DESIGNING OF A GROUNDWATER PRODUCTION SCHEME FOR THE NORTHERN OIL FIELDS, KUWAIT

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ABSTRACT

The Kuwait Oil Company's (KOC's) future development plans propose an increase in the production and utilization of groundwater reserves in the northern oil fields, where new groundwater gathering centers are to be constructed for water handling processes. In order to preserve the natural resources of the country, and realizing the fragility of the fresh/brackish/saline coexistence in the groundwater resources of northern Kuwait, the Water Research Center (WRC) of the Kuwait Institute for Scientific Research (KISR) conducted this study on behalf of KOC. The main objective of the project was to design, locate and set a production schedule of groundwater wells to produce 10,000 m^3/d with salinity less than 10,000 mg/l for a specific period of time. This study will enhance the potential of utilizing brackish water at the project area while maintaining minimum mixing between brackish and saline groundwaters. To fulfill its objectives, this study conducted data collection followed by designing and constructing several production and observation wells that were used for a program of pumping and recovery tests. During this field work, a campaign of groundwater sampling and water level measurements were conducted. The water samples were analyzed in the appropriate laboratories for physical, chemical, and biological parameters according to international standards. Then, another stage of numerical modelling took place to simulate the movement of saline and brackish waters putting all the newly drilled wells into operation. The results showed that it is possible to extract 10,000 m^3/day from the project area with a salinity ranging between 3,500 and 10,000 mg/l indicating brackish water quality. The groundwater in the study area is of sodium chloride and sodium sulphate type, and no organic contamination of groundwater was detected in the study area. However, the study also shows that it is not possible to extract water from certain locations because the salinity will be elevated above the design limit of 10,000 mg/l.

Keywords: Brackish water lenses, saline aquifers, solute transport modelling, SUTRA, pumping tests

1 INTRODUCTION

In Kuwait the existence of freshwater is very limited; therefore the exploitation of brackish water is normally a good alternative source of water. There is a continuous increasing demand for brackish water especially for oil processing (wash tank), drilling operations, firefighting systems and irrigation. However, exploitation of brackish water is normally associated with saline water up-coning which ends in a mixing process between brackish and saline waters and thus deteriorates the quality of brackish water. Therefore, locating pumping wells in the target area (Fig. 1) to extract brackish water requires a careful design to avoid mixing effect with saline water (El-Naqa and Al-Shayeb, 2009) and according to the sustainable yield of the target aquifer (Domenico and Schwartz, 1990).

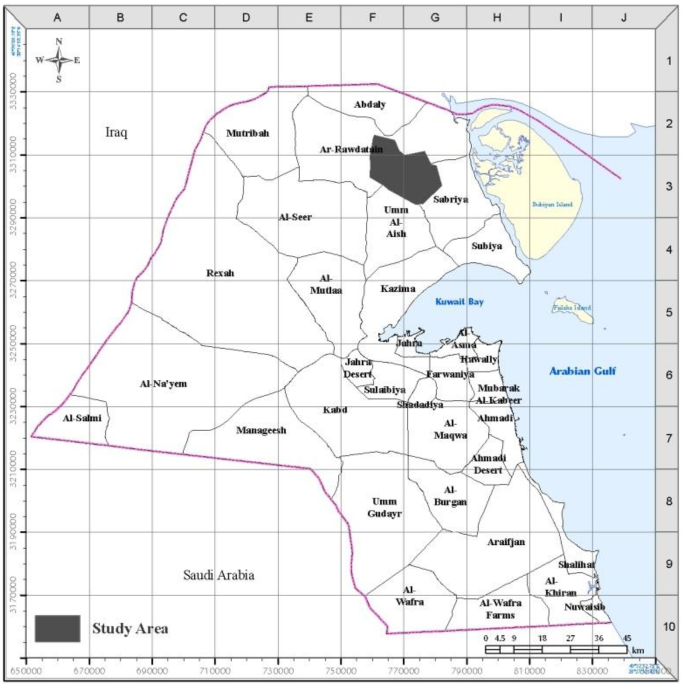


Figure 1. Location of the study area in northern Kuwait

In order to avoid mixing between brackish and saline waters under pumping conditions, the pumping rates from the brackish water wells need to be regulated according to the hydrogeological conditions that prevail in the target aquifer. In the northern Kuwait, there is a need to increase the production of brackish groundwater for oil exploration activities, by constructing a new brackish groundwater gathering center. However, this increase should be designed carefully to avoid deterioration of the water quality of the existing brackish water. The study area is under the management of the KOC that currently uses 8 groundwater wells to produce brackish water. From the hydrogeological consideration, these 8 wells tap the underneath shallow aquifer, which is locally called Dibdibba Formation that has a very limited recharge. The total pumping rate of these wells is about 7,000 m^3/d. These wells have a total depth of 100 m on average, with screen intervals extending over the bottom 50 m of the wells. The reported initial total dissolved solids (TDS) at the time of construction of these were about 4000 mg/l. The depth to groundwater table is about 40 m. As a result of pumping, water salinity measurements show that TDS levels were elevated to 20,000 mg/l. This is clearly a case of unplanned mining of the aquifer, where a significant portion of the reserve is being lost to saline water up-coning from the deeper aquifer. Now, the KOC is planning to add one more gathering center to increase brackish groundwater production to 10,000 m^3/d so that TDS does not elevate above 10,000 mg/l. This situation calls for scientific plans for groundwater production at the study area. This problem is researched carefully in this paper to design a new utilization scheme of brackish groundwater. A number of studies have conducted the potential and suitability of groundwater resources in Northern Kuwait (Parsons, 1964; Senay, 1973 and 1975; Omar et al., 1981; Al-Sulaimi et al., 1988; Hadi, 1993; Viswanathan et al., 1997; Fadlelmawla et al., 2006); However, information on the sustainable production of fresh/brackish water was limited (SMEC, 2003). Senay (1977) concluded that the inappropriate location of the production wells was the main cause of the salinity problem in the produced water.

In Northern Kuwait, groundwater in Kuwait is extracted from the upper aquifer, which is the Kuwait Group aquifer. It comprises of unconsolidated sediments of silty, gravelly sand. The fluviatile sediments within the Kuwait Group aquifer was originally deposited with high porosity. The precipitation and cementation of authigenic calcite in pore spaces have resulted in the reduction of large original pores to microscopic sizes (Al-Senafy and Al-Fahad, 2000). In northern Kuwait, brackish groundwater with a TDS of 2,000 to 10,000 mg/l is used for irrigation in the farming areas, urban landscaping, gardening and blending with desalinated water. The study area is located on the eastern Raudhatain groundwater basin and about 80 km north of Kuwait City. It covers approximately 300 km^2 and includes Umm Al-Aish groundwater basin and KOC's Raudhatain and Sabriya oil fields. The groundwater field in the study area was designed in 1964 to produce water with a rate of 15,000 m^3/d using 26 wells (Senay, 1977). After significant quality deterioration, eleven of these wells were shut down in 1973. This paper aims at locating groundwater wells to utilize brackish water in Northern Kuwait so that the salinity of the produced water does not increase above 10,000 mg/l. Fig. 2 shows the location of the production wells drilled in the study area shown in Fig. 1.

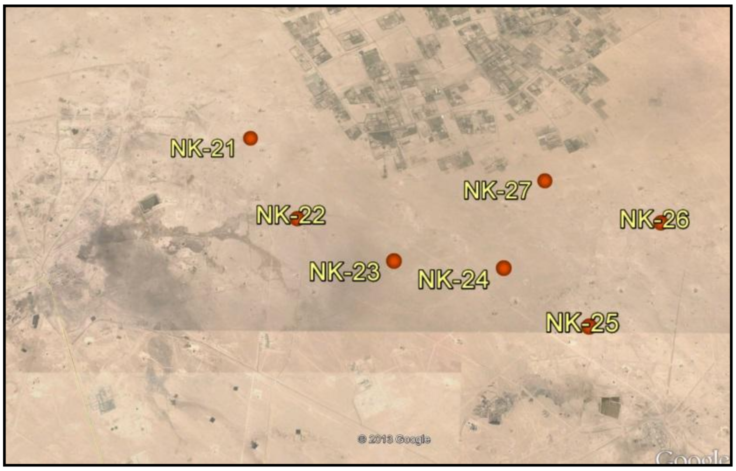


Figure 2. Location of the drilled wells in the study area

2 METHODOLOGY

Hydrogeological and hydro-geochemical investigations as well as groundwater flow and solute transport modelling for the movement of saline water under pumping wells form the methods used in this study. Seven production wells and seven observation wells were designed and constructed. These wells were utilized for soil sampling, groundwater sampling and water level determination. Several pumping tests were conducted on the newly drilled wells. The pumping data generated from the pumping tests were analyzed using the method of Tartakovsky-Neuman (2007). All the field data and their analyses were incorporated in a numerical model to determine the pumping rate of the wells based on mixing results between brackish and saline waters. The software used to simulate the movement of saline water towards brackish water lenses are SUTRA (Voss, 2008) and visual MODFLOW (McDonald and Harbaugh, 1983, 1988, 2003).

3 RESULTS, ANALYSIS AND DISCUSSIONS

3.1 Local Aquifer Lithology

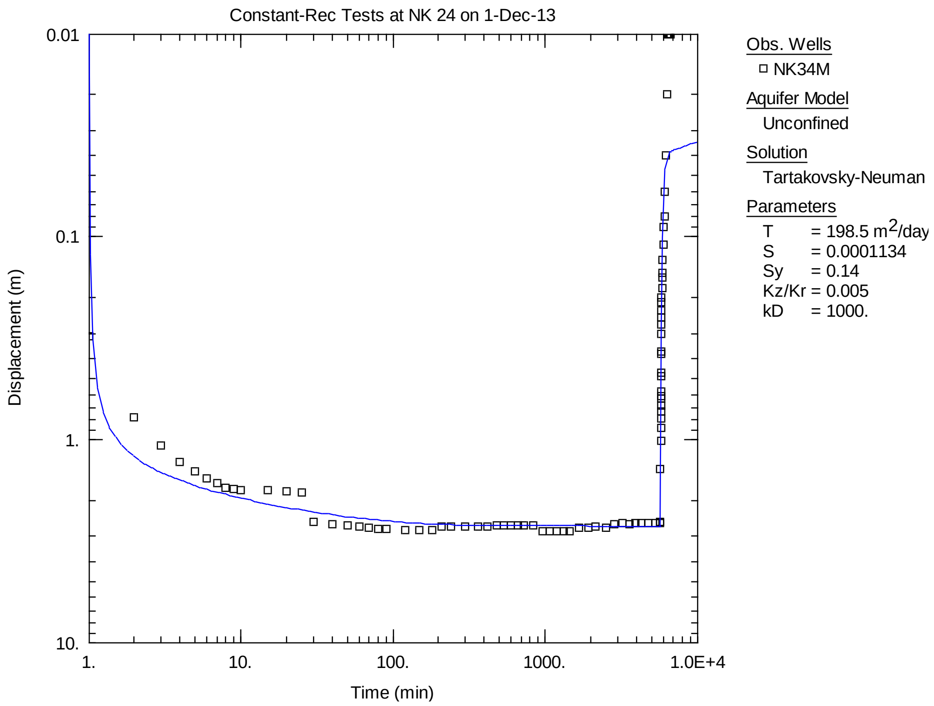
The lithological study indicated the occurrence of four sediment types within the drilled sequence of the Kuwait Group aquifer within the study area. They are sand, gravel, gravely sand and calcareous muddy sand. It is believed that the gravely and coarse sandy clastics in the Dibdiba Formation were deposited during severe floods, and the muddy and fine sand layers were deposited under low flow conditions (Al-Sulaimi, et al., 1988). Gravely sand consists of more than 40% gravel, and the rest comprises coarse sand that was found to be the most dominant deposit within the drilled sites. Partial stages of cementation by calcium carbonates were identified within the lower drilled sequence at about 30 m and deeper. The mud contents were mostly associated with the calcareous horizons. Table 1 presents the lithological descriptions for drill cuttings at the location of well No. NK27.

Table 1. Lithological section at Well No. NK 27

Depth (m)	Lithology
1 – 18	Gravely Sand
18 – 23	Sand
23 – 27	Gravely Sand
27 – 32	Sand
32 – 41	Gravely Sand
41 – 64	Calcareous Muddy Sand
64 – 71	Sand
71 - 83	Calcareous Muddy Sand

3.2 Pumping Test Analysis

The results of the analysis of the pumping and recovery data in the study area using AQTESOLV software package show that the average transmissivity value is about 330 m^2/d. An example of pumping test analysis for well NK-24 with observation well NK24M is shown in Fig. 3. The specific yield for this test was 14%.



Obs: Observation, T: Transmissivity (m2/d), S: Storativity in the pressurized part of the aquifer, Sy: Specific yield, β: Saturated thickness (m) = TDD – SWL.

Figure 3. Pumping tests analysis of Well NK-24 (constant and recovery tests)

3.3 Groundwater Quality

All the samples collected from the production wells and monitoring wells of the study area were analyzed for water quality and plotted on Piper (Fig. 4) and Durov (Fig. 5) diagrams. Piper and Durov diagrams show the water type as sodium chloride (NaCl) and sodium sulphate ($NaSO_4$) dominated by sodium, chloride sulphate, calcium, magnesium and bicarbonate ion with a mixing process between brackish and saline waters.

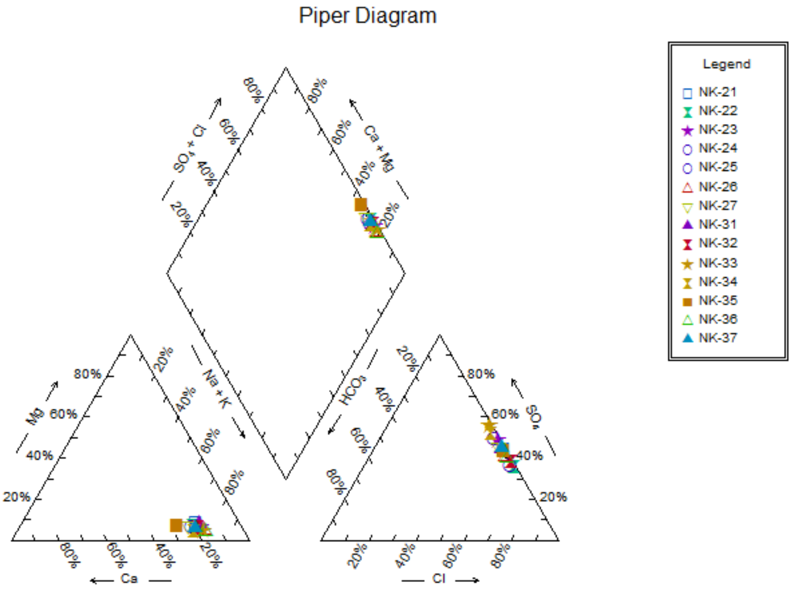


Figure. 4. Piper diagram for the groundwater quality in the study area

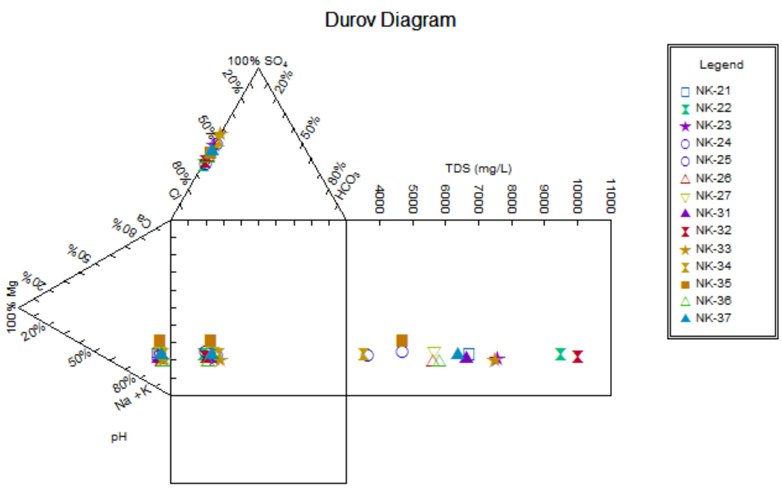


Figure 5. Durov diagram for the groundwater quality in the study area

The salinity as TDS in mg/l at the end of pumping water from the newly drilled wells for a few wells is shown in Table 2.

Table 2. Pumping rates and total dissolved solids values at the wells at the end of pumping tests

Location	Pumping Rate (m^3/d)	TDS at the end of the pumping test (mg/l)
NK21	1008	6754
NK22	878	9519
NK23	878	7615
NK24	936	3670
NK25	850	4721
NK26	1037	5659
NK27	1037	5678

From Table 2, it is clear that in the location of well NK22 the salinity level after a few days of pumping is approaching the design limit of 10,000 mg/l. To further investigate, a numerical model (using SUTRA and VMF) was developed to simulate the movement of saline water under pumping conditions and the results are shown in Fig. 6.

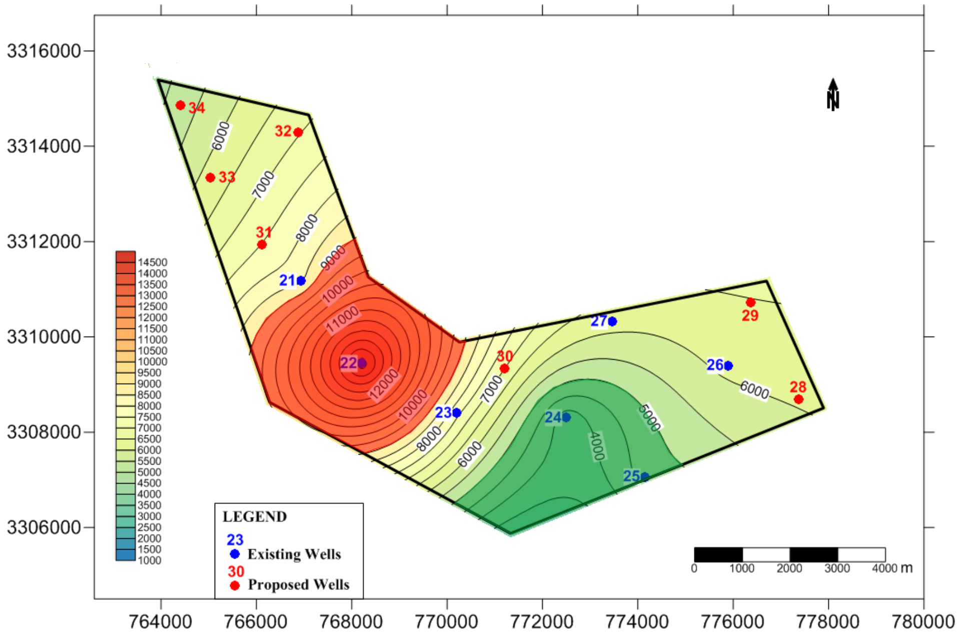


Figure 6. Areas of possible utilization from the study area

It can be concluded from Fig. 6 that the area in the middle should be avoided for further development of groundwater resources because salinity will be elevated around the limit design, which is 10,000 mg/l.

4 CONCLUSIONS

The aquifer study area has brackish water. Saline water up-coning under pumping conditions in the study area encroach the middle of area that is recommended for no additional pumping activities. Accordingly, the unmanaged groundwater production from the water well field will cause vertical and horizontal movements of saline water, which will lead to the deterioration of the pumped water quality. This implies that to enhance the potential of utilizing brackish water at the study area by producing 10,000 m^3/d with a salinity which is less than 10,000 mg/l while maintaining no effect on the brackish water body , and a minimum mixing between the brackish and saline groundwater, the following have to be done:

- Regulate pumping rates at 40 to 45 m^3/hr.
- Avoid production of water from the area in the middle around the well NK-22 to avoid up-coning of saline water quality.
- Avoid production of water from the existing wells NK-24 and NK-25 to protect the strategic groundwater reserve where the salinity is less than 4,000 mg/l.
- Drill seven new production wells in the proposed locations, with their total depth not exceeding 100 m. The distance between any two production wells (existing and new) should be greater than 1000 m. The screen interval should cover an entire saturated zone (50 m) to avoid the up-coning of saline water.

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