Water Budgets and Groundwater Volumes for Abandoned Underground Mines in the Western Middle Anthracite Coalfield

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http://pa.water.usgs.gov/projects/groundwater/westernmiddle

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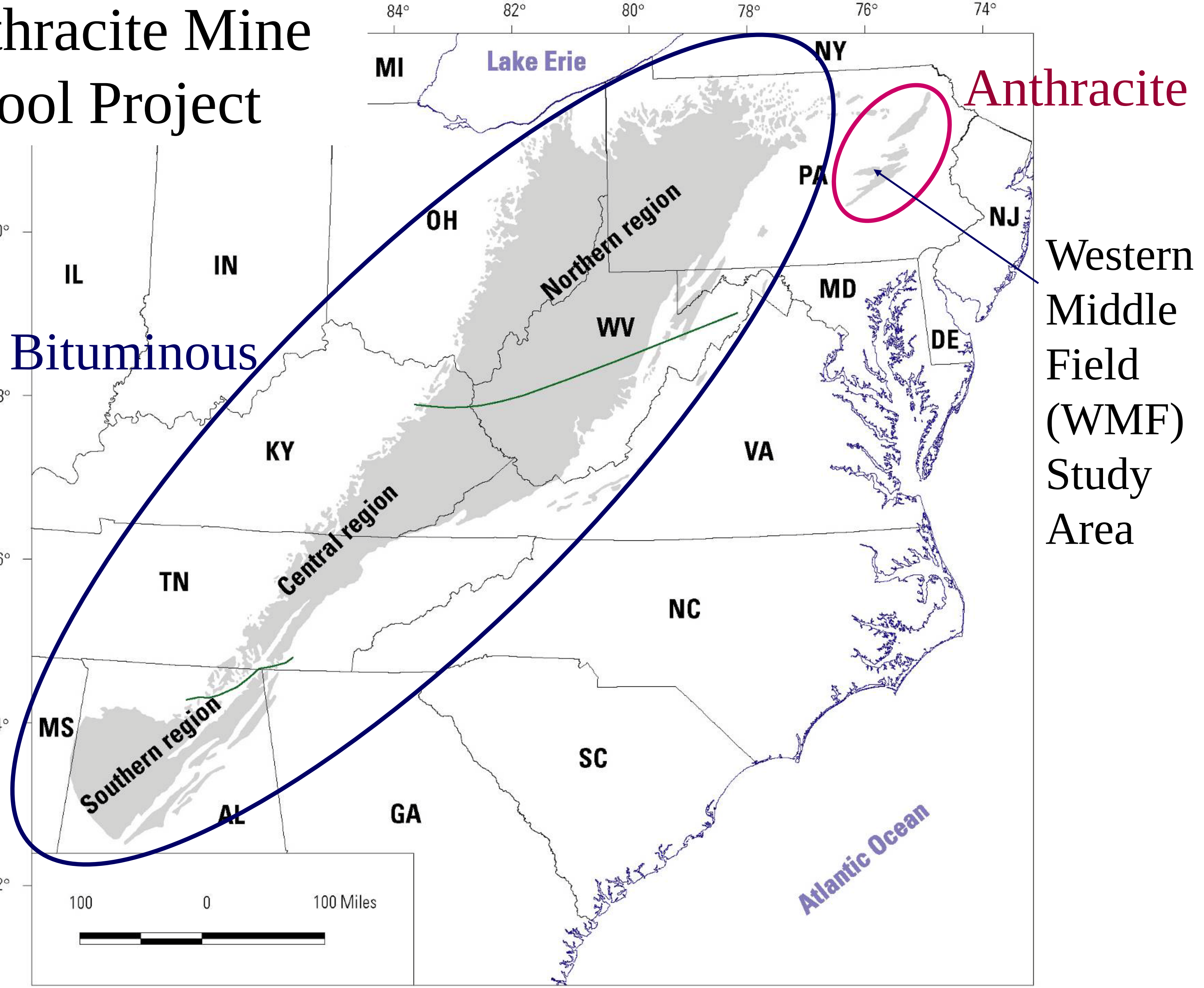
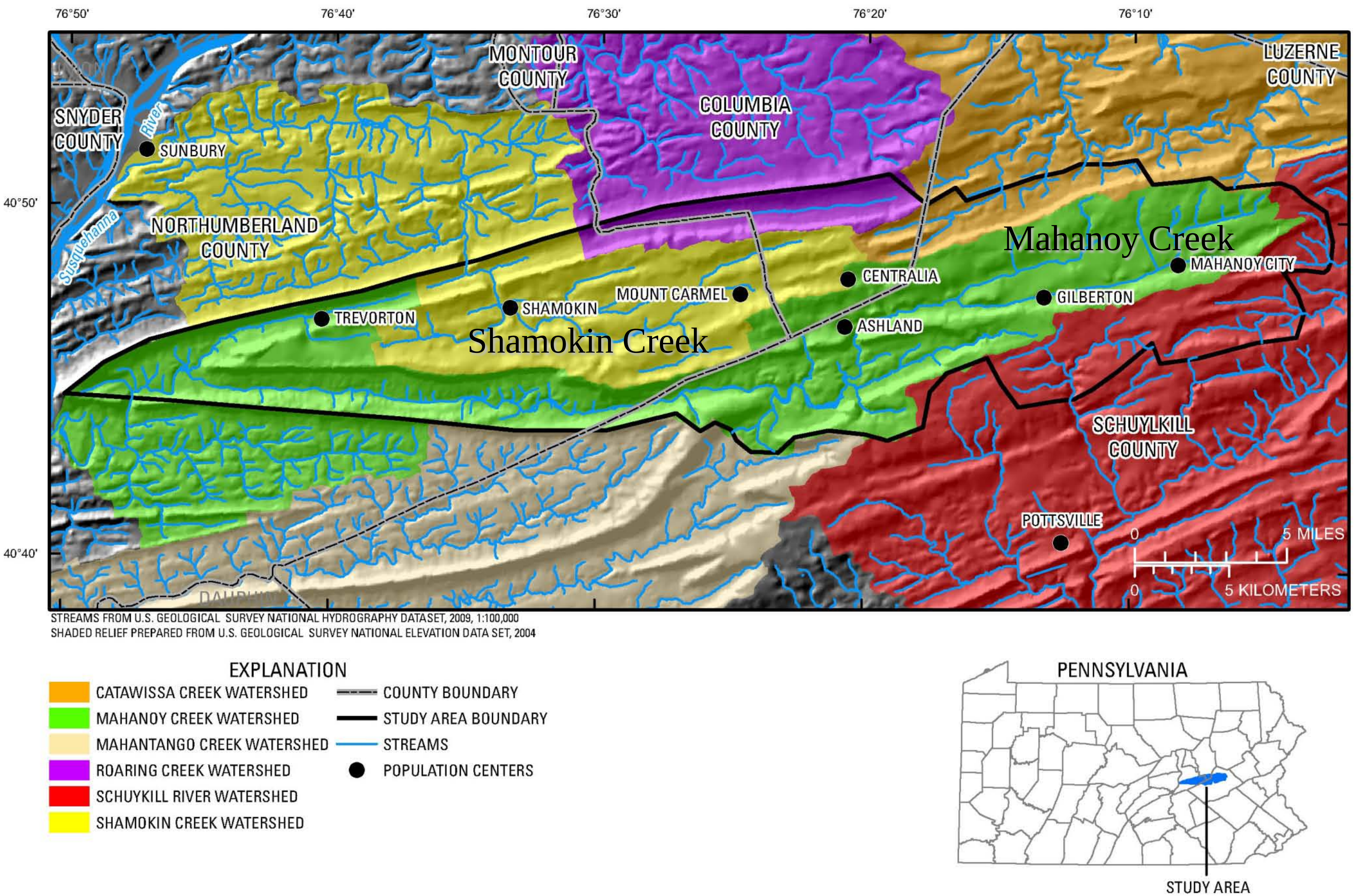
Anthracite Mine Pool Project



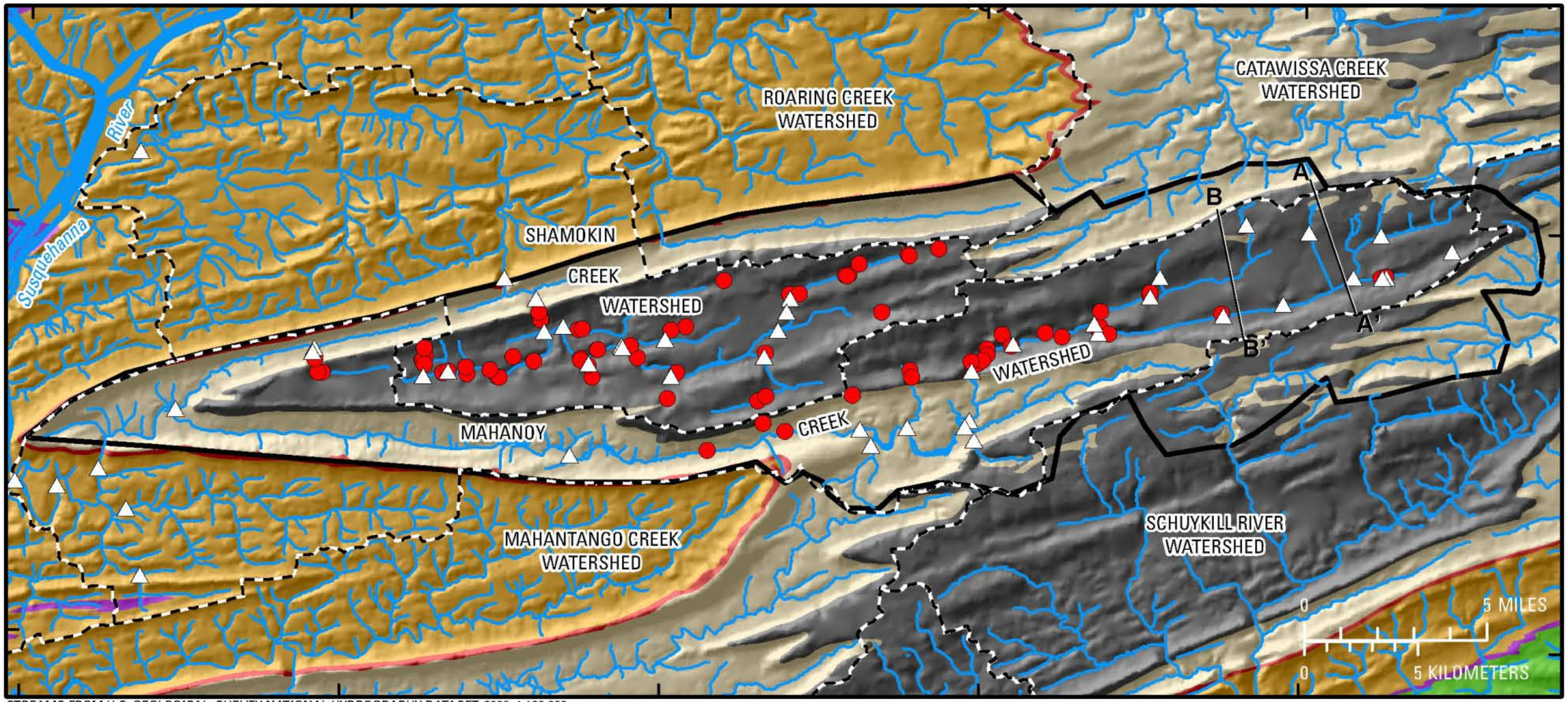
Watersheds Draining the Western Middle Field (WMF) Study Area

Shamokin Creek and Mahanoy Creek basins occupy large parts of the study area



Bedrock Units of WMF Study Area

AMD from Pennsylvanian bedrock affects streamwater quality to the Susquehanna



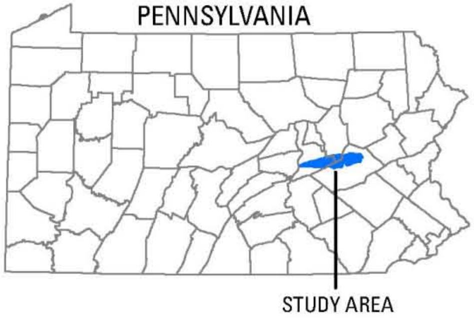
STREAMS FROM U.S. GEOLOGICAL SURVEY NATIONAL HYDROGRAPHY DATASET, 2009, 1:100,000
SHADED RELIEF PREPARED FROM U.S. GEOLOGICAL SURVEY NATIONAL ELEVATION DATA SET, 2004

EXPLANATION

PRINCIPAL BEDROCK UNITS
- PENNSYLVANIAN
- MISSISSIPPIAN
- MISSISSIPPIAN AND DEVONIAN
- DEVONIAN
- DEVONIAN AND SILURIAN
- SILURIAN

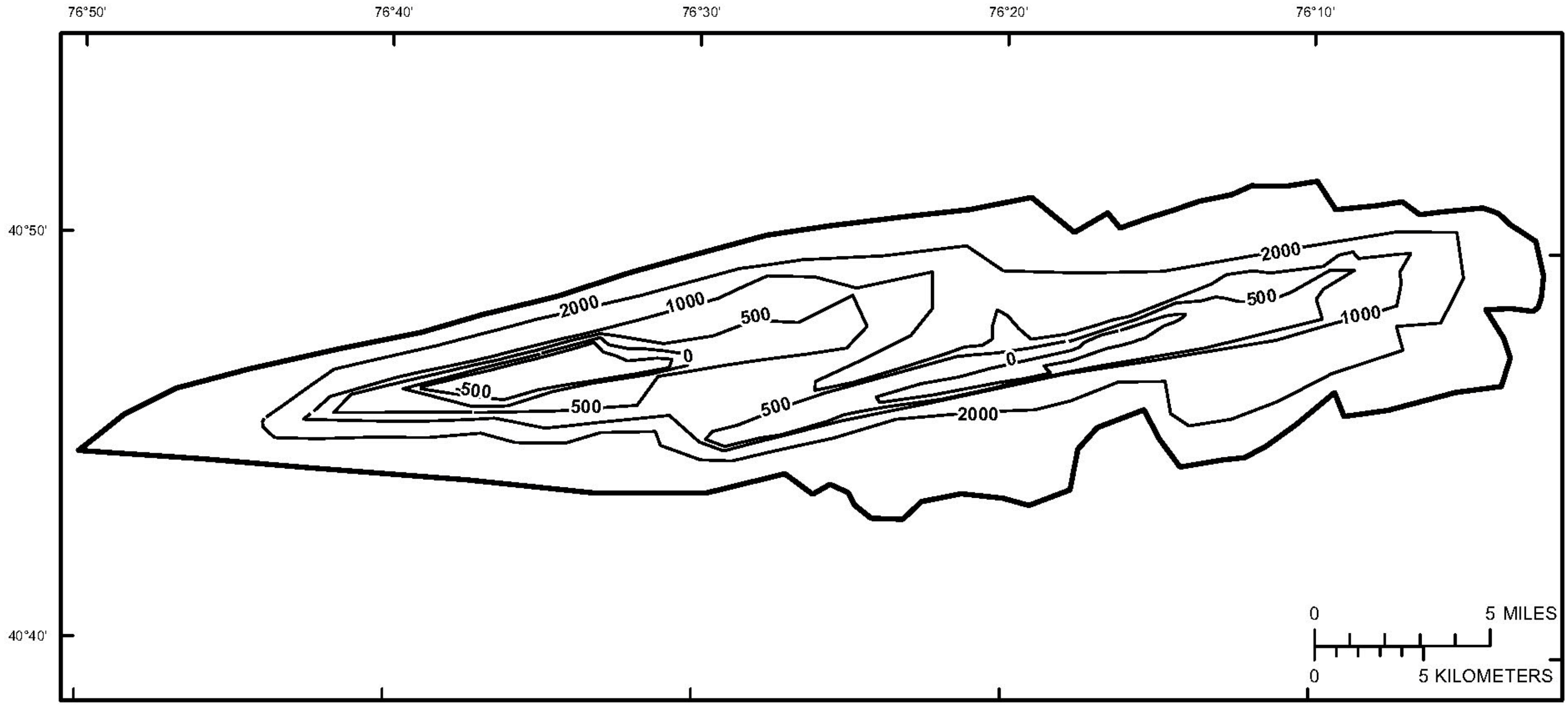
- STUDY AREA BOUNDARY
- WATERSHED BOUNDARY
- STREAMS

MONITORING SITES
- STREAMFLOW
- MINE DISCHARGES



Simplified Structure Contours of Buck Mountain Coalbed

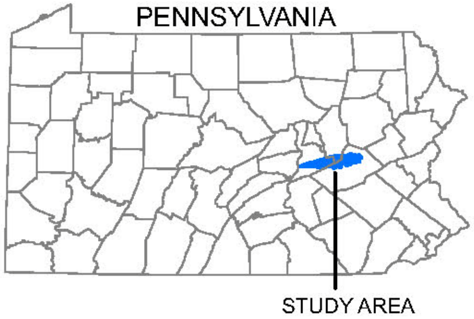
“Canoe-shaped” structure subdivided by parallel faults into parallel sub-basins



EXPLANATION

STUDY AREA BOUNDARY

BUCK MOUNTAIN STRUCTURAL CONTOURS, SMOOTHED, IN FEET



Bedrock Structure of WMF Study Area

North-south cross sections show complex folding and faulting of coal-bearing bedrock

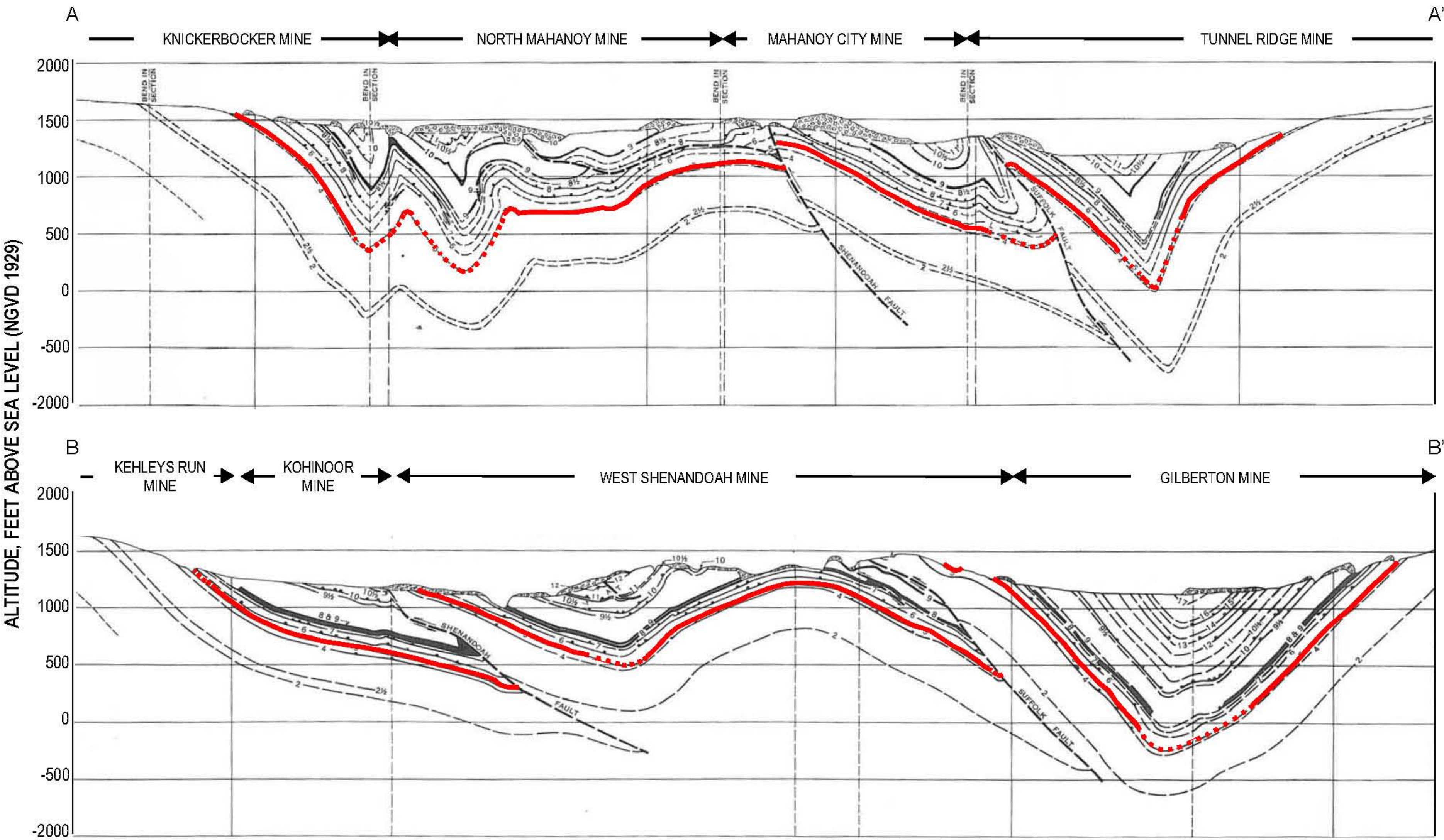


Table 1: Average thicknesses and relative altitudes of economically important coalbeds above the Buck Mountain coalbed in the Western Middle Anthracite Coalfield in Eastern Pennsylvania

Coalbed Number[a]	Coalbed Name	Average thickness of coalbed (feet)[b]	Relative altitude above base of Buck Mountain coalbed (feet)	Average percentage of noncoal waste in coalbed[c]
20	Rabbit Hole	4.6	1705	n.d.
19	Tunnel	5.5	1480	n.d.
18	Peach Mountain or Spahn	6.2	1410	16.1
17	Little Tracy	4.4	1315	14.3
16	Tracy	3.7	1250	24.8
15	Little Diamond	4.3	1150	20.1
14	Diamond	4.6	1065	23.8
13	Little Orchard	4.8	945	22.9
12	Orchard	5.5	840	26.2
11	Primrose	6.2	705	15.2
10 1/2	Rough	4.0	600	14.0
10	Holmes	5.9	460	12.8
9 1/2	Four Foot	3.7	435	19.0
9	Mammoth Top Split	7.4	315	13.9
8 1/2	Mammoth Middle Split	7.0	285	10.9
8	Mamoth Bottom Split	6.4	270	15.4
7	Skidmore	4.6	190	25.4
6	Seven Foot	4.0	65	25.9
5	Buck Mountain	6.4	0	22.1
4	Coal D (Little Buck Mountain)	2.3	-110	22.8
3	Coal C (Whites)	2.6	-160	8.5
-	Coal B	2.0	-260	n.d.
2 1/2	Coal A	3.8	-355	16.6
2	Lykens Valley no. 4	4.4	-485	19.1

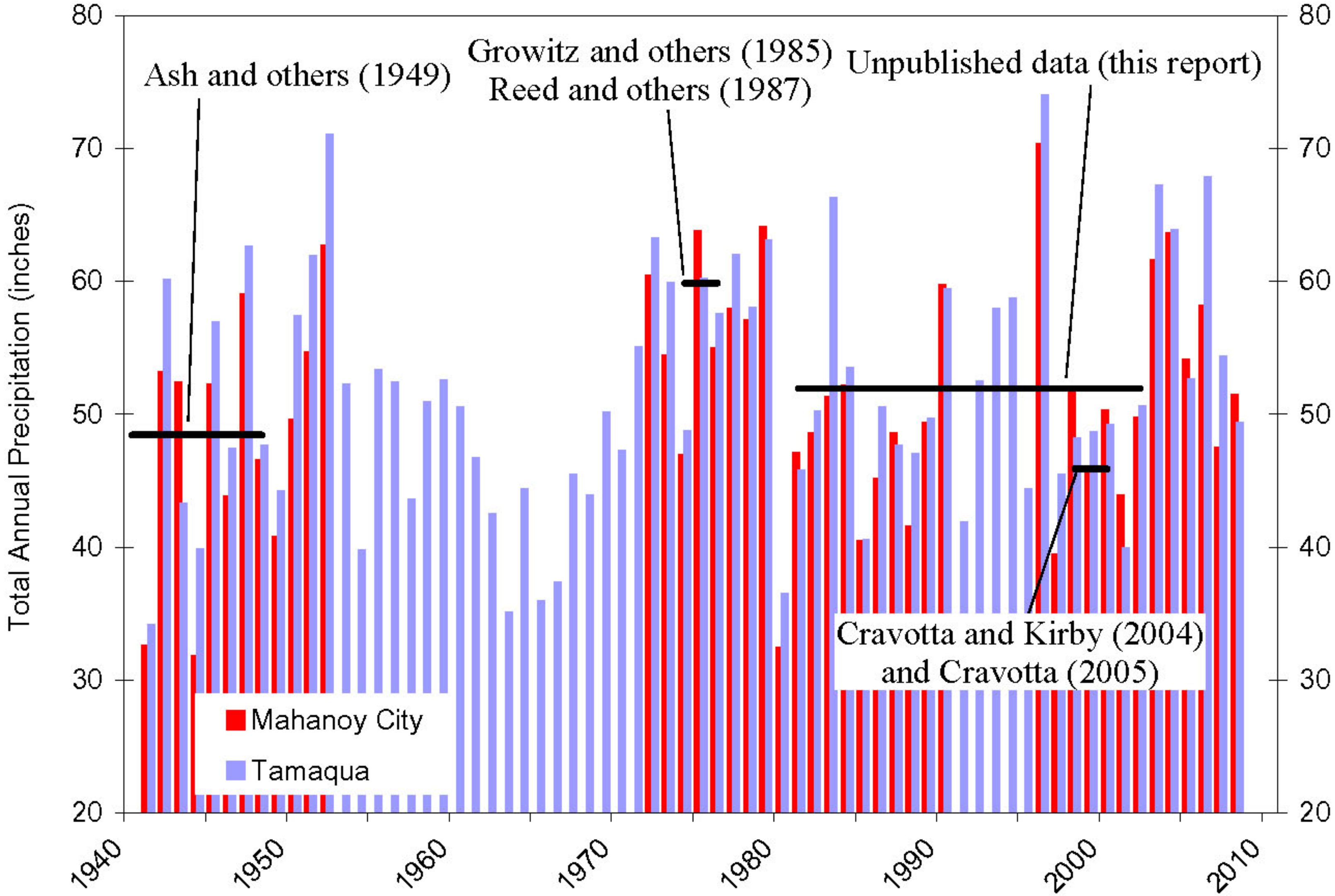
a. Coalbed numbers and names adapted from USGS coal-investigation maps (Arndt and others, 1963a, 1963b; Danilchik and others, 1955, 1962; Haley and others, 1953, 1954; Kehn and Wagner, 1955; Maxwell and Rothrock, 1955; Rothrock and others, 1950, 1951a, 1951b, 1953). Shaded rows indicate coalbeds that typically were mined, accounting for more than 90 percent of the coal production (Eggleston and others, 1999).

b. Average coalbed thickness and altitudes adapted from Eggleston and others (1999).

c. Average percentage of noncoal refuse computed from tables in USGS coal-investigation maps.

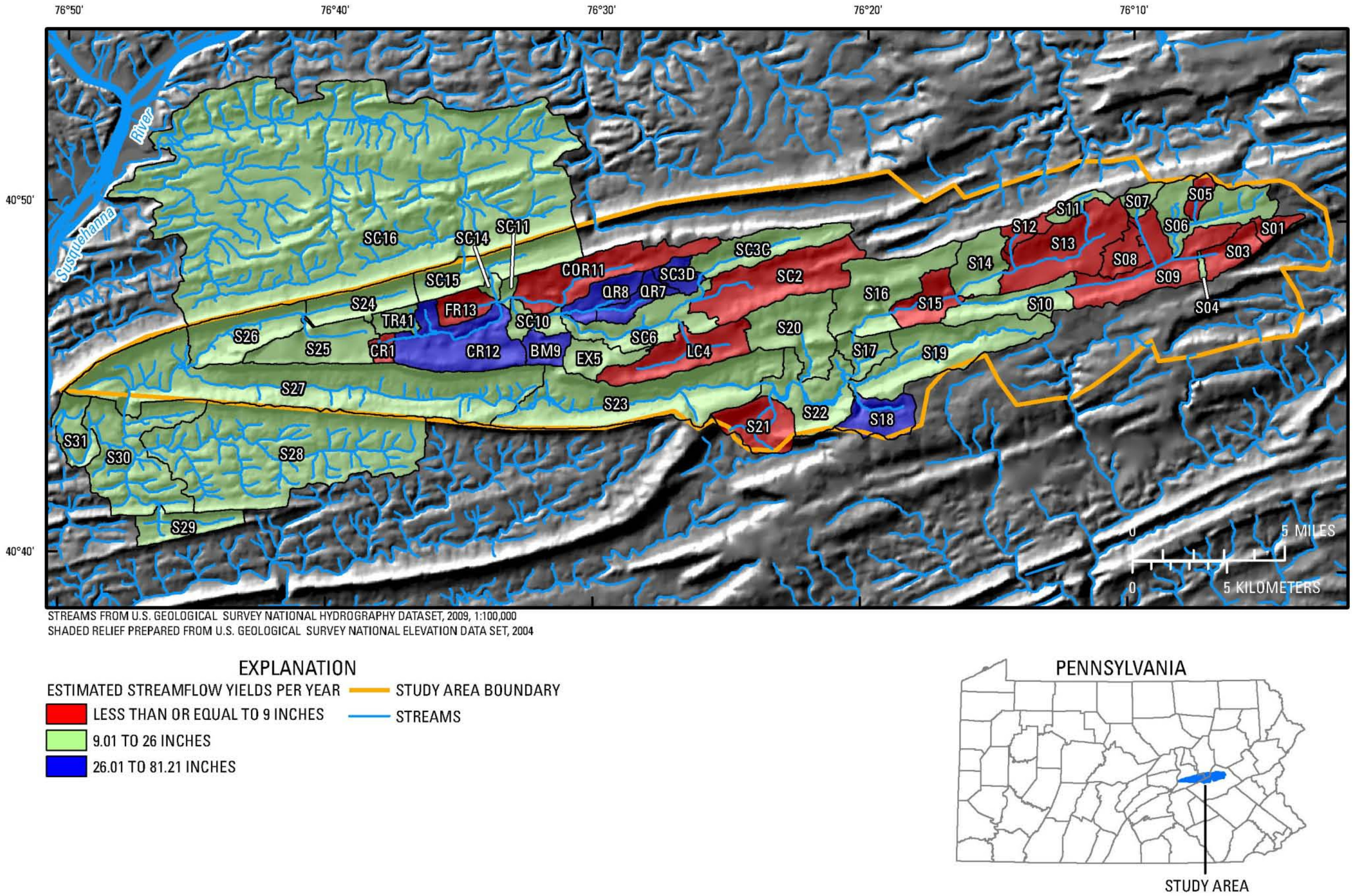
Total Annual Precipitation at Mahanoy City & Tamaqua PA, 1940-2008

Horizontal lines are averages at Tamaqua during previous investigations



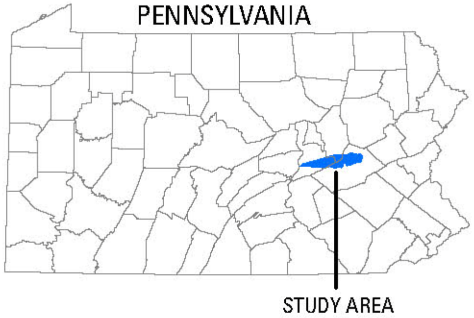
Streamflow Yields of WMF Study Area

Streamflow yields were abnormally low or high in areas underlain by abandoned mines

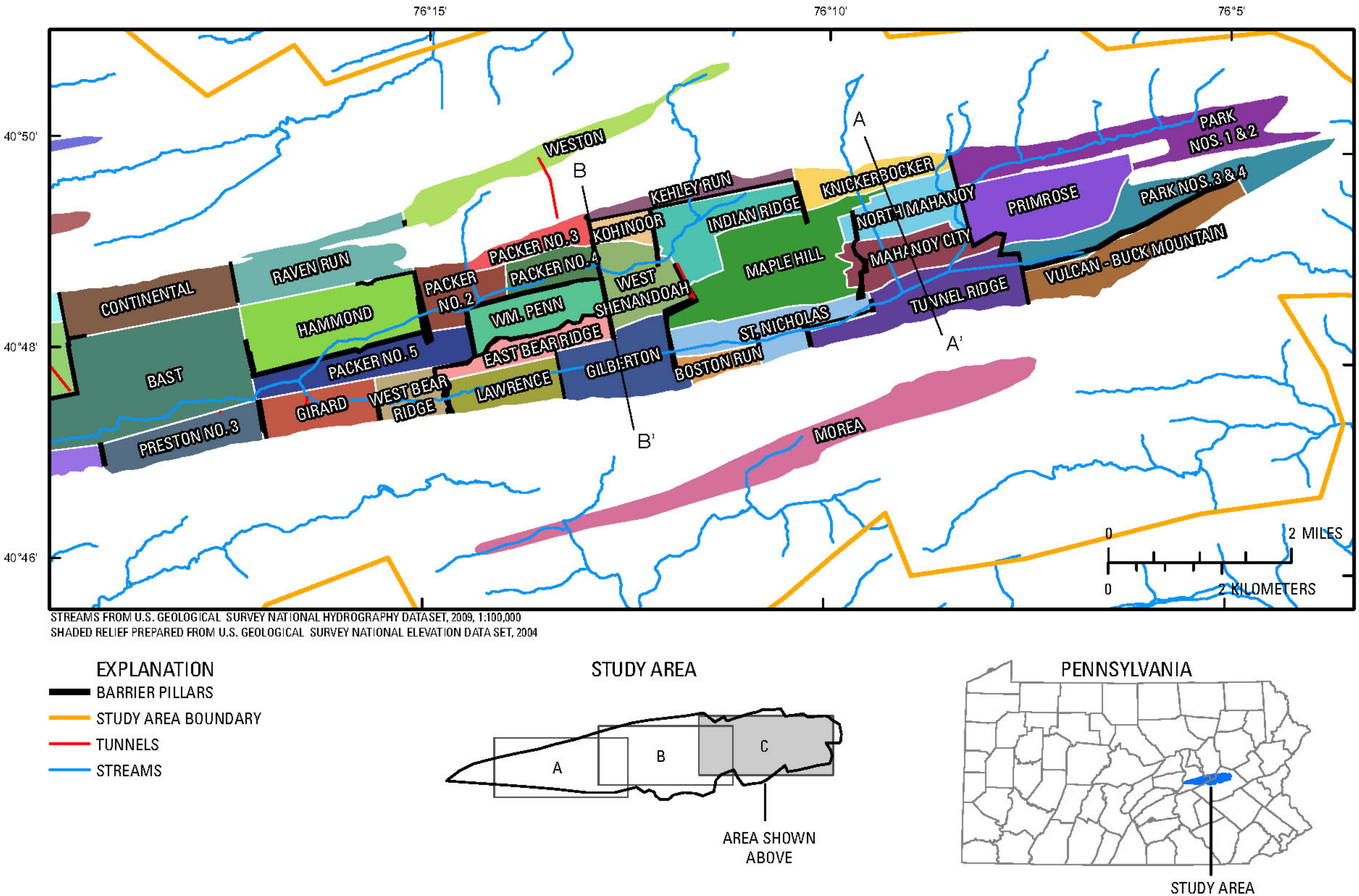


“Multicolliery Hydrologic Unit” (MCU) of WMF Study Area

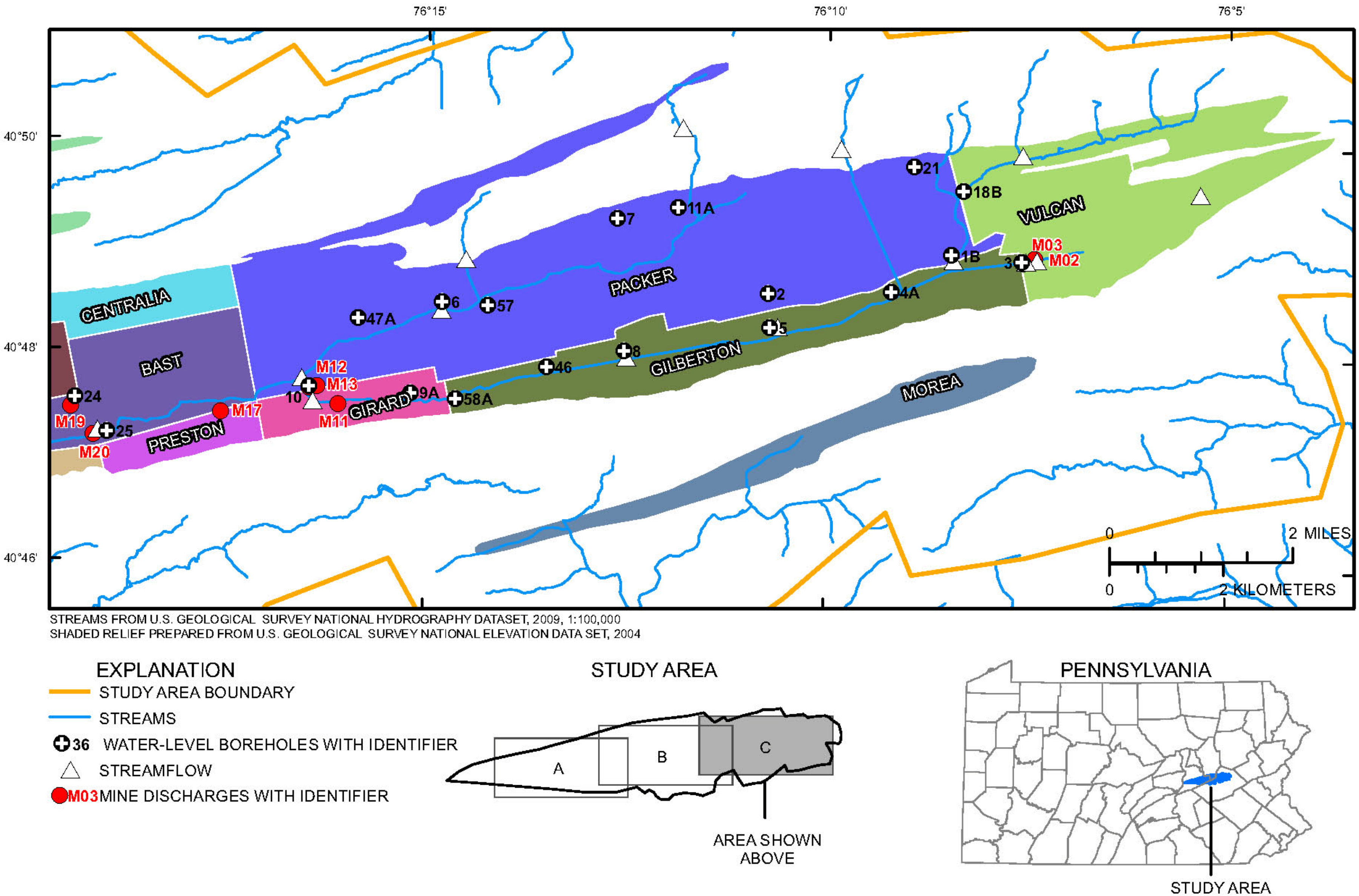
69 mapped mines were grouped as 19 MCUs, which had a common AMD outlet



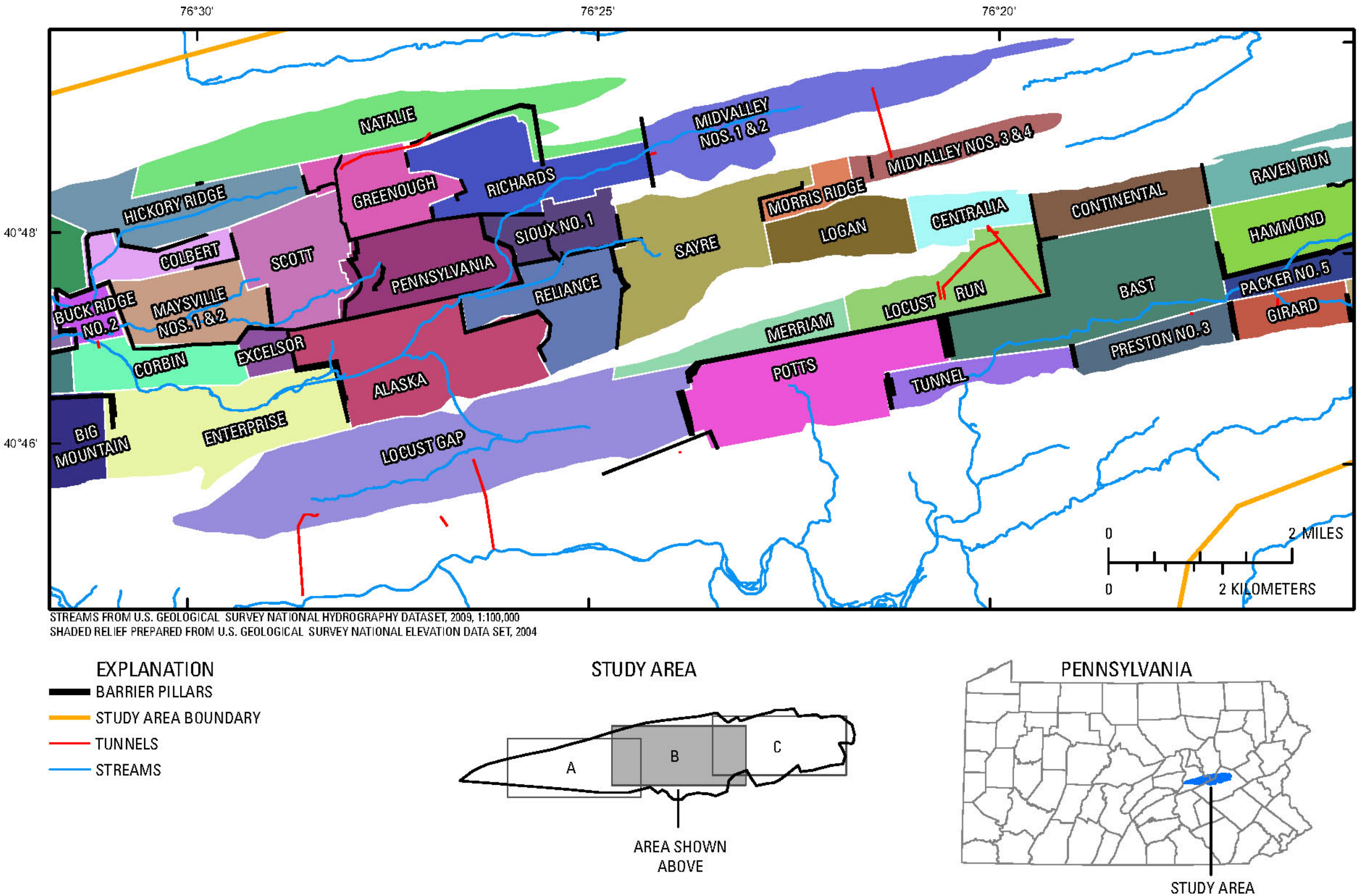
Mines in Eastern Part of WMF Study Area



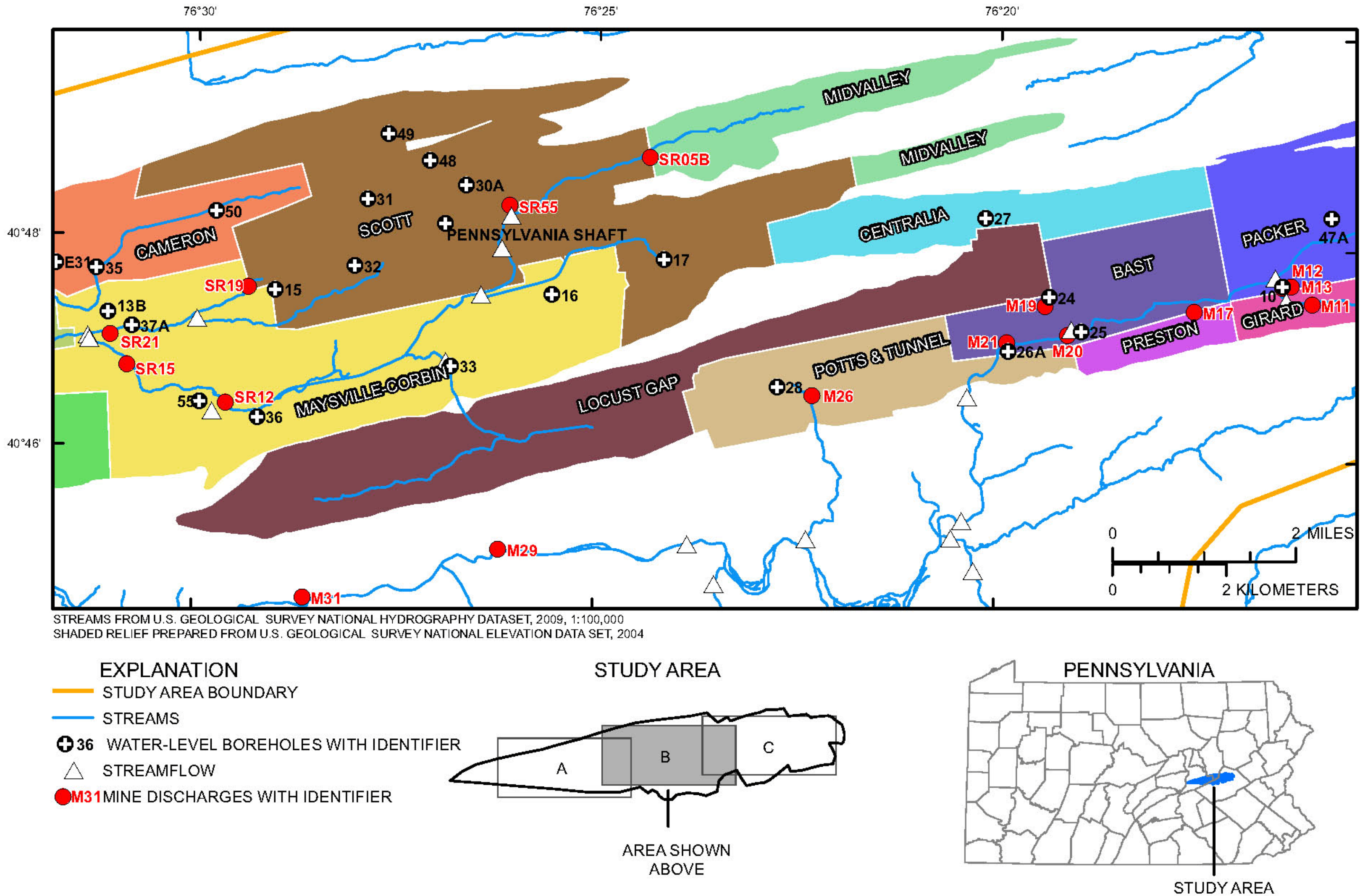
MCUs in Eastern Part of WMF Study Area



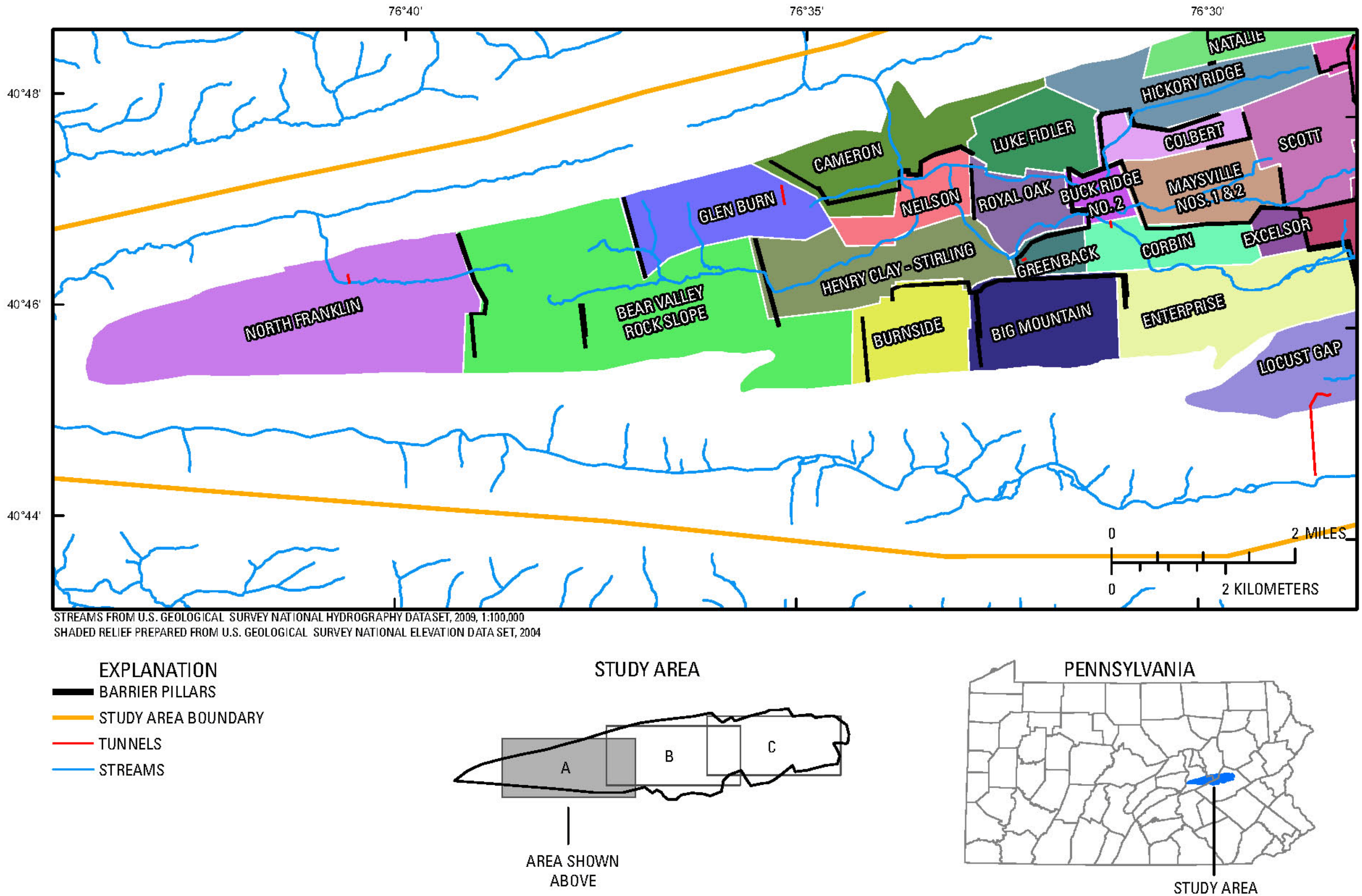
Mines in Central Part of WMF Study Area



MCUs in Central Part of WMF Study Area



Mines in Western Part of WMF Study Area



MCUs in Western Part of WMF Study Area

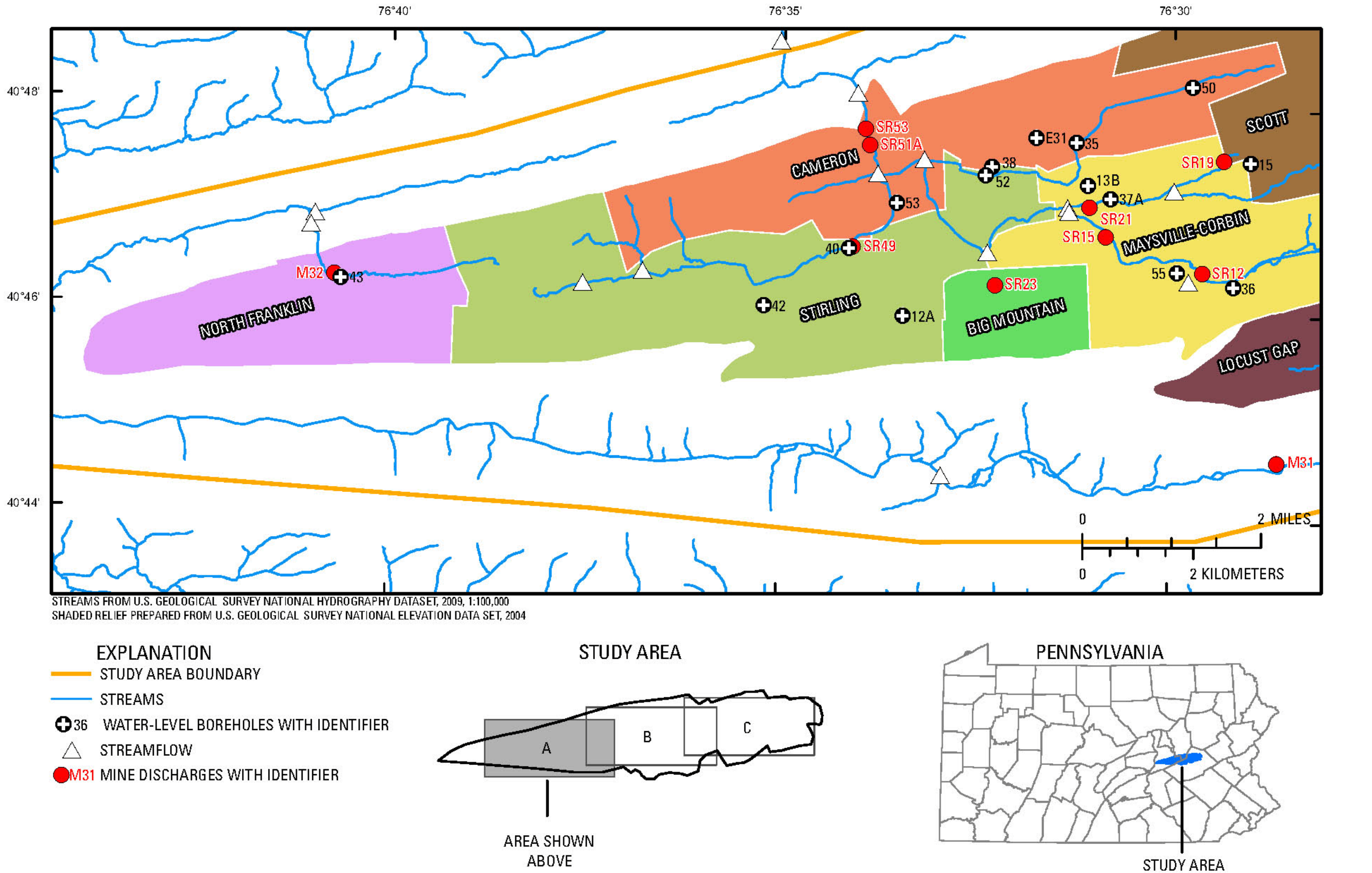


Table 6: Names, areas, estimated discharge, and measured discharge from multicolliery hydrologic units in the Western Middle Anthracite Coalfield in Eastern Pennsylvania [mi^2, squre miles; ft^3/s, cubic feet per second]

MCU Name	MCU Area (mi^2)	Estimated Discharge (ft^3/s)[a]	Measured Discharge (ft^3/s)[b]		AMD Site Number[b]
			min	max	
Vulcan	4.67	6.19	2.64	14.07	M03+M02
Packer[c]	11.69	15.49	8.76	15.06	M05+M07+M12+M13+M08+M09
Girard	0.96	1.27	2.73	4.10	M11
Gilberton	4.02	5.33	0.00	10.83	M04
Centralia	2.49	3.30	2.43	3.86	M19
Bast	2.77	3.67	2.70	6.90	M21+M20+M18
Preston	0.69	0.92	0.67	2.23	M17
Midvalley	2.89	3.83	3.24	7.80	SR05B+SR05A+SR04+SR02
Potts & Tunnel	3.05	4.04	0.77	1.96	M24+M25+M22+M23+M26+M27
Scott	11.35	15.04	9.43	25.66	SR19+SR06+SR31+SR55
Locust Gap	6.91	9.16	8.28	20.72	M29+M31
Maysville-Corbin	9.29	12.30	9.36	20.45	SR12+SR15+SR11+SR21
Cameron	7.26	9.62	5.27	10.02	SR53+SR51A+SR51+SR52+SR36A+SR20
Big Mountain	1.62	2.15	0.51	3.60	SR23
Stirling	9.40	12.45	2.04	15.42	SR49+SR48+SR42+SR22A+SR22B
North Franklin	4.68	6.20	2.56	6.45	M32
Morea	1.92	2.54	1.40	15.00	USGS162

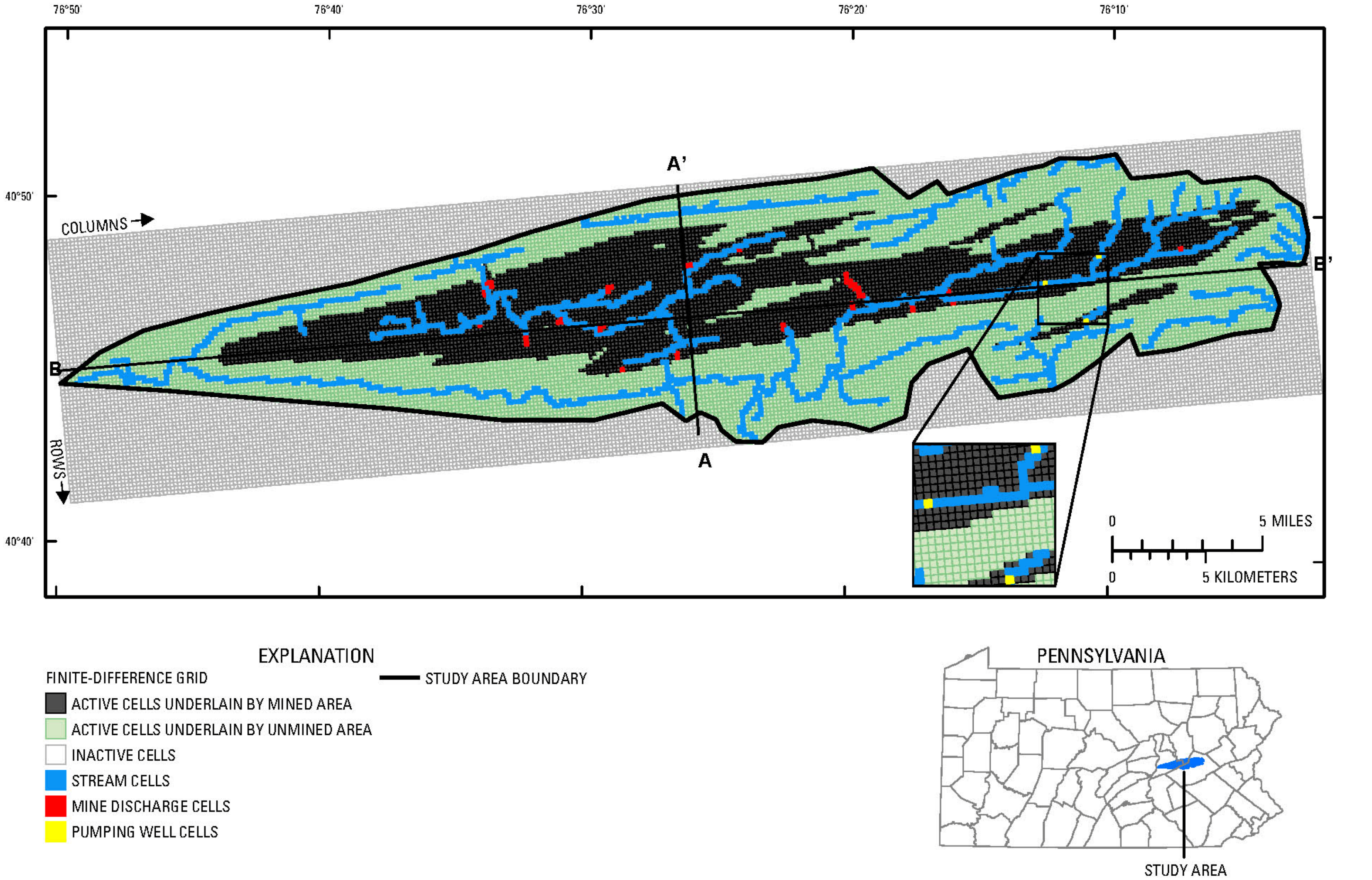
a. Estimated discharge was computed as the product of MCU area and assumed recharge rate of 18.0 in/yr.

b. Measured minimum and maximum discharge was computed as the sum of the minimum or maximum measured discharges, respectively, for sites identified in table 3.

c. Although initially considered separate MCUs, the Weston Mine and Raven Run Mine were included with the Packer MCU for consistency with Reed and others (1987). Some AMD sources associated with these mines could not be measured as reported by Cravotta (2005).

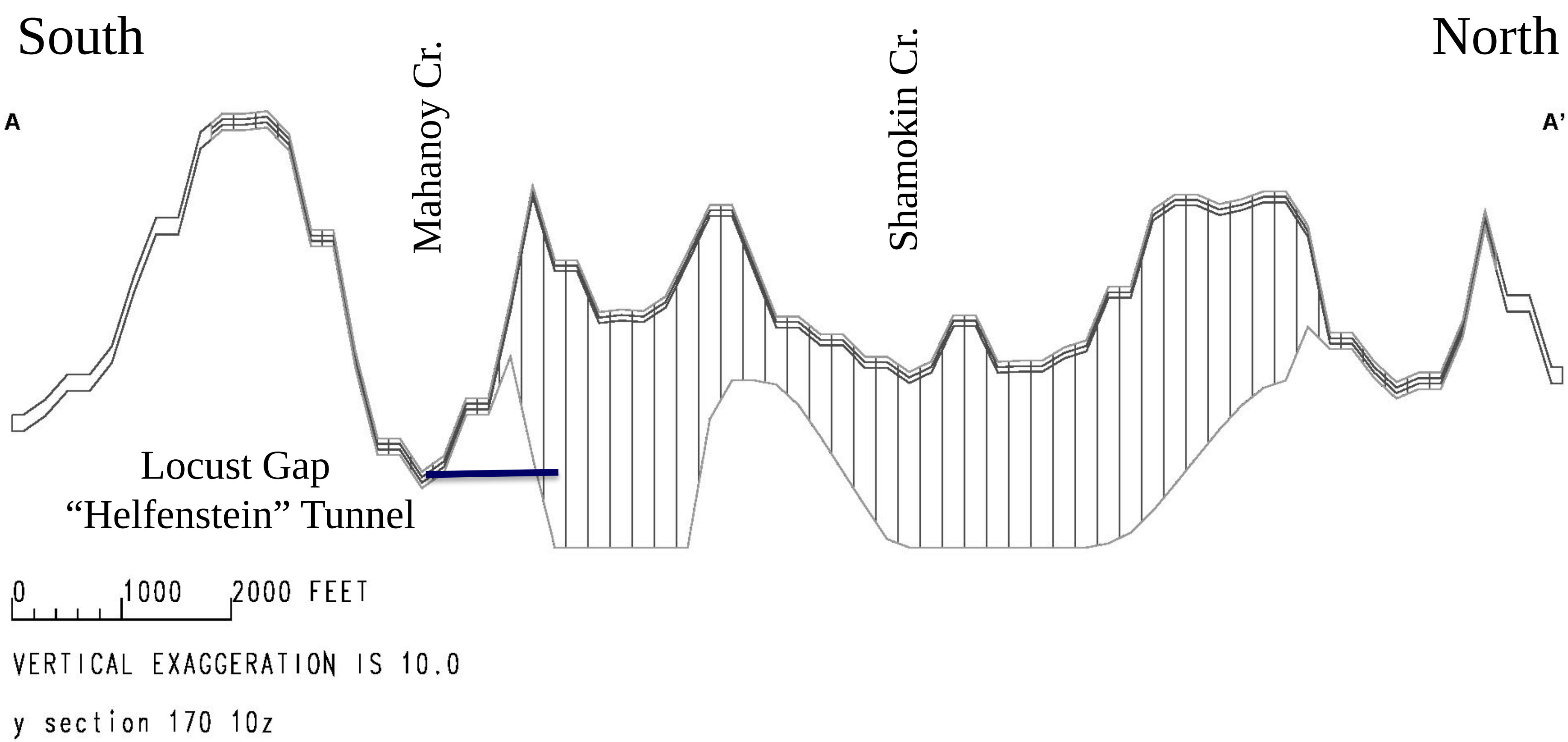
Groundwater Model Grid of WMF Study Area

MODFLOW integrates data on mining features, hydrogeology, and streamflow



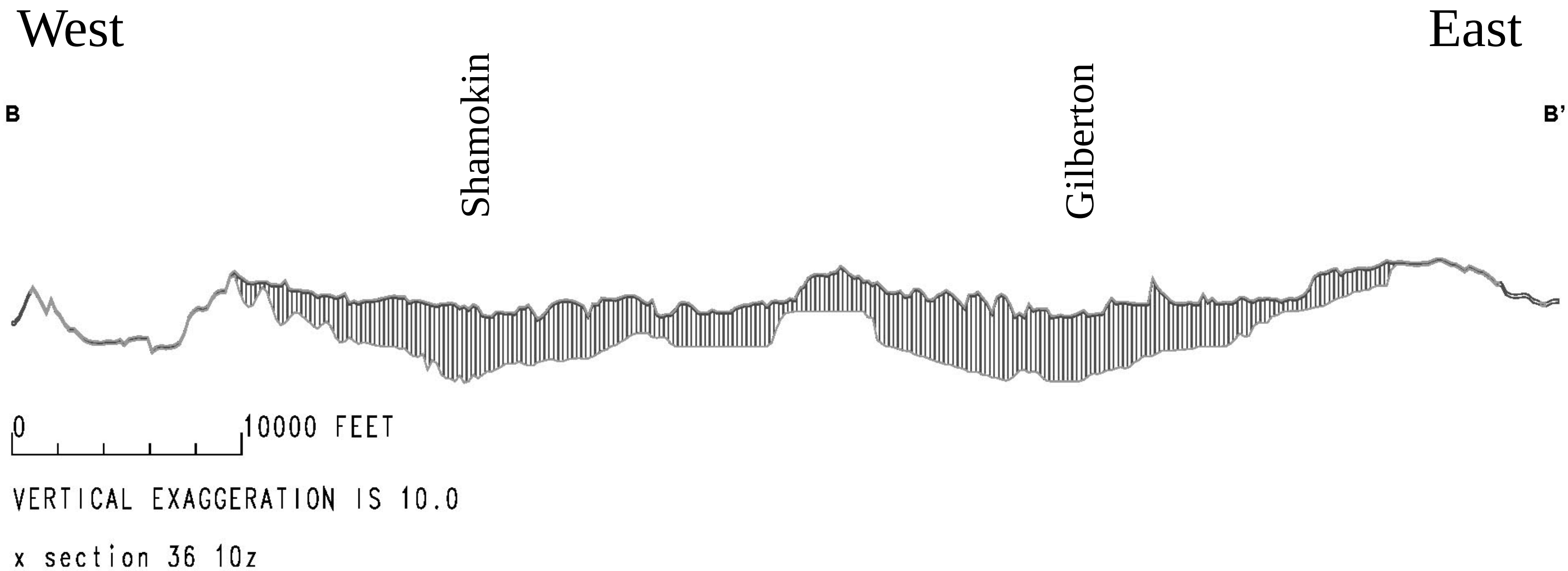
Model Cross Section of WMF Study Area

Layers 1 (soil, spoil) & 2 (weathered bedrock) overlie layer 3 (mined rock)



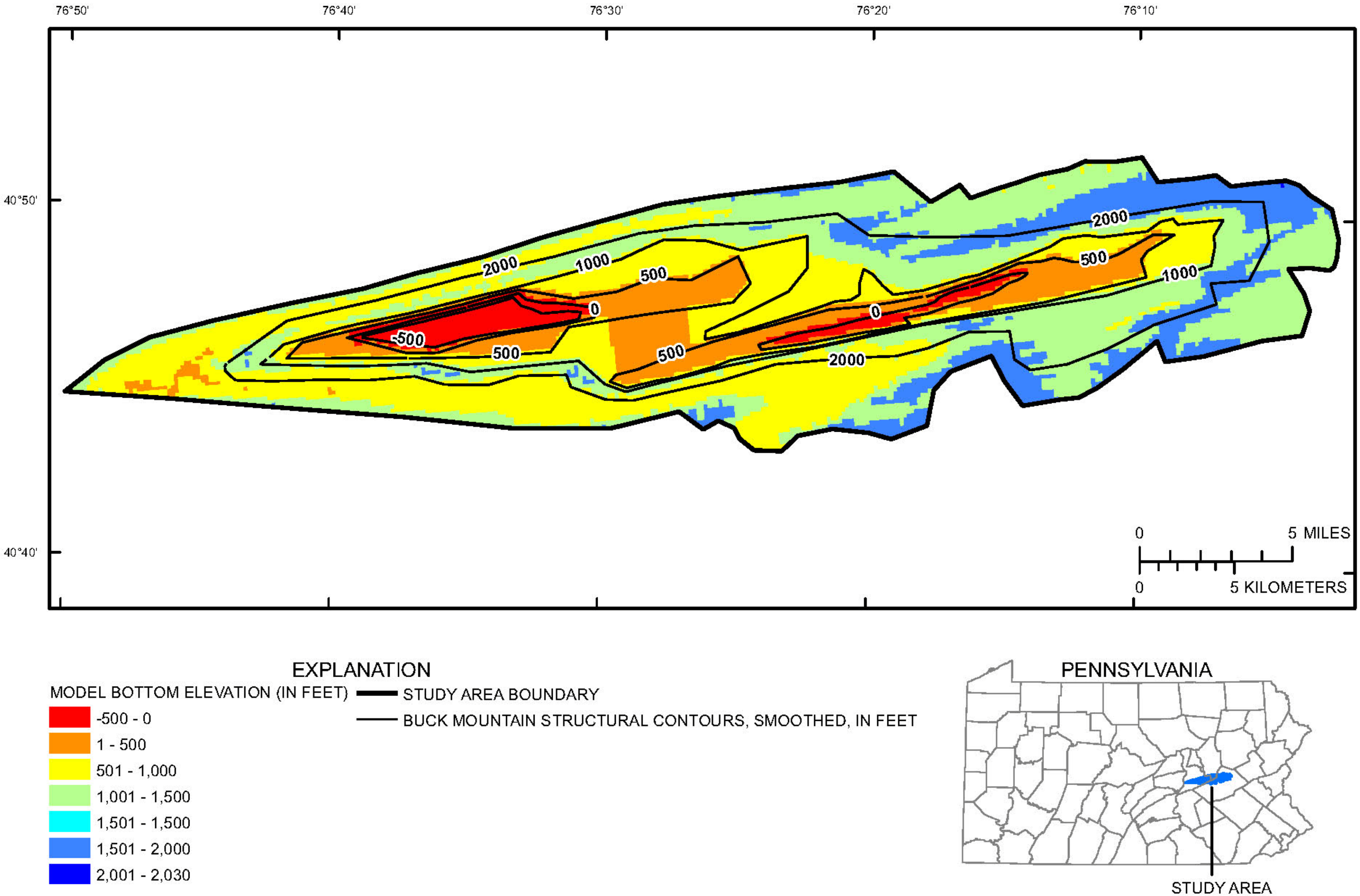
Model Cross Section of WMF Study Area

Layers 1 (soil, spoil) & 2 (bedrock) overlie layer 3 (mined rock)



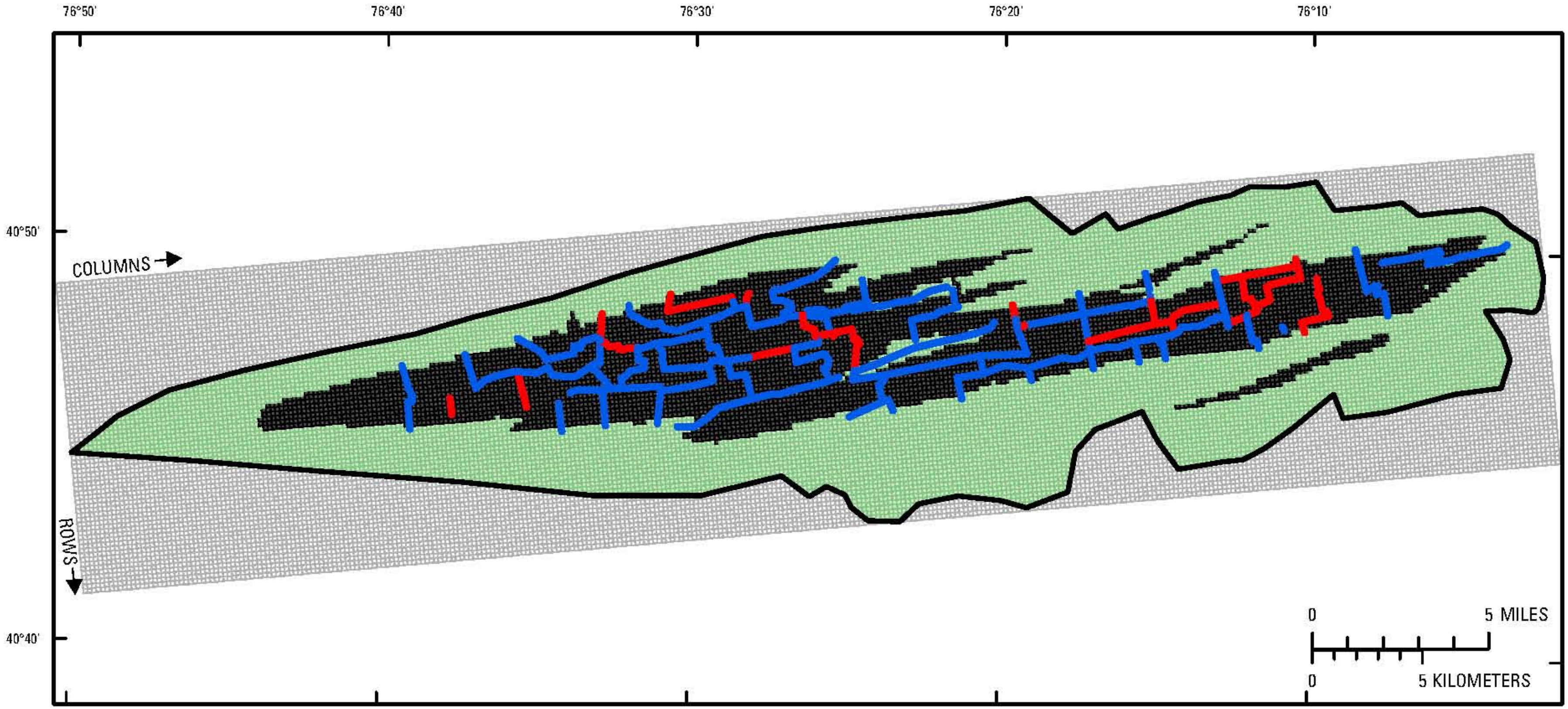
Groundwater Model Boundaries of WMF Study Area

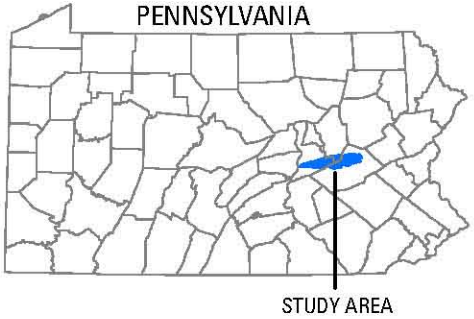
Structure contour of Buck Mountain or maximum depth of mining indicated bottom



Flow Barriers between Mines of WMF Study Area

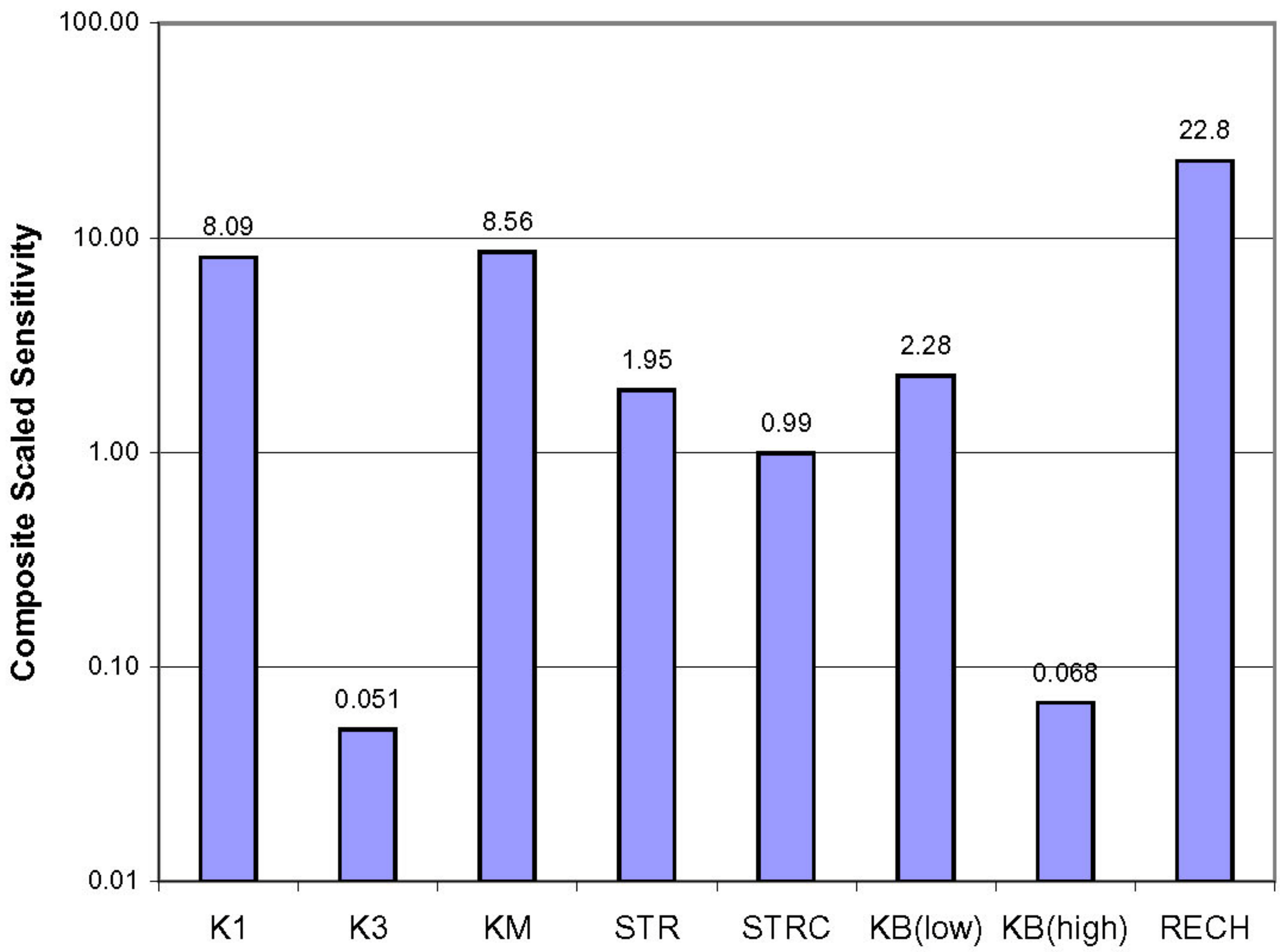
MODFLOW integrates data on mining features, hydrogeology, and streamflow





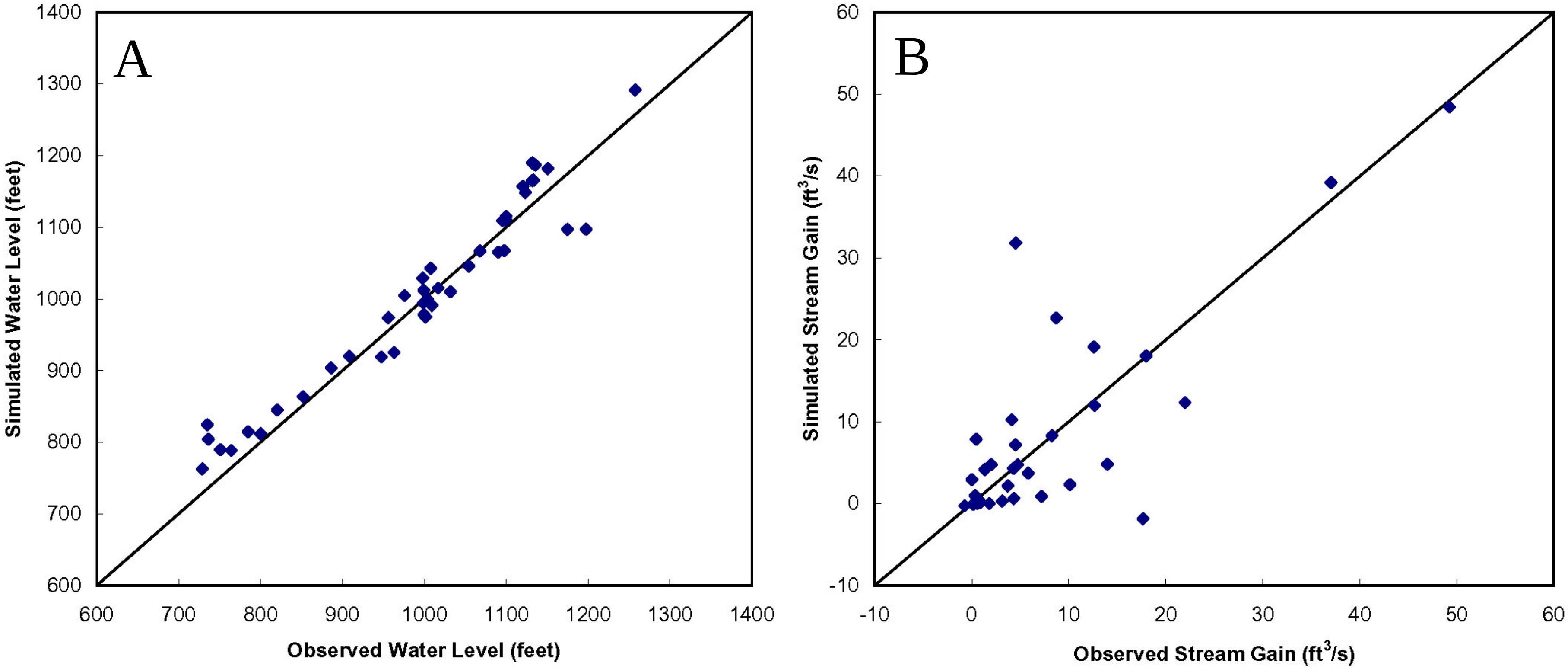
Adjusted Parameters for Groundwater Model of WMF Study Area

Eight parameters were used to represent hydrologic properties in the model



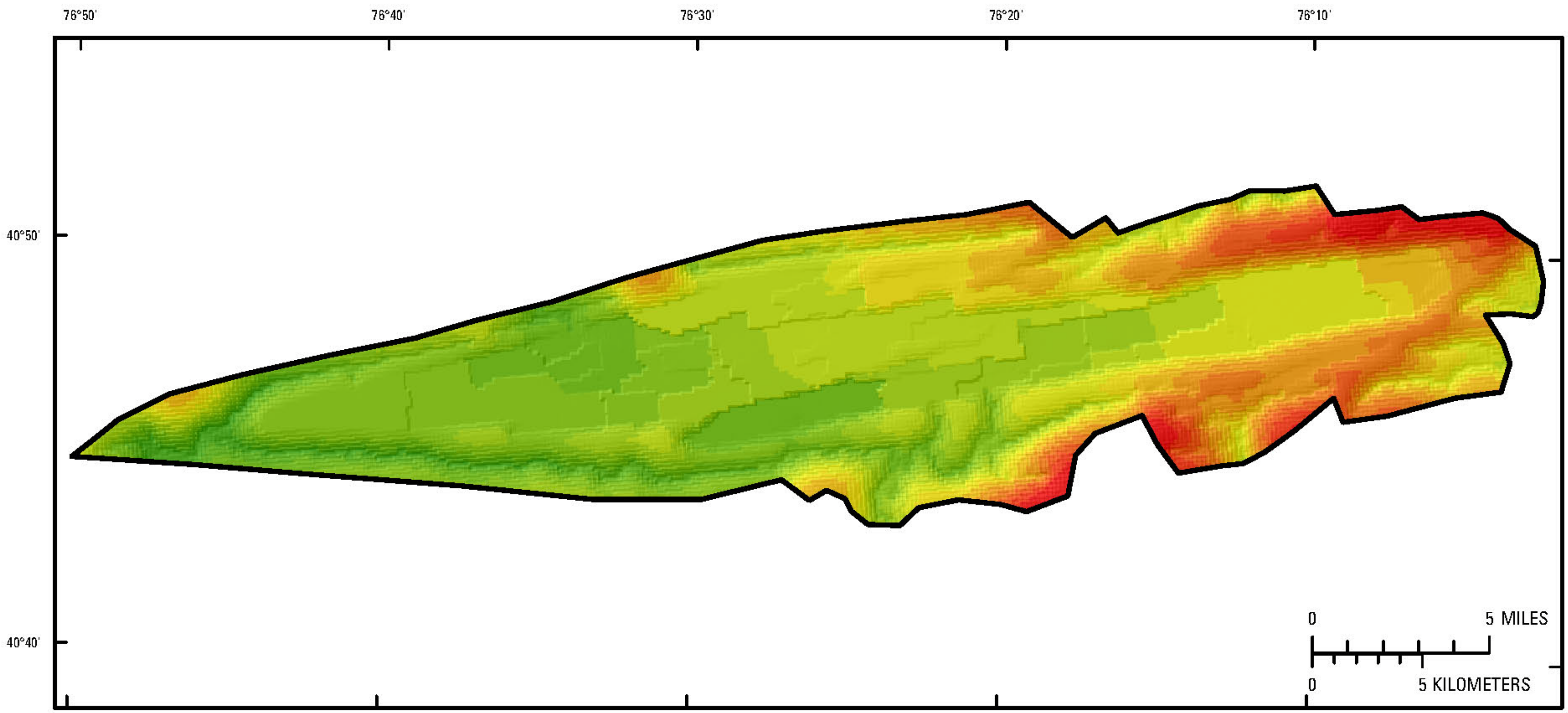
Observed vs. Simulated Values for WMF Study Area

Comparison of groundwater levels and base-flow gain or loss in modeled streams



Simulated Groundwater Elevations of WMF Study Area

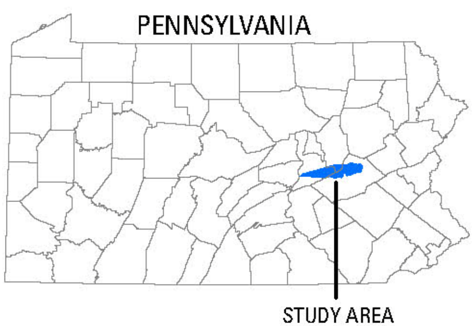
Simulated groundwater elevations are consistent with MCU conceptual model



EXPLANATION

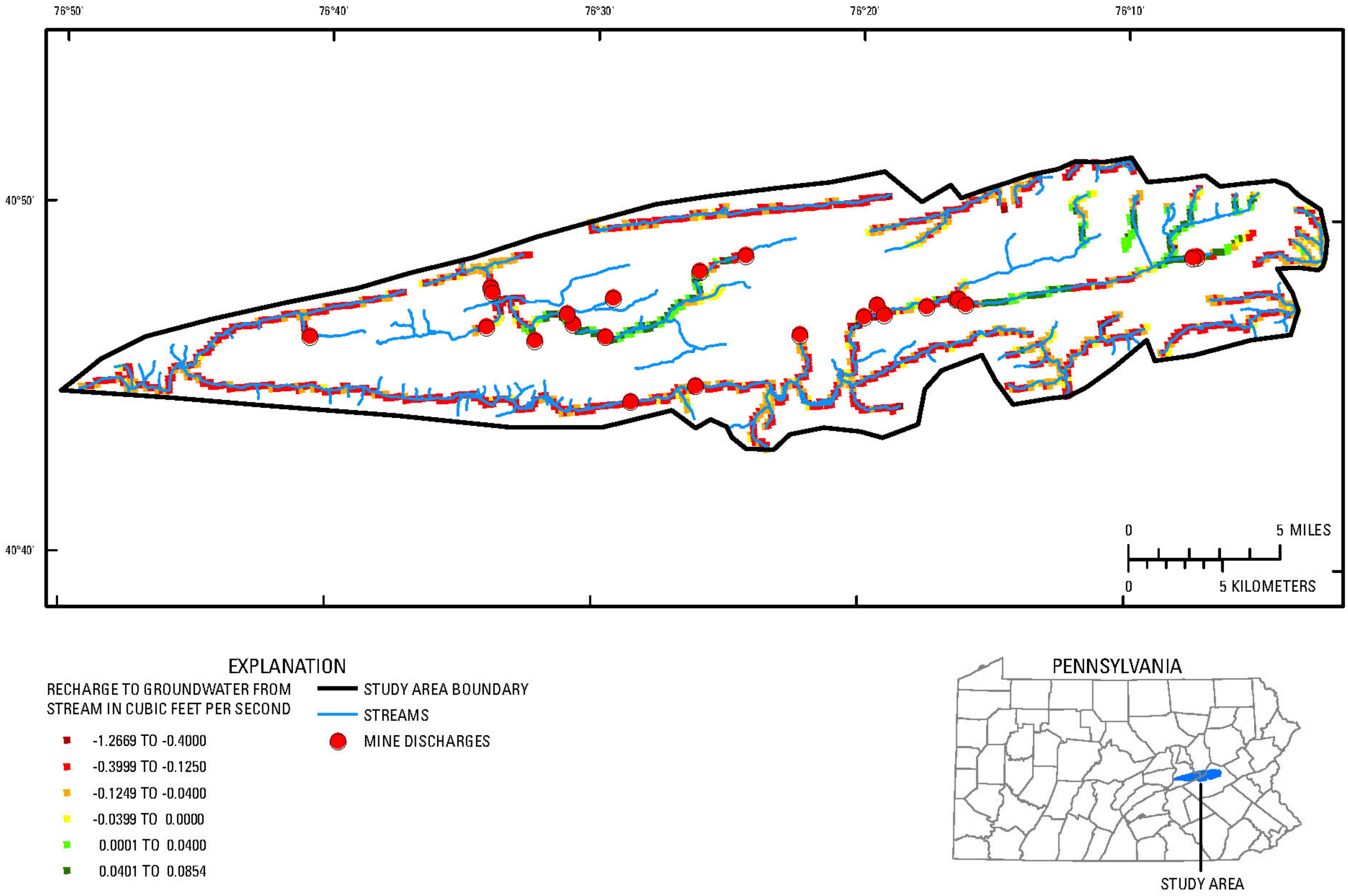
SIMULATED WATER LEVELS IN THE COAL MINE LAYER

- 506 TO 600 FEET
- 601 TO 700 FEET
- 701 TO 800 FEET
- 801 TO 900 FEET
- 901 TO 1,000 FEET
- 1,001 TO 1,100 FEET
- 1,101 TO 1,200 FEET
- 1,201 TO 1,300 FEET
- 1,301 TO 1,400 FEET
- 1,401 TO 1,500 FEET
- 1,501 TO 1,600 FEET
- 1,601 TO 1,700 FEET
- 1,701 TO 1,800 FEET
- 1,801 TO 2,120 FEET



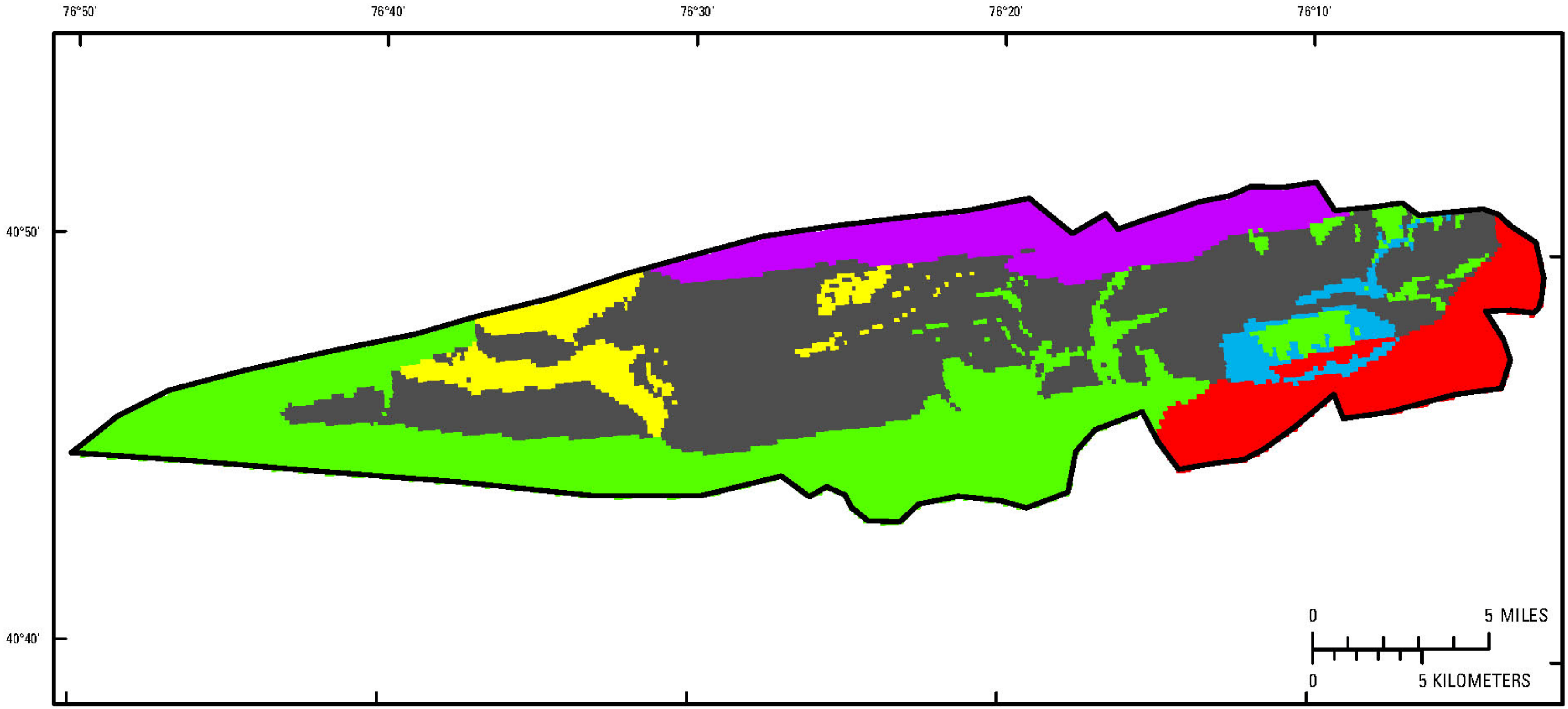
Stream Base-Flow Gains and Losses in WMF Study Area

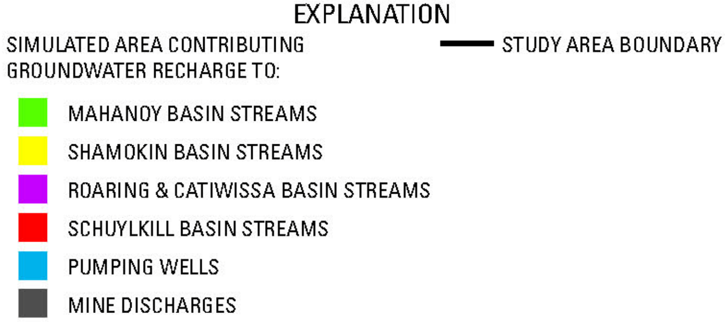
In mined areas, stream losses are common; outside mined areas, streams gain flow

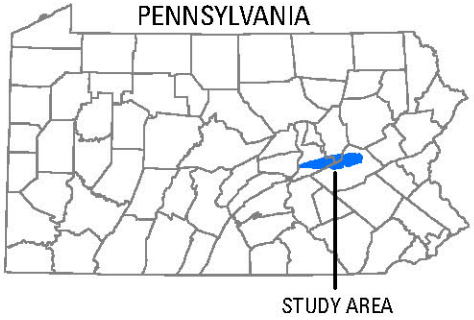


Recharge Areas for Streams, Pumping Wells, & Mine Discharges

In mined areas, most recharge is captured by mines and is discharged as “AMD”

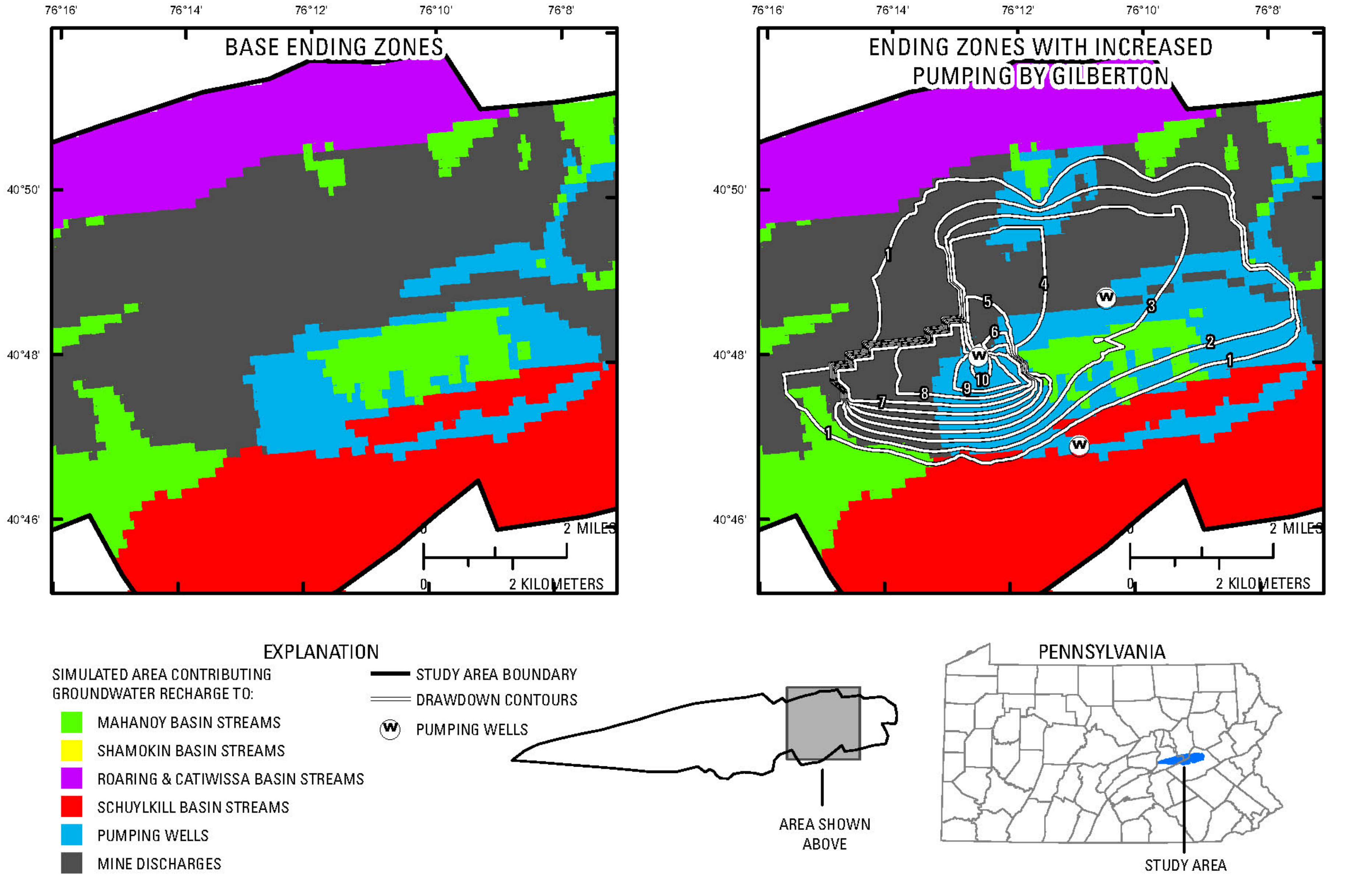






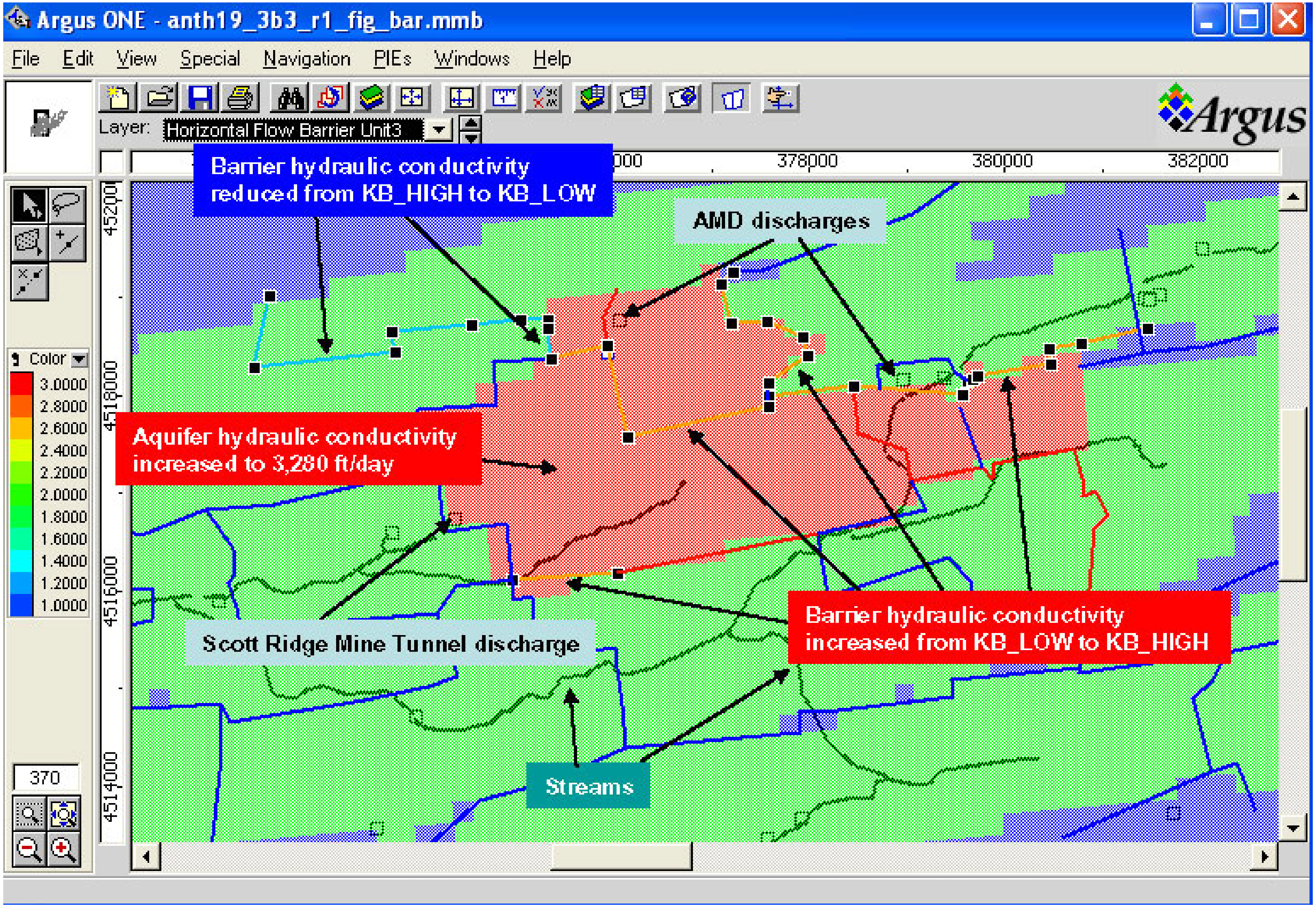
Simulated Pumping Withdrawal from Mine Pool in WMF Study Area

Increased pumping from Gilberton Mine captures groundwater from mine discharges



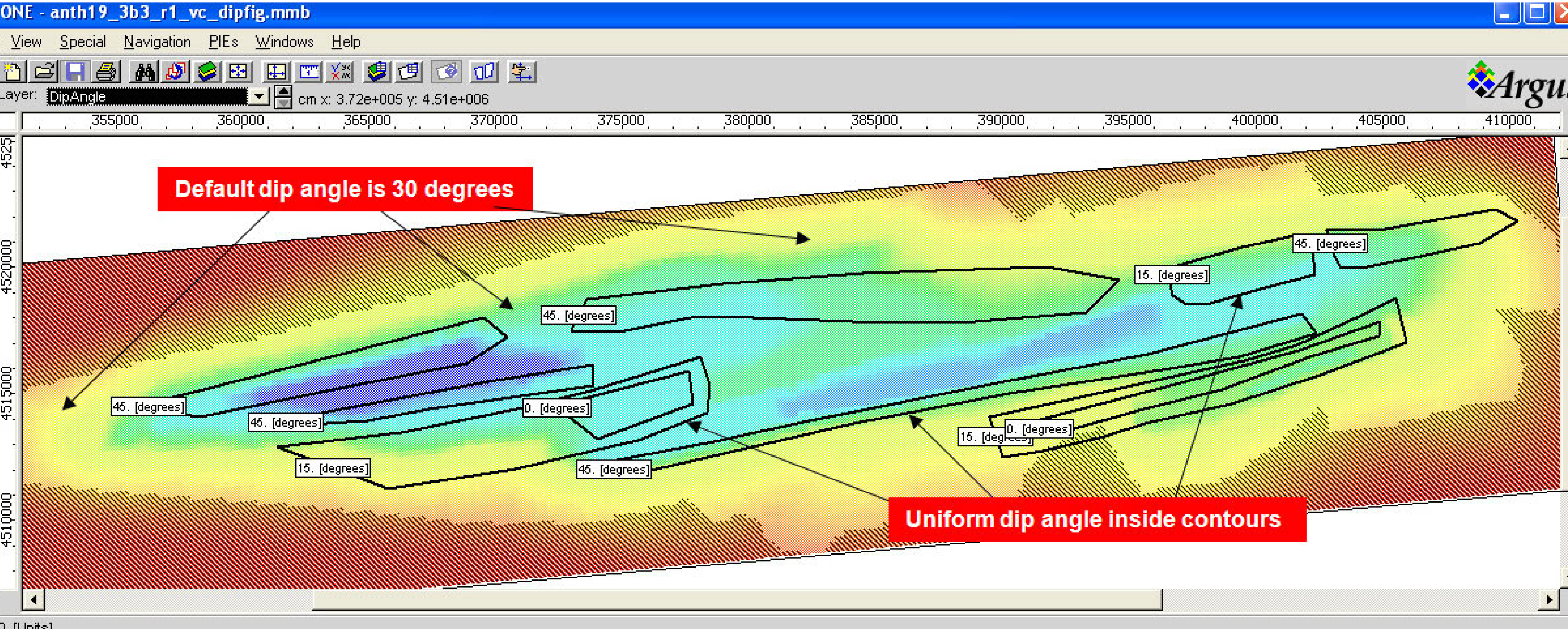
Model Adjustment to Match Discharge from Scott Ridge Mine Tunnel

Hydraulic conductivities of mine barriers and mined strata were modified locally to increase simulated discharge from 0 to 17.6 ft^3/s



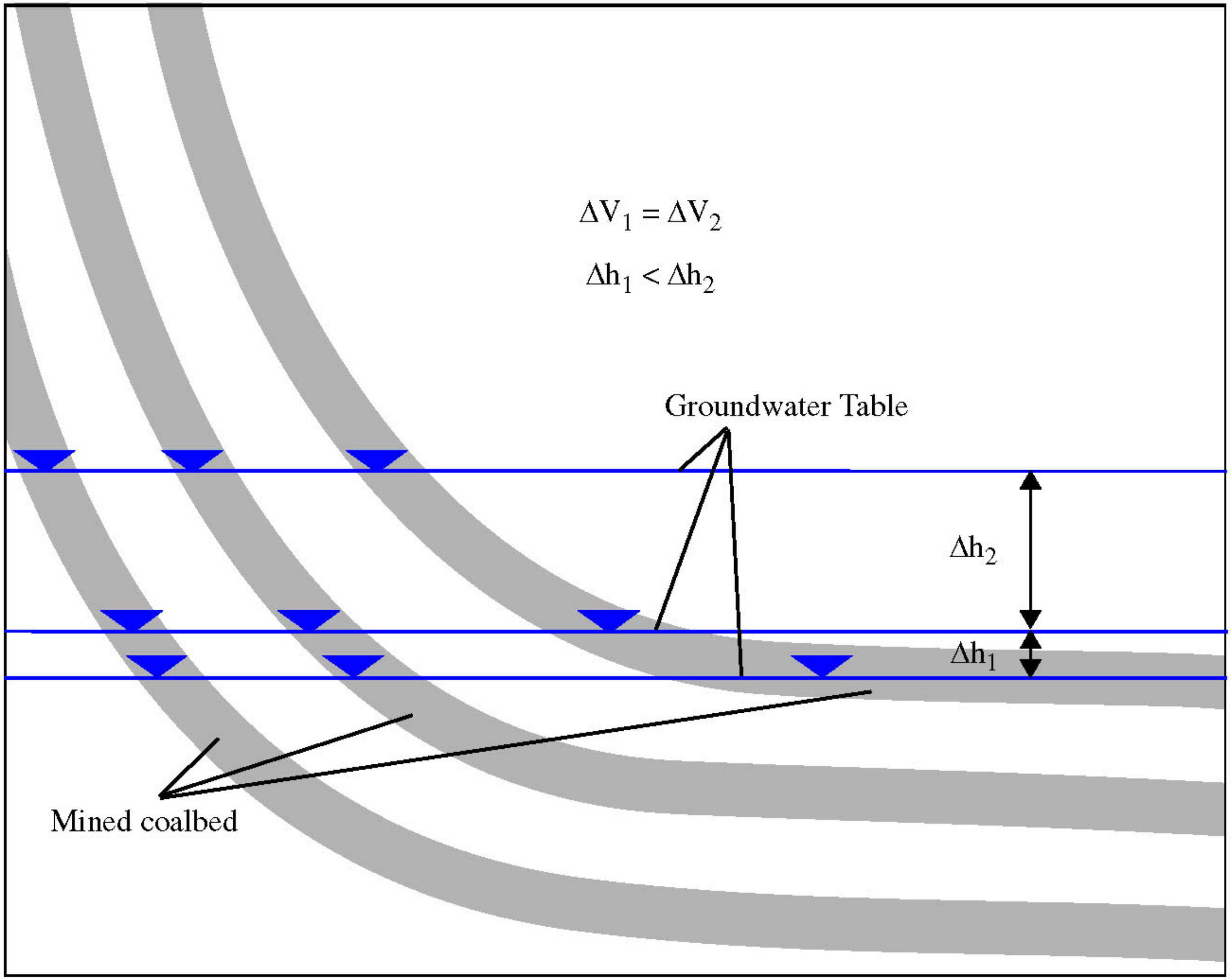
Generalized Dip of Coalbeds in WMF Study Area

Estimated volume of groundwater in mine pool considered dip of coalbeds



Flooded Void Volume & “Beach” Area in WMF Study Area

Changes in groundwater level are greater if the available volume of voids is smaller



Estimated Volumes of Groundwater in WMF Study Area

Estimates considered simulated water levels and volume of coal mined (0.40)

Table 10: Estimated storage volumes and discharges of groundwater by flooded underground mines in the Western Middle Anthracite Coalfield, Schuylkill, Northumberland, and Columbia Counties, Pennsylvania
[ft, feet above National Geodetic Vertical Datum of 1929; ft^3/s, cubic feet per second; Mgal, million gallons]

		Ash and others (1949)		Reed and others (1987)			This report, measured [a]		This report, estimated[b]		
MCU Name	Principal Colliery Name	Water Level in Principal Colliery (ft)	MCU Volume (Mgal)	Water Level in Principal Colliery (ft)	Discharge to AMD Sources	MCU Volume (Mgal)	Water Level in Principal Colliery (ft)	Discharge to AMD Sources (ft^3/s)	Range of Water Levels in MCU (ft)	Discharge to AMD Sources (ft^3/s)	MCU Volume (Mgal)
Vulcan	Vulcan Buck Mountain	1,250	2,396	1,253	7.4	2,543	1,252	8.4	1,262 - 1,668	10.2	6,721
Gilberton	Gilberton	975	6,668	1,102	9.2	9,780	1,100	11.9	1,069 - 1,198	18.6	11,756
Girard	Girard	986	1,424	n.d.	8.0	1,424	n.d.	3.4	982 - 1,069	1.1	4,203
Packer	Packer No. 5	74	2,796	957	51.6	16,244	956	11.9	969 - 1,678	15.9	38,730
Centralia	Centralia	1000	301	n.d.	11.0	301	n.d.	3.1	938 - 1,070	0.0	1,026
Preston	Preston No. 3	948	571	n.d.	2.6	571	n.d.	1.5	934 - 963	1.3	2,764
Bast	Bast	757	3,679	908	7.5	3,679	908	1.5	903 - 1,005	14.2	8,701
Potts & Tunnel	Potts	251	653	999	4.8	794	1,002	1.37	904 - 1,000	0.0	14,603
Locust Gap	Locust Gap	1,173	145	892	17.4	1,750	n.d.	14.5	713 - 1,011	31.7	10,305
Midvalley	Midvalley Nos. 3 and 4	1,212	490	1,212	6.5	489	n.d.	5.5	1,072 - 1,403	2.7	3,545
Scott	Scott and Scott Ridge	886	7,142	999	17.8	8,128	1,000	17.5	963 - 1,144	0.0	30,809
Maysville-Corbin	Maysville Nos. 1 & 2	333	2,102	855	3.3	13,319	852	17.3	789 - 1,037	12.3	25,040
Cameron	Cameron	443	2,251	714	9.8	3,880	736	7.6	680 - 1,060	21.4	24,151
Big Mountain	Big Mountain	869	823	n.d.	2.0	825	n.d.	2.1	790 - 900	0.0	3,319
Stirling	Henry Clay - Stirling	770	5,208	778	11.2	5,213	780	8.7	763 - 889	14.6	23,679
North Franklin	North Franklin	870	1,597	870	8.3	1,597	873	4.5	848 - 891	3.2	7,805
Morea	Morea	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1,433 - 1,559	0.0	2,679
TOTAL:			38,245		197.0	70,538		120.8		147.3	219,835

a. Measured values based on average water levels or sum of discharges for MCU (see tables 5 and 6).
b. Estimated values based on results of preliminary, calibrated steady-state model of groundwater flow for the study area.

Estimated Volumes of Groundwater in WMF Study Area

Range of estimates considered porosities of 0.40 and 0.11

Table 11: Estimated storage volumes and average residence times of groundwater in the mine pools considering different porosities for mined coalbeds in the Western Middle Anthracite Coalfield, Schuylkill, Northumberland, and Columbia Counties, Pennsylvania in 1999-2001

[ft^3/s, cubic feet per second; Bgal, billion gallons; yr, years]

		Outflow rate to:			Porosity factor = 0.40		Porosity factor = 0.11	
MCU Name	Total outflow rate (ft^3/s)	Wells (ft^3/s)	Mine discharges (ft^3/s)	Other MCUs or aquifer (ft^3/s)	Mine water volume (Bgal)	Average residence time of water (years)	Mine water volume (Bgal)	Average residence time of water (yr)
Vulcan	15.34	0.00	10.16	5.18	6.7	1.9	1.9	0.5
Packer	51.51	1.83	15.91	33.77	38.7	3.2	10.7	0.9
Girard	6.21	0.00	1.09	5.12	4.2	2.9	1.2	0.8
Gilberton	36.01	2.67	18.62	14.72	11.8	1.4	3.2	0.4
Centralia	9.61	0.00	0.00	9.61	1.0	0.5	0.3	0.1
Bast	18.29	0.00	14.24	4.05	8.7	2.0	2.4	0.6
Preston	2.99	0.00	1.31	1.68	2.8	3.9	0.8	1.1
Midvalley	6.85	0.00	2.73	4.12	3.5	2.2	1.0	0.6
Potts & Tunnel	9.01	0.00	0.00	9.01	14.6	6.9	4.0	1.9
Scott	33.02	0.00	0.00	33.02	30.8	4.0	8.5	1.1
Locust Gap	39.46	0.00	31.68	7.78	10.3	1.1	2.8	0.3
Maysville-Corbin	40.91	0.00	12.27	28.64	25.0	2.6	6.9	0.7
Cameron	48.88	0.00	21.45	27.43	24.2	2.1	6.6	0.6
Big Mountain	4.74	0.00	0.00	4.74	3.3	3.0	0.9	0.8
Stirling	33.31	0.00	14.64	18.67	23.7	3.0	6.5	0.8
North Franklin	5.92	0.00	3.22	2.70	7.8	5.6	2.2	1.5
Morea	4.30	0.89	0.00	3.41	2.7	2.6	0.7	0.7
TOTAL	366.36	5.39	147.32	213.65	219.8		60.5	

Conclusions

- ✓ Simulated groundwater levels indicate low gradients within an MCU and abrupt changes in water levels between MCUs, consistent with the concept of high-permeability mined areas separated by low-permeability barriers.
- ✓ Model results indicate that the primary result of increased locallized pumping from the mine pool would be reduced discharge as AMD to streams near the pumping wells; intact barriers limit the spatial extent of mine dewatering.

Conclusions

- ✓ Considering the simulated groundwater levels, depth of mining, and assumed bulk porosity of 11 or 40 percent for the mined seams, the water volume in storage in the mines of the WMF mine pool was estimated to range from 60 to 220 billion gallons, respectively.

- ✓ Details of groundwater-level distribution and rates of some mine discharges are not simulated well using the model. Model results should be limited to evaluation of the conceptual model and its simulation using porous-media flow methods, overall water budgets, and approximate storage volumes of underground mines in the WMF area.

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[http://pa.water.usgs.gov/projects/groundwater/western middle/](http://pa.water.usgs.gov/projects/groundwater/westernmiddle/)

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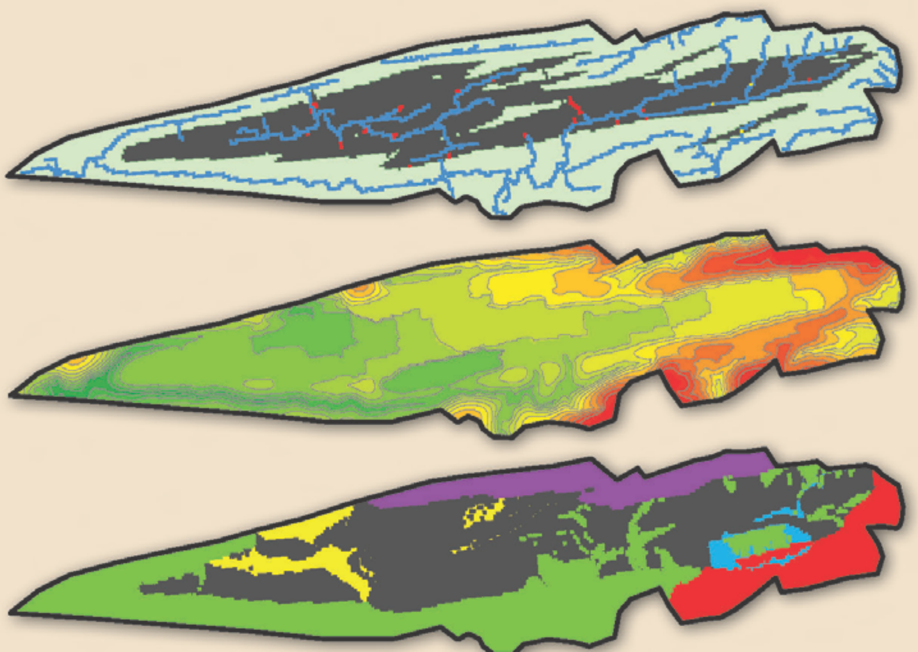
Water Budgets and Groundwater Volumes for Abandoned Underground Mines in the Western Middle Anthracite Coalfield, Schuylkill, Columbia, and Northumberland Counties, Pennsylvania—Preliminary Estimates with Identification of Data Needs



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