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Evaluation of Biodegradation in an Aquifer Contaminated with Petroleum Hydrocarbon

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요약문

To evaluate the biodegradability of contaminants in an aquifer, computer modeling with RT3D model (Clement, 1997) was used. The RT3D model simulates the biodegradation of organic contaminants using a number of aerobic and anaerobic electron acceptors. The RT3D model was applied to a well-studied petroleum hydrocarbon plume in a shallow unconfined aquifer in Uiwang, Korea. The results of this study demonstrate the importance of biodegradation processes in the monitored natural attenuation and in reducing contaminant concentrations in a shallow aquifer. The modeling results tell that the amount of electron acceptors is the key factor affecting biodegradation of TEX, the petroleum hydrocarbon contaminants in shallow groundwater.

Key word: biodegradation, shallow aquifer, hydrocarbon, groundwater contamination, RT3D

1. Introduction

This study site was studied for several years by pre-researchers (Lee, 2000; Lee et al., 2000, 2001) and well characterized in hydrogeologic and environmental aspects. The main constituents of contaminants are toluene, ethyl benzene, and xylene isomers (TEX). It is assumed that these contaminants are released by leakage from ground and underground raw material storage tanks. The contamination was first discovered in 1983 (Lee, 2000). Therefore the period of contamination is at least 17 years.

In this study, the two pre-defined modules of RT3D were used, the modules of instantaneous aerobic decay of BTEX, and kinetic-limited degradation of BTEX using multiple electron acceptors. The physical flow and transport parameters for the model are obtained based on field studies, while some kinetic data for biodegradation are obtained from the literature (first-order degradation constant, etc.) and field studies (concentrations of electron acceptors, etc.).

The objectives of this study are to evaluate how much the electron acceptors affect the biodegradation of contaminants in groundwater and whether it is sufficient for the site remediation with only the monitored natural attenuation (MNA) mainly contributed by biodegradation.

2. Groundwater flow and reactive-transport simulations

The principal model input parameters for flow and transport simulations are summarized in Table 1. The resultant hydraulic head contours are presented in Figure 1a from flow simulations with MODFLOW. In comparison with the equipotential head contour by interpolation of field-estimated values in date May 26, 1999 (Figure 1b), this simulated output (Figure 1a) is similar to that in reasonable level.

Table 1. Aquifer Parameters for Flow and Transport Simulation

Simulation Parameter	Layer 1	Layer 2	Description
Hydraulic Conductivity (m/s)	1.0×10^{-3}	2.0×10^{-6}	
Specific Storage, Ss (1/m)	1.0×10^{-4}	4.0×10^{-6}	
Specific Yield, Sy	0.3	0.26	
Dispersivity (m)/ ratio of T/L*	10.0/ 0.1	10.0/ 0/1	
Effective Porosity	0.3	0.2	
Total Porosity	0.33	0.4	
Recharge (mm/yr)	100.0		infiltration

*transverse/ longitudinal dispersivity

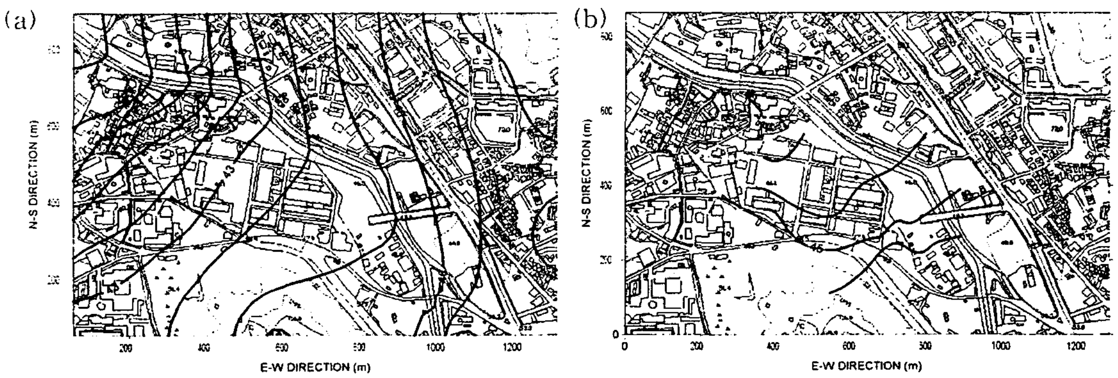

Figure 1. Hydraulic Head Contours: (a) simulated, (b) observed.

With the simulated flow field, two reactive transport RT3D modules, 'instantaneous aerobic decay of BTEX' and 'kinetic-limited degradation of BTEX using multiple electron acceptors', are applied. The governing equations of RT3D are well described in Clement et al. (1998). The principal parameters used in these reaction simulations are summarized in Table 2. The distribution coefficients are calculated based on literatures (Fetter, 1999; Domenico and Shwartz, 1990), and the first-order rate constants are

* concentrations where it is not contaminated

** assumed value

decided on the bases of field data and literatures (Lee et al., 2000; Clement, 1997). Initial concentrations were estimated from the field data collected in 1999 (Table 2, Figure 2a, b). A background concentration for dissolved oxygen (DO), for example, of 3.5 mg/L was selected based on the maximum measured DO concentration. And the background concentrations of ferrous iron and methane were assumed based on Lee (2000).

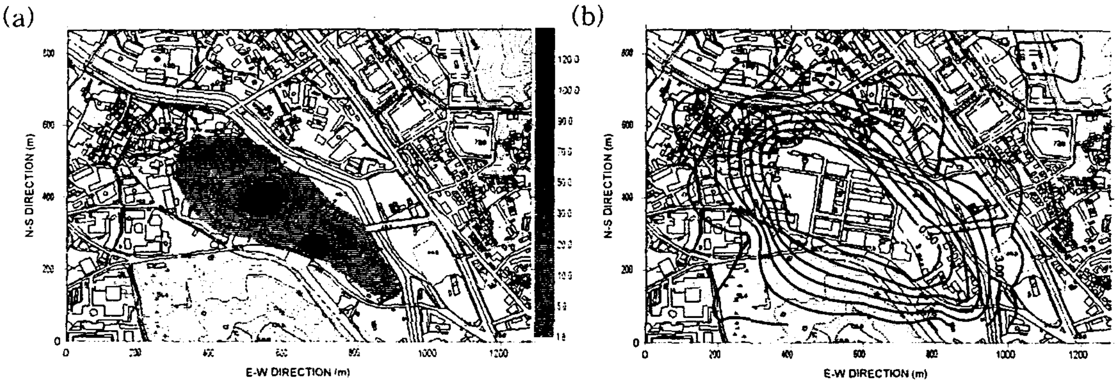

Figure 2. Initial Concentration Contours (Field Data): (a)TEX, (b)DO, Unit: mg/L

3. Results

Figures 3a and b show the results of instantaneous aerobic BTEX decay simulation at 10 and 20 years, respectively. And figures 4a and b show the results of multiple electron acceptors used kinetic-limited BTEX degradation simulation at 2 and 10 years, respectively. In the results of instantaneous reaction simulation, the initial maximum concentration of 137.6 mg/L was reduced to 35.3 mg/L at 10 years, and to 19.2 mg/L at 20 years. In the results of multiple electron acceptors used simulation, the same initial concentration was reduced to 5.34 mg/L at 2 years, and to 0.85 mg/L at 10 years.

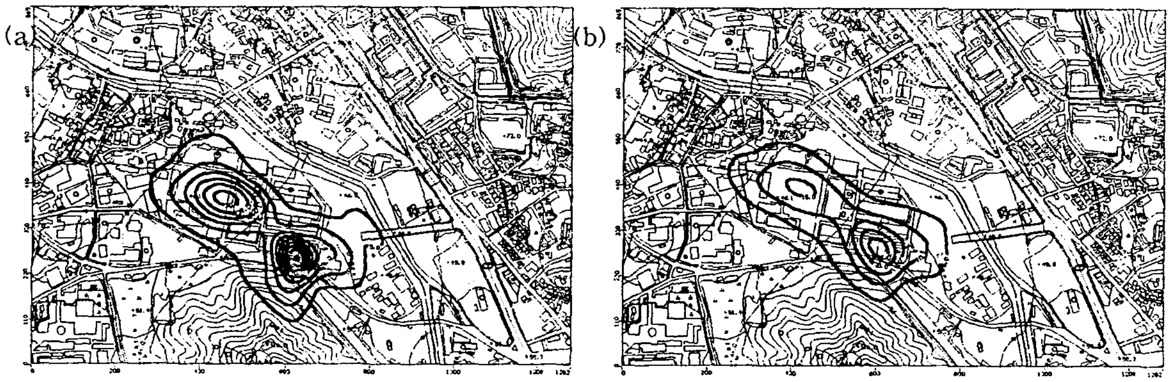

Figure 3. The Results of Instantaneous Aerobic BTEX Degradation Simulation
(a) at 10 years, contour: 5.0, 10.0, 15.0, 20.0, 25.0, 30.0, 35.0, 40.0, 45.0 mg/L

Table 2. Major Input Data for Sorption and Reaction Using RT3D

Parameter Description	Distribution Coefficient, K_d (L/mg)	First-Order Rate Constant (day^{-1})	Background Concentration* (mg/L)
BTEX	2.0×10^{-5}	·	0.0
Oxygen	2.0×10^{-5}	0.01 (via aerobic process)	3.5
Nitrate	2.0×10^{-5}	0.008 (via denitrification)	2.0
Fe^{2+}	1.0×10^{-5}	0.0005 (via iron reduction)	1.0×10^{-10} **
Sulfate	2.0×10^{-5}	0.00025 (via sulfate reduction)	20.0
Methane	1.0×10^{-5}	0.0001 (via methanogenesis)	1.0×10^{-10} **

(b) at 20 years, contour: 5.0, 10.0, 15.0, 20.0, 25.0 mg/L

Figure 4. The Results of Multiple Electron Acceptors Used Simulation
(a)at 2 years, contour: 1.0, 2.0, 3.0, 4.0, 5.0 mg/L, (b)at 20 years, contour: 0.1, 0.2 mg/L

4. Conclusion

The results indicate that the reaction using multiple electron acceptors is conspicuously more effective to contaminants reduction than only aerobic decay process. Because the electron acceptors like dissolved oxygen, nitrate, and sulfate are present in the field, the groundwater contamination level will be reduced prominently by biodegradation through those electron acceptors after 10 or 20 years. But on account of very high level of present contaminant concentration, time about 10 or more years is needed to reduce the level down to unharmful and drinking water level, like the results of multiple electron acceptors used simulation. Then additional engineering remediation methods are necessary to the monitored natural attenuation.

5. References

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