West Virginia **department of environmental protection**

WVDEP 2019 Annual I&E Training

Underground Mining Basics and Mine Pools

STEVE BALL AND JOSH BONNER

Presentation Overview

- **Introduction**
  - Basic Hydrology and Geology
- **Underground Mining**
  - Introduction
  - Above and Below Drainage Mines
  - Entry Types
  - Underground Mining Methods
  - Multiple Seam Mining
- **Subsidence**
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  - Modes of Subsidence
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  - Subsidence-Related Landslides
  - Hydrologic Effects of Subsidence
- **Mine Barriers**
  - Outcrop Barriers
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- **Mine Seals**
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  - Surface Infiltration
  - Hydraulic Conductivity
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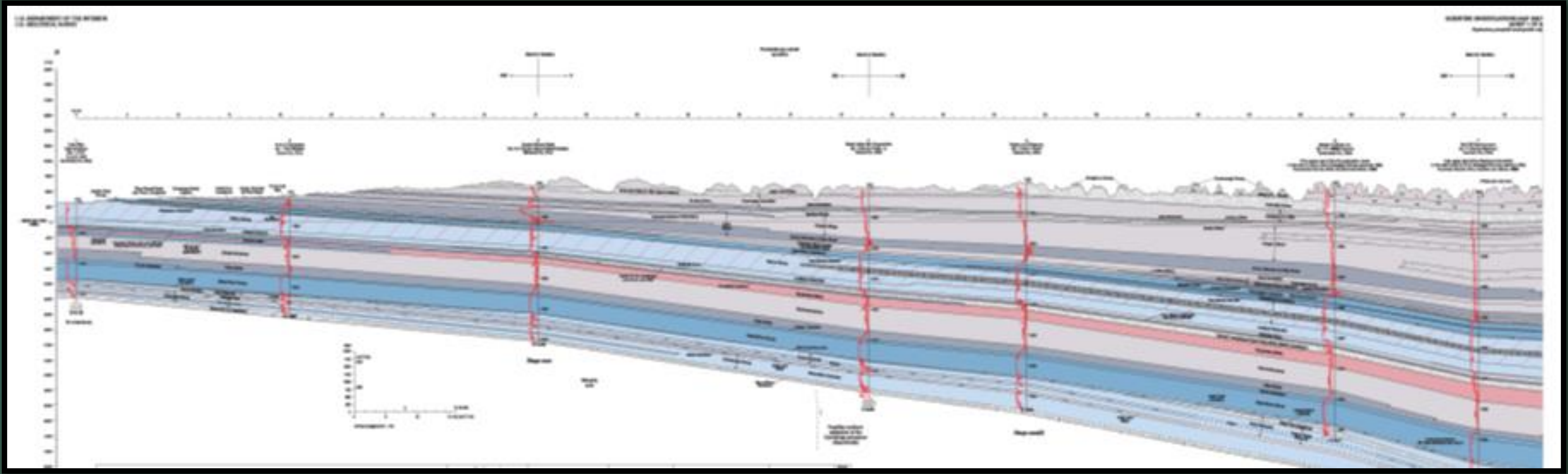
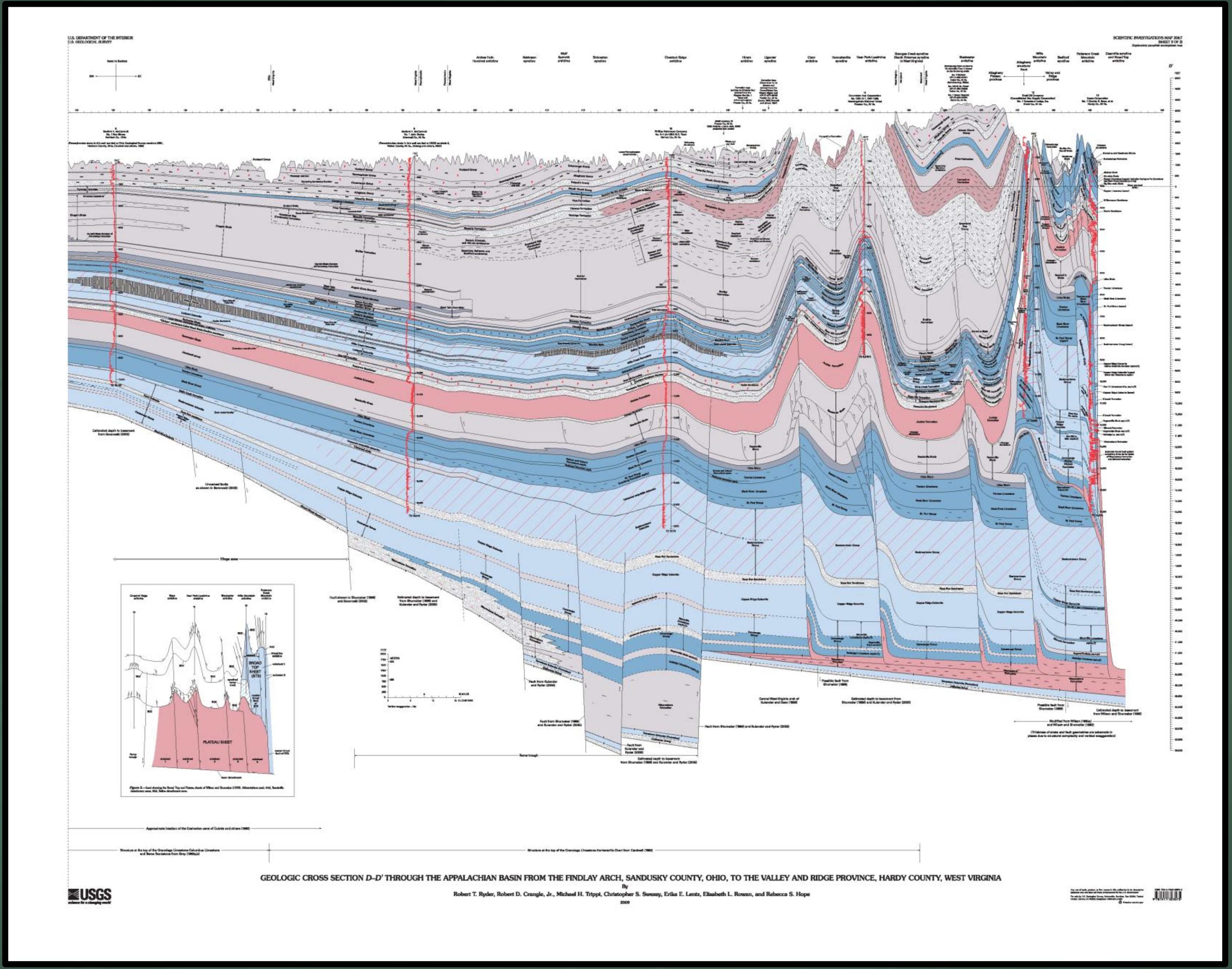
Introduction

Basic Hydrology and Geology





U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

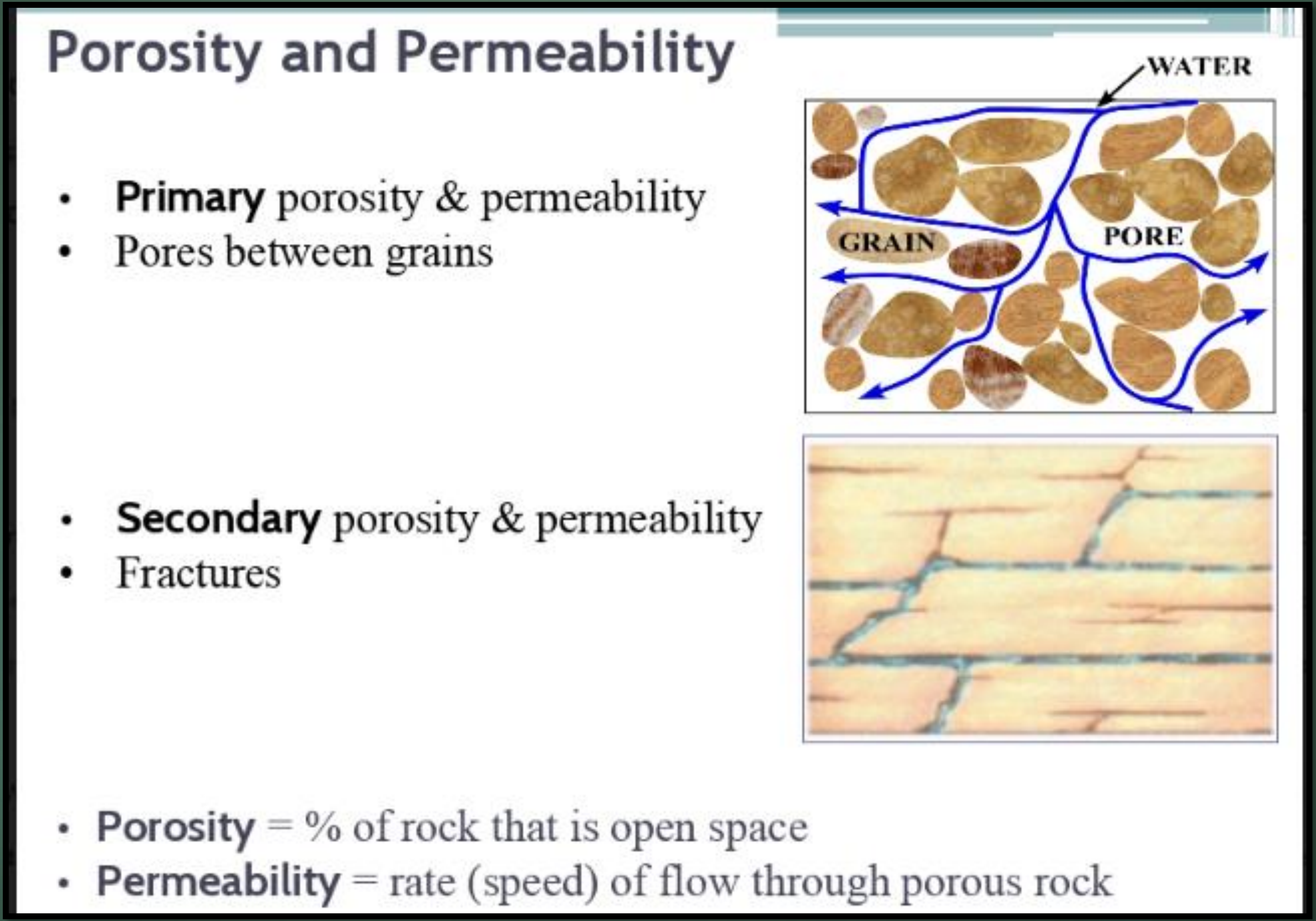
SCIENTIFIC INVESTIGATIONS MAP 3067
SHEET 2 OF 2

GEOLOGIC CROSS SECTION *D–D′* THROUGH THE APPALACHIAN BASIN FROM THE FINDLAY ARCH, SANDUSKY COUNTY, OHIO, TO THE VALLEY AND RIDGE PROVINCE, HARDY COUNTY, WEST VIRGINIA

By

Robert T. Ryder, Robert D. Crangle, Jr., Michael H. Trippi, Christopher S. Swezey, Erika E. Lentz, Elisabeth L. Rowan, and Rebecca S. Hope

2009



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.

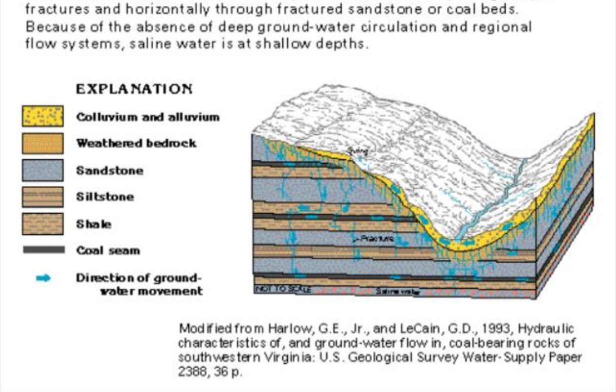
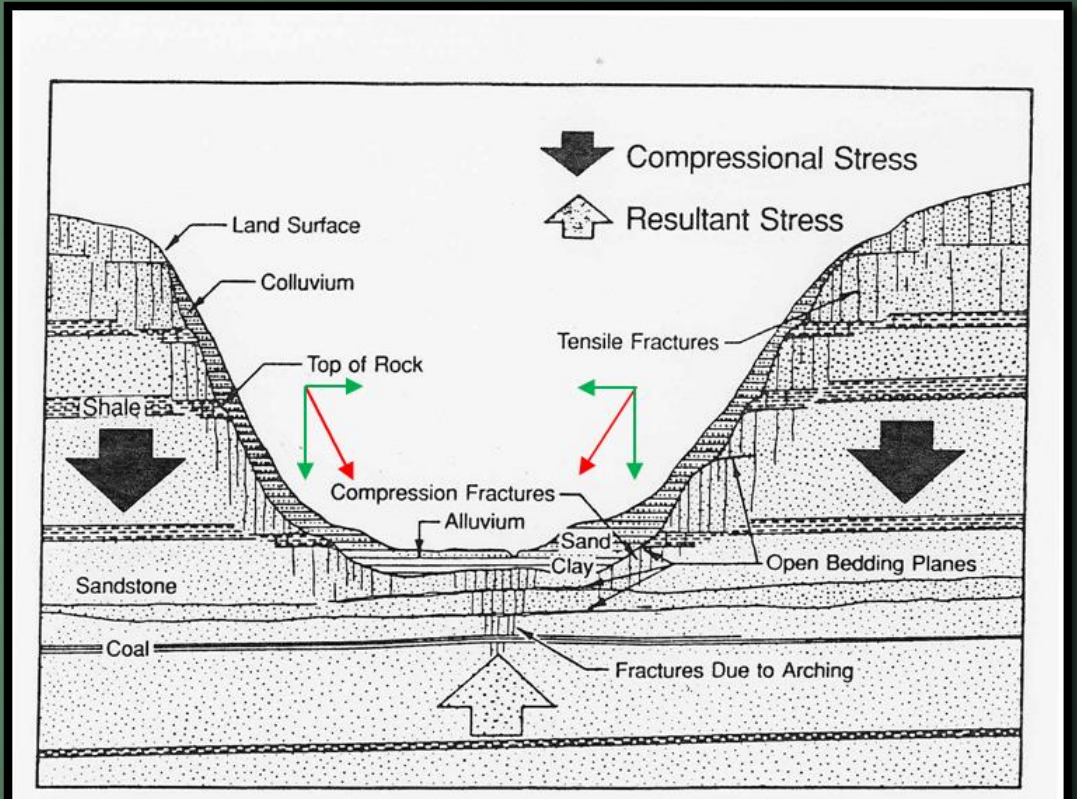


Figure 90. Topography and shallow fracture systems determine ground-water movement in the aquifers of the Appalachian Plateaus. Water infiltrates weathered bedrock and moves mostly through near-surface fractures; some water moves in a steplike fashion vertically along deeper fractures and horizontally through fractured sandstone or coal beds. Because of the absence of deep ground-water circulation and regional flow systems, saline water is at shallow depths.

Modified from Harlow, G.E., Jr., and LeCain, G.D., 1993, Hydraulic characteristics of, and ground-water flow in, coal-bearing rocks of southwestern Virginia: U.S. Geological Survey Water-Supply Paper 2388, 36 p.



Generalized geologic section showing features of stress-relief fracturing [after Ferguson (1974)]

Rock Properties

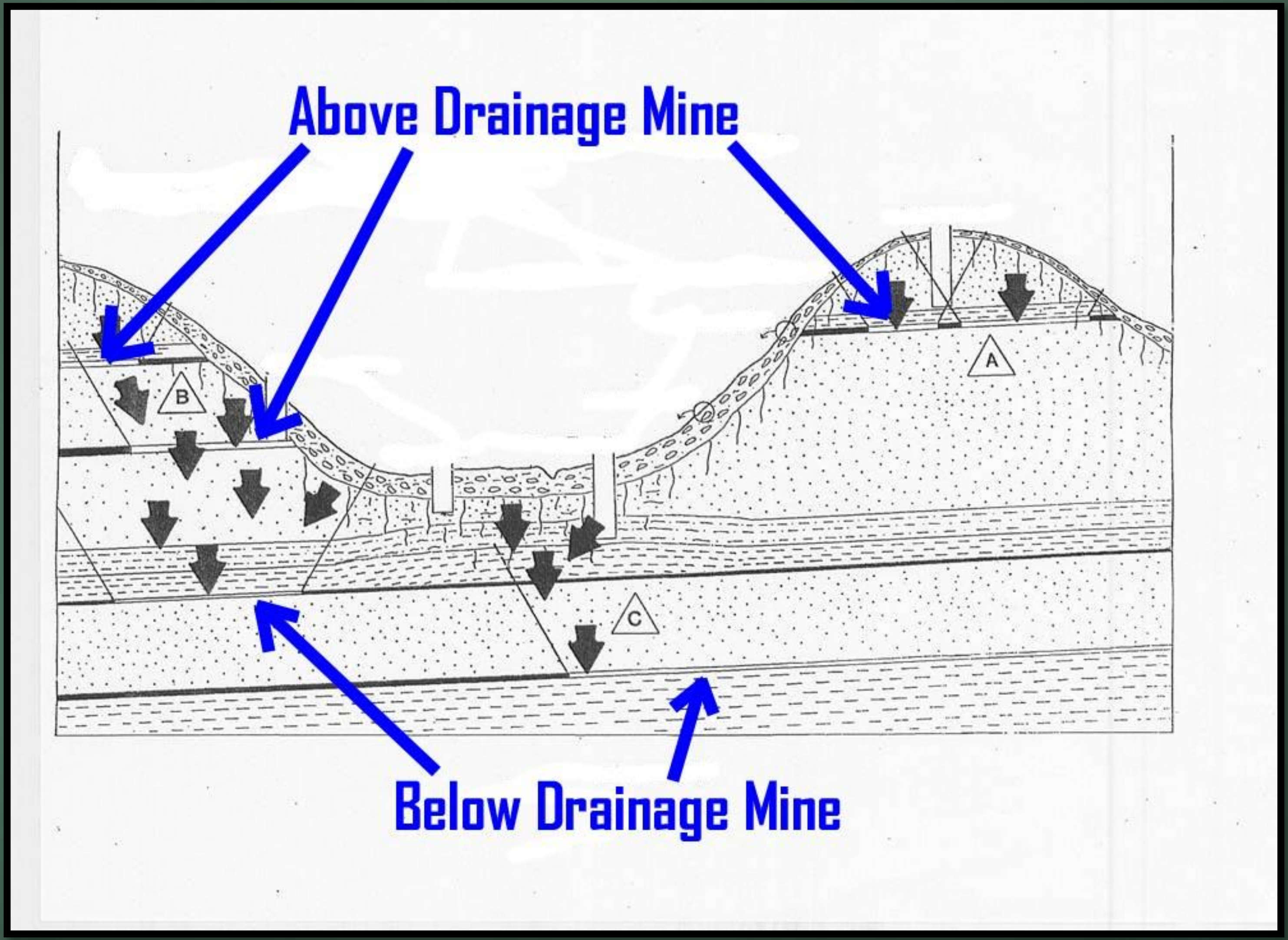
- Sandstone – can be hard and brittle
- Coal - can be hard and brittle
- Limestone - can be hard and brittle
- Shale – fine grained, can be flexible or resilient
- Claystone - fine grained, can be flexible or resilient

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

Above and Below Drainage Mines



Drift, Slope & Shaft Entries

- Drift Entry
- Slope Entry
- Shaft Entry

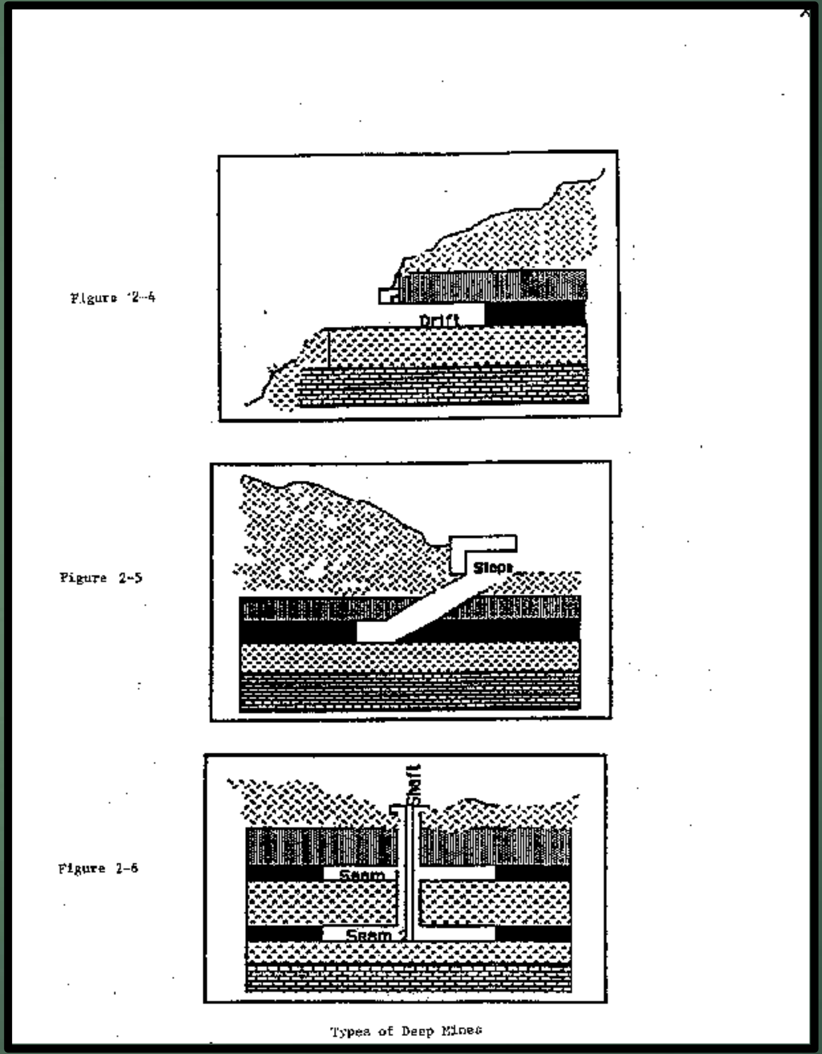


Figure 2-4

Figure 2-5

Figure 2-6

Types of Deep Mines

Underground Mining Methods

- Conventional
- Continuous Miner
- Longwall

Conventional Mining Equip.

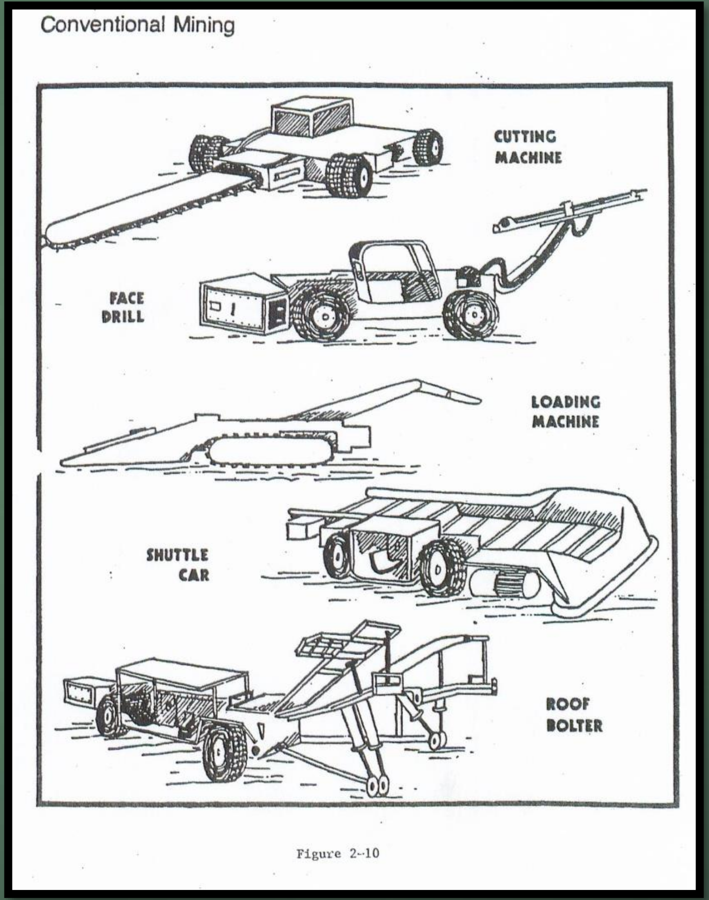


Figure 2-10

Conventional Mining - Blasting

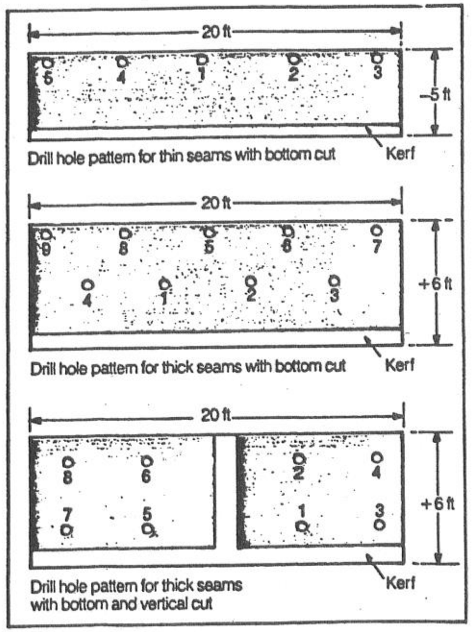
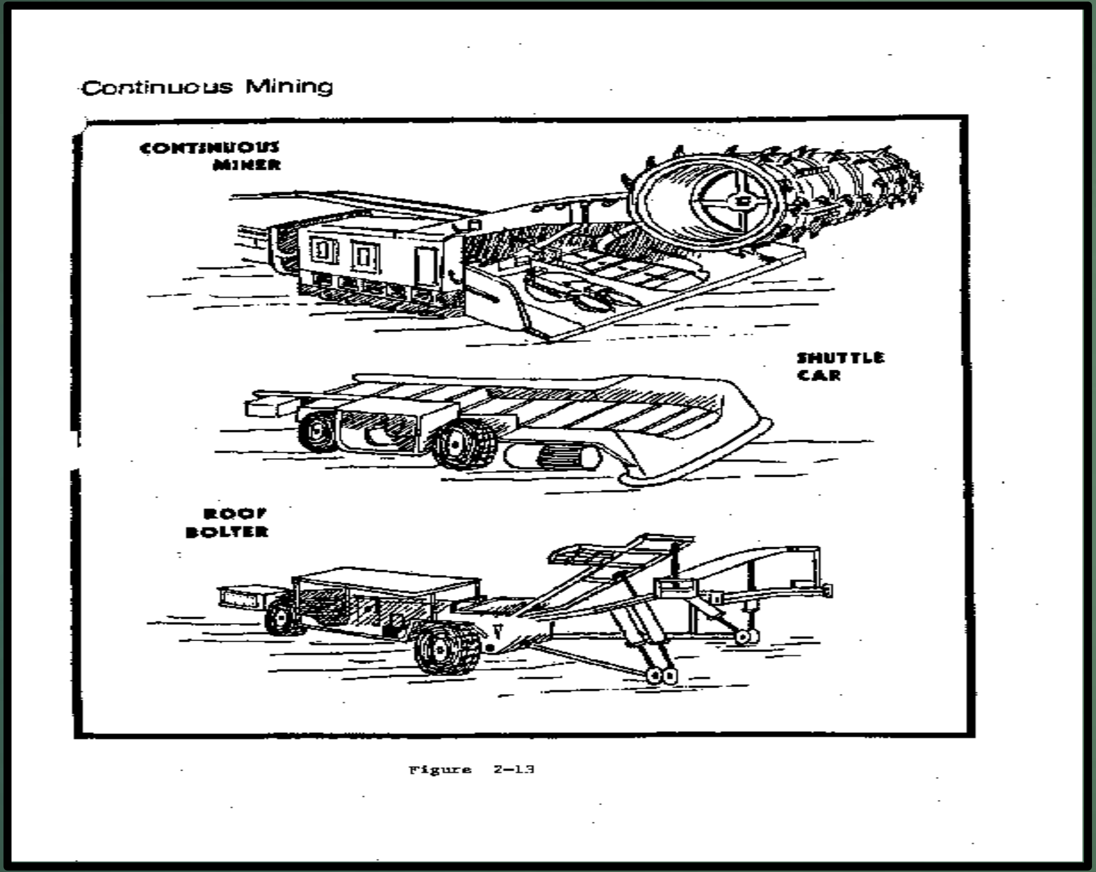
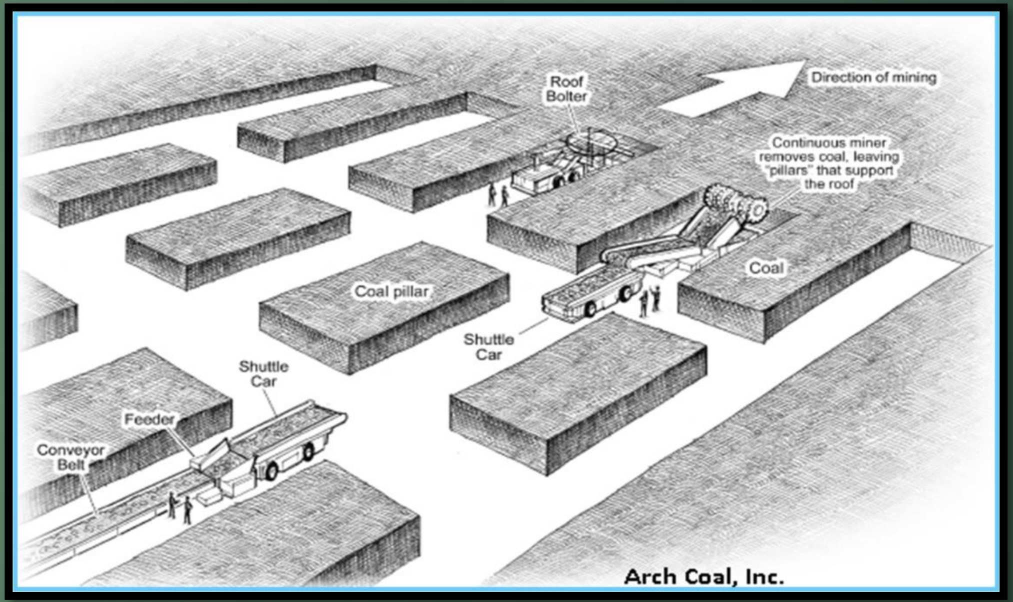


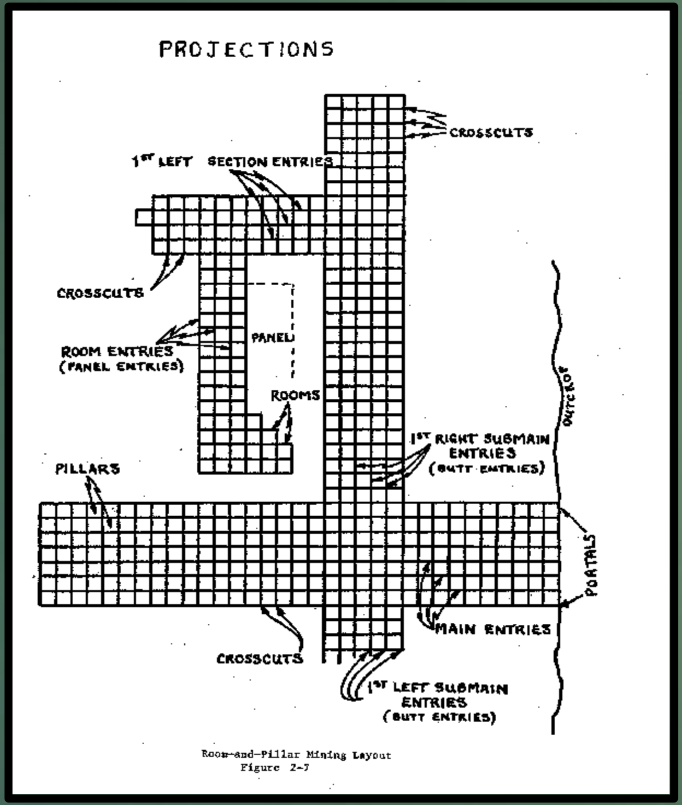
Figure 2-11

Continuous Mining Equipment

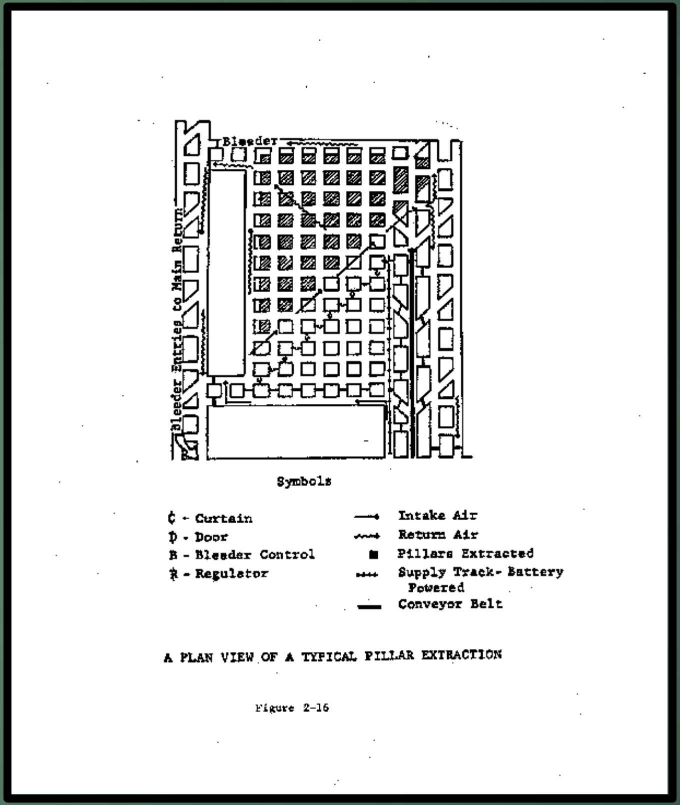




Continuous Mining Layout



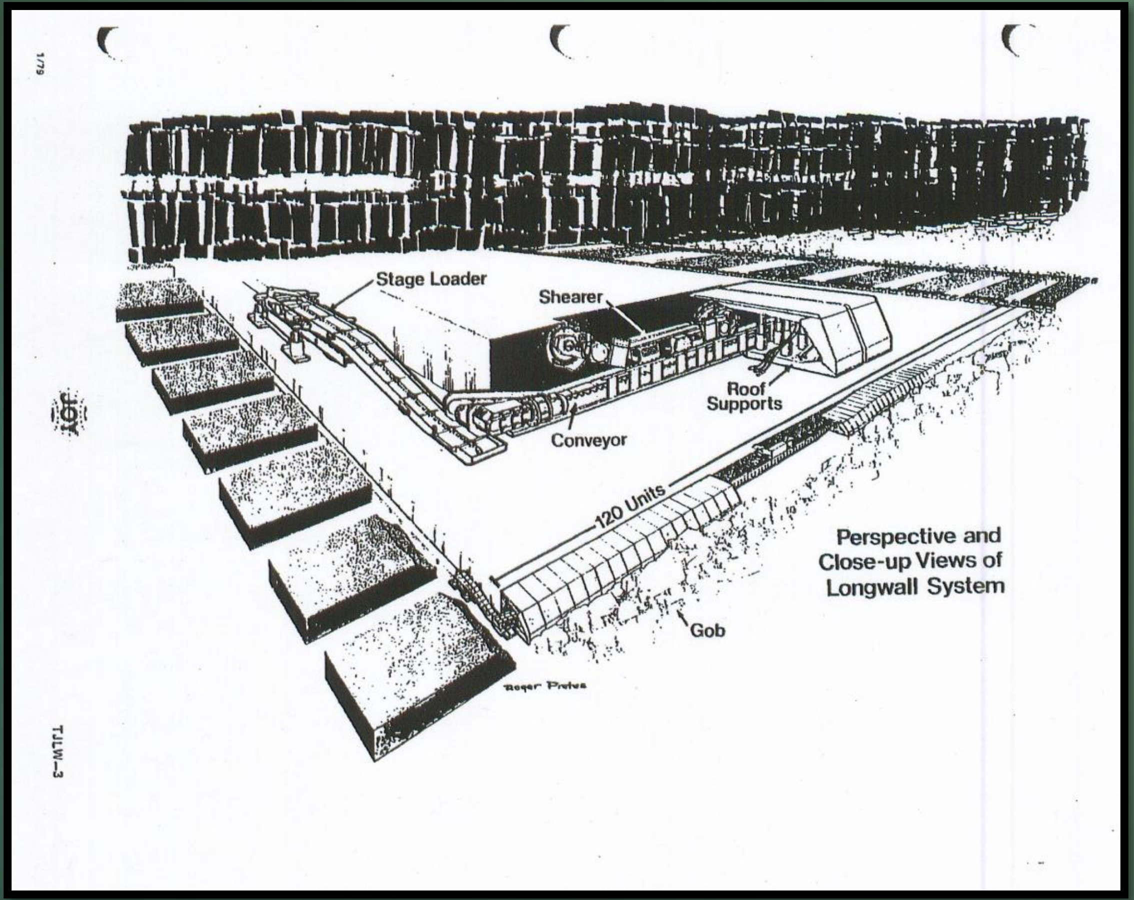
Room-and-Pillar Mining Layout
Figure 2-7



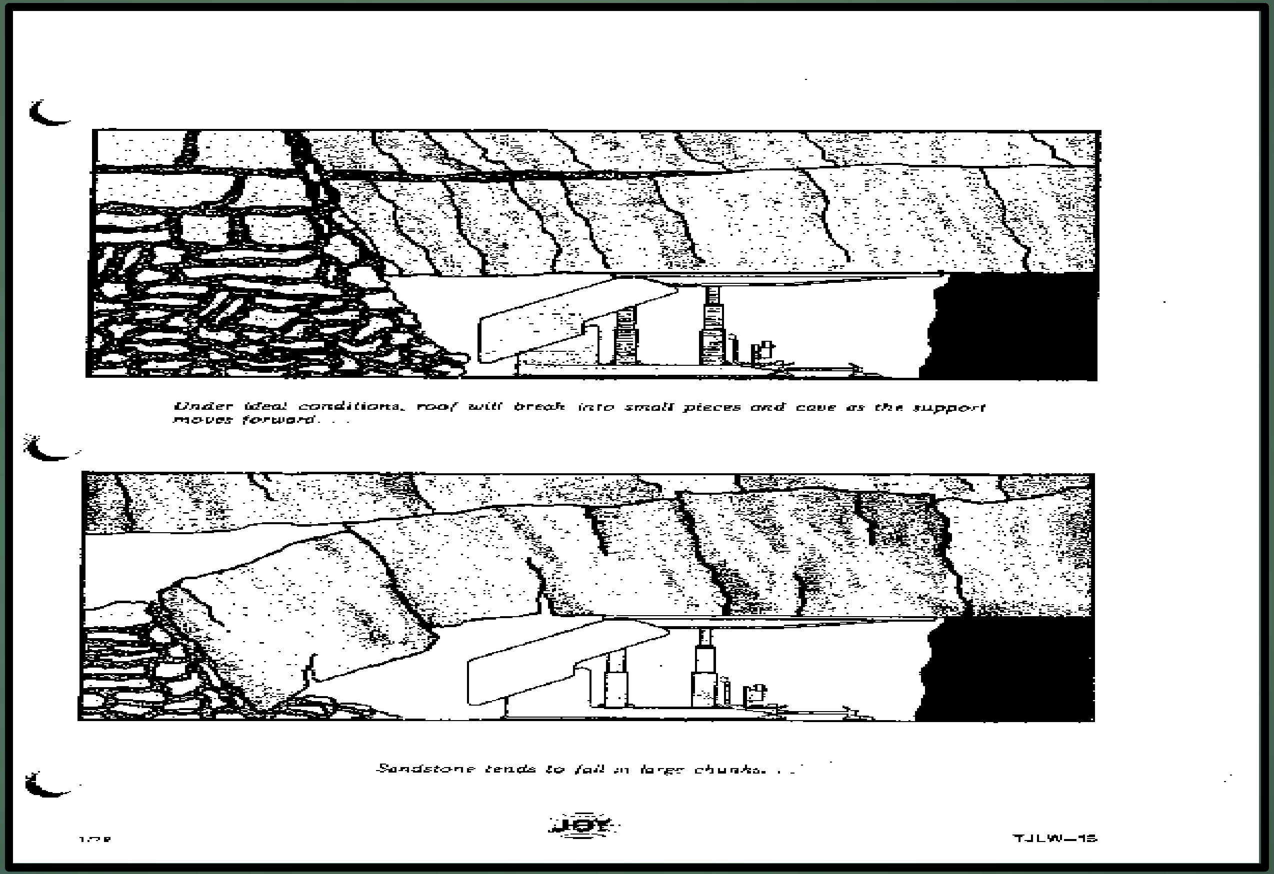
A PLAN VIEW OF A TYPICAL PILLAR EXTRACTION

Figure 2-16

Longwall Mining



Longwall Mining:
Roof Support and Breakage


Under ideal conditions, roof will break into small pieces and cave as the support moves forward. . .

Sandstone tends to fall in large chunks. . .

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Longwall Development

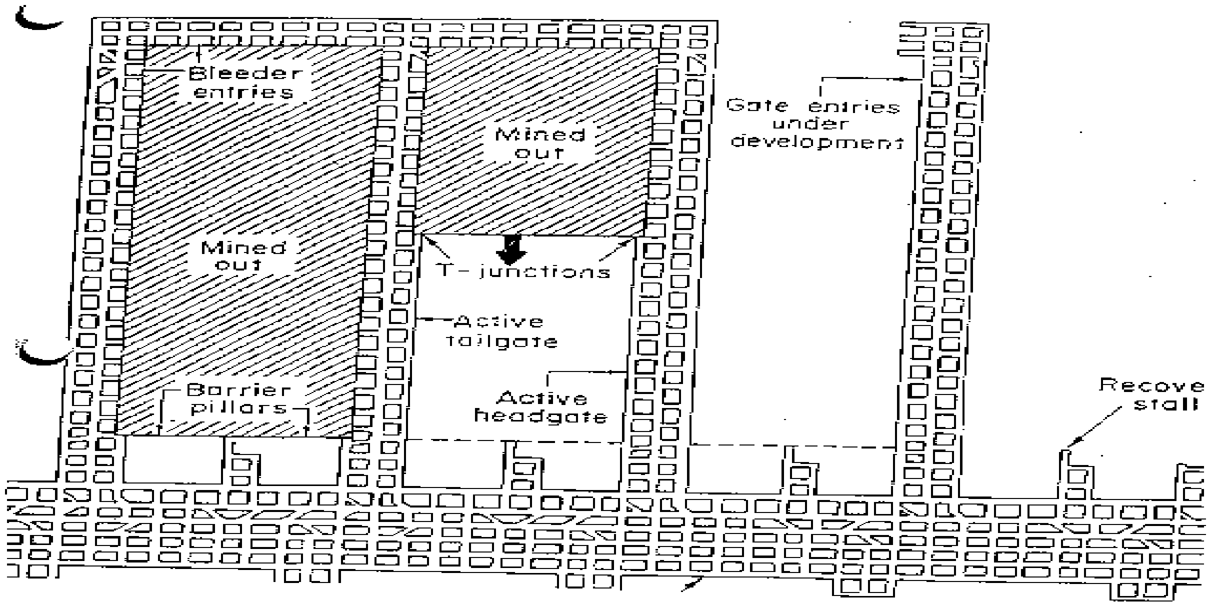


Fig. 1.4a Longwall Mining Panel Layout

Auger Mining

Auger Machine

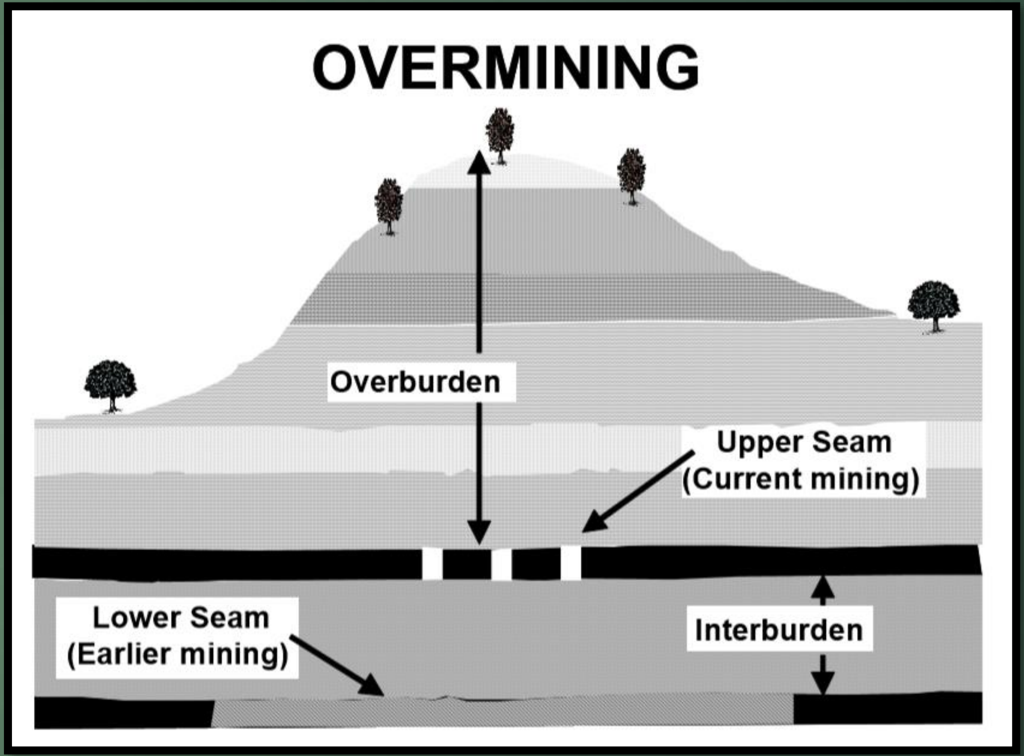
Auger Holes

Highwall Miner

Highwall Miner

Multiple Seam Mining

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



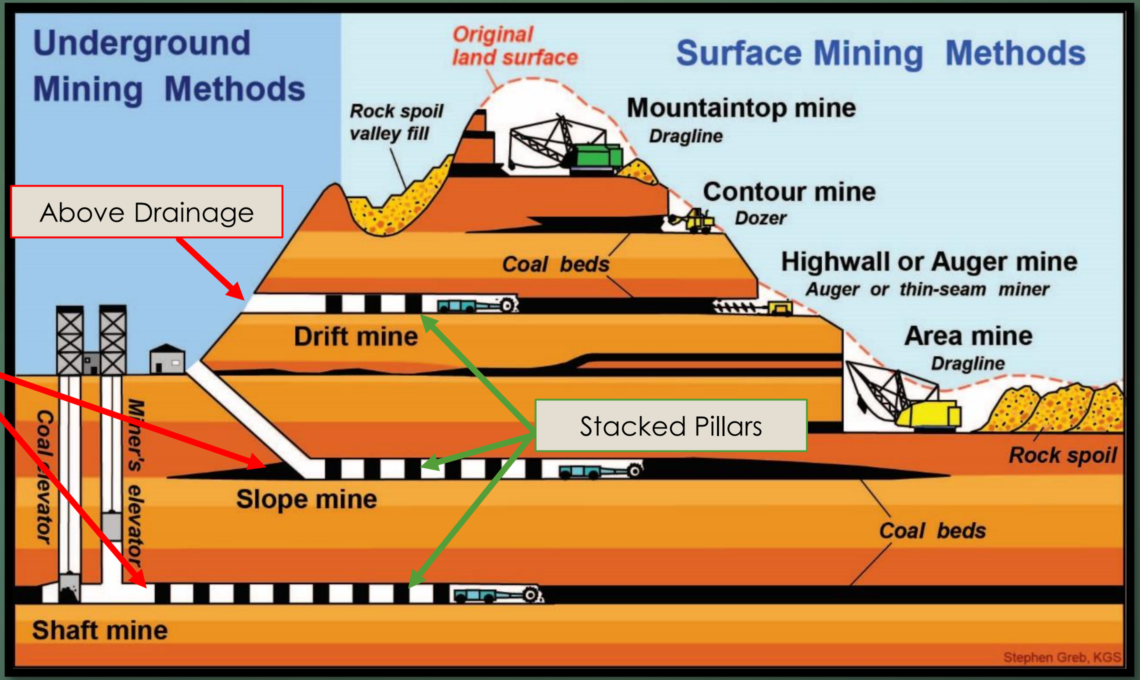
Multiple Seam Mining

- 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

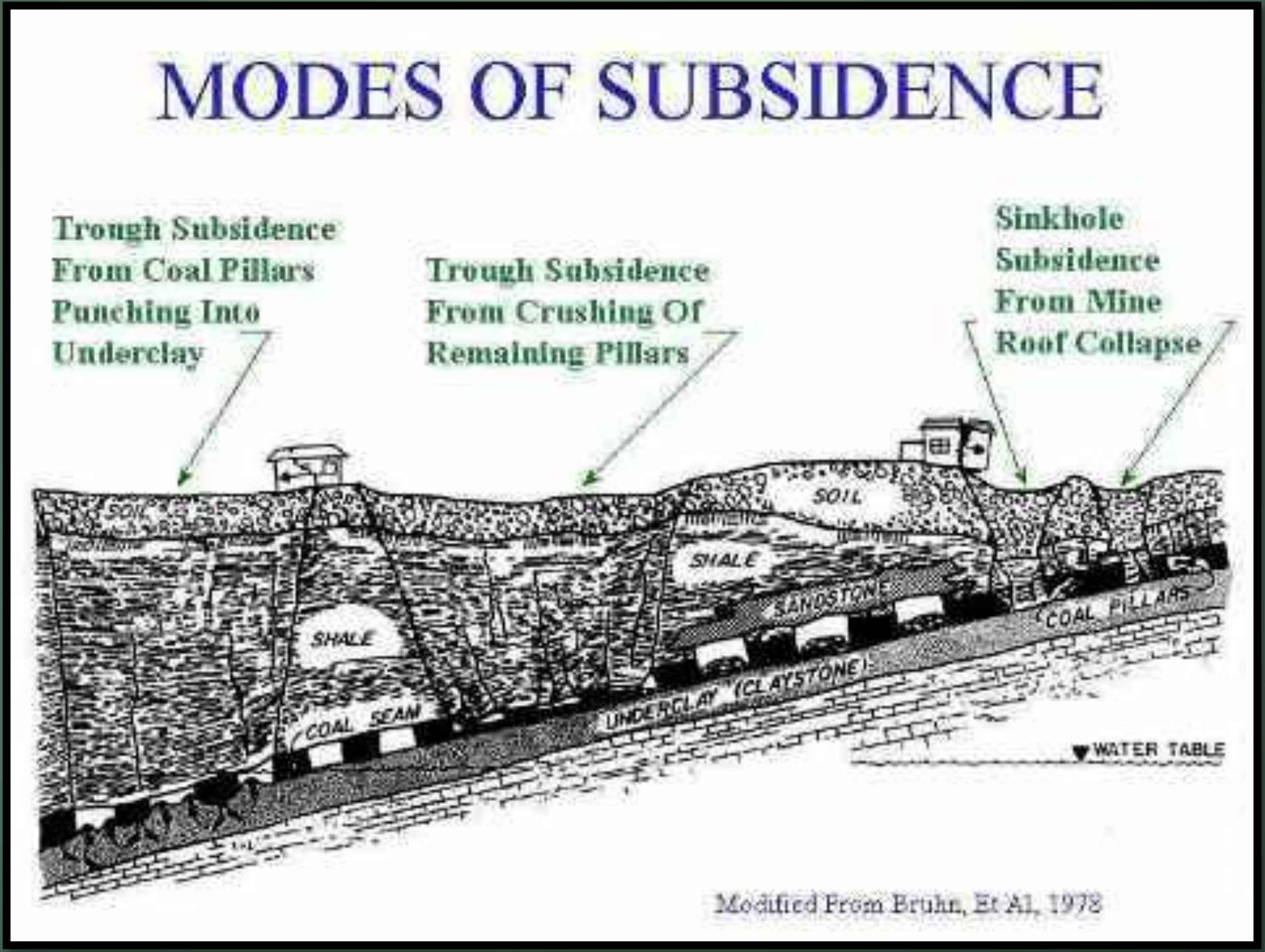
Below Drainage

Stacked Pillars

Subsidence

Modes of Subsidence

Surface Effects of Limited Extraction/Shallow Mining



MODES OF SUBSIDENCE

Trough Subsidence From Coal Pillars Punching Into Underclay

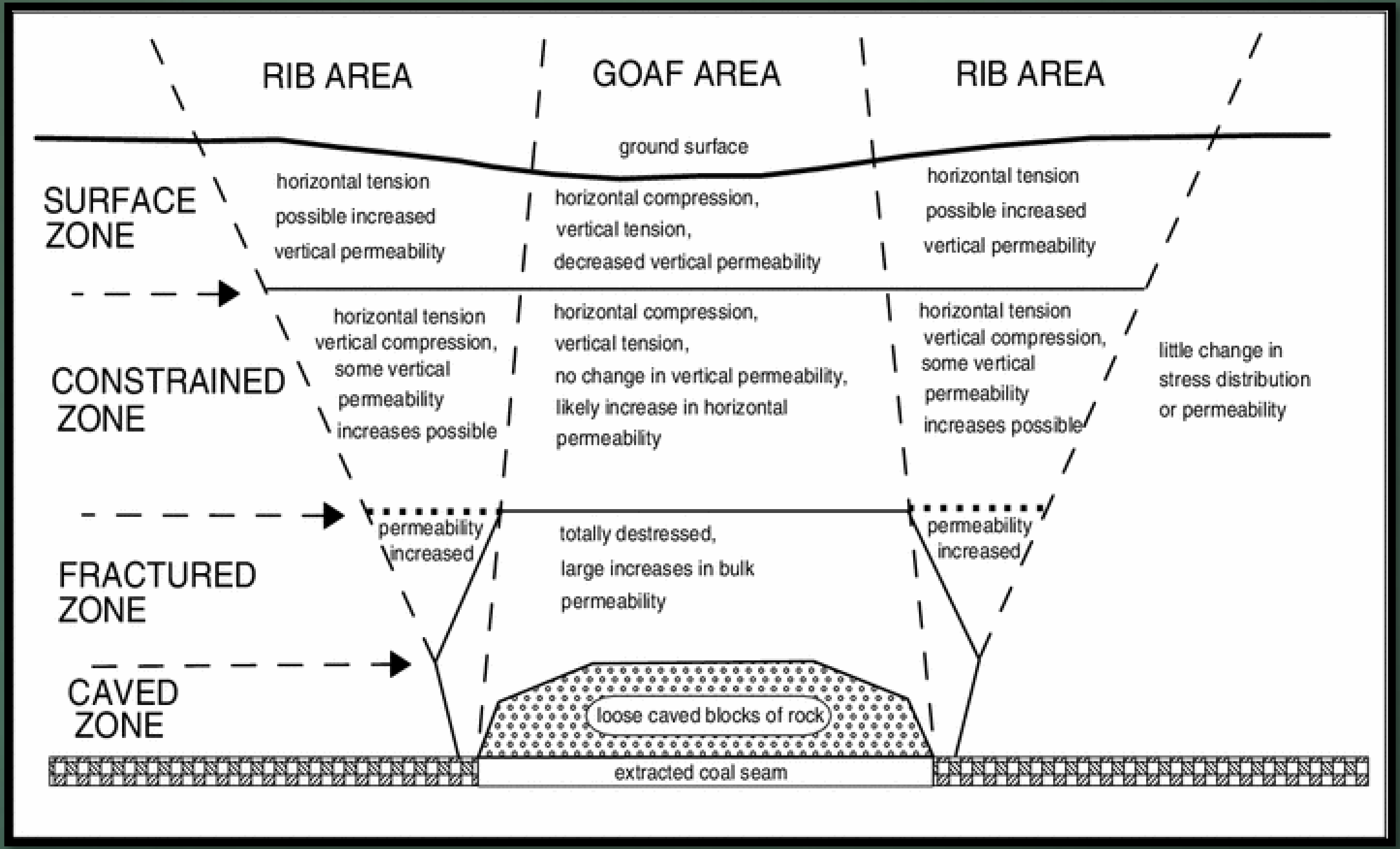
Trough Subsidence From Crushing Of Remaining Pillars

Sinkhole Subsidence From Mine Roof Collapse

Modified From Bruhn, Et Al, 1978

Kendorski Model

Longwall/High Extraction Mining



Subsidence – Stream Damage

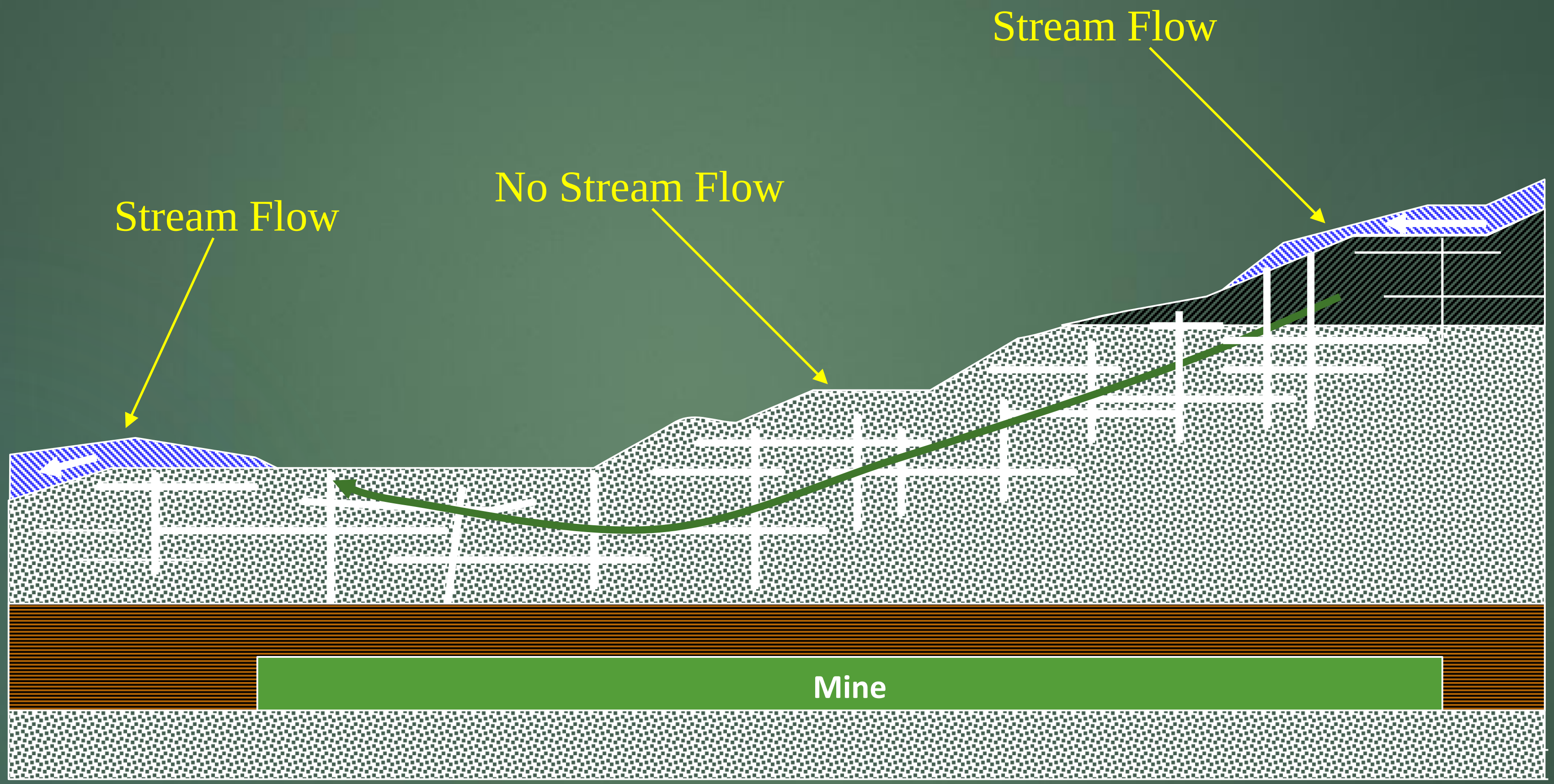
- Water Loss In Stream Channel
- Loss Of Base Flow
- Changes In Grade Of Stream Channel

Subsidence – Stream Damage

Subsidence – Direct Stream Loss

Subsidence – Stream Damage

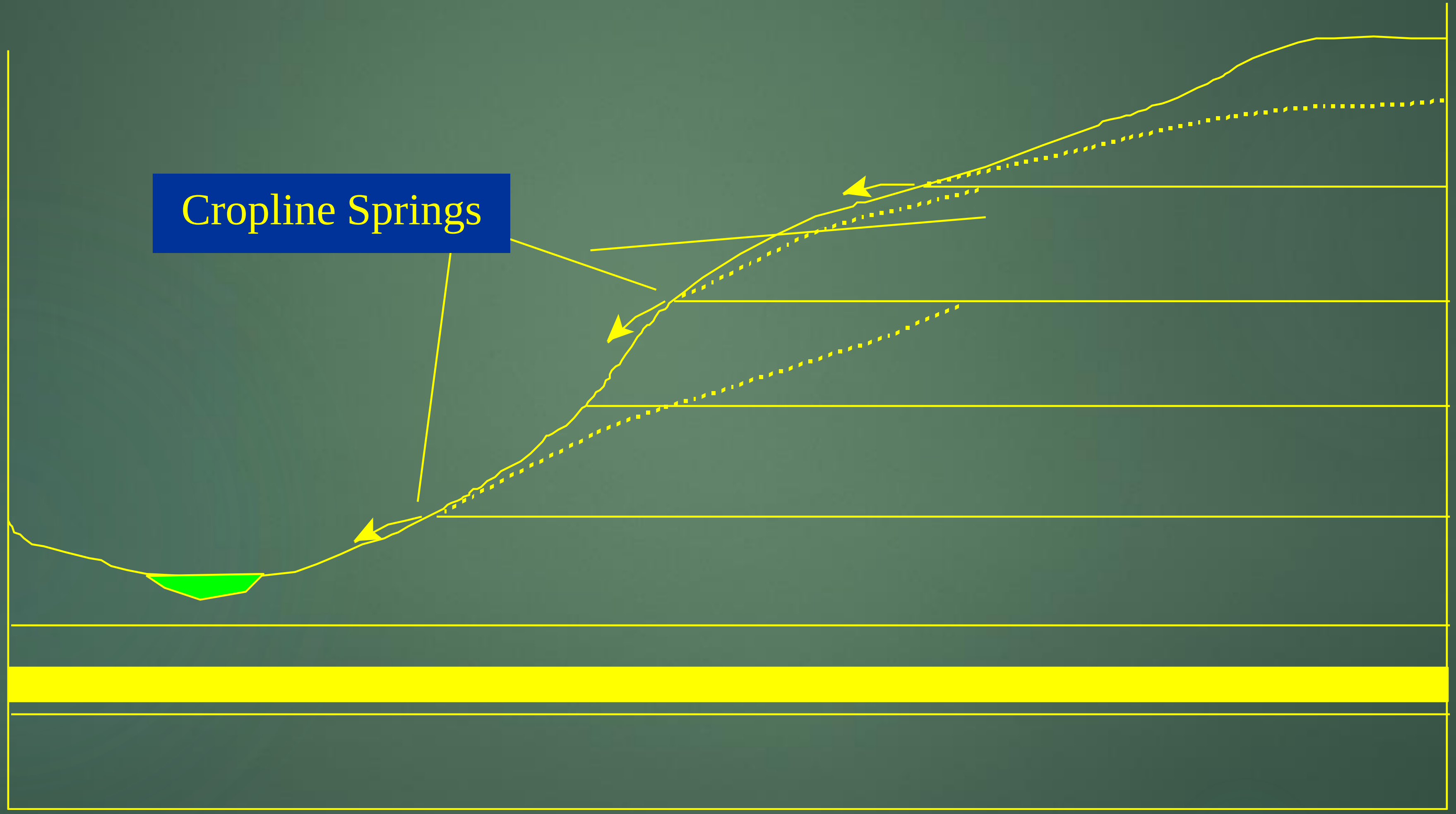
Subsidence – Stream Damage


Stream Flow
No Stream Flow
Stream Flow
Mine

Stream Repair – Grouting Channel

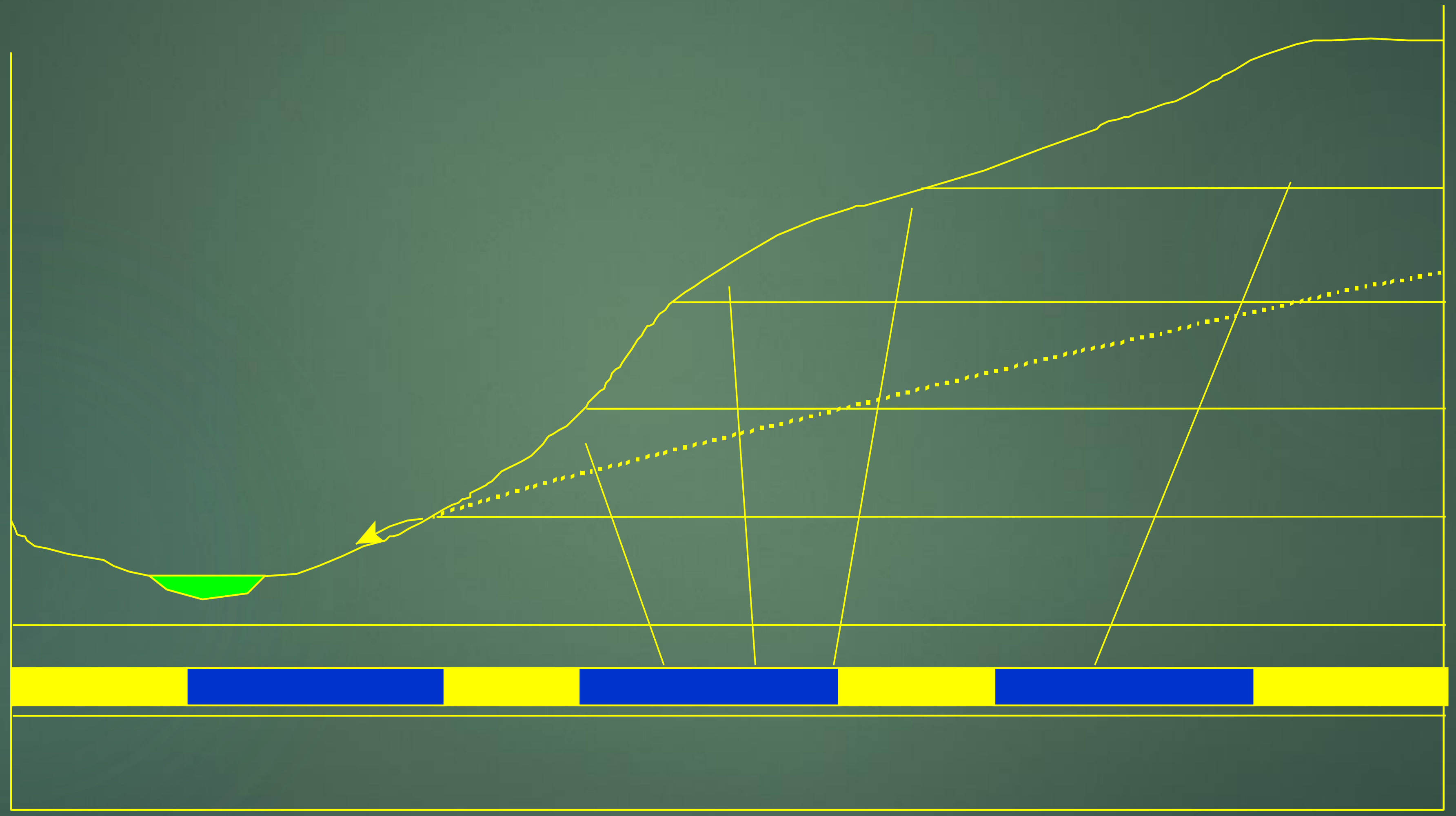
Stream Repair – Grouting Channel

Spring Flow Prior to Mining



Cropline Springs

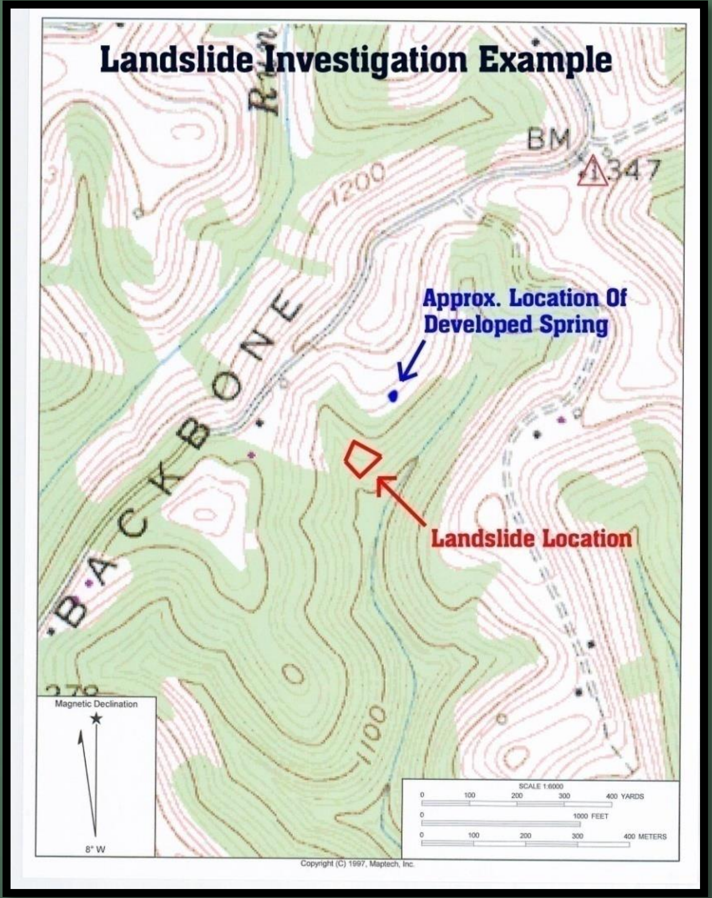
Spring Flow After Mining



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

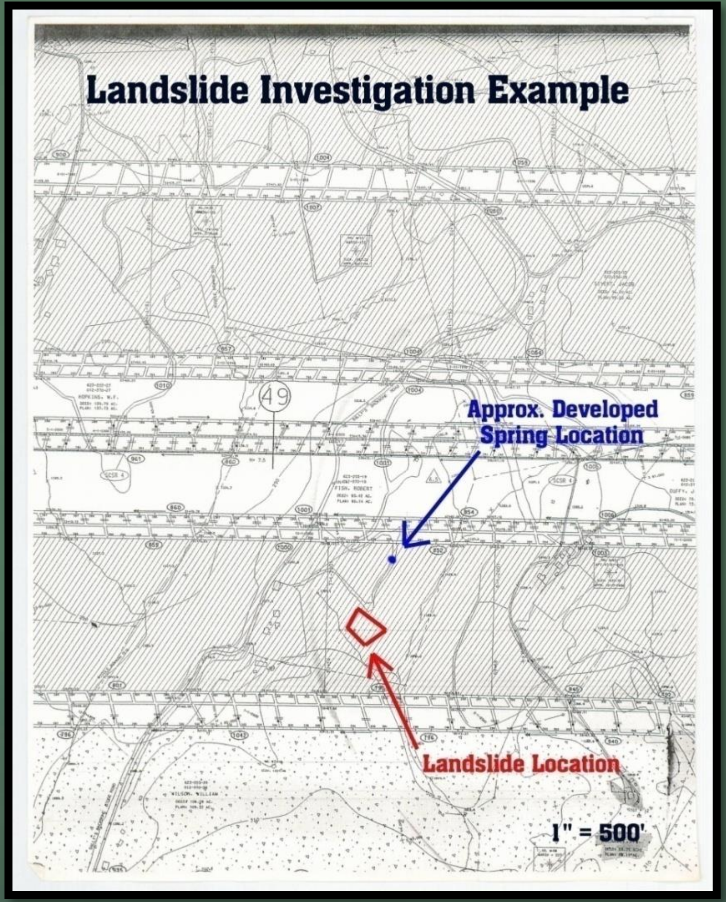


Landslide Investigation Example

Approx. Location Of Developed Spring

Landslide Location

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 * 6* 144 * 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

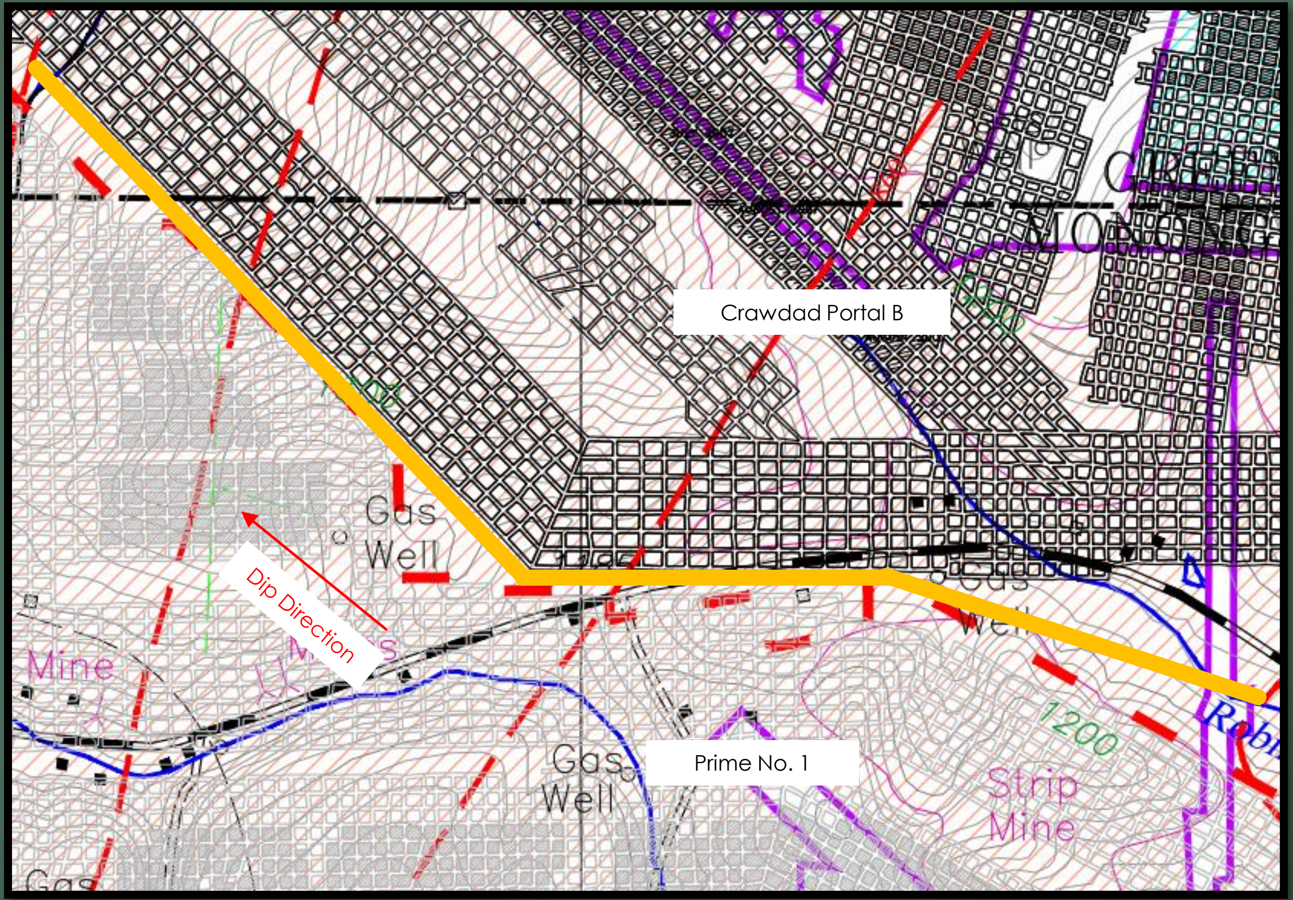
- Geologic features such as faults, existing slope failures, stress relief joints, weather, etc. can facilitate leakage across outcrop barriers.
- When these features exist, they should not be considered as part of the outcrop barrier width.
- A site-specific design incorporates a comprehensive assessment 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

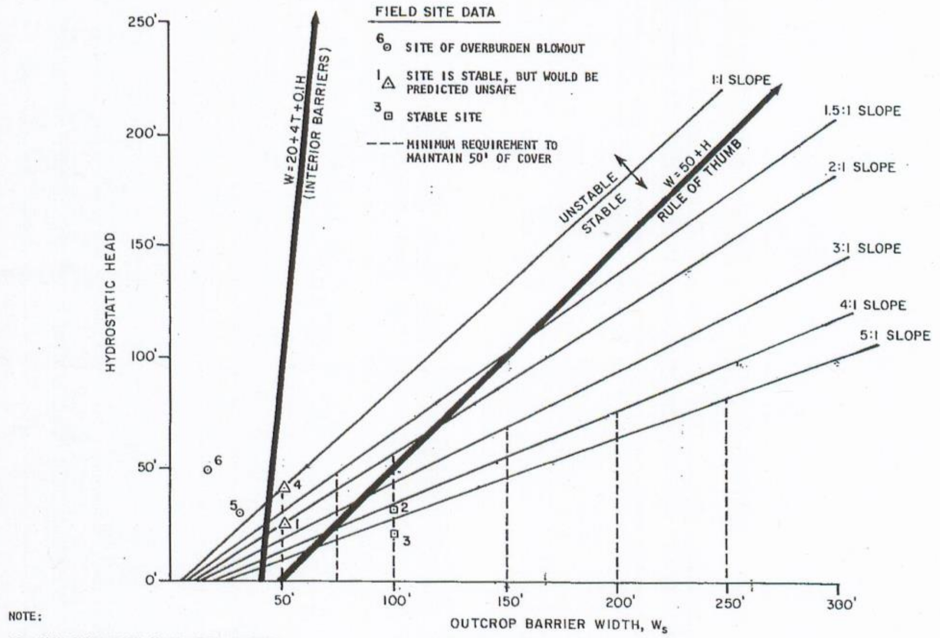
Guidelines for Estimating Barrier Widths

- **Ashley Formula (Interior)**
  - $W = 20 + (4 * T) + (0.1 * D)$
    - 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)



NOTE:

FOR EACH OVERBURDEN SLOPE, THE UNSTABLE BARRIER WIDTH IS ABOVE THE LINE AND THE STABLE BARRIER WIDTH IS BELOW THE LINE.

FIGURE 47

BARRIER WIDTH REQUIRED TO MAINTAIN A SAFETY FACTOR OF 1.5

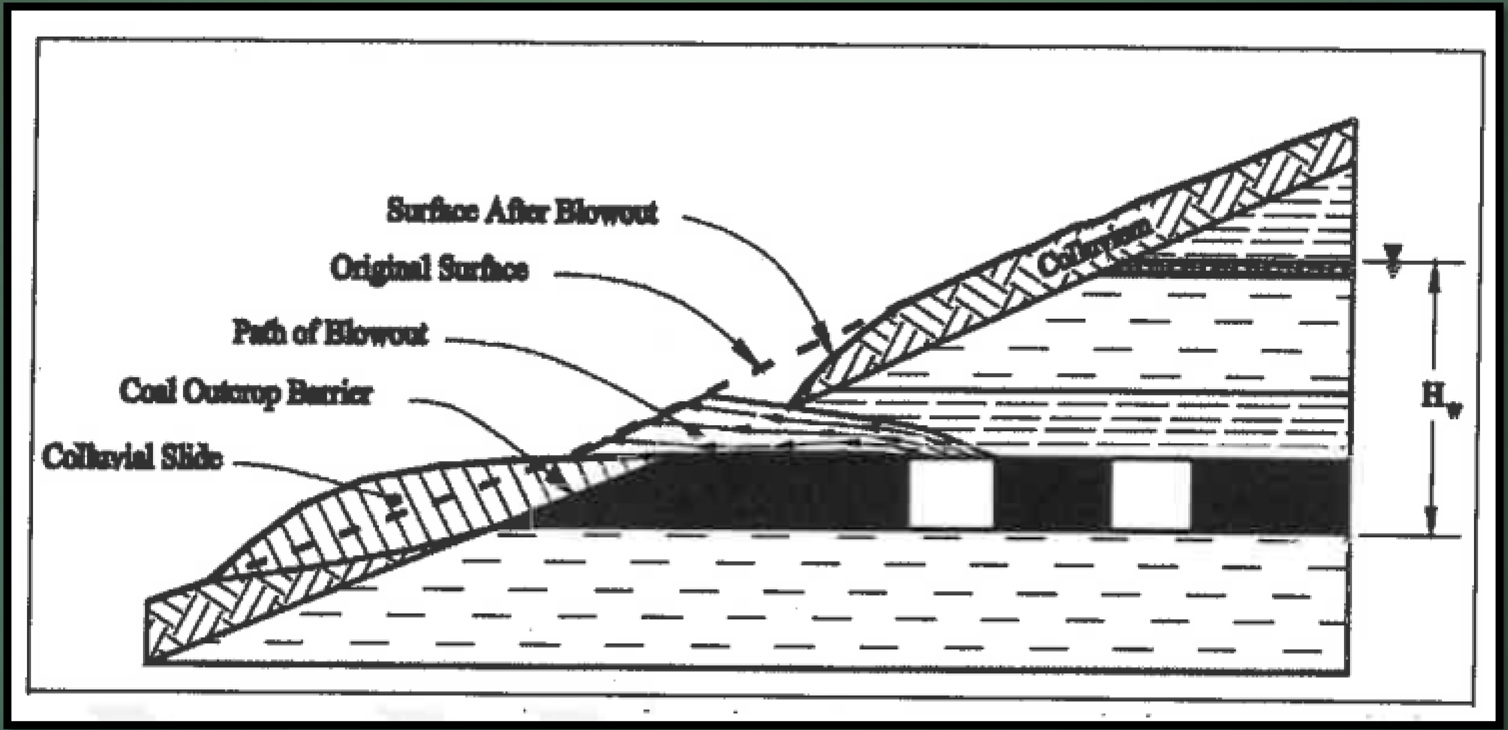
Barrier Failure

Major Causes of Blowouts

- Vertical Displacement
- Wedge-Type Failure
- Surface Landslides

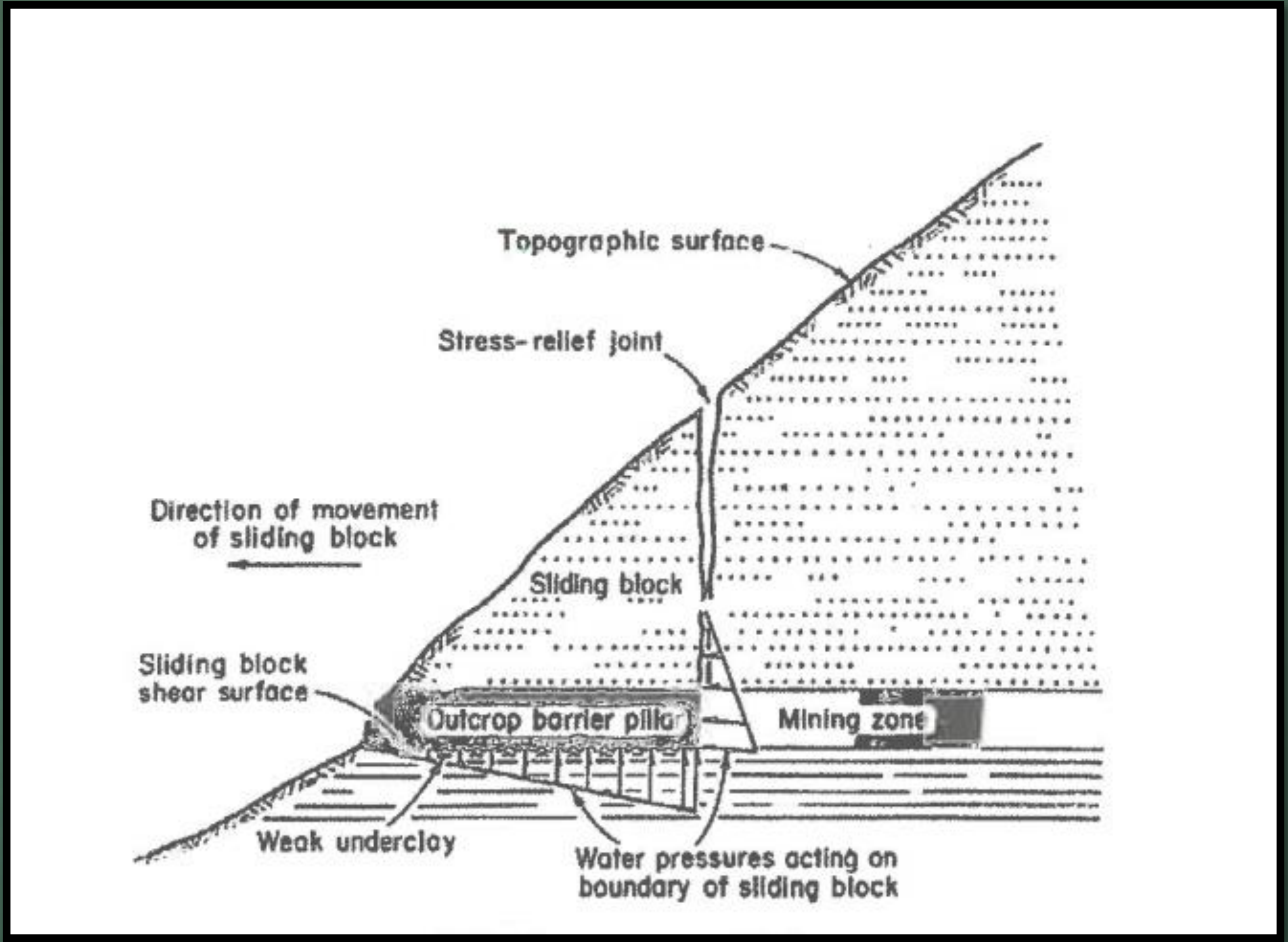
Barrier Failure

Vertical Displacement

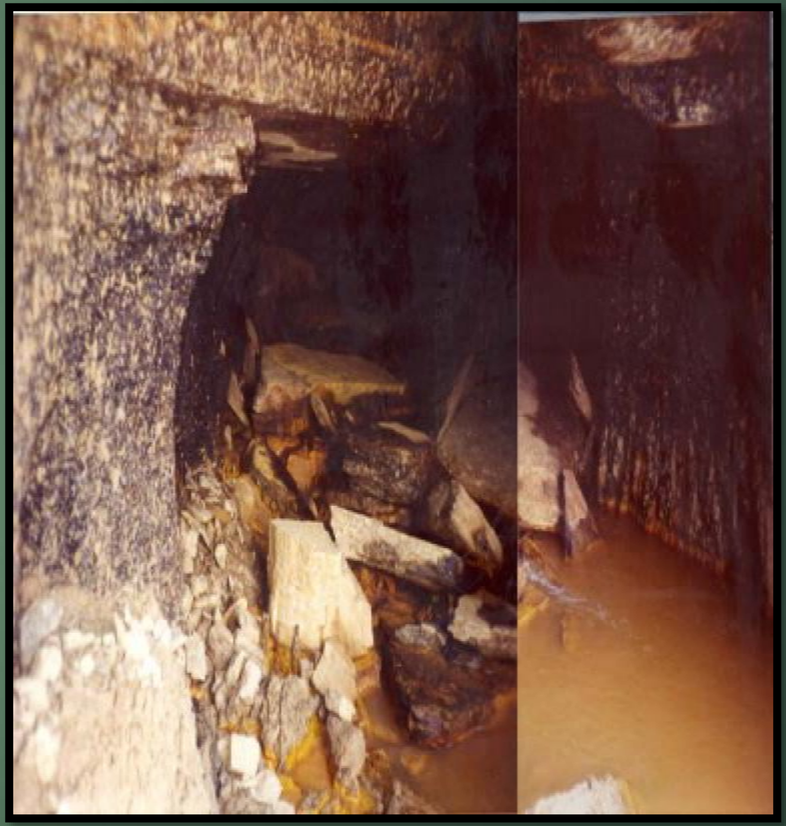


Barrier Failure

Wedge-Type Failure



Blowout From Below



Barrier Failure

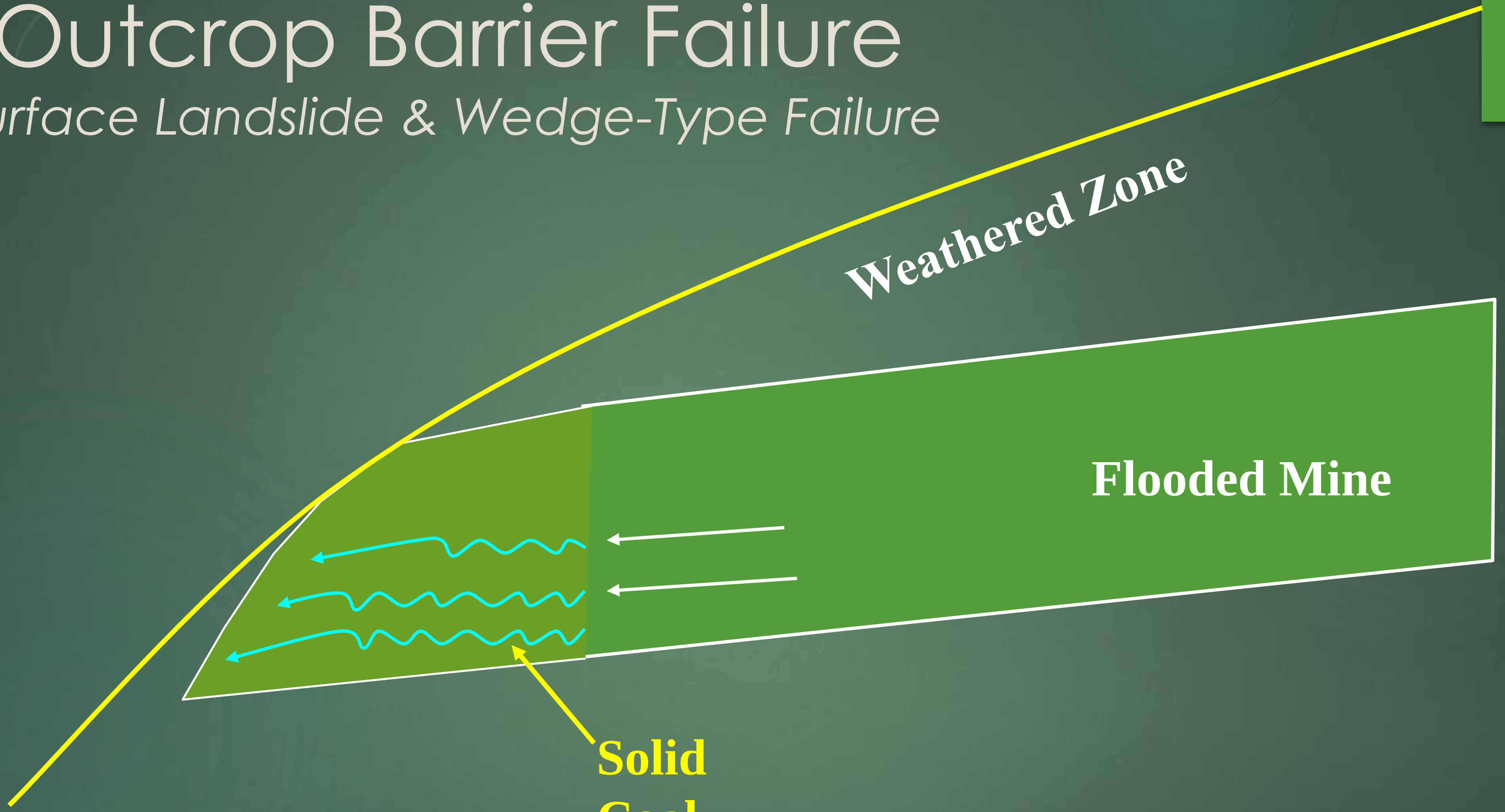
Surface Landslides

- 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

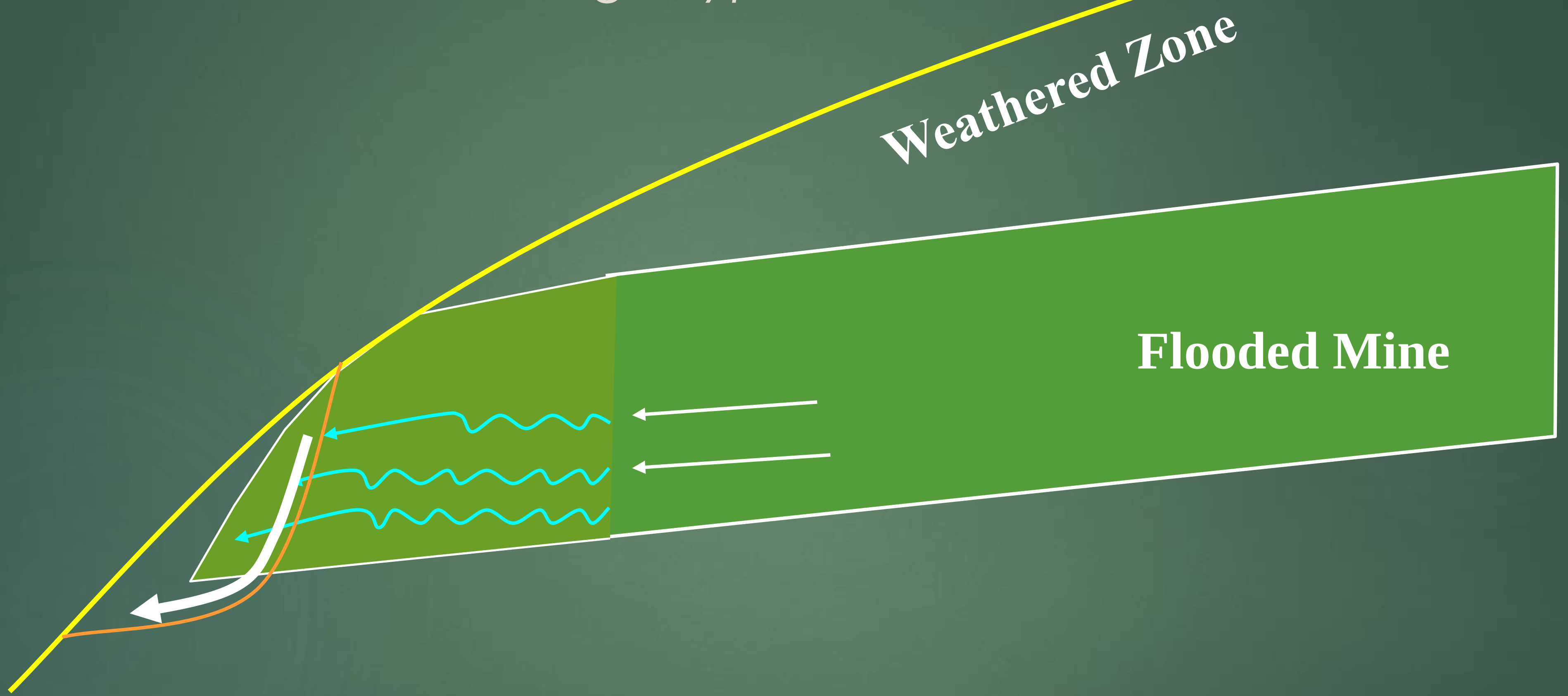
Outcrop Barrier Failure

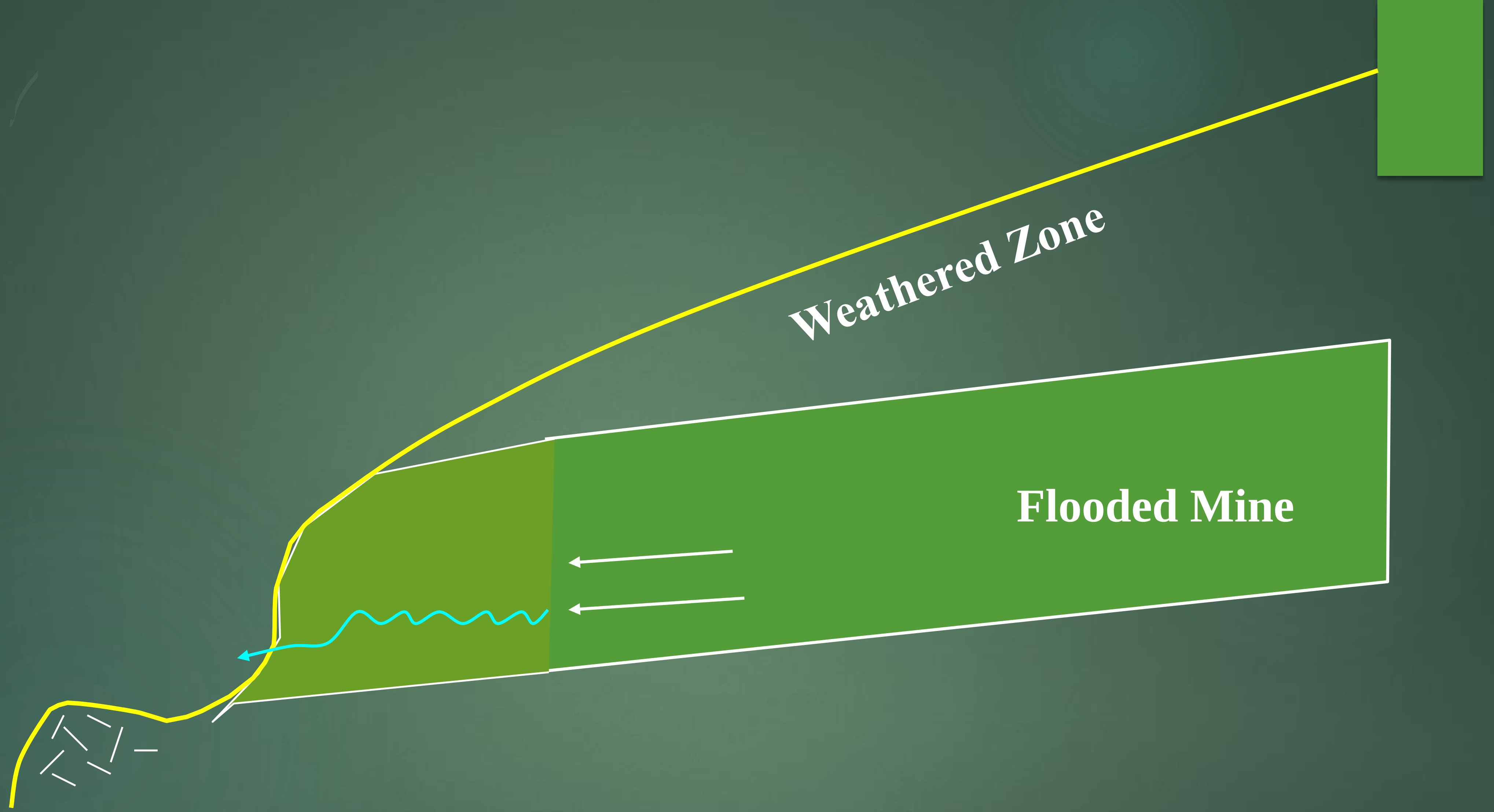
Surface Landslide & Wedge-Type Failure



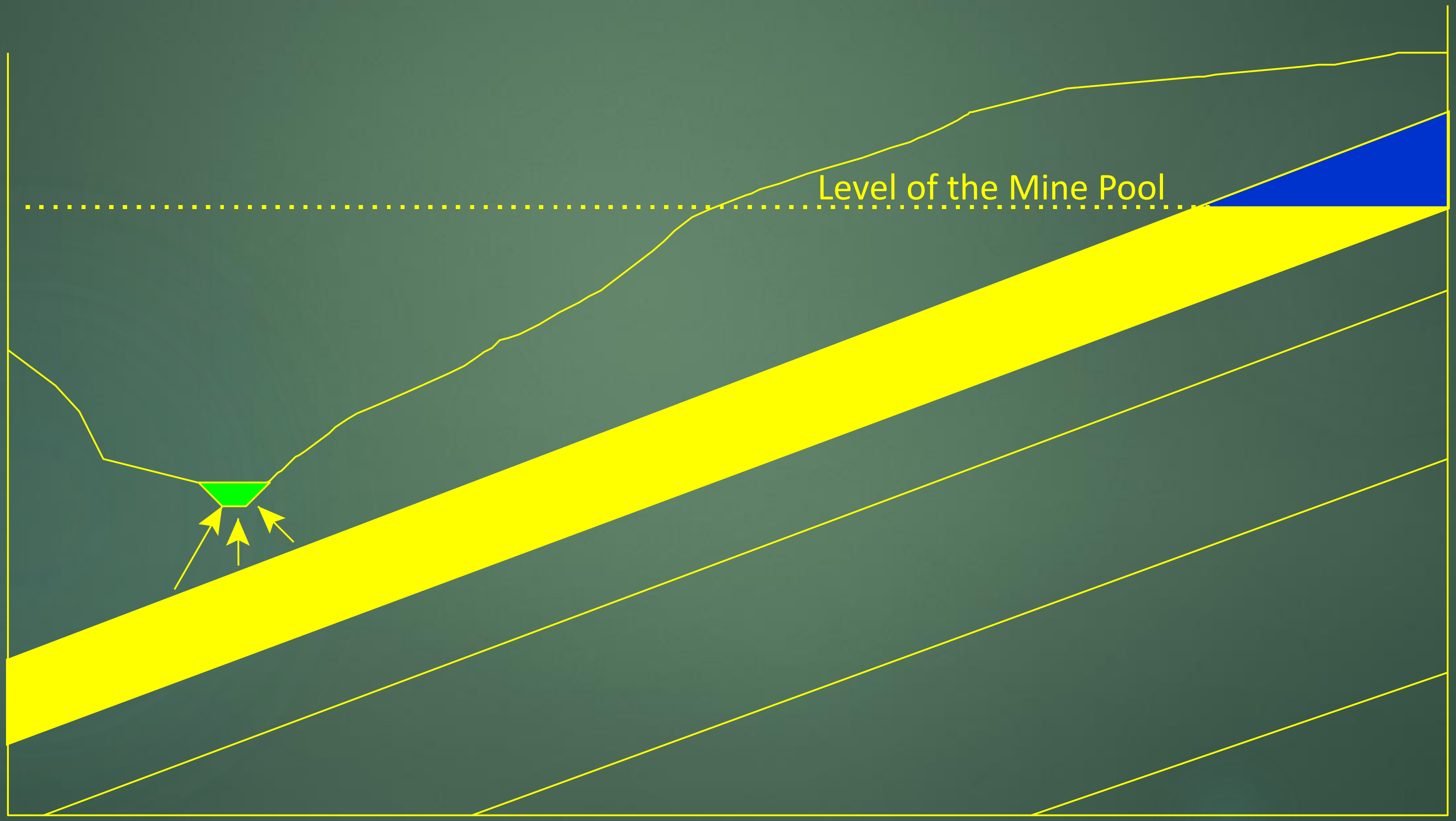
Outcrop Barrier Failure

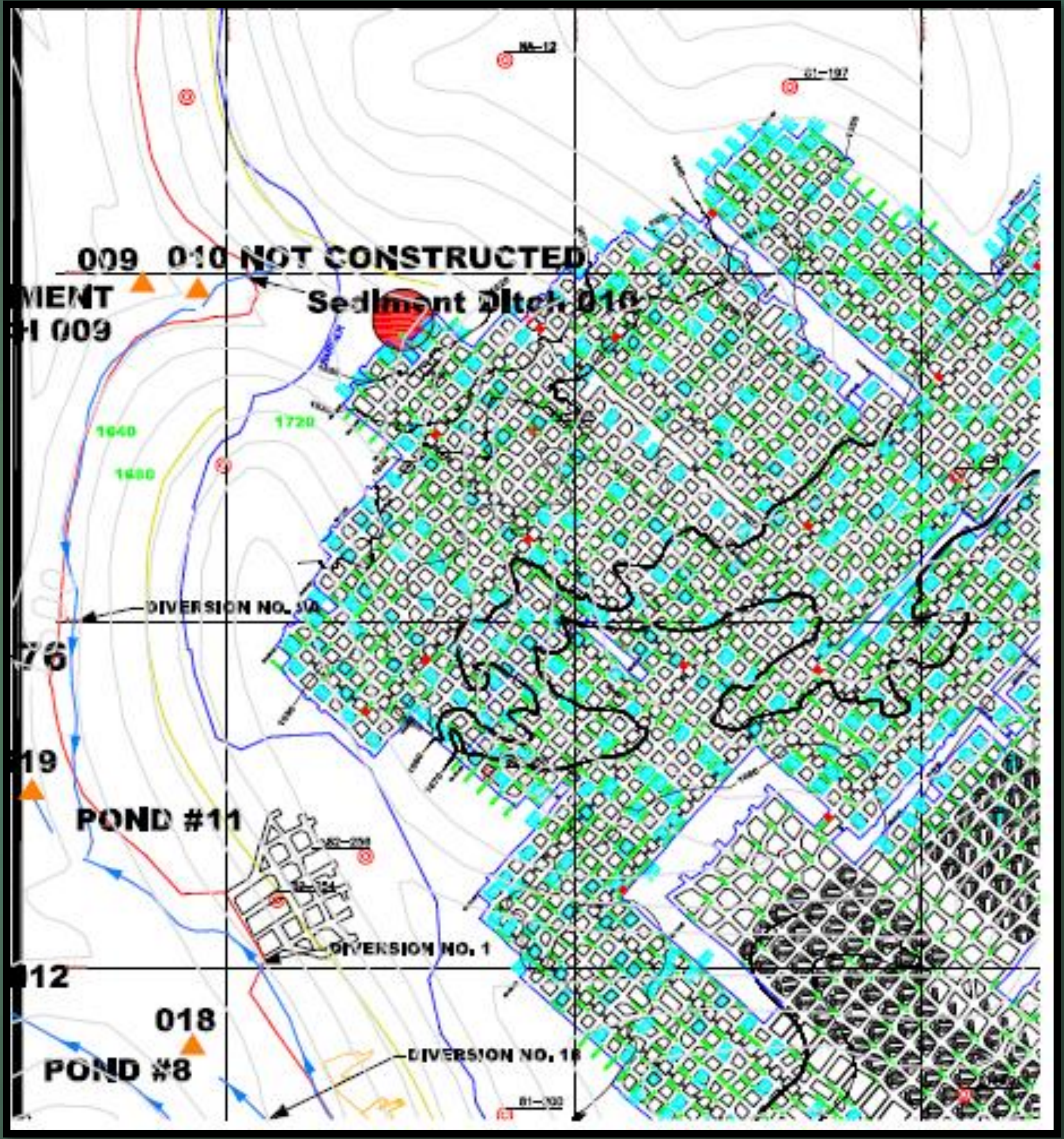
Surface Landslide & Wedge-Type Failure




Weathered Zone
Flooded Mine

Upwelling Mine Waters

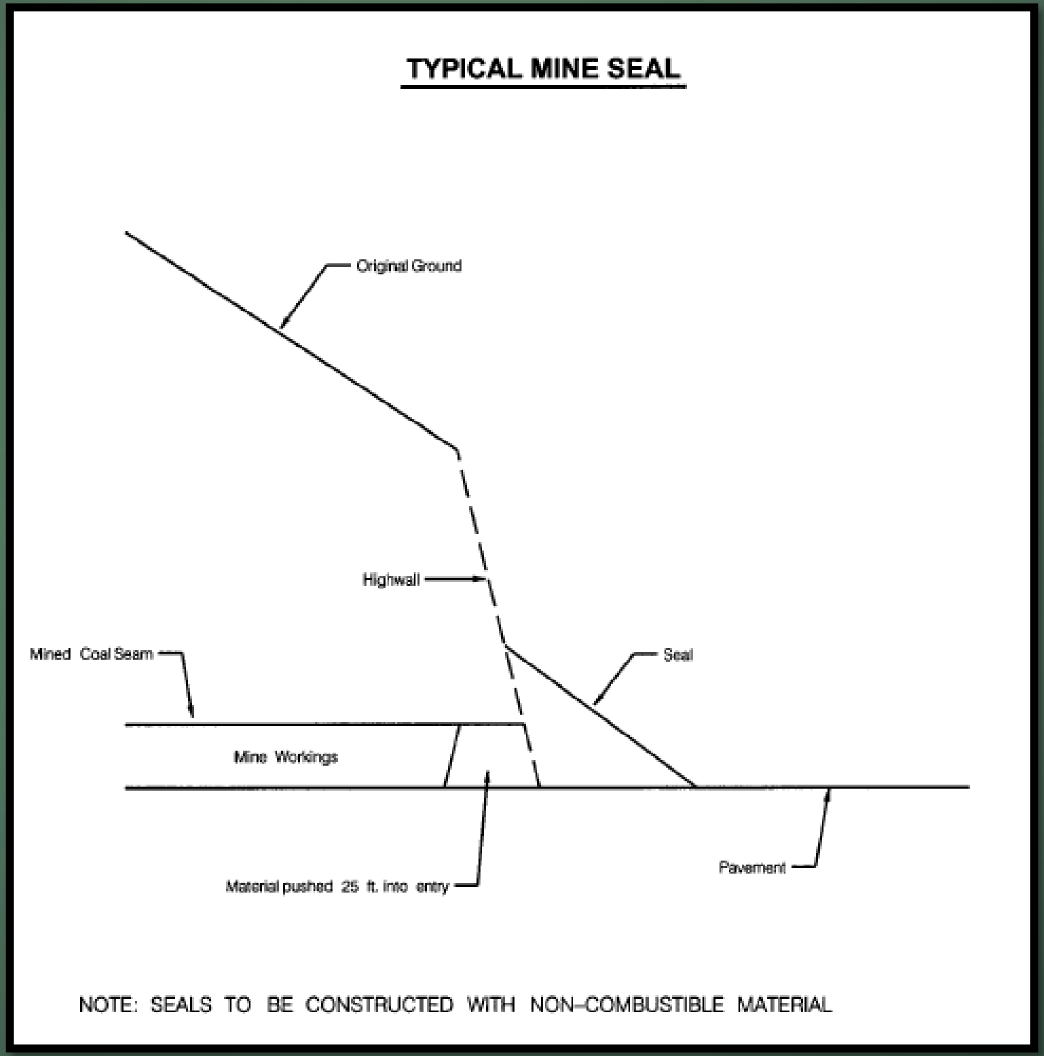



NA-12
81-197
009
010 NOT CONSTRUCTED
MENT
I 009
Sediment Ditch 010
1720
1640
1680
DIVERSION NO.
76
19
POND #11
DIVERSION NO. 1
12
018
POND #8
DIVERSION NO. 1B
81-200

Mine Seals

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

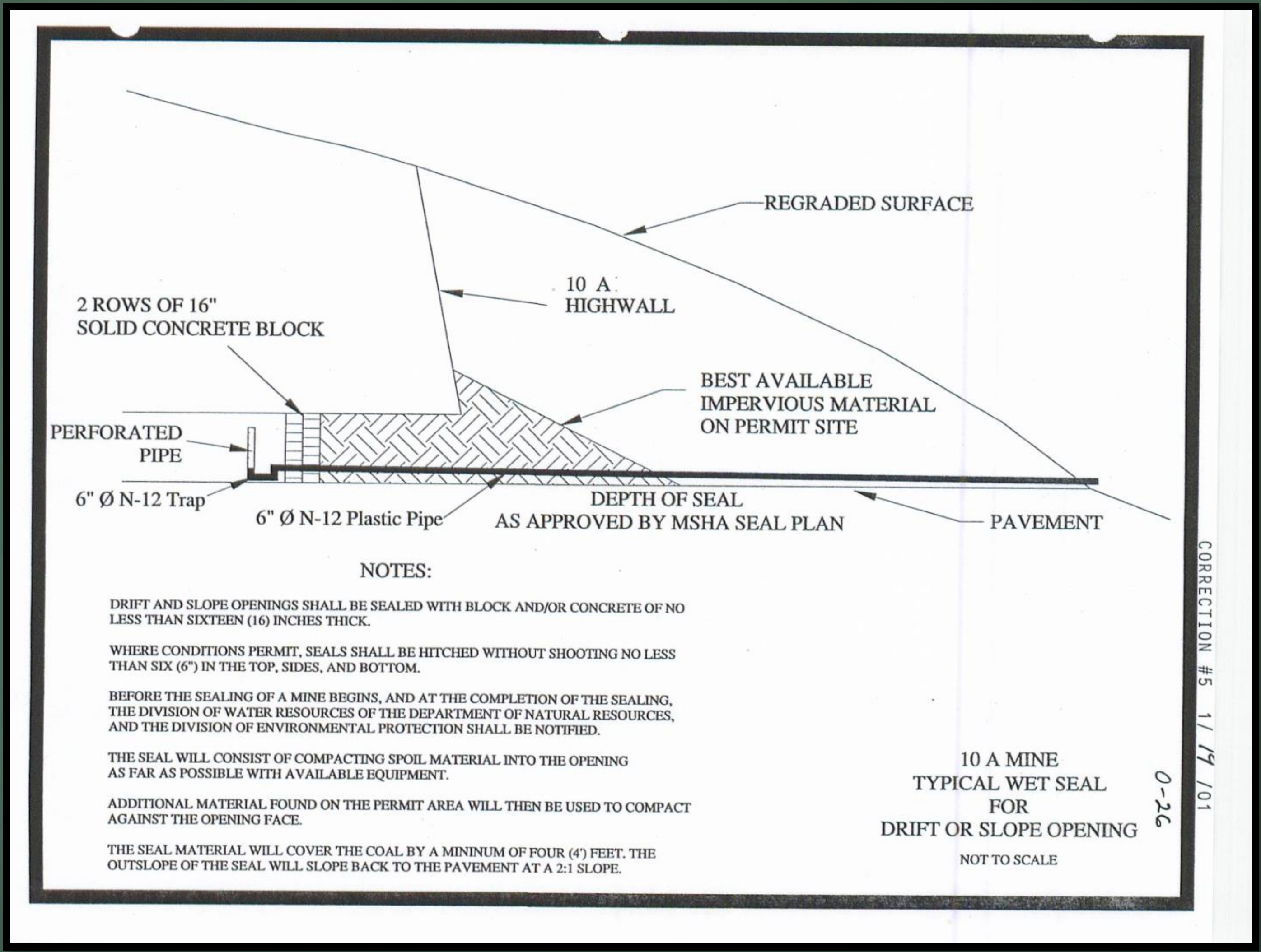
Drift Opening – Dry Seal



TYPICAL MINE SEAL

NOTE: SEALS TO BE CONSTRUCTED WITH NON–COMBUSTIBLE MATERIAL

Drift Opening – Wet Seal



NOTES:

DRIFT AND SLOPE OPENINGS SHALL BE SEALED 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.

BEFORE THE SEALING OF A MINE BEGINS, AND AT THE COMPLETION OF THE SEALING, THE DIVISION OF WATER RESOURCES OF THE DEPARTMENT OF NATURAL RESOURCES, AND THE DIVISION OF ENVIRONMENTAL PROTECTION SHALL BE NOTIFIED.

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 MININUM OF FOUR (4') FEET. THE OUTSLOPE OF THE SEAL WILL SLOPE BACK TO THE PAVEMENT AT A 2:1 SLOPE.

10 A MINE
TYPICAL WET SEAL
FOR
DRIFT OR SLOPE OPENING

NOT TO SCALE

CORRECTION #5 1/19/01

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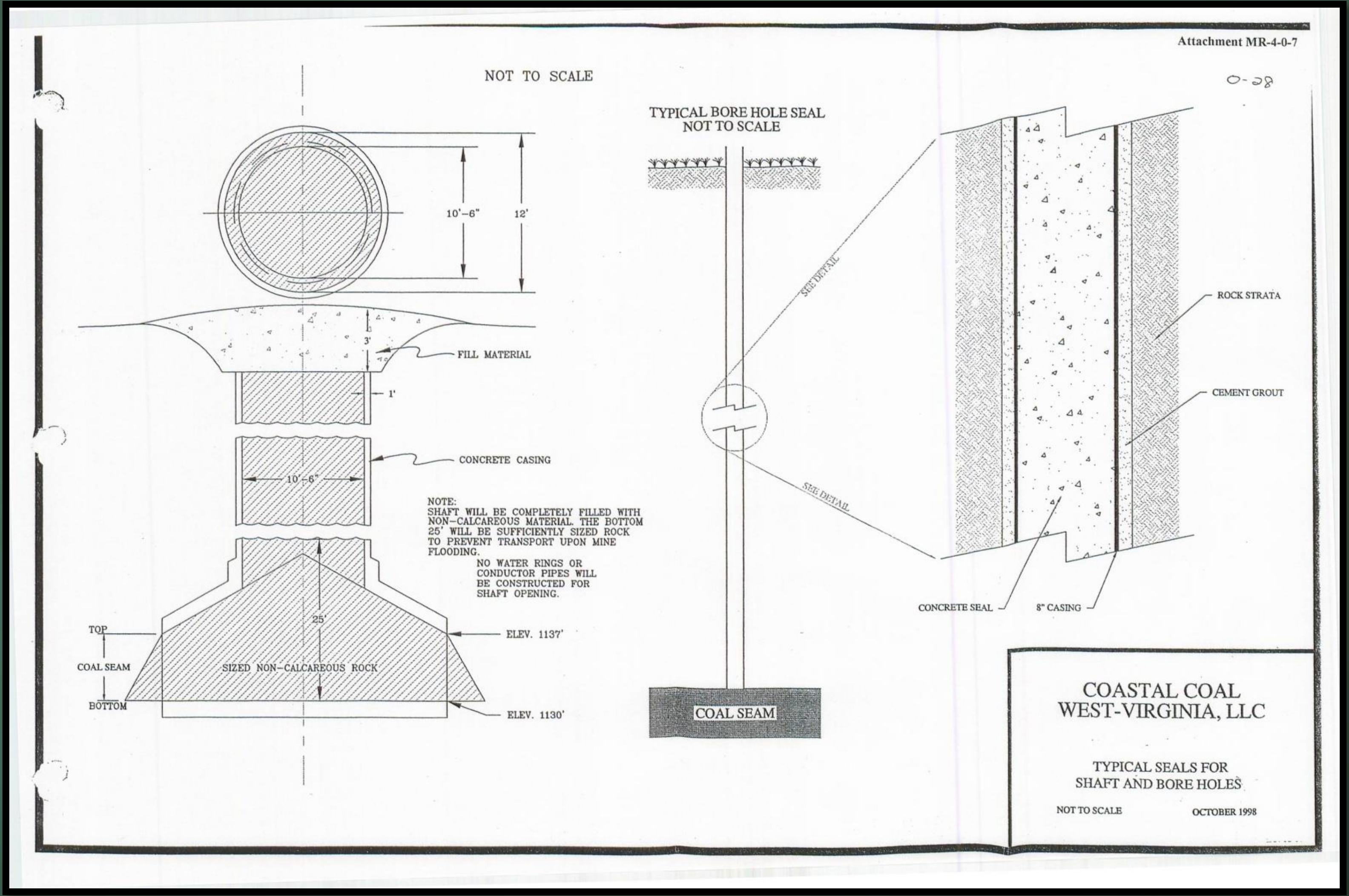
Shaft and Borehole Seals



NOTE:
SHAFT WILL BE COMPLETELY FILLED WITH NON–CALCAREOUS MATERIAL. THE BOTTOM 25' WILL BE SUFFICIENTLY SIZED ROCK TO PREVENT TRANSPORT UPON MINE FLOODING.

NO WATER RINGS OR CONDUCTOR PIPES WILL BE CONSTRUCTED FOR SHAFT OPENING.

COASTAL COAL
WEST-VIRGINIA, LLC

TYPICAL SEALS FOR
SHAFT AND BORE HOLES

NOT TO SCALE
OCTOBER 1998

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

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

Post-Closure Mine Pool Development

Surface Infiltration – Range of Reported Recharge Rates

Summary

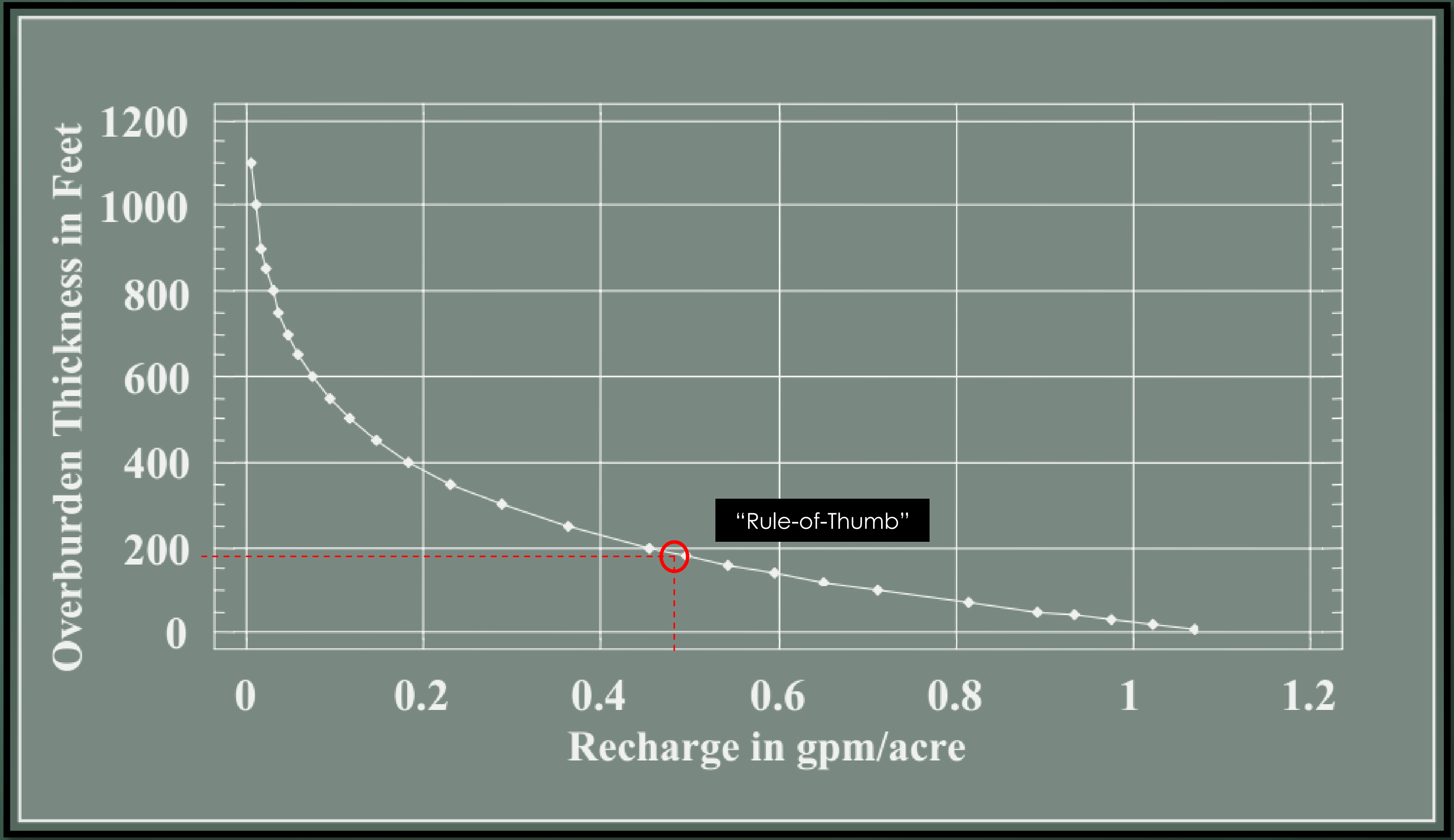
Range of reported values
0.01 to 2.92 gpm/acre
Mean = 0.59 gpm/acre

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



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)

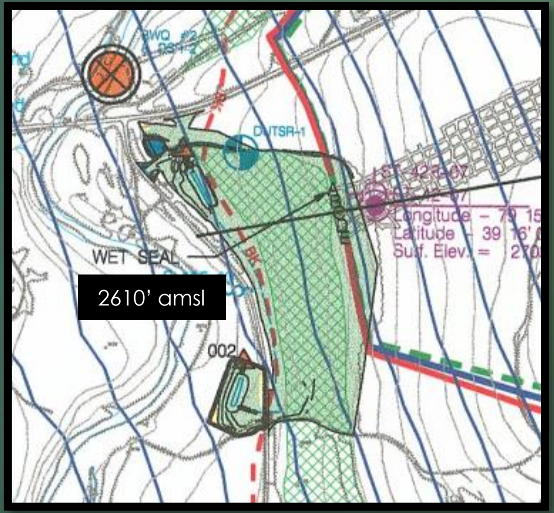
Post-Closure Mine Pool Development

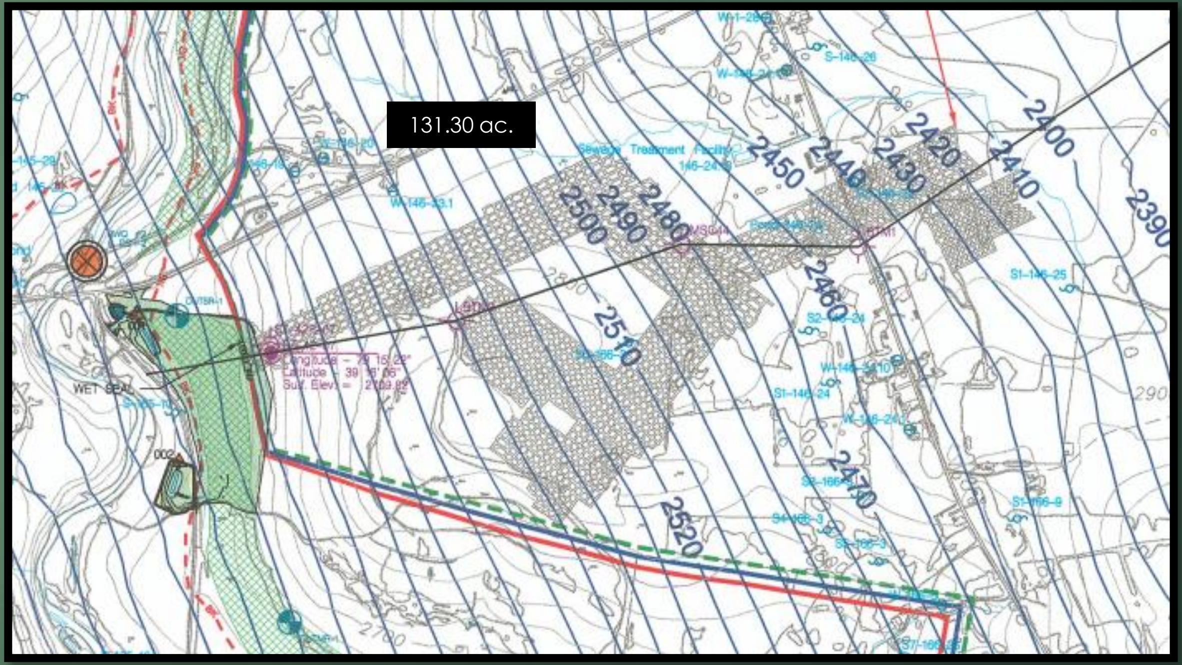
Surface Infiltration – Time to Total Inundation Example (1)

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

$$V_c = (A * (M/A)) * b,$$

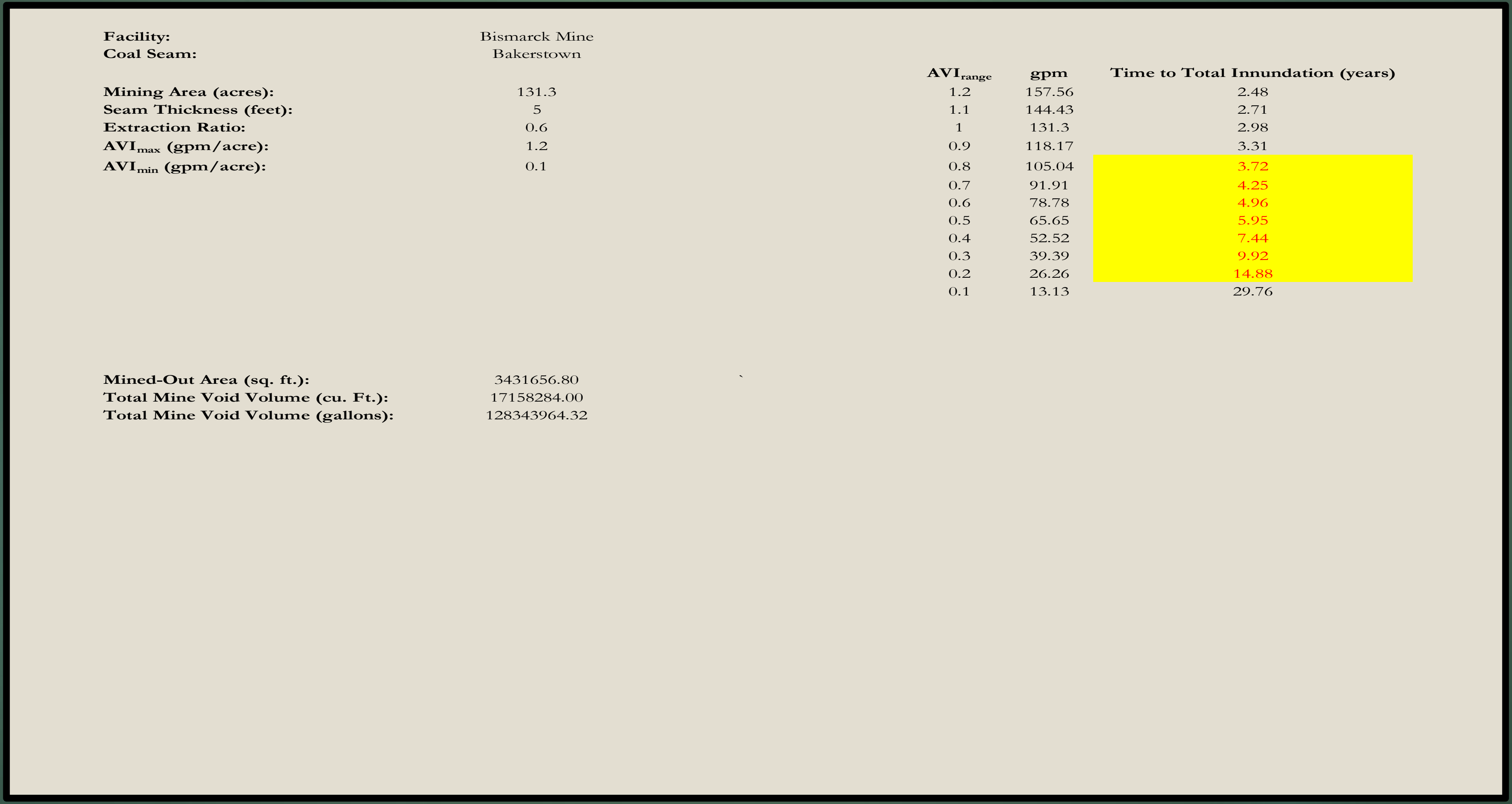
where, V_c = Mined Coal Volume, M = Mined Acreage, b = Seam Thickness, M/A = Extraction Ratio


2610' amsl


131.30 ac.

Post-Closure Mine Pool Development

Surface Infiltration – Time to Total Inundation Example (1)



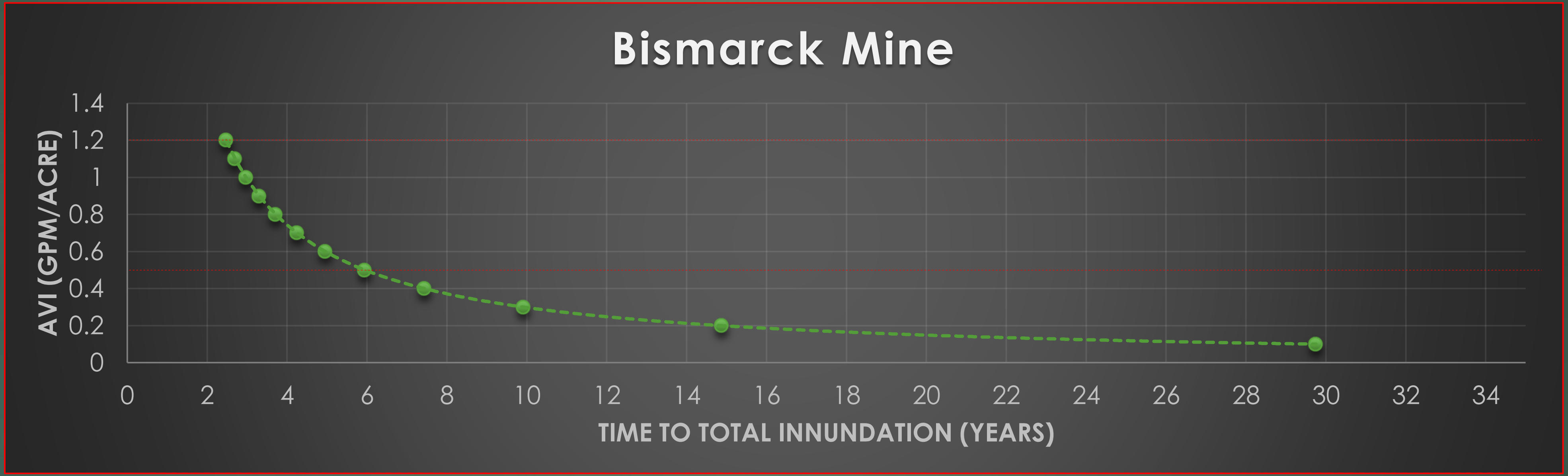
Facility:	Bismarck Mine
Coal Seam:	Bakerstown
Mining Area (acres):	131.3
Seam Thickness (feet):	5
Extraction Ratio:	0.6
AVI_{max} (gpm/acre):	1.2
AVI_{min} (gpm/acre):	0.1

AVI_{range}	**gpm**	**Time to Total Innundation (years)**
1.2	157.56	2.48
1.1	144.43	2.71
1	131.3	2.98
0.9	118.17	3.31
0.8	105.04	3.72
0.7	91.91	4.25
0.6	78.78	4.96
0.5	65.65	5.95
0.4	52.52	7.44
0.3	39.39	9.92
0.2	26.26	14.88
0.1	13.13	29.76

Mined-Out Area (sq. ft.):	3431656.80
Total Mine Void Volume (cu. Ft.):	17158284.00
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.

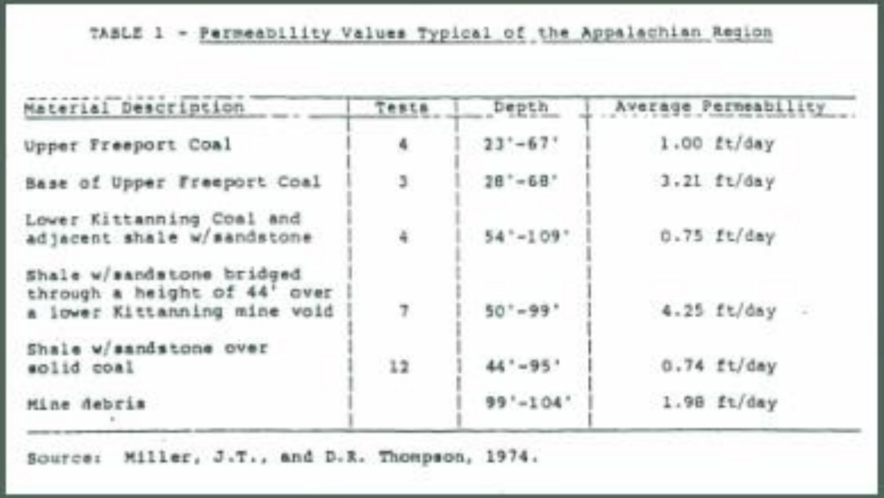


TABLE 1 - Permeability Values Typical of the Appalachian Region

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.

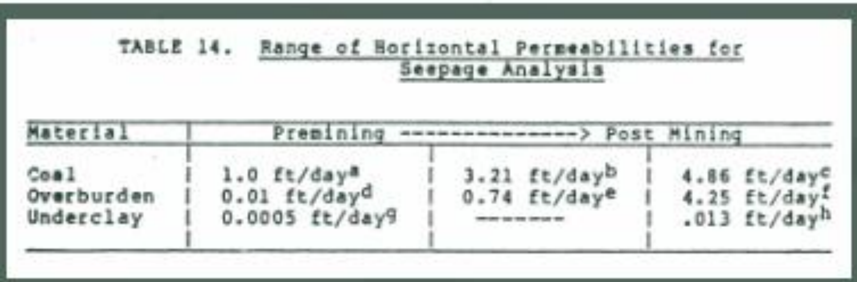


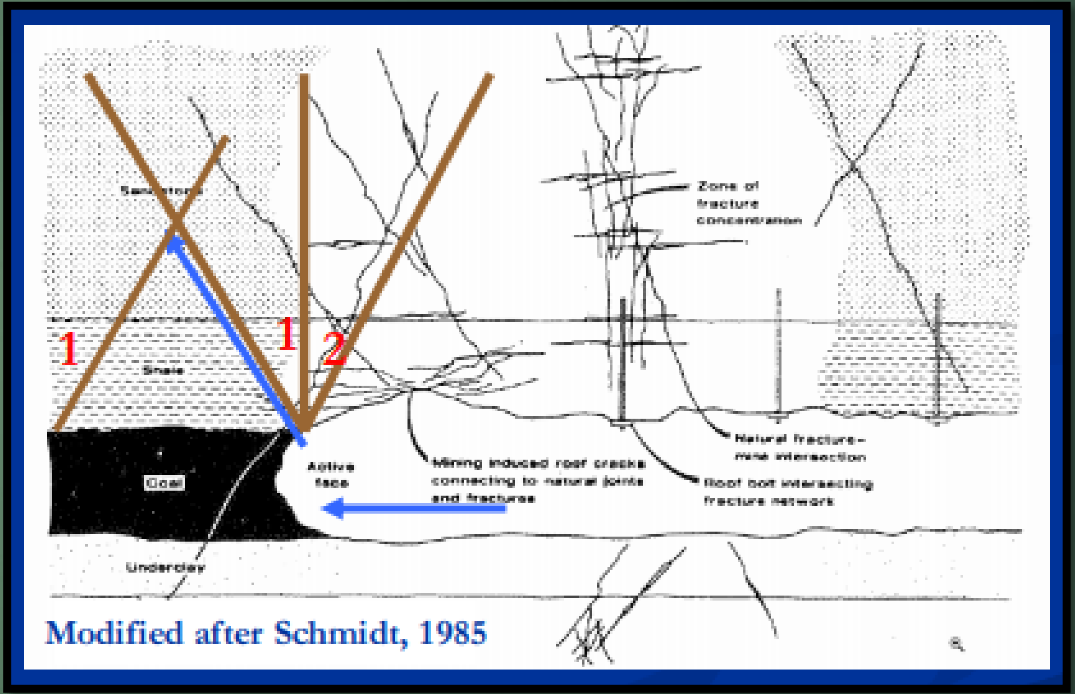
TABLE 14. Range of Horizontal Permeabilities for Seepage Analysis

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]

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

Darcy’s Law

In modern format, using a particular sign convention, Darcy's law is usually written as:

$Q = -KA\, dh/dl$

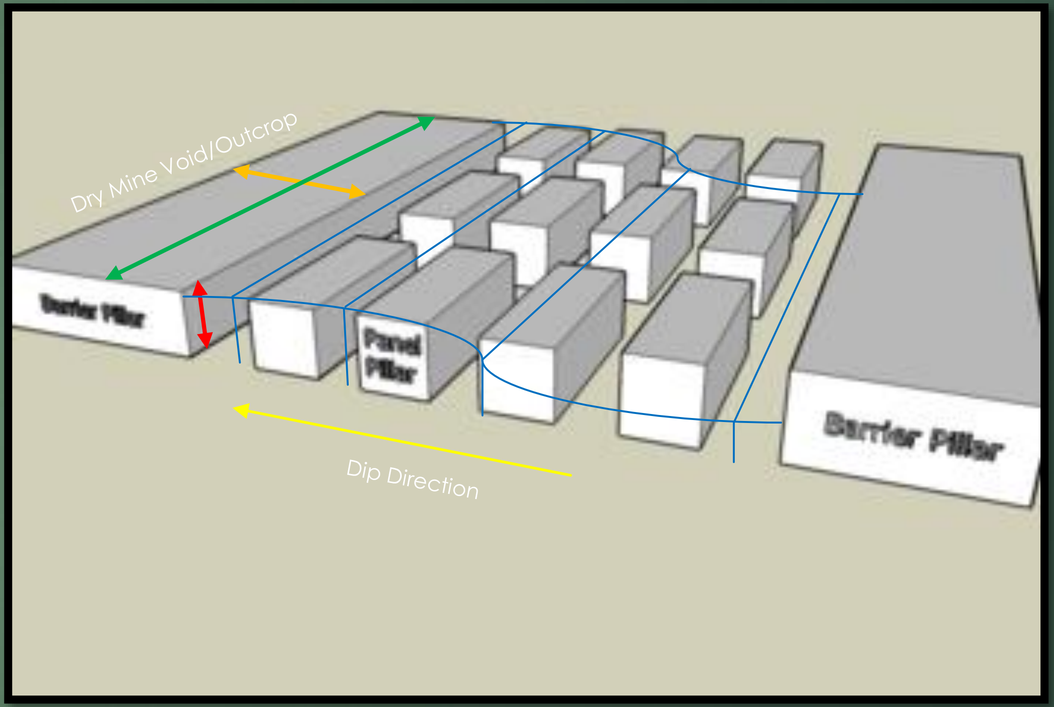
where:

Q = rate of water flow (volume per time)

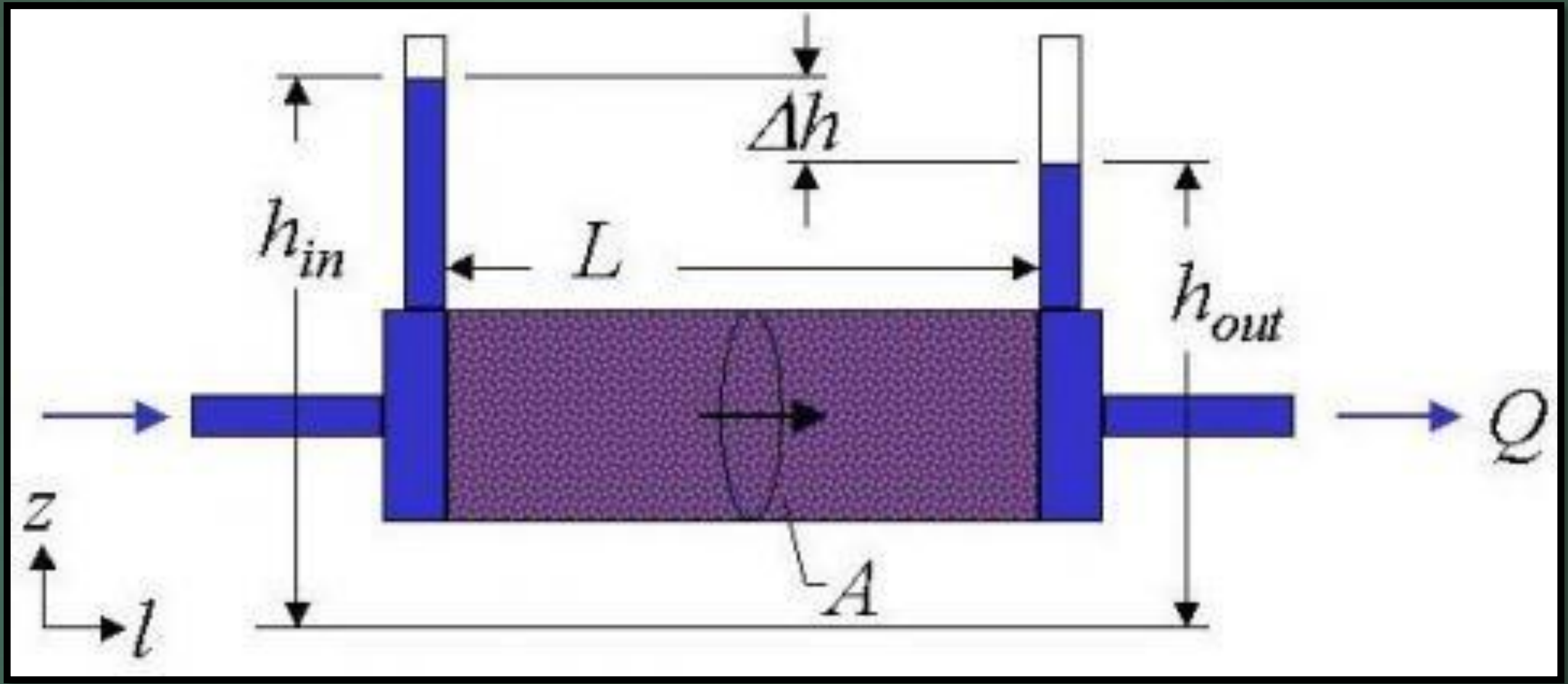
K = hydraulic conductivity

A = column cross sectional area

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)

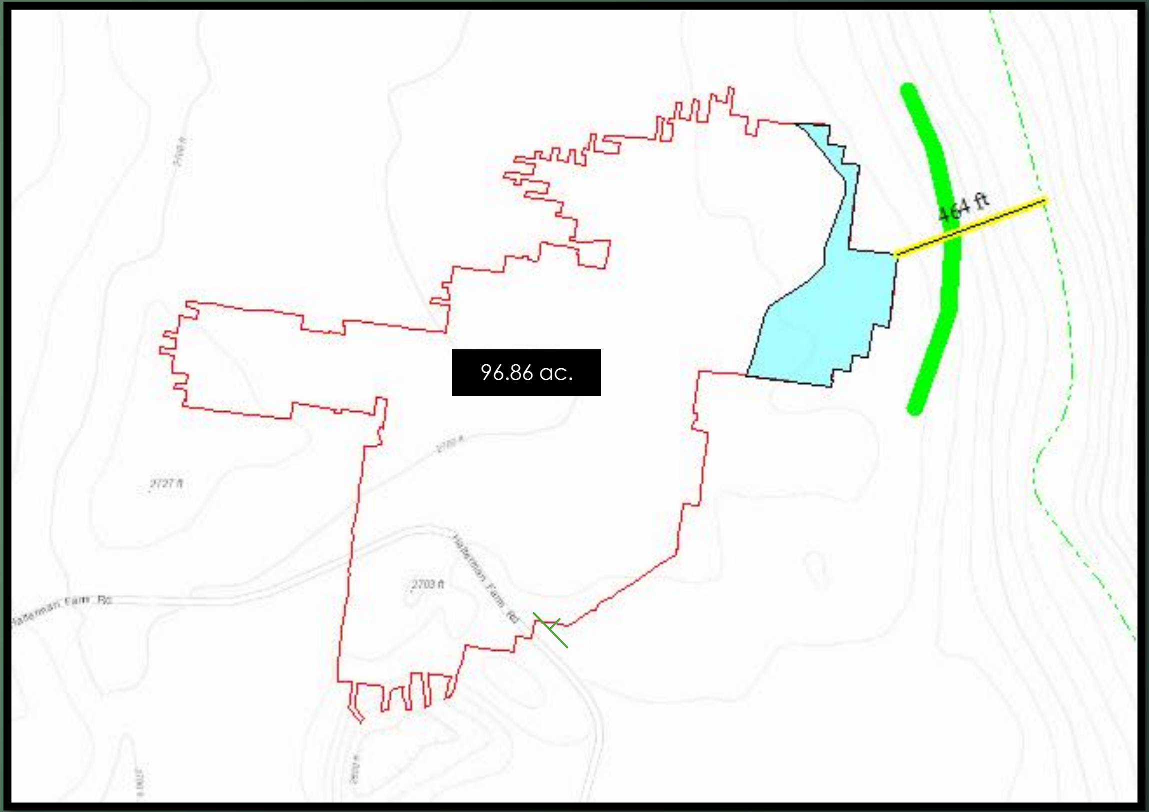
-------- BAK Outcrop

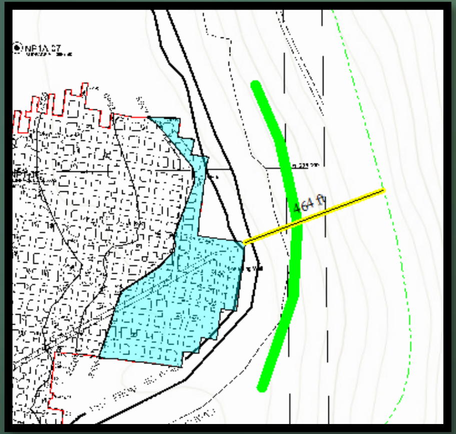
Mine Pool – 2555' amsl:

Barrier Segment No. 1:

$L_1 = 991.90'$

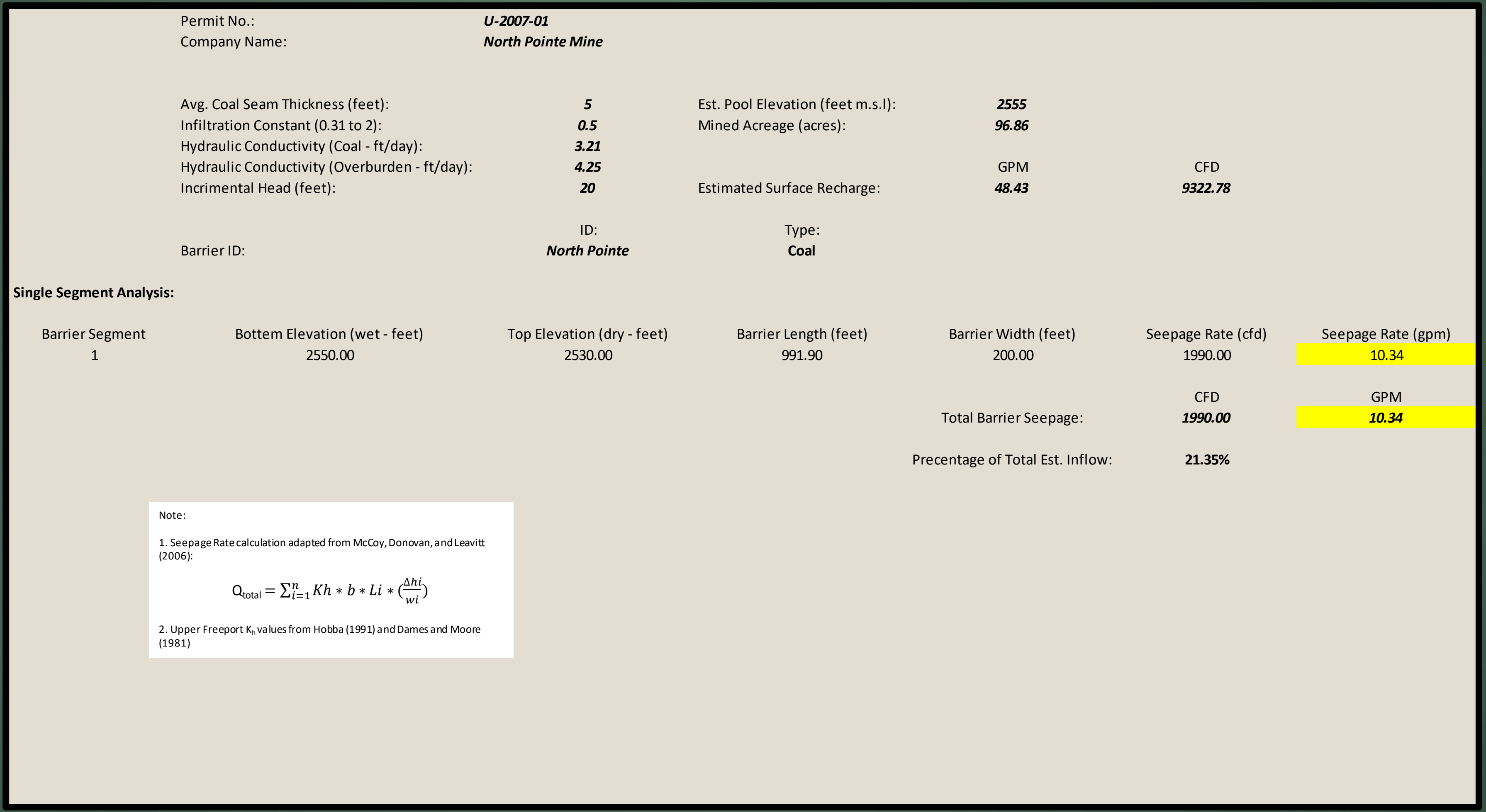
$w_1 = 200'$ (Highwall Mining)





Post-Closure Mine Pool Development

Barrier Permeability



Permit No.: *U-2007-01*
Company Name: ***North Pointe Mine***

Avg. Coal Seam Thickness (feet):	***5***	Est. Pool Elevation (feet m.s.l):	***2555***	
Infiltration Constant (0.31 to 2):	***0.5***	Mined Acreage (acres):	***96.86***	
Hydraulic Conductivity (Coal - ft/day):	***3.21***			
Hydraulic Conductivity (Overburden - ft/day):	***4.25***		GPM	CFD
Incremental Head (feet):	***20***	Estimated Surface Recharge:	***48.43***	***9322.78***

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

Single Segment Analysis:

Barrier Segment	Bottem Elevation (wet - feet)	Top Elevation (dry - feet)	Barrier Length (feet)	Barrier Width (feet)	Seepage Rate (cfd)	Seepage Rate (gpm)
1	2550.00	2530.00	991.90	200.00	1990.00	10.34

	CFD	GPM
Total Barrier Seepage:	***1990.00***	***10.34***
Precentage of Total Est. Inflow:	**21.35%**	

Note:

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

$$Q_{total} = \sum_{i=1}^{n} Kh * b * Li * (\frac{\Delta hi}{wi})$$

2. Upper Freeport K_h values from Hobba (1991) and Dames and Moore (1981)

Post-Closure Mine Pool Development

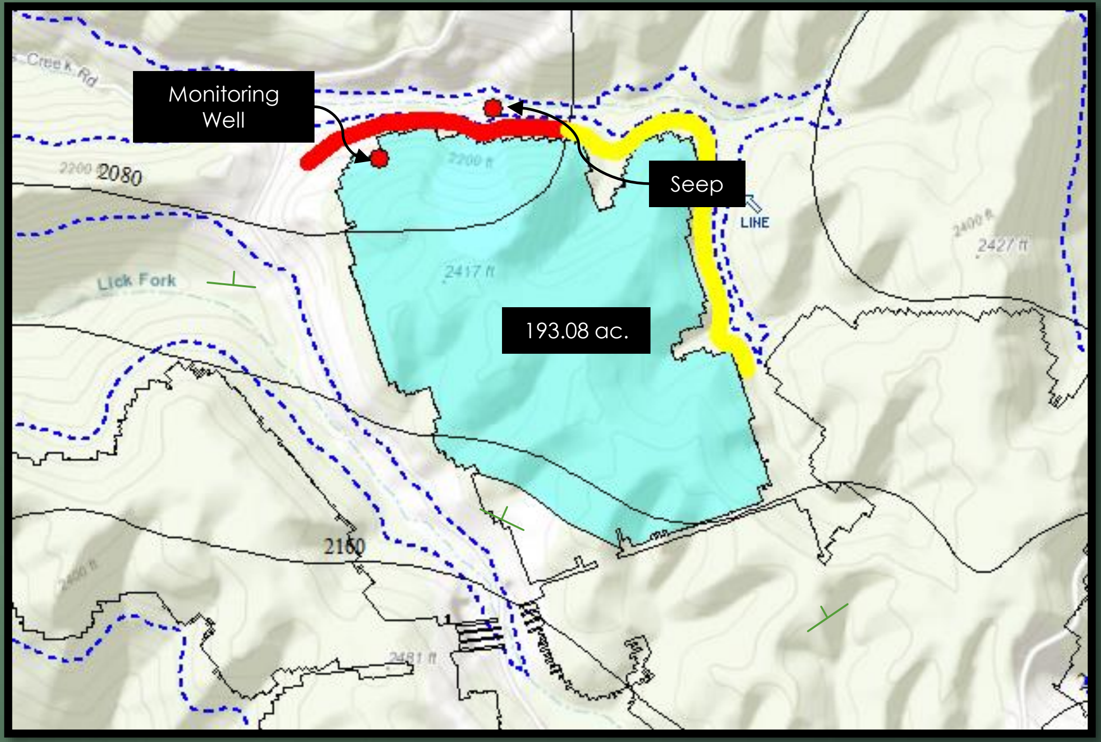
Barrier Permeability – Outcrop Barrier Seepage Example (2)

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

Mine Pool – 2120’ amsl:

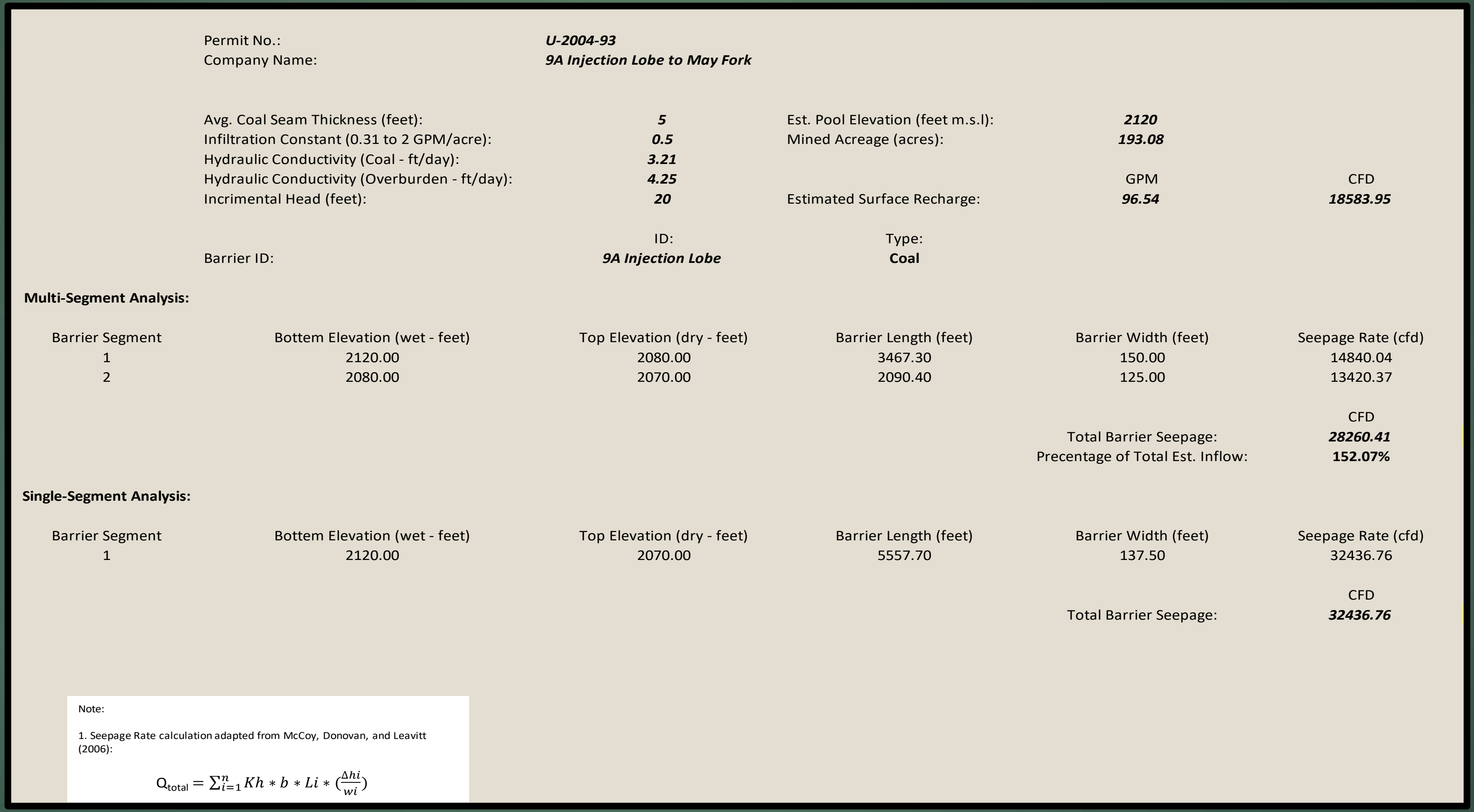
Barrier Segment No. 1:
L_1 = 3467.30’
w_1 = 150’

Barrier Segment No. 2:
L_2 = 2090.4’
w_2 = 125’



Post-Closure Mine Pool Development

Barrier Permeability



Permit No.: ***U-2004-93***
Company Name: ***9A Injection Lobe to May Fork***

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***
Incrimental Head (feet): ***20***

Est. Pool Elevation (feet m.s.l): ***2120***
Mined Acreage (acres): ***193.08***

	GPM	CFD
Estimated Surface Recharge:	***96.54***	***18583.95***

	ID:	Type:
Barrier ID:	***9A Injection Lobe***	**Coal**

Multi-Segment Analysis:

Barrier Segment	Bottom Elevation (wet - feet)	Top Elevation (dry - feet)	Barrier Length (feet)	Barrier Width (feet)	Seepage Rate (cfd)
1	2120.00	2080.00	3467.30	150.00	14840.04
2	2080.00	2070.00	2090.40	125.00	13420.37

	CFD
Total Barrier Seepage:	***28260.41***
Precentage of Total Est. Inflow:	**152.07%**

Single-Segment Analysis:

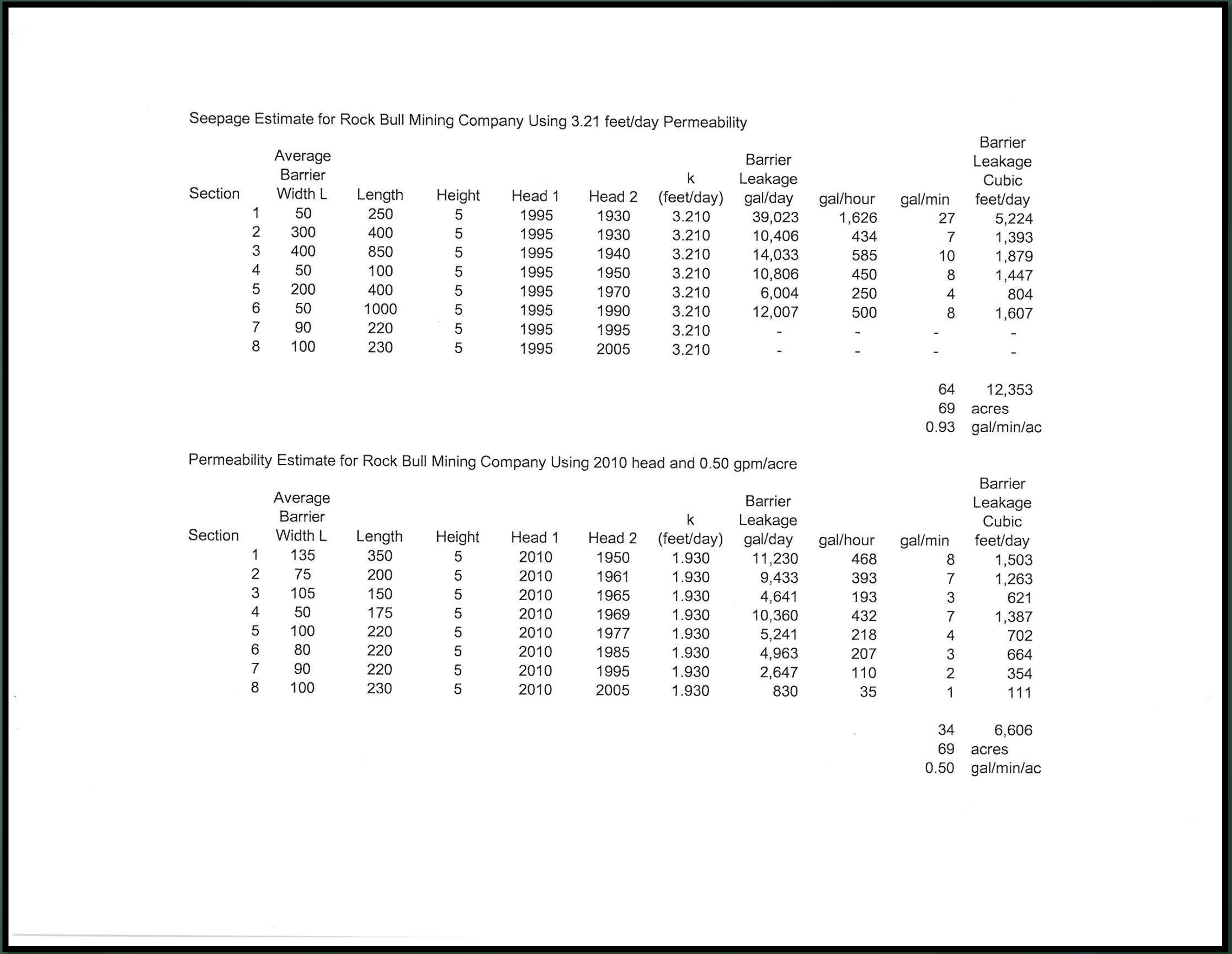
Barrier Segment	Bottom Elevation (wet - feet)	Top Elevation (dry - feet)	Barrier Length (feet)	Barrier Width (feet)	Seepage Rate (cfd)
1	2120.00	2070.00	5557.70	137.50	32436.76

	CFD
Total Barrier Seepage:	***32436.76***

Note:

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

$$Q_{total} = \sum_{i=1}^{n} Kh * b * Li * \left(\frac{\Delta hi}{wi}\right)$$



Seepage Estimate for Rock Bull Mining Company Using 3.21 feet/day Permeability

Section	Average Barrier Width L	Length	Height	Head 1	Head 2	k (feet/day)	Barrier Leakage gal/day	gal/hour	gal/min	Barrier Leakage Cubic feet/day
1	50	250	5	1995	1930	3.210	39,023	1,626	27	5,224
2	300	400	5	1995	1930	3.210	10,406	434	7	1,393
3	400	850	5	1995	1940	3.210	14,033	585	10	1,879
4	50	100	5	1995	1950	3.210	10,806	450	8	1,447
5	200	400	5	1995	1970	3.210	6,004	250	4	804
6	50	1000	5	1995	1990	3.210	12,007	500	8	1,607
7	90	220	5	1995	1995	3.210	-	-	-	-
8	100	230	5	1995	2005	3.210	-	-	-	-
									64	12,353
									69	acres
									0.93	gal/min/ac

Permeability Estimate for Rock Bull Mining Company Using 2010 head and 0.50 gpm/acre

Section	Average Barrier Width L	Length	Height	Head 1	Head 2	k (feet/day)	Barrier Leakage gal/day	gal/hour	gal/min	Barrier Leakage Cubic feet/day
1	135	350	5	2010	1950	1.930	11,230	468	8	1,503
2	75	200	5	2010	1961	1.930	9,433	393	7	1,263
3	105	150	5	2010	1965	1.930	4,641	193	3	621
4	50	175	5	2010	1969	1.930	10,360	432	7	1,387
5	100	220	5	2010	1977	1.930	5,241	218	4	702
6	80	220	5	2010	1985	1.930	4,963	207	3	664
7	90	220	5	2010	1995	1.930	2,647	110	2	354
8	100	230	5	2010	2005	1.930	830	35	1	111
									34	6,606
									69	acres
									0.50	gal/min/ac

Ventilation Fan