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EVALUATION OF DESIGN PARAMETERS OF SKIMMING WELLS IN JERICHO GOVERNORATE, PALESTINE

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Abstract:*In Palestine the existence of fresh groundwater overlying saline water in groundwater systems is widespread. Fresh groundwater lenses are a vital water resource where other surface and sub-surface resources of water are not sufficient. Therefore, it is important to understand how to economically extract the maximum amount of fresh water from the aquifer whilst preventing the mixing of both fresh and saline waters. Many part of the West Bank including Jericho suffers from water scarcity, and at the same time from the phenomenon of salt water instruction. Drought and heavy exploitation in the district have led the water table to decline and salt water intrusion and upconing near some of the wells in the area. This is restricting the future utilization of the agricultural land in the area.*

It is of great importance to the response of the saline movement under a discharge well is required for the safe exploitation of a layer of limited thickness overlaying saline groundwater. This paper provides a better understanding of the saline water movement under a discharge well using the data of some wells in the Jericho area. Sensitivity analyses were carried out on each of the primary design parameters using the finite difference simulation model RASIM. A criterion for the design of the discharge wells in the Jericho district has been established in order to achieve optimal fresh water recovery from these wells.

INTRODUCTION AND BACKGROUND

Water in Palestine is a scare resources. It is foreseen that water will play as the major limiting factor for economic development. For that reason, development of the water resources in Palestine is considered to be one of the top priorities for the Palestinian Authority.

The increase in population and standards of living in the West Bank can place the available resources of water and their quality under a serious threat. Groundwater is always suggested as an alternative water resource whenever shortage of water resources occurs. However groundwater is fragile. Its sustainability depends on natural replenishment and water demand. Drought and heavy exploitation of groundwater can create problems such as saline water intrusion. To prevent these backside effects from the groundwater extraction and to ensure optimum use, careful groundwater development is needed.

The existence of fresh water overlying salt water in the groundwater system is widespread in the area of the Jordan Valley in the West Bank. For this reason it is important to understand how to recover the available fresh water in the area so as the saline intrusion can be controlled. The Jericho district have been chosen due to the importance of its groundwater supply system and to the urgent need to develop them. The salt-water intrusion problem is widespread in the district. Over-exploitation to the main resources in the district has resulted in declining the water table levels and severe increase at salinity. At the same time as a result of the salinity intrusion, about 30 wells in the district are already not operating, while the existing ones are forbidden from increasing their pumping capacity (CDM, 1997). In most of the cases their is no permissions for exploiting new wells in the district.

The Jericho district is located in the eastern boundary in the West Bank, about 7km to the west of the Jordan River . It has a desert climate, classified as arid, with hot summer and warm winter, while its water resources shapes its oasis character. Elevation of the area is about 300m under the mean sea level. Several mountains surround the district from the west, which belong to the West Bank Mountains. Intrusion of saltwater due to overpumping represents a serious threat to the fresh water supply potential in the Jericho district. Between 1983 and 1990, water samples from the Jericho 5 Boreholes show a change from the calcium bicarbonate type to sodium chloride, which indicates that the saltwater is being drawn to the area (ARIJ, 1995).

Skimming or shallow wells are means of extracting freshwater from the above the steady state fresh saline water transition zone. When skimming well pumping starts in the freshwater side of the system, a new equilibrium can be obtained in which the transition zone develops a new stable cone. This new equilibrium where a balance is achieved between the upward potential due to the pumping of a partially penetrating well and the gravity potential due to the unconing of the denser saline water (Reilly, 1987). Theoretically, if the screen is located above the new position of the interface, then the well will discharge fresh water. Overpumping from the well will cause the saline water to rise above the bottom of the well screen, which results in pumping saline water.

METHODOLOGY

After collecting all data available of the water resources in the area, step-drawdown tests have been developed to assess well performance. In a step-drawdown test, the well is operated at several successively higher pumping rates over three steps or more. For each step, the drawdown is recorded. Each step will last the same period of time (normally one or two hours). Step-drawdown tests were developed to measure the affects of laminar flow in the aquifer and turbulent flow in the well on drawdown (Nasser eddin, 1998). The equation is given below:

$$S = AQ + BQ^2 \quad (1)$$

Where:

S: drawdown (m)
A: coefficient of aquifer loss (day/m^2)
Q: well discharge (m^3/day)
B: coefficient of well loss (day^2/m^5)
AQ: a laminar term represents the aquifer loss
BQ^2: a turbulent term represents the well loss

The ratio of laminar head loss to the total head loss is called the L_p ratio (well efficiency)

$$L_p = \frac{AQ}{AQ+BQ^2} \times 100\% \qquad (2)$$

The importance of this ratio is that it show how much percentage of drawdown was attributed to laminar flow.

The density-dependent Fluid Flow and Solute Transport Equations developed by Aliewi (Aliewi, 1993) has been used in the Modeling within the Model RASIM. RASIM is as a finite difference simulation model. It consists of approximately 4000 statements written in FORTRAN-77. The double precision accuracy (16 significant digits) is used. RASIM consist of a main program and 27subroutines.

RASIM couples dependent fluid flow and solute transport in a multi-layer confined/phreatic aquifer system of isotropic/anistropic nature in axi-symmetrical cylindrical coordinates.

RASIM is used to simulate flow problems in confined and unconfined aquifers, and to simulate solute transport problems, and to simulate salt water intrusion problems, therefore RASIM is used to simulate problems addressed in this paper.

In solving the flow and solute transport equations the following assumptions were integrated in RASIM:

- Cylindrical orthogonal coordinates are used. Radial

- symmetry about the vertical axis is assumed. The vertical axis is orientated directly downward.
- The primary variables are fluid pressure and solute mass concentration.
- Density is a linear function with concentration.
- Fluid viscosity and aquifer porosity are independent of time and space.
- The porous media and the fluid are compressible.
- Darcy’s law is valid.
- Permeability varies spatially. The system coordinates are
- aligned with the principal coordinates of the permeability tensor. The porous media can be anisotropic and hetergenous.
- A velocity-dependent dispersion coefficient with tensorial
- nature is used. Off-diagonal terms are not neglected. Both longitudinal and transverse dispersivity are dependent on flow direction and solute travel distance.
- Molecular diffusion is simulated.
- Boundary conditions can be of several types: no-flow
- boundary, specified flow boundary and specified pressure boundaries with specified concentration. At the phreatic surface pressure-dependet recharge/discharge mechanism is assumed.
- Initial pressure is assumed hydrostatic.
- Adsorption and chemical reactions are not included.
- No pure solute source is assumed.

RESULTS OF THE PUMPING TEST

A preliminary pumping test was conducted on the Arab Development well 13-19/081 to assess its performance. Well's depth was 140m below ground level while its static water level was at 30m below ground level. The well was operated successively at several higher pumping rates, namely 12m^3/hr, 43m^3/hr and 75m^3/hr with drawdowns of 1.25, 4.05, and 11 meters respectively.

The step drawdown test was conducted in order to measure the losses of the laminar flow in the Pleistocene aquifer and of the turbulent flow in the well. The following aquifer characteristics were determined:

- Results of the specific Capacity that reflects the productivity of the well. Show that the well is still developing.
- Well efficiency: the average efficiency is estimated at 27% using the step drawdown test results. This shows that the well needs a rehabilitation process.
- Transmissivity: the transmissivity is calculated to be equal to 202 m^2/day.

MODELLING THE MOVEMENT OF SALINE WATER UNDER SKIMMING PUMPING

An understanding of the response of the saline water movement under a skimming well is required for the safe (salt-free water) exploitation of a layer of limited thickness of freshwater overlying saline groundwater. In Jericho area, this is the situation for all the agricultural wells. Sensitivity analyses are carried out on each of the primary design parameters of the skimming well in order to gain an enhanced understanding of the behavior of the saline water movement around a skimming well under different operational conditions.

Initial and Boundary Conditions:

RASIM has been set up to model the field conditions observed at well site No. 13-19/081. The initial location of the top of the transition zone is set to 130m bgl. The width of the transition zone was 6 m before commencing pumping. It is reported (WBWD, 1991) that chloride level of freshwater is 1000 mg/L and that of the saline water is 10,000 mg/L. The initial concentration for the simulation period is set to the salinity of the fresh water and saline water in the fresh and saline bodies respectively. In the transition zone a linear increase is assumed from fresh to saline salinity. The initial pressure variation with depth is set to be hydrostatic. A hydrostatic pressure distribution was also specified at the lateral boundary away from the well. The lateral boundary associated with the skimming well contains two conditions, a flow-boundary condition that represent the screen of the well and a no-flow boundary condition for all other points. An impermeable base to the aquifer is assumed in this study.

Assessment of the Saline Water Response:

The movement of the saline water has been assessed by studying the behavior of the following output variables from RASIM:

- Depth to top of transition zone, denoted by ‘totz’.
- Width of transition zone at well, denoted by ‘wotz’.
- Rate of upconing, denoted by ‘rou’.
- Pumping recovery ratio, denoted by ‘RR’.

Response of Upconing Rate and Top of Transistion Zone (Totz)

Results from RASIM show that the rate of upconing of the transition zone approaches equilibrium after nearly 1530 days since pumping began and when the ‘totz’ reaches the bottom of the well screen as shown in Figure 1. The state of equilibrium is assumed to be reached in this study when the upward movement of the transition zone was at 0.01 cm per day. The transition zone was moving towards the well screen with almost a steady rate of 0.92 cm per day over the portion of marl layer and when the totz was at a distance greater than 12 m from the bottom of the screen. When the ‘totz’ reached the gravel layer at nearly day 1250 since pumping started, the rate of upconing increased to a value just greater than 10 cm per day. After totz has passed through the gravel layer at about 107 m bgl, totz has become in the area underneath the bottom of the screen which is considered as a high vertical velocity zone which means that dispersion is great there too, therefore, the rate of upconing has increased to nearly 15 cm per day until the saline water reached the bottom of the screen where equilibrium was achieved shorter afterwards.

Response of the Width of the Transition Zone

Results show the distribution of the concentration over the well profile and isochlore lines distribution respectively. Results show a dispersed zone at the well to a width of about 28 m.

0m												
		Screen 70-100 meter depth										
80m												
85		Pumping rate = 1200 cubic meter/day										
90												
95												
100												
105												
110												
115												
120												
125												
130		Time since pumping began (days)										
135												
140												
		0	250	500	750	1000	1250	1500	1750	2000	2250	2500

Figure1 : Depth to Transition Zone with Time

The initial width of the transition zone was assumed 6 m. Numerical instability at the screen nodes is normally caused by space and/or time discretisation problems. The results agree with the analysis conducted by Reilly and Goodman (1987). These simulations were used to understand the behavior of the transition zone beneath skimming wells. Results provide evidence that the transition zone is not symmetric around the 0.5 isochlor. The interpreation of the above observation relies on the bahaviour of the waters during mixing by dispersion. The distribution of velocity near and below the bottom of well screen shows higher vertical values in the region near the top of the transition zone than in the more saline water within the transition zone. This means that the vertical dispersion will be greater above the 0.5 isochlor which will result in a wider dispersed region above the 0.5 isochlor.

TESTING THE EFFECT OF DESIGN PARAMETERS ON SALINE UPCONING

Sensitivity to Well Capacity

The well capacity of the standard run was equal to 1200 m^3/day. The capacity was first increased to 1700 m^3/day and then reduced to 900 m^3/day to test the sensitivity to well capacity. The following were observed when the well capacity was increased to 1700 m^3/hr:

- Upconing rate reached equilibrium much earlier (at day 1050) than that of the standard run (at day 1530). This is because the saline water enters the well screen earlier as a result of higher capacity.
- The distribution of salinity isochlors at the well at the end of the simulation period shows that the transition zone is wider between 0.5 isochlor and the bottom of the transition zone than that portion between the 0.5 isochlor and the more diluted part of the transition zone. This is interpreted as follows : the ‘totz’ reaches the bottom of the screen much earlier than it is in the standard run. As the pumping continues to complete the simulation period, the transition zone advances towards the bottom of the well screen until it reaches the high velocity area just below the bottom of the screen. When the ‘totz’ intersects the screen, the salinity of the water extracted by the screen starts to increase. Continuing pumping decreases the thickness between the 0.5 isochlor and the bottom of the screen until the 0.5 isochlor reaches the bottom of the screen.
- The salinity profile shows that the width of the transition zone at the end of simulation period has a width of 22 m which is less than that in the standard run by 6 m. This is due to the fact that converging flow effects took place when the 0.5 isochlor was close to the well screen.

When the well capacity was reduced to 900 m^3/day, the following results were observed:

- The rate of upconing was almost constant over the entire simulation at nearly 0.5 cm per day. It should not be concluded that this is advantageous because equilibrium was not achieved. It can be shown that if the simulation period was increased, the totz will reach the well screen eventually. Therefore, controlling well capacity to lower values is not going to stop or suppress the vertical movement of saline water specially for the hydrogeological conditions of the Pleistocene aquifer in the Jericho area.
- Since equilibrium was not achieved, the upper part of the transition zone was closer to the high velocity zone which is located beneath the well screen. Therefore, the area between the 0.5 isochlor and the 0.15 isochlor is wider than the bottom portion of the transition zone.
- The salinity profile along the well suffers from almost no instability problems due to the fact that velocity distribution did not introduce numerical dispersion. The width of the transition zone was about 14 m. This because the transition zone did not move enough to reach the zone of high velocity distribution. It is anticipated that when this take place the transition zone will be wider especially if longer pumping periods are encountered.

Sensitivity to Screen Length

In this section, the bottom of the screen was altered first from 100 m bgl to 105, 115 and 120 m bgl for the same setting of the fresh/saline water interface which was at 130 m bgl. The results are summarised in Table1 below.

Table (1): Sensitivity Results of Altering Screen Length by Fixing Screen Top

Analysis	Screen Top & Bottom (m bgl)	Days to Equilibrium	Screen Length	RR (%)	totz (m bgl)	wotz (m)
Standard	70-100	1530	30 m	100	100.1	27.9
Run 2	70-105	1120	35 m	95	103.4	22.6
Run 3	70-115	350	45 m	92	111.6	3.4
Run 4	70-120	130	50 m	88	114	4

- Days to Equilibrium: results confirm the fact that fixing the top of the screen and extending the screen length in the direction of saline water, will result in reducing the time required for saline upconing to approach equilibrium. It can be shown that when the distances between screen bottom and the initial position of the transition zone were 20, 25, 15 and 10 m, the time required for this transition zone to stop significant encroachment was

1530, 1120, 350 and 130 days respectively. The reason is that when the screen bottom is closer to the transition zone, saline water will enter the screen at early stages, forcing the heavier water to balance the pumping stresses earlier. It should be noted that this is the principle of scavenger pumping. Full details about this subject can be found in Aliewi (1993).

- Recovery Ratio: in the standard run, totz was just below the screen bottom which means that the pump extracts only freshwater (i.e., water with salinity values greater than 1500 mg/I). Increasing the screen length from 30 m to 35, 45, and 50 m resulted in decreasing the recovery ratio from 100% to 95%, and 88% respectively. The reason is that totz has intersected the screen when its length was increased allowing more saline water to enter the well pump. For the same sequence of screen lengths, totz was at 100.1, 103.4, 111.6 and 114 m bgl respectively.
- Width of Transition Zone: Increasing the screen length has a remarkable effect on the final width of the transition zone at the well line at the end of the simulation period. Increasing the screen length from 30 m to 35, 45, and 50 m resulted in decreasing the wotz from 27.9 m to 22.6, 3.5 and 1.5 m respectively. Results confirm this fact with respect to the transition zone at the well section. This phenomenon can be interpreted as to the fact that when the transition zone is at the well screen, the effect of vertical dispersion will be much smaller than the advective flow convergence at the screen (Aliewi, 1993).

Sensitivity to Screening Gravel Sections and Casing Marl Sections

It was clear that reducing the pumping rate did not result in total prevention of saline upconing although the results show that saline water will take much longer time to reach the bottom of the well screen. The slope of upconing rate although small but did not flatten with time which means that in the long run, saline water will reach the well resulting in abandoning the well. The question that remains unanswered is how then it is economically feasible to protect the agricultural wells in the study area from saline hazards. In other words, what can be done in order to keep theses agricultural wells functioning as skimming wells, i.e., to extract water with salinity that is suitable for agricultural purposes. To answer this question two scenarios were undertaken with reference to screening only the gravel section and blank casing the marl sections. The two scenarios are as follows:

Scenario number 1:

Lithology	**Blank Casing**	**Screen**
00-15m marl	Blank casing	
15-17m gravel	Blank casing,	

17-30m marl	Blank casing	
30-35m gravel	Blank casing	
35-75m		Perforated
77-97.5m marl	Blank casing	
97.5-103.5m gravel		Perforated
103.5-107 m marl	Blank casing	
107-114m gravel		Perforated
114-132m marl	Blank casing	
132-134m marl		Perforated
134-140m marl	Blank casing	

It should be noted that the last perforated section lies within the initial position of the transition zone (the top of transition zone was located initially at 130m bgl). This means that from the beginning, this scenario accepts pumping saline water. Since saline water and freshwater are pumped through the same outlet, then the pumped water should have salinity greater than 1500 mg/1. In this context, it was calculated to be around 2000 mg/1 with a recovery ratio of 90%.

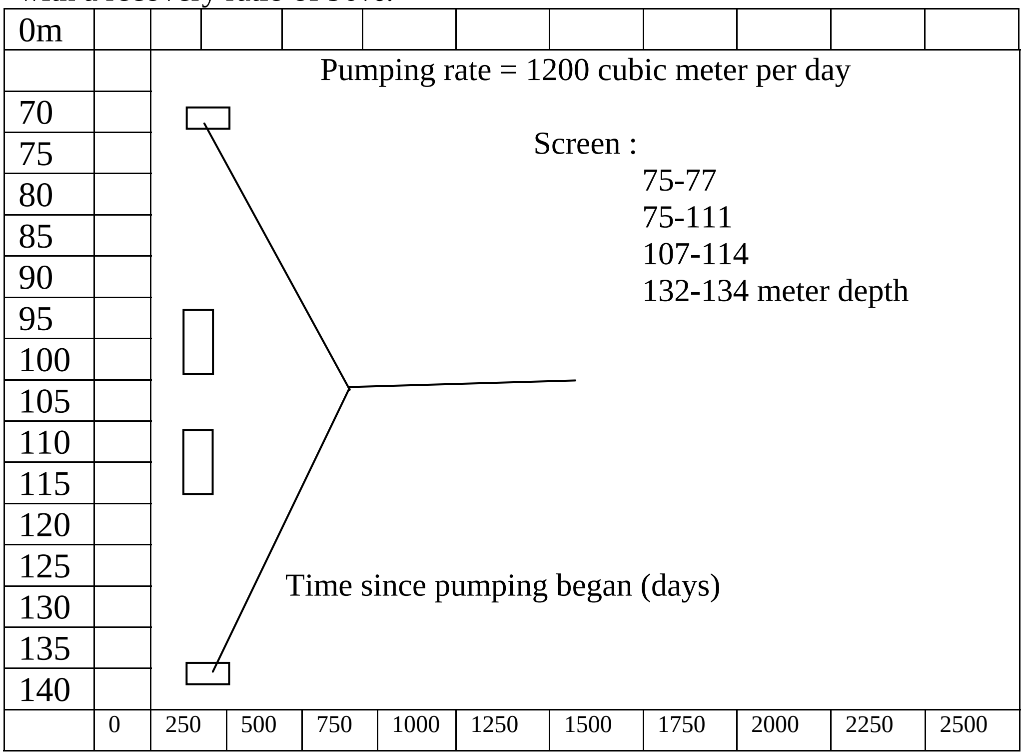

Figure (2): depth to Transition Zone with Time

The results of this run as shown in Figure 2 show that saline water upconing reached equilibrium at very early stages of simulation and specifically after 14 days only. The reason is very clear which is due to the fact that saline water is pumped from the beginning which means that a low pressure area was created alongside the section 132 to 134 m bgl which helps to reduce the saline water potential from a considerable vertical advancement towards the well screen.

Results shows that the isochlor line distribution did not differ considerably from the initial distribution, but with some convergent advection flow through the screen resulting in some reduction of the initial width of the transition zone at the well section.

The only difference between the two scenarios is that the perforated casing of the gravel section, 132-134m bgl, was replaced by a blank casing. This means that saline water (i.e., with salinity greater than 1500 mg/1) was not allowed to be initially pumped. The results of this scenario show that saline water can still reached the last perforated section where totz reached equilibrium at 113 m bgl. The recovery ratio related to this scenario was 87%. The totz took longer time (around 308 days) than the previous scenario to reach equilibrium.

Scenario number 2:

Lithology	**Blank Casing**	**Screen**
00-15m marl	Blank casing	
00-17m gravel	Blank casing,	
17-30m marl	Blank casing	
30-35m gravel	Blank casing	
35-75m		Perforated
77-97.5m marl	Blank casing	
97.5-103.5m gravel		Perforated
103.5-107 m marl	Blank casing	
107-114m gravel		Perforated
114-132m marl	Blank casing	
132-134m gravel	Blank casing	
134-140m marl	Blank casing	

CONCLUSIONS AND SUMMARY OF IMPORTANT SIMULATION RESULTS

The main conclusions from this paper are:

1. The steady state transition zone is asymmetric around the 0.5 isochlor. The narrowing/widening mechanism of the transition zone is controlled by the location of the screen well and whether it is installed as one unit or as segments each of them tap a gravel section.

2. The upconing mechanism seems to continue until saline water enters the well screen even when pumping rate was reduced. In the latter case, the rate of upconing will be less but long term runs show that saline that water will eventually reach the well.
3. The recovery ratio of freshwater is improved if the well screen is located in the upper part of the aquifer.
4. It is shown in this study that high vertical velocities exist in the area a few meters below the well screen which resulted in more dispersive saline water in that area demonstrated in wider zone between the 0.5 and 0.15 isochlors than between the 0.5 and 1.0 isochlors. It is also shown that the existence of marl layers has very little effect in that zone of high velocity to reduce the advancement of saline water.
5. The saline water upconing reached equilibrium very quickly when saline water was allowed to be pumped initially with an overall salinity value of to a great extent the pumped water of 2000 mg/I. This level of saline water is accepted knowing the nature of crops grown in the Jericho area. This was achieved when the only gravel sections were screened and marl sections were blank cased. It is, therefore, suggested, to screen all skimming wells in similar ways in the Jericho area in order to avoid saline water from further upconing to freshwater lenses of the aquifer

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