OPTIMUM STRATEGIES OF GROUNDWATER PUMPING REGIME UNDER SCAVANGER TUBEWELLS IN LOWER INDUS BASIN, SINDH, PAKISTAN

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ABSTRACT

In general Pakistan is an agricultural country, most of its area including lower Indus basin (LIB) lies in arid and semi-arid zones, where irrigation by canal water and groundwater is only option. Due to continuous seepage from canal irrigation network and infiltration from irrigated lands; without adequate provision of natural and artificial drainage and its appropriate outlet, water-logging and soil salinity problems were developed.

To combat these problems and to supplement canal water irrigation, 357 scavenger tubewells were installed in two districts (Nawabshah and Sanghar) of Sindh, Pakistan, under Left Bank Outfall Drain (LBOD) stage-1 project with the cost of US$ 12.75 funded by World Bank. In this paper, already calibrated groundwater flow model (MODFLOW) was linked with solute transport model (MT3D), and several simulation runs were performed using range of solute transport parameter of this region till the MT3D model was calibrated successfully for two sampled sites located at JRS-57 and JRS-60 tubewells during pumping tests.

Using the calibrated MT3D model, various scenarios were developed using suitable fresh-saline water pumping ratios and daily operational hours for achieving optimum management strategy for better control of fresh and saline water interface.

The study revealed that optimum management strategy to control saline water and fresh water interface was to operate scavenger wells at the operational factor of 0.55 (i.e. 13.2 hr/day) for JRS-57 and 0.5 (i.e. 12 hr/day) for JRS-60 with recovery ratio of 0.5:0.5 for both the tube-wells.

Keywords: Groundwater, Scavenger tubewells, MODFLOW, MT3D, Lower Indus Basin (LIB)

1 INTRODUCTION

Agriculture is the largest economical segment of Pakistan; about 90% agriculture production comes from irrigated land. Control irrigation system was introduced after construction of Sukkur Barrage in 1932 in Lower Indus Basin (LIB), which brought significant increase in agricultural production but on other ends continuous seepage from canals network and infiltration on agricultural lands without adequate drainage conveniences has created the problems of water-logging and salinity.

Left Bank Outfall Drain (LBOD) Project proposed in 1965 (WAPDA, 1965), and was started working in 1985 on left side of the Indus river in LIB covering an area of 1.275 million acres to provide drainage and supplement canal water irrigation (MMP, 1985). The activities of LBOD Stage 1 Project included the remodeling of canals and agricultural drains; and the components of the activities incorporated, construction of surface drainage net-work; installation of drainage tubewells; sub-surface tile drainage and interceptor drains; and construction of scavenger tubewells; together with access of power supply and necessary disposal infrastructure (Mott MacDonald, 1998). The prime areas covered by this Project included Nawabshah (Now Shaheed Benazirabad Bhutto), Sanghar and Mirpurkhas districts of Sindh province, Pakistan (Fig. 1).

As the varying depths of fresh ground water lenses have overlain highly saline ground water lenses in LIB. The traditional/skimming tube wells are normally constrained to those areas where the fresh ground water lenses are less than 90 m. In such circumstances pumping of skimming wells creates a problem of saline water upconing. To avoid upconing phenomena, scavenger tube wells were suggested to make sure sustainable fresh water recovery, and to achieve drainage objectives (Jones et al., 1994). Scavenger-well within the Caribbean Region has demonstrated three or four times more withdrawal of fresh water constantly without threat of upconing (Hama, et al., 2007).

Scavenger well consists of either having a single borehole with two pumps each in fresh and saline water aquifer or doub1e boreholes very close to each other, drilled in fresh and saline aquifers with separate pumps and motors. In the study area, first type of scavenger wells were constructed (Fig. 2). The pumped fresh water is used to supplement canal water irrigation while the saline water is disposed into safe disposal place through surface drains net-work.

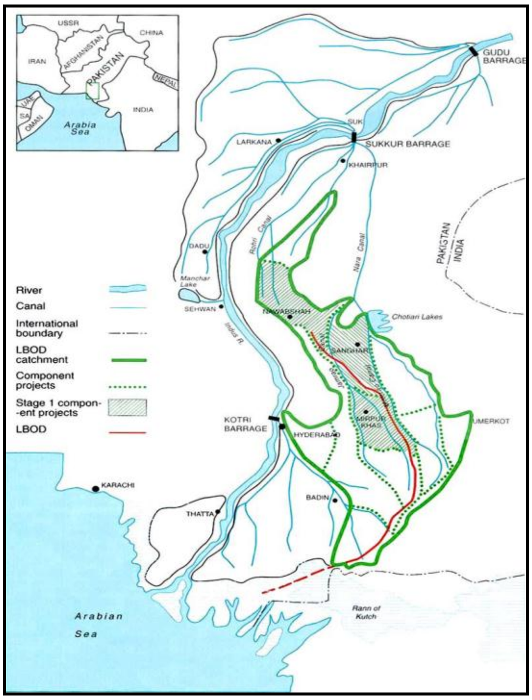


Fig. 1: Map of LBOD stage 1 project

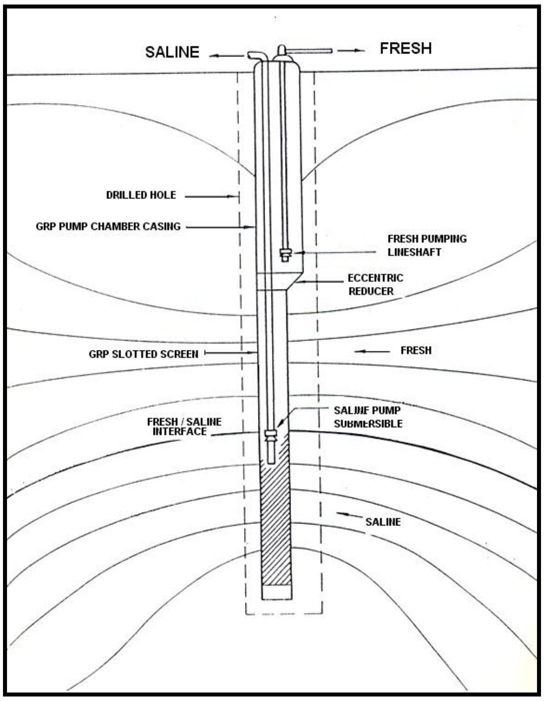


Fig. 2: View of scavenger well design

357 scavenger wells were constructed in Nawabshah and Sanghar districts, with the equipment cost of US$ 12.75 million (WAPDA, 1993). Kumbhar et al. (2002) conducted interviews from farming communities, and concluded that the escalation of land fertility which increases the reclaimed land area and its prices justifying the installation of scavenger wells.

As per suggestion of Chandio et al. (1985), the scavenger wells not only require high construction price but also need trained labor and continuous supervision. In addition, Ali et al. (2004) described that disposal of saline drainage effluent and seepage through disposal channels to adjacent agricultural land pose serious threat for scavenger well project sustainability.

Keeping in view the above points, present study was carried out to evaluate the effectiveness in stabilizing the interface in response to the dual pumping, computer modeling effect of different combination of fresh-saline water ratios and daily operational hours of already installed scavenger wells on movement of fresh-saline water interface. The evaluation was intended on modifying operational strategies to ensure suitable fresh water recovery achieving drainage objectives without disturbing fresh-saline water interface.

2 RESEARCH METHODOLOGY

2.1Study Area

Two scavenger wells (JRS-57 and JRS-60) installed along the right side of Jamrao canal under the boundary of Nawabshah component of the LBOD stage 1 project were selected as experimental sites (Fig. 3).

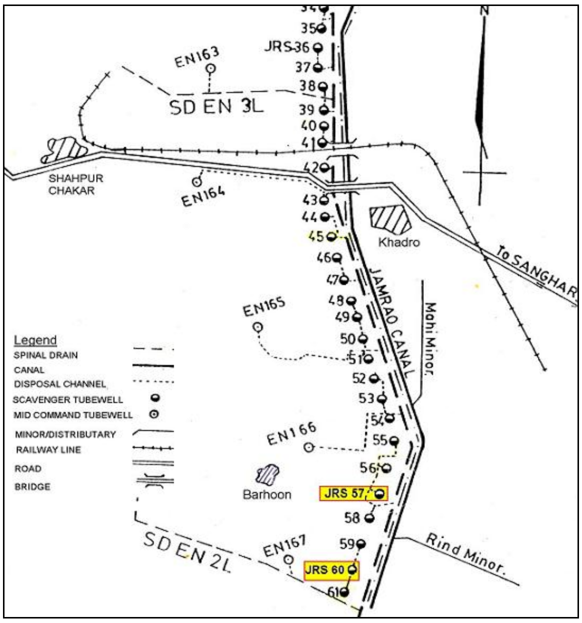


Fig. 3: Location map showing observation sites

2.2Experimental Setup

At each experimental site, individual and nested piezometers were installed to assess the change in hydraulic heads at different distances away from the tubewell and depth wise water quality in terms of Electrical Conductivity (EC) at the well during pumping tests. Typical layout of the installed piezometers is shown in Fig. 4.

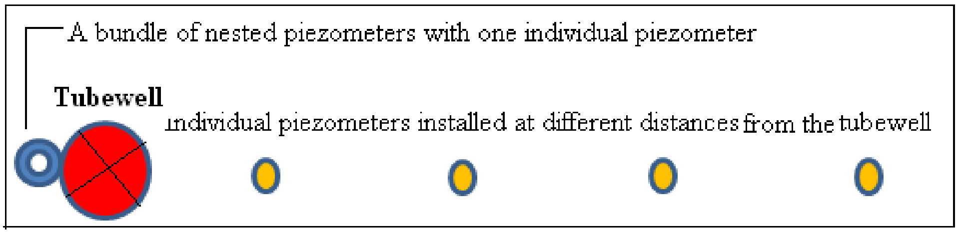


Fig. 4: Typical layout of the installed piezometers

At JRS-57 well site, five individual piezometers of size 6.35 mm diameter were penetrated up to mid depth of the well's strainer i.e., 32 m below ground surface (bgs) distances of 3.00, 9.10, 15.24, 33.52 and 73.00m away from the tubewell. Simultaneously, a bundle of seven small size i.e. 6.35 mm diameter nested piezometers were installed at depths of 17.37, 21.95, 29.57, 37.19, 41.76, 43.28, 44.81 m bgs just at 3 m away from the center of the well.

Similarly at JRS-60 well, four individual piezometers inserted at distances of 3, 20, 43 and 89 m from the well and a bundle of eight nested piezometers up to depths of 18.59, 23.17, 30.79, 36.88, 39.93, 42.98, 46.03, 49.07 m bgs.

3 GOVERNING EQUATION

Governing equation in Partial differential form for transport of contaminants in groundwater can be written as:

$$\frac{\partial C}{\partial t}=\frac{\partial}{\partial x_i}\left[D_{ij}\frac{\partial C}{\partial x_i}\right]-\frac{\partial}{\partial x_i}\left(V_iC+\frac{q_s}{\theta}C_s+\sum_{k=1}^{N}R_k\right) \tag{1}$$

Where, C is the contaminants concentration in groundwater (ML^{-3}), x_i is the distance along respective Cartesian co-ordinate axis (L), q_s represents the fluid sink/source or volumetric rate at which water is removed from or added to the system per unit volume of aquifer, t is the time (T), D_{ij} is hydrodynamic dispersion coefficient ($L^2\,T^{-1}$) V_i is linear pore velocity (LT^{-1}), C_s is the sources/sinks concentration (ML^{-3}), θ is porosity of the porous material (dimensionless) and R_k is the chemical reaction ($ML^{-3}T^{-1}$).

4 MT3D MODEL INPUT DATA

A number of groundwater computer models are available in the market to simulate the groundwater dynamic and solute transport parameter, such as SUTRA (Voss, 1984), HST3D (Kipp, 1987), PMWIN (Chaing and Kinzelbach, 1996) etc.

PMWIN (Processing Modflow for Windows) was selected for the present study, which offers great suppleness and integration for groundwater flow simulation with MODFLOW (Harbaugh, and McDonald, 1996a & 1996b), PMPATH, MT3D (Zheng, 1990), MT3DMS, MOC3D, UCODE and PEST. A widely used 3-D finite difference groundwater flow model MODFLOW was developed by U.S. Geological Survey in 1984 (McDonald, and Harbaugh, 1988).

In this paper, MT3D solute transport model based on dispersion approach, which is mixed Eulerian-Langrangian approach, is used to solve equation (1). In fact, to develop optimum strategies of ground water pumping regime, MT3D model would have to calibrate with groundwater solute transported field data. In this process, the calibrated MODFLOW is described in Kori et al. (2008). The generated meshes for domains of JRS-57 and JRS-60 scavenger wells are shown in Fig. 5.

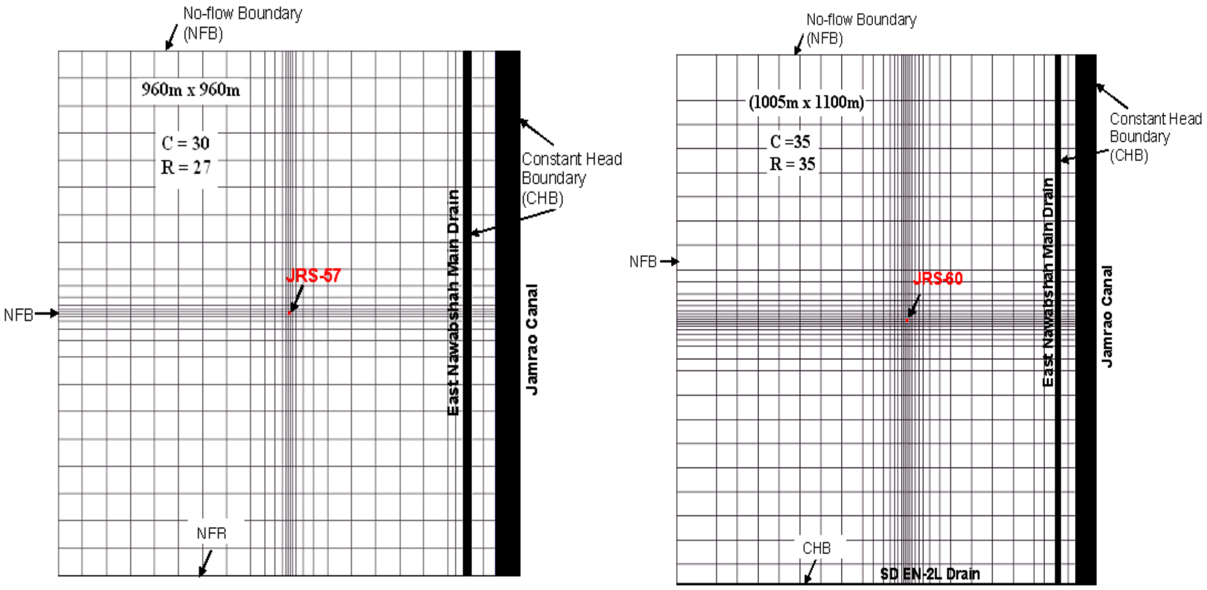


Fig. 5: Model grid generated for JRS-57and JRS-60 scavenger wells

The parameters used for advective solute transport for both the models were obtained from built in known values in the model for details, refer Qureshi et al. (2011). The parameters related to dispersive salt transport were adopted from LBOD stage 1 project are given in Table 1.

Table 1. Dispersive solute transport parameters

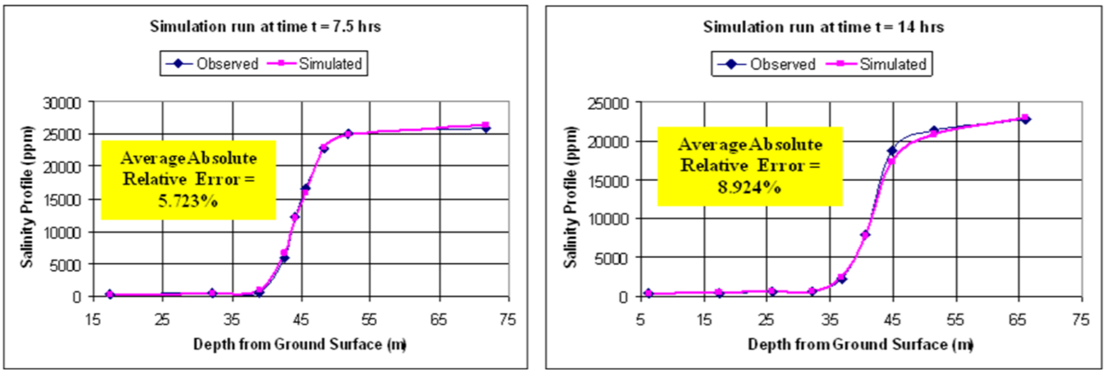
Parameters	Horizontal Transverse Dispersivity (m)	Vertical Transverse Dispersivity (m)	Longitudinal Dispersivity (m)	Porosity (fraction)
Ranges	0.018 – 0.097	0.00076 – 0.00289	3 – 15.24	0.18 – 0.35
Data Source	Gelhar et al, 1992			Leap, 1998

5 RESULTS AND DISCUSSIONS

5.1 Calibration and Validation of MT3D Model

The calibrated MODFLOW models for hydrodynamic parameters of JRS-57 and JRS-60 scavenger wells (Kori et al., 2008 and Kori, 2012) were linked with the solute transport model MT3D, keeping all calibrated parameters of groundwater flow model unchanged. The salt transport parameters i.e. vertical dispersivity, horizontal dispersivity, longitudinal dispersivity, and diffusion coefficient were predictable performing model simulations by trial and error method for both the scavenger wells. The models were calibrated using simulation periods of 7.5 and 14 hrs for JRS-57 and JRS-60 scavenger wells respectively (Fig. 6).

During calibration process several simulation runs were executed by changing salute transport parameters till the reasonable matching between simulated and observed salinity profiles were achieved. The average absolute relative error for both the tubewells are within the limit i.e. <10% which shows the satisfactorily matching.



(a) JRS-57 Well **(b) JRS-60 Well**

Fig. 6: Comparison of observed and simulated salinity profiles after calibration

The MT3D further validated using 23 and 25 hrs simulation periods for JRS-57 and JRS-60 scavenger wells respectively (Fig.7).

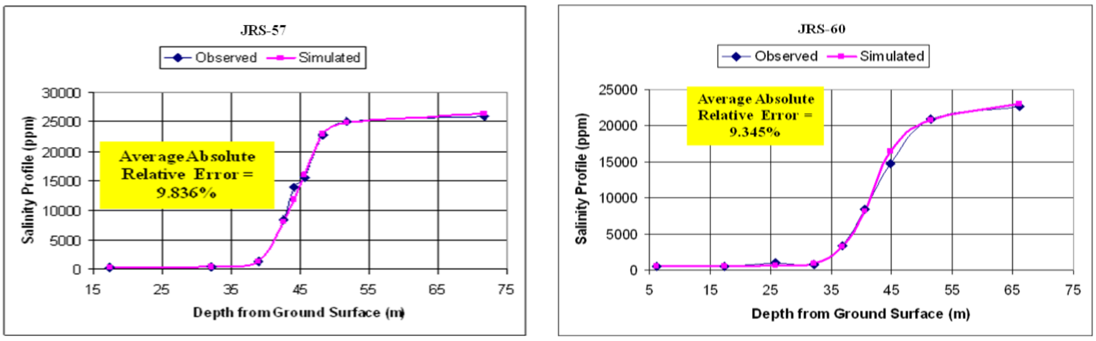


Fig. 7: Comparison of observed and simulated salinity profiles after

The average absolute relative error is less than 10% which indicates reasonable agreement between the simulated and observed salinity profiles. The solute transport parameters after calibration are shown in Table 2.

Table 2. Solute transport parameters after calibration

Parameters		Ratio of Horizontal Transperse Dispersivity to Longitudinal Dispersivity, TRPT	Ratio of Vertical Transperse Dispersivity to Longitudinal Dispersivity, TRPV	Longitudinal Dispersivity (m)	Diffusion Coefficient	Porosity
Values	**JRS-57**	0.009	0.0003	9.45	0.1	0.2
	JRS-57	0.0095	0.0028	9.5	0.2	0.2

5.2 Scenarios for Operational Strategies Development

The hydrological conditions of aquifer parameters i.e. Horizontal and vertical hydraulic conductivities, Porosity, Specific storage (Ss) and Specific yield and pumping depth in field condition remains unchanged. However, operational hours and fresh saline water recovery ratio can be changed and fixed for optimum extraction of fresh groundwater. Hence two last factors were studied through simulating the model for development of operational management strategies for safe yield of fresh water.

In this regard, following two types of scenarios were tested:

1. Constant recovery ratio with different operational factors
2. Constant operational factor with different recovery ratios

5.2.1 Scenario-I: Constant recovery ratio with different operational factors

Keeping constant fresh-saline water recovery ratio i.e. 0.5:0.5 (original designed ratio) for both the tubewells, the simulation runs were performed using calibrated models, with operational factors changing from 0.55 to 0.9 for JRS-57 and 0.5 to 0.9 for JRS-60 tubewell (Fig. 8).

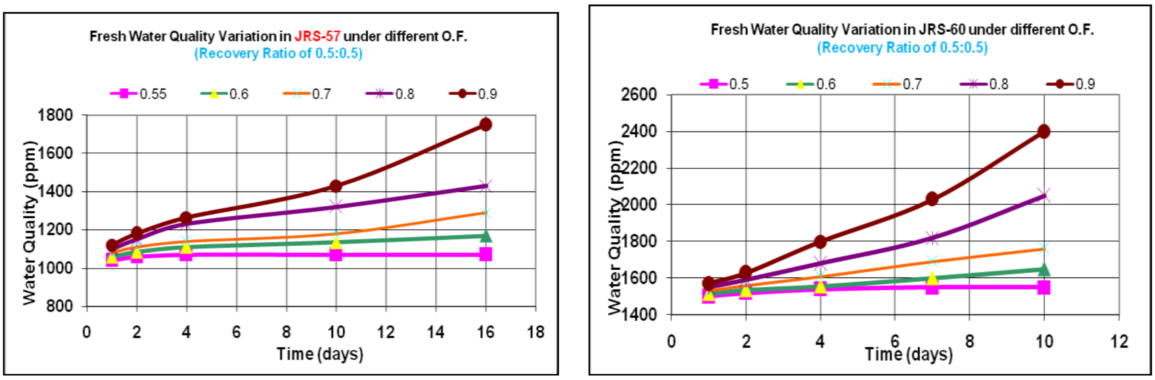


Fig. 8: Fresh water quality under different operational factor at JRS-57 and JRS-60

Fig. 8 reveals that, for constant fresh saline water recovery ratio of 0.5:0.5, the pumping fresh water quality remained unchanged up to operational factor of 0.55 (13.2 hr/day) for JRS-57 and 0.5 (i.e.12 hr/day) for JRS-60 scavenger well, but on increased values of operational factor beyond these limits, the fresh water quality deteriorated rapidly.

5.2.2 Scenario-II: Constant operational factor with different recovery ratios

For the above stabilized operational factors of 0.55 for JRS-57 and 0.5 for JRS-60 well, the models were simulated for different fresh-saline water Recovery Ratio between 0.4:0.6 and 0.8:0.2 for both the scavenger wells (Fig. 9).

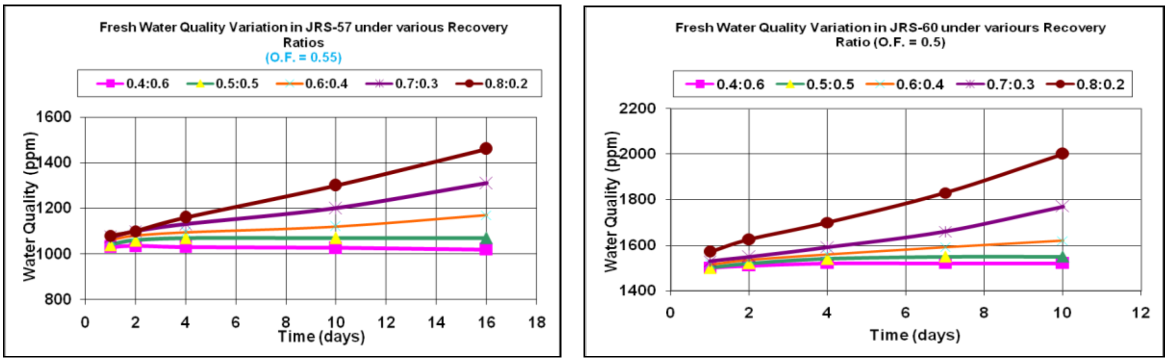


Fig. 9: Change in fresh water quality under different recovery ratios at JRS-57 and JRS-60

Fig. 9 indicates that, for constant operational factor of 0.55 and 0.5 for JRS-57 and JRS-60 respectively, the water quality remained unchanged with recovery ratios of 0.5:0.5 (13.2 hr/day) for both the scavenger wells.

6 CONCLUSIONS

MT3D model was calibrated and validated successfully with the field data. It was found that for controlling saline water upconing and optimizing the economic use of fresh groundwater, the operational factor of 0.55 (i.e. 13.2 hr/day) for JRS-57 tubewell and 0.5 (i.e12 hr/day) for JRS-60 while keeping the same recovery ratio i.e., 0.5:0.5 for both the tube-wells is the optimum strategy of groundwater pumping regime.

Study show that the scavenger well is a good tool to manage agriculture drainage and to supplement irrigation without generating saline water up-coning.

7 RECOMMENDATION

It is recommended that the calibrated MODFLOW and MT3D models could be used for developing optimized operational strategies for maximum safe exploit fresh groundwater under given hydro-geological conditions.

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