

# Potential Hydrogeologic Impacts Due to Mine Subsidence

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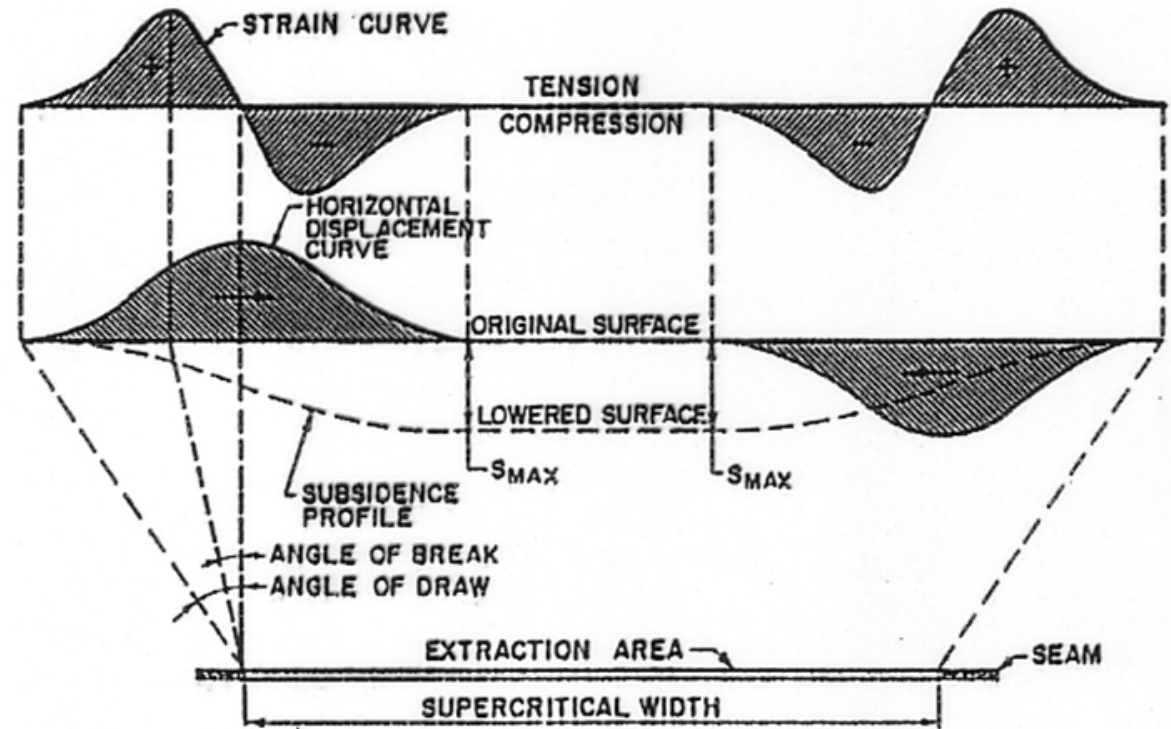
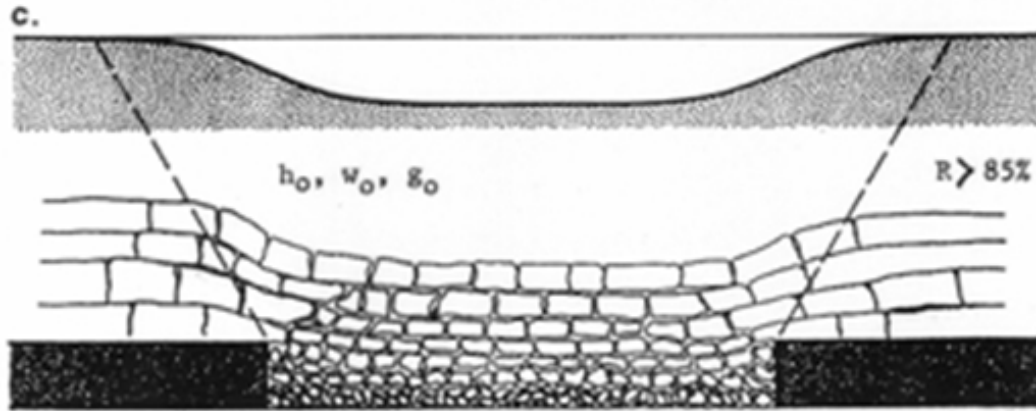


# Presentation Outline

- Ground movements due to underground mining
- Potential hydrologic impacts due to underground mining
- Methodology for assessing potential impacts to aquifers
- Example case study
- Discussion and conclusions



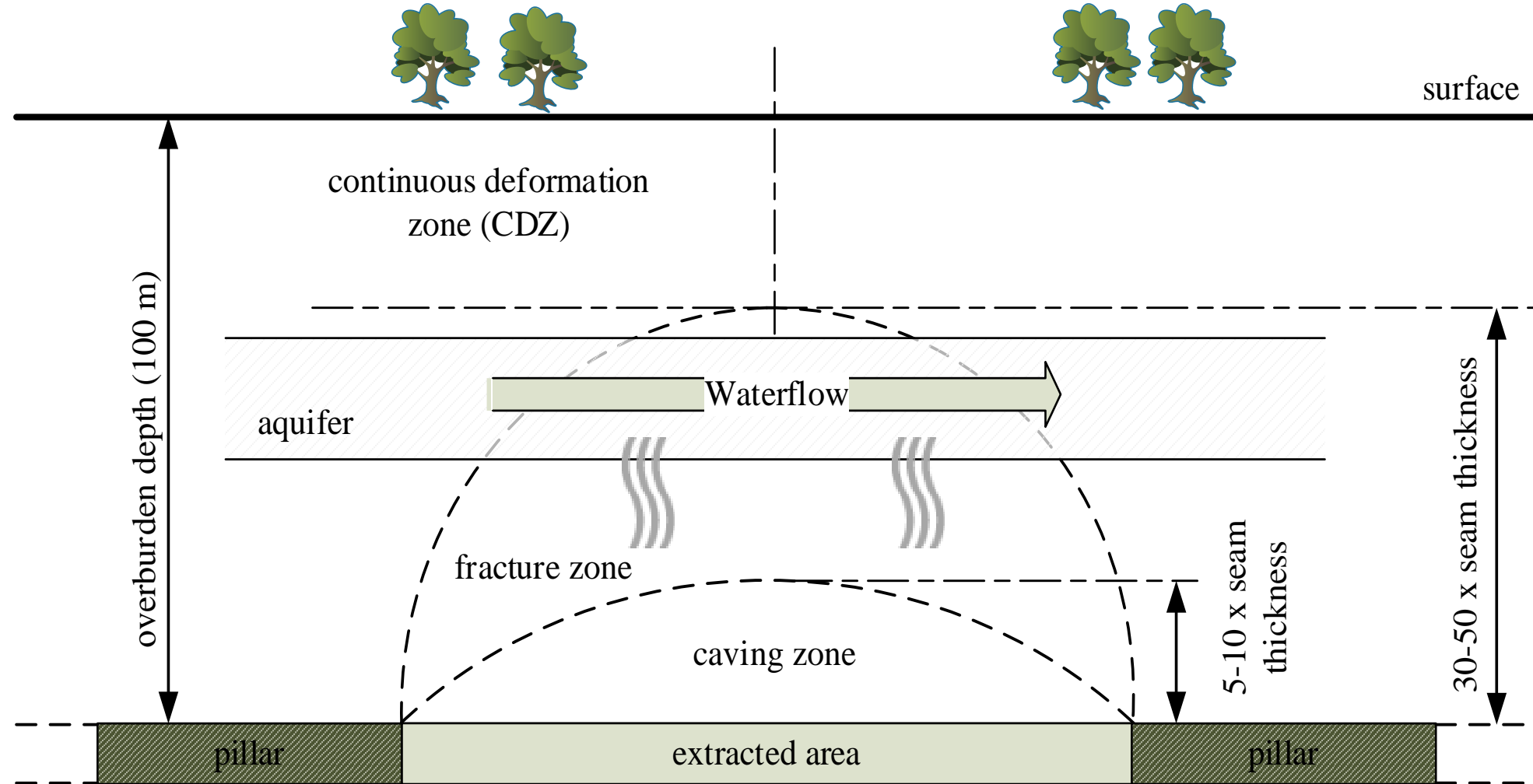
# Ground Movements



- Subsidence: The vertical movements of the ground surface
- Horizontal or ground strains develop due to unequally distributed displacements (vertical and horizontal)



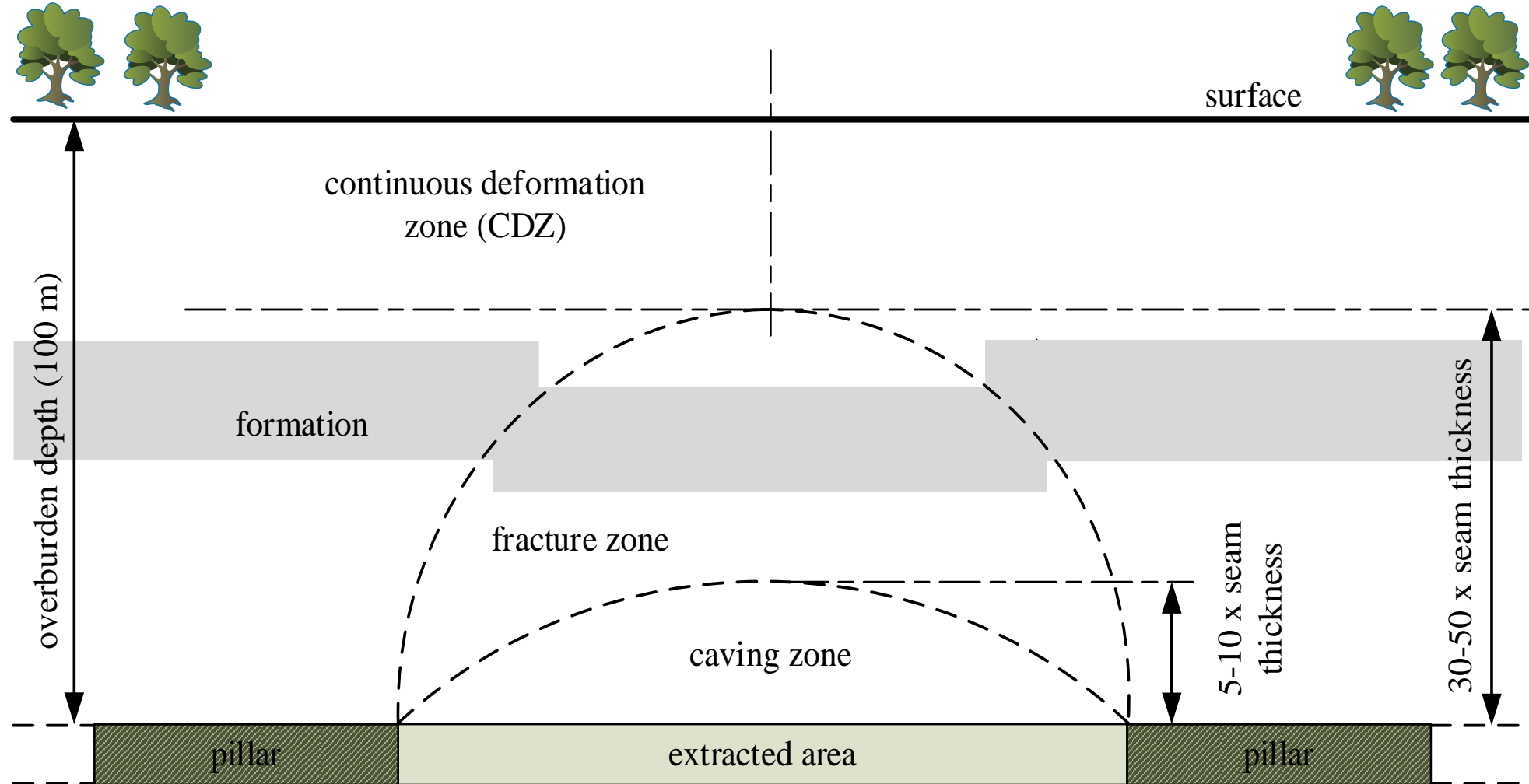
# Subsidence Zones and Possible Impacts to Ground Water



(adapted from Peng and Chiang, 1984)



# Subsidence Zones

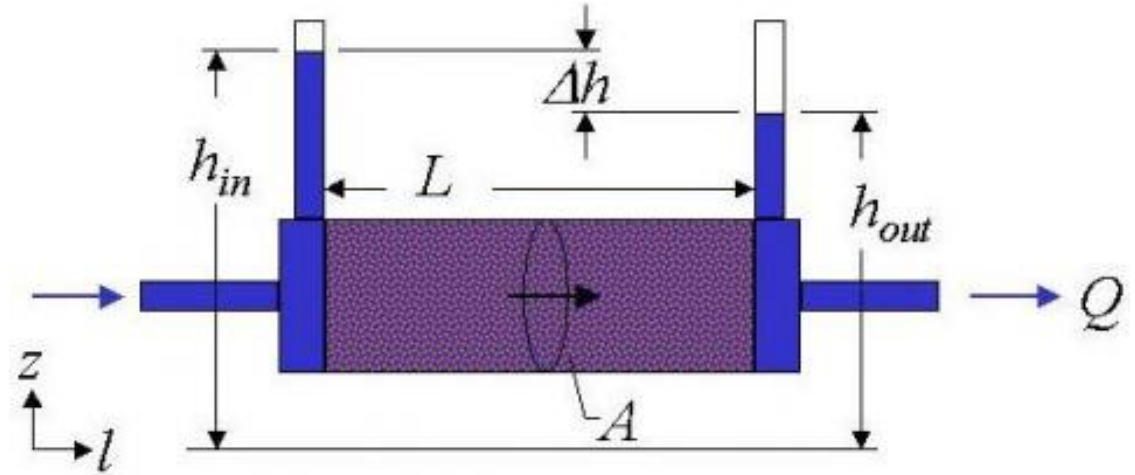


(adapted from Peng and Chiang, 1984)



# Groundwater Flow

$$Q = KA \frac{\Delta h}{\Delta L}$$



- Darcy's law describes the flow rate ( $Q$ ) through porous media proportional to the head loss ( $\Delta h$ ) and inversely proportional to the length of the flow path ( $\Delta L$ ).
- Hydraulic conductivity ( $K$ ) is the proportionality constant relating the amount of flow through a unit cross-sectional area ( $A$ ) of a unit element of the formation under a unit gradient of hydraulic head ( $\frac{\Delta h}{\Delta L}$ ).



# Potential Impacts to Water Bodies due to Mining

- Potential impacts include
  - Changes to surface water bodies (impacts to streams, lakes, etc.)
  - Changes to groundwater flow and head (impacts to aquifers, aquitards, etc.)
- The work presented here focuses on potential impacts to groundwater flow due to underground mining



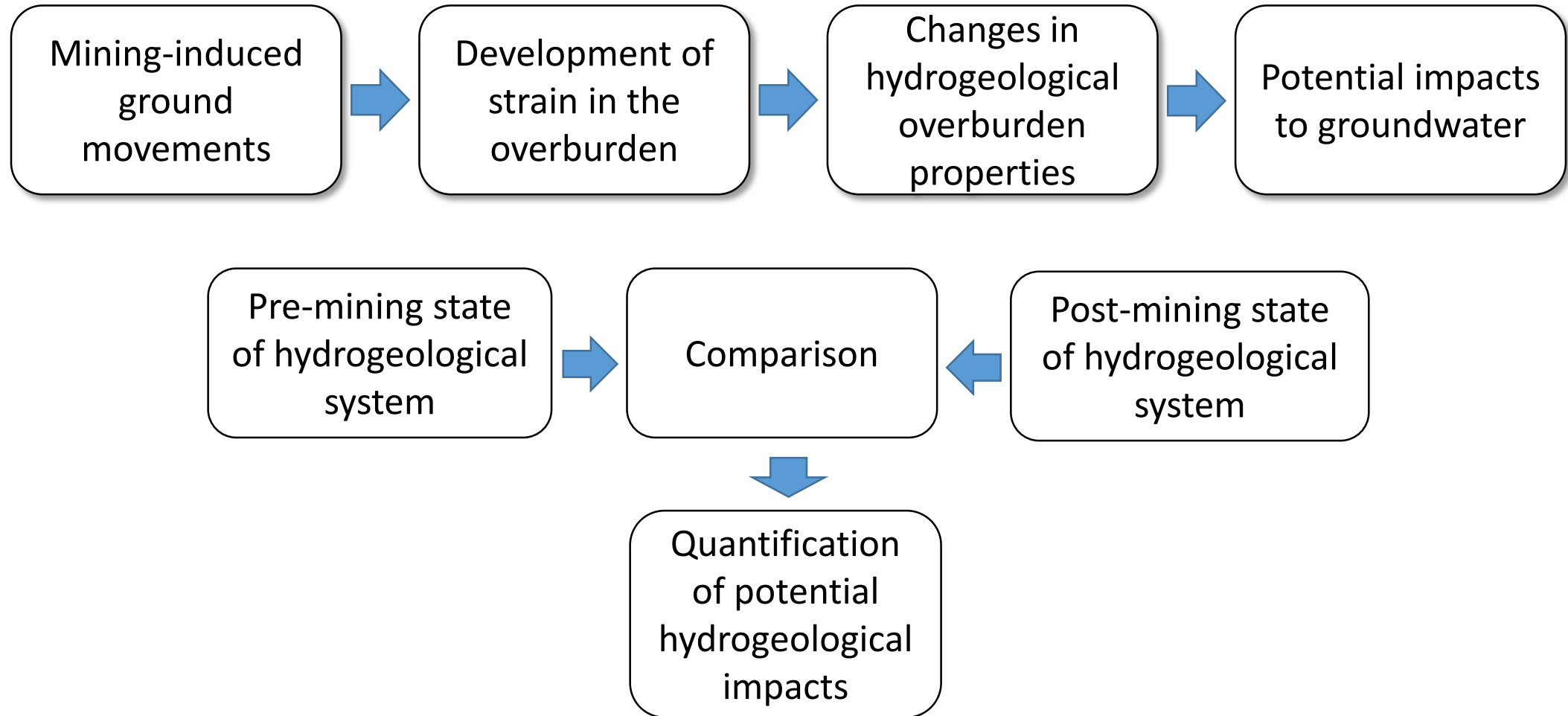
# Potential Changes in Post-mining Hydraulic Conductivity

- Depending on the mechanical and hydrogeological parameters of the overburden there may be changes in hydraulic conductivity (HC)
- Fracturing will typically result in increased hydraulic conductivity
- Shale: HC increases between one and three orders of magnitude.
- Sandstone: HC increases between one and two orders of magnitude.
- Limestone: HC increases about one order magnitude.
- According to Schubert (1980), horizontal conductivity values for undisturbed material are consistently greater than vertical values.
- According to Li, et al. (2015), longwall mining promotes the development of horizontal and vertical fractures, - especially the latter one.





# Methodology for Evaluating Potential Groundwater Impacts



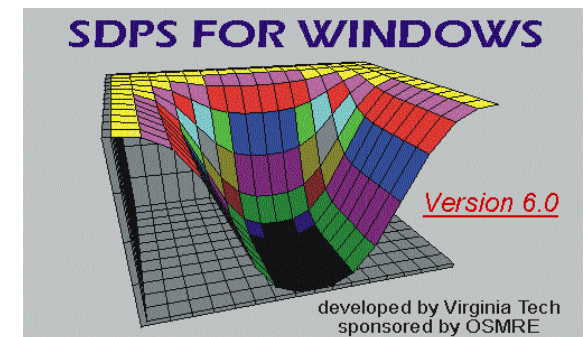
# Methodology for Evaluating Potential Groundwater Impacts

- 1) Calculate mining-induced subsurface horizontal strain magnitudes using SDPS
- 2) Estimate post-mining hydraulic conductivity using equations developed by Ouyand and Elsworth (1993)
- 3) Estimate groundwater flow and hydraulic heads within the hydrogeologic regime using the PMWiN software based on the USGS MODFLOW code
- 4) Compare pre- and post-mining hydraulic heads and quantify changes in heads within the hydrogeologic regime.



# Surface Deformation Prediction Software System

- SDPS is an integrated package for the calculation of surface deformations.
- Calculations are based on several empirical relationships, developed through the statistical analysis of data from a number of case studies.
- Although developed over 25 years ago, SDPS has been continually updated with new analysis and prediction features providing a reliable and versatile program for industry and regulators.
- The influence function formulation was used to calculate horizontal strains



# Determining Changes in Hydraulic Conductivity

- Relationship between mining-induced strata deformation and changes in hydraulic conductivity (Ouyand and Elsworth, 1993)

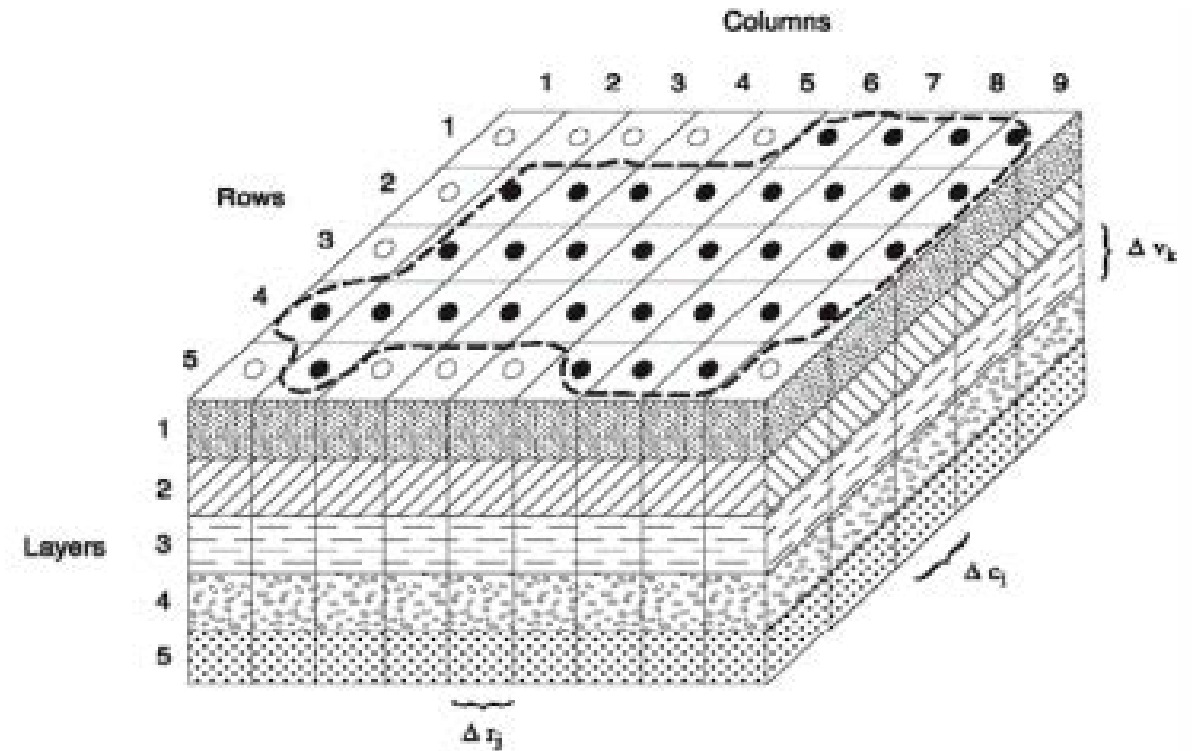
$$K_x = K_{x0} \left( 1 + \frac{b+S(1-R_m)}{b} \Delta\varepsilon_y \right)^3$$

$$K_y = K_{y0} \left( 1 + \frac{b+S(1-R_m)}{b} \Delta\varepsilon_x \right)^3$$



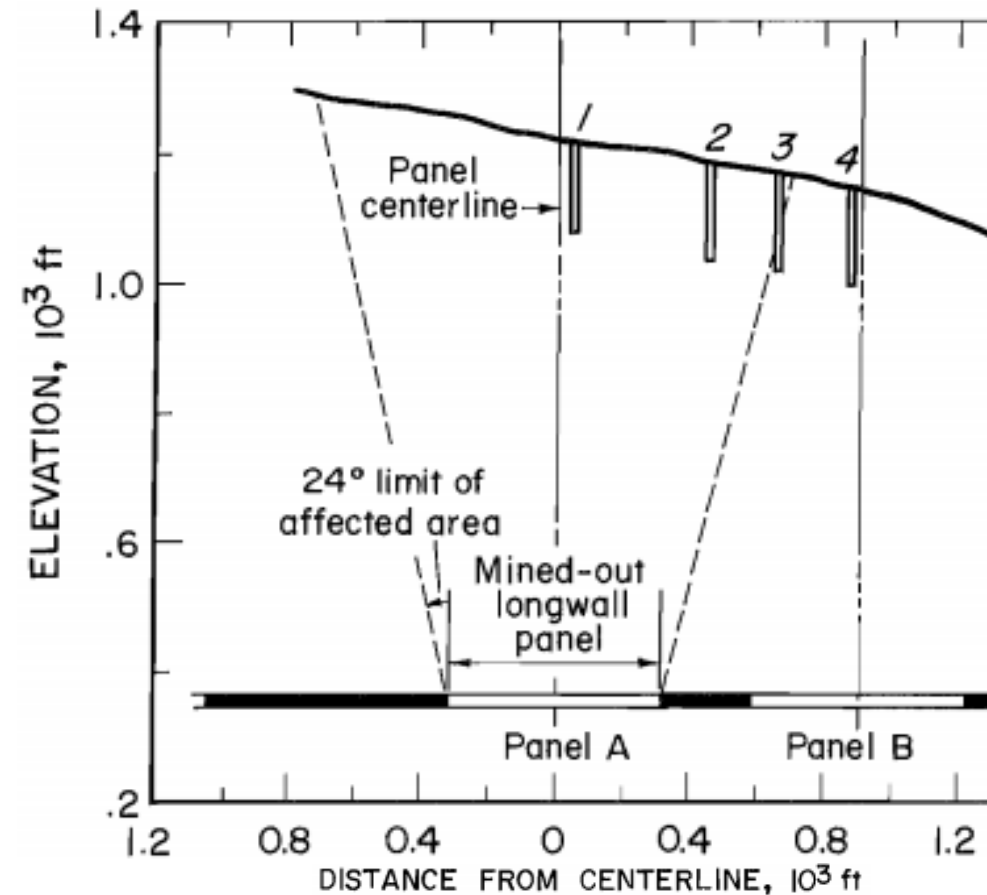
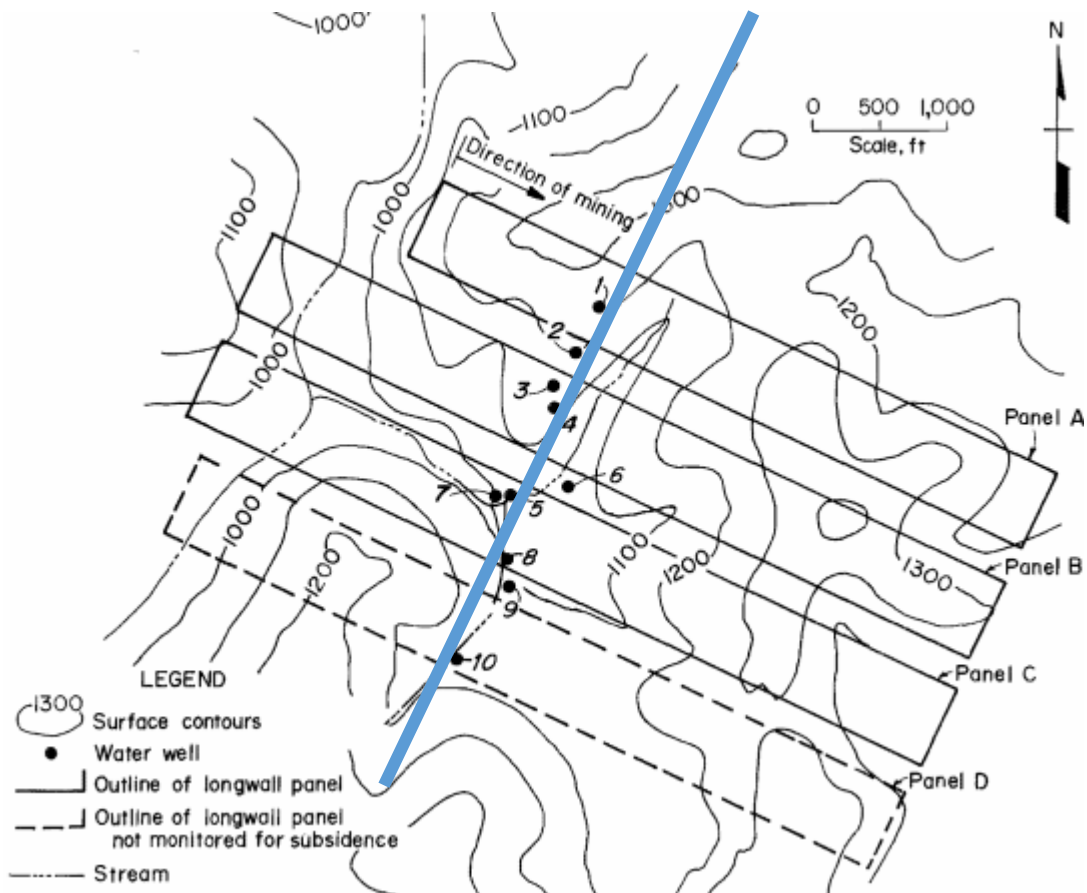
# The PMWiN Package

- Based on the USGS MODFLOW three-dimensional finite-difference code
- Describes ground water flow as well as surface-groundwater interactions
- Uses Darcy's equation for fluid flow through porous materials

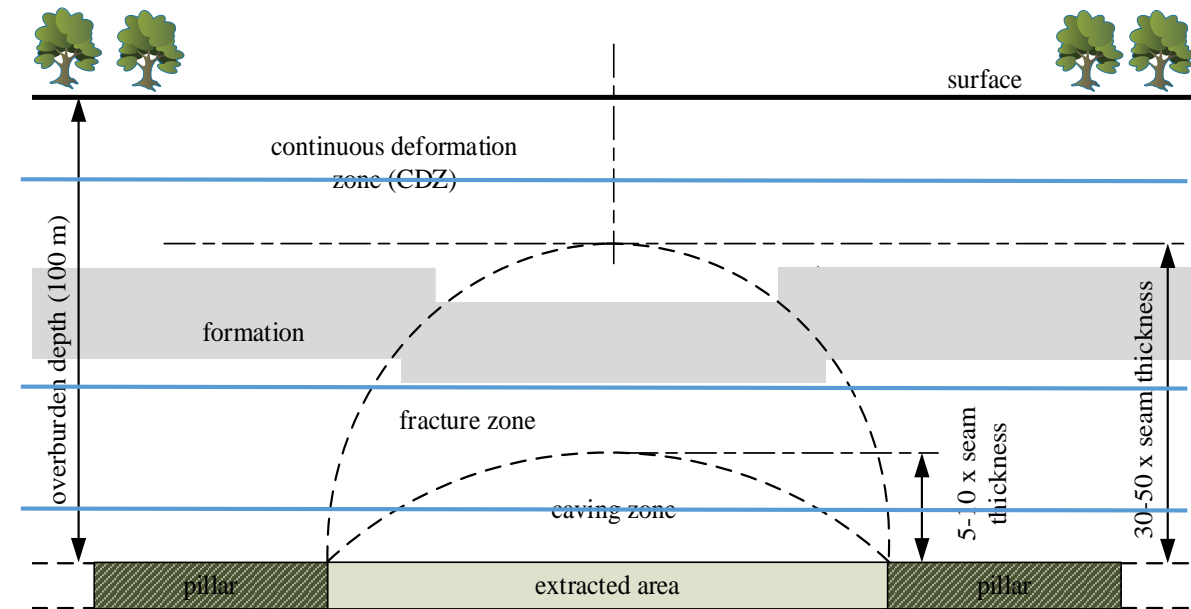
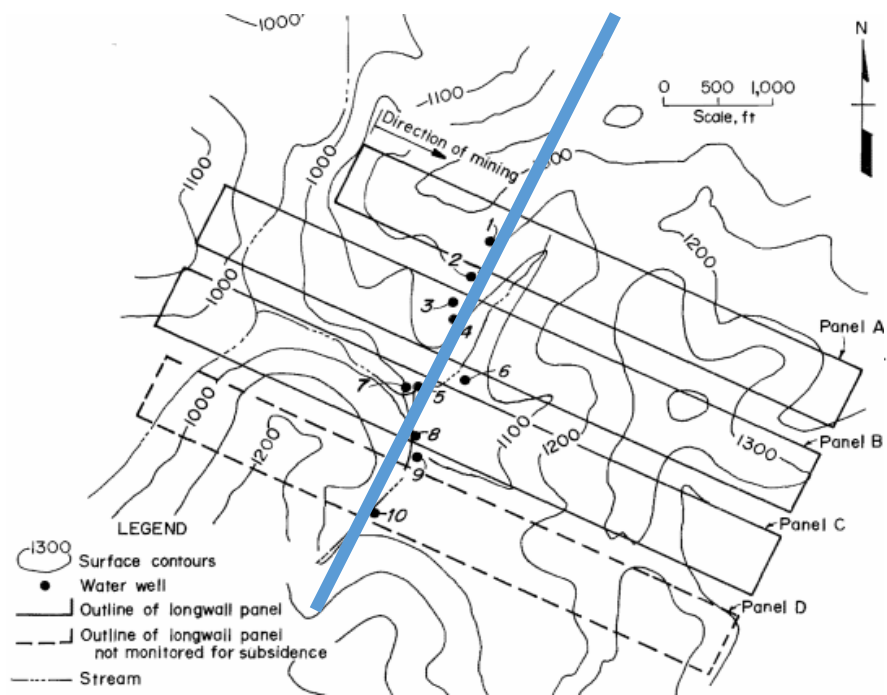


# Northern Appalachian Case Study

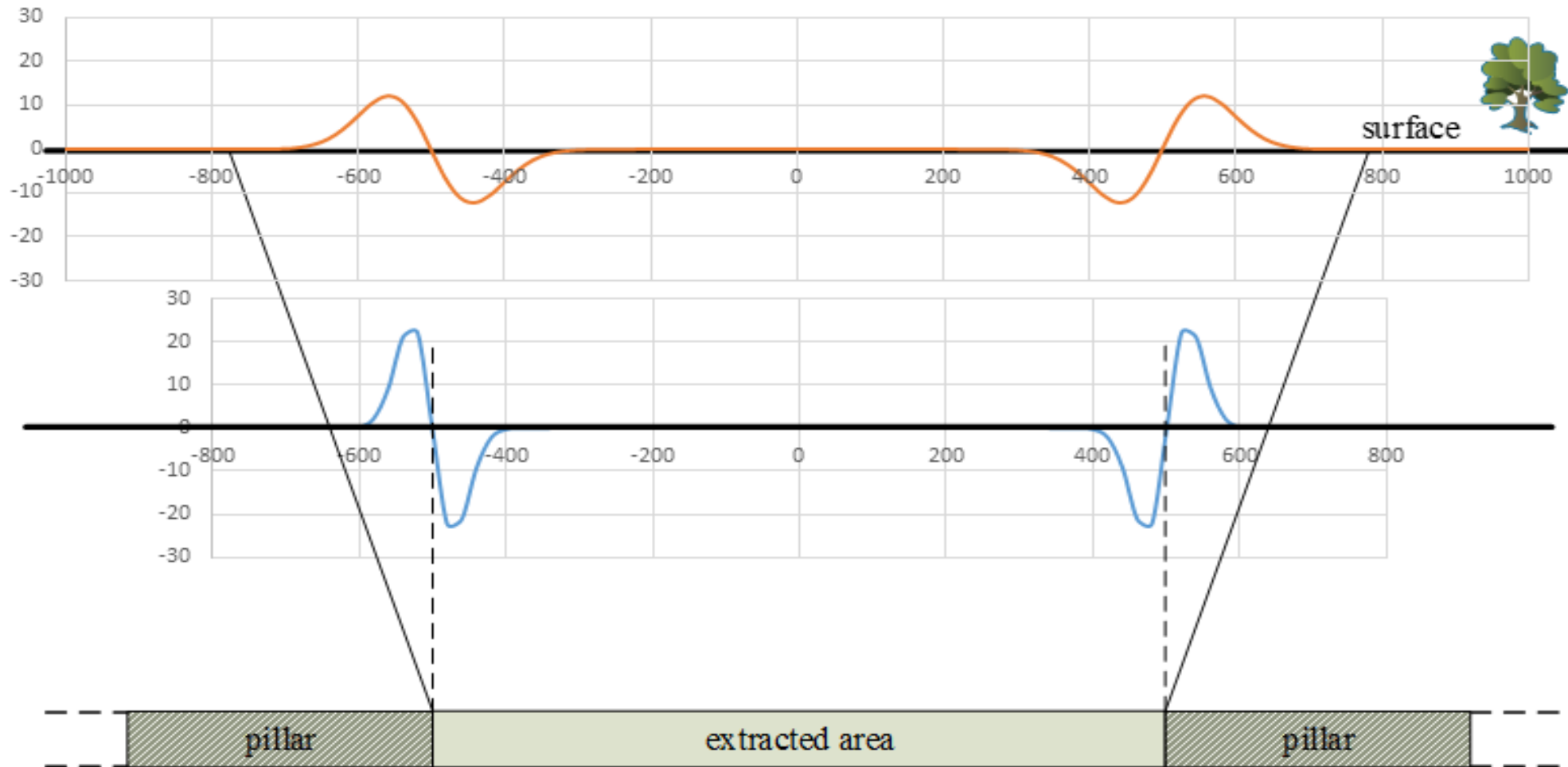
- USBM RI 9198 (Walker, 1988)



# Determining the strain regime over a High Extraction Area



# Strain at Varying Depths





# Calculation of Post-mining Hydraulic Conductivity

	Deformation Zones	Strain	S (m)	b (m)	$R_m$	$K_{y0}$ (m/d)	$K_y$ (m/d)	$K_y/K_{y0}$	Ratios used
Horizontal Strain (Tensile)	Aquifer (CDZ)	0.0041	1	0.001	0.8	0.77	4.67	6.07	1
	CDZ	0.0062	1	0.001	0.8	0.0077	0.09	11.33	1
	Caving and Fracture Zone	0.015	1	0.001	0.8	0.0077	0.5	64.72	100

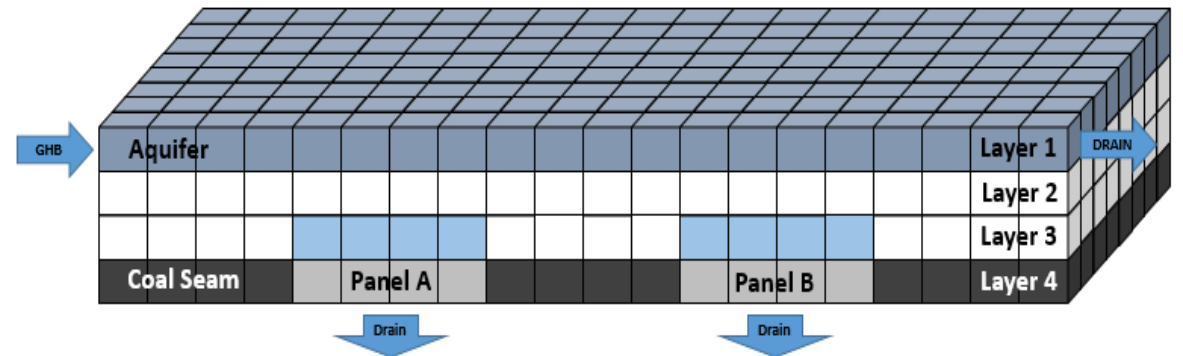
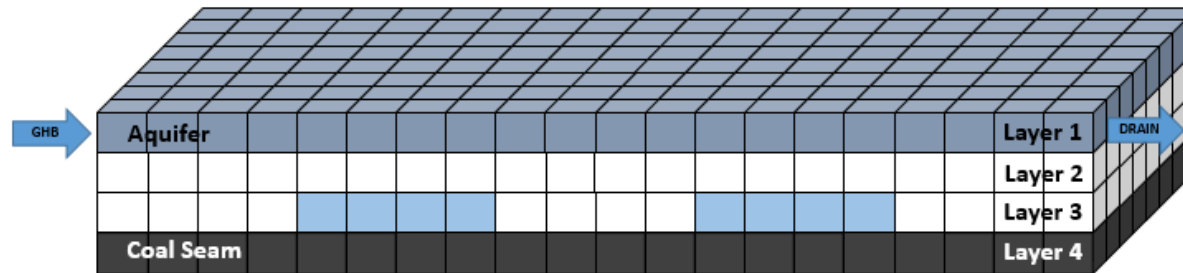
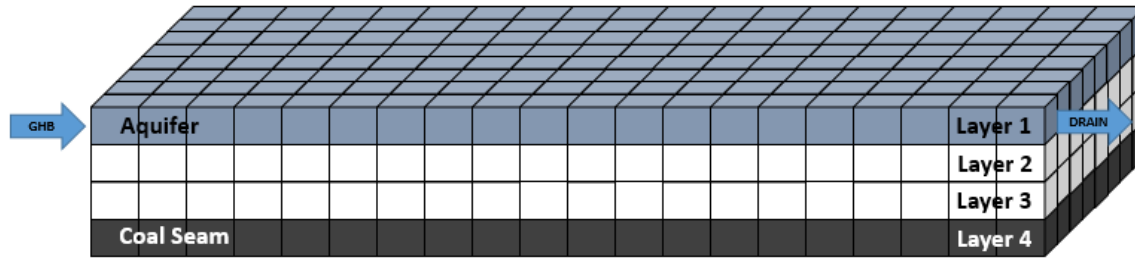


# Adjustment of Post-mining Hydraulic Conductivity

- To simplify the modelling assumptions horizontal HC values were set equal to vertical HC values
- Post-mining HC values were also simplified. The ratios calculated by the Ouyand and Elsworth equation were rounded down to one for the upper layers and rounded to 100 for the two lower layers.



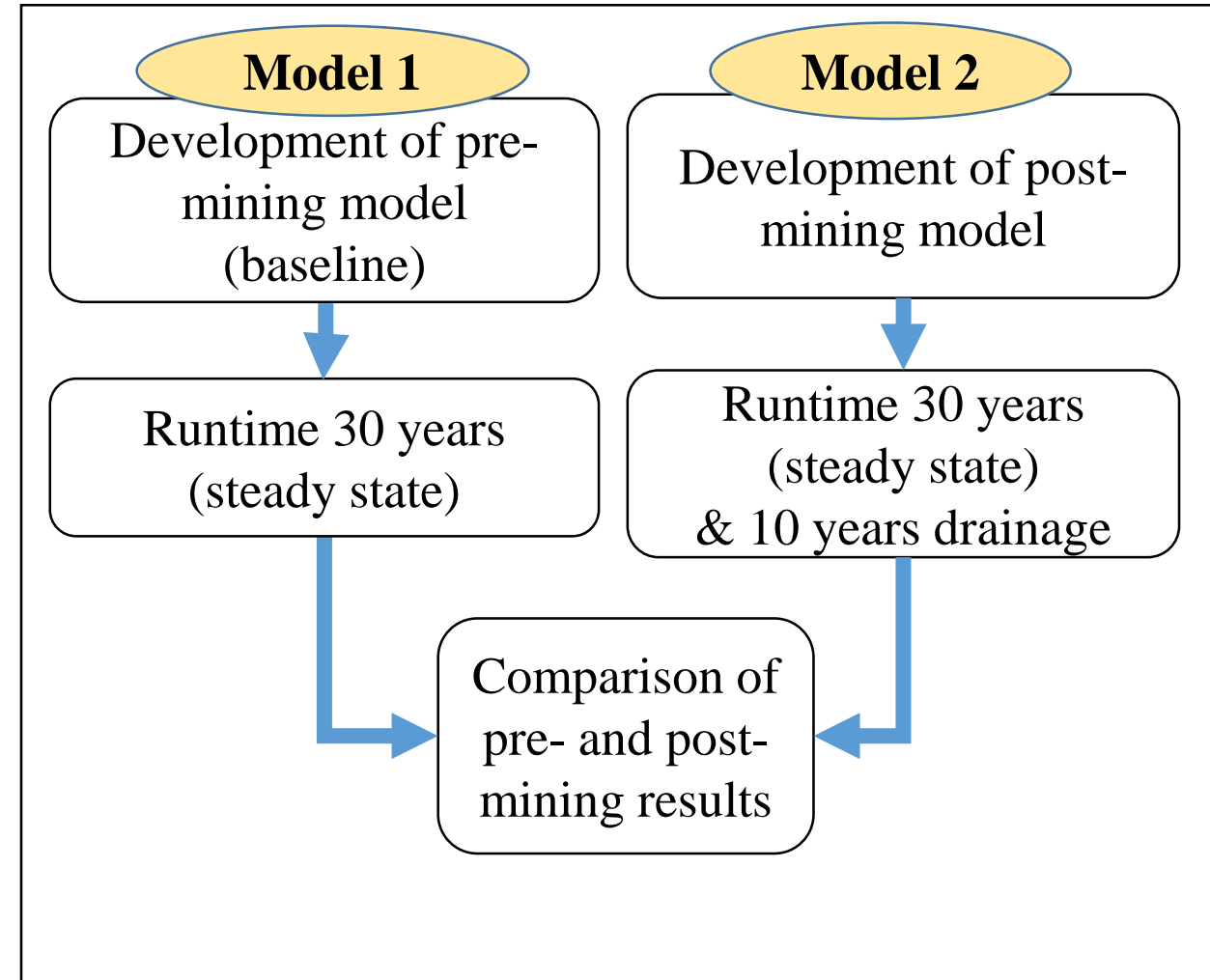
# Horizontal Pre-mining and Post-mining Models



# Development of Conceptual Scenarios

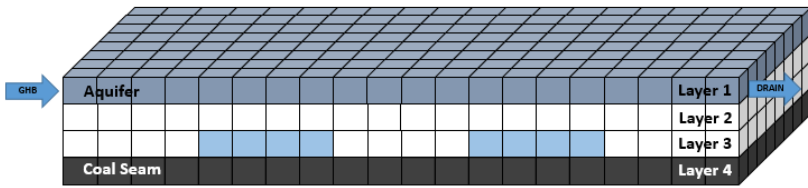
Evaluation of pre- and post-mining hydraulic heads on two conceptual scenarios:

- 1) Horizontal Surface
- 2) Inclined Surface

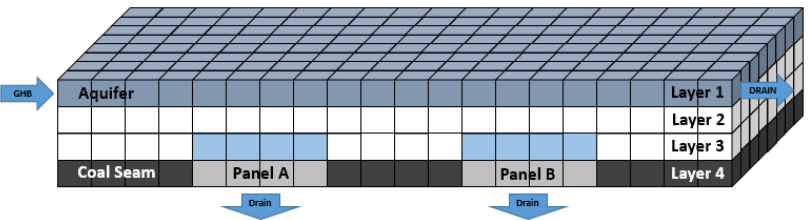


# Comparison of Horizontal Pre- and Post-mining Results

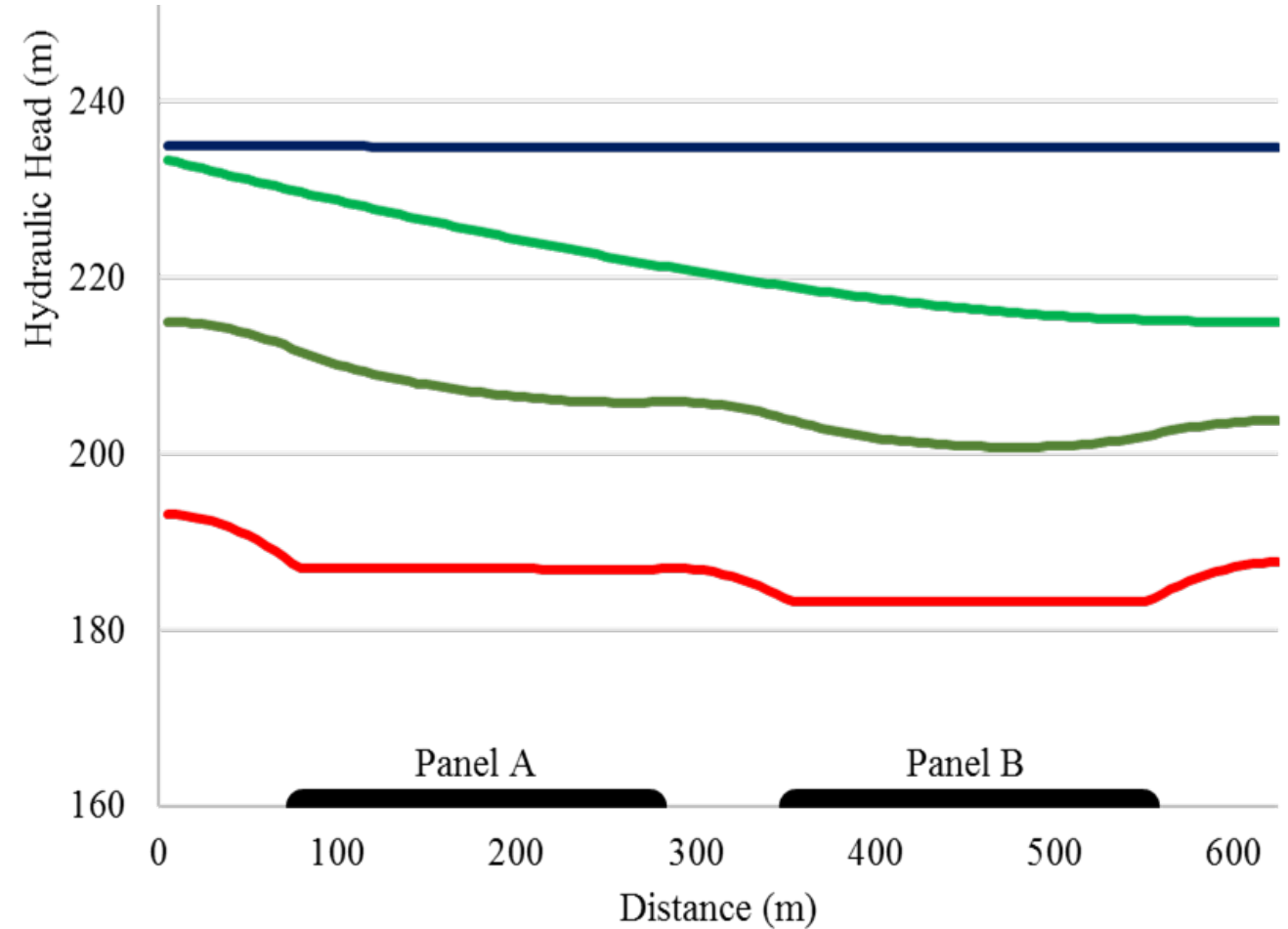
Model 1



Model 2

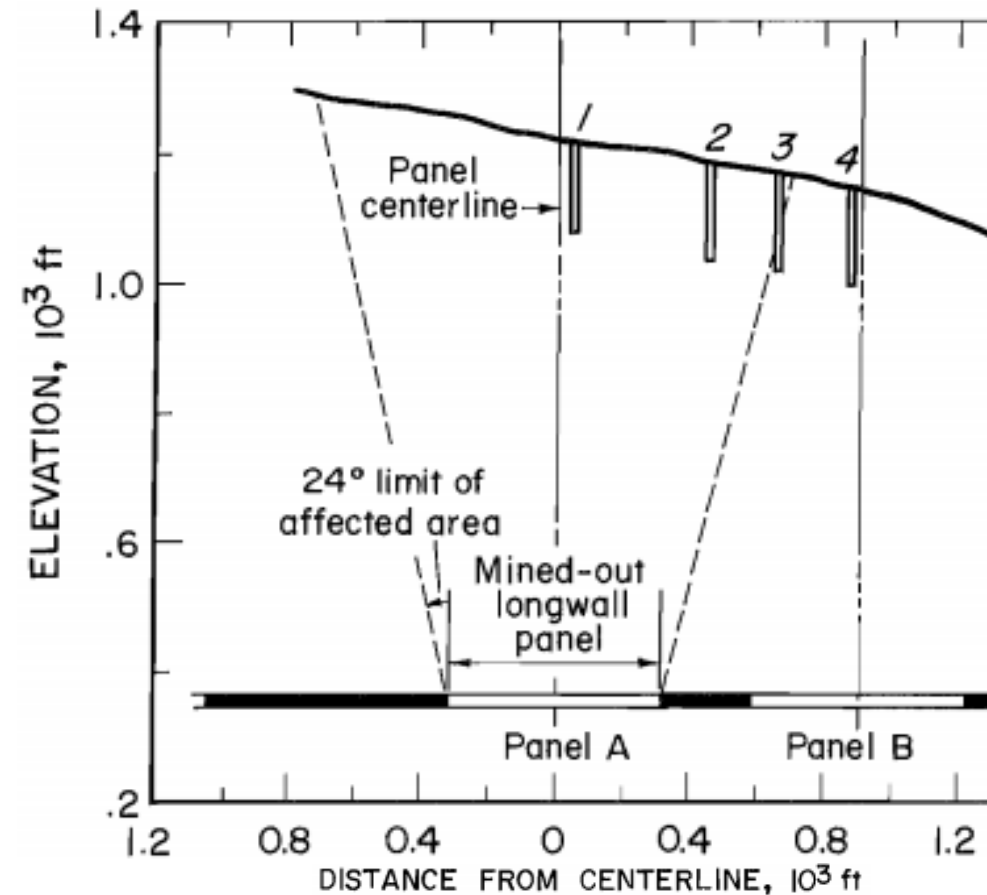
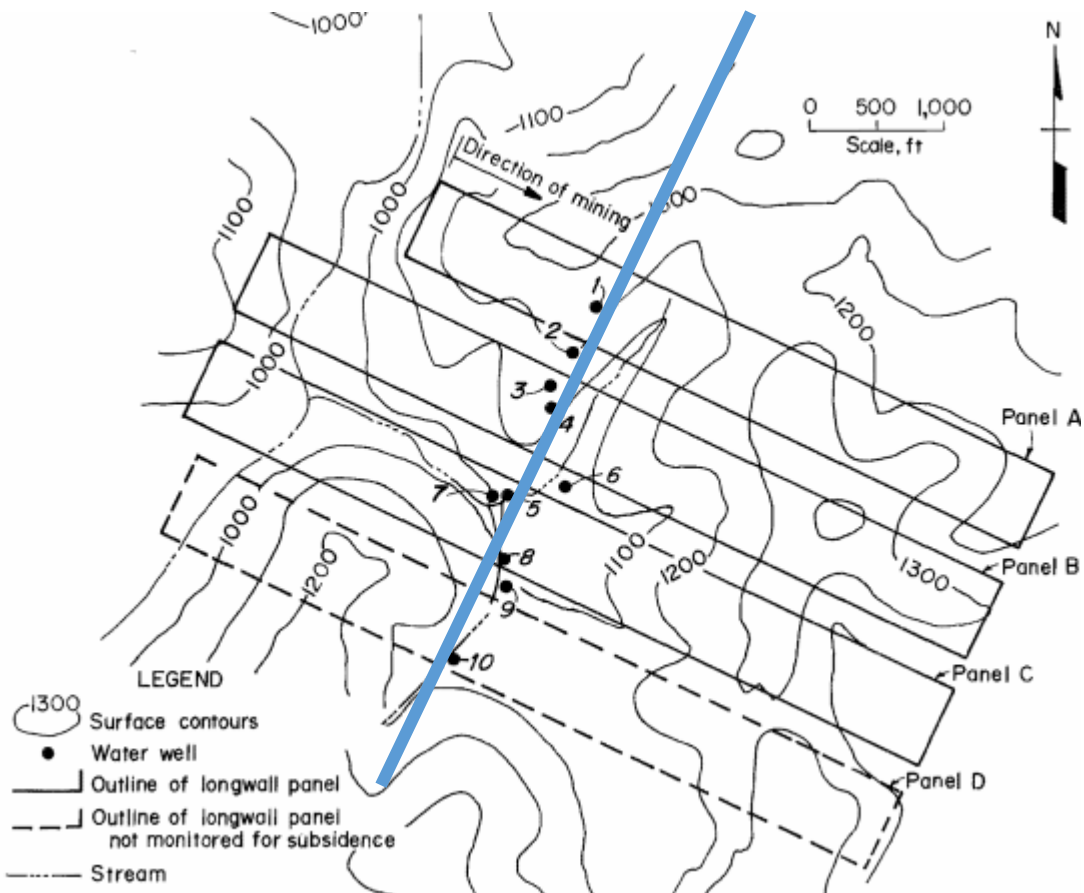


- Pre-mining Water level
- Post-mining Water level at Aquifer (CDZ)
- Post-mining Water level at CDZ
- Post-mining Water level at Caving and Fracture Zone

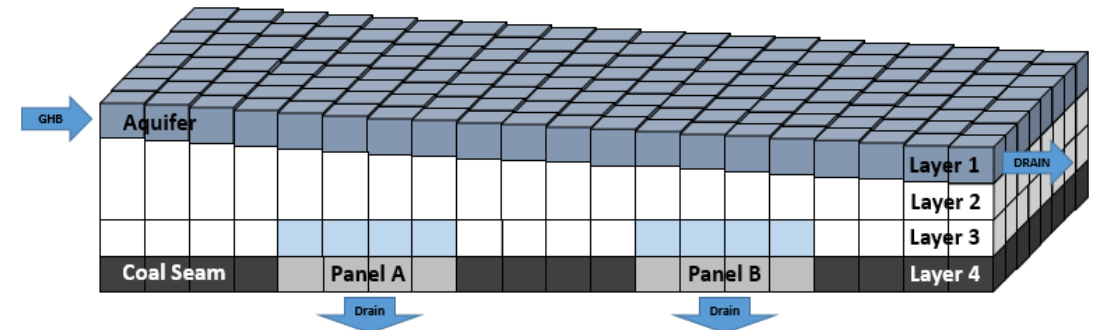
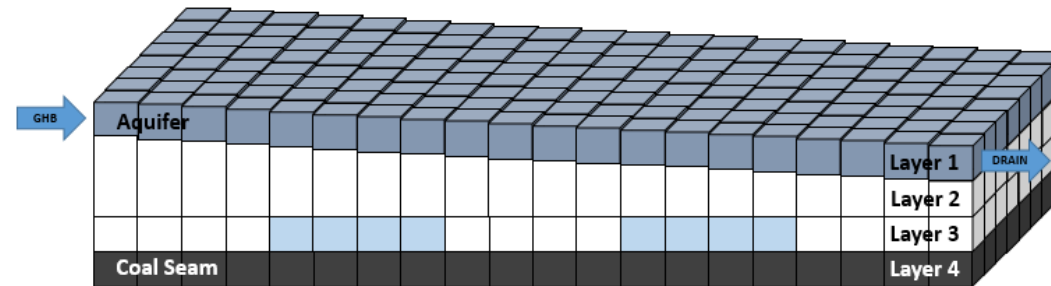
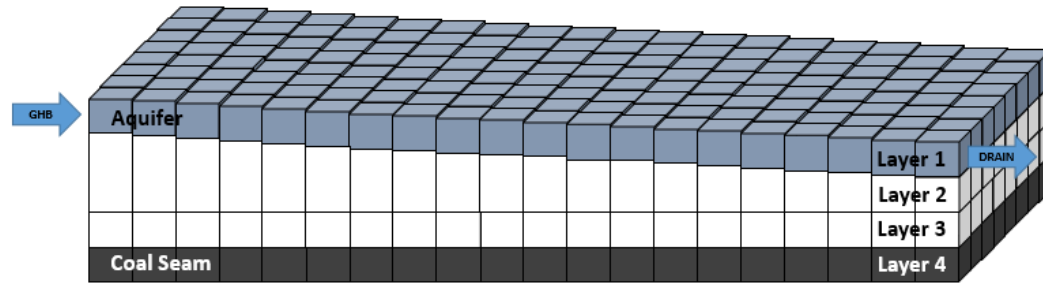


# Case Study in Northern Appalachia

- USBM RI 9198 (Walker, 1988)

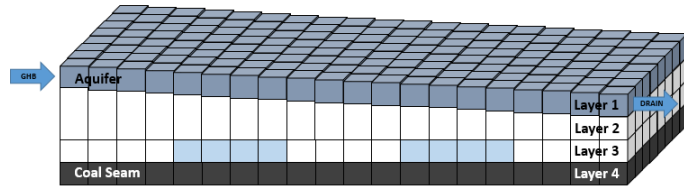


# Inclined Pre-mining and Post-mining Models

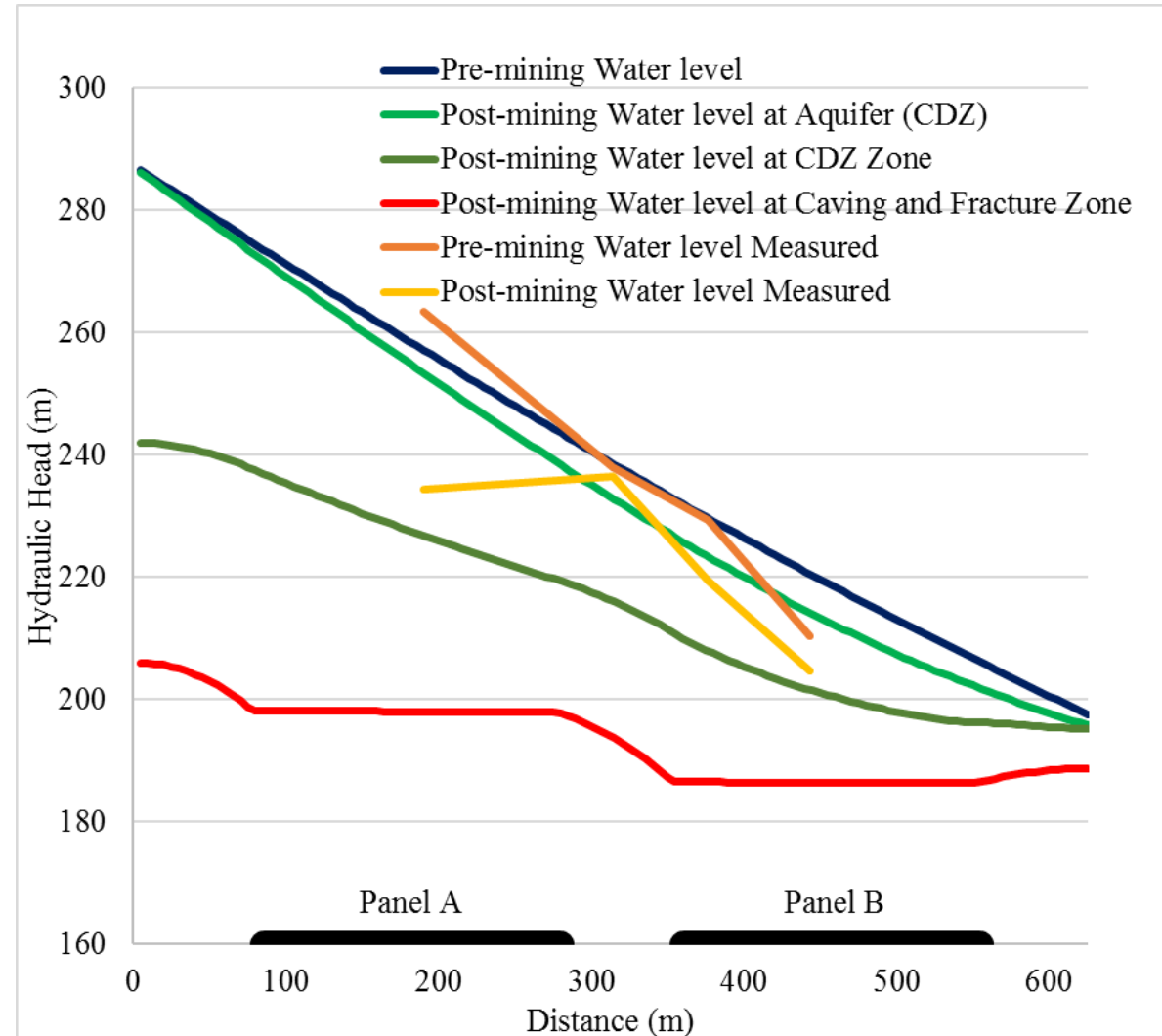
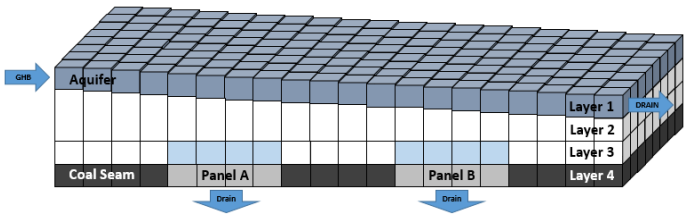


# Comparison of Inclined Pre- and Post-mining Results

Model 1



Model 2





# Summary

- A methodology for the evaluation of mining-induced impacts on subsurface bodies of water was developed.
- A number of conceptual models were developed in which the caved and fractured area above the mined-out panel was simulated as high hydraulic conductivity area.
- The methodology includes four steps:
  - 1) Calculate mining-induced subsurface horizontal strain magnitudes using SDPS
  - 2) Estimate post-mining hydraulic conductivity using equations developed by Ouyand and Elsworth (1993)
  - 3) Estimate groundwater flow and hydraulic heads within the hydrogeologic regime using the PMWiN
  - 4) Compare pre- and post-mining hydraulic heads and quantify changes in heads within the hydrogeologic regime.



# Conclusions

- Water levels (hydraulic head) related to the surface aquifers dropped as panels were mined, but water was not completely lost.
- Topography affected the post-mining distribution of water levels.
- Water levels rebounded away from the mining panels.
- Results show similar trends as described by case studies.
  
- More information: Newman, C., Agioutantis, Z. & Boede Jimenez Leon, G., (2017). Assessment of potential impacts to surface and subsurface water bodies due to longwall mining. *International Journal of Mining Science and Technology*, Vol. 27, No. 1, pp. 57 – 64.



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**Thank you for your attention!**

**Any questions?**

