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A risk based corrective action approach using computer modelling at an urban leaking underground storage tank site

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ABSTRACT: Leaking underground storage tanks (LUSTs) at gasoline service stations are a major source of groundwater contamination in urban areas. Application of a Risk-Based Corrective Action (RBCA) approach at a gasoline-contaminated underground storage tank site indicated that implementation of extensive soil and groundwater remediation was not warranted, nor was it always the most effective method of addressing soil and groundwater contamination problems. Data collected at an urban site in Queens, New York were used to model contaminant transport to predict the impact of known gasoline contamination of soil on the underlying groundwater. Computer models were calibrated with known site characteristics and estimates of contaminant mass loading to groundwater. Downgradient receptor concentrations were also obtained. The results of the RBCA approach utilizing computer modelling indicated that minimal risk of future groundwater contamination exists at the site, and that additional investigation and/or remediation is unnecessary.

1 INTRODUCTION

Given the staggering number of documented petroleum release sites in the United States of America, and the fact that the majority of State regulatory agencies are under-staffed, the United States Environmental Protection Agency (USEPA) has endorsed the American Society of Testing and Materials (ASTM) Risk-Based Corrective Action (RBCA) as an alternative tool to address sites based on potential risks. RBCA was conceived so that sites can be expeditiously mitigated, especially in areas of low risk, while assuring that human health and the environment are adequately protected. The USEPA's current position on RBCA was outlined in a recent directive issued by the Office of Solid Waste and Emergency Response (USEPA OSWER Directive 9610.17). The impetus for the directive was the need to help individual States build corrective action programs that are based on both sound science and common sense, and are flexible and cost-effective.

RBCA is a consistent decision-making process for the assessment and response to a petroleum release, based on the protection of human health and the environment (ASTM 1995). RBCA is a process for determining the amount and urgency of corrective action(s) necessary at a petroleum release site. It has evolved out of an explicit need to master a work load that has grown too large and appears to be out of control (LUSTLINE 1994).

As of October 31, 1994, more than 270,000 petroleum releases had been reported nationwide. In 1994 alone, there were 34,000 confirmed releases reported nationwide. The upcoming 1998 USEPA deadline for upgrading, replacing, or closing UST systems is expected to increase the number of petroleum contaminated sites as contamination is discovered during the upgrade or removal process at existing UST facilities (USEPA 1995).

The New York State Department of Environmental Conservation (NYSDEC) which oversees corrective action at petroleum contaminated sites located in New York State, recently issued an interim document entitled "Interim Procedures for Inactivation of Petroleum-Impacted Sites" in January 1997. The document was developed to improve the corrective action decision making processes and to minimize delays related to closure of petroleum spill sites as well as to maximize the use of limited resources (NYSDEC 1997). The interim document was adapted from the tiered ASTM RBCA approach. It clarifies and expands current State guidelines for site closure to include the RBCA process for petroleum impacted sites.

The following study applies the RBCA approach using computer modelling at an urban LUST site. The purpose of the study was to predict if known vadose zone contamination could adversely impact groundwater beneath the site at levels exceeding state and federal drinking water standards.

Two different modules of the same soil and groundwater contaminant transport modelling package were used. The American Petroleum Institute (API) Decision Support System (DSS) was selected to model the study area because it incorporates widely accepted industry developed models for the RBCA approach.

2 STUDY AREA

The study site is located in Queens, New York, U.S.A. The site was chosen because it is located in an area where groundwater has been adversely impacted due to extreme urbanization.

The subject site consists of an active gasoline service station located in a commercial and residential area in the northern portion of Queens County, New York. Queens County is located at the western end of Long Island, New York (Figure 1). According to the 1990 census, the borough of Queens encompasses an area of approximately 285 km^2 and has a population of 1.95 million.

3 HYDROGEOLOGIC SETTING

Pleistocene (Wisconsin Stage) glacial drift deposits cover approximately eighty percent of Queens County, New York, including the subsurface beneath the site. The remainder of the county is covered by shore and salt marsh deposits and manmade fill of Holocene age. The subject site is located at the top of a long regional ridge underlain by what is known as the Harbor Hill Terminal Moraine, which marks the farthest advance of the Wisconsin age glaciation in Queens County (Figure 1) (Swarzenski 1963) (Soren 1971).

The unconsolidated sediments underlying the area consist of Late Cretaceous to Pleistocene deposits were deposited unconformably on crystalline bedrock of Precambrian (?) age (Soren 1971). The bedrock beneath the county dips about 24 m per 1.61 km to the southeast which allowed the deposition of unconsolidated deposits ranging in thickness from 0 m in northwestern Queens to 335 m in the southeastern part of the county (Figure 2).

Four distinct aquifers have been identified beneath the area and include in descending order: the upper glacial aquifer, the Jameco Aquifer, the Magothy Aquifer, and the Lloyd Aquifer (Soren 1971) (Figure 2). The upper glacial aquifer directly underlies the subject site, and thus will be discussed in detail.

The upper glacial aquifer consists mainly of glacial outwash deposits of sand and gravel. Groundwater occurs under unconfined conditions in most of the aquifer especially south of the Harbor Hill Moraine. The thickness of the aquifer ranges from approximately 1 m in northwestern Queens to about 46 m in the southern part of the county (Figure 2). The upper glacial aquifer is designated as a potable source of water by the NYSDEC and is extensively pumped as a commercial and residential water source in the central part of the county between the Harbor Hill Moraine and Jamaica Bay (Soren 1971). The groundwater immediately beneath the site is not utilized for supply purposes; however, the Jamaica Water Supply Company operates two municipal supply wells within a two kilometre radius of the site (Figure 1).

4 INVESTIGATION METHODOLOGY

Test borings were drilled around the existing UST area at an active gasoline service station using the hollow stem auger drilling method. Soil samples were collected during drilling and sent to a laboratory where they were analyzed for gasoline components using EPA certified methodologies. The borings were drilled to varying completion depths with the maximum depth being 28 m, due to the limitations of the drilling method and the nature of the sediments.

The geology beneath the study site consists of compact fine to medium sand with some silt and fine gravel which extends below a fill unit from 1.8 m to 28 m be-

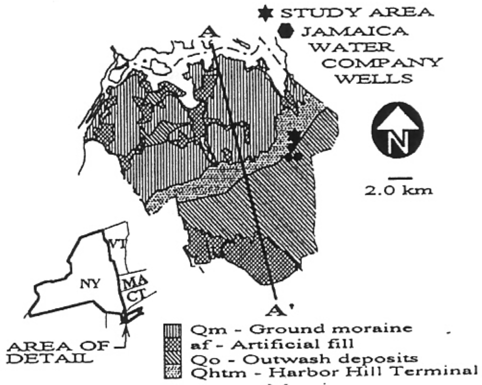

Figure 1. Plan view map of Queens County, New York; showing the surficial geology (adapted from Soren 1971).

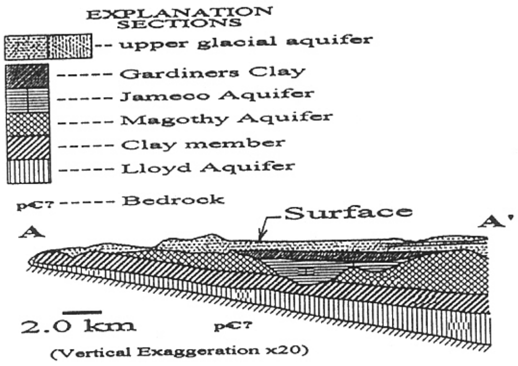

Figure 2. North-south cross section of Queens County, New York; showing hydrogeologic units (adapted from Soren 1971).

low grade. The groundwater table was not encountered suggesting that it is present below 28 m in the area of the facility. The location of test boring and soil sampling locations, are shown on Figure 3.

Results of the drilling indicate that the sediments encountered during the study were consistent with descriptions of the upper glacial aquifer reported by Soren (1971) and Swarzenski (1963). The results of soil sampling and laboratory analysis indicate that soils beneath the site were impacted by petroleum hydrocarbon compounds (gasoline) in the vicinity of the UST area. The hydrocarbon impacted soils were the result of documented LUSTs located in the central portion of the site (Figure 3).

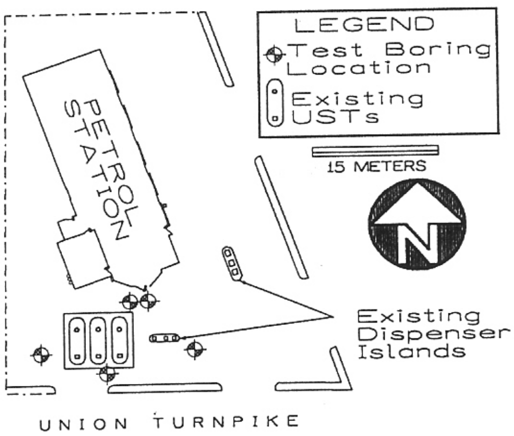

Figure 3. Site plan showing the study area.

5 CONCEPTUAL MODEL

To initiate the study, a conceptual model of the physical structure of the subsurface was developed using data collected from the subsurface investigation. The conceptual model included estimating the source area size, soil porosity, soil volumetric water content, depth to groundwater, and mass of adsorbed benzene contamination. The parameters obtained included the following: source area size = 8.53 m wide x 7.62 m long x 13.41 m thick; porosity = 0.35; volumetric water content = 0.15; depth to groundwater = 30.5 m; benzene concentration = 150 µg/kg.

For the purpose of the study, benzene (C_6H_6) was chosen as the indicator compound because it has the lowest NYSDEC Groundwater Quality Standard (0.7 µg/l), and it is also the most mobile of the aromatic hydrocarbons found in gasoline.

6 MODEL PREPARATION

A fate and transport model was prepared to evaluate the potential for adsorbed hydrocarbon contamination to migrate downward and impact the groundwater table beneath the site. The model was prepared because two Jamaica Water Company municipal supply wells are located within 1.6 km of the site.

The conceptual model parameters were used as input for two separate modules of the API DSS modelling package. The Jury unsaturated flow model was chosen to predict vadose zone contaminant transport and mass loading rates to groundwater, and the AT123D groundwater fate and transport model was subsequently utilized to predict contaminant travel times.

7 JURY UNSATURATED MODEL

The Jury model is an industry accepted unsaturated screening level model that estimates the chemical flux volatilizing from soil and time varying concentrations throughout the unsaturated zone (API 1994). The time varying concentration profiles are used to estimate the contaminant loading to the water table. According to Jury et. al. (1983) (1990), the model is based on the analytical solution of a differential mass balance equation that accounts for the following considerations: total soil concentration, time, first order decay of contaminants, chemical diffusion in the unsaturated zone, depth of the contamination, and contaminant velocity.

To address the modeling at the Queens site the Jury model calculated the annual mass loading to groundwater from user specified site and chemical data. The Jury model required input of the following soil column data: volumetric water content (0.15), effective porosity (0.35), soil bulk density (1.65 g/cm^3), fractional organic carbon (0.002 mg/mg), thickness of incorporation (13.41 m), thickness of soil cover (13.41 m), depth of unsaturated zone (30.50 m), x-dimension of contaminant source (8.53 m), y-dimension of source (7.62 m), thickness of boundary layer (0.5 cm), and infiltration rate (0.0173 cm/day). Chemical input data required in the Jury model include: total soil concentration (0.15 mg/kg), chemical air diffusion coefficient (7,517 cm^2/day), chemical water diffusion coefficient(0.84 cm^2/day), Henry's Law constant (0.25 mg/l/mg/l), K_{oc} (83 μg/g oc/μg/ml), chemical decay rate (0.00 1/day), and solubility (1,750 mg/l).

The Jury model was run using the API DSS software package as an interface. The model was run to predict mass loading rates to ground water 60 years into the future. The mass loading rates obtained were ultimately used in the AT123D ground water fate and transport model to predict resultant groundwater concentrations at a receptor point 17 m below and 10 m downgradient of the source.

8 JURY MODEL RESULTS

Results of the Jury model show that some benzene will migrate (leach) downward and enter the groundwater beneath the site (Figure 4). The highest mass loading calculated by the Jury model occurs between 8 and 18 years in the simulation. The peak mass loading occurs at 11 years at a rate of 1.75 g/yr. After 11 years, the mass loading rate declines steadily with some trace mass still entering the groundwater aquifer even at year 60 in the simulation.

As part of the computer modelling process, a sensitivity analysis was completed to evaluate Jury model input parameters. Volumetric water content, source size, and source concentration were determined to be the most sensitive variables.

Volumetric water content was determined to have the greatest impact on the resultant mass loading rates and arrival times. Changing the volumetric water content in the Jury model dramatically affects the mass loading rate to groundwater.

It is also important to note that the Jury model does allow for the input of a biodegradation factor, which was not used (set to 0.00 1/day) in the model so that the potential risk to groundwater and the environment was determined very conservatively. It is obvious that biodegradation will occur as the mass of contamination migrates downward toward the groundwater table. If the Jury model was run to include a biodegradation factor the resultant benzene mass loading to the groundwater would likely approach zero.

9 AT123D MODEL

The AT123D groundwater contaminant fate and transport model was run to calculate hypothetical benzene concentrations in groundwater beneath and downgradient of the site. The AT123D model uses a Cartesian coordinate system to describe the source and the location of a hypothetical receptor point (Yeh, 1981). The receptor point is an important element in the RBCA approach, because it is the nearest downgradient point where risk to human health and the environment must be determined.

The AT123D model idealizes the saturated zone and assumes that flow is one dimensional, steady, and uniform in the downgradient direction (American Petroleum Institute 1994). The differential mass balance (advective-dispersion) equation:

$$D_l \frac{\partial^2 C}{\partial l^2} - \bar{v}_l \frac{\partial C}{\partial l} = \frac{\partial C}{\partial t} \qquad (1)$$

(where, l = a curvilinear coordinate direction; $\bar{v}$ = average linear groundwater velocity; D_l = coefficient of hydrodynamic dispersion in the longitudinal direction; C = solute concentration) is internally solved to describe contaminant fate and transport in the saturated zone (Freeze & Cherry, 1979). Groundwater concentrations are then calculated across a number of equally-spaced vertical intervals using the following equation (American Petroleum Institute 1994):

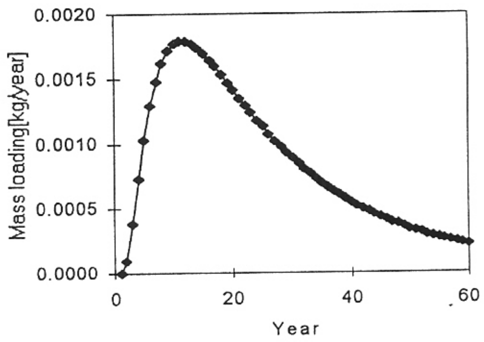

Figure 4. Predicted mass loading to ground water.

$$C_{well} = \sum_z \frac{C(z)}{N_z} \qquad (3)$$

where, C_{well} = vertically-averaged well concentration; $C(z)$ = concentration at depth z (mg/l); N_z = number of user specified intervals between top and bottom of the well screen. The concentrations are then internally vertically averaged. The method assigns equal weight to all vertical intervals between the top and bottom of the interval assigned.

To show maximum concentrations that could be present, a 1 m interval was chosen extending from the top of the water table into the saturated zone. The input data were again conservatively estimated where actual data were not available. The depth to groundwater was estimated to be approximately 30.5 m below the surface and approximately 17 m below the source of contamination. The hydraulic conductivity (k) of the aquifer material was estimated from the literature to be 1,112 m/yr (Freeze & Cherry 1979).

10 AT123D MODEL RESULTS

The results of running the AT123D model, using the Jury models' calculated mass loading values as input, conservatively show that very low concentrations of benzene are predicted in the ground water downgradient (10 m) of the source. Figure 5 graphically depicts the results obtained by the AT123D model.

Peak concentrations of benzene predicted for between 12 and 14 years at a maximum of 2.7 µg/l. After 12 to 14 years, concentrations decline to less than 0.5 µg/l, which is below NYSDEC Groundwater Quality Standards for benzene. The model was rerun to calculate concentrations of benzene at a greater distance from the source (100 m), and as expected, the results show that concentrations of benzene will be extremely low at this distance (<0.05 µg/l) and well below NYSDEC Groundwater Quality Standards.

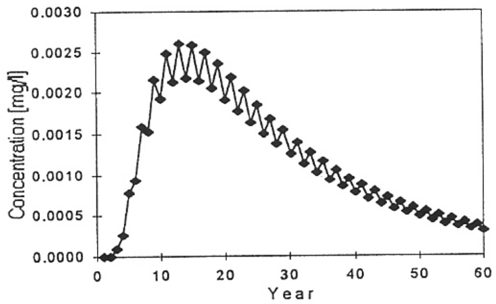

Figure 5. Predicted groundwater concentrations at the theoretical receptor point.

The data presented on Figure 5 show some concentration-time oscillations that are the result of hydraulic conductivity and hydraulic gradient input values. These oscillations occur because of the relatively large time step internally used by the model (1 year time step) (Yeh 1981). Tests on the model have demonstrated that if small time steps are used (<0.1 years), the amplitude of the oscillations are not significant (Yeh 1981).

11 CONCLUSIONS

The results of a RBCA approach using computer modelling indicate that the source of adsorbed benzene contamination present in the subsurface at the study site will not significantly threaten groundwater. This type of RBCA approach was both cost effective, beneficial, and demonstrated these findings to the regulatory agency, without using more invasive and costly investigative techniques. In this instance the RBCA approach was used in lieu of the more traditional practice of basing clean-up requirements on generic environmental standards that may or may not be appropriate to site-specific situations.

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