APPENDIX H: Yield Ratio Comparison Methods

H.1 - Comparisons among gages in the USGS Stream Gage Network

Available USGS data vary among gaging stations and can include stage, instantaneous discharge (15-minute interval), and daily averages. Daily discharge data (the average of all the streamflow data for the day) are used for comparisons among the gages in this analysis. Averaging daily data smooths storm responses if flow varies over periods shorter than a day (i.e., the storm flow peak is smoothed across the day). However, flow loss impacts are most important at low flows, and analytical approaches should be sensitive at low flows. The USGS gaged watersheds draining southwestern Pennsylvania range in size from <1 square mile to 4440 square mile (Table 8-2). This large range in drainage area makes comparisons of simple discharge difficult as bigger drainage areas, by definition, produce bigger flows. Therefore, the daily discharge data for each stream gage (https://waterdata.usgs.gov/nwis) were normalized, dividing the discharge by the watershed area to produce water yields and enable "apples to apples" comparisons among streams.

From the USGS discharge records, the University compared gages to select gage records representative of regional streamflow. Each gage yield was systematically compared to the other gages. For each gage pair, daily yield values were plotted against each other and compared with the one to one line. If precipitation is uniform across both watersheds and the hydrology of the watershed is similar, the yield in both basins should be similar and therefore plot near the one to one line (Figure H-1A). Individual points that deviate from this one to one line are cases where flow in one basin is either lower or higher than the comparison gage. For example, data plotting above the one to one line indicate that yield in South Fork Tenmile Creek is proportionately higher than Job Creek at low flows (Figure H-1B).

Deviation from the one-to-one line can occur as a result of both natural and human-made factors. For example, dams and other flow control measures that maintain flow in a stream can lead to enhanced base flows as storm flow is captured and released slowly according to management plans. Differences in watershed land-use can also alter streamflow patterns, as impervious surfaces such as roads can accelerate runoff. Natural factors such as the size of the aquifers feeding low flows can lead to differences in yield. Larger aquifer systems store more water and can sustain larger and more stable yield longer than streams fed by smaller perched and strata aquifers.

Each small watershed in the USGS network (<10 sq. mi in Table 8-2) was compared against the other small watersheds (Table H-1). Gages were evaluated based on the slope of the data fit and the strength of association (R2) value. Job Creek (avg. slope = 0.68) and South Fork Dunkard Creek (avg. slope = 0.58) had substantially smaller low flows when compared with the other small basin gages (Table H-1). Given this, gage records with relatively higher low flows were chosen to be conservative in subsequent analysis as use of lower flow streams in comparison with impacted streams would obscure impacts. The Fonner Run flow record was noisy relative to the other stream gages (avg. R2=0.64). Therefore, the gages the University chose as representative of regional small drainage water conditions are Unnamed tributary to Dog Run (avg. slope =

0.88, avg. R2=0.72) and Dunkle Run (avg. slope =1.06, avg. R2=0.70). Middle Wheeling Creek (avg. slope =0.61, R2=0.79) was also considered but its average slope deviated further from one than Unnamed tributary to Dog Run ("Dog Run") and Dunkle Run.

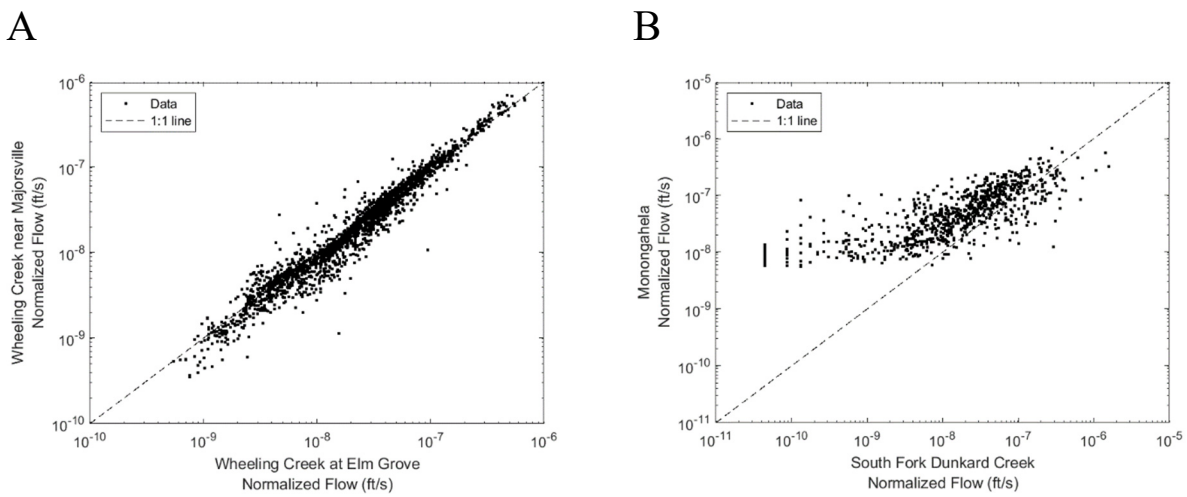

Figure H-1. A) Showing data plotting close to the one to one line B) Showing data that deviates from the one to one line. Note that this deviation occurs in the low flows.

However, these small basin gages were established as part of a special study and therefore only active for portions of the 5th assessment period (these gages were established in 2014 and ceased data collection beginning in 2017). Thus, they can only be used during this period and cannot be applied to future or historical HMR data. To expand this range, the University compared the selected small gage records with the longer USGS stream gage records collected in larger streams and rivers to select the best comparative long gage record for evaluation of HMR data. This allows evaluation of HMR data during periods where small basin gage data are not available.

The Dunkle Run and Dog Run records were compared to the stream gages in the five larger catchments (Table H-2). The Monongahela yield was larger than the Dunkle Run yield (slope =0.59, R^2 = 0.42) and larger than the Dog Run yield at low flows (slope=0.56, R^2=0.53). These differences in yield are likely due to the navigation dams on the Monongahela and resultant larger yields at low flows. So, the Monongahela gage is not a good comparison for undermined streams.

Table H-1. Fit statistics from pair wise comparisons of USGS small basin gages. Grey boxes are those selected as gage records for comparison with HMR data (Dunkle Run and Unnamed Tributary to Dog Run).

Gage	Fonner Run	Dunkle Run	Unnamed Tributary to Dog Run	Job Creek	South Fork Dunkard Creek	Middle Wheeling Creek
Fonner Run						
Dunkle Run	S=0.55 R^2=0.63 I=-3.25					
Unnamed Tributary to Dog Run	S=0.96 R^2=0.62 I=-0.53	S=1.023 R^2=0.79 I=-1.57				
Job Creek	S=0.78 R^2=0.59 I=-1.62	S=1.30 R^2=0.62 I=1.95	S=1.13 R^2=0.65 I=0.89			
South Fork Dunkard Creek	S=0.83 R^2=0.54 I=-1.23	S=1.55 R^2=0.64 I=3.83	S=1.23 R^2=0.59 I=1.58	S=1.03 R^2=0.87 I=0.24		
Middle Wheeling Creek	S=0.71 R^2=0.74 I=-2.14	S=1.12 R^2=0.77 I=0.75	S=0.90 R^2=0.76 I=-0.76	S=0.64 R^2=0.75 I=-2.7	S=1.36 R^2=0.74 I=0.57	

Next, Wheeling Creek at Elm Grove and Wheeling Creek near Majorsville gages were compared with Dunkle Run and Dog Run. Given that these gages are both on Wheeling Creek, the fits are not independent and could be biased by the similarity in flow. To avoid potential bias, the University did not use the Wheeling Creek gage records.

The Dunkard Creek and South Fork Tenmile Creek which had comparable statistics when compared with the small basins. While either are probably applicable, South Fork Tenmile Creek (avg. slope = 0.98, avg. R^2 = 0.81) was selected rather than Dunkard Creek (avg. slope = 0.96, avg. R^2 = 0.77) as it had an average slope that was closer to one and a stronger fit. Therefore, the South Fork Tenmile Creek record is used as the comparison yield datasets for evaluation of HMR records during periods where small basin data are not available.

Table H-2. Comparison of Dunkle Run and Unnamed Tributary of Dog Run to regional large stream and river records.

Large Drainage	Dunkle Run	Unnamed Tributary of Dog Run
Monongahela River	S=0.59 R^2=0.42 I=-2.92	S=0.56 R^2=0.53 I=-3.08
Wheeling Creek at Elm Grove	S=0.99 R^2=0.80 I=-0.15	S=0.82 R^2=0.78 I=-1.30
Wheeling Creek near Majorsville	S=0.96 R^2=0.70 I=-0.39	S=0.86 R^2=0.76 I=-1.03
Dunkard Creek	S=0.89 R^2=0.62 I=-0.9	S=0.81 R^2=0.69 I=-1.46
South Fork Tenmile Creek	S=0.93 R^2=0.71 I=-0.77	S=0.81 R^2=0.72 I=-1.54

H.2 - Comparison of HMR Data with USGS Stream Gage

The HMR points vary widely in area drained. Therefore, just as with the USGS gages, all HMR discharges were converted to yields. To determine HMR point drainage area, HMR points were plotted and matched to the nearest flow accumulation line derived from the 10-meter DEMs. As noted in the 4th assessment report, this requires a laborious QA process, (electronic submission of HMR point locations would simplify the following process). Given the detail provided in the SRE reports (e.g., Figure G-5) it is apparent the mining operators already track this data for impacted stream monitoring points.

To infer changes in yield at the HMRs and evaluate the subsidence impacts on groundwater storage, the yield ratio was used. The yield ratio is the HMR yield for a specific day divided by the USGS yield in the appropriate reference stream on that day. These ratios were calculated for HMR points. Monitoring points were primarily selected in watersheds undermined during the 5th assessment period or downstream of areas undermined during the 5th assessment period.