Factors Influencing Water Discharges from Pennsylvania Underground Coal Mine Pools

Anthony Iannacchione, Patrick Himes, Luke Mignogna & Michael Keener

Civil and Environmental Engineering
Swanson School of Engineering
University of Pittsburgh

THANKS TO: PA DEP, OSM, ROSEBUD MINING, AMFIRE

West Virginia Mine Drainage Task Force Symposium

March 25-26, 2014 Morgantown, WV

Overview

- Background
- Research Aim
- Method of Study
- Case Studies
- Examination of Factors
- Preliminary Recommendations

Problem -- Post-mining discharge

- Observable
- Impact on surface waters
  - Quality
  - Quantity

Photo by Brent Means (OSM), discharge near Grove 1 mining operations.

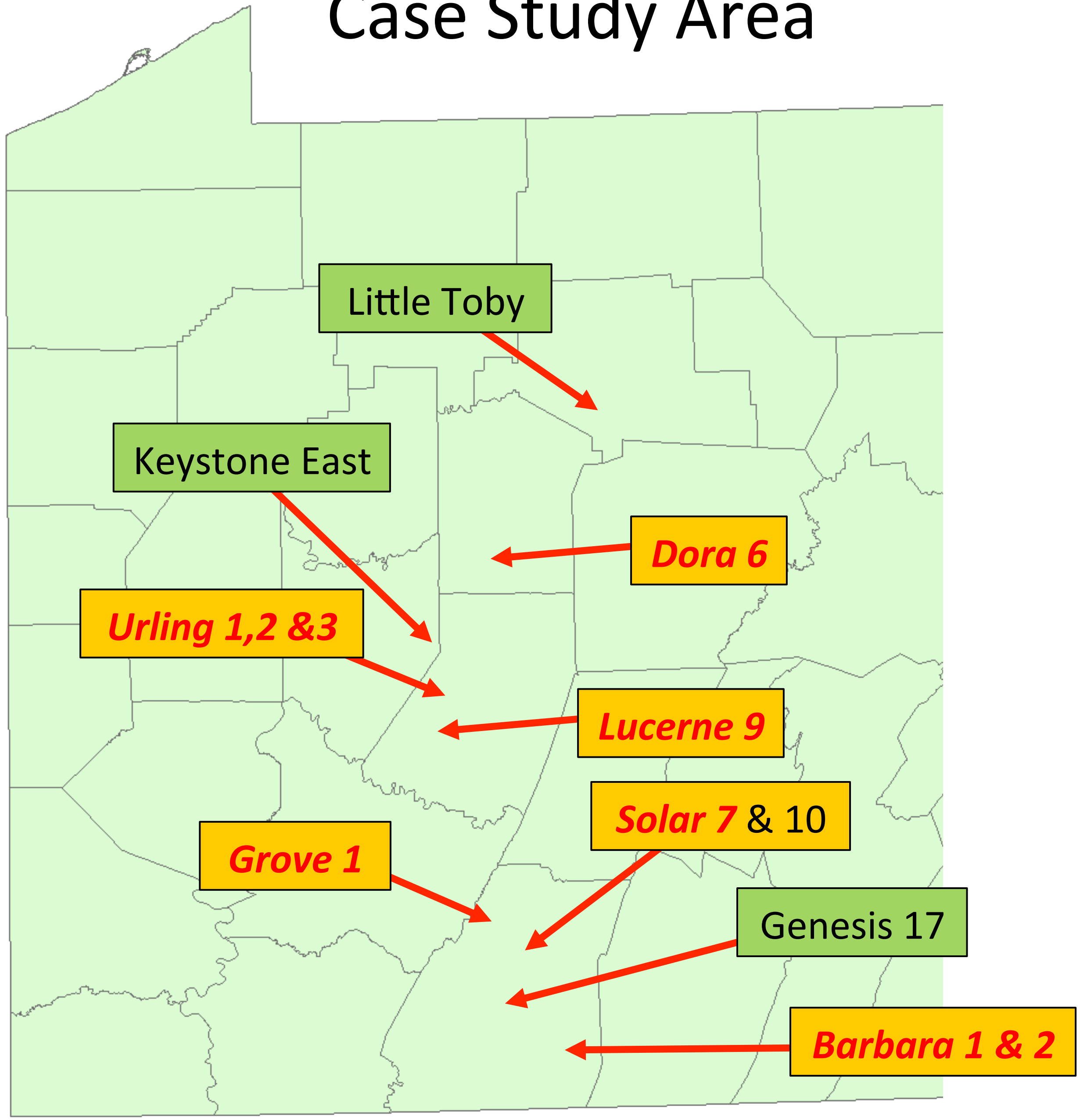
Method of Study

- 6-month mining maps
  - Hundreds of maps, mining methods, survey points
- Data from Companies & PADEP/OSM
  - Permit files, agent observations
  - Core logs, X-sections
  - Piezometers, water wells
- Field Research
  - Verify Locations
  - Measure mine pool
  - Sample mine water
- Data Analysis
  - ArcGIS, structure contours, overburdens
  - MODFlow
- Identify most significant factors
- Make recommendations

Research Aim

- Collect information on successful and unsuccessful designs
- Analyze and report on important conditions at each site
- Determine important factors controlling successful designs
- Where possible, make recommendations based on risk analysis approaches to mitigate future unplanned dis

Case Study Area

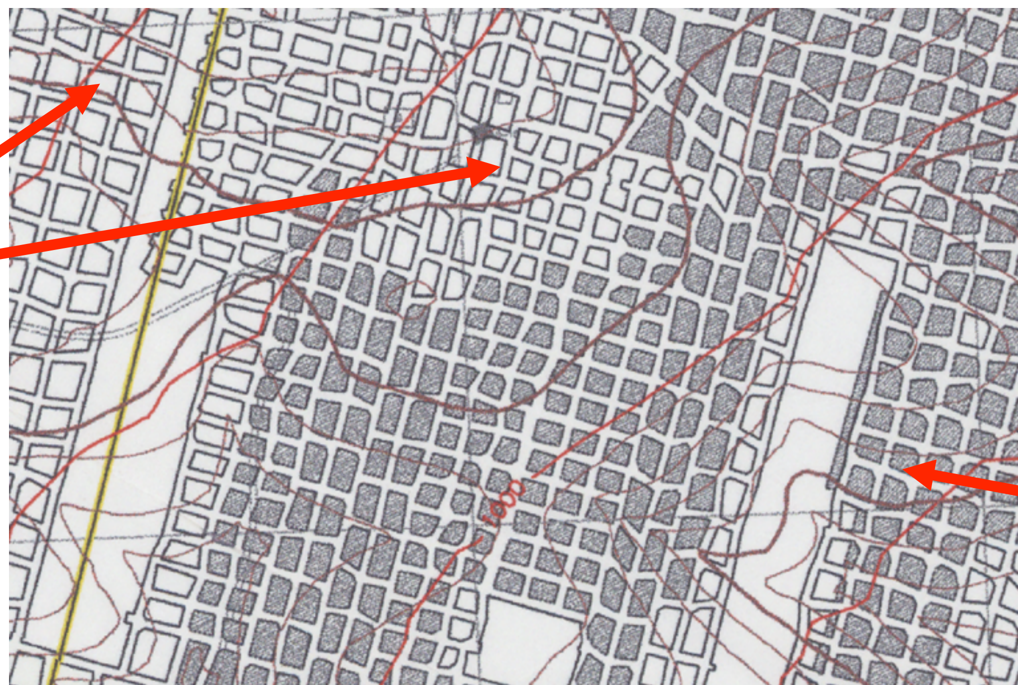


Factors Affecting Barrier Performance

1) Extraction ratio
2) Hydraulic conductivity
3) Hydraulic gradient
4) Geology
5) Location of critical hydraulic barrier
6) Barrier thickness measurement
7) Mine pool elevation w/box cuts
8) Overburden

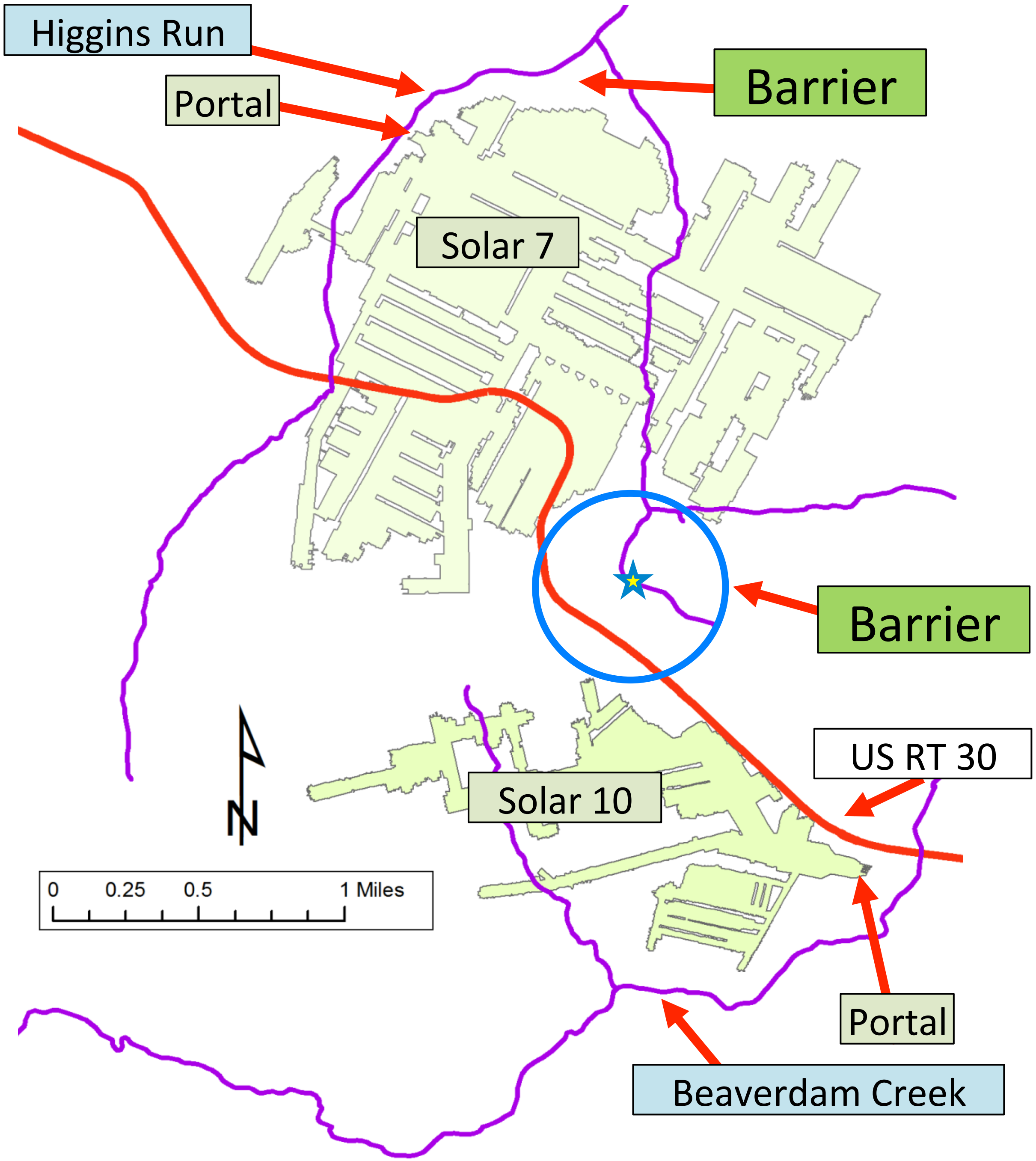
Factors 1 – <u>Extraction Ratio 'e'</u>

- 'e' = ~ 50% (no subsidence)
- Thin pillar = ~ 60 to 70% (development mining only)
- Pillar recovery (full and partial) = > 70%



Various room-and-pillar development mining 'e'

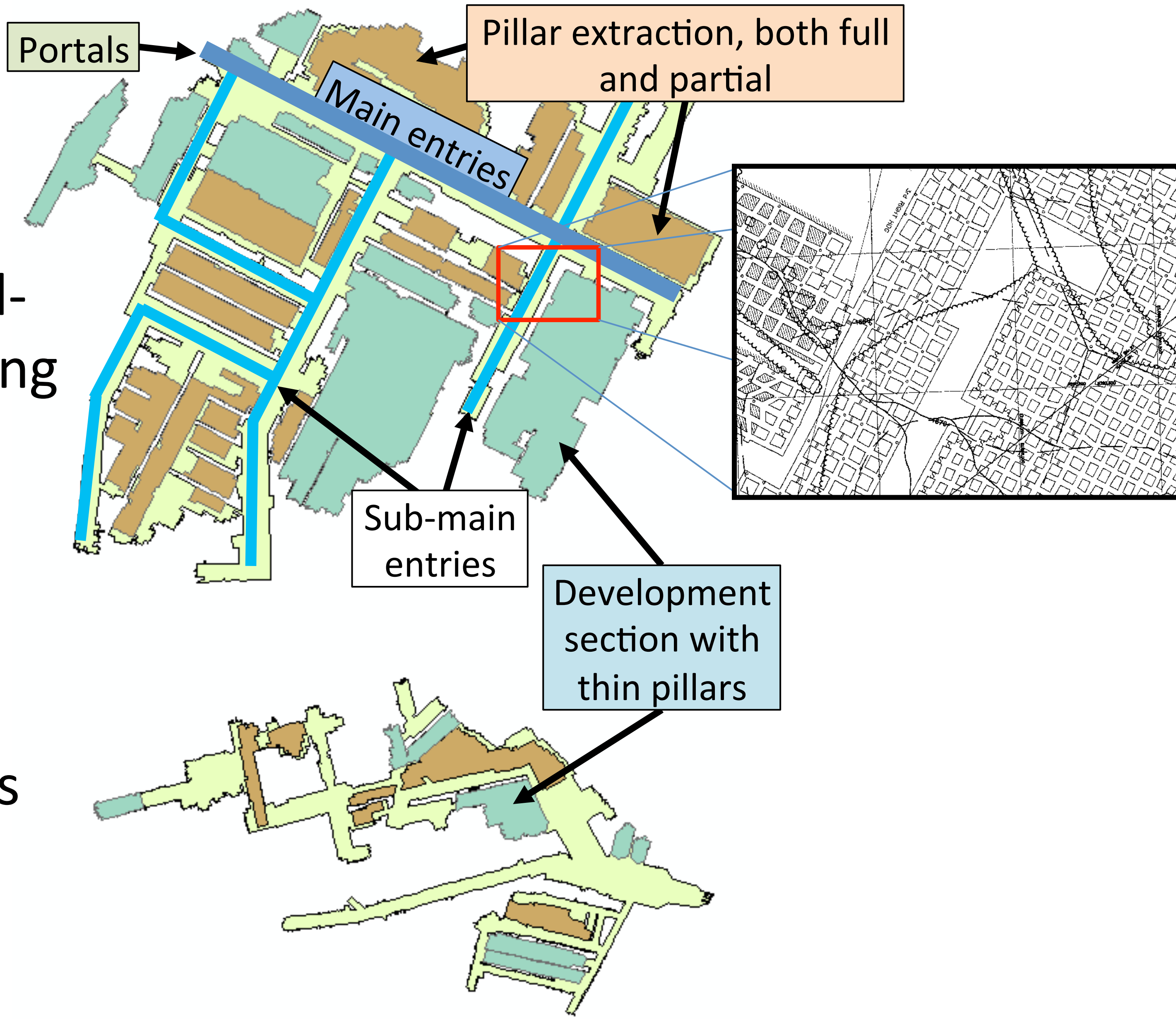
Pillar Recovery



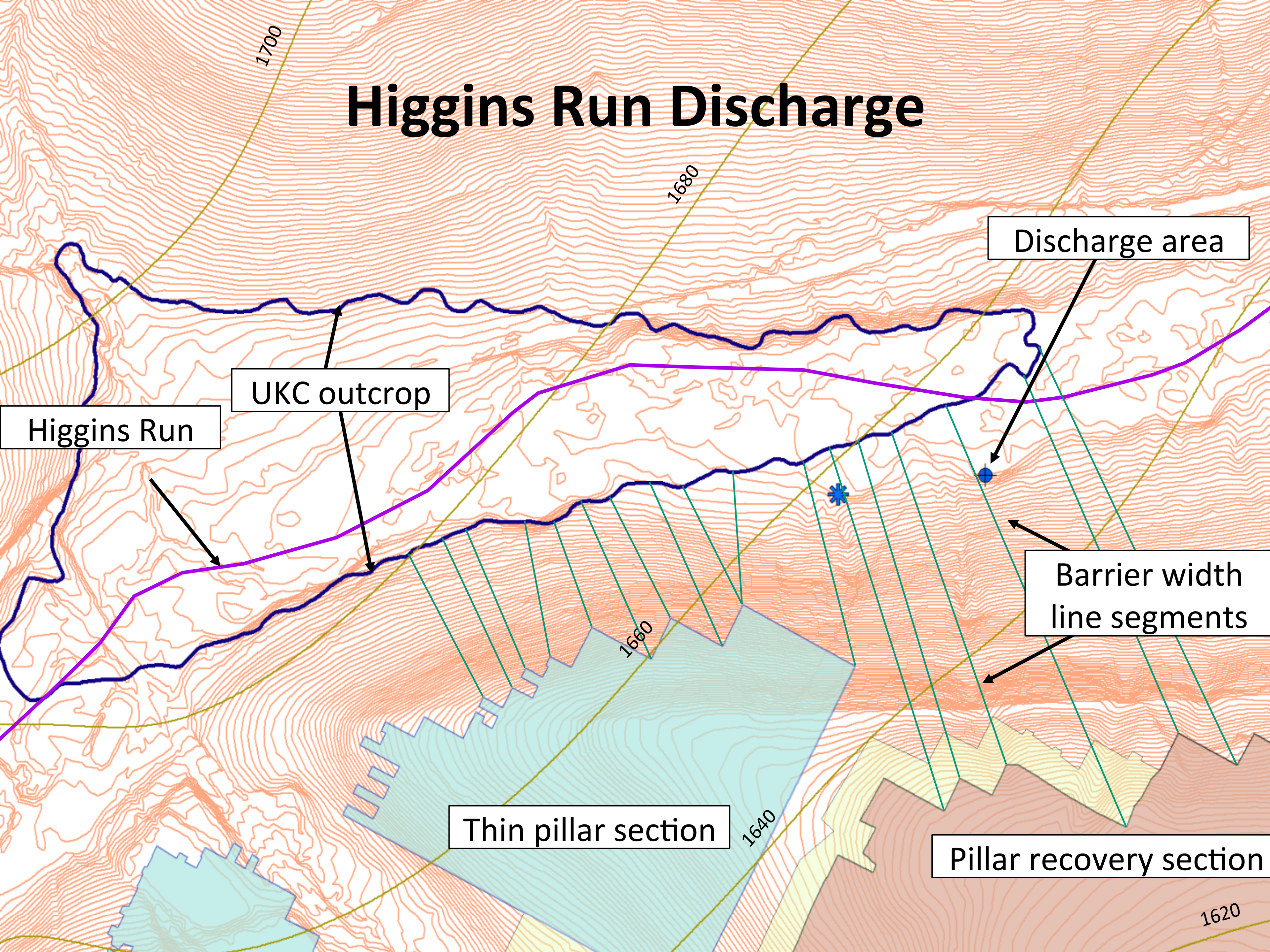
Higgins Run
Portal
Barrier
Solar 7
Barrier
US RT 30
Solar 10
0
0.25
0.5
1 Miles
N
Portal
Beaverdam Creek

Solar 7 & 10 - mining methods

- Room-and-pillar mining
- Full extraction
- Partial extraction
- Thin pillars



Higgins Run Discharge



‘e’ and Mine Characteristics

Mine Name	Discharge?	Extraction Ratio
Solar 7	Yes	**0.7 to > 0.9**
Solar 10	?	**0.67 to > 0.9**
Grove 1	Yes	**0.55 to > 0.9**
	No	***0.51***
Little Toby	No	***0.64***
	No	***0.72***
Genesis 17	No	***0.44***
Keystone East	No	***0.55 to 0.61***

Extraction ratios reflect values adjacent to the barrier

Preliminary Results -- The Dora 6, Urling 1 2 3 and Lucerne 9 sites will be added

Factors 2 – Hydraulic Conductivity

- Primary permeability – Darcy’s Law applies (assume laminar flow, constant head, no fracture flow)
- Secondary permeability – Darcy’s Law doesn’t apply (assume flow primarily through fractures, often associated with a unique geologic feature/ discontinuity)

Background (barrier design using Darcy's Equation)

Barrier leakage equation (McCoy, et al., 2006):

$$Q = \sum_{i=1}^{n} K_h \times t \times L_i \times (\Delta h_i / w_i)$$

Where:

Q	=	barrier leakage, ft3/day
K_f/K_b	=	hydraulic conductivity*
t	=	coal thickness, ft
L	=	barrier segment length, ft
Δh	=	head difference across barrier, ft
w	=	barrier width, ft

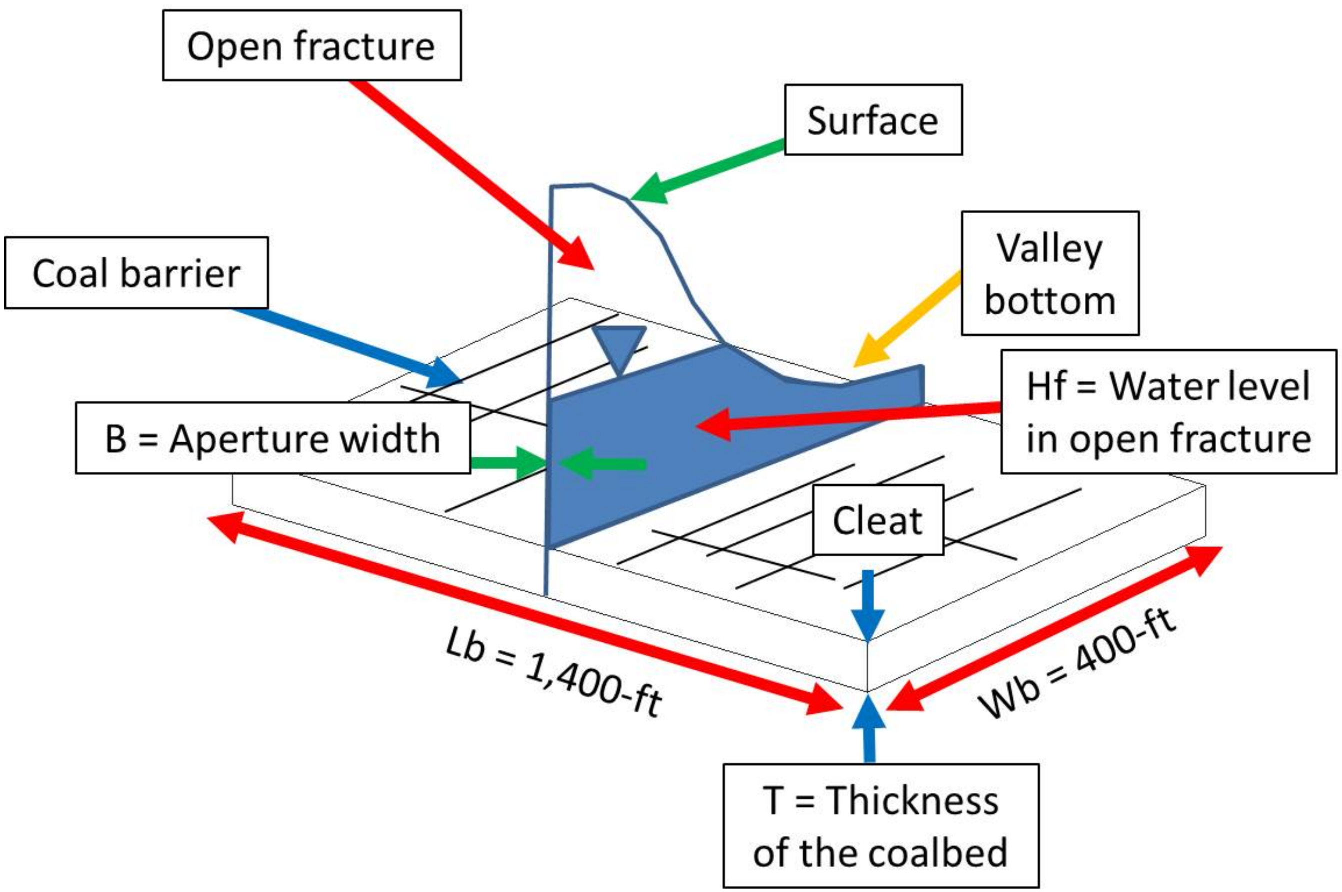
** - Hydraulic conductivity, Kh, values applied to the horizontal leakage equation ranging from* ***0.16 to 0.89 ft/day*** *for face cleat, **Kv, and 0.10 to 0.49 ft/day** for butt cleat, Kb.*

Solar 7 Discharge

- Discharge near Higgins Run (winter of 2004) at 1,660-ft
- The discharge (30 to 75-gpm) → narrow zone between 10 and 40-ft in width
- Mine pool →1,681-ft at maximum level
- The location was at an elevation higher than the mapped coal outcrop

Romm Fracture Flow Theory

$$Q = \rho_w g b^2 / 12\mu \; b w \, \delta h / \delta l$$



Flow Through a Single Fracture

- Consider a single fracture
- At 30-75 gpm → 0.08 to 0.11 inches wide

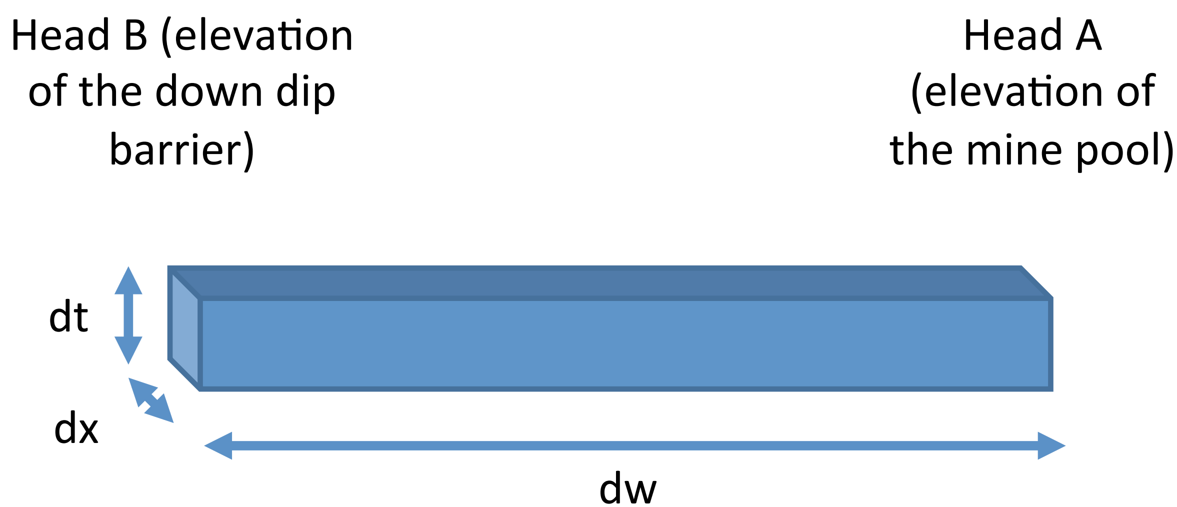
Factors 3 – Hydraulic Gradient (Δh/Δw)

- $q = dh/dw * K$

  q – discharge per unit area, ft/m

  K – hydraulic conductivity, ft/m

  dh/dw – hydraulic gradient (A – B)



Hydraulic heads and gradients

- Head values, by themselves, aren't significant
- Hydraulic gradients of 0.03 to 0.07 can result in discharges

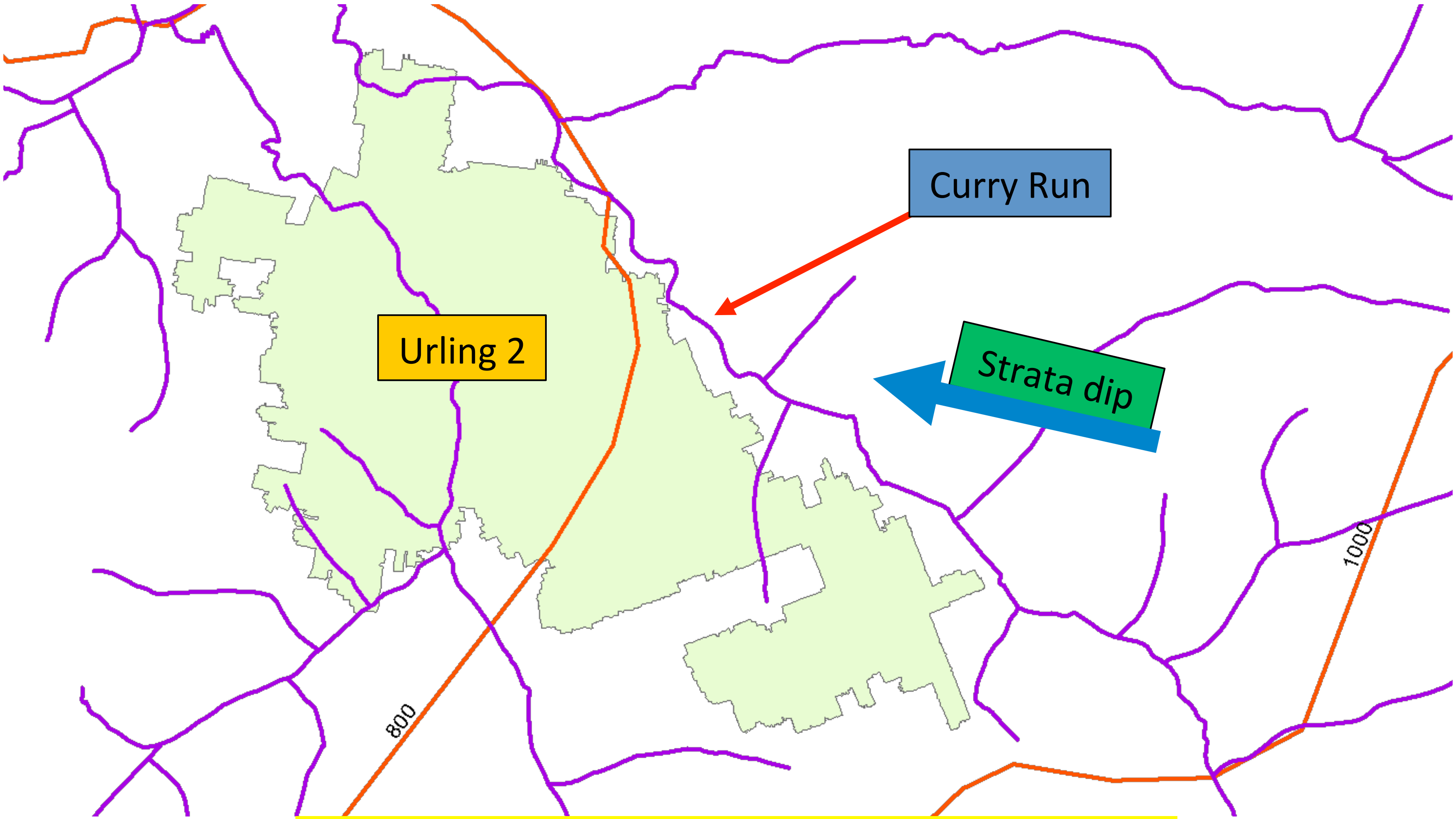
Mine Name	Discharge?	Hydraulic Head on Barrier, ft	Hydraulic Gradient
Solar 7	Yes	21	~0.05
Grove 1	Yes	86	~0.03

Preliminary Results –
More case studies are needed

Factors 4 – Geology

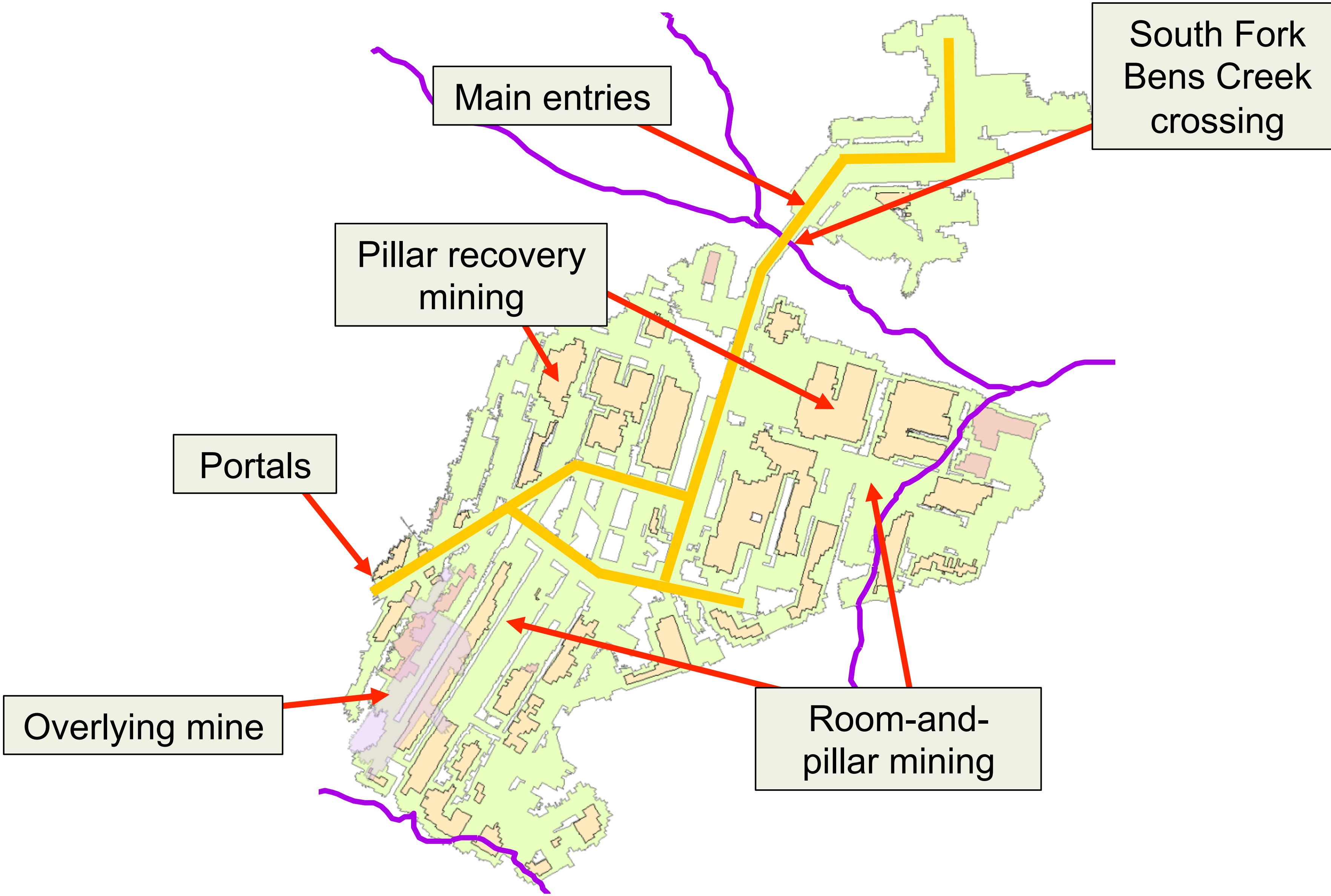
- Dip
- Fractures
- Horizontal stress (stress release fracturing)
- Lineaments, faults
- Bedding planes

Stream Valley Fracturing - Urling 2

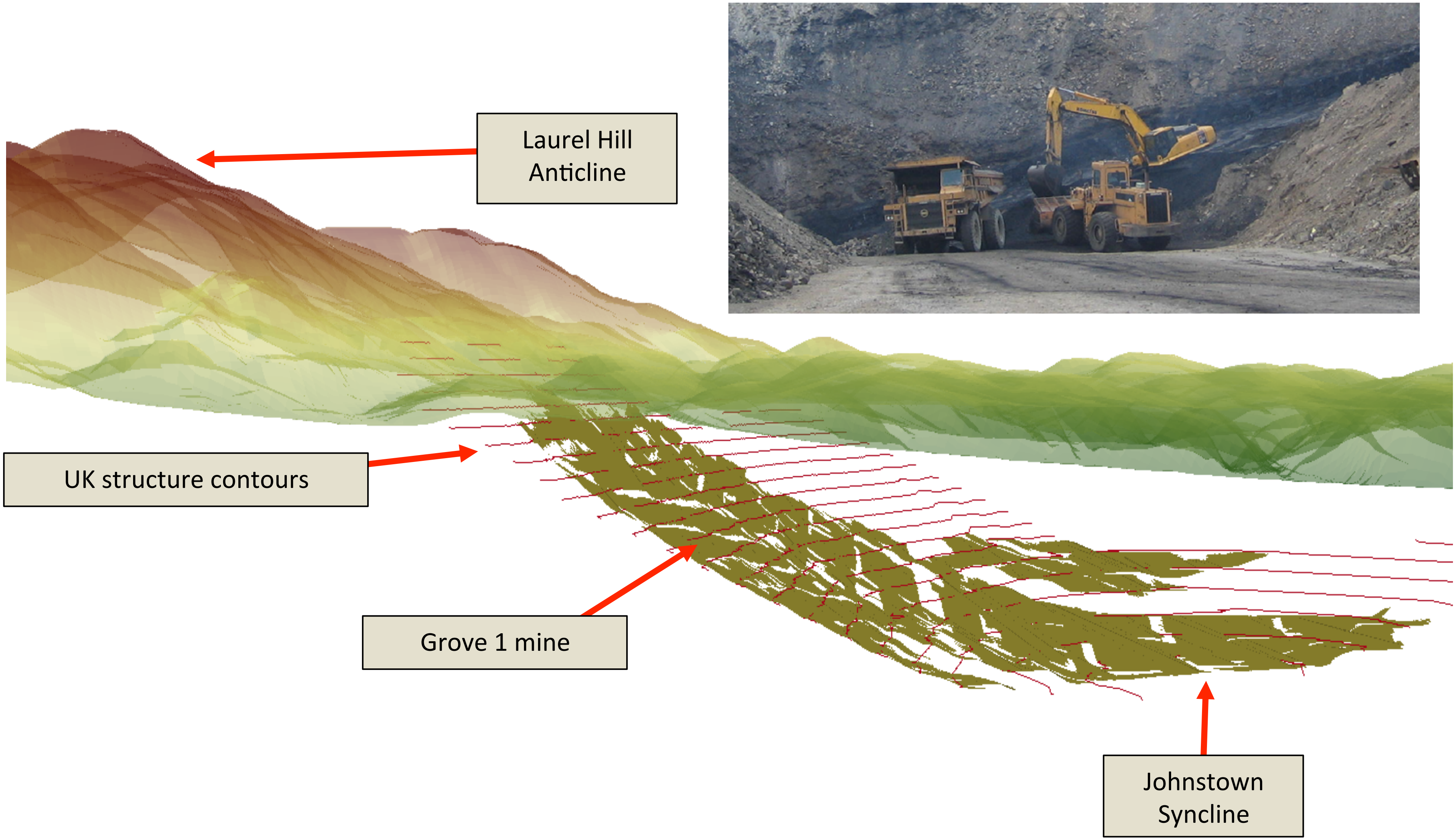


Reported inflows of 350-gpm along Curry Run

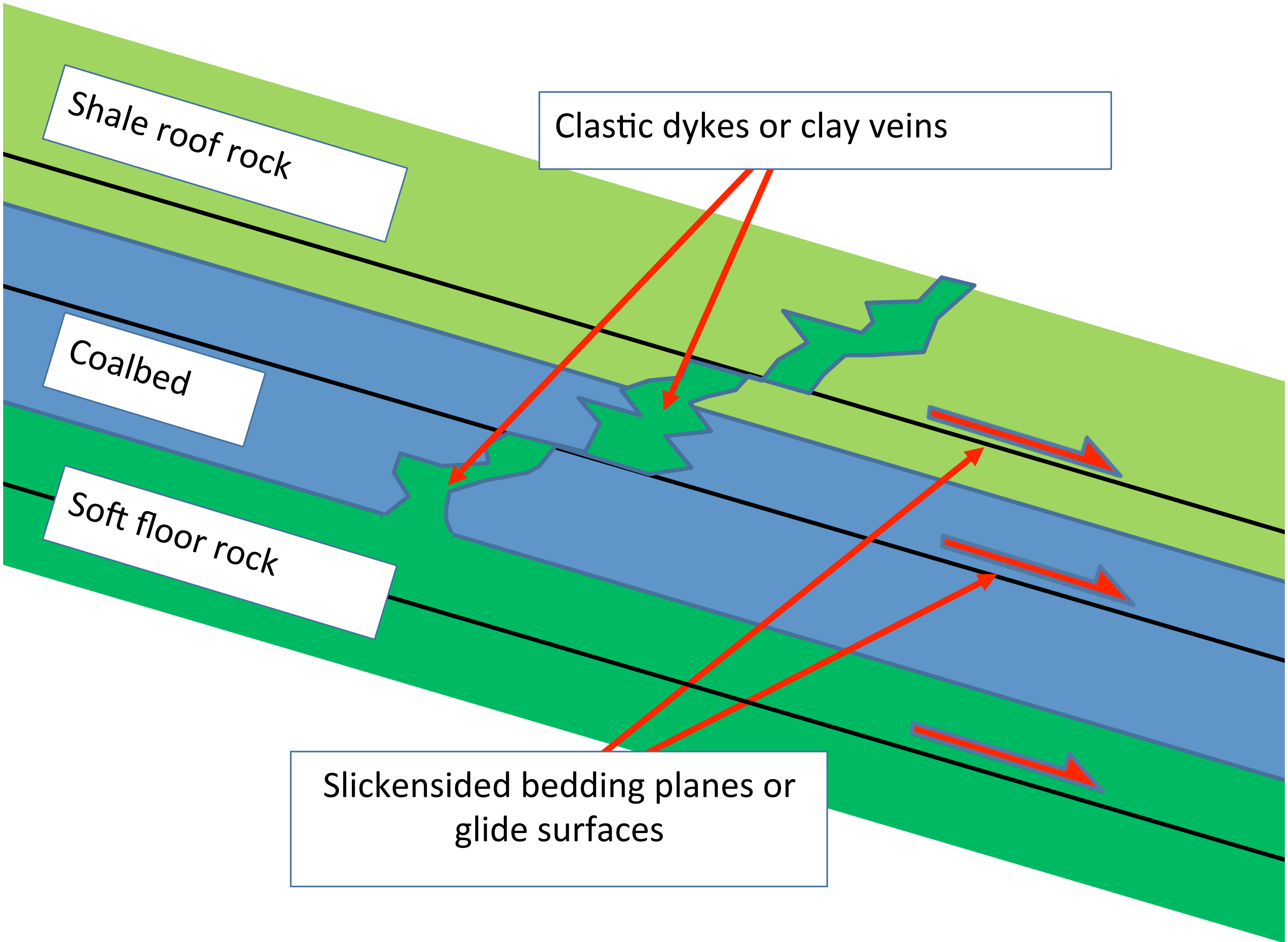
Grove 1 – South Fork of Bens Creek protected



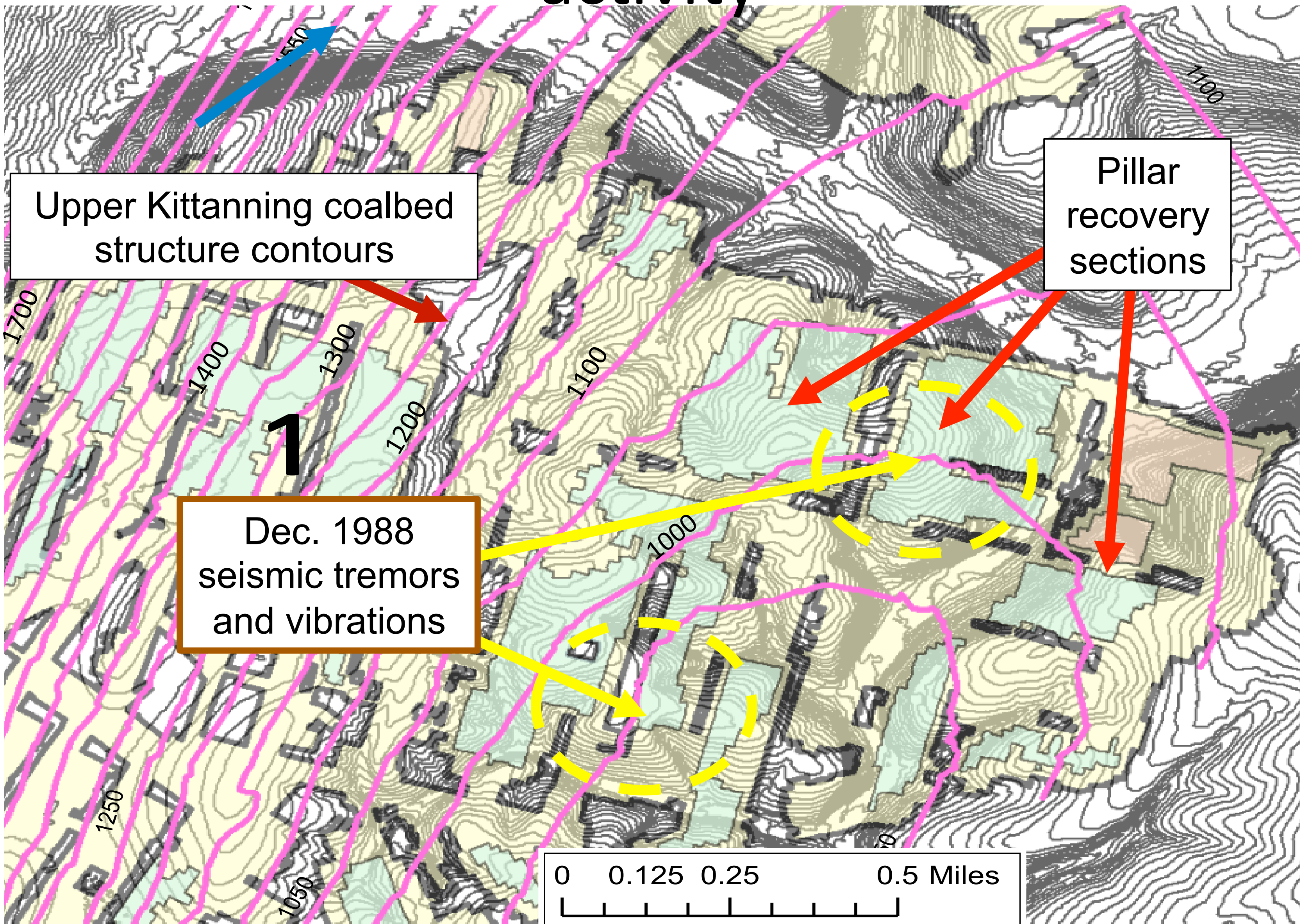
However, unique geologic conditions dominate



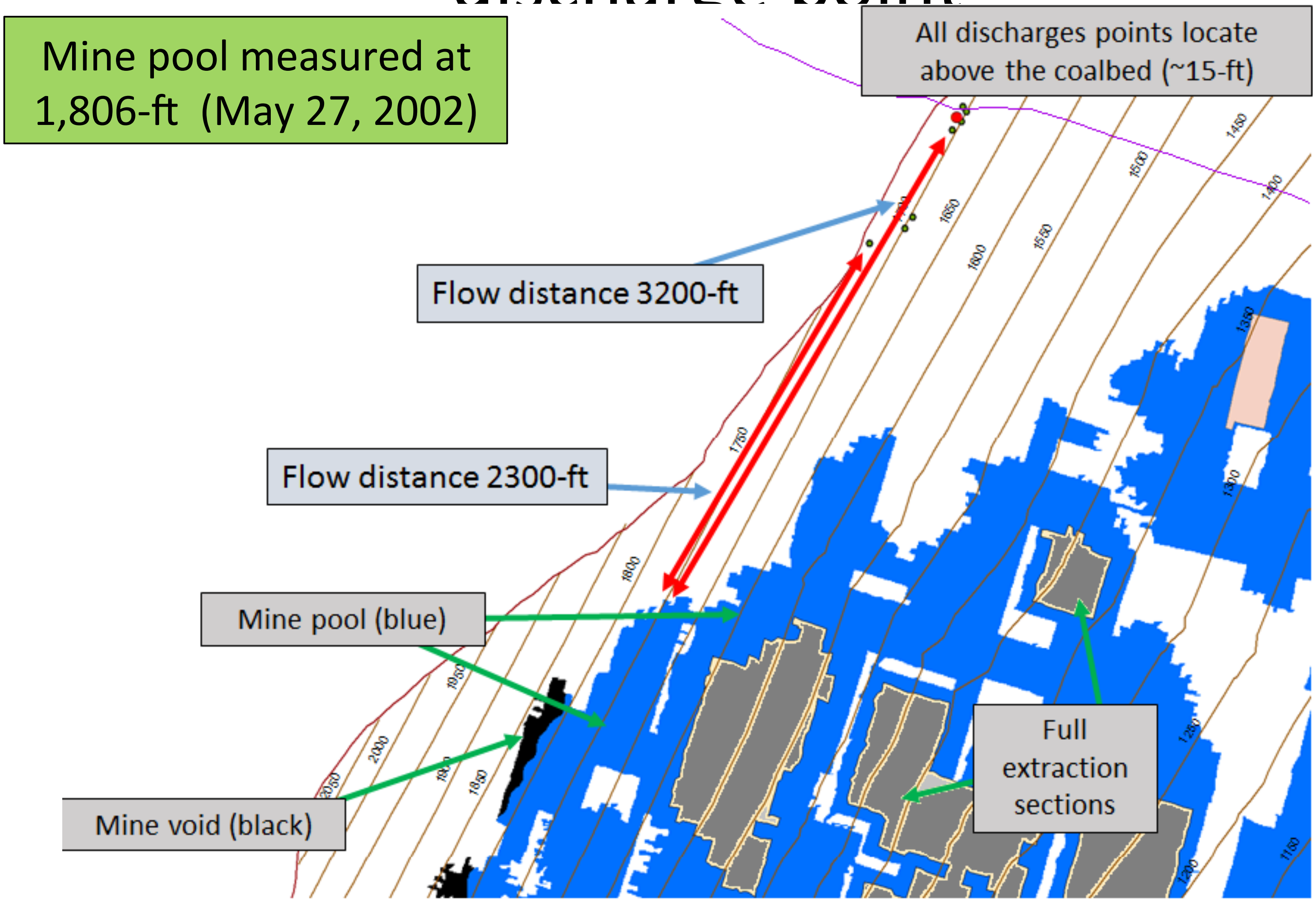
Pre-mining Strata Movement



MSHA study confirmed mining to seismic activity



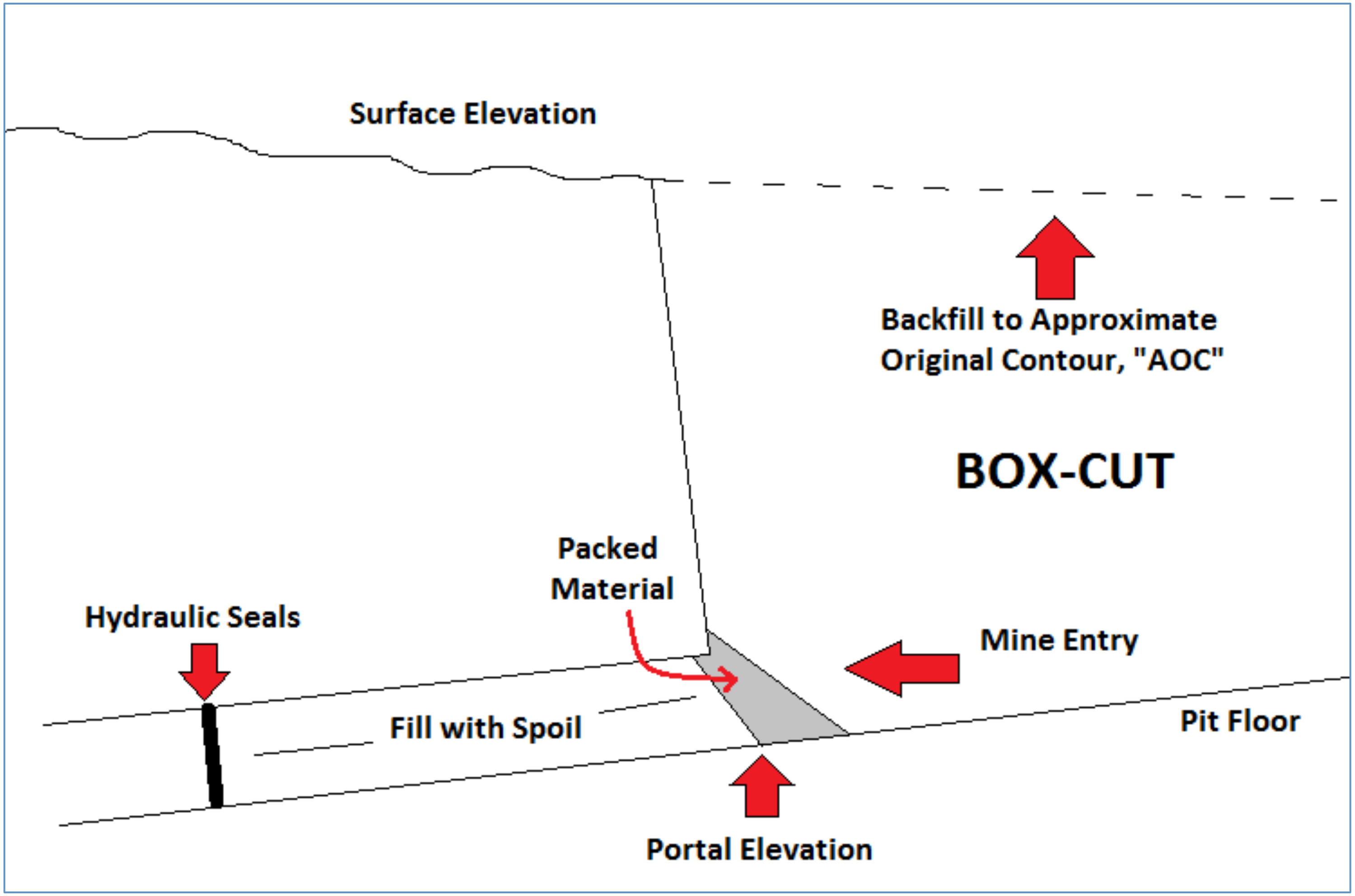
Mine pool water moved laterally great distances along geologic discontinuities to discharge point



Factors 5 – <u>Mine pool elevation w/box cuts</u>

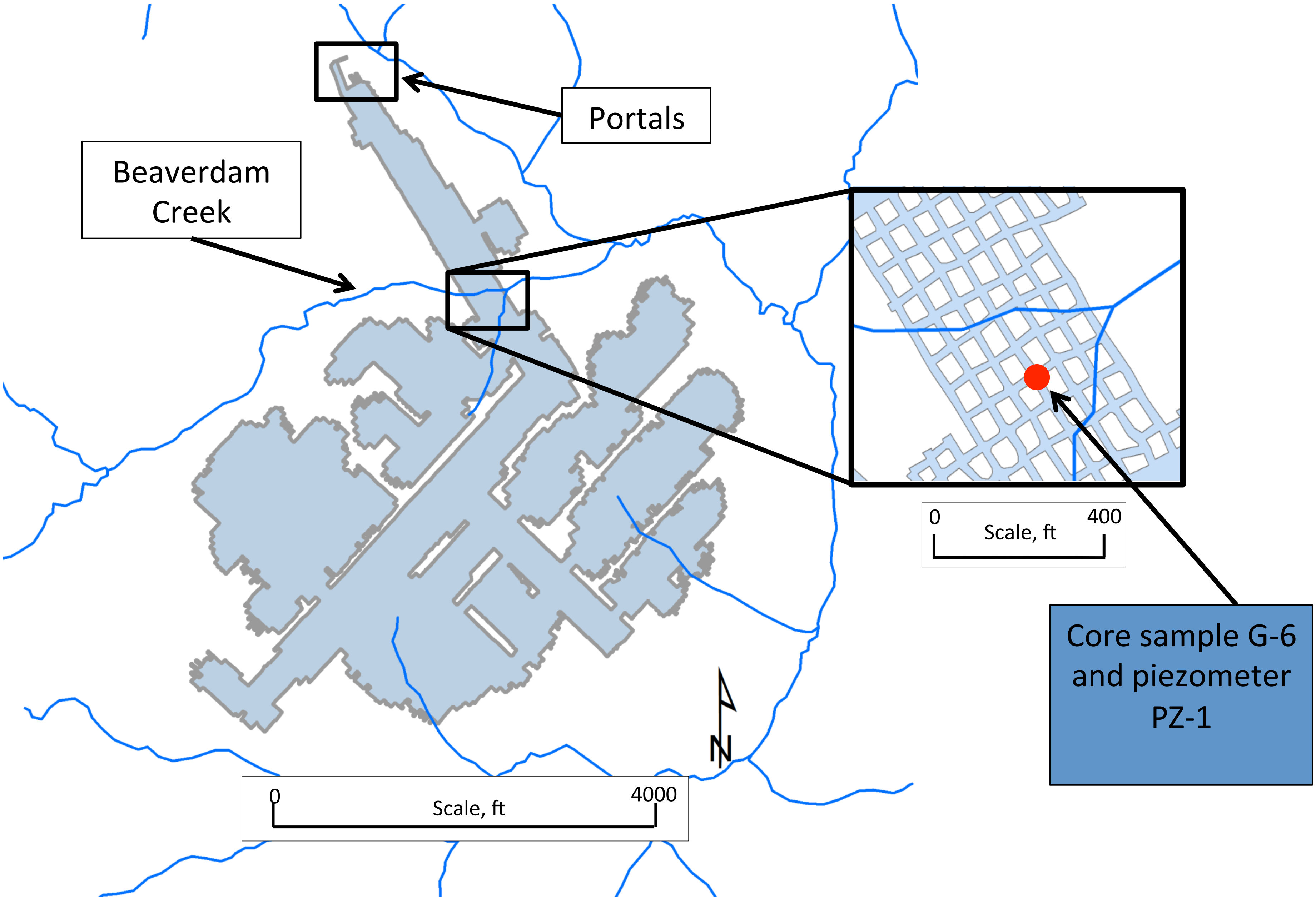
- Common technique to access room-and-pillar mines in PA

What is the maximum height of the mine pool?

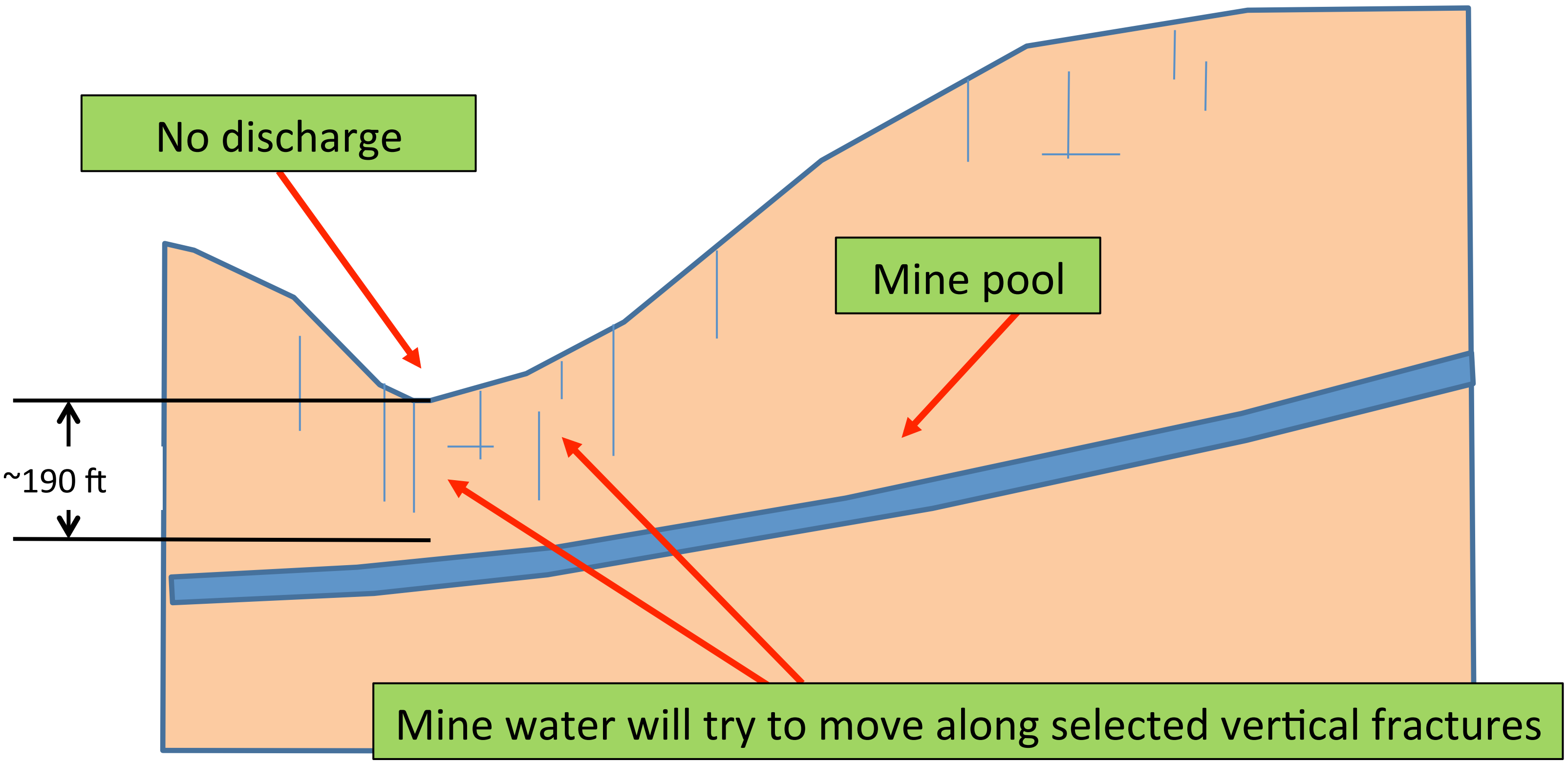


(PA DEP, Barbara No. 2: Module 8, Exhibit 23.3)

Genesis 17 barrier location

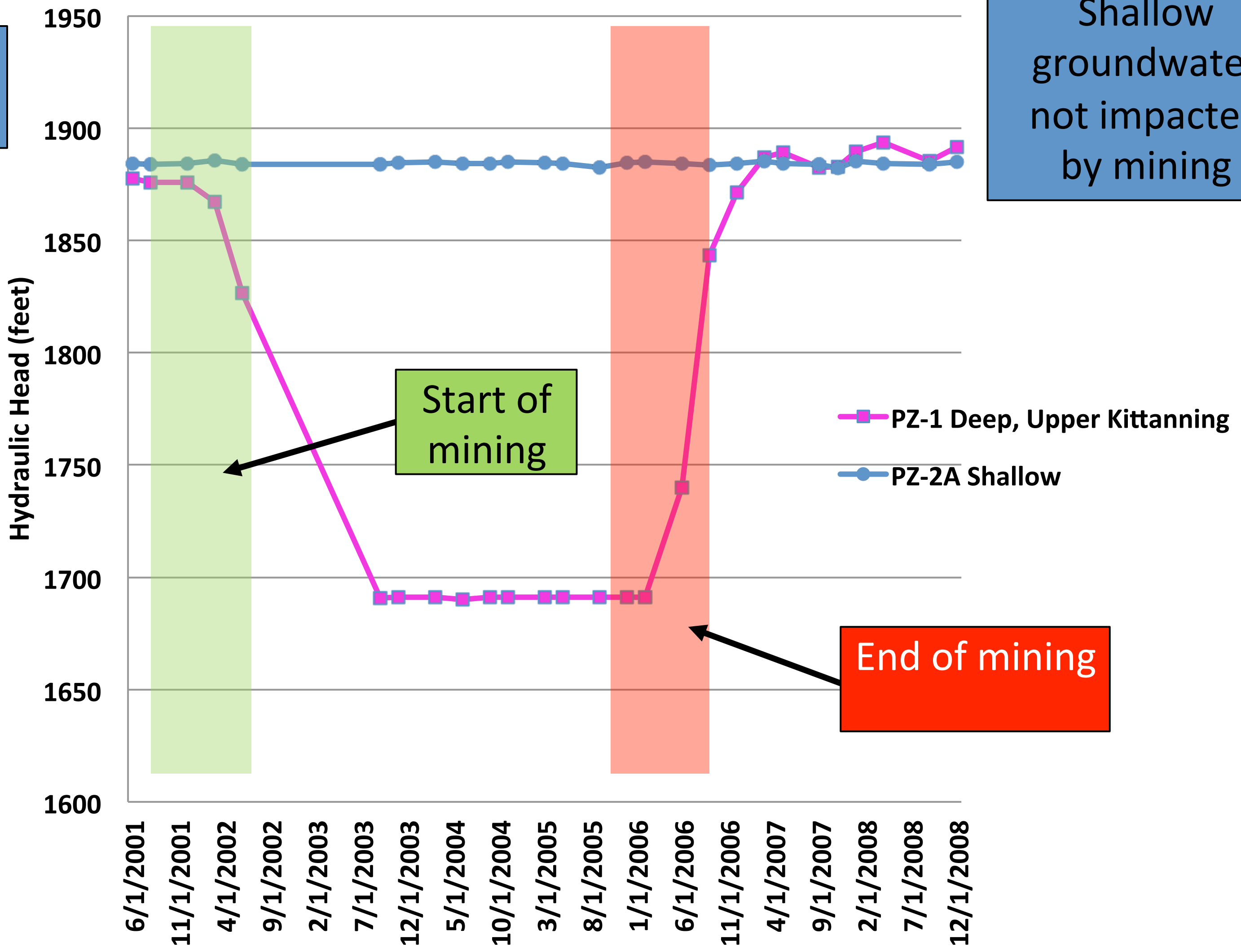


Barriers with < 250-ft of overburden



Genesis No. 17 piezometer data (mine pool 12-ft above surface!)

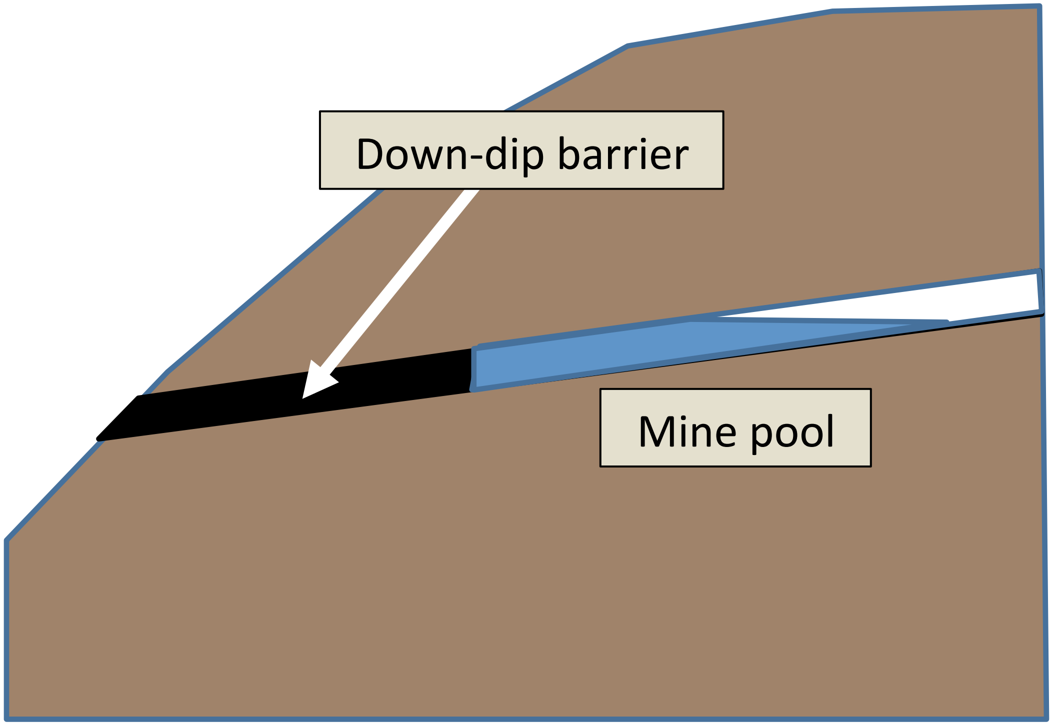
PZ-1 located in barrier 7



Shallow groundwater not impacted by mining

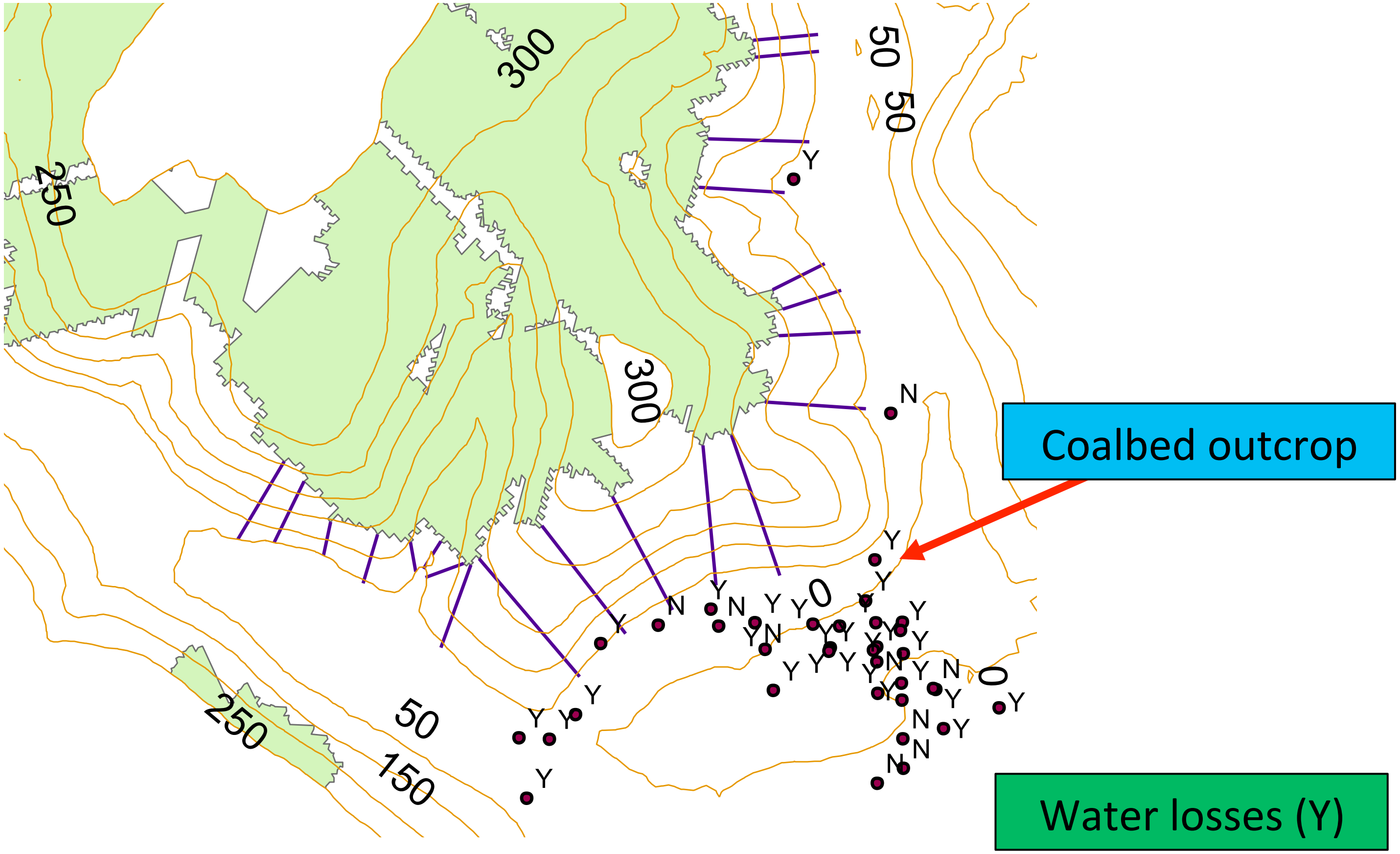
Factors 6 – <u>Critical hydraulic barrier above drainage</u>

- Dora 6 was permitted in the 70's
- After the mine closed it began to flood
- The down dip barrier was ~700-ft wide
- When the pool elevation reach a total of ~80-ft above the coalbed outcrop, a series of discharges occurred



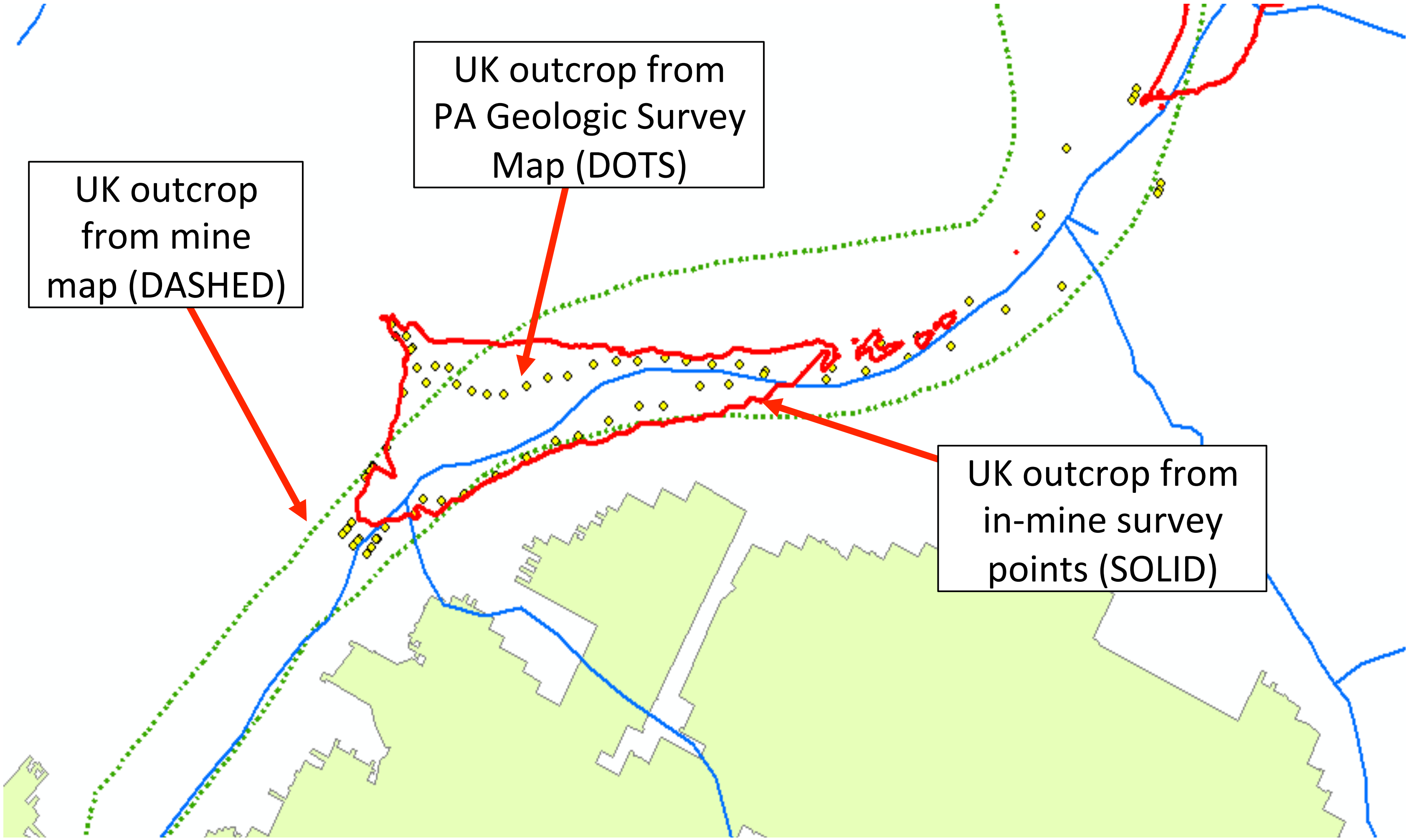
Dora 6 discharge occurred at and below the LK coalbed

- Coalbed outcrop at or above the surface
- Many water wells located at or below the level of the coalbed

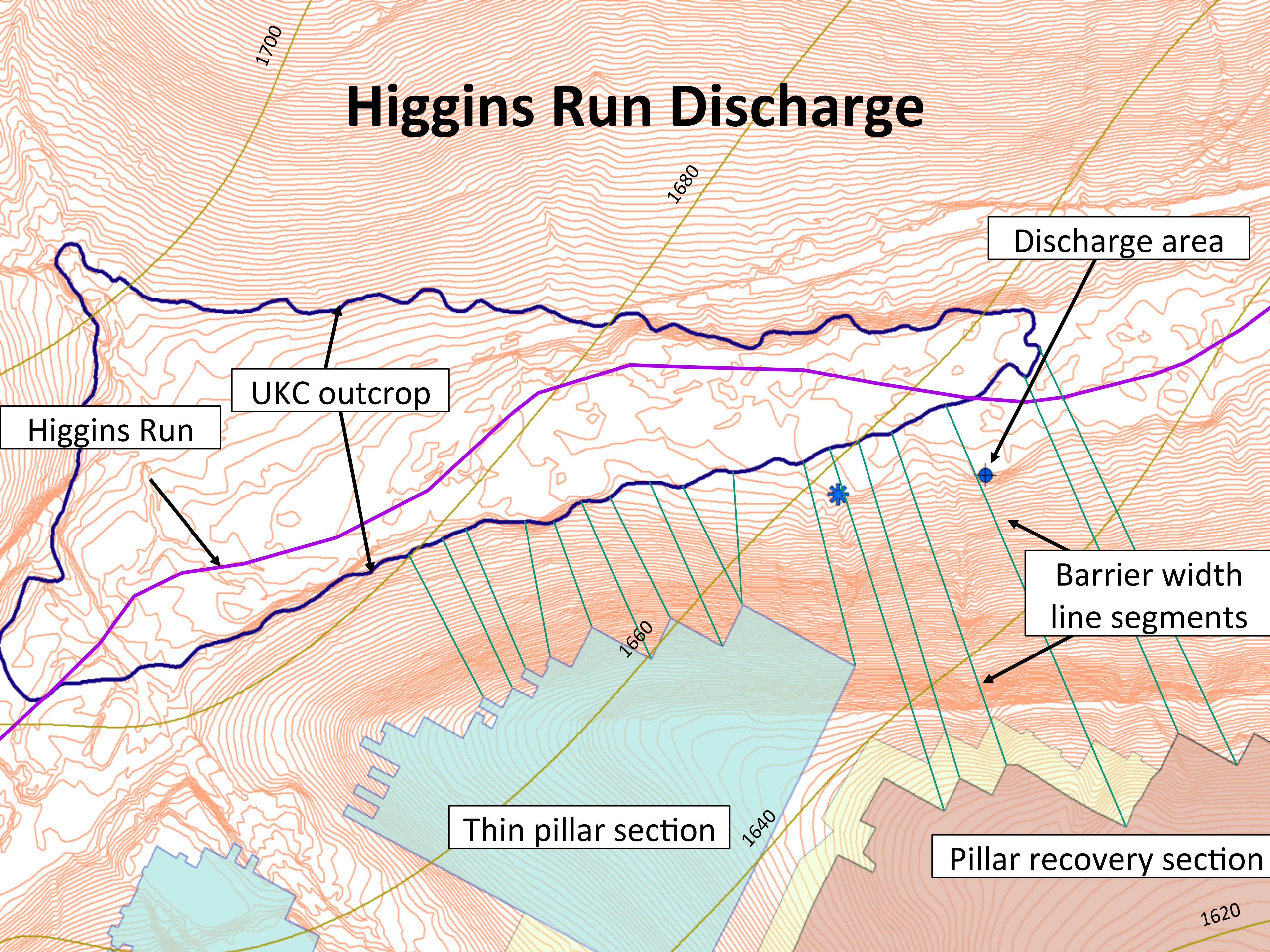


Factors 7 – Barrier thickness measurements

- The exact width of the barrier is a critical input value



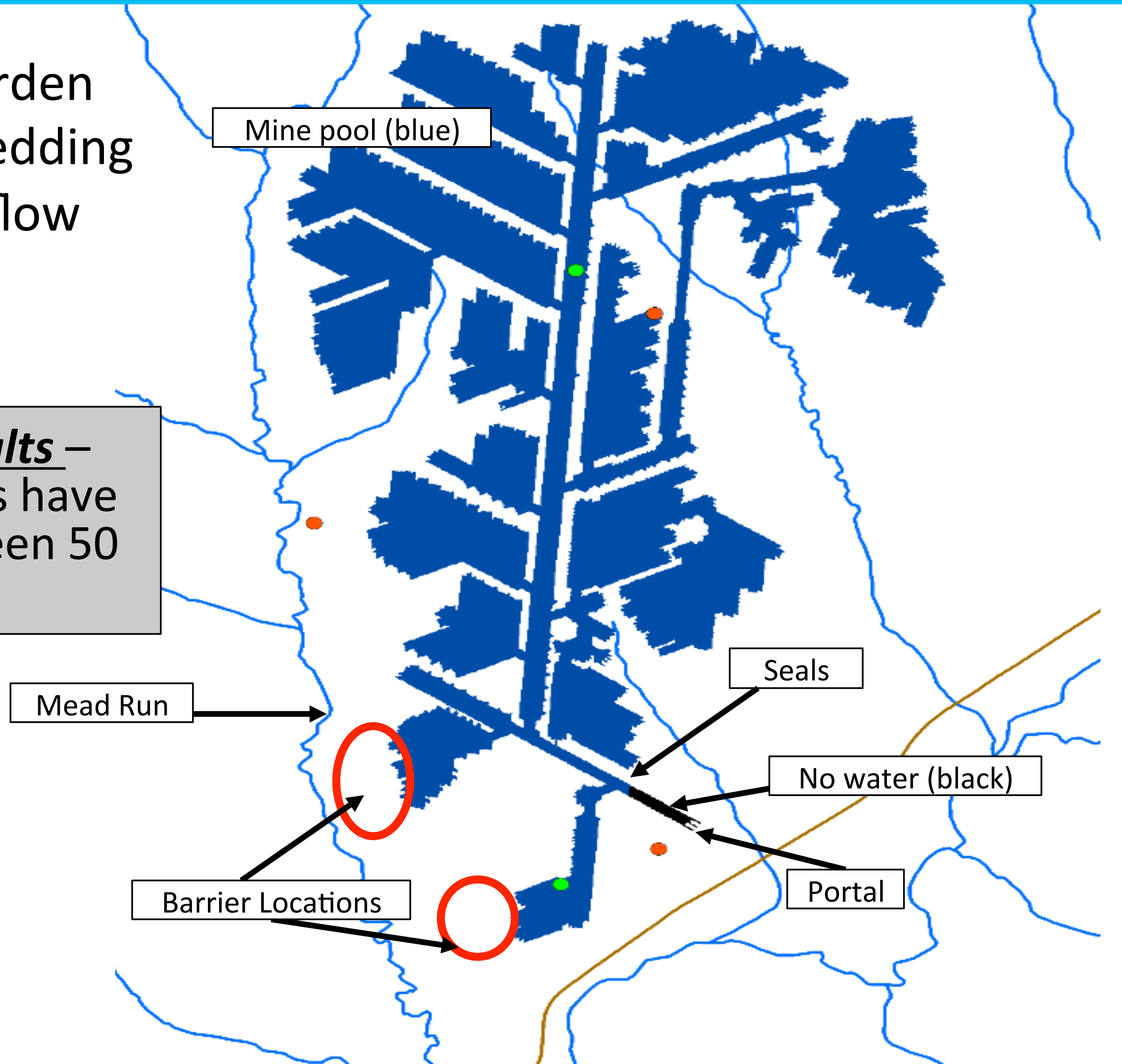
Higgins Run Discharge



Factors 8 – Overburden

- Increased overburden closes fracture/bedding planes, reducing flow potential

Preliminary Results –
Little Toby barriers have overburden between 50 and 200-ft

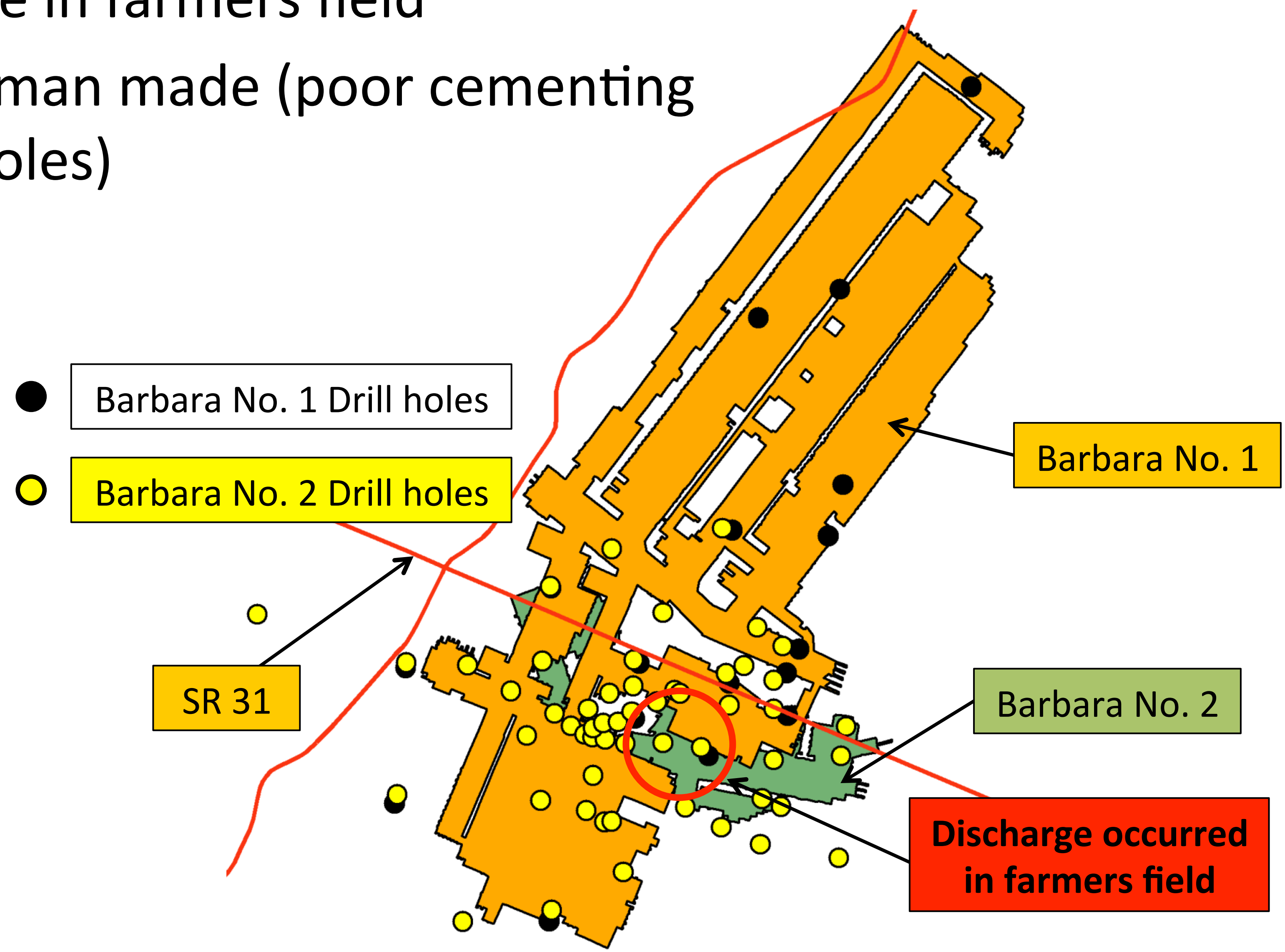


Factors Affecting Barrier Performance

1) Extraction ratio
2) Hydraulic gradient
3) Hydraulic conductivity
4) Geology
5) Location of critical hydraulic barrier
6) Mine pool elevation w/box cuts
7) Barrier thickness measurement
8) Overburden

Barbara No 1 & 2 (Other types of barrier failures)

- Discharge in farmers field
- Cause – man made (poor cementing of coreholes)



Final Report – is focusing on 'Probability of Discharge through Barriers'

Factor	Controlling Property	Preliminary Control Value	Probability of Discharge	
			High	Low
Extraction ratio	e	> 0.7		
Hydraulic gradient	dh/dw	< 0.05		
Hydraulic conductivity	K	> 1-ft/d		
Geology	Discontinuities	RQD < 80		
Location of critical hydraulic barrier above drainage/surface	Core data, geologic surveys	Yes / No		
Mine pool elevation w/box cuts	Post mining 1) mine pools elevations, 2) piezometers	Assume elevation to be highest point of minine		
Barrier thickness measurement	Precise structure contours	Mine survey points not used		
Overburden	h	< 100-ft		

If any of the above factors are recognized as 'High', the risk of a discharge increases

Questions