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Model assisted design of scavenger well system

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SUMMARY

A scavenger well system is designed to skim/pump fresh water from a fresh–saline aquifer. It consists of a production and a scavenging well in close vicinity tapping the shallow fresh water and the deeper saline water zones respectively. These wells pump fresh and saline waters from the same site simultaneously without mixing, through two separate discharge systems. The rise of interface (upconing) due to pumping of fresh water well is countered by the pumping of saline water well. This leads to a reduction in the upconing of the interface. A general numerical model has been developed for simulation of saltwater transport induced by pumpage from a scavenger well system. The model has been validated against an analytical solution and a set of published field data. The numerical model is invoked to develop two Artificial Neural Network (ANN) models of the relevant state variables viz. production well salinity and drawdown at well face. These ANN models are used for optimizing the scavenging discharge with respect to the position of the two screens and subject to the constraint on production well salinity and the drawdown to ensure functionality of the production well screen.

1. Introduction

Fresh water occurs over the underlying saline water in coastal aquifers as well as in many inland aquifers. When the fresh water is pumped from such a fresh–saline aquifer, pressure head in the vicinity of the well is lowered and consequently the underlying saline water rises towards the well to maintain a hydraulic equilibrium. This phenomenon called upconing, may increase the salinity of the pumped water. In such a scenario, the wells must be designed to *skim* fresh water from the aquifer without significantly *disturbing* the underlying salt water. Traditionally, this has been accomplished through partially penetrating wells that tap only the upper portion of the freshwater zone, leaving adequate cushion for the inevitable upconing of the freshwater–saltwater interface. This strategy may work well for the aquifers with thick enough fresh water zone. On the other hand the performance of the partially penetrating skimming wells in shallow fresh–saline aquifers with the fresh water thickness less than 30 m, may be severely jeopardized because of relatively quicker rise of the underlying salt water (Asghar et al., 2002).

One of the potential solutions to this problem is scavenger well system wherein the pumping from the production well is accompanied by salt water pumping from a *scavenger* well in the vicinity. The simultaneous scavenging pumpage attenuates the upconing of the interface, and hence improves the quality of the water emanating from the production well (Long, 1965; Zack, 1988 and Ali et al., 2004). In the lower Indus plain of Pakistan more than 400 scavenger wells have been installed to tackle water logging and soil salinity problems (Stoner and Bakiewicz, 1992; Sufi et al., 1998 and Ali et al., 2004).

The scavenger well system consists of two wells viz. production well and scavenger well, in a single bore hole or side by side. The production well taps the fresh water zone while the scavenger well taps the saline water zone. These wells pump fresh and saline waters from the same site simultaneously without mixing, through two separate discharge systems as shown in Fig. 1. The saline water pumped from the scavenger well needs to be disposed off. The rise of saline water due to upconing caused by pumping from the production well is countered by the downconing of the interface caused by pumping from the scavenger well. The pumping rates from the two wells are adjusted in such a way that the underlying saline water does not intrude into the production well. While an under-pumping from the scavenger well may cause salinization of the production well, an over pumping apart from increasing the costs of pumping and the saline water disposal, also creates downward gradient in the fresh water zone leadings to wastage of fresh water. So it is important to optimize the scavenging discharge.

A variation of the scavenger well system termed as the *doublet well* system was proposed and patented by Jacob in 1965

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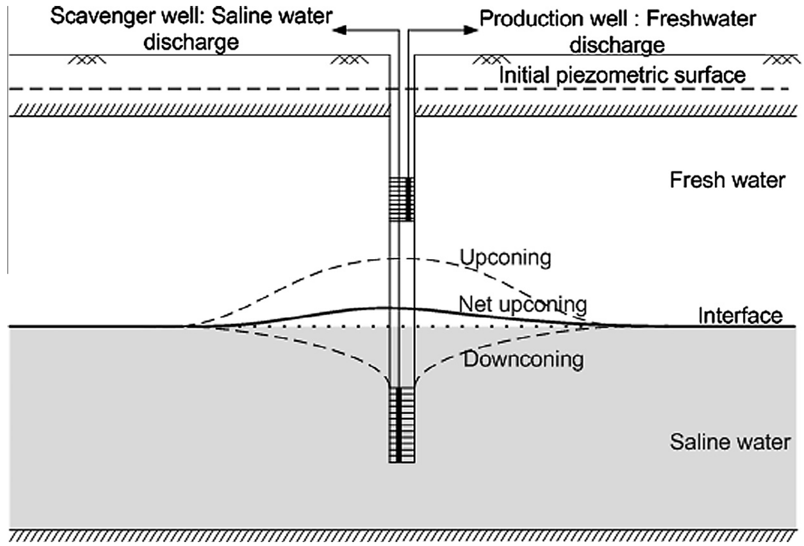

Fig. 1. Upconing under scavenger well.

(Wickersham, 1977). In this system the scavenging discharge is pumped back to a deeper formation. Field investigations for scavenger well applications are reported from Louisiana, USA (Long, 1965) and Puerto Rico (Zack, 1988). It was concluded that salinity of pumped fresh water depends on sum of discharge rates of fresh and saline water, locations of pumping screens, and hydraulic conductivities. Fukumori et al. (1986) developed a numerical model based on sharp interface approach to study the flow behavior in response to simultaneous pumping from the two wells. Birch and Wonderen (1990) found the scavenger well system to be economically effective provided the freshwater lens thickness is less than 90 m.

Beeson et al. (1992) conducted field experiments at four scavenger well sites in the lower Indus Plain with an objective to intercept canal seepage, recover fresh water and exercise salinity control. Sufi et al. (1998) employed a physical model and 3-D finite element (FE) numerical model VDGWTRN (Sakr, 1995) to evaluate the relative performance of different techniques of freshwater skimming. Zack and Lara (2002) conducted field experiments on scavenger well installations in Cozumel island aquifer of Mexico. They concluded that scavenger well installations effectively improved the pumped water quality by controlling the upward advance of saltwater. Aliewi et al. (2001) examined the movement of fresh and saline waters underneath scavenger wells in the aquifers of Gaza and Jericho using the finite element code SUTRA (Voss, 1984) and finite-difference code RASIM (Aliewi, 1993). The study showed that saltwater upconing in Gaza aquifer can be controlled by pumping from the saline water zone at half the rate of the freshwater discharge.

Kitching and Shearer (1991) applied SUTRA code to develop design criteria and operational strategies of scavenger wells appropriate to the hydro-geological conditions in lower Indus basin. Later investigations related to modeling studies in the Indus basin found that the SUTRA model could not adequately simulate the behavior of fresh and saline groundwater aquifer under a scavenger well (Aliewi, 1993 cited in Ali et al., 2004). Particularly, it could not handle the temporal changes in the dispersion zone (thickness and salt concentration distribution with time) near the well. Ali et al. (2004) studied the hydraulic performance of two scavenger wells in the lower Indus basin, using MODFLOW (McDonald and Harbaugh, 1988) and MT3D (Zheng and Wang, 1999).

Shearer and Wonderen (1992), Aliewi and Mackay (1998), Sufi et al. (1998), Aliewi et al. (2001) and Ali et al. (2004) studied the performance of the scavenger well system numerically. Aliewi and Mackay (1998) studied numerically the influence of position of production and scavenger well screen position on the production well water quality and concluded that the placement of the screens on the upper part of the aquifer is more effective. The reported numerical studies generally invoke the regional (cartesian coordinates) models that usually do not capture the rapidly changing pressure and concentration gradient in the vicinity of the well system.

1.1. Present study

The design of the scavenger well system involves stipulating the scavenging discharge and position of scavenger and production well screens for a given production well discharge and hydrogeological parameters. However, the designs so far have been based upon the field iterations or ill-suited regional numerical models. The present study is aimed at developing Artificial Neural Network (ANN) model of the scavenger well system, and linking it to an optimizer to arrive at an optimal design of the system. The ANN model facilitates the estimation of two state variables viz., production well salinity and the drawdown both at the steady state, for given production well and the scavenging discharge, screen locations, and the hydrogeological parameters. To train and validate these models, a numerical model of flow and transport in two-dimensional axis-symmetric cylindrical coordinate system is developed. The model permits computation of the time variation of the salt concentration in the production well water and the drawdown, for given production well and scavenger well discharge rates, hydrogeological parameters, and geometrical parameters of the scavenging well system. The optimization comprises minimization of the scavenging discharge subject to constraints including that of restricting the drawdown.

2. Numerical model

A general model of flow and salt transport towards a scavenger well system tapping a horizontal confined fresh–saline aquifer is developed. While developing the model, the scavenger well system is viewed as a single well with discharge intensity varying along its length. This strategy renders the proposed model quite applicable to two types of skimming well systems viz. partially penetrating and scavenger well system. In case of a scavenger well system,