Simulating Interbasin Transfer in Abandoned Coal Mines

Elkhorn area, McDowell County, WV

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Outline

1. Pocahontas No. 3 coal mine aquifer in Elkhorn, WV
2. Overview of field data collection
3. Topographic vs. Dip-driven flow: Assessment of groundwater basins
4. Context for the Elkhorn Model
5. Model Methods Summary – Aquifer Properties vs. Boundary Conditions

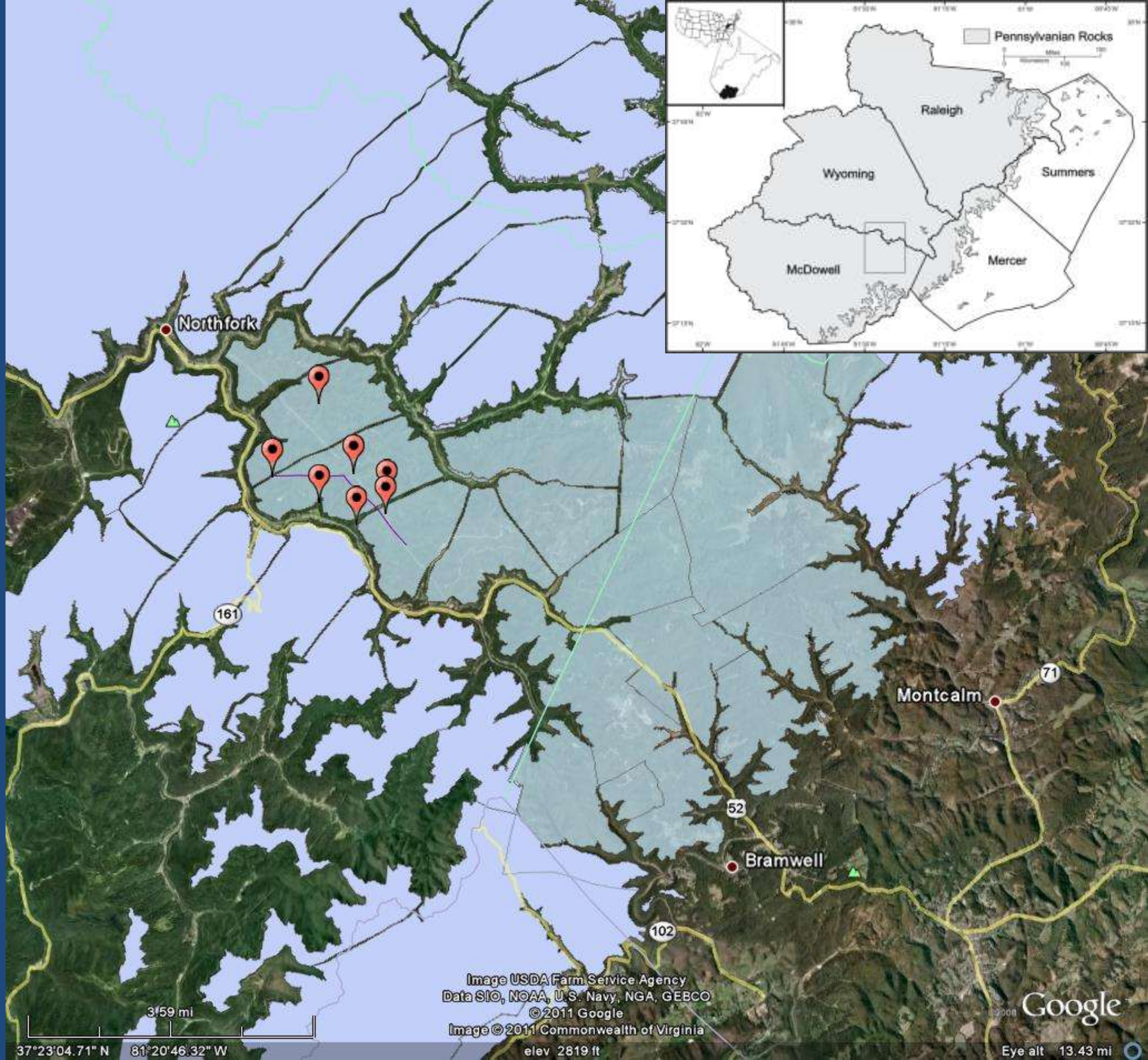
Elkhorn Area, McDowell County WV

Poca #3 Seam

Complete Mine-Out

Above-Drainage

Discharge Used for Water Supply



BOREHOLE LOGS

Cyclical Coal Sequences-
Massive sandstones
Permeability in Coals

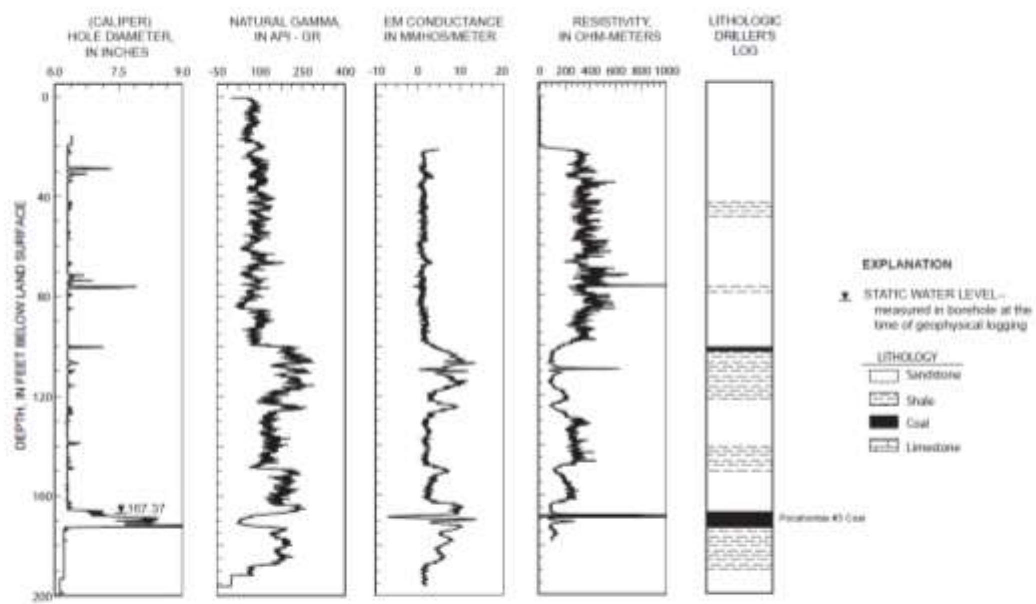


Figure XX. Borehole-geophysical logs for borehole Mcd-0205 (Well 7), collected on August 23, 2009, near Elkhorn, West Virginia.

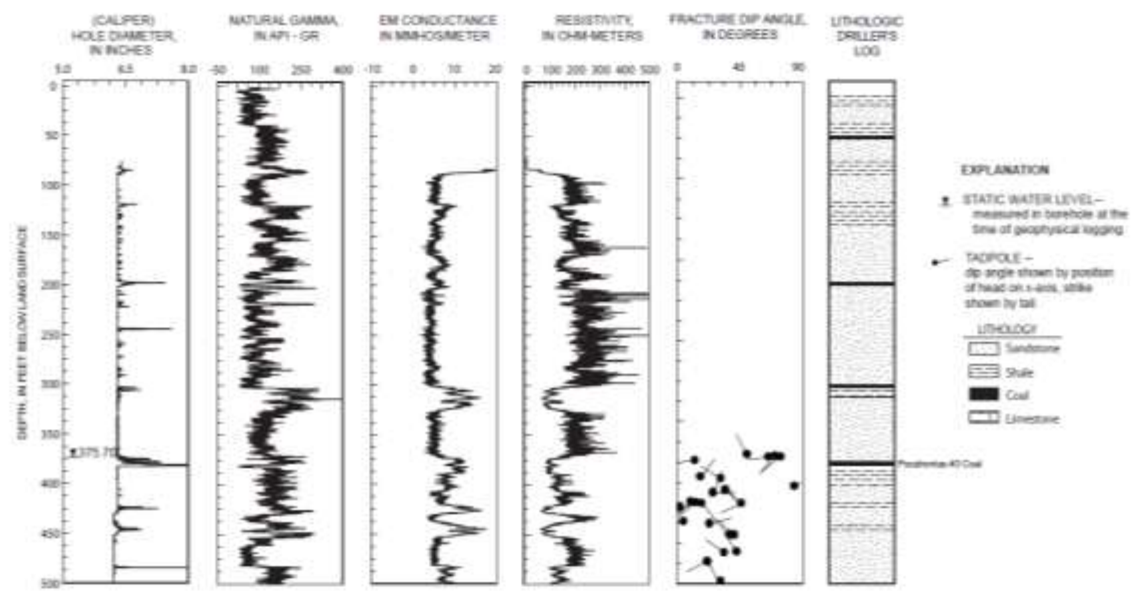


Figure XX. Borehole-geophysical logs for borehole Mcd-0206 (Well 5), collected on August 20, 2009, near Elkhorn, West Virginia.

WATER LEVEL MONITORING

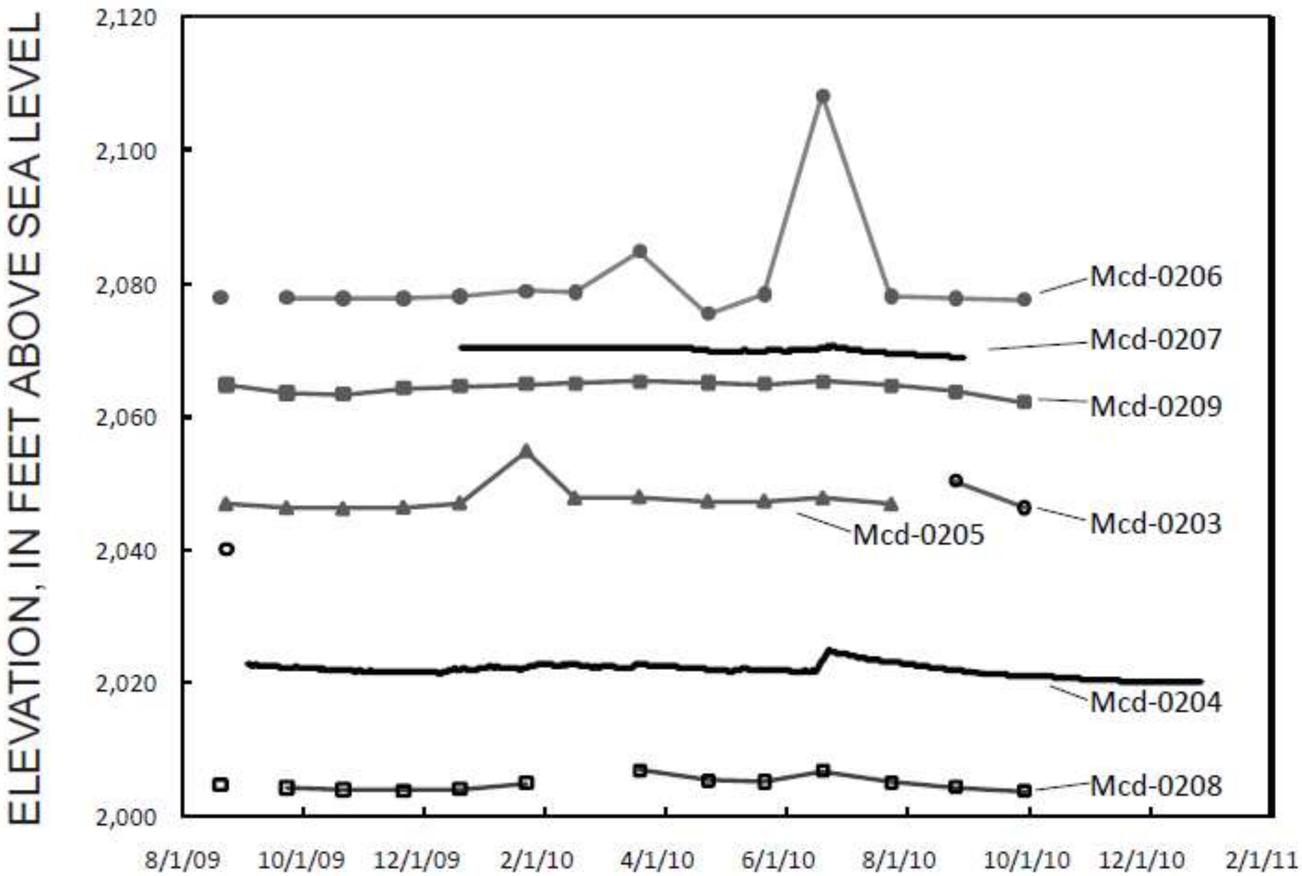
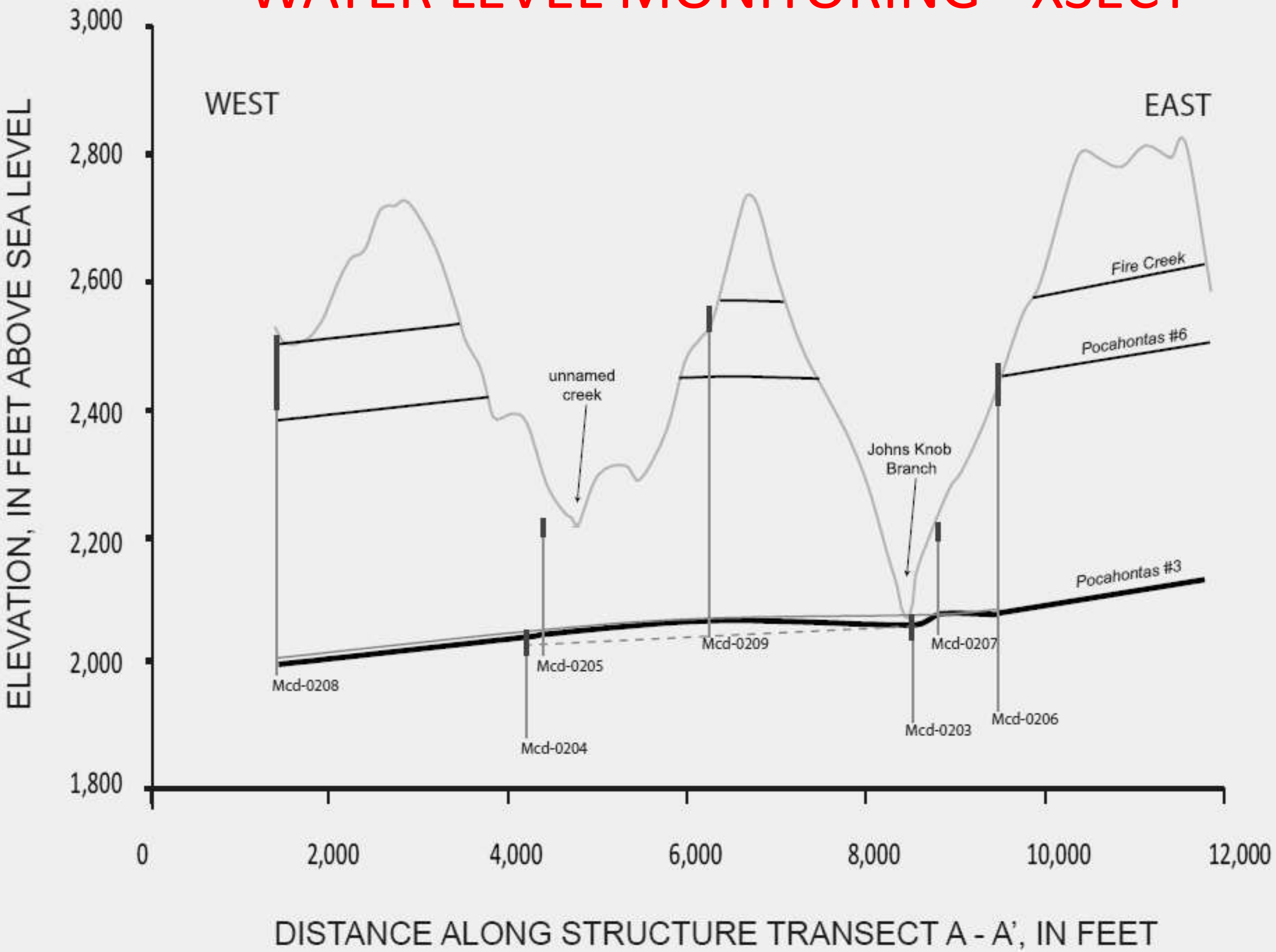
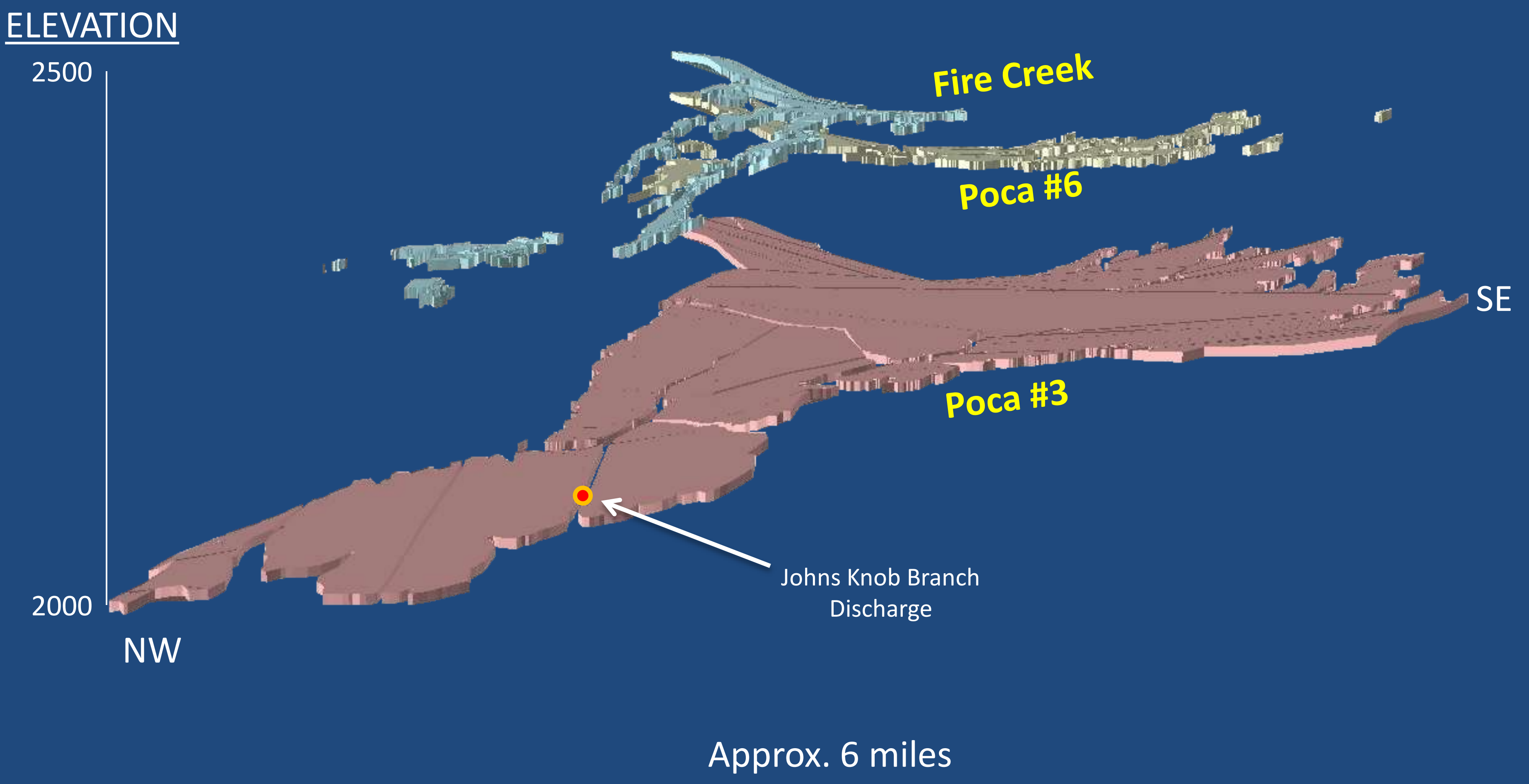


Figure xx. Ground-water level hydrographs from study area wells.

WATER LEVEL MONITORING - XSECT



Abandoned Workings on Structure Contours



Baseflow Separation for Groundwater Recharge

Table X. Streamflow and mean ground-water recharge rates estimated from baseflow recession (PART) of streamflow data in McDowell County, West Virginia.

[mi2, square miles; in/yr, inches per year; cfs, cubic feet per second; %, percent]

Site ID	Station name	Drainage area (mi^2)	Period of record	Mean streamflow (cfs)	Recharge (in/yr)	Recharge (cfs)	Baseflow index (%)
3212558	PUNCHEONCAMP BRANCH AT LECKIE, WV	1.4	1981	1.01	8.1	0.81	80.2
3212567	FREEMAN BRANCH NEAR SKYGUSTY, WV	0.3	1981	0.16	4.5	0.1	63.6
3212580	LEFT FORK SANDLICK CREEK AT ELBERT, WV	1.7	1981	1.27	9.0	1.12	87.9
3212585	RIGHT FORK SANDLICK CREEK NEAR GARY, WV	1.2	1981	0.51	3.2	0.29	56.2
3212600	TUG FORK AT WELCH, WV	85.9	1979-1980	103.53	12.0	76.04	73.4
3212640	JOHNS KNOB BRANCH AT ELKHORN, WV	0.8	2009	5.43	89.8	5.35	98.5
3212700	ELKHORN CR AT MAITLAND, WV	69.9	1979	149.83	23.9	123.19	82.2
3212703	ELKHORN CREEK TRIBUTARY AT WELCH, WV	0.6	1981	0.32	3.7	0.17	54.7
3212750	TUG FORK AT WELCH, WV	174	1986-1992	198.63	12.3	157.78	79.4
3212750	TUG FORK AT WELCH, WV	174	1997-2008	196.24	12.3	157.29	80.2
3212980	DRY FORK AT BEARTOWN, W. VA.	209	1986-1992	224.91	9.5	146.35	65.1
3212980	DRY FORK AT BEARTOWN, W. VA.	209	1997-2009	219.22	9.1	140.42	64.1
3212985	DRY FORK AT AVONDALE, WV	225	1979-1980	295.65	11.4	189.43	64.1
3213000	TUG FORK AT LITWAR, WV	504	1931-1983	555.44	9.1	338.86	61
3213495	CRANE CREEK NEAR PANTHER, WV	0.5	1981	0.44	6.2	0.25	56.6
3213500	PANTHER CREEK NEAR PANTHER, WV	31	1947-1985	35.17	7.4	16.83	47.8
3213500	PANTHER CREEK NEAR PANTHER, WV	31	2003-2008	36.17	7.5	17.06	47.2
			mean	119.1	14.1	80.7	68.4
			median	36.2	9.1	17.1	64.1

Source Water Variation to Above-Drainage Mine – Residence Times

- Dye Trace – Hours
- Stable Isotopes – Months/Yrs
- CFC - Decades

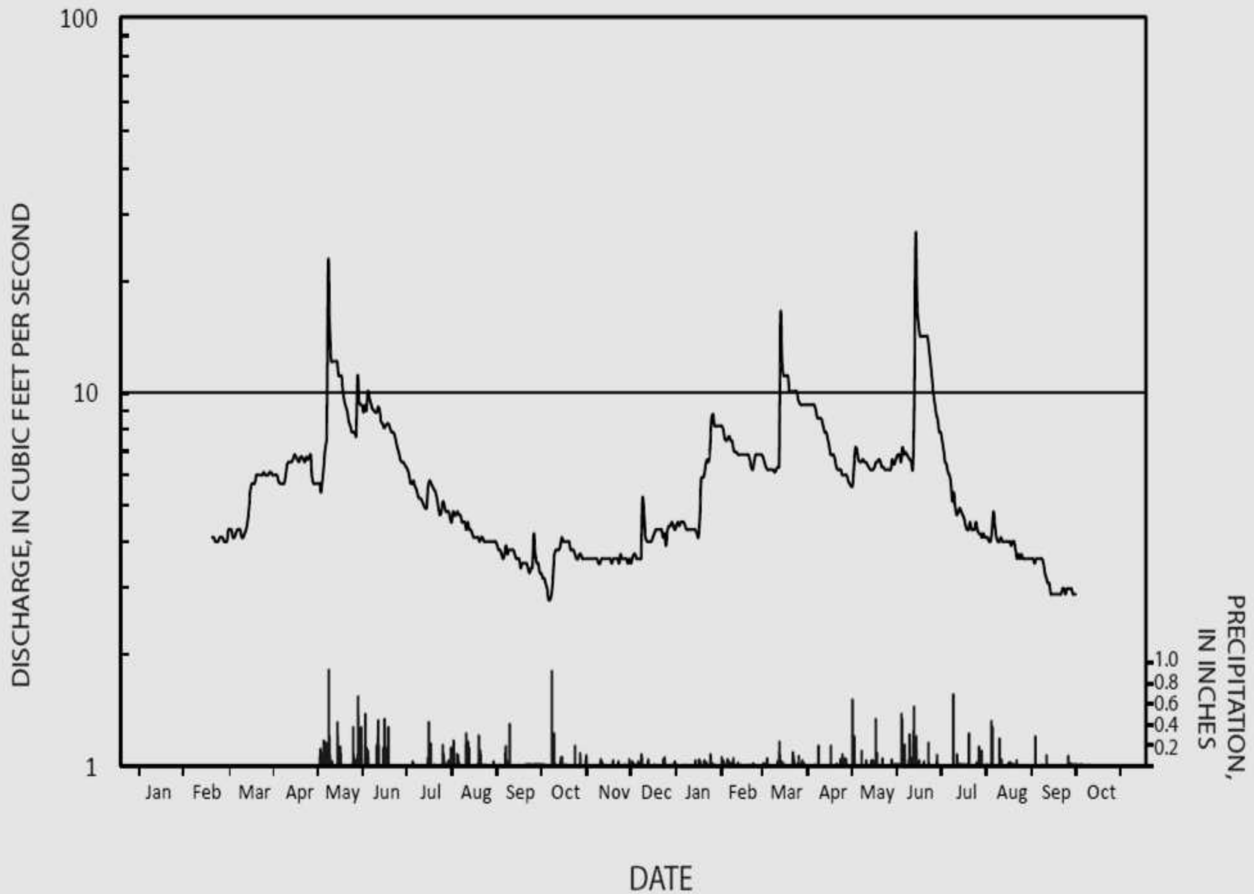


Figure xx. Hydrograph and precipitation from USGS gaging station 03212640 Johns Knob Branch at Elkhorn, West Virginia.

Pre-Mining Hydrology

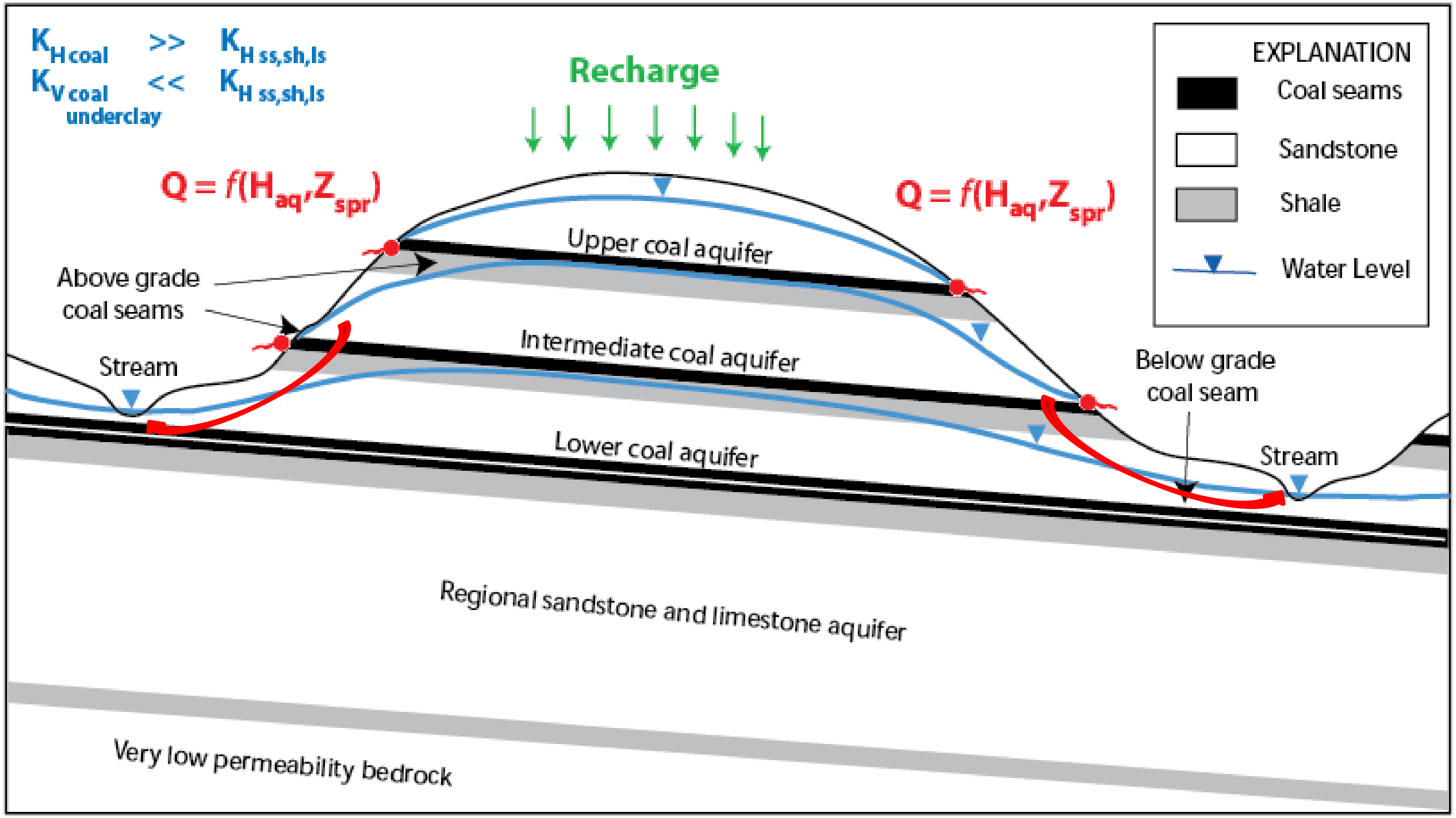
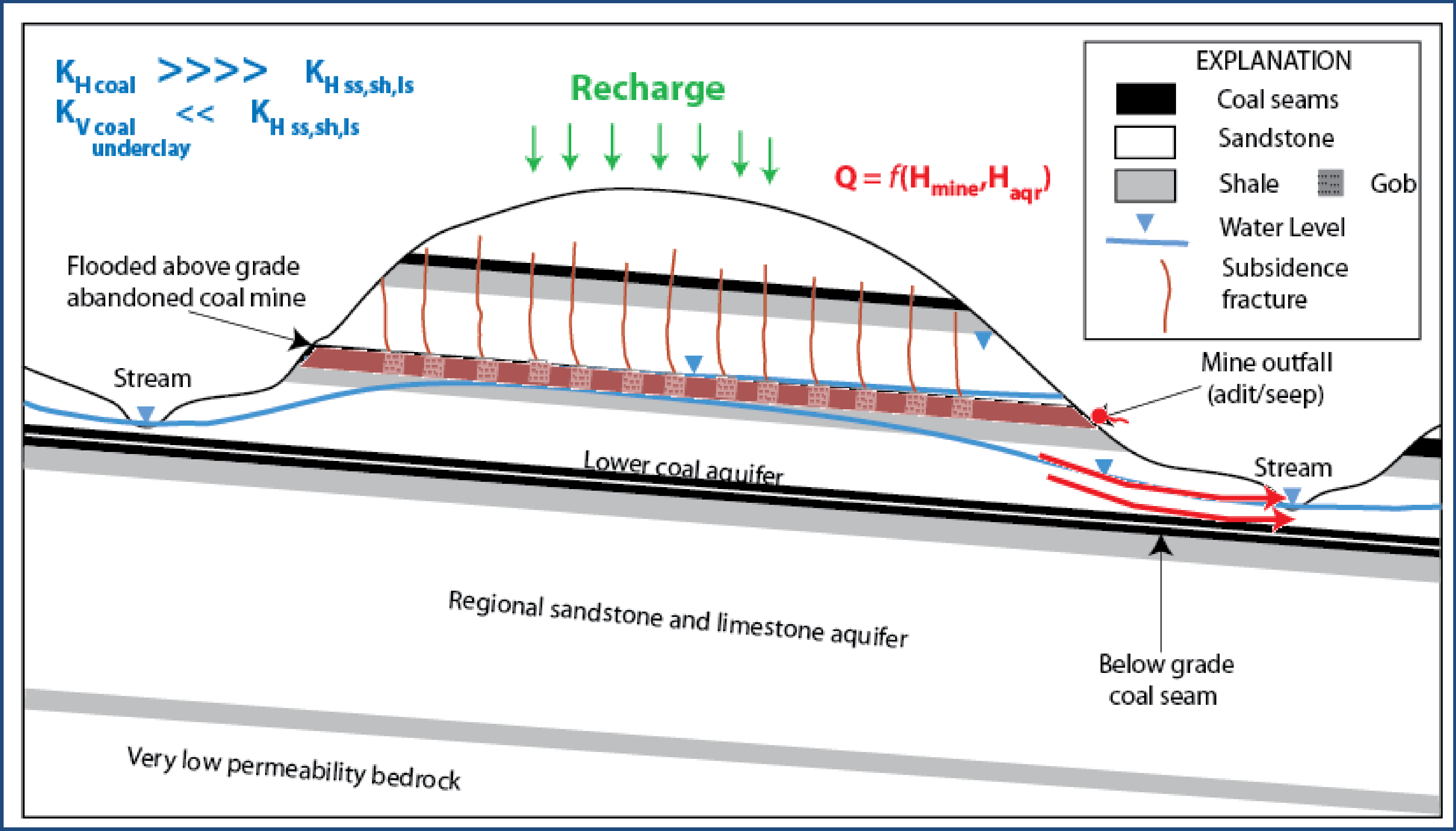


Figure ___. Conceptual model of perched aquifers in an unmined setting typical of the southern West Virginia coal province.

Topographically-Driven Flow

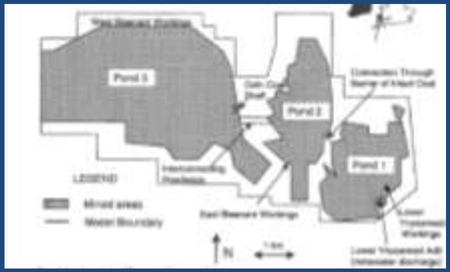
Post-Mining Hydrology



Dip-Driven Flow

MODELING and MINING

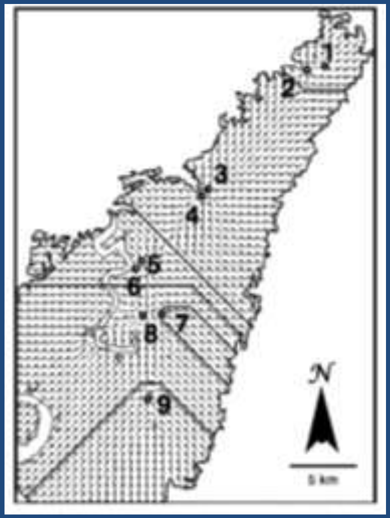
1. **MINE TO MINE INTERACTION** - GRAM (Sherwood and Younger, 1994)
   VSS-NET (Adams and Younger, 2001)



(Adams and Younger, 2001)

2. **FLOW TO AN ADIT** - MODBRNCH (Zhang and Lerner, 2000)
   MIFIM (Banks, 2001)

3. **ASSESS RESIDENCE TIMES** – ArcHydro (Winters and Capo, 2004).



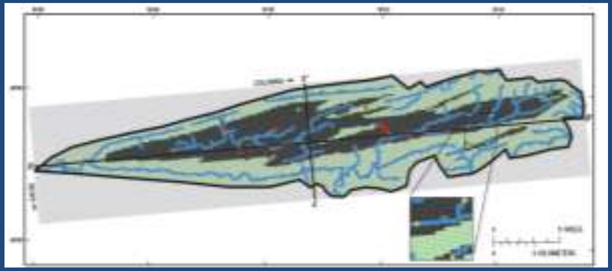
(Winters and Capo, 2004)

4. **INFLOW TO WORKINGS** - MIFIM (Banks, 2001);
   ArcHydro (Winters and Capo, 2004)
   MODFLOW (Zaidel and others, 2010)

5. **GROUNDWATER REBOUND** – MODFLOW (Toran and Bradbury, 1988)

6. **WATER BUDGETS** – MODFLOW (Goode and others, 2010)

7. **COMPLEX** – Hydromechanical, variably saturated
   (Elsworth and Liu, 1995, etc.)

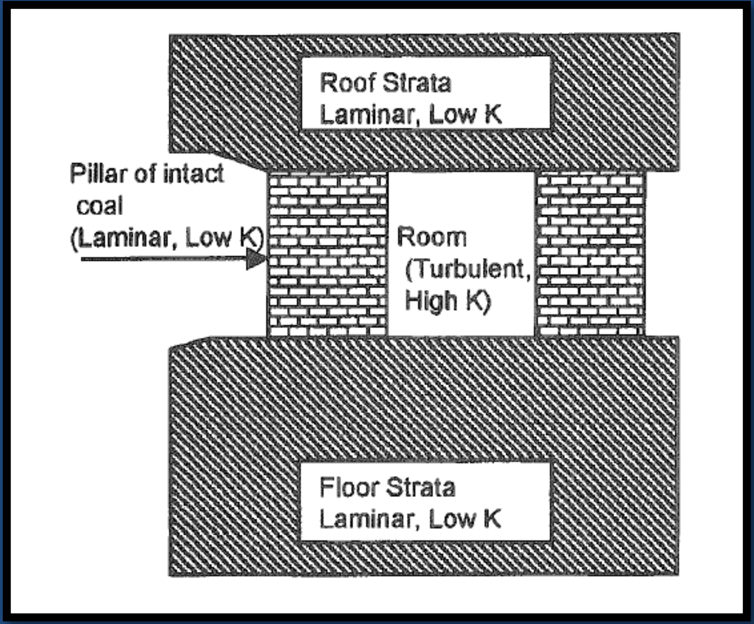


(Goode and others, 2010)

MODFLOW and MINING

Booth (2002) – "…generally quite inappropriate for the non-Darcian flow through the mine openings…"

"…variably saturated media above mine is problematical…"



(Adams and Younger, 2001)

"…problems encountered in relation to spatial and temporal discretization."

"…flow through large voids will often be turbulent

- Adams and Younger (2001)

" The unusual characteristics of mines and data limitations appear to have restricted the success of these models."

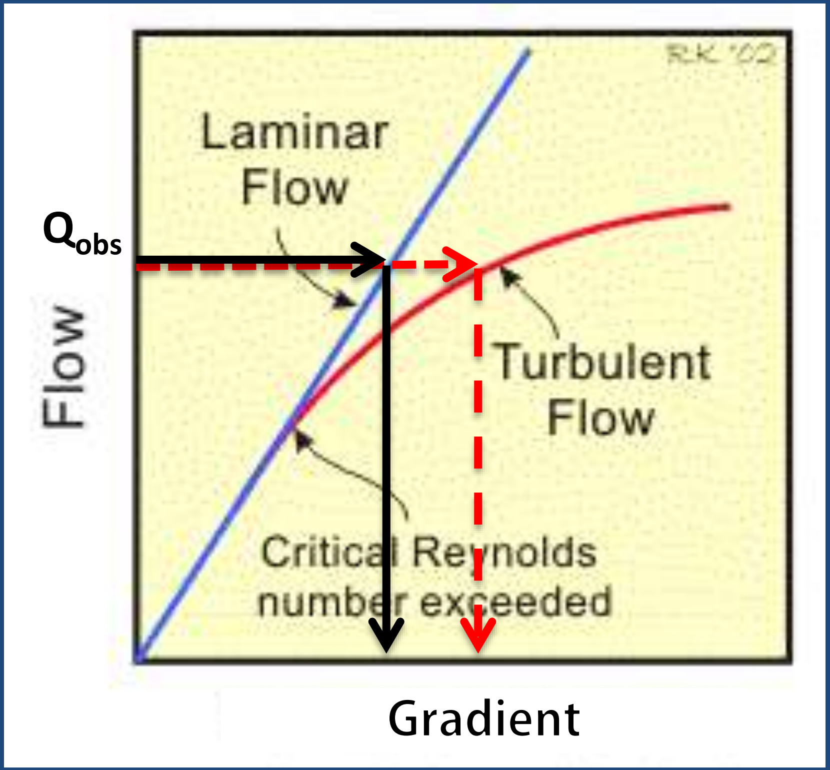
- Zhang and Lerner (2002)

MODFLOW and MINING

Summary of Problems:

1. **Turbulent Flow**:
   High K workings = High Velocity

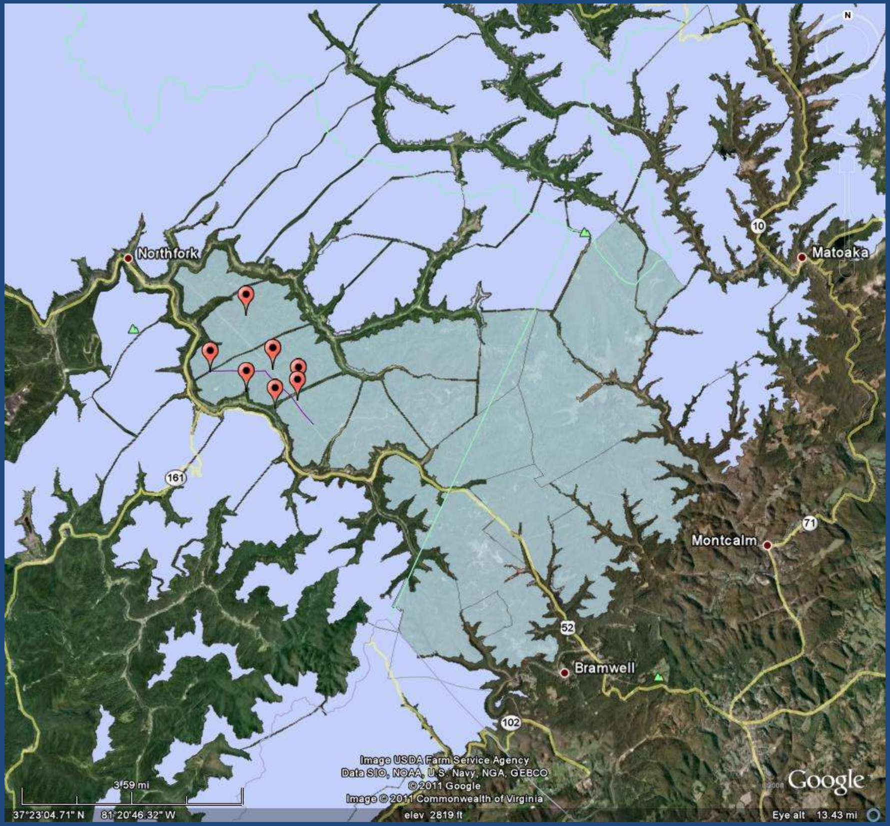
2. **Nonconvergence**:
   Geologic heterogeneities
   Explicit modeling of multiple seams
   Variable saturation



Adapted from
http://www.cvphysiology.com/Hemodynamics/H007.htm

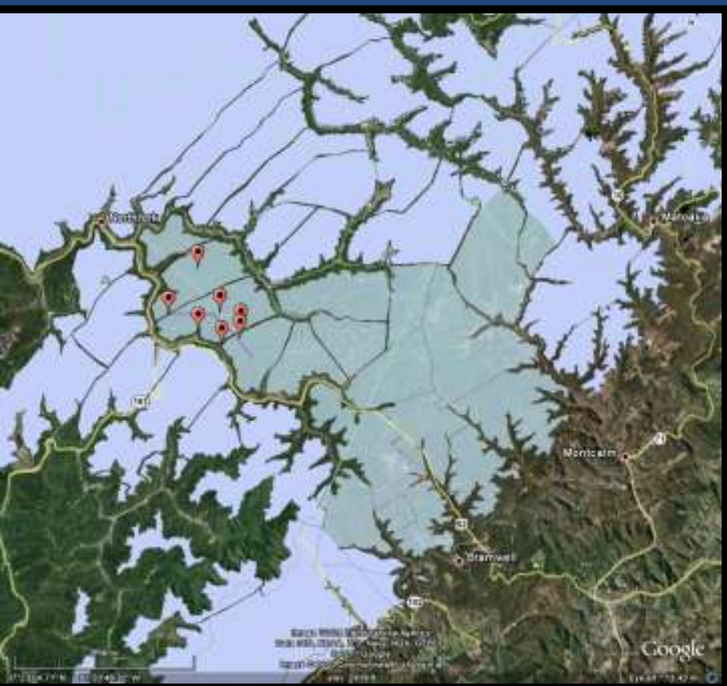
Purpose – Water Budget

- **Darcian modeling of mine aquifer systems is difficult, but results can be used for regional-scale (100s to 1000s km^2) water balance (Adams and Younger, 2001)**



Elkhorn Study Area = 152 km^2

Elkhorn Model Domain – Poca No. 3



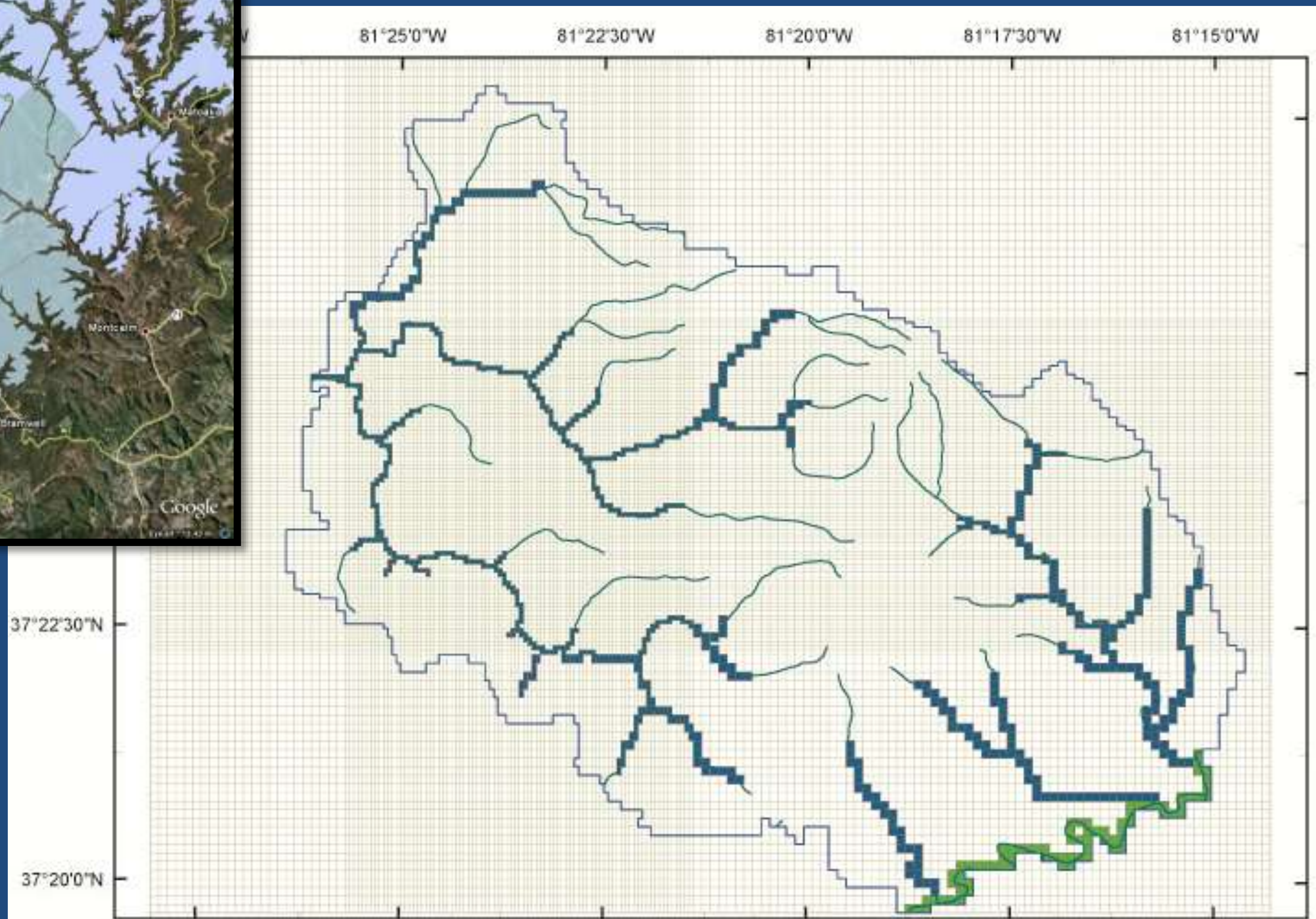


Figure #. Map showing the domain, drain cells simulating streams, river cells, no-flow boundaries, and the finite difference grid for the numerical groundwater-flow model developed for the Elkhorn area, McDowell County, West Virginia.

Model Layers

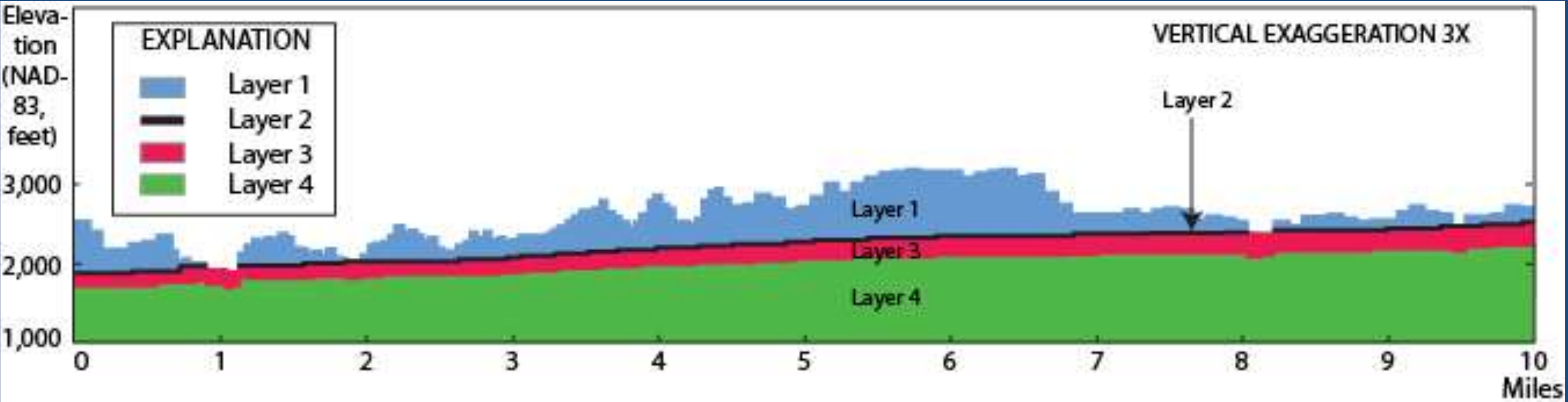


Figure 19. Cross section showing layers of the numerical groundwater-flow model developed for the Elkhorn area, Mcdowell County, West Virginia. [NAD-83, North American Vartical Datum of 1983; cross section patterened from row 89 of model].

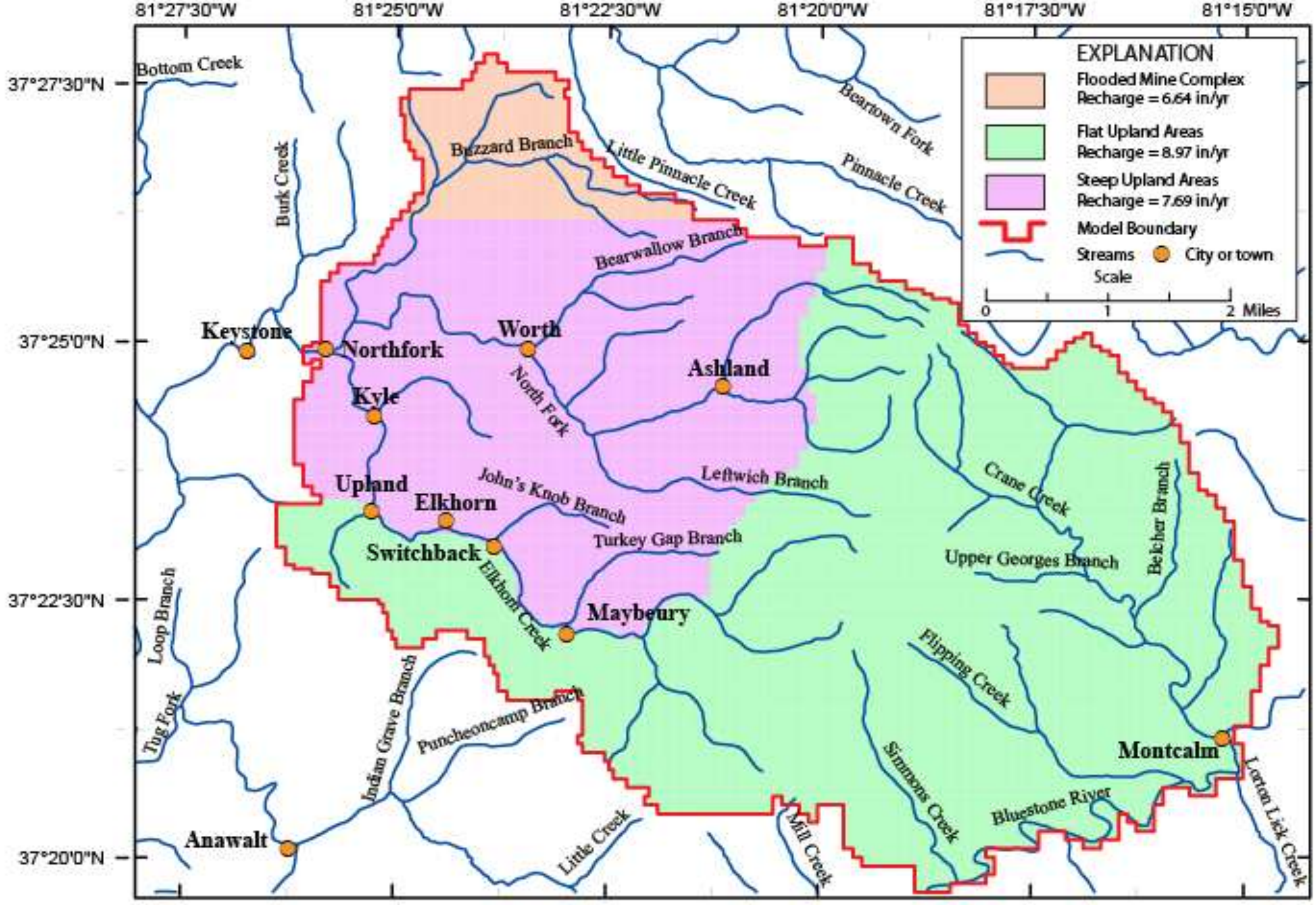


Figure 26. Recharge for three distinct regions within the numerical groundwater-flow model developed for the Elkhorn area, McDowell County, West Virginia.

Hydraulic Properties

Layer 1

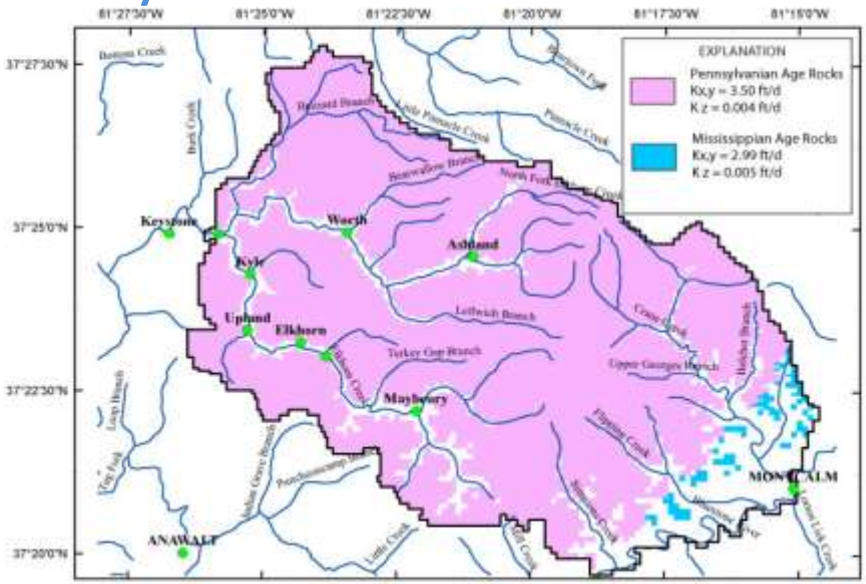


Figure #. Distribution of hydraulic conductivity in layer 1 of the numerical groundwater flow model developed for the Elkhorn area, McDowell County, West Virginia.

Layer 2

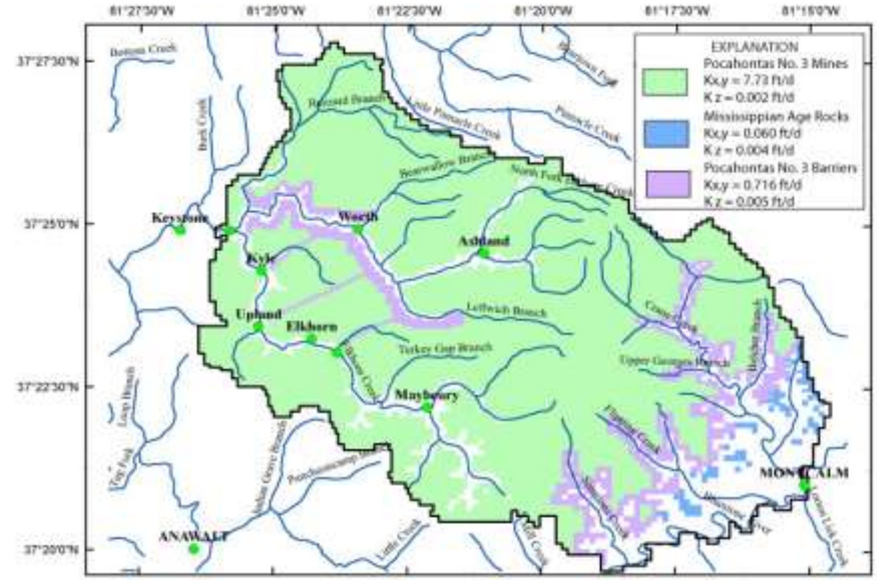


Figure #. Distribution of hydraulic conductivity in layer 2 of the numerical groundwater flow model developed for the Elkhorn area, McDowell County, West Virginia.

Layer 3

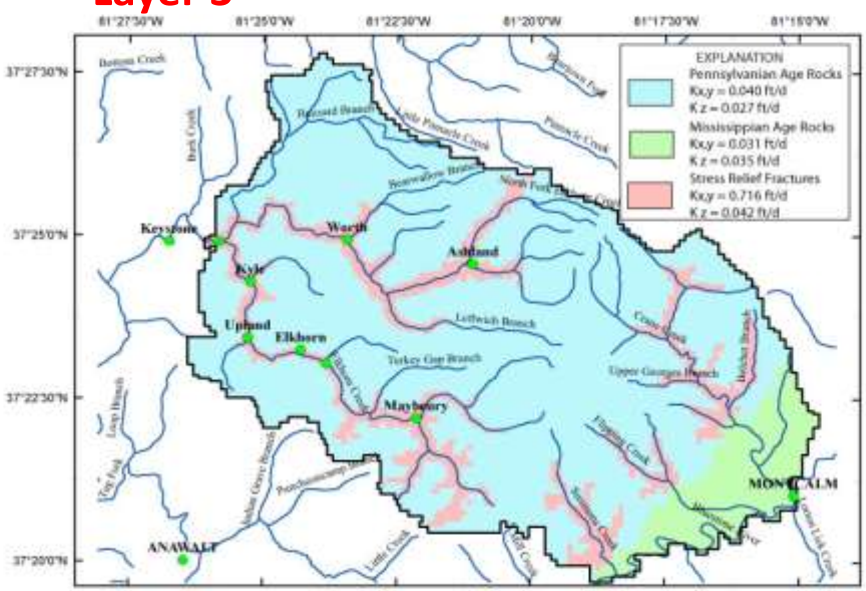


Figure #. Distribution of hydraulic conductivity in layer 3 of the numerical groundwater flow model developed for the Elkhorn area, McDowell County, West Virginia.

Layer 4

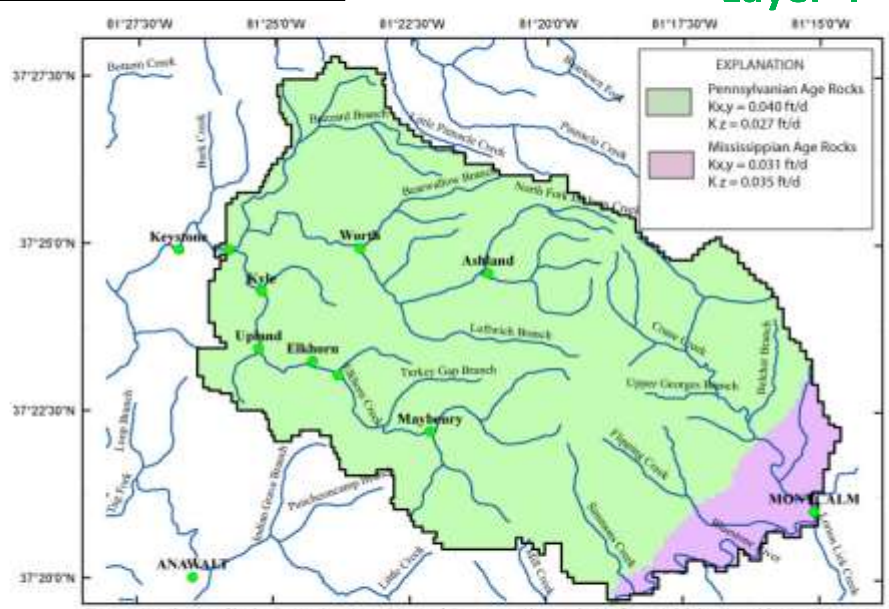


Figure #. Distribution of hydraulic conductivity in layer 4 of the numerical groundwater flow model developed for the Elkhorn area, McDowell County, West Virginia.

Results – High K Mine Aquifer Concept

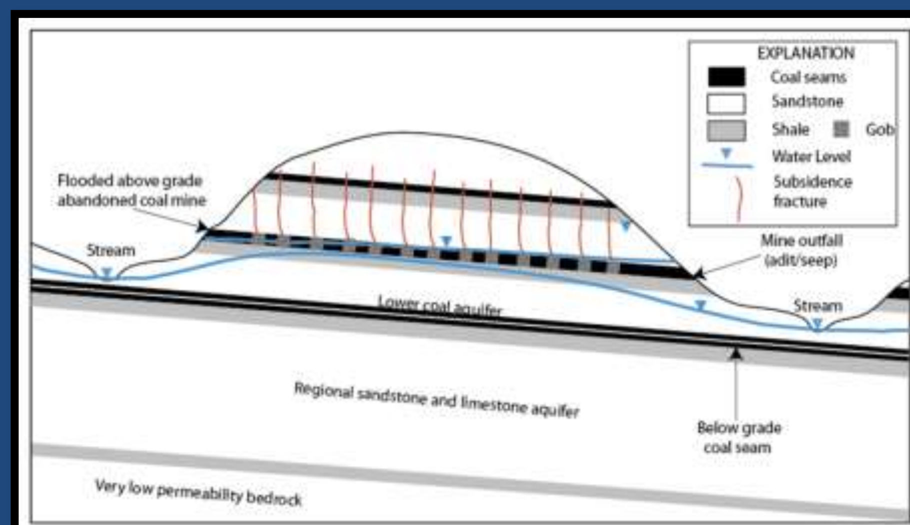
Method 1: $K_{coal} >>> K_{ss,ls,sh}$		
	Simulated flow ft^3/s	Measured flow ft^3/s
North Fork	11.23	9.07
Elkhorn Creek	11.71	16.5
Johns Knob Branch	0.39	3.13
Buzzard Branch	2.36	3.14

Highly Permeable Mine Aquifer

Method 2: $K_{haulage} >>>> K_{coal} >> K_{ss,ls,sh}$		
	Simulated flow ft^3/s	Measured flow ft^3/s
North Fork	11.18	9.07
Elkhorn Creek	12.17	16.5
Johns Knob Branch	0.52	3.13
Buzzard Branch	2.89	3.14

Highly Permeable Mine Haulways

1. Poor agreement with observed flow data
2. Heads 100s of ft above mine void
3. Topographic-driven flow



What is the role of the mine void?

- Permeability contrast alone cannot explain observed heads and flows
- Internal head dependent boundary condition (DRAIN)

$$Q_{mine} = f(H_{mine}, H_{aq})$$

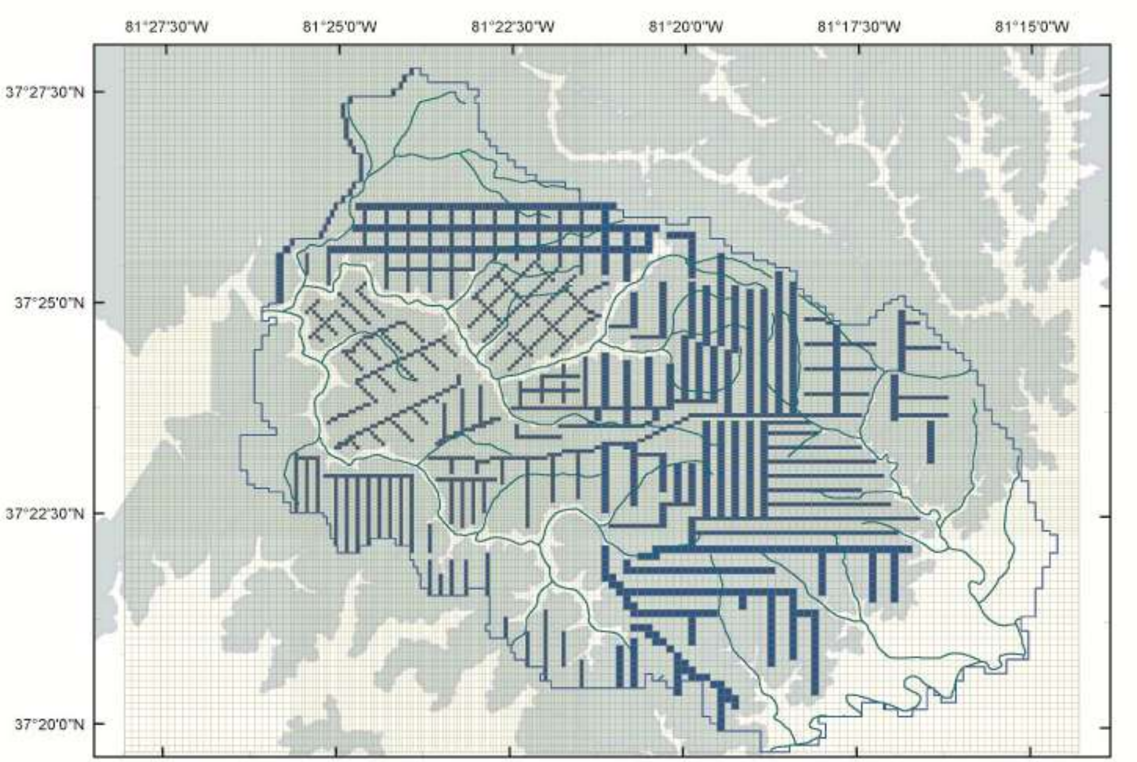


Figure #. Locations of drain cells used in the numerical groundwater flow model to simulatethe free-flowing mine entires of the abandoned Pocahonts No. 3 coal mine workings in the Elkhorn area, McDowell County, West Virginia.

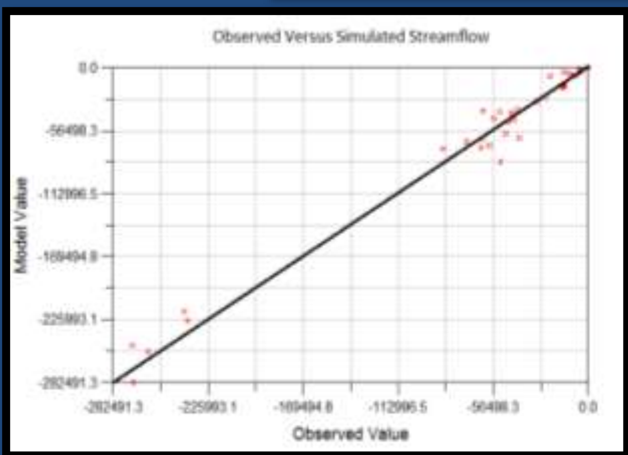
Revised Model Results

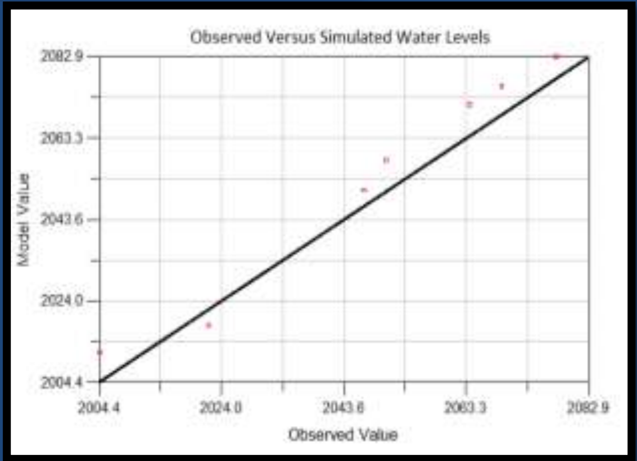
~~1. Highly Permeable Mine Aquifer~~

~~2. Highly Permeable Mine Haulways~~

3. Internal head dependent boundary

Method 3: Qmine = f(h_{mine}, h_{coal})		
	Simulated flow ft^3/s	Measured flow ft^3/s
North Fork	9.09	9.07
Elkhorn Creek	16.35	16.5
Johns Knob Branch	3.39	3.13
Buzzard Branch	2.45	3.14





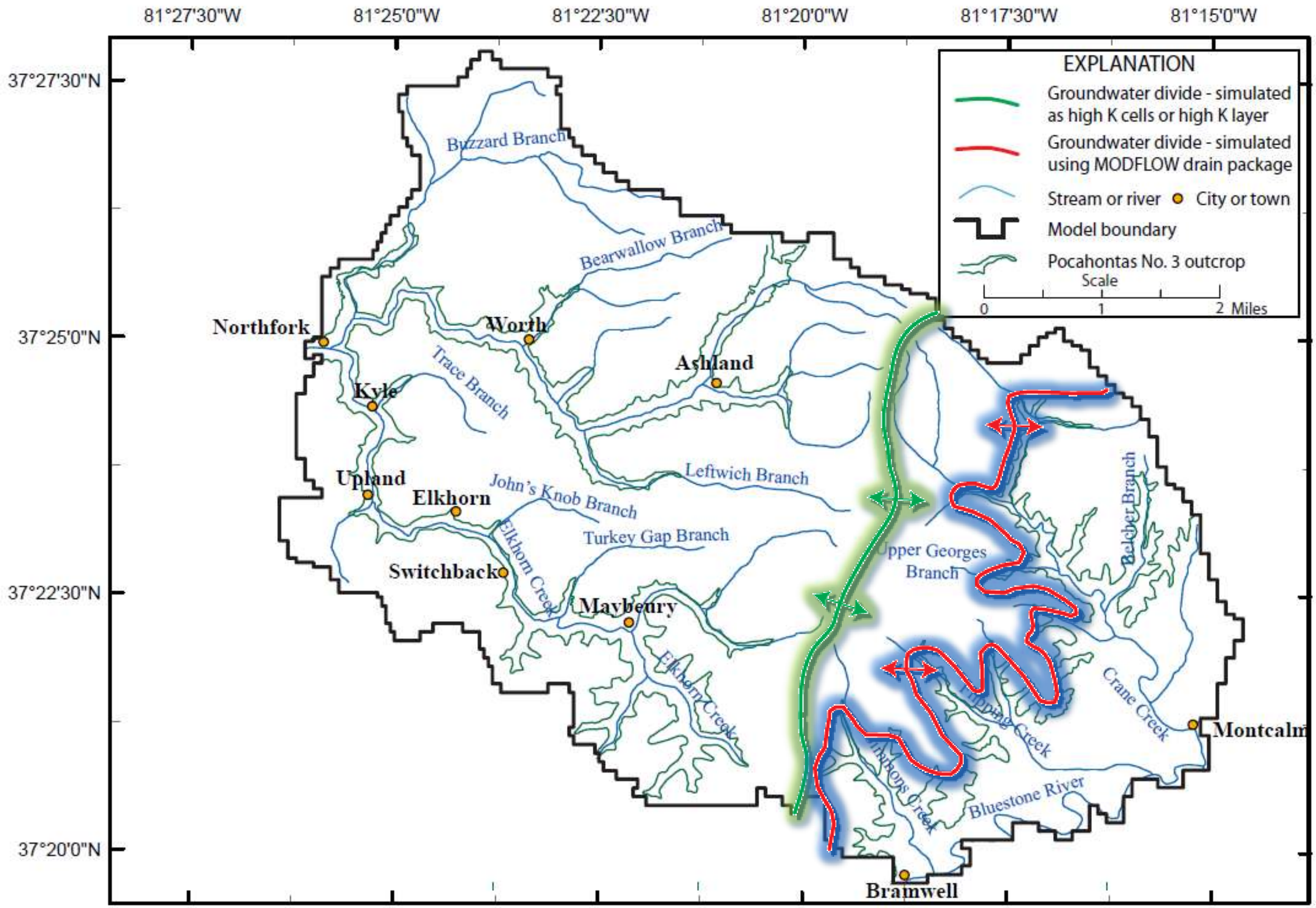


Figure __. Approximate location of groundwater divides simulated either as A) high K cells in a low permeability matrix or as a high K layer, or B) simulated as drains in the groundwater-flow model for the Elkhorn area, McDowell County, West Virginia.

Conclusions: Mining Hydrology

- Model simulation of mine workings is crude with many simplifying assumptions.
- Just beginning to place flow at adits in context of regional mass balance.
- **Role of the mine aquifer in conversion of topographic to dip-driven flow requires head dependent flux boundaries be satisfied.**