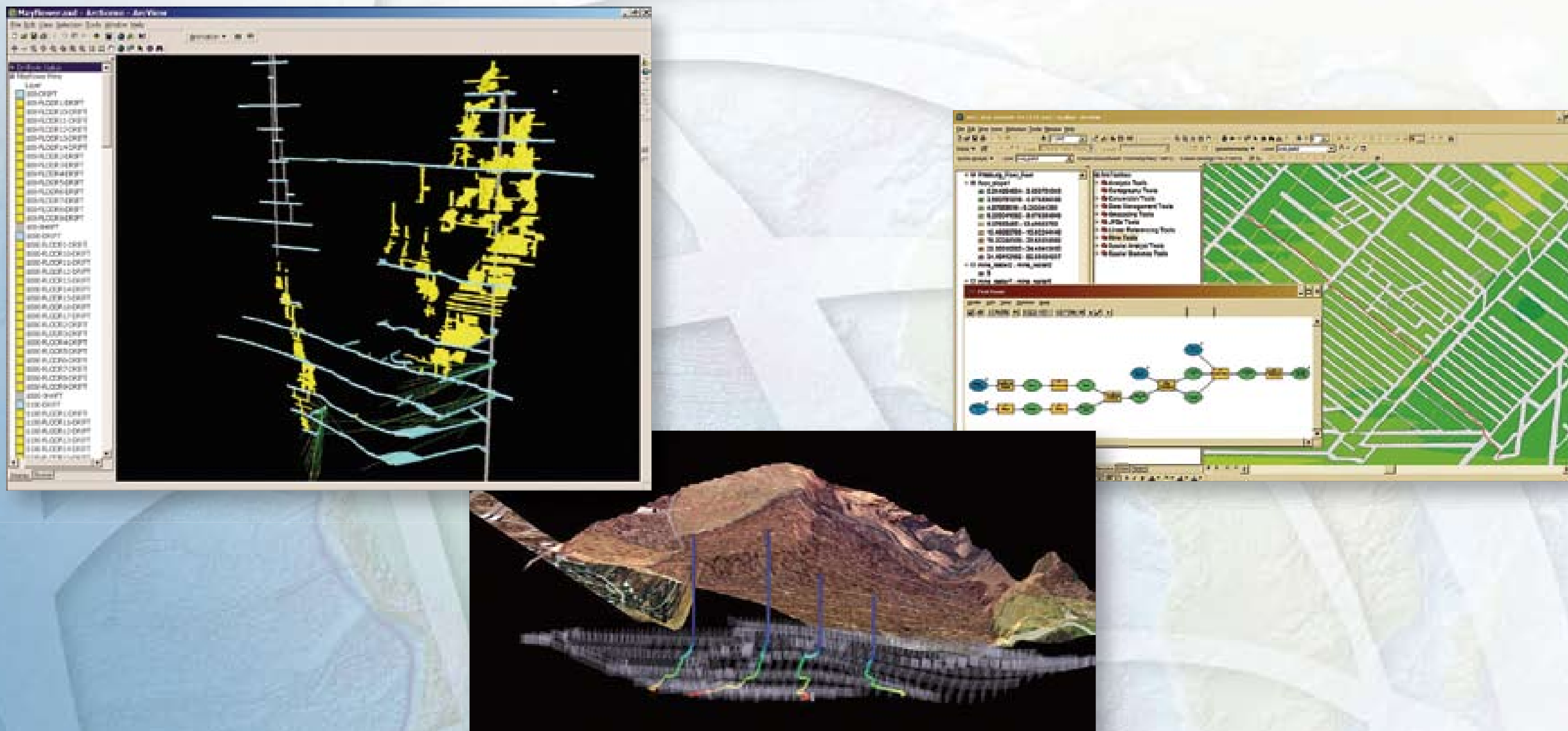
GIS Best Practices

Mining



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ESRI

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What Is GIS?

Making decisions based on geography is basic to human thinking. Where shall we go, what will it be like, and what shall we do when we get there are applied to the simple event of going to the store or to the major event of launching a bathysphere into the ocean's depths. By understanding geography and people's relationship to location, we can make informed decisions about the way we live on our planet. A geographic information system (GIS) is a technological tool for comprehending geography and making intelligent decisions.

GIS organizes geographic data so that a person reading a map can select data necessary for a specific project or task. A thematic map has a table of contents that allows the reader to add layers of information to a basemap of real-world locations. For example, a social analyst might use the basemap of Eugene, Oregon, and select datasets from the U.S. Census Bureau to add data layers to a map that shows residents' education levels, ages, and employment status. With an ability to combine a variety of datasets in an infinite number of ways, GIS is a useful tool for nearly every field of knowledge from archaeology to zoology.

A good GIS program is able to process geographic data from a variety of sources and integrate it into a map project. Many countries have an abundance of geographic data for analysis, and governments often make GIS datasets publicly available. Map file databases often come included with GIS packages; others can be obtained from both commercial vendors and government agencies. Some data is gathered in the field by global positioning units that attach a location coordinate (latitude and longitude) to a feature such as a pump station.

GIS maps are interactive. On the computer screen, map users can scan a GIS map in any direction, zoom in or out, and change the nature of the information contained in the map. They can choose whether to see the roads, how many roads to see, and how roads should be depicted. Then they can select what other items they wish to view alongside these roads such as storm drains, gas lines, rare plants, or hospitals. Some GIS programs are designed to perform sophisticated calculations for tracking storms or predicting erosion patterns. GIS applications can be embedded into common activities such as verifying an address.

From routinely performing work-related tasks to scientifically exploring the complexities of our world, GIS gives people the geographic advantage to become more productive, more aware, and more responsive citizens of planet Earth.

GIS for Mining

Mineral exploration geoscientists use diverse types of datasets to search for new economic deposits. Data sources vary from geologic maps, hyperspectral airborne and multispectral satellite images, and geophysical images to databases in many formats. GIS is an ideal platform to bring them together in a geoscientist's computer and deliver meaningful outcomes.

GIS is now able to help geoscientists in many aspects of their activities: data collection, management, analysis, and reporting. Field geologists can now capture field data electronically using ArcPad and global positioning system (GPS) receivers. Other datasets may be downloaded from the Internet. All of these datasets can be integrated, manipulated, and analyzed using GIS.

Pipelines, electric lines, roads, ramps, and other mining facilities change frequently. Engineers and operations staff use GIS for facility planning applications. Keeping track of existing infrastructure and integrating it with the mine plan and block models can be achieved with GIS. GIS can also be used to integrate recent survey data with block models or mine design data from other mining software packages such as GeoSoft, Vulcan, MineSight, SURPAC Range, or Mining Visualization System (MVS).

Most mining information, including financial and asset information, has some sort of spatial component that can be represented in map form. Management and mineral economists are using GIS in their evaluation of corporate and competitor assets. Mining companies also use GIS to actively monitor the environmental impacts that may be caused by their activities and conduct reclamation.

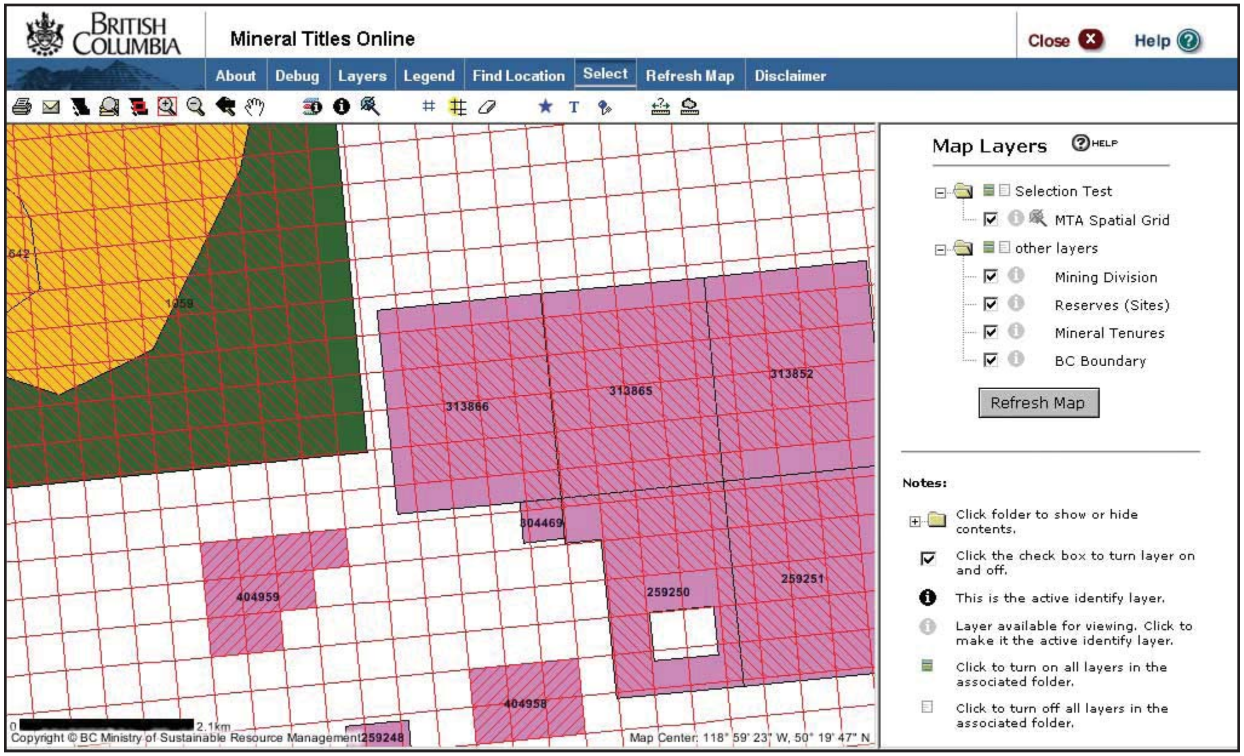
Various types of geologic datasets, such as geophysical images, geochemistry, geologic maps, radiometric measurements, boreholes, and mineral deposits, can be displayed, interrogated, and analyzed simultaneously using GIS.

British Columbia Administers Mining Titles Online

By Andy Lang, Pacific GeoTech Systems Ltd.

With the election of a liberal government in British Columbia in 2001, a new vision for efficient government administration was conceived. Government was reorganized, and most mapping and database management functions were grouped together.

These new ministries faced a reduction in the workforce as well as an increased need for reengineered technical applications and a leaner, enhanced administrative system. This called for a collaborative and integrated approach that forced government to utilize common infrastructure and IT services to achieve service delivery.



Mineral Titles Online is the first e-commerce, GIS Web-enabled system for mineral title acquisition in British Columbia.

British Columbia is committed to enhancing mineral title administration by adopting an e-commerce, GIS-based map selection system. Mineral Titles Online (MTO), a program of the Ministry of Energy and Mines (MEM), promotes efficient administration. Developed by ESRI Canada Limited Business Partner Pacific GeoTech Systems Ltd. in collaboration with the Titles Division of MEM as well as the Ministry of Sustainable Resource Management, its goal is to provide a positive administrative environment that will support increased mining exploration and development activity in the province.

MTO is the first e-commerce, GIS Web-enabled system for mineral title acquisition in British Columbia. With this system, members of the mineral exploration industry, authorized agents, and staff from mining companies can acquire mining rights by selecting a claim on an electronic map rather than staking a claim on the ground. Establishing secure title on an accurate digital map base integrated with other online resources will streamline the entire claim acquisition process.

Most existing claims are plotted on 40-year-old basemaps that are supported by a 14-year-old attribute database. The maps are digital, but the associated information can be incomplete or out of date. In 1998, the ministry began to convert all claim maps to a common computerized database called TRIM (Terrain Resource Inventory Mapping). The conversion process imports the existing mineral titles onto the map and corrects and updates the geographic details. These maps will provide a very accurate platform for MTO.

"When we first discussed map selection with our industry clients, it didn't take long for us to realize that tenure issuance had to be instant and that this required a major overhaul of our entire administration system," said Rick Conte, MTO project director.

In 2002, Richard Neufeld, the minister of Energy and Mines, announced the move toward a map selection acquisition system. An industry consultation process and research began in earnest. The need to make the selection of a title and the actual title issuance a nearly instantaneous process was imperative. MTO incorporates a digital map selection process and capitalizes on a host of governmentwide initiatives that offer Internet-based delivery of digital maps, greater access to information, and a secure administration system for electronic payments.

Powered by Pacific GeoTech Systems' truePERMIT solution, MTO was developed and implemented using ArcIMS, ArcSDE, XML, Java, Java 2 Platform, Enterprise Edition (J2EE), Apache Ant, Log4J, Oracle, Apache Struts Framework Model-View-Controller-2 (MVC2), design patterns, and the government's MIRA Java Payment and Internet Mapping Framework (IMF).

The entire MTO system is Web based and accessible through a standard Web browser. MTO provides robust, secure, and powerful geospatial capabilities and validation that works with electronic, graphic, and attributes standards and supplies online help.

The initial phase of MTO implementation in spring 2004 allowed internal authentication of client data, viewing of spatial and attribute data online, selection of tenure for acquisition via electronic maps, and acquisition of free miner certificates (FMC). These functions will allow for a full range of testing and training for staff and industry. In the future, MTO will also incorporate subsurface mineral and placer titles administration and provide recording of applications for all title transactions that is fully Web based.

MTO was unveiled by MEM and Pacific GeoTech at the Mineral Exploration Roundup Conference in Vancouver, British Columbia (BC), in January 2004. MTO Project Manager Jim Turner, who attended the conference, remarked, “We realized that with so many other leading edge e-commerce activities being developed within the BC government infrastructure, MTO became an obvious fit to develop a business application that could capitalize on developing e-government objectives in BC.”

With MTO, the tenure application process is more rigorous and efficient. Industry clients benefit from electronic selection, secure access to up-to-date government geospatial data, faster resolution of title conflicts, and-ultimately-faster permit processing. The e-commerce capabilities of MTO will also mean that payments can be securely made online, which further reduces processing time. MTO also allows MEM to provide enhanced services related to mineral claims and reduce processing and administrative costs, which fulfills British Columbia’s e-government objectives. In addition, MTO may be used for other MEM regulatory functions.

MTO will meet the current business needs of MEM and its clients. It will also help ensure government compatibility with other Web-based systems and applications developed in the future. The target for the implementation of MTO is January 2005, and the system will be further developed and tested over the next couple of years. Throughout the development of MTO, MEM will continue to ask for input from the mineral exploration industry, government agencies, and the public.

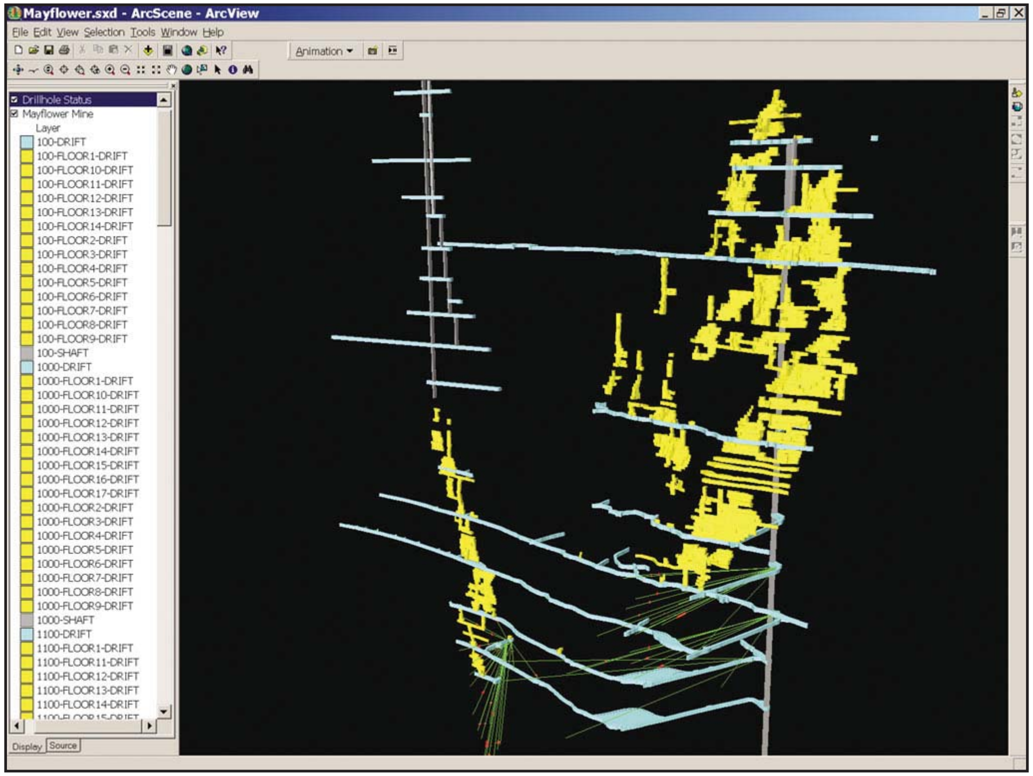
While the internal implementation will be staggered over a period of time, MEM will be responsible for maintaining an orderly and secure transition of title. MEM will also provide training and orientation to clients throughout the consultation phase and before implementation. All existing claims will continue and will be displayed relative to the new online map grid. The ministry is confident that most existing claims will be merged with the grid over time. A number of incentives will be put in place to achieve this goal. The ministry is also committed to continue improving MTO and offering assistance and training to clients.

(Reprinted from the October–December 2004 issue of *ArcNews* magazine.)

Mining Gold in Montana With GIS and Underground Modeling

Virtual 3D Model of the Mayflower Mine

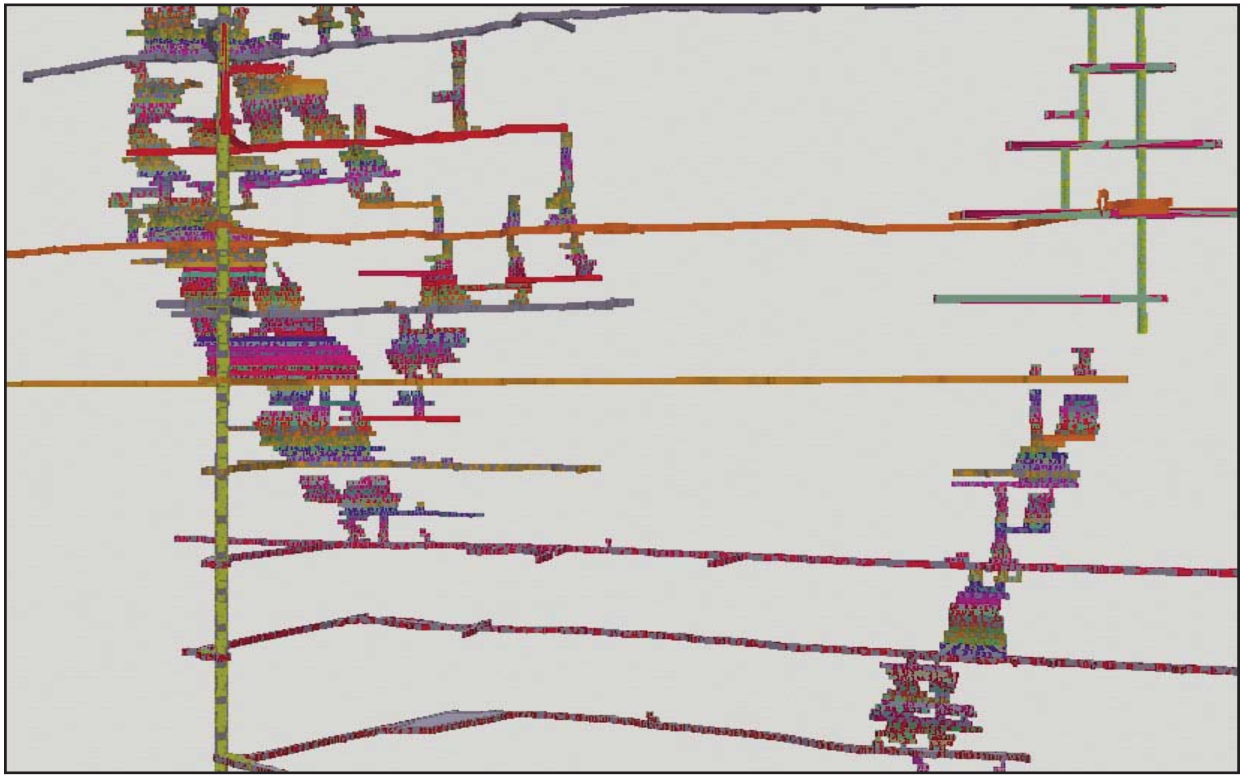
In the mid-1990s, Brimstone Mining, Inc., purchased the historic Mayflower Mine in southwest Montana. The Mayflower Mine had been a top gold producer in the 1930s. The value of gold when Brimstone bought the mine, along with the prospect of applying more advanced mining techniques, provided the stimulus to reopen the mine.



The Mayflower Mine complex visualized in 3D with ArcView and the 3D Analyst extension.
This view is to the southeast and shows the heavily mined western ore body (right) and the narrow eastern ore body (left).

Years of previous mining activity had left numerous “stopes,” open underground areas where ore had been extracted, and “drifts,” horizontal tunnels that led from the access shafts to the ore bodies. In all, mining had been conducted at 20 different horizontal levels reaching 1,900 feet below ground level. Detailed mapping of these excavations over the years reflect the times at which they were conducted. Brimstone had a collection of drafting on linen, old paper maps, and surveys of varying degrees of detail and accuracy.

Brimstone needed to bring in experts to help it make sense of the data. In 1998 it hired ESRI Business Partner DTM Consulting of Bozeman, Montana, to help it visualize the extent of the historic excavation and help plan future drilling by identifying and quantifying new reserves. DTM is a GIS consulting firm with a strong background in natural resources and earth sciences. DTM’s experience in the mining sector and detailed knowledge of the local geology, combined with its extensive GIS and CAD capabilities, made it a perfect choice for completing this task. The firm has clients in the areas of environmental assessment, water resource management, oil and gas, mining, and urban and rural planning.



This view is to the northwest and shows the heavily mined western ore body (left) and the narrow eastern ore body (right).

"What we did is to take all of the historic data sources and put them in a digital format so we could visualize them within the GIS," says Tony Thatcher, co-owner, DTM Consulting. "The process involved in the analysis and targeting of potential new gold reserves is greatly streamlined by working within the digital environment."

Much of the drafting of the old mine working surveys was done with a CAD system. The actual drafting was done with a large-format digitizer using CAD software and constructed in such a way that it could be easily imported into ArcView. Additional digitizing of geology, assay values, and other infrastructure within the mine was done within the GIS. All features were given 3D attributes such as elevation and height.

"We created a series of maps of constant elevation representing each drift, stope, and shaft level," says Marshall. "For instance, there might be a map called the 1,400 level, and that's all the information that's at 1,400 feet below ground level. There's a whole series of these stacked levels that, when combined, create a 3D model of the mine workings. Everything was digitized for import into ArcView 3.2 with the ArcView 3D Analyst extension."

One of the biggest challenges to DTM was compiling data from multiple sources of unknown reliability. Once exploratory drilling in the mine began, mistakes could prove very costly.

"The mined out areas throughout the complex really wiggle around all over the place as they followed the high-grade ore reserves," says Thatcher. "If you're just looking at paper maps, which are drawn at different times at different scales, it's very hard to visualize from that information how the whole mine is actually laid out and what the geologic control is. You want to start a new exploratory drill hole in a direction that hasn't been mined out. If you accidentally hit one of the drifts or stopes, that's a lost drill hole, and there goes about $30,000 down the tubes. If we're off by a degree or two, that might make the difference between success and failure. So we can drill these virtual drill holes in electronic space and really refine how the drill hole needs to be set up in order to hit a prospective target. This process can potentially save tens or even hundreds of thousands of dollars."

In addition to helping determine where to mine next, the 3D images and animation capabilities allowed DTM and Brimstone to demonstrate their plans in an easily understood fashion to potential investors.

"This type of project is usually not funded internally through the actual mining company, but rather through investment capital," says Marshall. "Being able to visualize what is taking place under the ground makes them a little more comfortable about putting their money down."

DTM worked with Brimstone for more than a year on the Mayflower Mine project. Unfortunately, about halfway through the project, the price of gold dropped dramatically. It fell from its 1996 price of more than $400 an ounce to less than $300 an ounce by the end of 1997 and has not fully recovered. Brimstone abandoned its plan to continue exploration and sold its interest in the Mayflower Mine.

However, the potential to explore and glean the remaining gold from the mine still exists—when the time is right. According to DTM, with a favorable gold price, a successful exploration project for a mine of this scale could yield between $20 million and $50 million.

In the meantime, DTM has been working with advancing GIS technologies and is ready to apply its skills to the Mayflower Mine again, if called on by the mine's new owners.

"One of the things we've worked on subsequent to this project has been a series of custom analytical tools that run within the ArcView 3.2 environment—Avenue extensions and scripts—that allow us to analyze the 3D geologic information," says Marshall. "We can even more accurately understand the geological environment in which these gold deposits formed. From that we can extrapolate where we might find more gold reserves. Overall, we've improved our analytical capability for this type of data."

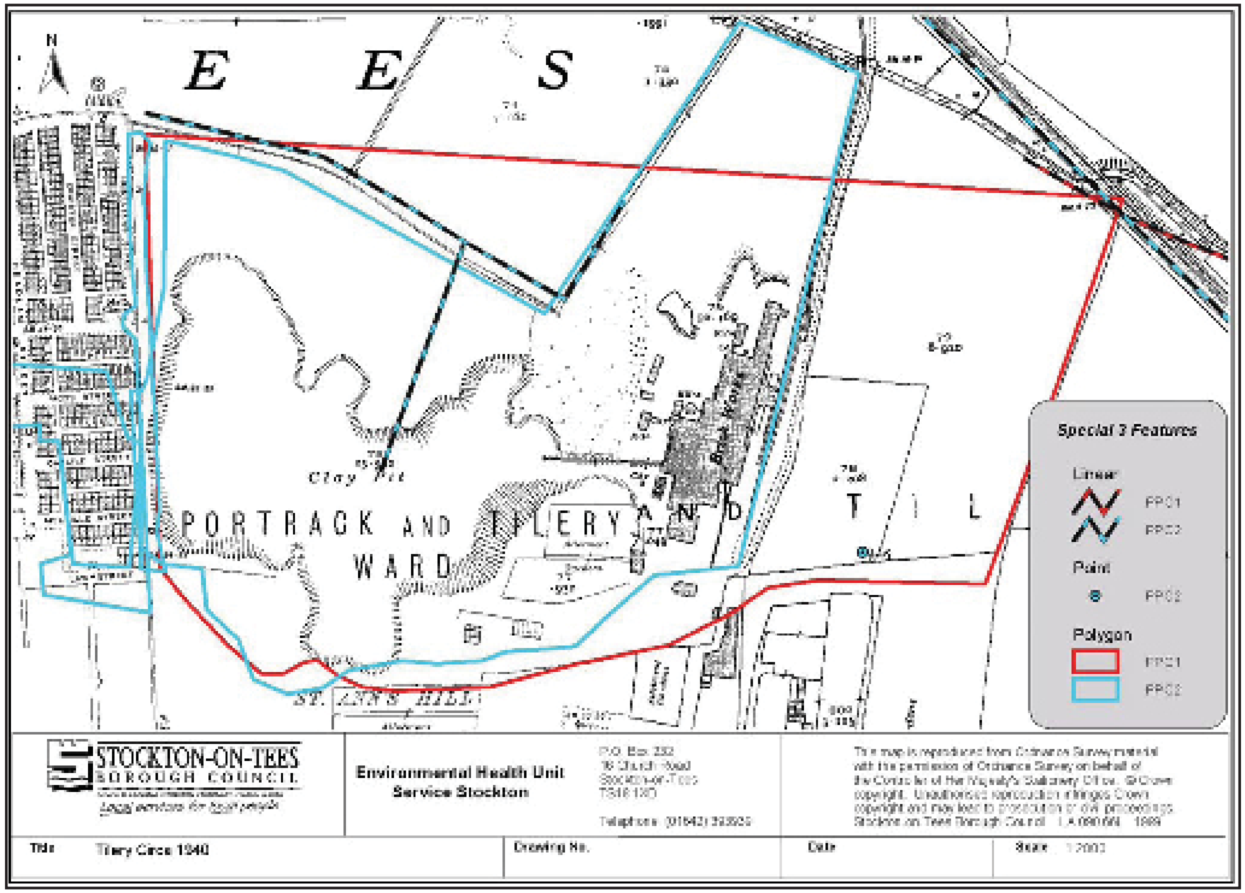
"We'd also probably bring this into the new ArcGIS 8.2 environment. The visualization capabilities within ArcGIS 3D Analyst are greatly improved," adds Thatcher. "We can do much better visualizations for potential investors including animated fly-throughs."

Although the Mayflower Mine project is on hold, DTM Consulting is far from idle. It continues to consult on other mining projects, but the DTM partners say that one of the most active and growing sectors of its Business is water resource management. The firm has been busy lately helping state regulatory agencies meet EPA mandates associated with the Clean Water Act.

(Reprinted from the Winter 2002/2003 issue of *ArcNews* magazine.)

Stockton-on-Tees, United Kingdom, Identifies and Remediates Potentially Contaminated Land With GIS

A mixture of busy town centers, urban residential areas, and picturesque villages, Stockton-on-Tees Borough Council (SoTBC) lies in northeastern England. It began as an Anglo-Saxon settlement close to the River Tees. In later times this area became the site of a Norman castle belonging to the Prince Bishops of Durham, and by the 17th century Stockton was established as the main port on the River Tees and had developed an important Baltic trade. It remained a largely agricultural district until the opening of the Stockton and Darlington Railway (the world's first public railway) in 1825, which brought about significant increases in the trade and population of Stockton. This began with the transport of lead from the dales and coal from local mines but later developed to the heavy industries that have left a considerable mark on the country today. These included mineral extraction, brick and tile manufacture, iron and steel manufacturing, shipbuilding, and engineering and chemical works.



Mapping capabilities include amalgamating historical land use maps such as this, circa 1940.

The Aftermath

As a result of this long and extensive industrial heritage, there is a considerable legacy of industrial and derelict land within the area. Today, the SoTBC covers 20,400 hectares with a population of approximately 180,000. Projects such as the £350 million Teesdale development have transformed large parts of the council area.

The United Kingdom government policy of limited greenfield site development requires that 60 percent of new urban development be carried out on brownfield (previously developed) sites. Consequently Section 57 of Part IIA of the Environmental Protection Act 1990 (known simply as Section 57) was enacted by the government. This act placed a duty on all British local authorities to take a leading role in managing historical land contamination within their area.

The legislation required strategy preparation, a strategic review of the entire SoTBC area to identify potentially contaminated areas, inspection of individual sites to assess risks, determination of contaminated land sites, and remediation of contaminated land. SoTBC adopted a progressive analysis-driven methodology to identify contaminated land.

Having considered a variety of options, and taking into account the requirements for a "traceable, rational, ordered, and efficient" process by which it could be demonstrated that all land was assessed in a consistent and repeatable manner, SoTBC decided that GIS was the ideal tool for the process. SoTBC assessed various options that were compatible with its corporate ArcView. Babtie Group was commissioned to work in partnership with SoTBC to implement a version of its contaminated land extension (known as Section 57 CoreTools). This methodology used more than 100 digital data sets split into three main groups:

- Areas with historical land uses that may have caused contamination. This would include heavy industries such as shipbuilding and petrochemicals, extractive industries, and any areas of landfill.
- Any potential pathways that may allow contaminants to travel between a contaminated site and a receptor. These typically include surface water, geological strata, and drift geology.
- Existing receptors, which would include anything that would be adversely affected by contaminants. This would not only include humans but also areas of environmental sensitivity.

The Section 57 CoreTools extension adopts established source–pathway–receptor risk assessment principles and applies them using the spatial analytical capabilities of GIS. The incorporated model is used to automatically assess these spatial relationships for the whole SoTBC area at one time.

The process automates the assessment methodology by customizing ArcView to provide a user-friendly application to implement the prioritization and risk assessment algorithms. In essence, the model outputs a risk ranked list of potentially contaminated areas to provide SoTBC with a rationale for focusing resources on detailed inspection of higher risk areas. Scores, or weightings, are assigned to potential sources according to their assessed "severity," pathways according to their likely "efficiency" in enabling contaminants to migrate, and receptors according to their "sensitivity."

These scores are then used in the risk assessment algorithm to derive an overall score for each potentially contaminated area. The scores themselves are not an absolute measure of the risk presented by an area and are intended merely to provide a measure of the relative risk to statutory receptors in comparison to other similar areas. The primary objective is to provide an internally consistent risk ranked list of potentially contaminated areas of land. This enables detailed inspections in a rational, ordered, and efficient manner, where areas with the highest likelihood of causing problems can be targeted first.

Steve Smith, environmental health officer of SoTBC, comments, "Given the complexity of the task, the need for transparency, and the number and variety of geodata sets involved in this project, it was clear that the use of GIS was essential, helping us meet these requirements in a highly effective manner."

Considering the large number and variety of geodata sets needed to fulfill the requirements of the risk assessment, robust data management was a fundamental part of the process. In recognizing this, the Section 57 CoreTools extension comprises

- ArcView tools (data management, modeling, mapping)
- Land quality management database (LQMD)
- First Metadatabase

Land Quality Management Database

After risk ranking the whole SoTBC area in a strategic and rational manner, the LQMD was implemented to record all relevant information relating to each potentially contaminated piece of land. The LQMD is populated with information about those areas that have the highest comparative potential to pollute. Since it is directly linked with ArcView shapefiles, the LQMD is an efficient extension to the data storage facilities of the GIS data sets. The reliable integration of ArcView and ODBC compliant databases provides users with a user-friendly map-based interface to their data, rather than their having to access it using less intuitive identifiers.

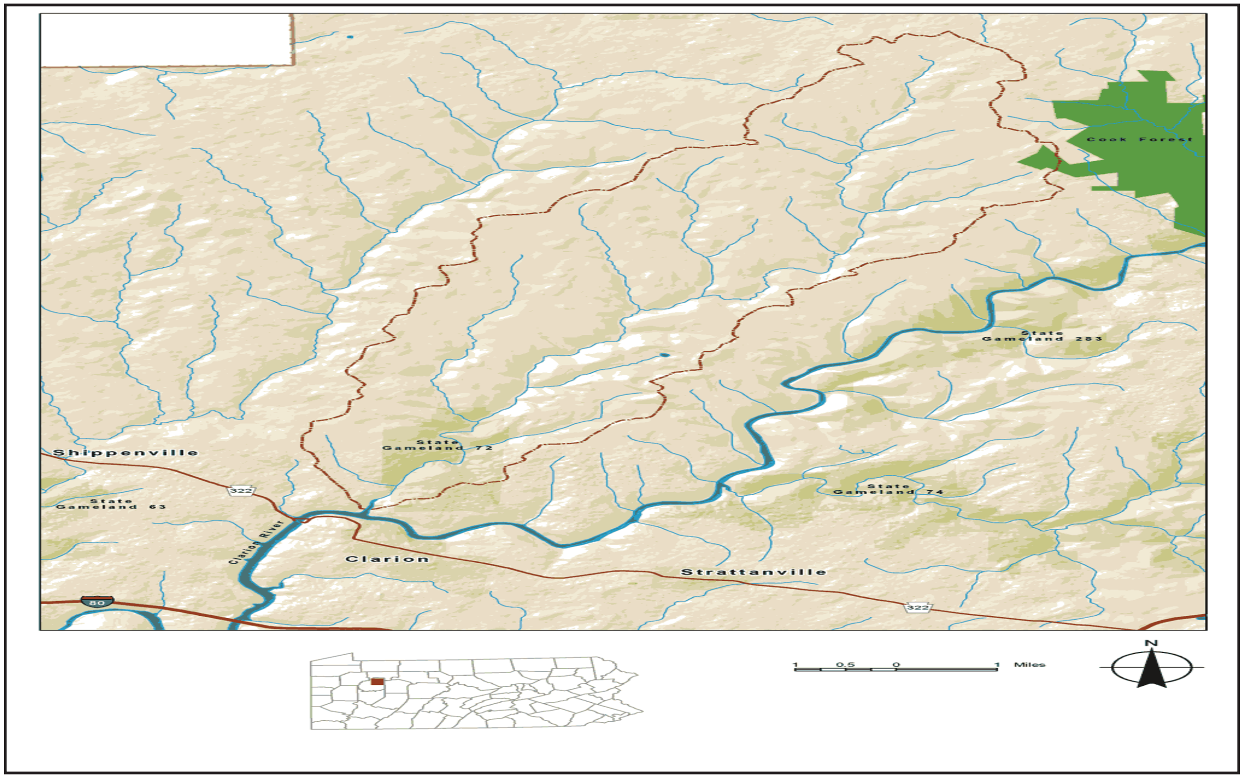
The LQMD stores a wide and diverse range of information relating to each area. A suite of spreadsheets, based on British Industry Profiles, provides a checklist for each contaminant that might be present for a particular industrial use and should be investigated. The LQMD allows nearly two dozen different types of information to be stored for each area—from agency forms to site investigation reports.

(Reprinted from the Summer 2004 issue of *ArcNews* magazine.)

Prioritizing Acid Mine Drainage Stream Remediation

By Yasser Ayad, Clarion University of Pennsylvania

Coal mining activities in the Clarion River basin, located in northwestern Pennsylvania, have left scars on the landscape and severely polluted many streams in the basin.



Streams are prioritized for remediation based on different combinations of acidity level and iron concentration.

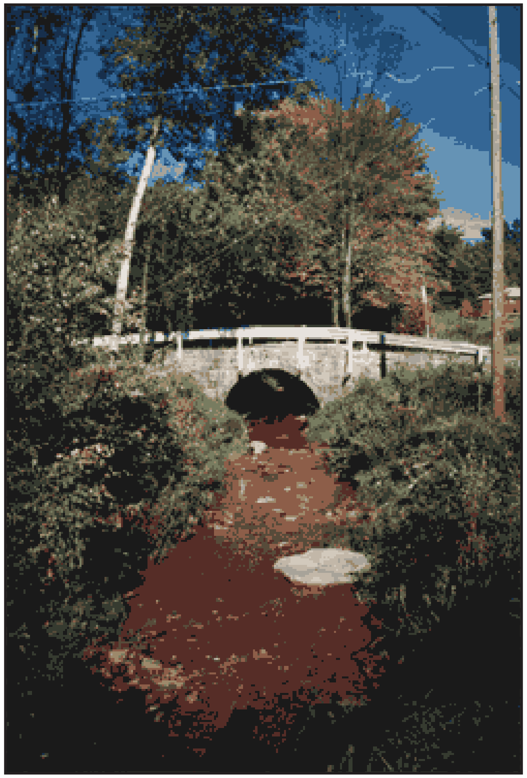
The area suffers from an environmental problem commonly associated with coal mining—acid mine drainage (AMD). Acid mine drainage results from the chemical reactions of sulfide minerals, principally pyrite. These minerals contain sulfur and iron and occur naturally in and around coal seams. When pyrite comes in contact with air and water, sulfuric acid, iron oxides, and hydroxides are produced. These pollutants are continuously released at surface mining sites that are exposed to rain and other surface water. In the Clarion River basin, tributary watersheds contribute approximately 72 tons of acid pollution each day.

The Toby Creek subbasin is one of the six polluted watersheds in the 200-square-mile Clarion River basin. Toby Creek rises in Farmington Township in northeastern Clarion County. It extends approximately 13 miles southwest and enters the Clarion River just north of the city of Clarion. Fed by many smaller tributaries, such as Engle Run, Little Toby, Step Creek, and Rapp Run, the 37-square-mile subbasin is long and narrow with an average width of 2.5 miles. It is characterized by steep hillsides and valleys in the south that give way to broad hilltop plateaus along the western perimeter and moderately rolling hills toward the north. Drainage patterns for the basin are typically dendritic (i.e., irregularly branching). The central portion of the basin is heavily vegetated with brush and forest. Strip mines and farms are located on the subbasin perimeter.

This watershed has been the subject of intensive mineral resource recovery operations since the early 1800s. These activities have included surface and underground extraction of bituminous coal and drilling for petroleum and natural gas. Portions of the watershed are affected by severe AMD that originates from several surface coal strip mines and a few abandoned deep shaft mines. Although mining activity ceased in the late 1930s, water quality problems persist to this day at several locations. Headwater stream reaches unaffected by mining activity have near-neutral pH and normal water quality characteristics that sustain modest populations of small native brook trout. The total absence of fish and other aquatic life in lower reaches of the stream is caused by the low pH values and very high iron and total dissolved solids content.

The stream remediation process needs to be organized based on stream location, pollutant levels, and contaminant concentrations. GIS provided a means for bringing spatial and informational data together to simplify prioritization of the stream remediation process. The outcome was a series of maps summarizing different stream conditions that suggested an intervention plan based on the concentration levels of stream pollutant factors.

For the project, a geographic database was built for streams that were sampled. Geographic database design was done using ArcGIS 8.3 and Microsoft Access. United States Geological Survey (USGS) topographic maps of the region were used as basemaps. The data collected from predefined locations included stream discharge; temperature; acidity level (pH); conductivity; and iron (Fe), sulfate, and nitrate concentrations.



The Toby Creek watershed shows the effects of pollution, particularly the high levels of iron concentrations on the surrounding vegetation.

Preliminary interpretation of the collected data showed interesting relationships to drought conditions, excess precipitation, and normal seasonal fluctuations in the water budget. In addition, the boundaries of Toby Creek watershed were queried and exported from a larger dataset downloaded from the Pennsylvania Spatial Data Access Web site. The resulting polygons were used to extract the study area from the datasets in the database. Hydrology maps were downloaded from the Geography Network Web site, clipped to the study area, compared with USGS topographic maps, and refined to fit the purposes of the study. Common stream data preparation operations, including checking the connectivity between line segments, adding missing streams, adjusting the stream lines to to fit the topographic map, and ensuring all datasets shared a common coordinate system, were performed. Finally, sampling points were interpolated to present the collected water samples on the prepared stream segments. Accordingly, water sample reading attributes were assigned to each stream segment using table joins.

Levels of acidity and iron concentration were classified as high, medium, or low. Because stream segments with high levels of both acidity and iron are extremely high priority sites for remediation, a subclass was created that combined iron concentration with pH classes. Another field for remediation class identification (class_id) was added to the streams attribute table for prioritizing segments using different levels of acidity and iron concentration classes. Using this method, four streams were ranked extremely high, six very high, and nine high for intervention.

In this study, GIS enabled researchers to prepare spatial information and join the field data collected to the streams attribute table. Querying each stream for different acidity levels and iron concentrations provided a simple and efficient method for selecting and categorizing stream segments that require immediate intervention. The resultant maps show the location and the type of pollution of different stream segments that are prioritized for future remediation or urgent action.

The development of a full watershed remediation plan should involve focusing on the details of implementing projects at identified sites, which might include considering the cost associated with different treatment methods, the effectiveness of each method for treating site conditions, and the presence of other elements and factors that might affect the water condition such as the direction of water discharge; rainfall; and aluminum, manganese, and sulfate concentrations. In addition, socioeconomic factors that impact local residents, landownership, and other legal aspects might be assessed in relation to a larger watershed remediation plan.

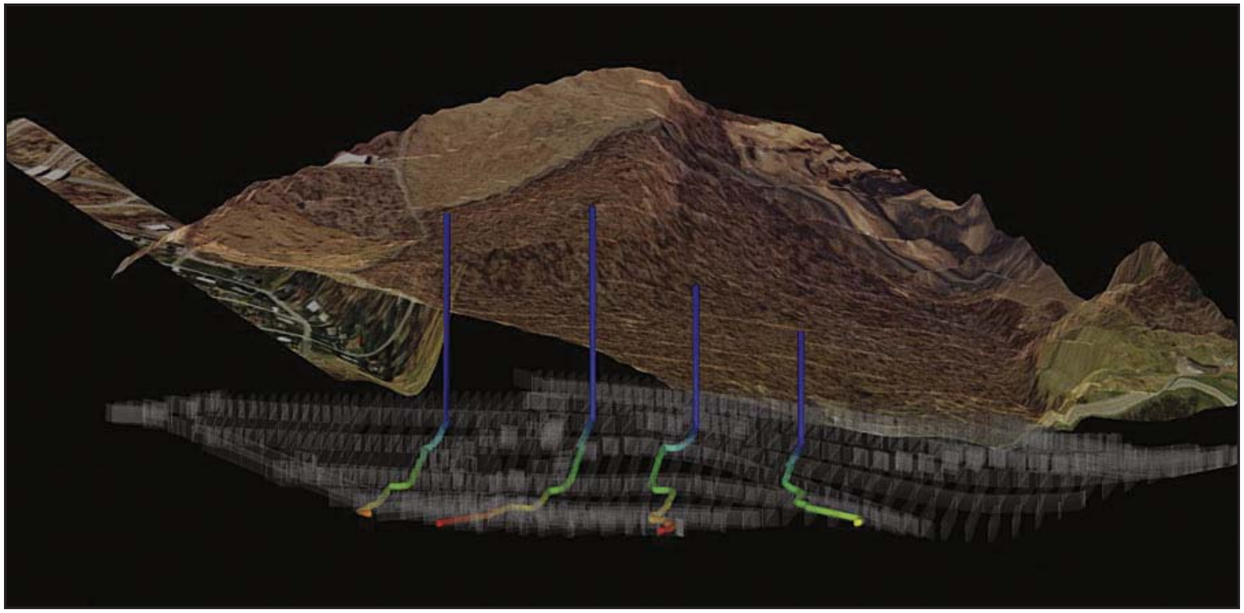
(Reprinted from the October–December 2004 issue of *ArcNews* magazine.)

In Maryland, Abandoned Coal Mine Stabilization Is Made Economical with GIS

Acid Mine Discharge Adversely Impacts Community Development

By Joseph F. Giacinto, ERM, Inc., Annapolis, Maryland

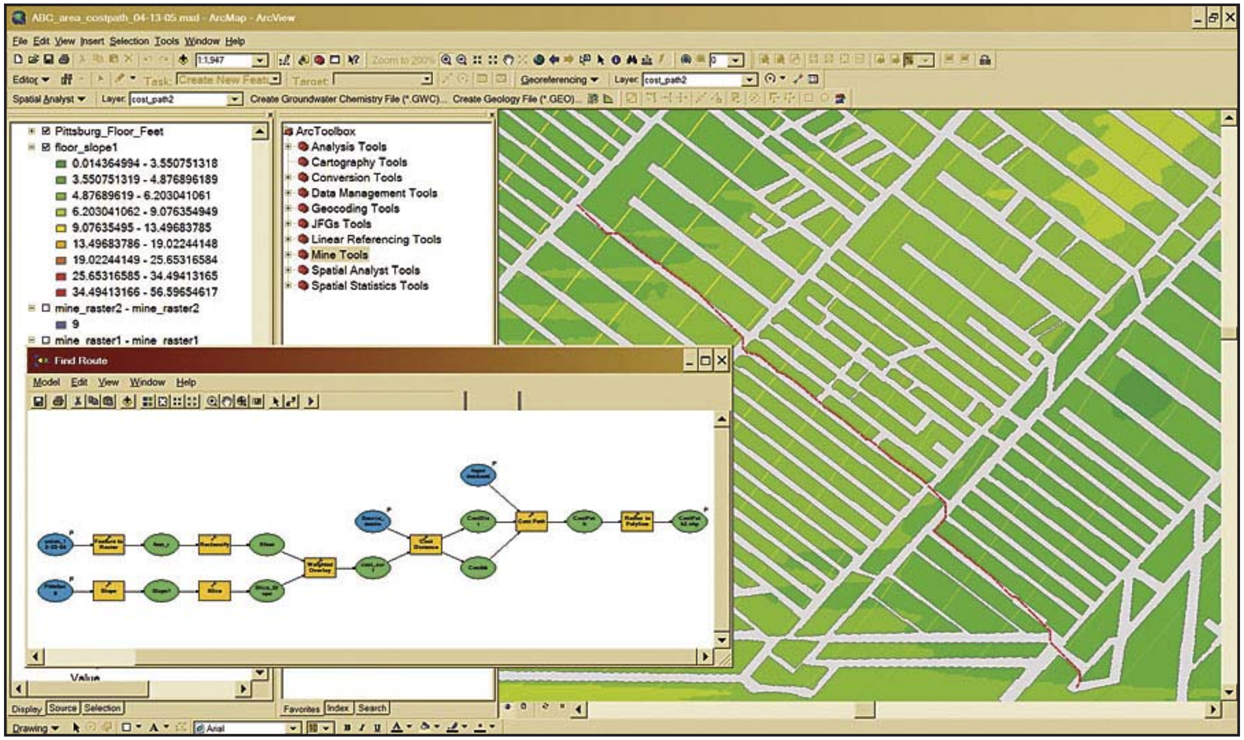
The Maryland Department of Natural Resources Power Plant Research Project (PPRP) was formed in 1971 to ensure that Maryland meets electricity demands at reasonable costs while protecting the state's valuable natural resources. A component of ensuring reasonable costs is the cost-efficient and environmentally friendly management of coal combustion by-products (CCPs) generated by coal-fired power plants in and around the state. As a legacy of coal mining, western Maryland is associated with detailed but often nongeoreferenced maps. The threat of land subsidence from mine tunnel (void) collapse and acid mine discharge (AMD) from these abandoned mines has adversely impacted development in and around increasingly sprawling communities.



Simulated grout movement through the mine tunnel voids starting from land surface to the lowest point in mine tunnels.

When mixed in the proper proportions with water, CCP grout is a viable and much cheaper alternative to conventional concrete and can be used to effectively fill abandoned mine voids and restore structural integrity to the subsurface, as well as mitigate AMD. The tunnel voids are filled by pumping CCP grout through boreholes that are drilled specifically to penetrate the mine voids. Therefore, an accurately georeferenced mine map for optimal borehole placement and spacing over mine voids is a prerequisite for efficient planning and implementation of mine void stabilization operations.

In western Maryland, pilot projects have been undertaken to demonstrate the effectiveness of CCP grouting in abandoned underground coal mines. The projects require georeferencing historic (circa early 1900s) mine maps typically available only in paper copies. From the initial work of scanning, digitizing, and georeferencing to production of the final maps and associated raster data, ArcGIS Desktop (ArcEditor) and ArcGIS Spatial Analyst are key components of the mine map and raster development process.



GIS environment for estimating grout flow through mine tunnel voids.

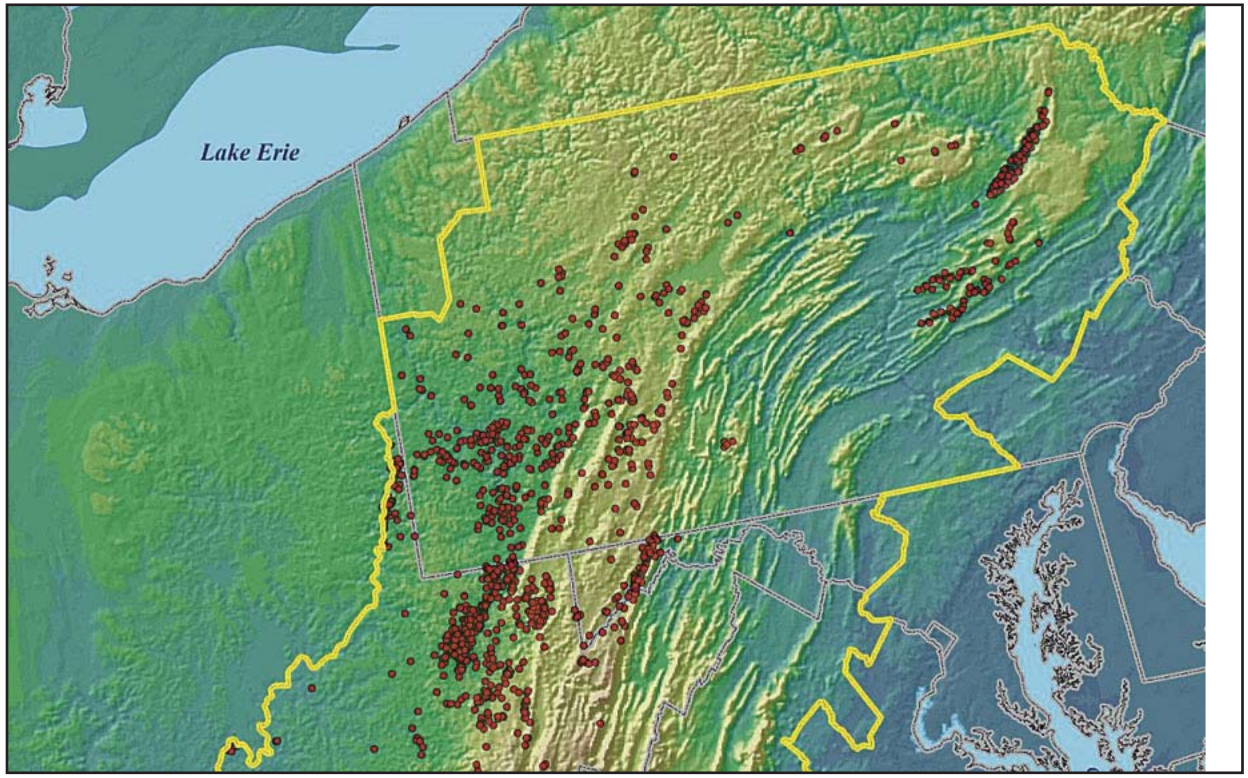
Although most of the old commercial mines were originally surveyed in a nongeoreferenced coordinate system, many of the survey reference points are inside inaccessible mines, and many former survey mine monuments have been destroyed or are overgrown. In these cases, field investigations using geophysical surveys and downhole video cameras to inspect borehole positioning with respect to tunnel voids may be required to adjust and translate the maps to a georeferenced coordinate system. A rotational adjustment to the maps is often necessary, as magnetic declinations depicted on old maps have changed since map production. Mine void grouting operations require a significant field effort of drilling anywhere from 50 to 100 or more boreholes to serve as grout conduits. The boreholes are relatively expensive to drill, and each borehole that does not hit a mine void must be redrilled. In addition to the requirements of an accurately georeferenced mine map, the internal mine geometry must be known, all shafts and entries must be located, and the regional hydrogeology must be understood before grouting operations can commence. The mine geometry includes parameters, such as mine floor elevation and slope, and the width, height, and direction of tunnels.

For developing mine floor elevation surfaces and slopes, ArcGIS Spatial Analyst is used in the associated raster development. Once the mine map and geometry (i.e., mine floor slope) is finalized, ArcGIS Spatial Analyst and ModelBuilder may be used to simulate the path of CCP grout through the tunnel network. This modeling becomes especially useful for planning field operations and optimizing grout injection points.

Developing and georeferencing the historical mine maps and associated data within ArcGIS involve an iterative multistep process. The initial step is to develop the maps based on the information available on the historical maps, the next step involves field surveys to uncover and survey any available mine monuments or reference points, and the final step involves integrating data from field surveys into the spatial adjustment of the mine maps.

With an extensive arsenal of ArcGIS tools and expertise, the Geospatial Research Group of Frostburg State University, Maryland, develops the mine map layers and provides iterative spatial adjustment and digitizing of the associated mine map layers for the western Maryland project areas.

A final refinement of the mine maps involves the integration of spatial data collected from field investigations. Under direction from PPRP, ESRI Business Partner Environmental Resources Management (ERM)—the environmental engineering integrator for PPRP—and the U.S. Department of Energy's National Energy Technology Laboratory have conducted field studies using equipment, such as video cameras inserted into exploratory boreholes that penetrate tunnel voids, and electromagnetic geophysical surveys to refine the georeferencing and mine geometry. Downhole cameras provide valuable insight into the exact position of the borehole with respect to a particular tunnel. Although dependent on subsurface conditions, electrical geophysical surveys may be particularly valuable in assessing the general accuracy of the tunnel system and configuration on the mine maps. These geophysical studies can generate multimillion-record databases that have typically been processed, analyzed, and displayed with the power of ArcGIS. Although the tunnel networks are shown on the historical mine maps, not all tunneling activity was recorded, particularly during the end of the mine life cycle. Therefore, field surveys and investigations are a vital component of confirming the tunnel configuration and mine geometry.



Abandoned underground mine lands in the Mid-Atlantic Highlands.

Once the mine maps are finalized, GIS can be used to create a grid of optimally spaced boreholes based on the mine floor slope (calculated with ArcGIS Spatial Analyst) and the flow (rheologic) distance characteristics of the CCP grout. The CCP grout can typically flow approximately 400 feet given a four- to seven-degree mine floor slope. Borehole locations determined in ArcGIS may be extracted and distributed to field crews for pinpointing drilling locations that will penetrate the mine tunnel network. Typically, a few exploratory boreholes will be drilled for iterative map adjustment prior to the drilling of the entire borehole grid.

Attributable in part to the efficiency of grouting operations, approximately 10 years after CCP mine void grouting, favorable results of the PPRP Winding Ridge (Frazee Mine) Project include a substantial reduction in acidity and harmful metals in the mine water with cured grout strengths equal to or greater than the typical surrounding rock. The fact that the grout maintained strength and low permeability demonstrated that CCP grout is adequate for controlling mine subsidence and mitigating AMD. The CCP grouting approach has the added benefit of reducing the stress on existing landfills to continually stockpile an ever-growing inventory of CCPs from coal-fired power plants.

While the Winding Ridge project demonstrated considerable success for one abandoned mine, abandoned subsurface mines number in the thousands across the Mid-Atlantic Highlands and are often overlaid by ever-expanding communities, towns, and cities. Emergency repairs to key community roads and buildings affected by mine void subsidence are an expensive proposition and may cripple a community disaster response plan. Using ArcGIS tools, many states in the Mid-Atlantic Highlands are developing coal mine mapping projects and repositories. The next step is to prioritize the risk associated with subsidence to key community infrastructures in a manner similar to the work done for interstate highways by the Federal Highway Administration (www.fhwa.dot.gov/engineering/geotech/hazards/mine/index.cfm). Once identified and prioritized, these risks can be mitigated with proactive measures, including the use of CCP grout, which has been demonstrated by PPRP to cost an average of 50 percent less than conventional concrete grouting applications.

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