

# Technical Review of the Ohio Abandoned Underground Mine Geographic Information System.

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May 8, 2008

## **Abstract**

The State of Ohio's Department of Natural Resources operates a public GIS database for the dissemination of abandoned mine data. This system allows users to assess mine geohazards which can affect property, environmental safety, and residential health. In addition to determining whether properties overly mined areas, users can retrieve highly-detailed maps to define precise passage and void locations. They can also study mineral and geological attribute data to estimate the relative strength and stability of individual mines. The design, implementation, and content of this system makes it stand out among its peers.

## **I. Introduction**

This paper investigates the Ohio Abandoned Underground Mine Locator GIS, or AUM GIS [1]. This GIS/IMS system is run by the State of Ohio's Department of Natural Resources and offers abandoned mine location and attribute data to the general public. It allows property owners, developers, researchers, and environmental scientists to estimate potential geohazards such as mine subsidence and flooding. Such hazards can affect property values, urban development, environmental contamination, and residential health and safety. In addition to determining whether properties overly mined areas, users can retrieve highly-detailed maps to define precise passage and void locations. They can also study mineral and geological attribute data to estimate the relative strength and stability of individual mines.

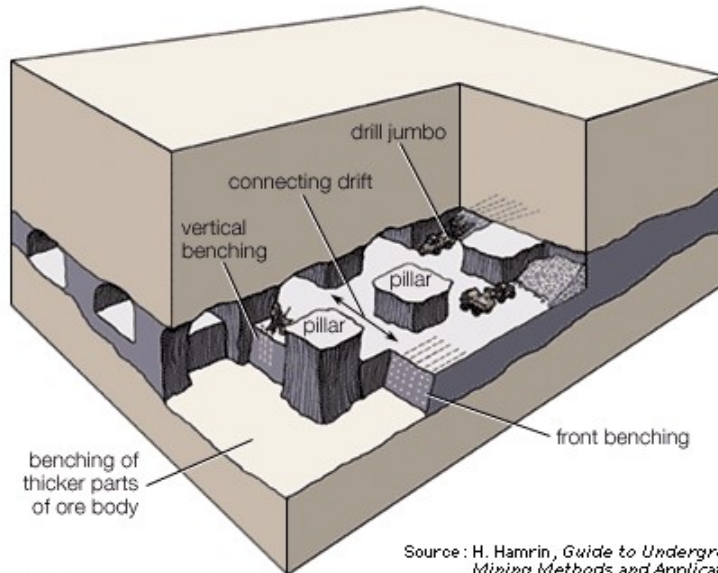
This system is interesting since it is one of few public-accessibly GIS mine databases, and offers some features not found in other such systems. In many other areas, locating subterranean geohazards involves painstaking archival research through many different sources, and requires experience with different types of maps, surveying methods, and geological data. Often, the final product from such studies is available only to a single organization, or may not meet the needs of other users. When government agencies release abandoned mine data, is it often incomplete, or in a format that is not immediately usable by the general public. While single-source collections such as Ohio's mine GIS may not catalog all existing sites, they provide a much simpler and more immediate overview of an area's situation for a much wider range of users.

## **II. Hazards associated with Abandoned Mines**

### **II.a. Geologic Hazards**

The most common problems associated with abandoned mines are collapse (where sinkholes or depressions form at surface points), and subsidence (where large areas of land drop in elevation due to the removal of an entire geological level). Soft-rock mines such as coal, clay, or gypsum are especially prone to collapse, due in part to the extraction methods used, and partly due to the weaker structure and water-solubility of softer minerals.

A common soft-rock mining technique is “room-and-pillar”, which leave columns of ore in place to support chamber ceilings. If these pillars erode or are later mined for the leftover ore (a process known as “Pillar Robbing”), the chambers can become unstable. In longwall mining, no roof support is provided, and mined-out areas are allowed to collapse. In both cases, these collapses can migrate upwards to the surface, forming depressions, sinkholes, or large areas of lowered surface elevation.



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Source: H. Hamrin, *Guide to Underground Mining Methods and Applications* (Stockholm: Atlas Copco, 1980)

*Figure 1: Room and Pillar mining (source: Encyclopedia Britannica online)*

Subsidence and collapse can also occur in hard-rock mines, or in mines penetrating geological formations of variable density and adhesion (such as sandstone, limestone, or shale). Precious-metals mines are often worked by the stoping method, which leaves large unsupported caverns below the surface. Stopes can later collapse into sinkholes or “Glory Holes”. In 1917 the Treadwell Mine underneath Gastineau Channel, Alaska, was destroyed by just such an event. Erosion and nearby blasting caused stope collapse to reach the seabed, flooding active workings [2].



*Figure 2: Wide-area subsidence and resulting new water bodies (source: Geological Survey of Ireland)*



*Figure 3: Mine collapse (source: National Geodetic Survey)*

In regions with histories of underground mining, geologic hazards are of huge interest to many different groups. Collapses and sinkholes can damage roads and buildings, break utility lines, alter stream flows, and cause subsidiary damage from cracked pipelines, sewers, and storage tanks. When urban sprawl intersects areas of historic mining, homes and businesses become endangered by the possibility of property damage. This can result in lower property values, higher insurance rates, and other problems [3].

Property developers must take care to avoid building above mine voids, or must use remediating measures such as backfilling. In St. Paul, Minnesota, redevelopment plans for a closing vehicle factory must consider historic silica sandstone mines beneath the property [4]. The nearby city of Minneapolis has a history of sandstone tunnel collapse. Several accidents in the late 19<sup>th</sup> century damaged roads and destroyed grain mills in the center of the downtown industrial district. [5], [6].

Shafts and raises create point hazards for collapse. Prior to standardized safety regulations, shafts were sealed by placing anything from boards to old bedframes across the tops, and then covering these with dirt. If something causes coverings to decay or break, the shaft can become a deadly trap. In 1981, a boy walking through a backyard in Centralia, PA nearly fell into a shaft which suddenly opened beneath him [7].



*Figure 4: Point-source collapse of abandoned shaft (source: State of Montana).*

## **II.b Environmental Hazards**

Abandoned mines below local water tables often flood once pumping systems have been shut down. This can cause decay of internal roof supports, as mentioned in the previous section. Especially hazardous are water-soluble minerals, which flooding can rapidly dissolve. Salt mines span 1,500 acres beneath residential and industrial areas of Detroit, Michigan, and are well below lake level. During a temporary closure from 1983 to 1997, these mines suffered groundwater leaks through abandoned shafts. As noted by Professor Nasim Uddin, “Long term seepage into the closed mine could result in solution of the salt and progressive collapse, potentially to the surface.” [8].

A rare, but very dangerous environmental hazard of abandoned mines is that of underground fires. In Centralia, Pennsylvania, an outdoor fire near an exposed coal seam spread into underground

tunnels. Gas and fumes from the fire, as well as ground subsidence and collapses caused the town of Centralia to be destroyed. Despite attempts to control the fire, these workings have been burning continuously since 1962 [7].

Other mines can suffer from hazardous fires as well. Gas and fumes from underground fires can seep into surface structures or become trapped in confined spaces underground. In 2004, several teenagers died from smoke and carbon monoxide poisoning in an abandoned Silica mine in St. Paul Minnesota [9].

Another major hazard of abandoned mines involves environmental contamination. Chemicals used in or produced as a byproduct of the mineral extraction process can include arsenic, cyanide, heavy metals, and other toxins. Water flowing through abandoned mines can carry these chemicals into the local water table, out into surface streams, or into the municipal water supply of nearby communities [10].

### **II.c Other Hazards**

Disastrous flooding can occur in active mines when water-filled abandoned workings are breached by new tunnels. If the locations of old mines are not well known, newer workings can suddenly tap into underground lakes, as happened in the Quecreek Mine in 2002 and at the Barbara coal mine in 2000, both in Pennsylvania [11]. In such cases, the pressure behind drill holes can mimic a water cannon, injuring or killing workers, scouring out walls and ceiling supports, and destroying power and communications systems within the active mines. In the 2002 Quecreek disaster, nine workers were trapped by flooding for three days [12].

On a smaller scale, urban-area mines can cause problems when intercepted by utility projects or other underground construction. In cities such as Bellingham, Washington, where abandoned tunnels exist close to the surface in the central business district, the construction of underground structures can be very challenging [13].

## **III. End-use applications of mine mapping.**

### **III.a Generalized risk assessment**

Analysis of abandoned mine geohazards can be categorized loosely into two approaches. The generalized approach combines attribute data into an overall estimate of regional hazards. Neighborhoods, parcels, or other geographic areas can be classified as having various degrees of risk, such as “high, moderate, low”, based on the depth, type, age, and geology of mines known to exist in those areas. This type of assessment is relatively inexpensive and can be done largely without field work. The drawback is that this gives only a general idea of the potential risk involved with a given location. The accuracy and usefulness of the assessment also depends on the quality of information available, and the mathematical models used to quantify and integrate the information [14].

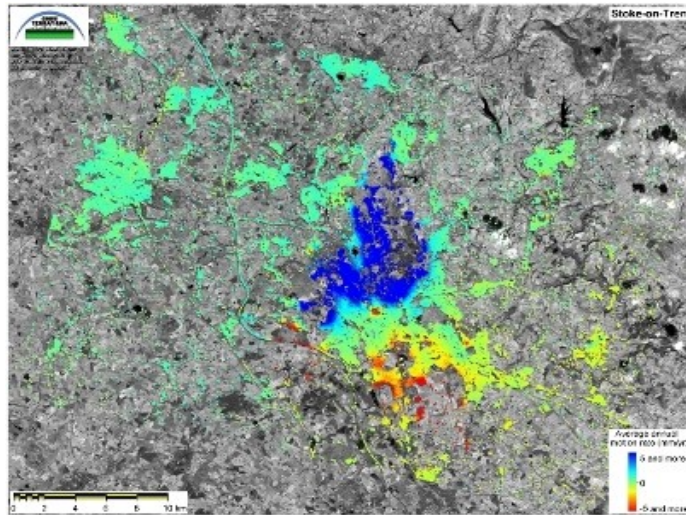


Figure 5: Generalized subsidence risk assesment (source: Geological Society of the UK)

### III.b Precision Risk assessment

A precision risk assesment can provide a more detailed and accurate estimation of risk for specific properties or structures. By providing digitized location data of mine passages and voids, researchers can determine exactly what underlies surface locations. Existing maps can be supplemented with field research, as discussed later.

Precision mapping is especially important for active mines which may intersect flooded workings. In these cases, the best map of an abandoned mine would be a three-dimensional rendering of its layout and structure. Companies such as DTM Consulting have successffully used combinations of Computer-Aided Design and GIS software to produce such 3D mine models [15].

Environmental assessments of pollution potential may require mine maps at a level of detail high enough to determine grade and slope of passages. This can allow derivation of a flow model for water entering and traveling through underground routes. Such flow networks can also be used in remediation efforts, to model the spread of sealant material pumped into underground chambers, and to plot the most effective distribution of injection points for sealant such as concrete or grout [16].

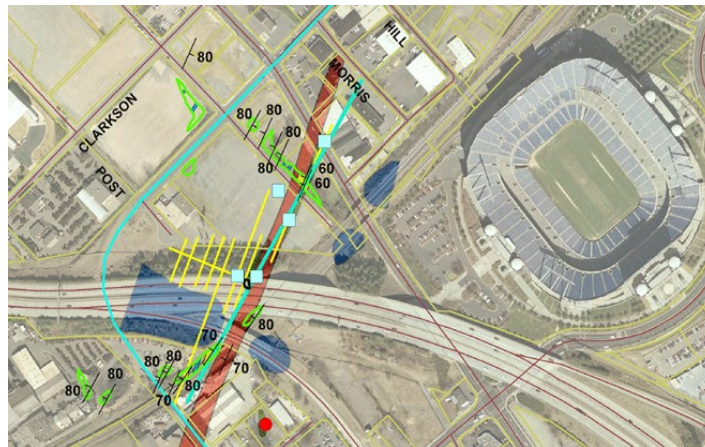


Figure 6: Site-specific precision hazard analysis (source: South Carolina Geological Survey)

#### IV. Importance of data availability

When researching abandoned mines, it is vital to know not only where underground voids may exist, but also what types of mines, minerals, and other underground features populate an area. A comprehensive analysis of potential geohazards must take into account many different subsurface conditions. The preliminary research for a mine GIS system must consider which attributes of mine objects will be important, both for the current users and for future users. At the very least, data modeling should be performed to map attributes of mineral types, mining methods, depth and elevation, and other geologic data for the extent of each mine.

From the geologic formation and the type of minerals extracted, researchers can estimate void wall composition and strength. Softer minerals can mean weaker tunnels. Hydrogeology and seismic history can be used to infer sources of support failure. The geological layers above a mine can be used to estimate upwards collapse migration and the probability of sinkhole formation.

The extraction method used in the mine is also an important detail. Maze-style or room and pillar mines are structurally stronger than longwall mines or chamber mines supported by wooden timbers. Mining techniques can also tell researchers what sorts of chemicals may have been used in the process, and what the potential for environmental contamination may be.

The depth of mine voids and passages can indicate where tunnels exist in relation to the local water table, how deep passages lie below the surface, and what geological layers the mines penetrate. Even if the majority of a mine was developed in stable rock, entry portals and shafts passing through glacial till, overburden, or shale may be less stable and more prone to collapse (see fig. 7). In addition to being less stable, flooded mines can release pollutants into local aquifers.

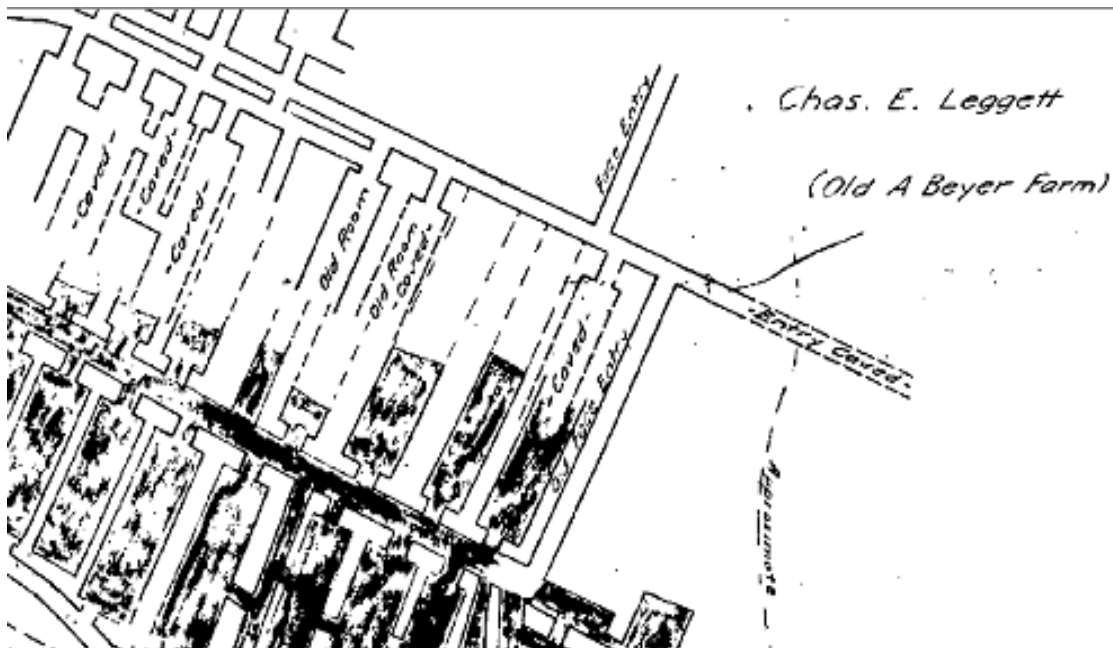


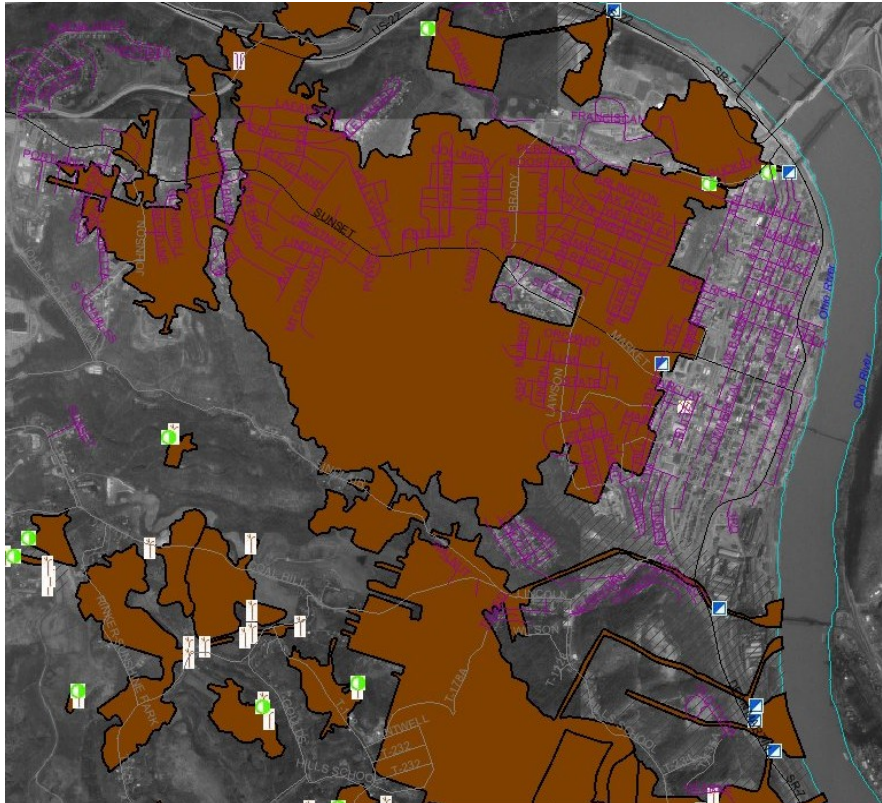
Figure 7: Detail of abandoned mine showing collapsed entrance tunnels and interior areas. [1]

#### V. Overview of Ohio Mine GIS system

The need for a centralized mine map repository was recognized in the late 1800s in Ohio, and in 1874 the state began requiring mine operators to submit copies of their maps. During the 1960s and 70s, the Ohio Division of Geological Survey and the Department of Industrial Relations began producing paper and microfilm copies of these archived maps for use by interested parties. Further

standardization and centralized filing took place in the 1980s.

In 1995 and 1996, the Ohio DNR began digitizing mine data in ArcGIS format, including entrance point locations and extent polygons (fig. 8), based on the standardized Abandoned Underground Mine maps produced in earlier years. These collections were further updated, improved, and checked against physical maps in 2002, and additional maps were scanned, georeferenced, and digitized from 2002 to the present. The initial GIS shapefiles were available to state agencies such as the Department of Transportation, which deals with mine subsidence under highways. The Ohio DOT also assisted in development, and contracted for detailed georeferenced source maps. In 2004 a selection of this AUM GIS data was made available to the public via an ArcIMS Internet portal. Ohio's DNR continues to solicit many different organizations and groups for additions to the database [17], [18].



*Figure 8: The multiple large mines underlying this Ohio city illustrate the need for an effective mapping system.*

## **V.a Technical Implementation**

The server-side data used by the Ohio AUM GIS was originally stored in a personal geodatabase, but has since been migrated to a multi-user geodatabase. The system uses ArcSDE as an access layer into a relational database running in SQL Server. This allows fast translation between the spatial logic used by ArcGIS and the relational logic used by SQL. The database integrates tabular dBase files containing information such as corporate and historical mine ownership, mineral extraction, geological identifiers, and local government jurisdictions. Shapefiles include mine extent polygons, centerlines, roads and boundaries, and shaft/adit points. Raster data includes topographic quadrangle maps and georeferenced subsurface maps. Associated non spatial data includes images of mine entrances, interior conditions, pollution or subsidence damage, and remediation projects. Much of the initial development and data-entry for this project was done by independent contractors, but later

updates and new data are added by various government agencies [19].

The data model implemented by the AUM GIS is shown in Figure 9 below. Base maps such as topographic quads, political boundaries, and roads are stored as a separate set of feature and attribute tables. Mine data is stored in a set of relational tables where openings, extents, and other mine-related objects are linked to unique identifier keys for each mine. Mines are linked to tables indicating their location within various political units (townships, counties, etc), and their location within a particular coal seam. This last piece of data is linked to a set of Overburden tables, which store details of non-commodity material overlying mineral deposits. Such information is of use for current and future mining [20].



# AUM System & Overburden Application Data Model

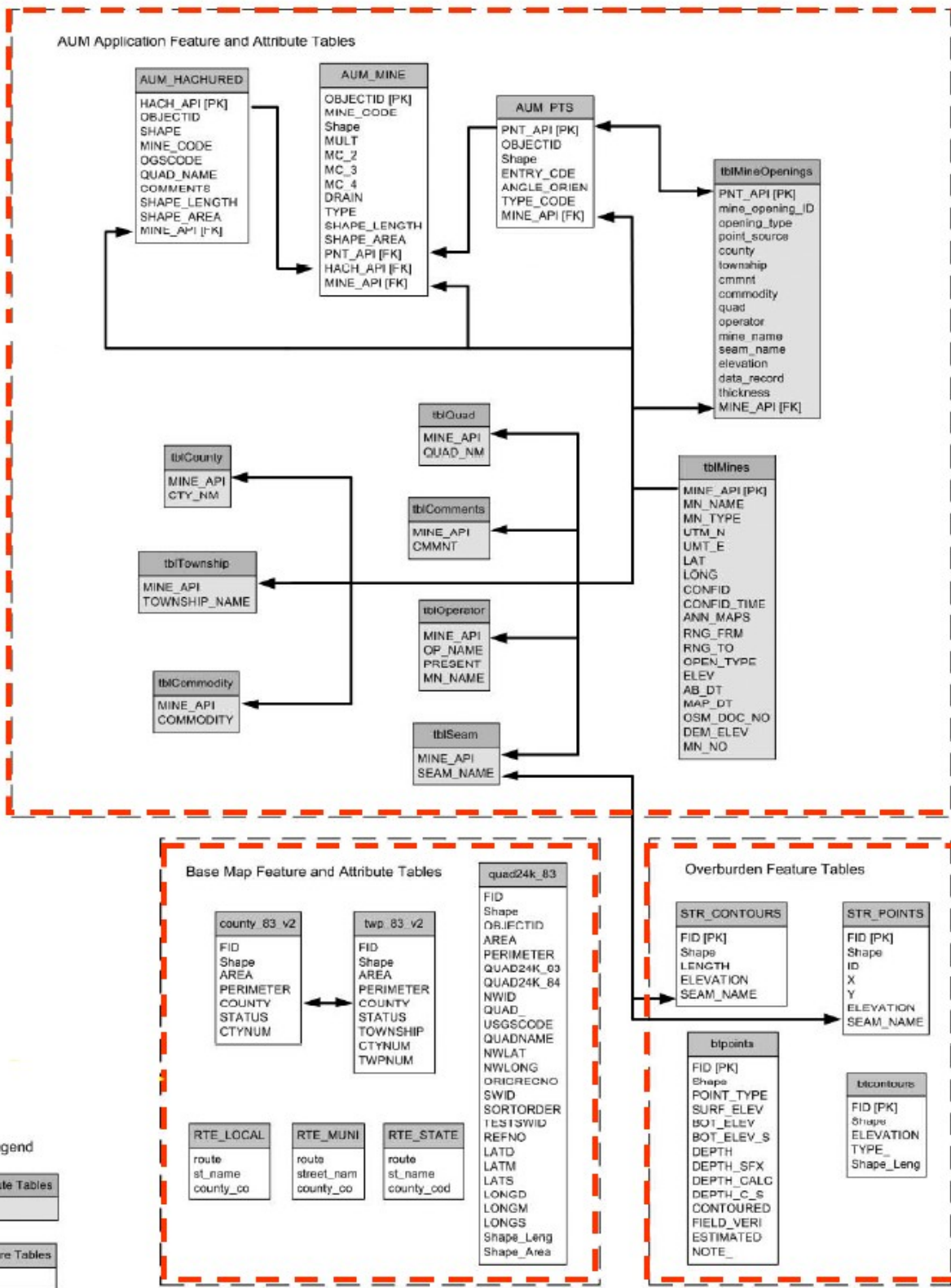


Figure 9: Ohio AUM data model [20].

The Ohio AUM GIS uses customizable ESRI input forms to add items into the database. Mine attributes can be entered singly through an interactive form, which allows editing and adding multiple attribute values to each item. Mines can be assigned to known political units or topographic quadrangles through a selection box. A custom overburden analysis tool allows plotting of mine and mineral seam depth as related to DEM elevation, bedrock elevation, and other geological layers. [21], [22].

### **V.b Applicability**

While initially developed with the goal of mapping mine and highway relationships, the Ohio AUM GIS has much wider-ranging potential uses. As previously mentioned, mapping mine locations and describing mine attributes below properties and surface structures is one of the biggest uses for such systems. Other uses include pollution investigation and remediation, surface-contour change study, and water network flows. Economic uses include calculation of insurance premiums and claims, estimates for governmental assistance funding, and penalties or fines assessed against mining companies for damages caused by their operations.

### **V.c Typical Users**

The primary user of this system is the Ohio Mine Subsidence Insurance Underwriters Association (OMSIUA). This state-established association controls mine subsidence insurance premiums and claims payments from member companies. The organization helps insurers properly manage and publicize such coverage, and keeps staff members trained to deal with mine-related claims.

Other users include the Ohio Department of Transportation, which deals with mine subsidence affecting state highways and roads. As an initial partner in field mapping and development of the GIS data, the ODOT uses detailed georeferenced maps as a resource for maintaining, repairing, and performing preventative actions on roads underlain by mine voids

Other users include individual insurance agencies within the state of Ohio, environmental agencies and nonprofit groups, property developers and construction companies, as well as the general public [19].

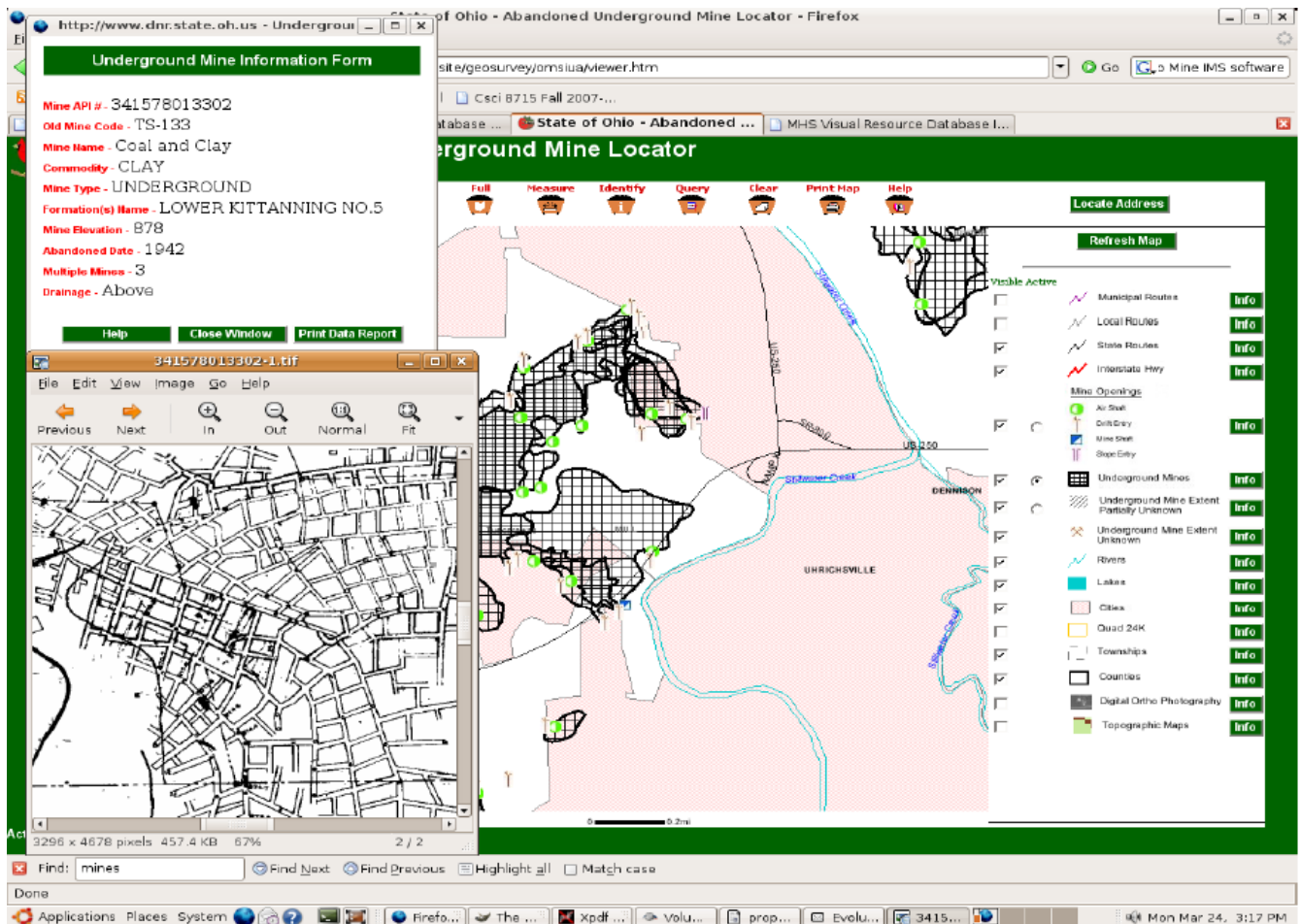


Figure 10: Ohio AUM GIS with spatial query results and detail map of selected mine.

### V.d Areas for improvement

Ohio's AUM GIS has several areas where potential changes or additions could improve the overall usability or effectiveness of the system. These include the user interface, compatibility, and data sources.

Currently the user interface for the Underground Mine locator is tailored to users seeking specific location data. The "Locate Address" tool is prominent while other standard GIS tools are less obviously present. The query interface uses a different input form than that commonly used in IMS pages, and while more user-friendly than a raw SQL input, is also less complete and offers only a few table columns to search. This somewhat limits the utility of the system for the average member of the public. Fortunately, the Department of Natural Resources also offers a direct server connection for users of ESRI ArcGIS software, from which more powerful standard query and spatial logic operations can be performed in a desktop environment [22].

The Ohio DNR Geological Survey is currently working to upgrade the user interface and appearance of the online Mine Map locator web service. The new design will be closer in appearance and dynamic scripting functionality to standard ArcIMS interfaces, as used by other Ohio DNR interactive web maps [19].

Currently the online mine locator fails to function with certain types of browser and operating system combinations, especially Linux and Unix-based systems running Firefox or Mozilla browsers. This appears to be due in large part to the custom query and attribute retrieval interfaces, and the way in which mine-map TIFF files are usually output through a viewer plugin. While some of these issues

can be avoided with careful end-user choices of software and file type associations, it would benefit the developers to improve cross-platform functionality for a wider user base.

One of the biggest pitfalls of GIS databases is the potential for end-user complacency. If the GIS system does not show mine features in a given area, it is easy to assume that no such features exist. However, such an assumption can be dangerously inaccurate in some cases. Mines that predate mandated map archival or even predate organized mapping may not be known to the persons entering data. Unmapped passages can exist outside the known boundaries of a mine, and the subsurface conditions represented by the most recent data may not indicate actual conditions at the time of mine closure.

To deal with these potential gaps in real-world knowledge, GIS data can be augmented with field data from a number of different sources. On-site investigation can be carried out by human investigators, but this is not always safe or even possible. Boreholes and remote cameras can provide limited data for specific sites in a mine, but the technique is expensive. Likewise, robotic investigation is slow, expensive, and at present, limited to the tether or communications range of the robots [23]

Remote sensing offers some promising additions to ground-based mine mapping data. Ground-penetrating radar can detect and measure voids beneath the surface, but further development is needed to increase depth and detection sensitivity. Mine shafts and entrances can sometimes be detected through thermal imaging, as subsurface air remains at a fairly constant temperature year-round. In regions such as Centralia, the extent of underground fires can also be tracked by aerial infrared imaging [24].

As with any map or GIS system, underground mine mapping applications can only represent reality based on the data available. While remote sensing, field investigations, and exhaustive research can help make these representations as accurate as possible, users must still be made aware that true real-world conditions may not always meet their expectations.

## **V. Alternative solutions**

A comprehensive geographic information system dedicated to detailed mine data collection and distribution is not always necessary for all applications. In some cases, simpler or older methods can suffice.

As mentioned previously, a common way to store and display mine geohazard data is in a pre-aggregated generalized map of hazard zones. Another common non-GIS representation scheme is non-georeferenced overlay mapping. Simply combining a mine layout with a surface map may be enough to show approximate tunnel locations.

Collections of original source data can be of use for any of these alternative solutions, as well as providing a reliability check on the data available in GIS systems. By offering source maps in local or centralized repositories, government agencies can rely on investigators to produce their own evaluations of available data without having to develop derivative data sets of their own. Such repositories can also allow GIS users to check the accuracy and validity of data. In the US, the National Mine Map repository offers original or duplicate source maps for public review. They also perform on-demand analysis and risk assessments based on collected materials [25].

### **V.a Comparison to other systems**

The popularity of online GIS for delivering mine data to the public has grown in the past decade. Previously, mine maps were available mainly in printed form, if available to the public at all. GIS databases, when developed, were largely intended for internal government use. Some of these internal data sets have now been released to the public as individual layers or within online viewing applications. In some cases these online data portals are general-purpose repositories for statewide data, and in other cases they are mine-specific.

Kentucky is one state which has embraced GIS to the same or greater degree as Ohio. Through the Kentucky Mine Mapping Initiative, all coal mines maps are being archived digitally and provided to the public through ESRI ArcIMS portals. Kentucky's Office of Mine Safety and Licensing performs much the same data input process as Ohio's DNR, scanning, georeferencing, vectorizing, and storing attribute data for historic maps. These maps are provided for much the same reasons as they are in Ohio; users can estimate subsidence geohazards and environmental risks, and mining companies can protect their workers by having access to maps of abandoned workings through a central source [26].

West Virginia is another state which uses GIS to organize abandoned coal mine data and maps. While detailed maps of individual mines are not currently available to the general public, the data that is available has been distributed in a wider variety of formats (including Google Earth files). As West Virginia has a large amount of coal mine data, some degree of automation and scripting was used to input maps and assign attribute variables to objects [27]

Jasper County, Missouri, is one of the few entities providing online maps of non-coal mines. In this region, major mineral production focused on Lead and Zinc. While the data is not as comprehensive as other systems, Internet users can superimpose scanned map images onto parcel and street vectors, as well as aerial photos, offering a generalized overview of geographic mine distribution [28].

The state of Iowa develops and publishes mine data including coal mine extent polygons and mine entrance point vectors. Development of the data sets was done similarly to Ohio, where map plots from pre-GIS compilations were digitized and vectorized. While the data is primarily intended for internal users, the shapefiles are available for download by the general public. Currently no online interface is offered, and users are expected to have their own GIS packages to work with files. The state intends to offer a web-accessible and searchable interface for these data collections in the future [29].

One advantage of the Ohio AUM GIS over other systems is its inclusion of non-coal mines in the database. Most other states and agencies offering underground mine data have focused on coal, especially in the Eastern United States where coal mining has caused widespread damage. The inclusion of non-coal data in Ohio's system means that this GIS can be used for other investigations and future studies not anticipated by coal-only systems.

The non-standard interface used by the Ohio DNR is a significant drawback for users unfamiliar with the system. Compared to other GIS web services, there may be a steeper learning curve before users can begin to extract useful data. The poor compatibility with non-windows systems may also be a detriment to widespread accessibility.

The simple fact that Ohio provides its mine data in GIS form rather than non-georeferenced or printed format easily lets it stand out from older approaches. The benefits of GIS for as-needed data analysis and output are easy to see. By giving Internet visitors an immediately accessible online interface to the data, as well as an Arc server interface, Ohio's system contains the best of both worlds for online data browsing and desktop data analysis.

## **VI. Conclusion**

GIS is an undeniably valuable addition to many different fields of work and study. The potential for such systems in subsurface geohazard analysis can be seen in the recent widespread adoption by regions with a history of underground mining issues. While some of the earliest adopters of GIS for underground mines have been coal-mining states in the Eastern US, Ohio has shown that an AUM GIS need not be limited to a specific mineral, end-use, or user base. The level of detail offered to the public by the State of Ohio will likely prove inspirational for other states and governments as new applications and users become apparent. While it stands to benefit from improvements in usability and completeness, the Ohio Underground Mine Locator stands out as a landmark in the field of subsurface GIS development.

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