SECTION 8: Groundwater

8.A – Overview

This section assesses the hydrologic data collected as a requirement of the coal mining permitting process in Pennsylvania, focusing on groundwater conditions above longwall mining. Groundwater and streams are impacted by longwall mining primarily due to subsidence induced fracturing (Booth 2006). The groundwater monitoring data provided to the University consists almost entirely of quarterly measurements of groundwater elevation and chemistry. These data are not sufficient to understand impacts that occur on timesteps less than quarterly. Therefore, analysis of the data, as they exist, explores the tight coupling between surface water and groundwater to examine changes in groundwater that occur over shorter time steps.

Subsidence due to underground mining interrupts the continuity of rock strata through deformation and fracturing, consequently altering surface topography (Peng 1992, Booth 2006). 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). Given most recently mined longwall panels are deeper than 500-ft in Pennsylvania (Section 3), a subsidence basin is expected to form at panel widths greater that 125-ft. Pennsylvania longwall panels tend to be greater than 1,000-ft wide, therefore subsidence basins are expected to form with every mined panel (Iannacchione et al. 2011, Tonsor et al. 2014). 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) (Figure D-1 in Appendix D and Figure 8-1).

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 D-1 in Appendix D). 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. Cracks may remain persistently open if located near or on the edge of the panel.

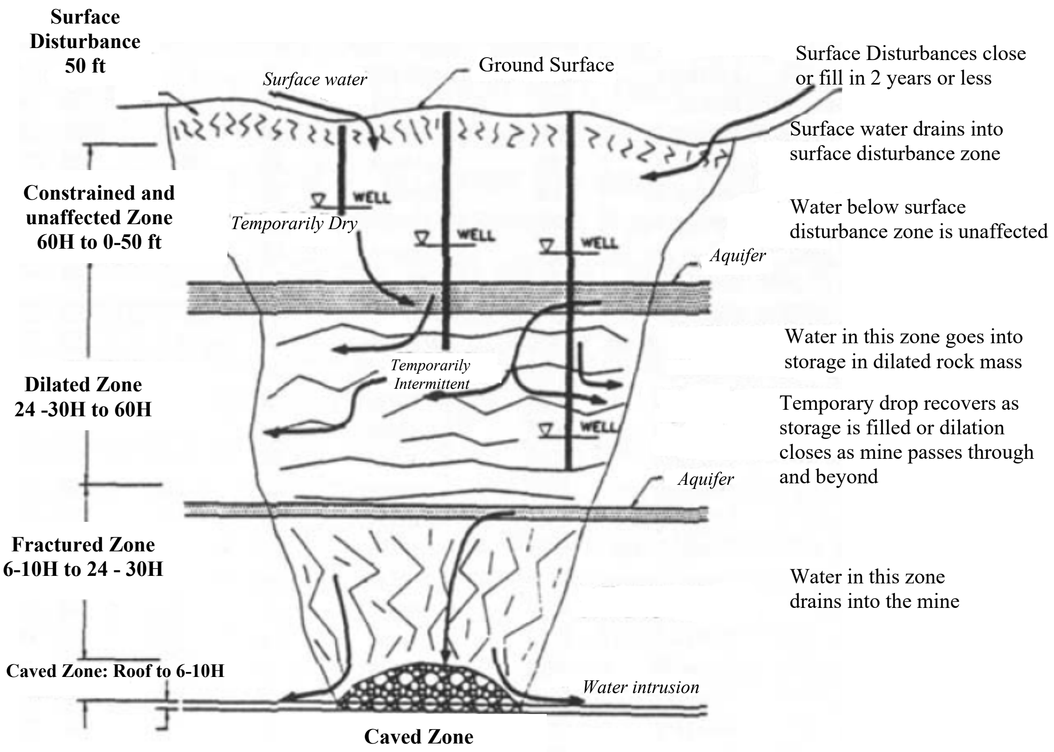

Figure 8-1. Overburden movement resulting from longwall mine subsidence and the 5 zones of overburden strata movement (Kendorski 2006). H = mining height. Note this is a conceptual diagram and not necessarily drawn to scale.

8.B – Groundwater and the Hydrologic Balance

To comply with the Pennsylvania Clean Streams Law, the mining regulations require “measures to be taken to ensure the protection of the hydrologic balance and to prevent adverse hydrologic consequences” (25 PA Code § 89.36(a)), discussed in Section 7 of this assessment report. The technical guidance document (TGD) for stream water protection “Surface Water Protection – Underground Bituminous Coal Mining Operations” (TGD 563-2000-655) is PADEP policy that provides directions for mine operators on how to comply with regulatory requirements to protect streams and to protect the hydrologic balance. For example, in the TGD the PADEP defines *mitigation* as “addressing adverse effects which may impair surface water quality.” For stream flow loss, mitigation includes “augmenting flow in stream segments that have experienced mining induced flow loss with appropriate quality water from a spring, horizontal well, artesian well, vertical pumping well, public water tap, water storage impoundment or other suitable source.”

PADEP guidance directs operators to prepare mining plans that provide for flow augmentation of sufficient quality and quantity to maintain the stream’s existing and designated water uses within 24 hours of a mining induced flow loss for areas where mining induced subsidence is likely to result in stream flow loss. Mining plans that have the potential to cause mining induced flow loss but do not pose a high probability of causing flow loss must provide a flow augmentation plan that would commence within 15 days of the occurrence of a mining induced flow loss. The regulations and the technical guidance document do not specify a measurement threshold for evaluating and predicting when mining plans are likely to result in flow loss. These determinations are made by the state on a case-by-case basis.

8.C - Water Sources for Stream Augmentation

When stream flow loss occurs, augmentation of streams commences generally from ground water or local public waters sources. Removal of substantial amounts of water to preserve flow can deplete groundwater aquifers and disrupt the hydrologic balance. Of 118 streams impacted by longwall mining and tracked in BUMIS during the 5th assessment period, 92 streams were augmented as indicated in BUMIS (Table 8-1). Of those augmented, 80 were augmented using wells or wellfields. Wellfields include a collection of wells and tanks that are connected with surface and buried pipelines that feed augmentation discharge points.

Of the twelve streams not augmented with wells, augmentation sources break down as follows:

- Four streams were augmented with frac tanks filled by water hauled by truck.
- 40452, Jackson Run was augmented using public water supply.
- 40592, Pursley Creek was augmented with both well and public water.
- 41814, Roberts Run was augmented from a pond filled with water hauled by truck.
- UNT 41741 R3 was augmented using stream water.
- 32618, UNT to North Fork Dunkard Fork was augmented using frac tanks filled with stream water.
- 41814 was augmented using water recirculated from a beaver pond downstream within the same stream.
- 32616, Whitethorn Run was augmented using well water hauled by trucks.
- 40447 was augmented from stream water with a pump at the confluence with Tenmile Creek.

In addition to the cases of augmentation with stream water, there are examples in BUMIS of agent observations of water being pumped from streams to tanks to later serve as augmentation if needed to maintain sufficient flow (water pumped from 32616, Whitethorn Run to augment UNT 32618 if needed). While these cases are not specified in the scope of work (Appendix L), they represent a case where the hydrologic balance may not be preserved and therefore "the natural, scenic, historic and esthetic values of the environment" may not be preserved. This is discussed in Section 11.

Table 8-1. Augmentations types by stream during the 5th assessment period.

Mine	PA WRDS Stream Code (BUMIS entry in parentheses if first-order tributary without WRDS Stream Code)	Stream Name	Augmentation Type
Bailey	32545	UNT to Barneys Run	well
Bailey	32554	UNT to Hewitt Run	well
Bailey	32594	North Fork Dunkard Fork	well
Bailey	32600	Kent Run	well
Bailey	32603	Polen Run	frac tanks
Bailey	32605	UNT to North Fork Dunkard Fork	well
Bailey	32616	Whitethorn Run	well and trucks
Bailey	32618	UNT to North Fork Dunkard Fork	frac tanks filled with stream water
Bailey	32620	UNT to North Fork Dunkard Fork	well
Bailey	NA (KR-3R)	UNT to Kent Run	well
Bailey	NA (NoF-14L)	UNT to North Fork Dunkard Fork	well
Bailey	NA (NoF-17L)	UNT to North Fork Dunkard Fork	well
Bailey	NA (NoF-18L,1R)	UNT to North Fork Dunkard Fork	well
Bailey	NA (NoF-19L,1L,7R)	UNT to North Fork Dunkard Fork	well
Bailey	NA (NoF-4.9R)	UNT to North Fork Dunkard Fork	well / tanks
Bailey	NA (PlnR-4L)	UNT to Polen Run	well
Bailey	NA (PlnR-6L)	UNT to Polen Run	well
Bailey	NA (PlnR-7L)	UNT to Polen Run	frac tanks
Monongalia County	41813	Roberts Run	pond filled via truck
Monongalia County	41814	UNT to Roberts Run	recirculated water from a beaver pond downstream in the same stream
Monongalia County	41815	UNT to Roberts Run	well

Mine	**PA WRDS Stream Code (BUMIS entry in parentheses if first-order tributary without WRDS Stream Code)**	**Stream Name**	**Augmentation Type**
Monongalia County	41823	UNT to Blockhouse Run	well
Monongalia County	41826	UNT to Blockhouse Run	well
Monongalia County	41834	UNT to Toms Run	well
Monongalia County	NA (TmsR-4L, 2R)	UNT to Toms Run	well
Cumberland	40592	Pursley Creek	well & public (city)
Cumberland	40615	UNT to Pursley Creek	well
Cumberland	41733	Bells Run	well and tank
Cumberland	41739	Tustin Run	well
Cumberland	41741	UNT to Tustin Run	well
Cumberland	NA (40615 L3)	UNT to Pursley Creek	well
Cumberland	NA (41639 L5)	UNT to Roberts Run	well
Cumberland	NA (41639 L6)	UNT to Roberts Run	well
Cumberland	NA (41733 R2)	UNT to Bells Run	well and tank
Cumberland	NA (41741 R3)	UNT to Tustin Run	stream water
Emerald	40447	UNT to South Fork Tenmile Creek	well
Emerald	40448	UNT to South Fork Tenmile Creek	well
Emerald	40452	Jackson Run	public
Emerald	40465	UNT to Smith Creek	well
Emerald	40466	UNT to Smith Creek	well
Enlow Fork	32777	Buffalo Creek	wellfield
Enlow Fork	32979	UNT to Buffalo Creek	wellfield
Enlow Fork	32980	UNT to Buffalo Creek	wellfield
Enlow Fork	32981	UNT to Buffalo Creek	wellfield
Enlow Fork	32983	UNT to Sawhill Run	wellfield
Enlow Fork	32984	UNT to Sawhill Run	wellfield
Enlow Fork	32986	UNT to Sawhill Run	wellfield
Enlow Fork	32987	UNT to Sawhill Run	wellfield
Enlow Fork	32990	UNT to Buffalo Creek	wellfield

Mine	PA WRDS Stream Code (BUMIS entry in parentheses if first-order tributary without WRDS Stream Code)	Stream Name	Augmentation Type
Enlow Fork	32991	UNT to Buffalo Creek	wellfield
Enlow Fork	32994	UNT to Buffalo Creek	wellfield
Enlow Fork	32996	UNT to Buffalo Creek	wellfield
Enlow Fork	32997	UNT to Buffalo Creek	wellfield
Enlow Fork	40285	Tenmile Creek	wellfield
Enlow Fork	40936	UNT to Tenmile Creek	wellfield
Enlow Fork	40947	UNT to Tenmile Creek	wellfield
Enlow Fork	40948	UNT to Tenmile Creek	wellfield
Enlow Fork	40952	UNT to Tenmile Creek	wellfield
Enlow Fork	40953	UNT to Tenmile Creek	wellfield
Enlow Fork	40954	UNT to Tenmile Creek	wellfield
Enlow Fork	40955	UNT to Tenmile Creek	wellfield
Enlow Fork	40959	UNT to Tenmile Creek	wellfield
Enlow Fork	NA (BufC-6.2L)	UNT to Buffalo Creek	wellfield
Enlow Fork	NA (BufC-7R)	UNT to Buffalo Creek	wellfield
Enlow Fork	NA (BufC-8L,2L,1L,3L)	UNT to Buffalo Creek	wellfield
Enlow Fork	NA (BufC-8R)	UNT to Buffalo Creek	wellfield
Enlow Fork	NA (BufC-9L,1L)	UNT to Buffalo Creek	wellfield
Enlow Fork	NA (BufC-9R)	UNT to Buffalo Creek	wellfield
Enlow Fork	NA (SawhR-3L)	UNT to Sawhill Tun	wellfield
Enlow Fork	NA (SawhR-3R)	UNT to Sawhill Run	wellfield
Enlow Fork	NA (SawhR-4L)	UNT to Sawhill Run	wellfield

Mine	PA WRDS Stream Code (BUMIS entry in parentheses if first-order tributary without WRDS Stream Code)	Stream Name	Augmentation Type
Enlow Fork	NA (SawhR-7R)	UNT to Sawhill Run	wellfield
Enlow Fork	NA (Sawhr-9R)	UNT to Sawhill Run	wellfield
Enlow Fork	NA (TenC-12L,2R)	UNT to Tenmile Creek	wellfield
Enlow Fork	NA (TenC-13L)	UNT to Tenmile Creek	wellfield
Enlow Fork	NA (TenC-14L, 1L)	UNT to Tenmile Creek	wellfield
Enlow Fork	NA (TenC-15L)	UNT to Tenmile Creek	wellfield
Enlow Fork	NA (TenC-16R, 1R)	UNT to Tenmile Creek	wellfield
Enlow Fork	NA (TenC-17L, 2R)	UNT to Tenmile Creek	wellfield
Enlow Fork	NA (TenC-17R, 1L)	UNT to Tenmile Creek	wellfield
Enlow Fork	NA (TenC-17R, 2L)	UNT to Tenmile Creek	wellfield
Enlow Fork	NA (TenC-17R,4R)	UNT to Tenmile Creek	wellfield
Enlow Fork	NA (TenC-8L, 1R)	UNT to Tenmile Creek	wellfield
Enlow Fork	NA (TenC-8L,2R,2R)	UNT to Tenmile Creek	wellfield
Harvey	40547	Patterson Creek	Well
Harvey	40552	UNT to Patterson Creek	well
Harvey	40561	UNT to Patterson Creek	well
Harvey	40562	UNT to Patterson Creek	frac tanks
Harvey	40565	UNT to Browns Creek	well
Harvey	40566	UNT to Browns Creek	well
Harvey	40567	UNT to Browns Creek	well
Harvey	NA (PatCr-11R)	UNT to Patterson Creek	frac tanks

8.C.1 – Augmentation in inaccessible streams

In Pennsylvania, the landowner owns both the stream (and access rights to it) and the streambed if they own the property on which the stream flows. If the stream bisects two properties, then each landowner owns to the middle of the stream. Thus, if the mine operator cannot obtain landowner permission to access the stream, then they cannot augment without trespass. There exist two examples of this problem recorded in BUMIS during the 5th assessment period.

Reaches of two streams (32985; 40552) were not augmented because landowners did not provide access to the mine operators for augmentation. The University recognizes the potential for landowners to create substantial challenges in the operator's effective and economic planning of mining, but also recognizes there are potential impacts to all citizens of the Commonwealth with the diminution of aquatic resources. The Commonwealth of Pennsylvania has not determined if failure to augment flow loss in streams due to access issues is an unacceptable impact to waters of the Commonwealth. Regardless, the University recommends that PADEP develop policy to minimize this situation. This solution may involve augmentation at points further upstream and may require more augmentation, but access issues are surmountable. For example, there was another instance described in BUMIS where a landowner did not provide access to augment (and the stream went dry), but the mine operator had permission to access and augment from a neighboring property.

8.D – Hydrologic Monitoring of Groundwater

The PADEP requested an evaluation of the groundwater data to determine adequacy and usability. The most consistent and voluminous sets of data are the groundwater elevations reported in the HMRs. Other than pre-mining background sampling of wells and springs required as part of the permit process, the University was not provided with other groundwater data, nor were data discovered as part of the analysis process. Therefore, to evaluate the completeness and adequacy of the groundwater data, the University will focus on these data in this section. In this section the University assumes the data are accurate, as determination of data quality is beyond the scope of this assessment.

After accuracy, the most important question in the evaluation of the data is adequacy. Accurate, but inadequate, data can preclude answering of the relevant question. In Appendix F the University has plotted the time series of groundwater hydrologic monitoring points with more than 8 records that were undermined or close to areas undermined during the 5th assessment period. These data are summarized in Table 8-2

Data are summarized in Table 8-2 as follows: If groundwater levels remain consistent before and after undermining, these records are called "No Change." Cases where undermining occurred early or late in the assessment period are "Insufficient Data" as water levels prior to undermining or after undermining are not available for comparison. In the remaining data, two responses were observed, either increased water level elevations or decreased water elevations. These changes can occur one to two quarters before undermining ("pre-mining"), in the same quarter as undermining ("coincident"), or one to two quarters after undermining ("post-mining").

Table 8-2. Water level responses observed in HMR time series with at least eight points from all undermined HMR points in the 5th assessment period.

Water level response to undermining		Number of piezometers/wells
No Change		3
Decreased Elevation	pre-mining	11
	coincident	4
	post-mining	9
Increased Elevation	pre-mining	1
	coincident	5
	post-mining	2
Insufficient Data		11

Potential impacts to groundwater systems are challenging to identify in the HMR data. The numerous impacts to water supplies (see Section 5) indicate groundwater systems are affected by mining. However, many water supply impacts are due to damage to well casings and the actual changes in water elevation are not clearly documented. The HMR data provide more specific information about changes in groundwater levels. Observed changes in water table do not seem to result from seasonal changes in water balance (i.e., the change persists across seasons). Yet, a connection of observed changes to mining is not clear in many cases. For example, a large number (11) of the decreases in elevation occurred a substantial amount of time before undermining. Determination of these cases is beyond the scope of this assessment. Undermining of adjacent panels would be a logical explanation, however, one such change is synchronous across many wells (occurring in early 2017), so a local effect is not certain.

Of the forty-three piezometers where a change in water level was observed, twenty-three occur at periods separate from undermining or do not have enough data to identify a change. This discrepancy diminishes an ability to tie changes in groundwater level to undermining, as it is challenging to rule out coincident causes independent of mining. It is not clear how to assure a water level change coincident with mining is due to mining if water level fluctuations occur predominantly during periods when mining is not active.

Examination of subsidence effects on groundwater systems requires more frequent data collection. Surface water flow is monitored daily for two weeks before undermining occurs. There is no equivalent requirement for groundwater monitoring during this period. With the widespread availability of logging water level recorders, collection of this additional data will not create substantial work. In fact, during site visits, the University commonly observed the installation of water level recorders in piezometers. The University recommends that groundwater elevations in piezometers and wells being undermined be monitored at least at frequencies comparable to measurements of surface water flow, and ideally much more frequently. With these additional data points, the influence of mining related influence can be determined more accurately.

Finally, in the technical guidance, there is no formal description of the characteristics of an impacted aquifer storage system. In terms of stream impacts, there can be pooling or flow loss. Flow loss and recovery is evaluated by comparing ranges of flows. There is no equivalent definition of an impacted aquifer. Nor is there a timetable specified for the repair of groundwater impacts. Streams are to be repaired within six years. The University recommends the PADEP define how to determine if a groundwater aquifer is impacted and the time frame for implementation of necessary remediation. If PADEP takes this step, then evaluation of this remediation could include comparison of consistent changes in surface water flow and groundwater conditions, clarifying the success of both.

8.E – Comparison of HMR data with Regional Gage Data to Understand Groundwater Dynamics

One of the challenges in HMR data analysis has been comparing flow conditions among hydrologic monitoring points and in undermined streams. Most hydrologic data are collected in a "milk run" fashion. That is, there is a day's worth of measurements laid out across a mine, and once every three months the circuit is made to collect data at each point. This collection is not necessarily synced with the monthly/weekly/daily measurements taken before undermining. Most longwall mines are large enough that all sampling locations cannot be collected in a single day. So, quarterly HMR data from within a mine are not synchronized and comparison of monitoring flows with flow monitoring during the undermining period is difficult or impossible given variability from day to day. Further, the choice for data collection date is not consistent among mines, so even mines that are close (e.g., Cumberland and Emerald or Bailey and Harvey) cannot be evaluated together. These asynchronous sampling dates limit assessment of flow conditions and therefore associated groundwater dynamics from the HMR datasets. However, during the 5th assessment period the USGS expanded their stream gage network in southwest Pennsylvania to include small drainage gages. In this section, the University examines the potential for using the new USGS stream gage data to clarify changes in the HMR that are difficult to detect because of the infrequent sampling and range of flow dominated by storm flows.

8.E.1 – USGS Stream Gage Networks during the 5th Assessment Period

In 2014, the United States Geologic Survey (USGS) expanded their network of stream gages in southwestern Pennsylvania and established more gages to record stream flow in Washington and Greene County (Figure 8-2 and Table 8-2). The analysis completed by the USGS on these new gages is documented in Hittle and Risser (2019). In this report, the University uses the USGS data in conjunction with the HMR data to try to detect deviations in low flow from regional flows and therefore reveal impacts to underlying aquifer systems (methods are summarized in Appendix H).

Table 8-2. USGS stream gages used in the hydrologic analyses. Gages include the watersheds from USGS's small watershed study in additional to the longer-term gaging stations that have been running for decades on the major streams.

	USGS Gage	Name	Period of Record	Drainage Area (sq. mi)	State	County
1	USGS 3072000	Dunkard Creek at Shannopin, PA	1/1/41 - present	229	Pennsylvania	Greene
2	USGS 3072655	Monongahela River near Masontown, PA	1/1/39 - present	4,440	Pennsylvania	Greene
3	USGS 3072890	Fonner Run near Deer Lick, PA	10/18/14 – 2/28/2017	0.99	Pennsylvania	Greene
4	USGS 3073000	South Fork Tenmile Creek at Jefferson, PA	10/1/31 - present	180	Pennsylvania	Greene
5	USGS 3111200	Dunkle Run near Claysville, PA	10/18/14 – 3/20/2018	7.7	Pennsylvania	Washington
6	USGS 3111235	Unnamed tributary to Dog Run at Dunsfort, PA	5/12/15 – 3/27/2017	0.28	Pennsylvania	Washington
7	USGS 3111675	Job Creek at Delphene, PA	9/25/14 – 10/19/2019	6.57	Pennsylvania	Greene
8	USGS 3111705	South Fork Dunkard Fork at Aleppo, PA	10/18/14 – 4/26/2019	8.14	Pennsylvania	Greene
9	USGS 3111890	Middle Wheeling Creek near Claysville, PA	12/12/14 – 2/22/2017	1.24	Pennsylvania	Washington
10	USGS 3111955	Wheeling Creek near Majorsville, WV	1/6/12 – 4/24/2018	152	West Virginia	Marshall
11	USGS 3112000	Wheeling Creek at Elm Grove, WV	10/1/40 - present	281	West Virginia	Ohio

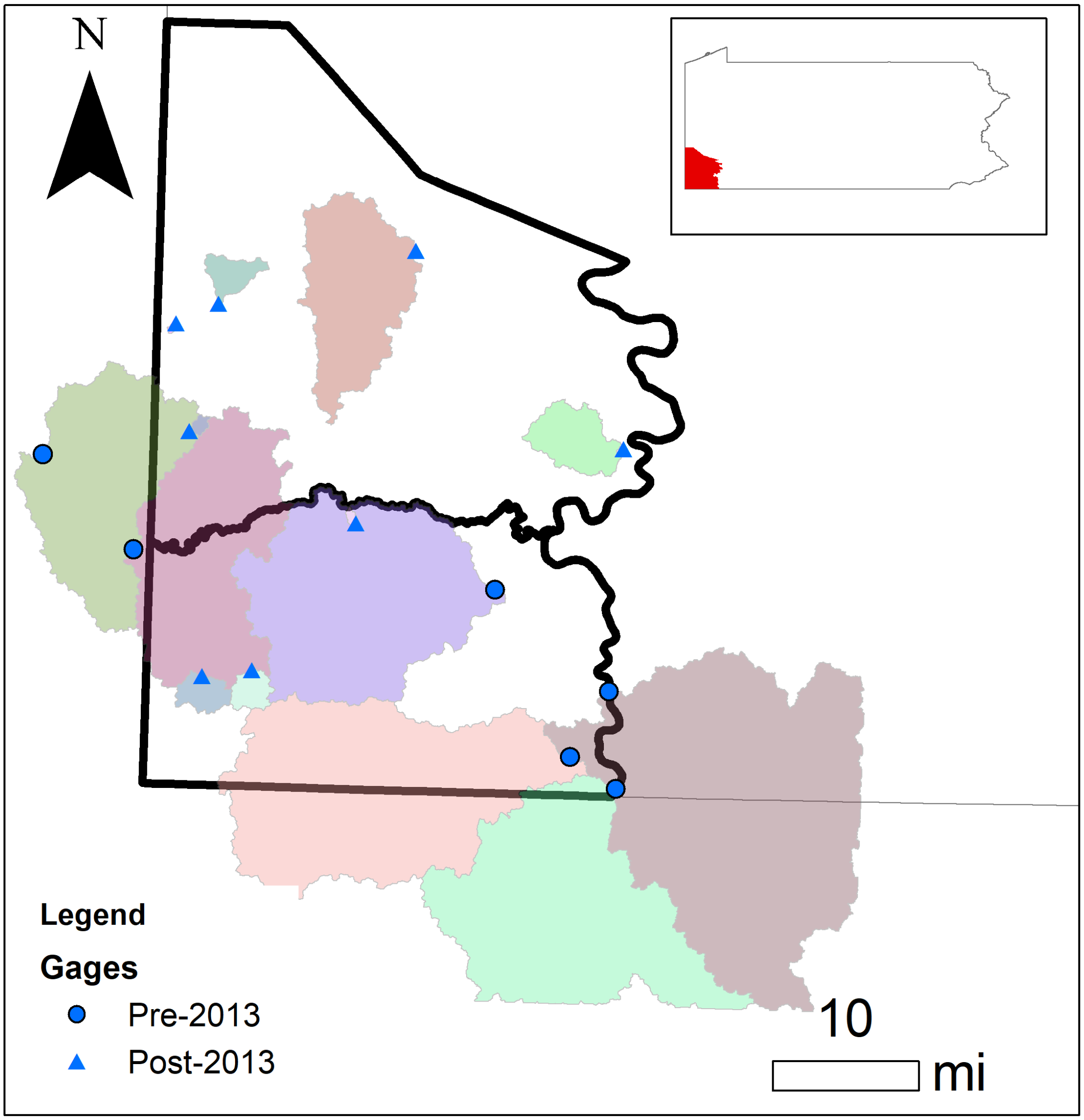

Figure 8-2. The distribution of USGS stream gages across Southwestern Pennsylvania and parts of West Virginia. Gages denoted with a circle were installed prior to the 5th assessment period whereas gages represented by a triangle were installed during this assessment period.

8.E.2 – A yield ratio approach to evaluation of HMR data

The use of the yield ratio allows comparison of flow at an HMR point to regional flow status using USGS flow data. These methods are detailed in Appendix H. Two watersheds were examined over the Emerald Mine: Smith Creek Watershed and Sugar Run Watershed. The yields from these watersheds were compared to the South Fork Tenmile Creek, Dunkle Run, and Unnamed tributary to Dog Run stream gages as described in Appendix H.

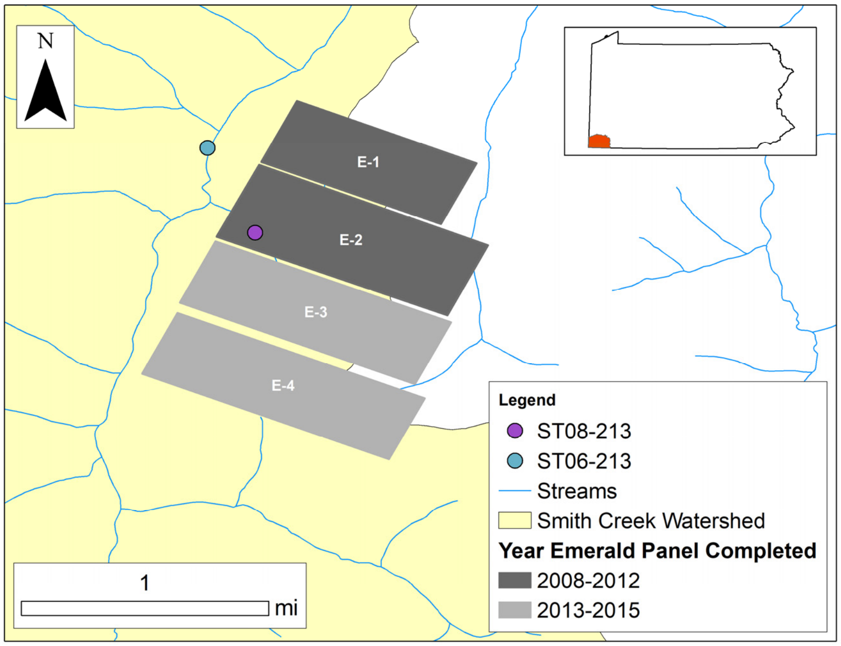

Figure 8-3. Map of the Smith Creek watershed showing the monitoring points ST06-213 and ST08-213. The Smith Creek watershed was undermined by the E panels between 2012 and 2014.

The Smith Creek watershed was undermined between 2012 and 2014 by the Emerald E-panels (Figure 8-3). Hydrologic monitoring points ST08-213 and ST06-213 measured discharge in Smith Creek and its tributaries during the assessment period (Figure 8-4). Monitoring point ST08-213 was undermined in 2012 by the E-2 panel. Downstream from this monitoring point is ST06-213 which was not undermined but drains these undermined upstream areas.

Further upstream in the Smith Creek watershed are the E-3 and E-4 panels which were mined between March 2013 and April 2014 (Figure 8-3). Mining occurred in the headwaters of UT 40466 (monitored by ST08-213) during January 2014. Data are unavailable for both ST08-213 and ST06-213 between January 2014 and February 2014. Therefore, changes in yield immediately following mining are not possible. On a quarterly basis however, data variability is predominantly driven by stormflow. One extreme discharge measurement at ST06-213 (2,162 cubic feet/sec) was removed from the record to allow visualization of HMR yields (Figure 8-4).

Yield from the monitoring point ST06-213 is, on average, larger that the yield at the three comparative stream gages (i.e., the yield ratio is greater than one) for most of the monitoring period before 2015. Yield from the watershed decreases after December 2014 with 50 % of the monitoring dates having no measurable flow. Given the arrangement of mining in the watershed, determination of cause is not simple (i.e., the monitoring point is distant from the mining activity). However, it also seems that this HMR point records substantial flow loss, even in a stream that seems to have yields larger than regional yields during pre-mining periods. This yield has not seemed to have returned by the end of the assessment period. The comparison of HMR yields with regional yields, validated by use of the USGS small stream data (Hittle and Risser 2019) provides a means to evaluate the HMR data in context.

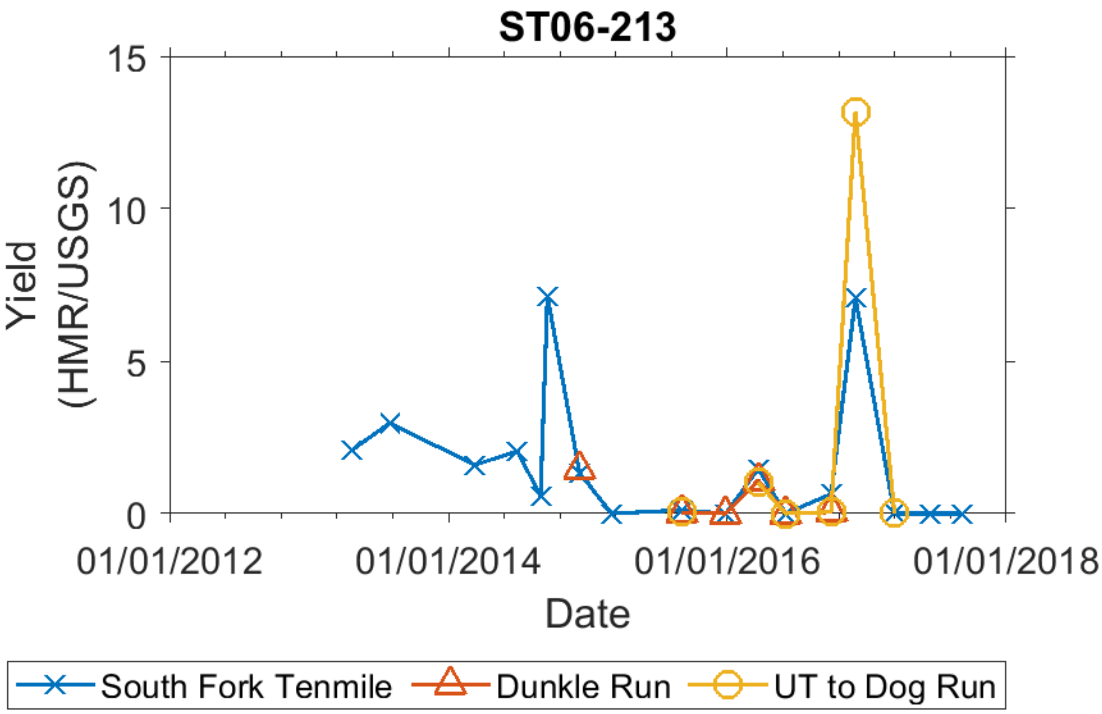

Figure 8-4. Time series of the yield ratio of ST06-213 i.e., the HMR monitoring point yield, normalized by the respective USGS gaging station record on the same days. One extreme flow (2,162 cubic feet/sec 2013) was removed to allow visualization of yield.

One important aspect of this analysis is the demonstration of how vulnerable small headwaters streams are to flow loss in southwest Pennsylvania. Hydrologic monitoring point ST08-213, when compared to the USGS stream gages, is a small fraction of the expected regional yield (i.e., the yield ratio is less than one) for most non-storm portions of the record (Figure 8-5). This means that this stream consistently generates less surface flow than regional systems, even at the scale of a small watershed. So, any flow loss impacts occurring in small headwaters streams have a disproportionate impact on these streams.

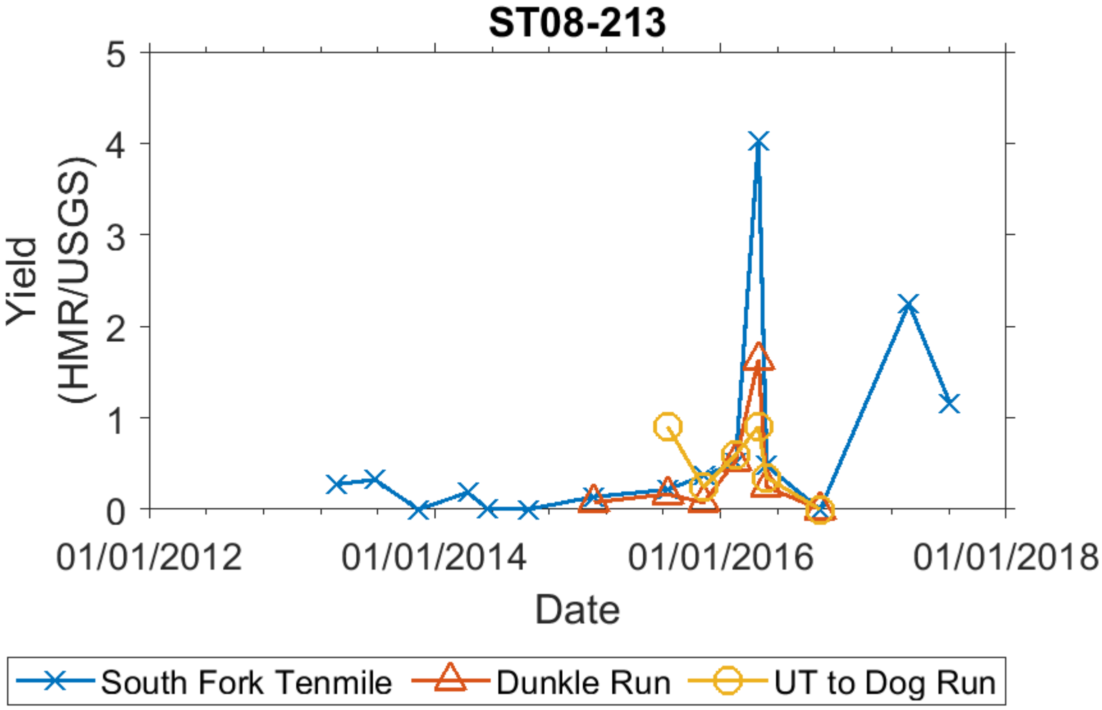

Figure 8-5 Yield from the ST08-213 HMR monitoring point compared with flow from three USGS gaging stations on the same days using a yield ratio approach.

The Sugar Run watershed was undermined by the E-1, E-2, E-3, and E-4 panels between 2012 and 2014 (Figure 8-6). During the 5th assessment period, the E-3 panel undermined the watershed between August and October 2013. Upstream of the E-3 panel is the E-4 panel, which undermined the headwaters of the Sugar Run watershed in April 2014. Hydrologic monitoring point SW-30, downstream of the E panels, recorded discharge throughout mining (Figure 8-7).

Between 2008 and 2018, yield at monitoring point SW-30 was less than the USGS monitoring gages for the majority of the available record. So, during the mining period, yield at SW-30 was consistently lower than yield at the South Fork Tenmile Creek stream gage (Figure 8-7). However, after 2016 and the completion of mining, the yield ratio grows more variable, ranging between zero and one. This variability is captured in all three gage records, providing additional credence to the observation. Increases in baseflow are consistent with increased water storage in riparian aquifers.

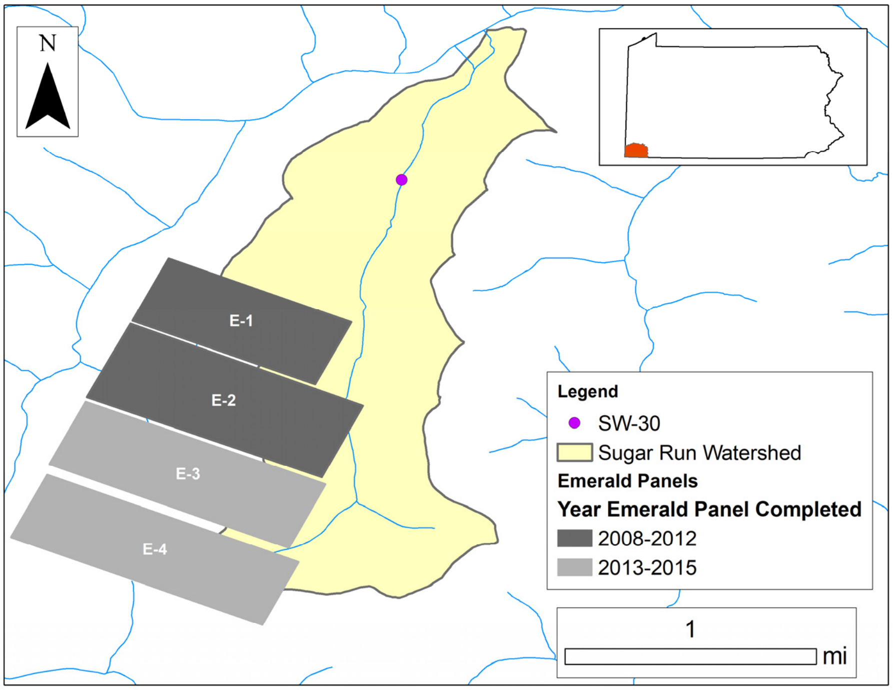

Figure 8-6. Map of the Sugar Run watershed showing monitoring point SW-30. Sugar Run watershed was undermined by the E panels between 2012 and 2014.

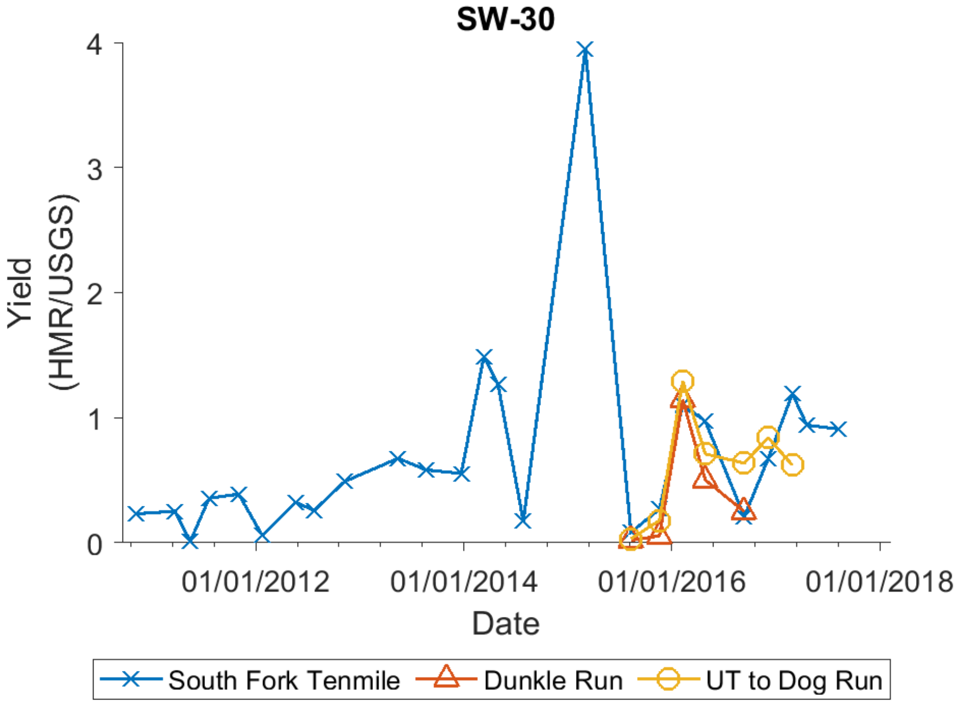

Figure 8-7. Yield ratio of the SW-30 HMR monitoring point. HMR yield normalized by the respective USGS gaging station on the respective sampling days.

These analyses reveal several insights about surface water HMR data:
- Yield ratios are sensitive to low flow changes and can identify shifts in yield that deviate from regional hydrological status (Figure 8-7).
- Yield from small headwater streams is sometimes smaller than regional yields, indicating these streams are not only sensitive because of flow volume, but also sensitive because of the proportional amount of water these streams yield.
- The small gage data are limited temporally, yet, they provide evidence comparisons with larger streams are valid in the evaluation of flow in small streams. That is, both small and large gage records generated consistent relative yield values.

These changes in flow are linked to important shifts in groundwater. If flow is lost, then an aquifer is likely receiving additional water input. If that aquifer is downstream, then discharge to surface water is smaller. If that aquifer is upstream, then discharge to surface waters increases. These HMR surface water data provide a window into general groundwater impacts following subsidence.

8.F – Summary

Groundwater HMR data are collected too infrequently to link observed changes in groundwater to mining activity. Piezometers that are damaged by subsidence but not replaced create incomplete records that do not provide a contrast between pre- and post-mining conditions. To clarify groundwater impacts, there may need to be additional piezometers and/or more frequent sampling of these sites.

The abundance of surface water data generated for evaluation of stream recovery provide some opportunities to infer changes in groundwater storage. More comprehensive evaluation of groundwater impacts can allow additional insight into how subsidence impacts to stream and groundwater degrade the hydrologic system (Appendix G). For example, surface water data, collected much more frequently than groundwater data, provide context and potentially clarify impact and recovery in processes that occur in periods shorter than quarterly. In addition, the small basin flow data collected by the USGS provides an opportunity to develop regional water status information that can be used to normalize observations made to meet Act 54 and increase monitoring sensitivity to geohydrologic change.

Finally, the water sources for 92 augmented streams were identified, mostly drawing water for augmentation from groundwater. In this analysis, four streams were augmented with stream water, sometimes from the same reach, which can be a problematic approach, in terms of water accounting. Further, there is no good solution for cases where mine operators cannot obtain access to augment streams. These streams, when impacted, remain dry.

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