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

Approximate limits of mine works

Dip 9%

Discharges

Treatment Inlet

Coal Outcrop
Discharges are piped, and collected.
And Treated.
Background

- 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

Flow Average (gpm)

Month


Grout Injection
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) vs. Month

Recharge Percentage of Precipitation

- Recharge (gpm/A)
- Recharge Percentage of Precipitation
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
Main Discharge Points
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.
Blacklick (Mid-Summer)
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
<table>
<thead>
<tr>
<th>Date</th>
<th>Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/30/05</td>
<td>1480</td>
</tr>
<tr>
<td>11/7/05</td>
<td>1484</td>
</tr>
<tr>
<td>2/15/06</td>
<td>1488</td>
</tr>
<tr>
<td>5/26/06</td>
<td>1492</td>
</tr>
<tr>
<td>9/3/06</td>
<td>1496</td>
</tr>
</tbody>
</table>

![Graph](image.png)

Lancashire 15

Elevation vs Date

- Dates: 7/30/05, 11/7/05, 2/15/06, 5/26/06, 9/3/06
- Elevations: 1480, 1484, 1488, 1492, 1496
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
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

Portal area
Potential impacts from AMD barrier outcrop seepage to receiving stream

### Seepage Analysis Computation Sheet

**Location:** Rocky Branch of Trough Fork

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

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

\[ Q = K \times (P/W) \times t \times l \]

Where:

- \( Q \) = flow of water through the coal barrier per foot of outcrop
- \( K \) = permeability of coal (ft/day)
- \( P \) = hydrostatic head existing above the coal in feet
- \( W \) = width of the coal barrier in feet
- \( t \) = thickness of the coal seam in feet
- \( l \) = length of the outcrop in feet

**Q** = 3,764 cubic feet/day

**K** = 3.12

**P** = 11,743 cubic feet/day

**W** = 30 cubic feet/second

**t** = 20 gallons per minute

\[ K = 4.24 \]

**l** = 28,815 gallons per day

\[ **K = 4.89** \]

**Respectfully Submitted:**

MINE #5
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).

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

Luo et al., 2001

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

Leavitt, 1993
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 58W and N 70W (Stoner, 1983)
    + Hobba (1991) N 68W
    + Boone County, WV, N32-78W (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.
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: $8 \times 10^5$ 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

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


### Table 14. Range of Horizontal Permeabilities for Seepage Analysis

<table>
<thead>
<tr>
<th>Material</th>
<th>Premining</th>
<th>Post Mining</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>1.0 ft/day*</td>
<td>3.21 ft/day*</td>
</tr>
<tr>
<td>Overburden</td>
<td>0.01 ft/day</td>
<td>0.74 ft/day*</td>
</tr>
<tr>
<td>Underclay</td>
<td>0.0005 ft/day</td>
<td>--------</td>
</tr>
</tbody>
</table>

* Source: Miller and Thompson, 1974.
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

#### December pumping history

<table>
<thead>
<tr>
<th>Date</th>
<th>Pump avg gpm</th>
<th>Pump max, gpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/31/1996</td>
<td>133</td>
<td>250</td>
</tr>
<tr>
<td>2/28/1996</td>
<td>175</td>
<td>250</td>
</tr>
<tr>
<td>3/31/1996</td>
<td>175</td>
<td>200</td>
</tr>
<tr>
<td>4/30/1996</td>
<td>113</td>
<td>200</td>
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<td>5/31/1996</td>
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<td>6/30/1996</td>
<td>15</td>
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<td>7/31/1996</td>
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<tr>
<td>9/30/1996</td>
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</tr>
<tr>
<td>11/30/1996</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>12/31/1996</td>
<td>38</td>
<td>50</td>
</tr>
</tbody>
</table>

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

**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
  - Angle of complete mining
  - Intersections of fractures from adjacent mines separated 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 adjacent unfractured strata

Modified after Schmidt, 1985
Coal barrier permeability adjacent to subsidence trough
Example: Ferrell Mine, WV

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

Kohli, 1983
The edges of the subsidence trough are wedges of highest permeability and flow. Example: Ferrell Mine, WV

Potential tensile fractures in coal barrier roof rock

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
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

<table>
<thead>
<tr>
<th>Segment 1</th>
<th>Segment 2</th>
<th>Segment 3</th>
<th>Segment 4</th>
<th>Segment 5</th>
<th>Segment 6</th>
<th>Segment 7</th>
<th>Segment 8</th>
<th>Segment 9</th>
<th>Segment 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>h2-h1 (ft)</td>
<td>148.5</td>
<td>148.5</td>
<td>148.5</td>
<td>148.5</td>
<td>148.5</td>
<td>148.5</td>
<td>148.5</td>
<td>148.5</td>
<td>148.5</td>
</tr>
<tr>
<td>Barrier Y (ft)</td>
<td>1010</td>
<td>1260</td>
<td>310</td>
<td>340</td>
<td>700</td>
<td>1390</td>
<td>740</td>
<td>290</td>
<td>1110</td>
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<tr>
<td>Seam thk. (ft)</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Barrier thk L</td>
<td>250</td>
<td>270</td>
<td>300</td>
<td>310</td>
<td>130</td>
<td>180</td>
<td>100</td>
<td>140</td>
<td>110</td>
</tr>
<tr>
<td>Q=k=0.10 (c/day)</td>
<td>377.78</td>
<td>415.80</td>
<td>92.07</td>
<td>169.44</td>
<td>415.80</td>
<td>1238.49</td>
<td>470.96</td>
<td>226.80</td>
<td>824.18</td>
</tr>
<tr>
<td>Q=k=0.159 (c/day)</td>
<td>565.58</td>
<td>623.70</td>
<td>138.11</td>
<td>239.16</td>
<td>623.70</td>
<td>1957.74</td>
<td>706.44</td>
<td>340.20</td>
<td>1236.26</td>
</tr>
<tr>
<td>Q=k=0.20 (c/day)</td>
<td>755.57</td>
<td>831.60</td>
<td>184.14</td>
<td>318.80</td>
<td>831.60</td>
<td>2476.98</td>
<td>941.91</td>
<td>463.60</td>
<td>1548.35</td>
</tr>
<tr>
<td>Q=k=0.25 (c/day)</td>
<td>944.46</td>
<td>1059.60</td>
<td>230.18</td>
<td>398.61</td>
<td>1099.50</td>
<td>3096.23</td>
<td>1177.39</td>
<td>567.00</td>
<td>2060.44</td>
</tr>
<tr>
<td>Q=k=0.50 (c/day)</td>
<td>1688.92</td>
<td>2079.00</td>
<td>460.35</td>
<td>797.21</td>
<td>2079.00</td>
<td>6132.45</td>
<td>2354.79</td>
<td>1134.00</td>
<td>4120.88</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Segment 11</th>
<th>Segment 12</th>
<th>Segment 13</th>
<th>Segment 14</th>
<th>Segment 15</th>
<th>Segment 16</th>
<th>Segment 17</th>
<th>Segment 18</th>
</tr>
</thead>
<tbody>
<tr>
<td>h2-h1 (ft)</td>
<td>148.5</td>
<td>148.5</td>
<td>148.5</td>
<td>148.5</td>
<td>148.5</td>
<td>148.5</td>
<td>148.5</td>
</tr>
<tr>
<td>Barrier Y (ft)</td>
<td>1010</td>
<td>1020</td>
<td>360</td>
<td>350</td>
<td>590</td>
<td>1090</td>
<td>150</td>
</tr>
<tr>
<td>Seam thk. (ft)</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
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<tr>
<td>Barrier thk L</td>
<td>100</td>
<td>70</td>
<td>240</td>
<td>230</td>
<td>110</td>
<td>210</td>
<td>260</td>
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<tr>
<td>Q=k=0.10 (c/day)</td>
<td>899.91</td>
<td>403.92</td>
<td>468.23</td>
<td>219.04</td>
<td>216.94</td>
<td>882.90</td>
<td>63.64</td>
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<tr>
<td>Q=k=0.159 (c/day)</td>
<td>1349.87</td>
<td>605.85</td>
<td>687.34</td>
<td>326.56</td>
<td>326.41</td>
<td>1324.35</td>
<td>95.46</td>
</tr>
<tr>
<td>Q=k=0.20 (c/day)</td>
<td>1799.82</td>
<td>807.84</td>
<td>916.45</td>
<td>438.08</td>
<td>433.88</td>
<td>1756.80</td>
<td>127.29</td>
</tr>
<tr>
<td>Q=k=0.25 (c/day)</td>
<td>2249.75</td>
<td>1009.80</td>
<td>1145.57</td>
<td>547.59</td>
<td>542.35</td>
<td>2207.25</td>
<td>159.11</td>
</tr>
<tr>
<td>Q=k=0.50 (c/day)</td>
<td>4499.65</td>
<td>2019.60</td>
<td>2231.14</td>
<td>1095.19</td>
<td>1084.70</td>
<td>4414.50</td>
<td>318.21</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>k (ft/day)</th>
<th>c/day</th>
<th>gpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>7686</td>
<td>33.93</td>
</tr>
<tr>
<td>0.15</td>
<td>1412</td>
<td>50.28</td>
</tr>
<tr>
<td>0.20</td>
<td>1517</td>
<td>75.84</td>
</tr>
<tr>
<td>0.25</td>
<td>1883</td>
<td>97.99</td>
</tr>
<tr>
<td>0.50</td>
<td>3740</td>
<td>194.75</td>
</tr>
</tbody>
</table>
“I think you should be more explicit here in step two.”
# Hampton No.3-4 Mines

## Roof Rock (Overburden) Seepage Flow Calculations

<table>
<thead>
<tr>
<th>Segment 1</th>
<th>Segment 2</th>
<th>Segment 3</th>
<th>Segment 4</th>
<th>Segment 5</th>
<th>Segment 6</th>
<th>Segment 7</th>
<th>Segment 8</th>
<th>Segment 9</th>
<th>Segment 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>h2-h1 (ft)</td>
<td>148.5</td>
<td>148.5</td>
<td>148.5</td>
<td>148.5</td>
<td>148.5</td>
<td>148.5</td>
<td>148.5</td>
<td>148.5</td>
<td>148.5</td>
</tr>
<tr>
<td>Barrier W (ft)</td>
<td>1060</td>
<td>1060</td>
<td>310</td>
<td>540</td>
<td>700</td>
<td>1300</td>
<td>740</td>
<td>280</td>
<td>1110</td>
</tr>
<tr>
<td>Banker thk L (ft)</td>
<td>250</td>
<td>270</td>
<td>300</td>
<td>190</td>
<td>190</td>
<td>190</td>
<td>140</td>
<td>110</td>
<td>120</td>
</tr>
<tr>
<td>Cm (sq mm saturated thk)</td>
<td>125</td>
<td>124</td>
<td>124</td>
<td>124</td>
<td>119</td>
<td>114</td>
<td>110</td>
<td>109</td>
<td>105</td>
</tr>
<tr>
<td>Cm-out= 3.0 ft/day</td>
<td>25696.00</td>
<td>26776.00</td>
<td>57085.85</td>
<td>68854.11</td>
<td>26776.00</td>
<td>75785.80</td>
<td>28019.50</td>
<td>129276.00</td>
<td>449175.38</td>
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<tr>
<td>Cm-out= 2.0 ft/day</td>
<td>17166.00</td>
<td>20065.60</td>
<td>65920.24</td>
<td>71864.00</td>
<td>511900.00</td>
<td>65813.00</td>
<td>96164.00</td>
<td>290450.00</td>
<td>29767.50</td>
</tr>
<tr>
<td>Cm-out= 1.0 ft/day</td>
<td>9535.64</td>
<td>9889.20</td>
<td>32951.37</td>
<td>86593.00</td>
<td>265994.00</td>
<td>93458.60</td>
<td>43692.00</td>
<td>149720.00</td>
<td>14588.75</td>
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<tr>
<td>Cm-out= 0.75 ft/day</td>
<td>5527.63</td>
<td>5669.68</td>
<td>14807.57</td>
<td>24384.01</td>
<td>6589.68</td>
<td>193406.40</td>
<td>65123.91</td>
<td>31886.08</td>
<td>11079.59</td>
</tr>
<tr>
<td>Cm-out= 0.65 ft/day</td>
<td>3156.72</td>
<td>3466.80</td>
<td>12366.07</td>
<td>21416.30</td>
<td>6565.60</td>
<td>193370.40</td>
<td>60714.23</td>
<td>26004.60</td>
<td>9873.33</td>
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<tr>
<td>Cm-out= 0.60 ft/day</td>
<td>2066.72</td>
<td>2296.60</td>
<td>9615.90</td>
<td>16475.68</td>
<td>42665.00</td>
<td>125977.30</td>
<td>46703.26</td>
<td>21546.00</td>
<td>7641.88</td>
</tr>
<tr>
<td>Cm-out= 0.50 ft/day</td>
<td>1363.60</td>
<td>1483.60</td>
<td>4756.96</td>
<td>8257.94</td>
<td>21481.00</td>
<td>63968.65</td>
<td>23551.63</td>
<td>10732.00</td>
<td>37421.28</td>
</tr>
<tr>
<td>Cm-out= 0.40 ft/day</td>
<td>723.45</td>
<td>889.30</td>
<td>1902.78</td>
<td>3295.14</td>
<td>6573.20</td>
<td>25596.48</td>
<td>9348.65</td>
<td>4300.20</td>
<td>14972.51</td>
</tr>
</tbody>
</table>

### Hampton 4 (Roof Rock) Overburden

<table>
<thead>
<tr>
<th>Overburden K</th>
<th>Overburden</th>
<th>Overburden</th>
<th>Overburden</th>
<th>Overburden</th>
<th>Overburden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overburden K</td>
<td>0.0</td>
<td>0.2</td>
<td>1.0</td>
<td>0.75</td>
<td>0.65</td>
</tr>
<tr>
<td>Overburden</td>
<td>429041.3</td>
<td>22345</td>
<td>8241</td>
<td>2133</td>
<td>1472471</td>
</tr>
<tr>
<td>Recharge rate</td>
<td>3708</td>
<td>1373</td>
<td>53645</td>
<td>4820</td>
<td>11029</td>
</tr>
<tr>
<td>Overburden</td>
<td>110.29</td>
<td>9.66</td>
<td>2.13</td>
<td>1.87</td>
<td>0.80</td>
</tr>
<tr>
<td>Overburden</td>
<td>120.50</td>
<td>28.03</td>
<td>6.79</td>
<td>0.93</td>
<td>0.23</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Mine</th>
<th>Streamloss</th>
<th>Overburden</th>
<th>Overburden</th>
<th>Barrier seepage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ft$^2$/day</td>
<td>ft$^2$/day</td>
<td>gpm/acre</td>
<td>ft$^2$/day</td>
</tr>
<tr>
<td>barrier segments</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hampton 3-unmined</td>
<td>384615</td>
<td>619477</td>
<td>0.63</td>
<td>6648</td>
</tr>
<tr>
<td>Hampton 4-Hampton 3</td>
<td>771165</td>
<td>713736</td>
<td>1.44</td>
<td>37490</td>
</tr>
<tr>
<td>Guyan-Hampton 4</td>
<td>498190</td>
<td>1101690</td>
<td>0.46</td>
<td>33418</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mine</th>
<th>Overburden + Barrier</th>
<th>Overburden + Barrier Normalized gpm/acre</th>
<th>Ov. + Barrier strmloss ft$^2$/day</th>
<th>Ov. + Barrier strmloss gpm/acre</th>
<th>Pool development time (years)</th>
<th>Streamloss to mine pool % contrib to mine pool</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>barrier segments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hampton 3-unmined</td>
<td>626125</td>
<td>0.86</td>
<td>721990</td>
<td>0.99</td>
<td>4.9</td>
<td>38</td>
</tr>
<tr>
<td>Hampton 4-Hampton 3</td>
<td>761225</td>
<td>1.78</td>
<td>1522381</td>
<td>3.60</td>
<td>1.5</td>
<td>61</td>
</tr>
<tr>
<td>Guyan-Hampton 4</td>
<td>1135108</td>
<td>0.48</td>
<td>1613848</td>
<td>0.67</td>
<td>7.4</td>
<td>31</td>
</tr>
</tbody>
</table>
Conceptual model of seepage flow from the Hampton No. 4 to No. 3 mine

Modified after McCoy et al., 2006
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 AutoCAD 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?
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
<table>
<thead>
<tr>
<th>Metals and Dissolved Solids</th>
<th>Acid</th>
<th>Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

What is the long term chemical composition of these mines when they flood? Do the acid mine-pools remain acidic?
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

<table>
<thead>
<tr>
<th>Site</th>
<th>pH</th>
<th>Alkalinity</th>
<th>TDS</th>
<th>Fe</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>SO(_4)</th>
<th>Cl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mine 38 Recharge</td>
<td>7.32</td>
<td>179</td>
<td>548</td>
<td>3.44</td>
<td>61</td>
<td>14</td>
<td>105</td>
<td>207</td>
<td>34</td>
</tr>
<tr>
<td>Mine 63 Intermed.</td>
<td>7.31</td>
<td>589</td>
<td>3301</td>
<td>33.9</td>
<td>158</td>
<td>33</td>
<td>853</td>
<td>1697</td>
<td>44</td>
</tr>
<tr>
<td>Dakota Siphon End</td>
<td>7.20</td>
<td>568</td>
<td>5194</td>
<td>135</td>
<td>251</td>
<td>90</td>
<td>1254</td>
<td>2812</td>
<td>119</td>
</tr>
<tr>
<td>Overburden</td>
<td>8.57</td>
<td>263</td>
<td>454</td>
<td>0.04</td>
<td>21</td>
<td>5</td>
<td>138</td>
<td>48</td>
<td>52</td>
</tr>
</tbody>
</table>

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.
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

Plot of Alkalinity, Duman Site

Flooding Overlying Mine-pool
Initial Flushing

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

Simple Moving Average Plot, Duman Influent Iron, 2000-2004

Iron, mg/L

Data
Trend line

Monthly Sample Interval, quality affected by pumping rate.
Effect of Pumping Rate on Discharge Quality, Lancashire 15 Mine-pool

<table>
<thead>
<tr>
<th>Discharge Rate (gpm)</th>
<th>pH</th>
<th>Alkalinity</th>
<th>Acidity</th>
<th>Iron</th>
<th>Sulfate</th>
</tr>
</thead>
<tbody>
<tr>
<td>3250</td>
<td>6.7</td>
<td>230</td>
<td>58</td>
<td>32.6</td>
<td>299</td>
</tr>
<tr>
<td>6500</td>
<td>6.5</td>
<td>169</td>
<td>94</td>
<td>47.7</td>
<td>402</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Site</th>
<th>pH</th>
<th>Total Acidity (mg/L)</th>
<th>Alkalinity (mg/L)</th>
<th>Fe (mg/L)</th>
<th>Al (mg/L)</th>
<th>Sulfate (mg/L)</th>
<th>Dis.O₂ (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooded After Closure</td>
<td>5.1</td>
<td>1500</td>
<td>40</td>
<td>837</td>
<td>N.D.</td>
<td>3432</td>
<td>N.D.</td>
</tr>
<tr>
<td>Flooded After 25 Pool Volumes</td>
<td>6.53</td>
<td>113</td>
<td>120</td>
<td>63</td>
<td>N.D.</td>
<td>614</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Partly flooded After Closure</td>
<td>2.6</td>
<td>968</td>
<td>0</td>
<td>313</td>
<td>82</td>
<td>2400</td>
<td>N.D.</td>
</tr>
<tr>
<td>Partly flooded After 25 Pool Volumes</td>
<td>2.9</td>
<td>340</td>
<td>0</td>
<td>72</td>
<td>27</td>
<td>905</td>
<td>~2.5</td>
</tr>
</tbody>
</table>
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.
A significant fraction of iron is being retained within the mine-pool aquifer even in very acid mine-pools (precipitation, adsorption etc?)
Thin overburden (less than 250 ft), rapid recharge and response to precipitation.
Seasonal Characteristics Within A Mine-pool

Seasonality in Iron From Two Discharges In a flooded Mine-pool

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

Before

Relative Ease of Replacement

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

After
## Cation Exchange in Lancashire 15 Mine-pool

<table>
<thead>
<tr>
<th>Source Waters</th>
<th>pH</th>
<th>Alkalinity</th>
<th>Fe</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>SO(_4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooded L. Kittanning</td>
<td>6.4</td>
<td>63</td>
<td>62</td>
<td>96</td>
<td>30</td>
<td>70</td>
<td>417</td>
</tr>
<tr>
<td>Unflooded L. Kittanning</td>
<td>2.8</td>
<td>0</td>
<td>113</td>
<td>85</td>
<td>34</td>
<td>35</td>
<td>767</td>
</tr>
<tr>
<td>Lower Freeport Ground-water</td>
<td>6.3</td>
<td>124</td>
<td>0.3</td>
<td>75</td>
<td>19</td>
<td>11</td>
<td>157</td>
</tr>
<tr>
<td>End of Flowpath</td>
<td>6.55</td>
<td>137</td>
<td>40</td>
<td>40</td>
<td>15</td>
<td>159</td>
<td>390</td>
</tr>
</tbody>
</table>
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) $Q = K \times P/W \times t.$, $Q = KIA$ – 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 $0.5 \text{ ft/day}$. 
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???
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/calculation of infiltration rate into the mine
  – Prediction/calculation 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 variability
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