# Design Methodology and Refined Guidelines for Managing Saline Groundwater Upconing

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## Abstract

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

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

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

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

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

## INTRODUCTION

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

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

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

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

## DESCRIPTION OF THE STUDY AREA

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

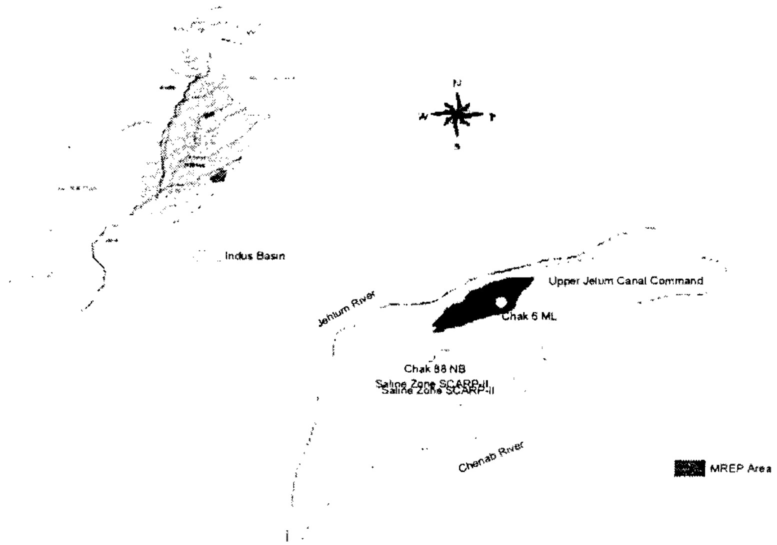


**Figure 1. Location Map of Study Project Area.**

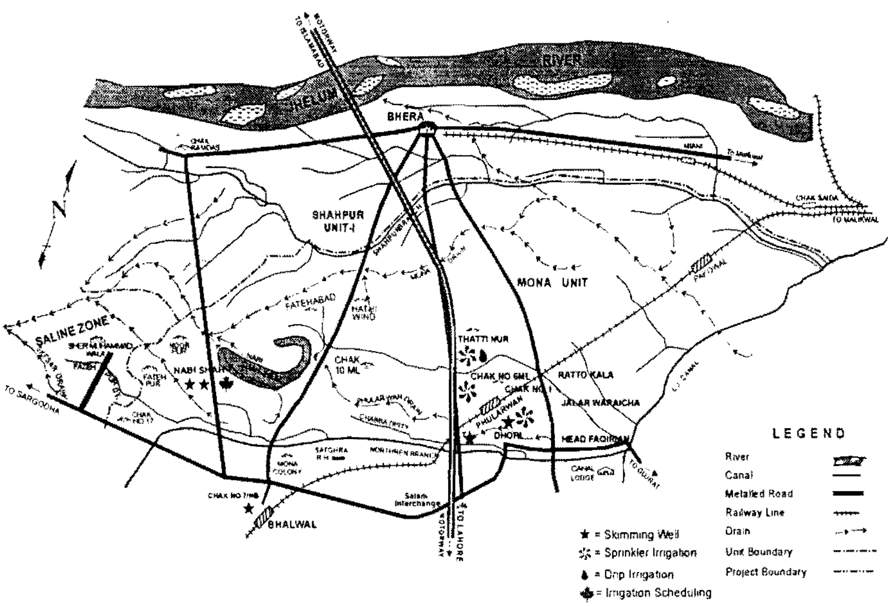


**Figure 2. Location Map of Mona Project Area Research Sites**

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

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

## MATERIAL AND METHODS

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

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

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

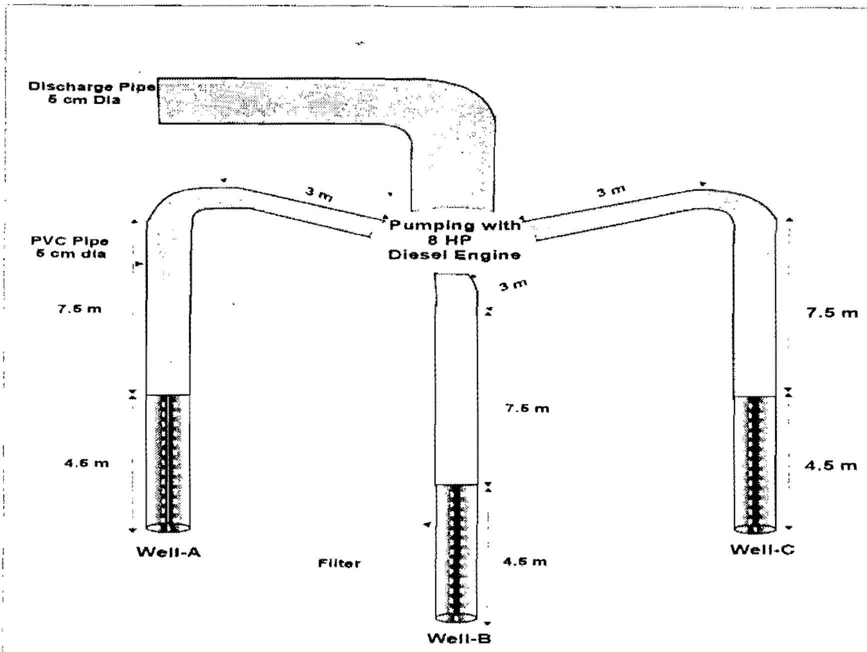


Figure 3. Layout of 3-strainers skimming wells (Chak 6/ML).

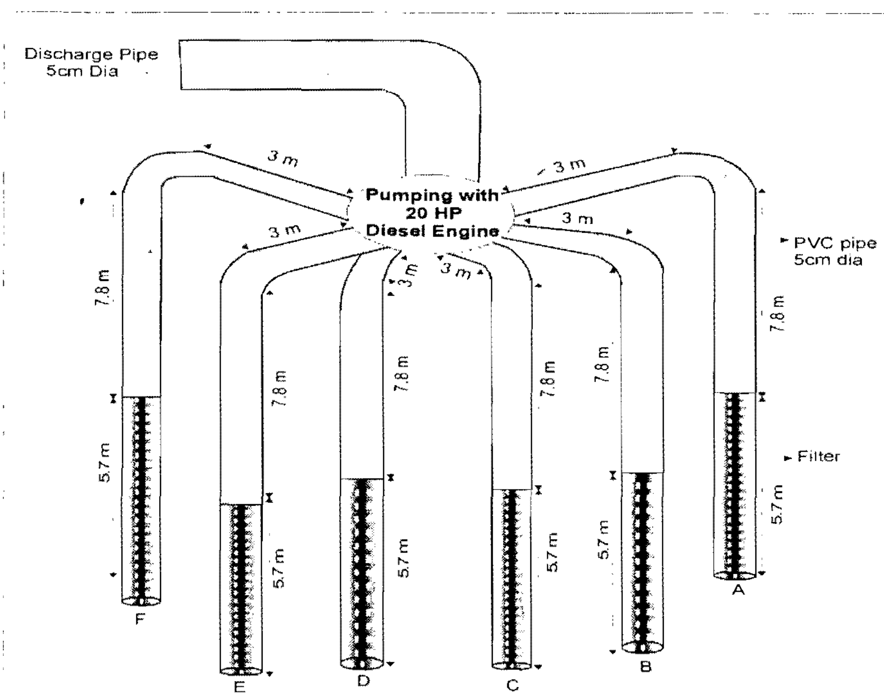


Figure 4. Layout of 6-strainers skimming wells (Chak 88/NB).

The following data was recorded regularly:

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

## RESULTS AND DISCUSSIONS

Various design and operational parameters were studied such as:

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

### Pumped Water Quality due to Intermittent Pumping

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

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

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

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

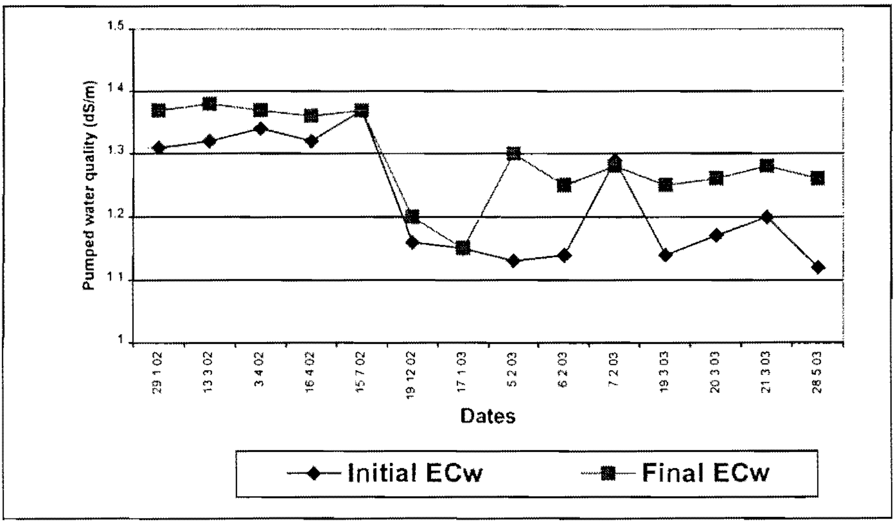


**Figure 5.** **Pumped water quality changes due to long terms pumping at Chak 6/ML.**

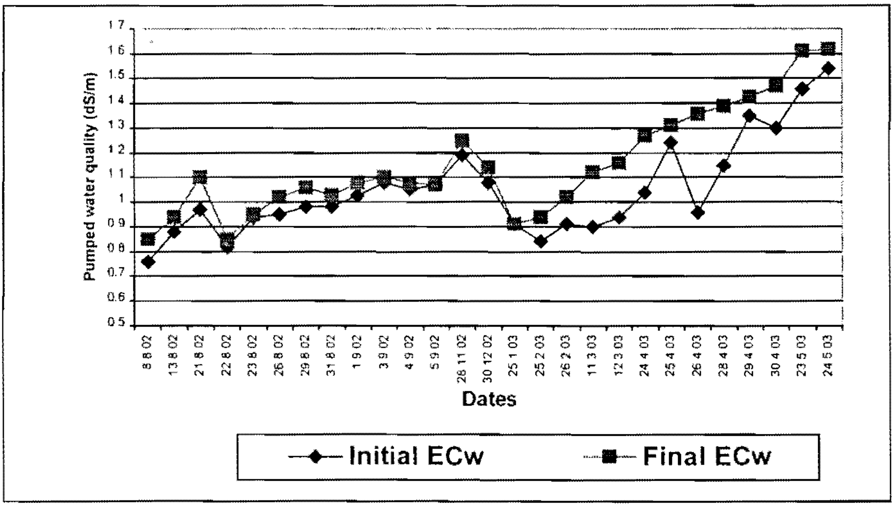


**Figure 6.** **Pumped water quality changes due to long terms pumping at Chak 88/NB.**

## Groundwater Quality with Depth and Time

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

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

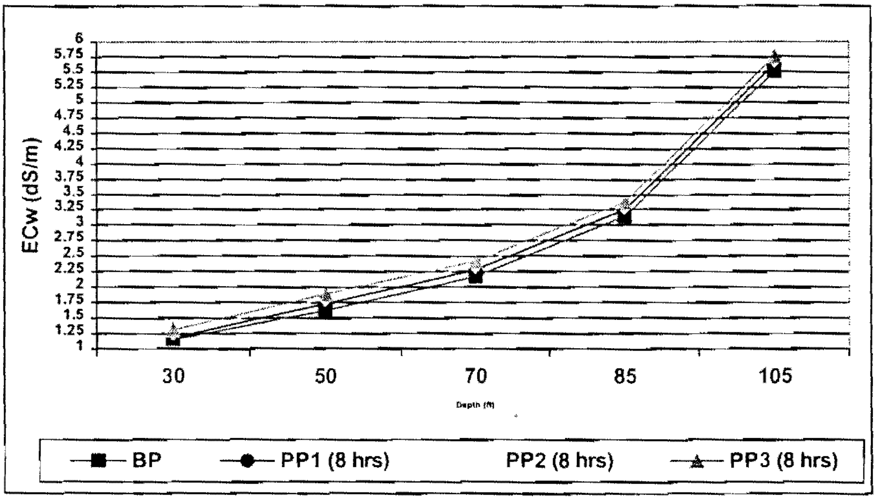


**Figure 7. Effect of pumping on groundwater salinity observation well-A (Chak 6/ML)**

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

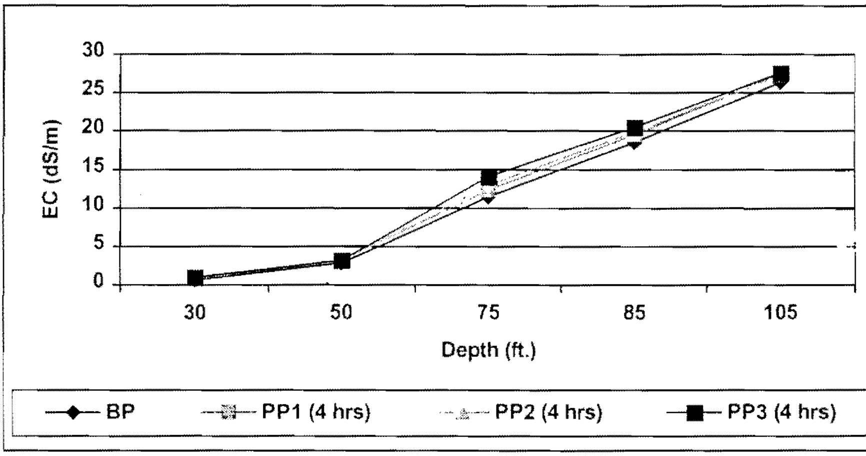


**Figure 8. Effect of pumping on groundwater salinity observation well-A (Chak 88/NB).**

## Watertable Behaviour

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

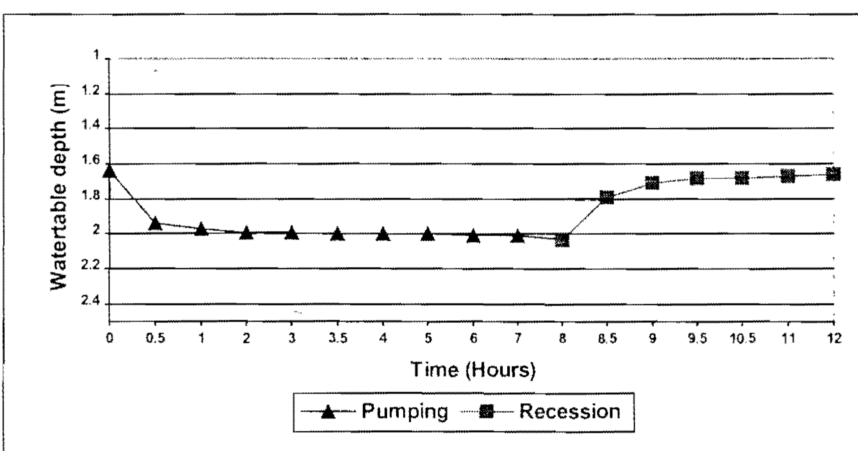


**Figure 9. Effect of pumping on watertable behaviour at Chak 6/ML.**

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

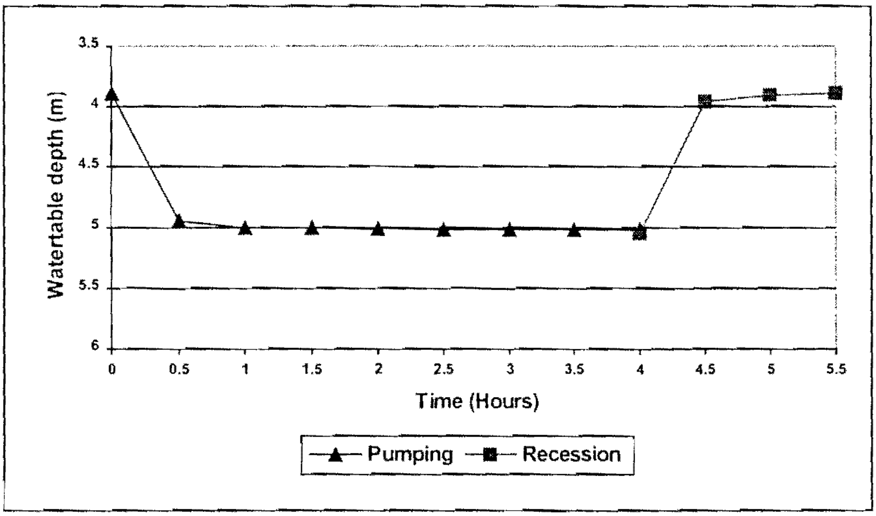


Figure 10. **Effect of pumping on watertable behaviour at Chak 88/NB.**

## Impact on Discharge due to Skimming Well Operation

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

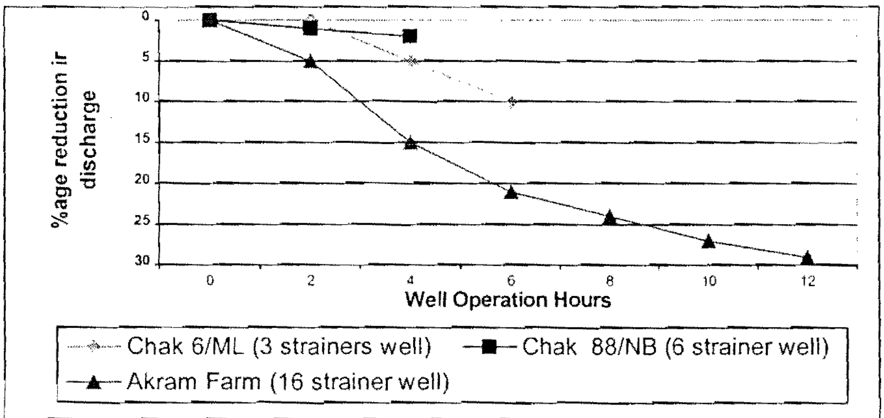


Figure 11. **Reduction in discharge due to skimming well operation with various well configurations.**

## Impact of Number of Strainers on Discharge Rates

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

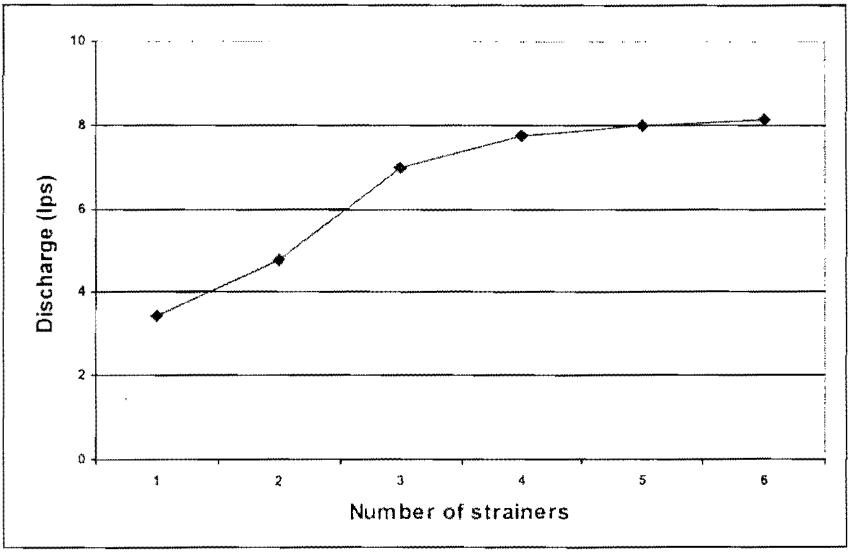


Figure 12. **Variation in discharge due to number of strainers at Chak 88/NB.**

# CONCLUSIONS AND RECOMMENDATIONS

## Conclusions

The following conclusions have been drawn from results of experimentation.

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

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

## Recommendations

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

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

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

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