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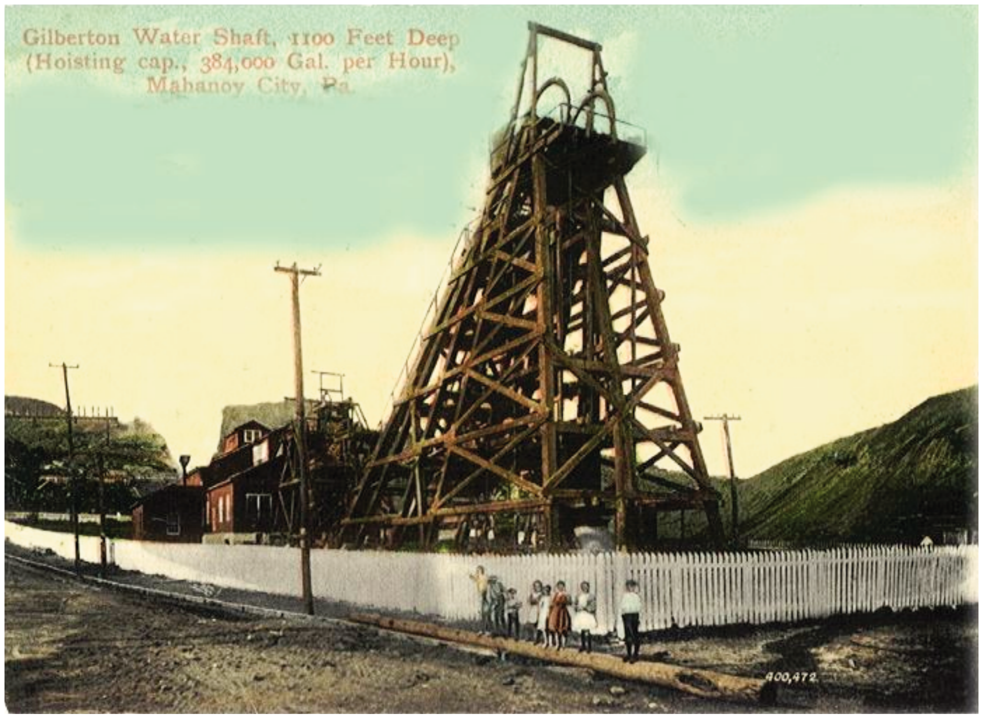

Gilberton water shaft in 1907 (see article on page 3). Reproduced with permission from www.mahanoyhistory.org/post-cards.html (accessed on September 26, 2018).

EDITORIAL

A Look Back and Ahead

Gale C. Blackmer, State Geologist
Pennsylvania Geological Survey

It's been quite a year. Mother Nature has not cut our state or country a break—there have been landslides, floods, volcanic eruptions, hurricanes, wildfires, and even an early-season snowstorm destined to become a Pennsylvania legend. We haven't been easy on each other, either. Whatever your involvement in the civic world, it has been difficult to avoid the increasingly hostile tone of public conversation. Maybe we can all learn to be just a little kinder to each other in the new year.

Here at the Bureau, we've weathered it all pretty well. Circumstances have brought us new opportunities for collaboration within state government. Although the effort was ultimately unsuccessful, we helped the Pennsylvania Emergency Management Agency (PEMA) apply for a federal disaster declaration because of landslides in Pittsburgh. In addition, we are advising the Department of Community and Economic Development (DCED) on underground natural-gas storage opportunities that would support economic development in western Pennsylvania. We aim to grow these relationships and look forward to others on the horizon for next year. The staff turnover you have read about on this page will also continue next year, as long-timers retire and newcomers fill the vacancies (we hope!). Although we can't predict everything the new year will bring, continuation of the Wolf administration gives us a stable platform from which to work.

As we prepare to close out 2018, I am grateful for the good people of the Bureau and the Department of Conservation and Natural Resources, and for our friends on the "outside." I hope that, wherever you are, you can say the same for your situation. Best wishes to you and yours for the new year!

Gale C. Blackmer

Evidence of Connectivity Between the Gilberton and Lawrence Mine Pools, Western Middle Anthracite Field, Pennsylvania

Joseph M. Sassaman[1]
Pennsylvania Department of Environmental Protection
Bureau of Abandoned Mine Land Reclamation

BACKGROUND

Introduction. Pools of water in underground coal mines, called mine pools (Table 1), exist due to the extraction of coal, which created openings in the bedrock, which were subsequently filled by groundwater and surface-water infiltration. It is hypothesized that four mine-pool flow systems exist below Gilberton Borough in Pennsylvania (Table 2). These pools fluctuate within the openings and conduits that miners created. Mine pools may need to be pumped in order to prevent the water from reaching the surface and causing flooding problems. When evaluating mine pools, the drawdown (lowering of the water level) is primarily within the conduit flow system, which responds rapidly to pumping. The other flow regimes are more difficult to analyze. The cone of depression (Table 1) created by pumping mine pools is only representative of the drawdown in the pool, or the water in the openings or conduits created by mining. The other flow systems are also influenced by pumping, but it has not been determined to what degree they are influenced. This study only examines the water in the mine pools that are part of the conduit flow system.

Table 1. Definitions

Barrier pillar	Solid blocks of coal that separate collieries underground.
Colliery	Coal mine, including all surface and subsurface facilities.
Cone of depression	A depression in the water surface surrounding a well where water is being withdrawn.
Gravity drain	Borehole(s) or tunnel(s) used to drain water by gravity from a colliery. No pumping is involved.
Hydraulic conductivity	Ability of water to move through geologic materials.
Mine pool	Water that collects in underground voids created by mining.
Multicolliery	A combination of underground mines that are considered to be interconnected

Table 2. Hypothesized Mine-Pool Flow Systems

Flow system	Description
Intact rock and coal	Solid rock (primary porosity)
Fracture	Joints and faults (secondary porosity)
Conduit	Tunnels, gangways, rooms, and other mining openings
Wash (regolith)	Unconsolidated material above bedrock

The Pennsylvania Department of Environmental Protection (DEP) (referred to as "department" in this paper),

[1] P.O. Box 69205, Harrisburg, Pa., 17106–9205, jsassaman@pa.gov.

Bureau of Abandoned Mine Reclamation, began pumping the Gilberton mine pool in the summer of 1972. The decision to install a Peerless deep-well pump in the Gilberton shaft that summer was influenced by June flooding in Gilberton Borough from a 19-inch rain event associated with Tropical Storm Agnes. Since that time, various projects have been proposed to reduce or eliminate the department's pumping to control the Gilberton mine pool. In this paper, the results of the monitoring of the Gilberton and Lawrence mine pools and the department's pumping at the Gilberton shaft are examined.

Previous Studies. Several previous studies about the mine pools around Gilberton exist. Technical Paper 727 of the U.S. Bureau of Mines (USBM) first identified the mine-water pools of the area and provided data on the elevation of the pools (Ash and others, 1949). The USBM published Bulletin 521 in 1953 that included important details concerning the barrier pillars (Table 1) in the Western Middle Anthracite Field (Ash and others, 1953). Sanders and Thomas, Inc., produced Operation Scarlift Report 197, which evaluated mine-pool elevations, flow between the mine pools, and the chemistry of the Gilberton shaft discharge (Sanders and Thomas, Inc., 1975). Conceptual Planners and Engineers, Inc., wrote a report on water availability of the Gilberton mine pool (Conceptual Planners and Engineers, Inc., 1985). This report also estimated annual inflow to the Gilberton mine pool and documented flow between the pools. The U.S. Geological Survey (USGS) released two reports on the Western Middle Anthracite Field: Water-Resources Investigations Report 85–4038 (Reed and others, 1987), and Scientific Investigations Report 2010–5261 (Goode and others, 2011). Reed and others (1987) described the water quality of mine pools in the Western Middle Anthracite Field. Goode and others (2011) modeled the regional groundwater flow in the Western Middle Field, estimated storage volumes, and introduced the multicolliery unit (MCU) (Table 1) concept. In 2011, the Eastern Pennsylvania Coalition for Abandoned Mine Reclamation (EPCAMR) released a report on mine-water resources in the anthracite coal fields (Eastern Pennsylvania Coalition for Abandoned Mine Reclamation, 2011). This report was a collaboration of work between the USGS, EPCAMR, DEP, the Susquehanna River Basin Commission (SRBC), and consultants. Extensive details are included about barrier pillar breaches, mine-pool elevations, and anthracite geology.

Location and Monitoring Setup. The Borough of Gilberton is located in Schuylkill County, Pa., approximately one mile north of Frackville (Figure 1). The borough was originally settled because of the vast deposits of coal in the area. The borough consists of three wards: Gilberton, Maizeville, and Mahanoy Plane. The easternmost ward, Gilberton, is the most susceptible to flood events. This susceptibility is, in part, the result of extensive coal extraction and subsequent surface subsidence equaling tens of feet in elevation throughout Gilberton Ward. The historic extraction of anthracite coal has created a permanent mine pool beneath the borough and has also contributed to surface and stormwater flooding problems.

The department had previously monitored the water levels in the Gilberton and Lawrence mine pools during 1976. It was decided to study these same mine pools again because of increasing costs of pumping (approximately $150,000 per year), the age/condition of the current pump, and to evaluate possibilities for developing alternative methods to attenuate flooding events. In March 2014, three Solinst Levelogger pressure transducers (loggers) and one barometer were installed in the Gilberton and Lawrence mine pools to measure water levels. Pressure transducers were placed in the Gilberton shaft and two monitor boreholes, BH–46 and BH–D1A (Table 3 and Figure 2). The barometer was also placed in BH–46 and was used to correct for atmospheric pressure influence on the loggers. The loggers were suspended in the boreholes with Kevlar cord attached to expandable locking well caps. The logger placed in the Gilberton water shaft was also suspended with Kevlar cord but was tied to a metal handrail located above the southeast compartment of the shaft.

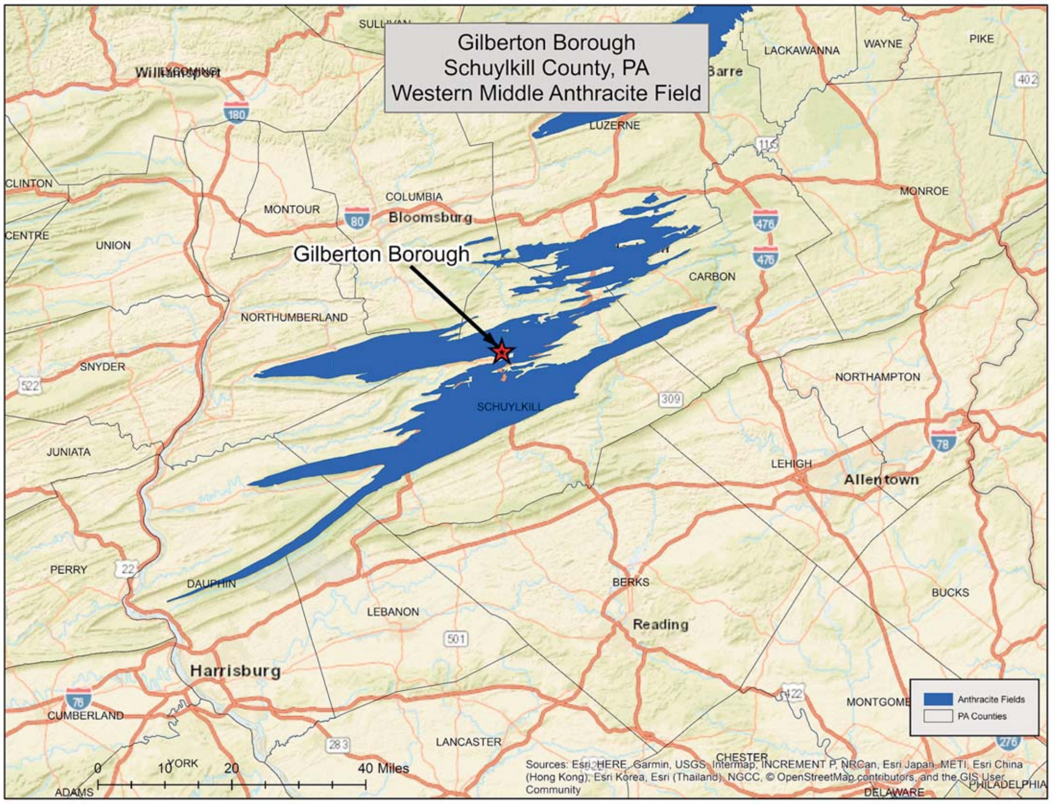

Figure 1. Location of Gilberton Borough.

The department also installed a Seametrics flowmeter/pressure meter/data logger on the discharge pipe of the department pump to monitor the flow rate of water being removed from the Gilberton water shaft. Between March 2014 and April 2015, all loggers and the Seametrics flowmeter were set to log data at 1-minute intervals. In April of 2015, all loggers and the Seametrics flowmeter were reset to log data at 15-minute intervals.

Water Withdrawals—Gilberton Water Shaft. The Gilberton water shaft (see cover photograph) contains a total of four pumps, two for the operation of the Gilberton Power Corporation's John B. Rich Memorial Power Station, one for Gilberton Coal's coal preparation plant, and one used by the department to manage the mine pool. The power station operates only one of its two pumps (keeping the second pump in reserve) for 24 hours a day, 7 days a week, at rate of approximately 1,000 gallons per minute (GPM). The preparation plant's pump is operated only when the plant is in operation, which is

Table 3. Details of Pressure Transducer Placement

(Datums: horizontal, NAD 83 state plane south; vertical, NAVD 88)

Location	Northing	Easting	Depth (ft)	Elevation (ft)	Operation range (ft)
BH–46 Barologger	2390724.09	537235.2546	5.4	1,145.92	n/a
BH–46 Levelogger	2390724.09	537235.2546	62.4	1,088.91	1,088.91–1,110.91
D–1A Levelogger	2385411.59	534882.824	37.7	1,087.19	1,085.18–1,107.19
Shaft Levelogger	2395086.971	538108.1828	45.7	1,091.13	1,091.31–1,121.13

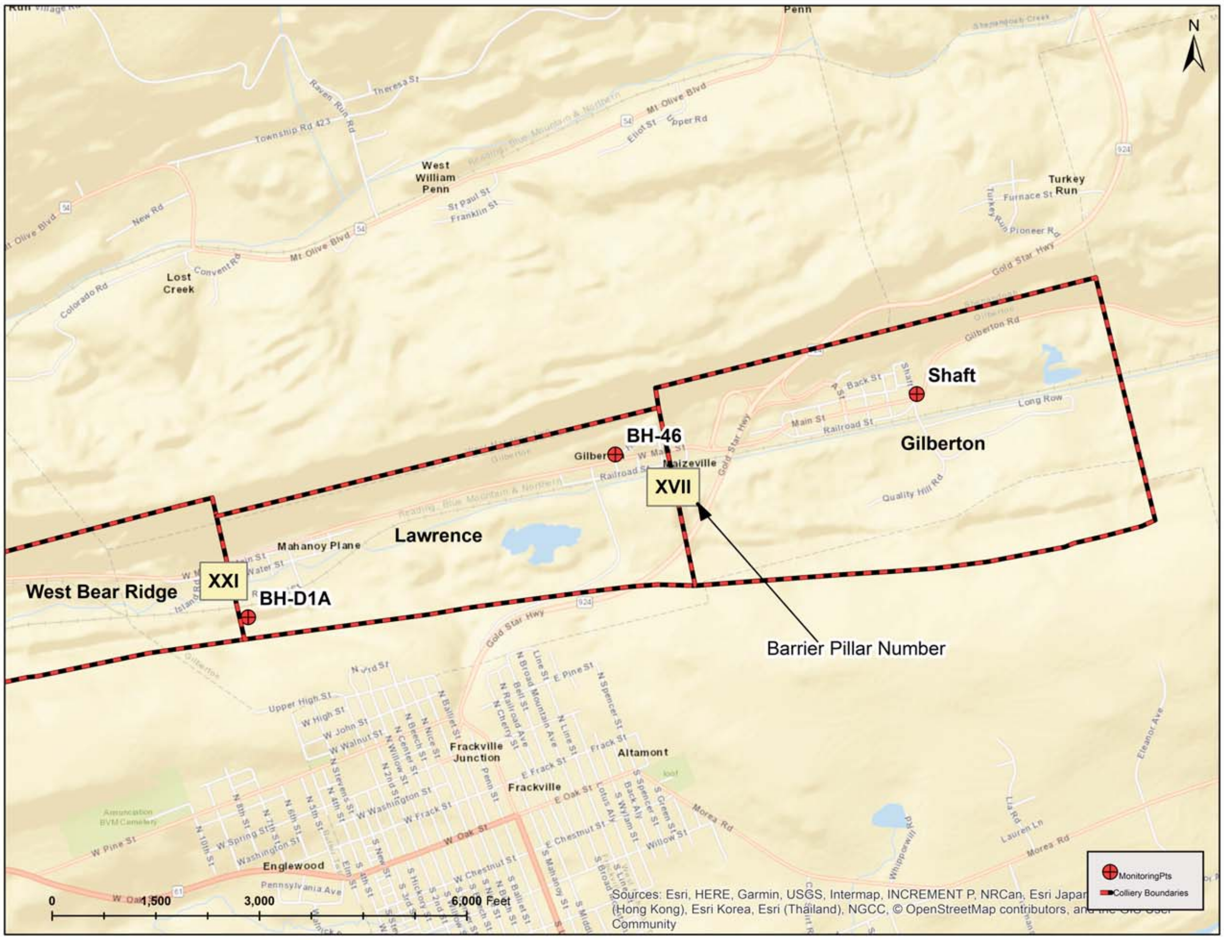

Figure 2. Monitoring locations in the Gilberton and Lawrence mine pools. The colliery boundaries are in the same location as the barrier pillars.

thought to be approximately 8 hours per day and 3 days a week. The department's pump operates 24 hours a day, 3 to 5 days per week, at an estimated average rate of 8,700 GPM (Kulish, 2014).

The power station maintains an SRBC Consumptive Use Permit to pump and consume up to 1.5 million gallons per day (MGD). The power station typically withdraws 1.4 MGD and returns 0.1 MGD to a settling pond that lies above the Boston Run and Saint Nicholas mine pools. The coal preparation plant excess and tailings water is returned to a retention basin where it infiltrates to the Gilberton MCU at an unknown rate (Kulish, 2014).

The department's pump provides the largest withdrawal from the Gilberton mine pool, with an average flow rate of approximately 8,700 GPM, and it discharges into Mahanoy Creek. This pump is operated manually by department personnel, who monitor the mine-pool elevation with a suspended tape measure and buoyant wooden block. The pump is turned on manually as needed to maintain the mine-pool elevation between approximately 1,090 feet and 1,105 feet as measured at the Gilberton shaft.

GEOLOGY AND MINING HISTORY

Geologically, the Borough of Gilberton is located in the Anthracite Upland section of the Ridge and Valley physiographic province and within the Western Middle Anthracite coal field. Bedrock in this area is of Pennsylvanian age and consists of the Llewellyn Formation and the underlying Pottsville Formation. The Llewellyn is the primary formation of interest and contains the mined coal beds within the project area. Noncoal lithologies of the Llewellyn Formation include conglomerate, sandstone, siltstone, and claystone (Danilchik and others, 1955). The Pottsville Formation contains lithologies similar to the Llewellyn Formation but with only one minable coal, the Little Buck Mountain bed. More than a dozen coal beds lie beneath Gilberton Borough in the Llewellyn Formation. Locally significant coal beds are listed in Table 4.

Significant structural deformation of the formation rock has also occurred in the Gilberton Borough area. The axis of the Mahanoy basin syncline lies nearly in the middle of the borough. Several smaller folds and faults are also located in the study area and are noted on the mine maps. The major fault in the area is the Suffolk fault, which is approximately parallel with Bear Ridge near the northern boundary of Gilberton Borough. This fault has thrust the Pottsville Formation above the Llewellyn Formation in many places and has impacted local coal thickness as well as deep mining in the Gilberton Borough area (Danilchik and others, 1955). Typically, the coal beds have a variable dip with an approximate range of 15 to 60 degrees; lesser dips are found near the axis of the syncline, and higher dips are found on both limbs of the syncline.

Table 4. Significant Coal Beds Below Gilberton Borough[1]

Significant coal beds below Gilberton	Approximate bed thickness (ft)
Diamond	7
Orchard	10
Holmes	9
Four Foot	5
Mammoth	42
Skidmore	7
Seven Foot	6.5
Buck Mountain	10

[1] Beds and approximate thicknesses based on a review of mine maps produced by the Office of District Engineer (Ashland, Pa.), dated 1922 (Office of District Engineer, 1922a–1922f). Actual thickness is variable within the Gilberton colliery.

Extensive surficial deposits referred to as "wash" are also present in Gilberton Borough. The wash is a poorly sorted (well graded) mix of clastic material having sizes ranging from clay to boulder. The wash is considered to be a combination of alluvial and colluvial material. According to the Mines and Minerals Journal of September 1898 (Hadesty, 1898), the unconsolidated material was 87 feet thick at the Gilberton shaft. It is likely that this wash material increases in thickness towards the center of the basin.

Gilberton Colliery. The Gilberton colliery, located north of Mahanoy Creek, was opened in 1862 by Kendrick and Tyson, which was succeeded by the Gilberton Coal Company in 1864. The colliery was operated by Gilberton Coal until the company closed and the operation was purchased by the Philadelphia and Reading Coal and Iron Company in 1879 (Zerbey, 1935). For this report, the Gilberton colliery also includes the Draper colliery, which was located south of Mahanoy Creek. The Draper colliery was opened in 1860 and was being operated by the Philadelphia and Reading Coal and Iron Company in 1893 (www.pagenweb.org/~Schuylkill/castle/castle43.jpg, accessed October 7, 2014). The Gilberton colliery was abandoned and all dewatering ceased in December 1938 (Shamokin News-Dispatch, 1938b).

Construction of the Gilberton water shaft began in 1895. The shaft was constructed through 87 feet of wash and 983 feet of rock and coal to a depth of 1,070 feet below the surface. Installation of the timbers was described by Hadesty (1898) as difficult due to "powerful pressure" and "so much water" that the wash resembled "quicksand." To maintain the integrity of the shaft, multiple layers of timbering were installed. The outermost layer was composed of 6-inch lagging, followed by 20-inch round

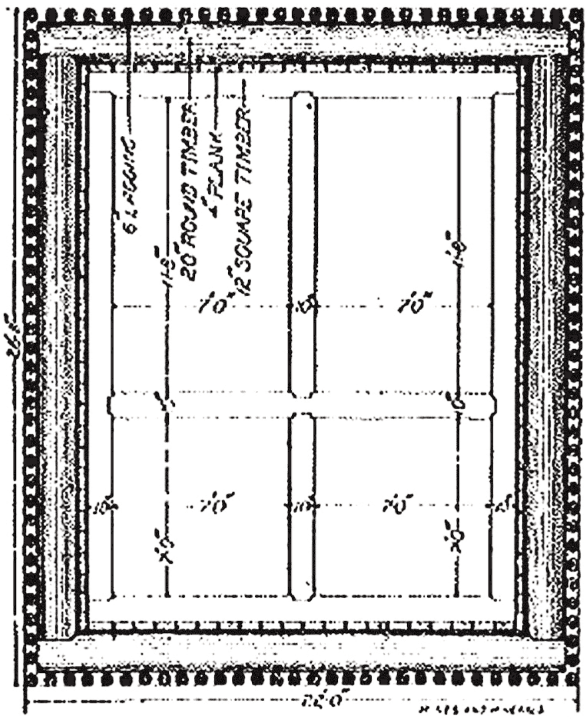

Figure 3. Gilberton shaft timber frame construction (Hadesty, 1898).

timbers; 4-inch planks were placed next, and the final set (innermost set) of timbers installed were 12-inch square beams (Figure 3) (Hadesty, 1898).

Cross-basin rock tunnels were driven from the south side of the basin (Draper colliery) to the north side of the basin (Gilberton colliery) to drain water from all the workings to the Gilberton Water shaft so the water could be removed from the mines. Originally, four large tanks were used to hoist (skip) the water out of the mine workings. Each tank had a capacity of 2,400 gallons and took 55 seconds to be lifted (Zerbey, 1935). The largest volume withdrawn from the shaft via hoisting was 292,800 gallons in one hour (Miller, 1904). This is equivalent to 4,880 gallons per minute.

The extraction of coal and water eventually led to surface subsidence over a large part of Gilberton Borough. According to Zerbey (1935), parts of Gilberton Borough had subsided up to 25 feet, and a large depression (sink) formed where a pool of water had collected. This pool was referred to as "Lake Stoddard" and was described as hazardous to the residents of Gilberton Borough. Zerbey also referred to Gilberton as the "Venice of Schuylkill County."

Lawrence Colliery. The Lawrence colliery was operated from 1868 until 1892 by Jacob Lawrence. It then came under control of others who worked the mine until 1905. It was idle until 1911 when the Harleigh-Brookwood Coal Company took over operations. In order to continue working the Lawrence colliery, two pumps with a combined capacity of 10,000,000 gallons per day (approximately 6,944 GPM) were used to dewater the mine workings. The workings in this colliery reached a depth of 340 feet below mean sea level (Madeira, 1915). Operation of the Lawrence colliery ceased in August of 1937. Dewatering of the mine stopped in December of 1938, shortly after the pumping operations ceased at the Gilberton colliery (Shamokin News-Dispatch, 1938a).

Barrier Pillars and Mine Pools. Barrier pillars are important features in underground coal mines to prevent migration of water from one mine to an adjacent mine. Barrier pillars, if left intact, would greatly reduce the flow of water between adjacent mines. It is important to understand barrier pillars when analyzing water movement between various mines, as their integrity influences how quickly and in what direction water moves underground. The barrier pillars of the Western Middle Field were detailed in Ash and others (1953). The mine pools were defined in Ash and others (1949). In the technical paper (Ash and others, 1949), the Gilberton mine pool was defined as Pool #16 and the Lawrence mine pool as Pool #17. The barrier pillar between these pools is Pillar XVII (Figure 2) (Ash and others, 1953). More recent work has defined the multiple mine pools detected in this area as an MCU. The MCU located here is called the Gilberton MCU and includes the following mine pools: Tunnel Ridge, St. Nicholas, Boston Run, Gilberton, Lawrence, and East Bear Ridge (Goode and others, 2011). There is evidence to suggest that all the above mine pools are connected to some extent. However, for this project, the focus has been only the Gilberton and Lawrence mine pools, because they were the pools originally evaluated in 1976.

The Gilberton and Lawrence mine pools are connected due to breaching on both the north and south dip of Barrier Pillar XVII. The barrier is breached on the south dip side of the syncline in the Holmes bed at elevation 1,058 feet, where a bootleg mine (a small mine operated illegally on someone else's property) was located (Office of District Engineer, 1922c). On the north dip side of the syncline, the barrier is breached in the Mammoth bed at elevation 1,024 feet (Office of District Engineer, 1922d). It is assumed that the breaches are consistent with the typical dimensions of gangways (underground passageways along the strike of the coal, used to transport men, equipment, and coal through the mine) in this region; widths between 9 and 14 feet and heights between 7 and 9 feet. The actual conditions of these breaches are unknown, but it is believed that water moves through them at a higher conductivity (Table 1) than a solid pillar would allow. The north and south dip sides of the basin are also connected by cross-basin rock tunnels, three in the Gilberton colliery and two in the Lawrence colliery (Figure 4).

RESPONSE OF MINE POOLS TO PUMPING

The department completed a pump test and calculations for a proposed gravity drain (Table 1) in the spring of 1976. During this test, the department determined that the Gilberton and Lawrence mine pools are connected and that a large-diameter, belowground gravity drain located in the Lawrence mine pool could maintain the water surface elevation in the Gilberton mine pool and would result in reduced pumping requirements at the Gilberton shaft. At that time, more than 62 pages of technical calculations were produced. These calculations were based on assumptions of discharge, colliery area, and water-level data from several boreholes (BH–8, BH–46, BH–58A, and BH–9A) and the shaft. Calculations also included information on flood routing and flood storage. Most notably, they indicated that the

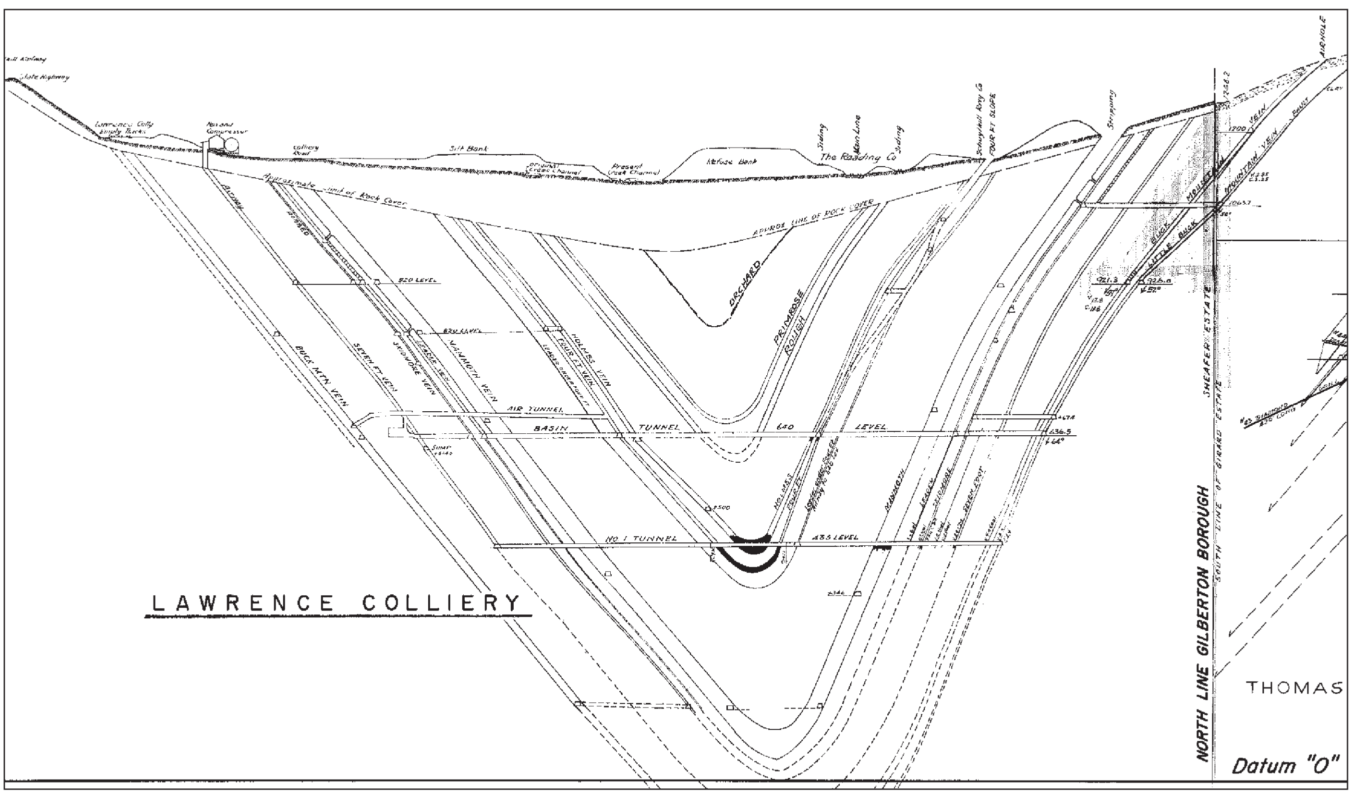

Figure 4. Cross section of Lawrence colliery showing multiple beds and tunnels. Harleigh-Brookwood Coal Company cross section (Harleigh-Brookwood Coal Company, [1920s?].

Gilberton mine pool would be several feet higher than the Lawrence mine pool even with the proposed gravity drain installed, and that pumping would still be required.

To confirm the results of the 1976 study, the department installed four Solinst pressure transducers in the Gilberton and Lawrence mine pools. Three of the transducers recorded water levels and one served as a barometer for atmospheric pressure corrections. Transducers were located in BH–D1A, BH–46, and the Gilberton shaft.

BH–D1A is located on the north dip side of the Lawrence colliery near the barrier with the West Bear Ridge colliery (Barrier Pillar XXI) (Figure 2). This boring was drilled in the 1970s to a total depth of 260 feet and penetrated a large void in the Mammoth bed at a depth between 210 and 241 feet. Investigations in August 2013 revealed that this borehole was plugged with debris. It was then opened to a depth of approximately 166 feet. An unknown blockage is located at this depth, but the elevation of the water level fluctuates within this boring, indicating a connection to the mine pool. BH–58A is the closest boring to BH–D1A having available historic water-level data. This boring (BH–58A) is north of BH–D1A, across the railroad tracks. A ten-year record of water levels (1982–92) is available for BH–58A. The ten-year average level for BH–58A is 1,095 feet. The average mine pool elevation for BH–D1A for the period of March through November 2014 is 1,099.7 feet. This is slightly above the ten-year average for BH–58A, but given the short duration of monitoring, it is believed that the long-term average of BH–58A better represents the average mine-pool elevation. Mine-pool elevations in BH–58A range between 1,087 feet and 1,111 feet. Similar conditions are expected in BH–D1A. The long-term average mine pool elevation at BH–D1A is considered to be 1,095 feet (although this fluctuates because of both pumping and rainfall).

BH–46 is located 4,448 feet west of the shaft on the south dip side of the Lawrence colliery west of Barrier Pillar XVII. Total depth of this boring is 196 feet and it terminates in the Four Foot bed (Reed and others, 1987). Boring BH–46 is open and represents the elevation of the Lawrence mine pool on the south dip side of the syncline. An average of the Lawrence mine pool elevations for the period 1982 to 2003 is 1,099.9 feet, with a range of 1,091 to 1,116 feet. From March to November 2014, an average of the Lawrence mine pool elevations was 1,101.4 feet. The long-term average of the Lawrence mine pool elevation at BH–46 is considered to be 1,100 feet.

BH–D1A is located 10,193 feet west of the department’s pump located in the Gilberton shaft. This boring is located in the area of a previously proposed gravity drain. Figure 5 shows the influence of pumping at the shaft on BH–D1A and BH–46.

The fluctuations shown in Figure 5 indicate that the pumping cone of depression extends to BH–D1A at Barrier Pillar XXI between the West Bear Ridge and Lawrence collieries, nearly 2 miles from the pump. Figure 5 also shows that BH–46 is influenced by the pumping at the shaft. Both BH–D1A and BH–46 respond similarly to the pumping. The difference in water elevation across the Lawrence mine pool is not fully understood, but it may be a result of the distance between the boreholes or the unknown condition of the cross-basin tunnels.

Water levels at the Gilberton shaft averaged 1,101.1 feet for the period of March through November 2014. This is similar to the 21-year average at BH–8, which is 1,099.69 feet. BH–8 is adjacent to the shaft but is plugged with debris. Gilberton mine pool elevations range between 1,094.63 and 1,119.48 feet at BH–8. The long-term average mine pool elevation at the shaft is considered to be 1,100 feet.

The long-term averages mentioned above were all recorded during a time when the department pump was operating. The static water elevation without pumping at the shaft is not known, but it is assumed to be at a higher elevation.

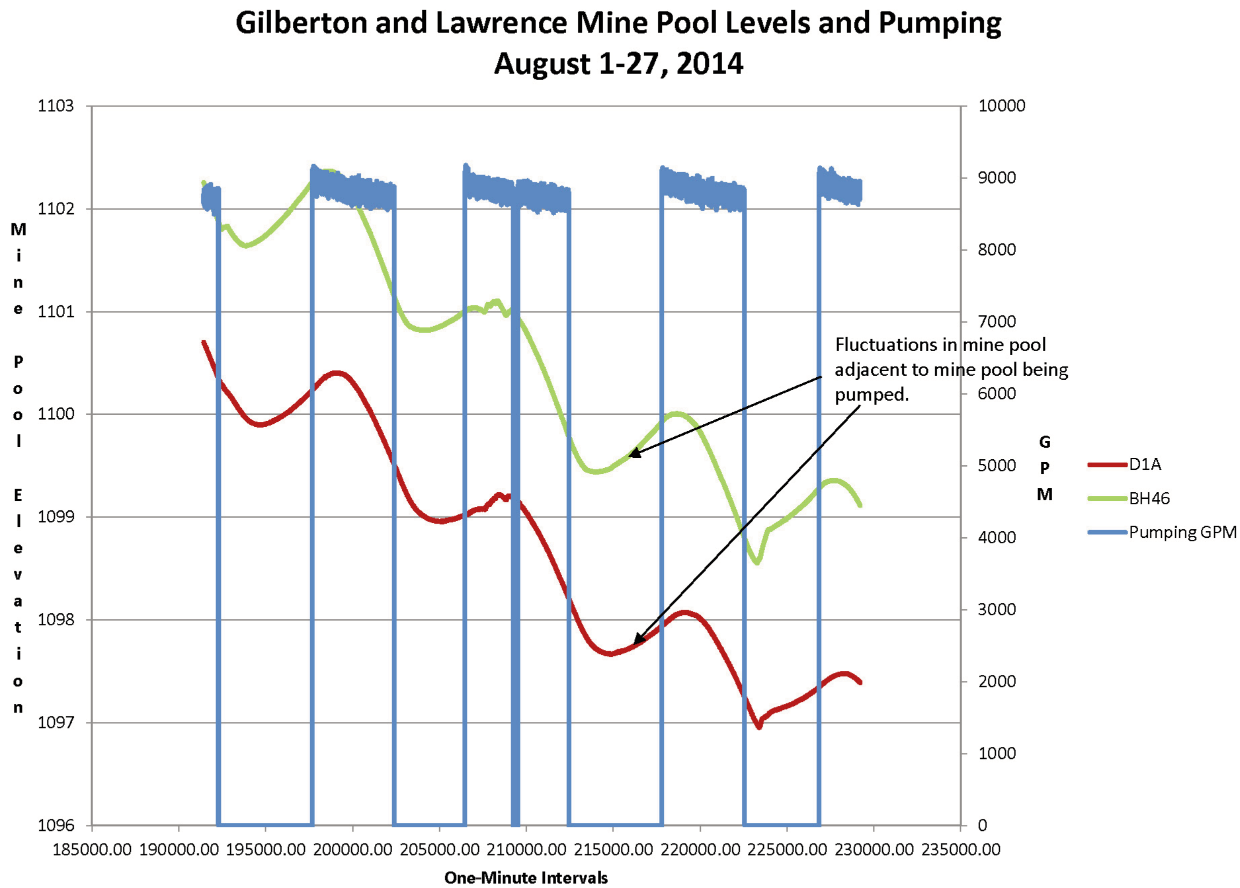

Figure 5. The influence of pumping on the Lawrence mine pool.

The mine-pool elevation at the shaft fluctuates dramatically, typically 10 feet during a pumping cycle. The Lawrence mine pool fluctuates only 1 to 3 feet during a typical 3- to 5-day pumping cycle (Figure 6).

The small dips in the level at the shaft (Figure 6, purple line) are believed to show when the preparation plant pump is operating. No attempt has been made to quantify all the inflows and outflows of the Gilberton and Lawrence mine pools. It is likely that a high percentage of annual precipitation makes its way to the mine pools. Sanders and Thomas, Inc. (1975), calculated that approximately 60 percent of rainfall in the Mahanoy Creek basin infiltrates into the mine pools. Figure 7 shows the flashy response of the mine pools to an inch of rain (as recorded at Tamaqua, Pa., 15 miles east). Infiltration into the Gilberton MCU mine pools is variable and enters through abandoned strip mines, crop falls, abandoned entries, storm-water basins, and through creek losses. Large rain events reduce the ability of the department's pump to dewater the mine pools.

The drawdown at BH–D1A was analyzed using AQTESOLV (software used to evaluate aquifer tests such as pumping tests), Microsoft Excel, and by manual methods to determine the transmissivity and hydraulic conductivity of the mine pools. Solutions were calculated using the Cooper-Jacob time drawdown method and the following assumptions:

- transmissivity is constant;
- pumping rate is constant;

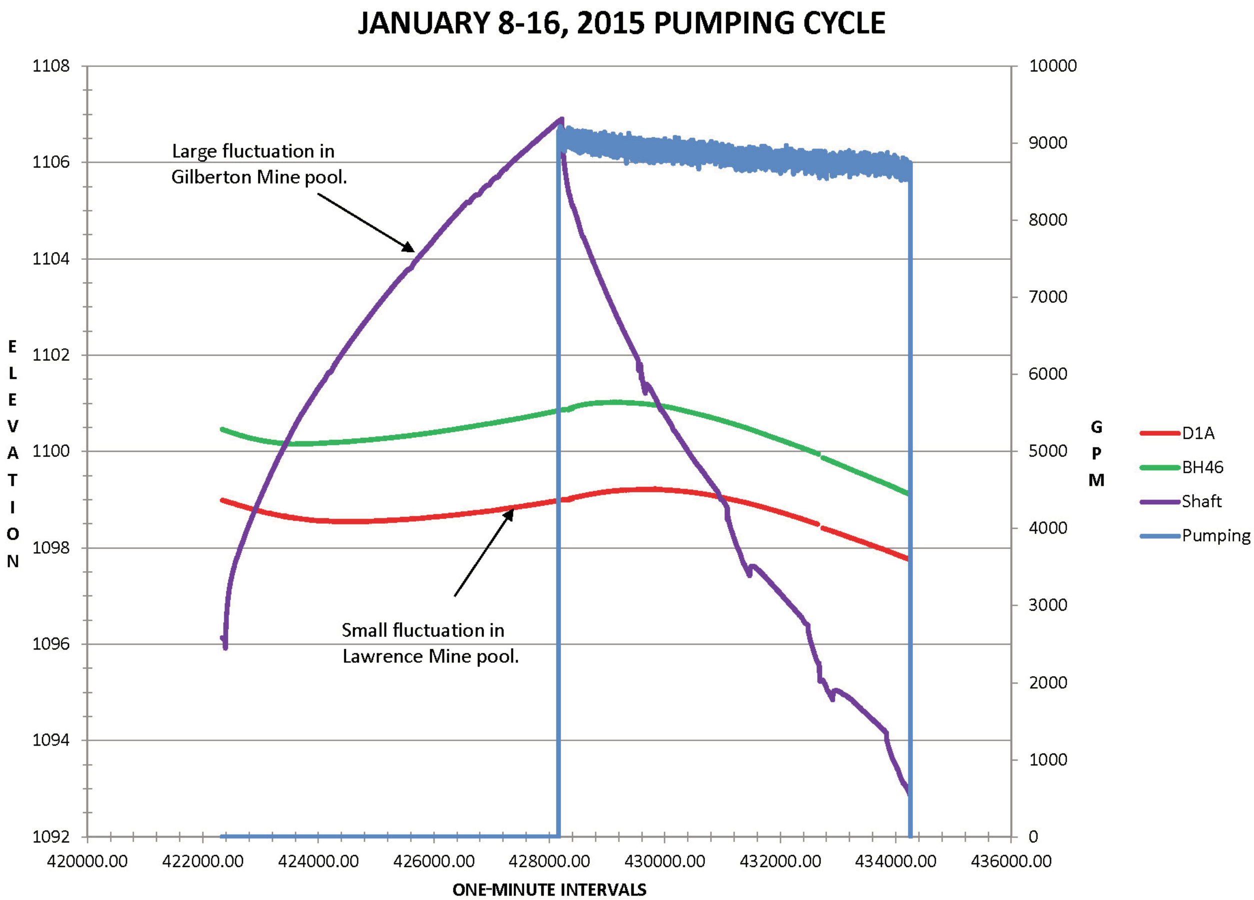

Figure 6. Typical pumping cycle showing the influence on mine-pool elevation.

- materials are homogeneous and isotropic;
- discharging well fully penetrates aquifer, and its diameter is small in comparison to the pumping rate, therefore, well storage is negligible;
- water withdrawn is entirely from storage and discharged instantaneously with a decline in head.

The hydraulic conductivity between the department's pump and BH–D1A was calculated to be between 128.7 and 197.6 feet per day, with transmissivities ranging from 132,800 to 204,000 square feet per day.

Due to generalized assumptions, this approach may not be the best method of quantifying the hydrogeologic properties of the mine pools; however, it indicates two things: the Gilberton and Lawrence mine pools are connected, and the cone of depression (in the mine-pool conduit flow system) extends farther than previous estimates. The 2010 Flood Insurance Study for Gilberton (Federal Emergency Management Agency, 2010) indicated that the cone of depression was only 1,600 feet. Recent monitoring shows that it extends over 10,000 feet in the down-gradient direction. Although not fully evaluated, it is hypothesized that the department's pumping cone of depression also extends to some of the up-gradient mine pools.

The flow of water between the mine pools varies depending on the elevation of the Gilberton mine pool. When the Gilberton mine pool is above that of the Lawrence mine pool, the flow direction is to the west from the Gilberton colliery to the Lawrence colliery. The direction is reversed when the

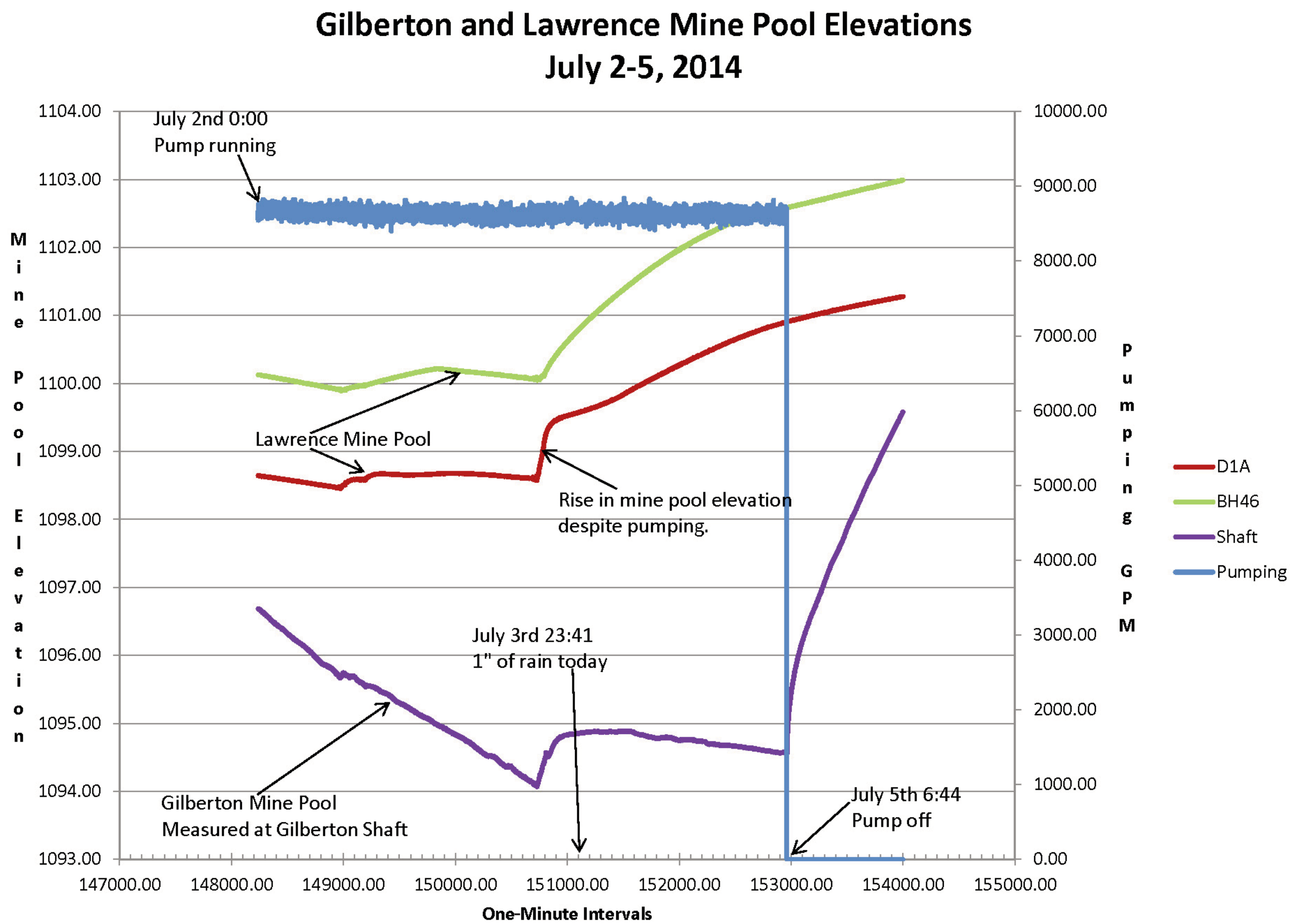

Figure 7. Influence of rainfall on mine pools. Flashy response indicates high infiltration rate. Rainfall was recorded at Tamaqua, Pa., 15 miles east of Gilberton Borough. Actual rainfall in Gilberton is unknown.

department's pump draws down the Gilberton mine pool to a level lower than the Lawrence mine pool. Thus, the water flow alternates in direction with the pumping cycles at the shaft.

Due to the complexities of the hydrogeologic conditions located in the mines, limited data points in the mine pools, and unknown boundary conditions, no water budget has been produced specifically for these mine pools. Additional complexities include seasonal variation of infiltration rate, inconsistent pumping at the preparation plant, and unknown contribution from the nearby settling basins.

CONCLUSIONS

This analysis confirms that the Gilberton and Lawrence mine pools are connected and that the cone of depression (in the mine-pool conduit flow system) extends at least 1.9 miles to the barrier between the Lawrence and West Bear Ridge mine pools. The full extent of the department's pumping on the larger Gilberton multicolliery unit mine pool remains unknown.

Future researchers should consider the following work: monitoring of upgradient mine pools, soil and rock sampling to characterize their material properties, analyzing the influence of rainfall on the mine pools, obtaining accurate values of all pumping withdrawals, and evaluating the loss of water from Mahanoy Creek to the mine pools.

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Revisiting the Pymatuning Earthquake Groundwater Effects 20 Years Later

Gary M. Fleeger
Pennsylvania Geological Survey (retired)

INTRODUCTION

September 25, 2018, marked the 20th anniversary of the largest earthquake ever recorded in Pennsylvania. The 5.2-magnitude quake, centered near the Mercer-Crawford county line near Jamestown, Pa. (Figure 1), struck on September 25, 1998, at 3:52:52 p.m. eastern daylight time. Because of its proximity to the Pymatuning Reservoir, it has received the appellation "the Pymatuning earthquake."

The quake caused minor structural damage to masonry structures and knocked items from shelves (Armbruster and others, 1998). There was one report of ground movement resulting in a pond overflowing its dam. But by far the most damaging consequence of the quake was the change in the groundwater system that resulted in the loss of water from 120 water wells (Figure 1). The majority of the affected wells were concentrated on a ridge between Greenville and Jamestown and in the narrow southern tip of a much larger adjacent hill to the northeast (called here the "NE ridge"). This NE ridge was the location of the epicenter (Figure 1). Details of the effects of the quake were reported in

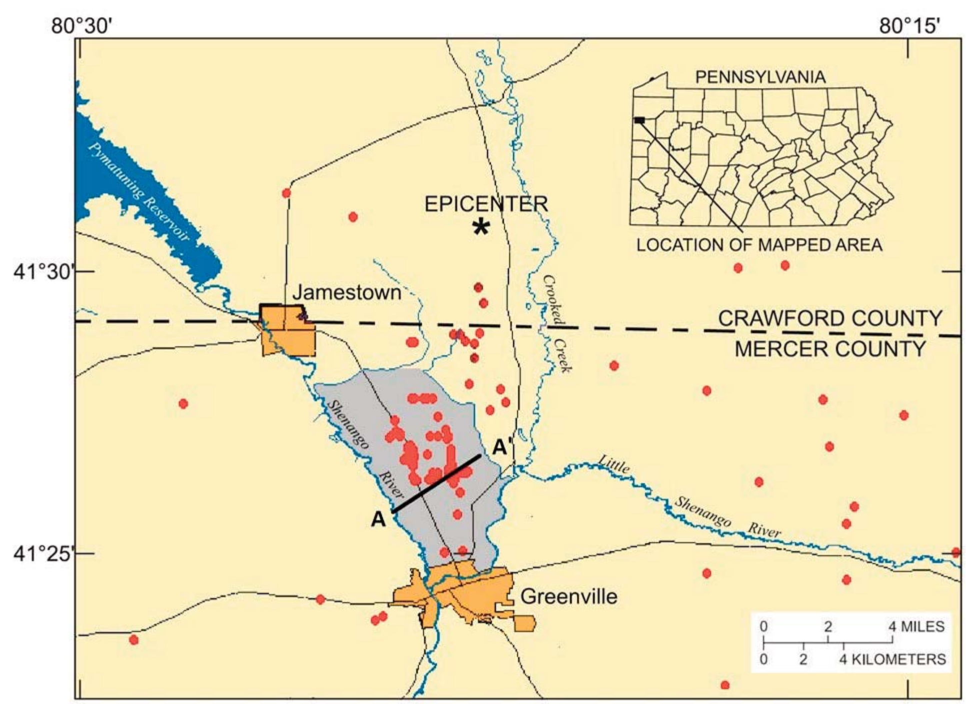

Figure 1. Location map and wells (red dots) that are known to have gone dry after the Pymatuning earthquake. Gray area marks the ridge between Jamestown and Greenville. The cluster of wells just northeast of the gray area is on the NE ridge. Line A–A' marks the line of section in Figure 2. Modified from Fleeger and others, 1999.

[Pennsylvania Geology (v. 29, no. 4)] (Armbruster and others, 1998), and the groundwater changes were documented in [Fleeger and others (1999)].

EARTHQUAKE-INDUCED CHANGES

The earthquake widened some bedrock fractures and liquefied a clay layer. This resulted in the increased transmission of groundwater from the hills to the adjacent valleys in northern Mercer County for both ridges.

The groundwater system in each of these hills has a separate shallow flow system that discharges into adjacent valleys. Poth (1963), therefore, referred to such hills as “hydrologic islands.”

Normally, the water table in a hydrologic island is mounded and is a subdued replica of the surface topography. Resistance to flow of water that falls on the hill, caused by the path of groundwater flow through small fractures and pores, causes the mounding. The more resistance to flow, the more mounding. The less resistance to flow, the flatter the water table. Where there is no resistance, such as above ground, the water surface is flat. A lake is a flat water surface that is the water table above the ground.

The reduced resistance to groundwater flow caused by the enhancement of fractures and bedding planes from the Greenville-Jamestown ridge hydrologic island resulted in a flattening of the water table beneath the ridge. SWLs (static water levels) in wells declined beneath the ridge and increased in the adjacent valleys (Figure 2). A similar effect probably occurred in the NE ridge. Water levels in wells

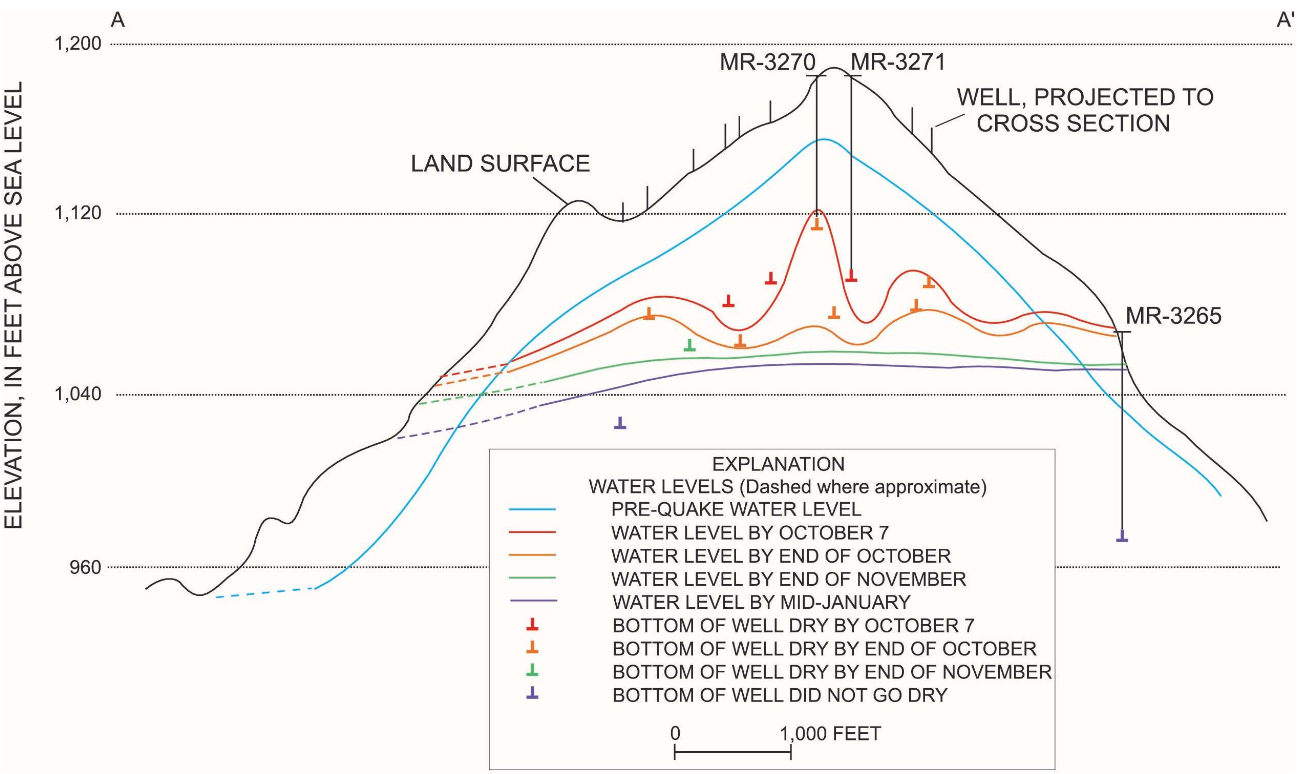

Figure 2. Cross section showing the progressive flattening of the water table from September 1998 through January 1999. The location of the cross section is indicated on Figure 1. MR numbers are U.S. Geological Survey water-well designations. Modified from Fleeger and others, 1999.

along the ridge tops and slopes declined, with many wells going dry, while water levels in adjacent valley wells increased. Some of the valley wells started to flow, and have continued to do so since.

TWENTY YEARS OF MONITORING

Since the earthquake, the Pennsylvania Geological Survey has monitored SWLs in select wells in the area. The goal was to see if the groundwater levels would partially or completely recover to prequake levels. We monitored wells in various topographic positions (hilltop, slope, and valley) on both the Greenville-Jamestown and NE ridges. Initially, we monitored monthly, but this was later reduced to bimonthly (1999), quarterly (2000), and since 2001, annually. The annual measurements were made in the spring, shortly before or after the emergence of vegetation from its winter dormancy. More precipitation in the fall, spring, and winter (when the ground is not frozen) infiltrates to the water table because the dormant vegetation does not transpire most of it back into the atmosphere. Therefore, the groundwater levels are typically at their highest seasonal levels at that time. Once the vegetation becomes active again, evapotranspiration causes the water table to decline through the late spring and summer.

Initially, 20 wells were monitored. However, over the past 20 years, many of the wells have become lost to monitoring because they were covered with structures, paved over, or otherwise made inaccessible. Nine wells were monitored for the entire 20 years. Two of those wells were modified during the period of monitoring, potentially having a minor effect on the SWLs in those wells.

RESULTS

As documented in Fleeger and others (1999), water levels under the ridges declined rapidly at first, and continued to decline for several months before stabilizing with the flattened water table by mid-January, 1999. Based on a few wells for which we had prequake-level estimates, hilltop and slope wells initially had rapid, substantial declines in water levels (Figures 3 and 4), and there was a corresponding increase in water levels in valley wells. By spring 1999, the hilltop and slope wells had increased in SWL by an amount much less than their initial decline. Most or all of this increase from fall 1998 to spring 1999 is likely a seasonal change, from an annual low level in the fall to the annual high level in the spring, and may not reflect an actual recovery from the earthquake.

Greenville-Jamestown Ridge. Measurements subsequent to 1999 have shown that the water levels have remained largely unchanged (Figure 3). Only seasonal variations and annual changes based on varying precipitation from year to year have occurred.

The lack of SWL recovery suggests that the fractures and bedding horizon have not healed, and that the quake-altered hydrologic characteristics of the area have remained the same since the quake. Whether these changes are permanent is unknown, but they have not changed in the 20 years since the quake.

NE Ridge. Only three wells were monitored on the NE ridge—two valley wells in close proximity to each other, and one slope well (Figure 4). The 20-year change in the SWL in valley wells is similar to the Greenville-Jamestown ridge in that there has been no change detected other than minor annual changes probably based on differences in precipitation.

However, in contrast to the slope wells on the Greenville-Jamestown ridge, the SWL in the slope well on the NE ridge has continually risen during the 20 years since the earthquake, increasing almost 29

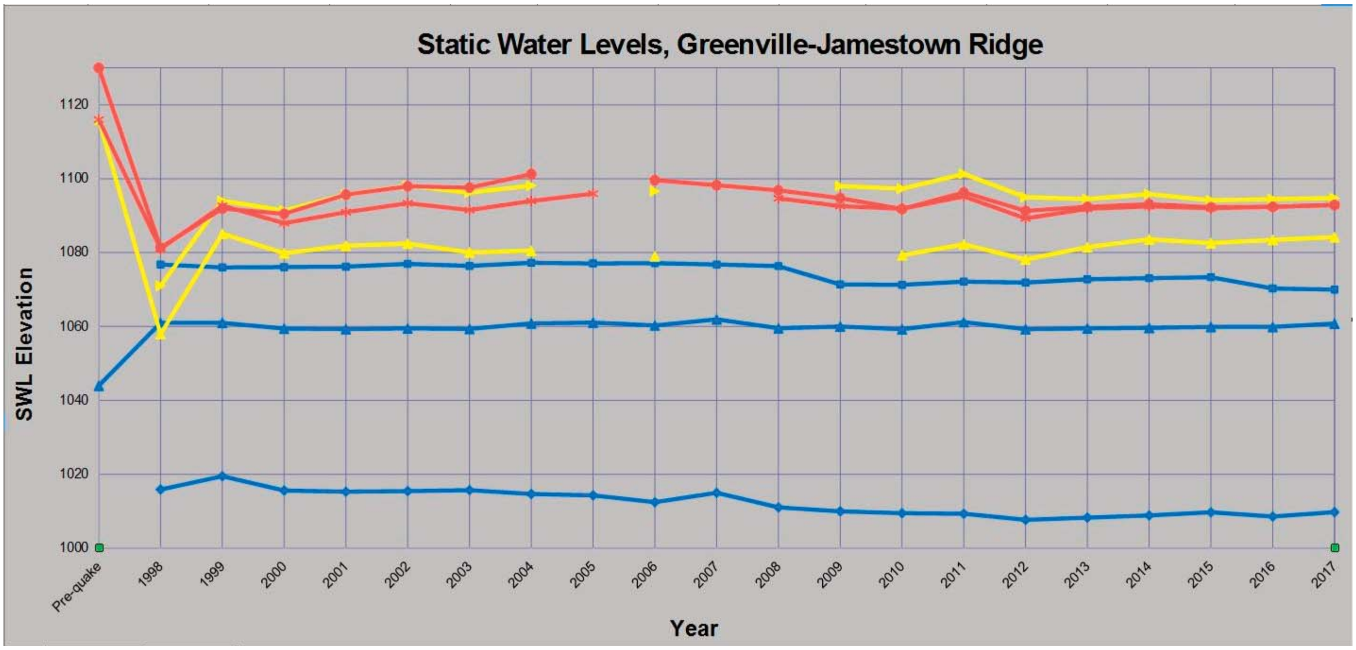

Figure 3. Graph of static water levels (SWLs) in monitored wells in the Greenville-Jamestown ridge over the last 20 years. Line colors are based on the topographic position of the wells. Blue lines represent wells in valleys, yellow lines represent wells on slopes, and red lines represent wells on hilltops. The measurements shown on the graph were all taken in the spring (mid-March to early May) before the emergence of vegetation, except for the prequake data and the 1998 data, which were taken in late November and early December, a couple of months after the earthquake. Prequake data came from Shiner and Kimmel (1976) and water-well records on file at the Pennsylvania Geological Survey for only some of the monitored wells; these were gathered over a span of time encompassing different seasons of the year. As a result, prequake well SWLs shown on the graph were not necessarily the SWLs of those wells immediately prior to the quake. The initial increase of hilltop and slope well SWLs from fall 1998 to spring 1999 may not be a recovery from the earthquake decline, but simply a seasonal increase.

feet since shortly after the earthquake. In addition, there was no apparent seasonal increase from fall 1998 to spring 1999 that was noted in the Greenville-Jamestown ridge wells, but just the small, steady annual increase that has occurred for 20 years. It is difficult to reach any definitive conclusions based on data from only one well. We can only speculate on a few possibilities, as follows.

1. Perhaps at this location, one or more fractures near this well have healed, allowing the SWL to recover locally. If so, the fracture(s) began to heal immediately after the quake, and SWL recovery has been continuous.

2. Another possibility is that this well was not affected by the earthquake, and its increase is related to an overall increase in precipitation over the last 20 years (Figure 4). The trend line for the annual precipitation data parallels the line showing the increase in SWL, although the SWL does not reflect significant differences in annual precipitation, especially in 2009, 2010, and 2013 to 2017. Unfortunately, we do not have a prequake SWL estimate for this well, so we cannot even determine if the SWL in this well declined due to the earthquake. Because wells on the NE ridge did go dry, and wells in the adjacent valleys showed SWL increases after the quake, it is unlikely that this well was not affected by the quake. Because of the lack of prequake data for this well, we are unable to determine the effect of the earthquake, nor if the increase has reached prequake levels.

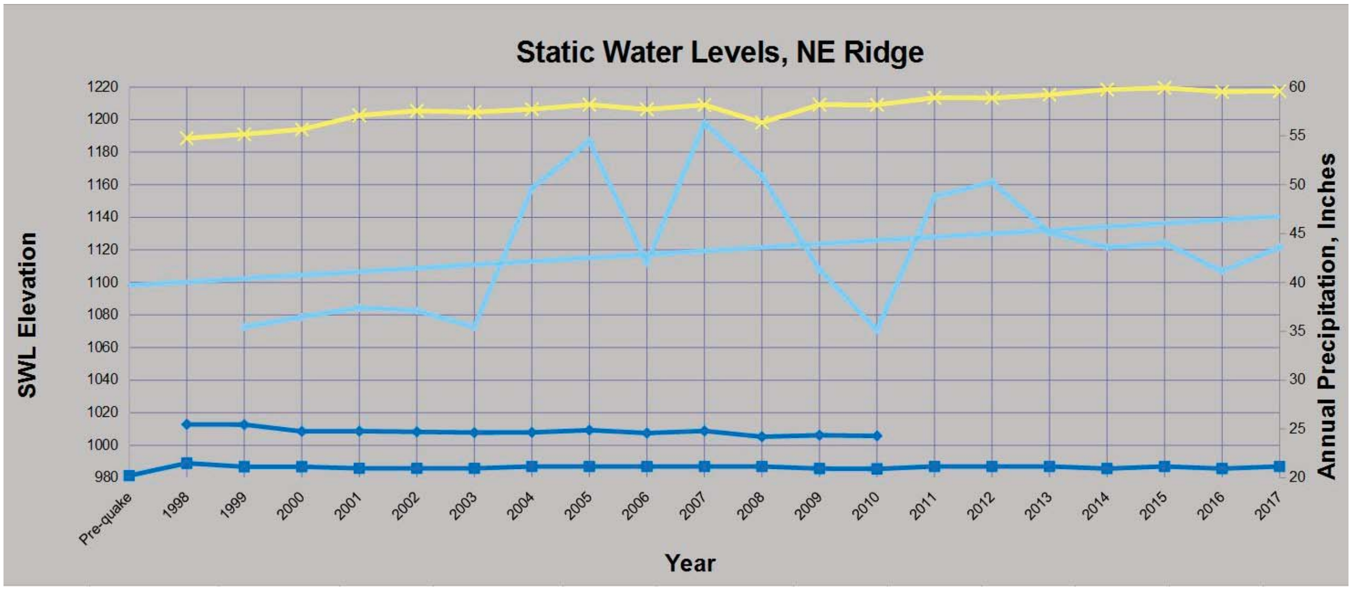

Figure 4. Graph of static water levels (SWLs) in monitored wells in the NE ridge over the last 20 years, and annual precipitation. Line colors are based on topographic position of the wells. Dark-blue lines represent wells in valleys, and yellow lines represent wells on slopes. The cyan lines show annual precipitation and its trend line. The SWL measurements shown on the graph were all taken in the spring (mid-March to early May) before the emergence of vegetation, except for the prequake data and the 1998 data, which were taken in late November and early December, a couple of months after the earthquake. Prequake data came from Shiner and Kimmel (1976) and water-well records on file at the Pennsylvania Geological Survey for only some of the monitored wells; these were gathered over a span of time encompassing different seasons of the year. As a result, prequake well SWLs shown on the graph were not necessarily the SWLs of those wells immediately prior to the quake. Annual precipitation data are from the weather station at the Pymatuning State Park office. The annual precipitation is from May 1 to April 30; therefore the precipitation is for approximately the 12 months preceding the SWL measurement for that year.

3. The NE ridge is a narrow southern extension of a broad upland area that would constitute a hydrologic island. Perhaps increased groundwater flow toward this southern extension after the earthquake might have caused the immediate and continual increase in water level in this well.

ACKNOWLEDGMENTS

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BUREAU NEWS

From the Stacks . . .

Jody Smale, Librarian
Pennsylvania Geological Survey

We continue to add new titles to the bureau's library collection. The scope of the collection includes an abundance of resources pertaining to all branches of geology. Resources are available for those just starting out in the field and for the seasoned earth scientist alike. Below is a list of some of the new titles added recently.

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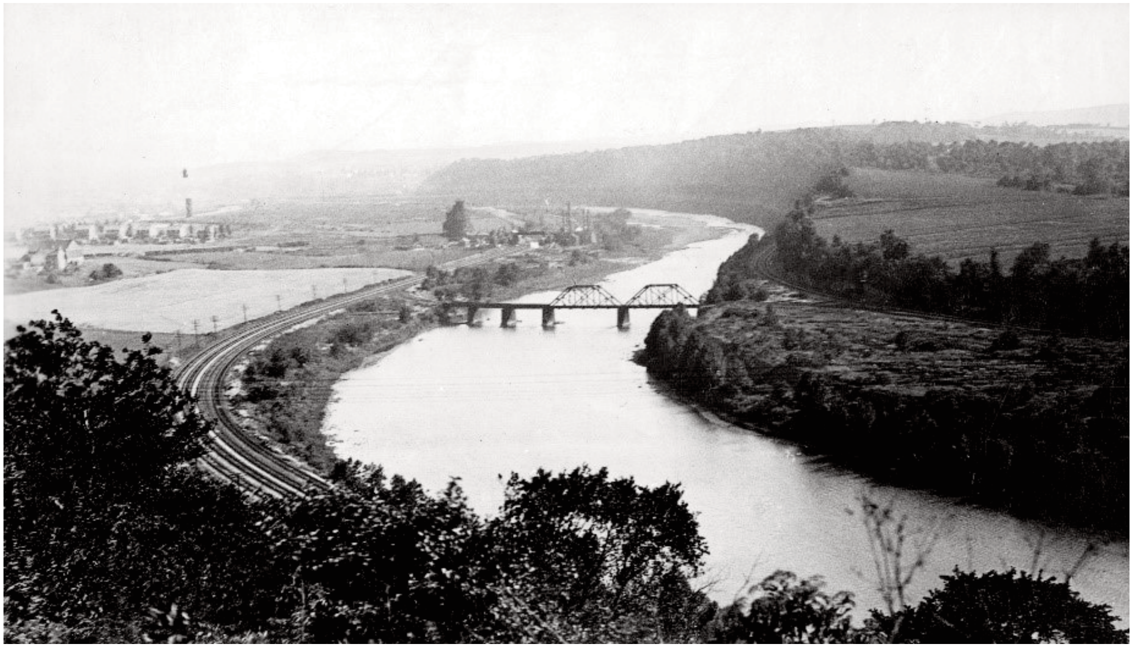
- ***Geothermal energy—An important resource,*** edited by Carolyn B. Dowling, Klaus Neumann, and Lee J. Florea / Geological Society of America Special Paper 519, 2016.
- ***Isabella and Trent's hot air balloon adventure—A kid's book of Pennsylvania geology,*** by Jeri Jones and Dennis Low / Year of the Book Press, 2018.
- ***Operational stage of the well—Evaluating the forms of water well deterioration and developing corrective actions,*** by Thomas M. Hanna, Michael J. Schnieders, and John H. Schnieders / NGWA Press, 2016.
- ***Pennsylvania caves and other rocky roadside wonders,*** by Kevin Patrick / Stackpole Books, 2004.

A Look Back in Time



The Youghiogheny River, two to three miles north of Connellsville (Fayette County), showing an undercut bank along one of the river meanders. The fields on the right are part of a gravel-covered terrace between the river alluvium and the Carmichaels deposit. [This is the original caption, which had been included with the photograph.]

Photograph taken in July 1934 by former Survey geologist William Orville Hickok.

To see more photographs from the bureau's archives, please visit the library's Historical Photographs Collection page.

RECENT PUBLICATIONS

Progress Reports **(October 2018)**

- Geologic Map of the Rich Valley 7.5-Minute Quadrangle, Cameron and McKean Counties, Pennsylvania
- Bedrock Geologic Map of the Farrandsville 7.5-minute Quadrangle, Clinton County, Pennsylvania

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Articles pertaining to the geology of Pennsylvania are enthusiastically invited.

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Feature Articles: All feature articles should be timely, lively, interesting, and well illustrated. The length of a feature article is ideally 5 to 7 pages, including illustrations. Line drawings should be submitted as CorelDraw (v. 9 or above) or Adobe Illustrator (v. 8 or above) files.

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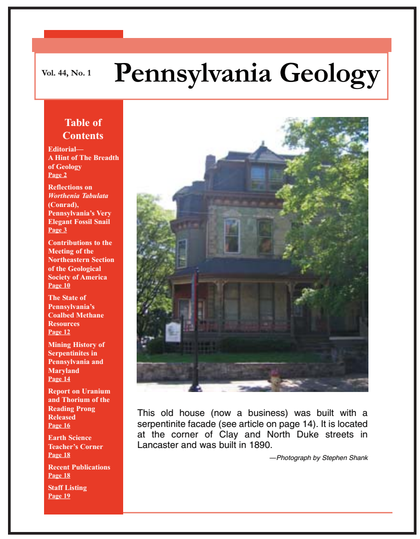
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This old house (now a business) was built with a serpentinite facade (see article on page 14). It is located at the corner of Clay and North Duke streets in Lancaster and was built in 1890.

—Photograph by Stephen Shank

Department of Conservation and Natural Resources
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Main Headquarters
3240 Schoolhouse Road
Middletown, PA 17057–3534
Phone: 717–702–2017

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