BENEFITS OF 3D VISUALIZATION AND QUANTIFICATION USING LARGE ENVIRONMENTAL DATASETS FOR MINING APPLICATIONS

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Introduction

Advancements in high-resolution data acquisition from aerial surveys and subsurface characterization methods, coupled with large historical databases, provide today’s mining restoration practitioners tremendous potential for remediation cost-savings - if they can effectively manage the challenges associated with large data sets rather than being overwhelmed. This presentation will demonstrate 3D visualizations of complex datasets and volumetric analyses performed using CTech's Mining Visualization System™ (MVS) software. Examples from mining project case studies will illustrate the integration of large datasets and information from a wide variety of sources (e.g. LIDAR topographic surveys, historical database queries, GIS information, geologic information, water levels, analytical data, AutoCAD drawings, aerial photographs, computer model output, subsurface tools, geophysical surveys). Resulting interactive 3D models may be zoomed, panned and rotated, allowing flexibility and control to view data or geologic features from any angle or magnification. Animations of temporal changes such as groundwater flow, or movement of plumes through time, will also be shown in the presentation.

Advantages of 3D Data Visualization for Mining Applications

3D data visualization dramatically enhances the ability to analyze large datasets, allowing complex information to be easily evaluated and understood by both technical and non-technical stakeholders. Understanding of the site from the regional volcanic, metamorphic, or depositional setting may be integrated with local, high resolution site stratigraphy and geologic structure, then readily shared with others. 3D visualizations based on large data sets illuminate factors controlling the occurrence of mineral deposits, controls on contaminant distribution and migration, and groundwater flow. Integration of all pertinent data and information (analytical data, water levels, GIS, CAD maps etc.) allow highly refined site conceptual models to be developed. The sophistication of today’s software allows expert human interpretations to be honored and incorporated as well. Thus, 3D visualization is an important part of the targeted approach to economic success, site characterization, and remedial design.

MVS visualizations may be produced as still graphics or animations. Fully interactive 3D models that can also show changes through time can be viewed using the CTech 4DIM Player, which is the companion viewer for MVS. Each frame of the 4DIM file can be zoomed, panned and rotated as a static 3D model, allowing an astounding degree of flexibility and control to view results from any angle or magnification. Thus, detailed analysis can be performed at any scale, from regional to an individual sample, within a single frame. 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, movement of plumes through time, or time-series model outputs. This paper includes still pictures taken from the interactive 4DIM files which will be shown at the presentation.

Development of Topography and Surficial Analysis

Successful site-specific characterization begins with a solid conceptual understanding of topographic features affecting surface and subsurface water flow. Topographic information for locations in the United States are available in resolutions to 10m from the United States Geological Survey (USGS). Site-specific aerial LIDAR surveys may also be incorporated.
A topographic surface generated from 10-meter USGS Digital Elevation Model (DEM) data is shown in Figure 1. The figure covers approximately 400 square miles and utilized over 11 million data points to generate the surface. Pits, ponds, and tailings piles can be clearly seen. Color enhancements and shading may be added to enhance ability to detect elevation changes and degrees of slopes (Figure 2). As these surfaces are based on precise coordinate systems, accurate measurements of lengths, areas, and volumes may be obtained.

Figure 1. Topographic surface generated from 10-meter USGS Digital Elevation Model (DEM) data.

Figure 2. Color ramp shading and shadows applied to DEM data.
These topographic maps are useful for planning areas of exploration and conveying locations for potential sampling efforts.

LIDAR elevation data may be visualized in 3D where extremely high resolution and accuracy are desired for volumetric analysis. Figure 3 represents a triangular irregular network (TIN) constructed from over 4 million XYZ measurements.

Figure 3. Triangular Irregular Network (TIN) developed from LIDAR survey.

After loading USGS DEM or LIDAR data into the 3D model, topographic contours may be generated for any desired contour interval. Figure 4 demonstrates contours at 20-ft intervals with continuous color ramp shading, and Figure 5 illustrates elevation color bands at discrete intervals. The elevation data may also be used to generate watershed areas, stream channels, and ridgelines, which can be exported to surface water runoff and flood control models. Particle tracking from operational locations can also be generated and displayed as a component of Spill Prevention, Control, and Countermeasure (SPCC) plan preparation.
Combining Aerial Photographs, other Maps with Surficial Analysis

Information from various media (e.g. aerial photographs, USGS topographic maps, USGS digital elevation models) may be combined to represent the ground surface in three dimensions, with the photographs or maps precisely placed on the topographic surface. The three-dimensional models may then incorporate lithologic information from boring logs, as well as analytical results from soil and groundwater samples. The synthesis of this information into an interactive database computer...
visualization tool allows the distribution of ore bodies or contaminants to be clearly shown within the hydrogeologic framework and can be used to demonstrate how the various media interact in the subsurface.

Figure 6 illustrates a georeferenced high-resolution aerial photograph texture mapped on the topographic surface. High-resolution aerial photographs are widely available for the United States at 1 meter per pixel resolution. However, local agencies are providing higher-resolution aerial photographs in some instances, with resolutions as great as 0.15 feet per pixel in some areas. These high resolution aerial photographs allow exquisite evaluation of fine details, with clear visibility of features such as individual wells. Overlaying high resolution aerial photographs on topography may be used to digitize XYZ coordinates for features which have not been surveyed, such as old wells, boring locations, or historic operational structures.

Figure 6. High resolution aerial photograph overlain on DEM surface.

Any other type of map, or even figures from historic reports, may be georeferenced and overlain on topography. Figure 7 demonstrates a geologic map combined with a transparent aerial photograph. Fault traces and well screen intervals, with the rock type within the screen interval, are also shown. This approach is applicable to soil, vegetation, ecological surveys, or any type of map desired. The ability to adjust transparencies of individual maps allow “hybrid” maps to be created consisting of multiple maps.
Visual Databases

Ore exploration activities or environmental investigations at mine sites may include hundreds of cores, borings, or wells, with thousands of samples including analytical data and physical property data. The large volumes of data are cumbersome to access, usually occurring within stacks of reports, and typically only a handful of experts have sufficient knowledge to access specific information. Evaluation of data trends spatially or through time is difficult, and information cannot be easily shared and discussed with team members in other locations.

Preparation of interactive, 3D visual databases as 4DIM files allow the difficulties above to be overcome. Any type of data can be visualized – analytical, lithologic or soil type, visual observations, groundwater levels, geophysical, geotechnical, etc. The 4DIM files can incorporate individual states in one file so that the user can step through as many constituents as desired, or through as many time intervals of data as needed.

An example of this approach is shown in Figures 8 and 9. Figure 8 shows borings from five investigation phases which took place over several decades. The 3D model was built with data from 1660 soil samples, with 11 metal species from each sample, resulting in a “visual database” of 18,260 analyte records. For each metal, individual states were prepared showing boring identifications, sample intervals, and analytical results. Figure 9 shows a close-up of results for Arsenic. The analytical value is shown to the right of each sample, and the depth ranges are shown to the left of each sample. The samples are color coded using three distinct risk assessment thresholds, allowing the user to quickly identify borings or regions with “hot spots”, or target zones for specific remedial actions.

The ability to package all constituents in individual states allows one 4DIM file to contain and display the database for the entire site. The visual database 4DIM file can be easily distributed to all team members so that they can easily access all data no matter what their particular subtask is or what subsection of the site they are evaluating. The files are small enough to email or FTP, allowing team experts to access the data from anywhere in the world. These capabilities allow effective, powerful communication, improve the quality of data analysis, and save substantial time.
Figure 8. Visual database from five investigations spanning approximately 20 years.

Figure 8. Visual database with close-up of Arsenic results (right side) and sample depth intervals (left side).
Case Studies Combining Visual Elements and Large Geophysical Survey Datasets

**Study 1**

An Inverted Resistivity (IR) geophysical survey was performed to assess bedrock topology and sediment thickness along a 4-mile stream length. Twenty two traverses were completed, with over 30,000 XYZ and IR values collected. Figure 10 shows a view of the survey traverses incorporated with the 10m USGS DEM, an overlain aerial photograph, and GIS shapefiles of the mapped surficial stream deposits. Figure 11 illustrates a collection of raw IR data for 6 distinct traverses.

Figure 10. Geophysical survey traverses with aerial photograph and opaque GIS shapefiles of mapped stream deposits.
The individual raw data fences were then kriged to develop individual continuous fences, which were in turn interpolated to develop the bedrock topology and sediment thicknesses shown in Figures 12 and 13. After the sediment thicknesses were determined, calculations of sediment volumes between traverse pairs were performed.

Figure 12. Bedrock contacts and sediment thickness contours generated from inverted resistivity fences.
Figure 13. Example of sediment volume calculated from inverted resistivity data.

Study 2

3D data visualization was applied to an aerial flyover inverted resistivity survey. This survey collected nearly 2 million X,Y,Z,IR data points over many miles of terrain, penetrating to depths of up to 360 feet. Visual processing of the data in 3D enabled evaluation of presence and depth of permafrost. Numerous visualizations of IR plumes at various resistivity thresholds, cross sections, and block model cutaways were prepared. Visualizations are not shown due to confidentiality agreements in effect at the time this manuscript was submitted. However, description of this study is included as these 3D visualization techniques would be applicable for the large datasets provided by airborne surveys of any type.

Case Study Combining Visual Elements, Large Analytical Datasets, and Volumetrics

Extensive 3D data visualization and volumetrics analyses were performed for remediation of a former smelter site. Topographic surfaces were constructed from a pre-operation historical company map from the early 1900s, and two LIDAR surveys performed in 2008 and 2011. Data from decades of investigations were compiled and visualized as described in the “Visual Databases” section on page 6, and illustrated in Figures 8 and 9.

Other items incorporated into the 3D model for display included:
- Volumetric cut/fill comparisons of historic, current, and planned surfaces
- Volumetric analysis of slag pile volumes (both surficial and buried)
- Volumetric analysis of an existing metals-impacted landfill requiring excavation and relocation in a lined landfill
- Analytical results of metals in groundwater through time

Figure 14 illustrates elements used to calculate a volume of metals-bearing soils from a historic landfill that required excavation and removal to a new lined landfill. The high-resolution LIDAR surface data was used to texture map an aerial photograph, which is opaque so that the arsenic data posts may be seen. The data were used to define the lower surface of material above the selected risk threshold. The gray object in the center represents the volume of material requiring removal.
Figure 14. Volume of soil exceeding risk threshold to be excavated.

Figure 15 demonstrates the ability to take to complex surfaces and perform thickness and volume calculations. The underlying gold surface represents the bedrock surface as it existed in the early 1900s. Over time, large slag piles were collected in certain areas of the site, and other areas had substantial volumes of soil moved. The upper, transparent surface was generated from the 2011 LIDAR survey. Using borings to delineate the buried slag extents, and using the lower bedrock and upper surfaces as bounds, the volume of slag to be excavated from this portion of the site was determined.

Figure 15. Volume of buried slag in channel between historic pre-operation surface and 2011 topographic surface.
3D drawings generated with AutoCAD may be imported into MVS, allowing for straightforward integration of surface feature maps and engineering drawings. Figure 16 illustrates the integration of an extremely detailed AutoCAD-generated excavation and fill surface (shown in blue), and the planned Class I landfill (white with contour lines). The ability to assemble different elements in 3D enables tremendous volumetric calculation capabilities. Surfaces of virtually unlimited complexity can be brought in from any 3D CAD or GIS software and used to perform volume computations. 3D modeling allows volumetric analysis of impacted material and overburden materials. Volumetrics can also be performed using unions or intersections of multiple decision criteria.

Figure 16. Incorporation of 3D AutoCAD objects: planned post-excavation topography and new landfill.

MVS allows analysis of groundwater flow to be combined with lithologic and site features to illustrate subsurface controls on groundwater movement. Figure 17 shows groundwater flow through buried incised channels in the bedrock. Two channels in the northern portion of the site converge into one channel, funneling arsenic impacted groundwater through this portion of the site. Two permeable reactive barriers (PRBs) have been emplaced to remediate the impacted groundwater. The flow vectors are animated in the 4DIM, allowing stakeholders to understand how the groundwater remediation system is designed. Figure 18 shows the buried bedrock channels, the groundwater flow vectors, and an aerial photograph mapped on the 2008 topographic surface.
Figure 17. Impacted groundwater flow through buried arroyos with two permeable reactive barriers (PRBs) shown.

Figure 18. Groundwater flow towards a PRB with cutaway showing historic topography (brown) and aerial photograph on 2008 surveyed surface.
Visualization of Other Model Outputs

Numerical models are sophisticated tools that simplify the process of solving multiple mathematical algorithms on large data sets within a prescribed framework used to simulate site conditions. However, modeling codes are generally focused on reading complex input files and solving flow and transport equations, and as such are typically incapable of graphically displaying site-specific input and output at the high level of complexity used to develop the site-specific model. Linking numerical models to state-of-the-art visualization tools allows the graphical limitations of the models to be overcome. The 3D time series visualization capabilities allow for complex models of transient groundwater pumping or reagent injection/extraction scenarios to be evaluated visually.

Figure 19 illustrates a single time step from an acid injection / ore extraction model with 85 wells, 70 time steps and 125,000 data values. Finite element software modeling codes can handle the computational demands of large models well, but are cumbersome and limited in their ability to examine their output. A preferable process is to export data from the finite element model into the 3D software so that the nuances of varying injection and extraction rates from specific wells can be easily seen. Interactive 4DIM files allow easy examination of every time step either individually, or played through as a video so that changes through time are readily apparent. This approach efficiently allows operational parameters to be optimized to maximize ore recovery while minimizing reagent injection volumes, thereby maximizing profits. Such models allow effects of shutting off wells either purposefully or unintended failure situations to be evaluated.

Figure 19. Modeled time-series potentiometric surface resulting from acid injection/ore recovery system with 85 wells.

Summary and Conclusions

3D visualizations and quantification tools are well-suited for large datasets generated by mining exploration and restoration applications. These tools unite state-of-the-art data analysis, visualization, GIS, and animation tools to assist in decision making to optimize return on investment. Mining and environmental applications for 3D visualization include the following:

- mineral exploration
- volumetrics of ore and overburden
• site assessments for mine or smelter restoration
• remediation planning
• computer model output/ input
• regulatory permitting and reporting
• public relations and investor presentations
• litigation support

The benefits of visualizing data interactively in 3D include expedited, higher-quality expert team analysis, as well as the ability to explain complex technical concepts to stakeholders from a wide variety of backgrounds. Resulting visualizations can be an invaluable aid in operations planning, evaluating remedial alternatives to minimize costs, and communicating future plans to decision makers. Application of 3D visualizations and volumetrics analysis typically results in substantial savings of time and money.