Recharge to Underground Mines

Why is this Important?

- Inflow rate during mining.
- Rate of flooding after mining.
- Ultimate discharge rate once equilibrium is reached (inflow = outflow).
- Impact the post-mining head expressed by the mine.
- Strongly impact treatment plant set up and cost of treating post-mining discharges.
- Other factors to be considered.

Background

What is the source of the recharge water?

- Precipitation
- Ground water stored in aquifers
- Direct stream loss
- Seepage from adjacent flooded mines
- Interaction of overlying or underlying mines
- Wells and other manmade structures acting as conduits

Range of Recharge Rates Reported

Recharge Rate in gpm/acre	Source	Context
0.47 - 0.76	U.S. EPA, 1975	From Research in PA
0.011	Permitting Info.	SW PA
0.20 and 0.464	Winters et al., 1999	PA <200' and avg. 250' OB
0.029 to 0.29	Lovell and Gunnett, 1974	PA
0.01	Tieman and Rauch, 1987	SW PA and Northern WV
0.654	Miller and Thompson, 1974	PA included barrier seepage
0.16	Hollyday and McKenzie, 1973	MD
0.76 to 1.20	Hlortdahl, 1988	MD
1.74 to 2.92	Booth, 1986	PA mountains
0.21 to 0.35	Burbey et al., 2000	VA
0.16 to 0.96	Cifelli and Rauch, 1986	Northern WV
0.21 to 0.174	Donovan et al., 1999	Southern Mon. Basin
0.41	McCament et al., 2003	Southern Ohio
0.52 to 0.775	Stoertz et al., 2001	Southern Ohio
1.0	Hobba, 1987	Upshur Co., WV
0.35 to 0.70	Carpenter and Herndon, 1933	Northern WV
0.35 to 0.75	Hawkins and Perry, 2005	Central PA

Summary

Range of reported values
0.01 to 2.92 gpm/acre
Mean = 0.59 gpm/acre
Median = 0.44 gpm/acre

Rule of Thumb = 0.5 gpm/acre
based on Parizek's work from the early 1970's

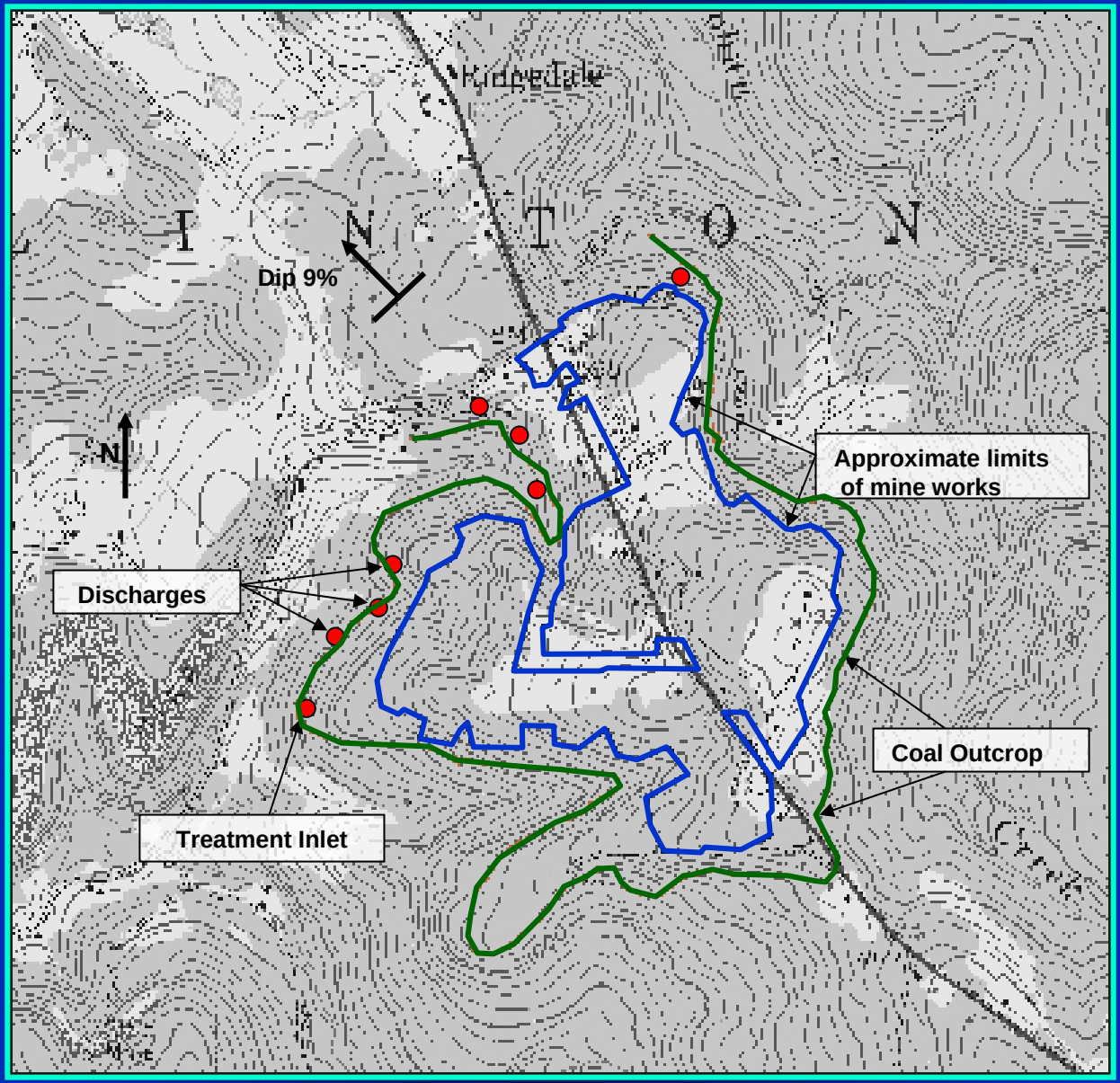
Three Brief Case Studies

Omega Mine - WV

Berlin – Pen Mar Mines - PA

Barnes & Tucker Lancashire 15 - PA

Omega Mine


Dip 9%
N
Approximate limits of mine works
Discharges
Coal Outcrop
Treatment Inlet

Discharges are piped, and collected.

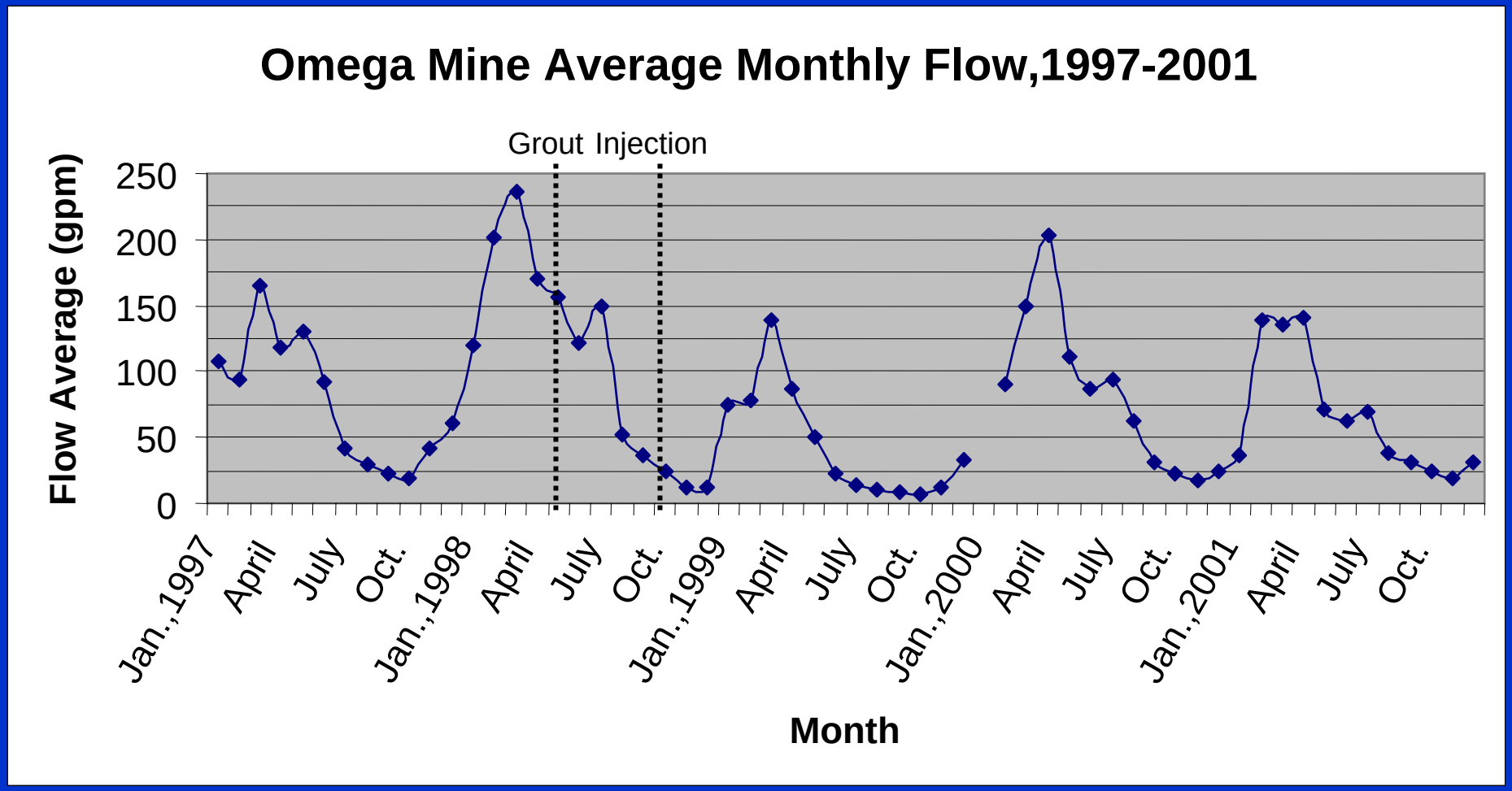
And Treated.

Background

- Mined in the 1980's; closed in 1989.
- A relatively small mine - 172 acres.
- Maximum overburden 171 feet thick with as little as 20 feet in shallow areas.
- Overburden primarily sandstones with some shale.
- Vertical (stress relief) fracturing prominent in the overburden.

More Background

- Isolated hilltop mine above drainage.
- No adjacent underground mines.
- Recharge is essentially all from precipitation.
- Partial grouting of the mine was conducted in an attempt to remediate the AMD.
- The mine discharges mainly through a series of horizontal boreholes.

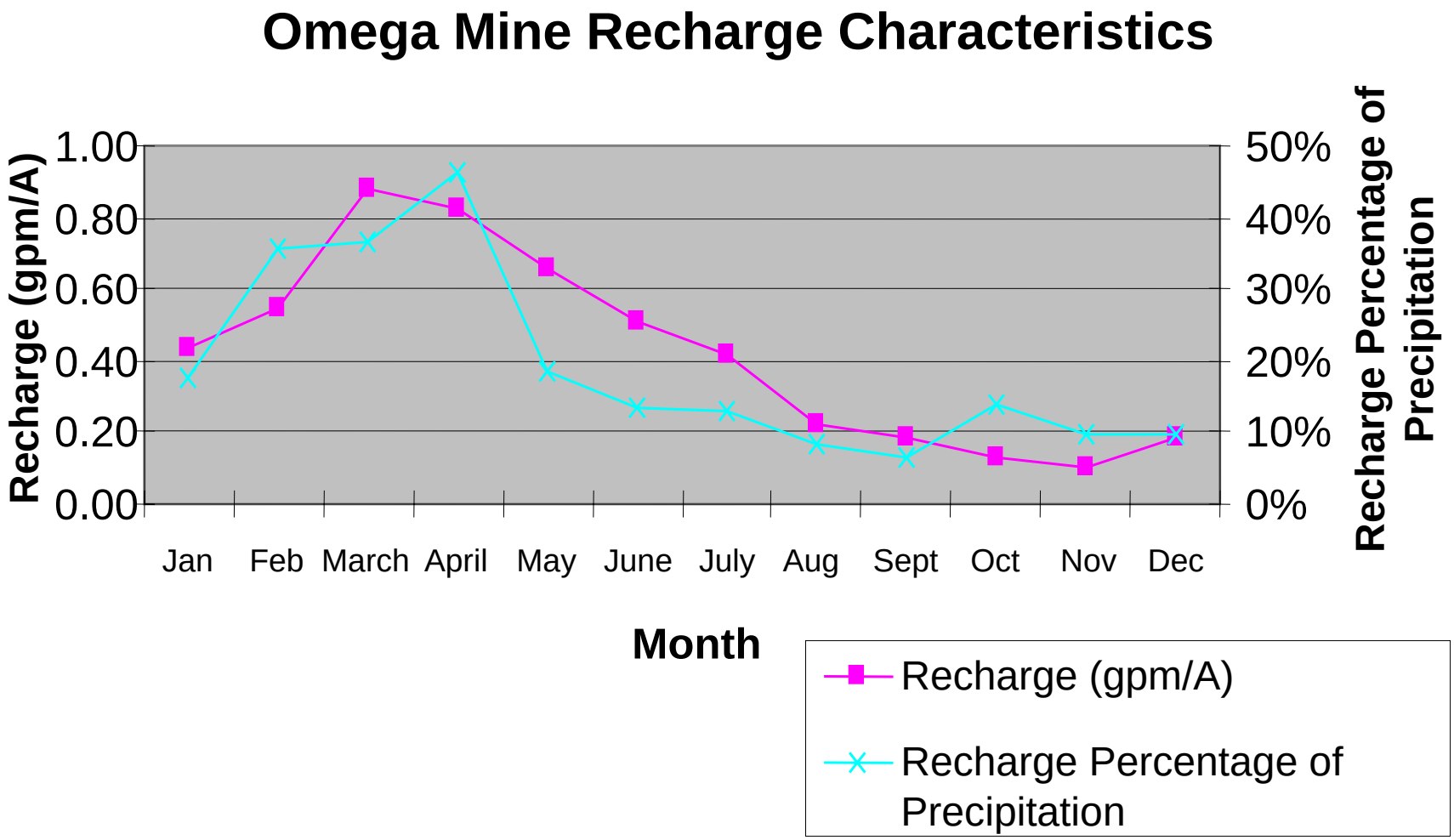

Omega Mine Average Monthly Flow,1997-2001
Grout Injection
Flow Average (gpm)
250
200
150
100
50
0
Jan.,1997
April
July
Oct.
Jan.,1998
April
July
Oct.
Jan.,1999
April
July
Oct.
Jan.,2000
April
July
Oct.
Jan.,2001
April
July
Oct.
Month

Summary

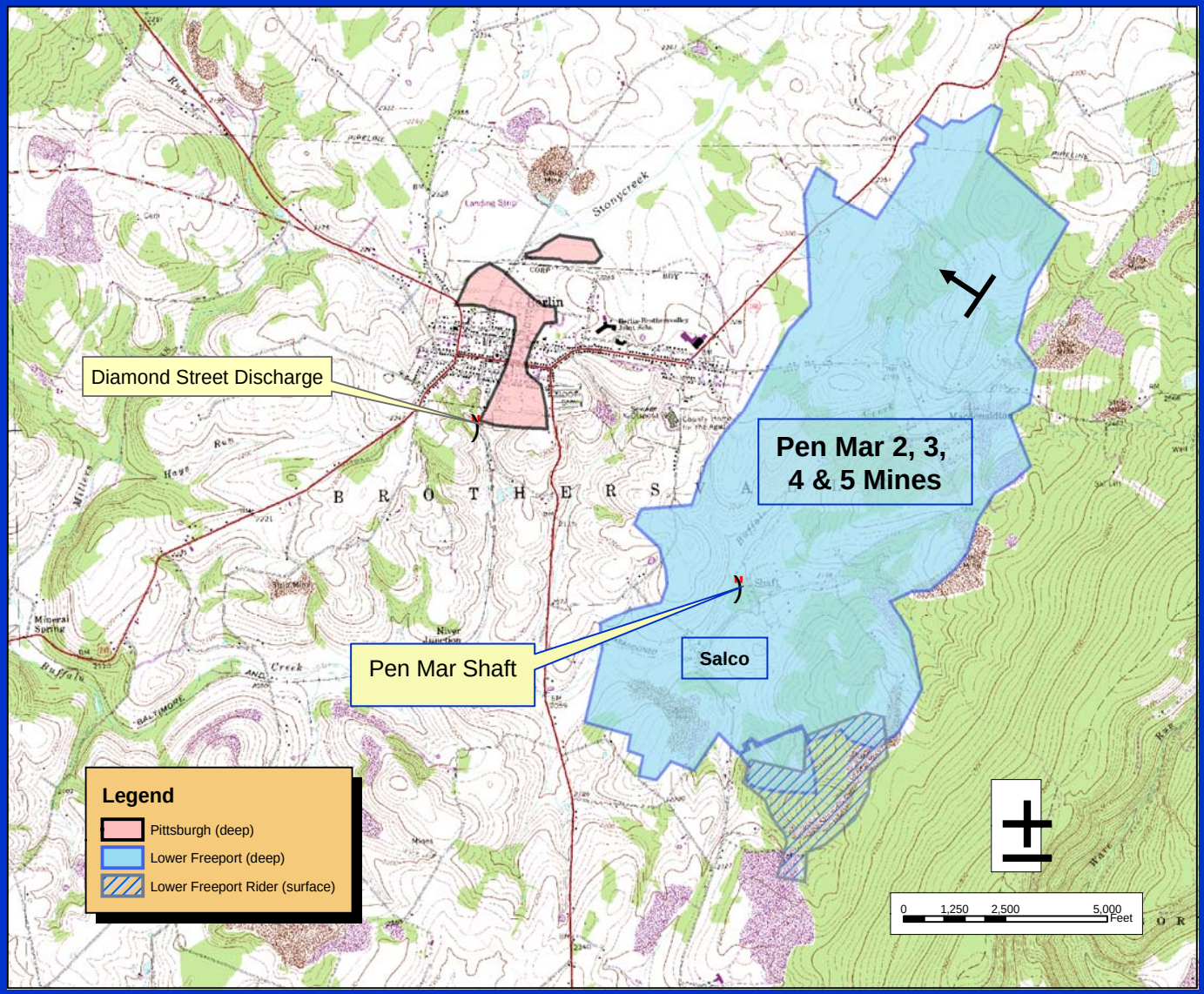
Recharge ranges from a mean of 0.105 gpm/acre in November to a mean 0.882 gpm/acre in March.

Overall mean and median recharge = 0.426 gpm/acre

Amount of precipitation recharging the mine ranged from 6.3 to 46.4 percent


Omega Mine Recharge Characteristics
Recharge (gpm/A)
1.00
0.80
0.60
0.40
0.20
0.00
50%
40%
30%
20%
10%
0%
Recharge Percentage of Precipitation
Jan
Feb
March
April
May
June
July
Aug
Sept
Oct
Nov
Dec
Month
Recharge (gpm/A)
Recharge Percentage of Precipitation

Pen Mar Location Map



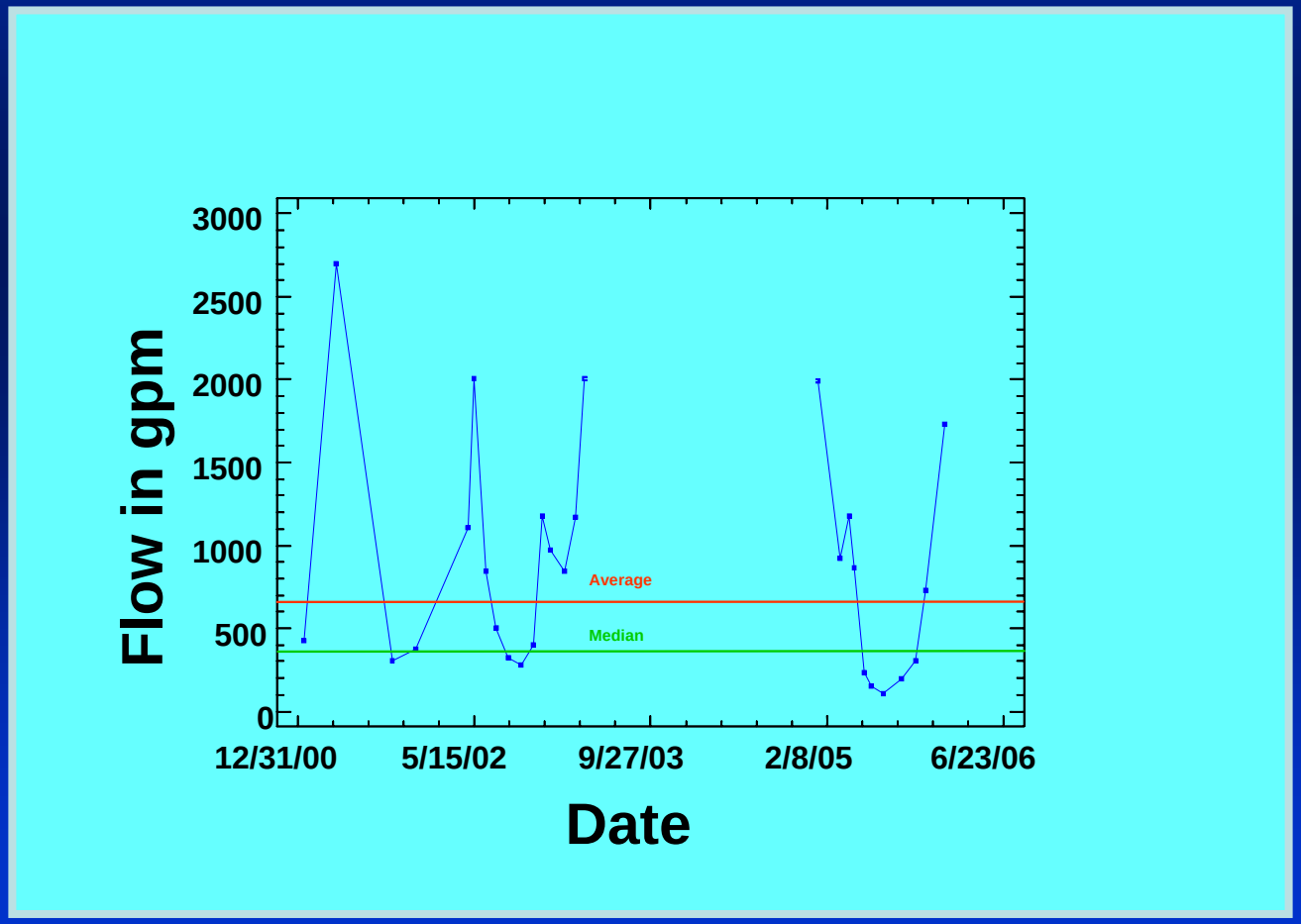
Pen Mar Shaft Discharge

Background

- Mined from the 1920's to 1940's.
- Mine extends from Lower Kittanning outcrop to the west and a depth of about 800 feet.
- Approximately 1,910 acres were affected.
- The entire mine discharges from a single shaft located in the south central portions of the mine.
- The mine water flows vertically about 400 feet to discharge.
- Discharge rate was determined by use of a large rectangular weir.

Background

- There are no known adjacent underground mines
- Recharge is primarily from the surface (precipitation and losing streams)



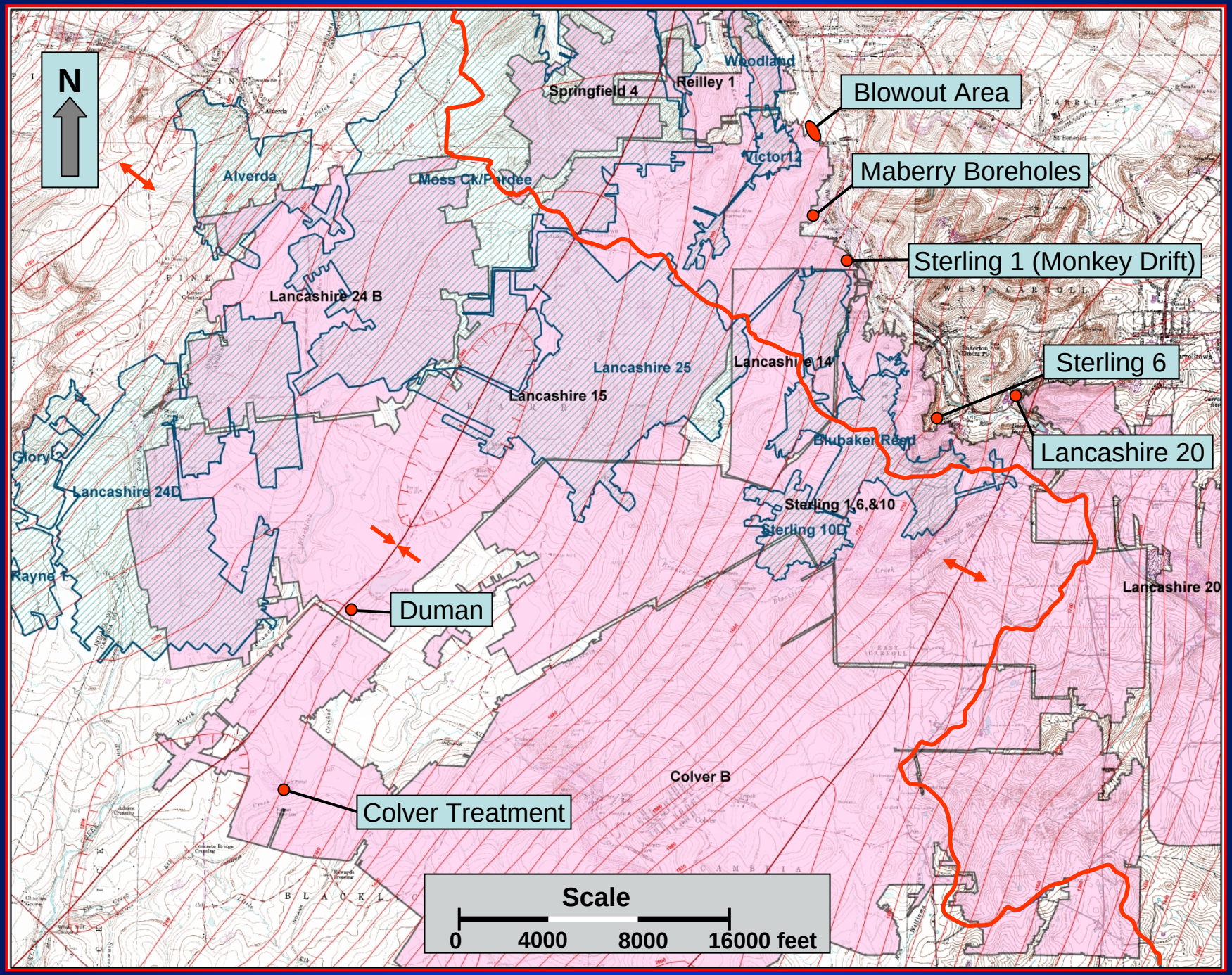
Summary

Recharge ranges from 0.10 gpm/acre during extreme drought to 1.42 gpm/acre during high recharge periods.

Mean recharge = 0.34 gpm/acre

Median recharge = 0.19 gpm/acre

Barnes & Tucker Lancashire 15


N
Blowout Area
Maberry Boreholes
Sterling 1 (Monkey Drift)
Sterling 6
Lancashire 20
Duman
Colver Treatment
Woodland
Reilley 1
Springfield 4
Victor 12
Alverda
Moss Ck/Pardee
Lancashire 24 B
Lancashire 25
Lancashire 14
Lancashire 15
Blubaker Reed
Glory 2
Lancashire 24D
Sterling 1,6,&10
Sterling 10D
Rayne 1
Lancashire 20
Colver B
Scale
0
4000
8000
16000 feet

Main Discharge Points

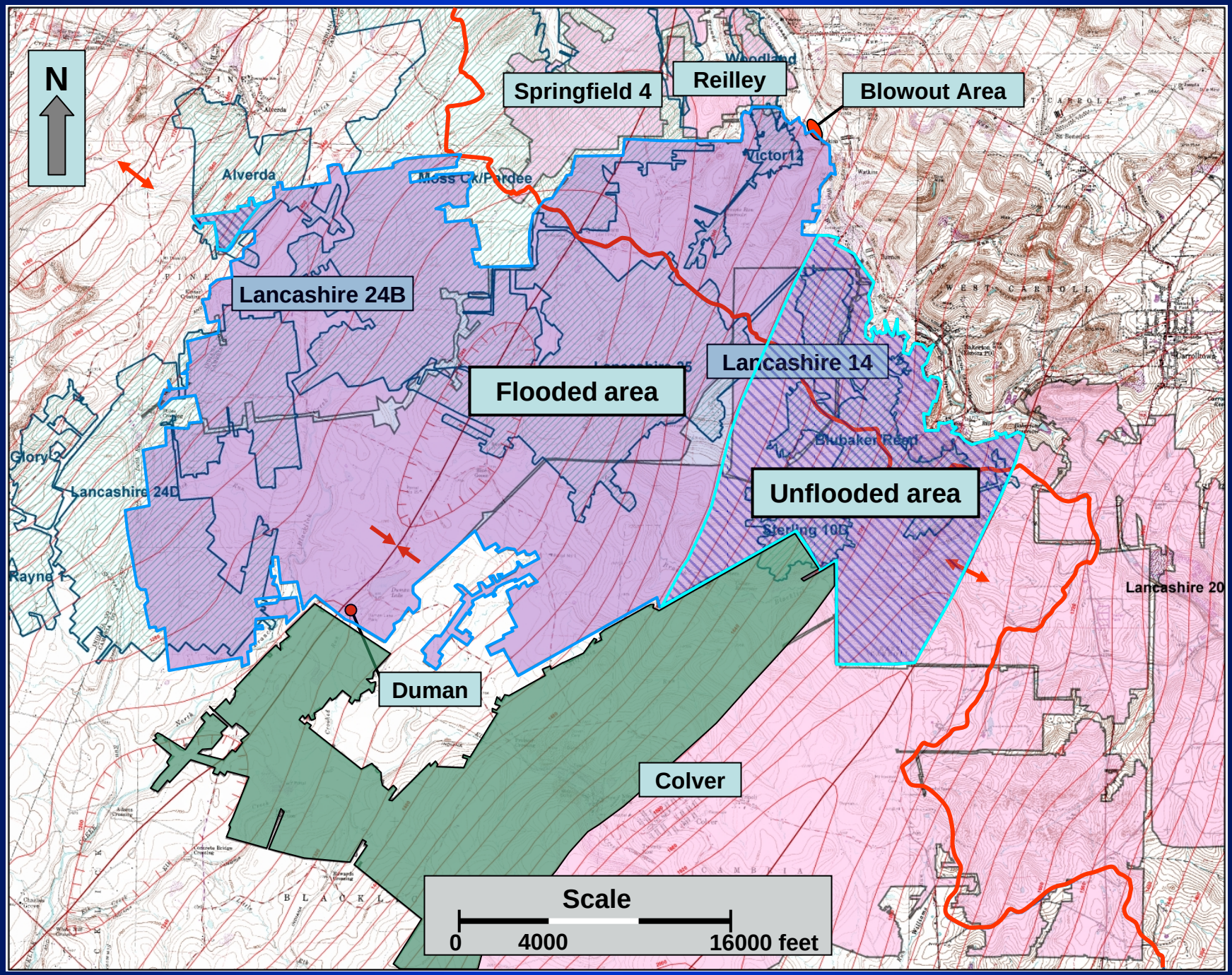
Treatment System

Background

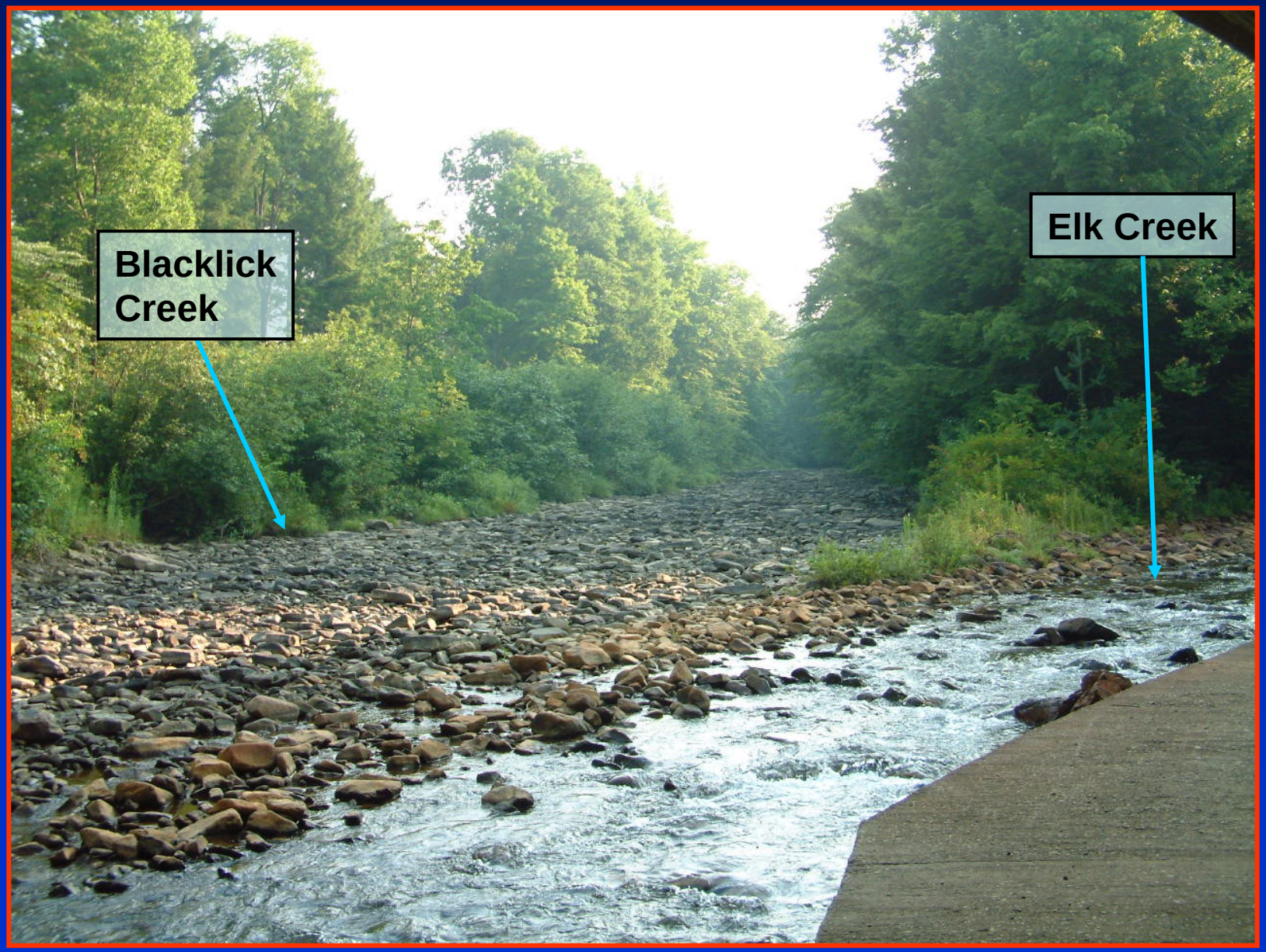
- Mined the Lower Kittanning (B) and the Lower Freeport (D) seams separated by 165 feet.
- Lateral interconnection between mines ranges from open pass-throughs to solid barriers 200 feet or more thick.
- Vertical interconnections are direct via open shafts to more restricted through natural and mining-induced fractures.
- Significant head differences exist between some adjacent mines with thick solid barriers.
- High-extraction mining occurred on both seams.
- There is now one main discharge point (Duman) and a few smaller ones.

More Background

- Lancashire 15 is ~ 11 square miles.
- Contributing mines cover over 25 square miles.
- Lancashire 15 closed on July 14, 1969 (pumps shut off) and it flooded.
- A major blowout occurred in late June or early July, 1970.
- Pumping and treating at Duman since 1971.
- Overburden depth ranges from 0 to 640+ feet.
- There appears to be significant stream loss in some of the major overlying streams.


N
Springfield 4
Reilley
Blowout Area
Alverda
Moss Crk/Pardee
Victor12
Lancashire 24B
Lancashire 14
Flooded area
Blubaker Road
Unflooded area
Glory
Lancashire 24D
Sterling 10D
Rayne 1
Lancashire 20
Duman
Colver
Scale
0
4000
16000 feet

Blacklick (Mid-Summer)

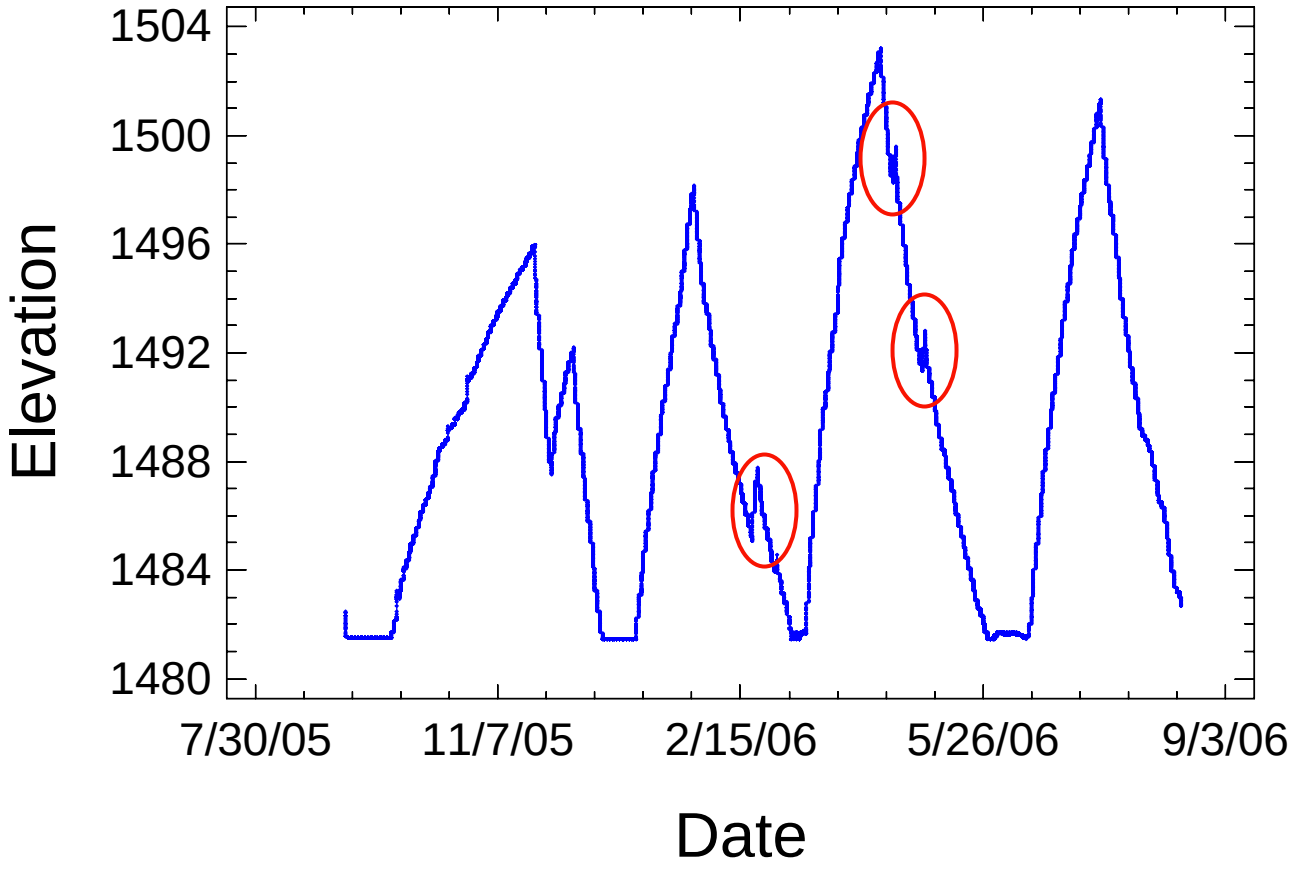


Summary

Recharge ranges from 0.15 gpm/acre during extreme drought to 0.54 gpm/acre during high recharge periods.

Mean annual recharge = 0.35 gpm/acre

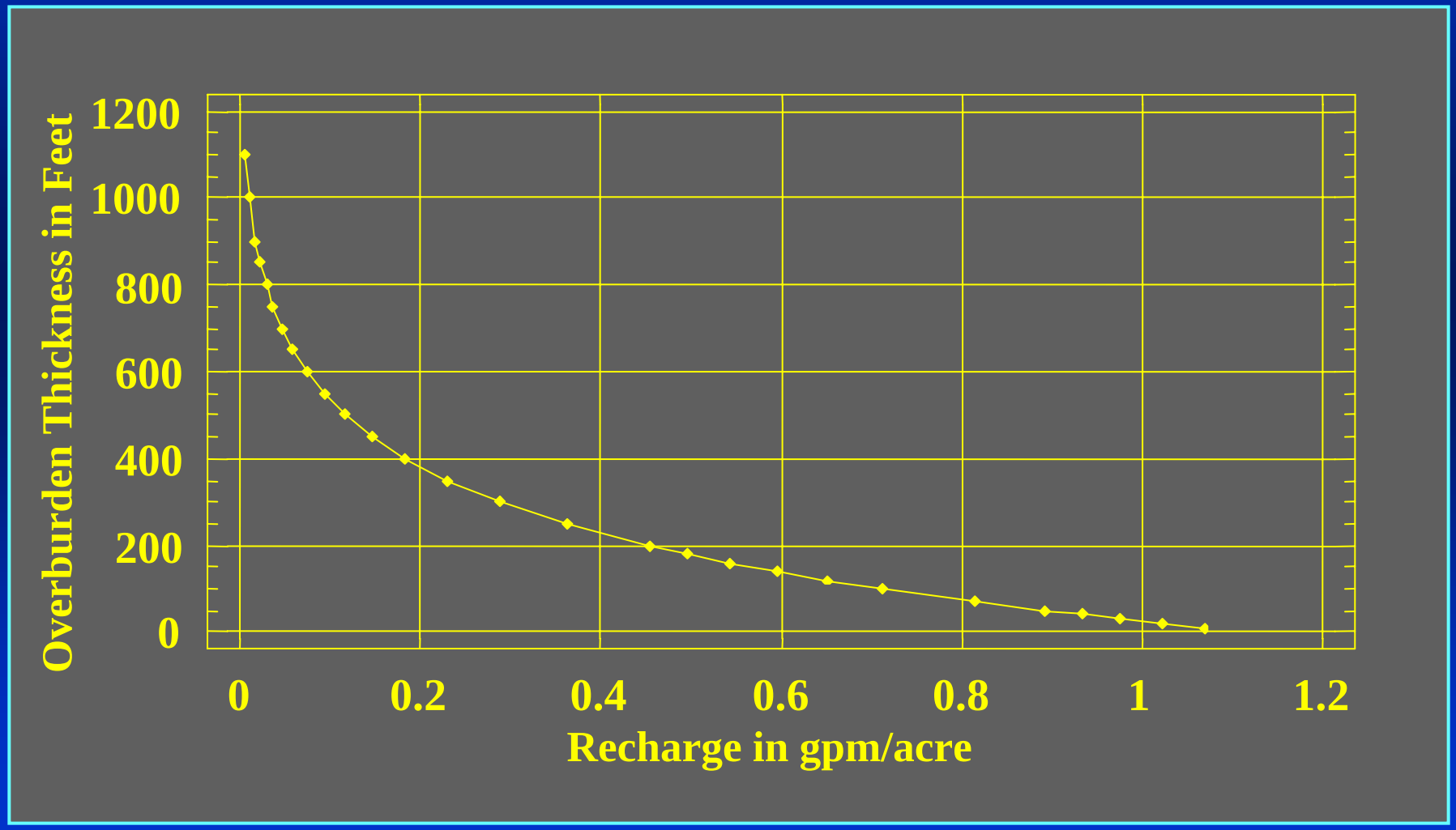
Lancashire 15



Food for Thought: Factors that Likely Impact the Recharge Rates

- Depth of cover (<150-200’ vs. >200’, etc.)
- Overburden lithology (sandstone vs. shales & claystones)
- Method of mining (e.g., longwall vs. 1st mining vs. retreat mining)
- Laterally, adjacent mines (flooded and unflooded)
- Lineaments, faults, fracture zones, etc. (presence or absence)

Relationship of Underground Mine Recharge Rate and Overburden Thickness



More Food

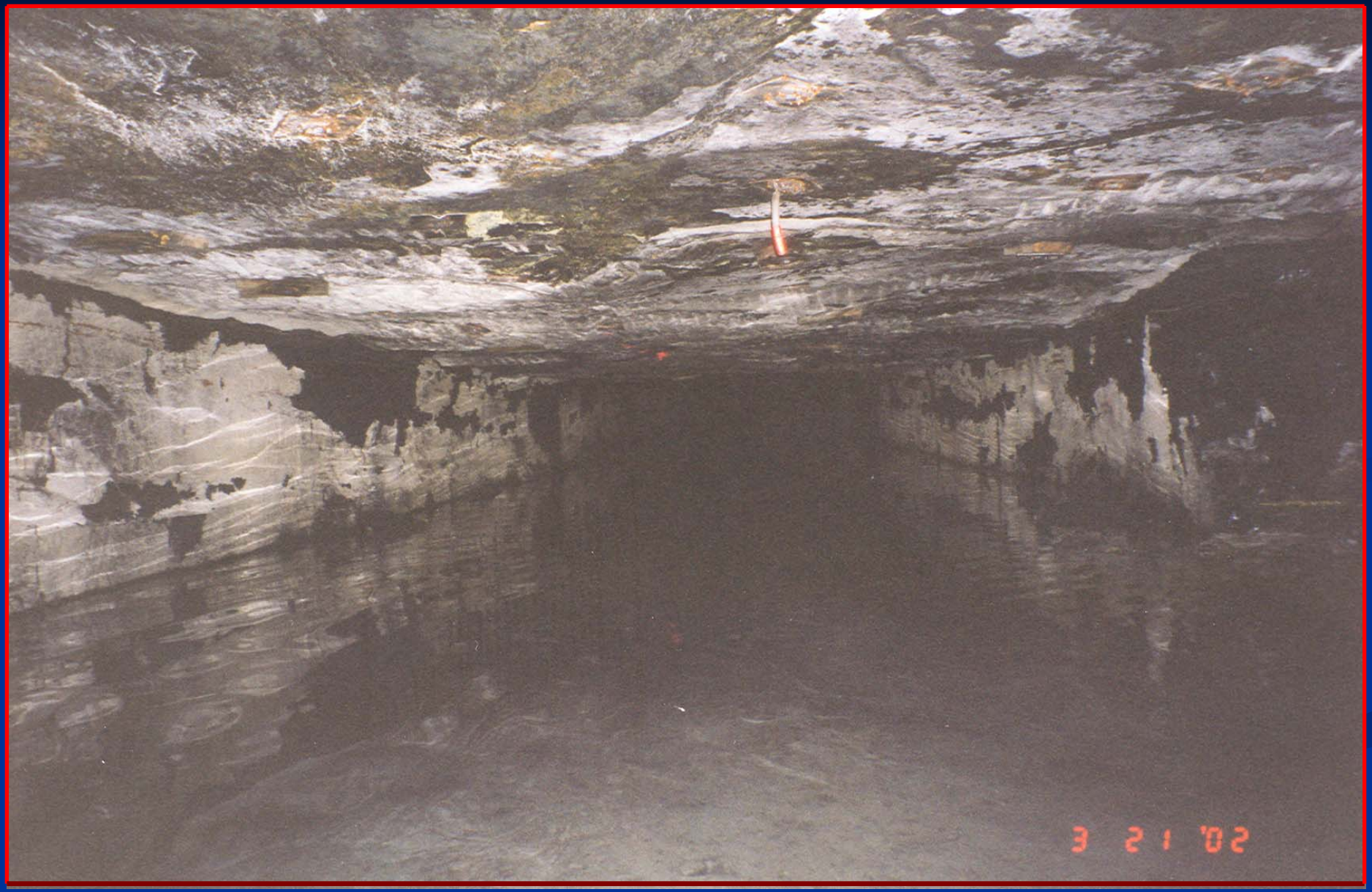
- Interaction with over and/or underlying mines
- Climatic data (rainfall, temperature, etc.)
- Land use/cover information
- Topography
- Manmade features (e.g., wells, shafts, etc.)
- Others?

Discussion

Mine Pool Forum

Seepage through and over coal barriers

Tom Galya
Physical Scientist
Office of Surface Mining
Charleston Field Office
Charleston, West Virginia
March 6-7, 2007


3 21 '02

Discussion points

- Salient factors that control
  - Seepage flow through coal barriers
  - Seepage flow over the coal barrier into the roof rock
- Permeability and K_h values of coal barriers and overburden
  - Isotropic versus anisotropic seepage (fracture) flow
- Coal barrier cleat systems and orientation of mine workings
- Relationship between coal barrier thickness and hydraulic conductivity
- Data availability for Darcian estimates of coal barrier and overburden seepage flow
- Example: Estimate of seepage through a coal barrier and roof rock (overburden) using Darcian assumptions

The role of barriers is a balancing act

- Safety concerns

  - Industry and government both realize that coal barriers are needed for mine safety from sudden release of water

  - Control of ventilation and fire

  - Prevention of blowouts, flooding, and landslides

  - Ashley and Inspector's formulas for prudent design

- Environmental concerns

  - Restrict rate of AMD mine water outcrop seepage

  - Restrict artesian effects from below-drainage mines

- Balanced coal barrier design

  - Not unnecessarily restrictive to industry, but address safety and environmental concerns

Seepage through coal barriers

Seepage flow through a coal barrier

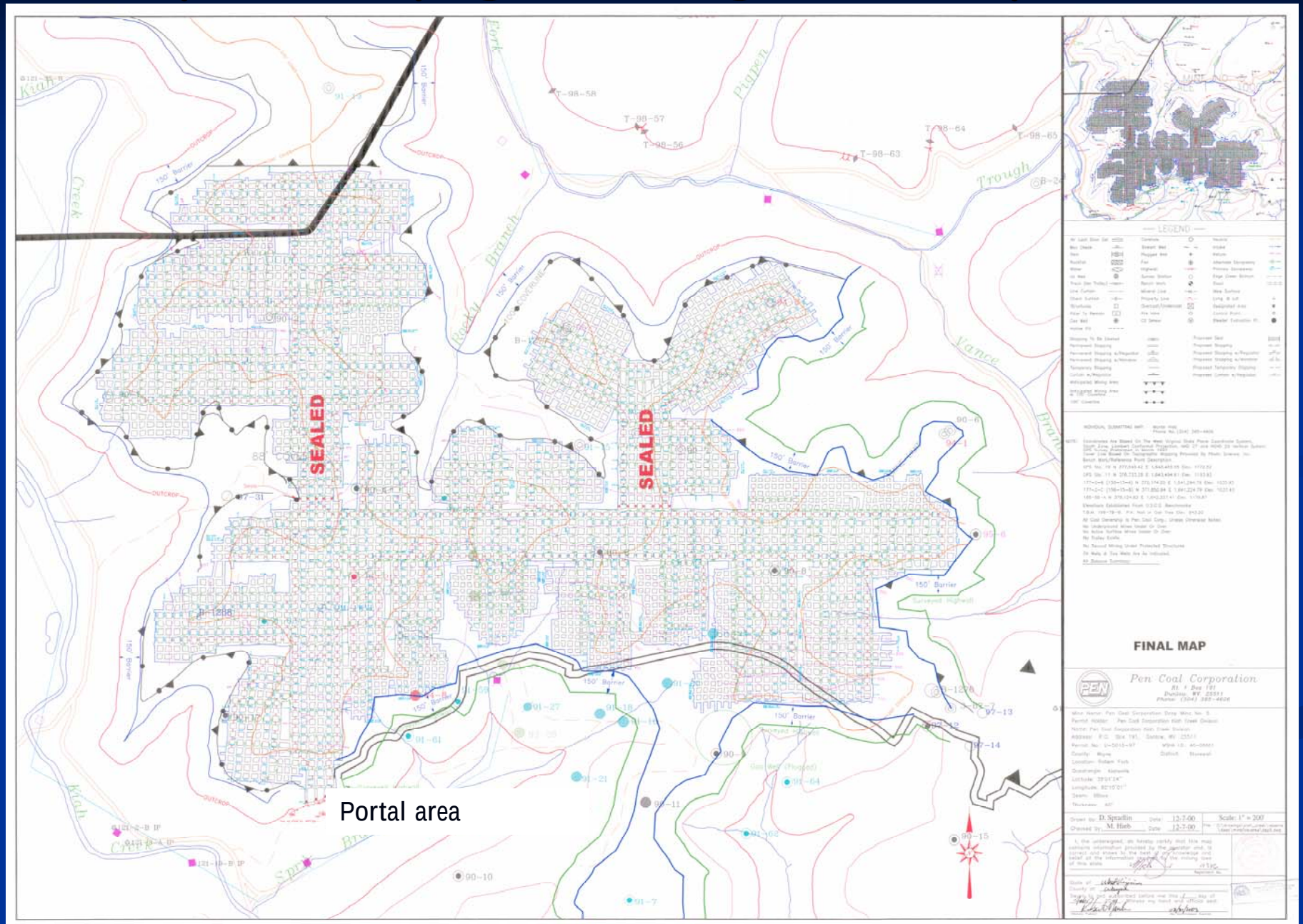
Hydrogeologic factors influencing barrier seepage

- Overburden depth
- Above vs below-drainage deep mines
  - Type and proximity of adjacent active and abandoned mining
- Geologic framework
  - Coal barrier thickness
  - Structure, hydraulic gradient
  - Lineaments, seam discontinuities
- Characteristics of the coal barrier, roof overburden, floor
  - Lithology, coal cleats, SRF and mine-induced fractures
  - Mine floor topography
    - + Gradual mine floor structure may be indicative of slower rates of water rise in flooding mines
- Roof and floor can behave as acquitards in flooding mines
  - Significantly lower K_h than adj. abandoned workings

Above-drainage mine coal barriers

- Outcrop seepage reflects the extent of mine flooding and pool development, depending upon
  - Mine geographic location, mine seals, seepage flowpaths
  - Even prudent design for outcrop barriers result in seepage
- Mining operations design ventilation punchouts at outcrop barriers that can also serve as NPDES discharge outlets
- Location of punchouts
  - Reflect health and safety concerns during mining
  - Control potential AMD discharges by downgradient mining
- Outcrop breakout points
  - Seepage from the mine pool expedites weathering and erosion of and along the coal outcrop barrier
- Pool breakout locations
  - Ground water discharge breakout (elevation) points
    + Streams, flowing artesian wells

Example: seepage through outcrop barrier



Potential impacts from AMD barrier outcrop seepage to receiving stream

STANDARD LABORATORIES, INC.

147 Eleventh Avenue, South Charleston, WV 25303
Telephone: (304) 744-5472 • Fax# (304) 744-4319

COMPANY NAME: PEN COAL CORPORATION
PERMIT NO'S:
SAMPLE ID: Sump Water From Deep Mine #5

LAB #'S	DATE SAMPLED	DATE ANALYZED	pH	TOTAL ALKALINITY mg/l	ACIDITY mg/l CaCO3	TOTAL SULFATE mg/l	TOTAL Al mg/l	TOTAL Fe mg/l	TOTAL Mn mg/l	TSS mg/l	TDS mg/l	SPEC. COND. UMHOS
9807-1858-1	7/23/98	7/30/98	3.68	0.0	239	1960	22.0	7.03	19.8	16.0	2400	3200
9807-1879-1	7/29/98	8/5/98	3.35	0.0	548	1950	44.2	38.0	27.7	<2.8	2900	3900
9808-1917-1	8/6/98	8/13/98	3.80	0.0	243	1410	37.6	6.07	30.8	20.0	2600	3121
9808-1949-1	8/14/98	8/27/98	3.52	0.0	298	1590	31.8	26.3	21.5	57.0	2000	3280
9808-1972-1	8/24/98	9/1/98	3.44	0.0	440	1890	35.3	49.2	24.8	11.0	2700	3600
9809-2076-1	9/17/98	9/29/98	3.51	0.0	549	2130	38.5	69.3	27.8	62.0	2800	3740
9809-2102-1	9/25/98	10/1/98	3.83	0.0	253	1770	22.4	7.55	20.4	25.0	2200	3100
9810-2148-1	10/2/98	10/8/98	3.57	0.0	400	1750	35.8	27.6	29.6	3.0	2500	3500
9810-2175-1	10/11/98	10/20/98	3.91	0.0	271	1900	24.4	33.8	20.3	25.0	2300	3400

Respectfully Submitted:

MINE #5

Seepage Analysis Computation Sheet

Location: Rocky Branch of Trough Fork

Barrier Section: **1** Length(ft): **4000** Head(ft): **30** Width(ft): **220**

Analysis of outcrop or barrier seepage for flooded mine utilizing the following formula:

$$Q = K * (P/W) * t * l$$

Where:

Q	= flow of water through the coal barrier per foot of outcrop		
K	= permeability of coal (ft/day)	=	1.0, 3.12, 4.24, 4.89
P	= hydrostatic head existing above the coal in feet	=	30
W	= width of the coal barrier in feet	=	220
t	= thickness of the coal seam in feet	=	6.9
l	= length of the outcrop in feet	=	4000

*K= 1

Q =	3,764	cubic feet/day
	0.04	cubic feet/second
	20	gallons per minute
	28152	gallons per day

K= 3.12

Q =	11,743	cubic feet/day
	0.14	cubic feet/second
	61	gallons per minute
	87834	gallons per day

K= 4.24

Q =	15,958	cubic feet/day
	0.18	cubic feet/second
	83	gallons per minute
	119364	gallons per day

**K= 4.89

Q =	18,404	cubic feet/day
	0.21	cubic feet/second
	96	gallons per minute
	137663	gallons per day

Below-drainage mine coal barriers

- Intact barriers
  - Barrier seepage from adjacent mines provide and contribute to inflow developing & maintaining mine pools
  - Pumping or artesian discharges provide outflow from mine pools
- Non-intact barriers
  - Breached by boreholes or entries between adjacent mines
  - Leaking sealed areas of the mine
- Mine pool breakout locations
  - When inflows > outflows then rising pool level
  - Ground water discharge locations
    - + Adverse hydrologic impacts to streams
    - + Artesian conditions to residents' homes, wells

Below-drainage mine barrier leakage

Relationship between barrier thickness and seepage flow rate

- Rate of coal barrier seepage measured by K_h
- Physical characteristics of the mined coal seam

  - Coal barrier thickness

  - Orientation of the mine barrier with respect to the coal cleat orientation
- Sufficient compressive stress applied to coal barriers

  - *Could* reduce the density of the secondary fracture flowpath network and its permeability (Luo et al., 2001)
- Effective K_h of coal barriers may be inversely related to barrier thickness (Leavitt, 1993), *perhaps* lithology and/or

  - Vertical and horizontal discontinuity of fractures, joints, coal cleats *may* impede seepage flow in the coal barrier

Relationship of the K_h of coal barriers to barrier thickness

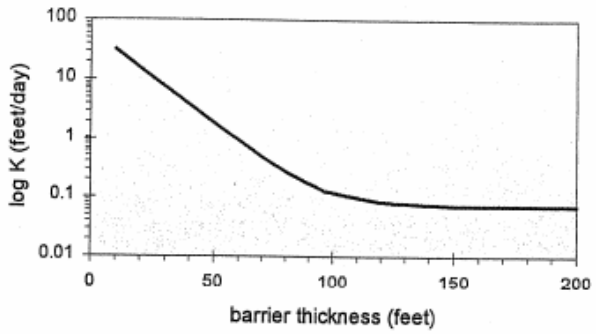
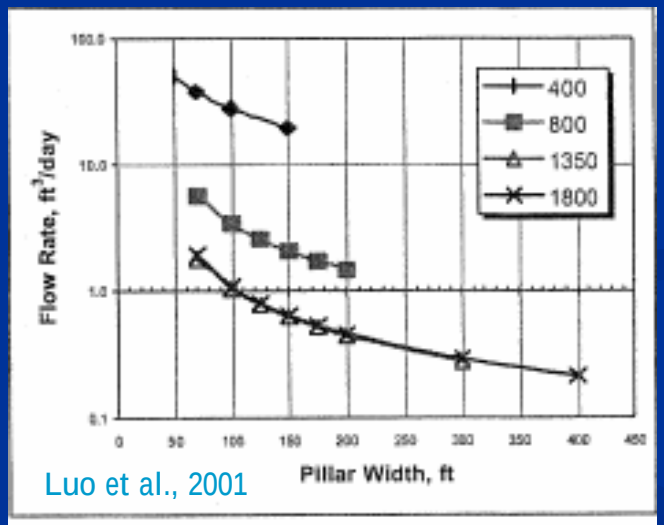


Figure 2-7. Exponential decline in average horizontal barrier hydraulic conductivity with respect to barrier thickness, according to the model of Leavitt (1993).

b' (ft)	K (ft/day)
10	30.89
20	15.07
30	7.374
40	3.626
50	1.802
60	0.914
70	0.482
80	0.272
90	0.169
100	0.119
125	0.080
150	0.073
175	0.072
200	0.072
250	0.072
300	0.072
400	0.072

Pittsburgh seam, Dakota-Jordan mine barrier

Leavitt, 1993



Luo et al., 2001

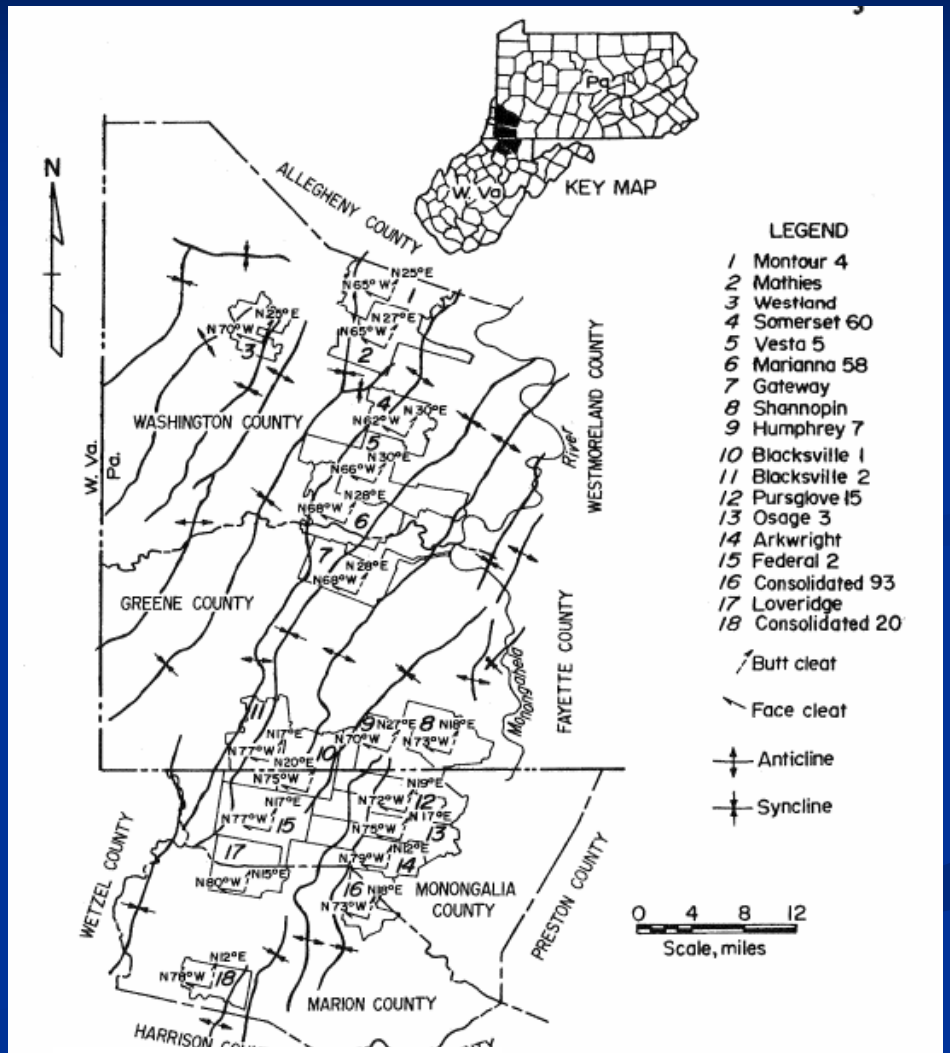
Fig. 10 Effect of Width of Barrier Pillar on the Rate of Seepage Flow

Coal barrier seepage flow occurs by anisotropic permeability via coal cleats

Jointed Winifrede coal face cleats

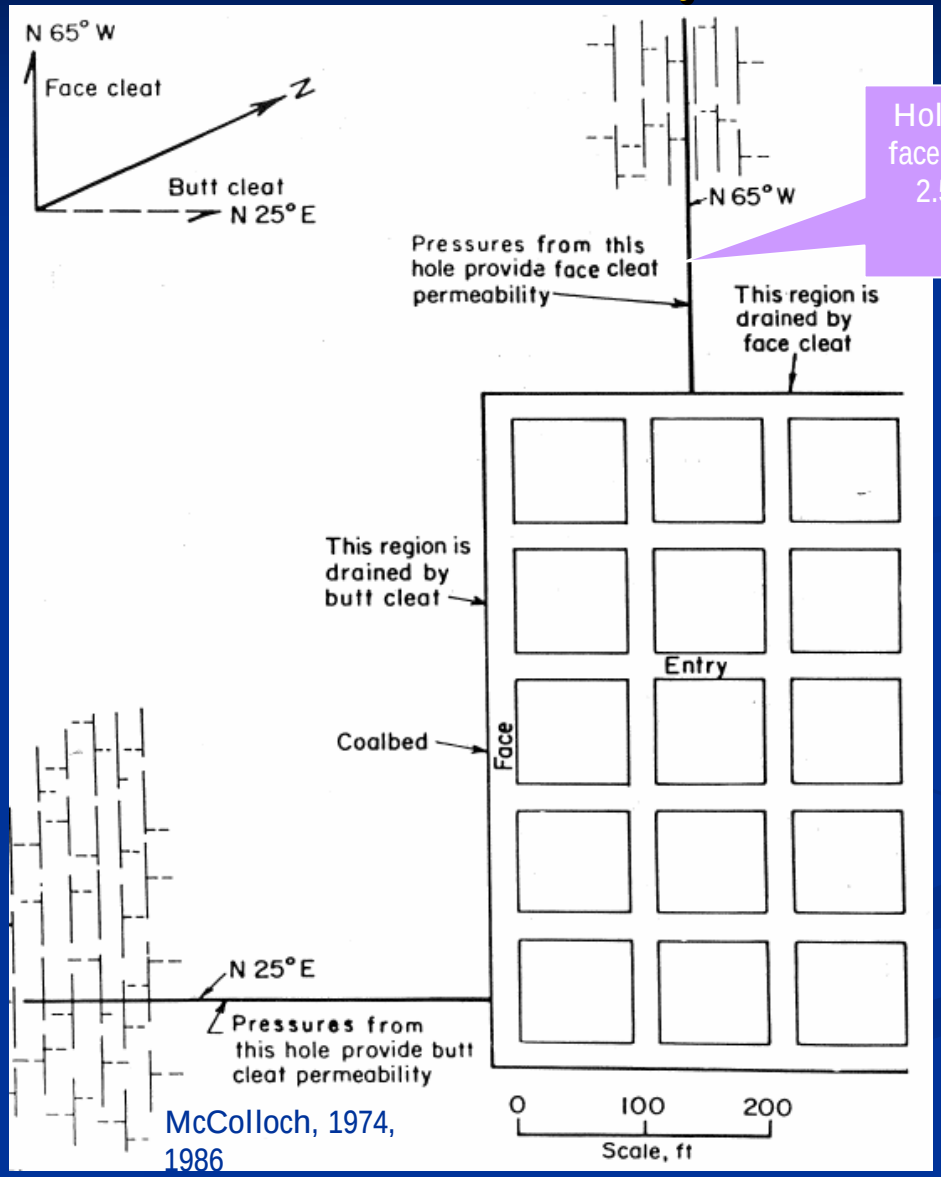
Coal barrier cleat system

- Cleat system follows regional structure- in PA & WV, Ex: Pittsburgh, No. 2 Gas seams
  - Face cleat: trend normal to regional folding approximately N 58·W and N 70·W (Stoner, 1983)
    - + Hobba (1991) N 68·W
    - + Boone County, WV, N32-78·W (USBM #9413)
  - Face cleat trend parallel to seepage flow, encourages flow
  - Butt cleat: trends parallel to regional structure
    - + Butt cleat shorter flowpaths, lower permeability



Diamond et al., 1976

Orientation of mine workings to coal cleat system



Holes drilled perpendicular to the face cleat yields seepage water and 2.5-10 times the amount of gas compared to the butt cleat

McColloch, 1974, 1986

Permeability of coal pillar and overburden seepage flow rates

- *Some* horizontal hydraulic conductivity permeability measurements in the available literature, largely isotropic
  - Outcrop and/or shallow mines
  - *Fewer* k_h measurements for deeper mines
  - K_h values for coal seams in the literature do not state that the values reflect isotropic or anisotropic flow paths
- Field permeability tests are more relevant than lab tests that measure primary porosity
- Comparison of field versus laboratory of Allegheny Fm. strata in PA (Schubert, 1980)
  - Lab measurements: 8×10^{-5} feet/day
  - Field measurements: 0.14 feet/day

Permeability of shallow and outcrop coal barriers and roof seepage flow rates

- Miller and Thompson (1974) data
  - Dames and Moore, 1981
- Relevant to outcrop and shallow mines values only not deep, below-drainage mines

TABLE 1 - Permeability Values Typical of the Appalachian Region

Material Description	Tests	Depth	Average Permeability
Upper Freeport Coal	4	23'-67'	1.00 ft/day
Base of Upper Freeport Coal	3	28'-68'	3.21 ft/day
Lower Kittanning Coal and adjacent shale w/sandstone	4	54'-109'	0.75 ft/day
Shale w/sandstone bridged through a height of 44' over a lower Kittanning mine void	7	50'-99'	4.25 ft/day
Shale w/sandstone over solid coal	12	44'-95'	0.74 ft/day
Mine debris		99'-104'	1.98 ft/day

Source: Miller, J.T., and D.R. Thompson, 1974.

TABLE 14. Range of Horizontal Permeabilities for Seepage Analysis

Material	Premining ----------> Post Mining		
Coal	1.0 ft/day[a]	3.21 ft/day[b]	4.86 ft/day[c]
Overburden	0.01 ft/day[d]	0.74 ft/day[e]	4.25 ft/day[f]
Underclay	0.0005 ft/day[g]	-------	.013 ft/day[h]

Jamison # 9-Odonnell mines barrier seepage flow

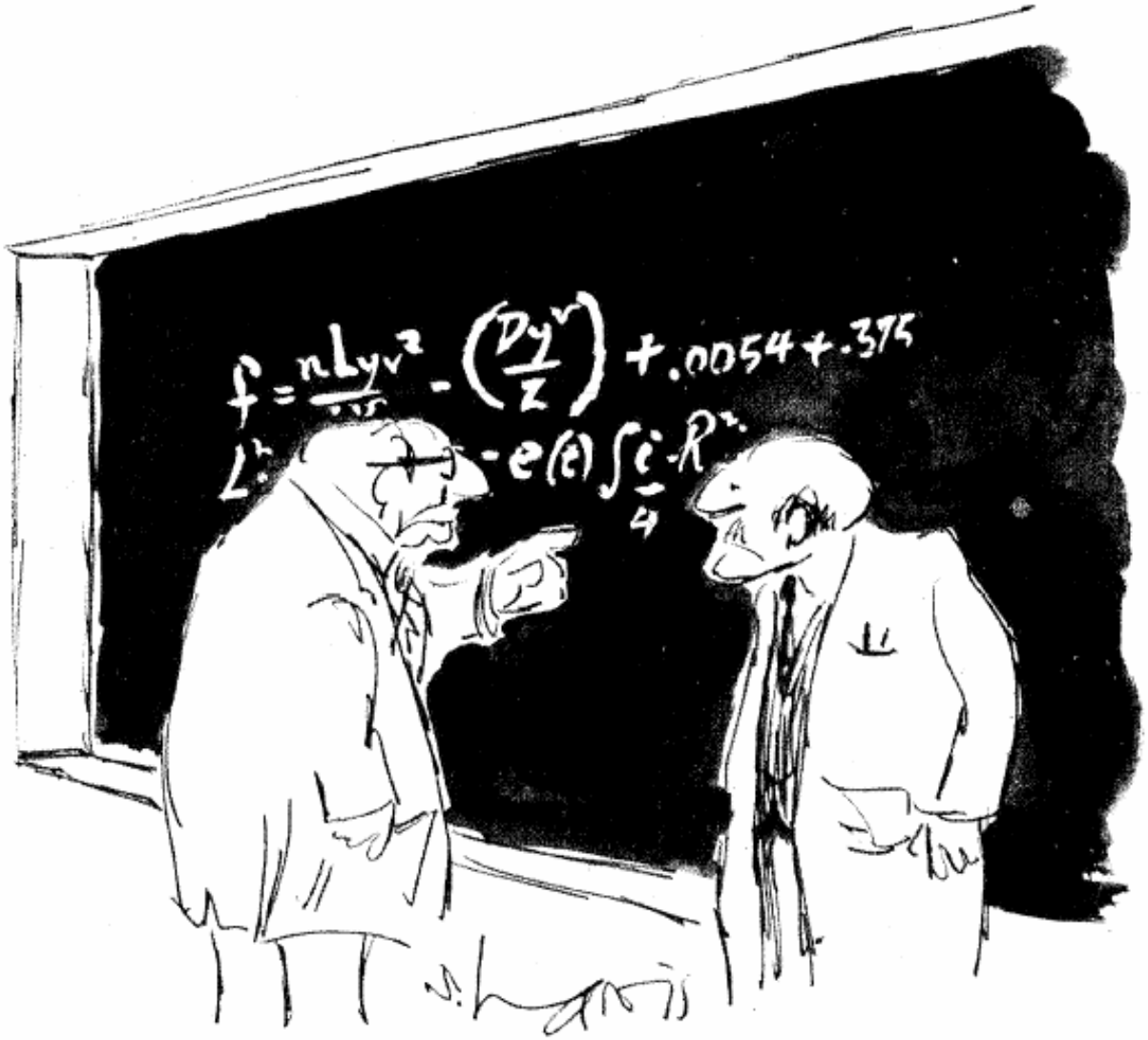
- McCoy et al., 2006 calculated K face and butt cleat values for the coal barrier between the Pittsburgh seam Jamison # 9 and Odonnell mines in West Virginia and Pennsylvania

  - K_f, face cleat 0.24 to 1.1 feet/day

  - K_b butt cleat 0.072 to 0.32 feet/day

  - Compare: isotropic K_h estimate of 0.12-0.59 feet/day
- Data showed Jamison # 9 barrier orientation lends to shorter flowpaths, lower permeability along the butt cleat
- Coal barrier orientation of entries that dip parallel in the direction of the face cleat will encourage seepage flow that will "let the water run with you" mining process

Darcian flow estimate assumptions



"Does this apply always, sometimes, or never?"

Fracture flow seepage model

Equivalent porous media approach treats the fractured rock mass as equivalent to a continuous and homogenous porous medium
(Schmidt, 1985)

Darcian barrier seepage estimate assumptions

- Mines are fully flooded, confined flow along the coal barrier, and at equilibrium (steady state)
- Homogenous coal seam barrier
- Seepage flow is laminar and follows cleat systems
- Horizontal conductivity K along the coal barrier
  - K_h is independent of:
    - + Barrier width
    - + Spatially uniform
- Horizontal flow could extend upward to above the coal barrier separating adjacent mines
- Isotropic and/or anisotropic fracture flow models

Are data available to use the Darcy equation?

Darcy equation data requirements

- Coal barrier characteristics
  - Barrier segments size determined from mine maps
  - Length and thickness of coal barrier segments
- Hydraulic head
  - Mine pool levels from piezometers and/or shafts
  - Coal seam elevations at coal barriers segments and saturated overburden thickness
- Aquifer characteristics: coal seam and overburden
  - Hydraulic conductivity K_h values (or Transmissivity data)
    - + No site-specific data largely available
    - + Literature values for K_h (largely isotropic K_h)
- Mine pump discharge history
  - Accurate K_h determinations *can* be made by using permittee pump history; RA data not suited for task

Mine pump data and regulatory data

Compare the two December pumping history

Date	Hours	Date	Hours	Date	Hours
11-25-96	33834.1	10-25-96	232.2	10-25-96	.5
12-2-96	34278.	10-27-96	236.8	11-28-96	.6
12-11-96	35270	10-28-96	238.1	11-18-96	20.7
12-12-96	3535.2	10-29-96	241.2	11-19-96	25.5
12-13-96	3535.2	11-4-96	253.7	[illegible]	[illegible]
12-15-96	3572.5	11-9-96	264.3	12-2-96	105.8
12-16-96	3591.3	11-11-96	262.2	12-3-96	115.1
12-17-96	3597.2	11-12-96	271.8	12-4-96	127.8
12-18-96	3597.2	11-18-96	283.6	12-5-96	136.6
12-19-96	3613.1	11-19-96	287.8	12-6-96	142.8
12-21-96	3627.7	11-20-96	289.2	12-7-96	155.2
12-23-96	3642.2	11-21-96	291.4	12-11-96	192.7
12-30-96	3687.2	12-2-96	335.9	12-12-96	203.2
12-31-96	3687.2	12-3-96	346.0	12-13-96	218.2
1-1-96	3687.2	12-4-96	358.0	12-15-96	239.9
1-2-97	3702.9	12-5-96	370.0	12-16-96	247.3
1-3-97	3702.9	12-6-96	376.0	12-17-96	252.0
1-5-97	3713.1	12-9-96	392.1	12-18-96	256.8
1-6-97	3722.8	12-11-96	404.8	12-19-96	261.2
		12-12-96	413.7	12-21-96	272.1
		12-13-96	416.5	12-23-96	280.8
		12-15-96	421.4	12-28-96	304.0
		12-16-96	424.5	12-29-96	308.4
		12-17-96	426.5	12-30-96	312.7
		12-18-96	437.1	12-31-96	316.5

Date	Pump avg gpm	Pump max, gpm
1/31/1996	133	250
2/28/1996	175	250
3/31/1996	175	200
4/30/1996	113	200
5/31/1996	200	200
6/30/1996	15	25
7/31/1996	250	250
9/30/1996	200	200
11/30/1996	20	20
12/31/1996	38	50

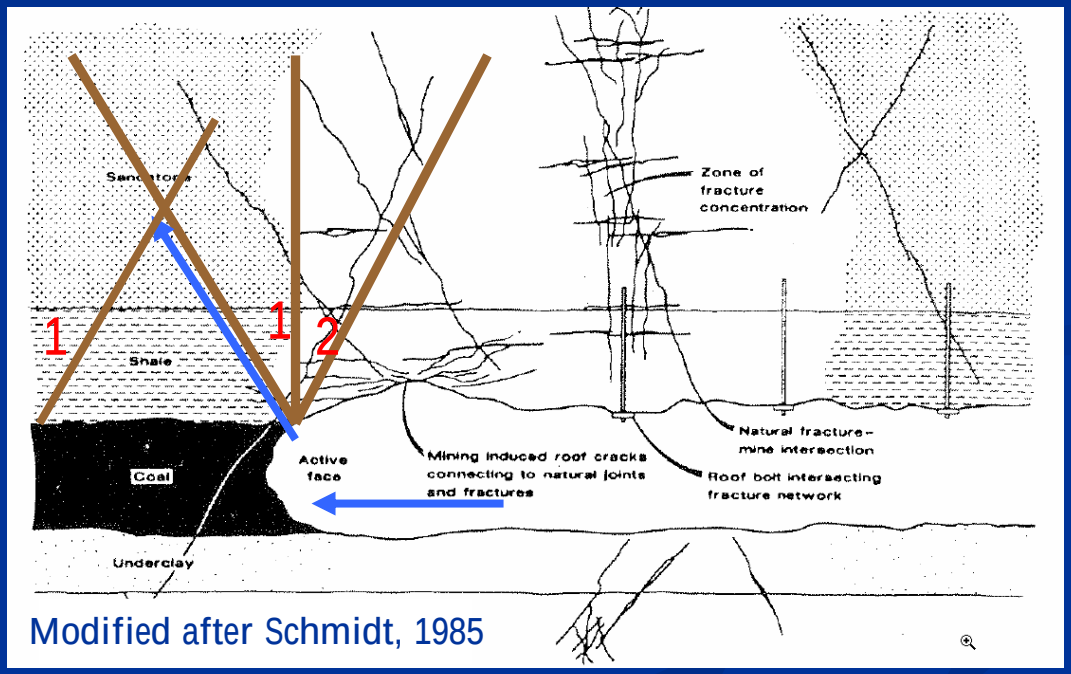
LEFT: Permittee data show approx 210 hour pumping during December: outlet max 1500gpm

RIGHT: RA DMR data shows 50 gpm max for an unknown period of hours/day during December

Seepage over the coal barrier

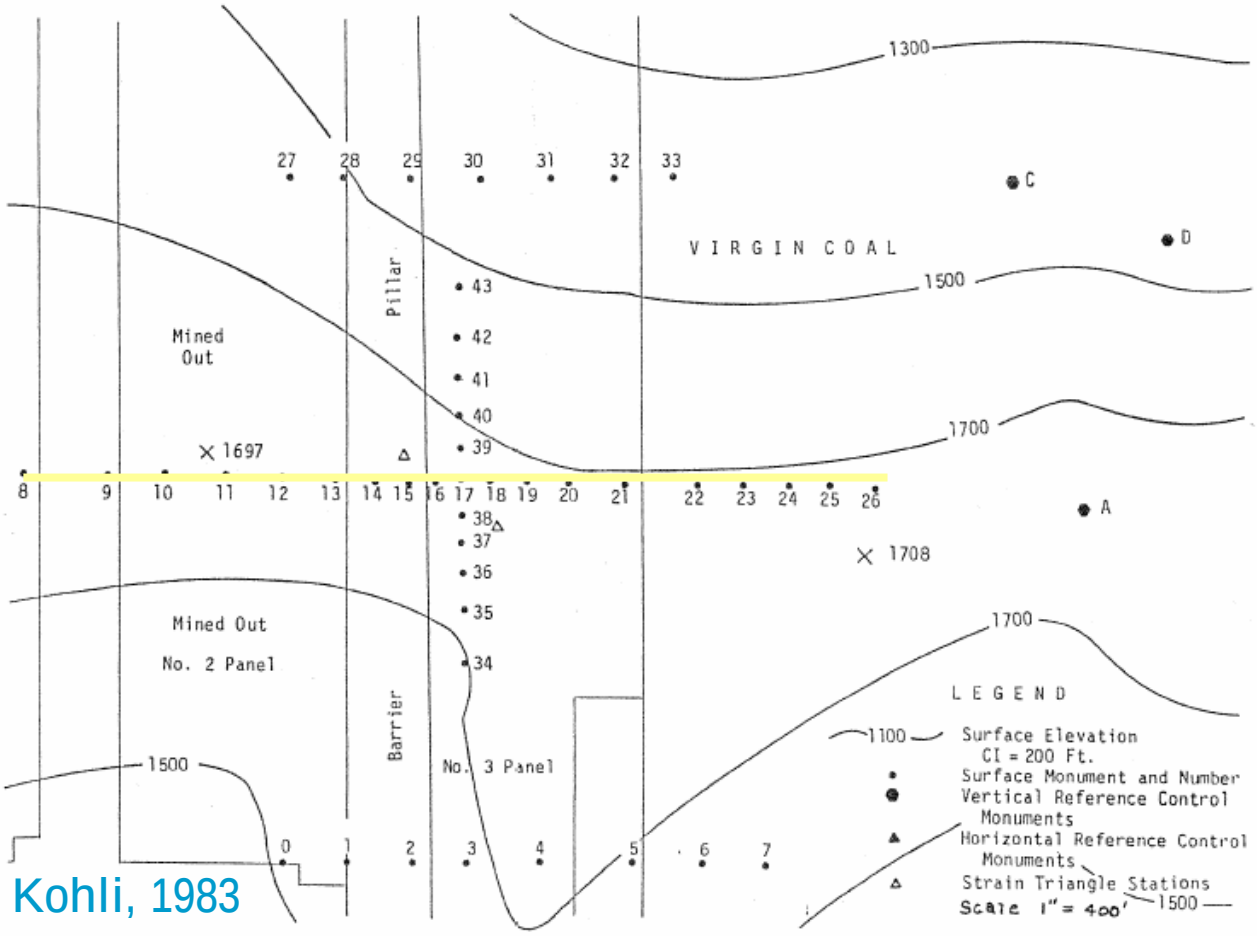
Mine roof controls seepage flow over mine barriers

- Draw slate (shale) in the roof acting as a confining layer
- Presence of fractures within mine roof (overburden)
  - Angle of advance influence-1
  - Angle of complete mining-2
  - Intersections of fractures from adjacent mines separ. by coal barrier
- Stress relief and mine-induced fractures occurring in zones
  - Horizontal and vertical continuity of fractures
- Inflows to flooding mines through Kendorsky 1993 Zones occur through fractures
- Zones of intense fracturing have K_h values order of magnitude higher than adj. unfractured strata



Modified after Schmidt, 1985

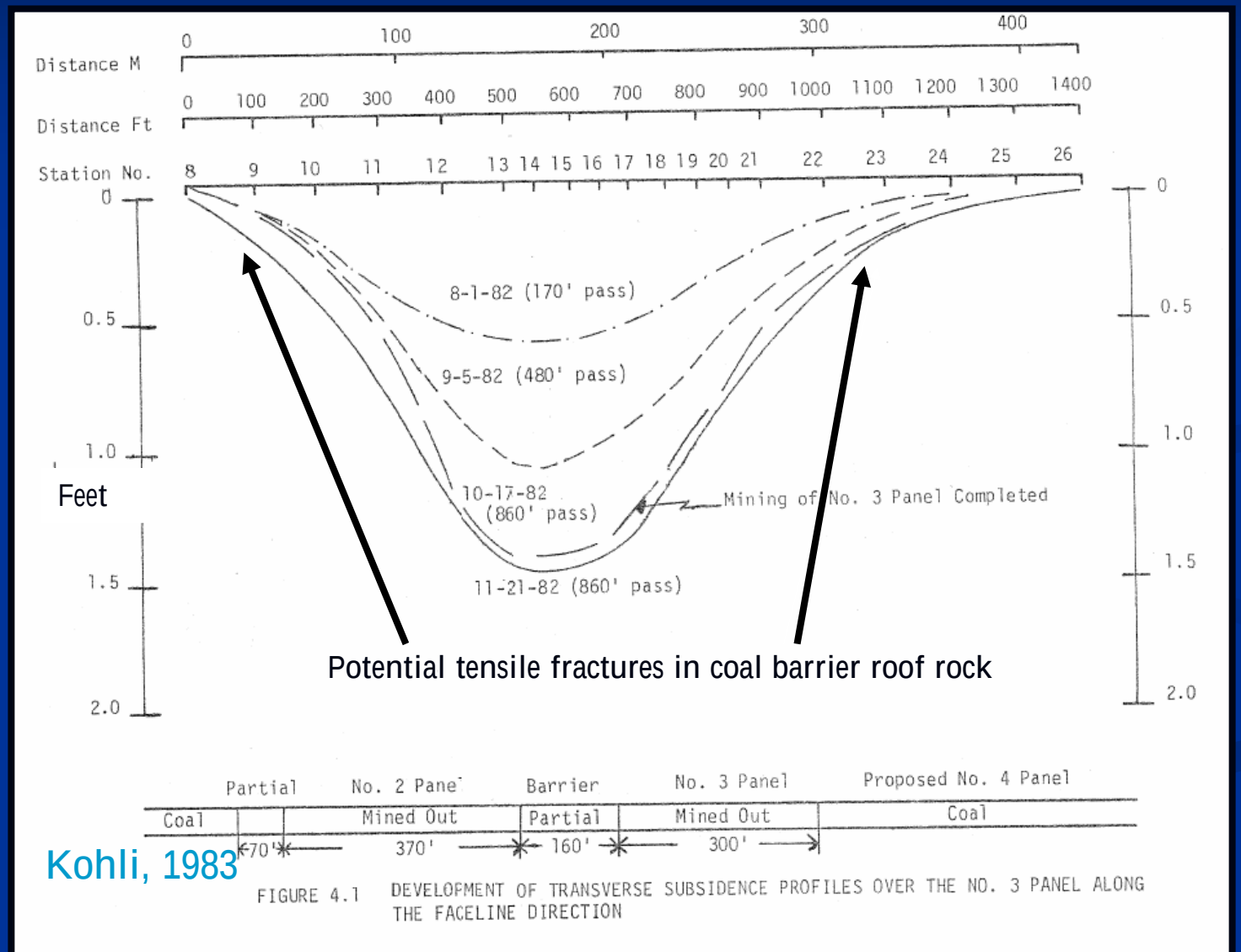
Coal barrier permeability adjacent to subsidence trough
Example: Ferrell Mine, WV



Kohli, 1983

FIGURE 3.1 LOCATION OF SURFACE SUBSIDENCE MONUMENTS OVER THE NO. 3 PANEL

The edges of the subsidence trough are wedges of highest permeability and flow
Example: Ferrell Mine, WV



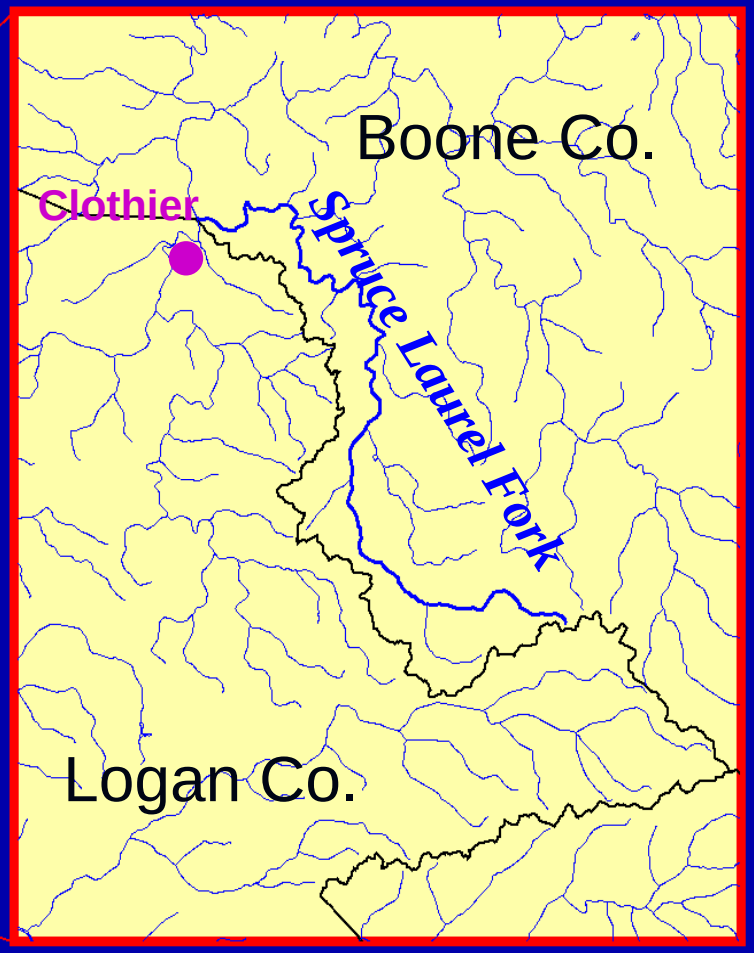
Kohli, 1983

FIGURE 4.1 DEVELOPMENT OF TRANSVERSE SUBSIDENCE PROFILES OVER THE NO. 3 PANEL ALONG THE FACELINE DIRECTION

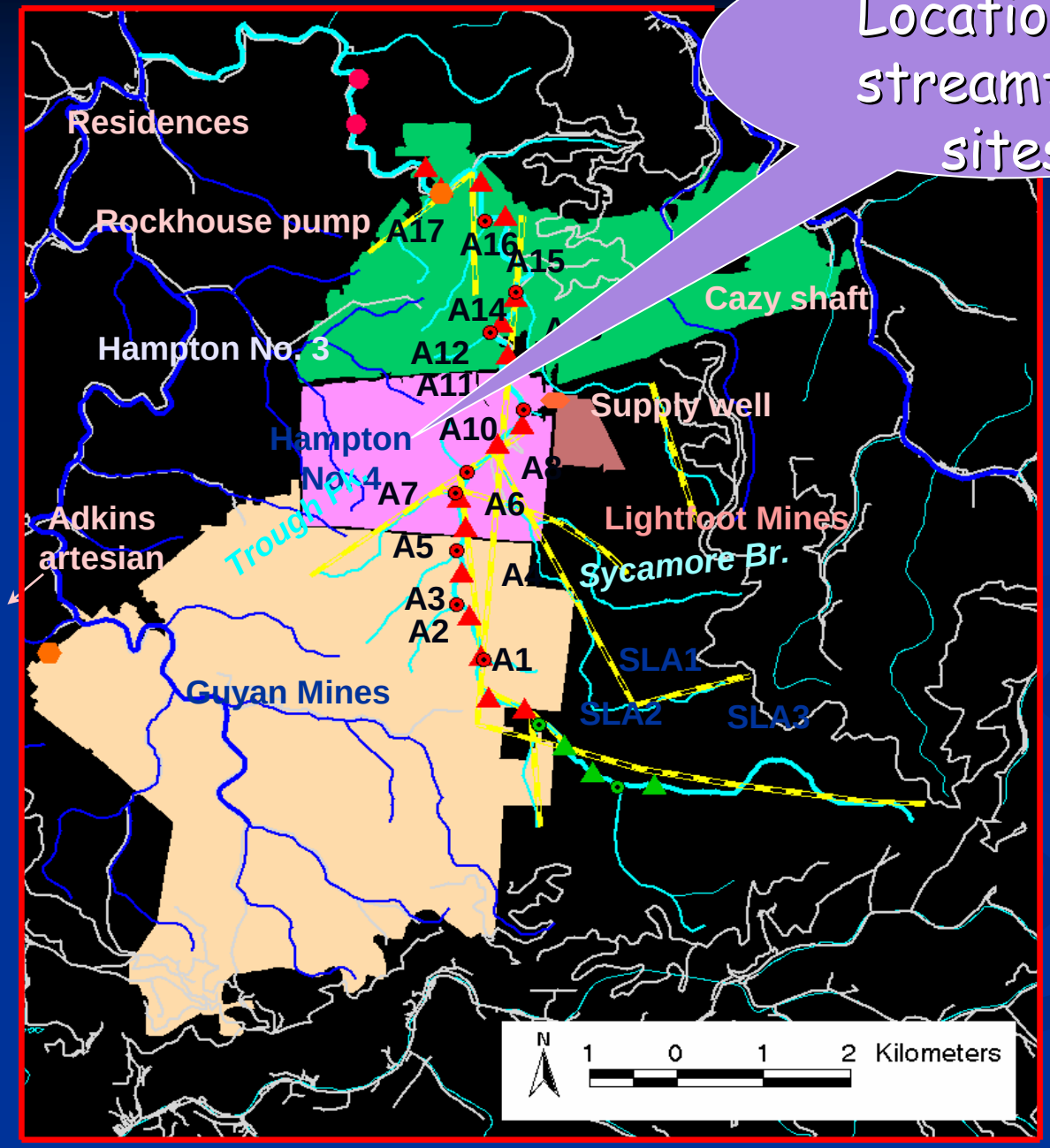
Example: Estimates of coal barrier and roof rock overburden seepage flow

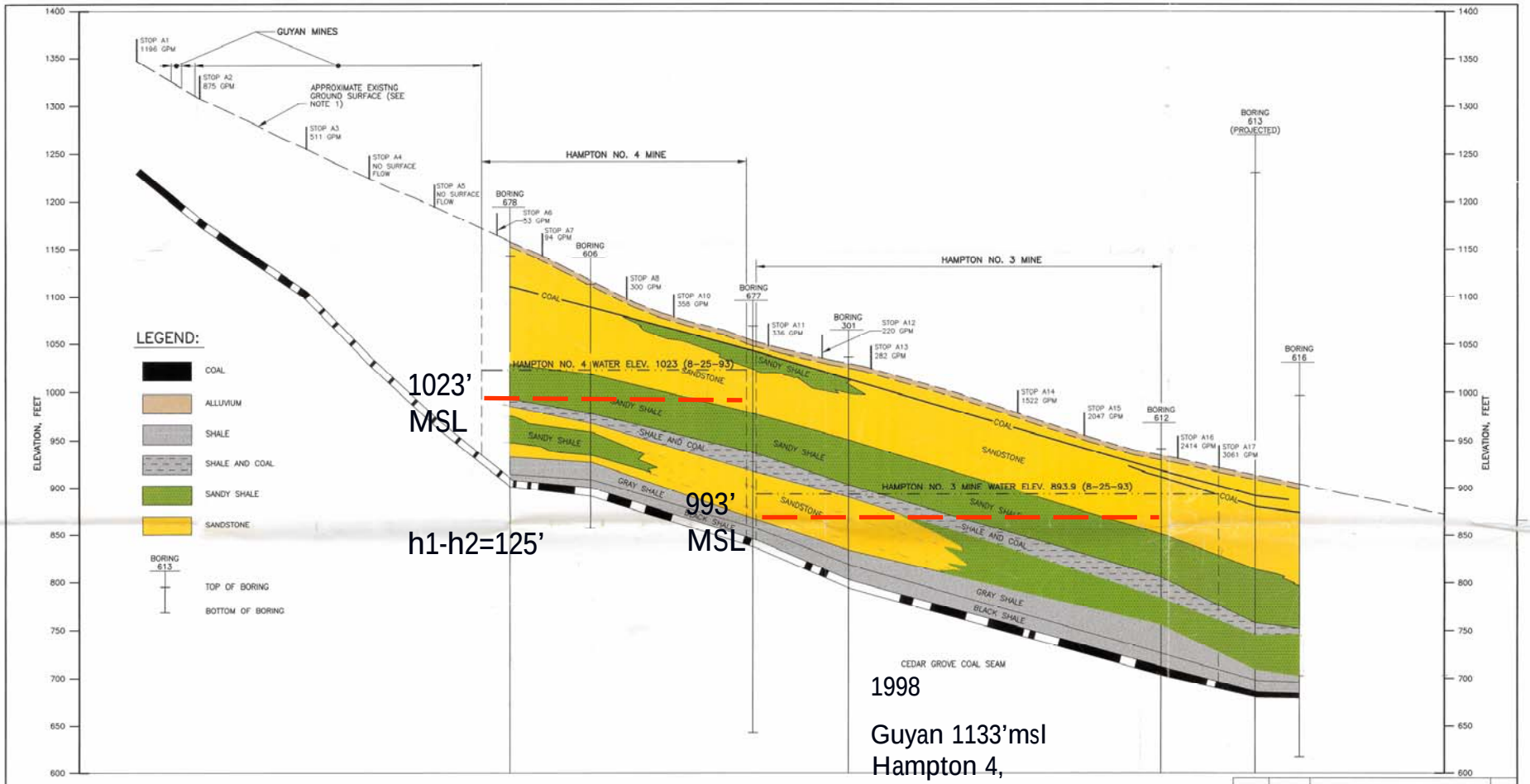
Guyan and Hampton Mines, Boone Co., WV

West Virginia



Location of streamflow sites





1998

Guyan 1133'msl
Hampton 4, 1034'msl,=99'
Hampton 3, 886' msl=149'

NOTES:

1. THE EXISTING GROUND SURFACE SHOWN REPRESENTS THE APPROXIMATE CHANNEL OF SPRUCE LAUREL FORK AND IS BASED ON THE 7 1/2 MINUTE TOPOGRAPHIC QUADRANGLE MAPS OF CLOTHIER, WV (DATED 1978), WHARTON, WV (DATED 1988) AND LORADO, WV (DATED 1976).
2. THE GEOLOGIC INFORMATION SHOWN IS BASED ON DRILLING LOGS PROVIDED BY WESTMORELAND COAL COMPANY AND ARE CONTAINED IN APPENDIX D.
3. THE POSITION OF THE CEDAR GROVE SEAM AND RELATED DEEP MINES IS BASED UPON MINE MAPS PROVIDED BY WESTMORELAND COAL COMPANY.
4. THE "STOPS" SHOWN REPRESENT THE APPROXIMATE LOCATION OF STREAM FLOW MONITORING POINTS UTILIZED WITHIN SPRUCE LAUREL FORK. THE FLOW RATES PRESENTED WERE DETERMINED FROM FLOW MEASUREMENTS COLLECTED DURING THE JUNE 17, 1993 JOINT EFFORT INVOLVING WESTMORELAND COAL COMPANY, THE WEST VIRGINIA DIVISION ENVIRONMENTAL PROTECTION (WVDEP), ALMES & ASSOCIATES, INC. AND APPALACHIAN LABORATORIES, INC. STOP A9 IS NOT SHOWN SINCE THE WVDEP HAS STATED THAT THEY HAVE DISCONTINUED USE OF THIS MONITORING POINT.
5. THE EXACT THICKNESS OF THE ALLUVIUM SHOWN IS UNKNOWN.

GEOLOGIC CROSS-SECTION

VERTICAL SCALE: 50 0 50 100 FEET
HORIZONTAL SCALE: 2000 0 2000 4000 FEET

REV.	DATE	DESCRIPTION	P.M.

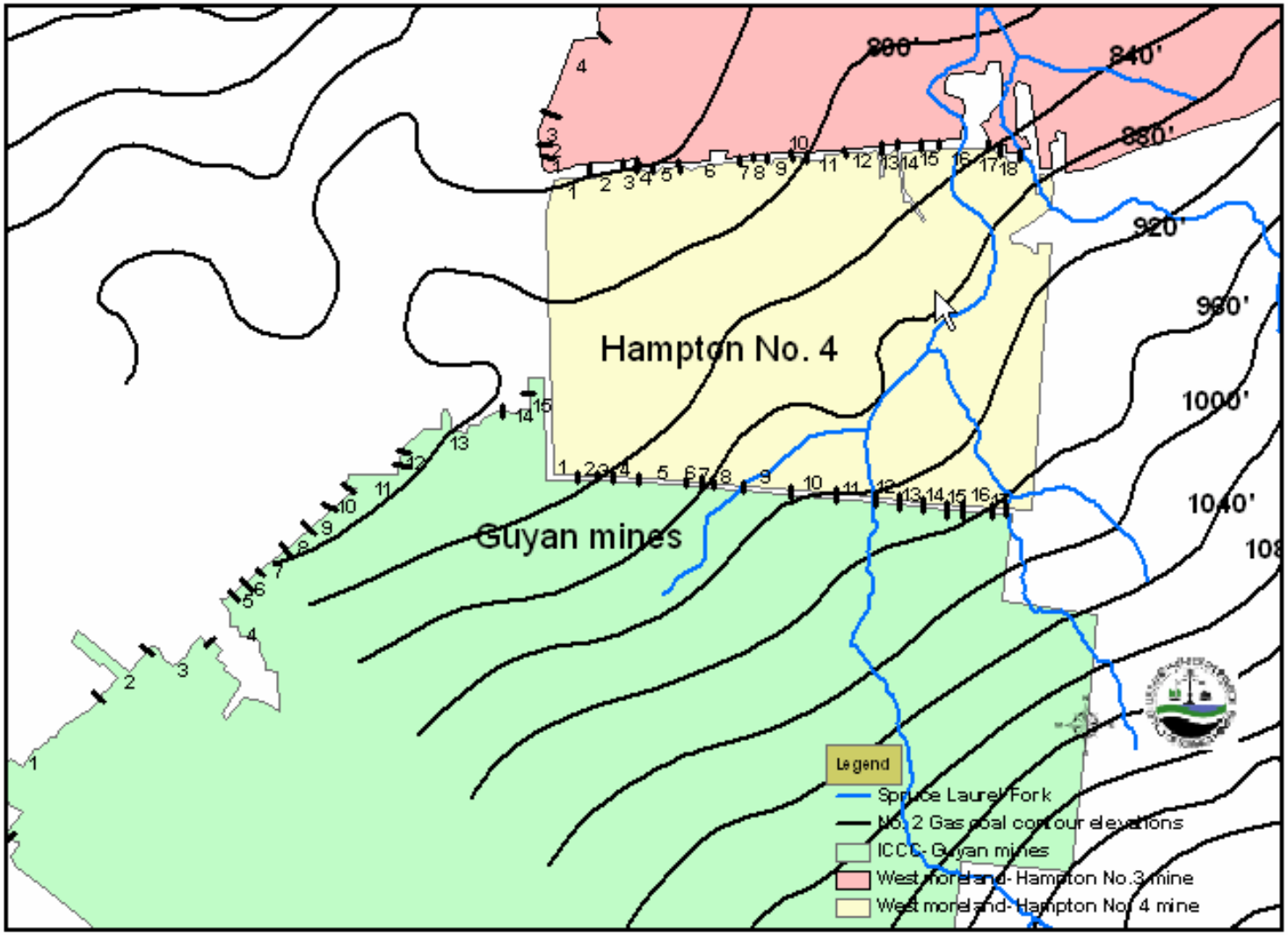
ALMES & ASSOCIATES, INC.
CONSULTING ENGINEERS
BECKLEY, WV 304-255-0491 PITTSBURGH, PA 412-744-3610

GEOLOGIC CROSS-SECTION ALONG SPRUCE LAUREL FORK
HYDROGEOLOGIC ASSESSMENT
GUYAN MINES AND HAMPTON MINE NOS. 3 AND 4
Prepared For
WESTMORELAND COAL COMPANY
BOONE COUNTY, WEST VIRGINIA

CAD BY	RRD	08/06/93	PROJECT NO. B93-70-29	FIGURE NO. 2
CHECKED BY				
APPROVED BY				DRAWING NO. B93-70-D1

PLOT USER 2

Figure 12: Location of coal barrier segments between the Guyan and Hampton # 4 mines



Seepage and water budget estimate

Darcian flow models

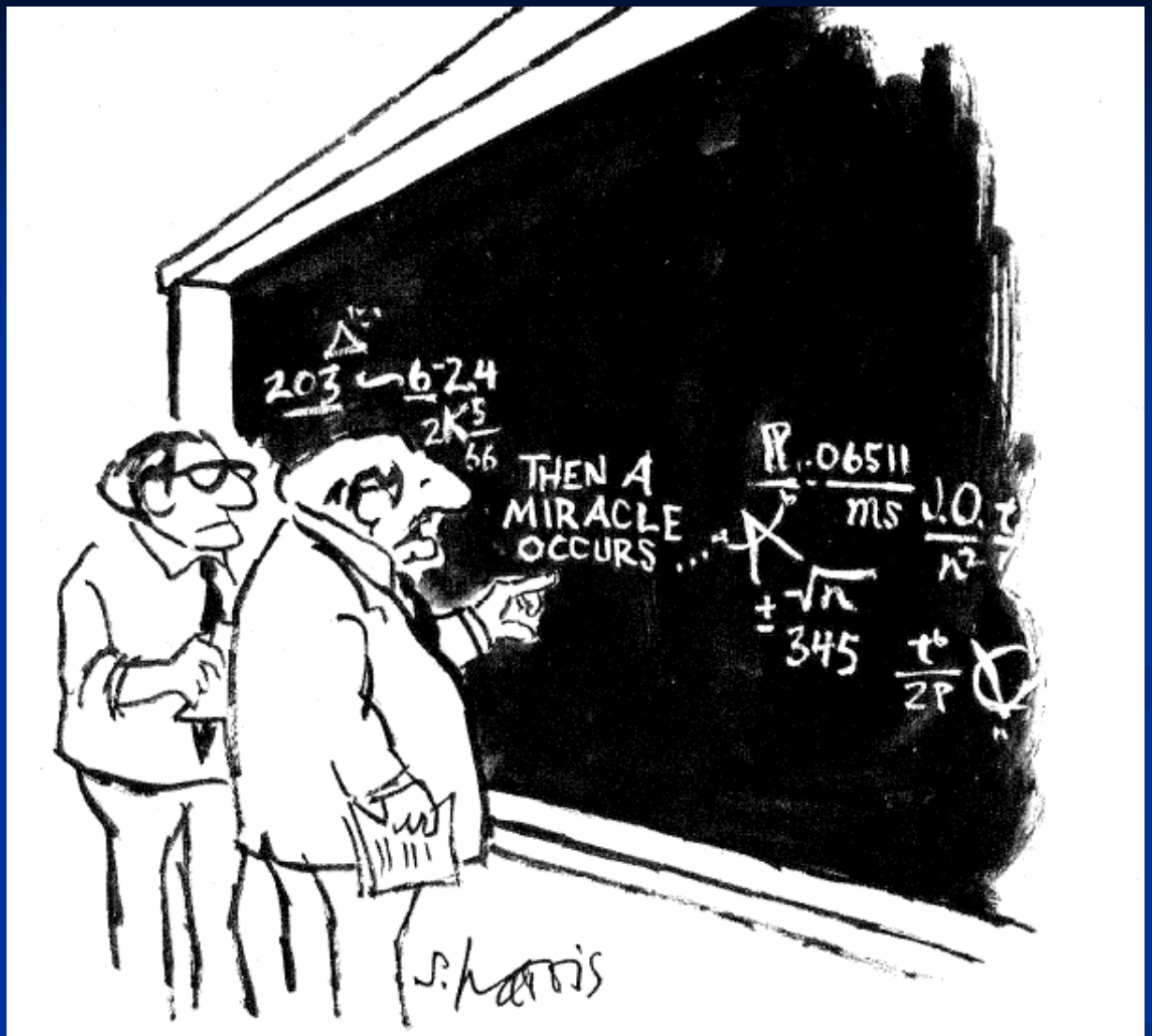
Hampton No.3-4 coal barrier seepage calculations

	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Segment 6	Segment 7	Segment 8	Segment 9	Segment 10
h2-h1 (ft)	148.5	148.5	148.5	148.5	148.5	148.5	148.5	148.5	148.5	148.5
Barrier W (ft)	1060	1260	310	340	700	1390	740	280	1110	210
Seam thk. (ft)	6	6	6	6	6	6	6	6	6	6
Barrier thk L	250	270	300	190	150	100	140	110	120	220
Q=k= 0.10 ft/day)	377.78	415.80	92.07	159.44	415.80	1238.49	470.96	226.80	824.18	85.05
Q=k= 0.15ft/day)	566.68	623.70	138.11	239.16	623.70	1857.74	706.44	340.20	1236.26	127.58
Q=k= 0.20 ft/day)	755.57	831.60	184.14	318.88	831.60	2476.98	941.91	453.60	1648.35	170.10
Q=k= 0.25 ft/day)	944.46	1039.50	230.18	398.61	1039.50	3096.23	1177.39	567.00	2060.44	212.63
Q=k= 0.50 ft/day)	1888.92	2079.00	460.35	797.21	2079.00	6192.45	2354.79	1134.00	4120.88	425.25

	Segment 11	Segment 12	Segment 13	Segment 14	Segment 15	Segment 16	Segment 17	Segment 18
h2-h1 (ft)	148.5	148.5	148.5	148.5	148.5	148.5	148.5	148.5
Barrier W (ft)	1010	1020	360	590	560	1090	150	740
Seam thk. (ft)	6	6	6	6	6	6	6	6
Barrier thk L	100	225	70	240	230	110	210	280
Q=k= 0.10 ft/day)	899.91	403.92	458.23	219.04	216.94	882.90	63.64	235.48
Q=k= 0.15ft/day)	1349.87	605.88	687.34	328.56	325.41	1324.35	95.46	353.22
Q=k= 0.20 ft/day)	1799.82	807.84	916.46	438.08	433.88	1765.80	127.29	470.96
Q=k= 0.25 ft/day)	2249.78	1009.80	1145.57	547.59	542.35	2207.25	159.11	588.70
Q=k= 0.50 ft/day)	4499.55	2019.60	2291.14	1095.19	1084.70	4414.50	318.21	1177.39

Summary: Seepage through Hampton No.4-Hampton No. 3 coal barrier (coal only)

k (ft/day)	cf/day	gpm
0.10	7686	39.93
0.15	11412	59.28
0.20	15137	78.64
0.25	18863	97.99
0.50	37490	194.75



"I think you should be more explicit here in step two."

Hampton No.3-4 mines roof rock (overburden) seepage flow calculations

	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Segment 6	Segment 7	Segment 8	Segment 9	Segment 10
h2-h1 (ft)	148.5	148.5	148.5	148.5	148.5	148.5	148.5	148.5	148.5	148.5
Barrier W (ft)	1060	1260	310	340	700	1390	740	280	1110	210
Barrier thk L (ft)	250	270	300	190	150	100	140	110	120	220
Ovb.(aq) saturated tk	126	124	124	124	124	124	119	114	109	105
Q=kovb= 3.0 ft/day)	238003.92	257796.00	57083.40	98854.11	257796.00	767863.80	280219.50	129276.00	449175.38	44651.25
Q=kovb= 2.0 ft/day)	158669.28	171864.00	38055.60	65902.74	171864.00	511909.20	186813.00	86184.00	299450.25	29767.50
Q=kovb= 1.0 ft/day)	79334.64	85932.00	19027.80	32951.37	85932.00	255954.60	93406.50	43092.00	149725.13	14883.75
Q=kovb= 0.74 ft/day)	58707.63	63589.68	14080.57	24384.01	63589.68	189406.40	69120.81	31888.08	110796.59	11013.98
Q=kovb= 0.65 ft/day)	51567.52	55855.80	12368.07	21418.39	55855.80	166370.49	60714.23	28009.80	97321.33	9674.44
Q=kovb= 0.50 ft/day)	39667.32	42966.00	9513.90	16475.68	42966.00	127977.30	46703.25	21546.00	74862.56	7441.88
Q=kovb= 0.30 ft/day)	23800.39	25779.60	5708.34	9885.41	25779.60	76786.38	28021.95	12927.60	44917.54	4465.13
Q=kovb= 0.25 ft/day)	19833.66	21483.00	4756.95	8237.84	21483.00	63988.65	23351.63	10773.00	37431.28	3720.94
Q=kovb= 0.10 ft/day)	7933.46	8593.20	1902.78	3295.14	8593.20	25595.46	9340.65	4309.20	14972.51	1488.38

	Segment 11	Segment 12	Segment 13	Segment 14	Segment 15	Segment 16	Segment 17	Segment 18
h2-h1 (ft)	148.5	148.5	148.5	148.5	148.5	148.5	148.5	148.5
Barrier W (ft)	1010	1050	360	590	560	1090	150	740
Barrier thk L (ft)	100	225	70	240	230	110	210	280
Aq.(ovb) saturated thk	104	104	104	101.5	99	96.5	94	89
Q=kovb= 3.0 ft/day)	467953.20	216216.00	238278.86	111161.53	107384.87	425999.25	29912.14	104787.96
Q=kovb= 2.0 ft/day)	311968.80	144144.00	158852.57	74107.69	71589.91	283999.50	19941.43	69858.64
Q=kovb= 1.0 ft/day)	155984.40	72072.00	79426.29	37053.84	35794.96	141999.75	9970.71	34929.32
Q=kovb= 0.74 ft/day)	115428.46	53333.28	58775.45	27419.84	26488.27	105079.82	7378.33	25847.70
Q=kovb= 0.65 ft/day)	101389.86	46846.80	51627.09	24085.00	23266.72	92299.84	6480.96	22704.06
Q=kovb= 0.50 ft/day)	77992.20	36036.00	39713.14	18526.92	17897.48	70999.88	4985.36	17464.66
Q=kovb= 0.30 ft/day)	46795.32	21621.60	23827.89	11116.15	10738.49	42599.93	2991.21	10478.80
Q=kovb= 0.25 ft/day)	38996.10	18018.00	19856.57	9263.46	8948.74	35499.94	2492.68	8732.33
Q=kovb= 0.10 ft/day)	15598.44	7207.20	7942.63	3705.38	3579.50	14199.98	997.07	3492.93

Hampton 4 (roof rock) overburden

kovb (ft/day) Overburden K	overburden cf/d	overburden gpm	Recharge rate OVB gpm/acre	Ovb-aq sat thk ft
3.0	4282413	22246	8.64	
2.0	2854942	14831	5.76	
1.0	1427471	7415	2.88	
0.74	1056329	5487	2.13	
0.65	927856	4820	1.87	
0.50	713736	3708	1.44	110.28
0.30	428241	2225	0.86	
0.25	394299	2048	0.80	
0.10	142747	742	0.29	

Summary of Hampton-Guyan mine flooding

Back-calculating the K_h of coal barriers and roof rock overburden seepage

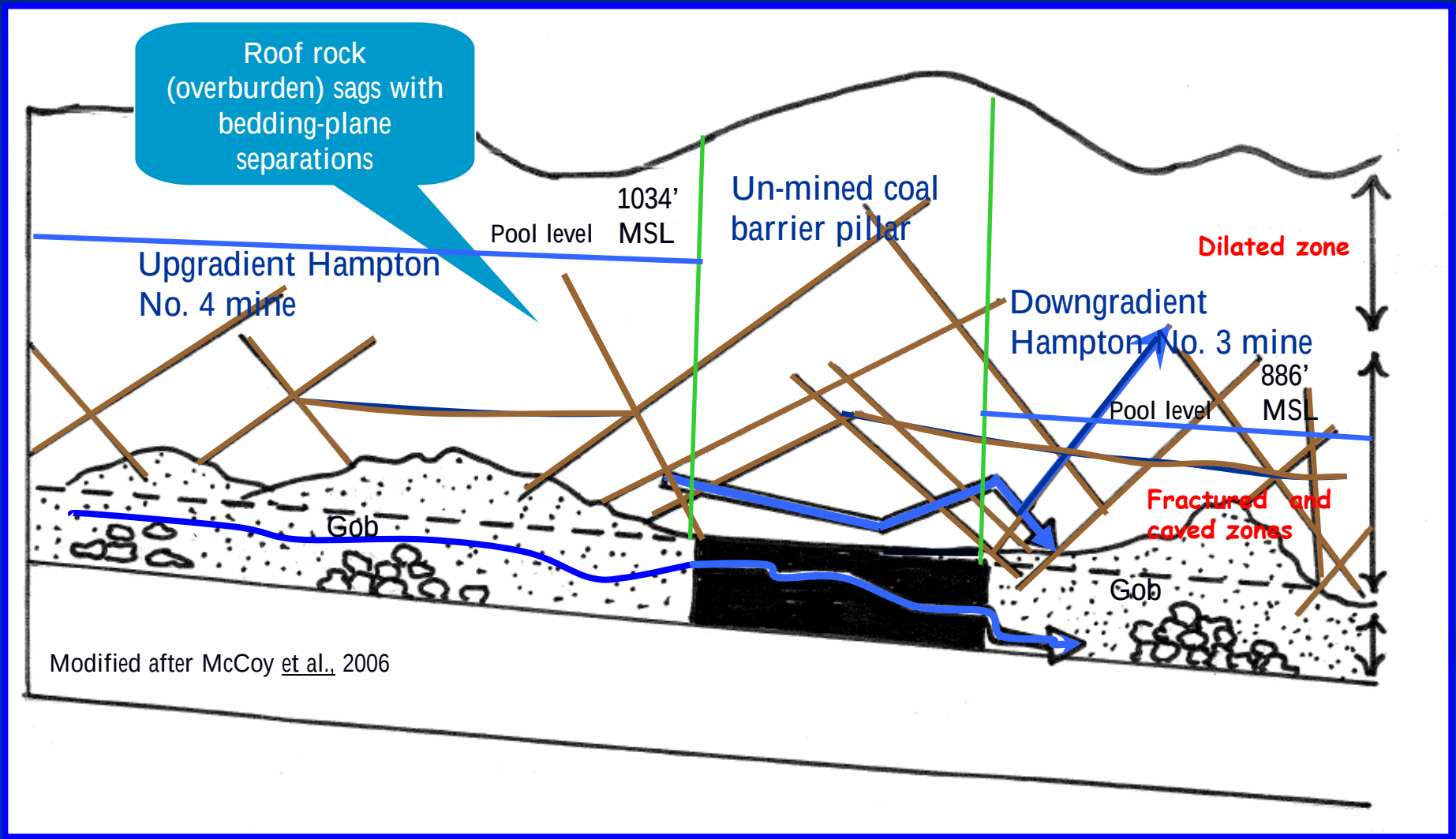
Hampton No. 3 closed in 1987; Res. complaints-1991-1992 = approx.5 year time-frame;

Hampton No. 4 closed in 1990; Res. complaints, 1991-1992 =approx.2 year time-frame;

Guyan mine closed in Jan.1978: Adkins Fk, artesian-1985 =approx.7 year time-frame.

Mine barrier segments	*Streamloss* *ft^3/day loss*	*Overburden* *ft^3/day*	*Overburden* *gpm/acre*	*Barrier seepage* *ft^3/day*		
Hampton 3-unmined	384615	619477	0.63	6648		
Hampton 4-Hampton 3	771155	713736	1.44	37490		
Guyan-Hampton 4	498190	1101690	0.46	33418		
Mine barrier segments	*Overburden + Barrier* *ft^3/day loss*	*Overburden + Barrier* *Normalized gpm/acre*	*Ovb.+barrier+strmloss* *ft^3/day loss*	*Ovb.+barrier+strmloss* *gpm/acre*	*Pool development* *time (years)*	**Streamloss to mine pool** *% contrib.to mine pool*
Hampton 3-unmined	626125	0.86	721990	0.99	4.9	38
Hampton 4-Hampton 3	751226	1.78	1522381	3.60	1.5	51
Guyan-Hampton 4	1135108	0.48	1613848	0.67	7.4	31

Conceptual model of seepage flow from the Hampton No.4 to No.3 mine



Conclusions

- Understanding seepage rates across coal barriers and in the overburden is important in planning post-mining mine closure flooding elevations
- To more accurately estimate seepage rates and post-mine flooding pool elevations, these data are necessary
- Mine maps provided in AutoCADD or ArcMAP format

  - Mine pool water levels from installed piezometers

  - Detailed permittee mine pump records

    + Yields important information about mine pumping rates per day and fluctuations in pool levels

  - Data could be utilized in TIPS ground water model apps.
- Permits utilizing more enhanced water level monitoring HRP plans through the life of mine would result in better water management, especially if the mine water is AMD

The End

Water Quality in Flooded and Partly Flooded Mine-pools

Eric Perry
Office Surface Mining
Pittsburgh, PA

Significance of Long Term Water Quality

- Estimate Whether Post-mining Water requires treatment
- Estimate Chemical Consumption and Duration of Treatment.
- Change in Water Composition, Chemical Consumption, or Potential Impacts Over Time

Flooded and Partly Flooded Mines

What separates flooded from partly flooded? What degree of flooding inhibits acid production?

Flooded vs. Partly Flooded (The Concept)

- Flooding excludes Oxygen, stops pyrite oxidation, acid pools may turn alkaline
  - Soluble salts may still be flushed, TDS can remain elevated.
  - Ferrous iron may still be present. Also manganese.

- Partly Flooded – D.O. greater than 1-2 mg/L, pyrite oxidation continues
  - Continuing acid generation, metals, dissolved solids

Initial Water Chemistry

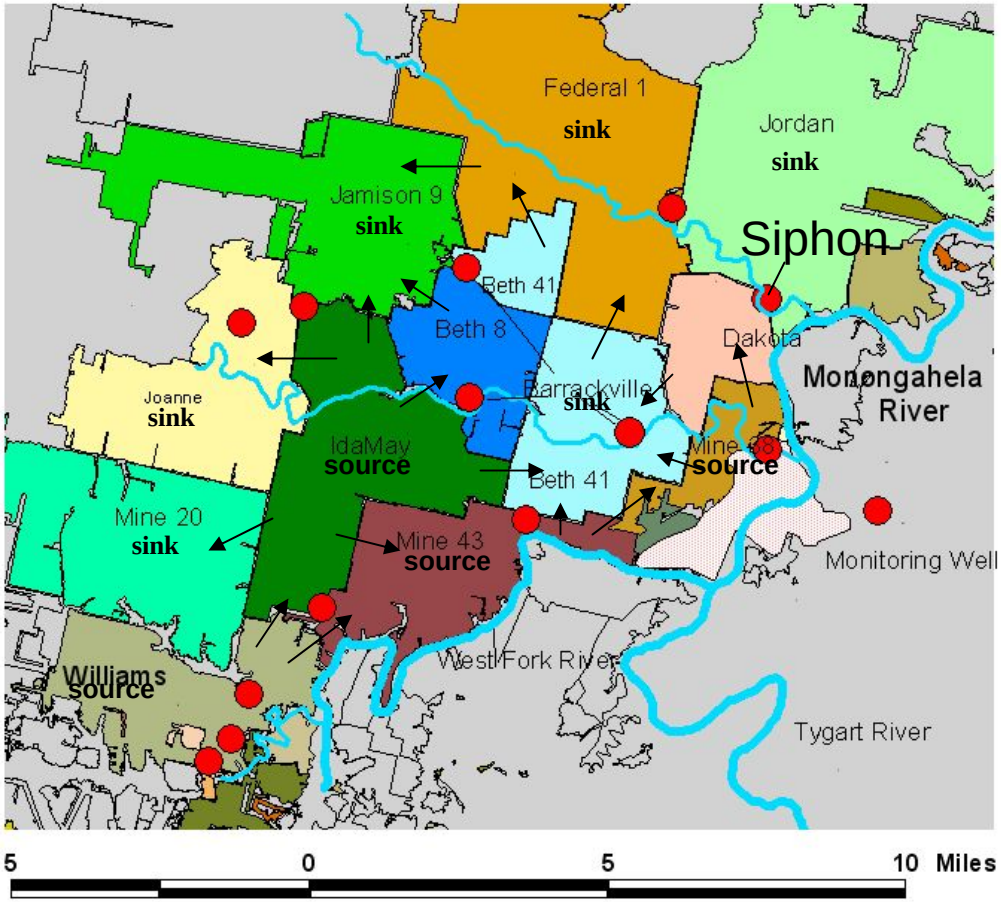
	Acid	Neutral
Metals and Dissolved Solids	Low	Low
Metals and Dissolved Solids	High	High

What is the long term chemical composition of these mines when they flood?

Do the acid mine-pools remain acidic?

Spatial Variation in Mine-pool Chemistry

Fairmont Mine-pool Monitoring Wells and Generalized flow Pattern



Ground water
Flow Direction →

Near 100% flooded, one main pump location (Siphon), barrier leakage and outflow to west

Water Quality of Fairmont Mine-pool in Different Parts of Flow System, 2003

Site	pH	Alkalinity	TDS	Fe	Ca	Mg	Na	SO_4	Cl
Mine 38 Recharge	7.32	179	548	3.44	61	14	105	207	34
Mine 63 Intermed.	7.31	589	3301	33.9	158	33	853	1697	44
Dakota Siphon End	7.20	568	5194	135	251	90	1254	2812	119
Over-burden	8.57	263	454	0.04	21	5	138	48	52

Mine 38 well in recharge area, Mine 63 well at intermediate flow path location, and Siphon at end of flow path. Dissolved constituents in mg/L.

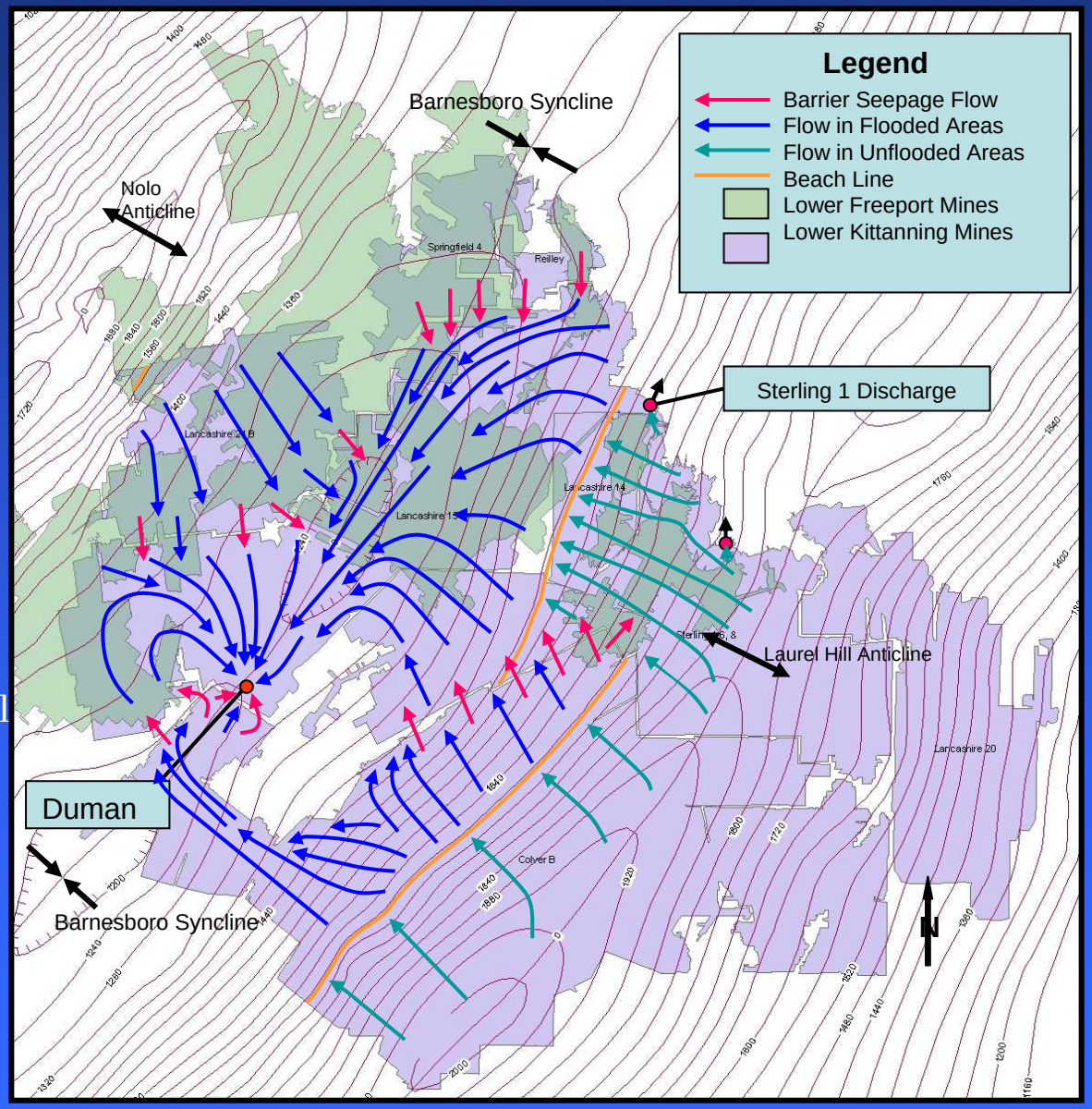
Structure and Ground Water Flow in Lancashire 15 Mine-pool

About 80% Flooded

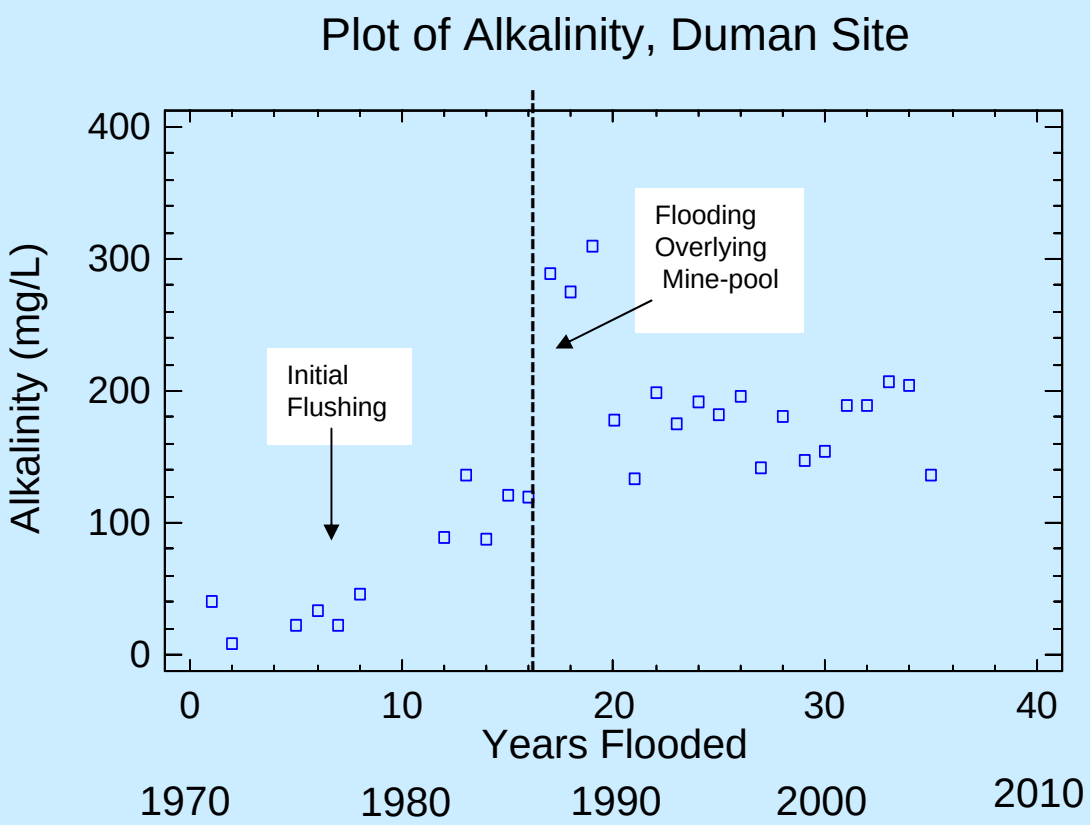
One pumping location – Duman

Main mine-pool in Lower Kittanning

Overlying mine-pool in Lower Freeport

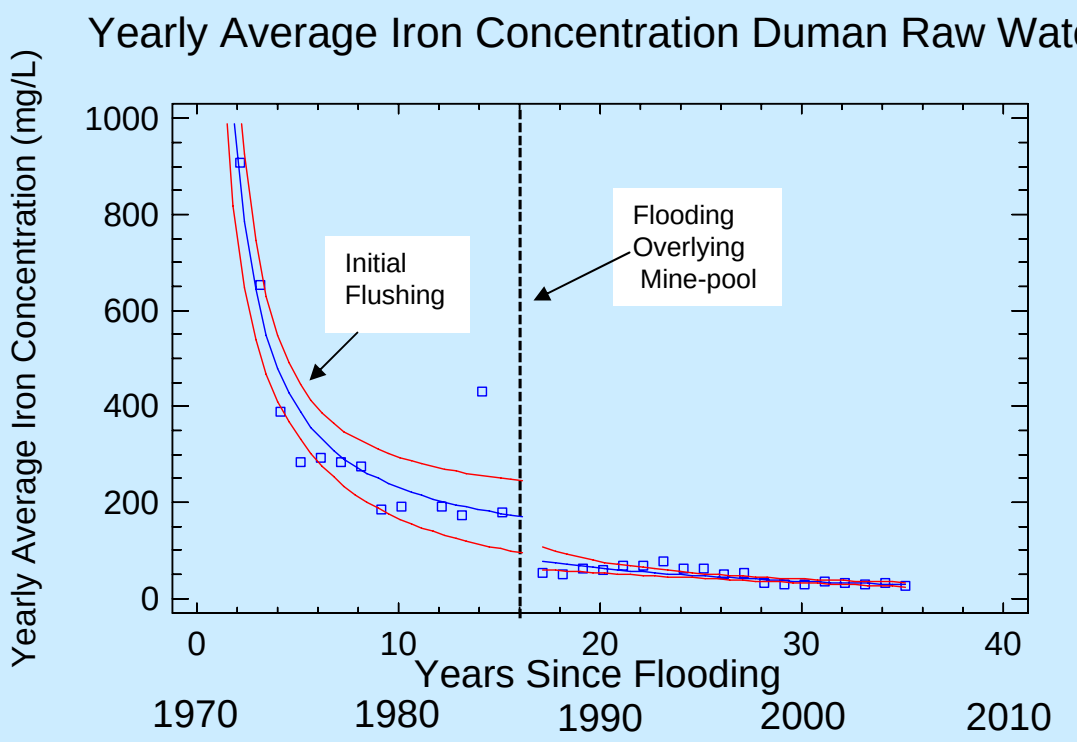


Effect of Flooding on Alkalinity Concentration, Lancashire 15 Mine-pool, Pennsylvania



Mine flooded 1970, initially acidic.

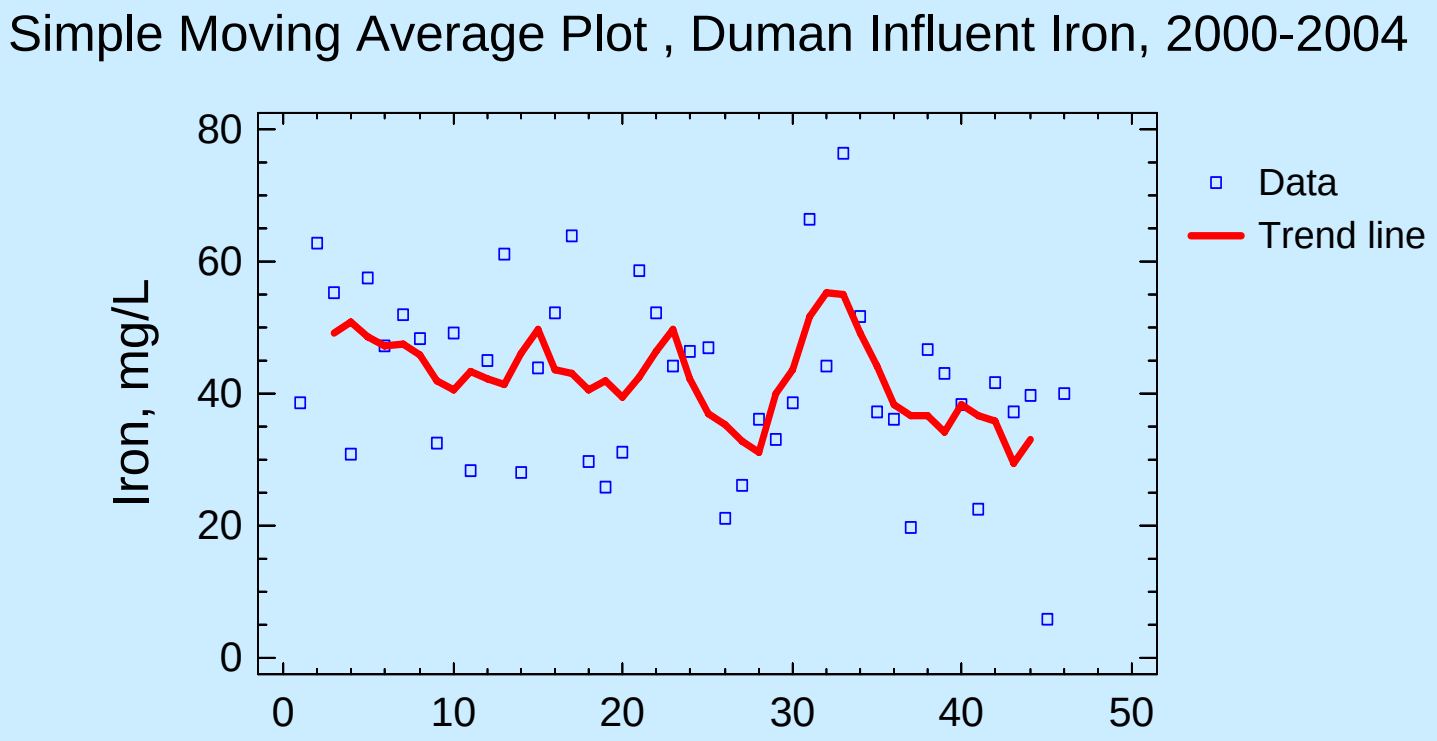
Temporal Change in Mine-pool Chemistry Average Annual Iron Concentration, Lancashire 15 Main Discharge



Fe Average (mg/L) = 82.5 + (1579.8/Years since flooding) 1971-1986

Fe Average (mg/L) = $1/(7.59 * 10^{-4} *$Years since Flooding) 1986-2004

Short Term Variation Mine-pool Composition, Lancashire 15 Main Discharge , Iron Concentration, 2000-2004

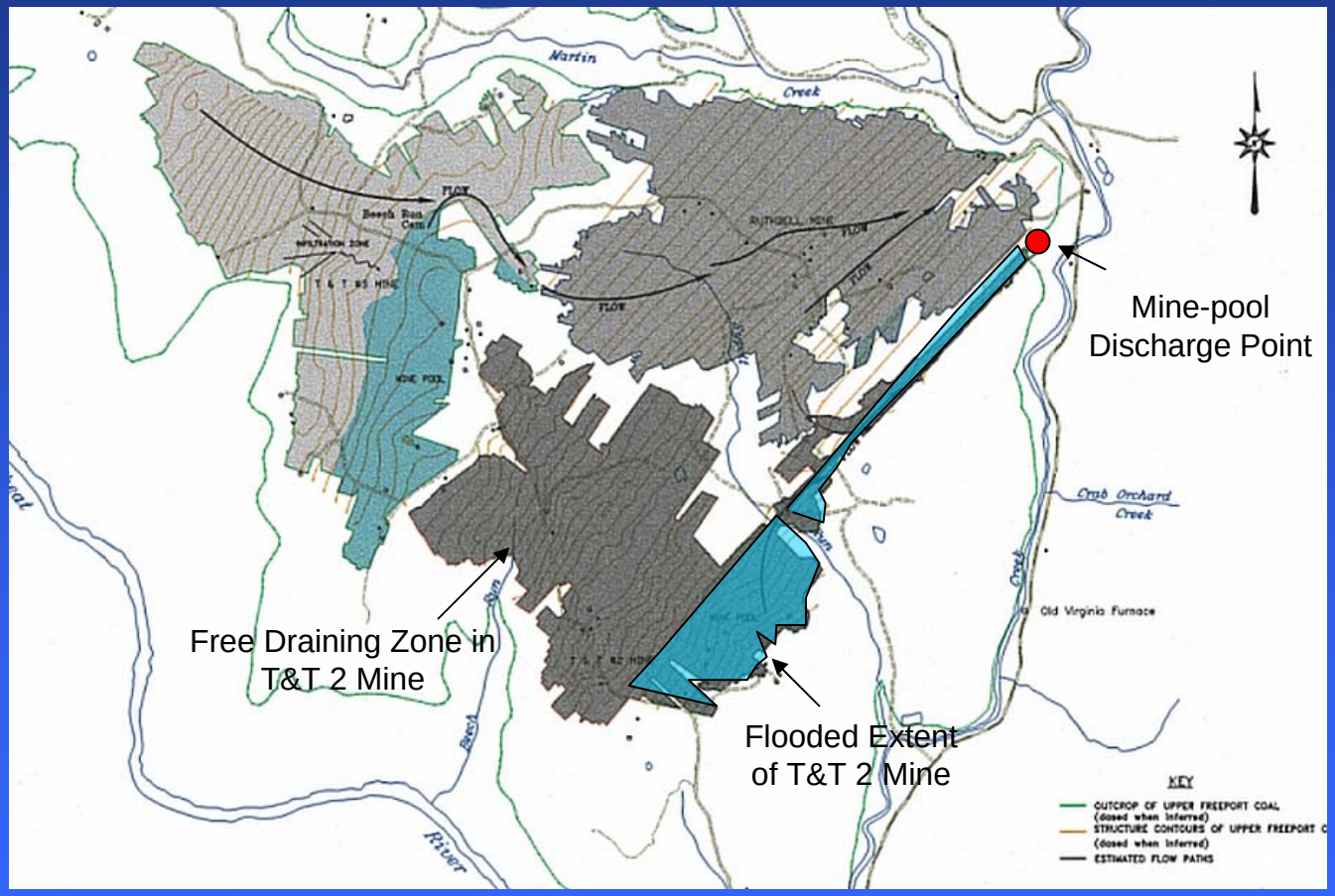


Monthly Sample Interval, quality affected by pumping rate.

Effect of Pumping Rate on Discharge Quality, Lancashire 15 Mine-pool

Discharge Rate (gpm)	pH	Alkalinity	Acidity	Iron	Sulfate
3250	6.7	230	58	32.6	299
6500	6.5	169	94	47.7	402

Hydrogeologic Setting of the Unflooded T&T 2 Mine-pool



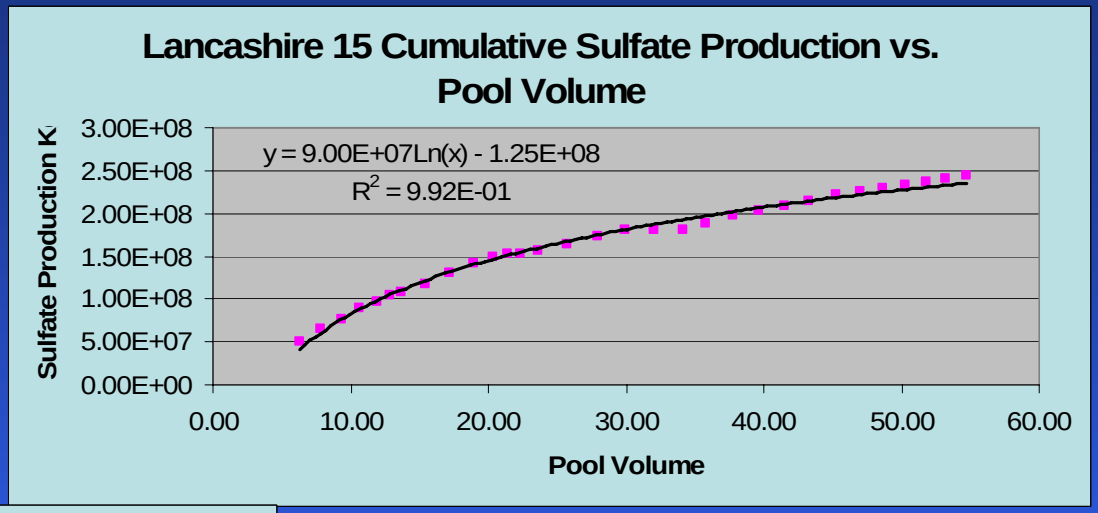
About 20% flooded

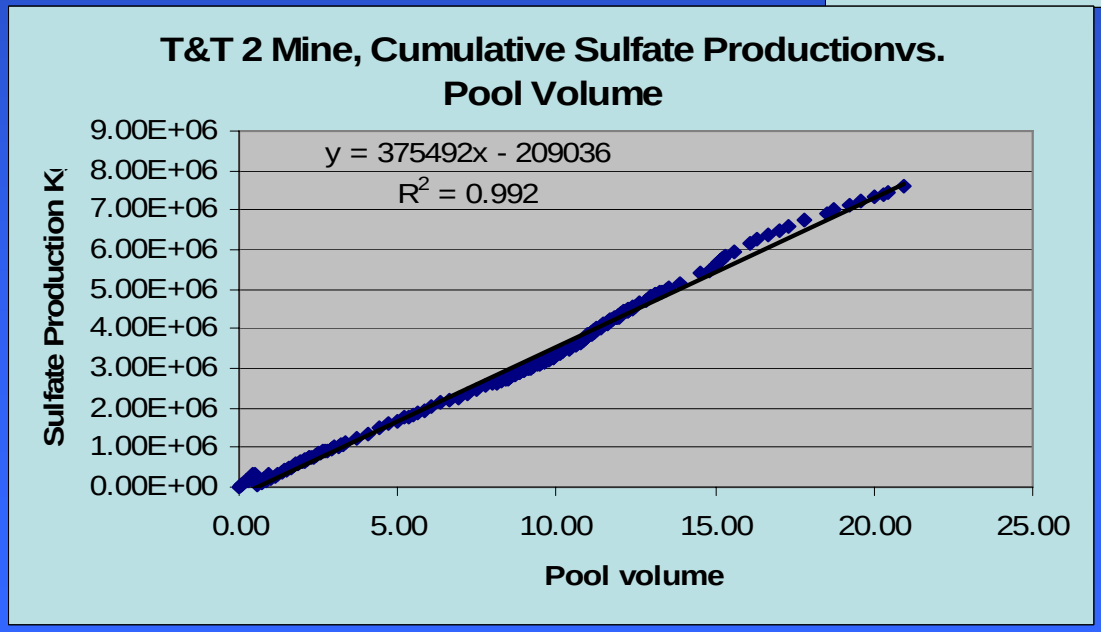
Water Quality Change Over Time

Median Water Quality for the Lancashire 15 (Flooded) and T&T 2 (Partly flooded) Mine-pools At Closure and After 25 Pool Volumes.

Site	pH	Total Acidity (mg/L)	Alkalinity (mg/L)	Fe (mg/L)	Al (mg/L)	Sulfate (mg/L)	Dis.O_2 (mg/L)
Flooded After Closure	5.1	1500	40	837	N.D.	3432	N.D.
Flooded After 25 Pool Volumes	6.53	113	120	63	N.D.	614	<0.5
Partly flooded After Closure	2.6	968	0	313	82	2400	N.D.
Partly flooded After 25 Pool Volumes	2.9	340	0	72	27	905	~2.5

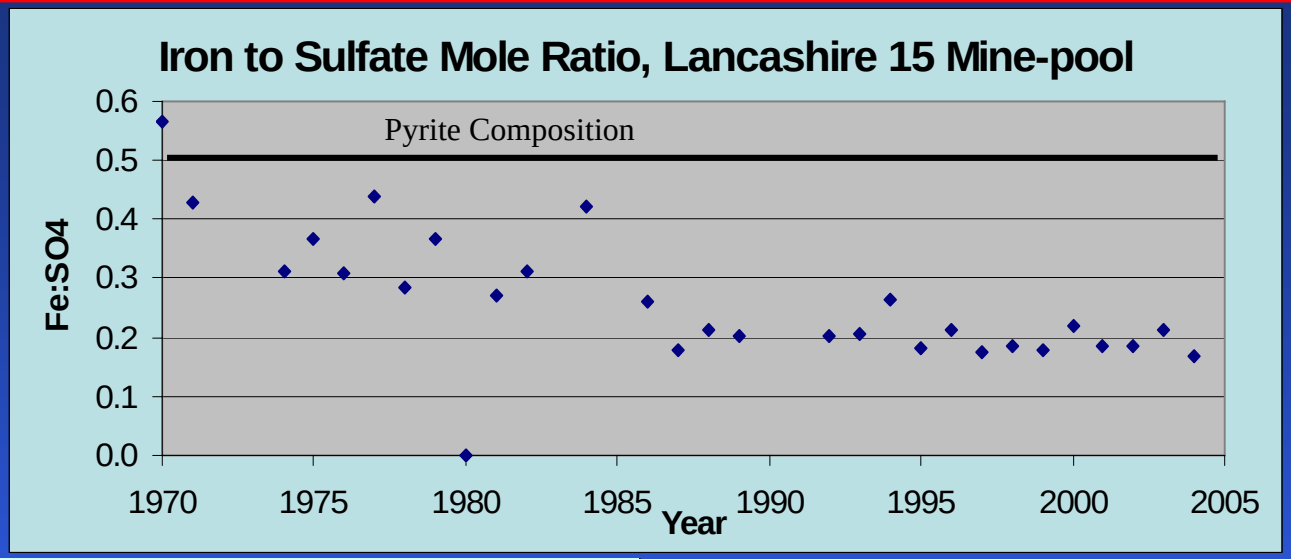
Plot of Cumulative Sulfate Production (Kg), Flooded Lancashire 15 and Partly flooded T&T2 Mines

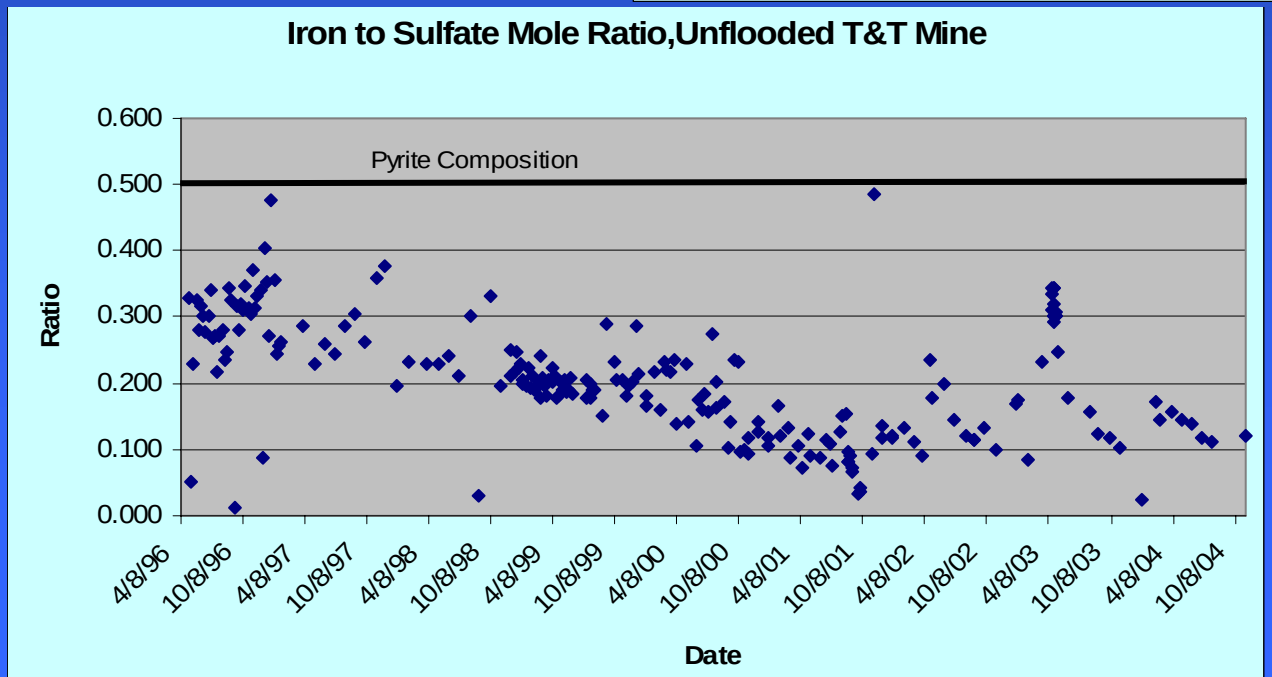




Sulfate production is decreasing in the flooded mine-pool but remains nearly constant in the partly flooded mine-pool. Indicates acid production is continuing in partly flooded conditions, but decreasing in the flooded mine.

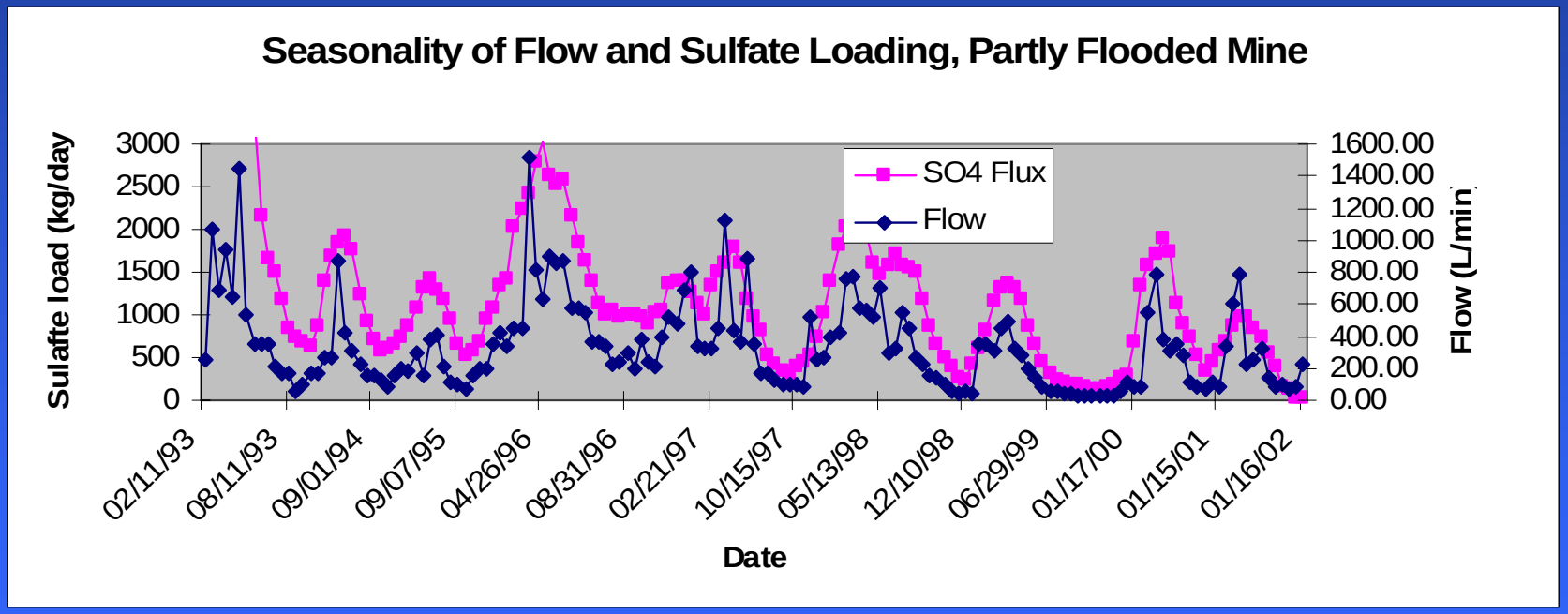
Iron to Sulfate Mole Ratio, Flooded Lancashire 15 Mine-pool and Partly Flooded T&T Mine-pool





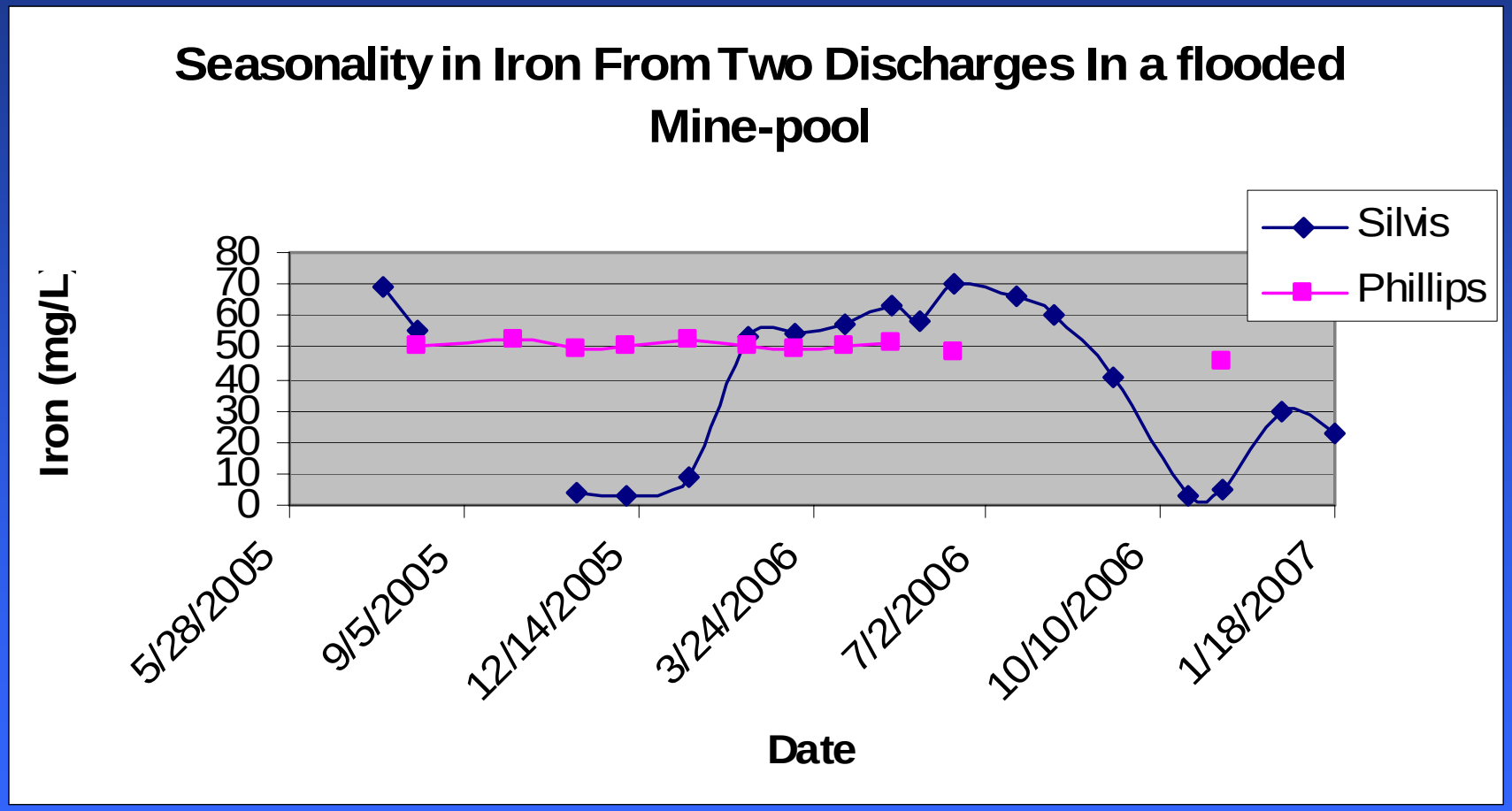
A significant fraction of iron is being retained within the mine-pool aquifer even in very acid mine-pools (precipitation, adsorption etc?)

Seasonality in a Partly Flooded Mine-pool



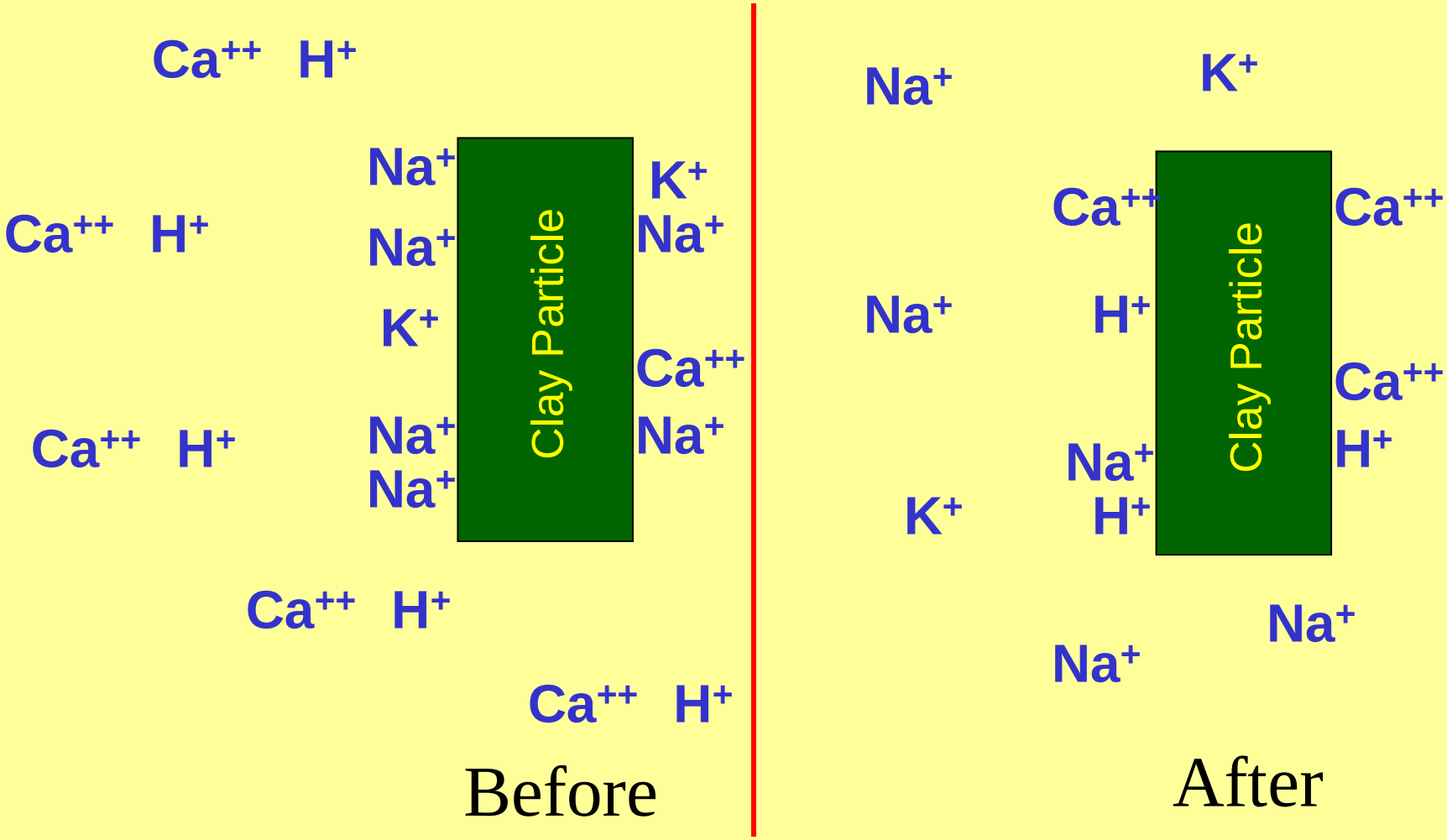
Thin overburden (less than 250 ft), rapid recharge and response to precipitation.

Seasonal Characteristics Within A Mine-pool



Phillips is a steady state discharge. Silvis is an overflow point for the mine-pool

Cation Exchange



Relative Ease of Replacement

$Ca^{++} > Mg^{++} > K^{+} > Na^{+}$

Cation Exchange in Lancashire 15 Mine-pool

Source Waters	pH	Alkalinity	Fe	Ca	Mg	Na	SO_4
Flooded L.Kittanning	6.4	63	62	96	30	70	417
Unflooded L. Kittanning	2.8	0	113	85	34	35	767
Lower Freeport	6.3	124	0.3	75	19	11	157
Ground-water	7.0	142	0.3	43	6	2	27
End of Flowpath	6.55	137	40	40	15	159	390

What do We Know About Long Term Mine-pool Chemistry?

- Poorest water quality at the beginning in the first flushing of the mine works.
- Mine-pool evolution includes an initial short term flushing followed by a longer term maturation period. *Same behavior observed in coal mine-pools in United Kingdom.*
- Initial flush is years to a decade, with variable water composition and rapid decline in pollutant concentration. Metals and sulfate decline more rapidly in flooded mine-pools compared to unflooded mines.
- The maturation phase is characterized by a continuing slow decline in most chemical concentrations and less variation. Maturation occurs over a period of decades as the mine-pools approach a steady-state condition.
- Part of the metals generated by chemical weathering are retained in the aquifer, even in acid mine-pools.
- Complete flooding suppresses or stops pyrite oxidation, and some acid mine-pools turn alkaline.

What We Don’t Know about Mine-pool Chemistry

- How do we use Acid Base Accounting data to estimate mine-pool chemistry?
- How to estimate metals and dissolved solids concentrations?
- What rocks control mine-pool chemistry (How far above/below the coal)?
- Does alkaline recharge from overlying aquifers influence water quality?
- How long for pollutant concentrations to decline to some acceptable level (How long is the “tail”)?
- What happens at the end of the “tail”?

Discussion Questions

- - Discuss the initial water quality of the mine pool and the changes in the water quality with time
- - What parameters changed with time and what was the time frame for the change?
- - What was the cause of the change in the water quality?
- - What type of data was collected to help determine the cause of the change?
- - Where the changes in the water quality predicted?
- - What procedure and method was used to measure the changes in the water quality?
- - How reliable is the data collected through the monitoring program?
- - Is it sufficient in quantity and quality?

Hydrologic Analysis for Underground Mine Permitting

WVDEP/OMR/Philippi Region

Two Major Types of Underground Mines

- **Below Drainage Deep Mines (Conventional Room and Pillar Mines and Longwall Mines)**

- **Above Drainage Deep Mines (Predominately Conventional Room and Pillar Mines)**

Below Drainage Deep Mines

- Deep Mines that are below local surface drainage or streams (Conventional Room and Pillar Mines and Longwall Mines)

  - **Water Quality Issues**
  - AMD Prediction
  - Artesianing of Mine Water into Streams and Aquifers
  - "Inter-Mine Barrier" Seepage
  - Mine Discharge Effects on Surface Water and Groundwater Quality

  Water Quantity Issues
  - Infiltration Rate Into Mine Workings
  - "Inter-Mine Barrier" Seepage
  - Flooding Rate of Mines
  - Subsidence De-watering of Streams and Aquifers

Prohibitions – Below Drainage Deep Mines

- Do not allow mining where hydrostatic head exceeds cover in a potential **acid producing seam,** unless they can demonstrate that this seam is non-acid producing.
- Can demonstrate it is non-acid producing with water quality data from adjacent mines in this seam, or, with benign coal sulfur or ABA data.

Above Drainage Deep Mines

- Deep Mines that are above local surface drainage or streams (Predominately Conventional Room and Pillar Mines)

- **Water Quality Issues**

  -AMD Prediction

  -Outcrop Barrier Seepage

  -Down-Dip Gravity Discharges (through down-dip punch-outs or boreholes)

  - Up-dip Discharges (from deep mines that are completely flooded and discharging)

  - Mine Discharge Effects on Surface Water and Groundwater Quality.

  Water Quantity Issues

  - Infiltration Rate Into Mine Workings

  - Outcrop Barrier Seepage

  - Flooding Rate of Mines

  - Subsidence De-watering of Streams and Aquifers

Prohibitions – Above Drainage Deep Mines

- Do not allow "gravity" discharges in a potential **acid producing seam,** unless they can demonstrate that this seam is non-acid producing.
- Can demonstrate it is non-acid producing with water quality data from adjacent mines in this seam, or, with benign coal sulfur or ABA data

Types of Data Used to Predict Mine Pool Quality

- **Geological and Geochemical Data**
  - Sulfur Content of the coal seam
  - ABA data of coal pavement and roof and of overburden
  - Review of Geologic Cross-Sections to determine overburden type.

  Water Quality Data from Adjacent Mines in the Same Coal Seam

  Data can be from discharges, boreholes into the mine, etc. A mine that will have the same flooding characteristics should be selected if possible.

- **Water Quality Data of Groundwater Sources or Aquifers That May enter the Mine**

  Either through natural infiltration or seepage or through infiltration and seepage enhanced by subsidence fracturing. (Alkaline GW, such as limestones above Pittsburgh coal, should inhibit AMD production. Acidic GW may promote AMD production).

Analyses Used to Predict Mine Pool Flow/Seepage/Flooding/Infiltration or Quantity

- **Barrier Seepage Calculations –** Use Dames and Moore Formula to Calculate Seepage Through a Barrier (Outcrop Barrier and Internal Mine Barrier) Q = K x P/W x t., Q = KIA – Darcy's Law

- **Infiltration Rate Calculations –** Use Rule of Thumb **(**0.5 gpm/acre) or a Site-Specific Number.

- Site-specific Number can be Derived From Pumping Rates of a Known Mine Area in the Same Seam in the Same Area with Similar Cover Conditions.

- **The above are not done with every permit application. There should be a particular reason for doing these calculations. Usually only do outcrop seepage for an acid-producing seam.**

Recent Activity

- In the Past 5 years most deep mine permitting activity in northern region has been for below drainage deep mining. Pittsburgh, Sewickley, Lower Kittanning, and Sewell coal seams. Most of these are revisions to existing permits
- So we have not done many outcrop barrier seepage calculations lately.
- Only occasionally do inter-mine barrier seepage calculations when there is a reason to do it. Shoemaker/Bailey Barrier K = 0.34 to 0.5 ft/day.

Surface Mine Application DEP Form MR-4

- Geologists in Philippi review sections I, J, O-8, U
- Section I – Geologic Information (ABA data, sulfur forms of coal, Geologic X-Section, etc.)
- Section J – Hydrologic Information (PHC, HRP, SW and GW Baseline data, Groundwater Inventory)
- Section O-8 – Toxic Materials Handling (for surface mines only)
- Section S - Mine Development and Subsidence Control Plan Map. (Engineer reviews most of this section)
- Section U – Water Monitoring Plan (SW and GW)

Deep Mine Review Section I-1

- Table for Sulfur Forms of the Coal Being Mined
- Have asked for this data from multiple holes. **Important to get raw sulfur data.**
- Recently have asked for raw sulfur isopleth maps. Note: Companies do not want this made part of the public file.

Deep Mine Review Section I-2

- Gravity discharge question – Is gravity discharge anticipated from a proposed underground mine or augering area?

  Gravity discharges per the regulations are freely flowing down-gradient discharges.

- A flooded mine spilling out an up-dip opening is not gravity discharge as per the definition in the regulations.

- A gravity discharge would be from a down-dip punch-out, for example.

- One question is how to consider outcrop seepage???

Deep Mine Review Section I-2 (cont.)

If answer is yes and the coal is a potential acid producer, they need to provide data to prove that it is not acid-producing.

- If AMD potential, I ask for data whether it will be a gravity discharge or not.

Deep Mine Review Section I-7

- Geologic Cross-Section
- Am now consistently requiring this for deep mine applications .

Section I-9

- Geologic Descriptions

- For subsidence revisions (mining area additions to deep mines), have not always asked for this section. Get most of this info in the PHC.

Deep Mine Review Section I-10

- Geologic Borehole Logs
- Normally at least ask for holes used to construct the Geologic Cross-Section.

Deep Mine Review Section I-11

- ABA Data

  Have begun to ask for more holes for deep mines.

  Asking for ABA data of coal, roof and floor of coal, and of a portion of the overburden.

- For overburden, asking for ABA data to represent the collapse zone (3 to 6 times coal thickness)

- Not a lot of historical data to compare with.

Deep Mine Review – Section J-2

- Groundwater Inventory

Try to sample all groundwater sources within one-half mile of the proposed deep mining area. Baseline quality, static water levels of wells, flow of springs.

These aquifers may or may not be subsided into the deep mine.

The quality of these groundwater sources may impact the quality of the mine pool if they do enter the mine.

Deep Mine Review Section J-4

- Baseline Groundwater Data
  - Get “raw water”data from adjacent mines in the same seam in this section
  - Best to try to get a sample from a mine that will have similar flooding conditions to the proposed mine.

Deep Mine Review Section J-6

- Probable Hydrologic Consequences (PHC)
  - **Discussion of quality and quantity issues, such as**
  - Prediction of post-mining pool quality
  - Prediction of post-mining pool level
  - Prediction/calculations of infiltration rate into the mine
  - Prediction/calculations of barrier seepage
  - Discussion of how mine discharges/seepage will impact surface water and groundwater quality. Have done mass balance calculations to determine the effects of these on stream quality.

The above should reference any data or calculations included in the application.

Problems/Difficulties

- Additions to large existing Pittsburgh Mines
  - We are now collecting ABA data for these, but, there is not much existing data from these old Pittsburgh mines?
  - Given the very large mined area in the Pittsburgh seam and the fact that these mines will likely become part of one or more large mine pools, is it possible to make any meaningful predictions with this new data?
  - Most abandoned below drainage deep mines (for instance, in the Pittsburgh coal) are not yet discharging.
  - The degree to which they are flooded is also not always known.
  - How do we get quality samples of these flooding pools?

Problems/Difficulties (cont.)

- What worth are samples of pumped discharges from active mining areas?

- Mine pool quantity calculations, such as infiltration rate from pumping data – How do you account for water stored in sealed sections of a mine.

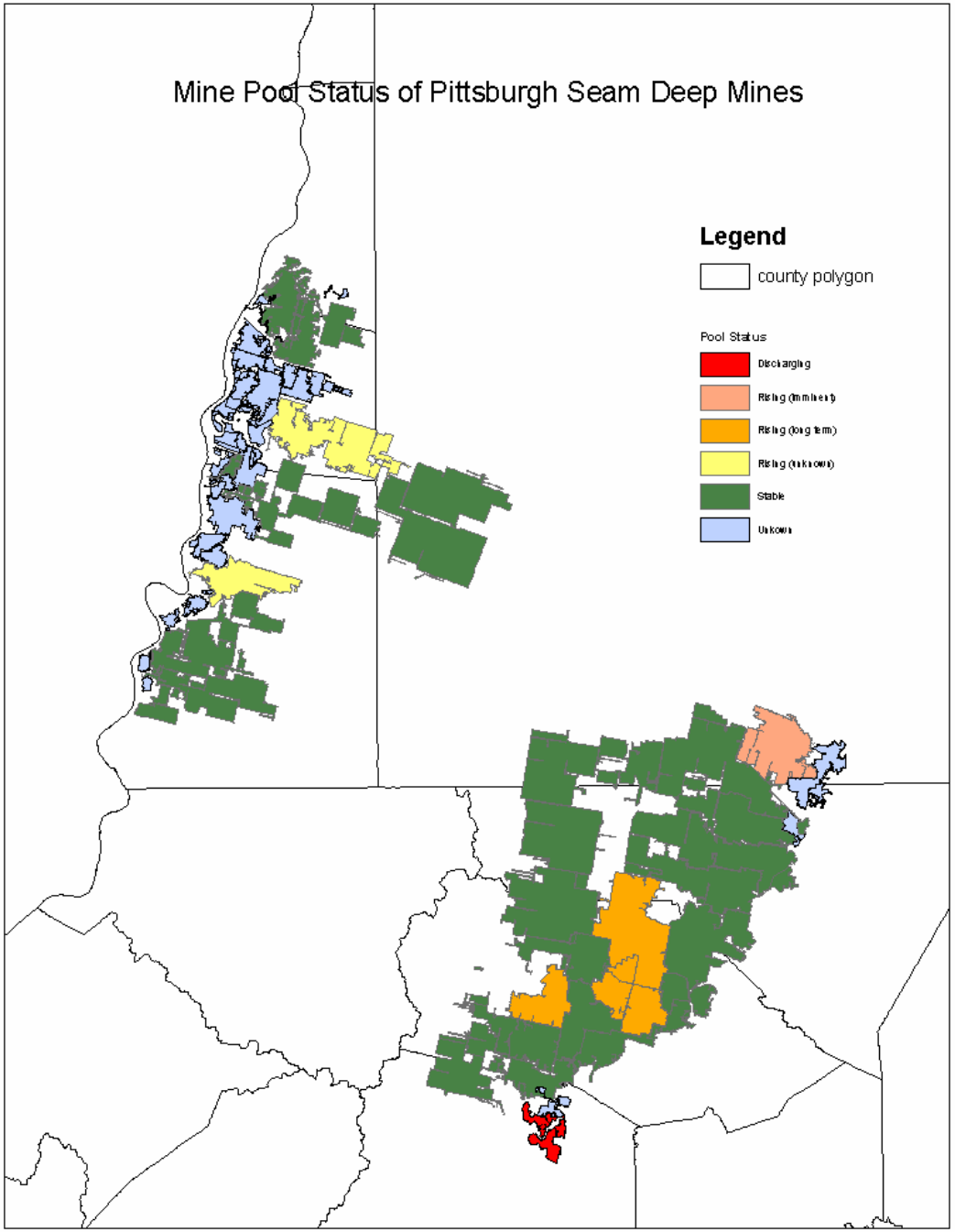
Other Mine Pool Issues

Nick Schaer, WVDEP

Blowouts and artesian discharges

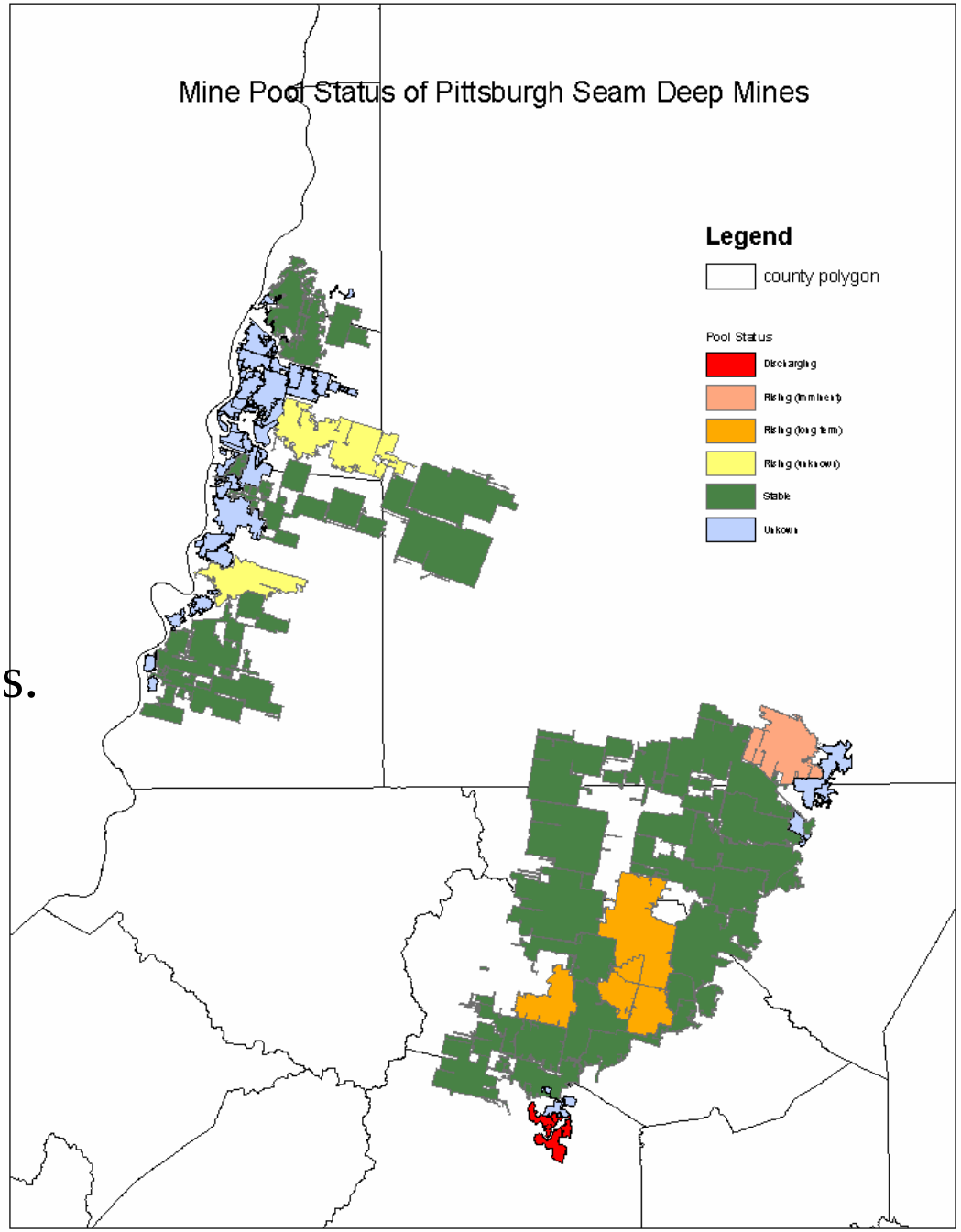
- Prediction Methods … everything discharges somewhere.
- Seepage, discreet and wetland creation.

Mine Pool spatial variabilty



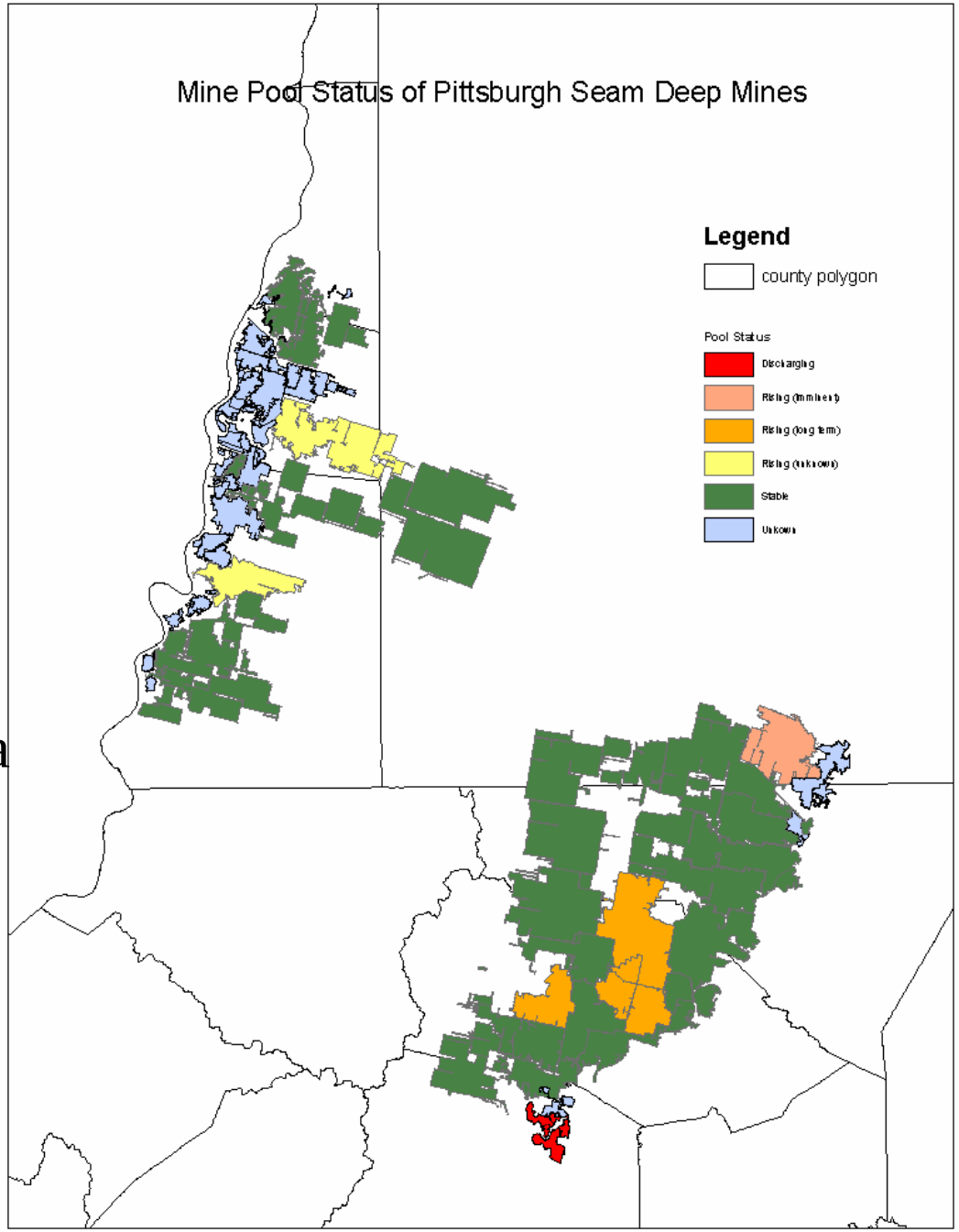
Mine Pool and deep mine mapping

MSHA vs. SMCRA sources.
Actual vs. proposed.
Contour grids, Thickness, pool info, etc.



Mine Pool legal issues

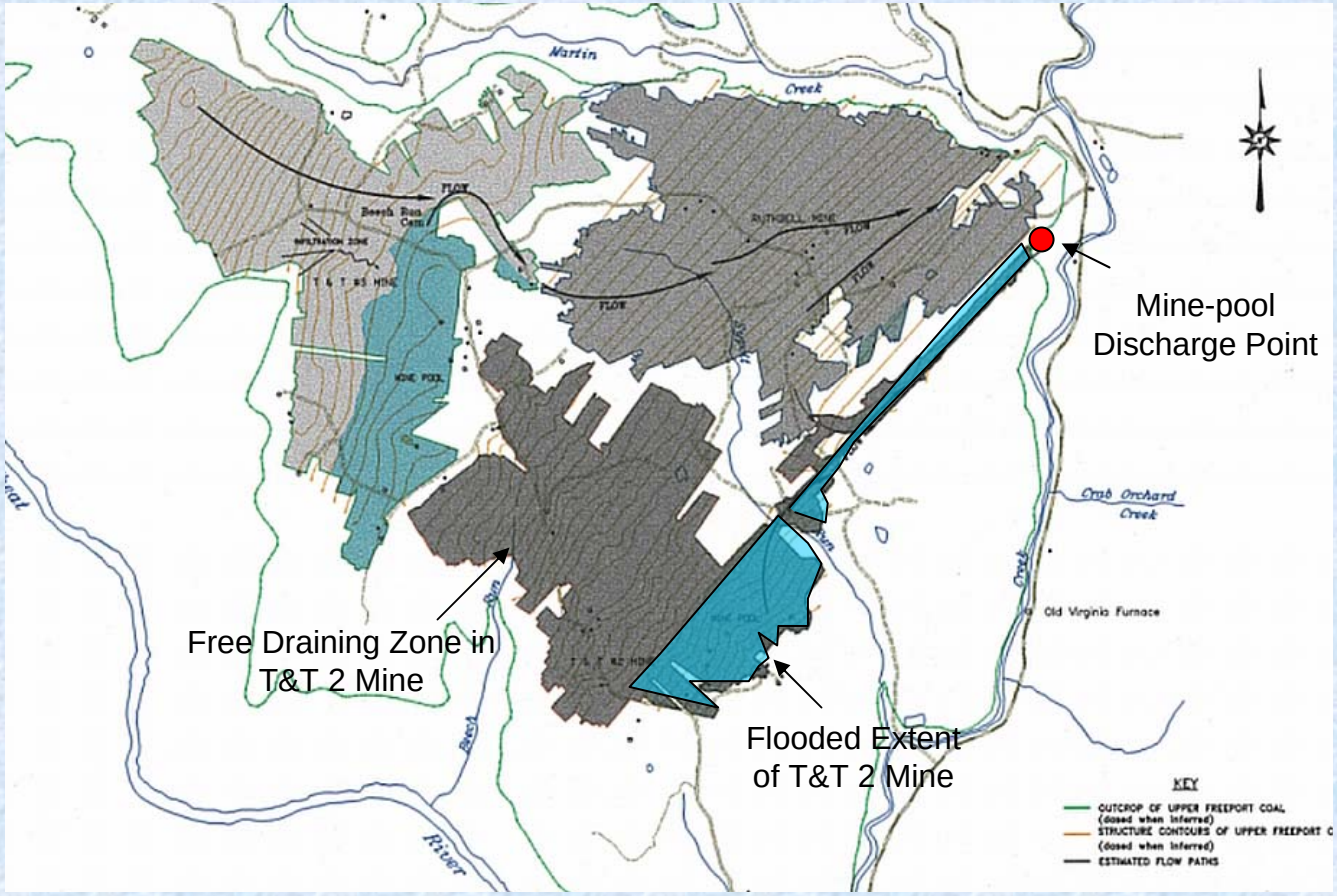
Post law/pre law
How do you treat 5.3% of a discharge?
No SMCRA permit



Forced mine pool migration

- Internal seals
- Siphons and u-pipes
- Large scale pumping issues.

T & T Mine



About 20% flooded

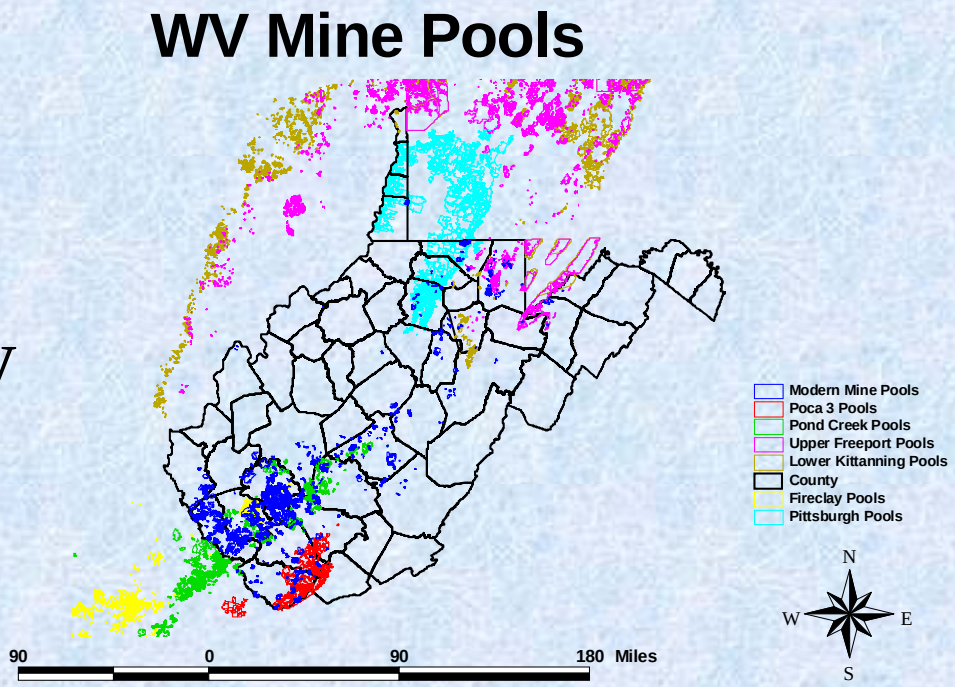
Contamination transport

- PCB and organic transport in mine pools
- UIC issue AMD, slurry, ash and others

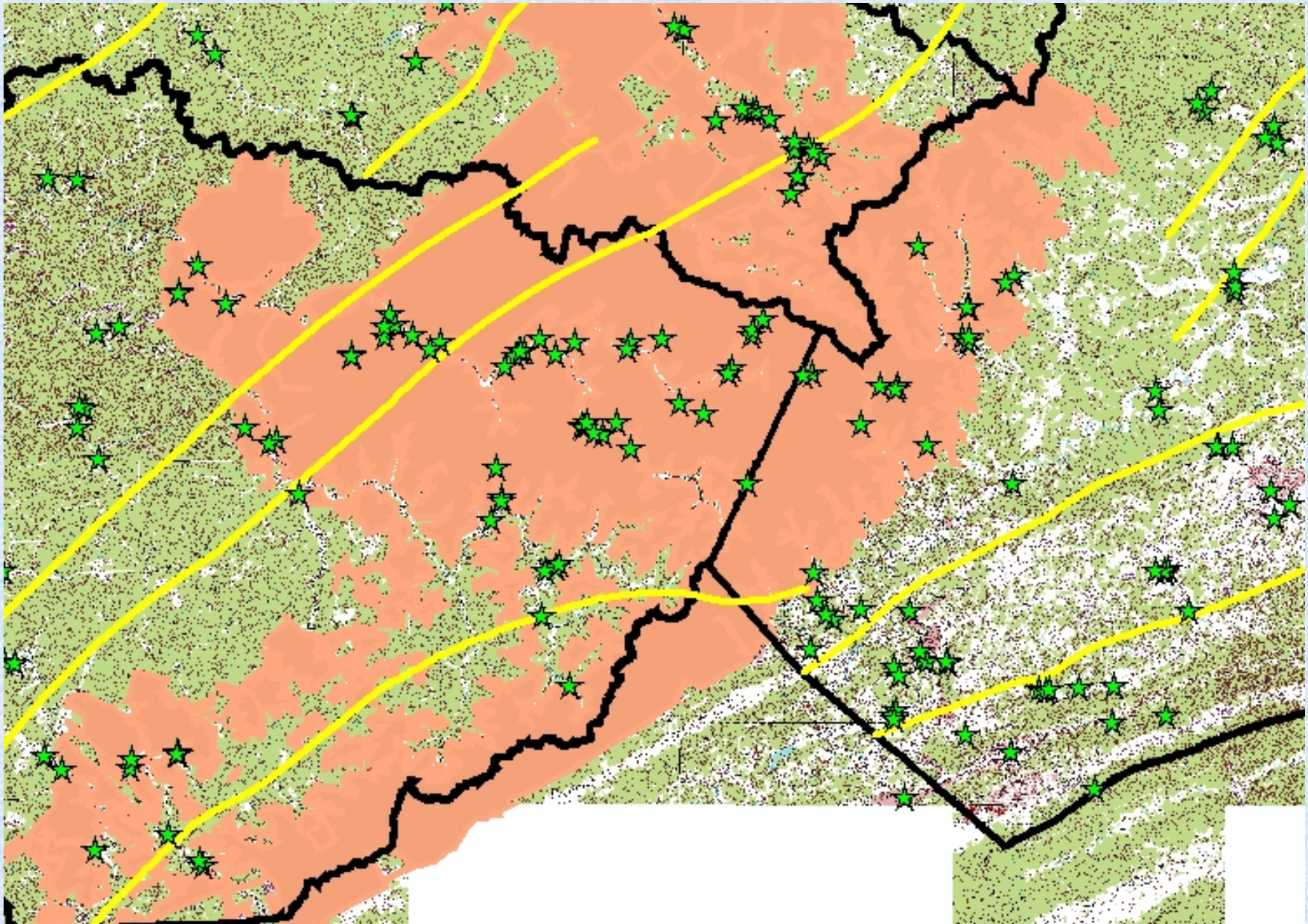
Mine Pool Resources

Mine pools need not be a liability, they are also a valuable resource.

- Mine Pool as a resource issues.
- Storage modeling
- Legal issues liability vs. resource
- Resource parameter definitions



PSD’s in the Poca 3 coal seam



Mine Pool Flow Systems

- Dynamic vs Steady State
- When “if ever” should MODFLOW be used?
- Use of karst hydrology flow models

ADTI and the creation of a mine pool internet database

http://aciddrainage.com/problem_summaries.cfm