Modeling of Underground Oil Fuel Leakage at Ayn Zara, Tripoli Coastal Aquifer

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ABSTRACT

A mathematical model using the three dimensional Heat and Solute Transport code (HST3D) is developed to simulate an underground oil fuel leak at Ayn Zara; a suburb east of Tripoli on the Mediterranean coast. The suspected oil leak at Ayn Zara; started approximately in 1973 and continued up to 1995, where at that year the suspected leaking underground storage tank was removed.

The model is developed to assess this problem for groundwater flow, contaminant transport and seawater intrusion. A 9 km vertical section extending south from the coastline at Ayn Zara with depth of 150 km is used to represent part of the unconfined upper aquifer of the Tripoli area.

The model was calibrated for steady state condition in 1957 and for transient condition in 1972 and 1994 for both flow and salinity concentration. The model was further used to simulate the ground flow, salinity and contaminant transport up to year 2010 under actual conditions and using pump - treat and inject remedial action plan. Simulation results revealed the extent of seawater encroachment and the oil plume spread up to 1995 and predictions up to year 2010 for both existing conditions and remedial action plan

INTRODUCTION

About 50% of the populations of Libya live in the Gefara plain where most of them reside in the Tripoli area. The Tripoli area is a part of Gefara plain that lies between the Mediterranean Sea and the Jabel Nafusa Mountain (Figure 1), and forms an important agricultural area, producing more than half the country’s crops. Rapid growth of the population in this area and the increased water demand for both agricultural, municipal and industrial needs led to excessive groundwater pumpage from the coastal aquifer that caused decline in water levels as shown in Figure 2 and landward migration of the saltwater interface. Only a very small area along the coast was influenced by seawater intrusion in 1957, however at present, the seawater intrusion covers an area of about 250 km² and is continuing to extend toward the inland area of the Tripoli region (Sadeg, 1996). Locally, this problem is further aggravated by the spreading of contaminant plumes due to some industrial spills, leaking oil pipelines and oil fuel tanks, sewer leaks and leachate from domestic waste disposal sites.

Several research models have been applied for Tripoli region aquifer. These studies were mainly focused on the seawater intrusion problem. However, limited studies have been focused on the groundwater contamination due to hydrocarbons or
Figure (1) Location Map of the Study Area

Figure (2) Observed Water Levels for Ayn Zara Profile
other wastes, and almost no research have been conducted to study the combined problem of seawater intrusion and the fate and transport of contaminants. The USGS Heat and Solute Transport model (HST3D) can be used to simulate the so-called three way problem in groundwater; namely flow, seawater intrusion, and fate and transport of contaminant (Ghazali, and Findikakis, 1993). This model is applied in this paper to simulate the problem of the oil fuel leak from an under ground oil-fuel storage tank at Ayn Zara. Model development and model calibrations for flow and salinity transport are outlined in this paper. Furthermore model simulations are used to assess existing conditions of seawater encroachment and plume migrations and to predict future status under existing conditions and under remedial action plans of pump-treat and inject.

HYDROGEOLOGY

Geology of the area comprises a number of aquifers in the northern half of the Gefara plain (Sadeg, 1996). These are separated by more or less impermeable aquicludes and they come together to form a single large unconfined aquifer. The upper aquifer that is of Quaternary- Pliocene-Miocene origin is unconfined and extends throughout the whole plain. It is in general about 100-150 meters thick and in the central and eastern parts of the plain it contains water of good quality (500-2000 ppm) except at the coastal locations.

Close to Tripoli three principal aquifers can be identified but they reduce in number as the confining horizons thin out towards the south. The deep confined aquifers in the Tripoli region contain water of brackish quality that cannot be used directly for domestic consumption.

MODELING OF AYN ZARA CROSS SECTION

The main objective of the cross-sectional model is to represent the situation of groundwater levels and water quality along Ayn Zara profile for the period 1957 to 1994. The modeling study for Ayn Zara cross-section is carried out in six different phases:
1) Construction of the cross-sectional model using all the available data.
2) Calibration of the model to reproduce steady state flow conditions (1957), to form initial values for the transient simulations
3) Calibration of the model to reproduce salt concentration in 1957.
4) Simulate flow and salt concentrations from 1957 to 1994 to reproduce flow and seawater intrusion.
5) Simulate flow, saltwater intrusion and plume migration from the oil fuel tank from 1973 up to 1995.
6) Perform prediction simulations of the aquifer situation for different scenarios up to year 2010.

Initial and Boundary Conditions

The initial and boundary conditions that were used in the calibration of the modified HST3D model for Ayn Zara cross-sectional are shown in Figure 3.
Calibration of the flow and Transport Model

By adjusting the spatial distribution of the hydraulic conductivities along the section so that they vary from 15 m/day nearest to the coastal down to 1 m/day at the southern boundary and by using longitudinal and transverse dispersivities of 25 and 1 m respectively, good agreement was achieved for both observed water levels (Figure 4) and salinity concentration for 1957 which was considered as the steady state conditions for this model.

![Figure 3: Boundary and Initial Conditions for the Model](image)

**Figure (3) Boundary and Initial Conditions for the Model**

**Calibration of the flow and Transport Model**

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![Figure 4: Comparison of the Observed and the Simulated Water Levels for Steady-state and Transient Conditions (1957, 1994)](image)

**Figure (4) Comparison of the Observed and the Simulated Water Levels for Steady-state and Transient Conditions (1957, 1994)**
Transient Model Simulation

Model simulations were performed for the Ayn Zara cross section for the period from 1957 to 1994. This was done since field data for flow and salt concentration are available for the year of 1972 and 1994. Transient data input were used for recharge and discharge, since it has significant effects on flow behavior and consequently seawater intrusion.

Model simulation of the aquifer was carried out on two stages, the first stage was from 1957 to 1972 where the observed water level declined from 15m above mean sea level at the landside boundary in 1957, to 7 m above mean sea level in 1972. Intermediate water level values for the landside boundary were obtained using linear interpolation. Similarly, the water level from 1972 to 1994 declined from 7m above mean sea level to 4.0 m above mean sea level in 1994. For the time period from 1972 to 1994, linearly interpolated vales were used for each one-year stress period.

Hydrological data were used in this model based on the average rainfall, runoff rates, and return from agricultural irrigation. However no specific pumping rates for wells were recorded, therefore pumping rate values were adjusted spatially along the model section within the over all mass balance for the simulation period (Sheikh Ali, 2000). Simulation results obtained by this model were in good agreement with the observed water levels for 1994 as shown on Figure 4.

Simulated salt concentration levels in 1972 are shown Figure 5. The extent of isochlor line representing concentration of 375 mg/l (0.02 mass fraction) is in reasonable agreement with the extent of contoured averaged line from the field measurement of the same concentration (Sheikh Ali, 2000).

Figure 6 displays seawater intrusion results as simulated by the model in 1994. The simulated isochlor line representing the 375 mg/l chloride concentration (0.02 mass fraction) extends to about 6.5 km from the seaside boundary, however the averaged contour line representing the same chloride concentration of 375 mg/l obtained from field measurements extends to about 9.5 km. This discrepancy may be explained by the fact that the model simulates the seawater front of less spreading
nature (sharper front) than what naturally happens in groundwater medium, which has a much wider diffusive front. Moreover the field data for the chloride concentrations were obtained as vertically mixed samples.

![Figure 6 Simulated Chloride Concentrations Distribution (mass fraction) in 1994](image)

**Simulations of the Oil Fuel Leak**

The HST3D model is used to simulate the groundwater flow, seawater movement and the fate and transport of the oil fuel plume. The suspected source of contamination was modeled as a continuous surface source that ensued in 1973 at the old power plant of Ayn Zara some 4.2 kilometers south of the coastline along the modeled section. An average contaminant source rate of 50 l/day was used for the simulations. This rate was based on the mass balance of recorded changing levels of the oil fuel level in the underground storage tank, which has a full capacity of 300 m$^3$.

The source of contamination was eliminated in the beginning of 1995 upon our recommendations at the time and therefore model simulations were performed up that time with the continuous source rate of 50l/day. Results of plume concentrations for the conditions in 1995 are shown on Figure 7. The results indicate the spread of the contaminant plume mainly seaward from the source location where the 20 ppm contour line extends up to one kilometer seaward from the power station. This confirms the detection of oil fuel traces by the local water well users in this area. The results also revealed that the contaminant plume migrates deep into the aquifer due to the flow system caused by the seawater intrusion.

Simulation predictions are performed for this site up to the year 2010 based on existing conditions of source elimination only. The results of this simulation are shown on Figure 8, and they illustrate the significant dilution of the contaminant plume and its movement seaward away from the power plant site however in this case only source elimination is applied.
Model predictions for the year 2000 based on remedial action plan scenario of pump-treat and inject are performed. The pumping is applied at the plume location, using pumping rates of 5 l/sec (18 m$^3$/hr) and the water is then treated and injected upstream from the plant site (southward). This remedial action scenario resulted in further significant dilution of the contamination plume as shown on Figure 9 for the year 2000. This dilution of the plume is equivalent to that shown on Figure 8 for the year 2010 under existing conditions. Simulated salinity concentrations for the year 2000 under the pump-treat and inject regime are shown on Figure 10. The salinity concentrations simulated for the year 2000 under the remedial action plan at the northern side upper part of the aquifer for depths of less than 90 m are less than those simulated for the 1994. This peculiar behavior in the 2000 simulations resulted from the injection of the treated water into the upper part of the aquifer. This caused the
salinity to decrease under the dilution effects. However at depths over 90 m the salinity concentrations for the year 2000 are higher than those for 1994 and the seawater is further intruded into the aquifer. This can be related to the further pumping caused by the pump-treat action.

![Figure 9 Simulated Plume Concentrations Distribution in ppm for pump-treat and inject in 2000](image)

![Figure 10 Simulated Chloride Concentrations Distribution (mass fraction) in 2010](image)

**CONCLUSIONS**

Extensive groundwater extraction in Tripoli region, for domestic, agricultural and industrial development has caused substantial seawater encroachment into Tripoli aquifer system. In recent years, the risk of contaminant spreading from industrial spills, underground storage-tank leaks, sewer leaks, farm wastewater and/or waste disposal sites is continually threatening the groundwater resources of the Tripoli area.
which forms one of the most economically significant area in the country. In this study, this potential problem is investigated and the groundwater flow, contaminant transport and seawater movement along Ayn Zara cross-section are simulated using the USGS three dimensional Heat and Solute Transport model (HST3D).

Simulation of the Ayn Zara cross-section was undertaken first to investigate the historical groundwater movement and seawater intrusion since 1957 until 1994. A good agreement between the observed and the computed water levels and salinity concentrations in 1957 and 1994 was obtained during the steady state and transient simulations. The model was used to simulate contaminant source due to leakage from an underground fuel oil storage tank located on the Ayn Zara section at the old power plant. The results for this case are presented showing the effects of seawater encroachment and water extraction system on the propagation of the contaminant.

Prediction simulations were performed up to the year 2010 after the leakage source was eliminated in 1995. The model simulations showed dilution of the contaminant plume in the year 2010 under existing conditions. Model results under remedial action scheme of pump-treat and inject indicted similar dilution of the oil plume in the year 2000, however further seawater encroachment was observed.

References


Keywords: Seawater Intrusion, Contaminant Transport, Ayn Zara, Tripoli Coastal Aquifer, HST3D.

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