DESIGN-PHASE GEOLOGIC FRAMEWORK MODELING FOR LARGE CONSTRUCTION PROJECTS

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ABSTRACT: A three-dimensional (3-D) geologic framework model (GFM) is developed and applied to site environmental issues during the design phase of a large, complex, rail construction project. The GFM enables the visual and quantitative assessment of geospatial relationships between structural, geological, and environmental data. Such data includes subsurface utilities, proposed structures such as bored tunnels, lithologic unit thickness, depth to bedrock, permeability distributions, the distribution of polychlorinated biphenyls (PCBs) and volatile organic compounds (VOCs) in soil, and the distribution of light non-aqueous phase liquids. The GFM quantifies areas of concern (AOCs) where environmental regulatory levels are exceeded and could be affected by construction activities. The case study presents the GFM quantification capability using analytical data for PCBs in soil. The 3-D concentration isoshells are first removed in order to identify an AOC. Next, the total volume of PCBs in soil exceeding the regulatory soil cleanup level is estimated. The identification of this AOC facilitates plans for disposal options of excavated material and for construction worker health and safety protection.

INTRODUCTION

A large rail construction project (the Project) is currently in progress and is projected to be complete in 2009. The completed Project will provide direct train service from a major rail yard (the Site) into a rail terminal in a large city via a tunnel under a river (the Alignment). The Alignment connects rail lines east of the major rail yard. The Alignment will proceed through a set of five tunnels under the active, major rail yard and then merge into two tunnels in a cut and cover section that begins at the edge of the major rail yard. These two tunnels will meet the existing tunnel connector and then proceed into the existing tunnel under the river to the urban rail terminal on the west side of the river.

An environmental investigation was conducted at the Site and included the GFM. The proposed structures at the Site of environmental concern are the cut-and-cover structure that will consist of watertight slurry walls, and soft-ground bored tunnels. The environmental goal of the Project is to determine how soil and groundwater may be affected by proposed construction activities such as excavation, tunneling, dewatering, and building demolition. Using the quantitative results of the environmental assessment, disposal methods and mitigation measures to prevent movement of any contamination in the Project areas can be identified, and worker health and safety plans can be planned for prior to construction. The GFM facilitates the design phase process in a cost-effective manner prior to field activities. This is so because data acquisition is a labor-intensive process due to scheduling, inaccessible areas, and physical hazard constraints at the Site.

Objectives. The GFM synthesizes all relevant and available geological, environmental, and structural data components into a 3-D model of subsurface conditions at the Site. The objectives for this case study are to provide interpolations of contaminant concentrations of PCBs in soils across the site based on available field data and to identify contaminant-related AOCs within the construction footprint.

MATERIALS AND METHODS

EarthVision® Modeling Software. EarthVision® (EV) is a proprietary, integrated software system produced and distributed by Dynamic Graphics Inc. of Alameda, California and was used to create the GFM. The main components of the EV software are 2-D and 3-D parameter gridding using minimum tension, kriging, and trend interpolation schemes, 3-D structural modeling using stacked and faulted sequences of 2-D surface grids, and sophisticated 2-D and 3-D visualization (Paradis and Belcher, 1990; Belcher and Paradis, 1992). The EV software integrates these three basic components such that comprehensive site conceptual models of geospatial data can be developed and updated in a timely manner and used to visually and numerically evaluate site data. The strength of the EV model is the unique ability to describe the geologic framework of a site and then incorporate parameter data such as contaminant concentrations and permeabilities, and engineering data such as borehole and tunnel orientations into the geologic framework.

Site-specific structural, geological and environmental data input components were integrated into the GFM. The development of each of these components is described below.

Structural Component. The structural component of the GFM includes pertinent existing and proposed structures and engineered features at the Site. Existing Site structures are: 1) position and depth of all wells and boreholes providing geologic data; 2) position and orientation of subsurface utilities such as storm water and sewer lines; 4) position and orientation the tunnel connector cut-and-cover structure; 5) position of roads; 6) position of railroad tracks; and 7) position of buildings. Proposed structures at the Site are the cut-and-cover structure with watertight slurry walls and soft-ground bored tunnels.

Geologic Component. The geologic component of the GFM is a stratigraphic model identifying the top of the ten hydrostratigraphic layers in the bedrock and the overlying unconfined glacial aquifer. In ascending order these layers are bedrock (layer L7); weathered bedrock (layer L6); glacial till (layers L5, L4a, L5a); mixed glacial deposits (layers L2, L3, and L4); peat (layer L8); and fill (layer L1). The hydrostratigraphic components of the GFM were created by interpolating surface elevations and lithologic unit thicknesses (isochore data) across the respective scale of investigation. The bedrock surface is present everywhere across the site-scale model boundaries. Adding or subtracting unit thickness grids from either the calculated bedrock surface grid or a grid of the topographic surface simulates the remaining unit horizons. Horizons for the fill and L8 layers are calculated relative to the topographic surface reference horizon. Horizons for the remaining seven layers above bedrock are calculated relative to the bedrock surface reference horizon. Reference surfaces in the GFM are constructed using EV minimum-tension gridding algorithms. Minimum-tension gridding uses a two-step interpolation process to assign estimated parameter values at grid nodes and honors all data points as closely as possible (Briggs, 1974). Geologic data for each layer in the GFM include lithologies, depth to bedrock, strata thickness, and hydraulic conductivity (K). K values are on the order of 10^{-3} cm/sec for the glacial unconfined aquifer and 10^{-5} cm/sec for the bedrock. Input data for the geologic component is derived from Project boring logs and permeability tests at the Site.

Thickness grids and surfaces that are not continuous across the model region and/or for which there are significant gaps in the data coverage are constructed using the EV isopach gridding algorithm. Included in this category are hydrostratigraphic units between ground surface and bedrock surface. The EV isopach gridding algorithm is similar to the minimum tension interpolation scheme with the exception of the manner in which zero contours are calculated. As such, the isopach gridding procedure places the zero contours between regions in the gridded area having positive and zero values. Negative values are used to assign minimum thickness. Negative values used in the construction of the GFM are assigned to boreholes that do not fully penetrate the lowermost unit.

Figure 1 provides a “chair-cut” view of the geospatial relationship between the stratigraphic units and subsurface structural features of the Site. Site-specific layers are listed in the lower left-hand corner of Figure 1. Graphic manipulation of the grids permits perpendicular slicing through the model to reveal subsurface structures such as the proposed cut and cover that connect with the proposed tunnels, and sewer lines. The slicing capability of the GFM also reveals the general stratigraphy in the vicinity of the proposed tunnels. Each layer has been labeled with the appropriate stratigraphic nomenclature as described previously. In ascending order, bedrock and unconfined glacial aquifer layers L6, L5A, L4A, L5, and L3 are exposed. The short vertical lines represent the sampling points (borings) used to construct the stratigraphy.

Environmental Component. The environmental component of the GFM consists of individual models of VOCs in soil, PCBs in soil, and a separate-phase petroleum product plume. Soil data represents various depths at selected sampling points at the Site. The soil concentration models are produced using the log of the concentration values that are converted to regular concentration units. The EV minimum tension gridding technique is used to produce 3D grids from the scattered datasets defining interpolated contaminant concentrations at each grid node. In order to prevent erroneous extrapolation of contaminant concentrations at the grid boundaries, data-fences are constructed at the upper (above the topographic surface) and lower (below the bedrock surface) surfaces and along the model boundaries distal from actual data points. Contaminant concentration values at points within the fences are assigned with non-detect values.

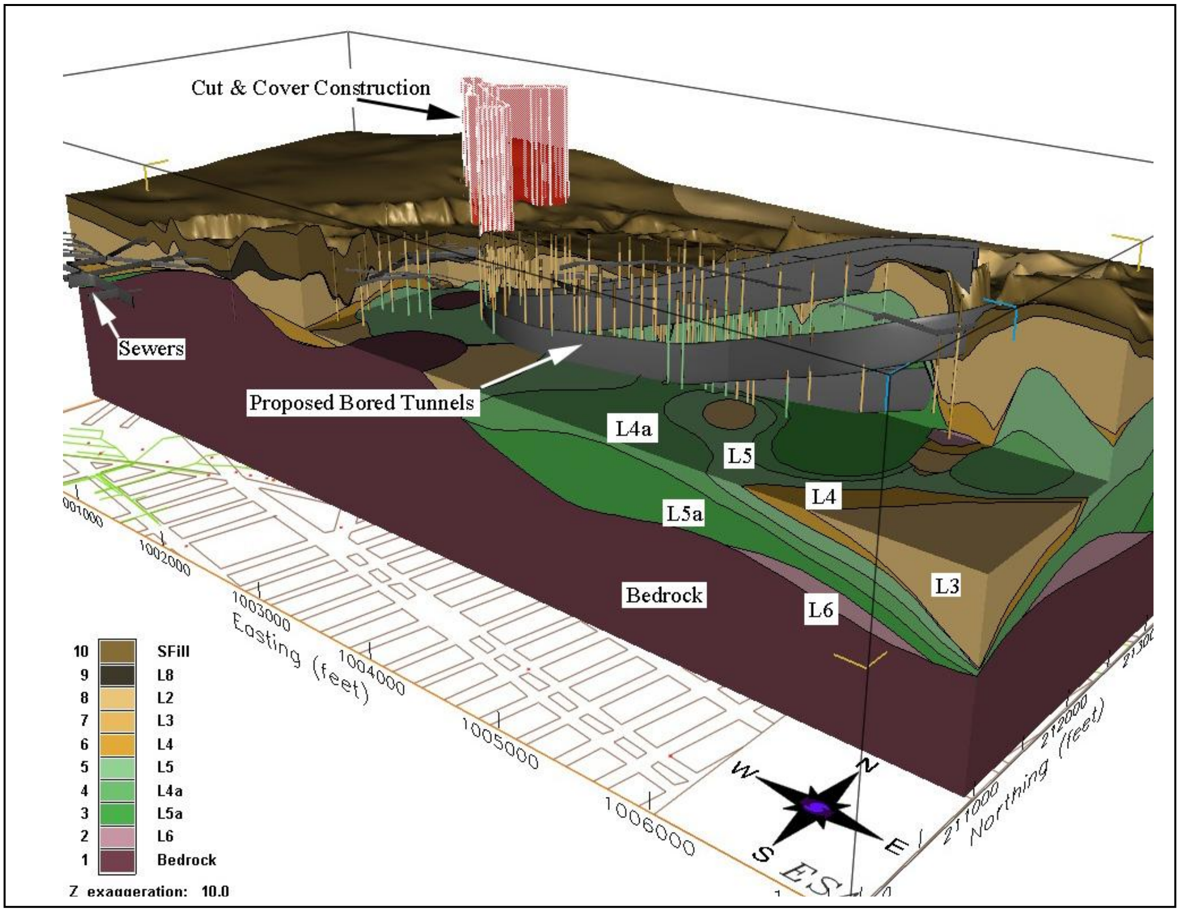

Figure 1. Stratigraphic component of the GFM showing the relationship between stratigraphy, boreholes, subsurface utilities, and proposed structures.

RESULTS AND DISCUSSION

For this case study, PCBs soil analytical data are used from numerous soil samples collected throughout the Site before and during the Project. After the grid calculations are completed, the contaminant models are constructed with 3-D concentration contours, or isoshells, defined at 0.5 concentration units. The isoshells are color-coded to reveal the internal geometry of the contaminant body and are labeled for this publication. Figure 2 presents all of the PCB in soil data at the Site where the outermost isoshell is 10 μg/kg. Note the PCB concentration isoshells in relation to the topographic surface and positions of the proposed Alignment. An aerial photograph of the Site is provided at the bottom for reference.

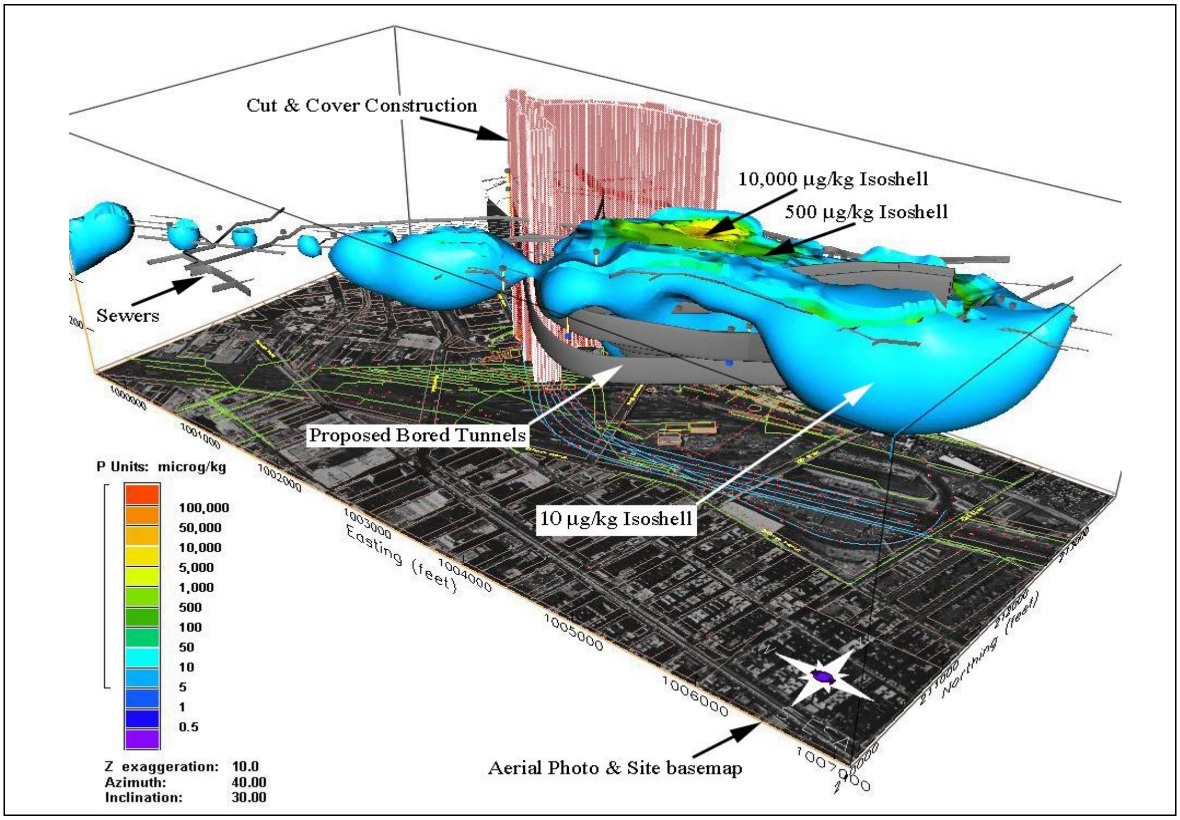

Figure 2. Interpolated total PCBs concentration in soil within the surficial units at the Site where the outer isoshell represents 10 µg/kg.

An example of the graphic manipulation of the model grids through the "peeling" of 3-D log concentration isoshells is presented in Figure 3. In the process, the soil sampling points are revealed and appear as little boxes. As can be seen, the outer log concentration isoshells are peeled away to the regulatory soil cleanup level of 10,000 µg/kg (or log 4.0 µg/kg units) for total PCBs in soil. The soil that exceeds the soil cleanup level within this 3-D area is referred to as an area of concern (AOC). The total volume of affected soil within the AOC is estimated to be 17,850 cubic yards (13,440 cubic meters). The AOC does not appear to intersect the proposed cut and cover or tunnel construction area where major excavation will take place. Nevertheless, it is situated in an area where some surficial excavation related to track replacement may occur. As such, construction-related contractual drawings and specifications will designate this area as an AOC, a potentially impacted area where construction workers may need to follow specific health and safety guidelines.

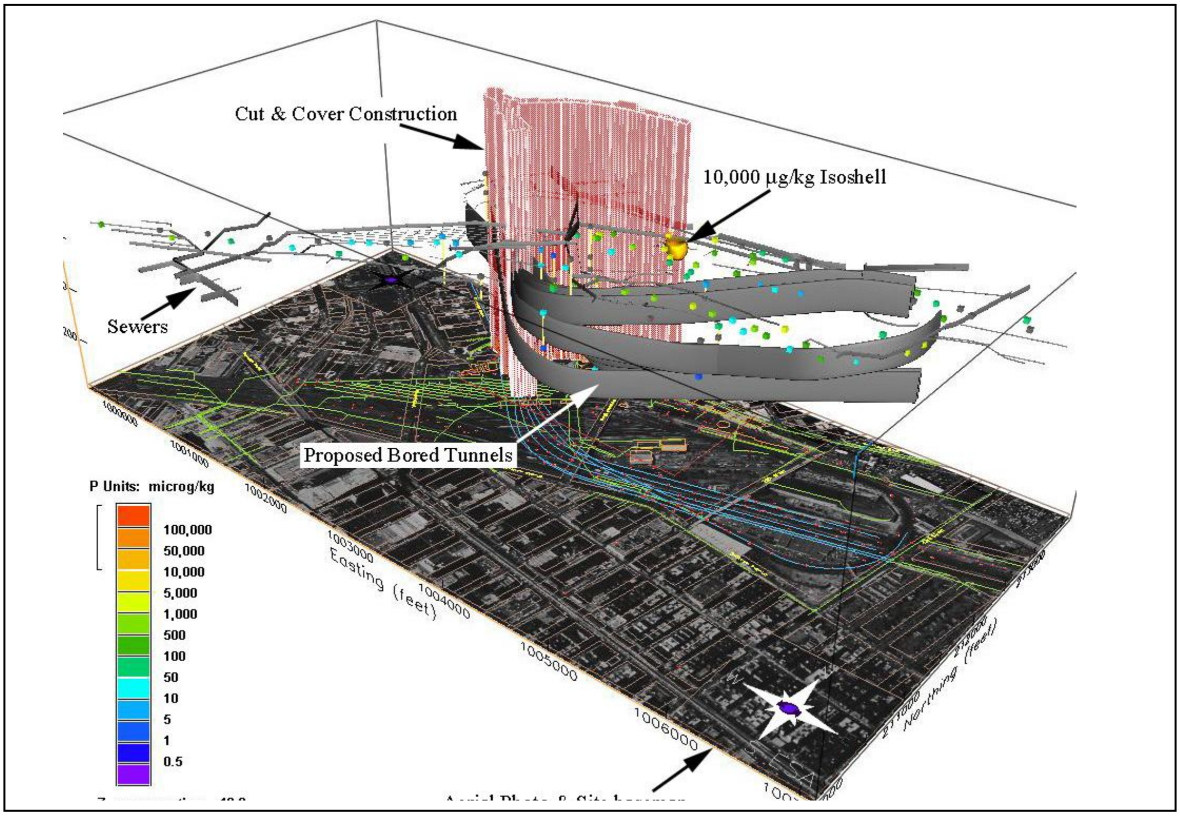

Figure 3. Interpolated total PCBs concentration in soil where the outer isoshell represents 10,000 µg/kg, the regulatory soil cleanup level.

Model Limitations. Confidence in predicted values of the environmental component of the GFM is affected by several considerations. The concentration zones in the environmental component of the GFM are well constrained in the X and Y directions, but less constrained in the Z direction. Predictions of contaminant concentrations will therefore be more reliable in the shallower part of the model region, where there is more data coverage. The fundamental limitation of the geologic component of the GFM centers on the confidence in the modeled unit thicknesses, horizon elevations, and soil concentrations in areas distant from the data constraint. The extrapolation of Site data to areas beyond the Site are limited due to lack of soil concentration data. Peer review of field and analytical input data through a quality assurance/quality control (QA/QC) program will help to ensure better model results. The various input datasets used in the construction of the GFM should be consolidated into a standard form including tables showing deviations between input and model values for all data points. This step would support potential QC concerns for future use of the GFM. Constant upgrade and checking all additional soil input data will facilitate the standardization of model input datasets.

CONCLUSIONS

The GFM is used to assess site stratigraphy and to quantify areas of concern (AOCs) where environmental regulatory levels are exceeded and could be affected by construction activities. Chair cuts, peeling of isoshells, and the volumetric estimation of an AOC are demonstrated in this case study using the GFM. This identifies an AOC within the construction zone and estimates potentially affected soil therein. Plans for soil remediation, proper disposal of excavated material, and for construction worker health and safety protection can be made more effectively.

The GFM has many other capabilities that can be applied in the analysis of the Site. One example is slicing in the X, Y, and/or Z planes through the strata to reveal geologic structures. Slicing, peeling and time sequence images can all be presented in animated form. For example, images of concentration isoshells as seen in Figures 2 and 3 can be generated in incremental logarithmic units and then subsequently viewed in sequence to form an animated view of the isoshells being "peeled" away. Historical soil plume data can also be generated and then animated for analysis. Some other GFM applications include cross-sections, structural surface contour maps, depth to bedrock, back-interpolated elevation, and property data values along selected transects. All of these are very useful when planning to conduct field activities such as monitoring well installation or pumping tests, the preparation of health and safety plans, and the preparation of construction contract drawings and specifications.

Future Application. The conceptual hydrostratigraphic framework of the GFM will be merged into a groundwater flow/fate and transport model. Groundwater analytical data will be incorporated into the GFM environmental component. The resulting hydrogeologic model will be used to predict the effects of construction on the groundwater regime and the fate and transport of dissolved and non-aqueous phase contaminant plumes within the Project area. Ultimately, the hydrogeologic model will optimize the design of a monitoring well network around certain proposed structures as per Project permit requirements, and for groundwater treatment options.

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