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A Large Scale Model to Study the Removal of
Aromatic Hydrocarbons from the Saturated Zone

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Management Perspective

Innovative groundwater remediation technologies are typically developed using laboratory columns, and then assessed in the field at the pilot scale. However, it is becoming difficult to conduct pilot-scale experiments in the field because of the potential negative environmental impacts. Therefore, in order to test new technologies at near field scale, a physical aquifer model was constructed and installed in the Aquatic Ecosystem Restoration Evaluation Facility (AQUEREF) at the National Water Research Institute in Burlington, Ontario. The large-scale model aquifer (a rectangular stainless steel box, 2.4 m x 6m x 2m deep) was designed with a separate head tank to provide uniform one-dimensional flow. A medium- to coarse-grained mixed sand was obtained from a local sand and gravel supplier and dry packed into the tank. Multi-level monitoring wells, consisting of 72 bundles of 1/8" o.d. stainless steel tubes, terminating at 5 different depths giving a total of 360 monitoring points were installed. This paper describes the initial hydraulic testing of the tank, the emplacement of a residual diesel fuel contamination source and the initial results of a pump-and-treat scenario which will be used as the basis of comparison for new experimental remedial technologies.

A LARGE SCALE AQUIFER MODEL TO STUDY THE REMOVAL OF AROMATIC HYDROCARBONS FROM THE SATURATED ZONE Suzanne Lesage, Kent S. Novakowski, Hao Xu, Greg Bickerton, Louise Durham and Susan Brown. Groundwater Remediation Project, National Water Research Institute, Environment Canada, Burlington, Ontario, L7R 4A6

ABSTRACT

Innovative groundwater remediation technologies are typically developed using laboratory columns, and then assessed in the field at the pilot scale. However, it is becoming difficult to conduct pilot-scale experiments because environmental authorities are increasingly reluctant to allow controlled spills followed by an experimental treatment. In order to test new technologies at near field scale, a physical aquifer model was constructed and installed in the Aquatic Ecosystem Restoration Evaluation Facility (AQUEREF) at the National Water Research Institute in Burlington, Ontario. The large-scale model aquifer (a rectangular stainless steel box, 2.4 m x 6m x 2m deep) was designed with a separate head tank to provide uniform one-dimensional flow. A medium- to coarse-grained mixed sand was obtained from a local sand and gravel supplier and dry packed into the tank. Multi-level monitoring wells, consisting of 72 bundles of 1/8" o.d. stainless steel tubes, terminating at 5 different depths (30 cm apart with depth), were installed at intervals of 30 cm (length), and 25 cm (width). The fundamental transport properties of the aquifer material were determined by conducting a conservative tracer experiment. To conduct the experiment, a uniform flow field was established by abstracting groundwater from a withdrawal well located at the end of the model opposite to the head tank. A mixture of Lissamine and sodium bromide tracers was introduced into the head tank and the subsequent migration was monitored using the multi-level network. The results of the experiment indicate that the aquifer material has a porosity of 28-32% and a longitudinal dispersivity of approximately 0.01 m. The average linear velocity during the experiment was approximately 0.02 m/hr. Bulk hydraulic conductivity was estimated independently at approximately 0.04 m/s. In a preliminary experiment to investigate the transport and remediation of aromatic hydrocarbons, petroleum was introduced as a saturated sand slurry into the up-gradient end of the aquifer material. The dissolution of aromatic hydrocarbons was tracked using Photovac GC analysis for the volatiles and HPLC for the PAHs. Monitoring of the transport process will involve more than 1000 analyses over the duration of the experiment. To accommodate the analysis requirements, a rapid method for the analysis of PAHs was developed. The method involves the use of a short HPLC column (3 cm) and a fluorescence detector, allowing for the completion of the analyses without sample preconcentration.

INTRODUCTION

Contamination of groundwater by gasoline and diesel fuels is a widespread environmental problem in Canada. Polynuclear aromatic hydrocarbons (PAHs) in the gasoline and diesel fuels are of particular concern because many are carcinogenic and degrade poorly. Aromatic hydrocarbons can represent up to 60 % of diesel fuels (Block, et al., 1991). Groundwater and soils contaminated with petroleum products must therefore be remediated.

The technology for the remediation of contaminated groundwater is typically developed in the laboratory, and then tested in the field at the pilot scale. One of the problems for conducting pilot scale experiments at real field sites, is that environmental authorities are increasingly reluctant at allowing controlled spills followed by a treatment that is yet to be proven effective. In order to test new technologies at near field scale, a model aquifer with a very dense monitoring network was constructed, providing controlled conditions only possible in a semi-artificial system. The physical aquifer model was designed and installed at the National Water Research Institute of Environment Canada in Burlington.

saturated from the head-tank end over a period of one week using tap water. The tap water was continually purged with helium to remove dissolved air and residual chlorinated compounds. The sand was allowed to settle for a few weeks prior to conducting the tracer experiments.

Tracer Experiment

A conservative tracer experiment was conducted by introducing, simultaneously, a mixture of Lissamine (2 mg/L) and sodium bromide (100mg/L) into the head tank (total volume 3120 L). A series of three gas diffusers were placed at the bottom of the tank to provide constant mixing. In addition, at the onset of the experiment, the head tank was vigorously mixed using manual methods. As the groundwater was depleted by pumping from the withdrawal wells (total pumping rate 400mL/min), the level in the head tank was maintained at a constant level by the addition of water through a float valve. This provided for a constantly decaying tracer source; that is the concentration of the tracers in the head tank decreased by dilution over the entire period of the experiment. Over the course of the following two weeks, samples at rows 0.76 m, 1.98 m, and 3.81 m down-gradient from the head tank were obtained around the clock. Over 5000 samples were collected and analyzed for Lissamine (by fluorescence) and for bromide (by conductivity). Figure 2 shows the distribution of tracer concentration in cross-section adjacent to the center-line for both the control and treatment sides of the model.

Estimates of the longitudinal dispersivity and porosity of the sand were obtained by interpreting breakthrough concentrations of bromide from selected sampling points. This was accomplished using a one-dimensional transport model (Novakowski, 1992) which accounts for an exponentially decaying source in the head tank and assumes the aquifer to be of semi-infinite extent. The governing equation is based on simple advection-dispersion and a third type boundary condition is employed at the interface between the head tank and the aquifer material. The model was formulated using dimensionless variables which incorporate the retardation factor directly. Interpretation of the breakthrough curves was conducted under the further assumption that the bromide tracer behaved conservatively during transport. To reduce the potential for boundary influences, the breakthrough curves selected for modelling were chosen from sampling points located close to the centre line of the tank and away from the withdrawal well and the head tank. The concentration profiles were then corrected for background and normalized to the initial bromide concentration in the head tank. Modelled fits to the concentration data were obtained by adjusting the independent parameters, longitudinal dispersion and porosity, and determining the average linear velocity from the pumping rate and specified porosity.

Emplacement of the Petroleum Source

The results of the conservative tracer experiment were used to determine the optimal placement of the petroleum source. Because the main goal of this study is to investigate methods for the cleanup of petroleum present at residual saturation in the groundwater zone, it was necessary to devise a method of emplacement that would provide a well defined source in terms of both

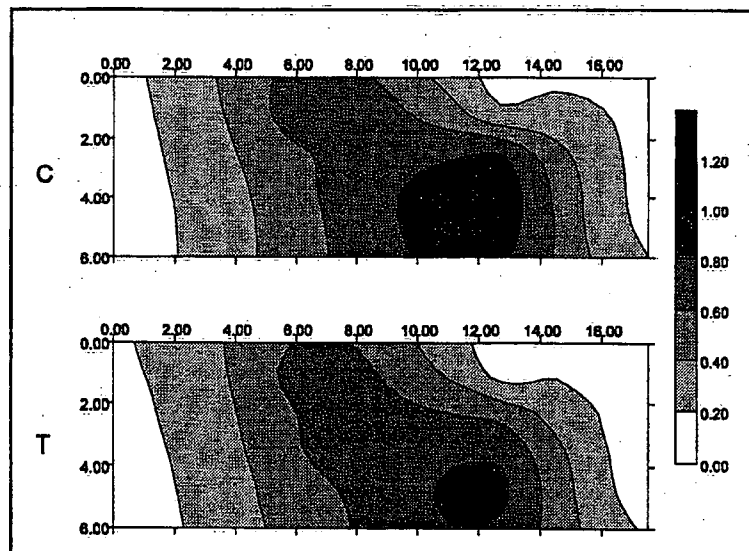


Figure 2 Contour plots of lissamine concentration (mg/L) at 310 hours in cross section for both the control and treatment side.

vadose zone were monitored for BTEX (benzene, toluene, ethyl benzene and xylenes) using headspace analysis. No BTEX was found in any of the wells except those in the immediate proximity of the source. The development of the diesel plume with time is depicted on Figure 4 as total PAHs. A similarly-shaped plume of BTEX was also found moving ahead of the PAHs. This is further evidence that the aromatic hydrocarbons were only transported in the dissolved phase. If the compounds were transported as droplets (i.e. undissolved phase), the BTEX and PAHs would not be separated spatially with time.

CONCLUSION AND FUTURE PLANS

A large scale aquifer model to study groundwater remediation technologies was successfully designed and constructed. The transport characteristics of the model aquifer were measured using a tracer experiment. A residual diesel source was emplaced and is being dissolved slowly such as would occur in a typical pump and treat scenario. Water will be pumped through until a steady state concentration has been achieved. Humic acid will then be introduced as an additive to enhance the dissolution process. The subsequent migration of the aromatic compounds and the humic acid, will be followed. Humic acids are being studied as an environmentally compatible alternative to surfactants (Xu et al., 1994).

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