SECTION VI: Effects of Mining on Water Supplies

VI.A - Overview

The PA DEP tasked the University to assess the impacts of underground bituminous coal mining on the water supplies undermined during the 3rd assessment period. This section provides details of the determination of liability, actions by the mine operators and PA DEP, development of permanent replacement water supplies, and length of time required to resolve these reported effects. This section also includes an inventory of water supplies undermined by the 50 mines active during this assessment. A conceptual model is provided to aid in assessing the vulnerability of water supplies based on their proximity to mining and their hydro geologic settings. A brief summary is also provided regarding the status of effected water supplies that were undermined during the 2nd assessment.

VI.B – Data Collection

An inventory of the undermined water supplies was accomplished by cross referencing the PA DEP's BUMIS database with the company submitted 6-month mining maps. A 200-ft buffer was extended from the edge of the mining that occurred during the 3rd assessment period to determine which properties and corresponding water supplies were considered undermined. Water supplies must have a use, as stated by the property owner in the pre-mining survey, to be considered in the inventory provided by BUMIS and the 6-month mining maps. The University compiled the inventoried water supplies, by mine, into an Excel spreadsheet, annotating the water supply type (well, spring, or pond) and the water supply use (residential, agricultural, commercial, etc.).

A water supply impact record was established in BUMIS when either the property owner or mining company contacted the CDMO and reported a problem. Using a BUMIS query tool, the University determined the total number of reported effects that occurred during the assessment time period. A second Excel database was created to track these reported effects by mine type, date of occurrence/resolution, type of effect, type of resolution, and actions taken by the DEP and mine operators.

The two Excel spreadsheets were joined to the spatial UGISdb, and the University researchers added additional details related to distances to active mining, topographic characteristics, and other relevant information. The University gathered these additional details via the archival permit and water loss files from the CDMO, the PaGWIS database, and both existing and University generated topographical maps.

VI.C – PA DEP Determination of Liability

In accordance with ACT 54, mining companies are required to restore or replace water supplies that are contaminated, diminished, or interrupted by their underground mining operations. The Act also requires the mine operator to notify PA DEP of any claim made by a landowner or water user. The PA DEP tracks the claims from origin to settlement. A mining company and a property owner may settle a claim without further PA DEP involvement as long as the owner is satisfied with the company's actions. If the property owner is not satisfied with the mining company's actions, a claim is filed with the PA DEP for further investigation of liability.

The PA DEP is responsible for determining the liability of reported effects when it is unresolved if mining is responsible for the water supply impairment. A liability buffer, or RPZ, is created by projecting a 35-deg line from vertical, from the edge of mining to the surface (PA DEP, 2008). If the water supply falls within this 35-deg angle, the mining company is assumed liable for the impact, and it is the company's responsibility to dispute this assumption. If the water supply is located outside of this buffer region, the PA DEP is responsible for proving that mining was the reason for the impact. Factors used in determination of liability include type of mining, proximity to mining, overburden, seasonality of the claim, pre-mining water supply data, and observed effects on neighboring water supplies. If the PA DEP determines that the mining company is responsible for the water supply impact, the company must provide the property owner with a temporary water supply, if the property owner is without water, until a permanent replacement of pre-mining quality and quantity or an agreement is established. During the 3rd assessment period, temporary water was provided to property owners in 277 cases for longwall mines, 69 cases for room-and-pillar mines, and 12 cases for room-and-pillar with pillar recovery mines. Permanent water supply replacements include repaired wells or springs, new wells or springs, or connection to public water.

Reported effects include *contamination, diminution, contamination and diminution, or damage to physical components*. A reported effect can also have the classification of *not an actual problem*, which describes a reported effect that upon investigation by the mining company or PA DEP was not impacted. *Not an actual problem* can also be assigned to a reported effect if a mining company provides a temporary water supply as a precaution.

Diminution can signify either a reduction of water quantity or a complete loss of the supply. During this assessment period, there were 683 reported effects to undermined wells, springs, and ponds; the effects were tabulated in Table VI-1 and sorted by mining type. The total number of reported effects included effects from mines that were active during the assessment period as well as effects from mines that ceased operation prior to the August 21, 2003 assessment start date.

Table VI-1- Number of reported effects tabulated based on mining type.

Mining Type	Reported Effects
Room-and-Pillar	238
Room-and-Pillar with Pillar Recovery	20
Longwall	397
Mines not in operation during 3rd assessment (Closed)	28
Total	683

A final resolution status indicates that there is no longer an impact to the water supply, or simply that the water supply case is closed. Final resolutions are divided into three categories: 1) Company Not Liable, 2) Company Liable, and 3) Unresolved or Resolution Pending. A reported effect classified as Company Not Liable indicates the case was withdrawn or there was not an actual water supply problem upon investigation by the mining company or PA DEP. The

Company Liable classification indicates that the water supply has recovered, been repaired or replaced, or that an agreement between the property owner and mine operator has been reached. The Company Not Liable classification is given to situations where 1) mining is not responsible for the reported effect, 2) the associated problem existed prior to mining, or 3) a claim was not filed within two years of mining. The determination of liability requires action on the part of the PA DEP at the CDMO. Table VI-2 lists the twenty categories used by the PA DEP when recording the final resolutions for water supplies with reported effects.

Table VI-2- Categorized effects based on final resolution status as of August 20, 2008.

Final Resolution		**Number**
Class	**Category**	
Company Not Liable (Unaffected / No Liability)	No Actual Problem	5
	Withdrawn	7
	No Liability	4
	Not Due to Underground Mining	159
	Water Supply Not Covered by BMSLCA	5
Company Liable (Assigned / Assumed Liable)	Agreement (Pre-mining)	1
	Agreement (Unspecified)	96
	Company Purchased Property	34
	Compensated	8
	Permanent Supply (Public) & O&M* Bond	2
	Permanent Supply (Public)	9
	Permanent Supply (Public) & Agreement	7
	Permanent Supply (Unspecified)	1
	Permanent Supply (Unspecified) & Agreement	1
	Permanent Supply (Well/Spring)	59
	Permanent Supply (Well/Spring) & Agreement	3
	Permanent Supply (Well/Spring) & O&M* Bond	3
	Recovered	19
	Repaired	6
	Resolved	20
Total		449

*Operation and Maintenance (O&M)

The Unresolved (Resolution Pending) classification indicates that the water supply case is not resolved or is still open at the end of the 3rd assessment period (Table VI-3). The interim status classification is divided into two categories: 1) Operator Assigned / Assumed Liability-Resolution Pending and 2) Under Investigation. Operator Assigned / Assumed Liability with Resolution Pending are cases where the mine operator is liable and is evaluating possible supply replacements or working to develop an adequate water supply. In some instances the permanent water supply has been developed but operation and maintenance (O&M) costs for yearly usage were being negotiated. The cost of operating and maintaining the new replacement supply cannot exceed the pre-mining O&M cost or the company must provide payment for the additional costs. The Under Investigation category simply means that liability has not yet been determined or monitoring of the water supply is still taking place.

Table VI-3- Categorized Unresolved (Resolution Pending) status reported effects as of August 20, 2008.

Unresolved (Resolution Pending)		**Number**
Class	**Category**	
Assigned / Assumed Liable	Agreement Pending	4
	Evaluate Permanent Supply	18
	Implementing WS Replacement Plan	27
	O&M Review	2
	Pending Owner Approval	2
	Public Water / O&M Pending	6
	Temp Water / Awaiting Public Water	5
	Temp Water / Will Be Undermined	21
	Temporary Water	3
	Well, Spring / O&M Pending	32
	WS Replacement Plan Under Development	13
	WS Replacement Plan Under Review	3
Under Investigation	Currently Monitoring	17
	In Litigation	2
	Unresolved	2
	Unresolved / Pending Investigation	17
	Outstanding Problem	60
Total		234

Figure VI-1 provides a visual summary of Tables VI-2 and VI-3. The Operator Assigned / Assumed Liability category has been divided into four subsections of Agreement / Compensation, Permanent Supply, Recovered / Repaired, and Resolved. The 234 reported effects categorized in Table VI-3 are all considered as resolution pending cases in Figure VI-1.

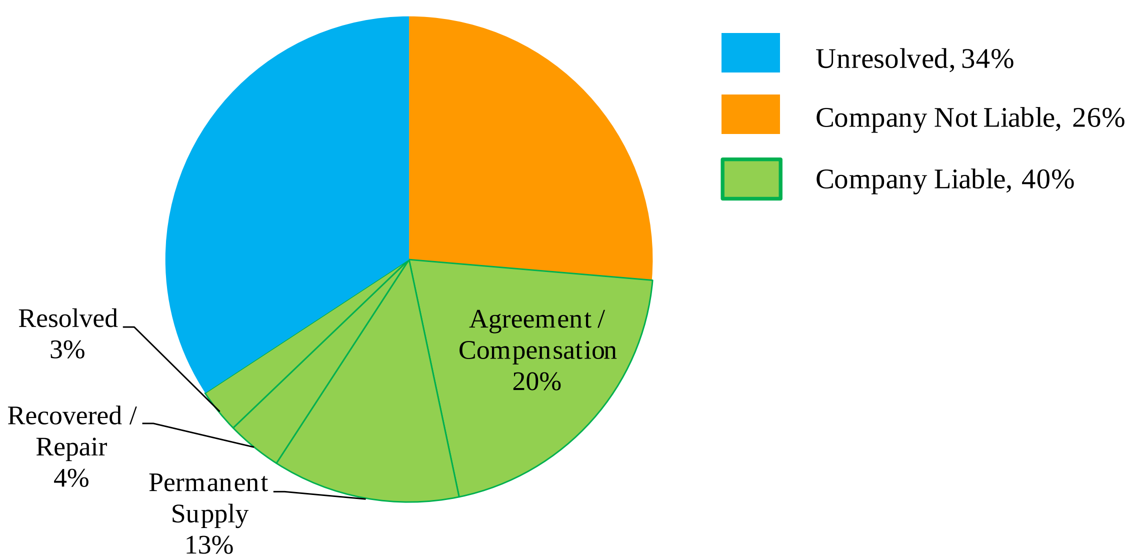

Figure VI-1 – Reported Effects (n=683) classification as of August 20, 2008. The Company Liable Classification has been separated into four categories: Agreement / Compensation, Permanent Supply, Recovered / Repaired, and Resolved.

As shown in Table VI-2, 449 reported effects were resolved during the 3rd assessment period; Table VI-4 provides the breakdown of the resolution types by mining type for each of these 449 reported effects. Figure VI-2, below, summarizes the number of days required for a reported effect to be resolved based on the resolution type and by mining type. The final resolution date and the date of occurrence were subtracted and then averaged to determine the number of elapsed days for each resolution type. The pending resolution effects were not analyzed because there was no final resolution date or the resolution date provided by BUMIS was after the 3rd assessment period. However, there were 12 cases exceeding three years without a final resolution; eight attributed to longwall mines and four to room-and-pillar mines. The No Liability category, represented in Figure VI-3, has the lowest average number of days that were required; the category of no liability is a based solely on the PA DEP ruling, not actions taken by a mine operator.

Table VI-4- Final Resolutions tabulated based on resolution type and mine type.

Mine Type	Company Not Liable		Company Liable			
	Unaffected	**No Liability**	**Agreement / Compensation**	**Permanent Supply**	**Recovered / Repaired**	**Resolved**
Room-and-Pillar	8	95	22	47	7	7
Pillar Recovery	0	4	0	4	6	0
Longwall	4	59	110	30	11	12
Closed Mines	0	10	7	4	1	1
Totals	12	168	139	85	25	20

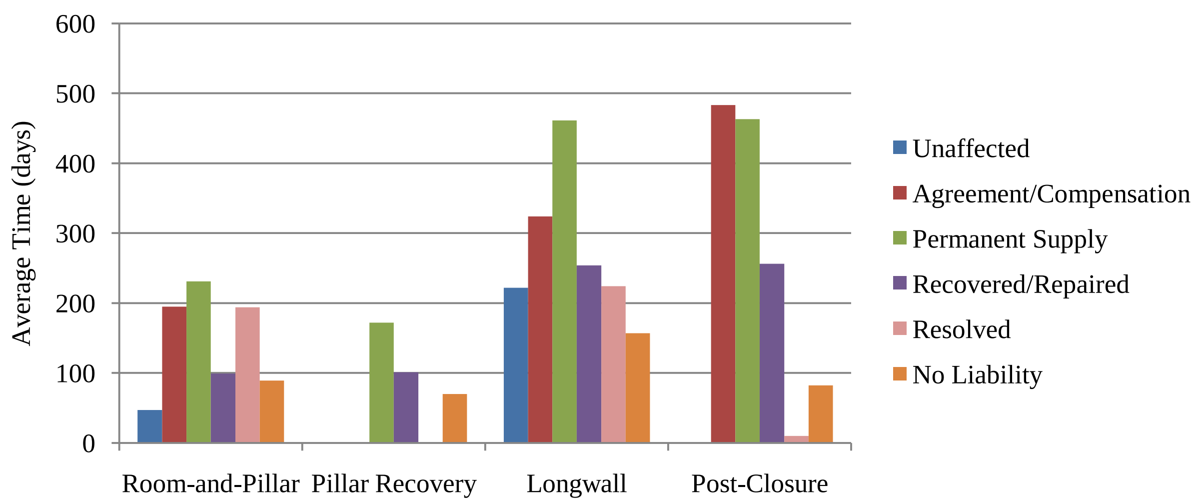

Figure VI-2 – The average number of days required to resolve the reported effects (n=449) classified by mining type and categorized based on the resolution status as of August 20, 2008.

Of the 683 reported effects, 248 claims were filed and required a resolution via a CDMO ruling during this assessment period. The 248 claims were divided by mining type (Table VI-5) and resolution status (Figure VI-3). There were a larger number of reported effects due to longwall mining as compared to room-and-pillar mining (Table VI-1), but there were a larger number of claims requiring PA DEP intervention associated with room-and-pillar mining. This may be the result of longwall mining companies tending to assume liability, and room-and-pillar mining companies tending to allow the PA DEP to make the final ruling; it could also be related to presumptions that room-and-pillar mining has less potential to affect water supplies because it causes less disturbance of overlying strata. Further discussion pertaining to the trends in determination of liability is presented Section VI.E.

Table VI-5 - Number of Water Loss (WL) Claims filed by mining type.

Mining Type	Number
Room-and-Pillar	141
Room-and-Pillar with Pillar Recovery	3
Longwall	86
Closed Mines	18
Total	248

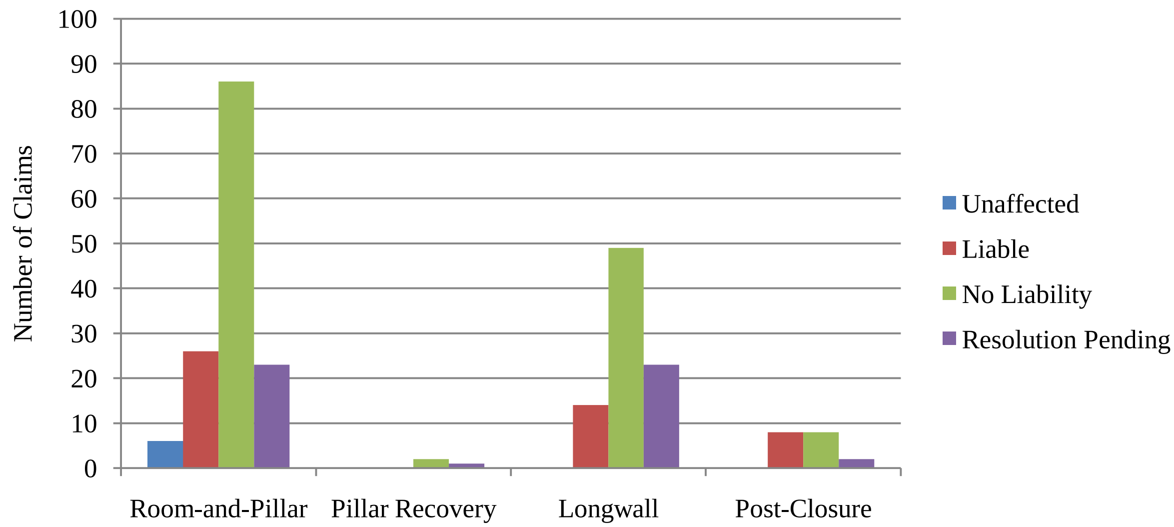

Figure VI-3 – Total number of claims (n=248) classified by mining type and categorized based on the resolution status as of August 20, 2008.

VI.D –Water Supply Analysis by Mining Type

This section provides an analysis of the influence of mining on water supplies by mining type. The section is divided into four parts to discuss: Room-and-Pillar Mines, Room-and-Pillar with Pillar Recovery Mines, Longwall Mines, and Closed Mines. Closed mines include room-and-pillar and longwall mines. Each subsection provides an inventory of the water supplies undermined and an analysis of the reported effects. Refer to Section I for details regarding the expected subsidence characteristics of mining type.

VI.D.1 – Room-and-Pillar Mines

Thirty-six underground room-and-pillar mines were in operation during the 3rd assessment period, with a total of 11,552 acres (see Section III). The room-and-pillar operations undermined 1,212 water supplies. Sixty-seven percent of undermined supplies were of residential use, 25-pct other/unknown, and the remaining 8-pct distributed among agricultural, commercial, recreational, and community/institution uses.

Although subsidence is generally not an issue with room-and-pillar mining, by creating a void in the earth within or below an aquifer there is a chance that the groundwater flow path can become altered, impacting overlying water supplies. The movement of water through the stratigraphic layers of the ground is influenced by permeability. Permeability may be classified as primary or secondary permeability. According to Wyrick & Borchers (1981), primary permeability refers to the movement of water through the intergranular pore spaces of the strata layers; whereas secondary permeability refers to groundwater movement through geologic features such as fractures, bedding plane separations, joints, and cleats associated with the strata. Western Pennsylvania hydrogeology is largely influenced by secondary permeability. Enlargement of fractures and bedding planes by subsidence will increase the secondary permeability of the strata. The total number of water supplies undermined and reported effects by each mine are shown in the Figure VI-4.

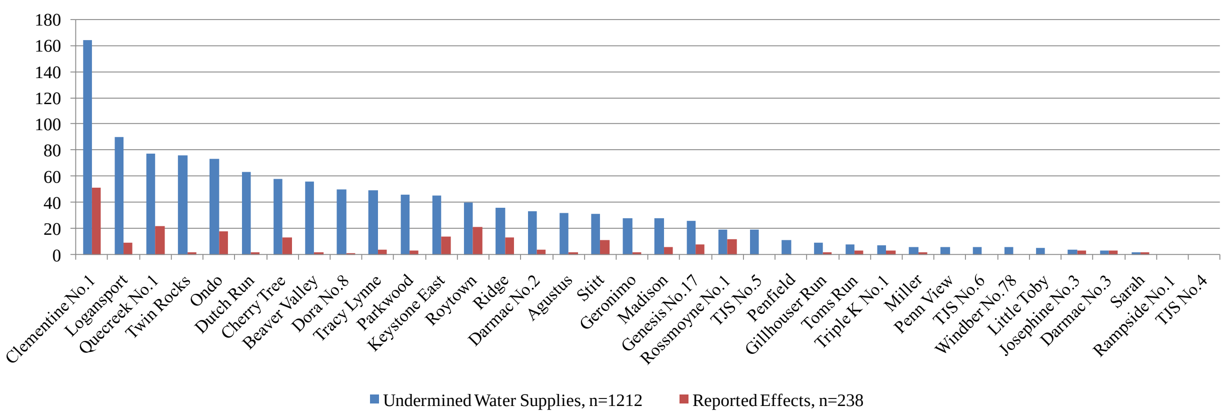

Figure VI-4 – Total number of undermined water supplies (n=1,212) and number of reported effects (n=238) associated with room-and-pillar mines.

Alteration of the groundwater flow path can cause diminution in the form of an insufficient quantity or total loss because of a drop in the groundwater levels. Contamination can also be an issue with altered flow paths as groundwater from contaminated sources such as mine pools or surface water is drawn into the recharge area or as fluctuating water levels cause oxidation of acid producing minerals in the overburden. As shown in Figure VI-5, diminution was reported most frequently as the cause of the water supply impacts, with a quarter of the impacts being the result of contamination. Of the 238 reported effects, 226 were wells and the remaining 12 were springs or ponds.

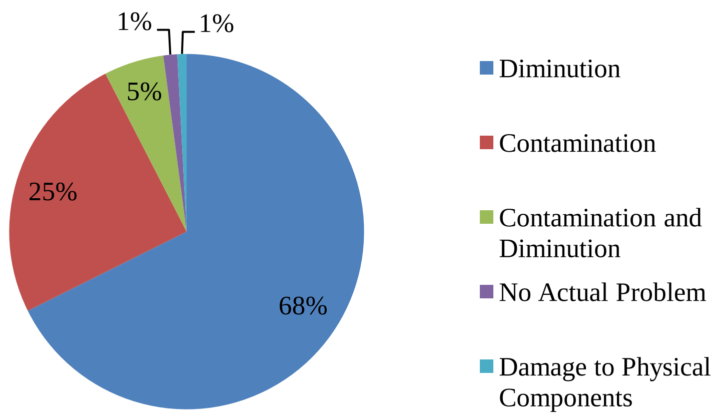

Figure VI-5 – Impact types for the reported effects due to room-and-pillar mining

Figure VI-6 tabulates the number of cases for room-and-pillar mining and their resolution status as of the end of the 3rd assessment. It was determined in 40-pct of cases, or 95 of the 238, that mining was not the cause of the water supply impact. Thirty-five percent of the reported effects were considered as liable impacts, and three percent of cases were unaffected after investigation. The remaining 22-pct of cases were unresolved at the end of the assessment period.

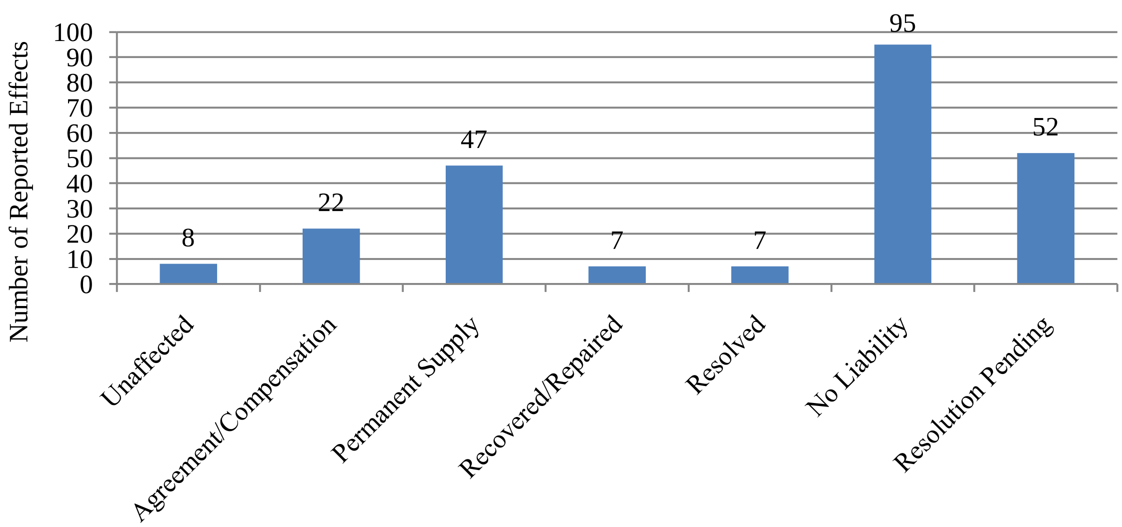

Figure VI-6 – Tabulation showing the status of the 238 reported effects for room-and-pillar mines.

VI.D.2 – Room-and-Pillar Mines with Pillar Recovery

Six underground room-and-pillar with pillar recovery mines operated during the 3rd assessment period, accounting for 2,097 acres undermined. The majority of contributing acres came from the conventional room-and-pillar method; only 13-pct (276 acres) were actually associated with the pillar recovery mining method (see Section III). Although the pillar recovery area is very small, the concepts discussed in the room-and-pillar subsection still apply. In areas where pillar recovery took place, additional impacts can be seen. As discussed in Section I, pillar recovery involves removing roof support pillars which will, in turn, allow the roof to collapse into the mined cavity. The overburden strata experiences additional fracture development, causing the secondary permeability to increase. These fractures are passageways through which groundwater may drain by gravity into the mine workings. As shown in Figure VI-7, there were 75 undermined water supplies, 20 of which had reported effects. Sixty-four of the 75 water supplies undermined were wells and the remaining 10 were springs. Uses of the 75 water supplies included 57 residential, 16 other/unknown, one recreational, and one of commercial use.

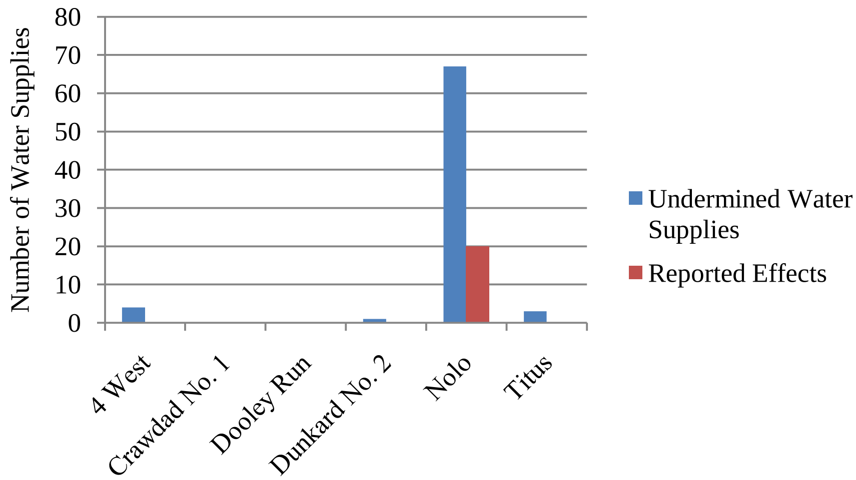

Figure VI-7 – Total number of undermined water supplies (n=75) and number of reported effects (n=20) associated with Room-and-Pillar with Pillar Recovery mines.

The 20 reported effects have been categorized based on impact and resolution type in Figure VI-8. Diminution was reported as being the cause of impact 90-pct of the time. As shown in Figure VI-9, mining company liability was assigned for ten of the 20 reported effects. Four cases were classified as no liability, and the remaining six cases did not have a final resolution status.

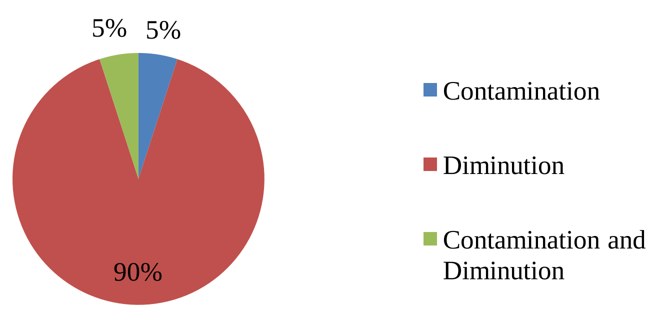

Figure VI-8 – Impact types for the reported effects due to room-and-pillar with pillar recovery mining.

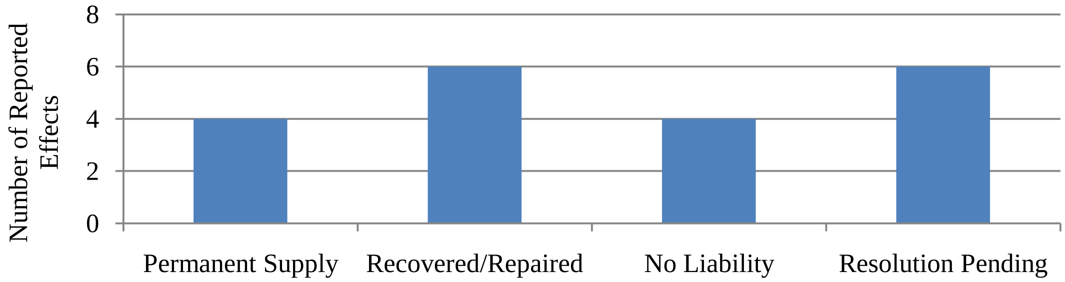

Figure VI-9 – Tabulation showing the status of the 20 reported effects for room-and-pillar with pillar recovery mines.

As shown in Figure VI-7, the Nolo Mine was the only mine with reported effects. Upon further investigation, the University determined that, on average, the distance of all water supplies to the pillar recovery portion of the mine were almost a mile (> 5,000-ft). Only one water supply was located directly above a pillar recovery section, and this water supply showed no reported effects.

VI.D.3 – Longwall Mines

Eight longwall mines operated during the 3rd assessment period. These eight longwall mines undermined 24,607 acres, approximately 64-pct, of the total 38,256 acres mined during the five year study period. Based on the data collection strategy, the University determined that 1,502 water supplies were undermined by longwall mines. Table VI-6 lists the total number of undermined water supplies for each of the eight longwall mines with a comparison to the total acres to determine the water supply density per acre undermined. The water supplies undermined included a combination of wells, springs, and ponds which are shown tabulated for each mine (Figure VI-10). Unlike the room-and-pillar mines, there are considerably more inventoried springs. Forty-nine percent of inventoried water supplies were of residential use, followed by 39-pct other/unknown, 11-pct agricultural, and 1-pct for both commercial and recreational.

Table VI-6- The inventory of undermined water supplies with water supply density calculation.

Mine Name	Undermined Water Supplies	Acres	Water Supply Density per Acre
Bailey	337	6311	0.05
Blacksville No.2	114	2880	0.04
Cumberland	159	3665	0.04
Emerald	199	2855	0.07
Enlow Fork	400	6339	0.06
High Quality	10	501	0.02
Eighty-Four	274	1984	0.14
Shoemaker	9	72	0.13

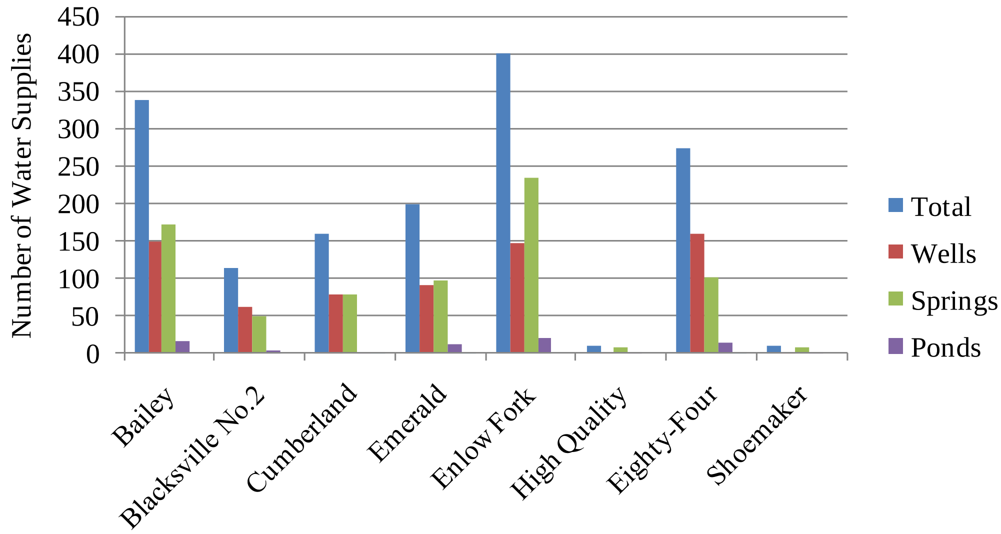

Figure VI-10 – Number of undermined water supplies (n=1,502) and the water supply type by each longwall mine

As discussed in Section I, longwall mining is a full extraction technique in which large panels of coal are removed and immediate subsidence occurs when the overlying roof strata collapses into the mine void causing a subsidence basin to form. According to Peng (1992) and shown in Figure VI-11, the subsided overburden strata are divided into four zones with differing degrees of fracturing. The variances noted in the height of the zones are primarily due to the types of material comprising the strata. The zone closest to the mine void, called the caved zone, is where the roof rock caves, irregularly, into the mined out void. The height of this zone can be two to ten times the thickness of the mining height. The mining height for the longwall mines averaged around 6-ft in thickness. Above the caved zone is the fractured zone. The strata within the fractured zone are highly fractured, but remain stratified. This zone thickness can range between 28 to 52 times the mining heights. The next zone is called the continuous deformation zone, where the strata bends and separates but does not fracture. The uppermost zone is known as the soil zone, and this is where the basin intercepts the ground surface. It is possible for tension cracks to develop in this zone and propagate downward from the surface. Based on the subsidence zones of movement descriptions, it is apparent that the fracturing the overburden strata can cause impacts to the natural hydrology of the overburden by increasing the permeability and groundwater flow pathways.

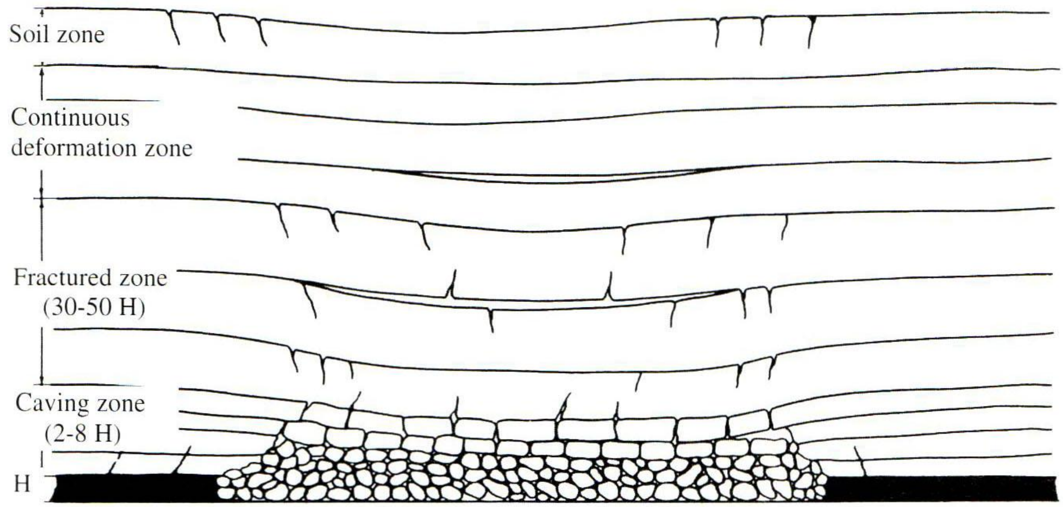

Figure VI-11 – Depiction of the four subsidence zones according to Peng (1992).

Of the 1,502 water supplies undermined by longwall mines, there were 397 with reported effects. The number of undermined water supplies and reported effects, by mine are shown in Figure VI-11. Figure VI-12 categorizes the reported effects by impact type. Diminution was reported as the leading cause of impact at 78-pct, with contamination reported in approximately 12-pct of cases. Eight percent of the reported effects were defined as No Impact / Not Affected, and generally these cases were entered in the records because temporary water was provided to the property owner in advance of mining as a precaution. Of the number of reported effects, 60-pct involved wells, 37-pct involved springs, and 3-pct involved ponds.

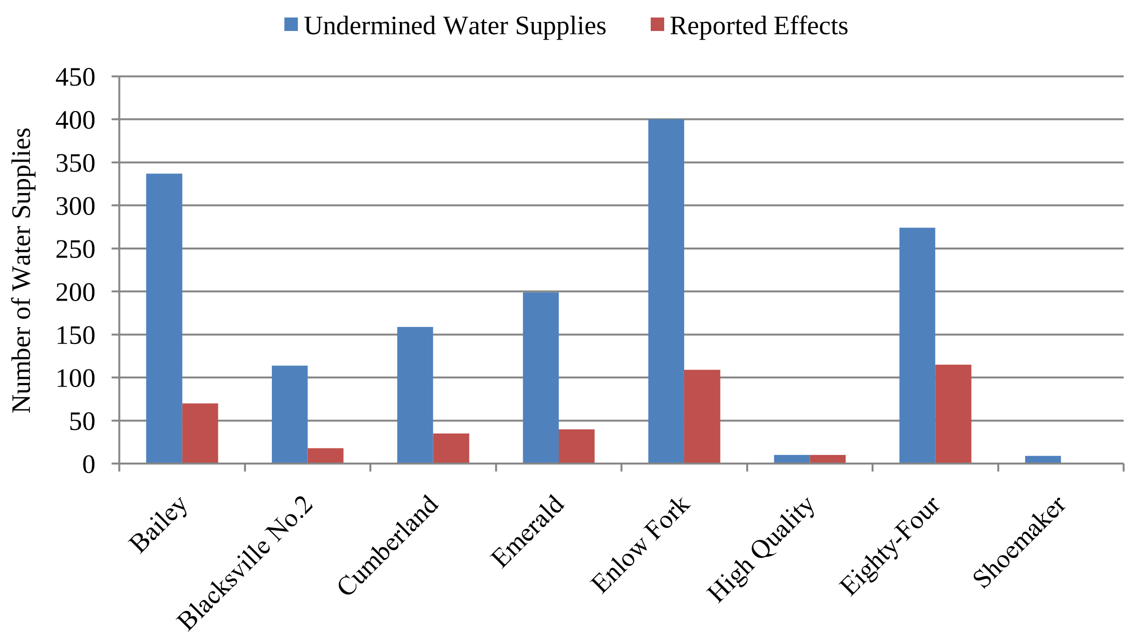

Figure VI-12 – Number of undermined water supplies (n=1,502) and the reported effects (n=397) by longwall mine.

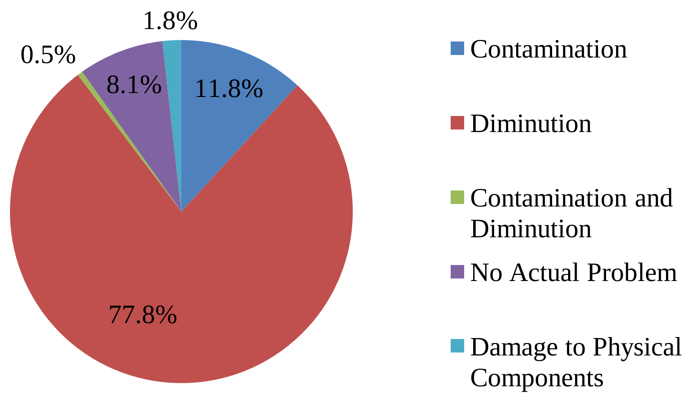

Figure VI-13 – Number reported effects (n=397) classified by type of impact.

Seven out of the eight longwall mines had reported effects associated with their longwall operations. The resolution statuses for each of the mines are presented in Figure VI-14.

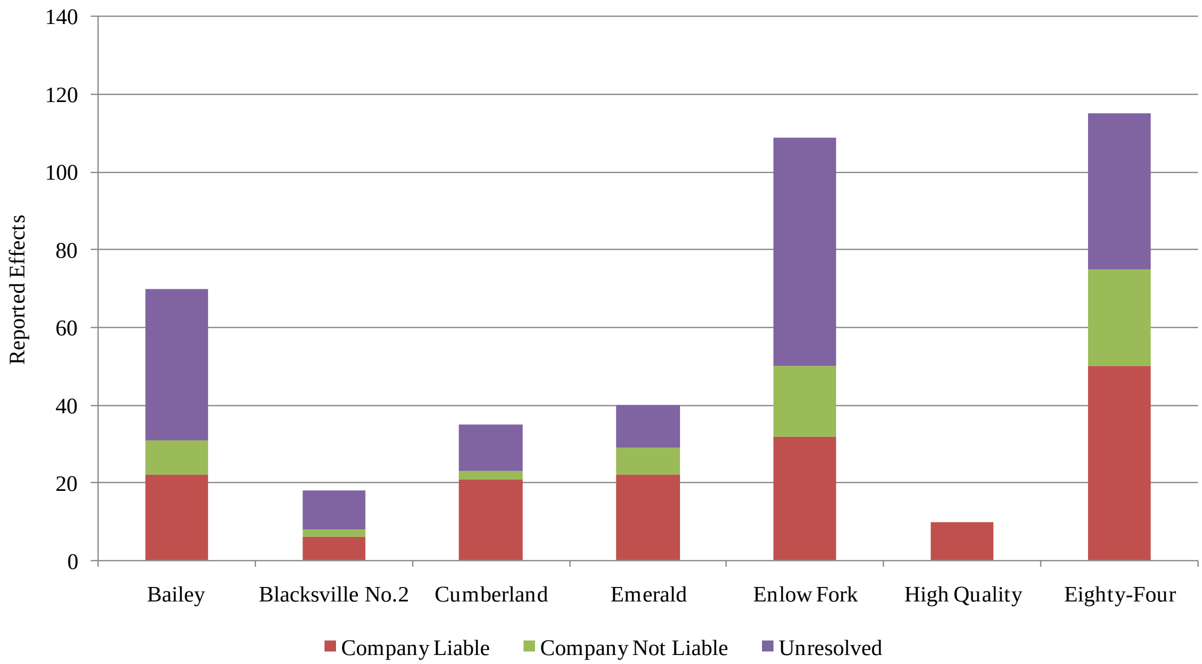

Figure VI-14 – Number reported effects (n=397) classified by resolution status and operation for longwall mines.

Figure VI-15 presents the percentage of liable effects out of all undermined water supplies associated with each longwall mine based solely on the resolved cases. The University expects these percentages to rise appreciably as the unresolved cases become categorized.

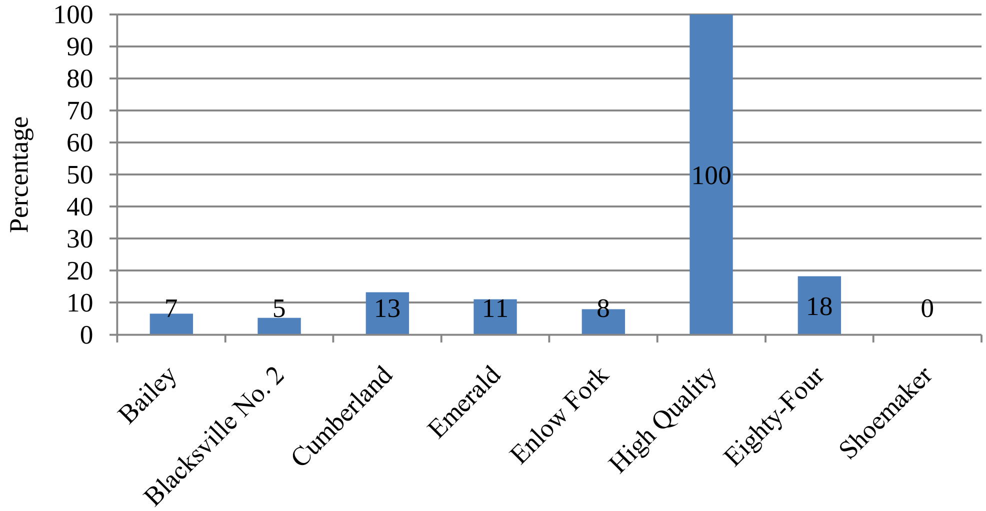

Figure VI-15 – Percentage of Liable effects versus total number of undermined water supplies by mine. The University expects these percentages to rise appreciably as the unresolved cases become categorized.

Longwall mine subsidence tends to alter the hydrogeology of the overburden. But to assess the overall impact of mining on the post-mining aquifer system, the University further analyzed the resolution statuses for the liable impacts to see how the impacted water supplies were being replaced. A permanent supply must be adequate to serve the pre-mining and reasonably foreseeable needs of the property owner. In some cases the pre-mining water supply needed repaired, replaced, or public water was provided to the property owner. For some of the more rural mines, public water lines were not available as a replacement water source. In other more populated areas, connection to public water is the most cost effective and efficient means of replacing a water supply. Figure VI-16 summarizes the permanent water supply types provided as a means of impact resolution for the longwall mining liable cases. The resolutions pertaining to agreements, compensation, and company purchasing properties are included in this figure under the agreement category. The impacts associated with these resolutions may be more complicated than just a water supply issue. Other issues pertaining to the property's land or structural damages may also play a role in the type of resolution that was established between the land owner and mine operator. While 83-pct of the finalized cases were resolved using some kind of agreement or compensation, 17-pct of the cases used a preexisting or new well or spring to establish a permanent water supply. Only in 7-pct of cases was public water used as the water supply replacement.

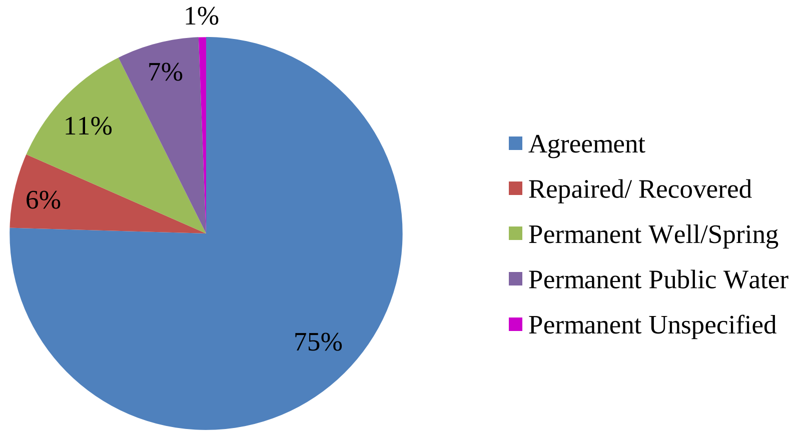

Figure VI-16 – Company Liable effects of longwall mining (n=163) tabulated by type of resolution detailing type of water supply replacement

VI.D.4 – Mines closed prior to the 3rd Assessment

A number of mines, which ceased operation prior to the 3rd assessment period, were reported as having post-closure effects on water supplies. The mines and number of reported effects are shown in Figure VI-17. The mines listed as having post-closure impacts include both room-and-pillar mines and longwall mines.

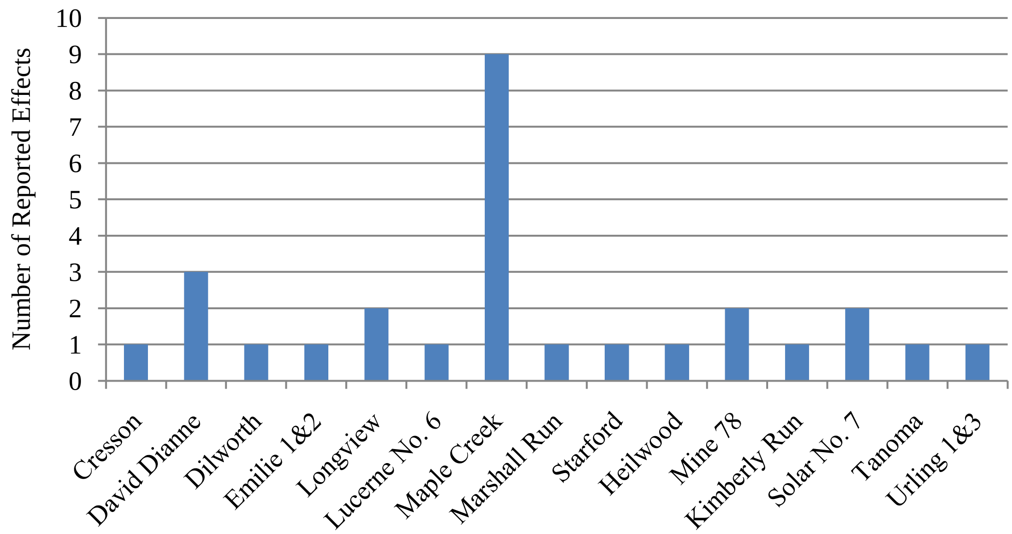

Figure VI-17 – Reported Effects (n=28) on water supplies of closed mines prior to August 21, 2003.

Of the 28 reported effects, 17 were diminution related, seven involved contamination, and four had an unspecified impact listed in the BUMIS description. In 13 cases the company was deemed liable, and in ten cases the company was deemed not liable. Five of the cases were pending resolution.

VI.E – Conceptual Model: Water Supply Vulnerability to Mining/Supporting Literature

Using the water supply assessment data, information from the permit files, and supporting literature, a conceptual model was created to aid in assessing the vulnerability of water supplies. This model was based on factors pertaining to the hydro-geologic setting, proximal location to mining, and the timing related to undermining. The focus of this section is to assess the hydrologic impacts due to longwall mining on the shallow aquifer system of Greene and Washington Counties. Additional descriptions of the hydro-geologic character of this region are contained in the Module 8 permit file information and the supporting literature. The Module 8 section of the permit files describes the topic of hydrology for each mine's location. The mine operator is required to provide information regarding natural hydrology, water supply and stream inventories, background sampling, prediction of hydrologic consequences/protection of hydrologic balance, and a hydrologic monitoring plan.

VI.E.1 – Hydro-geologic Characteristics of Greene and Washington Counties

In order to assess possible hydrologic impairment of the shallow aquifer system in Greene and Washington Counties, it is necessary to understand the natural hydro-geologic settings as they were prior to mining. The primary geologic units for Greene and Washington Counties are the recent alluvial deposits associated with the Pleistocene/Holocene and the Dunkard and Monongahela Group, which includes the current minable coalbeds.

The water bearing characteristics of interest to this study are found in many different hydro-geologic units above the Pittsburgh Coalbed and have been identified in geologic reports (Newport, 1973; Stoner, et al., 1987). These hydro-geologic units include:

- Pleistocene/Holocene Group:
    - The Pleistocene/Holocene Group contains the alluvium formation, resulting from material being deposited by the movement of water along large stream valleys. It is an adequate to excellent water bearing layer depending on the grain size distribution of the clay, sand, silt, gravel, etc. found in the local formation. According to Newport (1973), sand, gravel, or loosely cemented sandstone allow water to flow vertically and horizontally through the pore spaces.

- Dunkard Group:
    - The Greene Formation consists of shale, sandstone, and thin limestone; the sandstone units are generally the most important layers for water production in the region. Sandstones and coals are the most hydrologically productive stratigraphic units because of the large number of fractures and planes of weakness. Units such as shale, siltstone, or limestone have low hydraulic conductivities and are poor water producing layers. The Greene Formation has generally low yielding wells because of the scarcity of fractures within the stratigraphic units, and the large number of impermeable shale units within the formation. On average, most wells will yield approximately 2-gpm (gallons per minute) and the majority of wells are less than 120-ft deep (Newport, 1973).

  - The Washington Formation consists of shale, sandstone, limestone, and several coalbeds in Washington County. In both counties, wells penetrating the Washington Formation have an average yield between 2 and 3-gpm, and are approximately 30 to 300-ft deep. On average, the area springs discharge 0.50 gpm. According to Stoner, et al. (1987), discharge in the form of springs is common in the Washington and Greene Formations of the Dunkard Group.
  - The Waynesburg Formation is the lowest unit of the Dunkard group. This formation is reported to have an average well yield of 3.8-gpm, most likely from the sandstone and coal water bearing units.

- Monongahela Group:
  - The Uniontown and Pittsburgh Formations consist of limestone, shale, sandstone, and coal. The water bearing capabilities of the formation vary widely across both counties. The fine grained shale, found in Washington County, is largely impermeable; however there is water stored in the fracture and joint system. The median yield of wells in Washington County is around 1-gpm, and most wells exceed 100-ft deep. In Greene County, wells in the Uniontown Formation have a median yield of 8-gpm.
  - Generally the Pittsburgh Formation wells yield a sufficient quantity for domestic supplies in the eastern portion of Greene County, but the formation is too deep in the central and western portion of the county for domestic supplies. The basal unit is the Pittsburgh coal seam, which is where all longwall mining takes place in both counties.

The production of potable water from the geologic formations described above, not including the alluvium formation, is largely dependent on the secondary permeability of the strata, and not as much on the primary permeability. These natural groundwater conduits make it possible for water to move through the shallow aquifer system in the region. The secondary permeability decreases by an order of magnitude as the overburden increases every 100-ft (Stoner, et al., 1987). This is why the majority of the groundwater resources circulate within the first 200-ft of the ground surface. According to Wyrick and Borchers (1981), the natural stress relief fractures located in valley walls and valley bottoms will lead to increased secondary permeability, which also means that the fracture density will be higher in the valley bottoms as compared to the hilltop locations. Because of this principle, the hilltop will tend to produce less water as compared to the valley bottom.

Aside from permeability, the hilltop water supplies are located in the recharge areas. These areas are dependent on the amount of water infiltrating into the ground after a precipitation event. Valley bottoms are almost always areas of water discharge. Water enters into the groundwater system through infiltration, and flows from areas of high hydraulic head to low hydraulic head, or by gravity, to eventually discharge into the valley bottom. As water travels downward, it often encounters a stratigraphic layer of very low permeability, also known as perched or semi-perched aquifers. This impermeable layer will impede the water from percolating vertically, forcing the water to move laterally along the horizontal bedding plane to eventually discharge as a hillside spring or seep. These springs will exit the hillside where a fractured and permeable layer outcrops above an unfractured and impermeable layer.

Seasonal fluctuations in the amount of precipitation and the rate of infiltration can alter the amount of water circulating through the shallow aquifer system. Areas of recharge, or hilltop supplies, will see the greatest fluctuation of water levels during periods of low precipitation. In addition, recharge water takes more time to reach deeper supply levels because hilltop supplies tend to be deeper than valley bottom supplies. According to Stoner, et al. (1987), discharges from hillside springs and water levels in wells less than 100-ft deep can see large production decreases during times of low precipitation. However, springs lower on the hillside may prove more viable during times of low precipitation. Recharge rates are the highest between late fall and early spring. During the growing season (May to August) much of the recharge potential is lost to evapotranspiration (evaporation and vegetation usage). Therefore, the groundwater levels are generally highest in late winter, and lowest in late summer. According to Newport (1973), 40-pct of the average annual precipitation is lost to evapotranspiration throughout the year.

Generally the natural quality of the groundwater found in Greene and Washington County wells and springs is adequate for domestic supply. There are areas, however, that tend to have high levels of iron, manganese, sulfate, aluminum, or hardness, which may require treatment before human consumption.

VI.E.2 – Effects of Longwall Mining

The longwall mining technique, as described above, creates a subsidence basin and causes differing degrees of fracturing within the overburden. The subsidence basins also produce different regions of compressive and tensile stresses. Compressive stresses cause the strata to shift laterally along the bedding planes or rupture in shear; this process can open horizontal bedding planes and increase the lateral water movement, or create additional fracture planes when ruptured. The tensile stresses cause natural fractures to open up or new fractures to form, which can create new vertical pathways for water movement or additional space for water storage.

In addition to the subsidence zones provided by Peng (1992) and described above, Kendorski (1993) presents details on the hydrologic responses of five zones located above high-extraction mining. These zones include (from mine to surface) a caved zone, fractured zone, dilated zone, constrained strata zone, and surface fracture zone. Figure VI-18 shows a depiction of the five zones with their relative thicknesses and their hydrologic response descriptions.

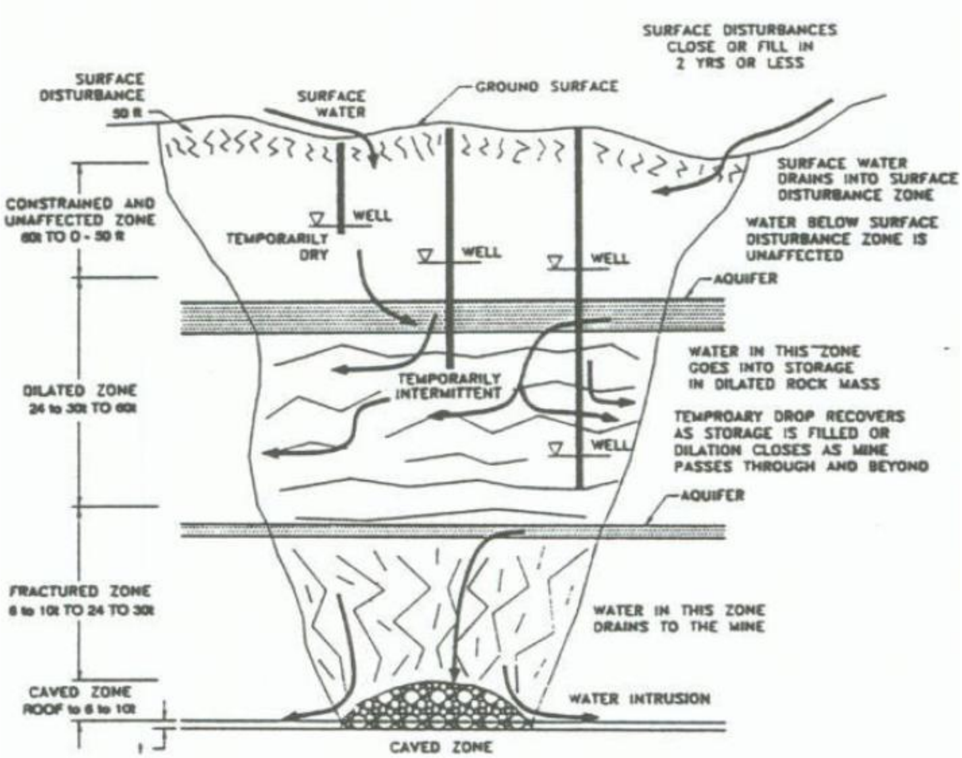

Figure VI-18 – Hydrologic response zone described by Kendorski (1993).

VI.E.3 – Vulnerability Influences

Certain factors will make a water supply more or less susceptible to the effects of longwall mining. These factors include:

- topography or overburden composition,
- lateral proximity to mining,
- location in relation to the longwall panel and the corresponding subsidence basin,
- climatic characteristics, and
- mine inflow.

The following subsections provide supporting data to substantiate or refute the influence of these water supply settings on the likelihood of an impact. The important matter of headwater springs is also addressed. The three categories used in this analysis are: 1) Unaffected, 2) Operator Liable, and 3) No Liability (Table VI-7). Reported effects that did not have a resolution status with an indication of liability are not included in the analysis; water supplies with pending resolutions that assigned liability were included in the liable impact count. The water supplies undermined that had no reported effects have been added to the unaffected category, along with the water supplies with reported effects that were later investigated and classified as having no impact.

Table VI-7 - The number of Unaffected, Company Liable, and Company Not Liable cases for each longwall mine are tabulated using the categorization listed above.

Mine Name	Unaffected	Company Liable	Company Not Liable
Bailey	268	46	9
Blacksville No.2	96	10	2
Cumberland	123	30	2
Emerald	162	28	6
Enlow Fork	293	85	17
High Quality	0	10	0
Eighty-Four	165	74	23
Shoemaker	9	0	0
Totals	1116	283	59

VI.E.3.a – Topography and Overburden Thickness

The water supplies were classified as being topographically located on a hilltop, hillside, or valley bottom using University generated surface and slope contours. Hilltops and valley bottoms were low slope areas classified by their relative high and low topographic elevations, respectively. Hillsides were areas of midrange elevations with high slope values. Using the overburden raster files generated by the University, the researchers were able to determine the overburden to the Pittsburgh coal seam for each water source undermined. The University determined that the average overburden for all eight longwall mines was approximately 687-ft with a standard deviation of 97-ft (Section III). For normally distributed data like longwall overburden, one standard deviation above and below 687-ft accounted for 2/3 of the data. Data in this range was considered average for this study. Overburden values less than 590-ft were considered shallow and, conversely, greater than 784-ft were classified as deep. The water supplies were classified based on their surface relief characteristic and overburden and sorted into one of the three categories of unaffected, operator liable, and no liability (Table VI-8).

Table VI-8 - The number of Unaffected, Company Liable, and Company Not Liable water supplies based on topographic and overburden characteristics

Depth	Topographic Location	Impact Category		
		Unaffected	Company Liable	Company Not Liable
Shallow	Hilltop	2	6	0
	Hillside	90	13	4
	Valley Bottom	150	47	12
Average	Hilltop	98	25	3
	Hillside	328	74	15
	Valley Bottom	223	55	6
Deep	Hilltop	102	24	6
	Hillside	111	31	4
	Valley Bottom	9	0	2
Unknown		3	8	7

The liable impact percentage to a water source was calculated based on the topographic position relative to the depth to mining. As shown in Figure VI-19, 75-pct of shallow hilltop water supplies were impacted by mining, as compared to a zero percent impact for deep valley bottom supplies. These findings coincide with the idea that hilltop supplies may be more vulnerable to small water level changes whereas valley bottom, or discharge areas, are more likely to recover. Because there were only eight shallow hilltops and 11 deep valley bottoms, out of nearly 1,450 water supplies, the University cannot state with certainty that this trend would apply using a larger data set. The other topographic and overburden scenarios resulted in approximately 80-pct retained viability, with only 20-pct of the water supplies impacted by mining.

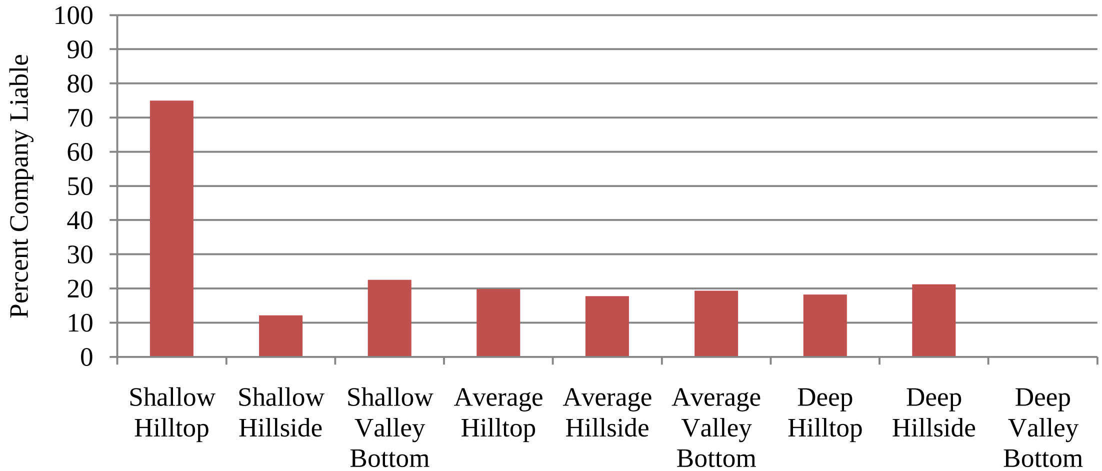

Figure VI-19 – Percent Company Liable calculated for each topographic overburden scenario.

VI.E.3.b – Lateral Proximity to Mining/ RPZ Discussion

The University measured the distance between each water source to the nearest longwall panel, and entered these distances into the GIS attribute tables. Using the lateral distance and the calculated overburden values, the University calculated the projection angles from the edge of the nearest longwall panel to each water supply (Figure VI-20).

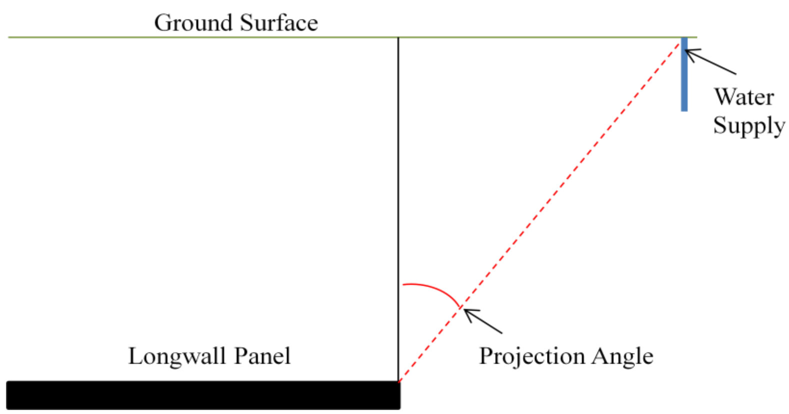

Figure VI-20 – Diagram showing the projection angle calculation from the edge of the longwall panel to the surface water supply.

The University recognizes that using a standardized range of lateral distances may not sufficiently depict the differentiation of hydrologic responses to longwall mining at varying overburden depths. The water supplies were categorized as being Company Liable or Company Not Liable and distribution curves were created. As discussed in the determination of liability section, the projection angle of 35-deg is used to presume liability of an impact. The results are shown in Figure VI-21. It is important to note that the CDMO determines liability in relation to all mining that has occurred in the vicinity of a water supply, and the University's distances were measured based on active mining during this assessment period only. Distances to mining were only provided in the BUMIS database when there was a record of a reported effect. Therefore it was necessary to calculate distance values based on the University generated mining outlines for all water supplies, impacted or not.

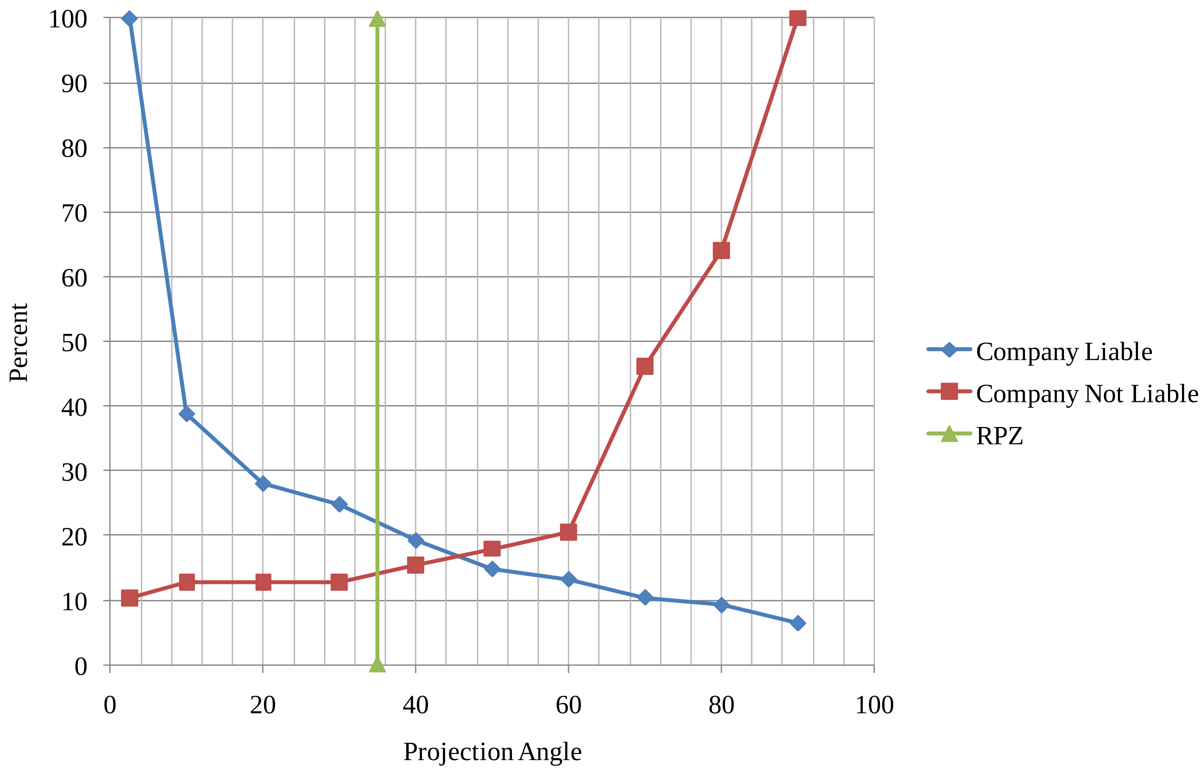

Figure VI-21 – Distribution curves representing the percentage of projection angle values within or outside of the RPZ.

Approximately 77-pct of water supply impacts were deemed Company Liable if within the RPZ. Conversely, 14-pct of Company Not Liable cases were within the 35-deg RPZ. The two distribution curves intersect at approximately 46-deg. Of the 22-pct of liable cases outside of the RPZ, factors pertaining to pre-mining agreements or non-water supply related impacts (i.e. structural or land impacts) could have occurred resulting in a liable resolution status. Regarding the 14-pct of water supplies within the RPZ that were resolved as no liability, the mine operator either successfully refuted the claim, the problem was pre-existing, or not caused by mining, i.e. drought conditions, poor water supply construction / maintenance.

VI.E.3.c – Panel Location/Subsidence

The research team created a model with quarter-width buffer for each side of the panel mined during the 3rd assessment. This buffer separated the panel into mid-panel (50-pct of the panel width) and quarter-panel (two outer 25-pct panel regions) sections. These regions depict the potential types of fracturing of the strata near the ground surface. As provided by Booth (1986), Figure VI-22 depicts the zones of compression and tensile fracturing within the subsidence basin.

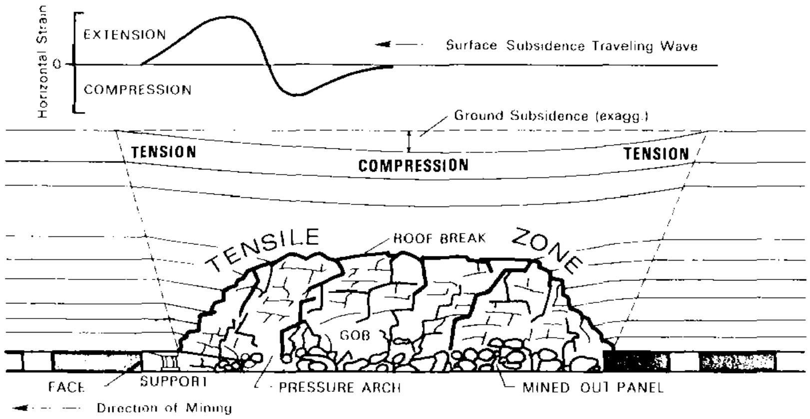

Figure VI-22 – Zones of compression and tensile strata fracturing from Booth (1986).

The water supplies were provided with an attribute in the UGISdb noting the panel location, as quarter or mid-panel. If the water supply was located outside of the panel, it was classified as being located over the gate roads or outside of active mining. The water supplies were categorized as being Company Not Liable or Company Liable and tabulated based on their panel location, as shown in the Table VI-9.

Table VI-9 - The number of Company Not Liable and Company Liable water supplies based on their panel locations.

Mine Name	Company Not Liable				Company Liable				N/A
	Mid	**Quarter**	**Gate**	**Outside**	**Mid**	**Quarter**	**Gate**	**Outside**	
Bailey	66	50	54	107	8	3	5	30	0
Blacksville No.2	13	24	12	48	2	2	2	4	1
Cumberland	40	32	30	23	8	7	12	3	0
Emerald	30	34	35	69	10	9	4	5	0
Enlow Fork	79	101	49	79	20	26	13	20	8
High Quality	0	0	0	0	5	2	2	1	0
Eighty-Four	30	38	27	89	18	25	8	21	6
Shoemaker	0	0	3	6	0	0	0	0	0
Total:	258	279	210	421	71	74	46	84	15

Figure VI-23 shows the liability percentages for each panel location scenario. Due to the formation of a subsidence basin directly over the mined panel, the expectation of an impact is greater over the panel, and less likely as the distance between the water supply and the longwall panel increases. This principle is affirmed in Figure VI-23. Water supplies located directly over mined longwall panels showed a 22-pct and 21-pct chance of being impacted by mining, based on their location whether over the mid-panel or quarter-panel regions, respectively. According to a study conducted by Walker et al. (1986), wells that were located in the mid-panel region of the longwall panel had greater water level fluctuations and head loss, as compared to wells located outside of this region. This can most likely be attributed to the change from dynamic extensional strains and fracturing to static compressive strains or recompression of fractures in the mid-panel region of the subsidence basin. The quarter-panel region, however, will be subject to extensional strains throughout the mining process. A report by Trevits & Matetic (1991) observed water level fluctuations that began approximately when the ground surface was subjected to tensile strains, and maximum rate of water loss and lowest water levels corresponded to the point of maximum tensile ground strains. That study also showed that water levels began to recover once the point of maximum compressional strain was achieved, most likely attributed to the closure or reduction of extensional fractures.

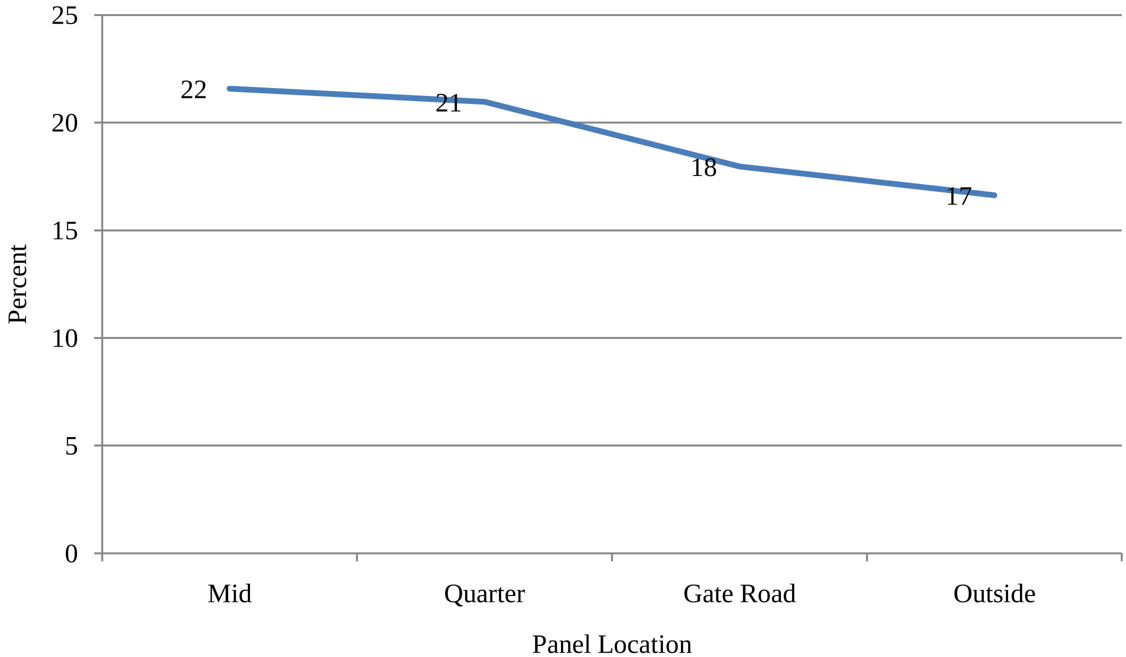

Figure VI-23 –The post-mining percentage of liable water supply shown for each panel location.

VI.E.3.d – Other Influences

The University team collected the daily precipitation totals for the duration of the assessment period. The precipitation totals were measured at the Waynesburg Wastewater Treatment Facility. These values are identical to the ones used by the CDMO. The daily totals were summed to calculate monthly totals during the assessment period. The monthly totals for the years 2003 to 2008 were compared to the long term average precipitation rates for each month for Waynesburg, PA (Figure VI-24). The long-term average values were collected from Canty & Associate's *Weatherbase* website (http://www.weatherbase.com).

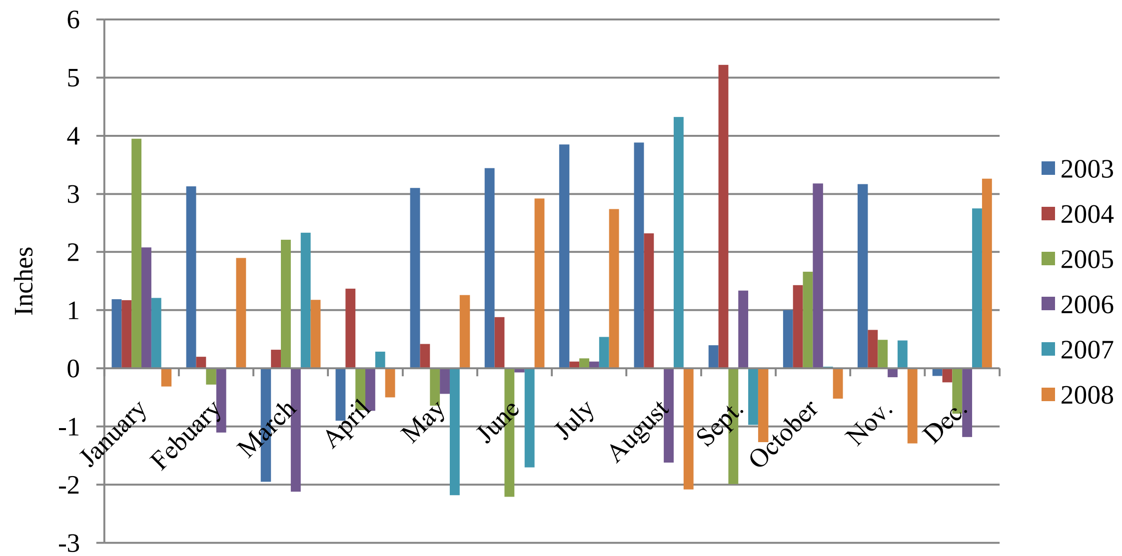

Figure VI-24 – Precipitation totals compared to the long-term precipitation averages determined from Canty & Associates' website for Waynesburg, PA.

The below average precipitation months include: December 2003 and 2004; February, April, May, June, September, and December of 2005; February through June, August, November, and December of 2006; May, June, and September of 2007; and January, April, and August of 2008. The months of the assessment period have been compared to the distribution of all reported water supply effects for longwall mines (Table VI-10). For this analysis the date of occurrence for the reported effects was considered.

Table VI-10 – The total number of reported effects (n=397) for all longwall mines is shown divided into month of occurrence is shown. Below average precipitation rates are shown in italic.

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2003								**0**	**0**	**11**	**2**	*1*
2004	**0**	**3**	**1**	**3**	**2**	**11**	**12**	**3**	**3**	**1**	**3**	*1*
2005	**2**	*3*	**3**	*1*	*1*	*6*	**3**	**7**	*7*	**9**	**9**	*5*
2006	**5**	*2*	*8*	*56*	*10*	*13*	**6**	*3*	**7**	**3**	*6*	*4*
2007	**5**	**1**	**5**	**5**	*6*	*5*	**9**	**11**	*4*	**21**	**23**	**24**
2008	*2*	**8**	**5**	*5*	**6**	**7**	**4**	*5*				

Italic & Underline = below average precipitation
Bold = above average precipitation

As shown in Table VI-10, there were a total of 397 reported effects attributed to longwall mining during the 3rd assessment; with 154 occurring in below average precipitation months and 243 occurring in at or above normal precipitation months. There were 22 months of below average and 39 of normal or above precipitation. By dividing the number of reported effects by number of months, the University determined that there was an average of seven effects reported per below average month, and 6.2 effects reported for above average months. This ratio shows that there may be a slight relationship between months of below average precipitation resulting in more reported water supply effects.

Additionally, the University was able to extract the mine inflow records for the majority of the longwall mines by referencing the Module 8 permit files for each mine. The mine inflow rates were converted into gallons per minute per acre, and shown in the Table VI-11. The value for Blacksville No.2 was not determined because discharges from the mine occurred in West Virginia.

Table VI-11 – The mine inflow rates (rates of pumping required) for each longwall mine.

Mine Name	Inflow (gpm/acre)
Bailey	0.032
Blacksville No.2	n/a
Cumberland	0.250
Emerald	0.130
Enlow Fork	0.005
High Quality	0.480
Eighty-Four	0.036
Shoemaker	0.009

These inflow rates were estimated by the rate at which water was pumped out of the mine. The water infiltrating into the mine can be moving in from the groundwater system above the mine or from nearby abandoned and flooded mines. As previously discussed, water will move by gravity or from pressure areas of high hydraulic head to areas of low hydraulic head. Some of the higher inflow rates, shown in Table VI-11, were the result of infiltration of water from adjacent mines.

According to Booth (1986), groundwater will only drain to the underground mine from the shallow aquifer system if they are hydraulically connected via the fractured strata. As shown in Figure VI-18, Kendorski (1993) describes a dilated zone of increased storativity with little or no vertical transmissivity. This zone is defined as the layer that prevents large amounts of surface and groundwater intrusion into the mine from above. The two layers below this layer are the fractured and caved zones, which account for approximately 30 times the thickness of mining. In order for the shallow aquifer system to infiltrate into the mine, with a mining height of 6-ft, the shallow aquifer system would predictably need to be within 180-ft of the fractured zone to hydraulically connect the shallow aquifer system directly with the mine. The overburden of the longwall mining that occurred during the assessment period was greater than 180 feet deep; therefore little infiltration of the shallow aquifer system was expected.

VI.E.3.e – Headwater Springs Discussion

Headwater springs are vital in contributing to the local stream flow in the region. Impairment of these springs can change the hydrology, biology, and overall health of headwater streams in the region. For the purposes of this analysis, the WPC's Pennsylvania Aquatic Community Classification (PACC) methodology (Walsh et al., 2007) was used to determine which Greene and Washington County watersheds were classified as headwater watersheds. According to the PACC methodology, headwater watersheds range from 0-2 square miles in area; these areas are the location of stream reaches that mainly support the headwater macro invertebrate communities. Using the PASDA GIS online database, the University downloaded the small watershed GIS layer, and calculated the areas of each watershed in square miles. The springs located in these watersheds were exported to the UGISdb for further analysis of the impacts associated with these springs. Table VI-13 provides an inventory of the number of headwater springs undermined by each longwall mine, and the number of associated reported effects.

Table VI-13- Inventory of headwater springs and whether there was an associated impact and the corresponding likelihood of impact.

Mine Name	Total Number	Company Not Liable	Company Liable	Unresolved
Bailey	30	26	0	4
Blacksville No.2	4	4	0	0
Cumberland	8	7	1	0
Emerald	19	17	1	1
Enlow Fork	0	0	0	0
High Quality	0	0	0	0
Eighty-Four	21	15	3	3
Shoemaker	7	7	0	0

As shown in the table above, the percentages of liable impacts on headwater springs are no greater than the overall percentages of likelihood of impacts for all water supplies undermined by longwall mines as shown in Figure VI-15.

VI.F – Status of Water Supplies Impacted during the 2nd Assessment

According to 2nd assessment period report published by Conte and Moses (2005), there were 684 reported effects attributed to the undermining of water supplies during the assessment period. Of the 684, 21.7-pct of reported effects were pending a final resolution (Unresolved) as of August 20, 2003. The current research team was not able to verify these exact case numbers as reported in the previous assessment. The University utilized a Discovery query associated with the BUMIS database in December of 2009, but since BUMIS is an ever-evolving database, the elapsed time may be the reason for the discrepancies in the number of reported effects that were extracted years later.

For this analysis the University used the number of reported effects and the resolution status of these reported effects as provided by the Discovery query from 2009. Table VI-14 summarizes the status of the reported effects occurring in the previous assessment.

Table VI-14- Inventory of reported effects of the 2nd assessment as of the end of the 3rd assessment.

Status	Reported Effects
Total Number that Occurred 1998-2003	603
Number Resolved as of 8/2003	359
Number Resolved as of 8/2008	212
Unresolved as of 8/2008	32

Figure VI-25 shows the breakdown of resolution statuses of the 244 reported effects at the end of the 3rd assessment period. The reported effects have been categorized based on their resolution status as being Company Liable, Company Not Liable, or Unresolved. Company Liable accounts for 81.6-pct of the total and has been shown divided into the classifications of Agreement / Compensation, Permanent Supply, Recovered/Repaired, and Resolved.

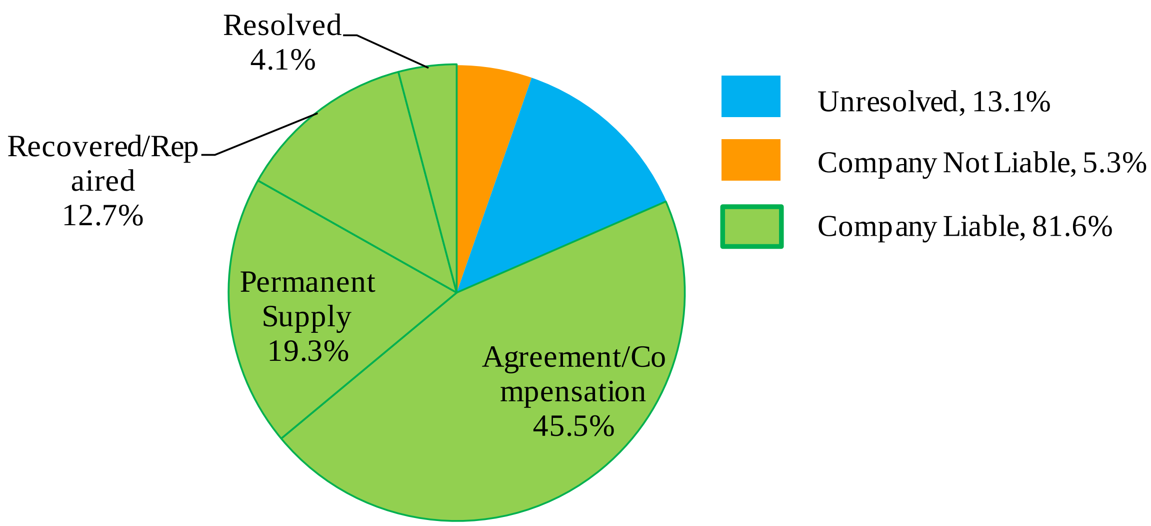

Figure VI-25– Resolution statuses of outstanding 2nd assessment effects resolved during the 3rd assessment period.

Based on categories used in the preceding figure, Figure VI-26 presents the average elapsed time required for a resolution to be finalized. As shown in the figure, the majority of the effects required over three years to resolve; with the Resolved category cases requiring the longest amount of time to resolve at 5.7 years. A few of these Resolved cases described the involvement of an insurance company, and the other provided no extra details to determine what actions were taken within those nearly six years. The Recovered / Repaired category may not reflect the actual average time to resolution because only one out of 31 cases was tracked for time. The remaining 30 cases were attributed to a mine pool contamination of the Dora No.6 Mine.

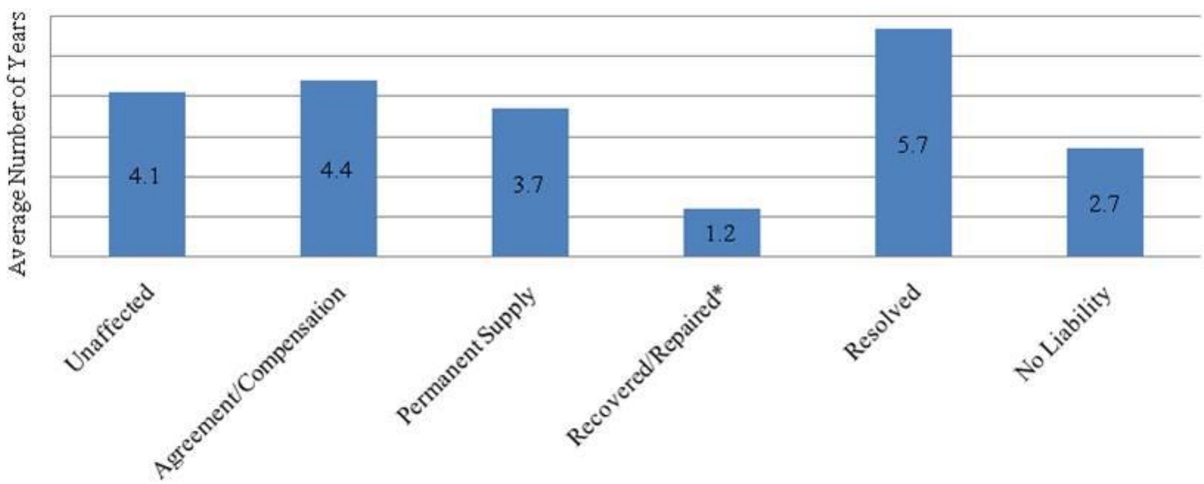

*Figure VI-26– Average number of years required for resolution of each type of resolution status. *Only one out of 31 cases was tracked to resolution time.*

There are 32, or five-pct, of 2nd assessment reported effects that are still not resolved as of August 20, 2008. These pending resolution cases are averaging approximately 6.8 years since the initial effect was reported. Table VI-15 categorizes each of the 32 reported effects based on their interim resolution statuses. The table identifies that the majority of cases are working toward a final resolution in some capacity.

Table VI-15- Interim Resolution status breakdown of the remaining 32 unresolved reported effects from the 2nd assessment period

Interim Status	Reported Effects
Agreement Pending	1
Implementing WS Replacement Plan	2
In Litigation	2
In Negotiation	1
O & M Review	5
O&M Bond Requested	3
Pending Owner Approval	5
Public Water/O&M Pending	3
Temp Water/Awaiting Public Water	3
Temporary Water	1
Well, Spring/O&M Pending	5
WS Replacement Plan Under Development	1

VI.G – Summary Points

The University determined that the total number of water supplies undermined during the 3rd assessment was 2,789 wells, springs, and ponds. The room-and-pillar mines accounted for 1,212 undermined water supplies, room-and-pillar with pillar recovery mines accounted for 75, and longwall mines accounted for 1,502 of the total undermined. There were 683 reported effects associated with the undermined water supplies; 238 from room-and-pillar mines, 20 from room-and-pillar with pillar recovery mines, 397 from longwall mines, and 28 from post-closure mines.

Seventy-four percent of reported effects were associated with water supply diminution. The date of final resolution was tracked and the University determined that 449 of the 683, or 66-pct, of the reported effects were resolved as of the end of the assessment period, leaving 234, or 34-pct of cases, still awaiting a final resolution. Of the resolved cases, it was determined that 256 out of the 449, or 57-pct, of resolved cases were deemed Company Liable. The average number of days required for a final resolution to be achieved was 143 days for room-and-pillar mines, 115 days for room-and-pillar with pillar recovery mines, 274 days for longwall mines, and 259 days for post-closure mines. There were also 12 cases exceeding three years without a final resolution. 212 of the 244 unresolved 2nd assessment reported effects were resolved during the 3rd assessment period. The remaining 32 reported effects were still unresolved as of August 20, 2008

Based on the extensive data collected, the University analyzed potential trends to help create a conceptual water supply vulnerability model. The potential vulnerability influences analyzed included topographic/overburden, lateral proximity/RPZ, longwall panel location, climatic, mine inflow, and headwater location. The following trends were observed:

- *Topographic/Overburden Influence:* Approximately 80-pct of water supplies remained viable after being undermined for all settings except for shallow hilltops where the impact rate was 75-pct and deep valley bottoms with 100-pct viability.
- *Lateral Proximity/RPZ Influence:* Approximately 77-pct of Company Liable impacts occurred within the 35-deg projection angle (RPZ). Nearly 86-pct of cases outside of the RPZ were determined as Company Not Liable.
- *Longwall Panel Location Influence:* Water supplies located over the mid or quarter-panel regions of the longwall panel were 22 and 21-pct likely to be impacted, respectively. When located over the gate roads or outside of mining the likelihood of impact decreased to 18 and 17-pct, respectively.
- *Climatic Influence:* The number of reported effects during the below average precipitation months was an average of 7 per month, and the above average months was calculated to be 6.2 effects per month; which may indicate a slight relationship between precipitation values and water supply reported effects.
- *Mine Inflow Influence:* There did not seem to be any data that would suggest that the shallow aquifer system is being lost to mine inflow. Generally, overburden values for the longwall mines of this study were not shallow enough to hydraulically connect the shallow aquifer system directly with the mine.
- Headwater springs were no more likely to be impaired by subsidence than any of the other water supplies undermined by longwall mining, but the impairment of these supplies can be detrimental to the biological health of the stream systems to which they contributed water flow.

During this study period, 256 water supplies were deemed impacted by mining out of a total of 2,789 undermined; therefore, on average, 9-pct of water supplies within 200-ft of active mining were affected. This shows that the process of underground bituminous coal mining affects the natural hydrogeologic characteristics of overburden strata.