Management of Saline Water Upconing into Overlying Shallow Fresh Ground Water Aquifers Using a Three Dimensional Finite Element Model

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Abstract

Due to intense land cultivation, water overexploitation and unbridle population growth, there has been a continuous decline in per capita availability of land and water resources. Especially, the water resources are dwindling day by day. It is projected that almost all future increases in food production need to be attained vertically; this could be achieved by growing additional crops during a given year on the same land with judicious use of available water resources. Recent shortage in surface water supplies leaves no other viable option but dictates to exploit the groundwater resources to supplement the declining irrigation supplies. In many areas, the fresh groundwater is floating over a dense saline layers hence appropriate techniques are required for proper skimming of such waters. Over exploitation and improper skimming well design would result in upconing of saline water into the fresh ground waters resulting in skimming of poor quality groundwater that ultimately would deteriorate the fertile agricultural land.

This study has been conducted to simulate the ground water flow and solute transport using Direclet boundaries. A three dimensional finite element model GWSFLOW has been calibrated against the field data using a double bore skimming well. The computer model was run for different well configuration ratios, i.e. skimming well filter length and total thickness of fresh groundwater below the bottom of the well. The calibrated model was used to determine the impact of different pumping rates on groundwater quality. The results of this study will provide a guideline to the farmers, managers, scientists and engineers in the country and elsewhere to adopt appropriate skimming well designs to harness the fresh water overlying saline water for irrigation without compromising on the quality of land and water.

Introduction

At present, Pakistan is facing the dilemma of water deficiency and the problem will aggravate further in the years to come due to continuing dry hydrologic cycle. In order to cope up the shortage and to meet the increasing water demands, the development, management, proper maintenance and utilization is the pursuing need of the country. The shortage in available surface water supplies dictates to exploits the groundwater resources. A recent study by Haq (2002) reveals that surface water shortage reduces to 51% during winter months which significantly affects the rabi crops with virtually no effective rainfall during the season. It has been observed that on the average 35% more tubewells were installed in the drought years as compared to the normal rainy years (Latif and Naghmi, 2004) without considering aquifer quality that has long term consequences. In many areas the fresh groundwater floats over the dense saline layer which requires a scientific approach to skim it.

Skimming well technology is getting popular in such areas and fresh groundwater is pumped through the partially penetrated wells without inducing the native saline water intrusion. Skimming wells provide flexible and reliable water supply, control water levels below the

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crop root zone in the water logged areas. Statistics reveals that more than 30% of the irrigated area of the country has potential to install the skimming wells to exploit the fresh groundwater resources (Zuberi and Mcwhorter, 1973; and Ashraf et al., 2001). However, over drawing through skimming wells would lead to mining of fresh layer and would result in upconing from under laying saline layer. The application of such water would ultimately deteriorate the quality of fertile agricultural lands.

In this study, an attempt has been made to simulate the groundwater flow and solute movements toward the double bore skimming well using a three dimensional GWSFLOW model. The model calibrated has been used to assess the impact of different well discharges and designs on the groundwater quality.

Materials and Methods

The study area is located in district Khairpur, Pakistan. The area is irrigated by Khairpur East Canal that takes off from the left side of Sukkur Barrage on Indus River. A double bore skimming well installed in a sandy unconfined aquifer was selected for this study. The soil lithology and groundwater salinity profile at study site is shown in Figure 1. Two wells each with 19.5 m length including 10.0 m filter (L_F) were spaced at 12.2 m distance. The wells were connected to operate as a single delivery unit. Total thickness (L_T) of useable groundwater with salinity ranging between 600 and 1568 ppm extends up to 28 m depth; hence a cushion of 7 m prevailed above the saline layer.

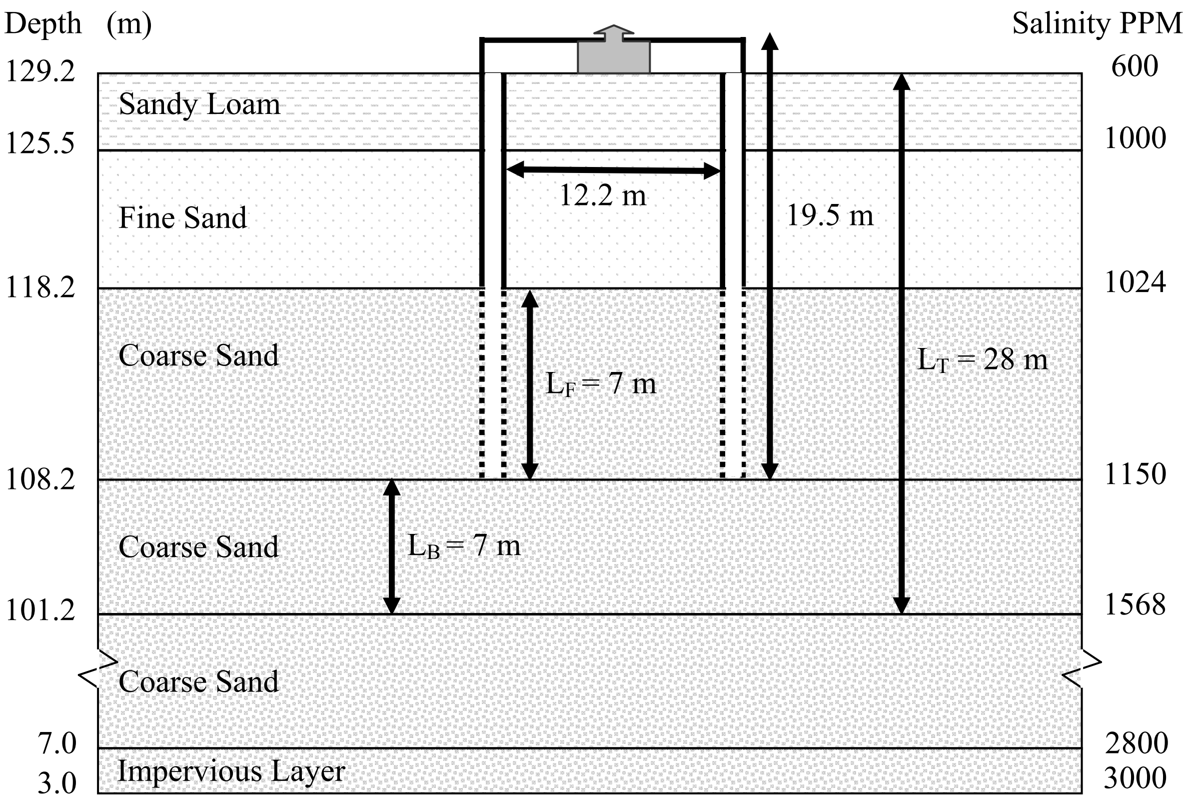

Figure 1 Soil lithology and groundwater salinity profile at the study site.

The observation wells were installed in the vicinity of the double bore skimming well to monitor the pumping effects. The Standard Operating Procedure explained by Haaker, (2001) was adopted to collect pumping test data. The draw downs were measured at observation wells and the water samples were collected from the skimming well to measure the changes in water quality with time. A three dimensional finite element model developed by Chandio (1983) which simulate the saturated groundwater flow and solute movement has been calibrated against observed data.

The data domain required in the model was based on the water table elevation, observation well location, well configuration and groundwater salinity. The domain was divided in seven vertical layers, subsequently; each layer was sub-divided into 14 x 14 node points and 13 x 13 elements. This domain structured to 364 nodes for constant head boundaries and 508 nodes for constant salt concentration boundaries, leaving 1008 nodes to compute unknown heads and 864 nodes to compute unknown salt concentration. With this domain discretization, the size of equation solver matrix for heads became 1008 x 1008 and for salt concentration 864 x 864.

The values of aquifer parameters like hydraulic conductivity in x, y, and z directions, specific storage and dispersion coefficient (longitudinal and transversal) were determined during model calibration. For each soil texture the values for hydraulic conductivity were assumed and model was run for steady state conditions. If a significant difference between observed and modeled values were found then model was re-run by readjusting hydraulic conductivity values until observed and computed values converged at all observation points. Once calibration for hydraulic conductivities was achieved then model was rerun for non steady state condition to determine the values of specific storage. In this case, calibration at observation points was made at various time-steps. Similarly, the calibration for solute transport was based on the determination of dispersivities in the same way as used for hydraulic conductivities, however, instead of heads, salt concentrations were used.

Results and discussion

The observed and computed heads against distance under steady state are illustrated in Figure 2a while those under transient condition for the time intervals of 10, 300 and 1040 minutes are shown in Figures 2b, 2c and 2d, respectively. The model computed values are pretty close to observed ones under steady state condition and two lines almost overlap each other. The similar trends were found under transient flow condition for all three time steps. These results suggest that model is quite effective in simulating groundwater flows.

Figure 3 shows salinity of water samples collected during pumping at different time steps to detect the saline water intrusion. The data reveal that salinity increases as pumping time increases. In the beginning, salinity of pumped water was 1134 ppm which increased to 1246 ppm after 1060 minutes of continuous operation. Though it is within the useable range but might become harmful if the pumping continuous for longer periods. The observed data was used to calibrate the model and the results are plotted in Figure 3. The results depict that the model under estimates salinity for initial 220 minutes and slightly overestimates afterwards, however the difference is diminutive and will not affect the overall groundwater quality. Results further reveal that there is sharp increase in the water salinity during initial 10 hours which is obvious from the slope of the curve, however, the change in salinity with time is negligible afterwards.

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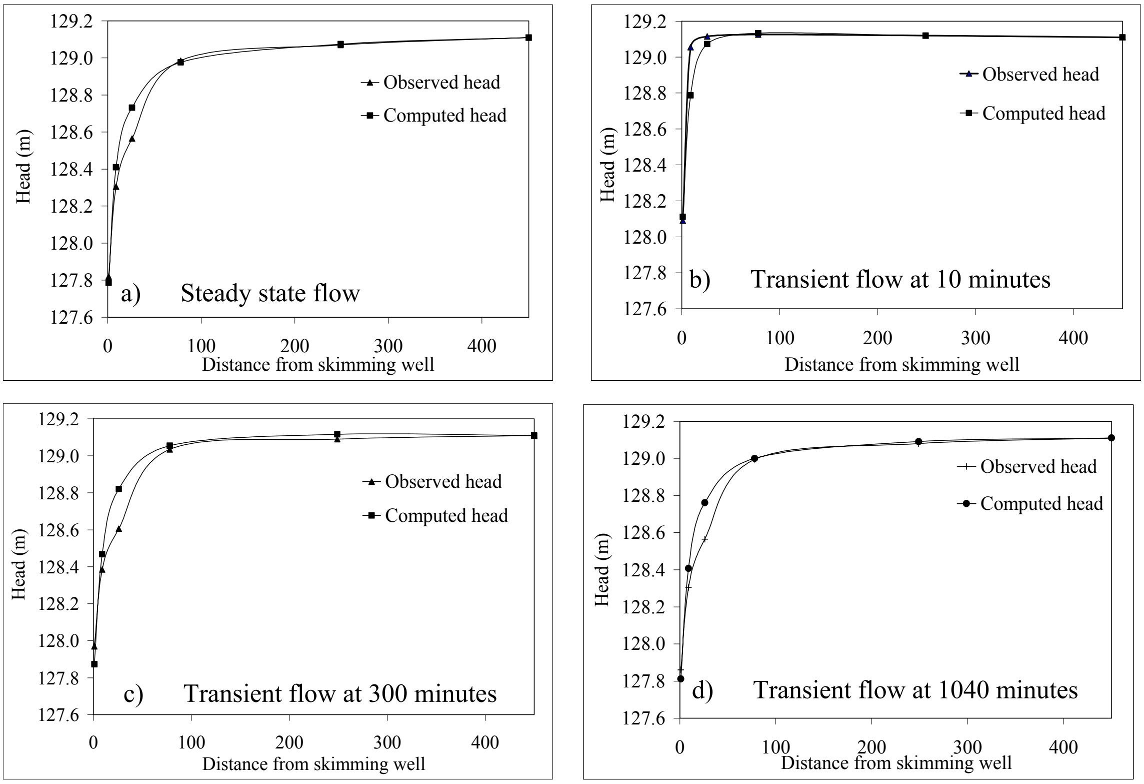


Figure 2. Computed and observed heads as a function of distance from skimming well

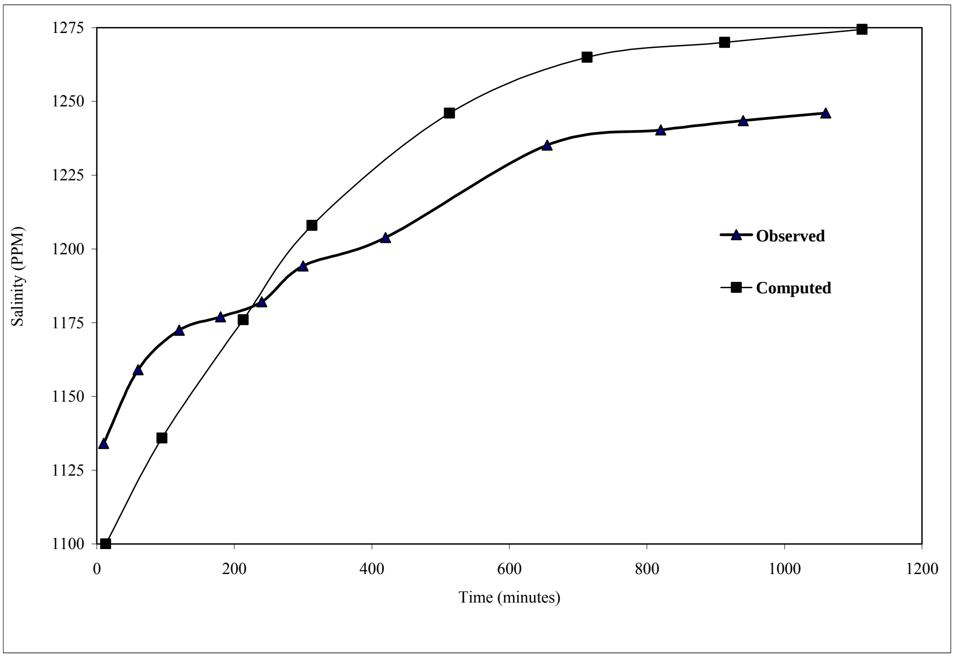
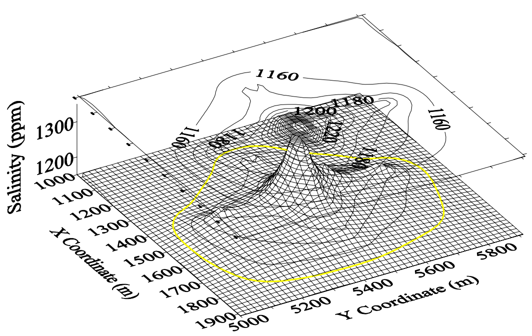


Figure 3. Observed and computed salinity of pumped water with time

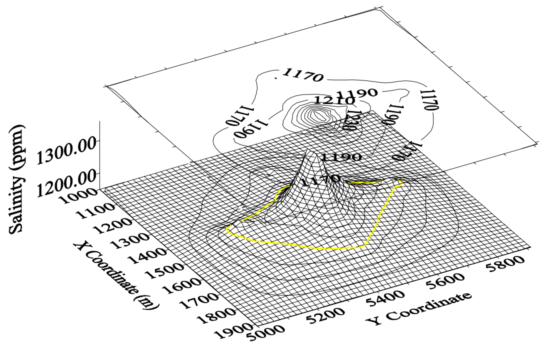
Impact of well discharge

The calibrated model was run for different well discharges to assess the water quality at the bottom of the skimming well. The changes in the groundwater salinity were plotted to form the contours. The results on contour formation for different flow rates are shown in Figures 4 a-c. The salinity plume rises from 1190 ppm at 200 m distance from the skimming well to 1365 ppm at the bottom of well when well discharges at 1.44 m^3/min (Figure 4a). The contours with salinity values > 1190 ppm were drawn to calculate the affected area below the well bottom. It was calculated that they cover about 12.5 hectares. Similarly, the contours drawn with well discharging at 1.8 m^3/min are shown in Figure 4b. The results show that the salinity contour with 1190 ppm starts at 255 m distance and its apex reaches to 1385 ppm that covers about 20.5 hectares. However, if well discharge reduced to 75% (i.e. Q = 1.08 m^3/min) then the salinity of groundwater ≥ 1190 ppm covered only 6.8 hectares as could be depicted from the Figure 4c.

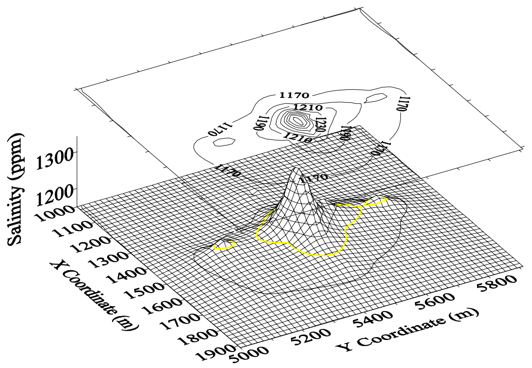
The impact of single bore well instead of double bore skimming well discharging at 1.44 m^3/min was tested and the results are illustrated in Figure 4d. It was observed that the salinity increased to 1377 ppm at the bottom of the well. The contours with groundwater salinity ≥ 1190 ppm and ≤ 1377 ppm divulge that about 15.9 hectares were affected under single well operation.



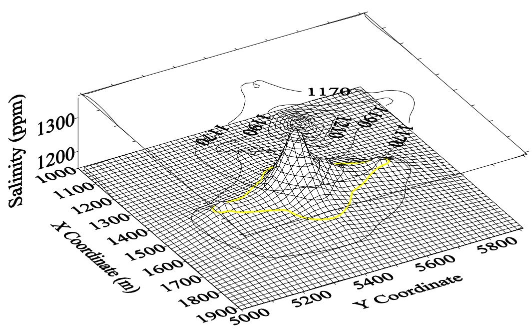
a) Q = 1.44 m^3/min, Double bore



b) Q = 1.80 m^3/min, Double bore



c) Q = 1.08 m^3/min, Double bore



d) Q = 1.44 m^3/min, Single bore

Figure 4. Groundwater salinity contours at the bottom of the well screen

Impact of well configuration

Different well configurations such as well filter length and well penetration ratios were tested to simulate groundwater salinity. As the filter length increased from 10.0 m to 14.2 m towards lower end of well, it reduced the thickness of the useable groundwater from 7.0 m to 2.8 m and resulted in a well penetration ratio (L_F/L_T) of 0.5 instead of 0.35. Under this scenario the salinity of groundwater increased to 1499 ppm. However, when the filter length increased from 14.2 to 18.3 towards the ground surface end while keeping the same (2.8 m) thickness of useable groundwater, the salinity did not increase and remained almost same as in previous case. This suggests that the length of useable groundwater below the bottom of the well is more dominant then the well penetration ratio.

Conclusions

The calibrated model simulated groundwater flow and solute transport for different scenarios with fair degree of accuracy. Once the model is calibrated and validated, it can be used at different sites with similar aquifer characteristics. In this study, it was observed that GWSFLOW model can effectively quantifies the groundwater quality for different pumping rates and well configurations.

The saline water intrusion in the fresh groundwater layer is directly related to well discharge. Results suggest that the low discharge double bore skimming well offers better alternative to control the saline water upconning. Length of useable groundwater below the bottom of the well is a key parameter to suppress the salinity mound developed at the bottom of the well. It was further observed that the farmers are unaware of saline intrusion process below the ground surface until saline well effluent affected the crop yield and degraded the fertile agricultural lands and the ultimate result is to abandon the well.

Acknowledgements

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