Enhanced 3-D Visualization as a Powerful Data Analysis and Stakeholder Communication Tool During Mine Closure

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Abstract Three-dimensional (3-D) subsurface geologic modeling and visualization techniques are well developed and have proven to be powerful data analysis tools for many geosciences problems, including site investigation and mine water management applications. However, they are currently underutilized by environmental practitioners to analyze geologic and hydrogeologic data and effectively communicate findings to non-technical stakeholders. This presentation highlights several examples of where MVS, a leading 3-D visualization software, was effectively applied at mine sites to more thoroughly understand and convey information on hydrogeologic and environmental conditions. These examples support our recommendation that 3-D analyses should be more widely applied.

Keywords 3-D visualization, modeling, data analysis, planning, design, groundwater investigation, discharge, treatment, site investigation, mine water management

Introduction

Three-dimensional (3-D) geologic modeling and subsurface visualization techniques are proven and powerful data analysis tools for many geoscience applications, and have been used in mine planning and design for many years (Armstrong 2012; Rogoff 2012; Rogoff 2009; Spurlin 2010). However, they are currently underutilized by environmental practitioners to analyze geologic, hydrologic, and contaminant data, and to effectively communicate the results to non-technical stakeholders. Empowered by advancements in computer technology, software with specialized capabilities for environmental applications, and increased use of high-resolution investigation methods, practitioners are in a better position than ever before to drive innovation and develop opportunities by leveraging these tools. While conventional two-dimensional (2-D) methods are commonly employed, only a full 3-D analysis can integrate all geologic data and reveal the spatial correlations critical for accurate conceptual site model development. The 3-D analysis can then be utilized for remedial evaluation and selection of designs that minimize costs while achieving remediation objectives, and ultimately enable mine site closure. This paper describes how 3-D visualization tools can be cost-effectively applied at mine sites to dramatically improve the understanding of site conditions and perform remedial evaluations.

Methods

The use of 3-D modeling and visualization software to integrate geologic, hydrologic and geochemical data into a comprehensive, 3-D framework, provides a unique opportunity to gather important information about the spatial variability in site conditions. The Mining Visualization System (MVS) is a state-of-the-art 3-D software package that integrates geology, hydrology, geochemistry, and site features and is designed specifically for this application. These extensive capabilities allow analysis of complex, large datasets, yielding insights into the spatial variability in site conditions, which would otherwise remain hidden. Specifically, the package was used to combine analytical results from soil and water analyses with lithologic data obtained during visual core logging, cone penetrometer testing (CPT), hydraulic profiling testing (HPT), and geophysical logging (*e.g.* gamma, resistivity, spontaneous potential, neutron), to develop a comprehensive conceptual site model (Fig. 1). Output from quantitative flow and transport models (*e.g.* MODFLOW and MT3-D) can be readily displayed alongside site geology and other site data. Modeling of hydrogeologic data in MVS can also be performed as a precursor to groundwater numerical modeling in order to provide more accurate spatial representations of hydrogeologic conditions (Fig. 2). Additional subsurface conditions, such as the orientations of bedding and major fracture sets and faults, hydraulic head and gradient, mobile and immobile porosity, soil bulk density and moisture content, can be utilized in combination with lithologic and contaminant data to identify preferred groundwater migration pathways and zones of high contaminant mass flux. Using MVS, practitioners can produce animations that show changes in contaminant plumes or groundwater levels through time. MVS can maximize the value of information stored in large databases generated over decades of site management by developing a visible record that is more readily accessible and utilized, and facilitates data quality review. Furthermore, MVS also allows incorporation of GIS information, high-resolution topography and aerial imagery, as well as drawings from external sources (eg. CADD), so that all information can be placed within visual contexts that are familiar and easily understood.

The primary advantage of this 3-D modeling approach is the preservation of spatial integrity through the development of truly quantitative models. Unlike traditional conceptual visualization, this approach honors site data and can incorporate expert interpretations based on fundamental geologic, hydrogeologic, and geochemical processes. This approach consistently provides deeper insights into site conditions that are often overlooked

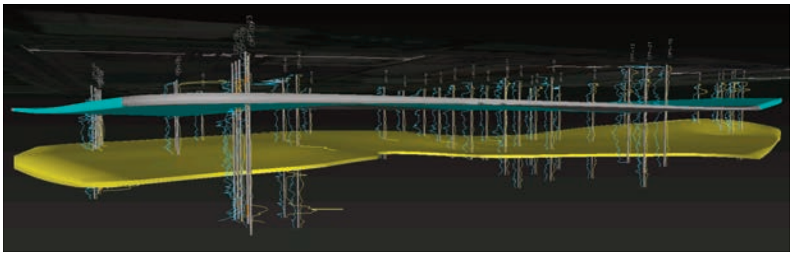

Fig. 1 *MVS can readily display and correlate characterization data obtained from CPT, geophysical and other high-resolution subsurface investigation techniques.*

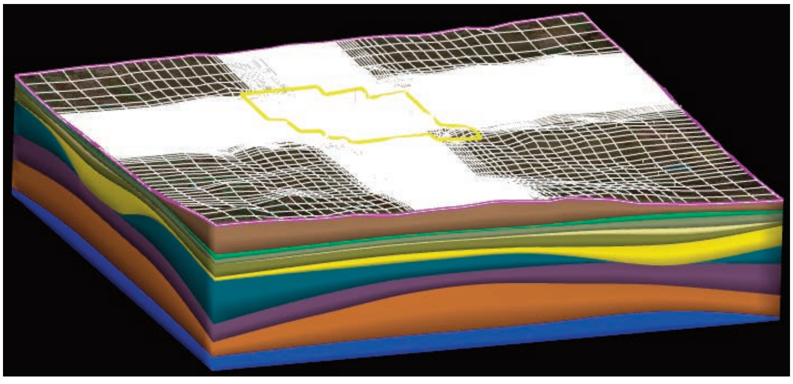

Fig. 2 *Modeling of hydrogeologic data in MVS can be performed as a precursor to groundwater numerical modeling in order to provide more accurate spatial representations of hydrogeologic conditions.*

with conventional 2-D analyses. Furthermore, a 3-D geologic model not only provides better insight into site conditions, but also serves as an effective communication tool for all stakeholders.

MVS model output is most commonly distributed using the Four-Dimensional Interactive Model (4DIM) Player, which is a free, standalone viewer. 4DIM Player files are fully interactive, and can contain multiple frames customized for data evaluation or communication of a focused message. Each frame can be zoomed, panned and rotated as a static 3-D model, allowing an astounding degree of flexibility and control to view results from any angle or magnification. The 4DIM Player can also run animations that allow full interaction by the viewer, which is a very effective way to illustrate groundwater or vapor flow, or movement of plumes through time. 4DIM modeling output is analogous to the portable document format (.pdf) file type; files are distributable and viewable by anyone with a viewer, and the content is controlled and locked from editing.

3-D geologic modeling is useful in many mining applications during the permitting, operation, and closure phases of the mine lifecycle. For example, MVS has been used to support baseline hydrogeologic characterization, ore body delineation, open pit operation, shaft and tunnel mining, solution mining, mineral exploration and extraction, and remediation design and performance assessment. Fig. 3 shows two examples where 3-D geologic modeling was used to understand complex bedrock structure and overall site geology. The first example provided an improved understanding of the spatial extent of vertical hydraulic communication between faulted and dipping water-bearing bedrock aquifer units and an overlying alluvial aquifer that is impacted with dissolved constituents sourced

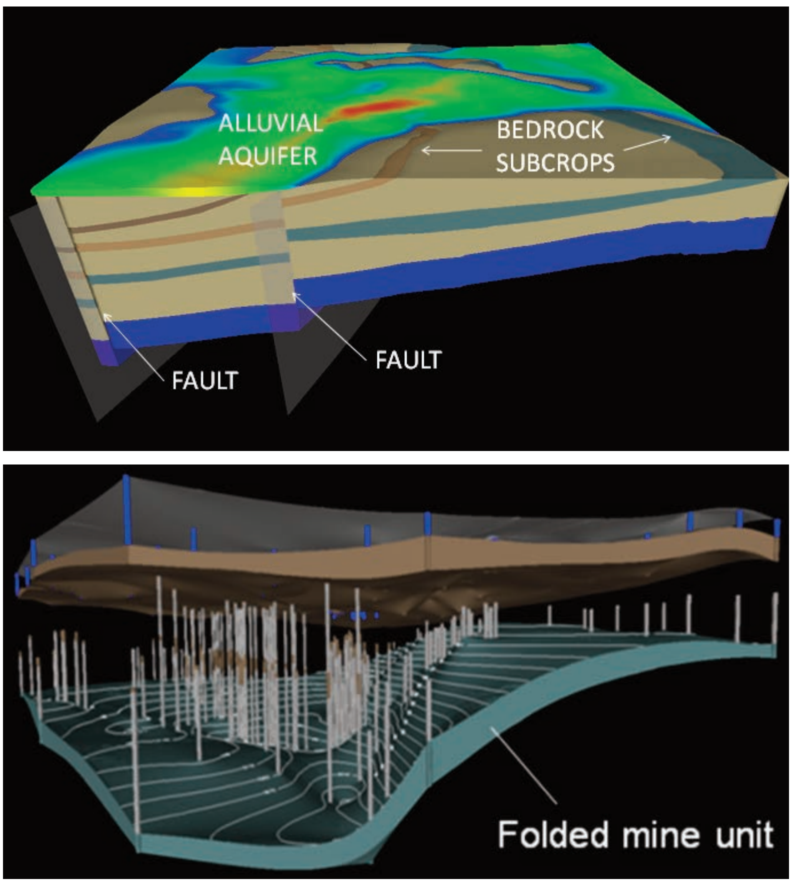

Fig. 3 *Two examples depicting the use of 3D geologic modeling at mine sites to understand and communicate complex bedrock structure and overall site geology.*

from an unlined mine tailings impoundment produced by milling operations. The second example was the basis for approval of an aquifer exemption petition where previous interpretations of a structurally folded, deep uranium ore mine unit was inaccurately characterized initially as a faulted and structurally offset feature acting as a potential source of dissolved radionuclides at an *in situ* leachate mine operation.

Fig. 4 further illustrates geologic modeling used to delineate the extent and saturated thickness of an impacted alluvial aquifer. The extent of the saturated alluvium was modeled as the intersection between the undulating eroded bedrock surface and the water table, which produced a highly accurate channelized geometry as a result of the high density of pertinent borehole locations.

Due to the data-driven nature of MVS, the modeling approach also serves as a quality control measure for available site information. Unlike conventional methods of data reporting (*e.g.* data tables or plan view location maps), this tool builds a "visual database" where missing data, discrepancies, and errors are readily identifiable. When coupled with expert interpretations by qualified practitioners, this intrinsic characteristic to 3-D modeling ensures the quality of all site data while permitting the seamless integration of various data sources.

Fig. 5 highlights several quantitative aspects of the MVS tool. In this example, 3-D modeling was utilized to assist with excavation planning for a former smelter site. A LiDAR (Light Detection And Ranging) mission was flown over the site to obtain a precise "point cloud" of surface elevations. The point cloud was converted into a TIN (triangular irregular network) surface and draped with an aerial image, producing an exceptionally accurate ground surface for subsequent quantitative assessment. The results of soil quality analyses from borings advanced within the slag pile were integrated into the model and iso-surfaces were generated at various potential target cleanup levels. MVS was then used to calculate impacted soil volumes and the total contaminant mass exceeding several environmental risk thresholds. These spatial results were then used as the basis for excavation planning. The value in this modeling approach was the high-degree of spatial accuracy and rapid visualization (within a single day), which were then used to assist with decision making, project planning and budgeting.

The costs associated with developing MVS models for mining applications depend on the project objectives, the volume and types of data to be incorporated, and the complexity of the site. Costs range from less than $5,000 for relatively simple tasks (*e.g.* posting analytical data), to more than $100,000 for comprehensive models with large historical databases and complex hydrogeology. Prior to commencing MVS modeling, a customized, well-defined scope should always be developed with buy-in from the project manager and the client to control costs while focusing on high-quality

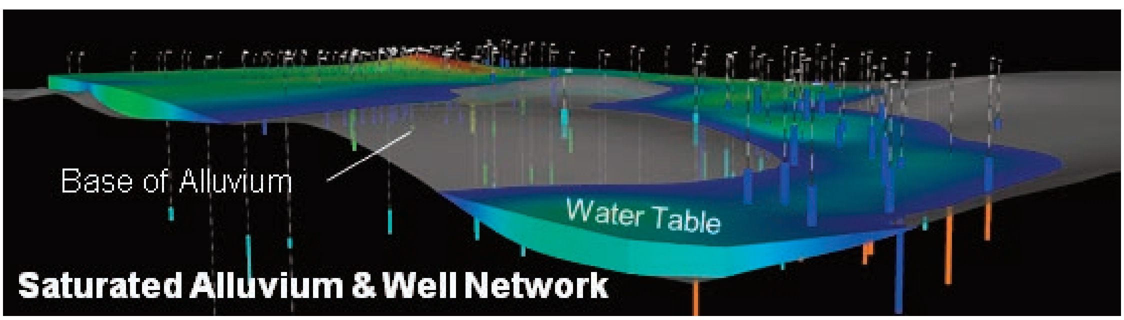

Fig. 4 *Geologic modeling of the extent and thickness of an alluvial aquifer.*

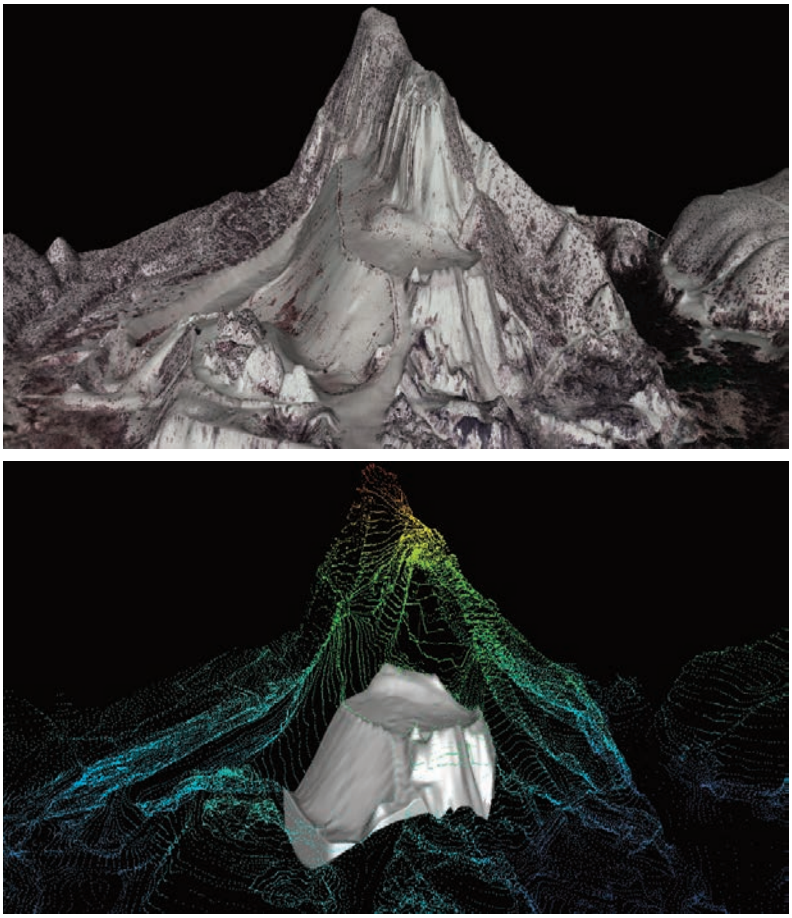

Fig. 5 *High-resolution LiDAR and soil quality data were integrated to calculate the soil volume and mass exceeding environmental risk thresholds within a slag pile.*

results. In this capacity, incorporating MVS into a project can be the most cost effective way to analyze and report site data, particularly in preparation for remedial planning and design ultimately focused on mine site closure. This is due to the ability of MVS to quickly incorporate data from sources that are typically already prepared (*e.g.* spreadsheets, databases, GIS shapefiles, CAD drawings). Integrating an MVS task into the project scope and budget at the early stages of project planning will typically reduce overall project costs over the lifecycle of the project.

Conclusions

In summary, 3-D geologic modeling can be powerfully applied at mine sites to more thoroughly understand hydrogeologic and environmental conditions, ensure the quality of all site data, and effectively communicate key elements of site conditions to all project stakeholders. MVS is a sophisticated tool for environmental practitioners and is a cost-effective, data-driven approach to integrate site data and maximize value for mining-related applications. This paper highlighted several examples of where 3-D modeling using MVS was effectively applied at mine sites and supports our recommendation that 3-D analyses should be more widely applied.

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