

PS New Data and Techniques for Evaluating Subsidence from Abandoned Underground Mines in Ohio*

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Abstract

Subsidence due to the collapse of abandoned underground mines is a geologic hazard that can affect buildings, highways, and infrastructure, potentially endangering lives and property. Further, damages from mine subsidence can cost millions of dollars. Between 2008 and 2011, the Ohio Department of Natural Resources (ODNR), Division of Mineral Resources Management invested more than \$2.4 million to complete 87 projects related to abandoned underground mines. The costs of mine subsidence are expected to rise as abandoned underground mines age and deteriorate and as further development occurs across the Ohio landscape.

The ODNR Division of Geological Survey (the Survey) has been responsible for mapping the locations of abandoned underground mines since 1977. The mapping process involves creating and managing a GIS of abandoned underground mines in Ohio. A recently developed custom GIS application allows Survey staff geologists to quickly gather any geologic data on file at the Survey that is relevant to a subsidence complaint. Once the information has been gathered into the GIS, a geologist writes a report summarizing the data and noting critical information. The report is submitted to either the Division of Mineral Resources Management or a consulting engineering company assigned to the complaint for further evaluation, site inspection, and potential remediation. The GIS software application provides easy access to digital geologic information for evaluation and potential property remediation.

New datasets also are being developed as part of the ongoing mapping program. The Survey is the archive for all final abandonment mine maps, which are scanned at a high resolution and georeferenced to existing ground control. Using georeferenced mine maps, the elevation, thickness, and information on the condition of each mine is captured into the GIS. These datasets, in addition to new statewide LiDAR and other digital geologic datasets, are used to identify areas at high risk due to mine subsidence. Variables analyzed as part of this study include age of a mine, depth to a mine, amount of unconsolidated overburden, and roof rock lithology. The new datasets will provide a better understanding on the variables controlling mine subsidence from abandoned mines.

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ABSTRACT

Subsidence due to the collapse of abandoned underground mines is a geologic hazard that can affect buildings, highways, and infrastructure, potentially endangering lives and property. Further, damages from mine subsidence can cost millions of dollars. Between 2008 and 2011, the Ohio Department of Natural Resources (ODNR), Division of Mineral Resources Management invested more than \$2.4 million to complete 87 projects related to abandoned underground mines. The costs of mine subsidence are expected to rise as abandoned underground mines age and deteriorate and as further development occurs across the Ohio landscape.

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INTRODUCTION

Underground mining for coal in Ohio was first reported in 1800 (Crowell, 1995). The majority of the underground mining takes place in coal- and clay-mining areas of eastern and southern Ohio (fig. 1). Other commodities have been mined underground within Ohio, including salt, gypsum, limestone, shale, and even peat. Geologists have estimated that over 8,000 mines have been in operation over the last 200 years (DeLong, 1988). With such a large number of mines being developed over a long period of time, there is an increasing probability that mines will collapse and subside as they age and deteriorate and as development occurs across the Ohio landscape.

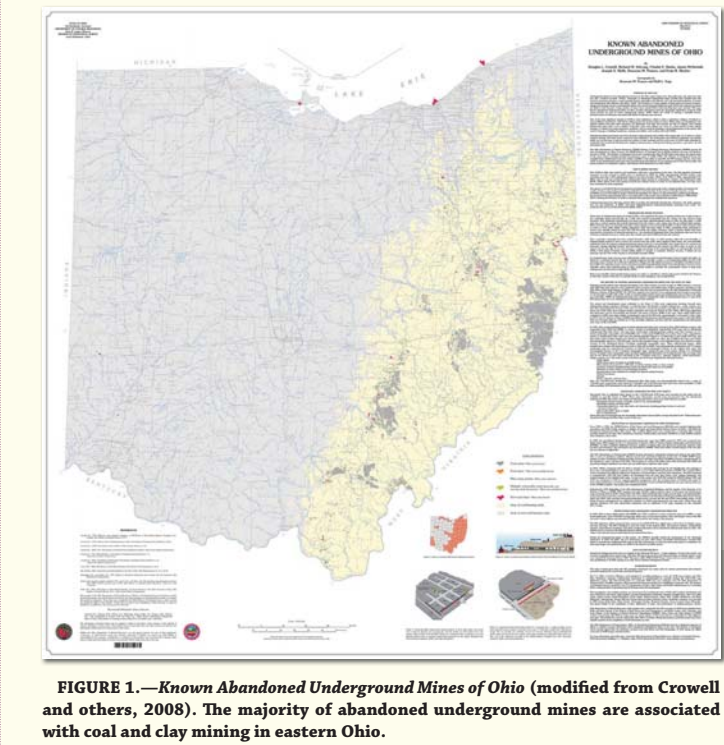


FIGURE 1.—Known Abandoned Underground Mines of Ohio (modified from Crowell and others, 2008). The majority of abandoned underground mines are associated with coal and clay mining in eastern Ohio.



FIGURE 2.—Aerial photograph showing location of mine subsidence in Youngstown, Ohio. In 1941, a property was inventoried by Fuller and Sturgeon (1941) as containing an abandoned mine shaft of the Foster #1 mine, which was abandoned in 1884 and was the most productive mine on the south side of Youngstown. Fuller and Sturgeon also noted that in 1876, a block of sandstone measuring 4' x 4' x 7' was taken out of the shaft and exhibited at the Centennial Exposition in Philadelphia. It won a gold medal for the best stone block on exhibition. In 1977, a garage collapsed into a mine shaft on a nearby property (Crowell, 1980; DeLong, 1988).



FIGURE 3.—Collapse of Interstate 70, near Cambridge, Ohio caused by mine subsidence (Crowell, 1995).



FIGURE 4.—Damage to a house from mine subsidence. Sugarcreek Township, Tuscarawas County, Ohio.

Mine subsidence in Ohio has been a problem that only has been recognized in the last 40 years. In 1977, a mine shaft collapsed 110 feet within a 230 feet shaft underneath a garage in Youngstown, Ohio (fig. 2). This incident led to the Survey mapping the detailed locations of abandoned underground mines (DeLong, 1988). Other prominent incidents have occurred, such as the collapse of Interstate 70 near Cambridge, Ohio (fig. 3; Crowell, 1995), and the recent subsidence underneath a house in Sugarcreek, Ohio (fig. 4). The cost associated with the remediation of abandoned mines is high. The repair of the collapse of I-70 near Cambridge cost approximately \$3.8 million (Crowell, 1995). As of 2005, the Ohio Department of Transportation had spent approximately \$14.3 million to repair highway damage caused by mine subsidence. In 2008, the ODNR Division of Mineral Resources Management invested more than \$1.3 million to complete 32 projects related to abandoned underground mines (Gordon, 2009). As abandoned underground mines age and deteriorate, we expect the costs associated with remediation of the abandoned mines to increase.

Most homeowner insurance policies do not cover damages from mine subsidence. In Ohio, the MineSubsidence Insurance Fund gives property owners the opportunity to purchase mine-subsidence insurance. In order to assist the Ohio Mine Subsidence Insurance Underwriting Association (OMSIUA) with the evaluation of insurance claims, the Survey has entered into an agreement with OMSIUA to provide geologic information and preliminary evaluation of the validity of the mine subsidence claims. When officials from the OMSIUA receive a claim from a property owner, Survey geologists are given the claim for further evaluation. The geologists automatically gather all digital geologic maps and documents for the claim location using a GIS software application. Once all the information is gathered into the GIS, the geologists evaluate the potential of an underground mine to underlie the property and then write a claim report. The claim report is submitted to a consulting engineering company for further evaluation and potential remediation. The GIS software application provides easy access to digital geologic information for insurance claim processing and potential property remediation.

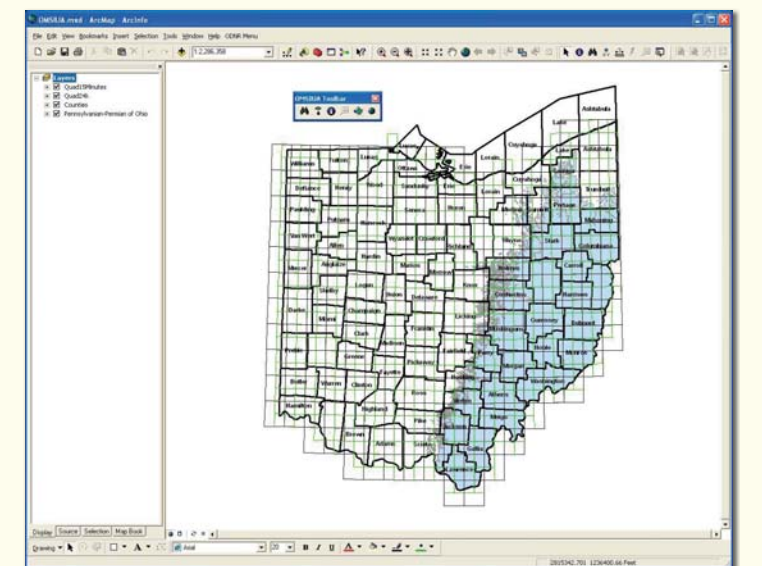


FIGURE 5.—OMSIUA Toolbar.

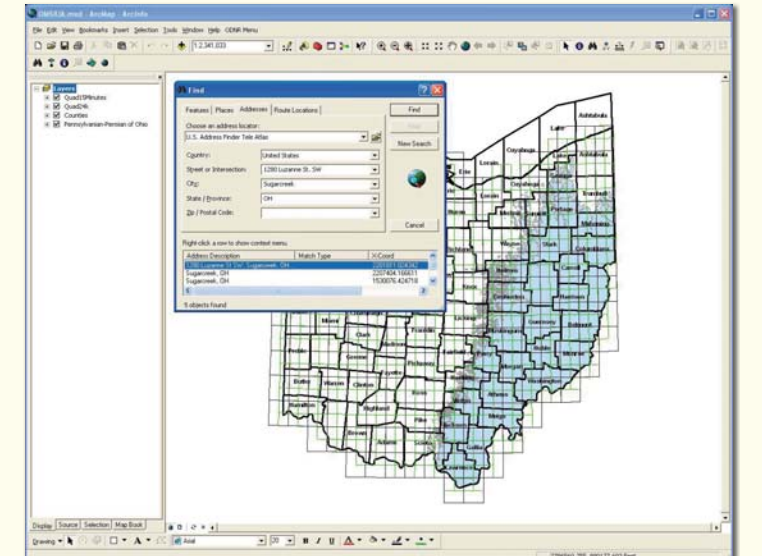


FIGURE 6.—Find tool on the OMSIUA Toolbar. The Find tool and the ESRI Address Locator are used to locate insurance claims based upon the claim address.

OMSIUA GIS APPLICATION

The OMSIUA GIS application consists of a toolbar with a number of tools. The tools contain a mixture of native ArcGIS tools and custom-designed tools using VBA for ArcObjects (fig. 5). To locate mine subsidence claims, two tools are used to zoom into the claim location and load all geologic maps and documents. The toolbar contains the native ArcGIS Find tool (fig. 6). This tool is used to locate insurance claims based upon the Address Locator function in the Find tool. The second tool on the toolbar is mine-subsidence Select Location tool (fig. 7). This tool will load all known digital geologic maps and all geologic GIS data into the ArcMap document for that location. Some of the GIS datasets include the abandoned underground mines, the permitted surface mines, the 1:24,000-scale bedrock geology, and the 1-foot resolution digital orthophotography. One of the most important historical records is the 15-minute thematic geologic maps. These maps have been scanned and indexed. The Select Location tool will identify all the scanned maps within a mile radius and load them into the ArcMap (fig. 8).

Once the information is loaded, the geologist can conduct a preliminary mine-subsidence analysis. The Underground Mine Information form (fig. 9A) will present the attribute information on abandoned underground mines. Using the form, the georeferenced abandoned mine maps can be loaded into the ArcMap (fig. 9B). Documents can be accessed using the native ArcGIS Hyperlink tool (fig. 10). Some of the documents that can be accessed are the measured stratigraphic sections, core descriptions, and oil-and-gas well completion cards. These three types of documents can have a description of a coal bed within them and possibly the notation that an underground mine is nearby.

After the analysis is completed, portions of the preliminary mine subsidence report can be automated. A tool will export thematic, page-size, PDF maps (fig. 11A). The page-size maps are generated with the correct titles (fig. 11B). The PDF maps, along with all the geologic documents within a half-mile of the site, will be exported to a temporary directory (fig. 11C). The geologist can then ZIP the files together and send them to the consulting engineering company for further analysis.

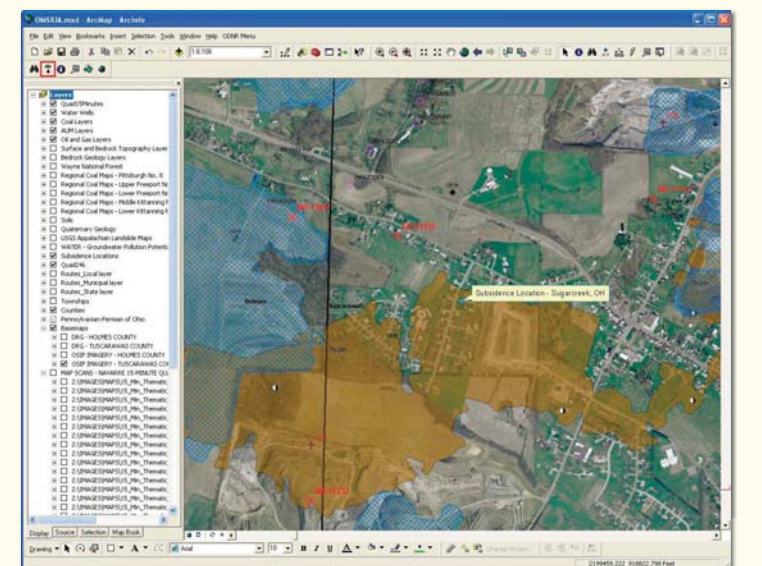


FIGURE 7.—Select Location tool. All geologic information is loaded into the ArcMap for the complainant location.

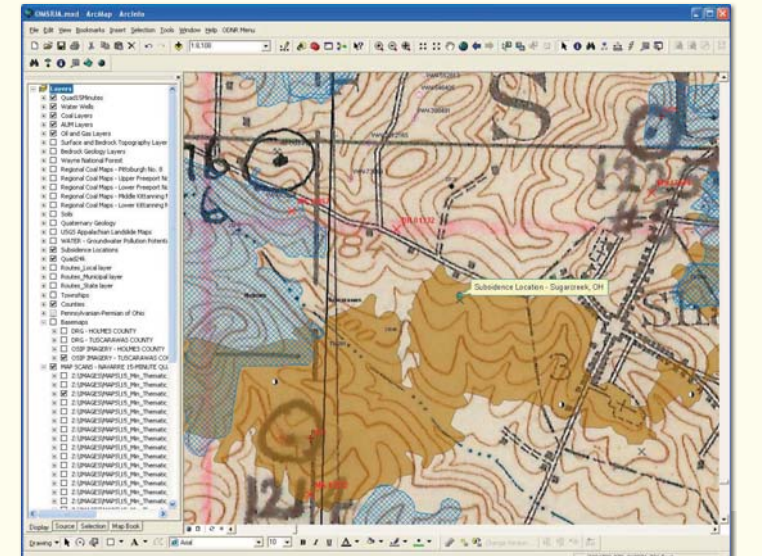


FIGURE 8.—Historic thematic 15-minute topographic map as a basemap. Map shows coal sample locations.

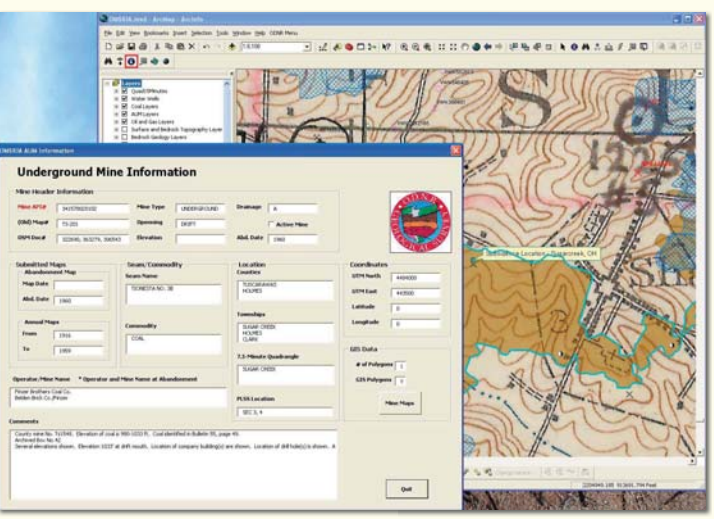


FIGURE 9A.—Underground Mine Information form.

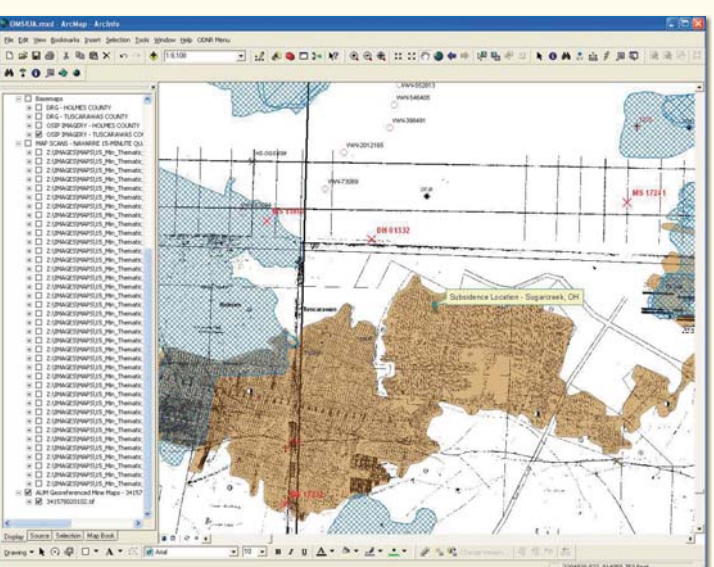


FIGURE 9B.—Georeferenced mine map can be loaded from the Underground Mine Information form.

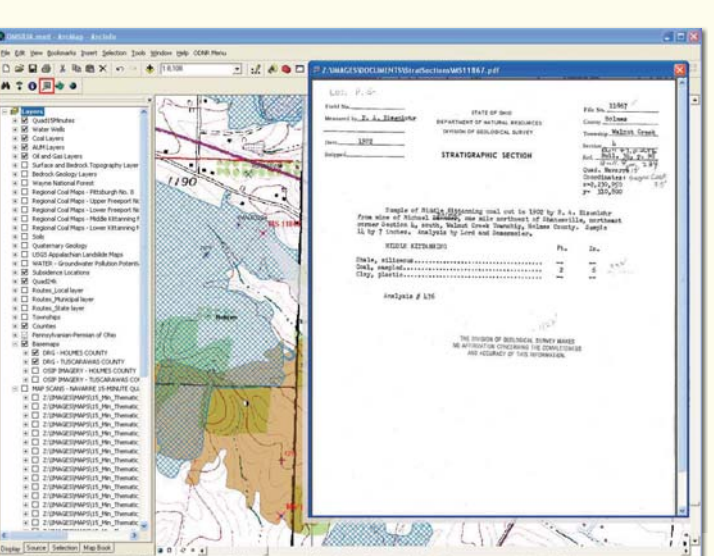


FIGURE 10.—Hyperlink to a Measured Section document.

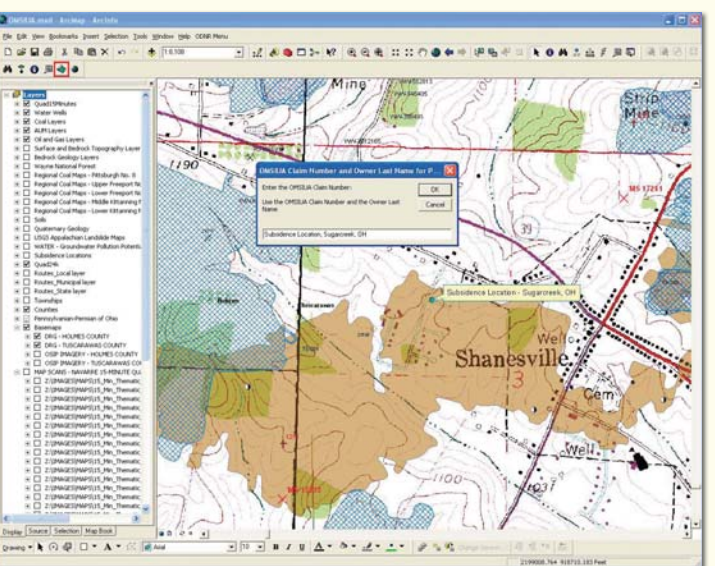


FIGURE 11A.—Automating the export of PDF maps.

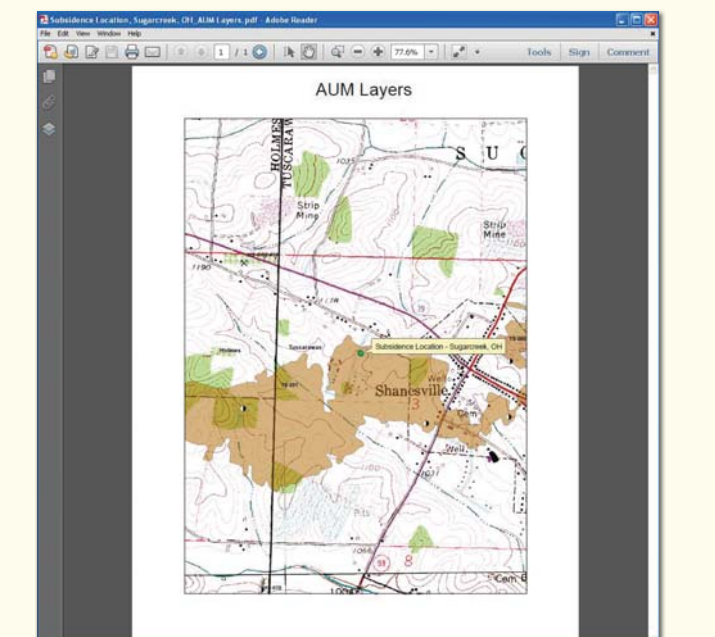


FIGURE 11B.—All automated PDF figures are generated with the correct titles.

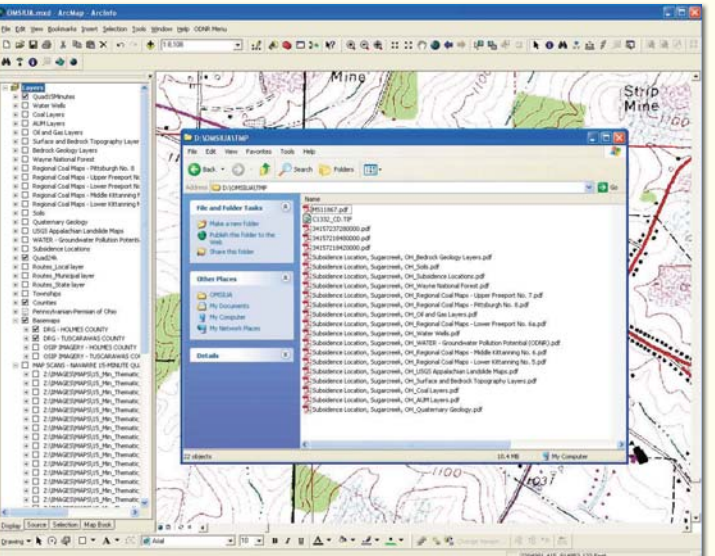


FIGURE 11C.—All documents within a half-mile radius and the PDF figures are copied to a temporary directory.

NEW DATA SETS

Since the early 2000s, new digital datasets have become available for mapping abandoned underground mines. These GIS datasets include the abandoned underground mine map images; the new 1:24,000-scale bedrock geology, bedrock topography, and structure contour GIS datasets; point data from the National Coal Resources Data System (Carlton, 2001) and elevation and thickness point data captured from detailed georeferenced mine maps; datasets on roof rock conditions and areas the pillars have been sliced or removed from the detailed mine maps; and high-resolution digital orthophotos and LiDAR data created for the State of Ohio. Each of these GIS datasets can be used to investigate mine subsidence claims and predict the potentially occurrence of mine subsidence.

Starting in early 2000s, the U.S. Department of Interior, Office of Surface Mines and the Ohio Mine Subsidence Insurance Fund board funded the scanning and georeferencing of the abandoned underground mine maps. Over 5,000 abandoned underground mine maps have been scanned at 72 dpi, 150 dpi, and 400 dpi. The 72 dpi images have been georeferenced (fig. 12A) and the 400 dpi images (fig. 12B) are currently undergoing georeferencing. The detailed mine maps allow for determining the accurate locations of the mines. The mine map images also provide detailed information on the occurrence of the room-and-pillar configuration, which can be used to aid in mine subsidence insurance investigations.

During the 1990s, the Survey embarked on a long-term project to remap the bedrock geology of the state of Ohio. The primary GIS datasets include

the 1:24,000-scale bedrock geology (fig. 13A), the bedrock topography (fig. 13B), and the bedrock structure contours (fig. 13C). The mapping project was completed in 1997, the maps were converted to GIS datasets by 2003 (McDonald and others, 2003) and released to the public in 2006. These GIS datasets are useful for identifying particular coal beds and for calculating the unconsolidated drift thickness within alluvial valleys and glaciated portions of the state.

In 2006 and 2007, the State of Ohio collected high-resolution, digital orthophoto imagery (1-foot resolution), and LiDAR for the entire state. A historical mine subsidence site (Nowell, 1970) is used to show how the high-resolution imagery and the LiDAR data can be used to identify pit subsidence features (Figs. 14A–14D).

The georeferenced mine maps have additional information that can be captured within the GIS. Elevations and thickness points are being captured from the mine maps (fig. 15). Roof rock and mined-out features are currently being captured from the georeferenced abandoned underground mine maps. In figure 16A, the mine map indicates a “Fault.” A fault or “horsebacks” indicate a fluvial sandstone channel that cut down through the overlying roof rock and into the coal bed. The edges of the sandstone fluvial channels are areas of weakness within the mine and are potential areas whereby a collapse can occur. Other typical features captured in the GIS include “Horseback” and “Bad Roof” (fig. 16B).

The last dataset used in this study includes publicly available mine subsidence events information from the U.S. Department of Interior, Office of Surface Mines (fig. 17).



FIGURE 12A.—Low-resolution mine map image (72 dpi) of the Puritan Coal Mine (GY-006), abandoned in 1921.



FIGURE 12B.—High-resolution mine map image (400 dpi). Note that the 400 dpi scan is far more readable than the 72 dpi images in figure 12A.

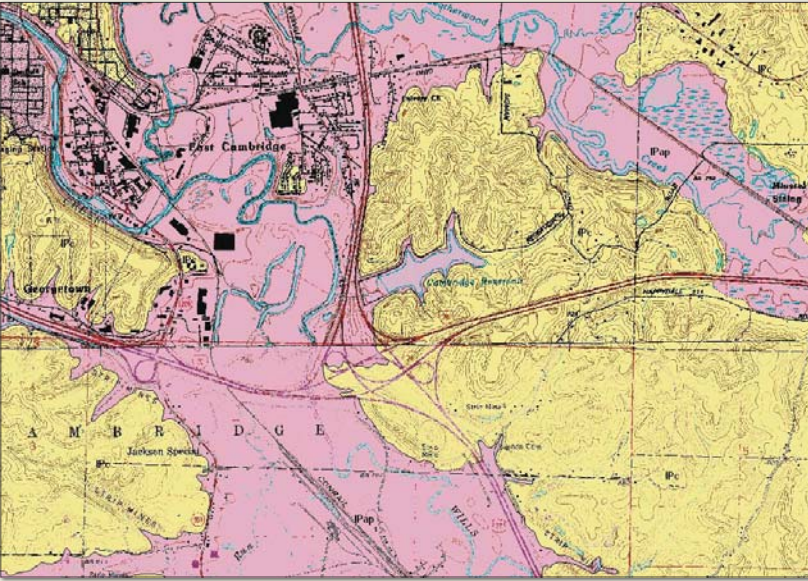


FIGURE 13A.—A portion of the 1:24,000-scale bedrock geology map in the Cambridge, Ohio area.

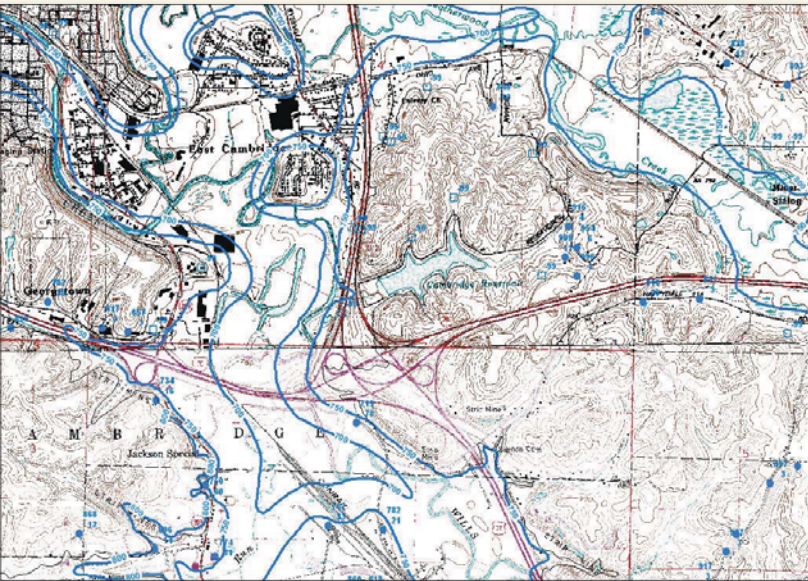


FIGURE 13B.—A portion of the 1:24,000-scale bedrock topography map in the Cambridge, Ohio area.

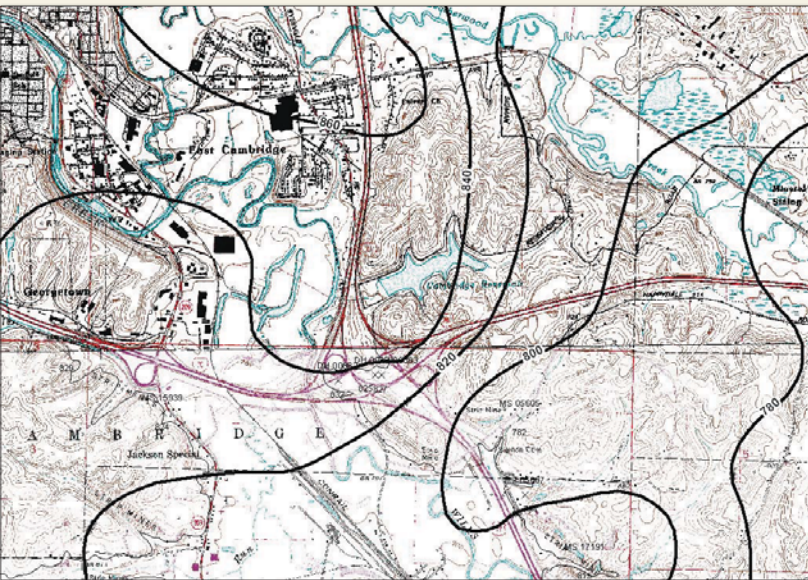


FIGURE 13C.—A portion of the bedrock structure contour map of the Upper Freeport coal bed in the Cambridge, Ohio area.



FIGURE 14A.—Location of historic mine subsidence features south of Byesville, Ohio (Nowell, 1970).



FIGURE 14B.—Zoomed-in view of the mine subsidence features south of Byesville, Ohio.



FIGURE 14C.—Hillshade overlay of the gridded LiDAR dataset. Some of the pit subsidence features can be easily identified, especially if the pit subsidence feature has a vertical resolution of greater than the LiDAR accuracy.

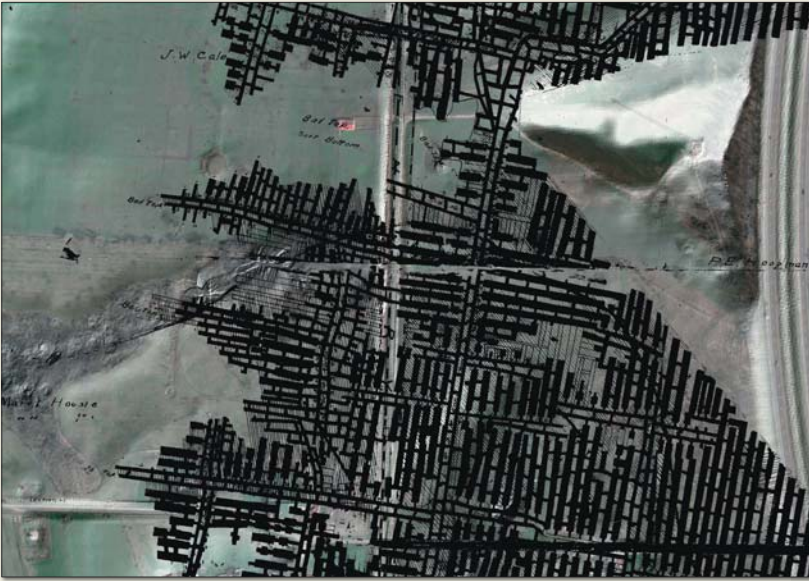


FIGURE 14D.—Overlay of the detailed abandoned mine map. Some of the pit subsidence features lie outside of the mapped mine workings, possibly indicating that the detailed mine map does not completely show the full extent of the mine workings.

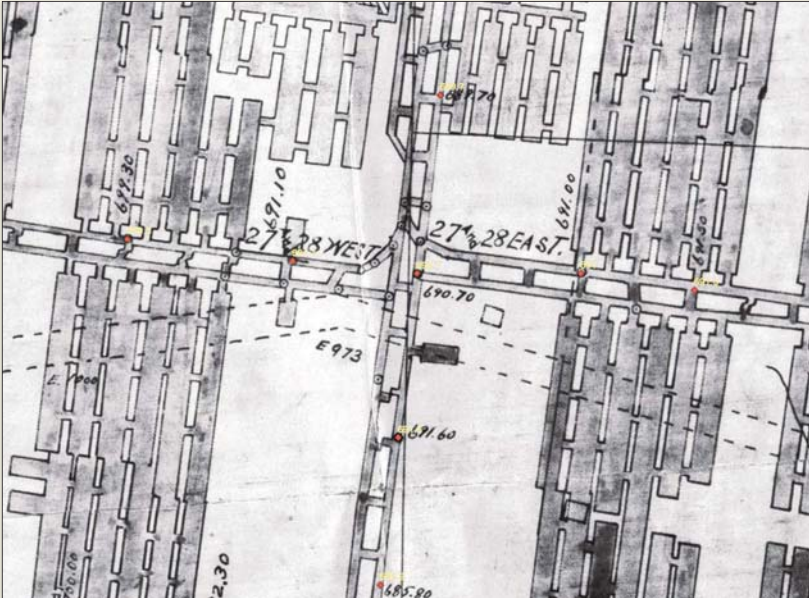


FIGURE 15.—Example elevation data points digitized from an abandoned underground mine map.

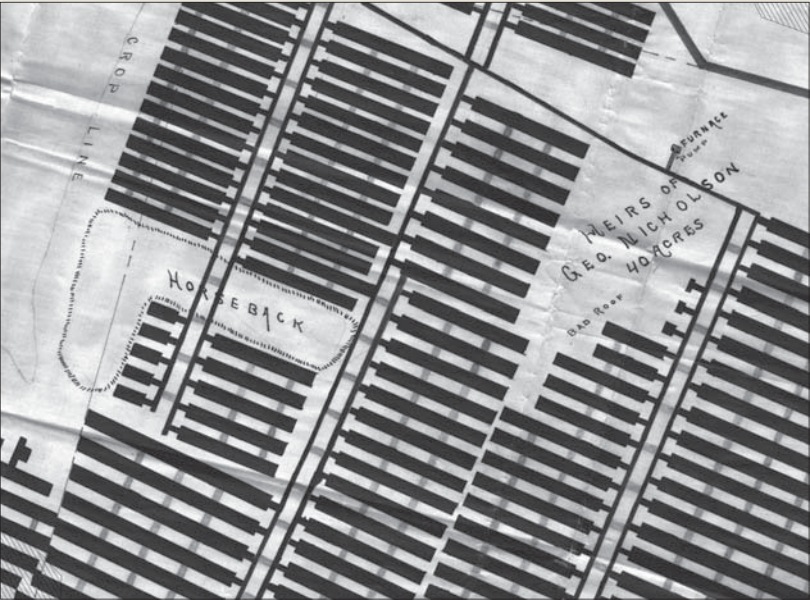


FIGURE 16B.—Roof rock features labeled “Horseback” and “Bad roof.” Again, these are areas of weakness whereby a collapse can occur.

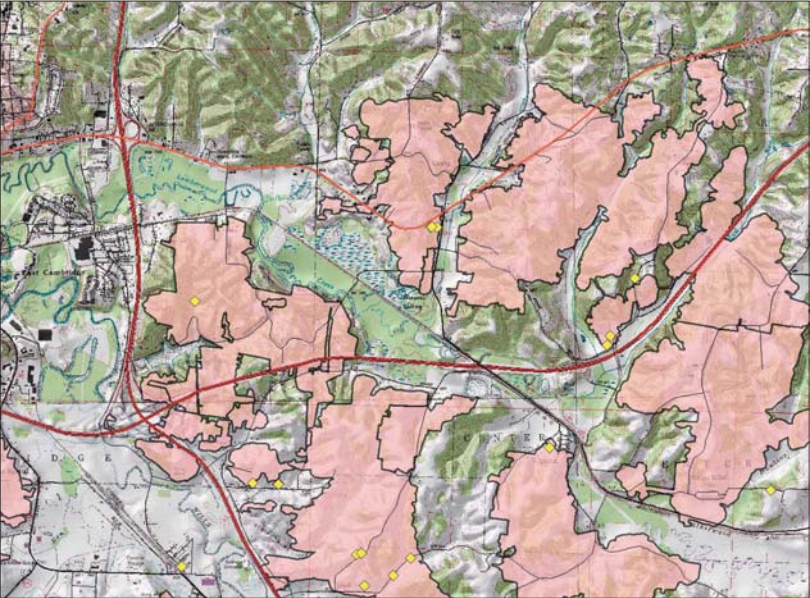


FIGURE 17.—Example map showing the mapped subsidence events and the abandoned underground mines near the I-70/I-77 interchange near Cambridge, Ohio.

FIGURE 16A.—Roof rock features that have been captured from an abandoned underground mine map. In this figure, the mine map indicates a “Fault.” A fault or “horsebacks” indicate a fluvial sandstone channel that cut down through the overlying roof rock and into the coal bed. The edges of the sandstone fluvial channels are areas of weakness within the mine and are potential areas whereby a collapse can occur.

New Data and Techniques for Evaluating Subsidence from Abandoned Underground Mines in Ohio

PILOT STUDY

In 2012 a pilot study was initiated to determine areas that are at risk for mine subsidence from abandoned underground mines. The pilot project area was located near Cambridge, Ohio (fig. 18). In 1995, there was a collapse of a mine underneath Interstate 70, near the I-70/I-77 interchange. Due to the large area covered by the Cambridge coal field, the age of the mines, and the potential danger of mine subsidence to damage the road network, the area encompassed by the Cambridge coal field was selected for the pilot project.

A number of different variables that may affect mine subsidence were examined. Variables analyzed as part of this study included age of a mine, depth to a mine, amount of unconsolidated overburden, and roof rock lithology. As mines age, it is thought that the deterioration of the mines will increase. Figure 19 shows a map of the coal mines in the Cambridge coal field, classified by age of abandonment. Figure 20 shows the subsidence events by age of abandonment of the mine. There is a weak correlation between subsidence events and abandonment date. This weak correlation probably is due to older mines being at a shallower depth, more than the increasing deterioration of the mine over time.

Using the NCRDS dataset and the mine elevation points (fig. 21), a detailed coal bed elevation surface can be created (fig. 22). The high-resolution overburden depth is created by subtracting the Upper Freeport elevation surface from the bald earth LiDAR DEM (fig. 23).

When the mine subsidence events are correlated with overburden depth to the mine workings, there is a good correlation showing that most of the mine subsidence events occur at an overburden depth of less than 100 feet (fig. 24). Using this result, the overburden depth to the mines of less than 100 feet can be extracted from the overall overburden grid surface. The extracted layer can then be used to identify highways, roads, properties, and structures that may be susceptible to mine subsidence damage (fig. 25).

ACKNOWLEDGMENTS

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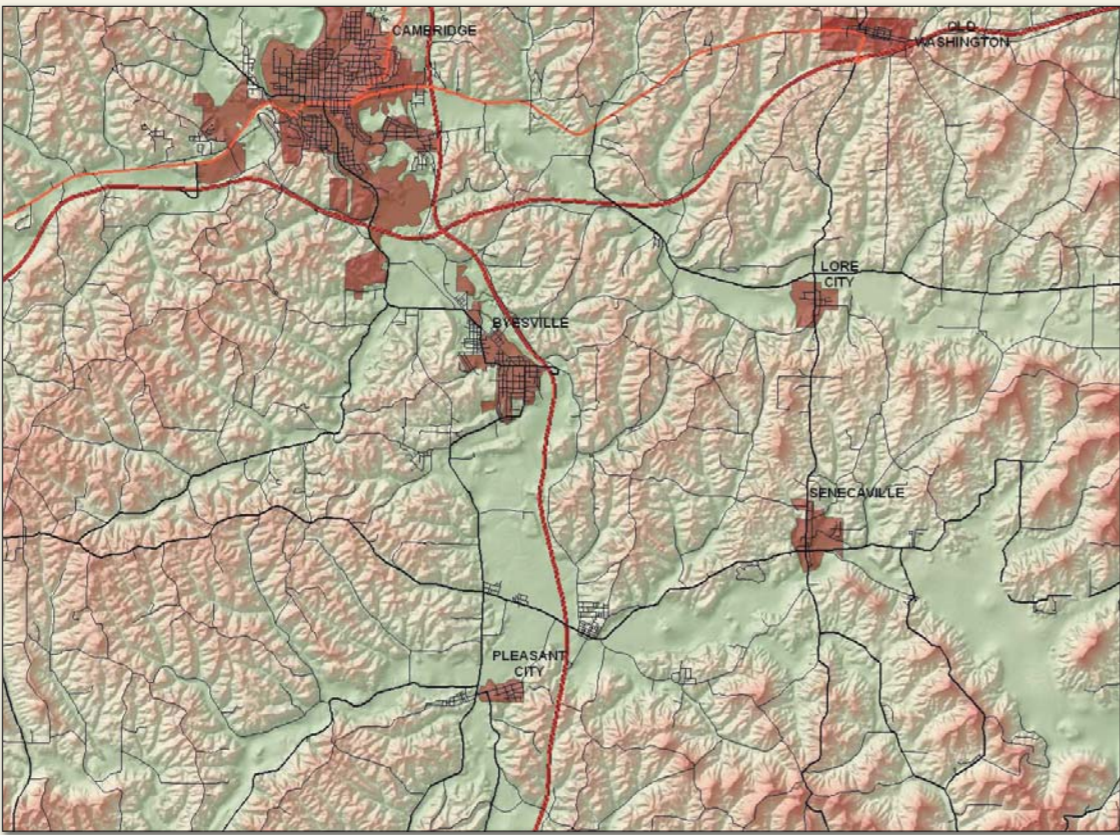


FIGURE 18.—Map showing the location of the pilot project study area in the Cambridge coal field, near Cambridge, Ohio.

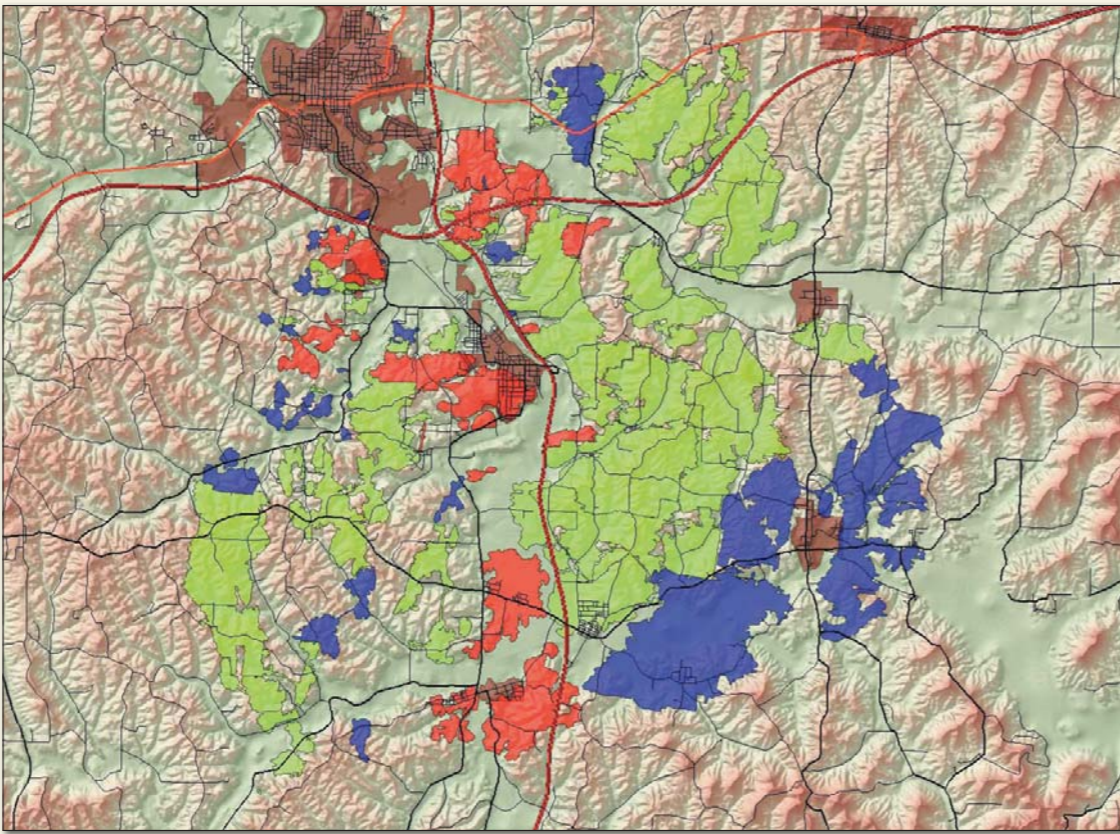


FIGURE 19.—Map showing the abandoned underground mines in the Cambridge coal field. The mines are color classified as to age of abandonment. Mines symbolized in RED were abandoned between 1890 and 1919; mines symbolized in GREEN were abandoned between 1920 and 1939; and mines symbolized in BLUE were abandoned between 1940 and 1960, when the last coal mine in the field was abandoned.

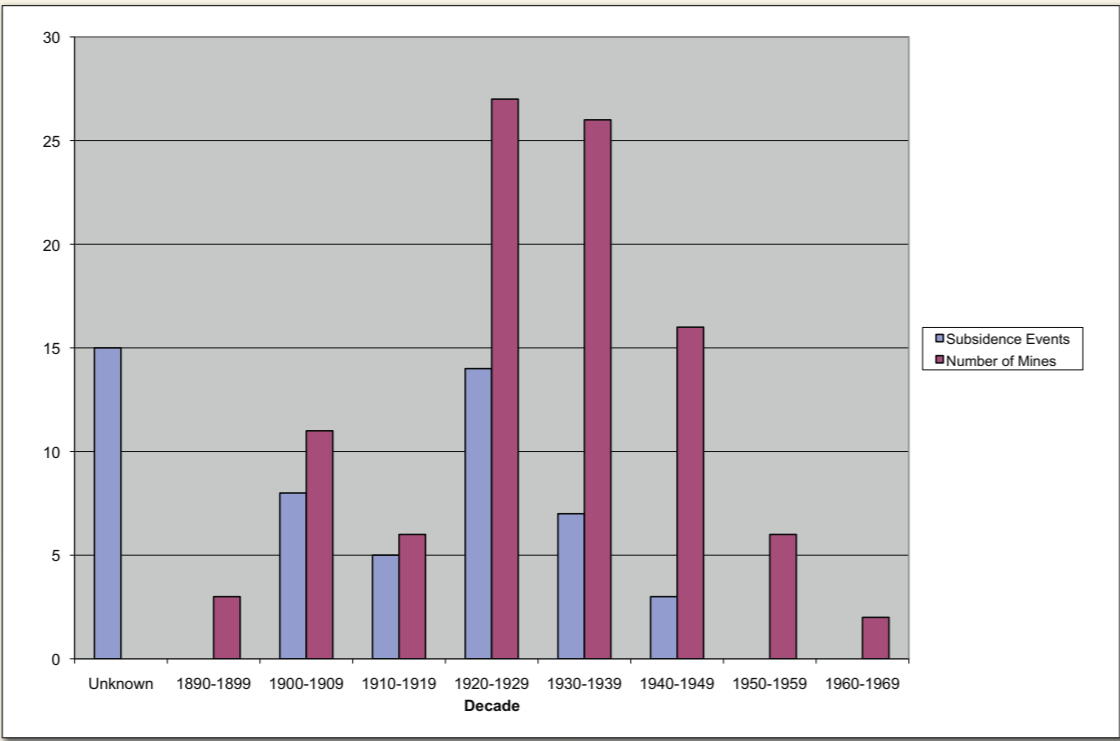


FIGURE 20.—Chart showing the date of abandonment and the subsidence events that correspond to the mine abandonment date. There is a weak correlation between subsidence events and abandonment date. This weak correlation is probably due to older mines being at a shallower depth, more than the increasing deterioration of the mine over time.

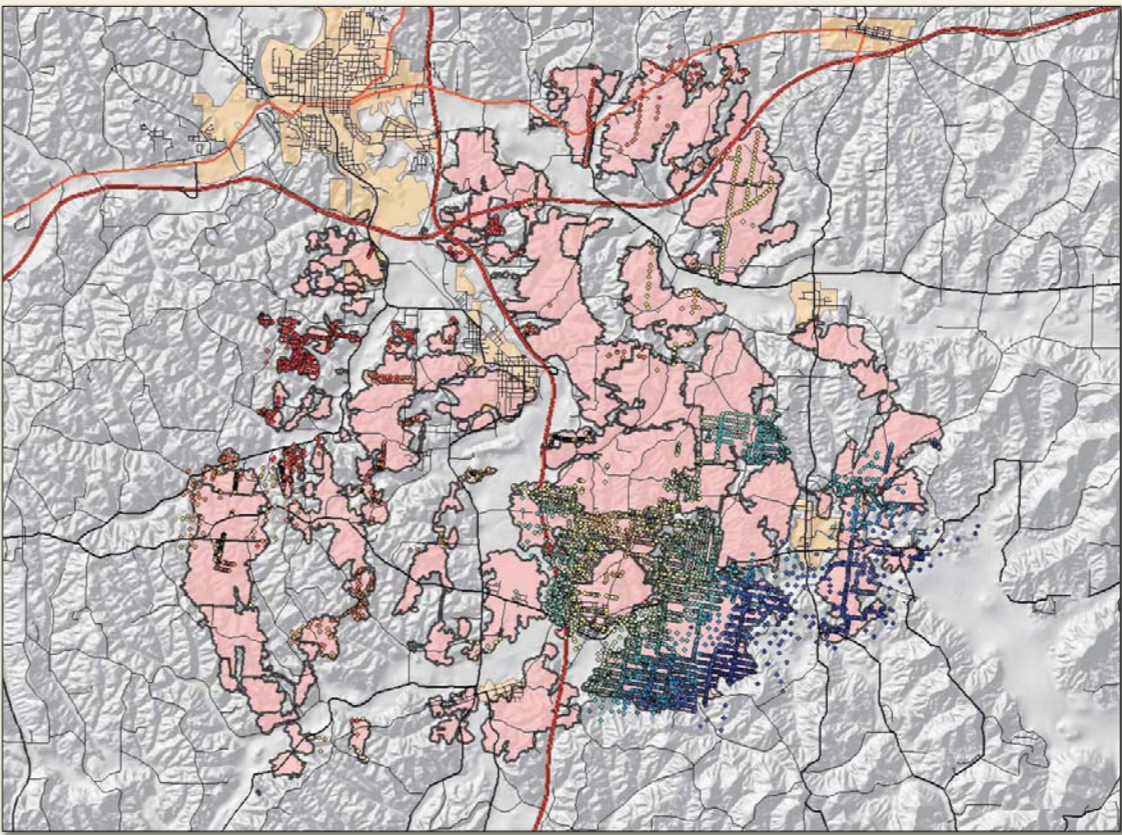


FIGURE 21.—Distribution of the mine elevation data points used to model the coal elevation surface.

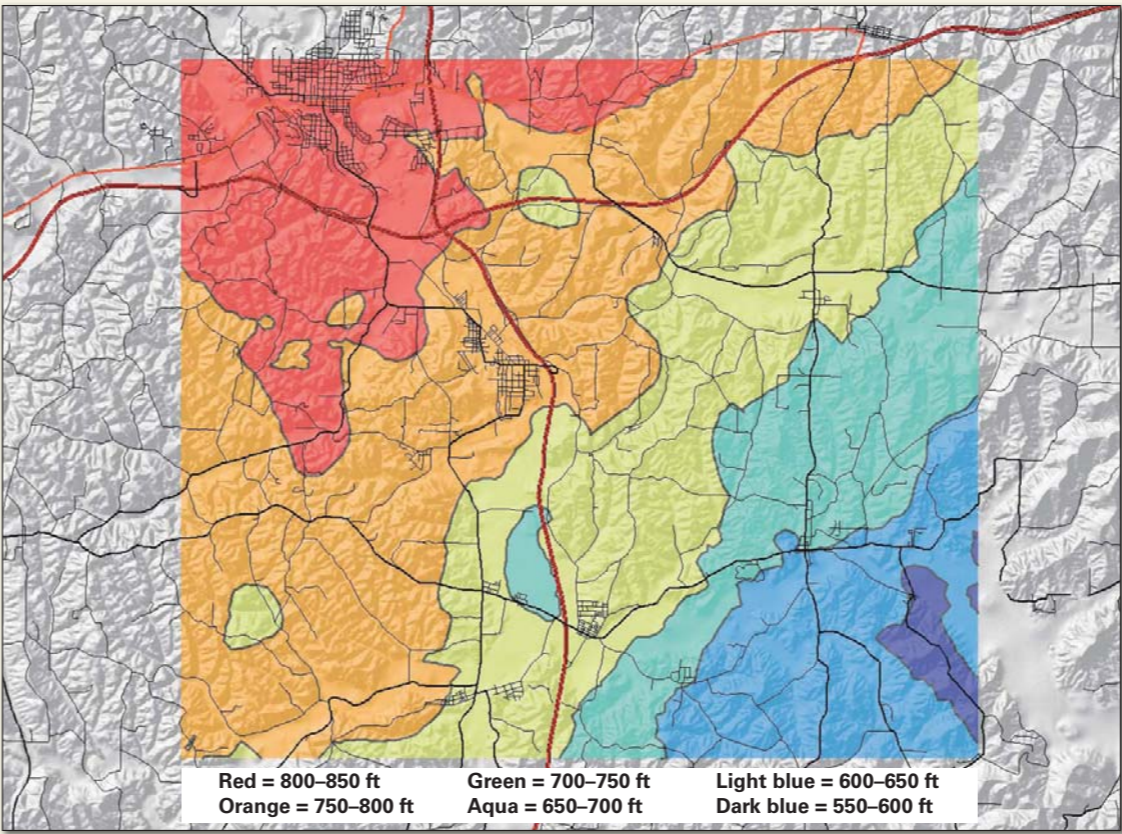


FIGURE 22.—Upper Freeport coal bed elevation surface. Data to model the surface included the mine elevation points, surface measured stratigraphic sections, core descriptions, and mine reclamation drill holes.

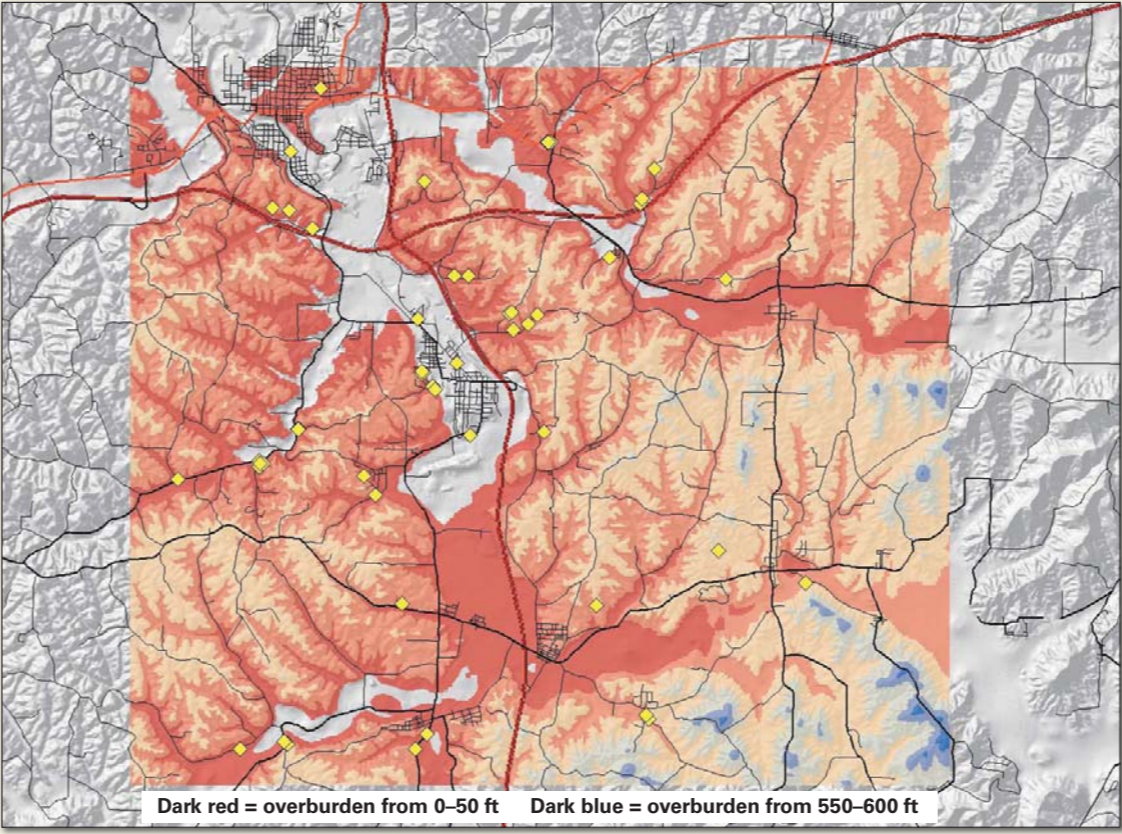


FIGURE 23.—Map showing the overburden thickness and the mine subsidence events. The high resolution overburden thickness is created by subtracting the Upper Freeport elevation surface from the bald earth LiDAR DEM.

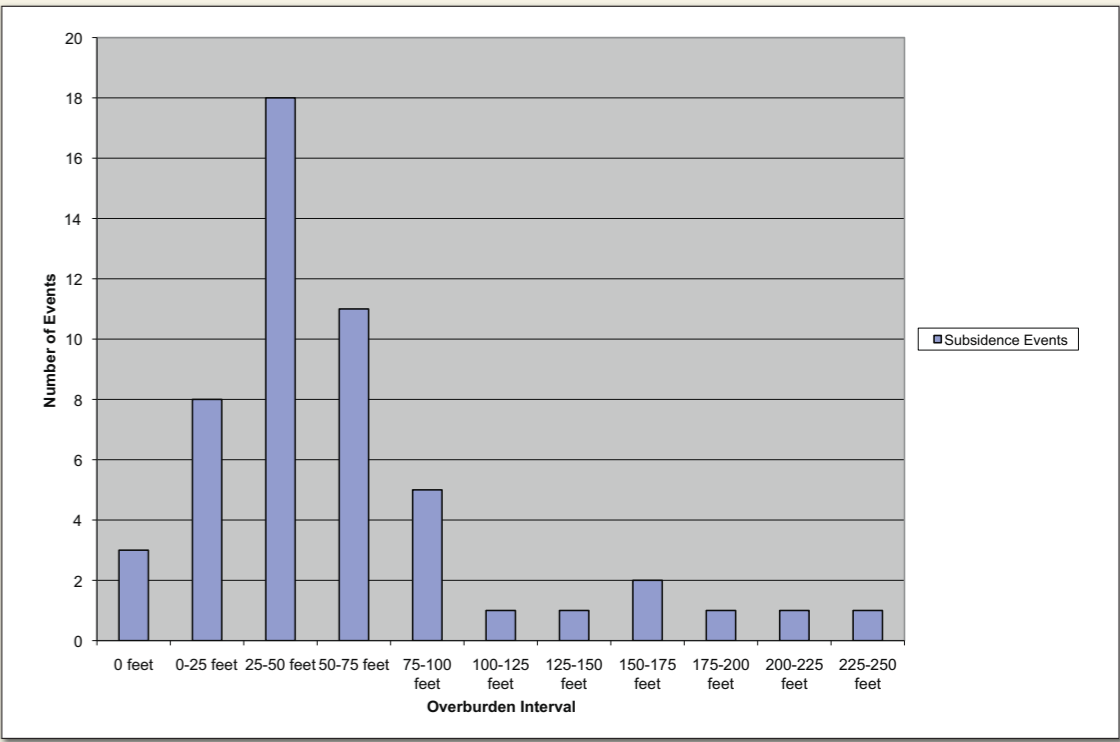


FIGURE 24.—Chart showing the depth to the mine and corresponding mine subsidence event. There is a good correlation showing that most of the mine subsidence events occur at an overburden depth of less than 100 feet.

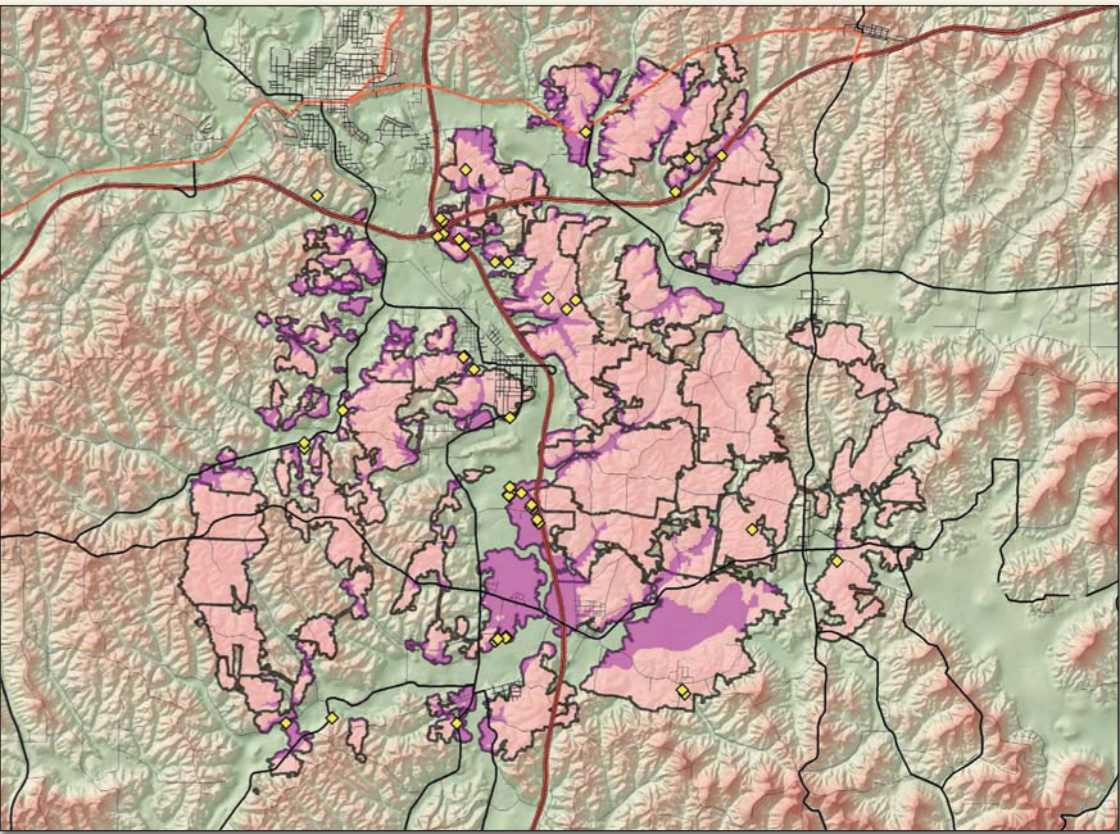


FIGURE 25.—Map showing the overburden depth of less than 100 feet and the highway infrastructure that may be affected by mine subsidence. Mines are represented by light purple while the overburden thickness of less than 100 feet is represented by dark purple.



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