The Use of 3D Modelling for Environmental Site Assessment

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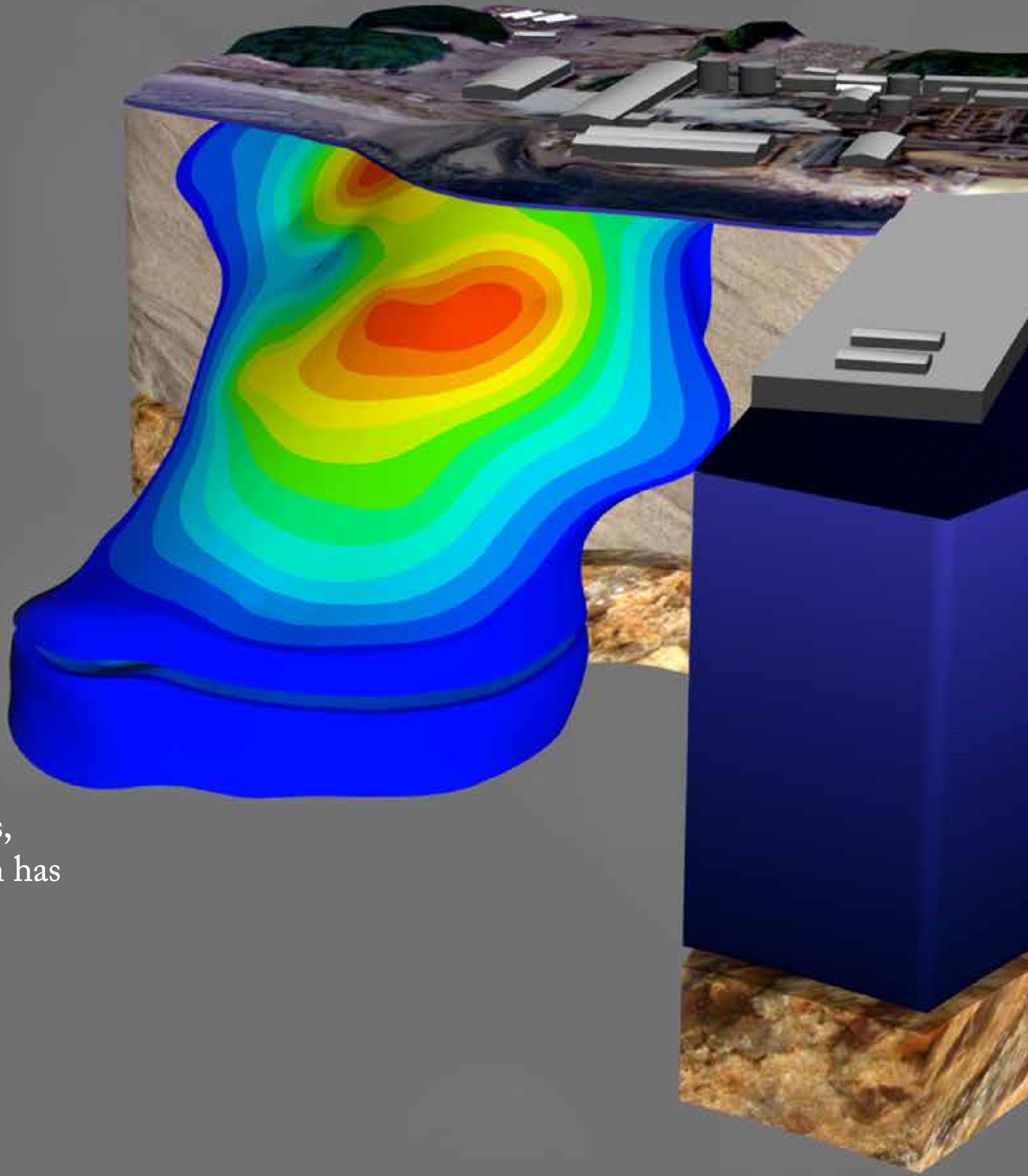


We live in an age of 3D movies and TVs, which means that 99% of the population has an opinion about what 3D means. However, most of them will be wrong. It is not enough to make a 3D representation of something, if that representation is only skin deep.

When we are dealing with the redevelopment of Brownfields and other contaminated lands, we are working with data that is collected volumetrically. The simplest definition of volumetric data would be data that is collected at multiple elevations for any X-Y location. To refine that further, we don't really need the x and y coordinates to be the same, since they would not be if samples were collected along a boring that was not perfectly vertical. The assessment of volumetric is one that is simple and virtually irrefutable. If there is data not only on the surfaces of the model, but also within the model, it must be considered volumetric.

Since it is obvious that virtually all contaminated sites have volumetric data, and therefore must be modeled volumetrically, it is ironic that most "3D" software does not perform volumetric modeling.

VOLUMETRIC MODELING REQUIREMENTS

For anyone ready to dive into true 3D volumetric modeling, the single most important requirement is that you have X, Y and Z coordinates for all your data. This is the steak and everything else is the parsley by comparison. When a prospective consulting client comes to us, there are many additional questions we ask to understand their data and their needs.

- **Do you have geologic information?**
- **What type(s) of analytical data is available?**
  - Soil contamination
  - Groundwater contamination
  - Detailed topography data
  - Water table elevations
  - Geophysics data (porosity, transmissivity, etc.)
- **How much data do you have?**
- **What additional annotation data can you provide?**
  - Aerial photos
  - CAD maps, roads, pipelines, tanks or buildings
  - GIS data
- **What is the primary purpose of the model?**
  - Communicate with your company team and/or management
  - Communicate to the public
  - Communicate with regulators
  - Litigation support
- **What form(s) of output do you want**
  - Images
  - C Tech's 4D Interactive Models
  - Bitmap Animations (e.g. AVI or MPEG)
  - 3D PDFs
  - Web published 3D models
  - 3D Printed models

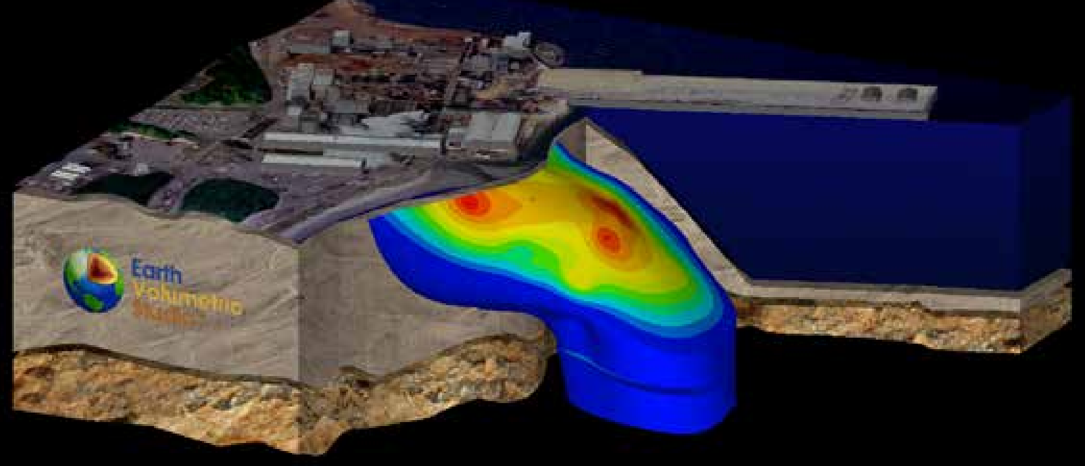
Clearly some of the above list is focused on collecting and compiling the data, whereas other questions allow us to determine the scope of a modeling project. Often, we can take a quick look at someone's data in a couple hours, whereas a comprehensive study for litigation support on a multi-million-dollar lawsuit requires that we try to address every possible challenge that the opposing side might present.

ENVIRONMENTAL MODELLING

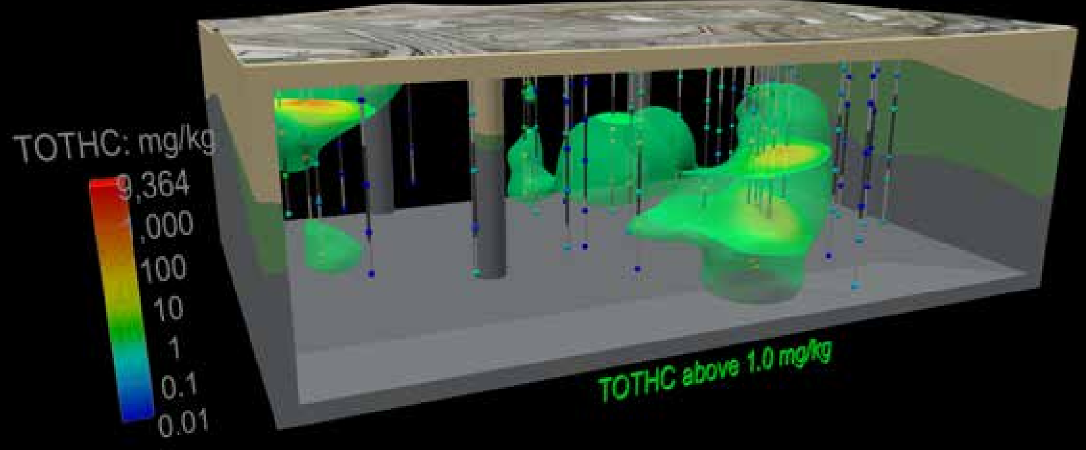
Contamination of the environment, whatever the type, inherently is a three-dimensional geological issue. Not only are the contaminants frequently distributed physically in three dimensions, but the processes by which the contamination was emplaced are almost always three-dimensional in nature. Additionally, designing remedial actions involves consideration of processes that must operate in 3D to be effective.

The use of three-dimensional volumetric modeling methods can be particularly powerful in such situations. Site characterization involves the collection of geologic data, physical samples, and analytical data, all of which have specific 3D spatial positions. Conventional site characterization data represents point or relatively short interval sampling within a much larger geologic volume of material. Modeling is required to create a coherent 3D representation of the distribution of contaminants throughout a site, and the degree of confidence or uncertainty in that representation.

A major consideration, involved in most instances involving environmental contamination and remediation, is the conveying of complex, detailed technical information to non-technical audiences. The public and adjacent land owners are the most obvious examples. Three-dimensional volumetric visualization methods are particularly useful for displaying the relationships among contaminant data, site infrastructure or processes potentially responsible for the contamination, the extent and bounds of inferred (but not yet sampled) contamination, and the remedial processes that may operate to remove or minimize residual contamination after site cleanup is completed. The ability to display these different types of information separately and to integrate them into a coherent visual picture of the entire system are also important within the regulatory and legal arenas.



This coastal facility contaminated the groundwater near the mouth of a stream near an active coastal waterway. The geology's affect on the contaminant flow is evident in the shape of the plume.



Soil contamination at an historic railyard dates back to the days when engine oil was dumped on the tracks to reduce dust and cleaning solvent was poured down the drains. In this model we are showing Total Hydrocarbon soil levels in the stratigraphic layers.

CAD VS. DATA DRIVEN MODELLING

Our software is neither CAD (Computer Aided Design) nor graphics software, both of which involve drawing. The models we create are data driven. There is virtually no drawing involved in creating our 3D models, though you can draw the 2D & 3D paths along which you wish to cut, tunnel or otherwise subset models. What we mean by "data driven" is that the data creates the model, and though the modeler makes many choices about the modeling processes, those choices don't require drawing. The data determines the nature, quality and level of refinement that should be employed in the model, and we utilize geostatistics to quantify the estimates, confidence and potential variability in that model.

We make it easy to incorporate 3D CAD models, GIS data, aerial photos and/or photographic textures on geologic materials, but we consider this additional data as model enhancements or annotations, since they don't influence the volume of contaminant plumes or the distribution of contaminants in a geologic unit.

VOLUMETRIC MODELLING JUSTIFICATION:

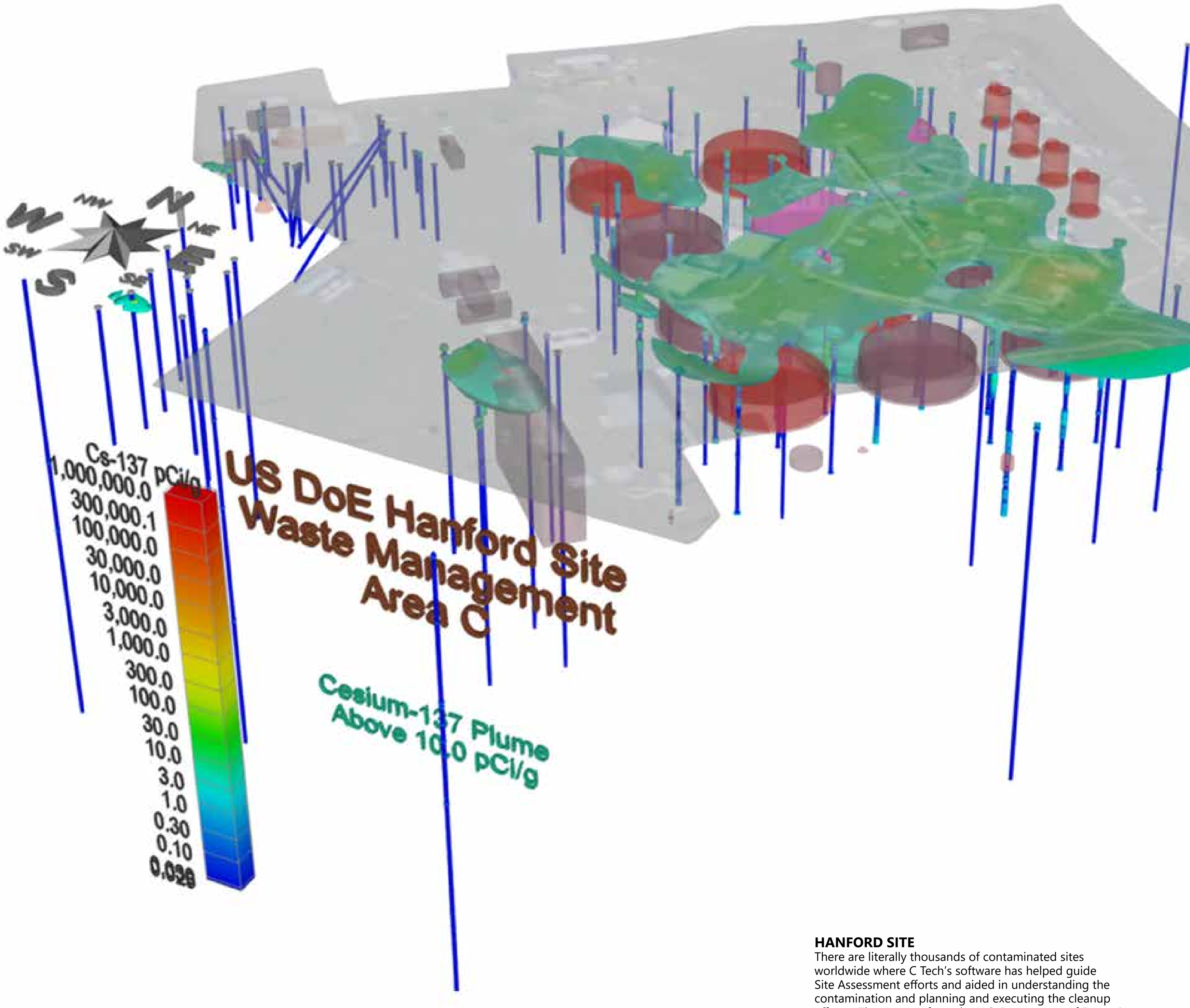
We have always believed that the rationale and requirement for 3D Volumetric modeling is stunningly obvious:

- **The sites we are modeling are volumetric**
- **The contaminant spills are volumetric**
- **The data we collect to characterize the contamination is volumetric**
- **All remediation methods, ranging from in-situ bioremediation, to pump-and-treat, to excavation are all volumetric.**

ANALYTICALLY GUIDED SITE ASSESSMENT

Remediation cannot begin without proper site characterization. In the U.S., many sites are tagged as Brownfields based on their history and/or obvious site characteristics, such as rusted oil barrels strewn about. However, many of these sites have not had any actual site characterization, and therefore their true status and degree of contamination may be unknown. Even when limited characterization has been performed, the hottest spots on the site and the full nature of the contamination is rarely known. For over 20 years, C Tech's DrillGuide© technology has been used to quantify site uncertainty, and determine where it is most efficient to collect additional samples to reduce that uncertainty and the corresponding statistical variation in the volume of the estimated contaminant plume. We refer to this process as analytically guided site assessment, and it has been proven to provide the lowest cost data collection and highest quality characterization of site contamination.

A DrillGuide© analysis uses geostatistics (kriging) to analyze all currently available samples at the site. When kriging is used to perform estimation, the standard deviation throughout the site is also determined. Standard deviation will be zero at the sampled locations



HANFORD SITE
There are literally thousands of contaminated sites worldwide where C Tech's software has helped guide Site Assessment efforts and aided in understanding the contamination and planning and executing the cleanup efforts. These range from the U.S. Department of Energy's Hanford Site, which is arguably the worst environmental disaster in the United States, to hundreds of small Brownfield sites like corner gas stations or dry cleaners.

and will increase as you move into areas away from measured samples. DrillGuide© assesses the distribution of predicted concentrations and standard deviations to determine the locations at the site where the concentration is predicted to be high, but the confidence in that prediction is low. It selects the optimal location for the next sample using this information and then creates a synthetic sample for that location and repeats the process.

To help explain this complex process, we present two images from a two-dimensional DrillGuide© analysis. We can perform this analysis in 2D or 3D, but we present the results from a 2D analysis here since it is simpler and a bit easier to understand. Below is the 2D characterization of a site with Diesel contamination. The surface is colored by concentration and there are three contour lines. The outer dark red line is the largest the 200 mg/kg plume is predicted to be with an 80% confidence, and the inner blue line is the smallest it might be with an 80% confidence. The green line in between is the nominal plume. In a well characterized site, these three lines would be nearly coincident.

After 50 cycles of DrillGuide©, which yields 50 new locations for sampling, the deviation between these three contours is significantly reduced, demonstrating a dramatic improvement in the quality of the site assessment.

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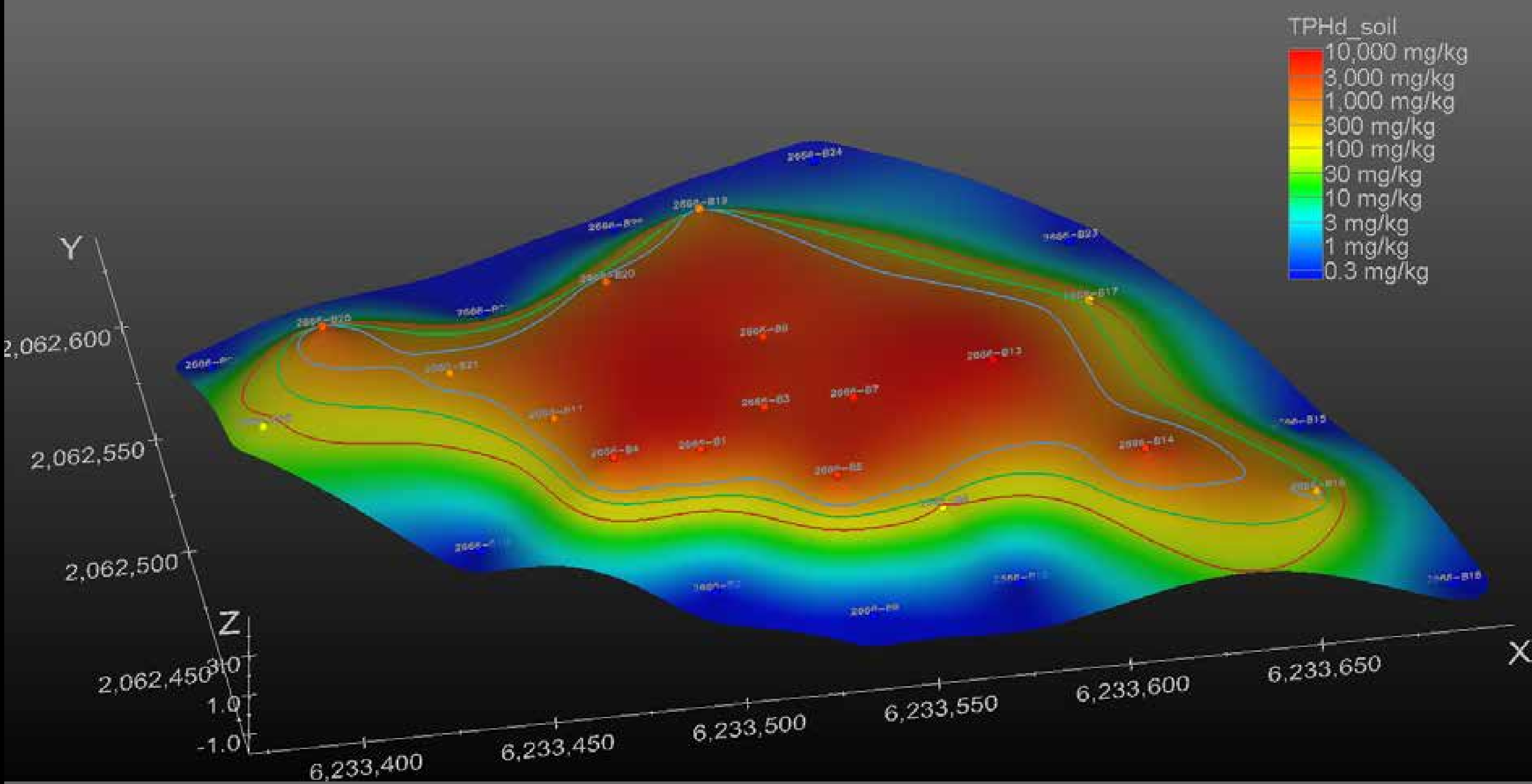
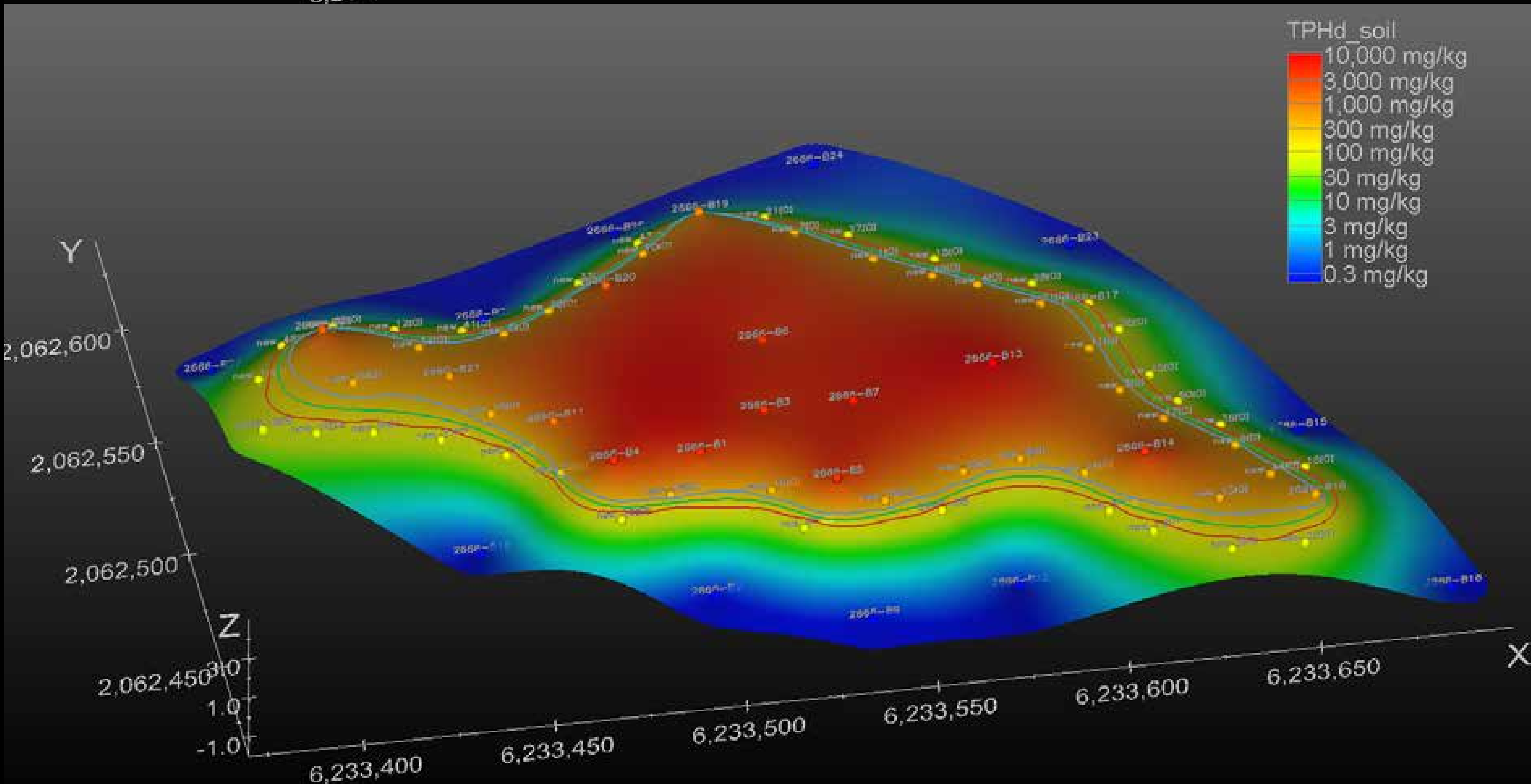
During our 28-year history, there have been tremendous advances in data collection methodology both for geophysical data, such as 3D Electrical Resistivity Tomography (ERT), but also for quantitative measurements of soil and groundwater contamination. MIP (Membrane Interface Probe) technology transformed the environmental industry. Where we typically would have 3-8 samples down each boring location, MIP provides hundreds or even thousands. In a perfect world, we would like to have our samples collected with relatively uniform spacing in X, Y & Z. Even when we had only a few samples down each boring, the spacing between these samples in a boring was generally much less than the distance between borings. This meant that our data was clustered in the borings. With MIP technology, this clustering or oversampling becomes





extreme and tends to break the standard numerical methods used in traditional geostatistics (e.g. kriging) codes. Since MIP is so common in our industry, C Tech has enhanced our kriging algorithms to handle this issue as shown in the model (right).

BEYOND SITE ASSESSMENT

Once the nature and extent of contamination at a site has been determined, additional 3D volumetric modeling is often required either to design a remediation process that will be effective in addressing the remediation requirements, to monitor the progress of the remediation process, or both.

During the remediation process, it is important to perform regular monitoring of the site to confirm the remediation progress and watch for anomalies. For example, during a pump-and-treat remediation (which involves extracting contaminated groundwater, treating the contaminated water, and then reinjecting it into the aquifer), if the mass of contaminants removed during treatment exceeds the reduction in contaminant mass observed during regular site monitoring, then it is likely that the original site assessment failed to identify some regions of high concentrations at the site. This means that the extraction well design may be spreading unidentified high concentration regions across areas of the site that may have been clean.

Some examples of other issues that need to be identified and addressed during remediation include:

- Groundwater plume migration due to seepage velocity
- In-situ bio-remediation
- Impact of site geology on remediation

CONCLUSION

We live in a three-dimensional volumetric world, and it is inappropriate to compromise the modelling of contaminated sites by using software that cannot deal with the volumetric nature of the problem ■

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