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Using Geospatial Models and 3-D Visualization to Advance Decisionmaking and Communication of Remedial Solutions to Environmental Programs

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Using Geospatial Models and 3-D Visualization to Advance Decisionmaking and Communication of Remedial Solutions to Environmental Problems

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ABSTRACT

Integrating and presenting technical information so that complex site conditions are readily understandable is a critical factor in successful negotiations with regulatory agencies and in the courtroom. During remedial investigations, a significant amount of data of varying quality and formats is collected and compiled in a multitude of database structures. The development of geospatial models provides a quick and technically defensible means for integrating these diverse databases and interactively visualizing environmental information in three dimensions (3-D). Geospatial models are comprehensive tools that effectively illustrate complex conditions common at environmental sites, such as the 3-D distribution of hydrostratigraphic units and important hydrogeochemical parameters. Thus geospatial models are powerful tools for conveying complex technical issues to laypeople and to decisionmakers. They are equally effective in boardrooms, courtrooms, and public meetings. The use of these models facilitates decisionmaking and consensus building within project teams as well as with regulatory agencies.

Geospatial models provide highly defensible and easily understood interpretations of complex hydrogeologic data, thereby providing better communication of environmental solutions and remedial alternatives. These models ultimately provide confidence in decisionmaking and communicate solutions to regulatory agencies. This paper presents two case studies to illustrate how geospatial models, developed using earthVision® software (Dynamic Graphics, Alameda, California), were used to communicate complex environmental information and solutions between engineers, clients, regulators, and the public and resulted in expedited remedial actions and favorable decisions.

Introduction

If a single picture is worth a thousand words, then 3-D visualization is invaluable in communicating complex technical issues. It is well known in the legal profession that presentation of visual evidence is significantly more effective (100 %) in retention of information by jurors than by oral presentation alone (Weiss-McGrath report)[1]. Even more significant is a 650% increase in juror retention of combined visual and oral presentation over oral presentation alone. In the environmental industry, helping regulators and the public understand technical information is necessary to facilitate resolution of issues with carefully planned decisionmaking. 3-D visualization provides more than pictures; it provides interactive viewing and analysis of technical data.

Geospatial modeling and 3-D visualization are technologies used to create "visual databases" of environmental information[2]. These technologies are both environmental information management tools and communication tools. Rodriguez[3] (1997) showed how these tools can be applied at many different phases in the flow of environmental information. For example, 3-D visualization can be used early on to identify data gaps and focus field investigations. Later in the process, as more data are collected, geospatial modeling is used to analyze the data and view the analyzed data in 3-D.

The process of geospatial modeling integrates different types of two- and three-dimensional environmental data in true spatial relationship and produces a 3-D model which can then be interactively visualized. Typical types of data input include lithologic data, geologic structure information, well construction specifications, water level data, and chemistry data. These diverse data are represented in 3-D space by creating spatially continuous surfaces or grids using industry-accepted algorithms to interpolate between data points, eliminating the necessity to interpret 3-D data in 2-D space. The accuracy of the correspondence of the geospatial model with the site data (conceptual model) can be assessed both visually and statistically. Credibility is gained by removing inconsistency of interpretation of geologic information and demonstrating accuracy of the model.

DATA INTEGRATION AND CONVEYING TECHNICAL INFORMATION

One of the primary advantages of constructing a 3-D geospatial model is the integration of multiple and independent data sets. The modeling process brings these data together in presentable format that enables a collective team, comprised of client representatives, project managers, technical staff, and regulatory advisors to examine site conditions in context with proposed remedial solutions. Prior to implementing remedial technologies to remedy environmental problems, it is imperative to gain a comprehensive understanding of the hydrogeologic framework to characterize site conditions that ultimately dictate the distribution of contaminants and consequently, the remedial solutions.

Geospatial modeling provides a cost- and time-effective technique for integrating the site data. These data typically consist of site infrastructure, engineering, geologic, geophysical, geochemical, and geohydrologic information. These data are combined into a master database and spatially analyzed to characterize the site conditions, such as sources of contamination and likely flow pathways, that influence remedial performance.

This spatial analysis is an advanced form of hydrogeologic characterization and typically illustrates the extent of essential aquifer units, contaminant distributions, contaminant source areas, groundwater flow processes, and site infrastructure. An example of the application of spatial analysis is characterizing geologic heterogeneities that influence contaminant source distributions and limit the effectiveness of most remedial technologies. For instance, the thickness and extent of water-yielding sand channels are commonly modeled to design remedial systems capable of intercepting contaminant plumes that preferentially migrate through these sand channels.

Most geospatial analyses for environmental sites utilize data collected by different methods, including lithologic borings, surface and borehole geophysical techniques, groundwater and soil sampling data, and geotechnical methods. These forms of data independently describe unique site characteristics, but in the framework of a geospatial model, these integrated data collectively provide a detailed characterization of hydrogeologic conditions that influence remedial solutions.

Geospatial modeling and 3-D visualization are extremely powerful methods of conveying complex technical issues to laypeople and decisionmakers since integration of diverse types of data into a single 3-D model clarifies site characteristics, reducing the need for interpretation. Interactive visualization of these models creates an impact because they can be viewed from different angles, sliced horizontally and vertically, and used to answer questions that arise on the spot. These models are equally useful in boardrooms, courtrooms, and public meetings, facilitating decisionmaking and consensus building within project teams as well as with regulatory agencies.

CASE STUDIES

The following case studies illustrate applications of geospatial modeling and 3-D visualization that improved communication and decisionmaking.

Case Study 1: Application of 3-D Geospatial Modeling to Evaluate Remedial Performance, Chambersburg, PA

A pilot study was designed to examine the capacity of in-situ chemical oxidation treatment to remediate unsaturated soils contaminated with chlorinated volatile organic compounds (CVOCs). 3-D geospatial modeling analyses were conducted to assist in the remedial design of the innovative technology and to evaluate remedial performance of the in-situ chemical oxidation pilot test.

Site Conditions

Historic waste disposal practices at this case study site included placement and subsequent burning of materials, including waste solvents, in shallow burn pits. This disposal practice led to soil and groundwater contamination. Sampling of soils beneath the burn pits indicated that CVOCs comprised over 75% of the total VOC mass. The maximum total CVOC concentration detected was 52,000 mg/kg. The most prevalent chlorinated solvent detected was 1,1,1-trichloroethane (1,1,1-TCA) at a maximum concentration of 49,000 mg/kg.

Soil in the burn pit area was a relatively uniform sandy loam. No dense non-aqueous phase liquids (DNAPLs) were encountered in the soil samples. Any DNAPLs remaining after the burn activities likely migrated downward through the vadose zone under the influence of gravity. Capillary forces of the soils adsorbed a component of the remaining pure-phase CVOCs. The soil chemistry data indicate that the adsorbed and to a lesser degree, residual phase saturation extended vertically through the vadose zone. Based on the relatively homogenous nature and moderate permeability of the sandy loam, a pilot study utilizing in-situ chemical oxidation was recommended to remediate the observed soil contamination.

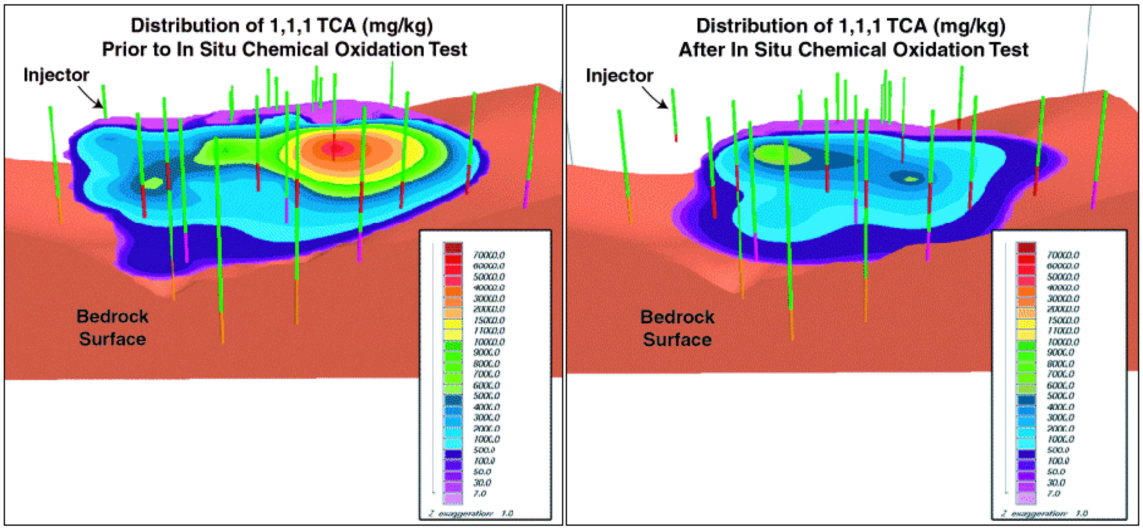
Application of 3-D Geospatial Modeling

Remedial Design

3-D geospatial analyses were conducted using the modeling software earthVision (Dynamic Graphics, Alameda, CA) to assist in the design of the in-situ chemical oxidation pilot study. The modeling was performed to aid the project team in making decisions relative to the engineered design of the pilot study as well as to facilitate the following activities: (1) Predicting the distribution of 1,1,1-TCA so that injector points could be located; (2) Estimating the amount of 1,1,1-TCA mass residing in the vadose zone; and (3) Identifying data gaps in the sampling program.

The distribution of 1,1,1-TCA was modeled using gridding algorithms developed by Dynamic Graphics. Details of the hydrid deterministic schemes (minimum tension gridding methods) that are incorporated into the earthVision code are presented in the earthVision Geospatial Modeling Code Manual[4]. The predicted distribution of 1,1,1-TCA indicated that the core of the plume was located in the center of the vadose zone in unsaturated soils, as opposed to residing at the soil and bedrock interface (see Figure 1). This distribution supports the contention that no DNAPLs remain. Based on this distribution, the placement of the injectors were designed to coincide with the core of the 1,1,1-TCA plume to optimize delivery of the oxidizing agents and maximize contaminant mass removal.

Figure 1: Visualization of pre- and post-injection distribution of 1,1,1-TCA using earthVision



Total Mass Reduction: 83%

The geospatial analyses provided estimates of the total volume of contaminated soil (2,150 cubic yards of vadose zone soils contaminated with CVOCs). A total CVOC mass of approximately 5,000 pounds was predicted to reside in the vadose zone soils at a depth of 5 to 23 feet below ground surface. Based on these estimates, the in-situ chemical oxidation system was designed accordingly. The technology is designed to destroy CVOCs in the soil by utilizing a network of controlled, pressurized injection points to deliver a solution of hydrogen peroxide (50%), catalysts, and surfactants. The chemical reaction generated by this solution creates a hydroxyl radical that actively oxidizes CVOCs and converts these compounds to carbon dioxide, oxygen, and water.

In addition, during the geospatial modeling analyses, it was clear where insufficient data had been collected because closure of contours could not be attained. Supplemental sampling locations were thus identified, enabling subsequent focused sample collection during the post-pilot study test.

Remedial Performance

The in-situ chemical oxidation treatment process involved the completion of a bench-scale test, installation of a temporary soil/cement cap, and the injection of approximately 24,000 gallons of hydrogen peroxide (50%) and catalyst into 17 injectors over 42 days. While treating the vadose zone, the progress of the reaction was measured by monitoring the concentration of carbon dioxide off-gas from vents and nearby injectors. The carbon dioxide concentrations ranged from 10% to 20%, while the reaction was actively breaking down the contaminants and dropped to 1% to 2% as the rate of the reaction diminished.

Geospatial model analyses were conducted using the post-injection sampling results to assess the remedial performance of the pilot test. The modeling results indicated that the total CVOC mass was reduced from approximately 5,000 pounds to 1,183 pounds (77% reduction) while the mass of 1,1,1-TCA was reduced from approximately 3,000 pounds to 526 pounds (83 % reduction). Figure 1 clearly shows not only the reduction of the mass of 1,1,1-TCA but also where in space the remaining mass is located. The distribution of the remaining CVOCs indicated the possibility that micro-scale heterogeneities or residual DNAPLs exist in the upper section of the vadose zone. These heterogeneiteies would have provided channeling of the chemical solution and may explain why portions of the upper treatment zone apparently did not receive adequate exposure to the chemical solution. Based on these findings, fate and transport modeling combined with risk-based analyses are being conducted to evaluate the threat to human health and the environment of leaving the remaining CVOCs in place and monitoring contaminant trends in the future.

These results were presented in 3-D to regulatory agencies at various points during the process of the pilot study and helped to expedite the decisionmaking process by clearly showing the conceptual understanding of the site characteristics as well as the results of the pilot study. 3-D visualization also helped in gaining public acceptance of the pilot study.

Benefits of 3-D Geospatial Analyses

Many advantages to using geospatial modeling analyses were recognized throughout the course of the pilot study. These advantages include:

1. Providing information that led to a cost-effective design for the in-situ chemical oxidation technology. Estimates of CVOC mass and distribution were used to quantify the amount of oxidizing agents required to destroy CVOCs.
2. Clarifying site characteristics expedited the regulatory approval process.
3. Measuring the remedial performance of the in-situ chemical oxidation technology by estimating the amount of CVOC destruction.
4. Visualizing the performance of the pilot study and facilitating technical discussions between client representatives project managers, geologists and engineers, citizens and regulatory advisors.
5. Identifying data gaps in the sampling program.

Case Study 2: Technical Impracticability at Pease Air Force Base, NH

Geospatial modeling and 3-D visualization were used to illustrate the hydrogeochemical characteristics at this site which led to a determination that the site was Technically Impracticable (TI) to remediate.

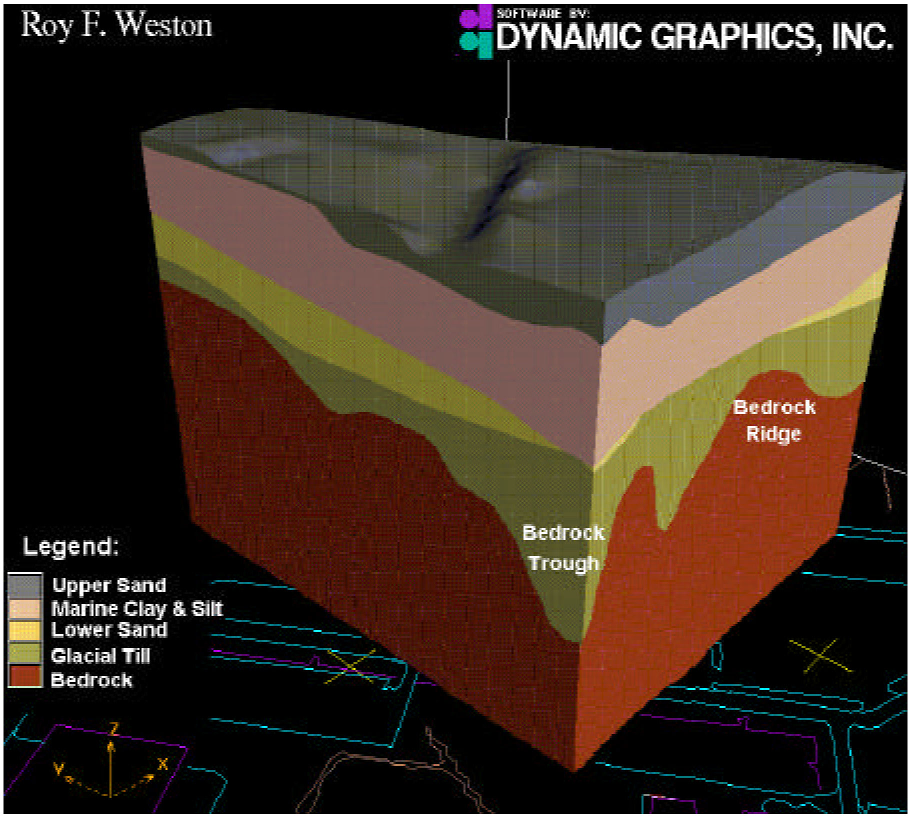
Site Conditions

Building 113 (Site 32) at the former Pease Air Force Base (AFB) in Portsmouth, NH, is a chlorinated solvent site which may have DNAPLs from a former waste trichloroethylene (TCE) underground storage tank (UST). The former UST, which received waste TCE from degreasing operations in Building 113, was excavated in 1988 when an underground overflow discharge pipe was found. The overflow pipe and associated contaminated soil were removed in 1990.

The site geology consisted of unconsolidated glacial sediments overlying bedrock. These sediments were classified as one of four lithologic units (see Figure 2):

- Upper Sand (US)
- Marine Clay and Silt (MCS)
- Lower Sand (LS)
- Glacial Till

Figure 2: Distribution of hydrogeolgic units from geospatial model

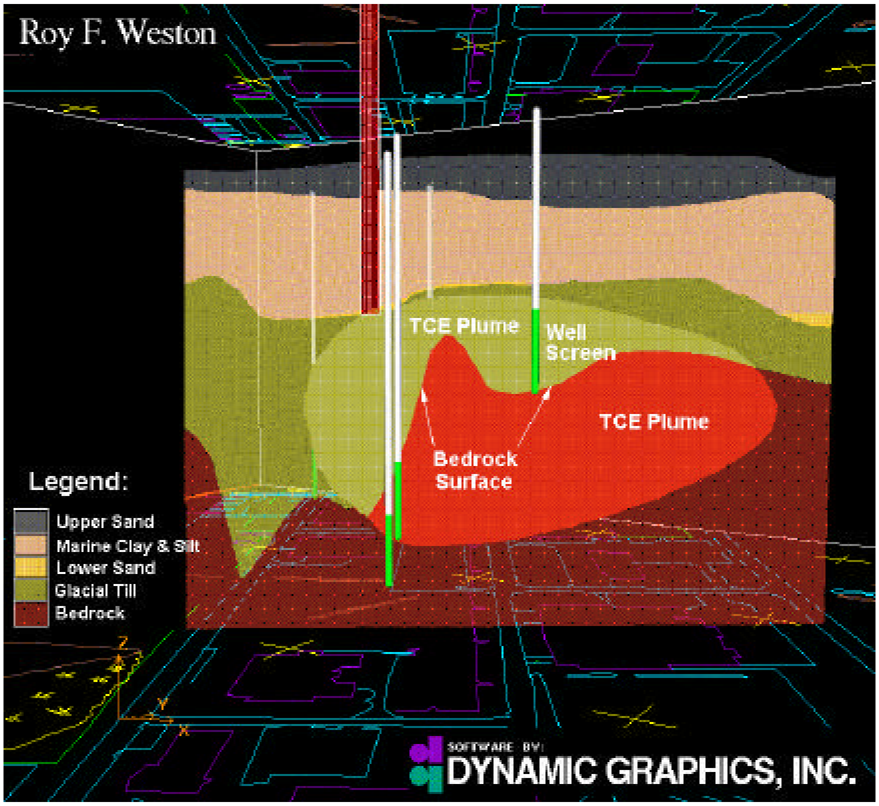


Bedrock underlying Site 32 consists of layered biotite quartzite and diabase dikes. Brittle fracturing is abundant in the shallow fractured bedrock. Depth to bedrock varies from 10 to approximately 60 feet below ground surface. Several bedrock topographic highs and lows (buried troughs and ridges) exist under the Site 32 area.

The various overburden and bedrock strata identified at Site 32 have different hydrologic properties; consequently, the hydraulic characteristics of the site vary laterally and with depth. The shallowest zone of saturation occurs within the Upper Sand (US), at depths from 0 to 6 feet below ground surface. The Marine Clay and Silt (MCS) typically behaves as an aquitard in the Site 32 area.

TCE, as a DNAPL, entered the subsurface environment from the waste TCE UST and overflow pipe at Building 113. The TCE is suspected to have migrated downward through the unsaturated US unit to the water table, and when sufficient mass of DNAPL was present, farther downward to the MCS. At the top of the MCS, the DNAPL likely spread out laterally, concentrating in topographically low areas. The DNAPL then accumulated, building up entry pressure, and moved through macropores, fractures, and sandy interbeds in the MCS to reach the Lower Sand/Glacial Till (LS/GT) and shallow fractured bedrock, where the highest concentrations of dissolved TCE have been detected (see Figure 3).

Figure 3: TCE plume in relation to the hydrogeologic units from geospatial model



Separate-phase DNAPL was not observed in samples from any of the Site 32 soil borings or monitor wells. DNAPL is extremely difficult to locate in the subsurface and it is likely that DNAPL exists at Site 32 principally as residual saturation in soil pore spaces and bedrock fractures rather than as pools.

Application of 3-D Geospatial Modeling

A three-dimensional geospatial model was created using earthVision® by Dynamic Graphics, Inc. This model included lithologic and water level data from borings and wells, as well as soil and groundwater VOC data. Figures 2 and 3 illustrate output from this model. The ability to incorporate groundwater VOC data with the geologic units and visualize in 3-D was most helpful in simplifying and relaying technical concerns at the site to regulators and the public.

These technical concerns included:

- High levels of bedrock contamination.
- Shallow depth to groundwater.
- Dewatering of the Marine Clay and Silt unit by pumping from the shallow bedrock leading to possible settlement of building foundations.

- Irregular surface of the bedrock and its fractured nature posing limitations on success of physical barriers to contain source area contamination.

- DNAPL residual saturation and the low yield of the overburden limit the effectiveness of pump-and-treat remediation.

Benefits of 3-D Visualization

Interactive 3-D visualization was used to present these complex technical issues to EPA Region I. Visualization, along with presentation of performance results from interim remedial measures and available research and guidance on the documented failure of most common remedial technologies in similar situations, demonstrated that remediation of the site was technically impracticable. As a result, the Site 32 TI determination became the first site in EPA Region I to have a Record of Decision for implementation of Technical Impracticability at a CERCLA site after the investigation stage of the CERCLA process. All prior TI determinations in Region I were made only after a final remedial action was implemented and failed to achieve the desired results. 3-D visualization helped simplify the technical issues and also was invaluable in gaining public acceptance of the TI determination.

The selected remedy for Site 32 included a determination of TI with containment of the source area using a combination of vertical and hydraulic barriers. Implementation of TI at this site saved the Air Force approximately $4 million in potential remediation that would have proven ineffective. Integration and visualization of the site data in 3-D were critical persuasive components in the success of the TI determination for this site.

CONCLUSIONS

Geospatial modeling and 3-D visualization were used in both case studies to integrate, analyze, and visualize complex data to facilitate remedial decisionmaking. Use of these tools streamlined the remedial investigations by identifying data gaps and focusing subsequent data gathering. These tools also provided a means to consistently analyze the data since all the data was integrated in a single model, which could then be interactively viewed and used for the decisionmaking teams to build consensus.

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KEY WORDS

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Technical impracticability
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Mass estimates