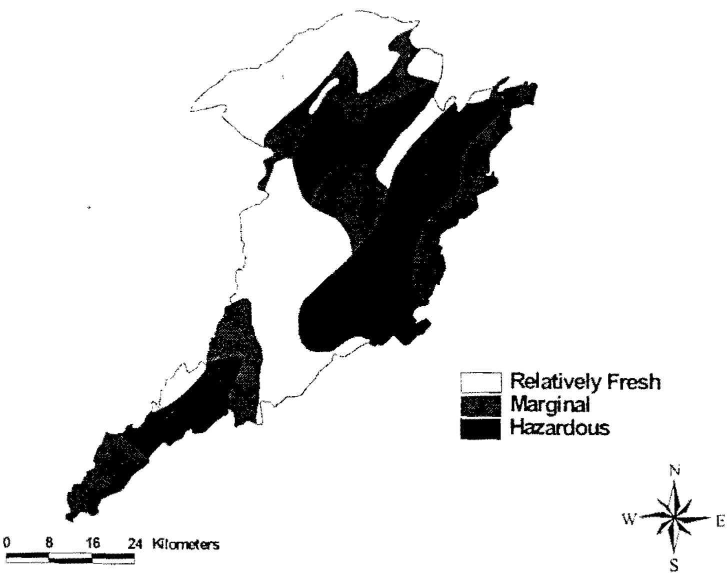

Figure 7. Groundwater quality of the 0-15m aquifer depths across the SCARP-II saline zone.

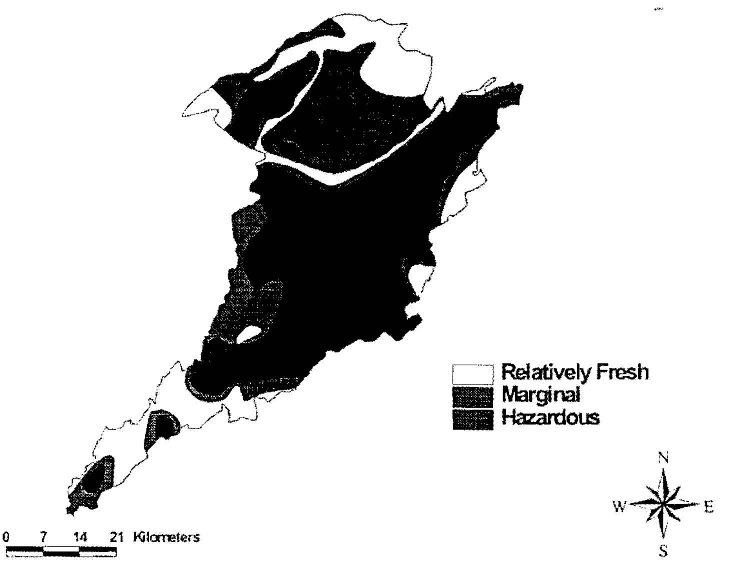

Figure 8. Groundwater quality of the 15-30m aquifer depths across the SCARP-II saline zone.

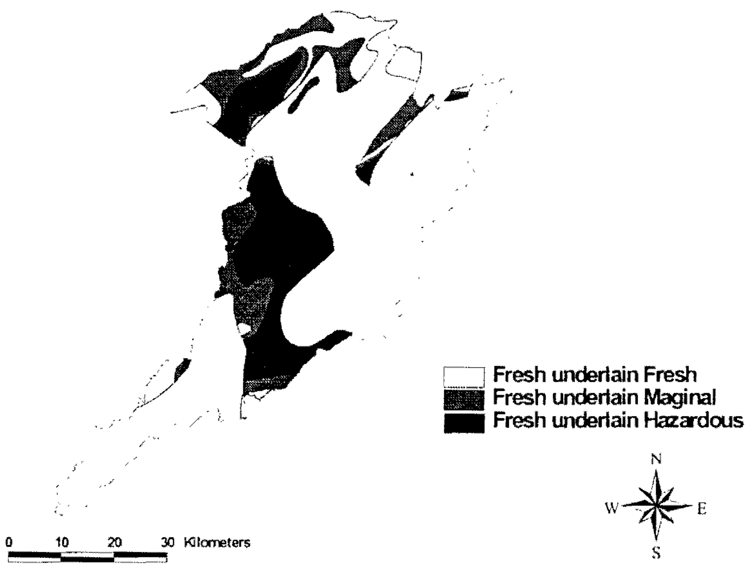

Figure 9. Groundwater quality zones across the SCARP-II saline zone.

Preliminary Survey

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

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

Diagnostic Analysis

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

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

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

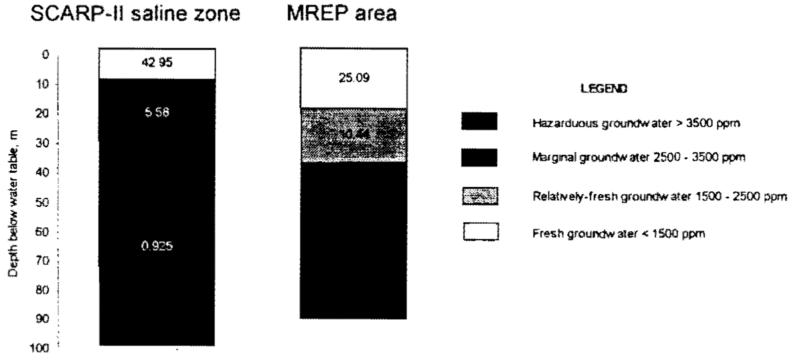

Figure 10. Resistivity survey results for two sites in the MREP area and SCARP-II saline zone.

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

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

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

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

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

PARTICIPATORY RURAL APPRAISAL

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

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

Table 9. Techniques used for participatory rural appraisal.

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

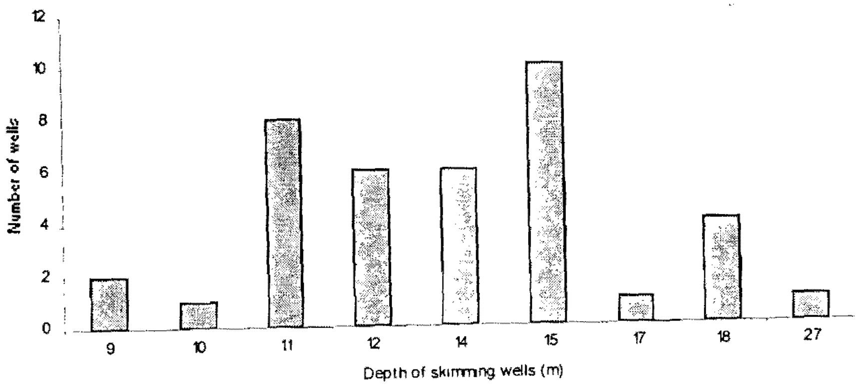

Figure 11. Variations in depth of farmers' skimmming wells.

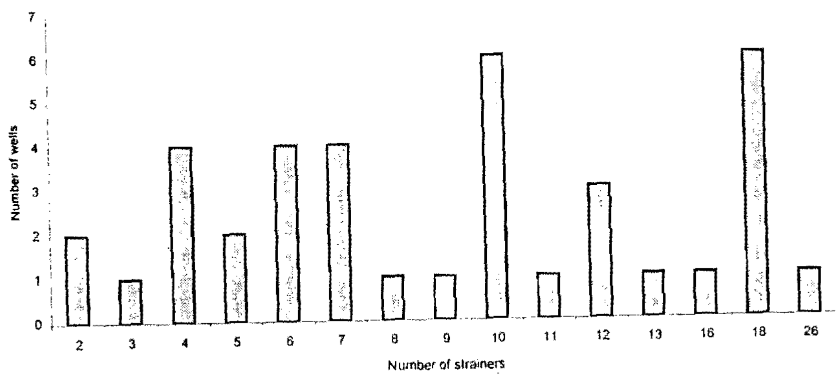

Figure 12. Variations in number of strainers in farmers' skimming wells.

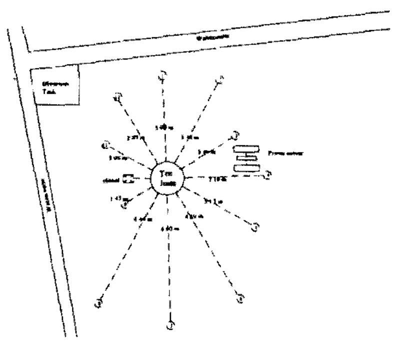

Figure 13. Variations in horizontal distance of strainers from suction point in farmers' skimming well.

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

PROJECT SITES

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

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