City of Pittston Mine Subsidence Study [1]

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Abstract

When a rash of mine subsidences appeared in the City of Pittston in a short period of time during 2006, the Bureau of Abandoned Mine Reclamation of the Pennsylvania Department of Environmental Protection was tasked to study and categorize subsidence prone areas in the city and then define those areas as high, medium and low risk for future stabilization. The areas were first evaluated with electronic mapping using AutoCADD and Carlson software. It also involved loading and georeferencing underground mine maps into CADD in order to survey each vein. GIS database and mapping was then used to spatially compare the geology and mining in the city with the history of complaints and past subsidence control projects. LiDAR coverage of the study area, with elevation accuracy to the foot, confirmed the subsidence trends and refined the problem area boundaries. After completion of the study, the area with the highest potential for mine subsidence was determined to be the Mill Street neighborhood and further field investigation using geophysical tools then commenced.

The Study

Background

The City of Pittston, Luzerne County, Pennsylvania in the Wyoming Anthracite field has a long history of deep mining that was ended by the Knox Mine Disaster in 1959 that flooded lower mine workings in a large section of the Wyoming Valley. The city has been subsequently plagued by the collapse of voids left as a result of these past underground mining activities. Subsidence features present within the city include shallow depressions in lawns, roadways and openings in the ground of varying diameter and depth. The surface expressions of the subsidence are sometimes a hazard to residents and cause damage to public and private structures, roadways, utilities, and other infrastructure.

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Residents of the community are well aware of the potential for damage due to subsidence events as reflected by the fact that as of July 3, 2008, there were 473 active mine subsidence insurance policies in the City of Pittston administered by the Mine Subsidence Insurance Board through DEP.

Deep Mining under Pittston City

The city of Pittston is underlain by several coal veins, but the investigation would concentrate on the three upper veins that are most problematic, the Checker, Pittston and Marcy veins. The orientation of the three veins varies from flat to a maximum inclination of 45° at the outcrops. The veins generally slope downward going from east to west. The roof rock overlying the Pittston vein is slate stone, while the other two veins have a sandstone roof.

Most of the Pittston area was deep mined by the Pennsylvania Coal Company's No. 9 Colliery. A small area in the northeast corner of Pittston was mined by the Pennsylvania Coal Company's Seneca Colliery. The Ewen Colliery was located in the southwestern end of Pittston, known as South Pittston, and the Butler Colliery affected a small area near the top of William and Butler Streets.

Historical mine maps indicate that portions of the Checker and Marcy veins were deep mined using traditional room and pillar mining. The mine maps also show crosshatched areas that indicate culm and refuse material may have been placed into the workings by the coal company to reduce the possibility of subsidence. In addition, the maps show numerous tunnels, some of which may possibly have been located above or below the coal veins, but are shown superimposed on the mine maps.

The available mine maps for the Pittston vein indicate much of the study area remains un-mined. The maps indicate mining had occurred only along the east, south west and northwest portions of the study area. However, historical borings indicate the presence of voids/openings in areas that were presumably not mined. Based on this information, it is assumed herein that a series of mining events have occurred within the Pittston vein throughout the study area beyond what is shown on the available mine maps.

Historical Mining, Geologic and Subsidence Data

Since 1942 the Pennsylvania DEP and its predecessor, Pennsylvania Department of Environmental Resources (PADER), as well as the U.S. Department of the Interior/Office of Surface Mining, Reclamation and Enforcement (OSM), have investigated 149 mine-related subsidence events in the city. Factors such as the type and depth of unconsolidated soil and overburden, rock, thickness and number of coal veins, the width and spacing of coal pillars, the depth and thickness of the rock interval between the various mined seams, underground water flow, infiltration of surface water and fluctuations in the mine pool all must be considered when trying to evaluate an area's subsidence potential.

The DEP, Bureau of Abandoned Mine Reclamation (BAMR), was tasked to further investigate the cause of these subsidences which had impacted several houses in the City of Pittston and to develop possible solutions to this problem. The results of this study were documented in an August 2008 report. The study summarized the history of mining and the geology of the region and identified 24 potential high risk mine subsidence areas. A major source of information for the study was the mine maps of these seams, their relationship with the surface, the slope of the seam, and other information on them. (See Figure 1). BAMR maintains a map repository that contains most of the available mine maps for the Anthracite Region.

Figure 1 - Mine Map of the Checker Vein in the City of Pittston

A long history of geological investigations has occurred at the site, intended originally to identify the location, depth and thickness of the coal seams, and later to assess the area for subsidence impacts. The earliest available boring logs were completed in the early 1900's by a variety of drilling firms throughout the Pittston area during the actual mining operations.

A subsurface investigation was performed by the PADER utilizing rotary drilling in 1973, including a total of 141 borings. This led to a flushing project in 1977. Seventy-one additional borings were performed by the PADER in Pittston in 1979 which included the study area. The data was analyzed and the results led to a mine flushing project during the years 1983 to 1985. Material was injected into the Checker, Pittston and Marcy veins through boreholes previously drilled by PADER, augmented by additional boreholes drilled as part of the OSM contract. Additional borings were completed in 1985 and 2005 in the project area by BAMR and OSM.

Data evaluated for the project included the previously mentioned subsidence investigations that were tied to street addresses to create a GIS database of historic problems. As built maps and drill logs from the various state and federal drilling projects in Pittston were also geo-referenced for the study area. We incorporated construction project reports from the numerous localized emergency stabilization projects the OSM has conducted, and from the two large subsidence control projects in Pittston (See Figure 2) that the DEP did in 1977 and 1985 (Total cost of $6.3 million).

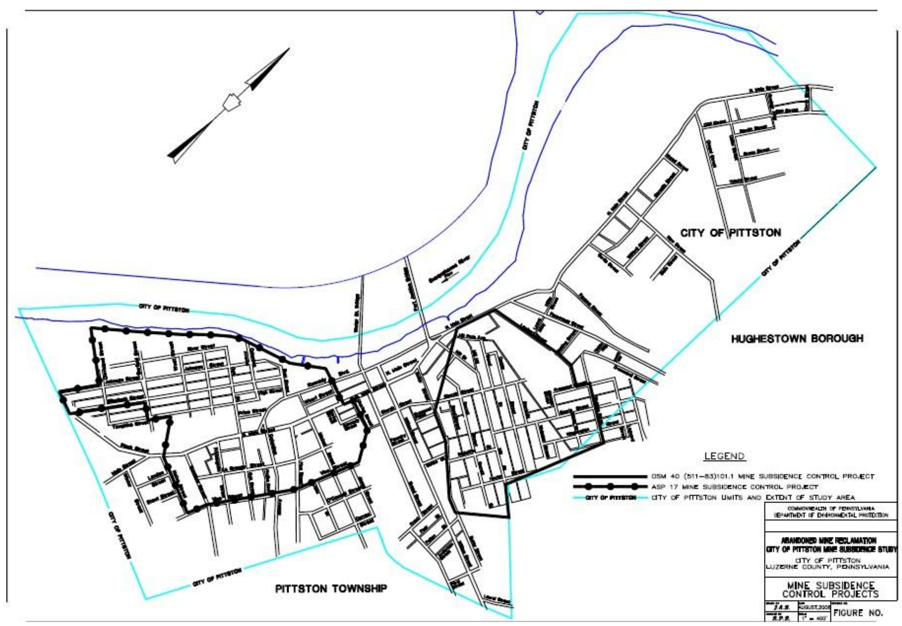

Figure 2 – Mine Subsidence Control Projects

Finally, a review of the LiDAR map for the City of Pittston revealed contour depressions indicative of surface subsidence, and helped delineate and confirm the risk areas.

Subsidence problems occur most often if the conditions involve very shallow mining of a thick vein of coal, little or no rock cover and a very cohesionless soil, such as sand, separating the mining from the surface. BAMR drew on its past experience with subsidence events by plotting exploratory drilling and subsidence projects over maps of coal vein depth and thickness, thickness of unconsolidated glacial material (wash), soil depth, and mine maps of individual coal veins. These spatial geologic and mining engineering maps were electronically overlain by the documented subsidence events. Correlations were recognized that defined the criteria for the high-risk areas. The criteria were defined as areas in which the mined coal vein outcrops near the surface or the rock strata are comparatively thin in relation to the wash and depth of the vein. For the purposes of the study, a high-risk area was defined as any area where the top of the first underlying mined coal vein has 35 feet or less of total cover and has 15 feet or less of rock. A medium-risk area occurs where the top of the first underlying mined coal vein is 45 feet or less from the surface and there is between 16 and 25 feet of rock cover. A low-risk area occurs where the top of the first underlying mined coal vein is 46 feet or more from the surface and there is 26 feet or more of rock cover.

The above areas generally describe the degree of risk of subsidence based primarily on the amount of rock cover over the first underlying mined coal vein. Such variables as the type and competency of the rock, the type of wash material (sand, clay, soils, coal refuse, ash, etc.), the number and depth and extraction percentage of other underlying mined coal veins, the existence and elevation of the mine pool, ground water levels and other geomorphic phenomena all become factors that could increase or decrease the risk. There were 24 areas in Pittston City defined as such, totaling 130 acres, or 12% of the city's area. (See Figure 3). The study provides recommendations on the priority that should be given to these identified areas for further investigation to determine justification of the need for additional action in the form of subsidence control projects,

http://www.portal.state.pa.us/portal/server.pt/community/abandoned_mine_reclamation/13961/subsidence/588961 .

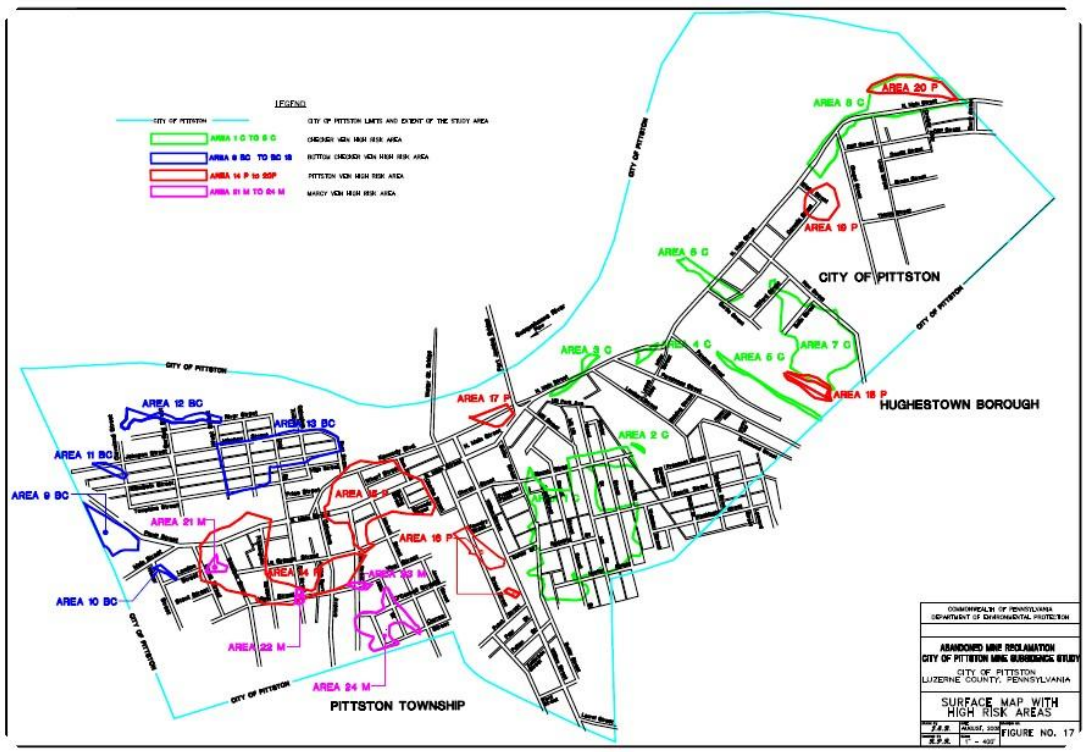

Figure 3 – High Risk Areas in the City of Pittston

Of these areas, Area 1C (the Mill Street area) was identified for further exploration. The site boundary of Area 1C is shown in Figure 4.

Figure 4- Mill Street Study Area.

Field Subsurface Investigation

To further investigate the subsurface conditions of the project area, BAMR contracted Kimball Engineering (Kimball) of Ebensburg, PA to accomplish the task and to provide recommendations to abate future subsidence problems. Portions of Kimball's final report have been included in this paper, http://www.lrkimball.com/ .

Another task that was assigned to Kimball was to investigate and evaluate a combined storm/sanitary sewer line in the high risk area on Mill Street. The sewer line sustained considerable damage during a possible subsidence event in 2008, and there was concern that the repairs to the line, as well as a future proposed sewer project, may be inadequate in the event of further subsidence. There is also concern that the partial failure of the brick sewer may have exacerbated the subsidence through washing of material previously placed in the mine voids.

Three Dimensional Model

In an initial effort to complete a comprehensive evaluation of the available site data, Kimball geologists prepared a functional, multi-layered, three-dimensional model of the study area. This model consisted of the existing borings and geology, the surface topography, and the approximate location and thickness of each stratigraphic layer, including the three primary coal veins of interest, and was prepared utilizing Environmental Systems Research Institute, Inc's (ESRI) ArcGIS, http://www.esri.com/products/products-alpha.html .

To create the three-dimensional model, Kimball first prepared a database of the historic boring logs located within and immediately surrounding the study area. As a first step, each boring was reviewed to determine the positional coordinates and surface elevation. If the boring logs included positional coordinates, they were used for the placement of the boring on the site mapping. Where only a description of the boring location was available, Kimball positioned the boring based on the description. In cases where no positional information was available, the boring was removed from the model. Based on this analysis, a total of 235 boring logs were reviewed and entered into the database. Of these 235 borings, 189 fall within the boundaries of the project study area. For each boring log, the recorded geologic profile was reviewed and categorized based on the stratigraphy and depth/elevation. Each of the stratigraphic layers noted in the boring logs were coded in the database as representing either overburden (wash), Rock above the Checker Vein, the Checker Vein, Rock between the Checker and Pittston Veins, the Pittston Vein, Rock between the Pittston and Marcy Veins, or the Marcy Vein. Furthermore, descriptions provided on the boring logs for each coal vein were further encoded to identify when the drilling encountered coal, broken rock, flush material or openings/voids.

The final database of borings was then linked to the geographic Information system (GIS) for processing and display. Utilizing the ArcGIS 3D-Analyst extension, a three-dimensional representation of the borings was produced, color coded as to the boring log stratigraphy and observations within each coal vein. This initial model provided the opportunity to view the spatial distribution (horizontally and vertically) of the study area geology and conditions encountered in the borings.

To build the solid three-dimensional model of the study area geology, Kimball first generated a surface topography layer using available Light Detecting and Ranging (LiDAR) data. Next, using the querying capabilities of the ArcGIS system, the bottom elevation of each stratigraphic layer was extracted from the boring database. A Triangulated Irregular Network (TIN) model of the bottom of each stratigraphic layer and coal vein was then produced. The coal vein contours derived from the computer model for the Checker vein is shown in Figure 5.

Figure 5 – Checker Vein Model Structure Contours.

By generating multi-patch features using the 3D Analyst Extension, solid three-dimensional representations of each stratigraphic layer and coal vein were produced. For a spatial reference, site imagery was draped over the topographic surface layer.

The study area model was then used to evaluate a number of site properties and subsurface conditions. Utilizing the three-dimensional representation of the borings, stratigraphy could be evaluated in relation to existing mine maps, mine voids and flushed areas. Finally, isopach (variation in thickness) contours of stratigraphic layers of interest could be developed to evaluate high risk areas within the study limits.

Evaluation of the three-dimensional model was used to develop preliminary locations for the active investigation of the site. Ultimately however, the geophysical investigation described below was constrained by available space limitations. General locations for the geophysical profiles were selected based on the model evaluation. Final geophysical traverses were laid out in the field as close as possible to planned locations based on available space and infrastructure.

Geophysical Investigations

As an initial field effort to define the mine void limits, and to attempt to assess mine subsidence/mine void issues associated with the existing brick sewers that run along Mill and Searle Streets, a geophysical assessment was completed by ARM Geophysics, a division of ARM Group, Inc. (ARM), Hershey PA, http://www.armgeophysics.net/. ARM collected 6 electrical resistivity (ER) traverses, 3 multi-channel analysis of surface wave (MASW) traverses, and ground penetrating radar (GPR) profiles within the survey area. The geophysical traverse locations are shown in Figure 6.

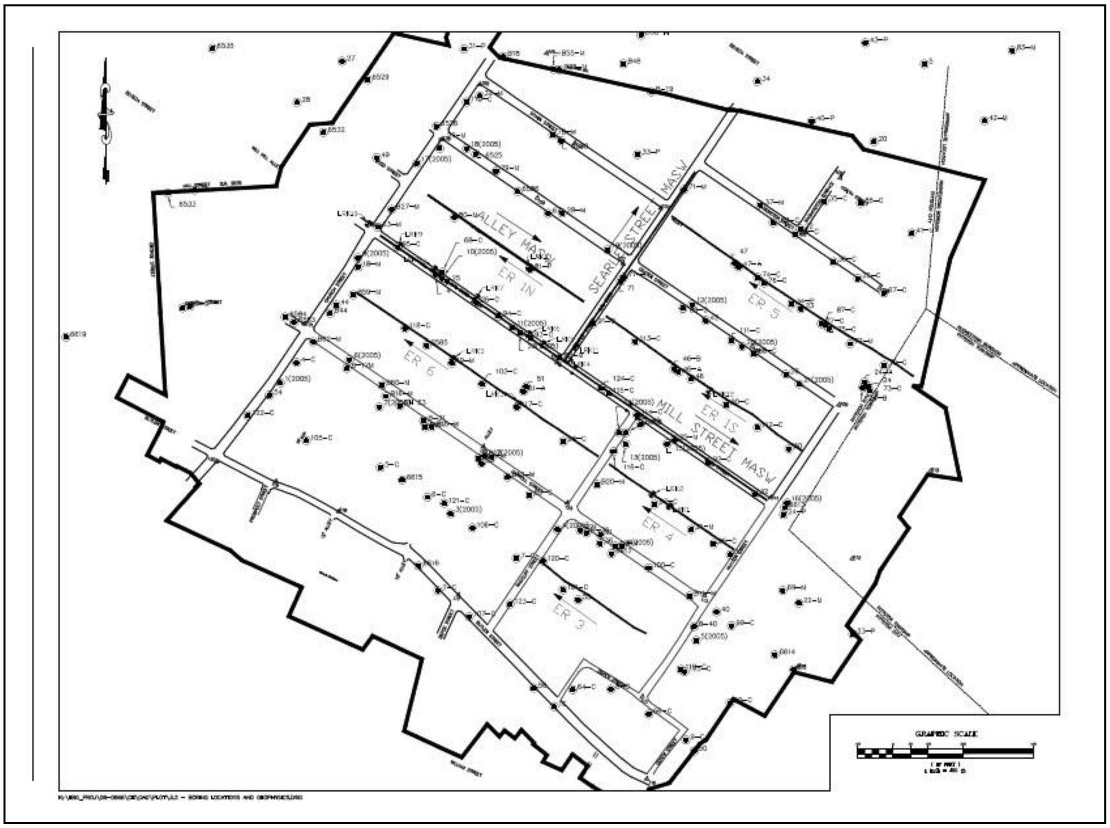

Figure 6 – Geophysical Traverse Locations.

Electrical Resistivity Imaging

Electrical resistivity imaging (ER) is typically conducted to measure the properties of the subsurface materials to transmit or conversely restrict electrical current, http://www.agiusa.com/supersting.shtml. The information collected during an ER survey is used to determine the location of relative change in geologic and soil strata which can suggest top of bedrock, areas of fractured or weathered bedrock, and changes in rock composition or competence. The method is also useful for mapping hydrogeologic and mineral resource boundaries.

In general, the geophysical investigation identified several near surface high resistivity anomalies that most likely represent bedrock pillars and bedrock. There are several very low resistivity anomalies that may represent the presence of grout material used in the flushing operations or water filled voids.

A sample of the ER data plot is shown in Figure 7.

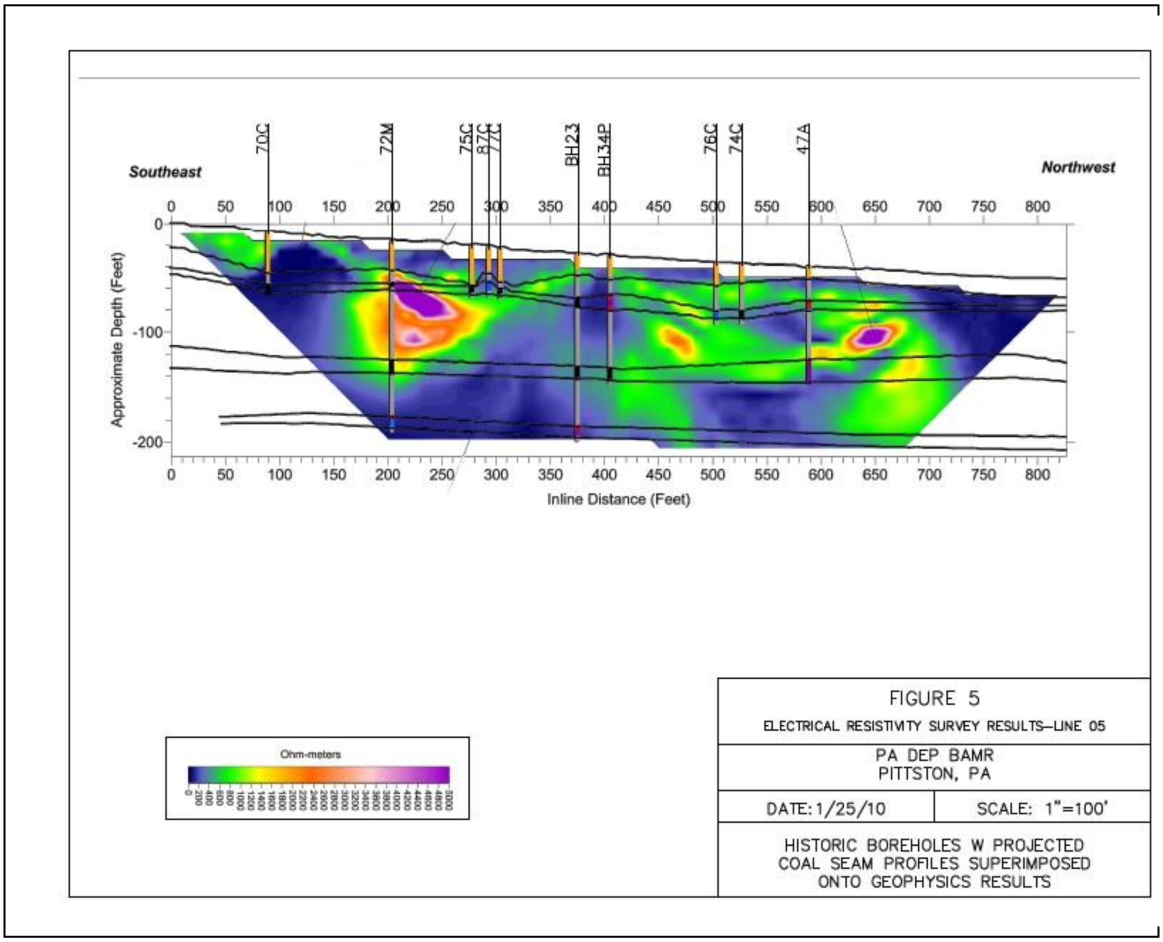

Figure 7 - Sample of Electrical Resistivity Imaging Data Plot.

Multi-Channel Analysis of Surface Wave

Three MASW profiles within the project area were performed with the first located along Mill Street, the second along Searle Street and the final profile located along the Alley immediately north of Mill Street. The MASW method employs multiple receivers (geophones) equally spaced along a linear survey line and measures the travel-times of seismic waves generated by an implosive source (e.g., sledge hammer), http://www.geomatrix.co.uk/stratavisor.htm. MASW is used to map bedrock topography, identify bedrock fractures, and abandoned mine workings, to depths upwards of approximately 120 feet Below Ground Surface (BGS). The MASW method was used along the main city streets because, as oppose to the ER method, it is generally not affected by urban noise sources such as buried utilities.

The Mill Street profile (Figure 8) was established along Mill Street between Hunter Street to the east and Church Street to the west. Nineteen borings, drilled as part of previous projects, were located along the profile. In addition, seven borings were drilled after completion of the geophysics assessment.

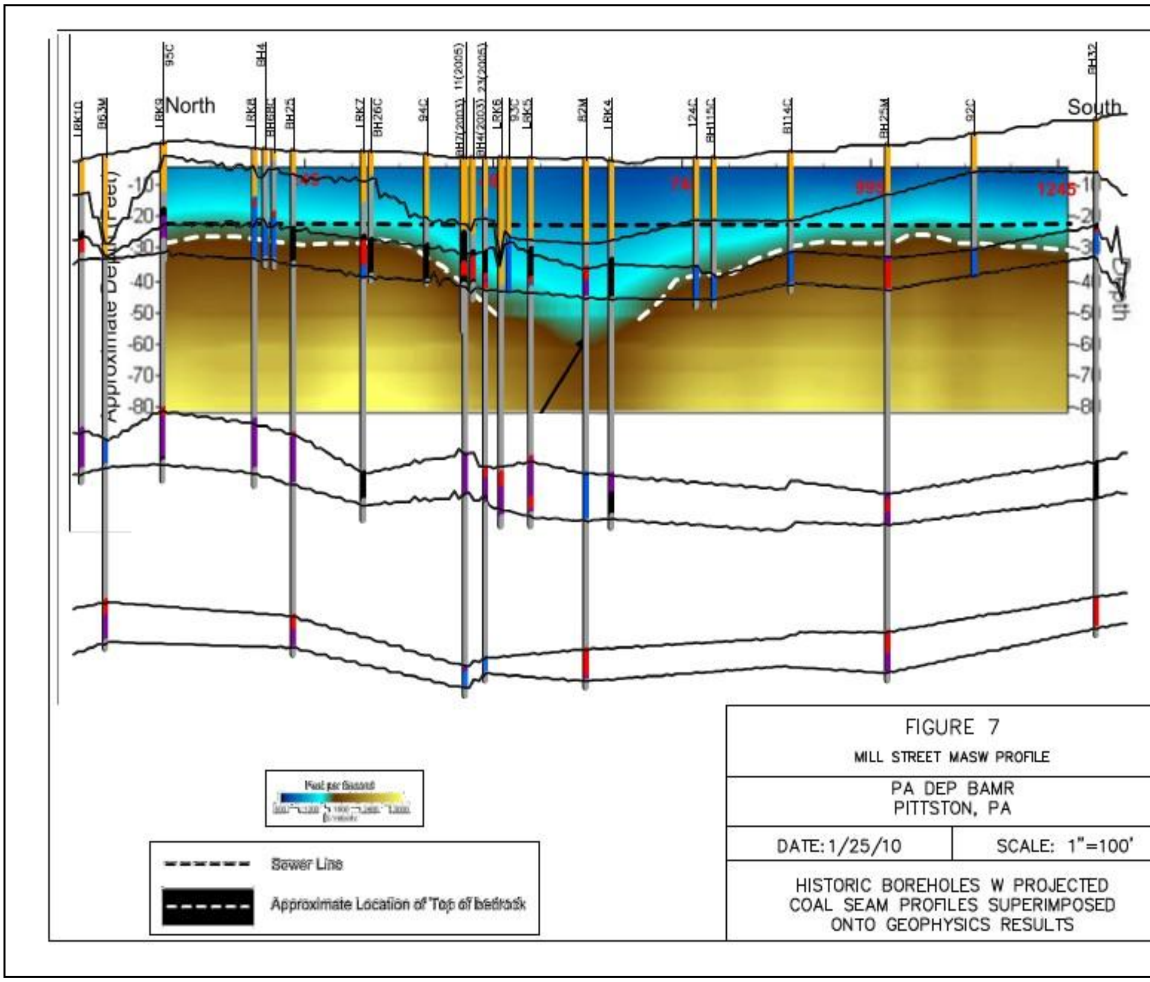

Figure 8 – Sample of Multi-Channel Analysis of Surface Wave Data.

The MASW data indicated the presence of a significant lowering of the bedrock surface below a portion of the sanitary sewer along Mill Street. This area may have provided a weak section along the sanitary sewer.

Ground Penetrating Radar

GPR systems produce cross-sectional images of subsurface features by transmitting discrete radar pulses into the subsurface and recording the echoes or reflections from interfaces between materials with differing dielectric properties, http://geophysical.com/. GPR profiles were collected along ER Lines as well as along the MASW Mill Street and Searle Streets profiles. In addition, ARM collected four GPR profiles in the back yard of the property at 136 Mill Street in an attempt to locate potential mine voids.

The GPR traverse found several parabolic-shaped anomalies with characteristics similar to possible utilities or different small rock pillars or possible voids. The GPR traverse along Mill Street was conducted along the sewer line to determine if there appeared to be any significant breaks in the line. Based on the GPR data, the sewer appears to be intact on the top section of the pipe. Investigations of the back yard of the property at 136 Mill Street were completed in order to attempt to locate potential mine voids. Two of the GPR profiles collected at 136 Mill Street have anomalies that appear as if the GPR energy was absorbed or scattered, which can be indicative of loose material.

Data Evaluation

Utilizing the querying and display functionality of ArcGIS, the boring database was filtered based on the presence of open or void space and flush material encountered within each of the coal veins. The data were then displayed using graduated symbols (sized and colored dots) to depict the thickness of either the void/open space or the flush material. Based on this analysis, Kimball was able to verify that the vast majority of open or flushed zones within the Checker and Marcy Veins fall within the limits of mining depicted on the available historical mine maps. However, a number of historical borings reported either voids/openings or flush material within the Pittston Vein at locations where mining is not indicated on the maps. Based on these observations it is assumed herein that the Pittston Vein has been mined throughout a significantly larger portion of the study area than is indicated on the mine maps.

Using the three-dimensional surfaces of the coal veins and rock stratigraphy in the computer model, Kimball generated an isopach (thickness) (ISO) surface of the upper most rock layer overlying the Checker Vein (Figure 9). Based on this analysis, it is clear that relatively thin overburden rock is evident in the northern and eastern portions of the study area. By superimposing the isopach thickness of the rock layer above the Checker Vein with the boring information on voids/openings and flush material thickness, the "high risk" portions of the study area were identified. The "high risk" areas were defined as areas where open/void spaces and flush material within the Checker Vein were reported in the borings that are overlain by relatively thin rock (less than 20 feet thick).

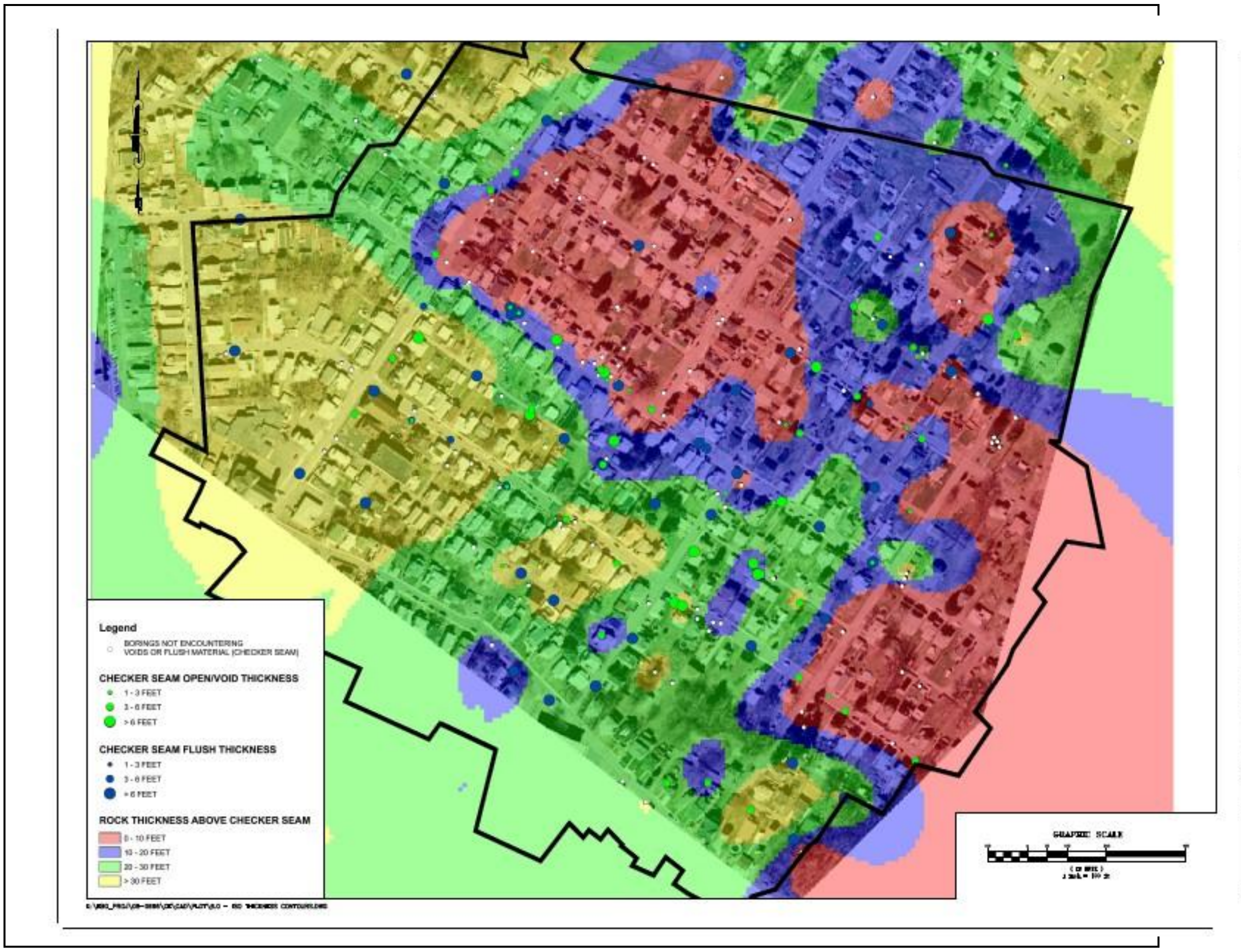

Figure 9 – Checker Vein ISO Map

The MASW traverses conducted along Mill Street and Searle Street indicated a potential historic subsidence event near the intersection of the two streets. The feature is supported in the computer model also. This apparent subsidence feature is interpreted to be a significant source of the problems associated with the residence at 136 Mill Street and may be of future concern to planned sewer replacement activities.

Conclusion

It appears that the historic mining beneath this area is extensive, and has led directly to subsidence impacts. It is also clear that mine subsidence within this study area is not complete, since numerous small and large voids were evident in several of the borings assessed. The use of the computer model with other new technology, coupled with historical data, helped the BAMR team identify areas that may have a potential for future subsidence problems and helped to design the proper remediation plan.

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