REMOTE SENSING, VISUALIZATION AND MODELING OF THE DIAMOND COAL MINE IN HAZLETON, PA[1]

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Abstract: More than two hundred homes in Hazleton, Pa. were found to have benzene vapors (a known carcinogen) from one of the largest underground gasoline storage tank spills in PA history. Remediating this site became the number one priority of USEPA Region III (EPA). A relic underground coal mine situated along a 3000 ft long plunging syncline beneath the Laurel Gardens neighborhood complicated site geology. The U.S. Army Corps of Engineers (USACE) determined if air filled mine voids existed and contained gasoline and gasoline vapors. The plan called for four study phases: Determining the mine location, Visualizing the geology and water table, Modeling mine pool effects on plume behaviors, and Field sampling to verify study results.

Mine Location: GIS was used to georeference and compare a 19th century mine map of unknown datum and coordinate system with old aerial photos, boreholes data and microgravity survey results. Extremely accurate location of the mine was critical for locating potential gas filled voids.

Visualization: A three dimensional geologic model was constructed from the GIS data and available site data depicting the relationship between site geology, the mine void, the mine pool elevation and the surrounding groundwater table. This predicted air filled mine voids in the upper areas of the syncline.

Modeling: A finite element groundwater model (FEMWATER) was developed to study mine pool effects on gasoline plume movements. Two different approaches were compared for modeling the mine pool. In one approach the mine void was modeled as high conductivity aquifer. In the adopted approach, it was modeled as an interior boundary with assigned heads. The model showed dissolved gasoline contaminants migrating to the mine.

Field Sampling: Using the gravity data and 3 dimensional mine model, several target areas for drilling were identified. Gas vapor explosion was a concern during drilling. The drilling plan incorporating the use of on-demand nitrogen gas connected to a drill rig. A gas filled mine void was encountered and an aqueous sample confirmed gasoline contamination in the mine.

Key Words: GIS, Microgravity, Mine Pool, FEMWATER

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Introduction

The Tranguch Site was the location of one of the largest underground gasoline storage tank spills in PA history. Benzene vapor was detected in more than two hundred homes in the Laurel Gardens neighborhood of Hazleton, Pa. Tranguch became a high-profile site due to public protests in Washington, D.C, and Harrisburg, PA and involvement of U.S. Senators Spector (R PA) and Santorum (R PA). Remediating this site became the number one priority of USEPA Region III (EPA). A relic underground coal mine known as the Diamond Coal mine situated along a 3000 ft long plunging syncline beneath the Laurel Gardens neighborhood complicated site geology. When the Diamond Coal mine operations ceased in about 1910, the steam pumps ceased operation and the mine flooded. The flooding was thought to have entirely inundated the mine with water which would have precluded any presence of floating free-phase gasoline within the mine. At the request of the USEPA, the USACE developed a plan to determine if any of the areas of the mine could be above the water table and therefore possibly be a conduit for gasoline and gasoline vapors. The multi-phase plan included four study phases: Determining the Mine Location, Visualizing the Geology and Water Table, Modeling Mine Pool effects on plume behaviors, and Field Sampling to verify study results.

Mine Location

The Tranguch Emergency Response Site is located in Hazleton, Pa. Several gas stations (including Tranguch Tire Service Inc.) in the Laurel Gardens neighborhood of Hazleton leaked large quantities of gasoline from their underground storage tanks. Gasoline-like odors were reported in 1990 (Ecology and Environment, 1996) although historic reports of gasoline odors had been documented in the area since the 1970s. During UST (Underground Storage Tank) removal at the Tranguch facility fist size holes in removed tank were reported. Gasoline, which leaked from the tanks, entered the groundwater beneath the homes in Laurel Gardens. Several residences were evacuated including one home in which free-phase gasoline flowed into the basement.

EPA began testing the air in homes in the project area for volatile Organic Compounds (VOCs). Benzene is a known carcinogen and comprises up to 5% of gasoline. Benzene is one of the most volatile of the many chemicals that make up gasoline. Benzene vapor was found in over 200 homes in the Laurel Gardens neighborhood. Several residents were diagnosed with cancer particularly leukemia, that many in the neighborhood attribute to benzene exposure. The correlation between benzene exposure and leukemia, however, has not been proven by the Centers for Disease Control for the Tranguch site. Health studies are currently underway in the community.

Mine Research

The USEPA understood the potential importance of the Diamond Coal mine and tasked the USACE with investigating the mine and its potential interaction with groundwater at the site. The USACE hired an experienced local mining engineer (Gerald Gatti) to research the history of this mine.

Gatti Report.

In March of 1997 the USACE tasked Gatti Research Inc of Hazleton, PA. with compiling a report on the history of the Diamond Coal mine. Gatti produced a report on May 20, 1997 detailing the known history of the mine. According to Gatti (1997), the mine is a "*small part of the Buck Mountain Vein South syncline*." Gatti researched the second geological survey mine map and noted that mining started in the Diamond coal mine around 1880 and concluded around 1900. Mining was conducted by Kemmerer and Company by hand drilling and blasting with black powder. The coal was loaded by hand and hauled in small cars by mules. Two different slopes were mined, the Harleigh #5 was mined first and the Fishtail slope was later driven on the south dip. The Jeddo Highland Company mined a small syncline adjacent to the Diamond coal mine, but never connected to it.

The Diamond Coal mine is part of a small syncline with fairly steeply dipping sides. The mine is approximately 600 feet wide by 2000 feet long (Fig. 1). The depth of the mine from the ground surface varies between less than 10 feet to over 130 in the Laurel Gardens Neighborhood. The thickness of the coal seam was generally between two and five feet. According to Gatti (personal communication, 2001) several vertical airshafts would have been

Figure 1 Historic Mine Photo with Superimposed Current Street Map

located around the perimeter of the mine, but no trace of these air shafts has been found. The video analysis of mine wells has shown that the mine appears to still be largely intact. Most of the wells penetrating the mine show the mine is still open and has not caved-in. The main mine shaft entrance is still visible today, but has been filled-in. A large sinkhole marks the entrance. Remnants of the original "old slope" (Harliegh #5) entrance also are visible but not accessible

The nearby Jeddo tunnel is an engineering marvel from the 1800's which was used to dewater Eastern Middle Anthracite Coal measures. The Jeddo Tunnel still exists today and has had peak flows exceeding 100,000 gallons per minute of acidic mine water which is dumped into the Little Nescopec Creek. It had been speculated that the Diamond Coal mine also drained into the Jeddo Tunnel contributing additional drainage to the Little Nescopec Creek. Gatti concluded that "*there was never a connection of the subject area to the Jeddo Tunnel*."

Gatti also stated (personal communication) that the mine was never properly abandoned and backfilled. He noted that most of the mine was submerged by groundwater and probably required steam driven pumps to keep water from the mine when it was active.

The normal custom in the northeastern coal region is to “rob” the coal once the mining is near completion by removing the structural pillars left during active mining. Pagnotti Enterprises provided the only known map of the Diamond coal mine. The Pagnotti map appears to show that the pillars were “robbed” in this mine. The map shows most of the pillars as being stippled instead of solid lines. Gatti (personal communication, 2001) believes that this denotes that the pillars were robbed although this is not noted on the map. He felt that robbing was a very common practice and that this mine would have been no exception. The USACE believes that some pillars must remain since voids have been noted is several locations. It is speculated that if there were no pillars, the rock above the mine would have already subsided. There are two sizable unmined areas within the mine. The USACE believes these represent areas of the mine that did not have economically viable coal. It is possible that these large pillars would not have been robbed even if the rest of the mine had.

Aerial Photography Analysis

The USACE did an extensive aerial photography search of the area. Photographs from 1938, 1950, 1957, 1967, 1969, 1981, and 1995 were obtained from various sources and examined. The USACE digitally scanned these prints into the site GIS database. The computerized images were then “morphed” into a film loop, which sequentially shows the surface changes from 1938 to 1995.

The underground mine followed a thin 3-5’ coal seam which approached the surface near 21st and 23rd streets in the Laurel Gardens neighborhood. The 1957 photo shows excavation activity particularly in the northwestern portion of the neighborhood a full 10 years prior to construction of houses in this area. One of the larger excavations near the corner of Mead and 23rd streets is situated adjacent to the former Diamond Coal mine. According to the original mine map this area had coal approximately 10 feet from the surface which would have been easily accessible to strip mining. Several houses in this area now show severe signs of differential settling. The USACE believes this settlement is due to the placement of uncompacted backfill in previously strip-mined areas.

Visualization

Study Area Regional Geology

The study area is located in the Valley and Ridge Physiographic Province of Pennsylvania. According to Summary Ground-Water Resources of Luzerne County, Pennsylvania (Newport, 1977), "*the geologic units in Luzerne County include the unconsolidated Quaternary deposits; the Pennsylvanian Llewellyn and Pottsville Formations; the Mississippian Mauch Chunk and Pocono Formations; and the Devonian Catskill Formation, marine beds and Hamilton Group*."

Tranguch Local Geology

The Tranguch Site is situated over a thin Alluvium deposit which in turn overlays the Pennsylvanian Pottsville Formation. According to Newport the Holocene Alluvium deposits are generally on the order of 10 feet thick and composed of "*mixtures of clay, silt, sand and gravel derived from reworking of glacial material and mine waste and from erosion of bedrock.*"

The underlying Pennsylvanian Pottsville Formation is characterized by "*fine to coarse conglomerate, fine to coarse-grained sandstone, siltstone, and thin shale and coal beds.*" The underground Diamond Coal Land Company coal mine (Diamond Coal Mine) is located within this formation. Bedrock voids currently exist in the Diamond Coal Mine where the coal seam within the Pottsville formation was removed. The thickness of the coal mine and hence voids, reportedly varies between 2 and 5 feet. It is likely that the Pottsville formation continues under the coal seam. The general thickness of the Pottsville is thought to be 300 feet in this area. In the study area, the depth to this formation has been determined from the installation of numerous test borings and monitoring wells. The aerial extent of the coal mine is shown on Fig. 1.

The Mississippian Mauch chunk Formation underlies the Pottsville and is composed of *"shale, siltstone, and fine to coarse-grained sandstone, chiefly reddish to greenish shale predominates over lighter colored rock."*

Computer-Generated Mine Visualizations

The only known map of the Diamond Coal mine was provided by Pagnotti Enterprises (which still owns the rights to the mine). The Pagnotti map is undated, and shows features that must have been added long after the mine was abandoned. The map contains three dated historic mine pool elevations. The USACE digitized the map and created a layer for the mine floor elevations by entering the hundreds of hand written survey elevations and coal seam thicknesses from the map. The USACE then used computer software (GIS) to interpolate the elevation of the mine floor between surveyed points. In the potentially unsaturated areas, floor elevation interpolations were enhanced by utilizing the floor dip angles from the old map.

Data from soil borings, wells, groundwater sampling, home vapor sampling, and soil gas results were also entered into the GIS database. In addition, the geology from the FEMWATER model was included in the GIS database. The results were used for several purposes. A three dimensional GIS computer animation was also constructed to graphically show the relationship between the overlying houses and the mine. Additionally, this data was used to determine the depth to the mine for each house within the affected area of the plume. EPA sent individual copies of the depth-to-mine to homeowners in the project area.

Mine Pool Modeling

In 1997 the U.S. Environmental Protection Agency, Region III (EPA) tasked the U.S. Army Corps of Engineers (USACE), Philadelphia District to develop a groundwater model in the vicinity of the former Tranguch Tire Service Station in North Hazleton, PA. The groundwater model was used to assist the EPA in gaining an understanding of groundwater flow and contaminant migration in the area.

The USACE suspected that the abandoned mine was an important factor in understanding groundwater flow in this area. Notes on the Pagnotti map, indicated the mine pool had been measured at elevation 1507 (date and datum unknown). Assuming this elevation was in NGVD and plotting it with available groundwater elevations showed the mine could significantly influence groundwater levels and flow paths in the vicinity of the mine (see Fig. 2). Under these conditions, the mine would act as a groundwater sink. Mine Pool Behavior

Wells were drilled into the mine as part of the 1998 study. These wells showed the mine void to be approximately 8 feet thick at these locations. In addition, water levels taken during investigations recorded a groundwater elevation of approximately 1513 ft. NGVD during February 1998. This elevation is considerably higher than those recorded earlier in the year (approximately 1505 ft. NGVD), which indicated that the mine pool elevation fluctuates. These

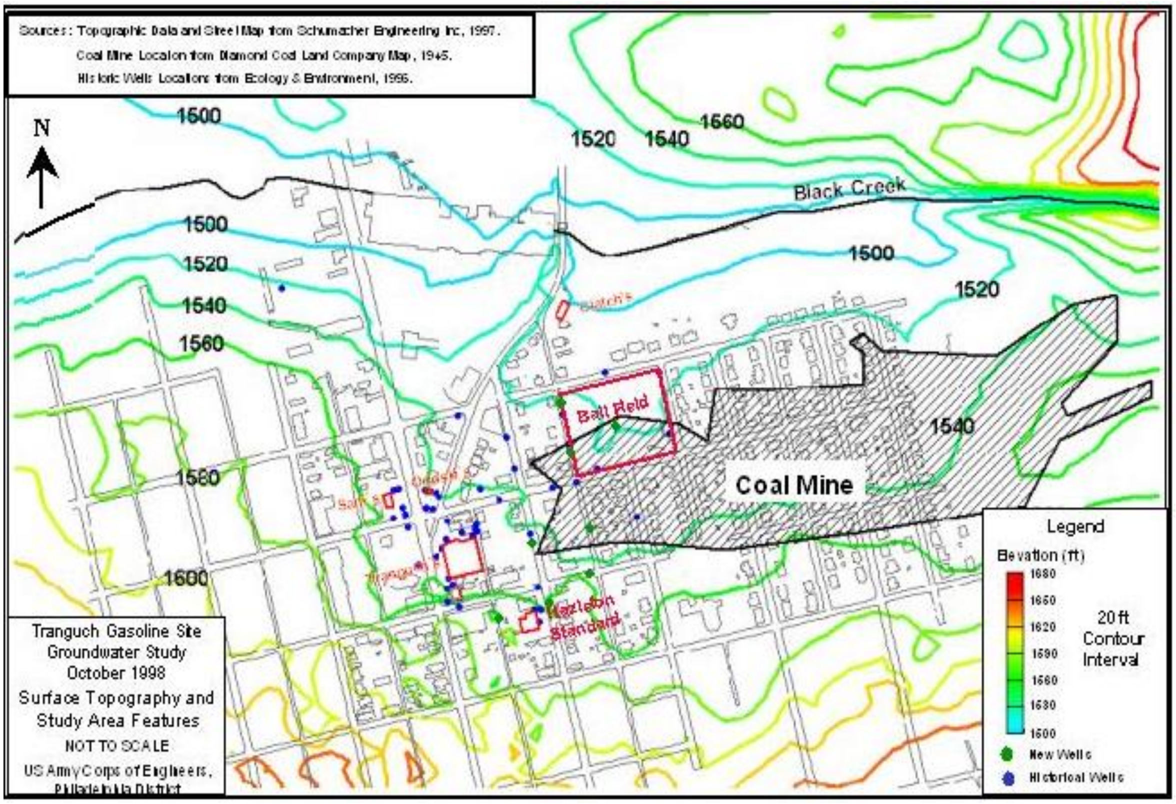

Figure 2 Surface Topography and Study Area Features

elevations bracketed the Pagnotti map elevation (1507). Subsequent investigations by the USACE during the fall of 2001 using transducers showed a 0.5 feet rise in only 2 hours followed by a slow recession. This is likely due to limited discharge capacity of the mine. It is estimated that 1 billion gallons of water reside in the mine.

Based upon these observations of groundwater elevations in the coal mine and surface water elevations in Black Creek (1495 to 1505ft NGVD in the vicinity of the mine), it is reasonable to conclude that some of the groundwater in the coal mine discharges through seeps into Black Creek. Field observations by PADEP and EPA noted seeps along the northeastern portion of Black Creek.

Model Selection

Due to the complex geology and groundwater flow conditions, FEMWATER was selected to model the site. The model's unstructured nature allows variable size mesh spacing that permits accurate definition of complex hydrogeologic conditions and the selective placement of resolution where it is needed to define creeks, potential plume paths and other physical features. FEMWATER is a modern, coupled implementation of two separate three-dimensional models: 3DFEMWATER (flow) and 3DLEWASTE (transport) (Gour-Tsyh Yeh et al, 1997).

Model Geology

Geology developed as part of the Visualization was translated to a three-dimensional finite element mesh using the Groundwater Modeling System (GMS). The resulting geology is shown on Fig. 3-5. The shape of the syncline and mine void are clearly shown in these figures. Fig. 5 shows a cross section cut along Wyoming Street. This section shows the "V" shape of the coal mine void. The mesh is comprised of 49,800 elements and 27,300 nodes in 20 layers. Land surface varies in elevation from 1607 to 1485 ft NGVD. Observed potentiometric heads range from a high of 1578 ft at the southern boundary of the model to a low of 1485 ft at Black Creek.

Boundary Conditions. Model boundary conditions were modeled as shown in Fig. 6. This was the first application of FEMWATER to model a mine void. As detailed below, two schemes were investigated to model the mine pool.

Mine Modeled as Coarse Media. Initially, mine void was modeled as course gravel with assigned heads controlling elevations along the model boundary. Conceptually this would approximate a collapsed mine where mine pool elevations and hydrographs significantly differed with location. The assigned conductivity controls the amount of hydrograph lag.

Mine Modeled as a Void. There mine pool elevations differed by tenths of a foot and the response to rainfall was uniform for monitored locations within the mine indicating good connection between sections of the mine. The most straightforward way to model this behavior was to model the mine as a void within the mesh and apply constant head boundaries to the mine face. Because mine pool elevations vary and were unknown at the time of the April 1995 observations which model calibration is based on, the value was set by trial and error. A final value of 1513 ft NGVD was the selected elevation for the calibrated model. This is reasonable given that April was a wet month and a high mine pool would be expected.

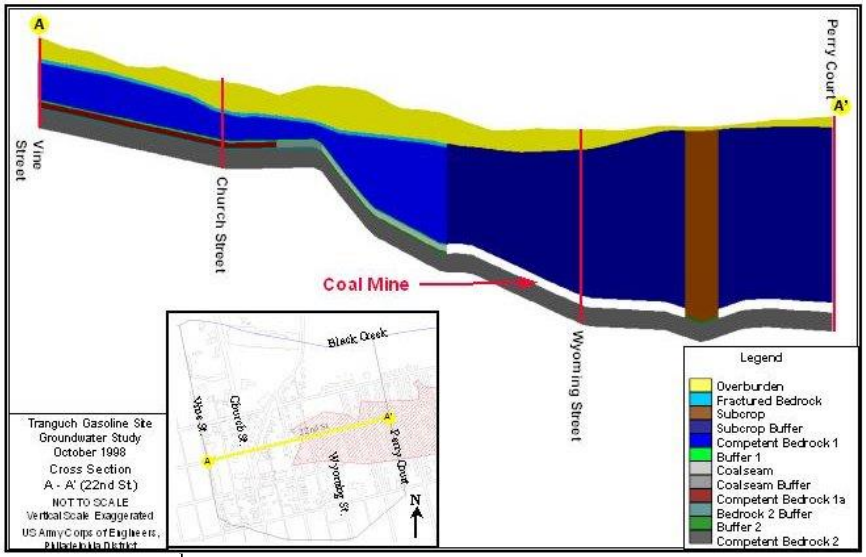

Figure 3 22[nd] St Model Cross Section

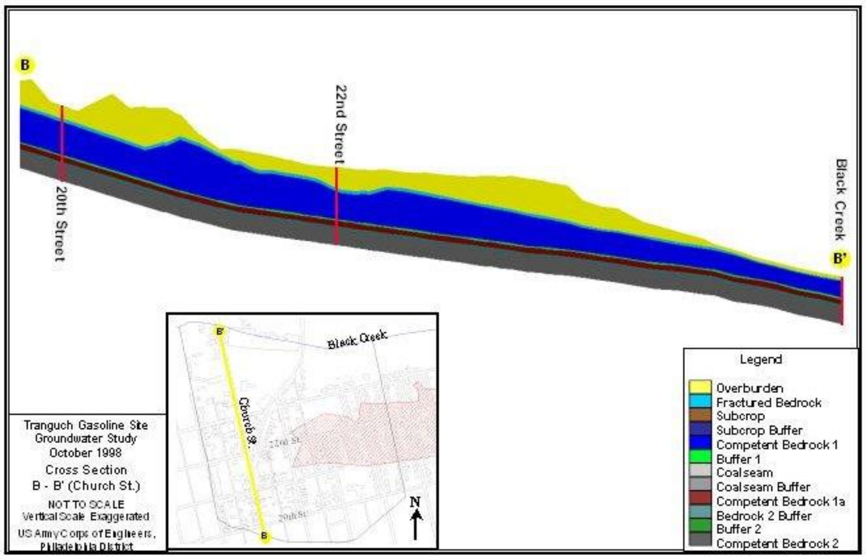

Figure 4 Church St Model Cross Section

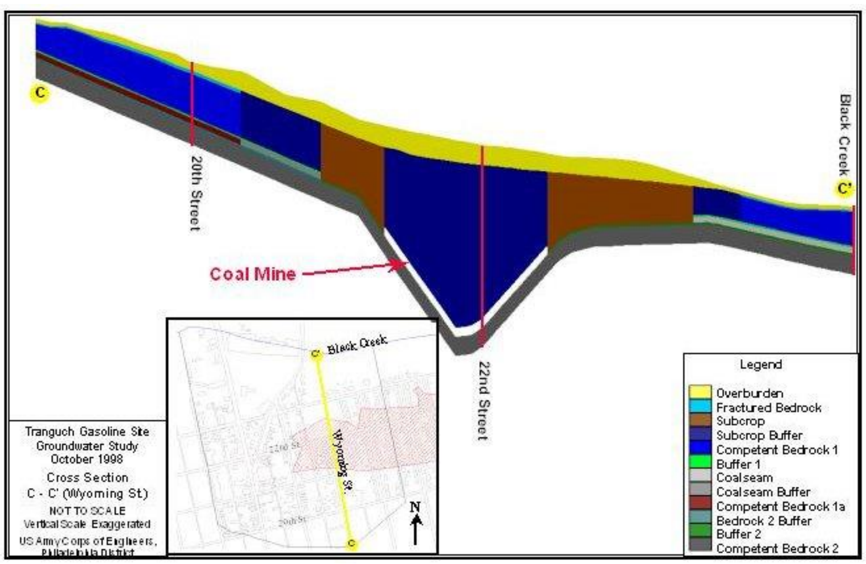

Figure 5 Wyoming St Model Cross Section

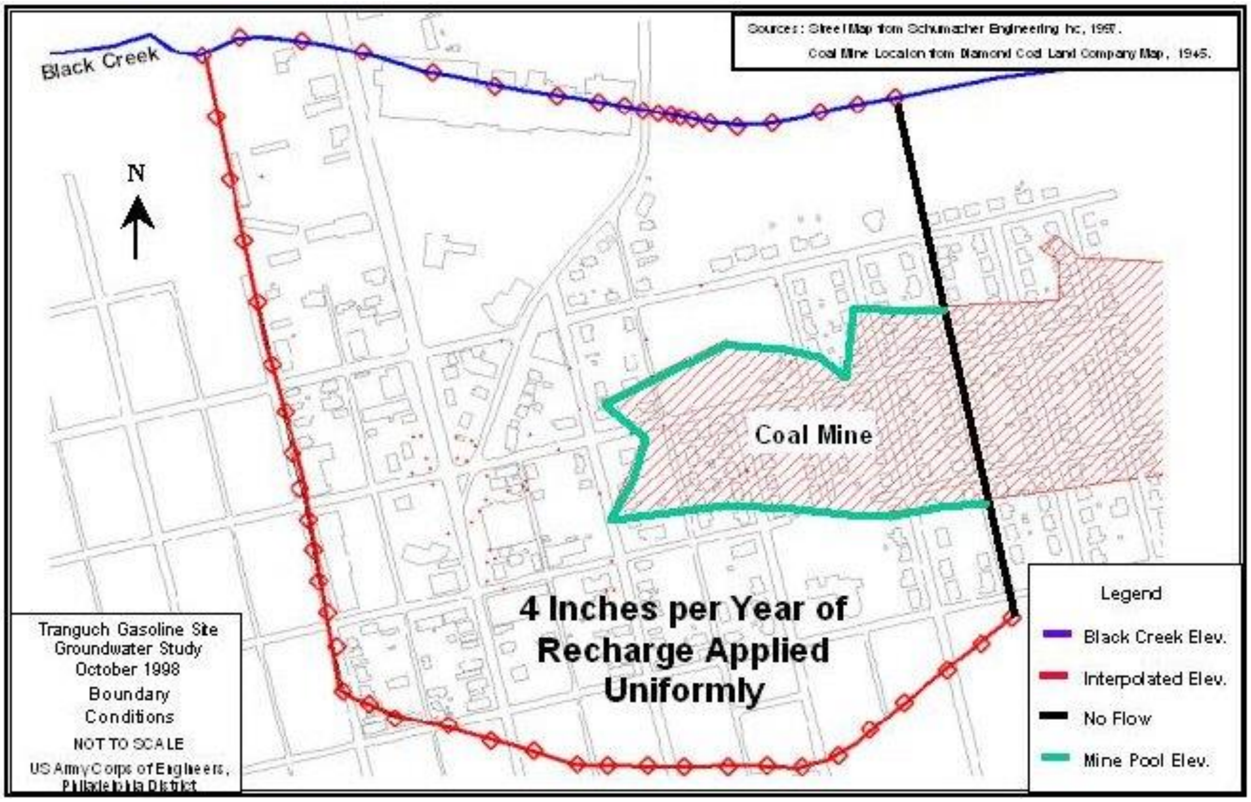

Figure 6 Model Boundary Conditions

Model Calibration.

The model was calibrated by trial and error adjustment of input parameters and boundary conditions to match simulated heads with observed heads in wells throughout the study area. Parameters were varied within reasonable ranges to achieve satisfactory calibration.

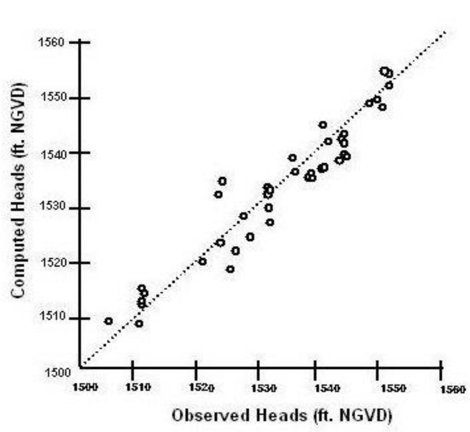

Figure 7 Observed vs. Computed Heads

As shown in Fig. 7 this model provides a reasonable match of the observed and computed groundwater elevations. In the calibration analysis, a root mean square error of 3.75 feet was achieved. Since the total change in observed head is approximately 100 ft, there is a three-percent error across the model. This error is less than the error associated with the topographic data, and is therefore considered acceptable.

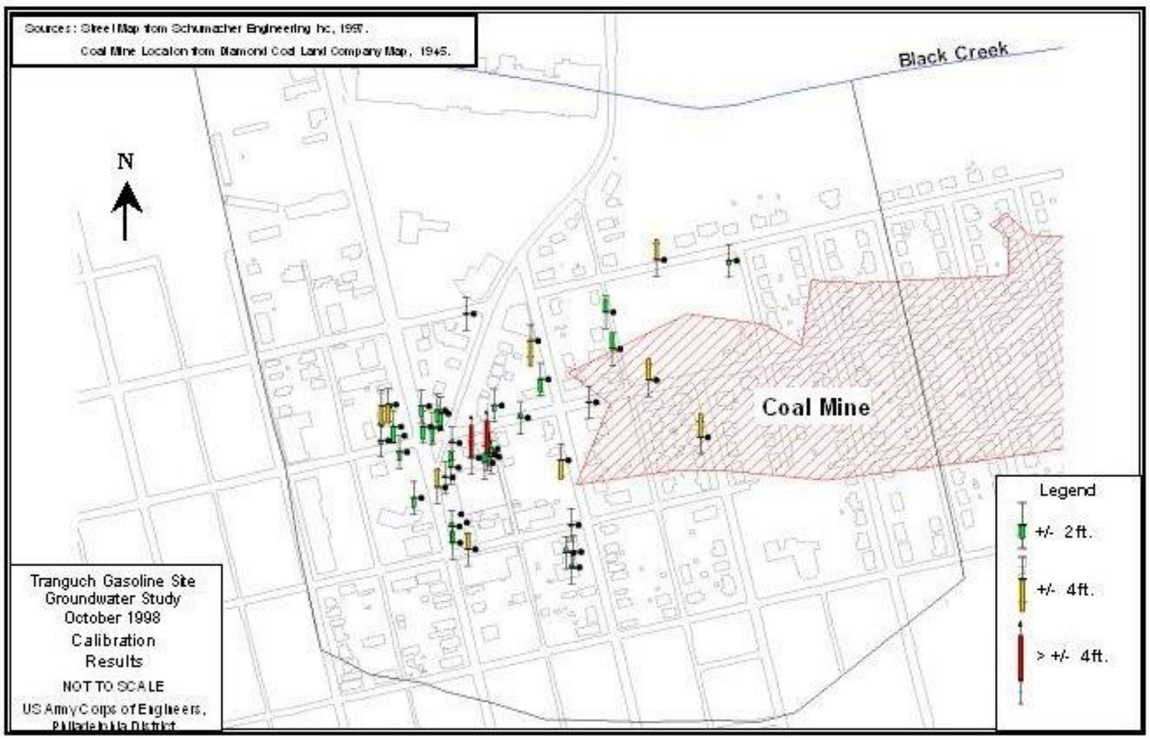

Figure 8 Model Boundary Conditions

Fig. 8 shows the calibration results within the model. The colored bars on the figure represent where calibration was conducted against the observed heads in the monitoring wells. Red bars represent points where the computed heads were greater than +/- 4 ft. from the observed heads. Yellow bars represent values that were between +/- 2 ft. to +/- 4 ft. Green bars represent points where the computed heads were within +/- 2 ft. of the observed heads. Overall, there is an excellent match between computed and observed water levels. Near the coal mine, the computed heads were slightly higher than the observed heads in the monitoring wells. While computed heads near Sam’s Amoco Station and Orloski’s Shell Station were slightly lower than the observed data.

Several factors explain the differences between the computed and observed heads particularly within the bedrock. During field investigations, many fractures were observed in the bedrock near the coal mine. Secondary porosity is a dominant factor in conductivities for the bedrock. Variations and trends in conductivity could not be described based on available data and average values were applied over the model domain. This yielded reasonable results on a macro scale and refinements were not attempted. In addition, the mine pool elevation at the time of the April 1995 field observations was not known. Mine pool elevation is a significant factor in the computed heads.

Results

The intention of the groundwater model was to show groundwater flow and contaminant migration in the area. Model results indicate that the mine pool elevation within the coal mine is a significant factor in the groundwater regime. Groundwater flow direction and contaminant migration varied depending upon the mine pool elevation within the coal mine. At low mine pool elevations (Fig. 9), the coal mine acts as the primary receptor for groundwater flow and contaminant migration. Through field investigations, a link was established between the coal mine and Black Creek through numerous seeps. Therefore, it can be reasonably assumed that Black Creek will be the ultimate discharge point for groundwater flow and contaminant migration. The model showed under high mine pool elevations (Fig. 10), groundwater flow and contaminant migration traveling northeast with Black Creek being the primary receptor and the coal mine being a minimal influence in the groundwater regime.

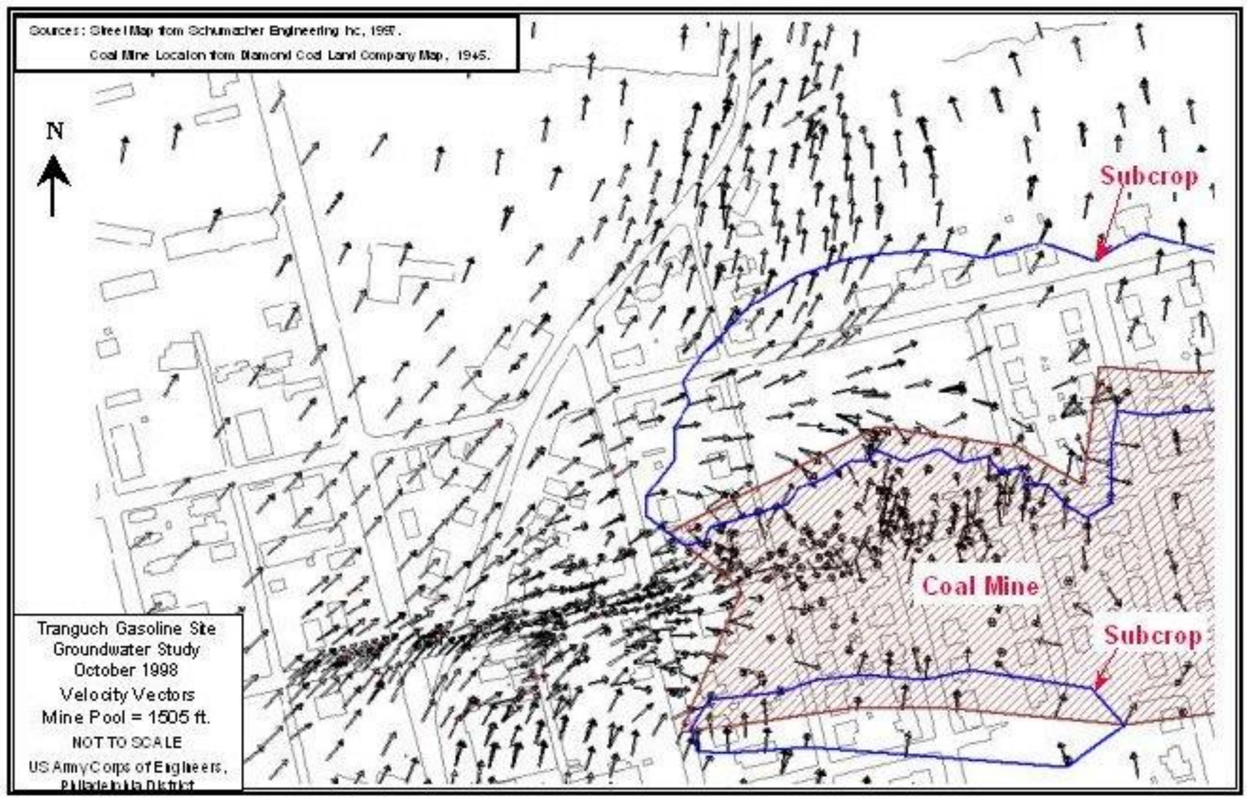

Figure 9 Low Mine Pool Velocity Vectors

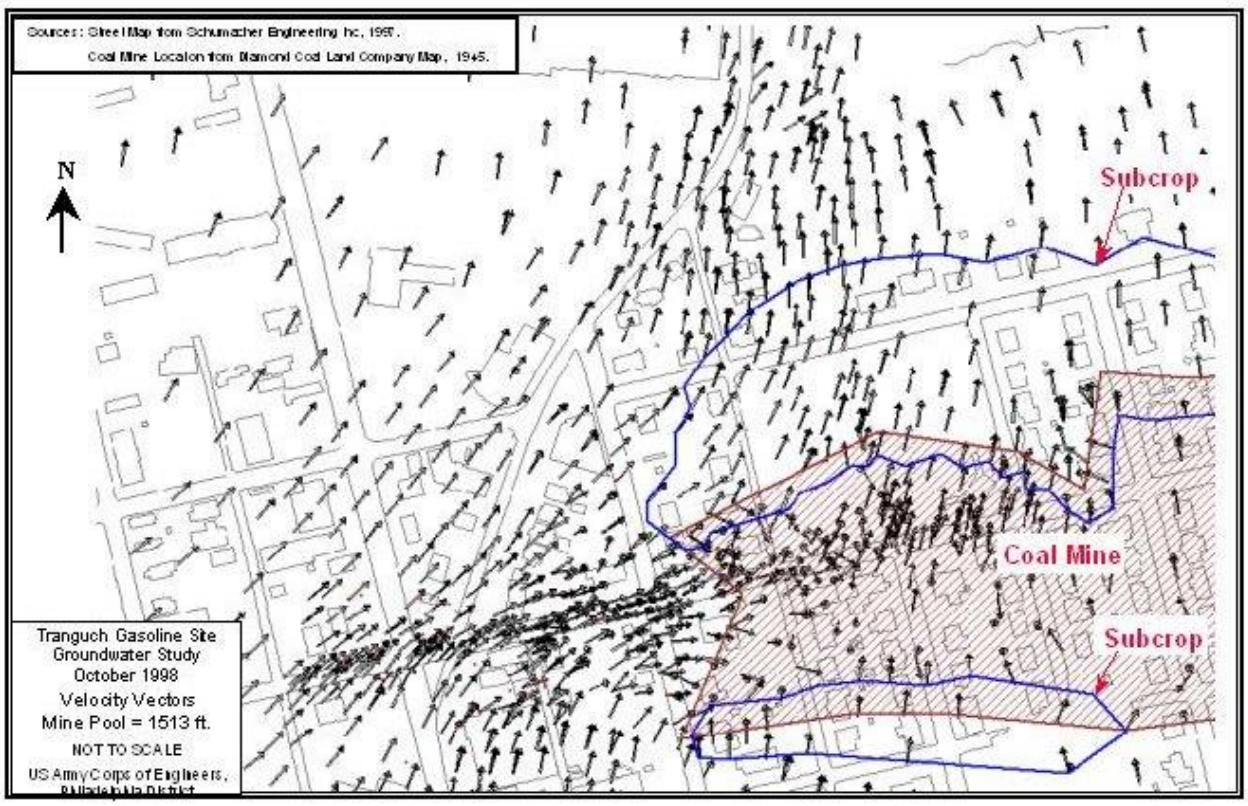

Figure 10 High Mine Pool Velocity Vectors

Field Sampling

Exploration of the Unsaturated Portion of the Mine

The Pagnotti mine map showed that little if any of the Diamond Coal mine would be above water. It should be noted that when the map was made there was no standard reproducible vertical elevation datum. Therefore, it was likely that the map would not be directly comparable to the standardized elevations currently used at the site for water levels and ground surface.

USACE Investigation

The USEPA realized the importance of verifying the elevation of the mine in areas that could potentially have unsaturated (dry) areas in the mine. The USEPA had prioritized the remediation of groundwater, sewer repairs and soil vapor extraction at the site. The USEPA tasked the USACE to begin preparations for locating and drilling into the unsaturated portion of the mine late in the summer of 2001. The USACE used the computer generated mine map which had been digitally overlain on the street map to identify potentially dry mine void areas (see Fig. 11). After these areas had been identified, the USACE had tasked Enviroscan Inc. to perform a microgravity survey done on three potentially dry mine void areas which would then be target areas for drilling.

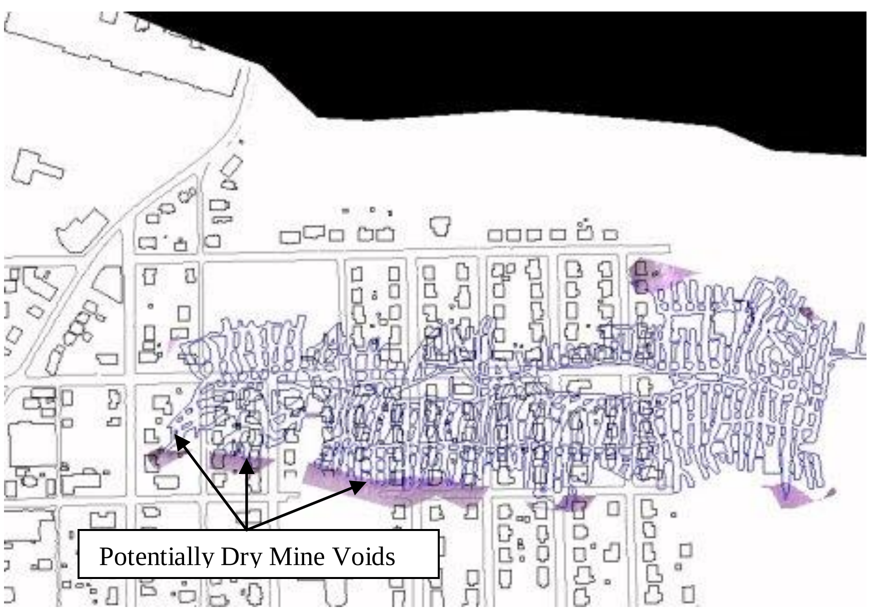

Figure 11 Potentially Dry Mine Voids

Microgravity Survey

For the microgravity surveys, Enviroscan made measurements at 5-foot intervals along profiles spaced 10 feet apart within the proposed survey areas. At each station, the acceleration of gravity was measured using a Scintrex CG-3M Autograv gravimeter. Enviroscan surveyed the locations and elevations of each microgravity survey station.

The gravity data were processed by applying the reference ellipsoid and earth tide corrections computed by the Autograv internal processing system. Drift, free air, and bouguer corrections were applied using standard formulae as computed in a spreadsheet. Due to the generally uniform relief across the site, terrain corrections were not necessary for this survey. The residual gravity data wee then contoured using the statistical kriging routine.

Based on the gravity survey, the USACE identified several target areas for drilling. Since the mine location was from a 19th century map, it was not clear that the drilling would successfully penetrate the unsaturated portion of the mine at any or all locations.

Drilling began in November of 2001. A total of 5 mine void wells were drilled. The first four locations did not encounter contaminated unsaturated areas.

Exploration of Contaminated Mine Borehole

The last borehole known as BAG-70 was the most difficult to drill. The location was on a residential property 20 feet from a residence. In addition, this location was suspected to be the most likely to be impacted by gasoline due to its proximity to the gasoline stations. During drilling, elevated Photo Ionization Detector (PID) readings indicating the presence of high concentrations of organic vapors were noted at the soil-bedrock interface (14 feet below ground surface). The unsaturated mine void was encountered at 26 feet below ground surface. Strong gasoline-like odors were accompanied by high PID and Flame Ionization Detector (FID) detections. Oxygen levels were less than 1%. The USACE had anticipated the possibility of gasoline vapors in the mine void and had jointly developed with its contractors an innovative method integrating nitrogen gas with the drill rig so that nitrogen gas could be pumped down into the drill hole. Nitrogen was connected directly with the circulation line of the drill rods, thus the nitrogen could be delivered to the drill head at any time. After the hole was completed, the nitrogen was pumped through a steel reinforced hose (resistant to melting) into the borehole to ensure that the oxygen level was below 5% to prevent ignition.

The USACE then retained Enviroscan to video the mine in the vicinity of this borehole. Enviroscan used a small tethered vehicle (Rovver 400) to perform the survey. They primarily utilized a crawler based pan-and-tilt color camera kit. Enviroscan also employed an external fluorescent light source in an attempt to illuminate the farthest reaches of the void. A small crawler was also mobilized for possible inspection of the void extents and for use in retrieval of a water sample.

The initial downhole inspection showed a void large enough that the supplementary light source could not sufficiently illuminate the furthest walls to make detailed observations. The inspection revealed that the borehole entered the void directly adjacent and slightly within a wall or pillar with a north/south strike. The coring apparatus appears to have spalled some rock off this vertical wall as it entered the void, allowing entry into the void (see Fig. 11). Unfortunately, the mine water was not visible from this location due to the orientation of the mine well (see Figure 12). The amount and size of the floor debris prohibited the use of the

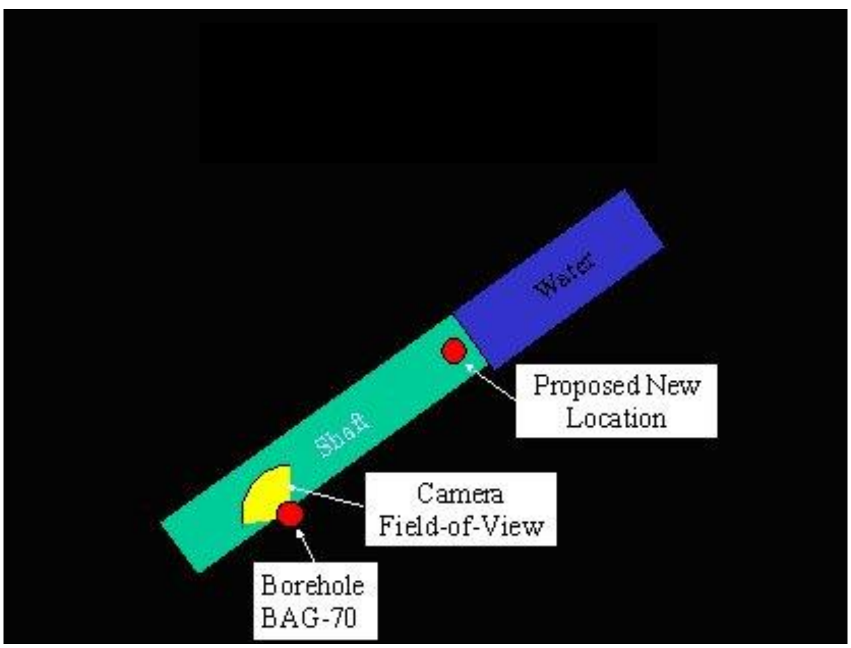

Figure 12 Borehole Orientation to Mine Shaft

small crawler unit; thus, robotic inspection of the void away from the borehole location was not possible. Therefore, it was decided that an aqueous sample could not be obtained from this location.

Enviroscan also performed an ultrasonic survey of the mine area. The ultrasonic survey was able to measure distances to walls in the mine in the darkness of the mine void. It was verified during this survey that the well had been partially drilled into the sidewall of the mineshaft. In order to measure dimensions of the inspected voids, Enviroscan employed a Senix Ultrasensor. The Ultrasensor is a non-contact ultrasonic distance measurer. The sensor operates by emitting an ultrasonic pulse and measuring the travel time of the echo return. Distance data were continuously transmitted and recorded on a computer at the wellhead.

The sensor was introduced into the void using a segmented rigid pole that allows the user to rotate the sensor to a known azimuth. The sensor distance readings, coupled with the known depth (pole length) and azimuth, permitted recording of a three-dimensional depiction of the line-of-sight from the borehole location into the void. The ultrasonic survey was able to measure the small unsaturated area and confirmed that there was not a clear path to the minewater.

Mine Vapor

The analysis of vapor, in the mine at BAG-70, sampled by EPA, indicated that high levels of gasoline compounds were present. High concentrations of hexane and heptane (both common gasoline hydrocarbons) confirmed that petroleum contamination had entered this mine tunnel.

The USEPA then tasked the USACE to obtain a groundwater (minewater) sample that would include *floating* free-phase product (if present) from the vicinity of BAG-70. The USACE used the GIS database to locate boreholes for groundwater sampling. Since the water level in the mine was constantly fluctuating and the unsaturated mine tunnel was at a fairly steep (20-25 degree angle) there was a degree of uncertainty about the exact boring location required to encounter the air-water interface in the mine tunnel. It was decided that the USACE would drill a well large enough to accommodate a 50 pound 4-wheel drive tethered remote vehicle. This vehicle would move underground in the tunnel to the minewater and retrieve a sample. Prior to drilling the large diameter hole, a small diameter hole was to be drilled in the same location to ensure that the vehicle would have an unhindered path down-slope to the mine water.

Installation of Second Borehole in Contaminated Mine Tunnel

On August 21, 2002 an additional microgravity survey was completed in the target area. This survey was designed to select a viable location for the second well. Arrangements were then made for the second borehole.

This borehole drilling program was custom designed to maximize safety and minimize any exposure to workers or surrounding residences. One thousand pounds of dry ice (solid carbon dioxide) was purchased to be placed in existing upgradient well BAG 70. The purpose of the dry ice was to ensure that the atmosphere in the mine tunnel had oxygen below the level that could support ignition. It was anticipated that the addition of this dry ice would cause fugitive emissions of gasoline vapors from the borehole. The USACE incorporated an innovative vacuum extraction system, which was designed to collect and filter the vapors emanating from the borehole, thus protecting workers and local residences from any concentrated mine vapors. The system was designed to collect vapors exiting the mine, but not to draw a vacuum on the mine. Drawing a vacuum on the mine would eventually bring the oxygen levels in the mine into the range of ignition. Since the drilling and video surveys could potentially provide a spark, it was imperative that the oxygen levels in the mine stay below 5% during drilling and video surveys.

Using the microgravity survey and rock core results a second location was determined and on Sept 4, 2002 borehole BAG-83 was installed. Unfortunately, the mine was not encountered at the predicted depth and the hole was abandoned. It was noted that at the base of this borehole were sediments that could have been cave-in materials. On Sept 5, 2002 a second boring BAG-83a was installed just a few feet from BAG-83. This location was selected based on the recent microgravity survey. The USACE predicted that the top of the mine would be located approximately 27 feet below the ground surface. The mine was encountered at 29.5 feet below ground surface. The USACE made a field decision to convert this borehole to a well. This decision was based on the unexpected depth of the mine and the failure to encounter the mine at BAG-83. The vacuum extraction contractor estimated that the system removed about 35 pounds of volatile organics from the mine simply by collecting the vapors exiting the mine during the drilling and investigation.

The USEPA tasked the USACE with performing an additional video and ultrasonic survey of well BAG-83a to clarify if this location would be viable for the installation of the large diameter well. On Oct. 7, 2002 the USACE and its subcontractor Enviroscan performed a video and ultrasonic survey of well BAG-83a. This ultrasonic rangefinder survey revealed that the open space encountered in BAG-83a was very small. Obstructions were encountered 4-5 feet from the borehole in most directions. The video survey revealed that water was present just a few feet from the borehole. Additionally, four small mine ceiling braces were noted in the vicinity. They appeared to be made of wood and were about 2 feet in height. Upon careful inspection of the videotape, the dry ice that was poured in upgradient well BAG-70 (for this inspection) was visible. The dry ice appeared to be on the hanging wall of a normal or thrust fault between wells BAG-70 and BAG-83a. The BAG-83a side was approximately 2 feet lower than the BAG-70 side. This would explain why the mine was encountered several feet lower than expected at BAG-83a and why groundwater was found at this borehole. It should be noted that other small faults were described on the Pagnotti map of the Diamond Coal mine, but none in this portion of the mine. Another explanation could be that subsidence occurred in the shallower portion of the tunnel and that the difference in elevation was due to a roof collapse.

<u>Contaminated Mine Water Sample</u>

Since it was not anticipated that the borehole would be so close to the air water interface, a field decision was made to take a sample using this new 4-inch diameter borehole. The USACE and USEPA contractors field-improvised a method of obtaining a groundwater sample. A new Tygon^{tm} sampling tube and 40 ml sample vial was taped to a series of thin fiberglass poles supplied by the video subcontractor. This sampling arrangement was then lowered down the hole and guided to the water by the downhole video camera. After several attempts, the vial and hose entered the water in the mine. A small vacuum pump was attached to the other end of the Tygon^{tm} tubing. The vacuum pump was started and after a few minutes, the sampling hose and vial were pulled from the borehole. The hose and vial contained enough liquid to completely fill three 40ml vials and partially fill a fourth. Sheen was clearly noted on one sample and droplets of contamination were noted in a second vial. The odor of weathered gasoline was clearly noted in all samples. The samples were then turned over to the EPA for lab analyses.

Other unsaturated (dry) areas of the mine tested did not contain gasoline vapors. It is unlikely that other areas of the mine contain gasoline since most of the mine is underwater. The other unsaturated areas of the mine are not located near the gasoline stations.

Conclusion

The Exploration and investigation of the Diamond Coal Mine beneath the Tranguch Emergency Response site was completed through the use of modeling, remote sensing, and visualization techniques. These tools allowed the USACE to successfully drill a borehole into a narrow target area of an underground mine thus allowing the USACE to obtain aqueous and vapor samples. The USEPA was then able to provide the community with important information about the contamination residing in the coal mine beneath the homes of the Laurel Gardens neighborhood.

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