HYDROLOGIC CHARACTERIZATION OF A LARGE UNDERGROUND MINE POOL IN CENTRAL PENNSYLVANIA[1]

Jay W. Hawkins[2], Eric F. Perry, and Mike Dunn

<u>Abstract:</u> Major proposed changes in drainage control from a large underground mine pool required a detailed assessment of the hydrology, geochemistry, and impacts on the receiving streams. Proposed changes entail relocation of the withdrawal and treatment facilities to an adjoining, but separate watershed and increasing the pumping rate by 35%.

Fifteen major and numerous smaller mines in two coal seams comprise the mine pool system. Degree of interconnection between mines ranges from horizontal and vertical seepage through natural fractures, subsidence-induced fractures, and coal cleat to open pass-throughs, slopes, and shafts. Water levels of several mines rise and fall in a mirrored fashion with only a few meters of head difference. An adjacent mine pool with 59.7 meters of head and an intact barrier ranging from 9.4 to 457 meters thick contributes at least 28% to the discharge rate. Mine storage capacity (5.38 billion liters) equates to a porosity of about 11%, a significant reduction from the original extraction volume of 63%. Mean ground water yield of the complex is 28 million liters per day. Recharge rate of 0.41 liters per minute per hectare is less than expected due to the thick overburden over much of the mine complex. The mine complex responds sharply to large precipitation events and large-volume pumping due to the relatively low storage volume and large aerial extent of the mine complex. Water levels respond to large precipitation events within three days and rises exceeding one meter have been recorded. Conversely, current maximum pumping at 35.6 million liters per day will draw the pool down an average of 0.09 meters per day. The proposed pumping of 37.9 million liters per day will, over the long term, exceed ground-water recharge and will dewater large portions of the mine complex. This will adversely impact the water quality, may induce additional subsidence, and could dewater some domestic water wells. Addition of water from an adjacent mine would allow the discharge of 37.9 million liters per day.

Additional Key Words**:** mine water storage, dewatering, barrier seepage.

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Introduction

This paper assesses the quantitative hydrogeologic system of a complex of abandoned, interconnected underground coal mines in central Pennsylvania. In-mine storage, vertical recharge rates, seepage from and to adjacent mines, open shafts and boreholes, and portals all have significant impacts on the hydrologic regime. A detailed assessment of the hydrologic regime was necessary to determine the potential impacts of relocating the present treatment facilities in the center of a synclinal basin to an area near the coal outcrop along the northern margin. The discharge point would be moved across the Eastern United States Continental Divide from a watershed that drains to the Allegheny River and to a watershed that drains to the Susquehanna River.

The mine pumping rate is proposed to increase from an average of 28 million liters per day to nearly 38 million liters per day. Concerns were raised as to possible changes in water quality, fluctuating mine pool levels, impacts to the present and proposed receiving streams and changes in contributions from adjacent flooded mines caused by the increased withdrawal rate. There also were concerns for the potential of domestic well dewatering due to lowering of the mine pool levels by increased pumping.

The water quality issues are addressed by a companion paper in these proceedings (See Perry et al., 2005). The well water loss and receiving stream issues are addressed in the project final report and are not discussed here. This paper covers aspects of mine interconnections, mine-pool storage, potential impacts of pumping and possible dewatering, recharge rates, seasonal variations, and the present hydrologic regime. The purpose of this paper is to present the hydrologic regime of a large mine complex and how the system will behave to proposed changes. The information presented will aid investigation into the similar hydrologic systems throughout the Appalachian Region.

Background

The study area is located in east central Pennsylvania near the towns of Ebensburg, Carrolltown, and Northern Cambria (See Fig. 1). The study area encompasses approximately 175 square kilometers and is drained by the Blacklick Creek watershed in the south and the West Branch of the Susquehanna River watershed in the north.

The area is characterized by a series of broad southwest to northeast trending folds. The distance between fold axes ranges from 5.5 to 6.7 kilometers with changes in elevation of the coal beds of up to 158 meters (See Fig. 2). Dip is generally 2 degrees or less.

Two coal seams have been mined in the area, the Lower Kittanning ("B") and the Lower Freeport ("D") seams. The main mine pool is in the Lower Kittanning coal bed, which lies about 50 meters below the Lower Freeport. The strata are characterized by channel sandstones interbedded with shales with mineable coal beds and a minor limestone unit near the level of the Lower Freeport coal. The channel sandstones are thickest toward the northeast diminishing toward the southwest. The Lower Kittanning averages about one meter thick while the Lower Freeport averages 1.5 meters.

Mining within the study area on the Lower Kittanning was conventional room-and-pillar with extensive retreat mining. Some Lower Kittanning longwall mining occurred in adjacent mines beyond the extent of the study area. Earliest mining on the Lower Freeport was also room-and-pillar with extensive retreat mining. More recent Lower Freeport mining has been a combination of room-and-pillar and longwall.

Figure 1. General study area map.

The mine pool complex is composed of 15 major mines and several smaller ones (Fig. 2). The main mine of interest is the Barnes & Tucker Lancashire 15 (L-15). This mine closed in 1969 and the dewatering pumps were shut off on July 14, 1969 allowing it to flood. Between March 13, 1970 and June 12, 1970, the mine began to discharge large amounts of highly acidic metal-laden water along the northern margin (Fig. 2, Blowout Area). This blowout substantially degraded the West Branch of the Susquehanna River and caused fish kills for at least 160 kilometers downstream. The discharge was eliminated by pumping at Duman (Fig. 2) and lowering the mine pool level below the blowout elevation. The mine pool has been controlled using this pump and treat system from 1970 to the present. Several of the smaller mines in the basin nearer the outcrop closed prior to L-15. Since L-15 closed, several more large mines have likewise closed. Presently, there is no active mining in the basin that has an impact on the mine pool complex.

There are several adjoining mines that are directly or indirectly hydrologically connected to L-15. Lancashire 24B, Lancashire 14, and Sterling 1, 6, and 10 are connected to L-15 by open pass throughs. Springfield 4, Reilley and Colver mines are adjacent to L-15 separated by intact coal barriers of variable thickness (Fig. 2). There is some seepage through and/or over these barriers.

Mines in the overlying Lower Freeport include Blubaker/Reed, Sterling 10D, Lancashire 24D and 25, Moss Creek/Pardee 61, Victor 12, and Woodland mines. These mines are in some cases directly connected via open slopes and shafts. In other cases, the connection is via naturally-occurring, subsidence-accentuated naturally-occurring and subsidence-created fractures. The magnitude of vertical flow via fractures between the mines on the two seams is, by accounts of the miners and indicated by the hydrologic data, substantial.

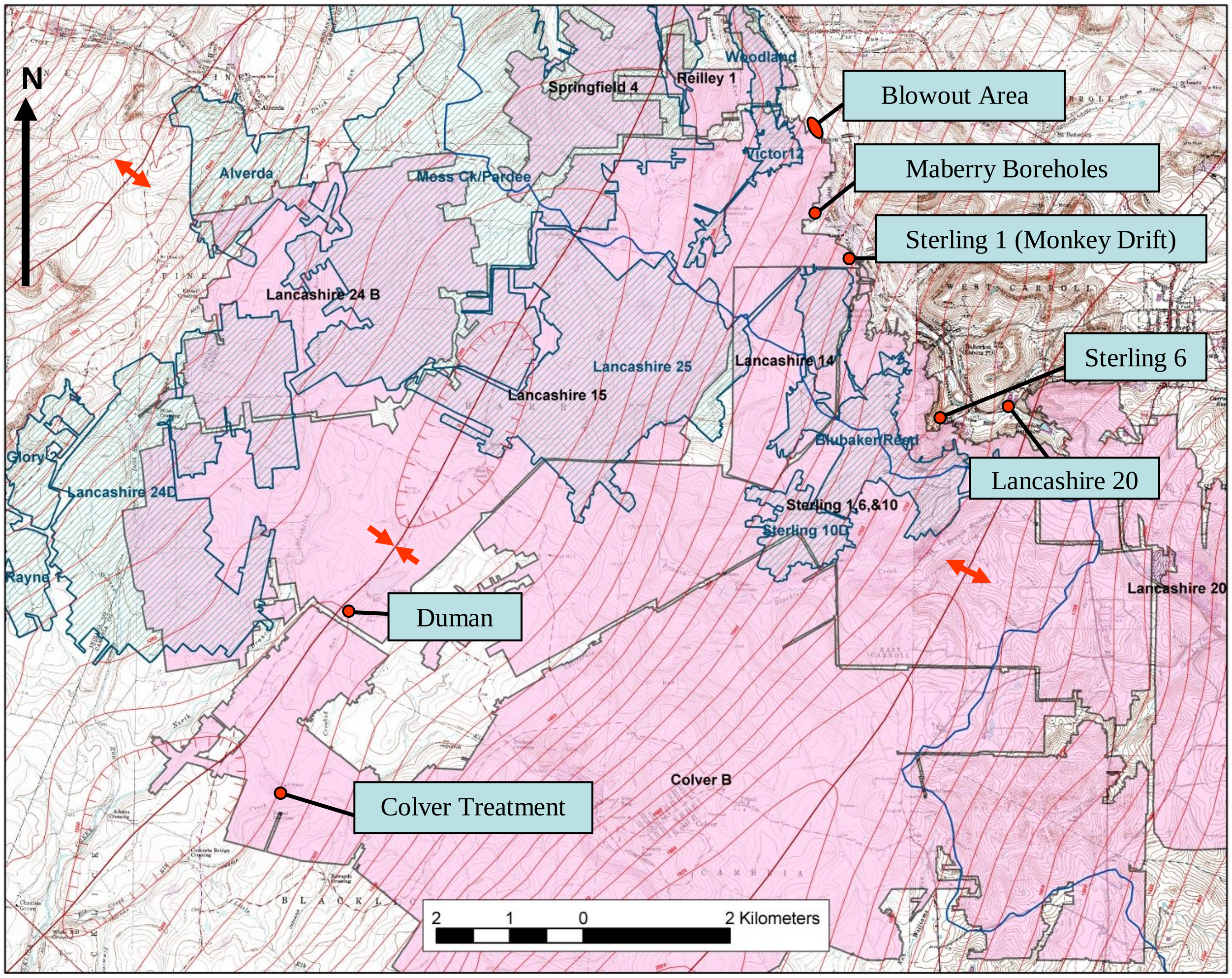

Figure 2. Map of mined areas with fold axes. The mines in pink are in the Lower Kittanning. The mines in green are on the overlying Lower Freeport coal.

Data and Discussion

Mine Water Storage

Critical to answering a number of the hydrogeologic questions of the L-15 mine complex is estimating the volume of mine water storage, recharge and discharge rates as well as other hydrologic characteristics. While conducting this study, more than sufficient data were found to assess the past and present hydrologic properties of the mine complex.

Flooding time for the L-15 mine until the blowout reportedly occurred (Blowout Area) was between 242 to 333 days. The average net pumping rate after flooding in 1970 to 1985 was 17.1 million liters per day. The 1970 to 1985 net pumping rate was determined from the average total pumping rate minus the average sludge injection rate (21.7%). Back calculations based on these data yield an in-mine water storage total between 4.14 to 5.69 billion liters. These storage volumes and others discussed below assume that porosity of the fractured rocks overlying the mines (estimated <1.0 percent) is negligible compared to the mine storage (Mackay and Cherry, 1989; Burton, et al., 2002). In 1986, pumping rate increased average of 63.7% (10.9 million liters per day) after Lancashire 24B and D mines closed.

Storage volumes derived above are only 12 to 22% of the initial projections based on the area mined, average coal thickness, and a known coal extraction percentage. Initial estimates of the potential storage were 25.3 to 32.9 billion liters for 50 and 65% extraction rates for 4,748 hectares (maximum possible storage at the time), respectively. The 4,748 hectares is based on a maximum mine water level of 550.1 meters m.s.l., which is the lowest point along the axis for the Laurel Hill Anticline on the southeastern edge of the complex.

Subsequent to using the estimated extraction rates, we were able to calculate a more accurate value based on the known total coal extracted from the L-15 mine (26,317,550 tonnes) (Bowman, 1973). The total tonnage was converted to cubic meters and combined with average coal thickness and the area mined to yield an actual extraction rate of 62.6%.

Based on the 62.6% extraction rate, the mine water storage was projected at 31.7 billion liters for 4,748 hectares (maximum mine area flooded). However, the mine water storage based on the time required to flood the complex is between 13.0% and 17.9% of this projected storage.

It is likely that the actual storage volume of the mine when the blowout occurred was less than 4,748 hectares. Based on records, the minimum possible level of the mine pool at the time of the blowout was near 466.3 meters m.s.l. (measured at the Maberry borehole, Fig. 2). This water level equates to a flooding area of 3,787 hectares with a projected storage of 25.3 billion liters for 62.6% coal extraction.

Considering the head (pressures) normally required to trigger a blowout, it is probable the mine pool level was above 466 meters m.s.l. at the time. A mine volume was calculated for a pool elevation 508.4 meters m.s.l., which is midway between 466 and 550.8 meters m.s.l. An elevation of 508.4 meters m.s.l. creates roughly the head required for the blowout of the type of hydraulic seals (2.8 kg/cm^2) (Michael Baker, Jr., 1978) commonly used at area mines. At the above referenced elevation, the mine pool covers 4,277 hectares, which is estimated storage of 28.6 billion liters for a 62.6% extraction rate. Based on the midway flooding data for a 62.6% extraction rate, an average porosity percentage for the Lancashire complex is now 17.2% of the available 62.6% or an absolute value of 11%.

When Lancashire 24B and D closed in 1986, the flow of Lancashire 15 increased about 63% and those mines have no known other discharge points. This indicates a direct connection to the L-15 mine complex. Lancashire 24B became part of the L-15 complex at that time and its storage volume is included in the total storage volume after 1986. Using the 11% porosity value, a storage volume for the Lancashire 24B seam mine is extrapolated to be roughly 1.25 billion liters. This storage adds between 21.9 and 30.1% to the original calculated storage volume at the time of initial flooding.

Present storage volume of the Lancashire mine complex of approximately 5.4 billion liters is based on a 11% porosity for 4,690 hectares, the area flooded at a mine water level of 454.5 meters m.s.l. (the present average water level). The relatively low porosity value indicates that a considerable amount of subsidence has occurred, reducing the void spaces left by coal extraction. The mine maps indicate most areas were extensively retreat mined. According to Hershey and Meiser (2001), Penn State University study indicated that there was up to one foot of subsidence at the ground surface over these mines. The porosity (storage) values are similar to slightly lower than what has been determined as an average for surface mine spoil (Hawkins, 1998) and a mine pool in West Virginia (Perry and Hawkins, 2004).

With the water level ("beach area") located near the 454.5 meters m.s.l. about 79 percent of the L-15 mine complex is completely flooded. The remaining approximately 21 percent is unflooded and free-draining. Small portions of the L-15 complex along the northern edge drain freely and discharge at Sterling 1 (Monkey Drift) and Sterling 6 portals.

Mine Interaction

Previous studies and reports of this region (Kernic, 1999; Waite, 1980) indicate that there is a high degree of interaction between several of the mines. Some of the interconnections are from open entries (pass throughs), slopes, and shafts, while others are via naturally-formed fractures and fractures created and/or accentuated by subsidence. Several normal faults with minor displacement were recorded for the adjacent Lancashire 20 mine. Maximum displacement recorded was 1.5 meters vertically (Iannacchione and Puglio, 1979). These types of faults can also provide a vertical avenue of flow between the B and D seams.

Ground water moves from shallow aquifer zones to underlying mines if there is a hydrologic connection (Booth, 1986). Booth (1984) noted a direct relationship between seasonal rainfall amounts and inflow into Lancashire 20 indicating that vertical ground-water movement is significant at mine depths. Fracture permeability is a cube root function of the aperture opening (Witherspoon et al., 1980). Therefore, a small dilation of a fracture opening caused by subsidence will have a significant impact on the ability of fractures to transmit ground water. Wahler and Associates (1979) noted that at the Lancashire 20 mine fractured zones were hydrologically connected to the surface and the largest mine inflows were associated with fracture zones associated with prominent stream valleys.

L-15 is directly connected to Lancashire 14 by open pass throughs. In turn, the Sterling mines 1 and 6 are connected to Lancashire 14 by pass throughs (Kernic, 1999). Increases in flow at Duman with the closing of Lancashire 24B and D illustrate that there is an unrestricted connection between these mines as well. Lancashire 24B and D mines are directly connected via an open slope portal.

The Moss Creek/Pardee 61 "D" seam mines have a strong connection to the underlying L-15. This is illustrated by the fact that the L-15 mine had a large inflow of water when they first mined under the Moss Creek mine. Coincidental with the mine water inflow into the L-15 mine, the Moss Creek mine experienced subsidence (support timbers dislodged and had to be reset)(Anonymous, 1970). When the water level in L-15 is lowered from 451.1 to 438.9 meters m.s.l. the flow at the treatment plant (Duman) increases by 3.8 million liters per day and the discharge of the Moss Creek complex is decreased by 1.9 million liters per day (Gwin, Dobson

& Foreman, 1972). Flow is reversed when the water levels in L-15 are allowed to rise. According to Waite (1980), the connection of the Moss Creek/Pardee 61 mine to the L-15 mine complex is through the Lancashire 24B seam mine, but anecdotal data indicate a more direct vertical connection as well.

There also appears to be a substantial hydrologic connection between Sterling 7 and the L-15 mine. Hydrographs of the L-15 and Sterling 7 mine pools show similar trends during the pumping down of the former (Gwin, Dobson & Foreman, 1972).

The Lancashire 25 seam mine overlies substantial portions of the L-15 mine and has water levels above the L-15 mine complex. From 1986 to 1992, the data show that the two mine pools responded in mirrored fashion to seasonal variations (See Fig. 3). In early 1993, the water levels in Lancashire 25 dropped about 22.3 meters from an average of 488.3 to 466 meters m.s.l. This may have been caused by additional mine subsidence in the underlying L-15 mine creating a more open and direct avenue for downward ground-water movement. It also has been stated that drill holes now connect these two mines. However, the water levels in Lancashire 25 have remained above those of L-15.

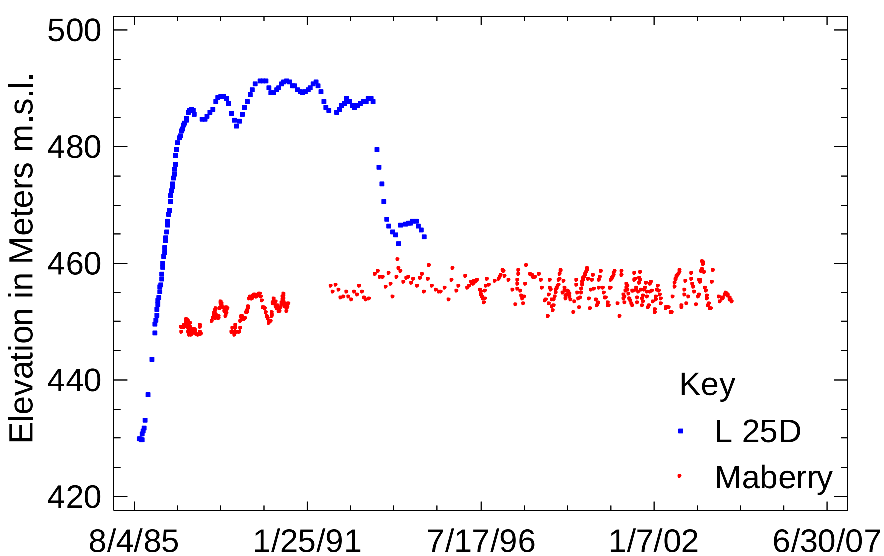

Figure 3. Hydrograph of the Lancashire 15 and 25 mine pools.

While there are no open pass throughs linking the Colver Mine and L-15 Mines, there is no doubt considerable flow by barrier leakage from Colver to L-15. The lengthy barrier of variable thickness along with a large head difference (59.7 meters plus) between the two mines indicates that there is considerable flow from Colver to L-15. The following section discusses seepage from Colver to L-15.

Colver Hydrologic Connection to the Lancashire 15 Mine Complex

Colver and the L-15 mine complex share a common coal barrier that runs approximately 13,685 meters. Barrier length measurements exclude areas with large thick blocks of intact coal. Of the entire barrier, 7,852 meters includes flooded portions of the Colver mine. Barrier thickness ranges from 9.4 to over 457.2 meters. The importance of the barrier is that it prevents free flow of mine waters from Colver to L-15, but the barrier does permit significant seepage from Colver to the L-15.

A series of calculations based on one-dimensional Darcian flow through the barrier, were conducted to estimate the contribution (seepage) of the Colver mine to the L-15 mine complex. The barrier was separated into 20 segments with the average thickness determined for each segment based on 10 or more equally spaced measurements along that segment (See Fig. 4). Minimum mean head difference (59.8 meters) was determined from the average elevation for the L-15 mine complex as measured at the Maberry borehole (454.4 meters m.s.l.) subtracted from the minimum elevation of the water flowing (artesian) from the Colver mine (≥514.2 meters m.s.l.). Head values for the sections of Sterling 1 & 6 that are up gradient of the L-15 flooded sections (beach area) (454.4 meters m.s.l.) are based on the mine floor structure contours. High, low, and median hydraulic conductivity values for the Lower Kittanning in this area, obtained from area testing (unpublished), were applied to the seepage calculations. The high and low hydraulic conductivity values yielded clearly unrealistic values of over 100 and less than 0.3 percent of the Duman discharge, respectively. Therefore, the median value (2.64×10^{-6} m/s) was determined to be suitable and was applied to the final estimates.

Extreme head differences between the two mines indicates that the barrier is completely intact and has a relatively low permeability. Seepage estimates indicate that a mean of at least 5,368 liters per minute may be presently entering the L-15 complex from the Colver mine. This represents 27.9 percent of the mean discharge from the L-15 complex. These calculations are conservative because they are based on a water level of at least 514.2 meters m.s.l. for the Colver mine. The actual level is likely somewhat higher. These estimates indicate that the Colver mine significantly contributes to the total flow at the Duman treatment plant.

A series of increasing-head calculations were conducted to estimate the impact of higher water levels in Colver and increasing the L-15 drawdown would have on seepage rates. Table 1 illustrates, as expected, the Colver contribution increases with increases in head differential. Seepage rate increases are slight and not highly sensitive to increasing head. Changes are fairly small (<1 to 8%) given changes in head up to 21.3 meters. The contribution of Colver to the discharge at Duman is at least 28% presently and may increase to roughly one third if the drawdown is increased and the water level in Colver is higher than estimated.

At a water level of 514.2 meters m.s.l., about 53 percent of the Colver mine is completely flooded. The remainder is unflooded and drains freely west toward the flooded portions. If the water level in Colver was as high as 524.3 meters m.s.l., the flooded percentage only increases to approximately 55 percent.

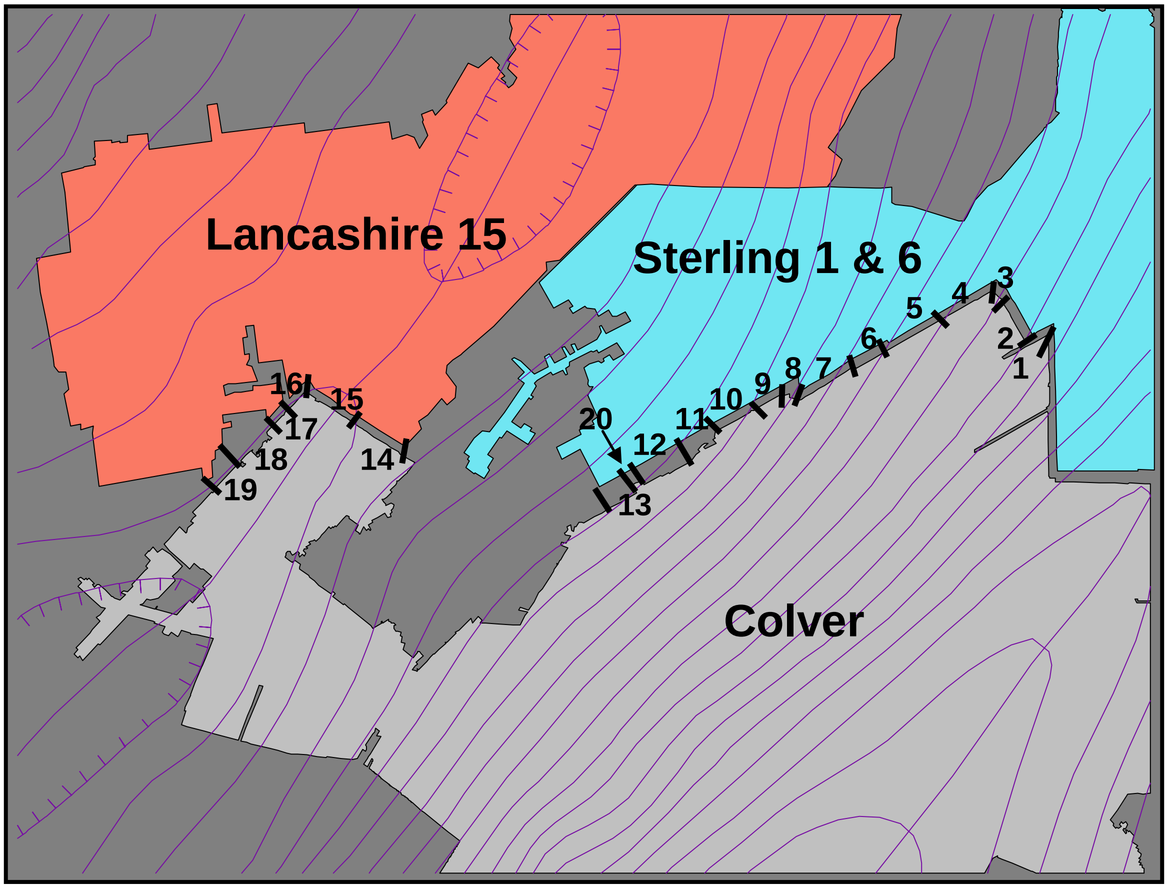

Figure 4. Saturated coal barrier between the Colver and the Lancashire 15 mine complex.

Impacts of Pumping

Average total pumping rate at the Duman treatment plant is 28,480,640 liters per day; based on the time period of January 1, 1996 to May 18, 2004. Presently, the sludge injection rate is between 11.4 and 18.9 million liters per month (Dennis Lloyd, personal communication). This injection rate averages 15.1 million liters per month or 1.77% of the monthly total pumped at Duman. Therefore, the net withdrawal rate from the L-15 mine complex averages 27,976,540 liters per day for the most recent seven plus year period. The water level and the mine storage volume over that time period is essentially unchanged; thus the net pumping rate equals the total mine complex inflow (recharge) rate.

It has been proposed to move the treatment facilities to a location near the original breakout area (Fig. 2) and to pump the mine complex at a rate of 37.85 million liters per day for 300 days per year. However, the present mine recharge rate averages 27,976,540 liters per day. Therefore, if the mine is pumped at 37.85 million liters per day, there will be an average deficit of 9,877,582 liters per day. This deficit will total 2,963,274,600 liters over 300 days of pumping.

If the mine recharges for 65 days (no pumping) at an average rate of 27,976,540 liters per day, the recovery will be 1,818,475,000 liters, which still leaves a deficit of 1,144,799,600 liters per year. With the estimates of total storage of the L-15 mine complex at present equal to 5.4 billion liters, the total amount of mine dewatered would be roughly 55.0% (volumetrically) at the end of 300 days. The amount of dewatering would be reduced to 21.3% of the total storage after 65 days of recovery. If the pumping is continued for 365 days per year the deficits are even greater, up to 66.9% by volume in the first year.

Table 1. Percentage of the Colver seepage contribution to the Duman discharge under changing head differential.

Drawdown in the L-15 Complex	Water Level in Colver		
	514.2 meters m.s.l.	517.3 meters m.s.l.	520.3 meters m.s.l.
Present Conditions	27.9%	30.0%	32.1%
3.05 meters	28.7%	30.8%	32.9%
6.10 meters	29.5%	31.6%	33.7%
9.15 meters	30.2%	32.3%	34.5%
12.20 meters	30.9%	33.0%	35.2%
15.25 meters	31.6%	33.8%	35.9%

Any net mine pool dewatering during a pumping cycle will be problematic for several reasons. First, the mine water storage will be overtaxed and an eventual reduction in the mine pool yield of 37.85 million liters per day will result. Secondly, if the mine is dewatered to a great extent, a large portion of the Lower Kittanning (B) seam mine works will be subaerially exposed. This will cause water quality to deteriorate significantly from the present conditions due to additional pyrite oxidation and subsequent mine drainage production (Perry et al., 2005). This rapid and significant water quality degradation will cause the treatment facilities, designed for present conditions, to fail. The neutralization system will be inadequate and settling ponds will be undersized. Third, if the mine pool is dewatered there is a chance that some domestic wells located in low-cover areas could be dewatered. Finally, additional subsidence causing damage to surface structures may occur, if the hydrostatic pressures are removed or reduced by dewatering. Similar responses to dewatering have occurred elsewhere in the Eastern Coalfields (Hoffman et al., 1999).

The mine pool cannot be pumped at 37.85 million liters per day for 300 days per year without dewatering a significant portion and eventually, over several years, entirely dewatering it. Dewatering any more than a small percentage of the mine will likely be a detrimental to the water quality that will ultimately be pumped from the mine.

Subsidence related to dewatering of underground mine workings has been documented elsewhere in the coalfields of the Appalachian Plateau. Hoffmann et al., (1999) reported on a

2000 foot portion of I-70 in Guernsey County, Ohio that was damaged in 1994 by subsidence triggered by dewatering of abandoned underground mines during surface mining activities. The two underground mines that subsided were reportedly both first and second mined in the Lower Freeport coal. The mines were abandoned and allowed to flood in 1927 and 1935. Subsidence occurred shortly after pumping began at the surface mine. Overburden in the vicinity of I-70 ranged from 19.5 to 24.4 meters. Once the surface mining was completed, the water levels in the abandoned underground mines rebounded to previous levels of approximately 6.1 meters above the mine roof. It is plausible that dewatering portions of the L-15 mine complex could trigger similar subsidence. There are areas within the mine complex where the hydrostatic head is much greater than 6.1 meters above the roof and cockpit subsidence is already known to exist in shallow cover areas.

<u>Colver Mine Yields</u>

As discussed above, the Barnes & Tucker L-15 mine complex alone cannot yield 37.85 million liters per day on an annual basis. Another source is needed to augment the yield. Yield of the adjacent Colver Mine was reviewed to determine if it could supplement the Barnes & Tucker yield and prevent a projected shortfall.

Discharge and water quality data for the Colver Mine were obtained from Peabody Energy. Combined average annual discharge at the two treatment plants at the Colver Mine between 1980 and 1999 is a mean of 13,423,000 liters per day. These data illustrate that the Colver Mine should make up the projected average deficit of 9,877,582 liters per day on a 365 day pumping schedule. If the 300 day pumping schedule is employed the additional water from the Colver Mine should make up any needed difference.

If all of the Colver Mine water were added to the Barnes & Tucker discharge a total average 41,501,740 liters per day could be discharged into the West Branch of the Susquehanna River. If only 37.85 million liters per day are needed, the difference (average of 3,545,417 liters per day) could continue to be discharged into the Blacklick Creek watershed. This excess water may give an additional margin of protection for a consistent 37.85 million liters per day discharge during low-flow periods while minimizing the mine dewatering.

<u>Discharge Rates Under Low-Flow Conditions</u>

The above calculations for the potential withdrawal rates are based on the average yields of the L-15 and Colver mines. By definition, when a data set is normally distributed, the mean is the best representation of the central value and the data will be somewhat evenly distributed about the mean. Therefore, roughly 50% of the time the amount of water available for pumping will be below the mean. The question is what is the potential discharge rate during low-flow conditions? Data sets for the L-15 mine complex and Colver were analyzed with respect to characterizing low-flow conditions.

Based on a 95% confidence level, the expected low-flow rate for L-15 is about 17.9 million liters per day. This value was determined from analysis of weekly average pumping rates from January of 1996 through July of 2004. These data required a log transformation to obtain an approximate normal distribution. A low-flow value of 17.9 million liters per day was determined by the conventional two standard deviations from the mean (95% confidence interval). Therefore, only 2.5% or less of the time the discharge should be equal to or below 17.9 million liters per day.

The Colver data set yielded a low-flow of 8.5 million liters per day. This low-flow value was based on a breakdown of annual flow data at a 95% confidence interval. No transformation was required for these data. Additionally, monthly flow data for 1980 through 1985 showed a low-flow period (month) where the average flow was 6.25 million liters per day, which is well below the statistically projected value.

There may be short periods during dry spells where the combined discharge rates of L-15 and Colver will not be able to yield 37.85 million liters per day. Combined discharge rates of L-15 and Colver mines during low-flow conditions may be between 24.2and 26.5 million liters per day. During these periods, a minimal amount of mine dewatering may be possible without triggering major problems.

<u>Mine Pool Drawdown Rates</u>

Average recharge rate for the L-15 Mine Complex is 27.97 million liters per day. As expected and by definition, close monitoring of mine water levels throughout the summer of 2004 illustrates that there are times when the recharge rate is much higher and lower than this average.

There are several precipitation events where the water level rose during a period the Duman treatment plant pumped approximately 35.43 million liters per day. Conversely, there were periods when pumping at the same rate caused a sharp steady (linear) decline in mine water levels. Four of these decline periods were extracted as subsets from the entire data set. Simple linear regression analyses were performed on these data to determine the rate of decline over time. The r-squared values exceeded 99% with P values less than 0.01 for all analyses. Fig. 5 is an example plot of the linear regressions performed.

The mine pool, when being pumped at 35.43 million liters per day and when not appreciably impacted by preceding precipitation, averages a decline of 0.091 meters per day with a range of 0.082 to 0.098 meters per day. While this rate of drawdown is not precisely as it would be with a pumping rate of 37.85 million liters per day, it indicates the magnitude of the potential dewatering rates. This rate is likely the most conservative drawdown that would occur with pumping 37.85 million liters per day under similar hydrologic and climatic conditions.

Other factors will impact the rate of drawdown. As drawdown occurs, portions of the pool will be dewatered, diminishing the total potential storage volume, which will cause the water level to decline at an increasing non-linear rate.

On the other hand, as the mine pool is drawn down, the head differential between the mine pool and overlying recharging units is increased. With an increase in the head difference and all other factors being the same, the recharge rate should initially increase somewhat. The authors have seen the inverse of this effect (decreasing recharge rates) as pool levels of flooding mines approach the surface. This increase in recharge due to increasing head will be most evident as the shallow cover areas are dewatered. Where the pool is dewatered into areas with thicker overburden (>46 to 61.0 meters), these overlying units tend to yield less water. Additionally, once the head drops below the level of the mine roof, the recharge becomes free-draining (i.e. non-Darcian) and will become more constant in those areas, depending on the recent precipitation.

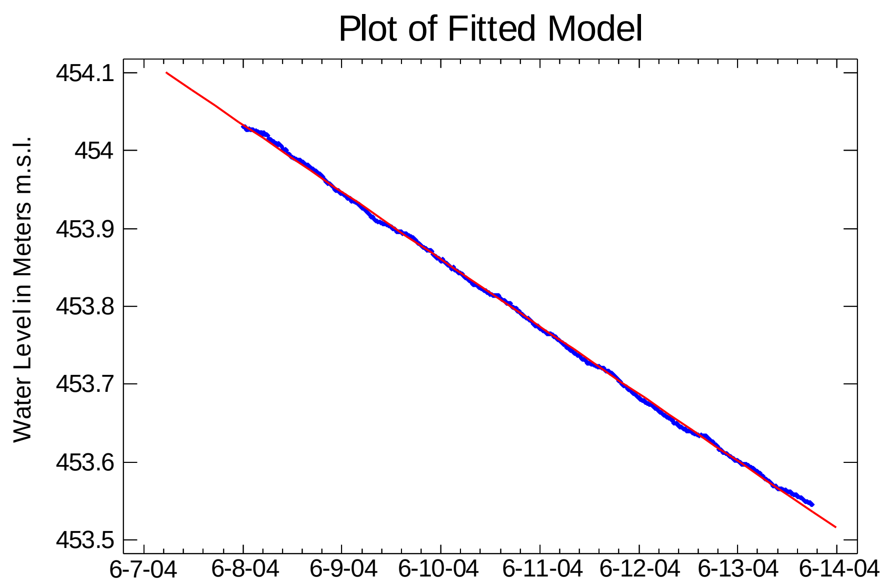

Figure 5. Drawdown of the Lancashire 15 mine complex.

Mine Water Level Responses to Precipitation Events

Precipitation data recorded at the Ebensburg weather station was used to compare to changes in water levels recorded at the Maberry Borehole. The weather station located at the sewage treatment plant is roughly 12 km from the central portion of the L-15 mine complex. The precipitation data are given on a daily basis, while the water level data are recorded every 15 minutes.

Based on several rainfall events, the median lag time between a significant event and a response (rise) in water level in the L-15 mine complex is three days. The range of lag times is from a low of 2 to a high of 5 days depending on the preceding climatic conditions. Fig. 6 is an example of 3-day lag in the mine pool level response to a 2.1 cm rain event followed by a 1.5 cm rain. Water level increases exceeding 0.61 meters within 3 days of a significant rainfall have been recorded.

The fairly quick and distinct response of the L-15 mine pool to precipitation illustrates the close link of the mine pool complex and the shallow ground-water systems. Booth (1984) observed a similar relationship for the Lancashire 20 mine. This close relationship to the shallow ground-water system and the diminished storage capacity of the mine pool are why the water levels can rise and fall several meters (>3.4 meters) over a short time period (two months). The author’s experience with other large mine pools indicate that this magnitude of water level fluctuation range over time 60 days is not common.

Mine Recharge rates

Average recharge rates were estimated for components of the L-15 mine complex as well as area other mines. Estimates of recharge for the L-15 mine complex without a Lancashire 24B component was 2.53 liters per minute per hectare (Lpm/hectare). By comparison, Booth (1984) determined that the Lancashire 20 had a recharge range of 10.85 to 19.83 Lpm/hectare, although he recorded a decrease of recharge with time. Lancashire 24B yields an average of 7.02 Lpm/hectare. Lancashire 24B is directly connected the overlying Lancashire 24D mine which is in much shallower cover and thus is expected to have a higher recharge rate. The estimated recharge rate for the Colver mine at 2.90 Lpm/hectare is strikingly similar to L-15.

Recharge rates of 2.53 Lpm/hectare for the L-15 without the contribution of Lancashire 24B and D and 2.90 Lpm/hectare for Colver are somewhat lower than anticipated for mines in the mountains of the Appalachian Plateau. Hlortdahl (1988) recorded recharge rates of 7.11 to 11.22 Lpm/hectare for mines in the mountainous areas of western Maryland. A range of 4.30 to 7.11 Lpm/hectare was determined for similar areas of Pennsylvania (U.S. EPA, 1975). Conversely, Winters et al., (1999) noted that mines with an average overburden greater than 61.0 meters had an average recharge rate of 1.87 Lpm/hectare in a non-mountainous area. The average recharge rate for Lancashire 24B and D (7.02 Lpm/hectare) is similar to those recorded by Hlortdahl (1988) and the U.S. EPA (1975). However, a portion of the Moss Creek mine appears to also drain into the Lancashire 24B mine (Waite, 1980). Higher recharge rates of Lancashire 24B and D are likely related to the shallower cover over the D seam mining and the longwalling that occurred. Recharge rates given by Booth (1984) for Lancashire 20 also appear to be related to the high percentage of longwall mining and the shallower cover over much of the mine.

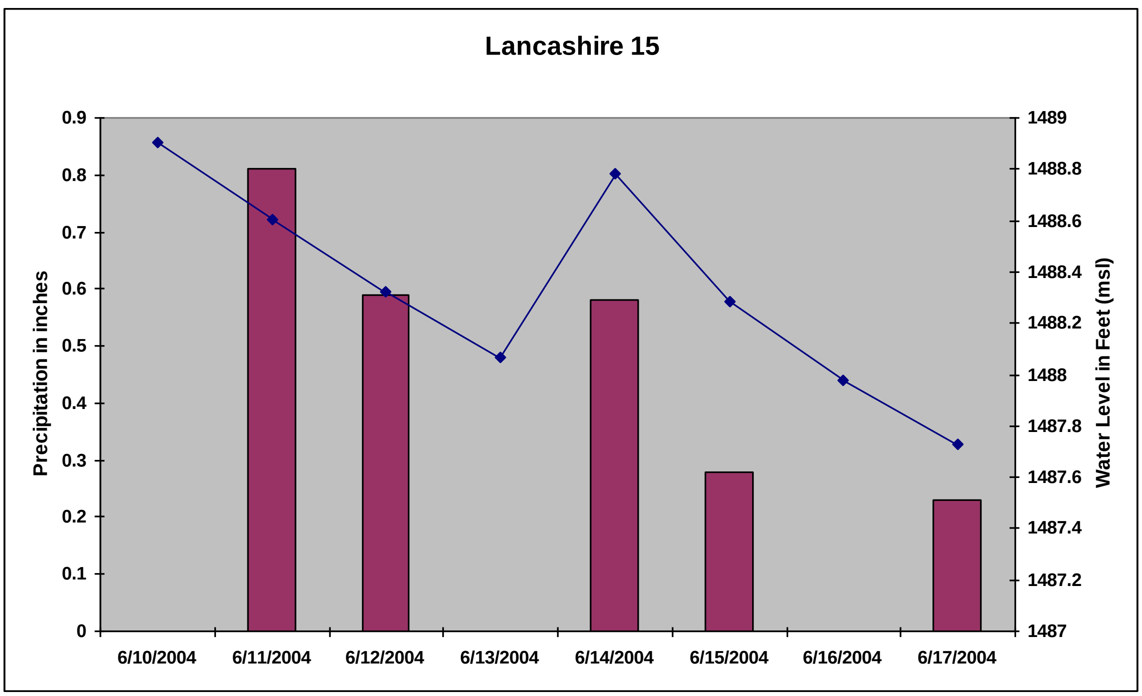

Figure 6. Example water level response to precipitation.

Summary and Conclusions

Quantitative hydrogeologic properties of a large mine-pool were deduced from examination of pumping records, water level and precipitation data and mine mapping. Present storage of the Lancashire 15 mine complex is approximately 5.38 billion liters. The effective porosity is 11%, which is considerably less than the original estimated coal extraction rate of 62.6%. Lower porosity has resulted from a reduction of voids caused by mine subsidence.

The comparatively low storage capacity for the size of the mine complex is due to the relatively thin coal seam (~ 1 meter) and subsequent the low effective porosity (11%). Limited storage volume facilitates mine dewatering with moderate increases in the pumping rate. Present average yield is about 28 million liters per day. If the pumping rate is increased to nearly 38 million liters per day, up to 67% of the mine pool volume would be dewatered the first year. Pumping at 38 million liters per day for just 300 days with recovery allowed for the following 65 days still will have a net dewatering of 21.3% of the mine pool volume. At the present pumping rate, the mine pool volume turns over on the average of every 192 days or twice in slightly more than a year.

If a consistent 38 million liters per day are needed and mine dewatering avoided, the projected shortfall of water could be obtained from the two borehole artesian discharges of the adjacent Colver mine. The Colver mine yields an average of 13.4 million liters per day.

There is a high degree of hydrologic connection and interaction between mines. Many of the mines in the same seam have open pass throughs. Vertical connection between mines in separate seams is facilitated by naturally-formed and subsidence-induced fractures, naturally-formed fractures accentuated by subsidence, and open mine shafts and slopes. Hydrographs of monitoring wells in several of the mines show the water levels rise and fall in concert.

A minimum of 28% or at least 5,368 liters per minute of the water expressed by the L-15 mine complex is barrier seepage from the adjacent flooded Colver mine. The seepage rates are fairly insensitive to water level changes. Moderate raising or lowering of the head differential (up to 15.2 meters) caused only minor changes in seepage rates.

Under average flow conditions, the Lancashire 15 mine complex and the Colver mine combined can produce in excess of 37.85 million liters per day. However, during extreme low flow combined discharge rate is projected to be between 24.2 and 26.5 million liters per day. Any pumping scenario should take into consideration periodic low-flow episodes.

Monitoring of the mine pool when pumping at 35.43 million liters per day and when not being impacted by recent precipitation, showed an average decline of 0.091 meters per day with a range of 0.082 to 0.098 meters per day. Pumping at 38 million liters per day should have a similar, but slightly higher drawdown rate. On the other hand, the mine pool responds (rises) on the average of three days after a major precipitation event.

Estimates of recharge for the Lancashire 15 mine complex without a Lancashire 24B component was 2.53 Lpm/hectare. By comparison, Booth (1984) determined that the Lancashire 20 had a recharge range of 10.85 to 19.83 Lpm/hectare. Lancashire 24B yields an average of 7.02 Lpm/hectare. Colver has an estimated average recharge rate of 2.90 Lpm/hectare. Lower yield rates of L-15 and Colver are primarily due to the thicker overburden over much of the mine.

Low storage volume, comparatively rapid recharge from precipitation, and the synclinal basin setting cause the mine pool complex to rise and fall more quickly and to a greater degree other mines that we have monitored. This behavior could be termed flashy with respect to underground mine pools.

Under most conditions, the L-15 mine complex, with augmentation from the Colver mine, will be able to yield a consistent 38 million liters per day. However, there may be periods of drought where that yield rate will not be possible. Dewatering portions of the mines more than present conditions is not recommended due to the potential to degrade the water quality and induce additional subsidence.

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