Technical Paper #2003

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For Presentation at:
Remediation of Chlorinated and Recalcitrant Compounds,
Second International Conference
Monterey, California

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00P-0567

THE INFLUENCE OF AN INTEGRATED REMEDIAL SYSTEM ON GROUNDWATER HYDROLOGY

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ABSTRACT

This paper summarizes the development of a remedial system designed to hydraulically contain and ultimately reduce a plume consisting of primarily 1,1,2,2-tetrachloroethane (1,1,2,2-TeCA). The system consists of groundwater circulating wells or extraction wells located in the core of the 1,1,2,2-TeCA plume to provide active source control, combined with monitored natural attenuation (MNA) and phytoremediation instituted to further reduce dissolved-phase contaminants. Monitoring of natural attenuation parameters indicates that abiotic and biotic degradation is significantly reducing 1,1,2,2-TeCA concentrations. Phytoremediation is provided by a 4.5-year-old plantation of 172 hybrid poplars observed to be seasonally influencing groundwater hydrology. A 3D-geospatial model (earthVision®), which was constructed based on extensive geological, geophysical, and chemical data, defines both the hydrostratigraphic framework and the 1,1,2,2-TeCA distribution and is the basis for a 3D-groundwater flow (MODFLOW) and contaminant transport (RT3D) model. Model results indicate that the system may remove 85% of the total 1,1,2,2-TeCA mass after 30 years, with groundwater wells and MNA providing the bulk of mass removal. Phytoremediation emerges as a significant contributor by providing 7% of the total mass removal. Field evidence and modeling indicate that the integrated remedial system is capable of effectively reducing contaminant mass, thereby satisfying the remedial objective.

INTRODUCTION

Objective

The objective of this study was to determine the feasibility of deploying an integrated system to remediate a 1,1,2,2-TeCA plume. A 3D groundwater flow and contaminant transport model was developed to estimate the capacity of the proposed remedial technologies to hydraulically contain and ultimately reduce the 1,1,2,2-TeCA plume. The model was used to determine the well configurations that achieve optimal mass removal while minimizing impacts to a freshwater marsh. In addition, the model was used to assess mass removal generated by natural attenuation and phytoremediation and to estimate the contaminant loading to the freshwater marsh. Finally, the model was used to identify significant data gaps.

Site Description

The J-Field site is located in the Edgewood Area of Aberdeen Proving Ground, MD (Figure 1). Groundwater in a surficial aquifer is impacted by primarily 1,1,2,2-TeCA and trichloroethene (TCE) as a result of past disposal activities (Argonne, 1996). The 1,1,2,2-TeCA plume is bilobed and extends

82 meters toward the southwest and 110 meters to the east (Figure 2). The 1,1,2,2-TeCA source area resides within a local groundwater recharge area. Groundwater flow in the surficial aquifer is through a fine sand and clayey silt unit that exhibits a bulk hydraulic conductivity of approximately 0.3 to 1.5 m/day (Quinn et al., 1996).

MODELING APPROACH

A phased modeling approach was used to simulate the fate and transport of the 1,1,2,2-TeCA plume and examine the effectiveness of the integrated remedial system in removing contaminant mass.

3D-Geospatial Model

A comprehensive 3D-geospatial model was constructed based on extensive geological, geophysical, and chemical data using earthVision® (Dynamic Graphics, 1999). The geospatial model defines both the hydrostratigraphic framework and the 1,1,2,2-TeCA distribution at the site and is the framework for a 3D-groundwater flow (MODFLOW) and contaminant transport (RT3D) models (McDonald and Harbaugh [1988], Clement [1998]). The 3D-geospatial model assisted the remedial design efforts by characterizing the primary hydrostratigraphic units and subsequently defined the model layers in MODFLOW. The geospatial model illustrates that the thickness of the surficial aquifer varies between 7 and 12 meters and the underlying first-confining unit extends continuously from the study area to beneath the Chesapeake Bay with no evidence of breaching by paleochannels (Figure 3).

The distribution of contaminants was modeled using 3D minimum tension interpolation techniques and integrated within the hydrostratigraphic framework (Schneider and Wrobel, 1998). The distribution of VOCs existing within the framework of the 3D-geospatial model was exported to the RT3D model and used to represent the initial conditions in RT3D. The geospatial model and existing hydrogeologic data were used to estimate both dissolved- and sorbed-phase contaminant mass (Table 1). 1,1,2,2-TeCA mass was also incorporated into the model to represent residual-phase materials that are suspected of feeding a local hot spot. Quantifying the contaminant mass enabled the project team to establish remedial goals by identifying the amount of VOC mass that requires removal.

Table 1
Estimated Contaminant Mass

Contaminant	Dissolved Mass (lb)	Sorbed Mass (lb)	Estimated Residual Source Mass (lb)
1,1,2,2 - TeCA	1,320	1,820	1,400
TCE	475	1,310	-

Groundwater Flow Model

A groundwater flow model was developed by incorporating data from the geospatial model (e.g., hydrostratigraphic framework) into MODFLOW. The model grid was telescoped using 82 rows, 86 columns, and 6 layers with minimum lengths of 3 meters (Figure 4). The flow model was calibrated to mean groundwater elevations based on continuously measured data. Inverse modeling techniques were applied to achieve acceptable model calibration with the aid of UCODE (Poeter and Hill, 1998). Details of the MODFLOW model and the structured approach to model calibration are presented in Quinn et al. (1996) and WESTON (2000).

Contaminant Transport Model

The fate and transport of 1,1,2,2-TeCA, TCE, and their respective transformation products was simulated using a contaminant transport model (RT3D) that contains a multi-species, reactive transport module. This module uses first-order, rate-limited kinetics that characterize the sequential VOC degradation used to represent natural attenuation processes at J-Field. The degradation rates and pathways for VOCs were based on site-specific data and differed between hydrostratigraphic units. Details of natural attenuation are outlined in the following sections as well as in Yuen et al. (1998).

SIMULATED REMEDIAL PROGRAM

Each component of several potential integrated remedial systems: (1) groundwater circulating wells (GCWs), (2) extraction wells, (3) phytoremediation, and (4) monitored natural attenuation (MNA) was incorporated into the MODFLOW-RT3D model using the techniques presented in the following subsections.

Groundwater Circulating Wells

The GCWs were simulated using the well package in MODFLOW. The circulation process was replicated in the model by segmenting the surficial aquifer into multiple layers. The rates of extraction and reinjection applied to the model were 1.9 liters/min determined from aquifer tests. The withdrawal rates of the GCWs were held constant during the course of the 30-year simulations. The placement of the GCWs was focused in the area of highest 1,1,2,2-TeCA concentrations.

Groundwater Extraction Wells

Groundwater extraction wells were simulated using the well package in MODFLOW. The simulated flow rates were held steady at 1.9 liters/min based on aquifer tests. The placement of extraction wells coincided with the GCWs to compare their performance.

Phytoremediation

Phytoremediation provides a natural mechanism for providing additional VOC reduction. The plantation consists of 172 deep-rooted poplar trees planted in buffer groups adjacent to the marsh. The poplar trees were simulated using the MODFLOW well package based on the premise that the poplar trees act as solar-driven pumps that siphon from the groundwater table. The rate of groundwater withdrawal for each tree was calculated using a site-specific crop index (CI) generated from 4 years of sap flow, weather, leaf, stem, and land area data collected at J-Field.

Predicted withdrawal rates for each poplar tree were incorporated into the well package using 30 1-year stress periods. These stress periods are essentially an average rate of the groundwater withdrawal compiled for a given water-year cycle based on the respective seasonal uptake rates (spring, summer, fall, and winter). Based on the CI, these steady-state groundwater withdrawal rates were projected to increase as the plantation matures and trees increase in size. The CIs indicated the plantation withdrew approximately 4,162 liters/day upon reaching maturity at 10 years. The removal rates and methods used to determine the average flow rates for the poplar trees that were the basis of the modeling approach are outlined in a report detailing J-Field phytoremediation activities (Dynamax, 1999).

Estimates of the mass removal predicted for the trees required the use of a transpiration stream concentration factor (TSCF) to describe the degree of partitioning that occurs at the poplar tree root surfaces. TSCFs of 0.79 (1,1,2,2-TeCA) and 0.74 (TCE) were based on methods outlined by Schnoor (1996).

Natural Attenuation

A comprehensive natural attenuation study conducted at J-Field concluded that VOC degradation is actively occurring both in the surficial aquifer, where iron-reducing conditions exist and abiotic processes predominate, and in the marsh, where methanogenic conditions support biotic degradation (Yuen et al., 1998). Field data support these findings as evidenced by the widespread distribution of transformation products and the rapid decline in 1,1,2,2-TeCA and TCE concentrations in groundwater as the plume migrates to the marshes. A simplified representation of the primary degradation pathways and rates was simulated using the RT3D model (see Table 2).

Table 2
VOC Degradation Pathways and Half-Lives (Days)

Surficial Aquifer	1,1,2,2-TeCA	→ TCE	→ DCE	→ VC	→ Eth
(Upland Area)		1900	2320	2600	2930
Surficial Aquifer	1,1,2,2-TeCA	→ DCE	→ VC	→ Eth	
(Marsh Area)		90	460	1730	

MODEL RESULTS AND CONCLUSIONS

The combined models proved useful for evaluating the capacity for the integrated remedial system to effectively remove contaminant mass. Figure 5 illustrates an example of a 30-year simulation that indicates the integrated remedial system is capable of removing 78% of the total 1,1,2,2-TeCA mass after 30 years. Groundwater wells and natural attenuation processes contribute the bulk of predicted contaminant mass removal. The model results agree with existing data that J-Field contains an ideal hydrogeologic setting (highly reduced groundwater chemistry and low groundwater flow velocities) that promotes both biotic and abiotic degradation of 1,1,2,2-TeCA. In addition, existing low-permeability, organic-rich marsh sediments effectively retard contaminant migration. These conditions also appear ideal for successfully implementing phytoremediation based on the predicted 7.5% removal of total 1,1,2,2-TeCA mass generated by the poplar trees. Field data indicate that the plantation produces hydraulic containment of the southeastern edge of the 1,1,2,2-TeCA plume during the mid- to late-summer months.

While the hydrogeologic conditions encourage the successful application of natural attenuation and phytoremediation, the low-permeability sediments reduce source removal rates by limiting sustainable well yields to 1.9 liters/min. Despite the low yields, the wells do provide an active mechanism for achieving 1,1,2,2-TeCA source reduction, and field data demonstrate that mass removal by wells is achievable. Field evidence and modeling indicate that the integrated remedial system is capable of effectively reducing contaminant mass at J-Field and satisfying the remedial objective.

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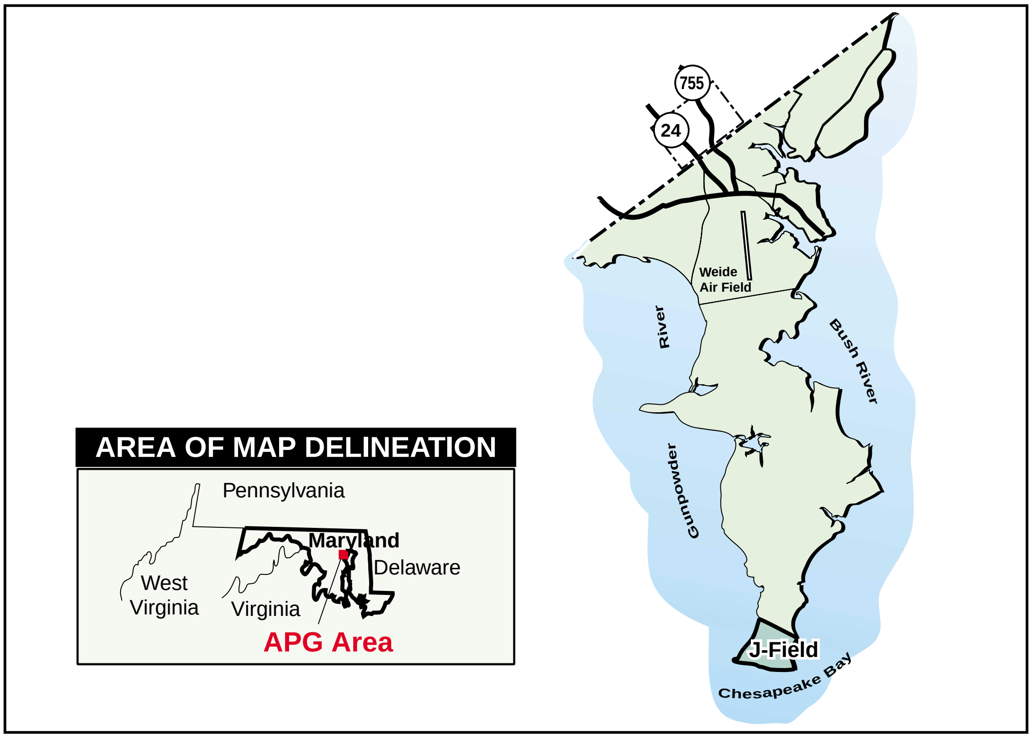

Figure 1. Location Map for J-Field, Aberdeen Proving Ground, MD

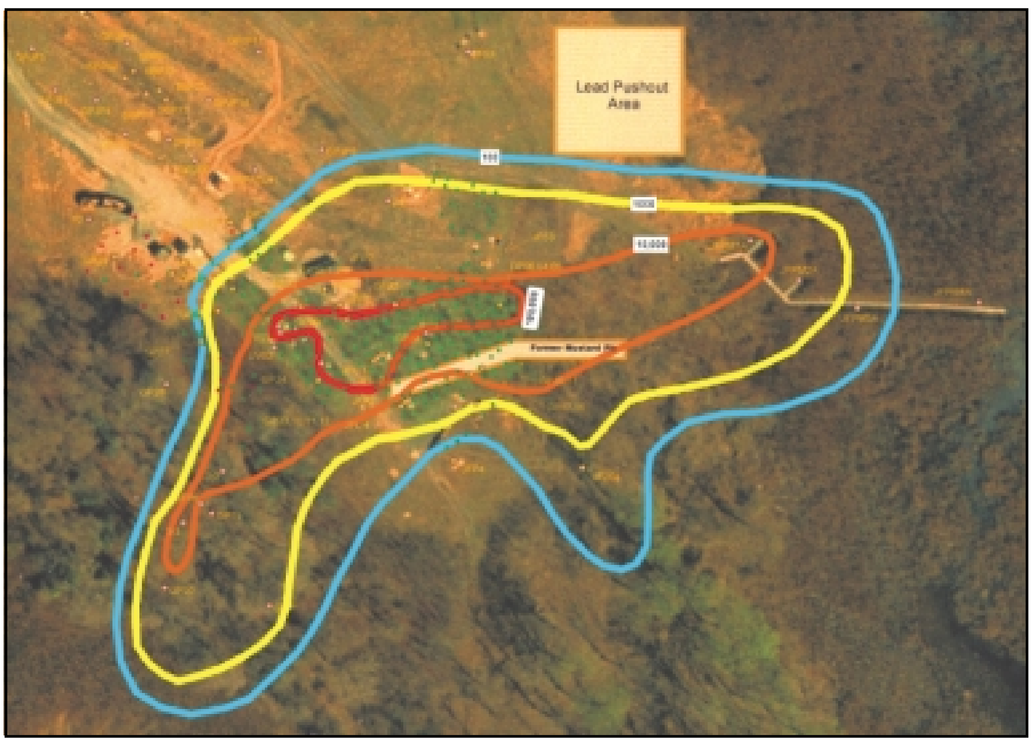

Figure 2. Distribution of 1,1,2,2-TeCA in Surficial Aquifer

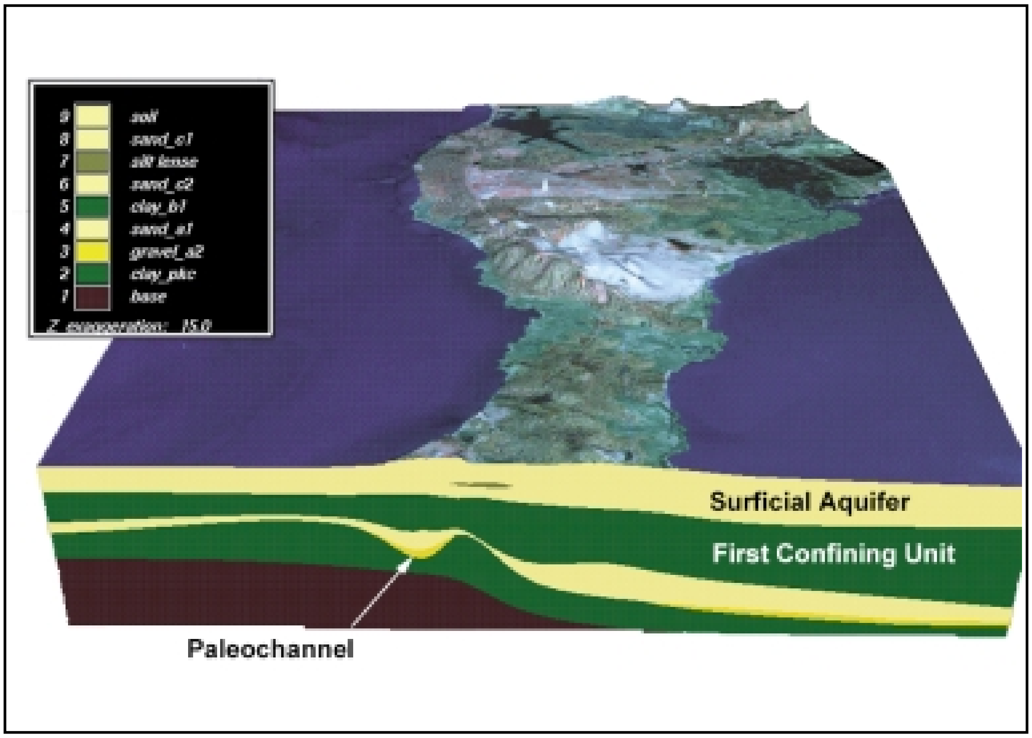

Figure 3. 3-D Geospatial Model Illustrating the Hydrostratigraphic Units

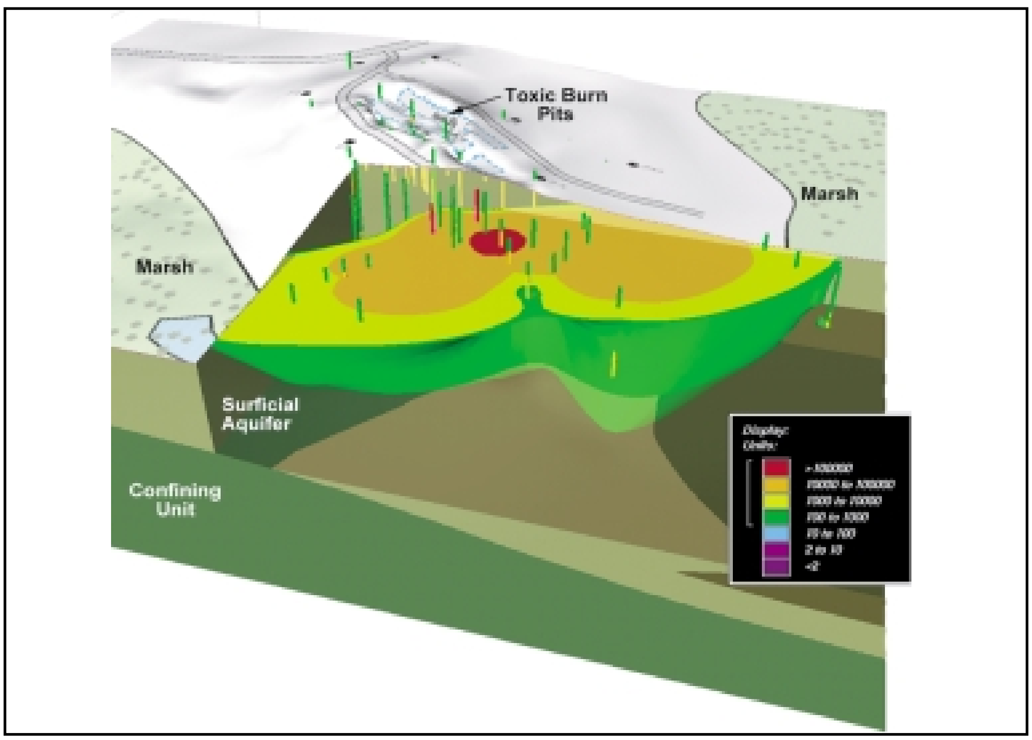

Figure 4. Geospatial Model Illustrating the 1,1,2,2-TeCA Plume

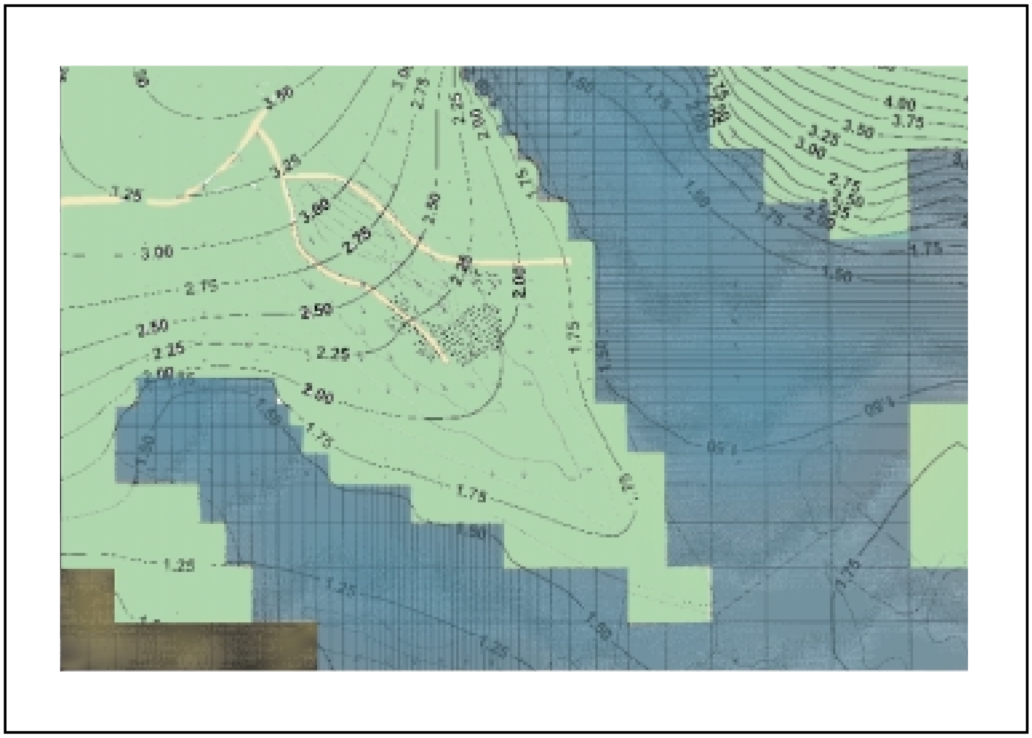

Figure 5. MODFLOW Grid Showing Simulated Hydraulic Head

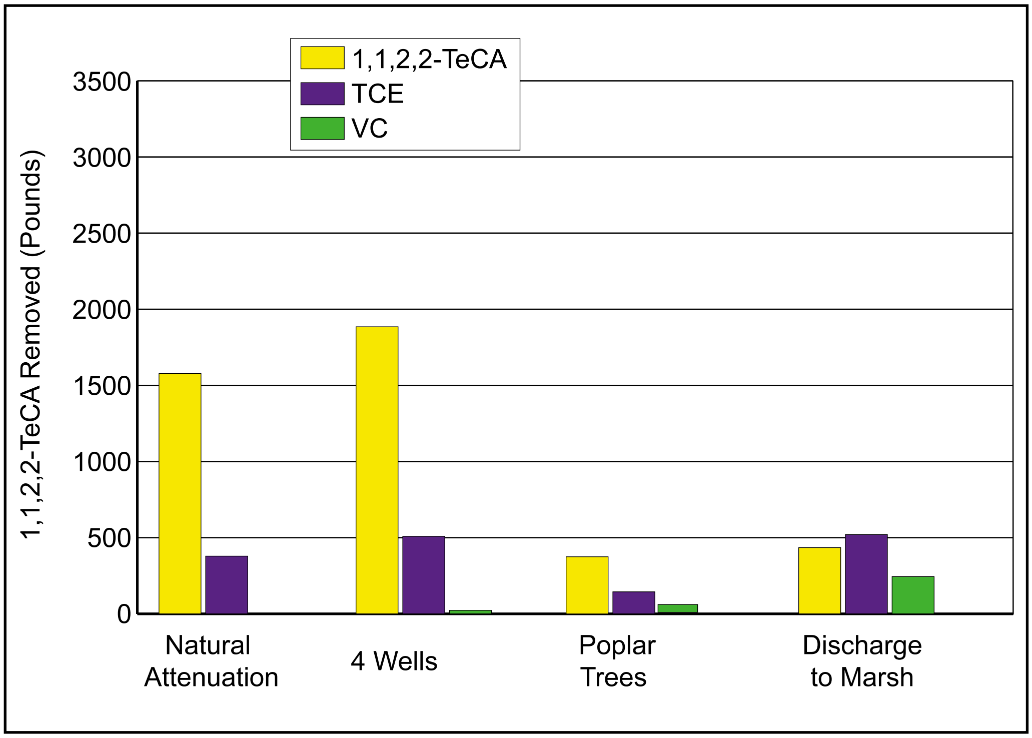

Figure 6. Simulated Mass Removal by Integrated Remedial System