USING GMS MODFLOW TO DEVELOP A GROUNDWATER FLOW MODEL TO TRACK PARTICLES ASSOCIATED WITH SLURRY INJECTION

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GENERAL OBJECTIVES OF MODEL

- FLOW DIRECTION
- TRACK PARTICLES INJECTED INTO THE SUBSURFACE FROM DEFINED SOURCES/SINKS
- DETERMINE DISCHARGE\UPWELLING LOCATIONS

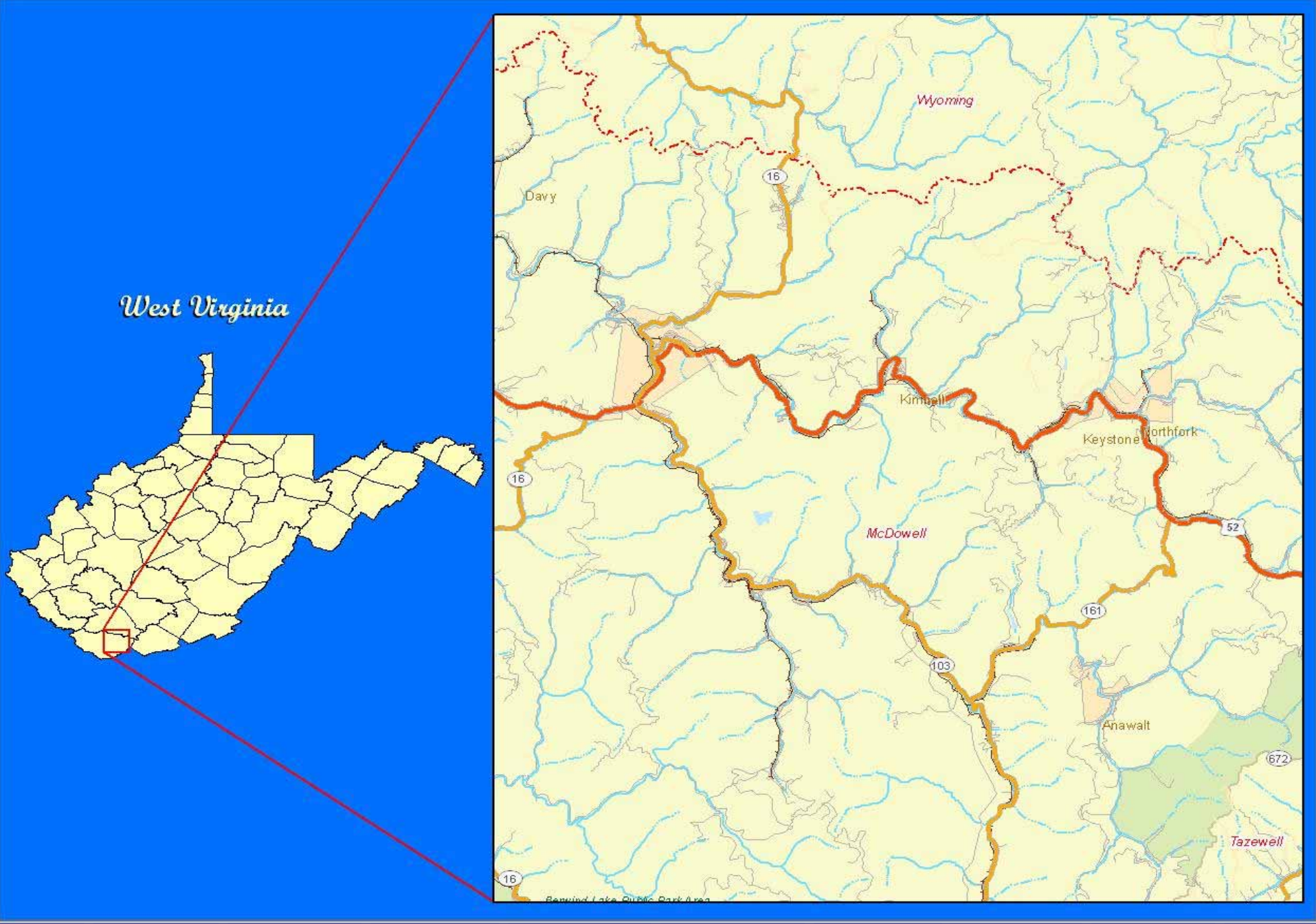
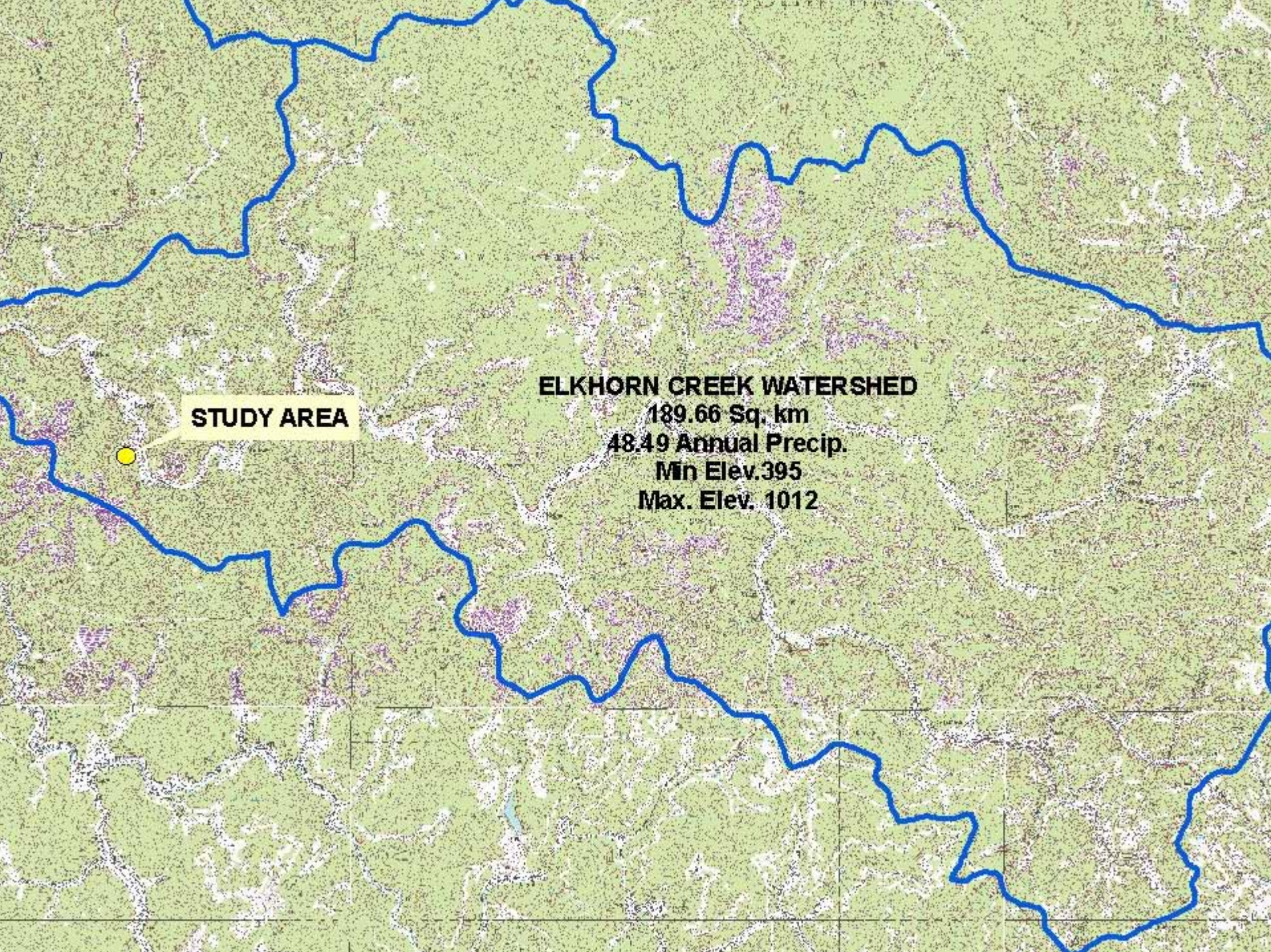
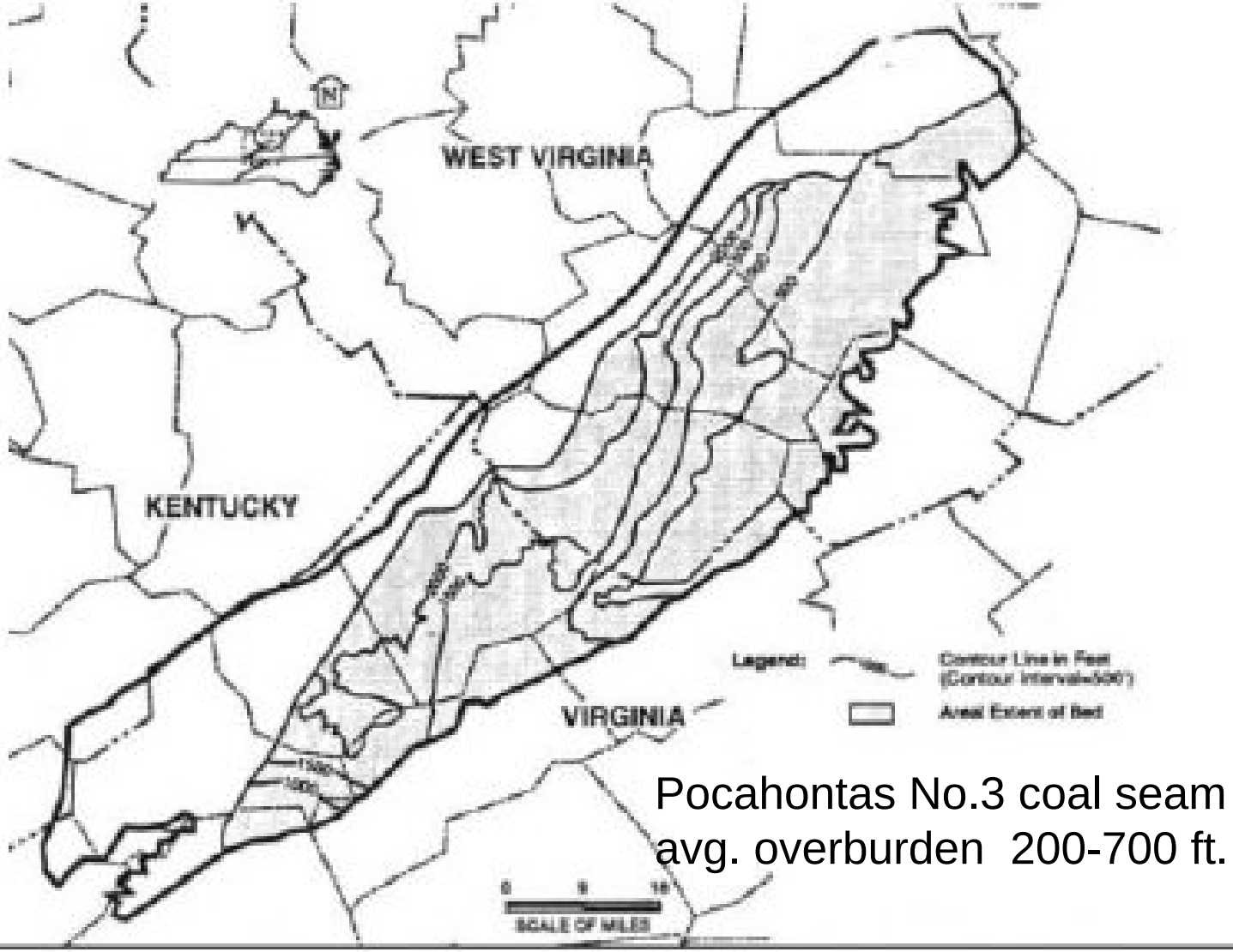


Figure 1. Location map of the study area


STUDY AREA
ELKHORN CREEK WATERSHED
189.66 Sq. km
48.49 Annual Precip.
Min Elev.395
Max. Elev. 1012

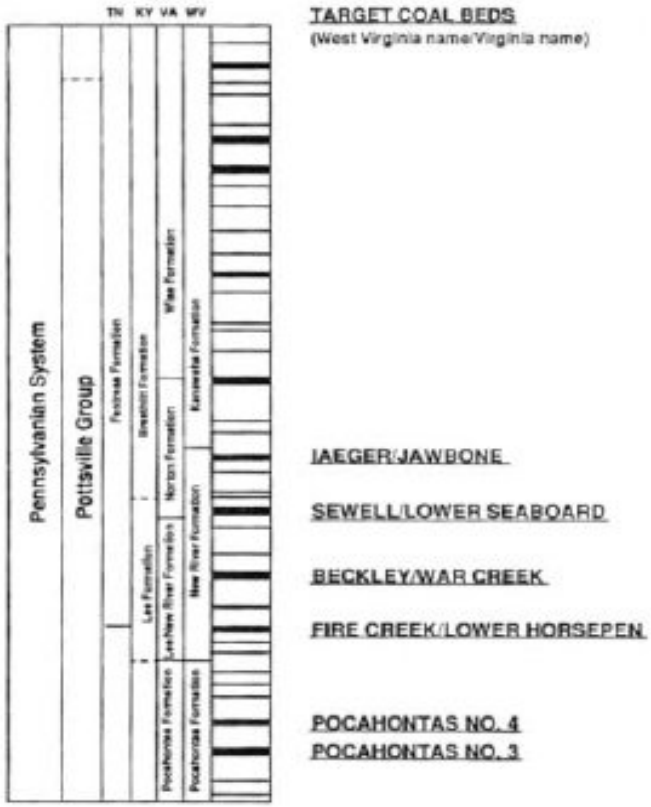


Pocahontas No.3 coal seam
avg. overburden 200-700 ft.

Isopach Map: Thickness of Cover Over the Pocahontas No. 3 Coalbed (Kelafant et al., 1988)

Figure A6-4

Figure 2. *Isopach* Map. Thickness *of cover over the Pocahontas No.3 Coal bed*



Representative Stratigraphic Column of Pennsylvanian Age Formations
(Kelafant et al., 1968)

Figure A6-3

Figure 3. Stratigraphic column of Pennsylvanian Age Formations

HYDROLOGIC BASIN

- Primary aquifers are Lower Pennsylvanian
- Pocahontas Formation is main source of public and residential groundwater usage
- Wells are commonly 50 to 300 feet deep
- Aquifer yields usually range from 1 to 50 gal/min from wells 200 feet or less in depth.
- Stress relief fracture system with unknown extent
- Secondary fracturing due to extensive mining
- Regional dip is 2% northwest/southeast trend
- Lateral discharge is seen as seeps or springs on hillsides

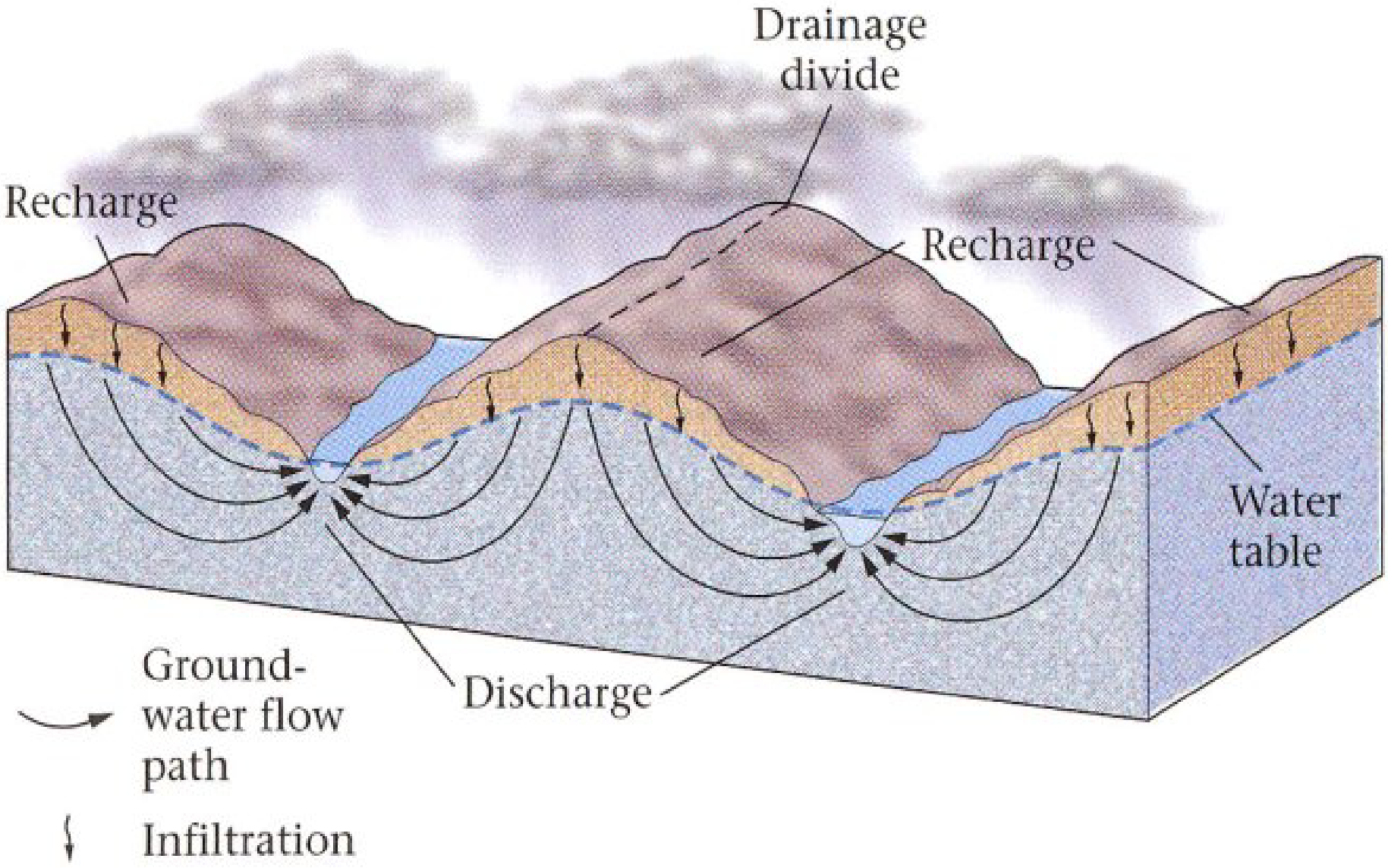


Figure 4. Flow lines from the recharge area top the discharge area curve through the substrate. Some groundwater descends to great depths and then rises back to the surface. (Marskal 2008))

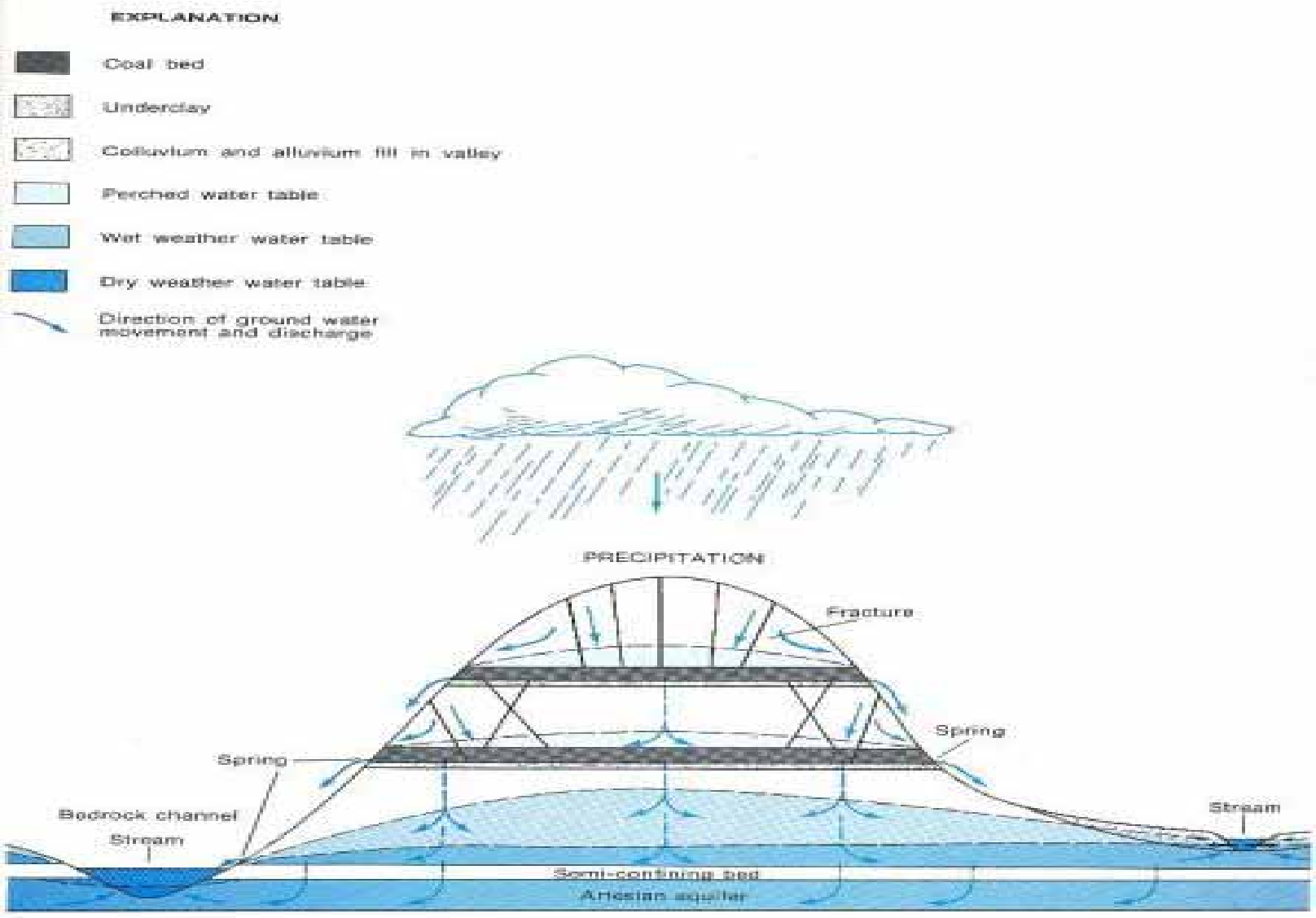


Figure 7.1-1 Generalized water movement in aquifers.

Figure 5. Generalized water movement in aquifers. (USGS)

Anything that moves requires an expenditure of energy and so does groundwater.

Hydraulic Head (h) is the energy per unit weight of water h = v2/2g + z + P/y.

Groundwater moving from point 1-> 2 Consumes:

Hydraulic Head (h) is the energy per unit weight of water h = v2/2g + z + P/y.

Hydraulic gradient is the change in hydraulic head/ distance of flow path dh/dl. Groundwater moves from higher -> lower head

Darcy's Law Governs the flow through a porous material

$$Q = k \ A \ dh/dl$$

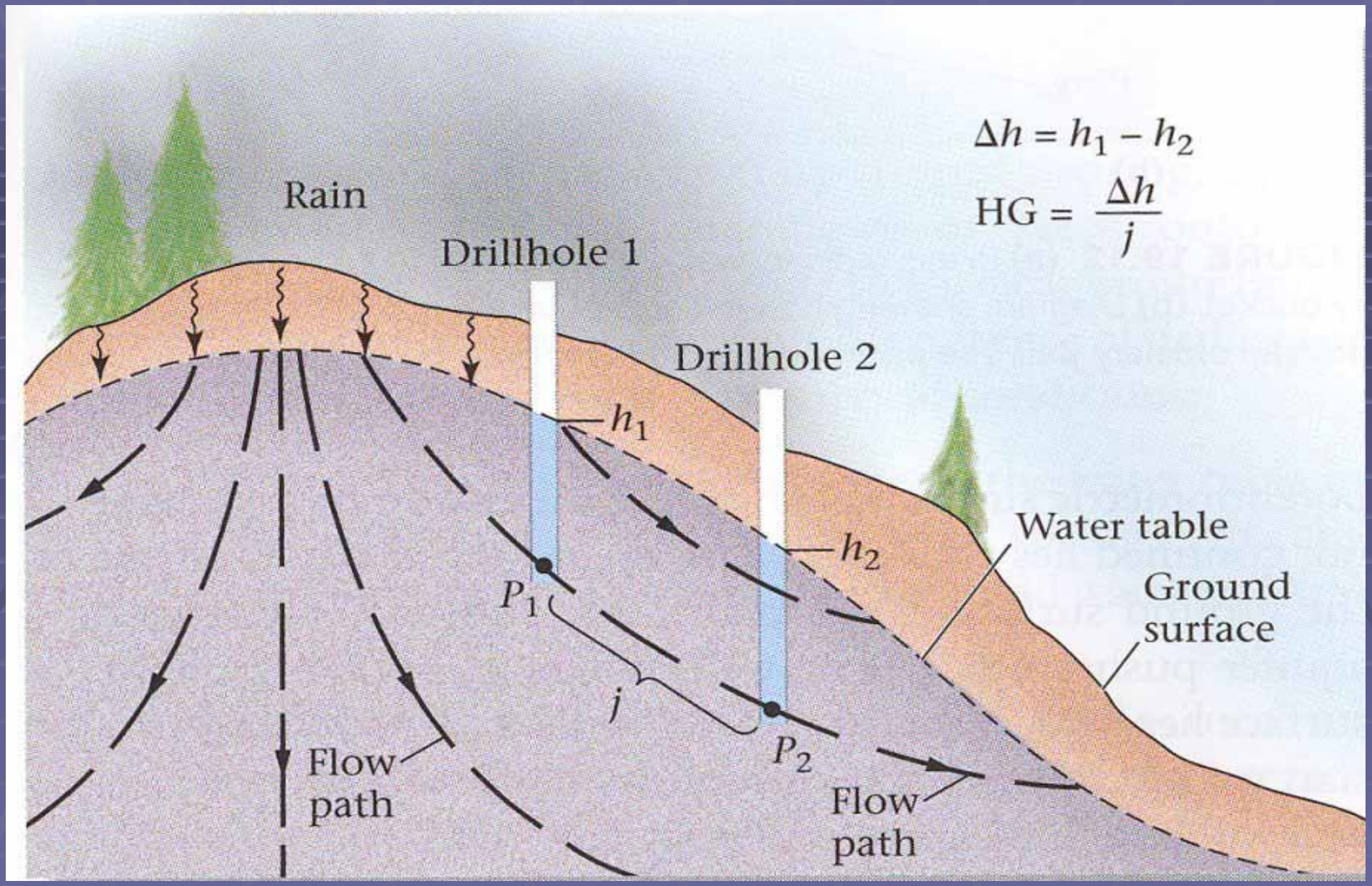
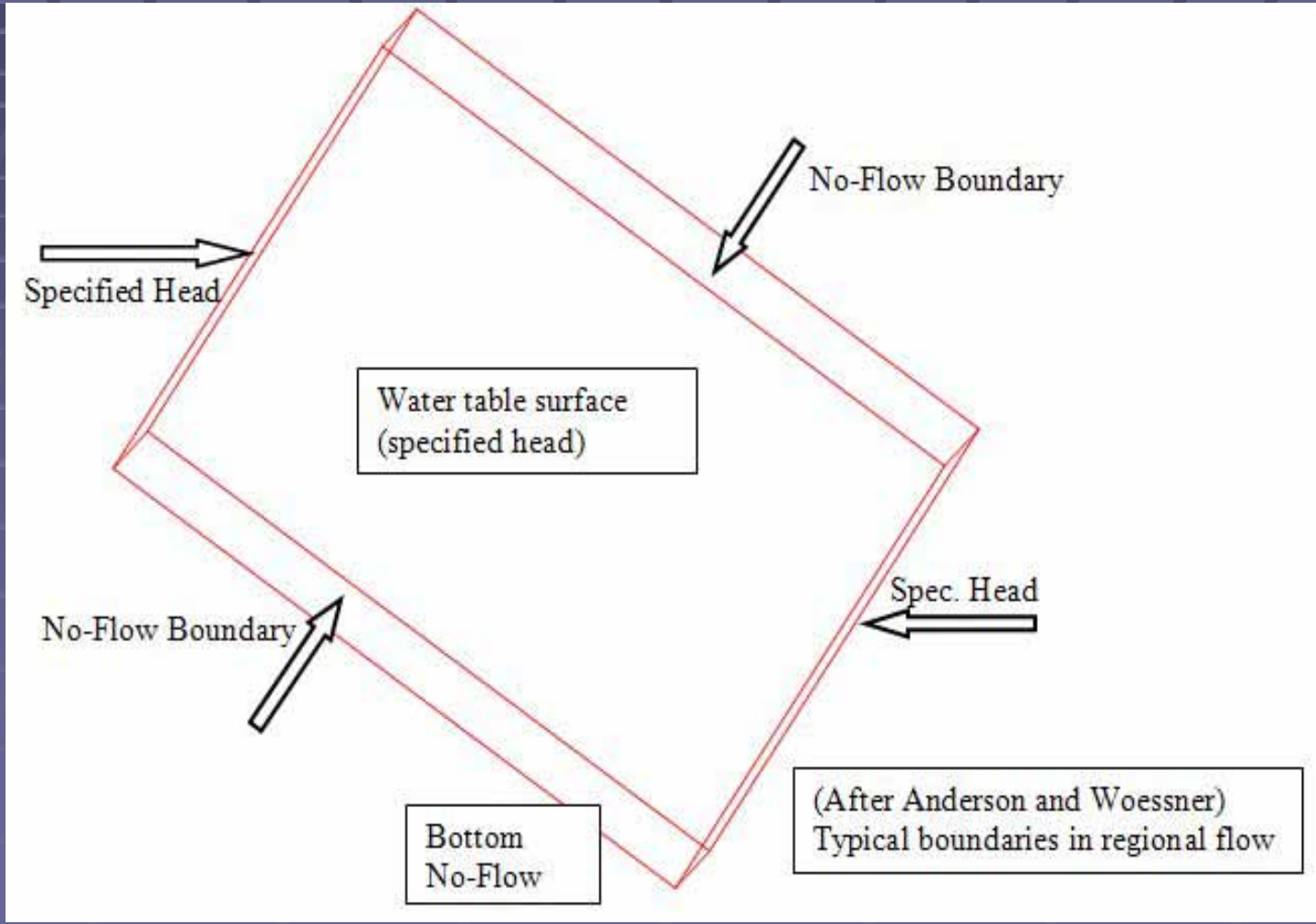


Figure 6. Hydraulic gradient (HG) is the change in hydraulic head per unit of distance between two points (j) along the flow path. (Marskal 2008)

DATA REQUIRED FOR MODEL

- Physical configuration of the aquifer
- Location, areal extent, and thickness of all the aquifers
- Boundary conditions
- Hydraulic properties including the variation of transmissivity or permeability and storage coefficient of the aquifers, the variation of permeability and specific storage of the layers
- Hydraulic connection between the aquifers and surface-water bodies.
- The conceptual model database coverage's were from GIS coverage's (NAD83, Zone 17).

BOUNDARY CONDITIONS



MOST OBVIOUS FORCE GRAVITY

There are three outside forces acting on ground water. The most obvious is gravity, which pulls water downward. The second influence is external pressure. Above the zone of saturation, atmospheric pressure is acting. The third force is molecular attraction, which causes water to adhere to solid surfaces.

The modeled area has a northwest dip of approximately 2% with a northwest-southeast trend as shown in Figure 12.

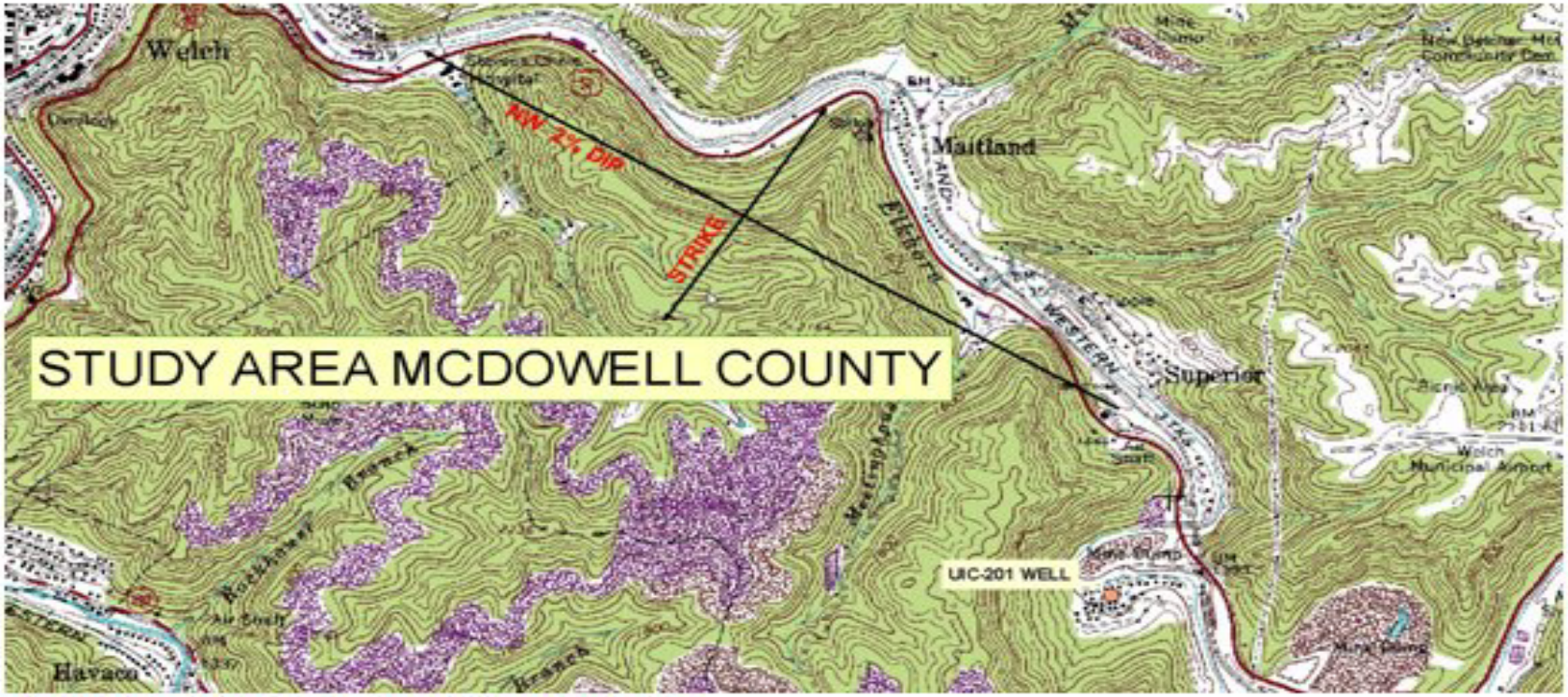
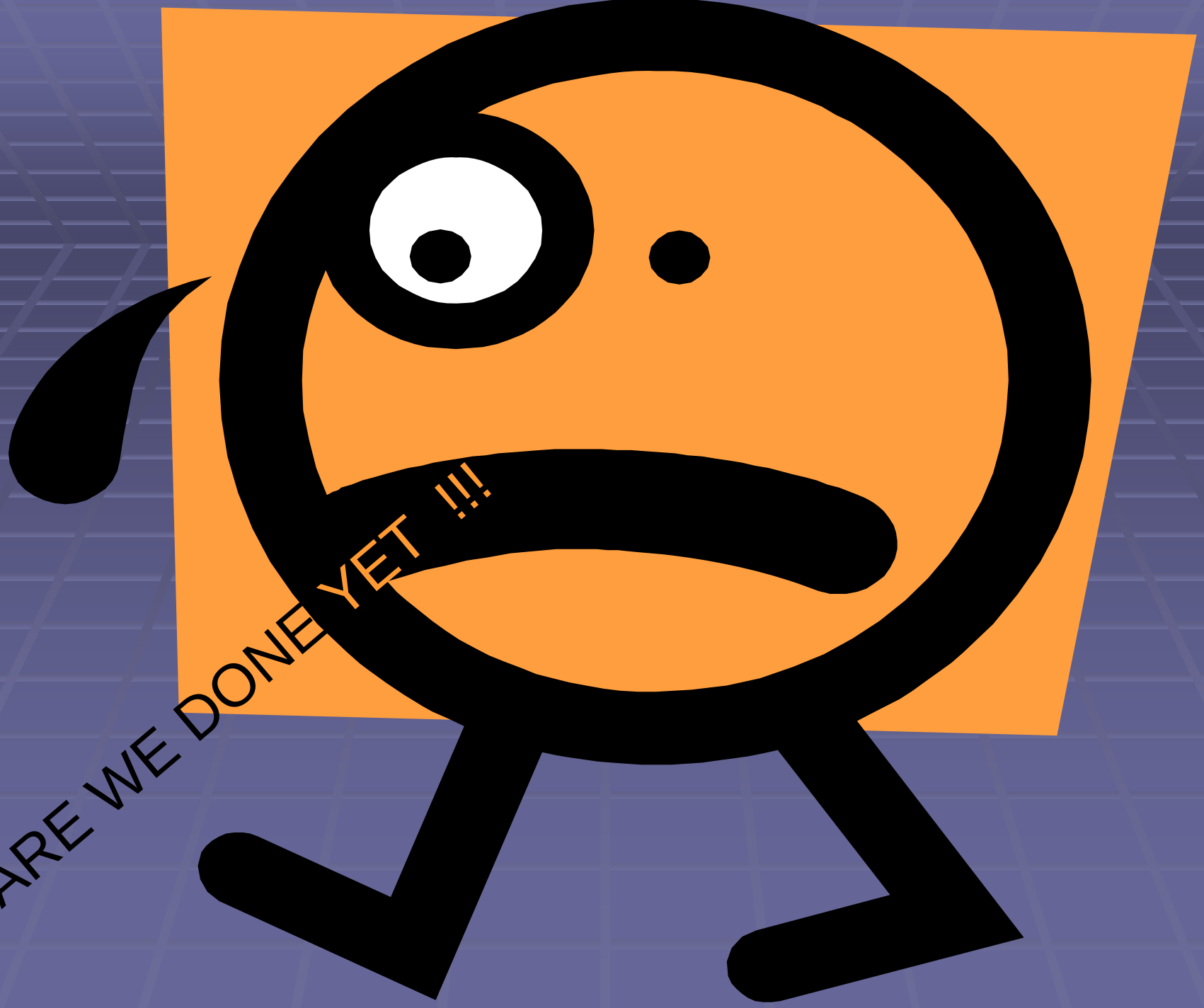


Figure 12. Strike and dip of modeled area.

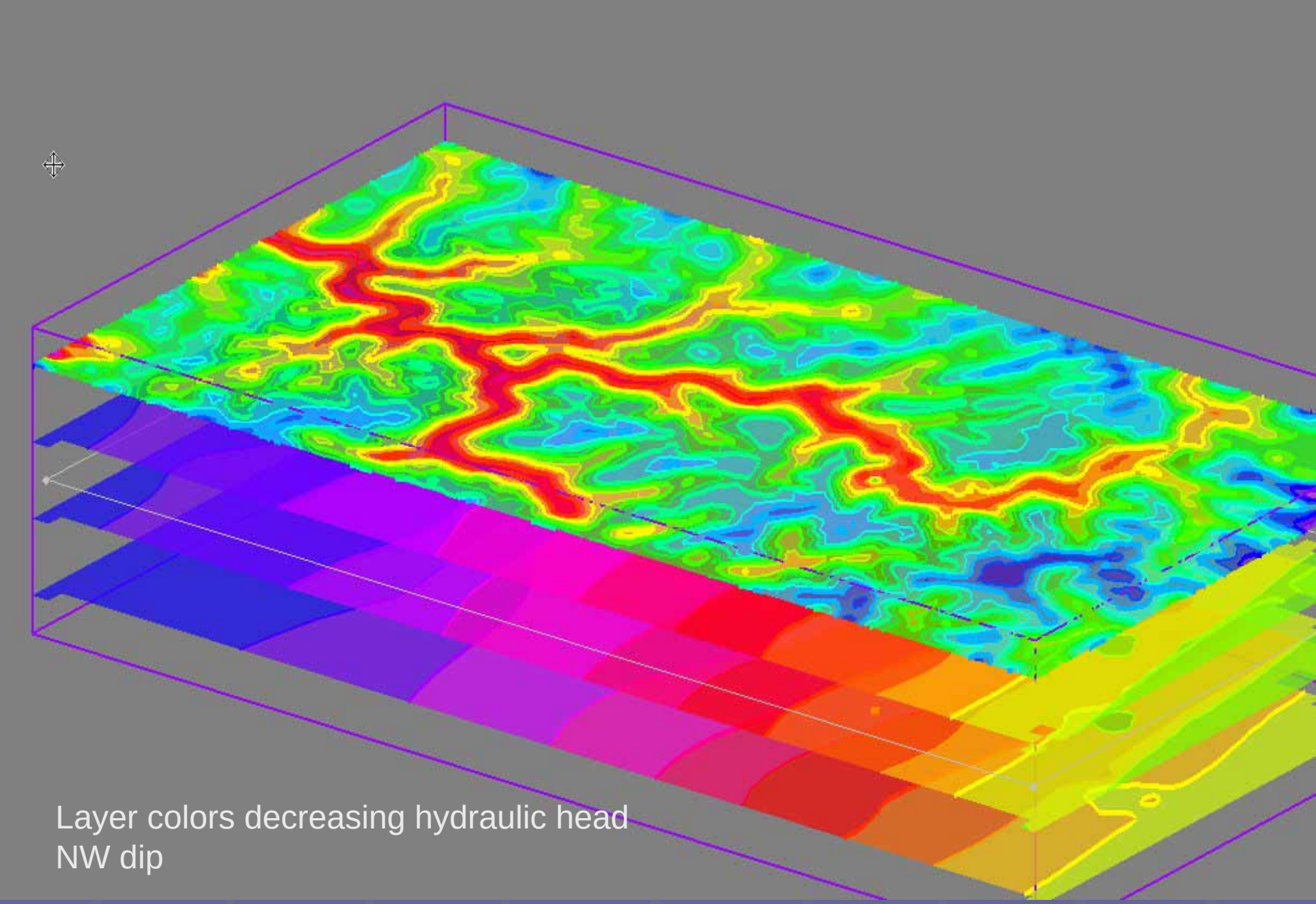
BOUNDARY INPUT

- In the area modeled the boundary conditions were mixed, with some portions having known head and some portions having known flux.
- Flux boundary conditions are used to specify a known flux rate [L/T] along a sequence of element edges on the perimeter of the mesh. They are often used to simulate infiltration. Flux into the system is positive and flux out of the system is negative. (After Anderson and Woessner)
- The hydraulic boundaries were determined from the topographically high and low areas.


ARE WE DONE YET !!!

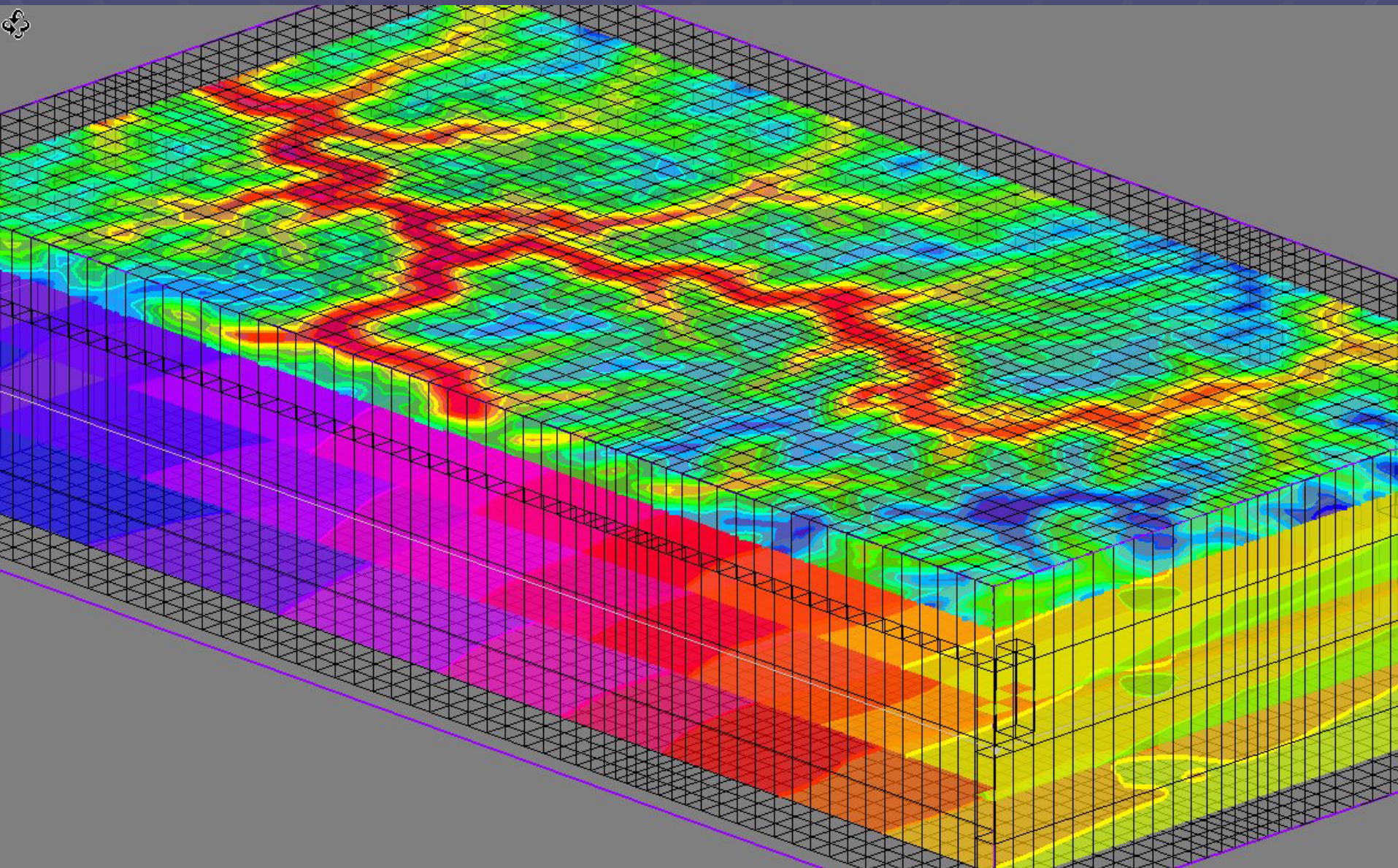
MODEL DEVELOPMENT

- The model is three-dimensional in that four layers of porous media were stacked with the layers having the same x-y grid dimensions and spacing.
- The delta-z dimension is not specified, but is determined indirectly.
- Transmissivity of each layer (hydraulic conductivity X delta-z) is specified.
- Top layer is considered convertible with top and bottom elevations specified.
- For each cell the model determines if it is confined (the head is greater than the elevation of the top) or unconfined (the head is less than the elevation of the top)



LAYERS DEFINING MODEL

CLOSE GRID SPACING IN ORDER TO CAPTURE STEEP GRADIENT



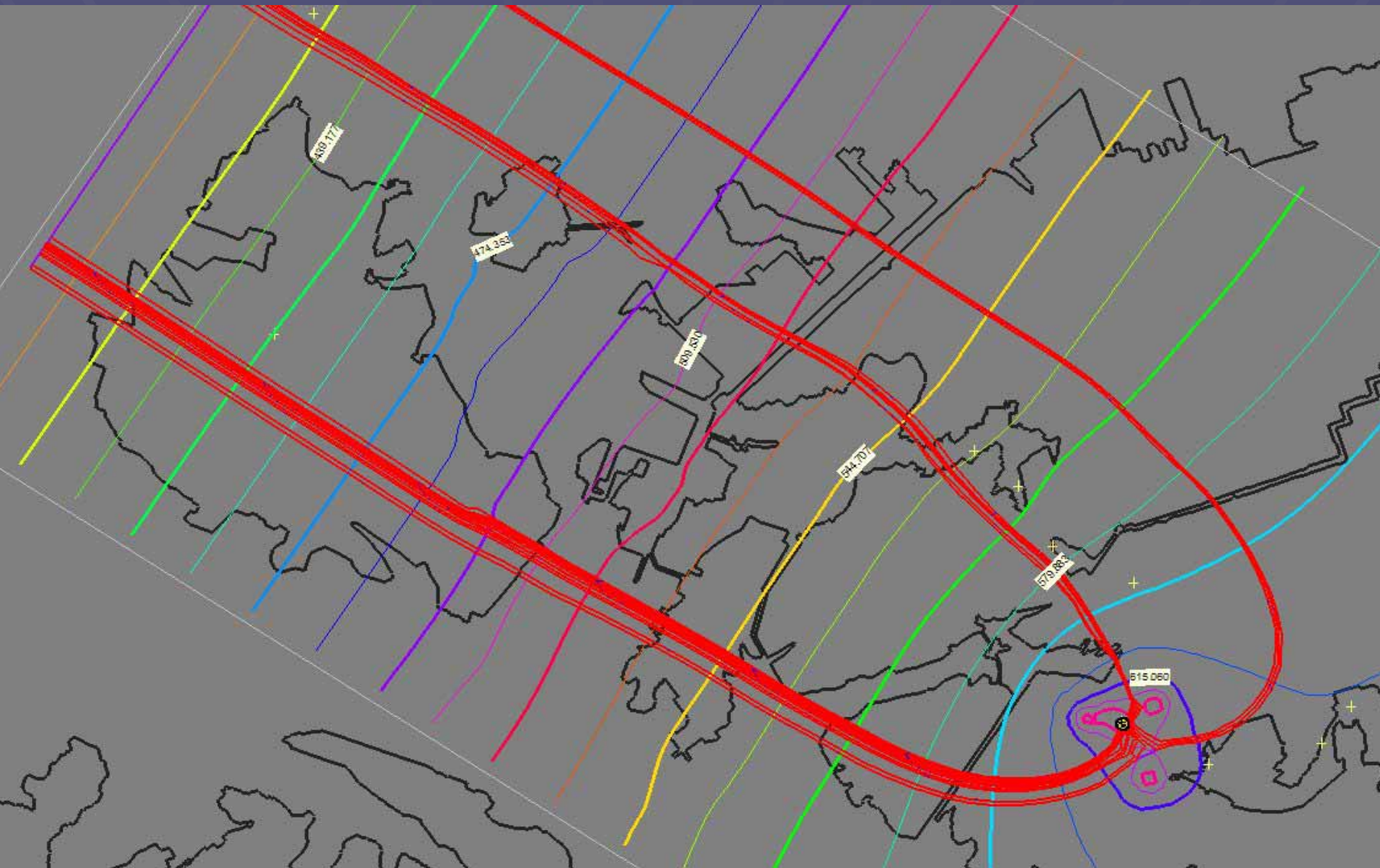
SOLVER PACKAGE

- The PCG2(Preconditioned conjugate gradient method) package was used.
- PCG2 solvers works with wetting capability
- Two important variables affecting stability:
- a. Wetting threshold
- b. Which neighboring cells are checked
- to determine if a cell should be
- wetted.

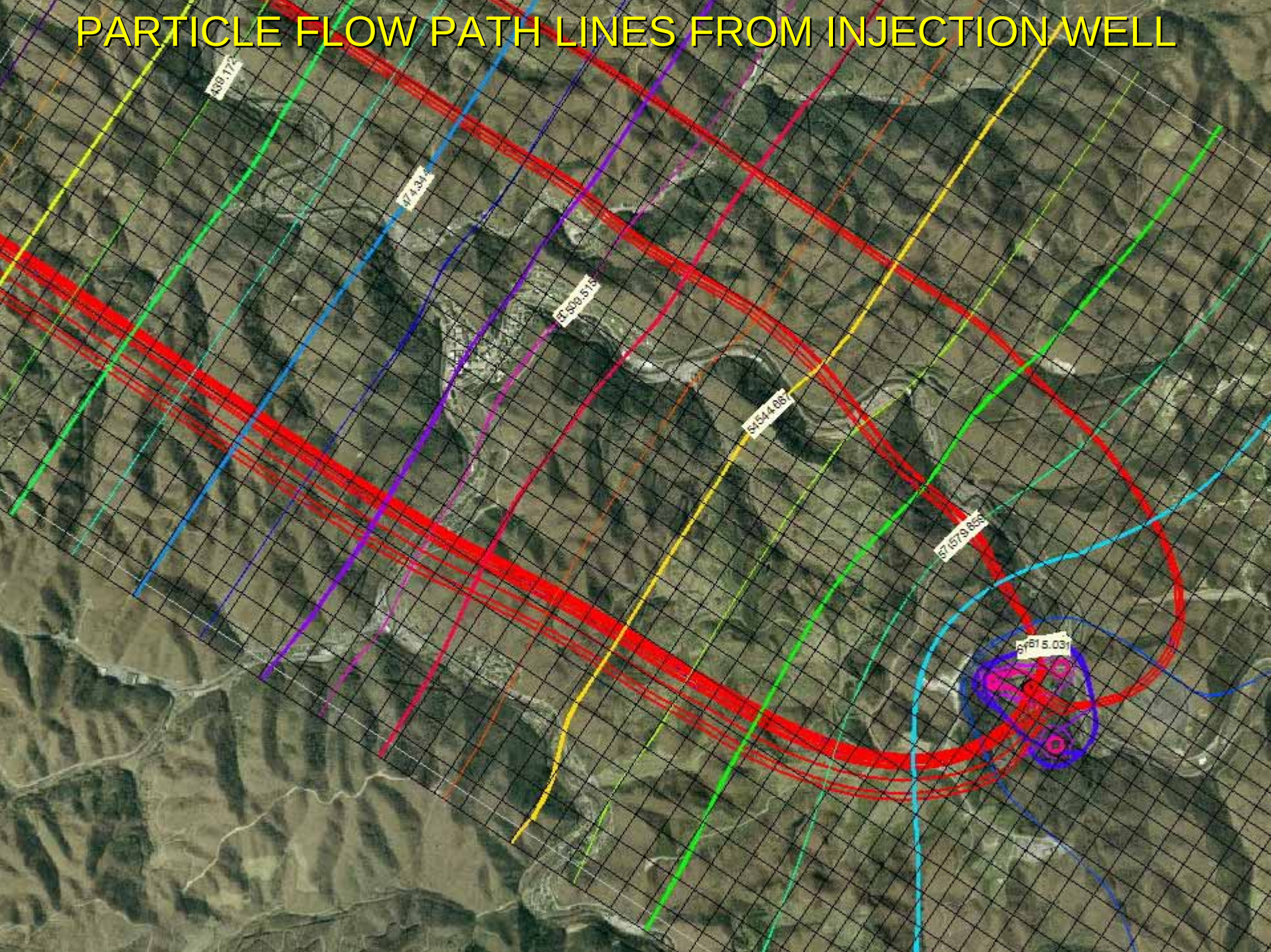
MODPATH

- Used for particle tracking.
- Post-processing package to compute three-dimensional flow paths using output simulations by MODFLOW (USGS)
- Uses steady state or transient flow (David W. Pollock 1994)
- Semi-analytical scheme that allows an analytical expression of the particle's flow path to be obtained within each cell
- Particle paths are computed by tracking particles from one cell to the next until a boundary is reached.

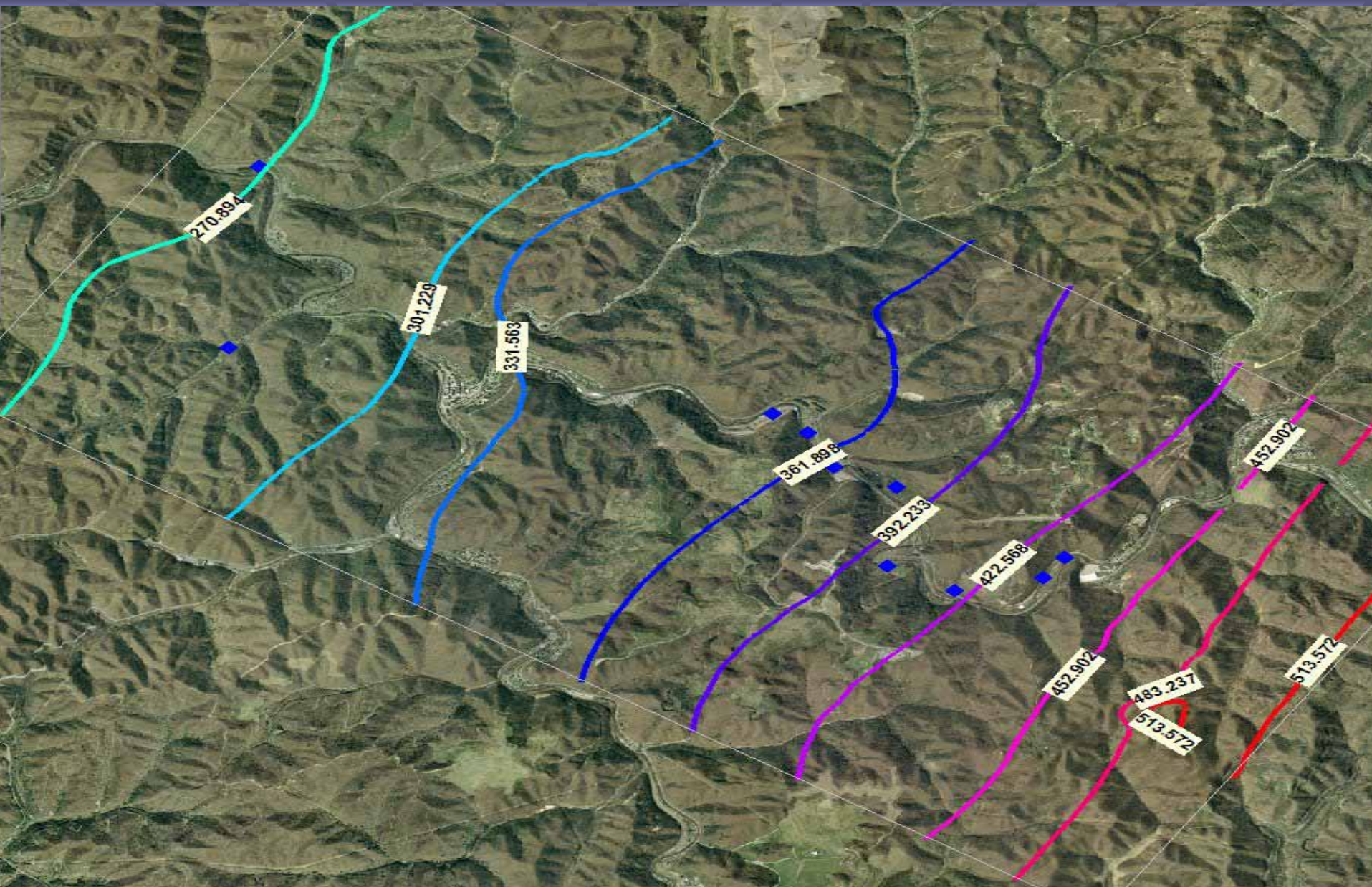
Particle Flow Over Mined Area



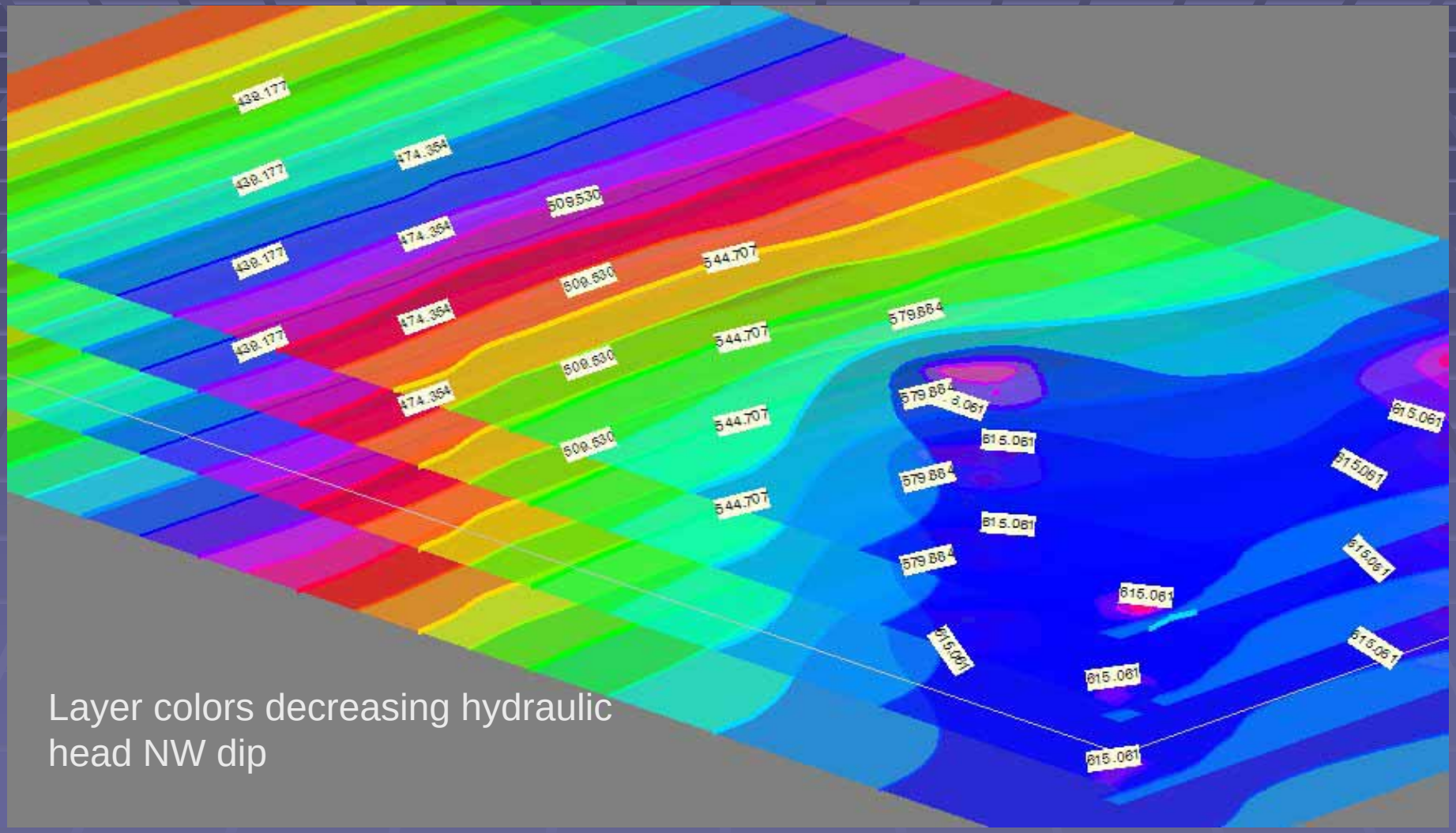
PARTICLE FLOW PATH LINES FROM INJECTION WELL



DECREASING HYDRAULIC HEAD NW_DIP



MODELED DECREASING HEAD VALUES

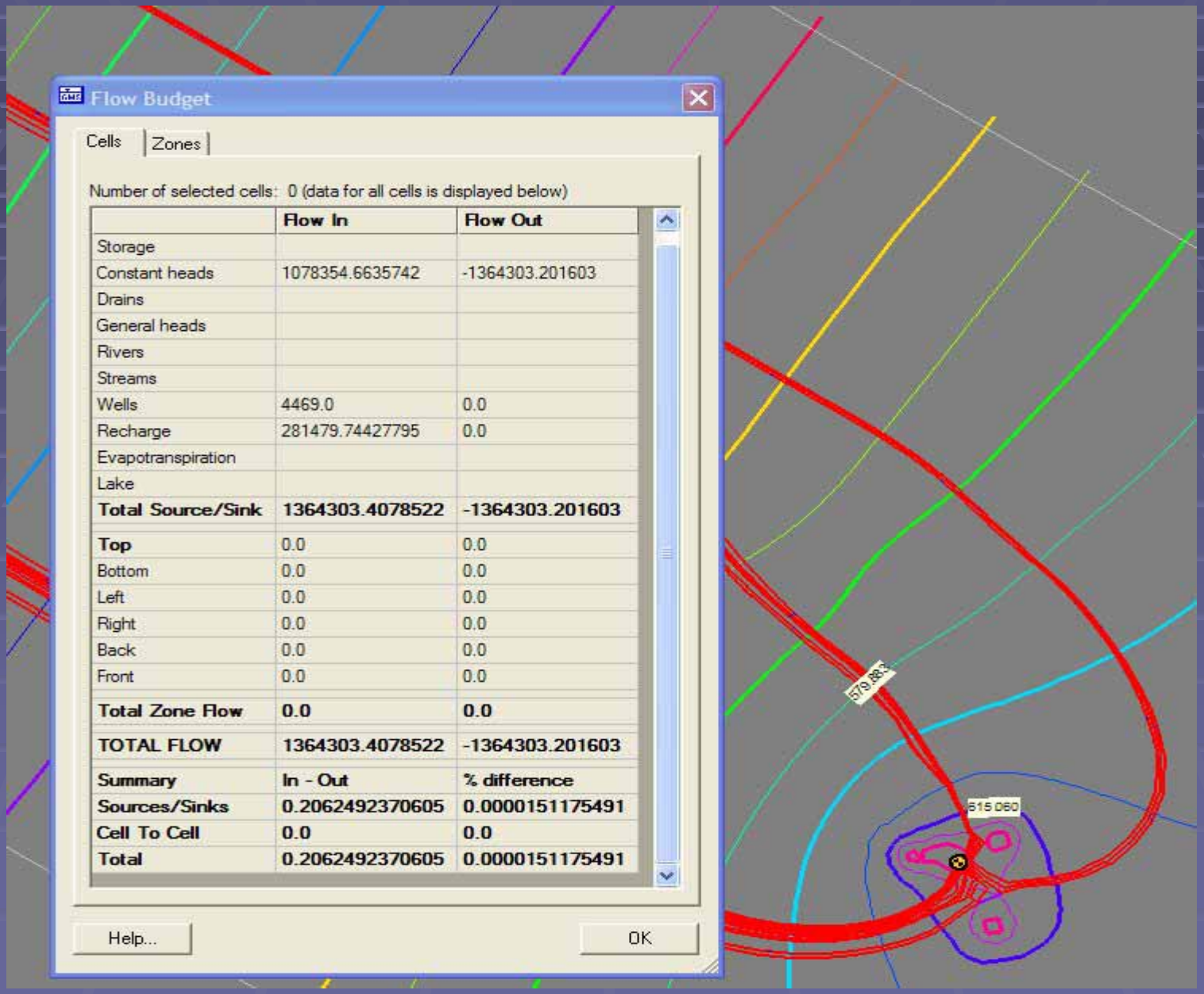


Layer colors decreasing hydraulic head NW dip

FLOW BUDGET

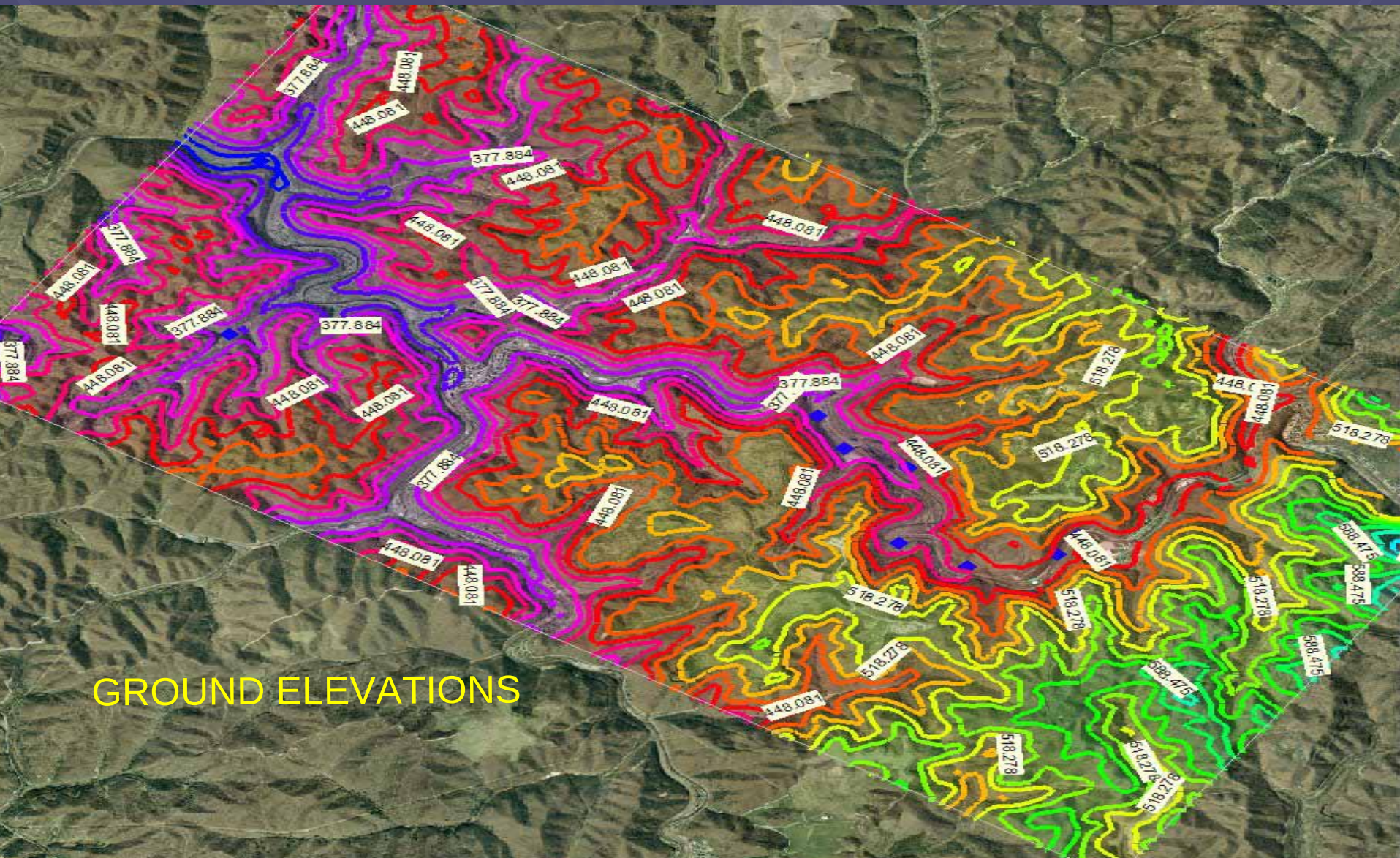
- Budget ID’s are assigned
- Flow budgets for each zone can be viewed
- Flow budget table can be rendered as a summary
- The model indicated that 79.04% of flow is from the constant heads with recharge contributing 20.63% to the system and the well only contributing .33%.

FLOW BUDGET SUMMARY



	Flow In	Flow Out
Storage		
Constant heads	1078354.6635742	-1364303.201603
Drains		
General heads		
Rivers		
Streams		
Wells	4469.0	0.0
Recharge	281479.74427795	0.0
Evapotranspiration		
Lake		
Total Source/Sink	**1364303.4078522**	**-1364303.201603**
Top	0.0	0.0
Bottom	0.0	0.0
Left	0.0	0.0
Right	0.0	0.0
Back	0.0	0.0
Front	0.0	0.0
Total Zone Flow	**0.0**	**0.0**
TOTAL FLOW	**1364303.4078522**	**-1364303.201603**
Summary	**In - Out**	**% difference**
Sources/Sinks	**0.2062492370605**	**0.0000151175491**
Cell To Cell	**0.0**	**0.0**
Total	**0.2062492370605**	**0.0000151175491**

MODEL CLOSELY PROJECTED ACTUAL KNOWN FIELD OBSERVATIONS IN AREAS OF DISCHARGE AND SEEPS



Conclusions and Recommendations

- The groundwater model tests how well we understand the actual site conditions by comparing observed and modeled data.
- Observed and modeled water levels, flow direction, and velocities should be similar as is the case in the study area.

CONCEPTUAL MODEL INDICATIONS

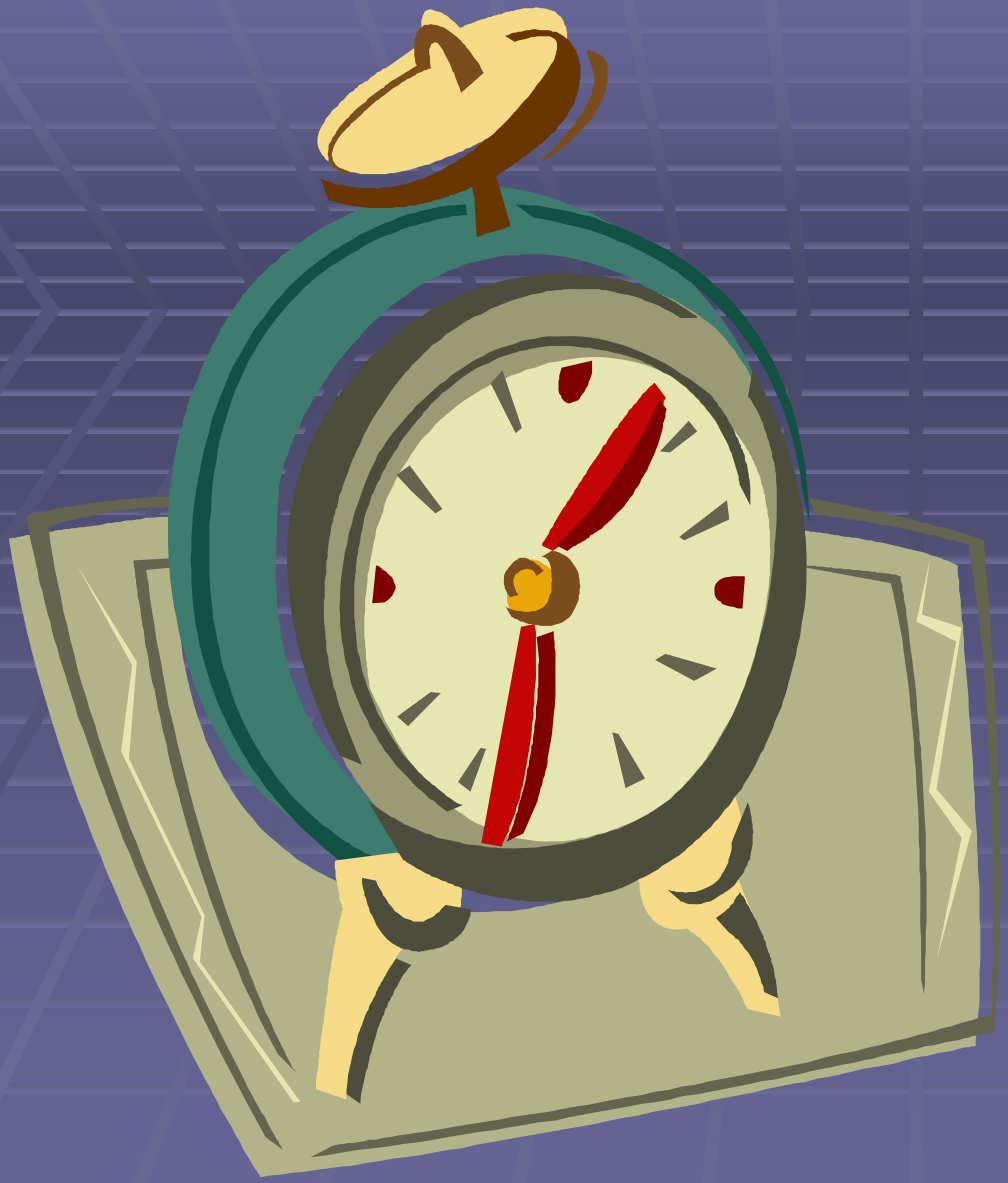
- Flow follows down gradient northwest dip
- Flow indicates decreasing hydraulic head in down gradient dip
- Flow follows bedding planes/DIP of the coal

MODPATH TRACKING

- Particles indicate northwest down-dip flow pattern
- Any potential contaminates will follow down gradient flow in flooded cells
- It appears that from the injection at the well the water table is erased and a local groundwater high allows some of the flow to traverse in a southeasterly direction before re-establishing a down-dip northwesterly flow path.

CONTINUED IMPROVEMENTS TO MODEL

- Gather more data relating to boundary conditions
- Expand boundary to a regional model to include major streams or features
- Gather more accurate information relating to hydraulic conductivity and recharge
- The study of slurry injection will continue by using MT3DMS module for simulating the migration of contaminant plumes over time.



THE END

Questions????