Utilization of 4-Dimensional Data Visualization Modeling to Evaluate Burial Ground Contaminants at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky

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ABSTRACT

This paper describes how 4-Dimensional (4D) Data Visualization Modeling was used to evaluate historical data and to help guide the decisions for the sampling necessary to complete a Remedial Investigation/Feasibility Study (RI/FS) for the burial ground sites at the Department of Energy (DOE) Paducah Gaseous Diffusion Plant (PGDP). DOE at the Paducah Site is primarily involved in environmental cleanup and landlord activities.

The scope of this project was to prepare a work plan for identifying the data available and the data required to conduct an RI/FS for the Burial Ground Operable Unit (BGOU) located within and near PGDP. The work plan focuses on collecting existing information about contamination in and around the burial grounds and determining what additional data are required to support an assessment of risks to human health and the environment and to support future decisions regarding actions to reduce these risks.

INTRODUCTION

Purpose

This paper will discuss how the 4D Data Visualization Modeling technique was utilized to show the vast amount of data already available and how additional sampling was held to a minimum to meet the Data Quality Objectives. Utilization of this tool was regarded highly by the U.S. Environmental Protection Agency (EPA) and the local Citizens Advisory Board (CAB).

Data visualization is best used as a tool to elevate the level of understanding among all stakeholders so that appropriate decisions can be made. Visualization tools can integrate multiple sources and types of data into one medium for evaluation, thus addressing the multi-dimensional nature (both spatial and temporal) of the data. Such tools allow individual data components to be viewed and assessed within the context of the whole conceptual model, and often provide a mechanism to assess data gaps and other areas of uncertainty within the conceptual model. When used appropriately, data visualization can be used to support and convey technical opinions with clarity and force.[2]

Background

The scope includes an RI, baseline risk assessment, evaluation of remedial alternatives, remedy selection, and implementation of actions, as necessary, for protection of human health and the environment for the BGOU. The BGOU encompasses the following burial grounds: C-749 (Solid Waste Management Unit [SWMU] 2), C-404 (SWMU 3), C-747 (SWMU 4), C-746-F (SWMU 5), C-747-B (SWMU 6), C-747-A (SWMUs 7 and 30, which includes the area beneath SWMU 12), the residential/inert borrow area and old North–South Diversion Ditch (NSDD) disposal trench (SWMU 145), and additional disposal areas that might exist beneath the scrap yards. Project uncertainties that could affect the scope and schedule include the amount and scope of RI characterization needed (e.g., test pits, angle borings) and the possible need for additional actions beyond capping.[1]

Several documents have been produced containing data pertinent to the various SWMUs within the BGOU. In most cases, the previously prepared documents grouped several SWMUs together and did not study one particular SWMU. These documents and the various monitoring wells installed throughout PGDP provide considerable usable data for this RI/FS Work Plan. Seven of the eight SWMUs had previous RI studies performed, which generated many data points (168,000). Data, limited to the past ten years for screening purposes, were downloaded from the site database. The contaminants chosen for modeling were based on contaminants detected above action levels during the risk screening process and showing a sufficient number of detections for valuable presentation.

Project Goals

The goals for the BGOU RI/FS are consistent with those established in the Federal Facility Agreement (FFA) and the Site Management Plan (SMP) negotiated among DOE, EPA, and the Kentucky Department for Environmental Protection (KDEP). The FFA requires that PGDP identify, investigate, and remediate Areas of Concern and SWMUs that pose a threat to human health and the environment. The goals of this RI/FS are as follows [1]:

- Goal 1: Characterize Nature of Source Zone—Characterize the nature of contaminant source materials using existing data and, if required, by collecting additional data

- Goal 2: Define Extent of Source Zone and Contamination in Soil and Other Secondary Sources at All Units—Define the nature, extent (vertical and lateral), and magnitude of contamination in soils, sediments, surface water, and groundwater by using existing data and, if required, by collecting additional data; determine the presence, general location (if practicable), and magnitude of any dense, nonaqueous-phase liquid (DNAPL) zones as defined in the Paducah SMP

- Goal 3: Determine Surface and Subsurface Transport Mechanisms and Pathways—Gather existing quality data and, if necessary, collect additional adequate-quality data to analyze contaminant transport mechanisms, evaluate risk, and support an FS

- Goal 4: Support Evaluation of Remedial Technologies—Determine whether the existing data are sufficient to evaluate alternatives that will reduce risk to human health and the environment and/or control the migration of contaminants off-site

CONCEPTUAL MODEL

The conceptual site model presented identifies the probable and potential contaminant migration and exposure pathways at BGOU SWMUs. From the source, two probable pathways are identified: (1) a probable pathway to the adjacent subsurface soils and (2) a probable pathway to groundwater due to leaching and dissolution of contaminants. These probable pathways will be the focus of the investigation activities. Trichloroethene (TCE) is considered a potential source beneath the buried waste. Potential exposure to contamination at BGOU SWMUs via air is currently limited, since the areas are covered with caps and/or vegetation.[1] Figure 1 shows an illustration of the typical conceptual model for these burial grounds.

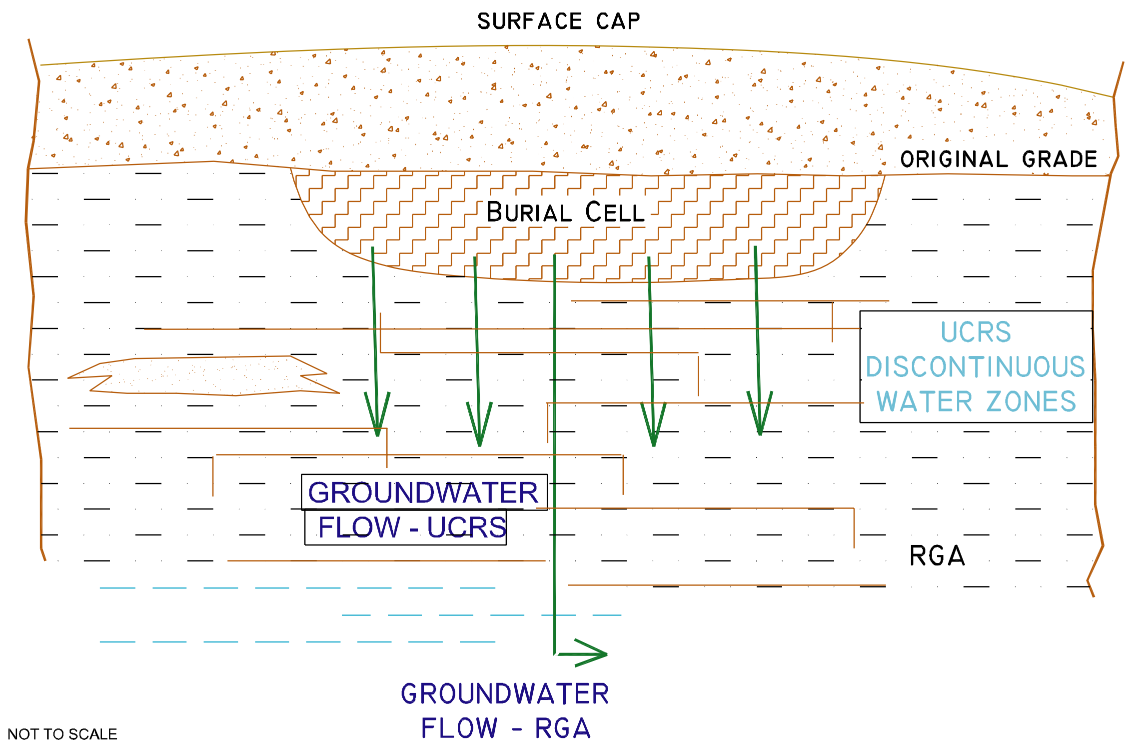

Fig 1. Typical conceptual model for PGDP burial grounds

PREVIOUS SITE INVESTIGATIONS

The historical data set was used to compile various risk-screening tables required by the DOE PGDP methods document for scoping activities. 4D figures were created using C Tech's Environmental Visualization System (EVS) and Mining Visualization System (MVS) software to show the major contaminants for the eight SWMUS within the BGOU. Both soil and groundwater models were created. The contaminants chosen for modeling were based on contaminants detected above action levels from the risk screening process and showing a sufficient number of detections for valuable presentation. For some SWMUs, such as SWMUs 7 and 30, TCE is modeled – even though it did not meet these criteria – to show that the contaminant was evaluated in the historical data set.[1]

BGOU 4D MODELS OF HISTORICAL DATA

Methodology for Data Visualization

Successful site-specific characterization begins with a solid conceptual understanding of the regional setting. Examples of regional information typically obtained to provide a foundation for site-specific visualizations include topographic features affecting surface and subsurface water flow; location of the site in relation to known or suspected contributors of contamination; and locations of existing or potential receptors. Regional information commonly used includes aerial photographs and topographic maps. Depending on the purpose of the investigation, other types of maps (e.g., geologic, soil, vegetation, ecological) may also be obtained for development of visualizations .[3]

Geographic information system (GIS)-based visualization tools may also be linked to database queries of analytical data, making information on selected locations of interest easily accessible. Users can easily locate sample locations as they are plotted precisely over the georeferenced aerial photographs. By clicking the mouse on the desired sample point, the user can view the data in a separate window, allowing for easy evaluation and comparison of data. GIS programs allow various types of data and information to be placed into a common coordinate system, and then exported for three-dimensional analysis in the EVS program for a virtual recreation of the site.

Site-Specific Information

EVS is used to integrate GIS information, database queries, geologic information, and computer model output into a single database. EVS also enables the user to present data visually for any desired area of a site, at any scale, in any time frame, for any analytical parameter. Lithology, flow, and analytical data may be viewed in three dimensions, with virtually unlimited zoom, rotational, and animation capabilities.

After developing the regional context of the visualization, building the site-specific model usually involves the addition of subsurface physical property data. This is usually obtained from boring logs collected during site investigations. Input files include the X, Y, and Z coordinates for the top of each boring, the depth to each lithologic interface, and the lithologic classification of materials between the interfaces. The various lithologies can be marked with distinct colors so that lithologic changes with depth or laterally between borings can be easily observed. Once the boring log information has been entered, lithologies can be further evaluated by generating cross-sections, fence diagrams, and block diagrams. Geostatistical analysis can be used to interpolate between data points based on prescribed confidence levels. Lithologic types may be selectively shown or hidden to allow insight into the depositional setting, and to illustrate lithologic controls on groundwater flow and contaminant distribution. Geologic layers, lenses, and faults are readily illustrated in three dimensions. Figure 2 presents a visualization combining lithologies encountered in soil borings, a cutaway of the geologic block interpolated between borings, the location of DNAPL plume, and groundwater table elevation contours.[3]

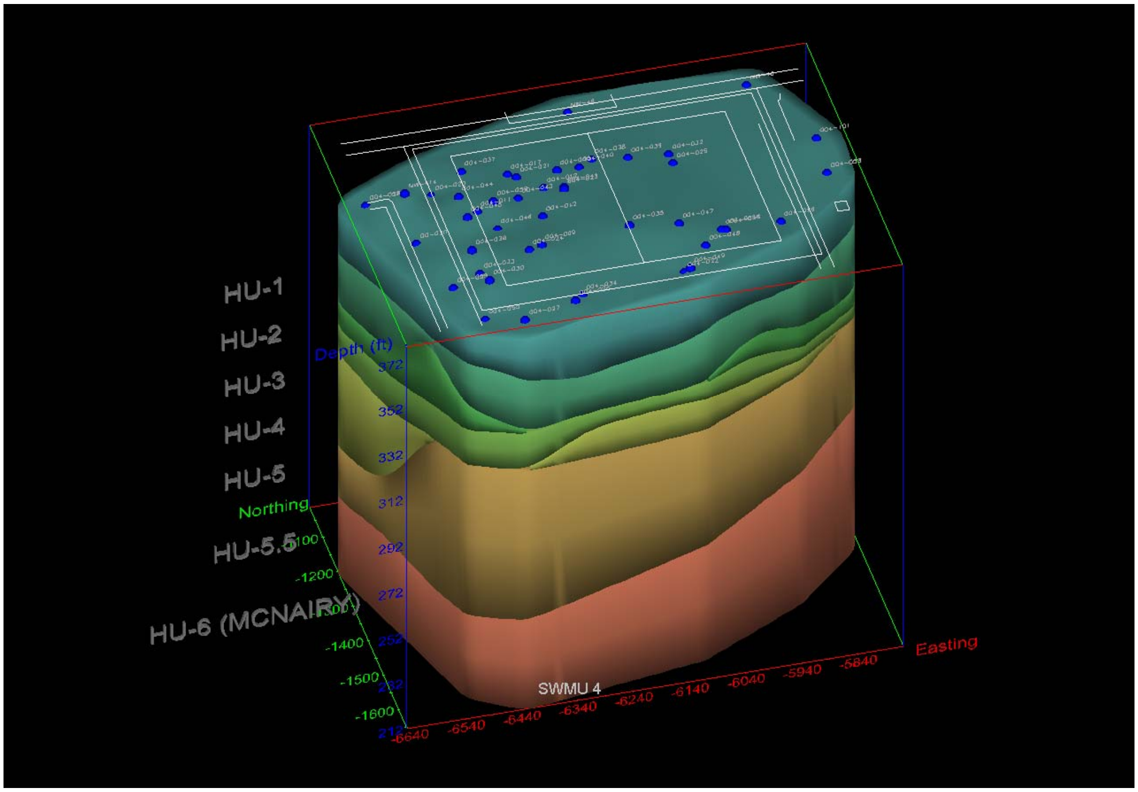

Fig 2. Geologic block cutaway illustrating lithologic distribution, sampling locations (in Blue), and SWMU outline and other features, such as roads (in white)

Chemical analytical data are entered as the next step. Soil and groundwater data are plotted at the proper X, Y, and Z locations, and symbols representing the values are typically colored and sized according to data value ranges. EVS may then be used to generate plumes contoured by concentration thresholds as desired. The sample name and data value may also be labeled, allowing the data to be easily shown. If desired, visualization programs can perform mathematical operations on data sets and model coordinates.

Drawings generated with AutoCAD® may also be imported into EVS, allowing for straightforward integration of surface feature maps and engineering drawings. The ability to integrate databases – including precise survey coordinates, lithology, and analytical results – is valuable for evaluating parameter distributions and lithologic controls on migration. Groundwater fate and transport models do not have graphical capabilities equal to those of EVS. Linking numerical models to state-of-the-art visualization tools available in EVS, combined\with select GIS tools, enables users to overcome the graphical limitations of the models.[2]

Visualization Output Formats

Once completed, visualizations may be output in various standard formats for highly effective yet technologically simple presentations. Complex video sequences of data varying in time or space may be created and output on VHS tapes, CDs, or DVDs. Another option is to use C-Tech's 4DIM Player, which is the companion viewer for EVS applications. The name 4DIM is an acronym for Four-Dimensional Interactive Model Animations, and was chosen because these models represent a 3D scene changing in time (the fourth dimension). C Tech unites state-of-the art analysis and visualization tools into extremely powerful software systems developed to meet the needs of geologists, geochemists, environmental or mining engineers, oceanographers, archaeologists and modelers. C Tech provides true 3D volumetric modeling, analysis and visualization to help users examine data and discover trends. The more advanced versions of C Tech's software allow for highly customized analysis and visualization. Each frame of the model can be zoomed, panned, and rotated as a static 3D model, or the viewer can interact with the 4DIM animation as it is playing. The 4DIM player allows much flexibility and control to view results from any angle or magnification, making it an outstanding litigation support tool.[3]

BGOU WORK PLAN OUTPUT FORMAT

CDM utilized the 4DIM Player and incorporated playable files and the player in a menu-driven, self-running CD. This CD was included in the work plan provided to the stakeholders, including EPA and KDEP. Once the CD is inserted into the computer, the viewer files can be downloaded onto the computer and the menu will function to help the reader identify which SWMU, media, and contaminant to view. Figure 3 is a screen shot of the CD menu.

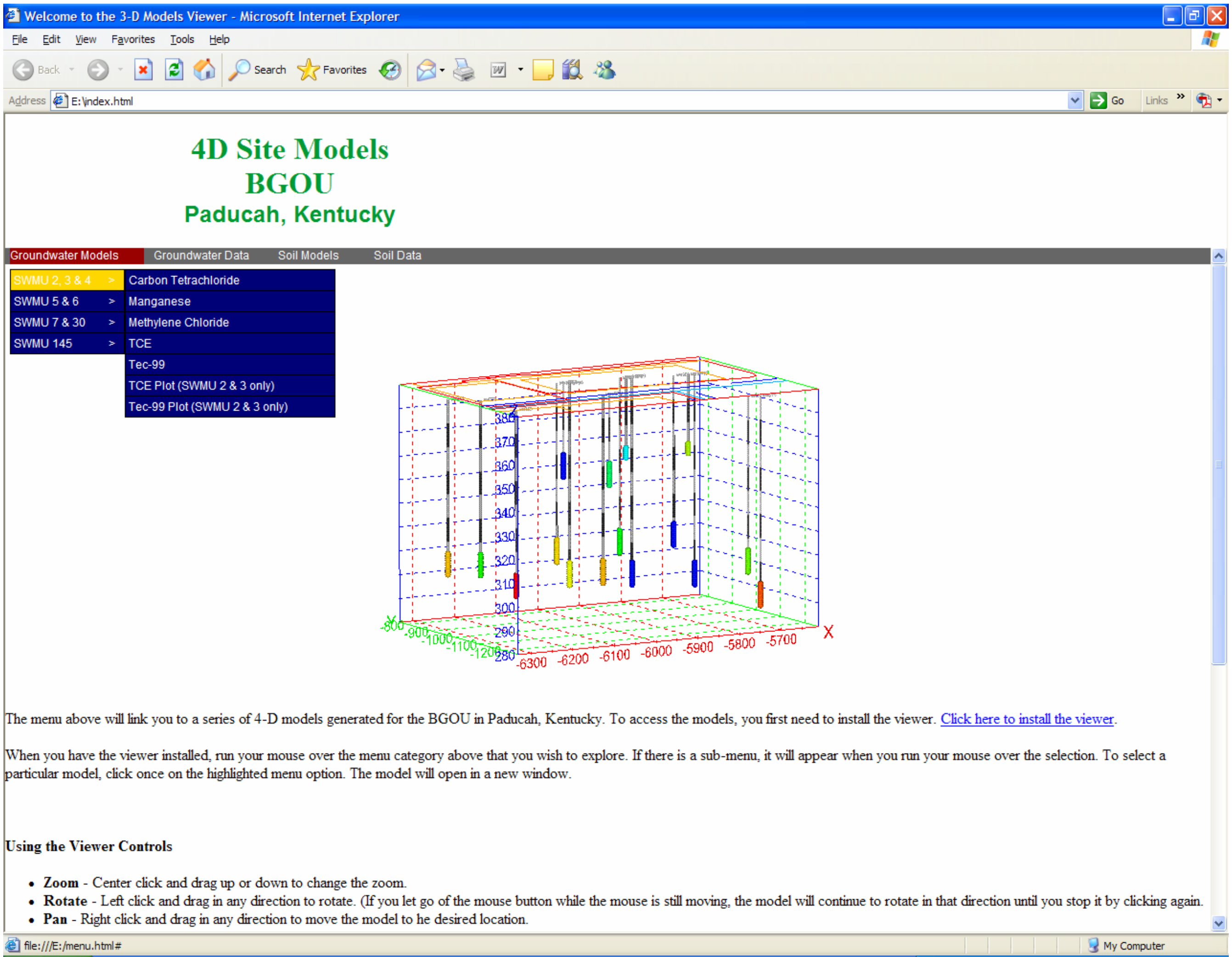

Fig 3. BGOU Contaminant Visualization Menu

Figure 4 is an example of groundwater data from borings collected around SWMUs 2, 3, and 4. Larger sections of color indicate the screened zone of a monitoring well. Discrete dots indicate a discrete sample collected at varying depths within a boring. Some burial cells are included as drawn from results of geophysical studies and historical information.

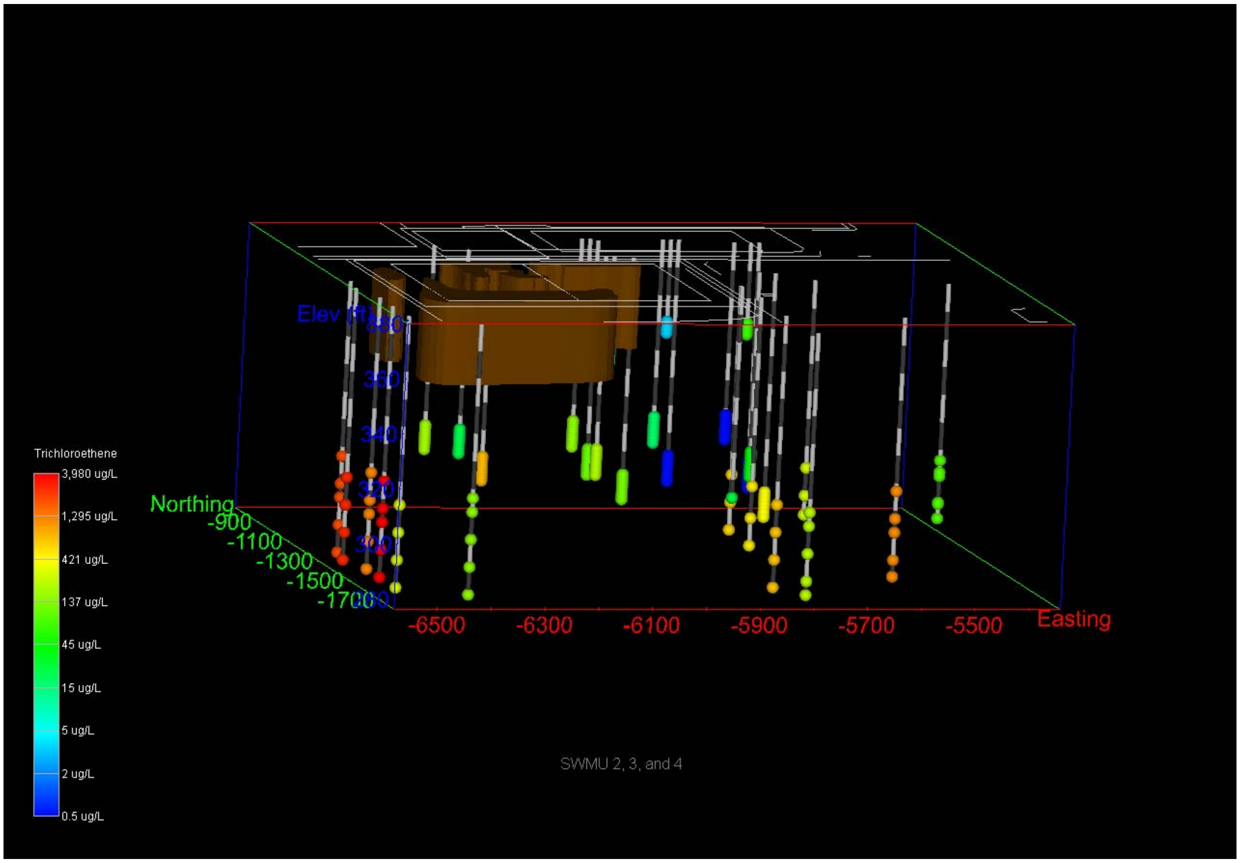

Fig 4. BGOU SWMUs, 2, 3, and 4 TCE in groundwater.

There is an extensive set of TCE data surrounding the SWMU 4 area. This information was modeled and the kriging feature of C Tech's EVS software was used to project a view of the TCE plume below the unit (Fig. 5). Kriging is a geostatistical technique for interpolation that uses information about the spatial autocorrelation in the vicinity of each point to provide "optimal" interpolation (in the sense of greater use of the information provided by the spatial arrangement). Kriging is based on sound mathematical and statistical concepts implemented by EPA for contaminant delineation.

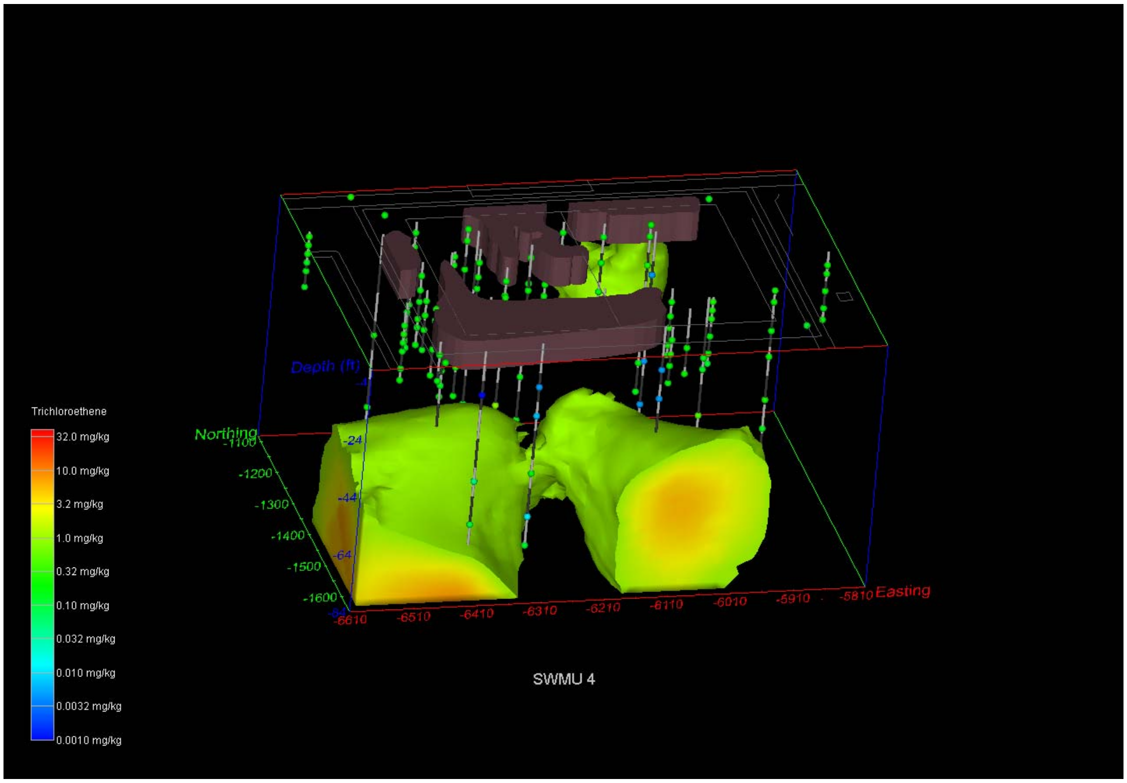

Fig 5. BGOU SWMU 4 TCE kriging.

RESULTS

Once the historical data were evaluated and the 4D models were reviewed in-depth, it was successfully demonstrated to the stakeholders that few data gaps existed for the BGOU. The primary focus of the BGOU RI/FS became collecting field and analytical data necessary to determine the nature and extent of any soil and groundwater contamination originating from, and immediately under, the burial cells. For most of the SWMUs, the primary data gap is the presence and extent of soil and groundwater contamination, if any, directly below the burial cells. To close this data gap, the sampling strategy is focused on collecting soil and groundwater samples from angle borings drilled adjacent to the burial cells (without penetrating the cells) and terminating under the burials cells and above the Regional Gravel Aquifer (RGA). Sampling activities will focus on the soils and groundwater beneath the burial pits down to a depth of 60 feet below ground surface.

CONCLUSIONS

C Tech's EVS software proved useful in evaluating a large data set relating to eight sizeable units to be investigated. It also allowed the use of visualization to see burial cell depth related to contaminant distribution in a variety of media (shallow soil, soil at depth, and groundwater). The 4DIM Player, which incorporated playable files, was used to create a menu-driven, self-running CD. This CD was used by the regulators and stakeholders during their review and evaluation of the BGOU RI/FS Work Plan. The display enabled them to avoid many hours evaluating tables of data and manually graphing the contaminants by media and depth. The software allowed the users to manipulate the images in order to see upgradient and downgradient distribution.

Members of the local CAB reviewed the BGOU RI/FS Work Plan and were supportive of the sampling strategy in part because they could easily see where previous sampling had taken place and the levels of contamination. The 4D models gave them good information and sufficient justification to accept the proposed sampling strategy.

After the work plan sampling is complete and information to fill the data gaps is gathered, the software provides the ability to estimate waste volumes for remediation. The 4D kriging technology helps reduce cost impacts associated with uncertainty by calculating uncertainty using a proprietary C Tech algorithm. This calculation provides a more realistic estimate of the most probable actual conditions. This estimate minimizes the volume of soil and groundwater that will require remediation or removal.

REFERENCES

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2. United States Environmental Protection Agency, March 2000, *Environmental Technology Verification Report, Environmental Decision Support Software, C Tech Development Corporation, Environmental Visualization System Pro (EYS-PRO):* EPA/600/R-00/047. Office of Research and Development. Washington, D.C. 20460.
3. Data Visualization Tools for Litigation - Practical Uses and Ethical Considerations. Cross, B., and Rogoff, E., LFR Levine Fricke. *Proceedings of the 2005 NGWA Ground Water and Environmental Law Conference, July 2122, 2005, Baltimore, MD.*