WVDEP 2019 Annual I&E Training

Underground Mining Basics and Mine Pools

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Presentation Overview

- **Introduction**
  - Basic Hydrology and Geology

- **Underground Mining**
  - Introduction
  - Above and Below Drainage Mines
  - Entry Types
  - Underground Mining Methods
  - Multiple Seam Mining

- **Subsidence**
  - Conditions Governing Subsidence
  - Modes of Subsidence
  - Kendorski Model
  - Subsidence-Related Landslides
  - Hydrologic Effects of Subsidence

- **Mine Barriers**
  - Outcrop Barriers
  - Internal Barriers
  - Barrier Design
  - Barrier Failure

- **Mine Seals**
  - Dry Seals
  - Wet Seals
  - Borehole/Shaft Seals

- **Mine Pool Development**
  - Factors Influencing Flooding
    - Inflows
    - Outflows
  - Surface Infiltration
  - Hydraulic Conductivity
  - Barrier Seepage
Introduction

Basic Hydrology and Geology
Porosity and Permeability

- **Primary** porosity & permeability
  - Pores between grains

- **Secondary** porosity & permeability
  - Fractures

- **Porosity** = % of rock that is open space
- **Permeability** = rate (speed) of flow through porous rock
Stress Relief Hydrology

- Black arrows indicate compressional stress, white arrow indicates resultant stress.
- Unequal stress distribution leads to vertical and horizontal fracturing along valley walls and horizontal fractures along the valley floor. This fracturing increases secondary permeability and increases hydraulic communication with near-surface aquifers.
- These fracture zones contribute to increased recharge to mine voids.
Rock Properties

- Sandstone – can be hard and brittle
- Coal - can be hard and brittle
- Limestone - can be hard and brittle
- Shale – fine grained, can be flexible or resilient
- Claystone - fine grained, can be flexible or resilient
Water-Bearing Fractures

- Most ground water is yielded by a few fractures. Most fractures do not yield or accept water. They are there, but essentially “dead” in terms of ground-water movement.

- Morin and others (1997) noted only 18% of fractures were water-bearing.

- Rasmuson and Neretnieks (1986) noted that 5 to 20% of the fractures carries more than 90% of the water.

- Based on experience, I use the 90/10 rule. About 90% of the water is moved by 10% of the fractures.
Underground Mining
Drift, Slope & Shaft Entries

- Drift Entry
- Slope Entry
- Shaft Entry
Underground Mining Methods

- Conventional
- Continuous Miner
- Longwall
Conventional Mining Equip.
Conventional Mining - Blasting
Continuous Mining Equipment
Continuous Mining Layout
Longwall Mining
Longwall Development
Auger Machine
Auger Holes
Highwall Miner
Highwall Miner
Multiple Seam Mining

- Undermining
- Overmining
- Simultaneous Mining
- Any combination of the above
Multiple Seam Mining

- Overmining is more difficult than undermining, because of the potential for rock damage caused by subsidence. Generally, retreat mining (pillar removal) in these situations should be avoided.

- Multiple-seam mining problems (surface subsidence issues) can be lessened by mining both seams at the same time or by vertical stacking of pillars (remaining pillars are vertically aligned in all mined seams).

- Where previous mining exists above or below a proposed operation, the site-specific mining and geologic conditions should be carefully considered.
Comparison of Mining Methods

Above Drainage

Below Drainage

Stacked Pillars
Subsidence
Modes of Subsidence
Surface Effects of Limited Extraction/Shallow Mining
Kendorski Model
Longwall/High Extraction Mining
Subsidence – Stream Damage

- Water Loss In Stream Channel
- Loss Of Base Flow
- Changes In Grade Of Stream Channel
Subsidence – Stream Damage
Subsidence – Direct Stream Loss
Subsidence – Stream Damage
Subsidence – Stream Damage
Stream Repair – Grouting Channel
Stream Repair – Grouting Channel
Spring Flow Prior to Mining
Spring Flow After Mining
Landslides Resulting From Underground Mining

- Causes
  - New Springs Developing on Slopes
  - Changing Slope of Hillside due to Mining-Related Subsidence
  - Open, Subsidence-Related Cracks Causing Surface Water to Lubricate and Saturate Slope Material
Landslides – Spring Relocation
Subsidence - Landslides
Subsidence - Landslides
Mine Barriers
Coal Barriers

- There are two types of coal barriers associated with underground mines:
  - Outcrop Barriers
  - Internal Barriers

- Importance of Barriers – Safety and Environmental Concerns

  - Control of mine discharges.
  - Prevention of blowouts.
  - Prevention of flooding of adjacent mine works.
  - Prevention and control of landslides.
  - Control of surface swamping and flooding.
Hydraulic Head

- Head is the amount of water above a barrier.

- Water creates a force equal to 0.433 p.s.i. for each foot of head, therefore 100 feet of head will exert 43.3 p.s.i.

- At 100 feet of head, an entry 18 feet wide and 6 feet high would have \((18 \times 6 \times 144 \times 43.3 / 2000)\) 337 tons of force against it.
Outcrop Barriers

- Outcrop barriers are solid coal barriers between the mine workings and the coal seam outcrop in above drainage mines.

- Below drainage mines do not have outcrop barriers.

- These barriers are designed to minimize post-mining seepage along the outcrop and prevent rapid, large volume discharges from mine pools that may develop in abandoned underground mine workings (blowout).

- Outcrop barrier design specifications must be included in each permit application that involves expansion of underground mining area (typically SCP Revisions and some IBR’s).

  Plans for preventing the buildup of hydraulic head at, or below, an elevation that will not exceed the design limitations of down-dip outcrop barriers.

- When necessary, pumping and designed gravity dewatering of the mine workings may be required to safeguard against potential blowout.
Outcrop Barriers On Mine Maps

- Outcrop Barrier (Lower Kittanning Seam)
Outcrop Barrier Design

- Geologic features such as faults, existing slope failures, stress relief joints, weather, etc. can facilitate leakage across outcrop barriers.

- When these features exist, they should not be considered as part of the outcrop barrier width.

- A site-specific design incorporates a comprehensive assessment of the various influencing factors, including the geology and structure of the site, weather, faulting, erosion, slope stability and hydrogeologic factors.
Internal Barriers

- Internal coal barriers are barriers between adjacent mines in the same coal seam.

- These barriers are designed to minimize mechanical effects and seepage from adjacent mine workings.

- Internal Barriers must be designed to withstand the pressures applied by the impounded pool in the adjacent mine workings in order to prevent catastrophic failure.
Internal Barriers on Mine Maps

Internal Barrier between Crawdad Portal B and Prime No. 1 Mines (Sewickley Seam)
Barriers Between Mines
Example Of Mining Through Required Barrier
Guidelines for Estimating Barrier Widths

- **Ashley Formula (Interior)**
  
  \[ W = 20 + (4 \times T) + (0.1 \times D) \]
  
  - \( W \) = the barrier thickness that you are calculating
  - \( T \) = the thickness of the coal seam
  - \( D \) = the thickness of the overburden or potential hydraulic head

- **Rule of Thumb (Exterior)**
  
  Minimum Barrier Thickness = 50’ plus the expected hydraulic head
Vertical Barrier Design

(Dames and Moore 1981)

**Figure 47**

Barrier width required to maintain a safety factor of 1.5.
Barrier Failure

Major Causes of Blowouts

- Vertical Displacement
- Wedge-Type Failure
- Surface Landslides
Barrier Failure
Wedge-Type Failure
Blowout From Below
Barrier Failure
*Surface Landslides*

- Similar to Vertical Displacement Failures, slope failures that are unrelated to uplift generated by hydraulic head pressure can cause a blowout.

- Surface Landslides may act alone or in conjunction with one, or a combination, of the previous failure modes.
Outcrop Barrier Failure
Surface Landslide & Wedge-Type Failure

Weathered Zone

Flooded Mine

Solid Coal
Outcrop Barrier Failure
Surface Landslide & Wedge-Type Failure
Upwelling Mine Waters
Mine Seals

- Drift Opening - Wet Seals
- Drift Opening – Dry Seals
- Shaft Seals
- Borehole Seals
Drift Opening – Dry Seal

TYPICAL MINE SEAL

NOTE: SEALS TO BE CONSTRUCTED WITH NON-COMBUSTIBLE MATERIAL.
NOTES:

DRIFT AND SLOPE OPENINGS SHALL BE SEAL WITH BLOCK AND/OR CONCRETE OF NO LESS THAN SIXTEEN (16) INCHES THICK.

WHERE CONDITIONS PERMIT, SEALS SHALL BE HITCHED WITHOUT SHOOTING NO LESS THAN SIX (6”) IN THE TOP, SIDES, AND BOTTOM.


THE SEAL WILL CONSIST OF COMPACTING SPOIL MATERIAL INTO THE OPENING AS FAR AS POSSIBLE WITH AVAILABLE EQUIPMENT.

ADDITIONAL MATERIAL FOUND ON THE PERMIT AREA WILL THEN BE USED TO COMPACT AGAINST THE OPENING FACE.

THE SEAL MATERIAL WILL COVER THE COAL, BY A MINIMUM OF FOUR (4) FEET. THE OUTLIFE OF THE SEAL WILL SLOPE BACK TO THE PAVEMENT AT A 1:1 SLOPE.

10 A MINE
TYPICAL WET SEAL
FOR
DRIFT OR SLOPE OPENING

NOT TO SCALE
Shaft and Borehole Seals
Installation of Seals

- Seals must be certified by a Registered Professional Engineer.

- The certification should include pictures.

- It is good if the inspector can also observe and document seals.

- Approval for sealing a borehole that is currently, used for monitoring pool elevation should not be given until after the PUMA evaluation revision has been approved for the permit in question. At that time, the final pool monitoring requirements will be established and all surface connections to the mine workings, that are not required for post-closure monitoring, may be sealed as outlined in the permit.
Mine Pool Development
Post-Closure Mine Pool Development

- Hydraulic Conductivity
  - Horizontal Hydraulic Conductivity - $K_h$
  - Vertical Hydraulic Conductivity – $K_v$

- Surface Infiltration
  - Potential Sources
  - Apparent Vertical Infiltration (AVI)

- Barrier Permeability
  - Outcrop Barriers
  - Internal Barriers (Adjacent Mining)

- Static (Equilibrium) Pool Elevation
  - Inflow = Outflow
Post-Closure Mine Pool Development
Surface Infiltration

Background
Why is this Important?

- Inflow rate during mining – pumping/treatment rates
- Rate of flooding after mining
- Ultimate discharge rate once equilibrium is reached (inflow = outflow)
- Impact the post-mining hydraulic head
- Strongly impact treatment plant set up and cost of treating post-mining discharges
- Other factors to be considered
Post-Closure Mine Pool Development

Surface Infiltration

Background

What is the source of there 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
- Underground injection of mine waste (refuse slurry, AMD, etc.)
Post-Closure Mine Pool Development

Surface Infiltration – Range of Reported Recharge Rates

<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>Hobbs, 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>
Post-Closure Mine Pool Development
Surface Infiltration – Range of Reported Recharge Rates

Summary

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

*Rule of Thumb = 0.5 gpm/acre
based on Parizek’s work from the early 1970’s
Post-Closure Mine Pool Development

Surface Infiltration

![Graph showing overburden thickness in feet against recharge in gpm/acre with a "Rule-of-Thumb" marker.](image-url)
Post-Closure Mine Pool Development

Surface Infiltration – Range of Reported Recharge Rates

Factors that Likely Impact Recharge Rates

- Depth of cover (<150-200’ vs. >200’, etc.)
- Overburden lithology (sandstone vs. shale & claystone)
- Method of mining (e.g., longwall vs. 1st mining vs. retreat mining)
- Laterally adjacent mining (flooded and unflooded)
- Super- and Sub-adjacent mining (flooded and unflooded)
- Lineaments, faults, fracture zones, etc. (presence or absence)
Post-Closure Mine Pool Development

Surface Infiltration – Time to Total Inundation Example (1)

- Useful Conversion: 1 cu. ft. = ~ 7.48 gallons.
- Account for mining method/extraction percentage:

  \[ V_c = (A \times \frac{M}{A}) \times b, \]

  where, \( V_c \) = Mined Coal Volume, \( M \) = Mined Acreage, \( b \) = Seam Thickness, \( M/A \) = Extraction Ratio
## Post-Closure Mine Pool Development

**Surface Infiltration – Time to Total Inundation Example (1)**

<table>
<thead>
<tr>
<th>Facility: Bismarck Mine</th>
<th>Coal Seam: Bakerstown</th>
<th>AVI$_{range}$ (gpm/acre)</th>
<th>Time to Total Inundation (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining Area (acres):</td>
<td>131.3</td>
<td>1.2</td>
<td>2.48</td>
</tr>
<tr>
<td>Seam Thickness (feet):</td>
<td>5</td>
<td>1.1</td>
<td>2.71</td>
</tr>
<tr>
<td>Extraction Ratio:</td>
<td>0.6</td>
<td>1</td>
<td>2.08</td>
</tr>
<tr>
<td>AVI$_{max}$ (gpm/acre):</td>
<td>1.2</td>
<td>0.9</td>
<td>3.51</td>
</tr>
<tr>
<td>AVI$_{min}$ (gpm/acre):</td>
<td>0.1</td>
<td>0.8</td>
<td>3.72</td>
</tr>
<tr>
<td></td>
<td>0.7</td>
<td>0.7</td>
<td>4.25</td>
</tr>
<tr>
<td></td>
<td>0.6</td>
<td>0.6</td>
<td>4.96</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>0.5</td>
<td>5.98</td>
</tr>
<tr>
<td></td>
<td>0.4</td>
<td>0.4</td>
<td>7.44</td>
</tr>
<tr>
<td></td>
<td>0.3</td>
<td>0.3</td>
<td>9.92</td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>0.2</td>
<td>14.88</td>
</tr>
<tr>
<td></td>
<td>0.1</td>
<td>0.1</td>
<td>29.76</td>
</tr>
</tbody>
</table>

| Mined-Out Area (sq. ft.): | 5431565.80 | Total Mine Void Volume (cu. Ft.): | 17156284.00 |
| Total Mine Void Volume (gallons): | 128343964.32 |
Post-Closure Mine Pool Development

Surface Infiltration – Time to Total Inundation Example (1)
**Post-Closure Mine Pool Development**

**Barrier Permeability – Hydraulic Conductivity**

- **Hydraulic Conductivity**: A measure of the permeability of a lithologic unit (rock layers, coal seams). Given as a rate (feet/day).
- **Horizontal Hydraulic Conductivity – $K_h$**
  - Important when considering internal and outcrop barrier seepage rates.
  - May be higher depending on cleat orientation in relation to the coal barrier.
- **Vertical Hydraulic Conductivity – $K_v$**
  - Important when considering surface infiltration rates.
  - Generally higher in areas of greater secondary permeability – valley stress-relief fracture zones, low-cover mine voids.

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**Table 1**: Permeability Values Typical of the Appalachian Region

<table>
<thead>
<tr>
<th>Material Description</th>
<th>Test</th>
<th>Depth</th>
<th>Average Permeability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Freeport Coal</td>
<td>4</td>
<td>33'-61'</td>
<td>1.00 ft/day</td>
</tr>
<tr>
<td>Base of Upper Freeport Coal</td>
<td>3</td>
<td>38'-64'</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 46' over a lower Kittanning mine void</td>
<td>7</td>
<td>50'-91'</td>
<td>4.25 ft/day</td>
</tr>
<tr>
<td>Shale w/sandstone over solid coal</td>
<td>12</td>
<td>46'-95'</td>
<td>0.74 ft/day</td>
</tr>
<tr>
<td>Mine debris</td>
<td>99</td>
<td>10'-104'</td>
<td>1.98 ft/day</td>
</tr>
</tbody>
</table>

*Source: Miller, J.T., and D.H. Thompson, 1974.*

**Table 14**: Range of Horizontal Permeabilities for Seepage Analysis

<table>
<thead>
<tr>
<th>Material</th>
<th>Pre-Mining</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>0.013 ft/day</td>
</tr>
</tbody>
</table>

*Note:* The values are given in terms of permeability per unit area (ft/day).
Post-Closure Mine Pool Development

Barrier Permeability – Mine-Induced Fractures/Seepage over the coal barrier

- Presence of fractures within mine roof (overburden)
  - Angle of advance influence-1
  - Angle of complete mining-2
  - 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
- Zones of intense fracturing have $K_h$ values order of magnitude higher than adj. unfractured strata

Modified after Schmidt, 1985
In modern format, using a particular sign convention, Darcy’s law is usually written as:

\[ Q = -KA \frac{dh}{dl} \]

where:

- \( Q \) = rate of water flow (volume per time)
- \( K \) = hydraulic conductivity
- \( A \) = column cross sectional area
- \( \frac{dh}{dl} \) = hydraulic gradient, that is, the change in head over the length of interest.
Darcy’s Law
Post-Closure Mine Pool Development

Barrier Permeability – Outcrop Barrier Seepage Example (1)

North Pointe Mine (U-2007-01): Bakerstown Seam
A = 96.86 ac.
b_{avg} = 5’
M/A = 0.6 (60% Extraction)

------- BAF Outcrop

Mine Pool – 2555’ amsl:

Barrier Segment No. 1:
L_{1} = 991.90
w_{1} = 200’ (Highwall Mining)
**Post-Closure Mine Pool Development**

**Barrier Permeability**

<table>
<thead>
<tr>
<th>Permit No.:</th>
<th>U-2007-01</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company Name:</td>
<td>North Pointe Mine</td>
</tr>
<tr>
<td>Avg. Coal Seam Thickness (feet):</td>
<td>5</td>
</tr>
<tr>
<td>Infiltration Constant (0.31 to 2):</td>
<td>0.5</td>
</tr>
<tr>
<td>Hydraulic Conductivity (Coal - ft/day):</td>
<td>3.21</td>
</tr>
<tr>
<td>Hydraulic Conductivity (Overburden - ft/day):</td>
<td>4.25</td>
</tr>
<tr>
<td>Incremental Head (feet):</td>
<td>20</td>
</tr>
<tr>
<td>Est. Pool Elevation (feet m.s.l):</td>
<td>2555</td>
</tr>
<tr>
<td>Mined Acreage (acres):</td>
<td>96.86</td>
</tr>
<tr>
<td>GPM</td>
<td>48.43</td>
</tr>
<tr>
<td>CFD</td>
<td>932.78</td>
</tr>
</tbody>
</table>

**Incrimental Head (feet): 20**

**Estimated Surface Recharge: 48.43**

**ID:** North Pointe
**Type:** Coal

**Single Segment Analysis:**

<table>
<thead>
<tr>
<th>Barrier Segment</th>
<th>Bottom Elevation (wet - feet)</th>
<th>Top Elevation (dry - feet)</th>
<th>Barrier Length (feet)</th>
<th>Barrier Width (feet)</th>
<th>Seepage Rate (cfd)</th>
<th>Seepage Rate (gpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2550.00</td>
<td>2530.00</td>
<td>991.90</td>
<td>200.00</td>
<td>1990.00</td>
<td>10.34</td>
</tr>
</tbody>
</table>

**Total Barrier Seepage:**

- **CFD:** 1990.00
- **GPM:** 10.34

**Percentage of Total Est. Inflow:** 21.35%

**Note:**
1. Seepage Rate calculation adapted from McCoy, Donovan, and Leavitt (2006):
   \[ Q_{total} = \sum_{i=1}^{n} K_i (\beta + E_i \times \left( \frac{H_i}{L_i} \right) ) \]
2. Upper Freeport \( K \) values from Hobbie (1981) and Dames and Moore (1981)
Post-Closure Mine Pool Development

Barrier Permeability – Outcrop Barrier Seepage Example (2)

9A Mine: Lower Stockton Seam
A = 193.08 ac. (Injection Lobe)
b_{avg} = 5'
M/A = 0.6 (60% Extraction)

Mine Pool – 2120’ amsl:

Barrier Segment No. 1:
L_1 = 3467.30'
w_1 = 150'

Barrier Segment No. 2:
L_2 = 2090.4'
w_2 = 125'
### Post-Closure Mine Pool Development

#### Barrier Permeability

<table>
<thead>
<tr>
<th>Permit No.:</th>
<th>U-2004-93</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company Name:</td>
<td>9A Injection Lobe to May Fork</td>
</tr>
</tbody>
</table>

Avg. Coal Seam Thickness (feet): 5
Infiltration Constant (0.31 to 2 GPM/acre): 0.5
Hydraulic Conductivity (Coal - ft/day): 3.21
Hydraulic Conductivity (Overburden - ft/day): 4.25
Incremental Head (feet): 20

Estimated Surface Recharge: 18583.95

<table>
<thead>
<tr>
<th>Permit No.:</th>
<th>U-2004-93</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company Name:</td>
<td>9A Injection Lobe to May Fork</td>
</tr>
</tbody>
</table>

Avg. Coal Seam Thickness (feet): 5
Est. Pool Elevation (feet m.s.l.): 2120
Mined Acreage (acres): 193.08

Infiltration Constant (0.31 to 2 GPM/acre): 0.5
Hydraulic Conductivity (Coal - ft/day): 3.21
Hydraulic Conductivity (Overburden - ft/day): 4.25

Incrimental Head (feet): 20

Estimated Surface Recharge: 18583.95

### Multi-Segment Analysis:

<table>
<thead>
<tr>
<th>Barrier ID:</th>
<th>ID:</th>
<th>Type:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrier ID:</td>
<td>9A Injection Lobe</td>
<td>Coal</td>
</tr>
</tbody>
</table>

#### Barrier Segment

<table>
<thead>
<tr>
<th>Barrier Segment</th>
<th>Bottom Elevation (wet - feet)</th>
<th>Top Elevation (dry - feet)</th>
<th>Barrier Length (feet)</th>
<th>Barrier Width (feet)</th>
<th>Seepage Rate (cfd)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>2120.00</td>
<td>2080.00</td>
<td>3467.30</td>
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<td>2070.00</td>
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Total Barrier Seepage: 28260.41
Percentage of Total Est. Inflow: 152.07%

### Single-Segment Analysis:

<table>
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<tr>
<th>Barrier Segment</th>
<th>Bottom Elevation (wet - feet)</th>
<th>Top Elevation (dry - feet)</th>
<th>Barrier Length (feet)</th>
<th>Barrier Width (feet)</th>
<th>Seepage Rate (cfd)</th>
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</thead>
<tbody>
<tr>
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<td>2070.00</td>
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Total Barrier Seepage: 32436.76

### Note:

1. Seepage Rate calculation adapted from McCoy, Donovan, and Leavitt (2006):

\[ Q_{total} = \sum_{i=1}^{n} K_i h_i + b \times L_i + \frac{\Delta l}{\Delta y} \]
## Seepage Estimate for Rock Bull Mining Company Using 3.21 ft/day Permeability

<table>
<thead>
<tr>
<th>Section</th>
<th>Barrier Width L</th>
<th>Length</th>
<th>Height</th>
<th>Head 1</th>
<th>Head 2</th>
<th>k (ft/day)</th>
<th>Barrier Leakage</th>
<th>Cubic ft/day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>gal/day</td>
<td>gal/hour</td>
<td>gal/min</td>
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<td>1995</td>
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## Permeability Estimate for Rock Bull Mining Company Using 2010 head and 0.50 gpm/acre

<table>
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<th>Section</th>
<th>Barrier Width L</th>
<th>Length</th>
<th>Height</th>
<th>Head 1</th>
<th>Head 2</th>
<th>k (ft/day)</th>
<th>Barrier Leakage</th>
<th>Cubic ft/day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>gal/day</td>
<td>gal/hour</td>
<td>gal/min</td>
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<th></th>
<th>Barrier Leakage</th>
<th>Cubic ft/day</th>
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<table>
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<th>6,606</th>
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<table>
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<table>
<thead>
<tr>
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<th>0.50 gal/min/acre</th>
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</thead>
<tbody>
<tr>
<td>69 acres</td>
<td>69</td>
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</tbody>
</table>
Ventilation Fan