Battelle 2023 Bioremediation Symposium
Session D5: Modeling and Monitoring Approaches to Improve Remedy Design and Implementation (Group 2)

Optimization of Groundwater Recovery and Monitoring Network Facilitated by 3DVA and Innovative Hydrogeologic Evaluation Toolbox

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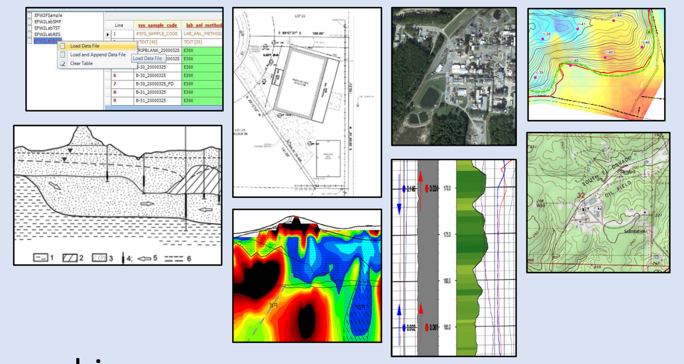
Background/Objectives

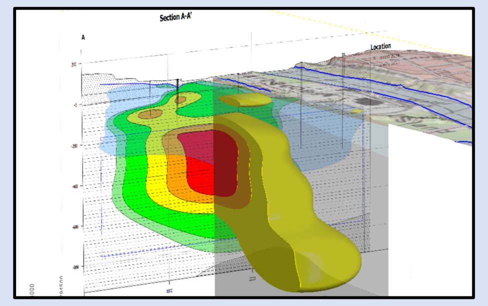
Optimization of long-term groundwater recovery and monitoring well operations often results in a lower future carbon-footprint through revised scale/frequency of activities or through incorporation of new aspects/components that result in a reduced remedial time frame. Optimization of these remedy components is being undertaken at the site of a chemical manufacturing facility with EDB-, EDC-, and chloride-impacted groundwater. The project objectives were to perform 3D Visualization and Analysis (3DVA) and hydrogeological evaluations to update the conceptual site model (CSM) in support of a larger groundwater recovery and monitoring well network optimization effort for the site.

Three-Dimensional Visualization and Analysis (3DVA) = the visual articulation of complex 3D data sets to activate key decisions



3D visualization models can assimilate and overlay a wide variety of datasets:

- Water, soil, sediment, and air quality data
- Groundwater elevation and flow data
- Site maps (computer-aided drafting [CAD], Geographic Information System [GIS] layers)
- Aerial photography
- Satellite and remote sensing images
- Stratigraphic, lithologic, and geophysical data
- Environmental Sequence Stratigraphy (ESS) data
- High-Resolution Site Characterization (HRSC) data
- Topography
- Cross sections
- PDF and scanned hardcopy historical report graphics



Approach/Activities

A 3D visualization model (3DVM) and digital archive was constructed from existing historical reports, figures, and data. Plume fate and transport was established using the 3DVM based on density-dependent flow of groundwater, a factor that was previously overlooked. 3D models of the hydrostratigraphic framework and groundwater plumes for contaminants of concern (COCs) were developed to compare their spatial distribution and reveal complex relationships. Data gaps in COC delineation at the site were identified using a proprietary 3D visualization process to highlight areas of uncertainty for additional characterization, constraining the plumes and increasing precision of plume mass/volume estimates. Visualizations developed to illustrate the refined CSM included interactive 3D models, short movies/animations, and hydrogeochemical cross sections. New cross sections were created by slicing the 3DVM at strategic locations to illustrate hydrogeology, impacted groundwater isovolumes, flow nets, and transport pathways.

A 3DVM used as a digital archive and nexus for key spatial findings from decades of historical studies can be a vital tool for institutional knowledge storage and transfer, limiting the impacts of staff turnover and bringing new team members up to speed quickly. Utilizing a 3DVM as the starting point for graphic-generation activities and spatial analyses throughout the project lifecycle provides multiple advantages, including leveraging historical findings, reducing rework, and minimizing data gaps. 3DVMs are no longer just pretty pictures, novelties, or useful just for the "wow factor". There are some very serious objectives being promulgated and achieved using this technology.

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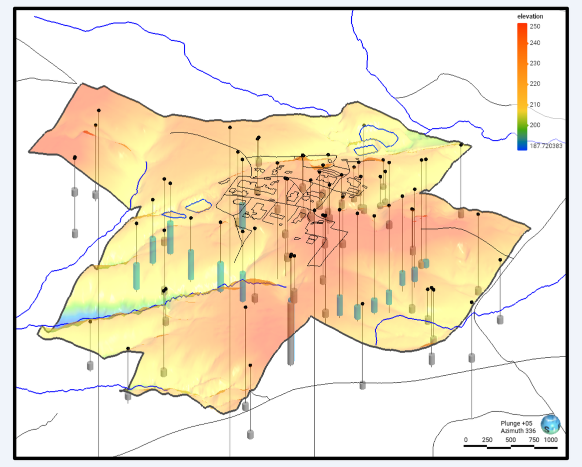
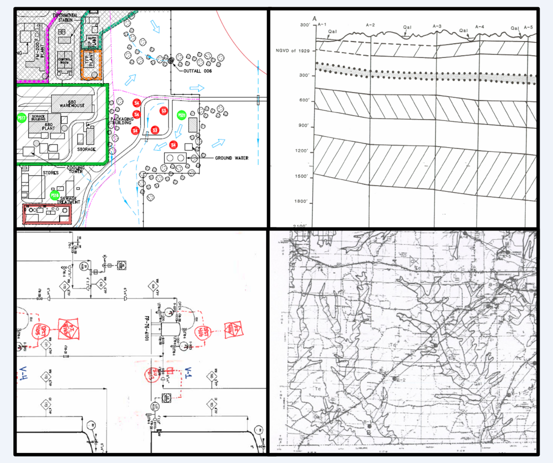
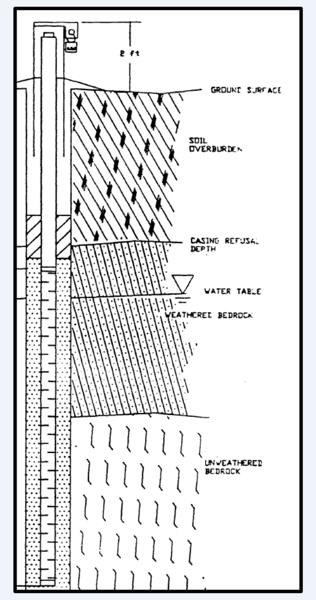
Building the 3D Visualization Model



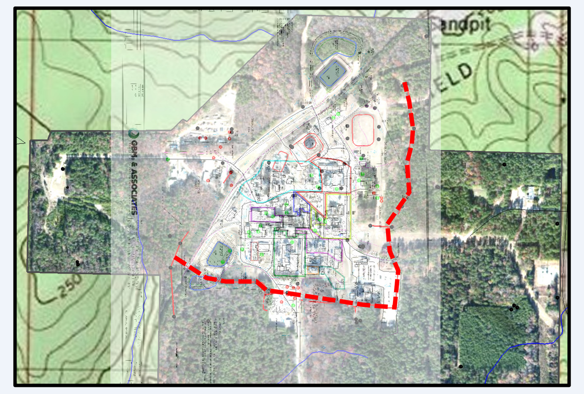
Create 3D groundwater wells and import topography and GIS/CAD basemap Layers



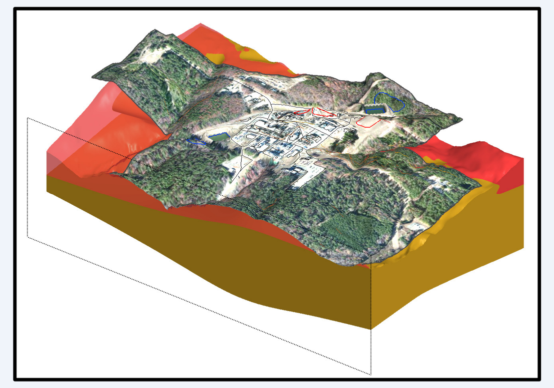
Digitize historical graphics and incorporate all significant findings



Digitize boring logs and well construction information (add to 3D database)

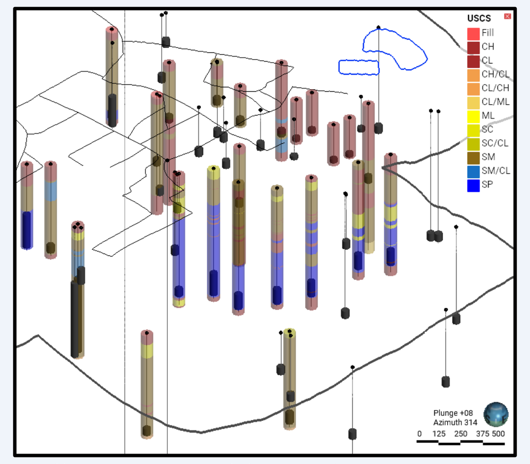


Overlay historical graphics and create new vector layers from important features

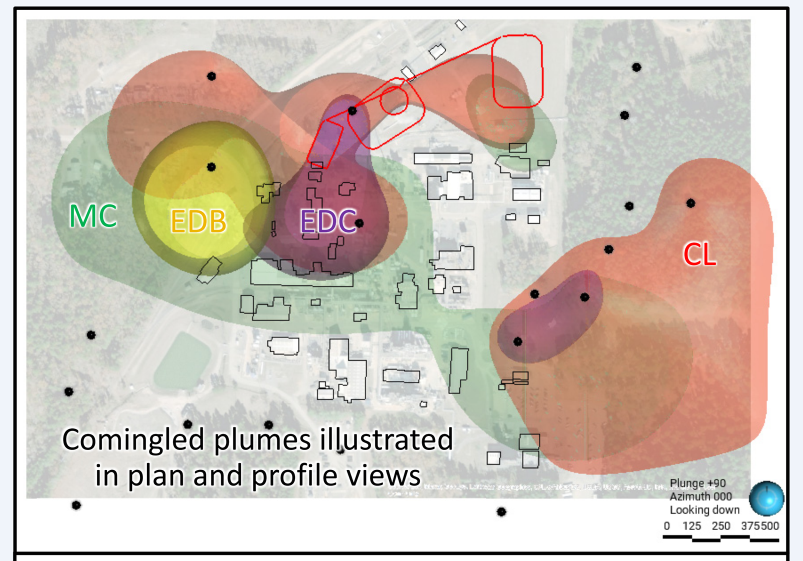


Develop 3D geological model from boring logs and downhole geophysical data

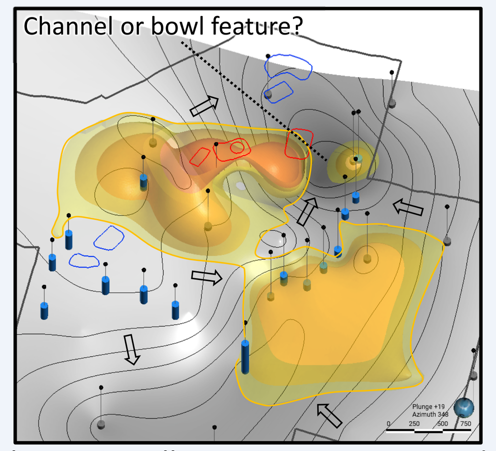
Visualizing and Analyzing Site Features and Processes



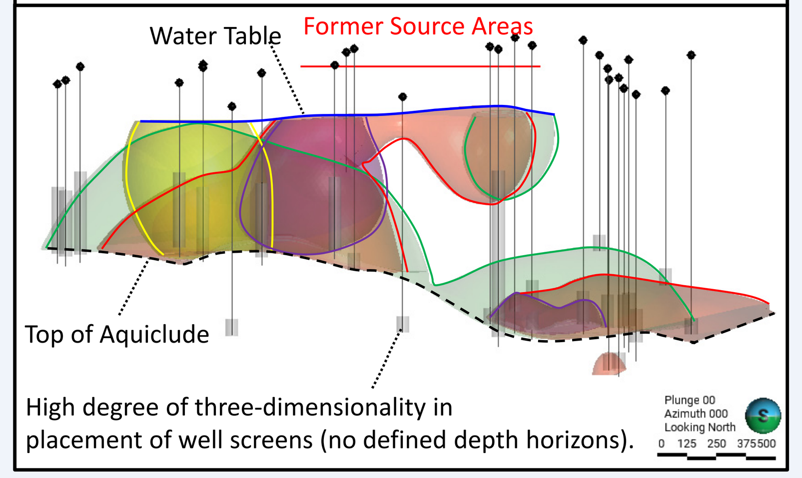
Well screens visible inside transparent downhole stratigraphic logging intervals



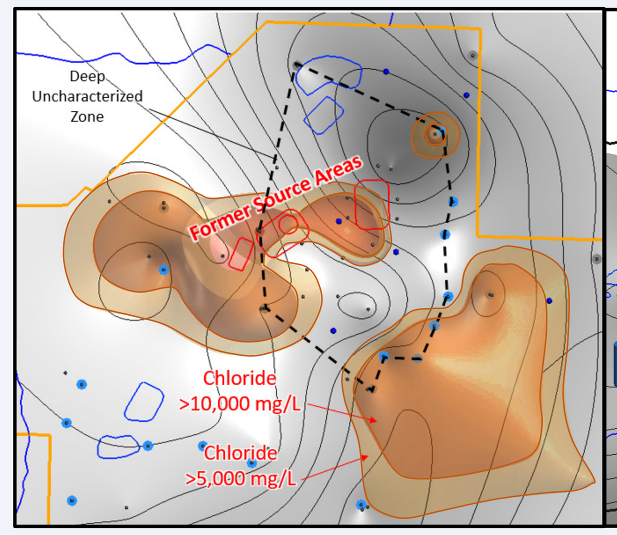
Comingled plumes illustrated in plan and profile views

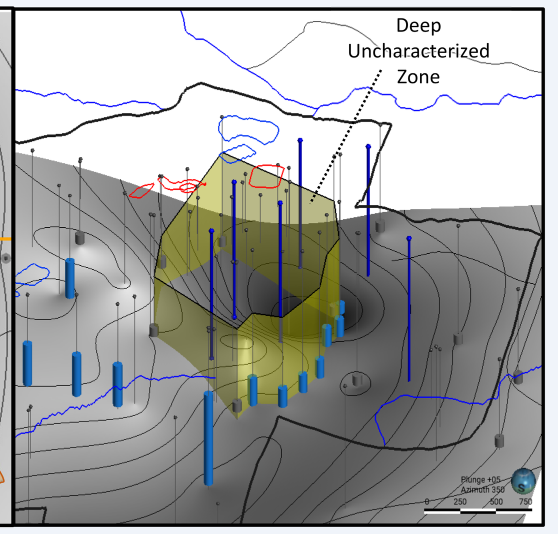


Oblique view illustrating transport and fate of high-density chloride plume controlled by slope of underlying aquiclude



High degree of three-dimensionality in placement of well screens (no defined depth horizons).

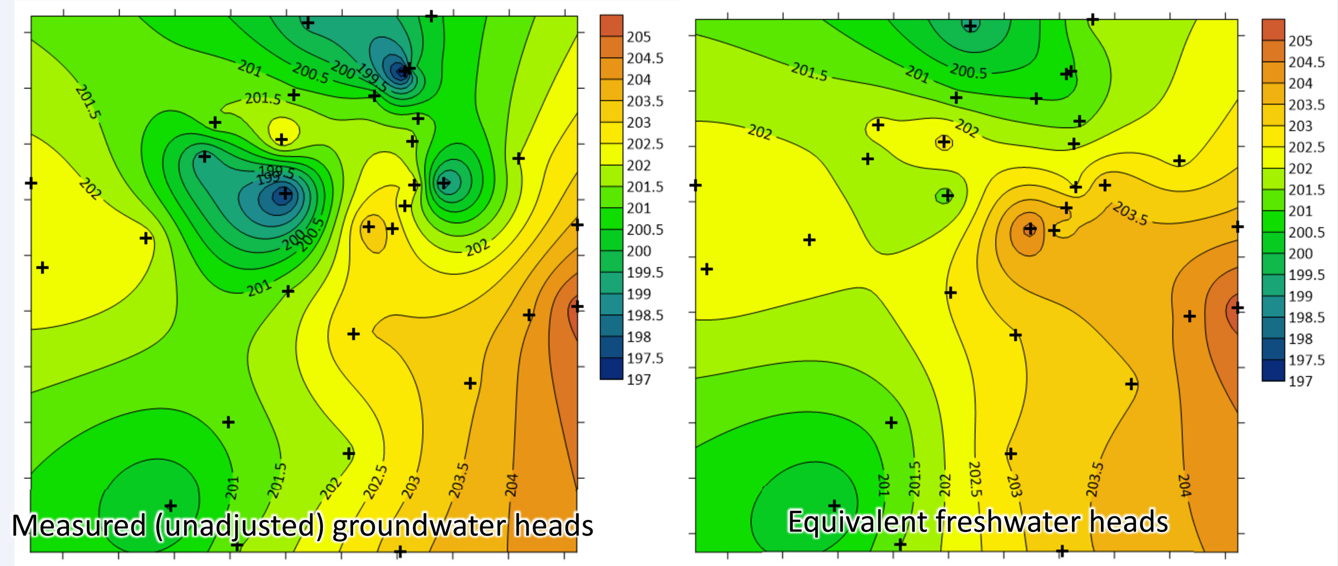




Uncharacterized deep portion of aquifer identified and targeted for new monitoring well installation

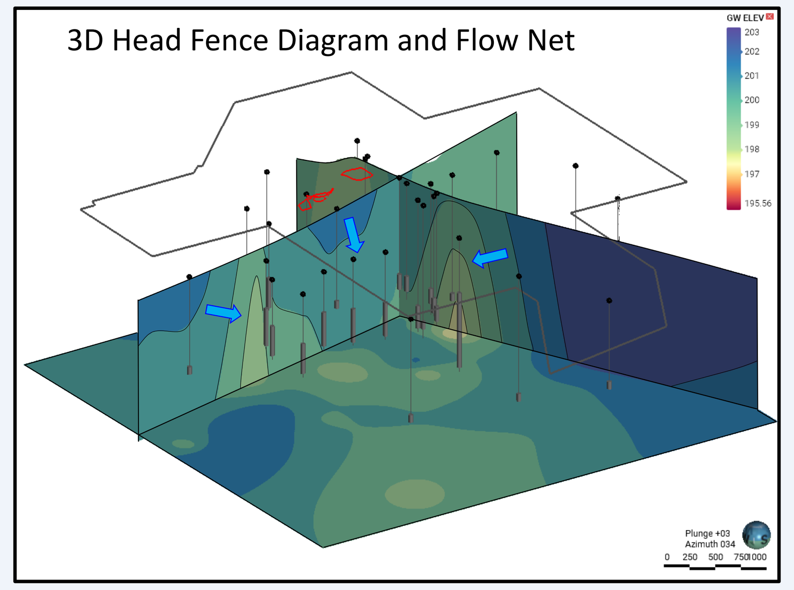
Historical groundwater recovery efforts initially pulled plume to west of former source areas. Pumping was stopped and plume transport was then controlled by slope of underlying aquiclude surface.

Hydrogeologic Evaluation



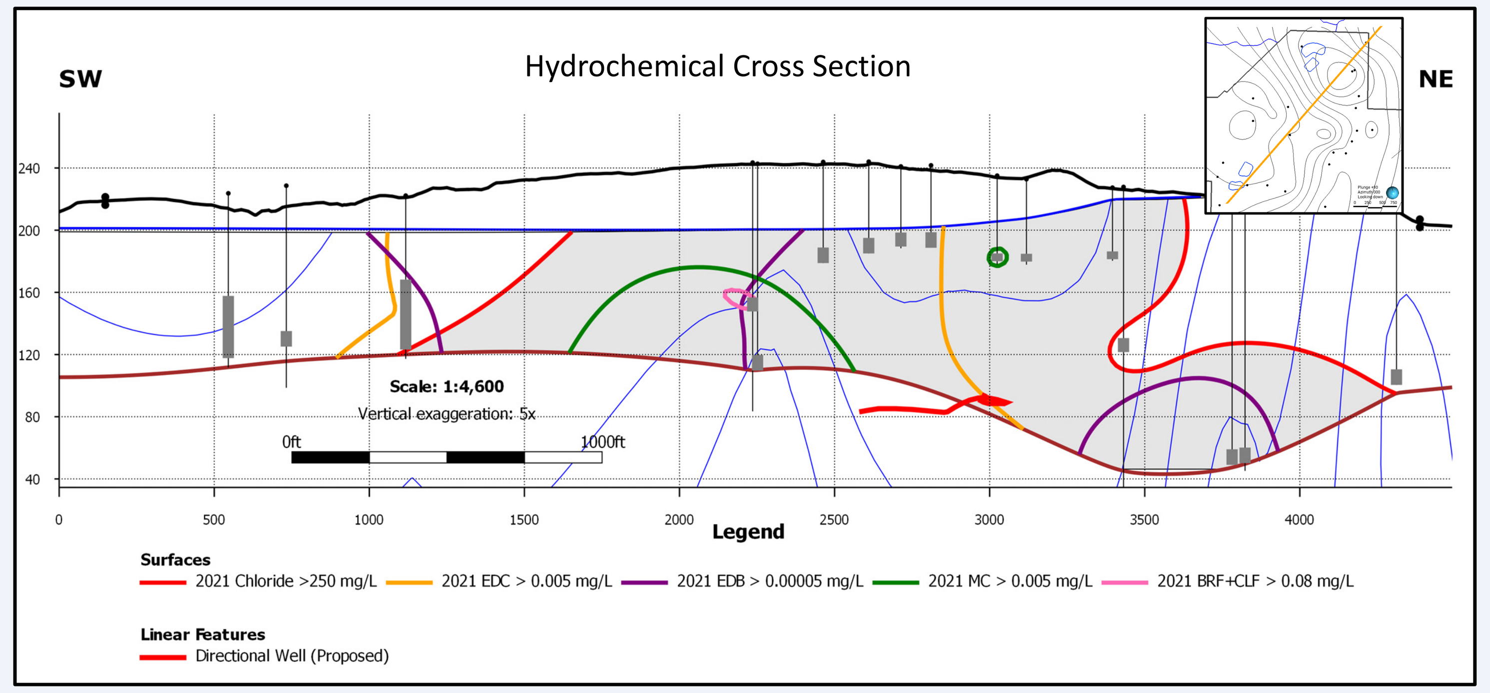
Measured groundwater heads converted to equivalent freshwater heads based on density ratios, resulting in elimination of artificial sinks in areas of high chloride concentration.

$$h_{p,f} = h_{p,i}\frac{\rho_i}{\rho_f}$$

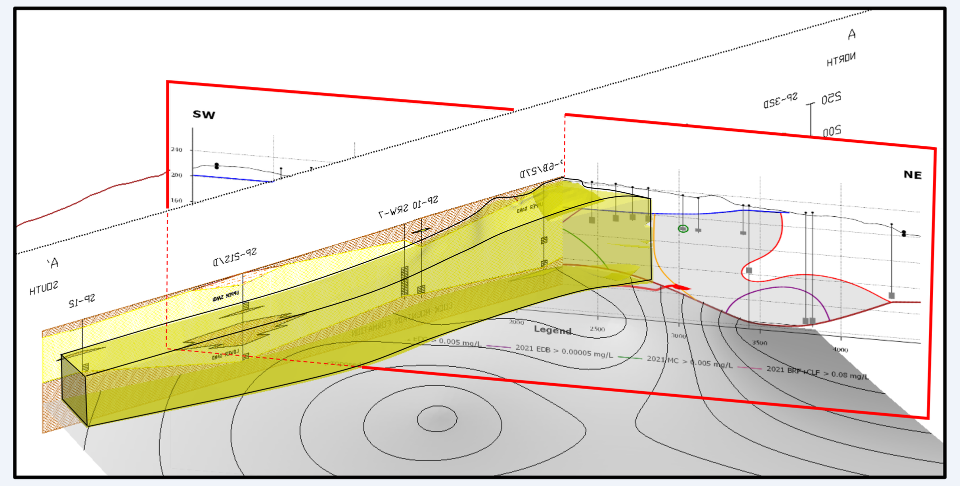


Heads interpolated in 3D and then sliced along vertical and horizontal planes for visualization, eliminating errors introduced via standard method of choosing subset of wells to interpolate in 2D within a depth horizon (e.g., shallow or deep).

Expert Tip: Finishing raw 3D model outputs in a graphics program like Adobe Illustrator® or even MS PowerPoint® (used for this poster) can provide that extra layer of sophistication and polish. 3D graphical outputs have even more impact when they are not just technically accurate but also elegant and aesthetically beautiful. The value of aesthetics in preparation of technical graphics has consistently been underappreciated in our industry.



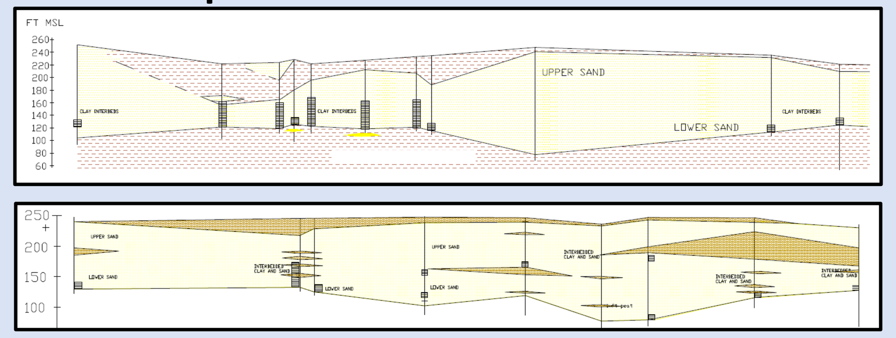
Hydrochemical cross sections created by slicing the 3D visualization model were used to show extent of comingled groundwater plumes in relation to existing and proposed monitoring and recovery wells and geological features like the underlying aquiclude.

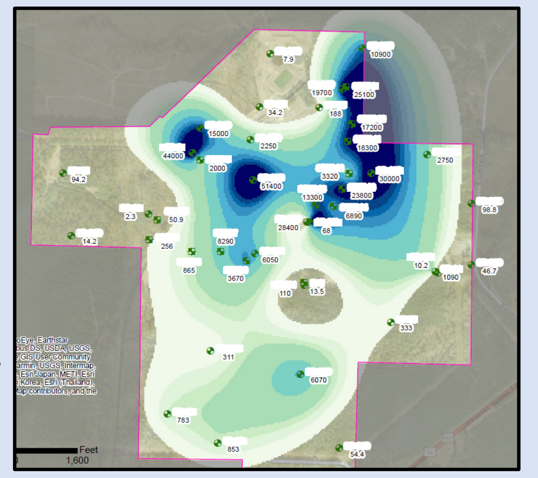


Oblique view of 3D hydrochemical section shown above added to 3D model viewer and displayed along with other model layers such as historical cross sections and 3D geologic model.

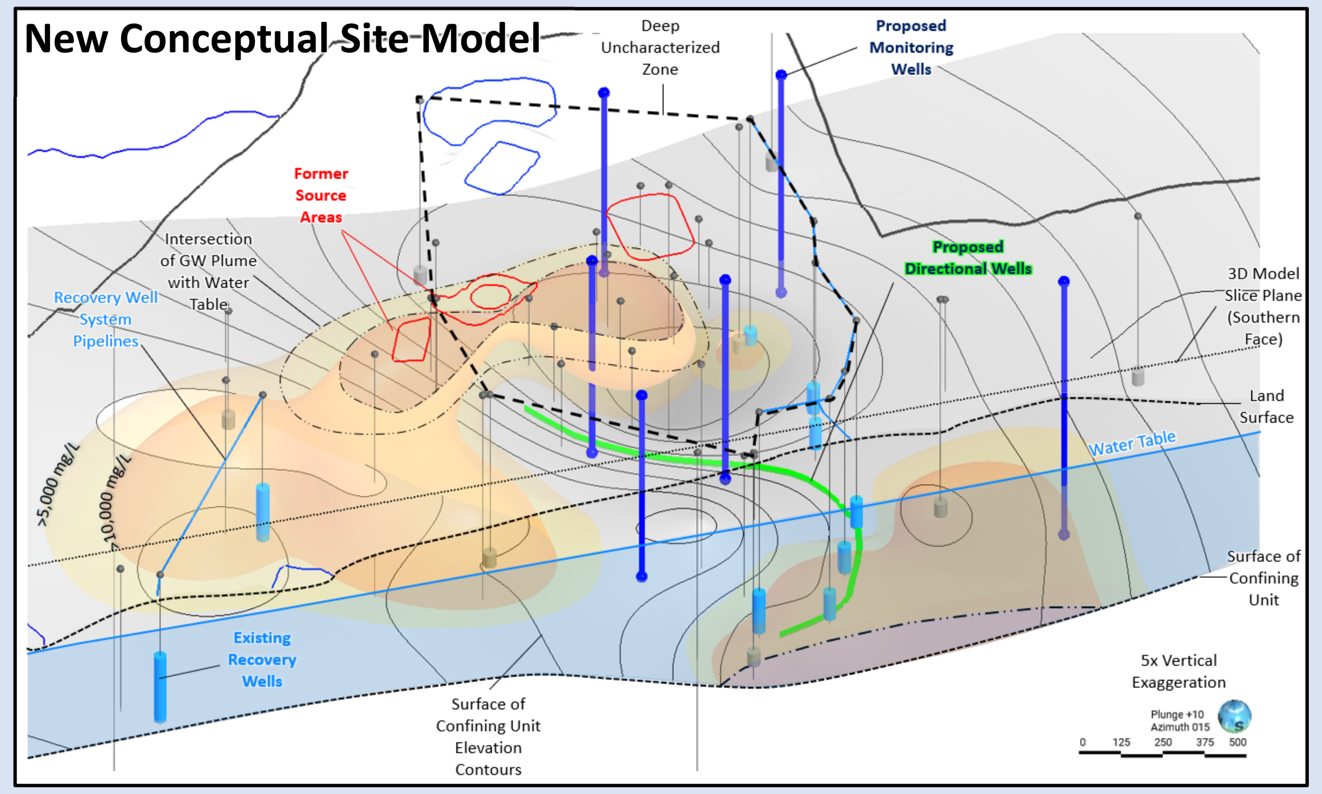
Updating the CSM

Old Conceptual Site Model





- Upper and lower sand units separated by discontinuous clay lenses
- Groundwater plumes interpolated within artificial upper and lower units, obscuring evidence of fate and transport
- Apparent complex flow patterns biased by variable density groundwater
- Unsophisticated, low-resolution graphics muddy the waters further



Results/Lessons Learned

3DVA revealed that the contaminated aquifer underlying the site is comprised of a single unit and not divided into separate upper and lower zones, as previously conceptualized. Additionally, groundwater plume movement was found to be driven by density, following the upper surface of an underlying clay aquitard/aquiclude which includes a trough that potentially conveys contaminants off site. The use of 3DVA led to optimal citing of five new deep monitoring wells to address existing spatial data gaps in a portion of the aquifer with high uncertainty located downgradient of the former source areas. In addition, 3DVA facilitated selection of a subset of the existing groundwater recovery wells to be further evaluated for feasibility of rehabilitation and reactivation as part of groundwater recovery/treatment system optimization. A field program was developed for further inspection via downwell camera and geophysical tooling, hydraulic testing, and sampling of the recovery wells selected for redevelopment in the optimized system. Geological and analytical data collected from the field program will be used in the 3DVM to identify a location for a new recovery well. Operation of the new recovery well and the selected existing recovery wells will be designed to prevent COC migration off site while discontinuing use of redundant/inefficient recovery wells. Density-adjusted groundwater elevation measurements (freshwater equivalent) prior to and during operation of the recovery system will produce more accurate potentiometric surface maps to aid in determination of the extent of constituent capture.

Intelligent application of 3DVA can quickly reveal complex relationships between distribution/transport of environmental contaminants and hydrogeology. A 3D visualization-centered approach that conveys complex CSMs visually can build confidence among the project team that the CSM is well-developed, facilitate client and regulatory approval of proposed remedial strategies, and improve communication with stakeholders, including the public.