

# **SECTION VI: Impacts of Longwall Mining on Groundwater**

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## **VI. A – Overview**

This section assesses the considerable body of hydrologic data collected during the coal mining permitting process in Pennsylvania, focusing on hydrologic conditions above longwall mining. In particular, the adequacy of the hydrologic data for assessing stream impacts, interactions between ground waters and streams, and the role of hydrologic change in affected supplies is evaluated. This assessment hinges upon an understanding of hydrogeologic conditions in the area. The first portion of the section focuses on the hydrologic and hydrogeologic conditions in southwestern Pennsylvania and summarizes the conceptual understanding of how these conditions interact with underground mining. Next, methods used to collect the hydrologic data and assess the data are outlined. These data are utilized to examine small-scale hydrologic processes, and the limitations of the data, as currently collected and reported, are demonstrated. Finally, the importance of soil water and the current uncertainty regarding hydrologic balance in soil waters is outlined.

## **VI. B – Regional Hydrology, Geology, Climate**

Pennsylvania straddles several physiographic provinces; provinces are defined as regions with consistent topography and landforms. Southwestern Pennsylvania is located in the Waynesburg Hills physiographic sub-province within the Appalachian Plateau Province. The Appalachian plateau was once a relatively flat surface that has been gently and periodically uplifted, allowing incision by streams and rivers and the formation of deep valleys (Wagner et al. 1970). Glaciation also strongly contributed to this incision process as glaciation in the northwestern part of the state directed the drainage of the large Ohio and Beaver paleo-rivers away from what became the Great Lakes region, forcing southwestern Pennsylvania paleo-streams flowing northward to flow south (Wagner et al. 1970). This geologic history is still evident in the modern landscape, particularly the high topographic relief.

### **VI.B.1 – Geology**

The bedrock formations of the Waynesburg Hills physiographic sub-province were deposited during the Pennsylvanian and Permian periods. These formations are composed of sedimentary layers of sandstone, shale, limestone, and coal. These consolidated rock layers generally have low primary permeability. Secondary permeability (fracturing) often facilitates the movement of water through rock layers (Figure VI-1) (Wyrick and Borchers 1981). These permeability features are important to the movement of groundwater.

During the 4<sup>th</sup> assessment period only rocks from the Pennsylvanian coalbeds were mined. The Pennsylvanian system contains six formations: Uniontown, Pittsburgh, Casselman, Glenshaw, Allegheny, and Pottsville. The two most prominent coal-bearing formations are the Allegheny and the Pittsburgh. The coal geology is covered in more detail in Section III.

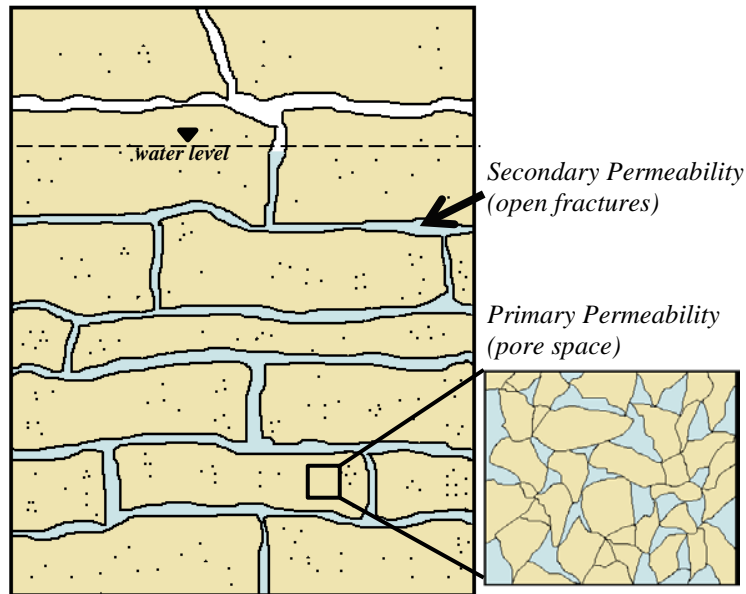


Figure VI-1. Primary and secondary permeability of a rock formation. Figure modified from Wyrick and Borchers (1981).

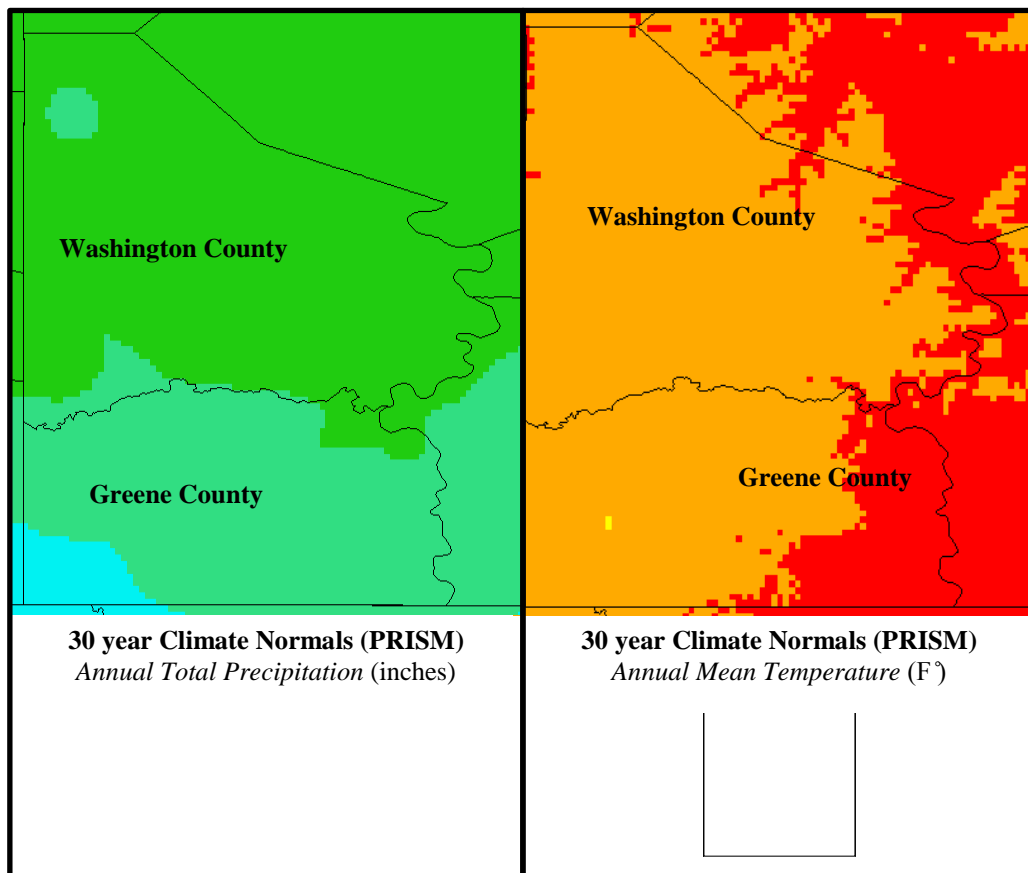


Figure VI-2. Climate data for southwestern Pennsylvania using 30 year normals obtained from <http://www.prism.oregonstate.edu/normals/>. Climate normals are averages of 30 years of daily data.

## VI.B.2 - Climate and Groundwater Hydrology

The climate of southwestern Pennsylvania is humid and moderate. Annual average rainfall ranges between 30 and 49 inches and average temperatures fall between 45 and 54 degrees Fahrenheit (Figure VI-2, <http://www.prism.oregonstate.edu/normals/>). Drainage basins within southwestern Pennsylvania are typically high relief. The climate and topography results in hydrologic flow paths across scales including: local (perched/strata aquifers), intermediate (riparian aquifers), and regional groundwater systems (Figure VI-3) (Poth 1963).

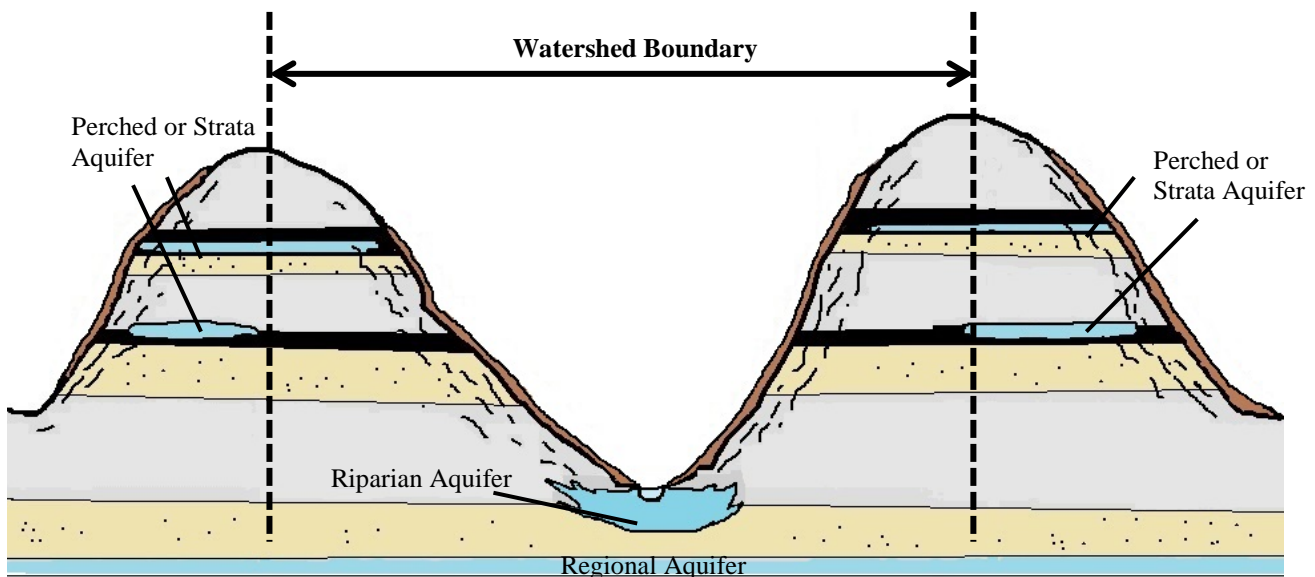


Figure VI-3. Conceptual model showing watershed boundaries and ground water aquifer. Source waters and discharge points for ground water drainage patterns are challenging to characterize due to independence from surface topography.

## VI.C - Longwall Mine Subsidence and Hydrologic Impacts

Subsidence due to underground mining interrupts the continuity of rock strata through deformation and fracturing, consequently altering surface topography (Booth 2006, Peng 1992) (Figure VI-4). A subsidence basin typically forms when the ratio of the extraction zone width (width of the longwall panel) to overburden thickness (depth of mine panel) exceeds 0.25 (Iannacchione et al. 2011). Since most recently mined longwall panels are deeper than 500-ft in Pennsylvania (Section III), a subsidence basin is expected to form at panel widths greater than 125-ft. Pennsylvania longwall panels tend to be greater than 1000-ft wide, therefore subsidence basins are expected to form with every mined panel (Iannacchione et al. 2011). Modern longwall mining has been practiced extensively in northern Appalachia for three decades, undermining

many surface and subsurface water resources (Peng 2008). Effects on surface and groundwater are dependent on many factors, including overburden thickness and stratigraphy location with respect to longwall mining panels (Peng 2008). It is important to understand how mining subsidence impacts both surface and subsurface landscape processes, particularly hydrological processes.

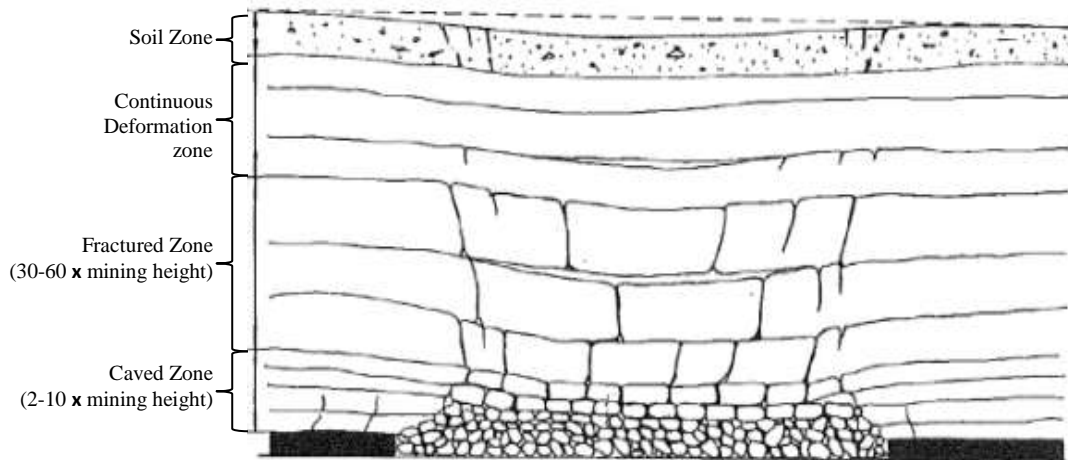


Figure VI-4. Subsidence model showing four subsidence zones as described in Peng (1992).

Many conceptual models have been proposed to describe subsidence processes and resulting alterations to overlying strata. Peng (2006) describes four subsidence zones that are created in the overburden following longwall mine subsidence (Figure VI-4). The immediate zone above the roof of the mine is the **caved zone**, in which the overlying strata fall into the void in irregular platy shapes, expanding to 2 - 10 times the mining height. Above this zone is the **fractured zone**, where strata are broken into blocks by vertical fracturing and by separation of horizontal rock layers resulting in horizontal fractures. The **continuous deformation zone** lies above the fractured zone, but it does not experience major fracturing that extends through the strata. Finally, the **soil zone** varies in depth, with fractures that may extend through the entire soil layer. Cracks can open and close as mining progresses and they may remain persistently open if located near or on the edge of the panel. The properties of these subsidence zones are important when considering impacts to ground and soil water flow. When considering Peng's model, groundwater flow through aquifers located within fractured and caved zones is expected to be persistently altered. Ground water loss located in the overlying continuous deformation zone is not expected to be permanent, but may temporarily be diminished. Water levels in the soil zone may also temporarily drop unless located near the edge of panels, where more persistent cracks may form parallel to the panel edge where soil and ground water rerouting is expected to be more persistent. Depth of mining influences impacts to water sources. The thickness of the fracture zone is generally 325-400-ft. If the depth of mining is less than 400-ft, there is a greater possibility that water loss in streams and wells will occur (Peng 2008).

Kendorski (2006) describes five subsidence zones based on the impacts of mining subsidence to groundwater flow as well as observed changes in rock properties (Figure VI-5). This model was published in 1979 and was the first proposed conceptual model of subsidence that was defensible

and could be used to predict changes to a mine's hydrological regime (Kendorski 2006). The five zones, established using observations made by subsidence engineers and hydrogeologists from multiple countries, are similar to Peng's four zones: 1) The caved zone is completely disrupted vertically and horizontally; 2) the fractured zone has high vertical transmissivity due to abundant vertical fractures; 3) the dilated zone contains an upper confining layer unaffected by mining that overlies an impacted zone with increased water storage potential; and 4) the constrained and unaffected zone has no significant effect on transmissivity and storativity of ground water following subsidence. The surface disturbance zone is described by vertical cracks in the surface relative to panel location that temporarily disrupt soil water flow for up to two years (Kendorski 2006).

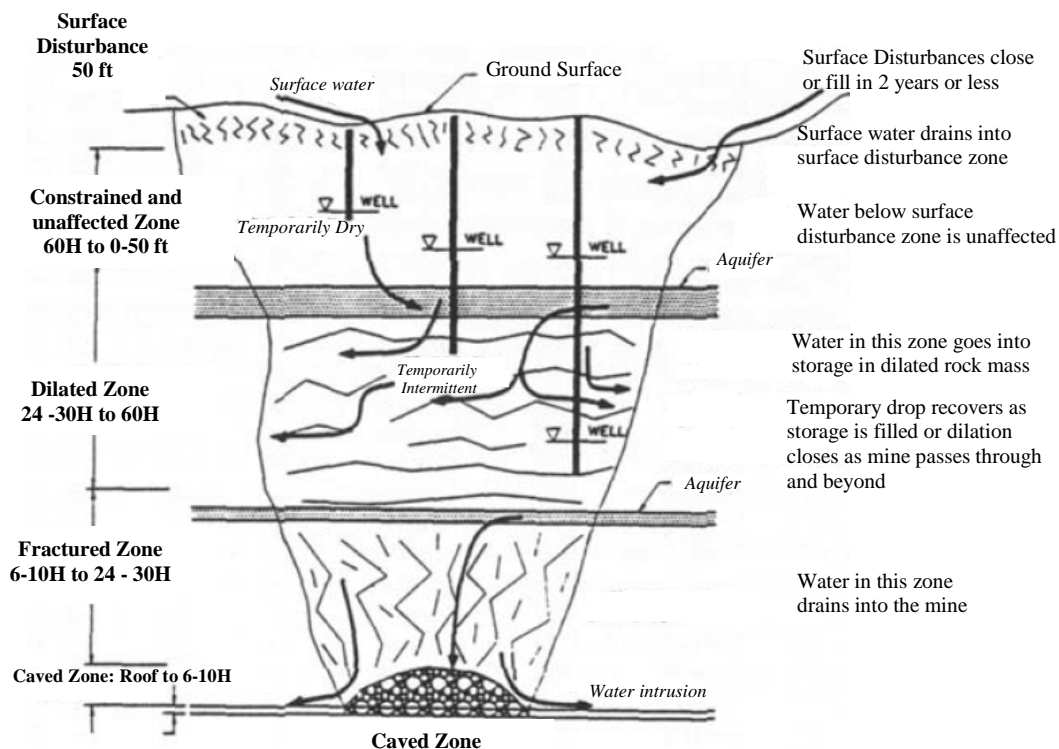


Figure VI-5. Overburden movement resulting from longwall mine subsidence and the 5 zones of overburden strata movement (Kendorski 2006).  $H$  = mining height.

### VI.C.1 - A Hydrologic Focus on the Eight Factors Impacting Flow Loss

There are many factors that influence the natural flow of groundwater and adequately describing these factors to predict subsidence impacts on surface water hydrology is challenging. As also described in Section VIII, eight factors have been identified as contributing to flow loss impacts on undermined streams (TGD 563-2000-655) and are summarized below along with explanations of how each factor contributes to post mining hydrologic change:

*1. Drainage/watershed area:* Streams with smaller watersheds are more susceptible to flow loss. During dry periods, "stored" water in a watershed can buffer surface flow. Smaller watersheds collect less water than larger watersheds. They have smaller catchment basins and can also be

missed by isolated conductive precipitation systems (thunderstorms). Thus during dry periods, their smaller stored water volume has a diminished flow buffering capacity. Therefore rerouting of water from the basin has a disproportionate effect on water storage and flow buffering capacity in smaller basins leaving them more susceptible to flow loss.

2. Streambed lithology: Streams with a larger percentage of exposed bedrock in the stream channel are more susceptible to flow loss. Brittle, consolidated rock underlying the stream channel or aquifers within a hillslope are more easily fractured and/or existing fractures more easily widened (therefore increasing secondary porosity). Altered fracture networks can re-route flow to deeper flow paths and diminish flow in surface waters and perched/bedrock aquifers. However, this flow loss may be temporary, as particles of weathered rock material can fill the fractures over time.

3. Depth of cover: Streams with shallow overburden depth are more susceptible to flow loss. This is simply due to the depth of the fracture zone that forms following subsidence. Shallow overburden depths increase the potential for fracture zones propagating to surficial zones and compromising confining layers underlying aquifers contained in these strata.

4. Overburden geology: Streams with a greater percentage of “hard rock” in their overburden are more susceptible to flow loss. This factor represents the interaction between mechanisms driving factors 2 and 3, as these interactions can result in positive feedbacks that extend and expand fracture networks.

5. Percent of watershed mined: Streams with a greater percentage of the watershed mined are more susceptible to flow loss. Subsidence impacts are greatest at topographic highs, increasing from valley floors, up the hillslope (Leavitt and Gibbens 1992, Tieman and Rauch 1987). Disrupted hillslope hydrology high in the watershed may lead to diminished flow in streams similarly located. Smaller watersheds that are undermined are, on average, likely to have a larger proportion of the watershed undermined.

6. Stream orientation: Stream orientation with respect to the direction of the maximum principle horizontal stress field can influence the tendency of streams to lose flow as fractures resulting from subsidence will tend to be oriented perpendicular to the least principal stress.

7. Presence of natural fracture zones: Streams already interacting with natural fracture zones (e.g. streams with predominantly straight reaches) are more susceptible to fracture propagation and therefore flow loss.

8. Mining height: As the mining height increases, the likelihood of flow loss on overlying streams also increases, due to the dependence of subsidence effects on coal seam thickness (Figure VI-5).

These eight criteria were identified as factors to aid in predicting flow loss to streams and other water resources post mining. Some of these factors are considered to have greater influence on post mining hydrological outcomes, based on observations and past experience. Those considered primary hydrologic variables are *Drainage/watershed area*, *streambed lithology*,

*depth of cover (overburden), and percent of watershed mined.* The remaining factors, *stream orientation, presence of natural fracture zones and overburden lithology,* are considered secondary and can greatly exacerbate impacts of the primary factors.

### **VI.D – Hydrologic Data and the Evaluation of Hydrologic Impacts**

Hydrologic drivers operate across widely varied time scales. Global circulation patterns direct air masses to specific regions, setting the basis for regional climate. The landscape history, ranging from active tectonics to Holocene glaciations, set the terrain and influence the evolution of drainage networks and aquifer systems. Fortunately, most of these dynamics occur so slowly that one can ignore these changes when evaluating the impacts of underground mining. However, beginning with decadal scale drought cycles and continuing through increasingly finer temporal scales, including the dynamics of storm flow generation, a wide variety of time-scales must be incorporated into a coherent and accurate understanding of changes in hydrologic cycling.

Currently, a wide variety of data are reported to PADEP to meet requirements of the permitting and monitoring process. Several of these data series can be used to understand hydrologic changes above underground mining, summarized below:

#### *Data this Section Focuses on*

1. Hydrologic Monitoring Reports: Mining companies monitor three types of hydrologic responses arising from underground mining: 1) Surface water flow and chemistry are monitored at surface water monitoring stations; 2) Groundwater elevations and chemistry are monitored in selected wells and nests of piezometers (i.e., wells that are “open” at specific depths to examine independent groundwater responses in different aquifers (e.g. shallow, intermediate, and deep), and 3) Spring flow and water chemistry are monitored at selected springs located over mining. In the hydrologic monitoring reports submitted to PADEP during this period, complete flow and chemistry data are generally collected quarterly, though some streams over the Bailey and Enlow Fork Mines included flow monitoring data that varied according to the relative position of undermining (see section VII.D.1 for relevant portions of permit requirements). Water chemistry is very rarely reported in cases where sampling is more frequent than monthly.

#### *Data Described in Detail in the Section VII*

2. Stream Biological Monitoring: Transitions in hydrologic conditions are one of the stressors that can alter benthic macroinvertebrate communities and therefore are reflected at least in part in the changes in Total Biological Scores reported for stream reaches.
3. Flow loss maps: The maps showing reaches without flow can be used to understand areas of substantial hydrologic impact.

#### *Data Described in the Section V*



4. **Water Loss Claims:** In water loss claim rebuttals, data on particular water sources is sometimes extensive, particularly pump test data from water wells. These data are reported on a frequent time interval basis, generally one to fifteen minute intervals. However, the intervals between sets of measures are variable and sometimes long and the data is not organized into a single source. Furthermore, the data is not directly connected to the other hydrologic and geologic and mining related data, making utilization difficult, largely due to difficulties in discovery.

#### *Other Data*

5. **Permit Data:** As part of the permitting process, a wide range of data are collected and reported to the DEP. Most useful in the present context are two data types:
  - borehole logs showing the local overburden stratigraphy and
  - surveys of water availability and quality in sources above the undermined areas.

In both cases these data are generally reported once, in the original permit or in a revision to the permit.

#### **VI.D.1 - Hydrologic Data Collection Methods**

In Pennsylvania, underground coal mining permits require a flow monitoring plan (5600-PM-BMP0324, 8.9 (PADEP, 2012)) that includes:

- i. Weekly measurements commencing six (6) months prior to undermining the area of concern.
- ii. Daily measurements commencing two weeks prior to undermining the area of concern and continuing until the potential for mining induced flow loss becomes negligible. (In the case of longwall mining daily measurements should continue until the longwall face has progressed a distance equal to the cover thickness beyond the area of concern.)
- iii. Detect and report all occurrences of flow loss to the district mining office within 24 hours of observation.
- iv. If flow loss occurs, daily observations or measurements commencing from the date of the observed loss and continuing until flow fully recovers or is fully restored or until underground mining operations are determined not to be the cause of the problem.
- v. Weekly measurements continuing six months after the conclusion of daily monitoring.
- vi. Corresponding measurements of flows in control streams (if applicable). [5600-PM-BMP0324, p. 8-3 to 8-4]

In addition, 5600-PM-BMP0324, 8.15 (PADEP 2012) requires a hydrologic monitoring plan that includes:

- a. Complete Form 8.15A (Monitoring Program Summary) identifying the points which will be used in the monitoring program, the parameters to be measured at each point, and the period and frequency of sampling at each point.

- b. Attach a narrative describing how the proposed monitoring points relate to the detection and mitigation of impacts discussed under Modules 8.9, 8.10 and 8.14.
- c. Provide plans and describe procedures to compute accurate discharge flow rates from springs, streams, drains, pipes, sediment/treatment ponds, and mine discharge points. The field system as well as the calculation method must be usable by monitoring personnel and PADEP mine inspectors.
- d. Describe how samples will be taken, preserved, and shipped to the laboratory.
- e. Indicate the name and address of the laboratory that will perform analyses.
- f. Provide the name and credentials of individual(s) performing well pumping tests.
- g. Address the scope, location, and frequency of postmining monitoring (e.g. mine pool level monitoring). [5600-PM-BMP0324, p. 8-8]

These sampling guidelines and the reporting of results from pre-mining monitoring are contained in the permitting instructions; however, requirements for reporting during mining are not clearly specified. Hydrologic monitoring reports (HMRs), reports including flow, water elevation, and water chemistry data are submitted on a quarterly basis to PADEP. Yet, within these reports, there is substantial variability in what is reported (e.g. some mine operators report high frequency flow monitoring during the undermining period, some do not). There are distinct differences in report formats among companies. Further the reporting formats often evolve over the course of the reporting period. Even more problematically, format changes occur within a single report for most of the mines. The reporting process seems to be improving in that, beginning in the second quarter of 2013, these data were provided to PADEP on digital media (e.g. digital video discs) and stored with the paper copies.

Compilation and organization of this data required a substantial amount of effort, and largely precluded the time necessary to clearly document the informal processes of information exchange between the coal companies and PADEP. Some data that is collected to meet permitting process requirements is not reported to PADEP in the HMRs. For example, of HMR data gathered, there were no points in Blacksville 2, Emerald, or Cumberland with more than 40 observations (i.e., all reported data from these mines on average captured less than 2 observations every quarter). These areas were all undermined, meaning the required high frequency flow data was not reported in the HMR.

The heterogeneity in the data reported and the reporting format necessitates making decisions to allow for comparison of the data among the mined areas. For this report, the University relied solely upon the hydrologic monitoring reports submitted to the PADEP and stored in the permit files at CDMO. The University did not anticipate that the more extensive data collected to meet permit requirements would not be reported. Therefore resources necessary to determine exactly how information informally flows between PADEP and the mining companies were not available. Most importantly, focusing on the materials readily available in the HMRs is a more reasonable approximation of the data available to citizens of the Commonwealth during file reviews.

This variability in format required substantial data gathering and organization (Figure VI-6). In general, the process was conducted as follows:

1. All available HMRs were gathered from the relevant portion of the permit file. Data quality was assessed during this step by examining files for temporal continuity, etc.
2. If digital files were not available, HMR's were made digital as follows:
  - a. HMR hard copies were scanned at 300 dpi resolution
  - b. Scanned copies were processed with optical character recognition software, converting the digital image to spreadsheets
  - c. Spreadsheets were compared with scanned images copies to check data accuracy.
3. Digital files required substantial reorganization for even rudimentary analyses (e.g. time series plotting). All files were reorganized into tables such that each sampling event was in its own row, identified by mine, station name, and date. All reported monitoring data was included in this row in the appropriate column. A separate table with all hydrologic monitoring stations reported in a single row along with appropriate geographic coordinates was also generated.
4. Both tables were stored in a database management system.

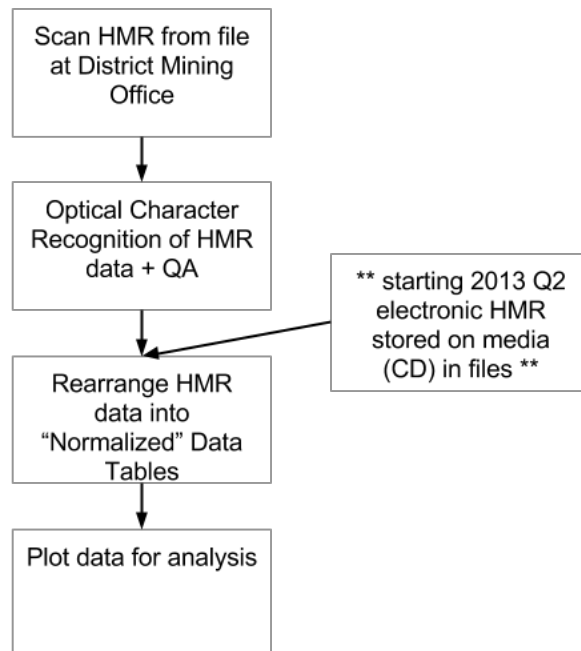


Figure VI-6. Flow chart showing processes involved in HMR data collection

This process was time and labor intensive. Moreover, given the relative timing of the assessment period, the last several quarters of hydrological monitoring arrived late during the University's working period. The University worked to compile complete records for the active mines (i.e., Bailey, Enlow Fork, Blacksville 2, Cumberland and Emerald), but there is inconsistency in the final quarter included in this analysis. In addition, several of the HMRs included data from earlier periods reported in current HMR. Table 1 shows the extent of time included in the database for each mine active during the 4<sup>th</sup> assessment period. For all analyses described below observations outside of the 4<sup>th</sup> assessment period were not included.

Table VI-1. Time period included in collected HMR data

Mine	Earliest Data Included	Latest Data Included
Bailey	Q1 2002	Q3 2013
Blacksville	Q4 2005	Q2 2013
Cumberland	Q4 2008	Q3 2013
Enlow Fork	Q3 2002	Q3 2013
Emerald	Q1 2009	Q3 2013

During the data gathering and organization process, HMR points without spatial coordinates listed in the HMR for at least some point during the assessment period were not included in the database. This decision was made early in the process. However, this process precludes quantification of the number of monitoring observations where observations are not usable. Counting of these instances would be a useful tool in future evaluation of the hydrologic data.

### **VI.E - Evaluation of HMR Data**

The resulting HMR database contains 756 hydrologic monitoring stations and more than 31,000 distinct sampling visits among these stations. The number of hydrologic monitoring points may be inflated as naming conventions are not always clear. For example, in the Enlow Fork HMR data, there are two stations named alternatively, “SW 35” and “SW-35”. Identical coordinates were provided for each station, however the stations were sampled on a unique set of dates. In cases like these, the University preserved both stations. This may result in an over-count of stations due to duplicative station names, but should not cause an over-count of unique sampling events.

In some cases, variable units for pertinent data were reported. Most importantly discharge was reported both as cubic feet per second and gallons per minute. Similarly water level elevations in wells were reported both as the actual elevation above sea level and the depth from the land surface elevation at the well. This inconsistency was problematic as in some cases units/datums were switched within a single HMR, requiring substantial vigilance to not misclassify gallons per minute or feet below land surface observations. Data were converted to a consistent format. Gallons per minute were converted to cubic feet per second by multiplying by 0.00223. Depths to groundwater were converted to elevation above sea level by subtracting the depth to groundwater from the reported land surface elevation at the well location. If no elevation data were provided (roughly 86 sampling events during the 4<sup>th</sup> assessment period), the groundwater elevations were not determined.

#### **VI.E.1 - Evaluation of HMR Data Quality – Mass Balance**

During the data organization process, problems in the reported data were evident. For example, water level elevation/flow data were reported in date format. In other cases, things like pH were reported in the wrong data row or column. In order to evaluate the general data quality in the HMRs, the University compared some of the simple chemical characteristics. Direct comparison of chemistry data with independent measurements is far beyond the scope of this reporting effort.

However, comparison of chemistry potentially allows examination of the rate of keystroke errors, misclassification errors, etc. The relationship of reported major anions (i.e., alkalinity (the sum of carbonate masses) and sulfate) and reported total dissolved solids were the primary data used in comparison. The comparison was based on the fact that surface waters remain neutrally charged. Therefore, the sum of anion mass must be less than total dissolved solid mass, as sufficient cations must present to offset the anion's negative charge. It is true that the cation mass can be minimal in acidic waters as the positively charged hydronium ion (i.e., H<sup>+</sup>) has a mass of 1. In the sampling period only 5 water samples were reported to have pH's below 6, indicating the contribution of hydronium ions appears largely negligible (i.e., less than 1-ppm). Therefore, as hydronium ions were not contributing to the total dissolved solids, the ratio of anions to total dissolved solids depends on the relative masses of the cations and anions. The maximum ratio, in most surface waters, is by definition less than 0.8. This would be the ratio in a pure magnesium sulfate solution, and the ratio would necessarily diminish with changes in the cation or anion mixture. In the 1,111 water samples in which total dissolved solids were reported, 563 had the ratio of the sum of alkalinity and sulfates to total dissolved solids exceeding 0.8. While this may result from common issues (e.g. reported pH's are in error and hydronium ions do contribute substantially, the waters have high dissolved organic acid content, or samples were not filtered) these explanations cannot be confirmed without a complete chemical characterization of the waters. However, the large proportion of the data in which water chemistry is substantially dominated by anions suggests the HMR data should be used with caution. This is particularly important as the water chemistry may provide useful information in future efforts to understand hydrologic changes associated with underground mining.

In addition, the University examined the relationship between total dissolved solids and specific conductivity to further evaluate the proportion of anions in samples where total dissolved solid concentrations were not reported. These total dissolved solids and specific conductivity were related as expected, with total dissolved solids (mg/L) 0.59 times the specific conductivity ( $\mu\text{mho/cm}$ ). This relationship was applied to the 6,878 water samples where a specific conductivity was measured. Of these samples, 2,595 (38%) of the samples had a sum of sulfates and alkalinity that represented more than 80% of the measured or estimated TDS, a better rate than the direct comparison with total dissolved solids. However, three percent of these 6,878 samples (198 samples) had a sum of alkalinity and sulfates that was greater than the reported TDS or the TDS estimated from the reported specific conductivity, violating mass/charge balance. Where mass and charge balance are not preserved, it seems data should be rejected and amended data submission required. This may occur, but it is not reflected in the HMR file.

The chemistry data assessment suggests the HMR data quality should be more carefully evaluated. While the chemistry data does not control the flow, it provides a means to assess processes of dilution, changes in reduction/oxidation conditions, etc. These changes can inform our understanding of source flow paths in impacted water bodies. There are non-trivial issues with mass balance in the reported data. Confirmation of a problem and identification of the source of the problem are beyond the scope of this reporting, but something that should be addressed in the long term.

## **VI.E.2 - Evaluation of HMR Data Adequacy – Variability in Hydrologic Conditions**

In general, the measurement of flow and water elevation is less prone to data quality issues due to the relative simplicity of the measurement. Water samples were collected by the field technician and transferred to the lab technician necessarily creating a gap in context. In contrast, water flows and elevations were generally measured by a few technicians and their experience with the sampling site can make small errors in math, transposition errors, etc. easier to catch and correct. However, while the redundancy in the chemistry data allows comparisons for consistency, flow and elevation data cannot be compared systematically with other reported data. Therefore systematic assessment of flow and elevation data quality was not completed.

Instead, the variability in hydrologic conditions was assessed with the HMR data. There were several instances in which flow for the same station was reported in separate parts of the HMR for the same day (Table VII-2). Most of these observations were not likely conducted at the same time, as the technicians would compare notes and minimize effort. In cases where both observations are identical (e.g. surface water stations with a difference factor of 1) it is likely these are the same data used in multiple reports to PADEP. However, in the remaining cases, the University assumes that the measurements are likely independent. In some cases, this is likely not true, as some differences seem to result from conversion errors (e.g. ST05-244 from Emerald on 12/12/2011 is similar to the conversion factor between gallons per minute and cubic feet per second (448.8)). However, the remaining data seem to be independent measurements over the course of the day. Most pairs resulted from cases where both daily hydrological monitoring and quarterly hydrological/chemical monitoring overlapped. In these cases, there is substantial variability in the flow levels (20-100%) measured within 24-hr of each other. In addition, groundwater elevations vary on average 9 inches over the 24 hour period. Data allowing attribution of this variability to measurement error, natural variability in flow/water table, etc. does not exist. However, the resulting implied level of uncertainty impacts the ability to detect changes in stream flow or water table due to mining impacts. A 20% change may be larger than changes arising from mining impacts. These data allowing comparison of measurements within a day are limited, however they indicate daily variability in hydrologic conditions could exceed potential hydrological impacts of mining. Therefore it is not clear that HMR are sufficient to detect and characterize these changes.

Table VII-2. Multiple observations of hydrologic conditions in a single day. The difference factor is the ratio of the larger observation to the smaller observation.

<b>Ground water Elevations</b>					
<b>Mine</b>	<b>Monitoring Point</b>	<b>Date</b>	<b>Measurement 1 (feet - MSL)</b>	<b>Measurement 2 (feet - MSL)</b>	<b>Difference (feet)</b>
By	PZ-H-I	15 October 2008	999.99	1000.91	0.92
By	PZ-H-S	15 October 2008	1022.31	1021.56	0.75
By	PZ-H-S	15 May 2009	1022.52	1021.79	0.73
By	PZ-H-S	14 July 2009	1021.53	1022.29	0.76
By	PZ-H-S	9 October 2009	1021.99	1022.34	0.35
By	PZ-H-I	18 January 2011	1001.26	1002.19	0.93
By	PZ-H-S	18 January 2011	1021.29	1022.12	0.83
By	PZ-F-S	3 December 2012	942.9	941.84	1.06
Ef	27-18-4.01- PZ-HI	8 September 2012	1157.7	1159.34	1.64
<b>Surface Water Flows</b>					
<b>Mine</b>	<b>Monitoring Point</b>	<b>Date</b>	<b>Measurement 1 (cubic feet per second)</b>	<b>Measurement 2 (cubic feet per second)</b>	<b>Factor of Difference (Max/Min)</b>
By	SW-17	17 September 2008	0.5	0.5	1
By	SW-17	9 June 2009	2.9	2.9	1
By	SW-17	2 December 2009	1.1	1.1	1
By	SW-17	2 March 2010	2	2	1
By	SW-17	20 October 2010	0.16	0.2	1.25
By	Strn H-02	10 February 2011	0.293	0.15	1.98
By	SW-17	14 February 2011	5	5	1
By	Strn H-02	7 November 2011	0.122	0.00022	546
By	Strn H-02	13 February 2012	0.158	0.217	1.37
By	SW-19	6 December 2012	0.001	0.47	470
By	SW-19	14 February 2013	5.4	5.4	1
Cu	S-81	26 April 2012	0.04	0.0397	1.01
Cu	S-82	26 April 2012	0.017	0.0172	1.02
Ef	SW28	6 March 2012	0.83	0.91	1.1
Ef	SW42	15 August 2013	0.08	0.11	1.38
Em	ST05-244	12 December 2011	0.014	6.36	454

Agencies such as the U.S. Geological Survey typically measure discharge/water table elevations at fifteen or thirty minute intervals and average these readings to report daily average discharges/water level elevations, smoothing this variability and collecting that data that allow detection of changes at shorter time scales. Examination of continuous stream flow measurements from such regional networks demonstrates the importance of more frequent measurements in the evaluation of hydrologic change. The U.S. Geological Survey (USGS) constantly measures stream flow in streams across the United States and stores these data in the National Water Information System (NWIS). Several gauging stations that record flow in streams draining areas lying over active and historical longwall panels are available for analysis: South Fork Tenmile Creek at Jefferson, Pennsylvania (USGS 03073000), Wheeling Creek at Elm Grove, WV (USGS 03112000), Chartiers Creek at Carnegie, Pennsylvania (USGS 03085500), and Dunkard Creek at Shannopin, Pennsylvania (USGS 03072000) (Figure VI-7). In addition, USGS groundwater monitoring network water level elevations were collected from the Greene (USGS 394655080014301) and Washington (USGS 400233080261301) County observation wells. These wells are further from the longwall mining activity (Figure VI-7), but the groundwater monitoring network is decidedly sparser than the surface water observation network and continuous records closer to underground mining activity do not exist.



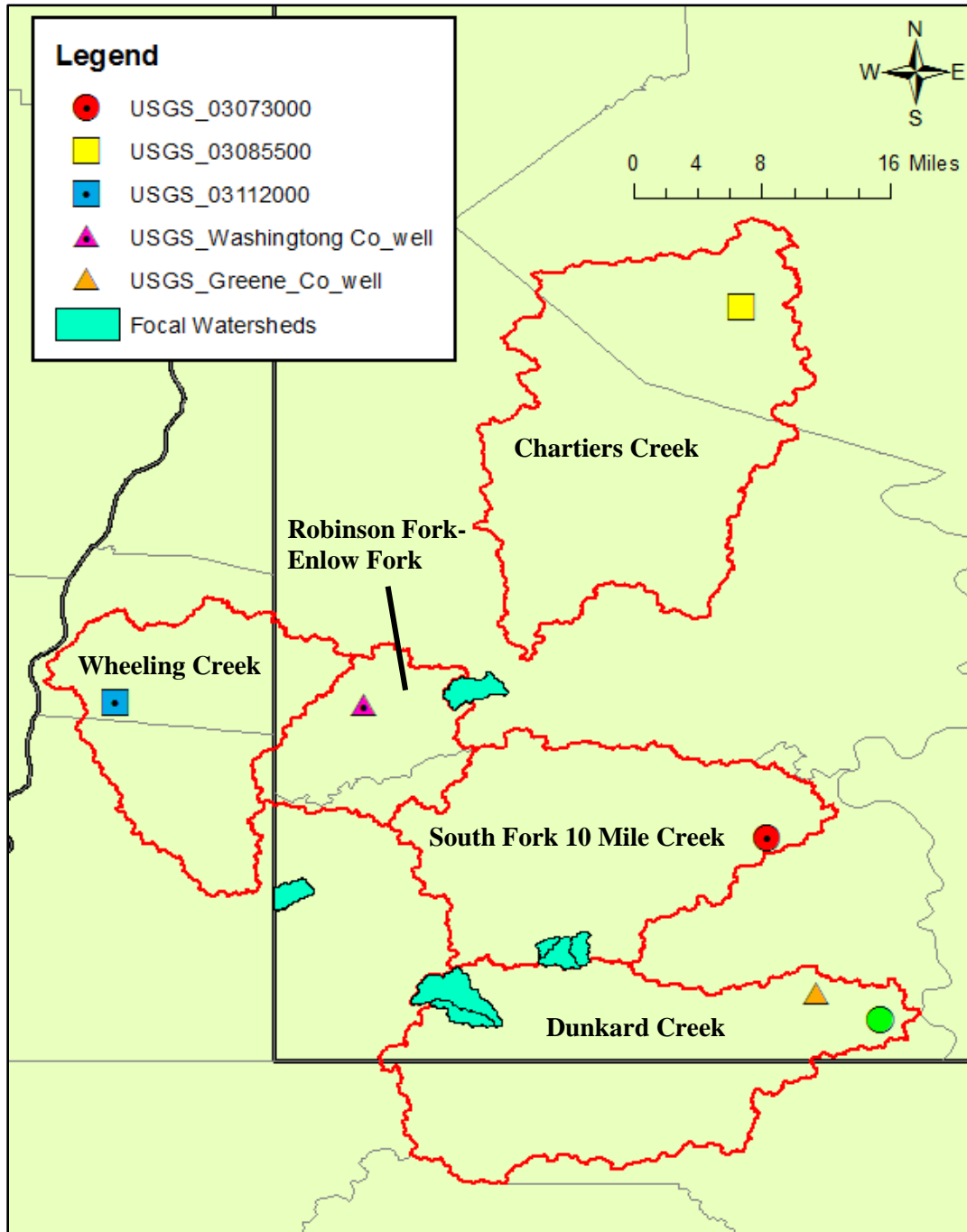
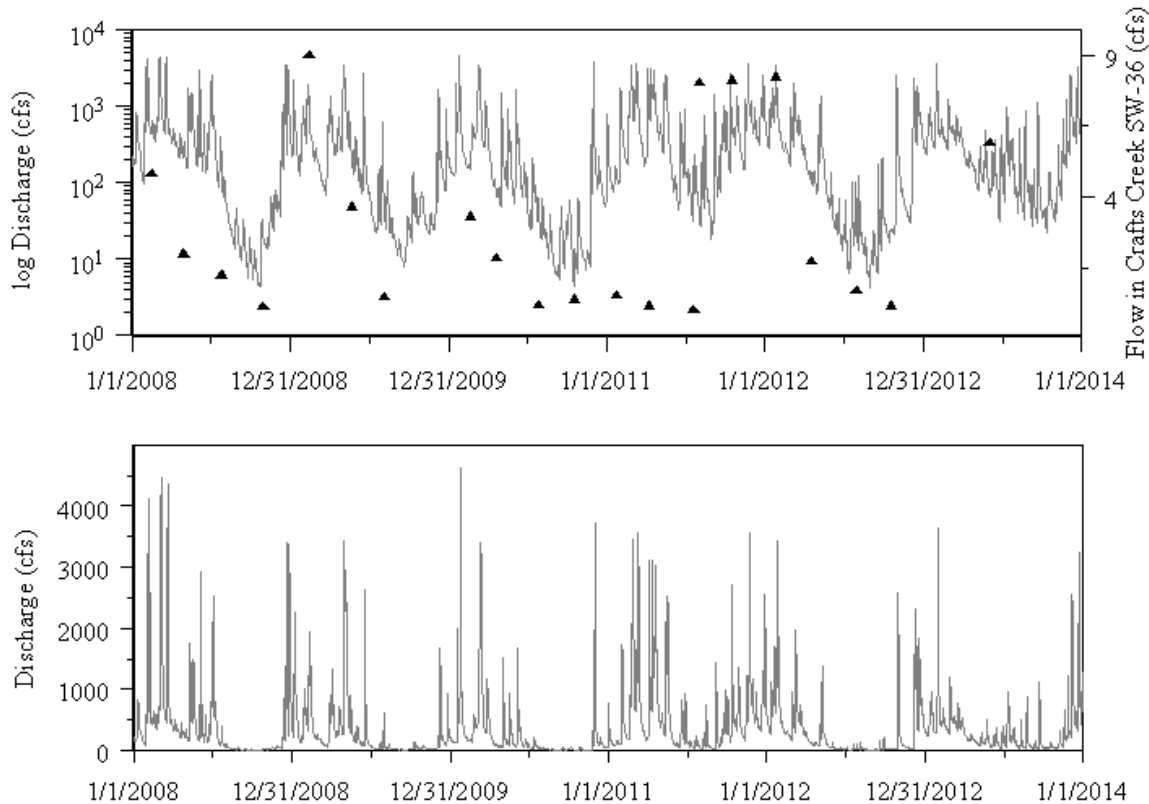


Figure VI-7. Locations of USGS stream gauges and groundwater monitoring wells relative to watersheds overlying areas of active mining. Red outlined areas are major HUC 10 watersheds in which the USGS monitoring points are located (<http://datagateway.nrcs.usda.gov/>).

Using the record from Wheeling Creek as an example, the variability in daily discharge over the course of the assessment period is considerable (Figure VI-8). The average daily flows range over two to three orders of magnitude in a typical year. This variability is even wider if the finer

time interval (e.g. average thirty minute discharge) data is examined. The sparse nature of water flow from Crafts Creek (reported for Enlow Fork point SW36), is challenging to interpret given this variability. The low discharges measured during 2010 and 2011 could conceivably be a function of timing and it is therefore challenging to attribute “changes” observed in the record to underground mining activities.



*Figure VI-8. Average daily flow at Wheeling Creek at Elm Grove, WV (USGS 03112000) over the course of the assessment period. Upper panel shows log transformed discharge and the discharges recorded at SW-36, a hydrologic monitoring point located on Crafts Creek above the Enlow Fork Mine (SW-36 discharges shown as triangles and depicted on right hand scale). Lower panel shows Wheeling Creek discharge data on an untransformed basis.*

Groundwater elevations do not vary over as large a range as stream flow. However, groundwater elevations are clearly influenced by the local hydrologic conditions at depth (Figure VI-9). In general, very limited hydrogeologic information is provided in module 8, in particular, logs of stratigraphic materials for these piezometers and groundwater wells are lacking. Therefore attribution of the wide variance in piezometers such as Bar R-PZ-1 and Bar R-PZ-2 (Figure VI-9) to shallow overburden or to an actual difference in hydrogeologic materials is not possible. In addition, the HMR data are more variable than the USGS data, likely due to the difference between a daily average and a single measurement during the day, particularly when reported data indicate that ground water elevations vary over an average range of 9 inches/day. Fundamentally, even the USGS monitoring wells are radically different, despite the fact that they are meant to represent hydrogeologic conditions in adjacent counties. Given these data

limitations, only groundwater data in close proximity to impacted areas of interest are appropriate for detailed analysis.

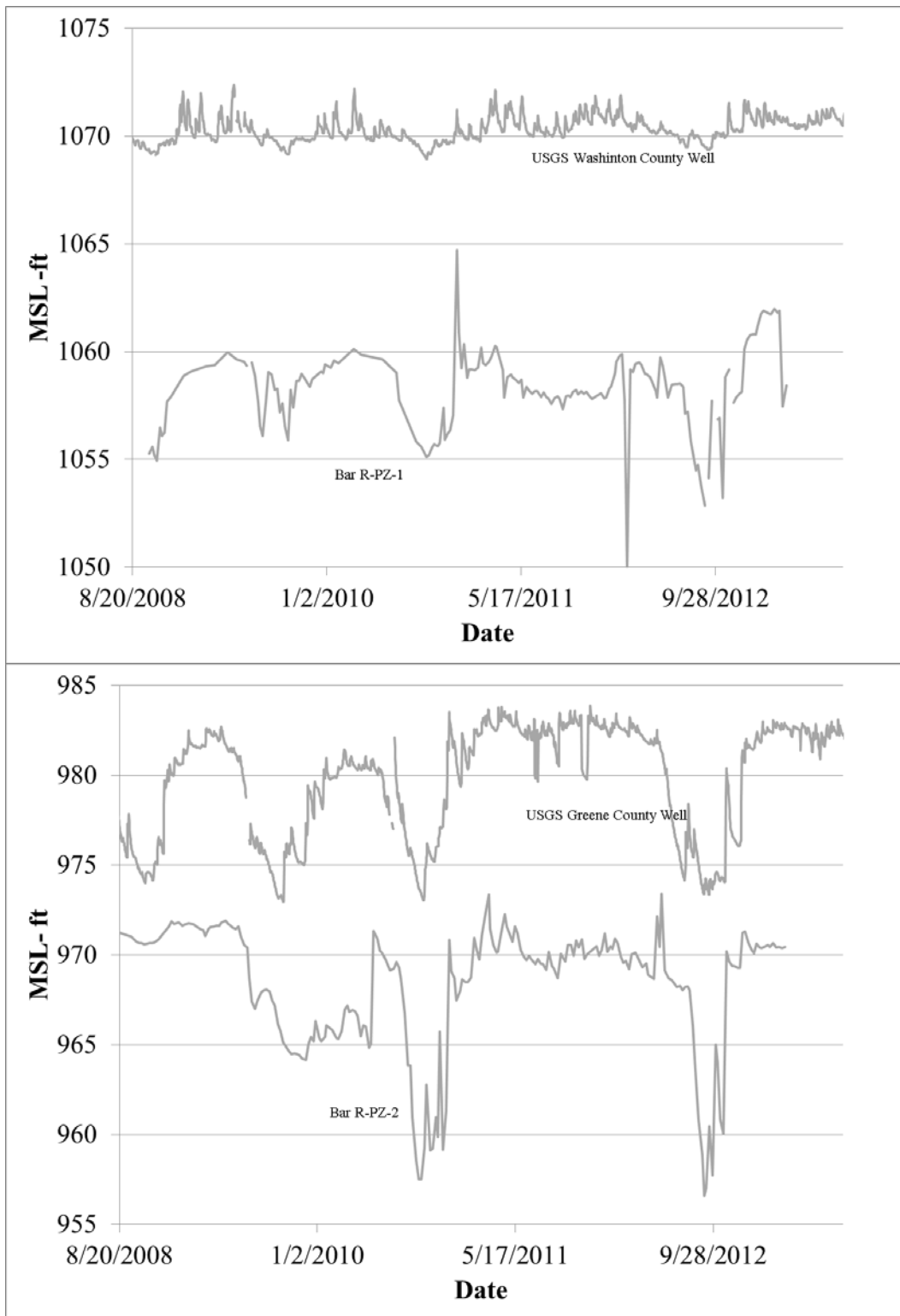


Figure VI-9. Average daily water level elevation in the USGS Groundwater Monitoring Network wells for Washington and Greene County, Pennsylvania, plotted with observations made at Bar R PZ-1 and Bar R PZ-2, two piezometers located in Barneys Run, over the Bailey Mine.

**VI.E.2 - Evaluation of HMR Data Adequacy – How much precision is necessary?**

The impacts of underground mining to hydrologic systems depend, at least in part, on the changes in variability in flow and therefore the changes in local shallow water table elevations. The most acute impact is the complete loss of flow in the stream. Intermittent flow is a natural occurrence in low order streams, as these streams are generally situated at elevations above regional ground water aquifers and diminished moisture status during summer months cannot be buffered by subsidies from these deeper ground water reservoirs. In low order streams, the timing and duration of periods without flow are controlled by relatively consistent processes (e.g. transpiration via local vegetation and evaporation due to climate) and the biota of those streams are generally adapted in ways that synchronize with these predictable patterns (Lytle and Poff 2004). Changes to either timing or duration of no-flow periods can interfere with strategies developed by in-stream organisms to survive dry periods. In general, the regional hydrologic observations (i.e., the USGS NWIS data) are made on larger streams that intercept regional aquifers. Therefore, these long-term records of flow generally do not include intermittent periods of no flow and characterization of these “natural” periods of flow loss is not clearly quantified. Impacts to in-stream macroinvertebrate communities can be inferred from the measurement of these communities. However, these measurements do not clearly allow assessment of other no-flow impacts. For example, nutrient buffering capacity of smaller streams is likely compromised or diminished during extended no flow periods, contributing to aquatic impacts further downstream. Mechanistic prediction of diminished buffering is not possible without clearer characterization of the flow regime changes following undermining.

The changes in water balance resulting in flow loss can be approximated by comparing the water augmentation data (described in Section VII) with annual average precipitation and used to estimate the relative amount of precipitation that is “lost” in dry streams following subsidence. For example, all weekly augmentation reported for Barneys Run (the focal watershed over Bailey Mine) during 2012 were converted to gallons by multiplying average gallons per minute values by the number of minutes in a week. The resulting gallons were summed to arrive at an approximate number of gallons augmented in 2012 (38.3 million gallons). Converting these gallons to cubic feet (5.12 million cubic feet/year) and dividing by the number of square feet that Barneys Run drains (81 million square feet) results in a depth of 0.063 feet or roughly 0.75 inches. This depth is analogous to a single precipitation event in the region, the proverbial 1-inch storm. Therefore, the augmentation done in Barneys Run in 2012 is equivalent to a climatically minor event. Given an annual rainfall of 42 inches (Figure VI-2), that means the impacts necessitating augmentation result from a relatively minor change in water balance.

The collection and reporting of more frequent hydrologic data is necessary to evaluate the impacts of underground mining. The limited data collection event at its maximum (once per day) still is substantially variable, variability that seems to be on par or greater in relative magnitude than the water losses causing impacts. If augmentation is equivalent to a single storm over the course of a year, the 20-100% variability in flow measurement / nine-inch variability in water level elevation seems to be large enough to obscure detectable changes in the hydrologic record. The collection of additional higher frequency data (i.e., at 15 or 30 minute intervals) should allow characterization of this variability and an accounting for it in the assessment of impacts. Most importantly, collection of hydrologic data at these shorter time intervals seemingly is

already occurring. Multiple cases of equipment deployed in groundwater wells to measure groundwater elevations were observed during field visits made as part of the assessment process. Formalization of these activities and communication of the result in a systematic format would enhance the PADEP's ability to assess the potential hydrologic impacts of underground mining.

Further, hydrologic system health depends on the storm flow responses. Storm flow hydrographs generally peak over relatively short periods (Figure VI-8). The magnitude of peak flow determines the characteristics of a wide variety of important factors ranging from the amount of scour disturbance to the timing of floods in lower reaches. The observations of mining-induced lengthening of no-flow periods coupled with the predominant conceptual models suggest that if anything, storm flow hydrographs will likely be diminished. However this expectation cannot be evaluated with currently reported data.

### **VI.E.3 – Incremental Reporting of Hydrological Data**

One of the challenges in reconstructing hydrologic changes following undermining is synthesizing the baseline information provided in module 8 of the mining permit, particularly given the incremental nature of changes made as part of the revisions to the permit.

To illustrate, the University selected a number of module 8 sections from recent permit revisions for comparison. These revisions were all submitted to the Enlow Fork permit as revisions allowing additional activities associated with mining and not covered in the original permit. All of the revisions selected have versions available in Microsoft Word format, enabling whole text comparison of the content. The relevant revisions are listed below:

- Revision 92, **Enlow Fork Mine Overland Conveyor - Phase 1 (Dec 2010)**
- Revision 97, **Enlow Fork Mine F23 Bleeder shaft**
- Revision 99, **Enlow Fork Mine Overland Conveyor - Phase 2**
- Revision 102, **Enlow Fork Mine 3 North No. 6 Airshaft**

In each case the University utilized the Microsoft Word Document Compare tool to detect changes made from one revision to the next. The complete set of changes in the module 8 text from revisions 92 to 97 are shown below:

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Section 8.1.a: a paragraph on shallow groundwater removed,

Section 8.1.b: the list of wells and well depths was altered to reflect local conditions.

Section 8.1.c:

**“Ground water from the hilltops and valley sides move toward the ground water discharge zone of Rocky Run or Long Run. Topographic relief in the area of the permit ranges from a high of approximately 1400 feet MSL to a low of approximately 1090 feet MSL along Rocky Run.”**

Changed to:

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**“Ground water from the hilltops and valley sides move toward the ground water discharge zone of Sawhill Run and tributaries of Sawhill Run.”**

Section 8.1.f: number of wells in the inventory changed.

Section 8.1.g:

**“There are no impacts associated with previous mining at the Enlow Fork Mine known to exist within the proposed surface activity permit boundary. No impacts are expected on the quality or quantity of local water resources as a result of the proposed overland conveyor belt installation. It is expected that surface flows, water levels, seasonal recharge characteristics, and water quality will be consistent with pre-existing conditions.”**

Changed to:

**“No impacts on the quality and quantity of local resources have been noted as a result of past shaft installations. CPCC has monitored water supplies and resources before and after shaft installations. Results of the monitoring at these stations indicate that flows, water levels, seasonal recharge characteristics, and water quality are consistent with pre-mining conditions.”**

Section 8.1.h: “overland conveyer system” replaced with “shaft”

Section 8.2: exhibit numbering changed.

Section 8.5: “1000feet” changed to “1,000 feet of the permit area”

Section 8.6: documentation of pond presence was removed due to change in locale

Section 8.7.b: rewording of language stating that no public water supplies exist in the permit area.

Section 8.13.a: Changes in exhibit numbering

Section 8.14.a.ii: added

**“Ground water elevations will return to their pre-mining condition because the temporary, artificial gradient caused by mining will be eliminated as the mine voids fill with water. The pool within the Enlow Fork Mine will be about 660 feet msl, or just above. The highest coal elevation in the Enlow Fork Mine will be about 660 feet msl. No discharges to the land surface upon site completion is expected because the lowest land surface elevation at the proposed openings is approximately 1332 feet msl.”**

Section 8.14.a.iv.(1): added

**“No post-mining discharge is predicted because the coal elevation does not exceed the surface elevation. The lowest surface elevation of the proposed openings is 1332 feet msl. As discussed above, the predicated post-mining pool elevation and maximum elevation of the Pittsburgh coal in the Enlow Fork Mine is 660 feet msl. No mine water will be pumped to the surface. Thus, no discharges to the land**

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**surface are predicted from the operations proposed in this application.”**

Section 8.14.a.iv.(4): language describing hazardous materials associated with belt operations removed from shaft application

Section 8.14.a.iv.(6):

**“There will be no storage of coal or spoil within the proposed overland conveyor system permit boundary. The proposed overland belt will be installed entirely on the ground surface with limited subsurface activity. The conveyor system will contain spill prevention trays and be monitored to limit other possible sources of contamination to water resources associated with the transportation of coal and spoil through the proposed permit area. It is expected that no adverse hydrologic effects will result from activities associated with this surface facility.”**

Changed to

**“No coal or spoil removal storage are proposed for this surface activity. The proposed shaft will be constructed with steel casing and be grouted. Refer to Module 23 for construction details.”**

Section 8.15.a: presence of springs added along with note specifying collection before treatment where possible.

Section 8.15.b: List of monitoring points changed to reflect locale.

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Changes from Revision 92 → Revision 99 and Revision 92 → Revision 102 were similar or even less dramatic than those summarized above.

Each permit revision’s module 8 was roughly fifteen pages long. In each revision that the University analyzed, the actual change in wording amounts to less than a page of actual content changes. Further, these changes mostly arise from specific characteristics of the permit area (addition or subtraction of spring monitoring, etc.). While this similarity in module 8 content is not unexpected given the relatively small distance separating permit areas, the usefulness of simply repeating the same content in these submissions is questionable, as the variability in things like hydrogeologic conditions are likely large (e.g. Figure VI-9). However, even if this additional site-specific information is not useful/feasible, by surrounding the relevant, incremental changes in the much larger, unchanged documents, the ability to comprehensively evaluate water resource changes is diminished.

For example, consider the case where an interested party wants to catalog the hydrologic monitoring points in an area and understand the hydrologic component (e.g. spring, well, surface water) these points monitor. The process shown in Figure VI-10 would have to be repeated four times for the permits above.



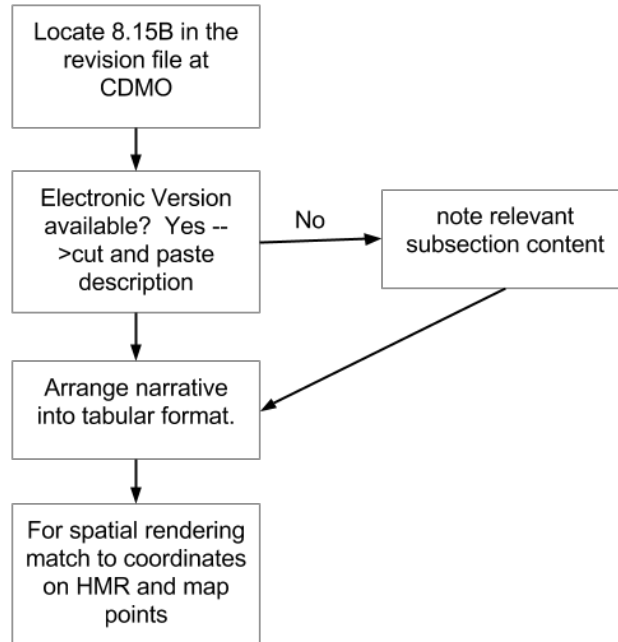


Figure VI-10. Process necessary to summarize module 8.15 (list of hydrologic monitoring points) data across permit revisions.

The adoption of content management tools could simplify both the reporting and evaluation process. Electronic versions of the permits could be maintained and revisions to each of the module subsections recorded and associated with the relevant section. Then, if a particular module sub-section were of interest, the original material and revisions could be viewed in the larger context. For example, Figure VI-11 illustrates the potential for such a system when reviewing Module 15.B. In this hypothetical case, the purposes of all of the hydrologic monitoring points could be accessed in single interface, allowing rapid evaluation of available information. Moreover, in such systems linkages to geographic information systems and other visualization tools would facilitate more and better evaluation of monitoring planning.

The state already implements similar tools in complicated data management systems, for example the PA\*IRIS well data system ([http://www.dcnr.state.pa.us/topogeo/econresource/oilandgas/pa\\_iris\\_home/](http://www.dcnr.state.pa.us/topogeo/econresource/oilandgas/pa_iris_home/)). Similarly, a system like the BUMIS database could be adapted to allow this sort of content management. Permit revision information linked to other relevant data would allow more effective understanding of the hydrologic impacts of underground mining.

8.15.B. Attach a narrative describing how the proposed monitoring points relate to the detection and mitigation of impacts discussed under Modules 8.9, 8.10 and 8.14.

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. <other revisions not shown for this example>

Revision 92 **There are 4 total long-term surface water monitoring points on Rocky Run and Long Run. Stream flows and water quality will be monitored quarterly at these points to determine if any changes occur. A surface water monitoring point is located upstream and downstream of the permit area on both Rocky Run and Long Run.**

**Three springs (27-25-2.0 S2, S3, S4) and one well (27-24-15 W1) will be monitored quarterly to determine if any changes in ground water quality or quantity occur. The proposed overland belt will be installed entirely on the ground surface with limited subsurface activity. The conveyor will contain spill prevention trays and be monitored to limit other possible sources of contamination to water resources associated with the transportation of coal and spoil through the proposed permit area. It is expected that no adverse hydrologic effects will result from activities associated with this surface facility.**

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Revision 102 **There are 4 long-term surface water monitoring points on tributaries to Buffalo Creek. Stream flows and water quality will be monitored quarterly at these points to determine if any changes occur during or after shaft construction. Surface water points 32994 BC-U1 and 32994 BC-D1 are located upstream and downstream, respectively, of the permit area. Unnamed tributary EF T3D will be monitored at the mouth and EF T1 will be monitored downstream of the permit area.**

**Monitoring points 27-3-16 S1 and 27-3-6 S1 will be monitored to determine any changes in ground water quantity or quality.**

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*Figure VI-11. Mock-up of a possible management information system interface allowing the review of permit module revisions in the context of other revisions.*

### VI.F – Focal Watershed Analysis

Assessing the impact of longwall mining on groundwater is complicated, particularly due to the variation in groundwater response across physiography. Wells in the region tap a variety of aquifer types, including perched aquifers, strata aquifers (both fractured and un-fractured), and riparian aquifers. In general, the economics of well drilling dictate that the shallowest aquifer providing a reliable water yield is tapped. This minimizes labor and casing costs, and further avoids deeper water's tendency to have increasing levels of dissolved solids due to longer water-rock contact times. However, given the geometry of aquifer systems (Figure VI-3), losses of water from the topographically higher aquifers can be rerouted to the alluvial aquifers lying under the valley soils. In some cases these changes in hydrologic flow paths can result in interactions with other groundwater sources, such as chemically reduced groundwaters (i.e., high in soluble iron) that would impact water quality when mixing with existing groundwater. As a result, longwall mining may diminish well production/water quantity at higher aquifers and diminish water quality in wells situated in lower aquifers.

Further, observations of groundwater are limited to relatively few and spatially limited points (i.e., wells). In general, HMR data is collected from a subset of existing wells and nests of piezometers (i.e., wells that are "open" at specific depths to examine independent groundwater responses in different aquifers (e.g. shallow, intermediate, and deep)).

Given the wide range of available data and the complexity of the hydrologic system, small (0.5 - 6 square mile) watersheds located over areas of active mining during the 4<sup>th</sup> assessment period were selected for intensive analysis (Table VI-3 and Figure VI-12).

*Table VI-3. Hydrological characteristics of focal watersheds.*

Focal Watersheds	Associated Mine	Watershed Area (acres)	# of Water Supplies	# of Affected Water Supplies	# of HMR Points in the watersheds			
					X	□	●	▲
Barneys Run	Bailey	1856	110	8	3	1	9	-
Roberts Run	Blacksville 2	1414	3	0	-	-	9	-
Blockhouse Run	Blacksville 2	4000	50	5	5	1	9	-
Turkey Hollow	Cumberland	474	21	4	3	1	5	-
Maple Run	Cumberland	960	25	0	2	2	13	1
Pursley Creek	Cumberland	5267	86	11	4	5	8	-
Crafts Creek	Enlow Fork	2387	119	4	2	-	9	1
<i>Symbol Key: X = Piezometer, □ = Well, ● = Stream, ▲ = Spring</i>								

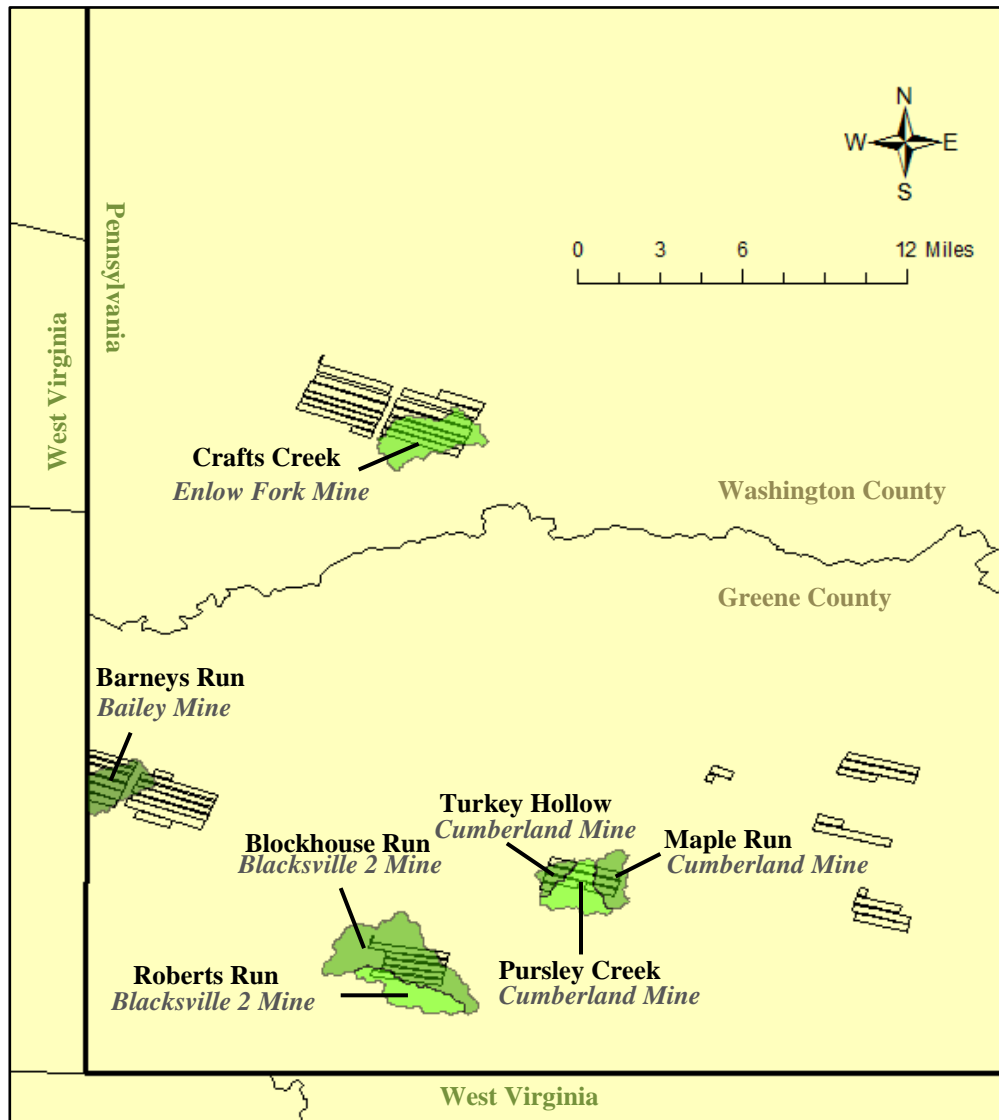


Figure VI-12. Locations of focal watersheds relative to active longwall mining during the 4<sup>th</sup> assessment period.

### VI.F.1 - Affected Water Supplies

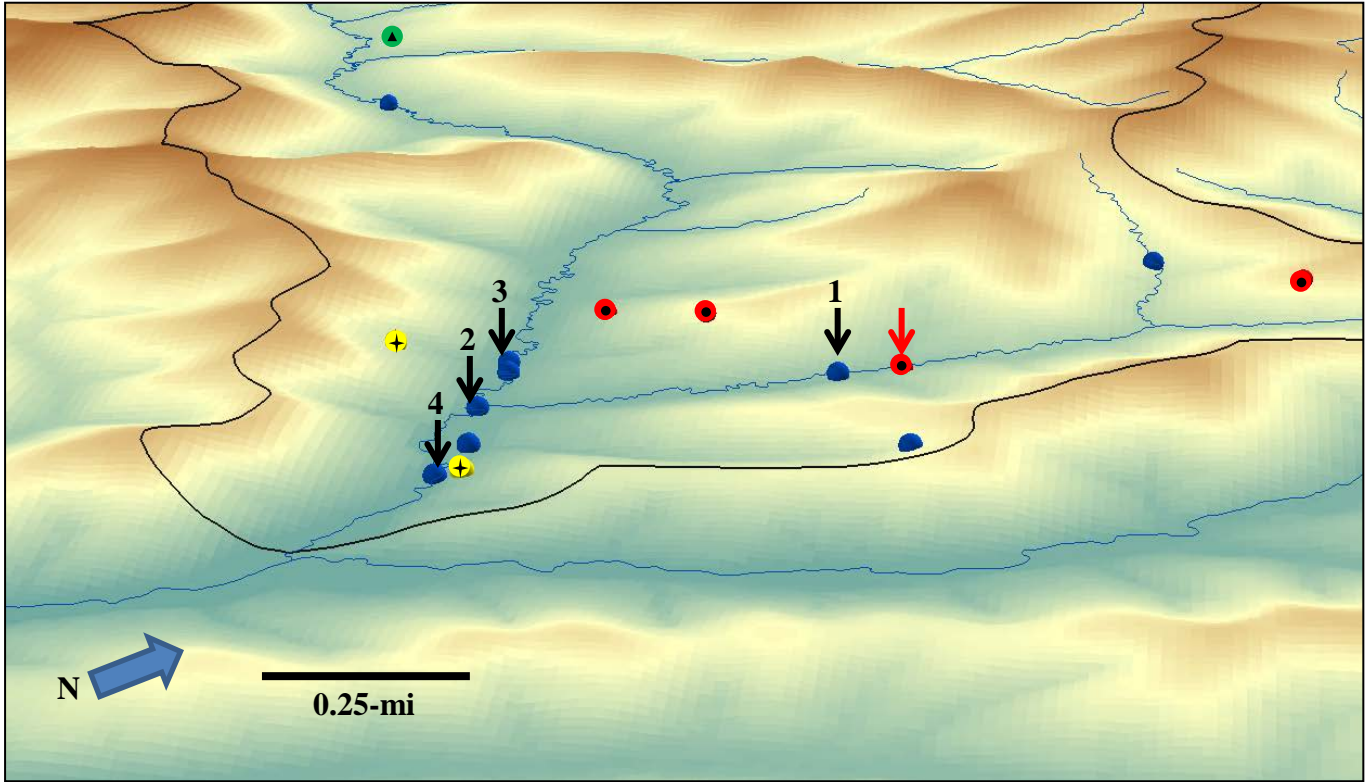
Analysis of affected water supplies relative to lowered water tables is challenging given the existing data is limited in spatial and temporal density. There are few HMR points within each of the focal watersheds (Table VI-3). For the seven focal watersheds there are 42 reported effects for water supplies. Unfortunately, only nine of these reported effects can be compared to HMR data, as the other sampling points are too distant from HMR sampling points to make clear comparisons. Reported affected water supplies were compared with HMR data from specific sub drainage areas where the effects occurred (i.e. the same tributary or stream branch). These sub-drainages were selected as the analysis unit as they provide a means to assess water balance and the interactions among ground and surface water determining this balance. Few piezometer,

spring, or well HMR points were in close proximity to most of the reported effects. Further, one reported water supply effect was near both a well and a piezometer, but the well data was mostly missing and the piezometer water elevation data reported in two different formats (MSL-ft and depth from surface) that were uncomparable due to missing elevation data for the HMR point.

The remaining reported effects to water supplies were located in drainages without HMR points in close proximity and cannot be assessed with HMR data. Overall, data necessary to determine if these reported effects are related to mining-induced fluctuation in groundwaters has not been reported in the HMRs.

### **VI.F.2 - Crafts Creek**

Of the four reported effects to water supplies in the Crafts Creek watershed, there is one water supply problem that is close enough to an existing HMR point to allow direct comparison (Figure VI-13). A spring 0.1-mi upstream of the stream monitoring point UNT 40939-U1 is reported in BUMIS to have lost flow and to have eventually gone dry (Figure VI-14). Both the initial diminution of the spring and loss of the spring occur during periods of low flow in the stream. However, it is not clear if the low flow periods are due to mining or natural fluctuations due to seasonal climate. When HMR data from surrounding points are compared, they all have similar flow patterns, suggesting the quarterly HMR data is capturing natural seasonal fluctuations (Figure VI-15). It is also important to note that at the time the water supply problem was first reported, the area had not yet been undermined (Figure VI-14). However, sections of a panel downstream of the water supply problem were mined in July and August of 2010, a period during which Washington and Greene Counties were under a drought warning. There is a drop in flow during that time period for HMR point UNT 40939-U1, but a similar drop occurs at the same time at other points within the watershed suggesting a seasonal fluctuation instead of a mining effect (Figure VI-15). As of 11 May 2011, the affected water supply has a resolution status of “unspecified agreement”



● Water supply problem ● Stream HMR + Well HMR ● Spring HMR ■ Piezometer HMR

Figure VI-13. Crafts Creek watershed showing HMR points and water supply problems. Numbered points on the map correspond to the plots below and are as follows: 1) UNT 40939-U1, 2) UNT 40939-D1, 3) SW 36, 4) 40938 D-1

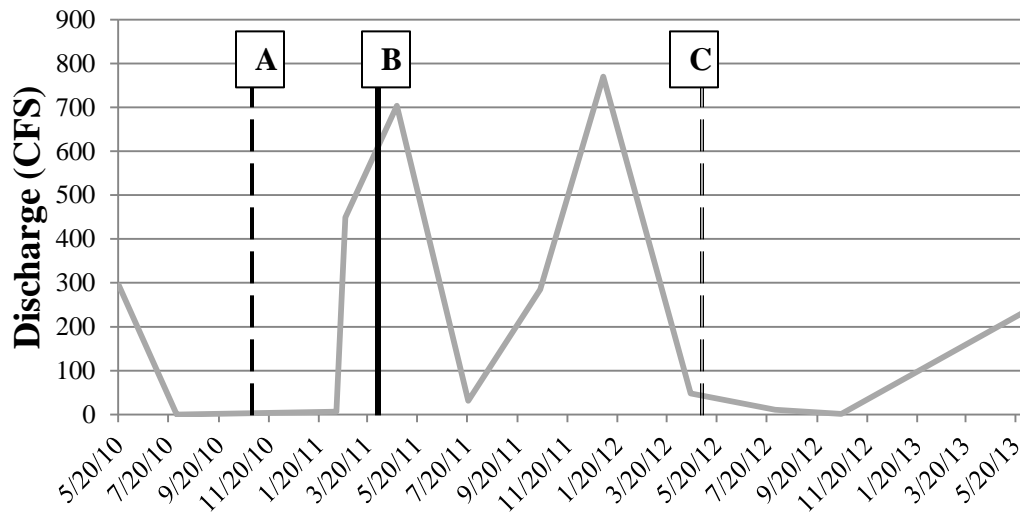
**HMR monitoring point: UNT 40939-U1**

Figure VI-14. HMR monitoring point near Crafts Creek water supply problem. The first dashed line (A) represents the date the supply problem was first reported (4 November 2010). The solid line (B) indicates the date the water supply was undermined (25 April 2011). The final dashed line (C) indicates the date that “total loss of spring” was recorded in the BUMIS (11 May 2011).

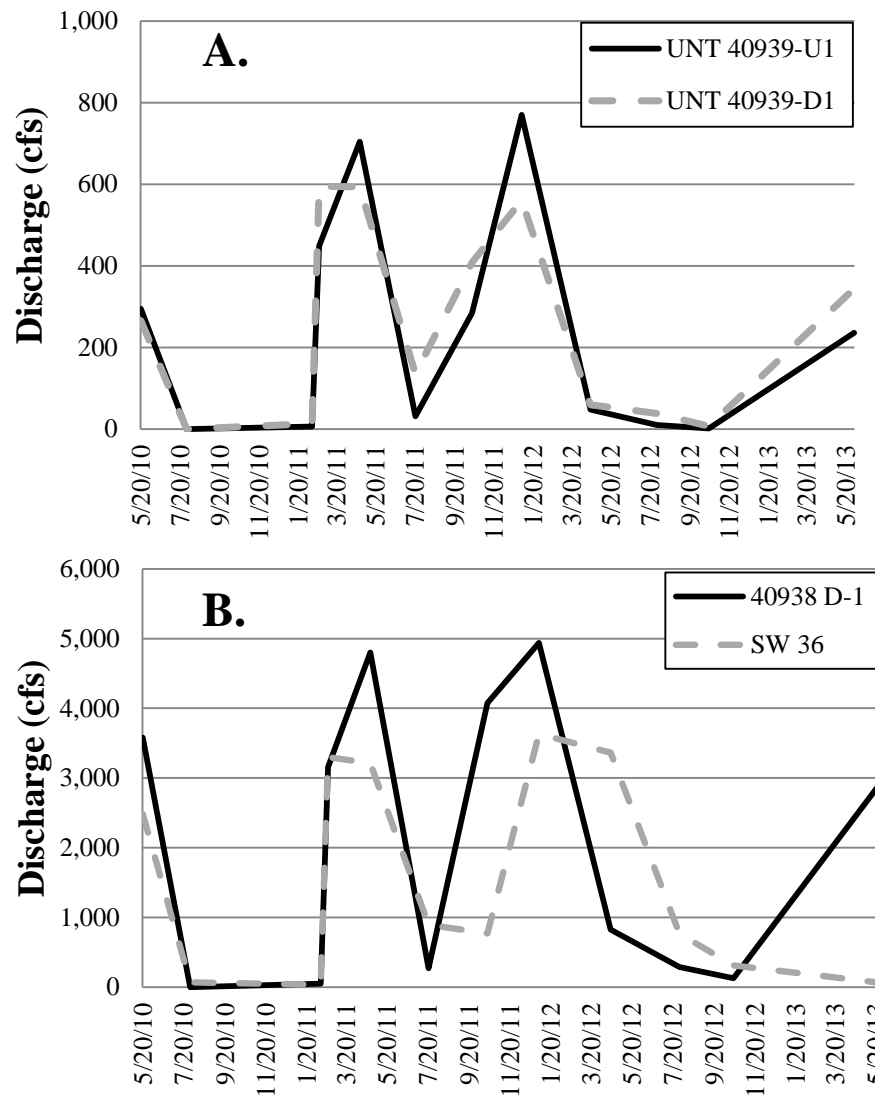


Figure VI-15. Comparison of HMR data between two tributary monitoring points (A) and two main stem Crafts Creek monitoring points (B) within the Crafts Creek watershed.

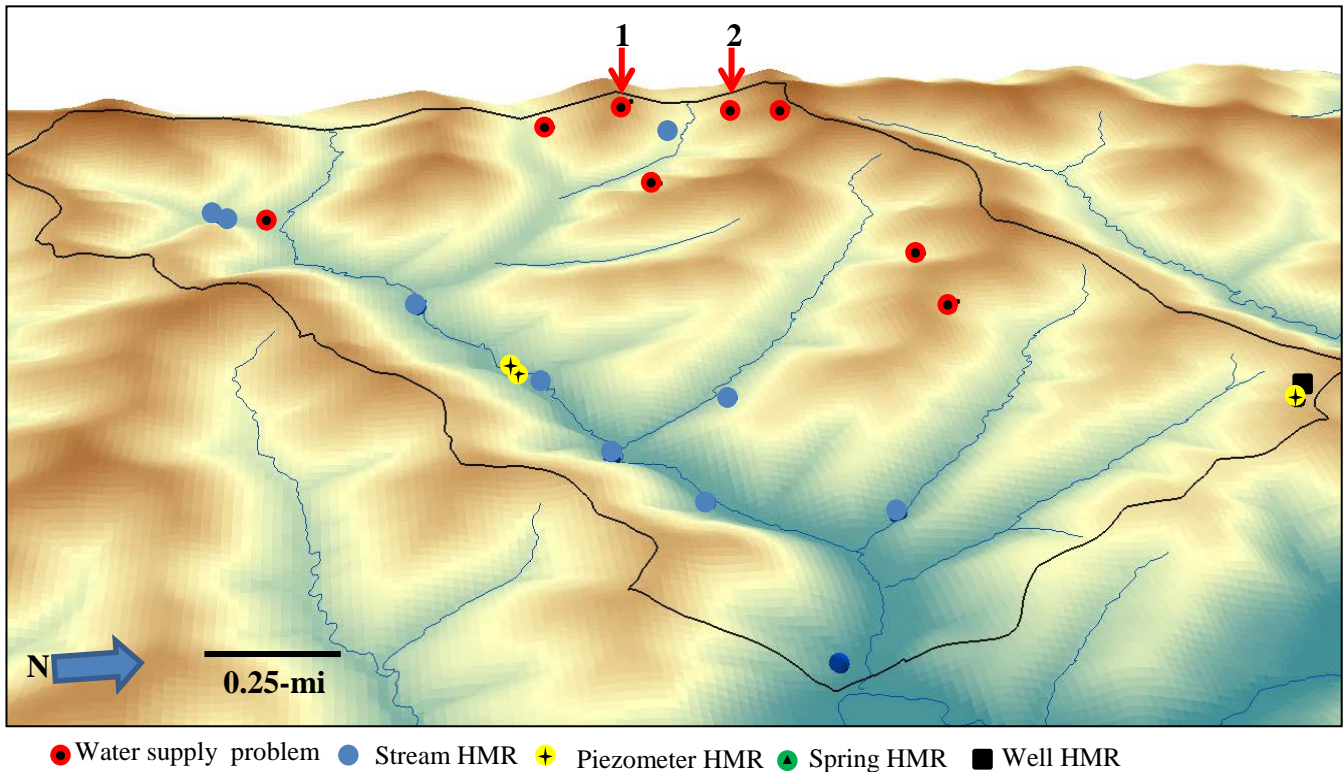
**VI.F.3 - Barneys Run**

Barneys Run, lying over the Bailey Mine, has eight reported effects to water supplies that have been recorded in BUMIS. Two of these may be hydrologically related to HMR point Bar-R3-02. Both water supply problems are within 0.1 and 0.2 miles of the HMR point:

- Reported Effect #1: Indicated by a #1 in Figures VI-16 and 17, SPRING108 experienced water loss according to BUMIS records on 29 June 2012. No final resolution indicated.



- Reported Effect #2: Indicated by a #2 in *Figures VI-16 and 17*, SPRING110 was noted in BUMIS to be dry. No final resolution has yet been indicated.



*Figure VI-16. Barneys Run watershed showing HMR points and water supply problems. Red arrows are the two water supply problems discussed in the text.*

Time since mining for both points is indicated in Figure VI-17. Both water supply problems were reported 29 June 2012, during time periods where low flow for the HMR point is typical and may represent seasonal fluctuations. The groundwater levels relative to these springs are challenging to determine from stream flow data.

## HMR monitoring point: BAR- R3- 02

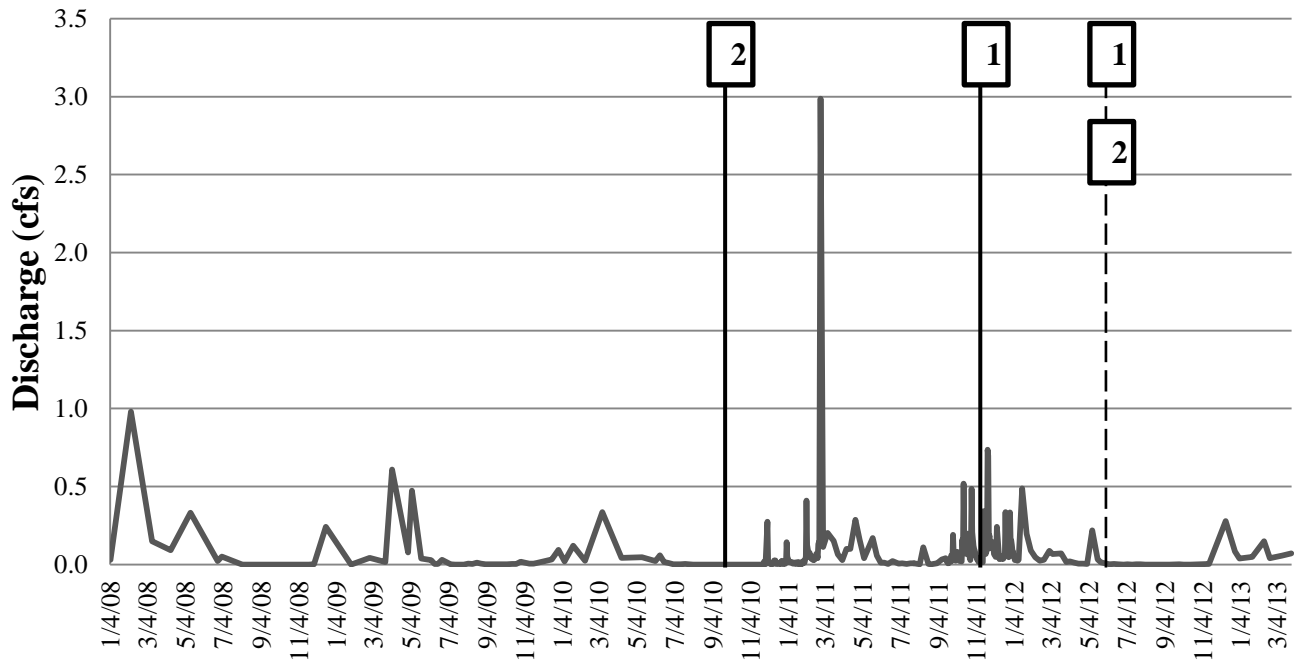


Figure VI-17. HMR monitoring point near the two Barney's Run water supply problems. The solid line with a number one indicates the date SPRING 108 was undermined (24 Oct 2011). The second solid line with a number two indicates the date SPRING 110 was undermined (27 Dec 2010). The dashed line represents the date given in BUMIS that both water supply issues were reported (29 June 2012).

### VI.F.4 - Blockhouse Run

There are two water supplies reported to be affected in Blockhouse Run that are close to HMR points. In the northern region of the Blockhouse Run watershed, an affected water supply is located 0.3-mi upstream from HMR piezometer 1305-105 PZ DS and 0.2-mi from a stream HMR point SW-15 (Figure VI-18). The affected water supply is labeled as both a spring and a well in BUMIS and the problem was reported as water loss to the spring on 29 Aug 2009. The nearby HMR spring data record begins on 14 Aug 2009 and has no recorded flow until March 2010 (Figure VI-19). Because there is only one HMR datum available before the reported effects, attribution to mining or seasonal water balance fluctuations is not possible. The nearby piezometer HMR data does not begin until one month after the reported effects and is not useful for assessing mining impacts on the nearby water supply. Also, based on available data, at the time of reporting the water supply had not yet been undermined. The closest mined panel to this point is 0.25-mi away and occurred 2-3 years after the reported problem. The BUMIS record indicates a final resolution status of "unspecified agreement" on 1 Nov 2010.

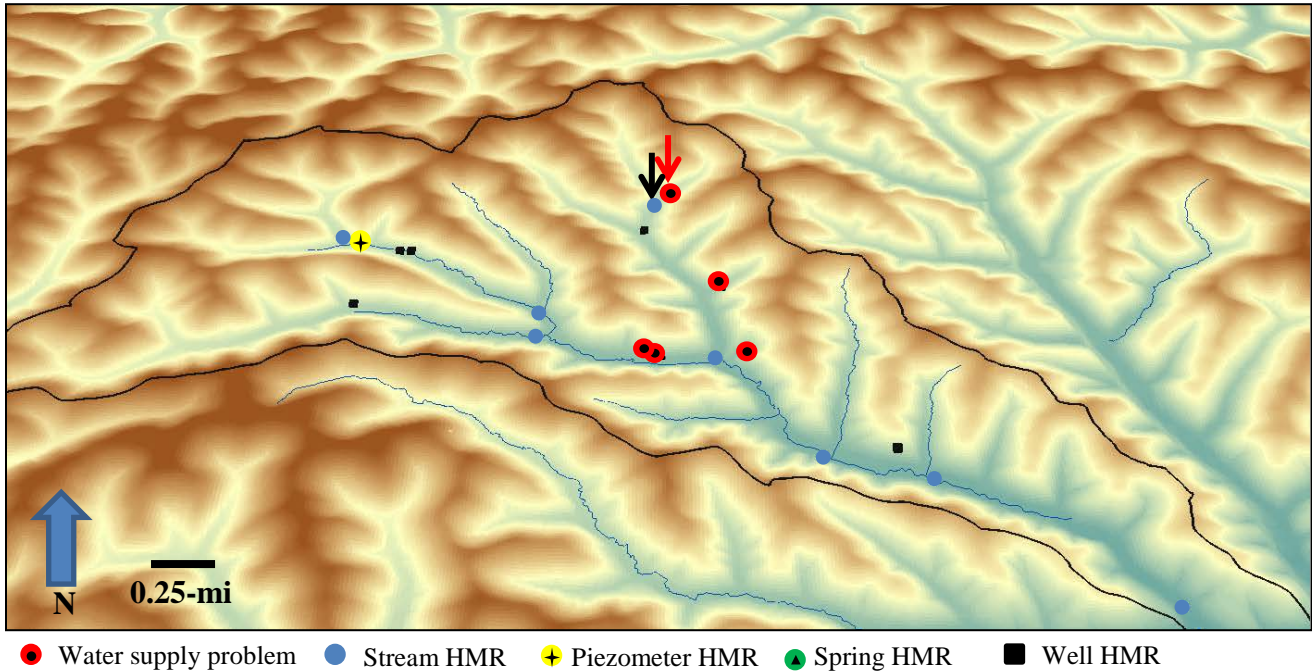


Figure VI-18. Blockhouse Run watershed showing HMR points and water supply problems. The red arrow is the water supply problem discussed in the text. The black arrow over the blue dot is the comparative stream HMR point SW-15.

### HMR monitoring point: SW-15

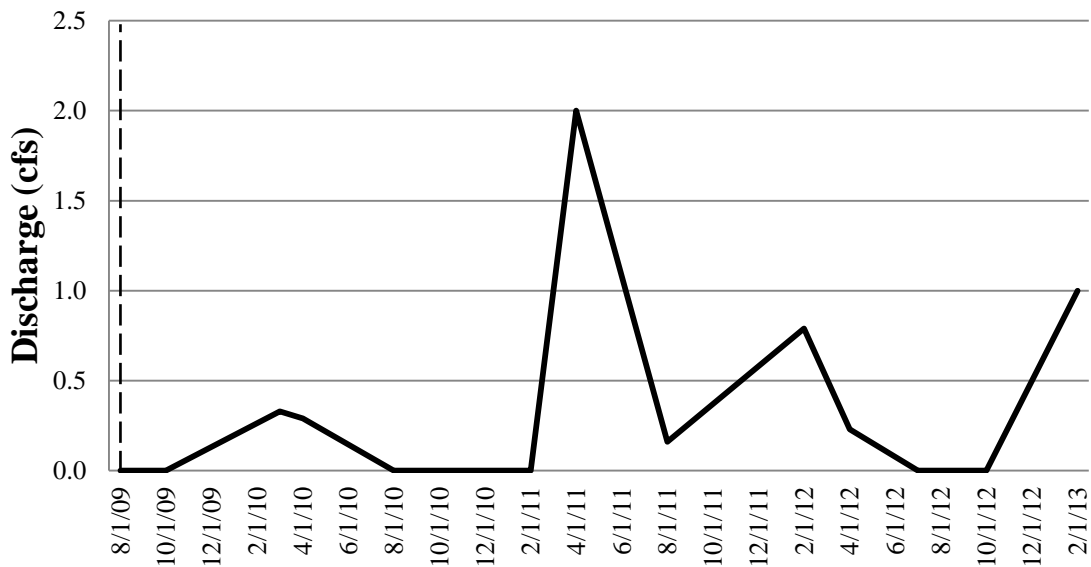


Figure VI-19. HMR monitoring point near a Blockhouse Run water supply problem. The dashed line represents the date given in BUMIS that the water supply issue was reported (29 Aug 2009). The HMR point has not yet been undermined.

### VI.F.5 - Pursley Creek

There are five water supplies with reported effects that are near HMR locations in the Pursley Creek watershed. The first impacted water supply is located in the southeastern part of the watershed and labeled “1” in Figure VI-20. It is 0.05-mi upstream from the stream HMR monitoring point S-77. The water supply type was not recorded in BUMIS, but is described as having diminished flow and therefore may be a spring. The diminishment in flow follows a peak in the flow data of S-77 (Figure VI-21). It is not clear if these two events are connected and are due to changes in the water table. No final resolution is indicated in BUMIS.

Three impacted water supplies are upstream from stream HMR point S-49 (Figure VI-22). The closest is 0.08-mi upstream, and the other two are 0.25-mi above the HMR point. The water supply problems are labeled “2”, “3”, and “4” in Figure IV-22. For two of the water supplies (#’s 2 and 3) the problem is described in BUMIS as “cloudy water” and recorded as contaminated with no known cause. Existing chemistry data for the HMR point indicates a large increase in total suspended solids, near the dates of the reported effects for the impacted water supplies (Figure VI-23). The final resolution of water supply issue #2 according to the BUMIS database was “No actual problem”, on 20 August 2013. A third water supply (#4) 0.25-mi upstream of HMR point S-49, is a well that experienced water loss on 7 July 2013 and coincides with a decrease in flow (Figure VI-24). Water supply problems #3 and #4 have no final resolution date.

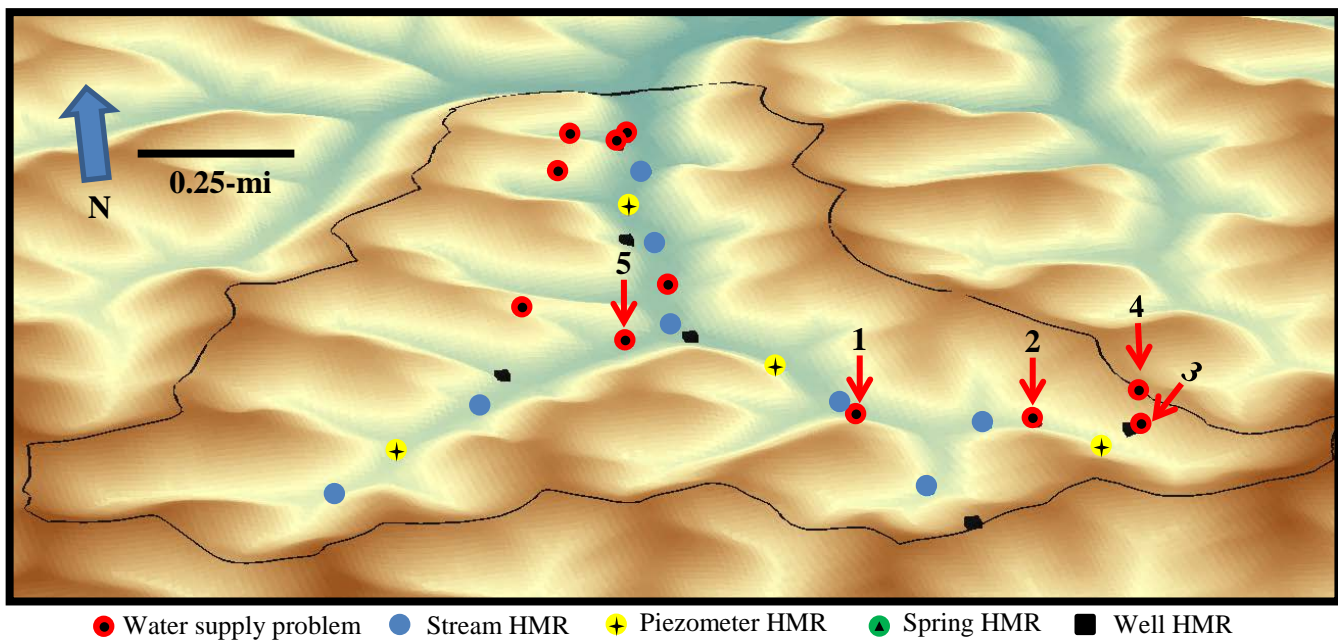
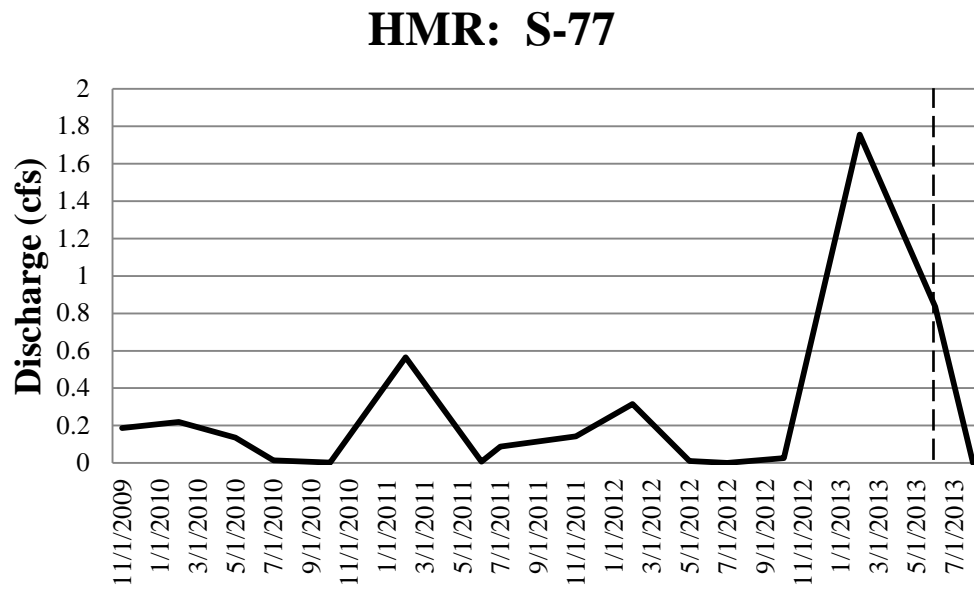


Figure VI-20. Pursley Creek watershed showing HMR points and water supply problems. The red arrows are the water supply problems discussed in the text.



*Figure VI-21. HMR monitoring point near a Pursley Creek water supply problem. The dashed line represents the date given in BUMIS that the water supply issue was reported (24 May 2013).*

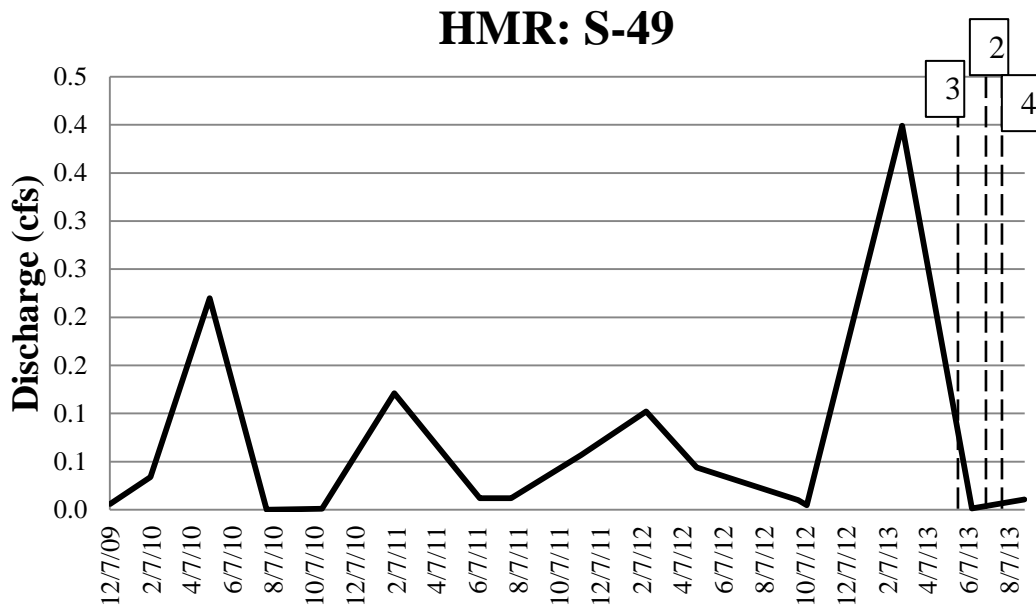


Figure VI-22. HMR monitoring point near a Pursley Creek water supply reported effects. The dashed lines represent the dates given in BUMIS that the water supply issues were reported: 2- 27 June 2013, 3- 17 July 2013, 4- 31 May 2013.

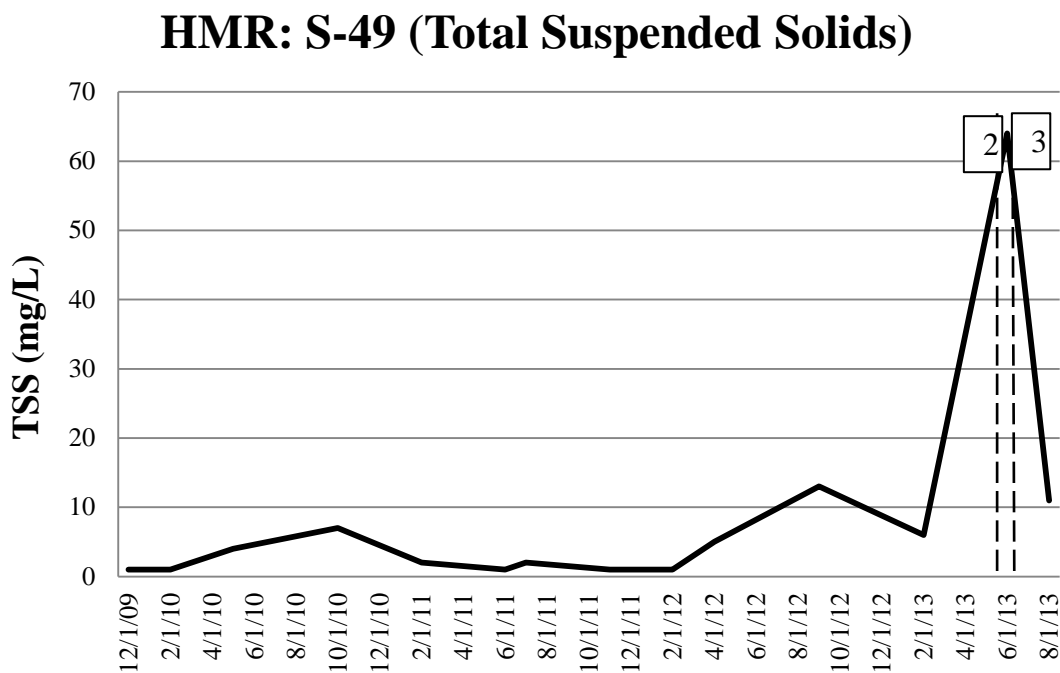


Figure VI-23. HMR monitoring point near a Pursley Creek water supply reported effects, displaying total suspended solids data. The dashed lines represent the dates given in BUMIS that the water supply issues (water contamination) were reported: 2- 27 June 2013, 3- 17 July 2013.

A fifth reported effect on a water supply is located in the southwest region of the watershed and is labeled “5” in Figure VI-20. It is 0.10-mi upstream of stream HMR point S-75. The affected water supply was reported on 1 December 2011 by the property owner (Figure VI-24) as having a funny taste and is labeled in BUMIS as contaminated. There is an increase in flow near the date the water supply reported effect occurred, but it is unclear whether the increase in flow is related to hydrologic changes due to mining in a nearby panel. HMR chemistry data for S-75 would help to elucidate changes to water taste in the impacted well, but does not exist until 26 April 2012. The final resolution was an unspecified agreement on 19 March 2013.

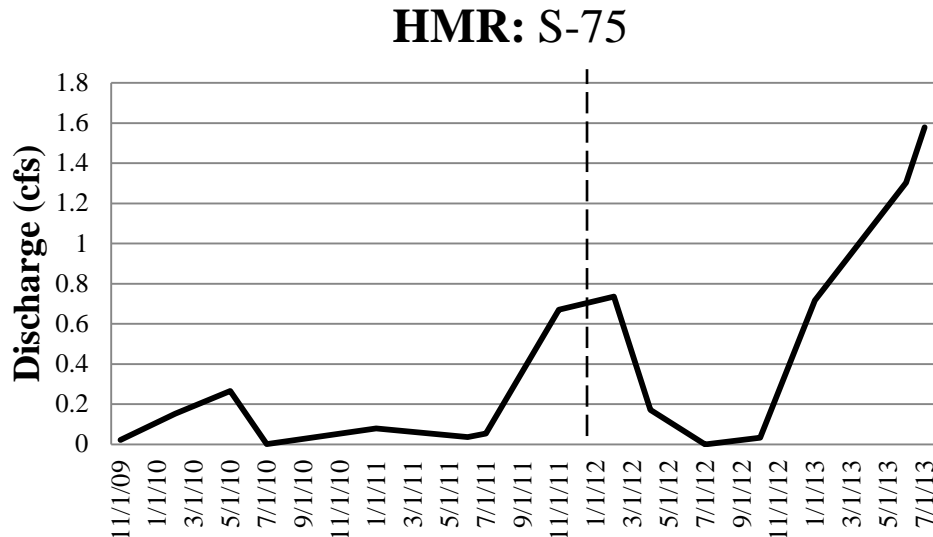
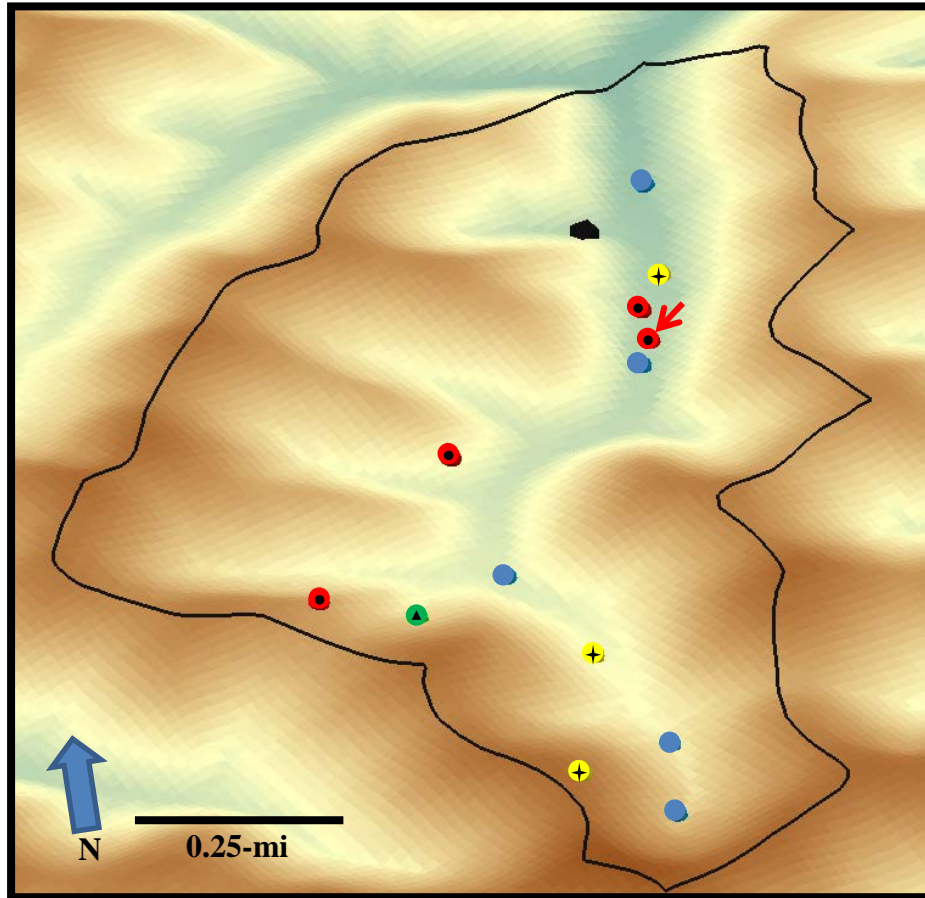


Figure VI-24. HMR monitoring point near a Pursley Creek water supply problem #4. The dashed line represents the date given in BUMIS that the water supply issue was reported (1 December 2011).

The Pursley HMR points and water supplies discussed in this section were not directly undermined via longwall mining during the 4<sup>th</sup> assessment period.

#### VI.F.6 - Turkey Hollow

There is one impacted water supply in Turkey Hollow that is 0.05-mi downstream of HMR point S-70 (Figure VI-25), reported on 14 June 2011. The reported effects in BUMIS are water loss and black specs in the water. There is a decrease in flow near the time of the reported effects and this may be related to diminished flow due to mining, as longwall mining took place in the underlying panel between 9 April 2011 and 3 December 2011 (Figure VI-26). However, there is also a similar dip in flow data at the same time in 2010 and 2012, potentially indicating seasonal effects. The final resolution is pre-mining agreement, with a resolution date the same as the date the problem was reported.



● Water supply problem   ● Stream HMR   + Piezometer HMR   ● Spring HMR   ■ Well HMR

Figure VI-25. Turkey Hollow watershed showing HMR points and water supply problems. The red arrow is the water supply problem discussed in the text.



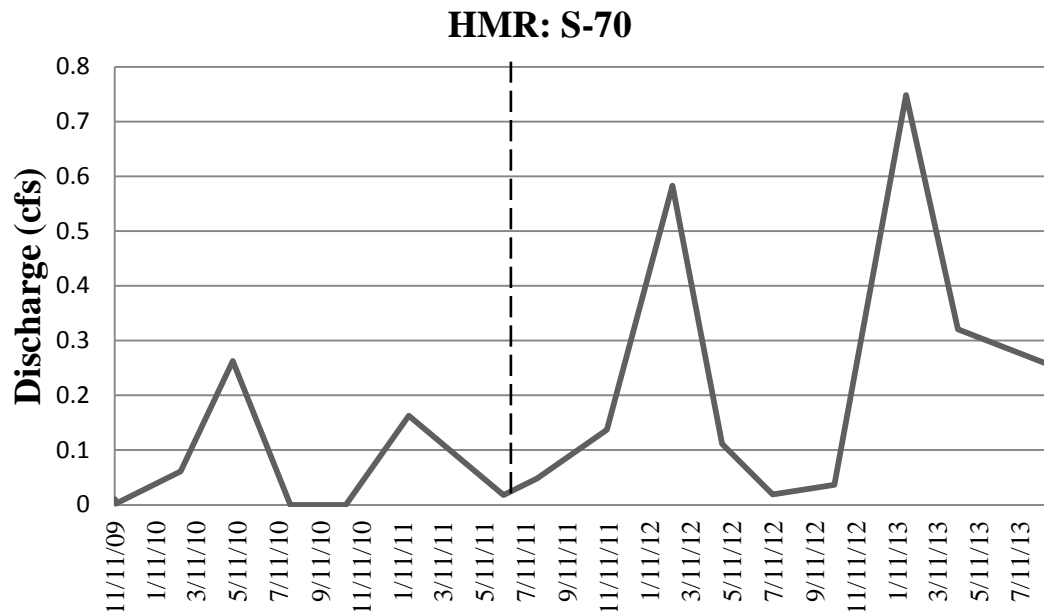


Figure VI-26. HMR monitoring point near a Turkey Hollow water supply problem. The dashed line represents the date given in BUMIS that the water supply issue was reported (24 June 2011).

### VI.F.7 - Roberts Run and Maple Run

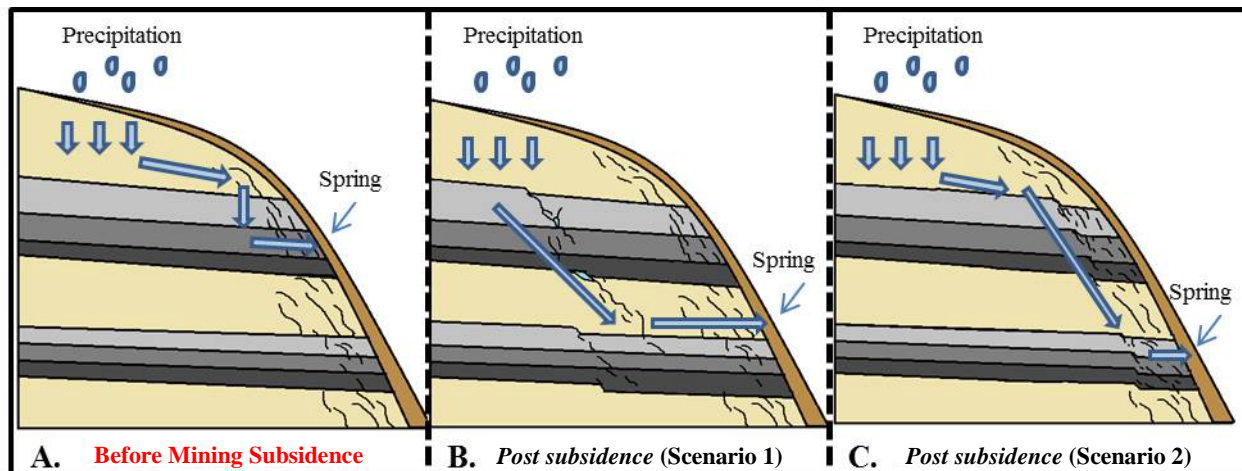
According to the BUMIS database, these watersheds do not contain any reported effects of mining on water supplies.

### VI.F.8 - Summary of Water Losses in Focal Watersheds

Overall, the analysis of affected water supplies relative to lowered water tables is challenging given the existing data. HMR data is spatial and temporally sparse. There are limited numbers of HMR points within each of the focal watersheds (Table VI-3). These watersheds were chosen in part due to their representativeness; therefore this is not likely a function of unlucky selection of study areas. Moreover, most HMR points with data are relatively distant from impacted water sources. Further, the low frequency of reported HMR data collection results in limited ability to garner insight as it is unclear from the reported quarterly HMR data whether the observed pattern of flow represents natural fluctuations or mining impacts to water supplies. A clear understanding of the role of groundwater in reported effects requires changes in the data collection regime.

## VI.G – Understanding Hydrologic Changes in the Hillslopes

Mining induced subsidence impacts vary with catchment size, so streams and aquifers located at relatively higher elevations (i.e., more headwaters environments) may be disproportionately impacted. Some have found valley bottoms to be relatively less impacted and hilltops more impacted (Leavitt and Gibbens 1992, Tieman and Rauch 1987). Even though impacts are potentially greater on the hillslopes, mining subsidence impacts on hillslope hydrology are poorly characterized compared to stream flow and ground water dynamics. For example, consider springs, hillslope locations where ground water flowing through the hillslope discharges to the land surface (Springer and Stevens 2008). Longwall mine subsidence can impair spring flow and may also result in the re-emergence of springs further down the slope (Figure VI-27). The redistribution of ground and soil water has the potential to impact human interactions with water beyond simple availability.



*Figure VI-27. Potential impacts of longwall mining subsidence on spring flow. A.) An original, un-impacted spring on a hillslope. Ground water drains in a step pattern down the hillslope. B.) In this first scenario a deep fracture alters hillslope drainage and changes the location of the spring further down the hillslope. C.) In a second scenario increased shallow fracturing of the hillslope surface diverts the spring further down the hillslope.*

The hillslope springs of southwestern Pennsylvania are numerous and support ecosystem components that are considered globally rare and threatened, as they provide a specific type of habitat for a diversity of organisms (Springer and Stevens 2008). Changes in spring hydrology can impact biota dependent in these spring systems. The diversion of shallow ground water away from the hilltops and hillslope shoulders can also result in reduced water availability to the surrounding forest through reduced soil moisture and reduced ground water access if levels drop below the rooting zones of trees (Figure VI-28). This increased dryness of the hillslope may reduce forest health and potentially magnify potential climate change impacts to forest ecosystems (Allen et al. 2010, Iverson and Prasad 2002).

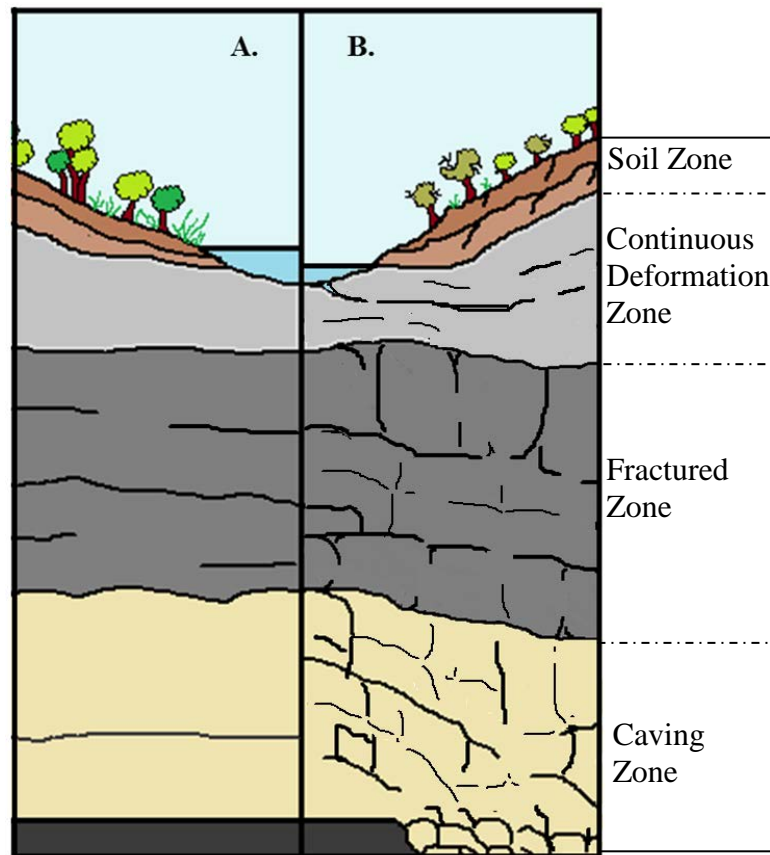


Figure VI-28. Modified Peng (2008) subsidence model before (A) and after mining (B), demonstrating how longwall subsidence impacts surface water and through surface water impacts potentially impacts forest ecosystems as well.

### VI.G.1 – Number of Monitored Springs vs. Actual Springs

Despite the potential importance of hillslope hydrological changes, very few springs are established as hydrologic monitoring points (Table VI-4). For the five longwall mines included in this assessment period, only 41 springs were monitored, and only five of these were actually undermined during this assessment period (Table VI-4). Moreover, these points are likely a small sampling of total number of springs present over longwall mining. For example, at an undisclosed mine in the northern Appalachian coalfield, monthly discharge data were examined for 77 undermined springs 12 months before and 12 months after the subsidence event (Silvis 2009). This study was able to identify significant impacts to the undermined springs, with 40% considered significantly impaired (Silvis 2009). Comparable data is not reported for the 4<sup>th</sup> Act 54 assessment period. Additional data collection is necessary to understand impacts to hillslope hydrology.

Table VI-4. Number of total spring hydrologic monitoring points vs. number of spring hydrologic monitoring points undermined in the 4<sup>th</sup> assessment period.

Mine	Total # of spring HMR points	Total # of spring HMR points undermined during the 4 <sup>th</sup> assessment period
Enlow Fork	15	2
Bailey	6	0
Blacksville 2	1	0
Emerald	17	2
Cumberland	2	1
<b>TOTAL</b>	<b>41</b>	<b>5</b>

### VI.H – Summary

The amount of data collected regarding hydrologic conditions as part of the coal mining permitting process is substantial (over 750 sampling stations and over 30 thousand samples collected from these stations). However, given the hydrologic complexity of the region and the resulting complexity in hydrologic response, the data, as reported, is insufficient to allow clear assessment of hydrologic impacts. With relatively minor changes in practice, the ability to apply data that is being collected can dramatically improve. Documentation of what should be reported and how it should be reported will make assessment easier and more accurate. Construction of data structures able to handle the variety and volume of data are essential to the actual use of the data. Adoption of simple quality assurance evaluation (e.g. is mass balance reasonable) would also make the hydrologic data better and therefore more useful. In addition to data improvements, data collection frequency and the spatial density of sampling both need to increase. The normal hydrologic variability in the region requires substantial data to allow clear separation of signal and noise and close spatial proximity to detect changes. Finally, the hydrologic balance of soil moisture, particularly in hillslopes overlying underground mining, is not sufficiently characterized to understand hydrologic changes following under mining.

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