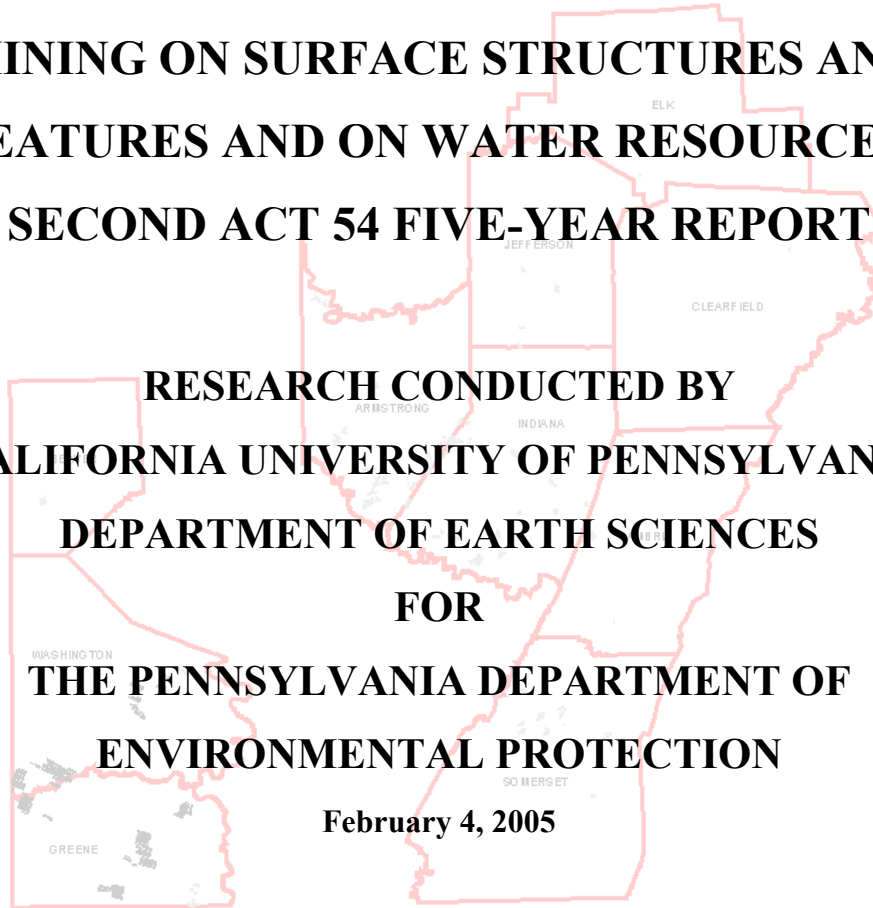


**THE EFFECTS OF SUBSIDENCE RESULTING
FROM UNDERGROUND BITUMINOUS COAL
MINING ON SURFACE STRUCTURES AND
FEATURES AND ON WATER RESOURCES:
SECOND ACT 54 FIVE-YEAR REPORT**

**RESEARCH CONDUCTED BY
CALIFORNIA UNIVERSITY OF PENNSYLVANIA
DEPARTMENT OF EARTH SCIENCES
FOR
THE PENNSYLVANIA DEPARTMENT OF
ENVIRONMENTAL PROTECTION**

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Section V: WATER INFLOW TO LONGWALL MINES

V.A. Overview and Methodology

This section applies a hydrogeological model that elucidates the relationships among geology, mining, and ground water in the area mined during the assessment period (see IA). The focus of the section derives from a concern that underground bituminous mining is “dewatering” a western Pennsylvania region. To address this concern, this section reviews the geological setting of mining and water loss and couples that review to a review of data on water movement in mines and surface water sources. This section also addresses a requirement of the MOU (see IA) to explain how the regional geology is related to mining-induced subsidence and the surface problems that it causes.

The University’s researchers extensively mapped, through GIS software, the locations of water sources over and in the proximity of undermined areas. Because site location with respect to mining is important, the researchers referred to “six-month maps” required of all mining operators and to data contained in BUMIS and public records. The maps were georeferenced (a process by which locations are registered with correct real-world coordinates) to make them useful for spatial analysis of water problems. In this section the researchers attempt to determine the potential for “well viability” with respect to distance from mining activities, a determination that takes into account the thickness of overburden, the location of the well on or near a longwall panel, and the PA DEP’s determination of “no liability.” The researchers also address the issue of water recovery and the PA DEP’s system of recording information on water sources.

V.B. Hydrogeologic Setting

Ground-water flow in the Pittsburgh Coal Basin is governed primarily by flow through fractures and bedding plane separations; this is called secondary permeability. Primary permeability is the ability of water to flow through the rock matrix itself. (Primary permeability can be visualized as water flowing through sand) Pennsylvanian and Permian Age (formed between 325-248 million years ago) rocks in the Pittsburgh Coal basin have been shown to have very little primary permeability. In 1980, Schubert

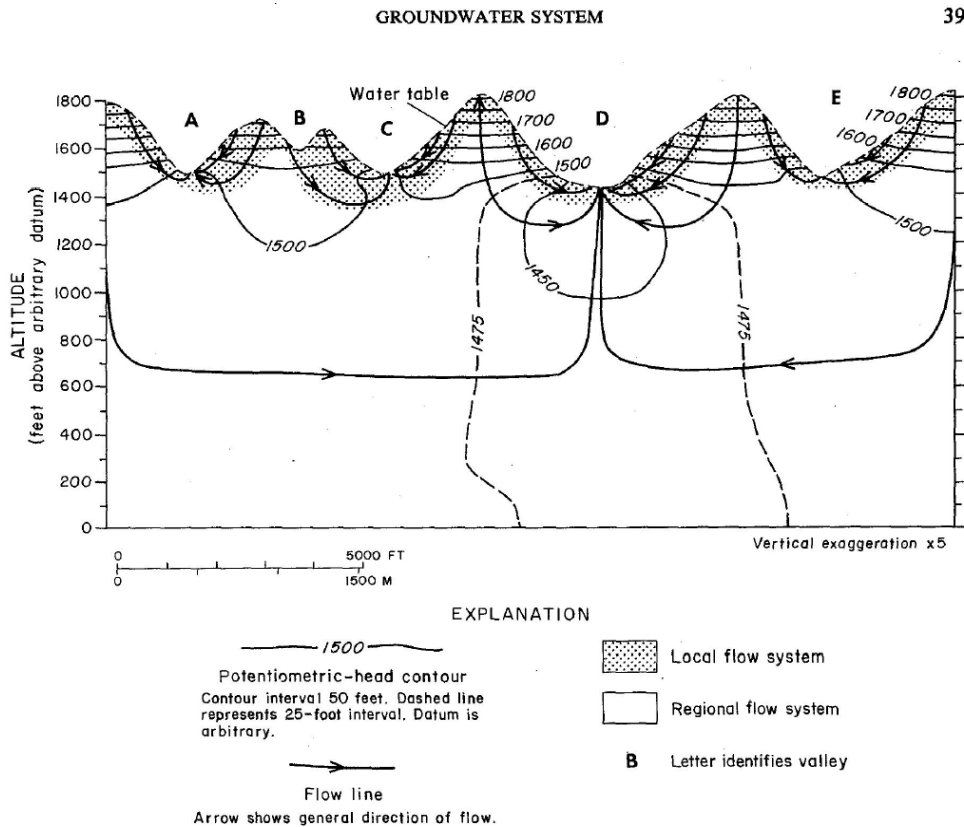
compared the hydraulic conductivities of core samples in Clearfield County Pennsylvania with the hydraulic conductivities observed in wells in the same area. From this comparison he concluded that the hydraulic conductivity observed in the field is at least 100 times greater than hydraulic conductivities (the potential to transmit water measured in distance over time) measured in the laboratory. This difference is ascribed to the presence of fractures. In 1987, Stoner et al. published a comprehensive study entitled “Water Resources and the Effects of Coal Mining Greene County, Pennsylvania.” Ground-water flow modeling in this study showed that the permeability of the undisturbed rocks overlying the Pittsburgh Coal decreases by a factor of ten for each 100 feet of depth below the land surface, and that the bulk of the ground water flow occurs near the land surface and not at the level of the mining operations. Figure V.1 shows the results of computer simulation modeling performed by Stoner et al. This conclusion is consistent with the findings of Wyrick and Borchers, 1981, who ascribe ground-water flow to stress-relief fractures in the valley bottoms and valley sides. Such fractures form parallel to the sides, or walls, of valleys after erosion removes horizontally oriented rock layers that provide lateral support. Stress-relief fractures often occur as surface and near-surface, interconnected sets of vertical breaks through which ground water is transmitted in rocks with low primary permeability.

The surface geology of the bulk of Washington and Greene Counties is dominated by the Greene Formation of Permian age. The Greene Formation ranges from 0 feet of thickness in the eastern and western river valleys to over 800 feet in thickness in the center of the counties. Stoner et al, 1987, has described the hydrologic potential of this formation in Greene County as:

“Generally a poor aquifer. The median reported yield of 55 wells is 2 gallons per minute. A few wells, especially along hilltops, were abandoned after drilling because yields were less than several tenths of a gallon per minute. ... About 75 percent of the wells had iron and manganese above recommended limits.”

Based on this investigation, it is clear that both water quality and water quantity are a concern even before mining takes place.

Singh and Kendorski, 1981, evaluated the disturbance of rock strata resulting from mining beneath surface water and waste impoundments. Their study looked at evidence and reports from many states, but some of the studies include the Pittsburgh coal seam.



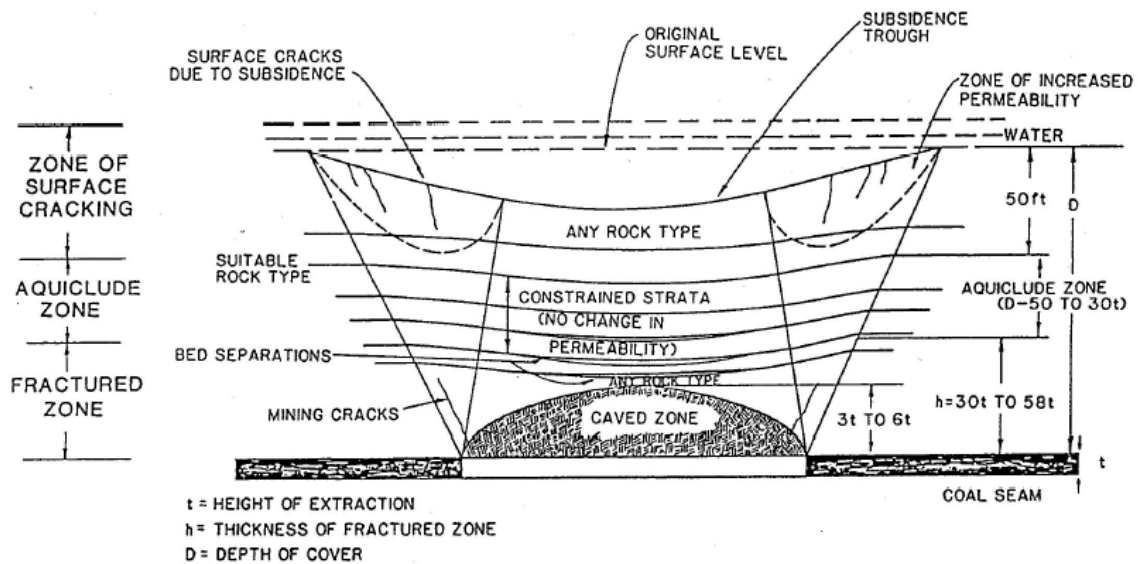
Distribution of potentiometric head computed from the calibrated steady-state model.

Figure V.1. Model showing the potentiometric head for a topography and subsurface indicative of that found in the bituminous coal fields of Greene County (after Stoner et al. 1987). A potentiometric head is hypothetical surface that indicates a level to which water will rise under the pressure of a hydraulic head in a cased well. Ground water moves through permeable rock under the pressure of a hydraulic head that represents the differences in elevation between two different sites.

In their analysis they describe a caved zone that extends from the mining level to 3 to 6 times the seam thickness, a fractured zone that extends from the mining level to 30 to 58 times the seam thickness, an aquiclude zone (a rock unit or units through which water

does not flow easily—“excluded”) where there is no change in permeability that extends from 30 times the seam thickness to 50 feet below ground surface, and a zone of surface cracking that is 50 feet thick. Figure V.2 is reprinted from their report.

In 1984, Coe and Stowe looked at two longwall operations in Eastern Ohio, one in the Pittsburgh Seam and one in the Clarion 4a seam. From their work they describe three zones in the overburden above longwall mines. The first zone is the “caved and fractured zone having increased secondary permeability. It extends 30-60 times the mined coal thickness....” The second zone extends from the top of the first zone to 50 feet below ground surface. In this second zone, “little change occurs in the rock permeability characteristics.” The third zone, which extends from the surface to a depth of 50 feet, is described as a zone where “increased fracturing occurs as the land subsides resulting in compressional and tensional stresses.”

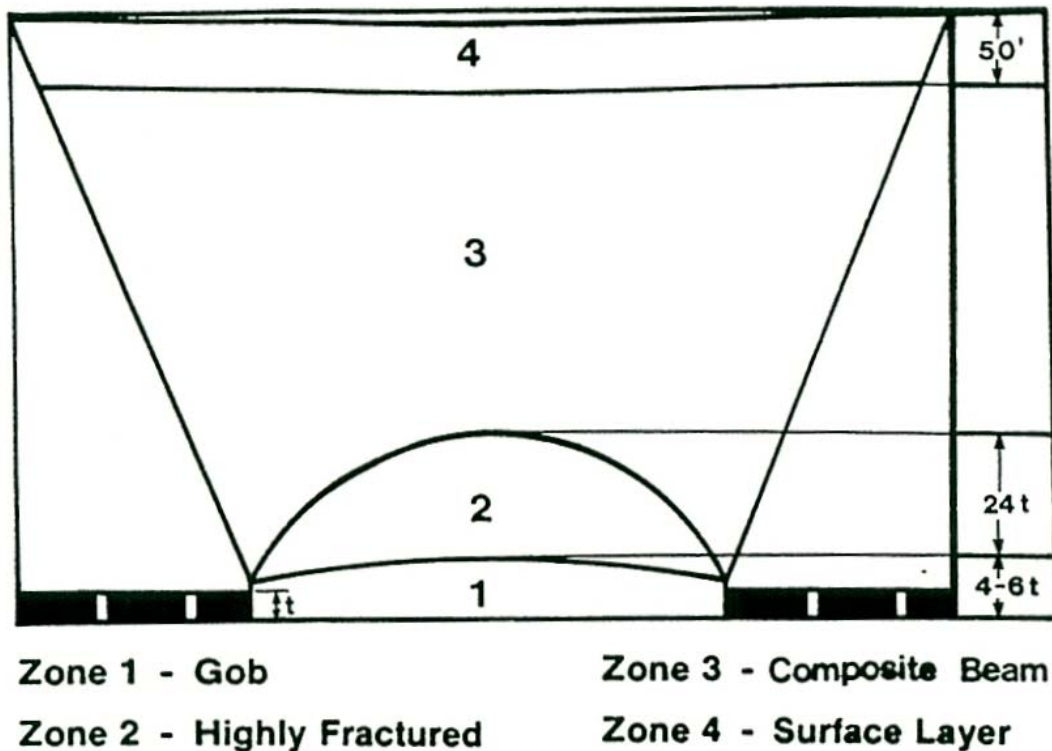


- Generalized Depiction of Strata Behavior With Total Extraction Mining

Figure V.2. A model of surface and subsurface zones applicable to the Pittsburgh coal seam.

In 1988, Hasenfus et al. described the hydrogeomechanics of overburden in “A Hydrogeomechanical Study of Overburden Aquifer Response to Longwall Mining.” Of the three studies cited, this study is the most specific to the Pittsburgh coal seam. The

study site was a highly instrumented Pittsburgh seam longwall panel in West Virginia. Land subsidence was monitored via surveying, four Time Domain Reflectometry¹ (TDR) holes were installed, ground water levels were measured in eight monitoring wells, the investigators conducted pre-mining and post mining coring and packer tests, and pre-mining and post-mining seismic surveys were conducted. Based on this work the authors divided the overburden into four zones. These are the Gob, the Highly Fractured zone, the Composite Beam zone, and the Surface Layer. Figure V.3 is reproduced from their report.



Conceptualized Representation of Overburden Response

Figure V.3. Four zones associated with the strata affected by underground mining. The combination of the thickness of the gob and the highly fractured zone is equal to 28 to 30 times the thickness. This is the same fractured thickness that is used by the PA DEP.

¹ TDR is a process that allows the measurement of the depth of horizontal fractures as they occur in a borehole over a longwall panel. TDR uses two probes inserted into the soil that emit and receive a high-frequency electromagnetic wave to identify discontinuities below ground. Water slows the signal.

This literature indicates that longwall mining should not result in large scale dewatering of the overlying strata due to diversion into the mine where the overburden thickness is greater than 230 to 410 feet thick. The Hasenus model supports a thinner highly fractured overburden, whereas the Singh and Kendorski model supports a thicker highly fractured overburden that is calculated using the factor of $30t$ or $60t$ where t is the mining height plus 50 feet. This example uses a six-foot mining height (the thickness of the coal seam). The University's researchers, to address the concern that Washington and Greene counties are being "dewatered" regionally by longwall mining, attempt, in this section, to see whether or not this relationship to overburden thickness applies to the two counties during the assessment period.

V.C. Data Collection and Analysis

As part of the existing permitting process, mining operators are required to provide information on the hydrologic effects of their proposed mining operations. These data are contained in Module 8 of the permit applications. When the permit is initially submitted and when mining acreage is to be added to the permit, the operator is required to estimate the amount of water that will flow into the mine. For existing mines this requirement is fulfilled by reporting the amount of water being pumped from the mine, then dividing this by the acreage that has already been mined and then multiplying this factor by the total proposed acreage. The University has obtained these data from the permit applications, and the data have been plotted for each mine and reported in gallons per minute per acre. This is shown in figure V.4. In the case of Dilworth mine the discharge data were obtained from the Discharge Monitoring Reports (DMR) because there had not been a significant acreage addition in recent years.

The most apparent feature of this graph is that the inflow to Dilworth mine is significantly greater than the inflow of any of the other mines. In fact, inflow to Dilworth may be even higher than represented. The reason for this is that the flow from the Kedive transfer pumps is not included in the DMRs. These pumps transfer water to the Robena Mine where it is pumped and treated. This pumpage is included in Robena's DMR, but the flow cannot be separated from Robena's own water flow.

Despite this weakness in the data, what is reported is an inflow rate to the Dilworth mine that is significantly higher than any other mine. There are at least two possible explanations for this. First, and most significantly, Dilworth is surrounded by three flooded or flooding mines, specifically, Crucible, Nemaquin and Mather. Up to 240 feet of water pressure is known to exist along the mine barrier with Nemaquin, and up to 180 feet of pressure is against the barrier with Crucible. Mather might have 80 feet of pressure head against its barrier with Dilworth. This pressure can cause water to leak through the coal barrier and into Dilworth. This hypothesis is further supported by the fact that Crucible, Nemaquin, and Mather are ***not*** discharging water from their underground workings. Secondly, the Dilworth mine is overlain in part by the Carmichaels Formation. The Carmichaels Formation is a deposit of sand, gravel, and mud, up to 80 feet thick that can serve as a source of recharge to the mine and that is not present at the other mines in the study. These environmental conditions lead to the conclusion that the Dilworth inflow data are not representative of the normal inflow to the Pittsburgh Seam mines. No determination is possible, with the available data as to the relative contribution of barrier leakage and vertical infiltration at Dilworth.

More significant than the Dilworth inflow is the low and in some cases very low rate of inflow to these underground mines. These inflow rates range from 0.005 gallons per minute per acre to 0.23 gallons per minute per acre. Absent Dilworth, these inflows range from 0.005 gallons per minute per acre to 0.095 gallons per minute per acre, and even the high value in this case is affected by barrier leakage (Maple Creek). Stoner et al, 1987, found that in Greene County about 21 percent of the average annual precipitation reports to (enters) the streams as base flow. This is equivalent to saying that 21 percent of the precipitation is ground-water recharge. The average annual precipitation for the area for the years 1971 through 2000 is 42.8 inches. Using this number, the University's researchers find that 8.99 inches of rainfall represents the amount of average ground-water recharge. This recharge rate can be converted to gallons per minute per acre resulting in a recharge rate of 0.46 gallons per minute per acre. It is now possible to compare the mine inflow with the average annual ground water recharge. Figure V.4 shows this relationship. Two mines, Enlow Fork and Cumberland receive

only about one percent of recharge. Emerald receives about 2.5 percent of recharge. Bailey and Mine 84 receive 7.0 and 7.8 percent respectively. Maple Creek receives 20.5 percent, and Dilworth receives 50.1 percent. As we have seen previously, the Dilworth number is believed to be anomalous, and the Maple Creek, and Mine 84 numbers may be overly representative of their true ground-water capture due to adjacent mine flooding. No data are available for either Blackville 2 or Shoemaker.

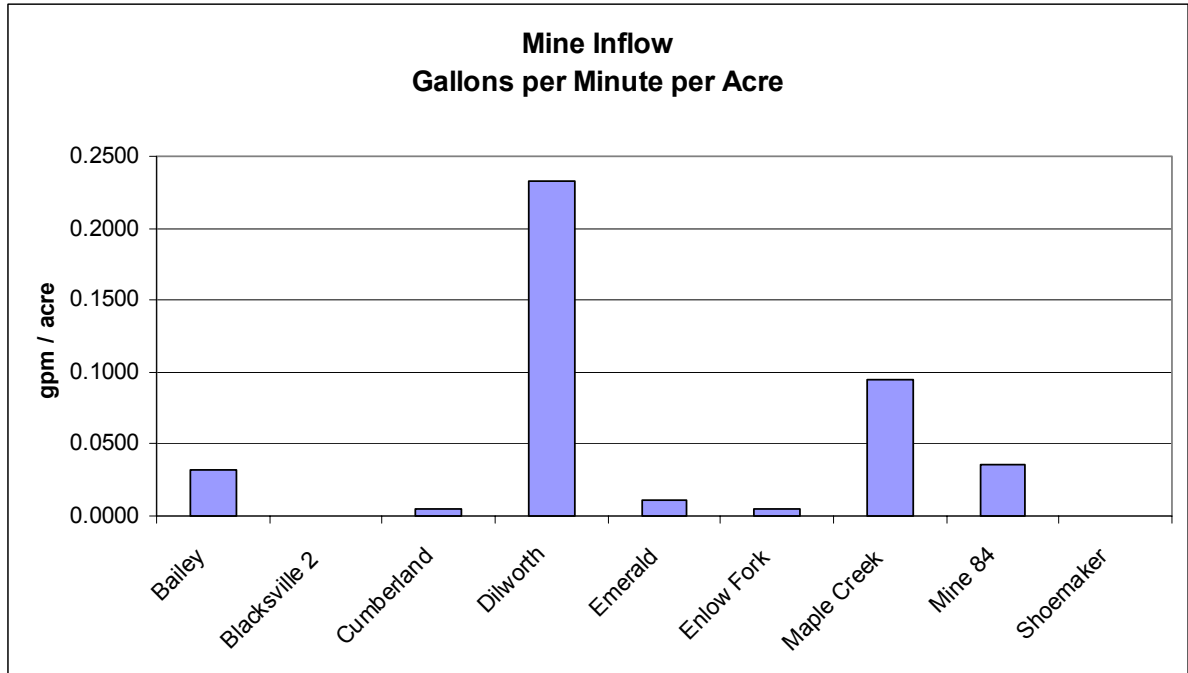


Figure V.4. Water reporting to mines as “inflow.”

Based on this analysis, the University’s researchers can state that the majority of the ground-water recharge does not flow into the mines of Washington and Greene Counties.

If this is true, then ground-water recharge that does not report to the mines is still available within the system. These results support the concept proposed by Singh and Kendorski; Coe and Stowe; and Hasenfus, et al., that the hydraulic conductivity of the rock units located above the caved zone and below the shallow fracture zone remains largely unaffected by longwall mining. Although the model appears to describe the conditions of Washington and Greene counties during the assessment period, the University wants to emphasize that this is a *regional phenomenon* that does not counter

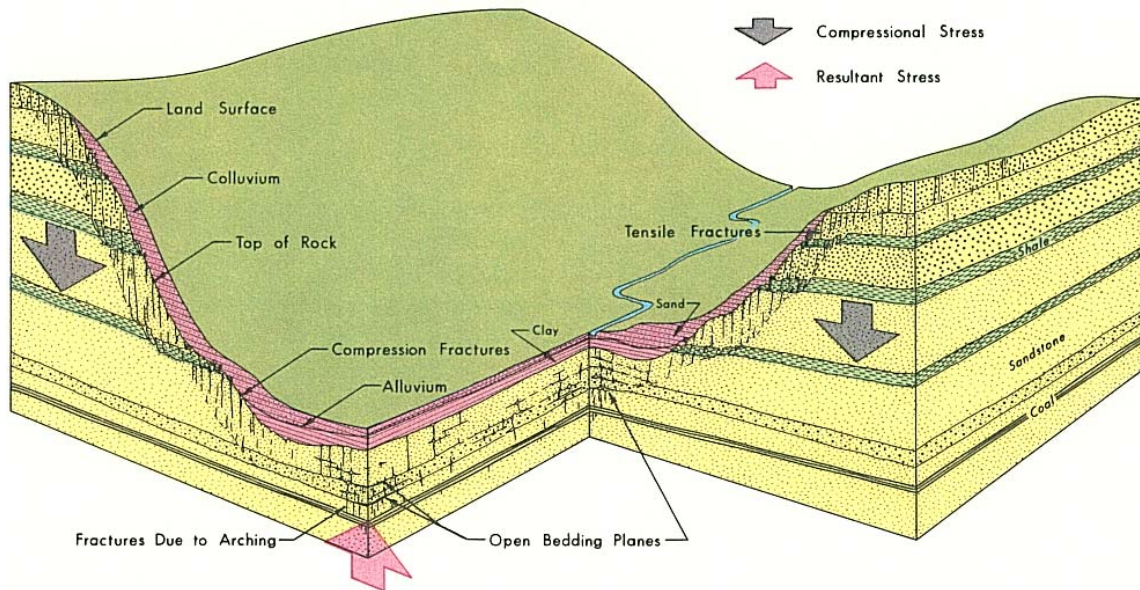
the observations, reports, and claims of individual property owners who might have suffered water diminution or loss during the five-year assessment period.

V.D. Conceptual Ground-Water Model

If the majority of ground-water recharge remains in the system, how then are water supplies that are dependent on that system affected by mining?

In 1974, Ferguson, working for the Army Corps of Engineers, described a consistent pattern of near-surface fractures and bedding plane separations that he attributed to stress relief fracturing. Such fracturing involves vertical fractures that occur parallel to the walls of valleys and in valley floors. They are generated when neighboring, supporting rocks are removed by erosion. Water can flow through the interconnected sets of stress fractures. This study was based on his work on the foundations of flood control and navigation dams in the Appalachian Plateau Region that includes southwestern Pennsylvania. In 1981, Wyrick and Borchers found that stress relief fractures are the dominant influence on ground water flow in the valley that they studied in West Virginia's analogous geology. In 1987, Stoner, found based on aquifer tests and historical well drilling practice that "the local aquifer system roughly parallels the land surface at a depth of 150 to 175 feet." This finding is consistent with ground water flow through stress relief fractures as described by Wyrick and Borchers. The stress relief fracture system is shown in Figure V.5 extracted from Wyrick and Borchers, 1981.

The Stress Relief Conceptual Model provides a context for understanding how longwall mining could affect near surface water sources without draining the water into the mine. Subsidence, whether caused by longwall mining or by full extraction room-and-pillar mining, will result in tension or compression in the near surface zone.



Block diagram of generalized geologic section showing features of stress-relief fracturing [after Ferguson (1974)]

Figure V.5. Stress-relief fractures are sites of secondary permeability.

Because ground water flows through, and is stored in, the near-surface stress relief fractures, movement of these fractures induced by subsidence can increase or decrease the ability of the fractures to either store or transmit water. If the ability of the fracture to permit ground-water flow is increased, then the water level can be expected to decrease because the ground water is able to flow toward stream level more quickly. At the same time, increased flow in the fracture system can result in higher yield to those wells that retain water.

Figure IV.12 (see section IV) shows that at least 49 percent of water supply replacements are either new wells or springs, with 27 percent being public water supplies. ***These data support the premise that ground water remains in the near surface environment. If ground water were not available in the near-surface environment, then replacement wells or springs would not be possible.***

V.E. Distance from Mining: Data Collection and Analysis

Distance from mining is used by the Department as one of the parameters for evaluating responsibility in water loss claims. In order to evaluate the significance of “distance from mining” the authors of this study combined PA DEP water loss records with water supply inventories from mining company permit applications. Each water supply identified in the pre-mining surveys was located, if possible, and recorded in the GIS database.

Similarly, each water supply for which a complaint had been filed in the five-year period of this study was located, if possible. These two data sets were then cross-referenced.

The combined data set was then evaluated to determine the distance in feet from longwall mining. Distance from room and pillar mining was ignored since no subsidence is expected from these development entries. Distance from longwall mining was separated into four ranges: 0 to 100 meters (0 to 328 feet), 100 to 500 meters (328 to 1640 feet), 500 to 1000 meters (1640 to 3,280 feet), and 1,000 to 2,000 meters (3280 to 6560 feet).

The total number of wells was determined within each grouping, and these wells were further classified in to the following categories:

- Unaffected
- Mining liability
- DEP determined no mining liability
- Resolution pending

Unaffected water supplies were those water supplies identified on the pre mine survey and for which a complaint had not been filed with the PA DEP, or where one of the following conditions occurred

- The complaint had been withdrawn
- It was determined that no problem existed
- The water supply recovered with out intervention

The inclusion of the water supply “recovered” in this analysis is open for some discussion. It is inferred that if a water supply has “recovered,” it was initially “affected,” and hence should not be included here. Whereas this is true, the researchers were also interested in identifying the response of the hydrogeologic system to the stress of longwall mining. Because these water supplies “recovered” without any additional human intervention, they have been included here in the unaffected category.

Mining liability includes those water supplies that had one of the following classifications.

- Repaired
- Compensated
- Property Purchase
- Permanent well or spring
- Public water
- Pre-mining agreement

Upon investigation of water loss claims, the California District Mining Office evaluates a number of parameters including distance from mining, overburden thickness, presence or absence of drought conditions, type and location of the water supply, and the nature of the impact. Based on these and other relevant data, the agency makes a determination about the validity of the claim. This category includes all agency findings of “no liability.”

Water supplies that are categorized as “pending” were found to be composed primarily of those supplies that have been determined to have mining liability but, for one of several reasons, to lack a final resolution as of the closing date of the study period (August 20, 2003). The other component of this category is made of those mines that have been recently included in the system and for which a determination of liability has not yet occurred.

In order to calculate *the percentage of wells that remained viable after longwall mining*, the University’s researchers divided the number of wells within each “distance from mining” range that were unaffected by the total number of wells within that range in the distance category, minus the number of wells determined by investigators from the California District Mining Office to whose associated claims they could assign the designation “no liability.” By calculating percent viability in this way, all of the supplies in the pending category are treated as though they were a mining liability. In addition, any effect that the agency determination might have on the outcome is removed.

Table V.1. Numbers of wells, distance to mining, and percent survival for each distance range.

Distance Meters	n	Unaffected	Liability	No Liability	Pending	Percent Survival
0 - 100	805	628	106	13	58	79.3%
100 - 500	599	495	32	54	18	90.8%
500 - 1000	288	264	9	13	2	96.0%
1000 - 2000	181	167	4	10	0	97.7%

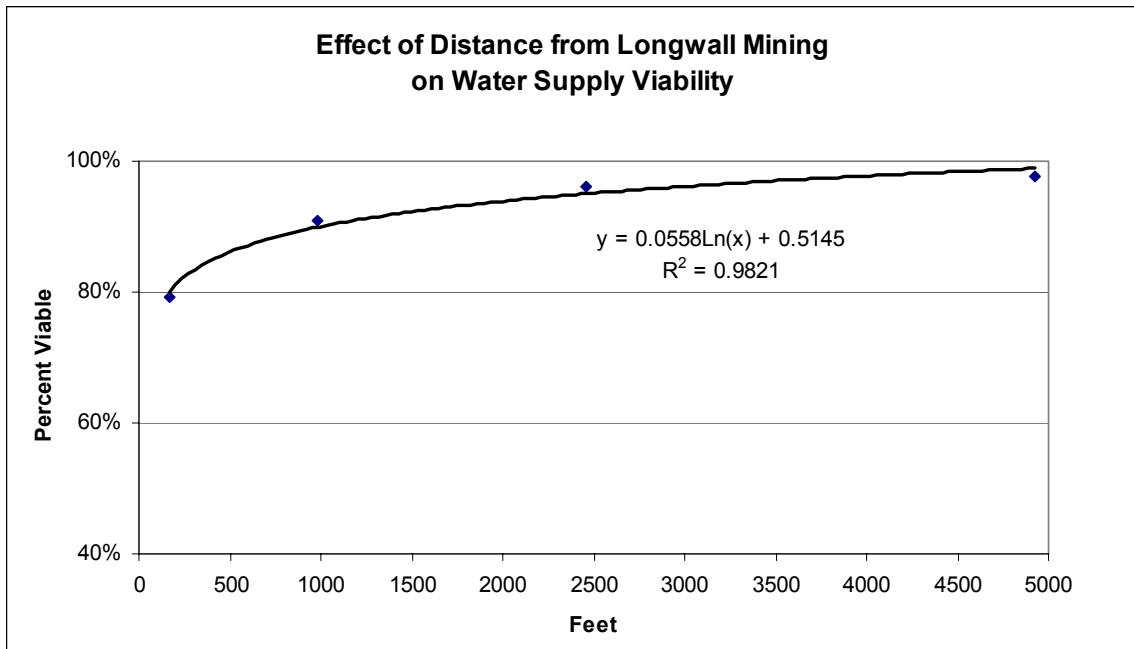


Figure V.6. The relationship between distance to mining and water supply viability.

Percent viability was calculated for each of the distance ranges listed above. These data are not cumulative but represent the percent of viability within that distance range. This is done so that the effect of different water supply populations (n) within each distance range does not skew the result toward the high data population distance. Table V.1 shows these results, and Figure V.6 shows these results plotted graphically with the data points located at the center of the distance range. For example the percentage viable value for the data range 0 to 328 feet was plotted at 164 feet. A regression analysis was performed on these data using a logarithmic model and the “best fit” line is also shown

on the graph. The calculated R^2 value of 0.9821 indicates that the line is highly correlated to the data. The formula for the curve is:

$$y = 0.0558 \cdot \ln(x) + 0.5145 \quad \text{where } x \text{ is in feet}$$

In this formula, (y) is the percentage of wells that are expected to remain viable given any distance (x) measured in feet from the edge of the longwall panel; (ln) is the natural logarithm.

*This analysis of data compiled for the assessment period clearly reveals that **distance to mining was a very significant factor in mining's effect on water supplies.** Water supplies that are less than 328 feet from mining have less than a 79 percent chance of surviving and as the distance to mining diminishes so do those odds. However, if the water supply is located 328 to 1640 feet from longwall mining then the odds of survival increase to 91 percent.*

Although the California District Mining Office uses distance to mining in its evaluations of water supply claims, the relationship shown in figure V.6 should add confidence to those determinations.

V.F. Overburden Thickness: Data Collection and Analysis

Based on the results from the distance to mining analysis, the GIS database was used to select those water supplies located within 328 feet of longwall mining. This data set contains 806 water supplies (springs and wells). Overburden thickness was determined for each of these water supplies by subtracting the elevation of the Pittsburgh Coal seam from the elevation of the water supply as determined from the USGS topographic maps. These overburden data were then grouped into 100-foot increments. *The depth of wells was not included in this analysis.* The water supplies were then separated into three classifications based on topographic setting. Valley supplies are defined as any source where the elevation is within 20 feet of the nearest valley floor. Hilltop supplies are located within 40 feet of hill tops, saddles, or peninsulas. All other water sources were

classified as hillside sources. Figure V.7 shows the relationship of water source viability to overburden thickness for each of the three topographic settings.

In some cases, there are very few water sources in a category. For example, hill top sources between 300 and 400 feet of overburden had only two sources and both survived resulting in 100 percent viability. However, two data points do not constitute a statistically significant set of data, and should not be used to identify a trend. Similarly, in the hill top source category, the interval from 400 to 500 feet had nine sources and the interval from 500 to 600 feet had five sources.

Hillside and valley sources show increased viability as depth increases up to 450 feet for valley sources and 550 feet for hill side sources. Hill top sources are more problematical. Once the overburden thickness of hilltop locations equals 750 feet, these sources are on a par with the valley and hillside locations; however, at lower overburden thicknesses the hill top data are more erratic. The lower survivability at hilltop sites with shallow overburden thickness might be true, and would not be surprising due to the small recharge area available at hilltop sites; nevertheless, the results relative to hilltop sites are questionable due to the small number of water supplies below 700 feet of overburden in the study data.

V.G. Intra-Panel Surface Subsidence: Data Collection and Analysis

Subsidence over longwall panels is not uniform. The greatest subsidence occurs in the middle of the panel and the least subsidence occurs over the adjacent unmined coal. In addition, as the longwall passes the land surface in the center of the panel is first placed into tension and then into compression. Along the panel edges the land surface remains in tension (extension), and this tensional force is the cause of surface cracking. These changes in the near surface stress field can translate into changes to the ground-water flow system in the near surface fractures. In order to evaluate these differences, all water

Water Supply Viability vs. Overburden Thickness for Water Supplies within 328 Feet of Longwall Mining

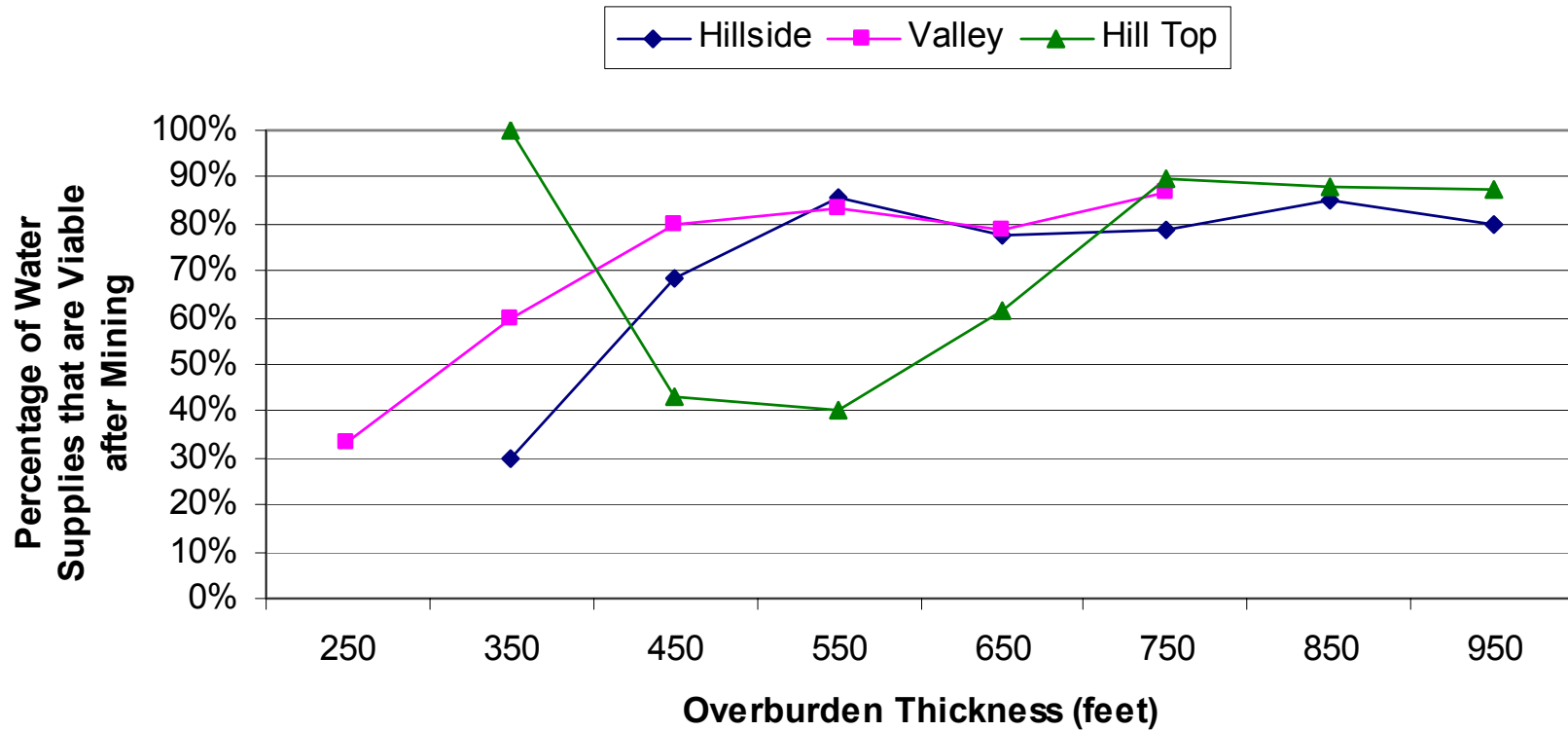


Figure V.7. The relationship between overburden and the viability of water supplies within 328 feet of longwall mining.

sources within 328 feet of longwall mining were sorted according to their positions in relation to longwall mining. By dividing each longwall panel transversely, the University's researchers selected four categories:

- Mid panel locations (25% to 75% of panel width)
- Quarter panel locations (0 to 25% and 75% to 100% of panel width)
- Gate locations (room-and-pillar mining around longwall panels)
- Unmined (water supplies located over unmined coal)

Figure V.8 shows the results of this analysis. Water supply viability over gate and mid panel locations was very similar at 82 percent and 81 percent respectively. Quarter panel locations had the lowest post-mining viability at 76 percent, whereas unmined locations had the highest water supply viability at 88 percent. *With the large number of water supplies in this data set, the University's researchers believe that these water supply viability numbers are representative of the true nature of mining's impact on the water supplies in Washington and Greene Counties, Pennsylvania.*

Based on this analysis, the location of water supplies over longwall panels is not as significant a variable as are distance to mining and overburden thickness. The higher viability of water supplies located over unmined coal is consistent with the earlier findings that distance to longwall panels is a key factor.

V.H. Angle of Hydrologic Influence: Data Analysis

Act 54 establishes a zone of presumptive liability for mining operations that is equal to the area of the mining operation plus an additional area bounded by the intersection of the surface and a line drawn from the base of the coal seam at an angle of 35 degrees from vertical. Within this zone, mining operations are presumed to be responsible for the damage, unless they can demonstrate that the water loss is due to another cause. Outside

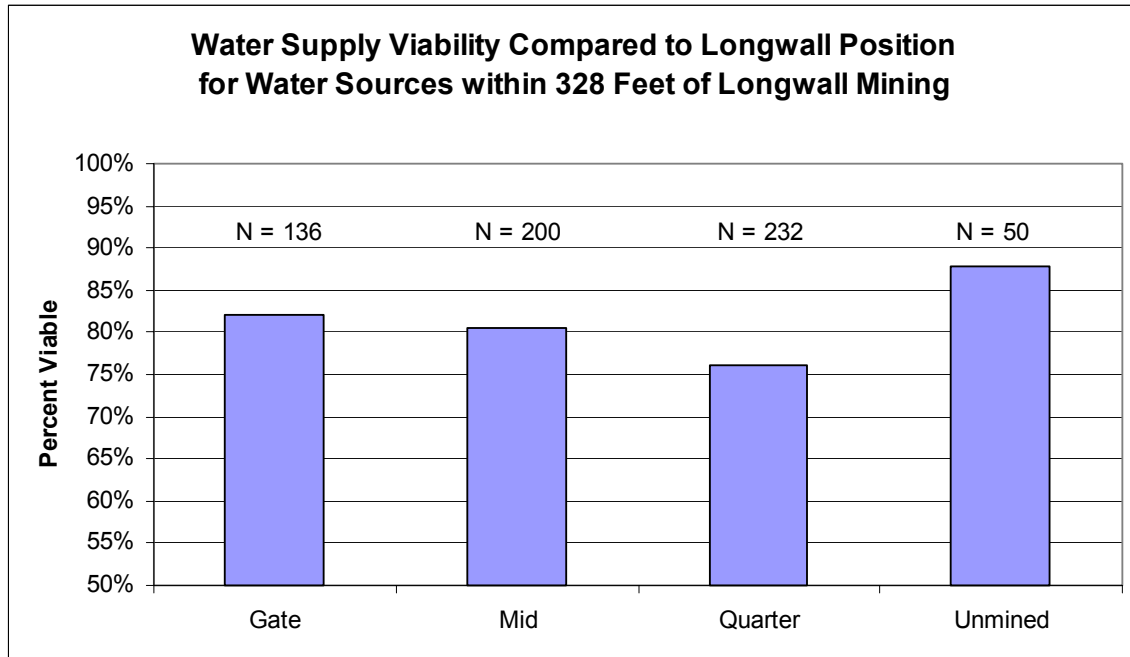


Figure V.8. Water supply viability as a function of location with respect to a longwall panel.

this zone, mine operators are responsible if the owner or the PA DEP can demonstrate that mining is responsible for the loss. This system is predicated on the belief that 35 degrees is a constant. Figure V.7 demonstrates that *at about 328 feet from the longwall panels 80 percent or more of the water supplies were viable while at less than 328 feet the viability drops off quickly*. If this value of 328 feet is applied to known overburden thickness, the “angle of influence” can then be calculated for each given overburden thickness. Figure V.9 is a plot of how the “angle of influence” would vary with overburden thickness given a constant distance from mining.

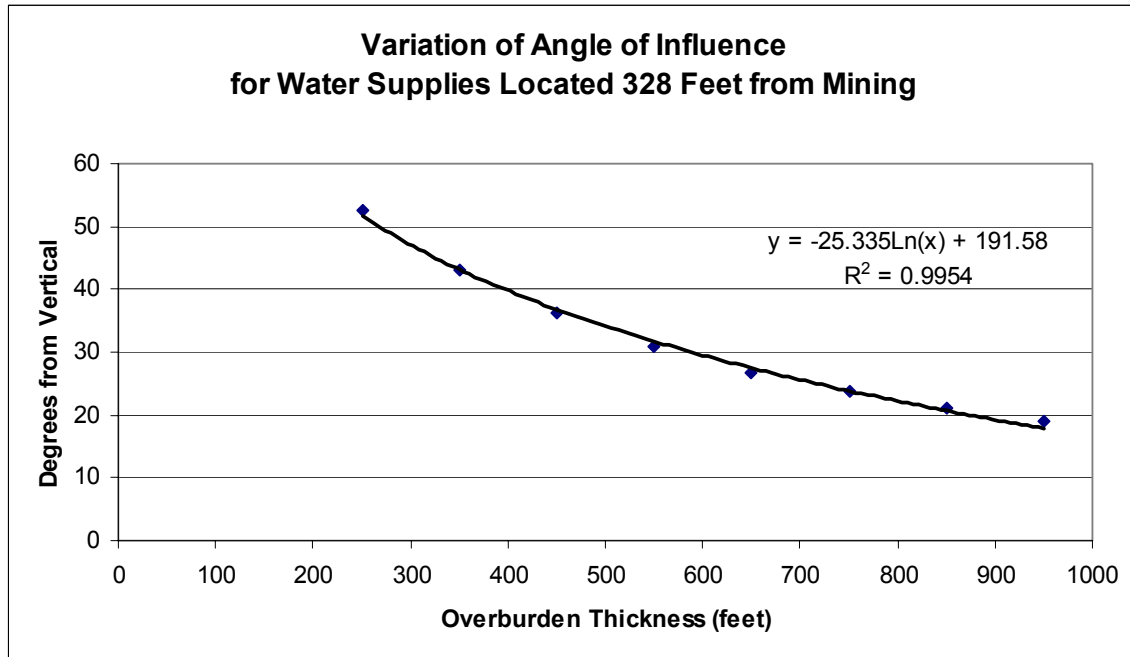


Figure V.9. The variation of the angle of influence with overburden thickness given a fixed impact distance

The plot in figure V.9 indicates that where thin overburden is present the angle of hydrologic influence would have to be increased to over 50 degrees to include those water supplies that are within 328 feet of longwall mining. Similarly, as the overburden thickness increases, the angle of hydrologic influence would have to be decreased to less than 35 degrees. At an overburden thickness of 950 feet the angle of hydrologic influence falls to less than 20 degrees.

The effect of distance from longwall mining to the water source is so significant that a presumption of liability based on an angle of hydrologic influence must be seriously questioned. If 80 percent viability of water supplies is used as a dividing line, then a presumptive zone of 328 feet from longwall panels is a better predictor than is a 35-degree angle of hydrologic influence, the current parameter established under Act 54. If a value other than 80 percent viability is preferred, then the formula provided in Figure V.6 should be used to calculate the corresponding distance from longwall mining to be included in the presumptive zone.

V.I. Evaluation of PA DEP’s “No Liability” Determination: Data Analysis

In addition to location, the GIS database was augmented with the water supply data assembled from BUMIS and other sources, such as the paper files contained in the California District Mining Office and the six-month mining maps. This allowed for the geographic and categorical separation of the data. The GIS database was used to count the number of water supplies that the California District Mining Office hydrologists had determined to have no mining liability within 328 feet of the longwall panels as well as the number of water supplies determined to have no mining liability between 328 feet and 6560 feet from the longwall panels. At the same time, the GIS database was used to count the number of water loss claims received within the same geographic area. The no liability determinations were then divided by the number of water loss claims received during the study period within each geographic area. This yields a percentage of claims with determinations of “no liability” The results of this analysis are shown in figure V.10. By this analysis, thirty-three percent of water loss problems reported from a zone within 328 feet (100 meters) of the longwall mining were found, upon investigation, to be instances for which the hydrologists of the California District Mining Office could not attribute liability for the problem to the mining operator. From 328 feet (100 meters) to 6560 feet (2000 meters) the percentage of instances for which the hydrologists could not attribute liability for the problem to the mining operator fell to 13 percent.

These results indicate that the California District Mining Office is more likely to make a determination of “No Liability” within the zone where most mining impacts are expected. This result is counterintuitive, and does not reflect the distance-to-mining vs. water-supply-viability relationship that has been previously established. Although this seems, at face value, to indicate that the PA DEP through the California District Mining Office is making unsound judgments, *such a conclusion is far from certain*. For example, this analysis considers mine workings as they appear at the end of the five-year assessment period, *whereas the California District Mining Office evaluations were based on the extent of mining completed as of the date of claim investigation. This difference can result in a water supply being greater than 328 feet from mining when complaint is filed*

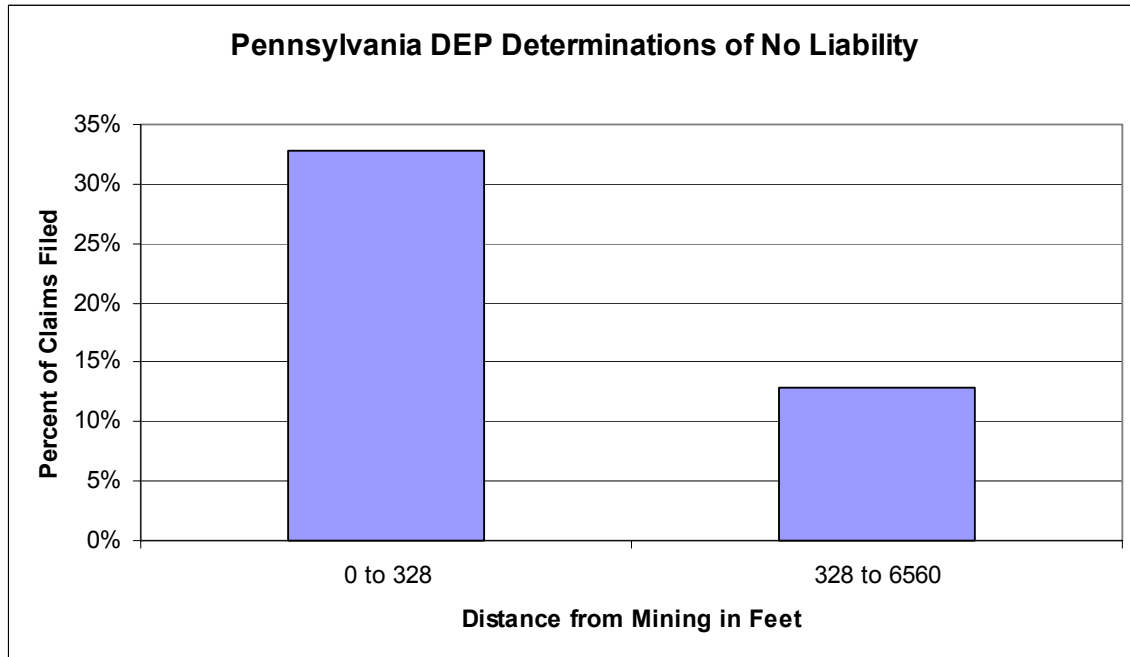


Figure V.10. PADEP determinations of “No Liability”

yet being less than 328 feet from mining when the assessment period ended. It may also be true that as longwall mining approaches an area and the water supply owner is notified of the impending mining, the owner may become more aware of variations in the water source (or supply) and attribute any change to mining operations.

Unfortunately, the water supply records that are currently kept by the PA DEP in the California District Mining Office are insufficient to resolve this issue, and no reliable alternative source of data is available. The basis for the determination of “no liability” is not part of the computer record unless it happens to be mentioned in the comment section that reflects the thoughts and observations of investigators. Because of the significance of this finding, it is recommended that the PA DEP initiate a study to investigate the cause of this apparent anomaly, and to recommend changes in data acquisition or data interpretation.

V.J. Water Supply Recovery

Natural recovery of water supplies has been reported anecdotally and in the literature. The water level in observation well (Gr-543) used by Stoner et al, 1987, was found to

decline as the longwall approached the well. This decline began when the longwall face was about 330 feet from the well. When the longwall panel had passed well Gr-543 by a distance of 100 feet, the water level in this well recovered by seven feet in just one day. Ultimately, the post-mining water level was found to be higher than the pre-mining water level. It should be noted that at 330 feet, the distance at which longwall mining affected this well, is just two feet beyond the 328 feet, the zone of “presumptive influence” established through an analysis of data for the current assessment period (see above).

Data on water supply recovery are not consistently tracked within the PA DEP database. For example, Table V.1 (previous section) shows that recovered water supplies constitute one percent of the water loss claims, seven water supplies. This table also contains the category of “no liability.” The “no liability” category itself contains water supplies that have recovered. The six recovered water supplies in the “no liability” category constitute two percent of the 272 determinations of “no liability.” When the researchers combine these two sources, the PA DEP data identify 13 recovered water supplies. There may be additional “recovered” water supplies hidden within the database. For example, there were 9 cases where “no actual problem” was found, and there were 8 cases in which the complaint was withdrawn. The underlying reasons for these determinations are unknown but they may include recovered water supplies.

Based on the available data, 13 water supplies or 2 percent of claims filed are found to have recovered. This result may understate the actual frequency of this occurrence due to current reporting methods.

V.K. Longwall Impacts on Wells and Springs

The GIS data were sorted by mine to identify all water supplies that are within 100 meters (328 feet) of a longwall panel. These data were then separated into the number of wells that were affected (liability), the number of springs that were affected (liability) in addition to the number of wells and springs where a determination of no liability was made. Table V.2 contains the results of this analysis. The table also contains a group of

“unaffected unknowns.” These are water supplies that were unaffected by subsidence, but the University’s researchers could not identify their nature as either springs or wells.

Including the California District Mining Office hydrologists’ determination of no liability the University finds that 73.9 percent of wells within 100 meters of a longwall panel are reported as unaffected by mining. Similarly, 82.2 percent of springs are reported as unaffected by mining. If the department’s determination of no liability is excluded from both the total number of wells and springs, and the total number of wells and springs that are unaffected, then the results are that 73.3 percent of the wells were unaffected and 81.9 percent of the springs were unaffected. The difference between well and spring survival with and without the Department’s determination of no-liability is 0.6 percent and 0.3 percent respectively. This difference is insignificant and is interpreted to mean that ***the Department’s determinations, as made by the hydrologists of the California District Mining Office, are not favoring the water supply owner or the mining company.***

The impact of longwall mining on springs, based on the data presented here, appears to be less than the impact to wells. This is a surprising result given the widespread belief that springs are more susceptible to subsidence impacts than are wells. Springs are also reported to move from a higher elevation to a lower elevation as a result of subsidence. The PA DEP data acquired by the California District Mining Office’s hydrologists were evaluated for evidence of this subsidence effect.

<i>Longwall Mine</i>	<i>Total</i>	<i>Total</i>	<i>Total</i>	<i>Number of Wells Affected (LIABILITY)</i>	<i>Number of Springs Affected (LIABILITY)</i>	<i>Number of Wells Affected (NO LIABILITY)</i>	<i>Number of Springs Affected (NO LIABILITY)</i>	<i>Number of Unaffected Wells</i>	<i>Number of Unaffected Springs</i>	<i>Number of Unaffected Unknowns</i>
	<i>Number of Wells within 100 meters of Longwall Panels</i>	<i>Number of Springs within 100 meters of Longwall Panels</i>	<i>Number of Unknowns within 100 meters of Longwall Panels</i>							
BAILEY DEEP MINE	90	69	1	10	5	1	1	79	63	1
BLACKVILLE 2 MINE	59	30	0	22	2	0	0	37	28	0
CUMBERLAND MINE	11	18	0	2	8	0	0	9	10	0
DILWORTH DEEP MINE	25	25	0	4	3	0	0	21	22	0
EMERALD DEEP MINE	65	51	0	18	5	2	1	45	45	0
ENLOW FORK MINE	62	117	6	13	24	3	2	46	91	6
MAPLE CREEK MINE	32	7	15	26	7	3	0	3	0	15
MINE 84	89	31	0	8	2	1	2	80	27	0
SHOEMAKER MINE	0	1	0	0	0	0	0	0	1	0
Total	433	349	22	103	56	10	6	320	287	22

Table V.2. Wells and springs affected within 100 meters of longwall mining. This information represents data from BUMIS and from the paper files in the California District Mining Office. “Unaffected Unknowns” refers to those entities that were water supplies, but were not identified as either as a spring or as a well. The researchers knew only that these supplies were unaffected.

Of the 56 impacted springs identified in table V.2, no documentation of spring migration could be identified. In 2000, Uranowski and Mastrorocco investigated streams and springs overlying longwall mining in southwestern Pennsylvania. In this study they identified four preexisting springs that went dry after mining, and they also identified the establishment of two new springs near the local stream elevation. The change in elevation from the dewatered springs to the newly created springs is reported to be 134 feet. These findings are similar to the findings reported by Carver and Rauch (1994) where springs were dewatered and new springs were established or their flow was enhanced at a lower elevation.

V.L. Findings

Distance to mining is a very significant factor in mining's effect on water supplies in the study area. Water supplies that are less than 328 feet from mining have less than a 79 percent chance of surviving and as the distance to mining increases the odds of the water supply surviving also increase.

The majority of ground-water recharge did not flow into the mines of Washington and Greene counties during the study period.

The zone above the caved zone and below the shallow fracture zone remained largely unaffected hydrologically by longwall mining during the study period.

Almost ½ (49%) of water supply replacements over longwall panels during the study period was in the form of either new wells or springs, indicating the presence of ground water.

During the study period, Dilworth mine had a significantly greater ground-water inflow than the other longwall mines.

The Dilworth inflow was not representative of the inflow to Pittsburgh coal seam mines during the assessment period.

V.M. Recommendations

With respect to springs and wells that are not directly undermined, Act 54 requires the use of the 35-degree angle of hydrologic influence. Analysis contained in this study supports a fixed distance approach as opposed to a fixed angle approach. The PA DEP through the California District Mining Office should consider the application of the fixed distance findings when evaluating water supply claims.

The PA DEP should designate the basis for a determination of “no liability. If possible, a check box system should be included in the Bituminous Underground Mining Information System that will allow single or multiple factors leading to the “no liability” determination

Because the basis for the determination of “no liability” is not part of the computer record unless it happens to be mentioned in the comment section that reflects the thoughts and observations of investigators, it is recommended that PA DEP initiate a study to investigate the cause of this apparent anomaly, and to recommend changes in data acquisition or data interpretation.

The California District Mining Office hydrologists should identify and map springs that have migrated (been replaced by down-slope springs) after subsidence-induced diminution or disappearance. Such mapping will enhance analysis of ground water changes that might have occurred as a result of underground mining.

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