MODELING THE HYDROLOGIC EFFECTS RESULTING FROM UNDERGROUND MINING USING WCMS-HSPF and GMS

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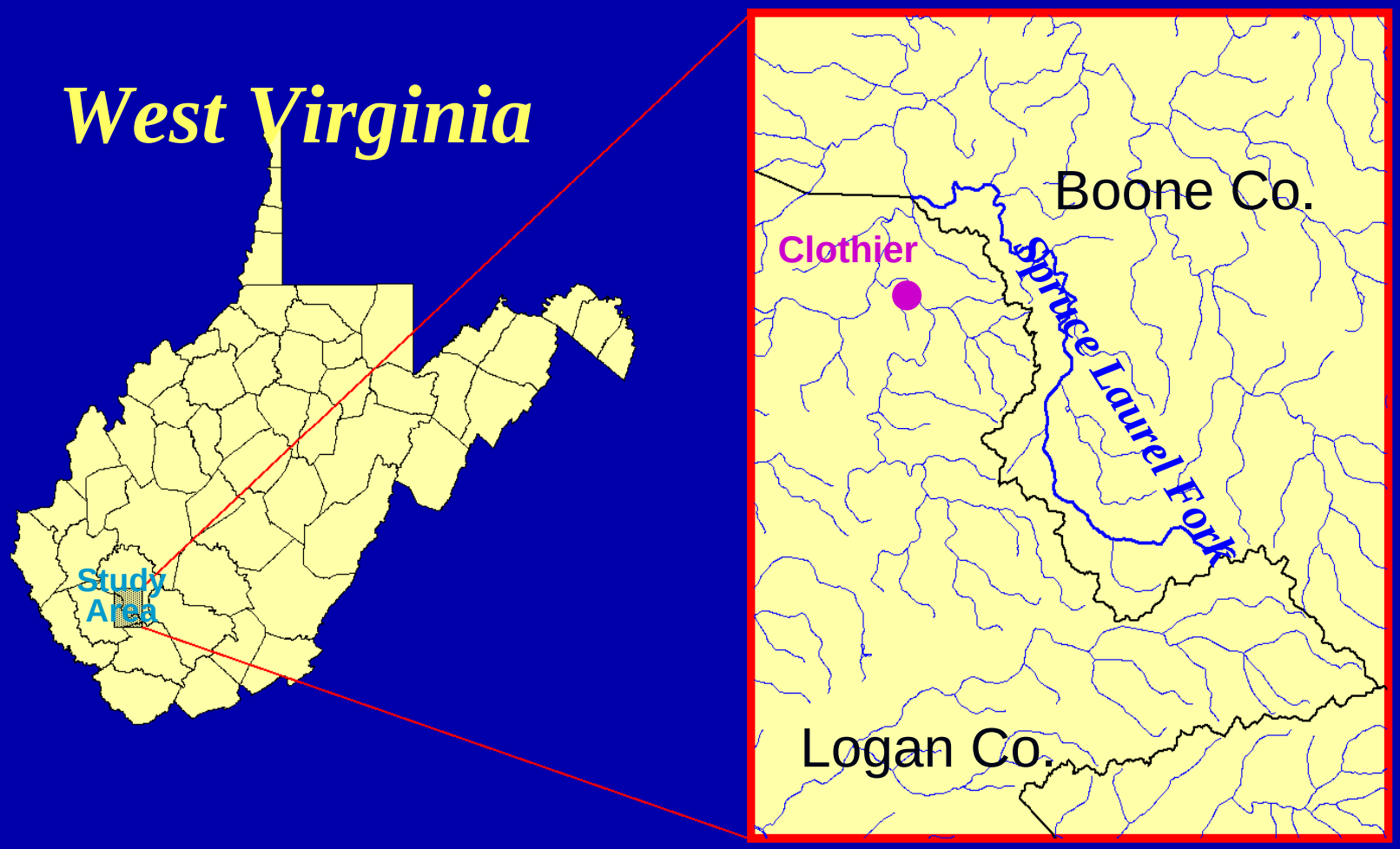
What are we modeling?

- Streamflow-WCMS-HSPF
- Ground water flow-GMS
- Effects from pumping mine pools at different rates on ground water flow

  - Low pump rates

  - High pump rates
- Interaction of surface and ground water
- Case example: Spruce Laurel Fork


West Virginia
Study Area
Boone Co.
Clothier
Spruce Laurel Fork
Logan Co.

Dewatered Spruce Laurel Fork

Historical Overview
Spruce Laurel Fork Watershed

- Study area of SLF watershed is 16,700 acres
- Pre-and post-SMCRA underground mining caused dewatered certain reaches of 9.5 miles of SLF
- Spruce Laurel Fork is a losing stream

  - Streamflow diverted to mines that develop pools
- 1991 flowing AMD artesian water flowed to residents' wells and residents' homes
- 1992 pumping lowered the Hampton No. 3 mine pool and eliminated downstream artesian effects

  - Pumping continues to control the mine pool level

Location of mining in the Spruce Laurel Fork Watershed

Headwaters of Spruce Laurel Fork

Photo by Tom Galya

Spruce Laurel Fork middle reaches

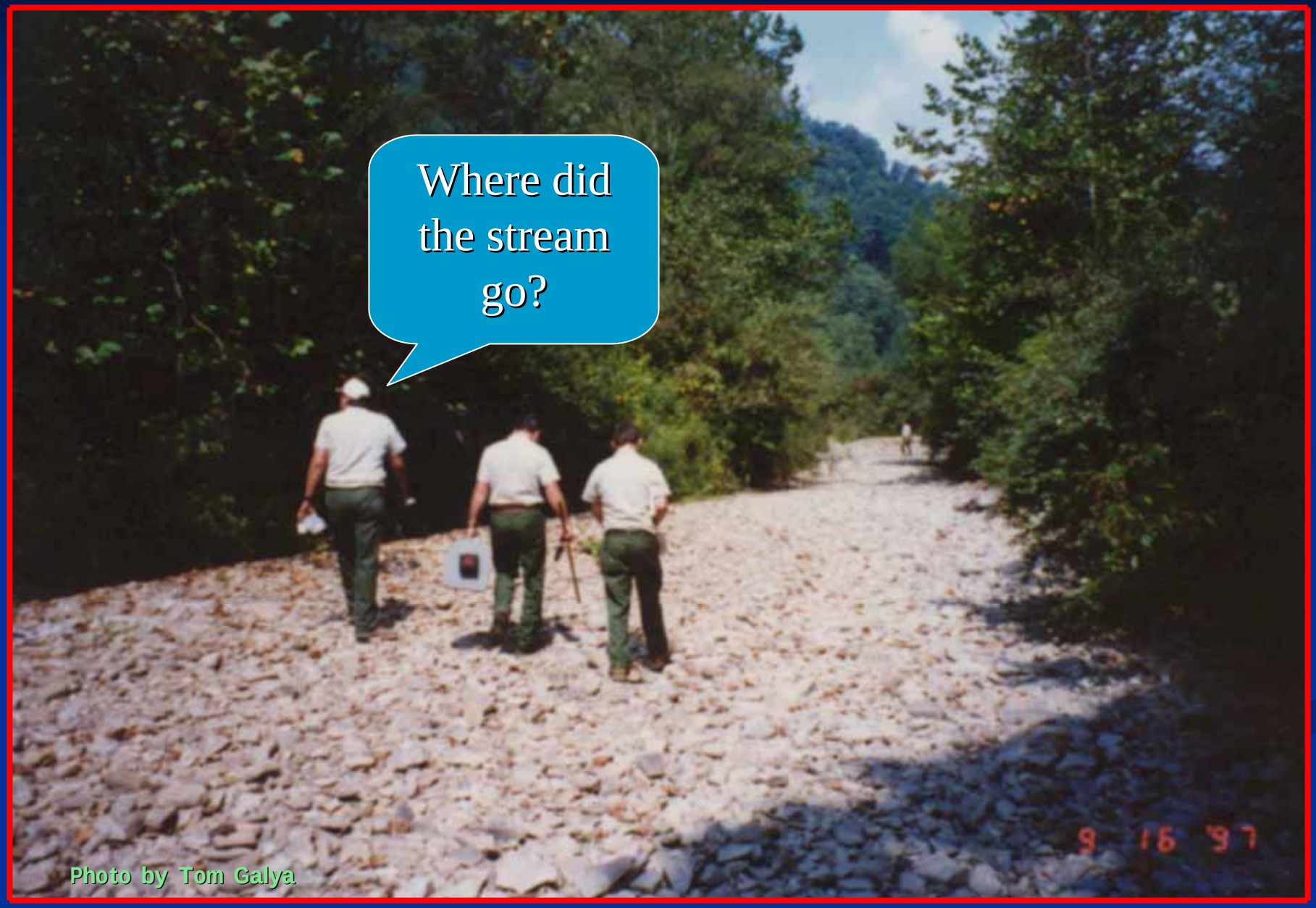


Photo by Tom Galya

Surface Effects on Hydrology from Subsidence

Subsided streambed of Spruce Laurel Fork

Hydrogeologic Factors Affecting the Models

- Overburden Depth
- Type and Proximity of Adjacent Mining
- Geologic Framework

  - Coal Barrier Thickness

  - Structure, Hydraulic Gradient

  - Lineaments, Seam Discontinuities
- Characteristics of the Coal Barrier, Roof Overburden, Floor

  - Lithology, Coal cleats, SRF and Mine-Induced Fractures

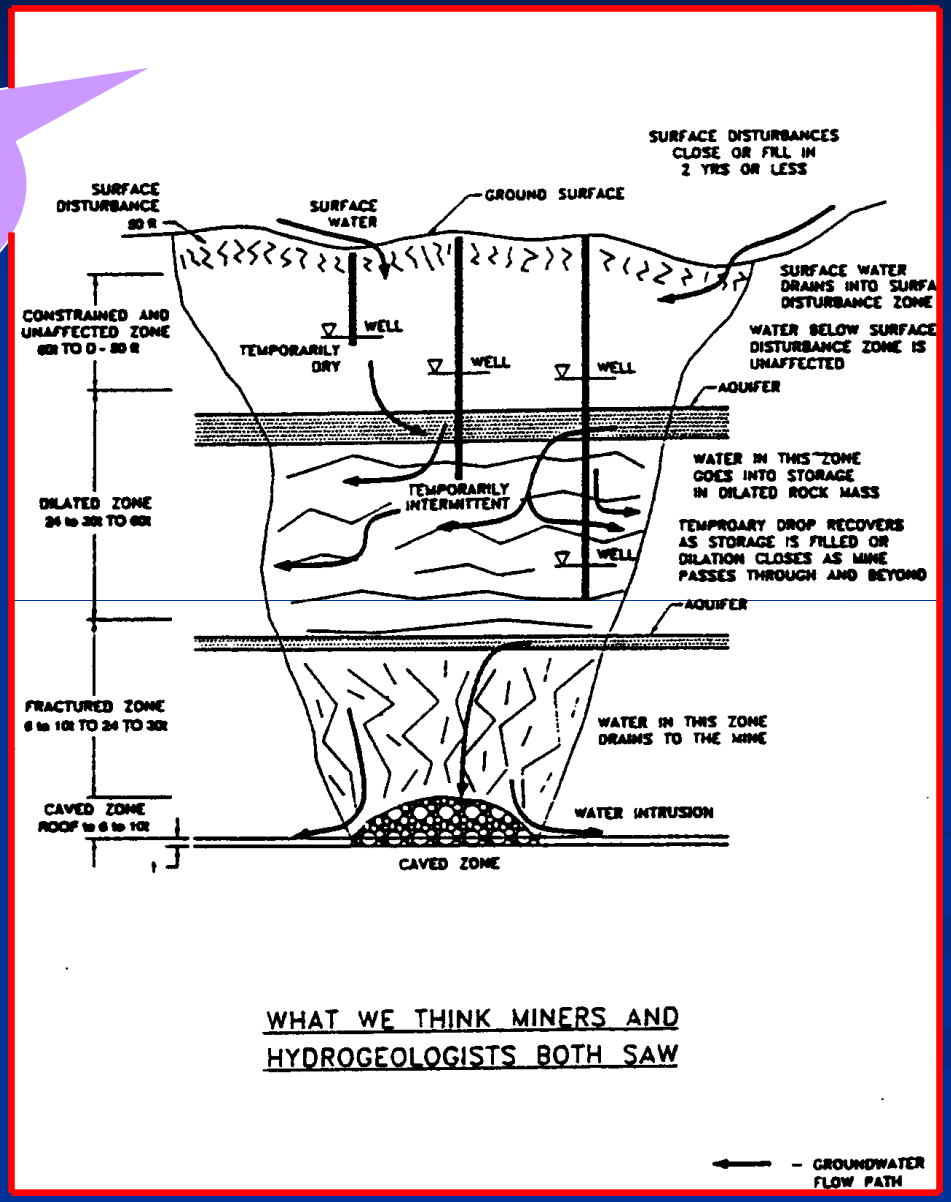
  - Mine Floor Topography

    Roof/Floor can behave as Acquitards in Mines

  - Significantly Lower K_h than adj. Abandoned Workings

High-extraction Mining: Roof Strata Disturbance Zones

Kendorski 1993 model



Guyan & Hampton mine pool levels

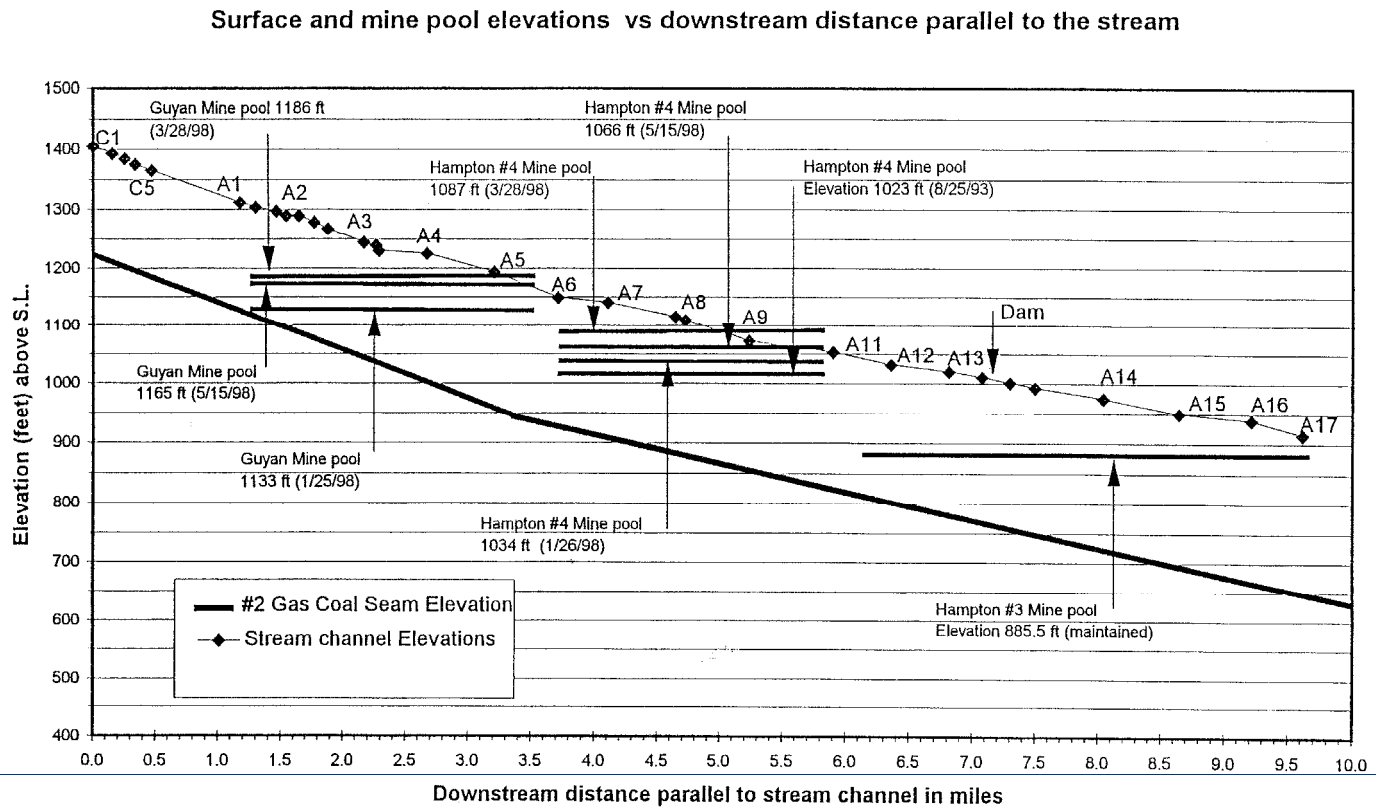
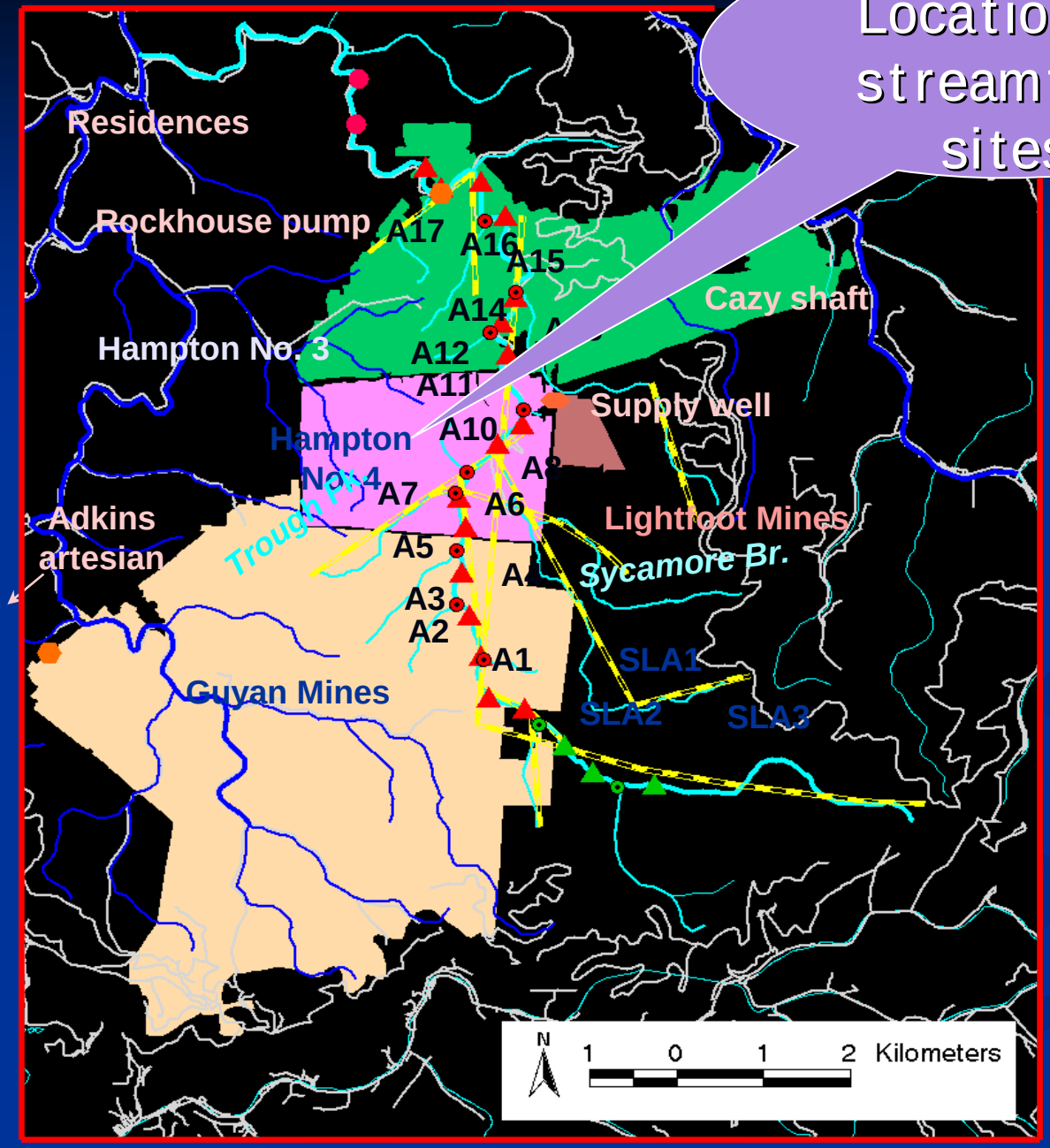


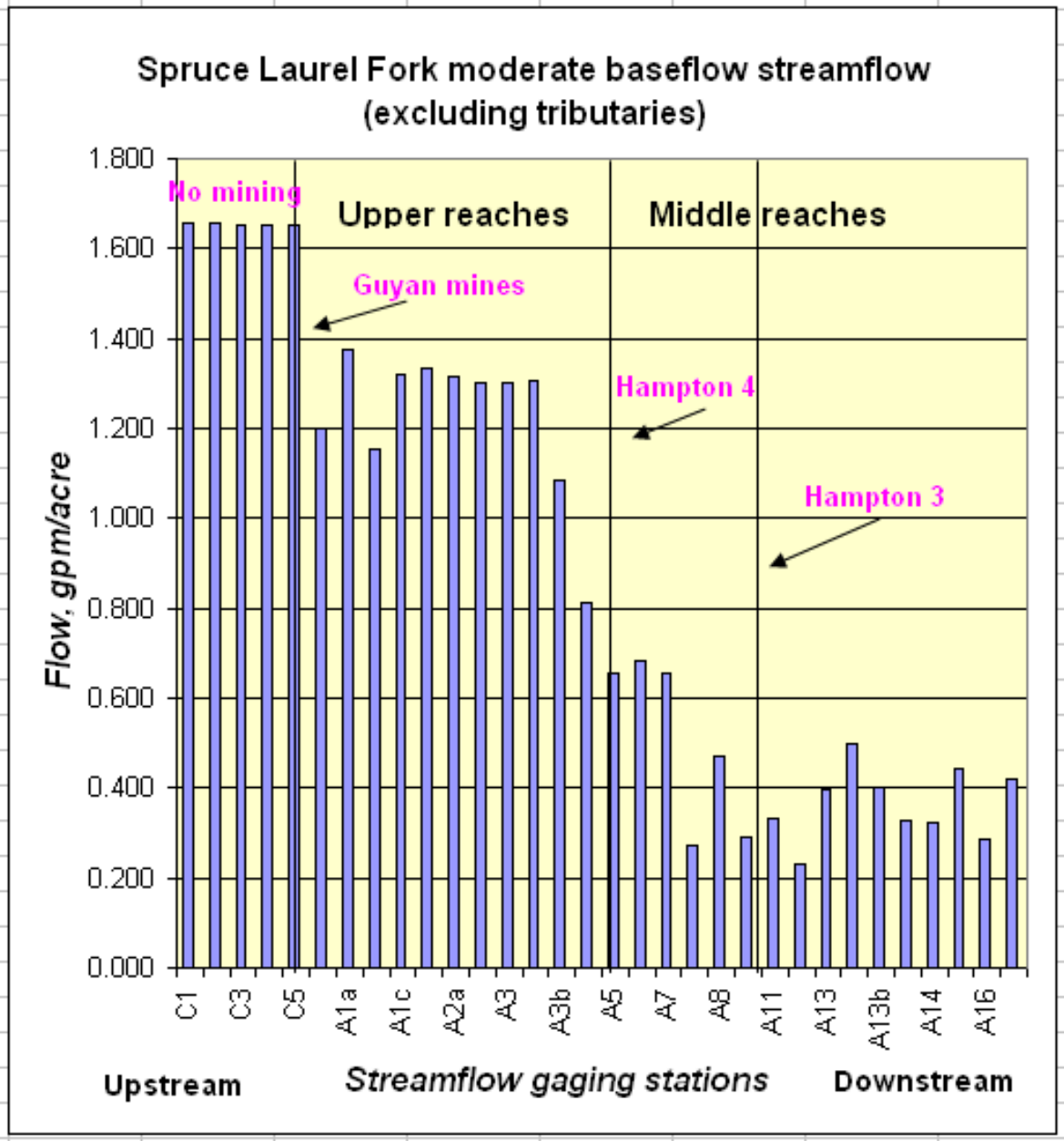
Figure 14: Plot of mine pool potentiometric surface elevations in relation to stream channel elevations and downstream distance along Spruce Laurel Fork. A 225 ft barrier exists between adjacent mines.

Location of streamflow sites

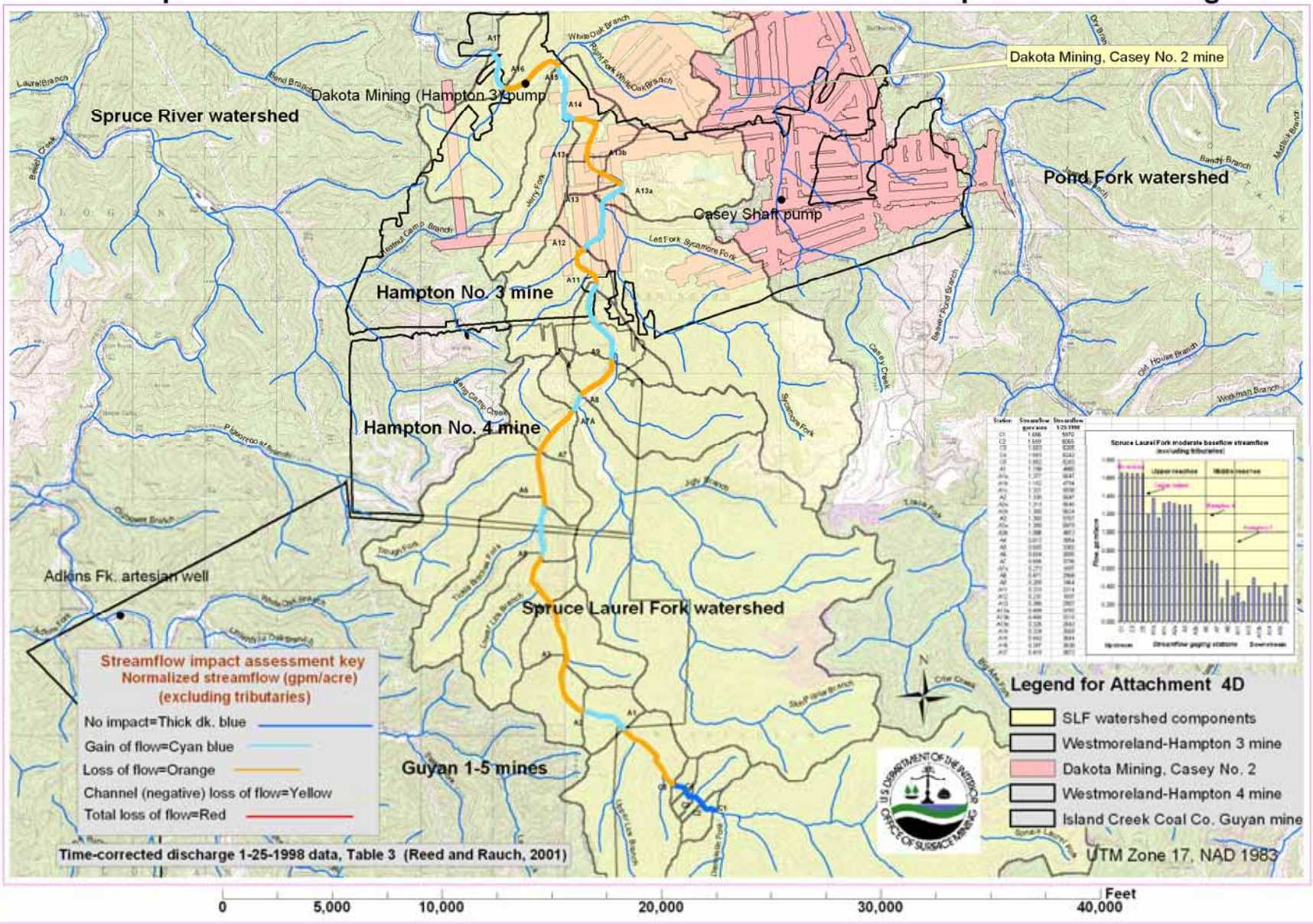


What the Streamflow Data Shows

Station	Streamflow gpm/acre	Streamflow 1/25/1998
C1	1.656	5970
C2	1.659	6065
C3	1.653	6205
C4	1.653	6242
C5	1.652	6283
A1	1.198	4880
A1a	1.377	5647
A1b	1.152	4794
A1c	1.321	5558
A2	1.335	5647
A2a	1.313	5645
A2b	1.300	5624
A3	1.300	5767
A3a	1.308	5979
A3b	1.086	4972
A4	0.812	3854
A5	0.655	3382
A6	0.684	3895
A7	0.656	3795
A7a	0.273	1697
A8	0.471	2968
A9	0.289	1964
A11	0.333	2314
A12	0.231	1697
A13	0.396	2957
A13a	0.499	3792
A13b	0.400	3215
A13c	0.326	2643
A14	0.324	2669
A15	0.442	3844
A16	0.287	2638
A17	0.419	3972



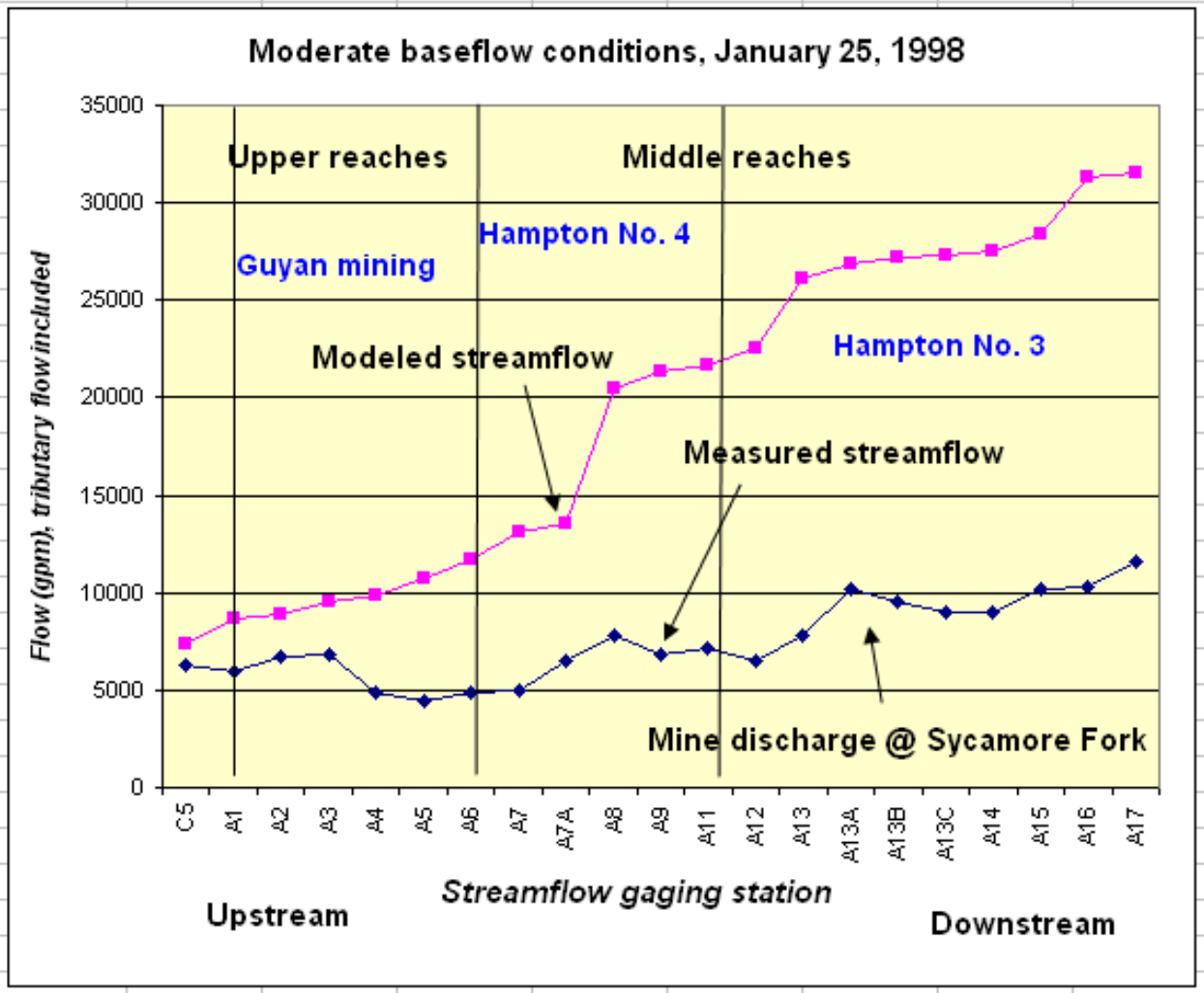
Spruce Laurel Fork moderate baseflow-assessment of impacts from mining



Using WCMS-HSPF to Model Streamflow

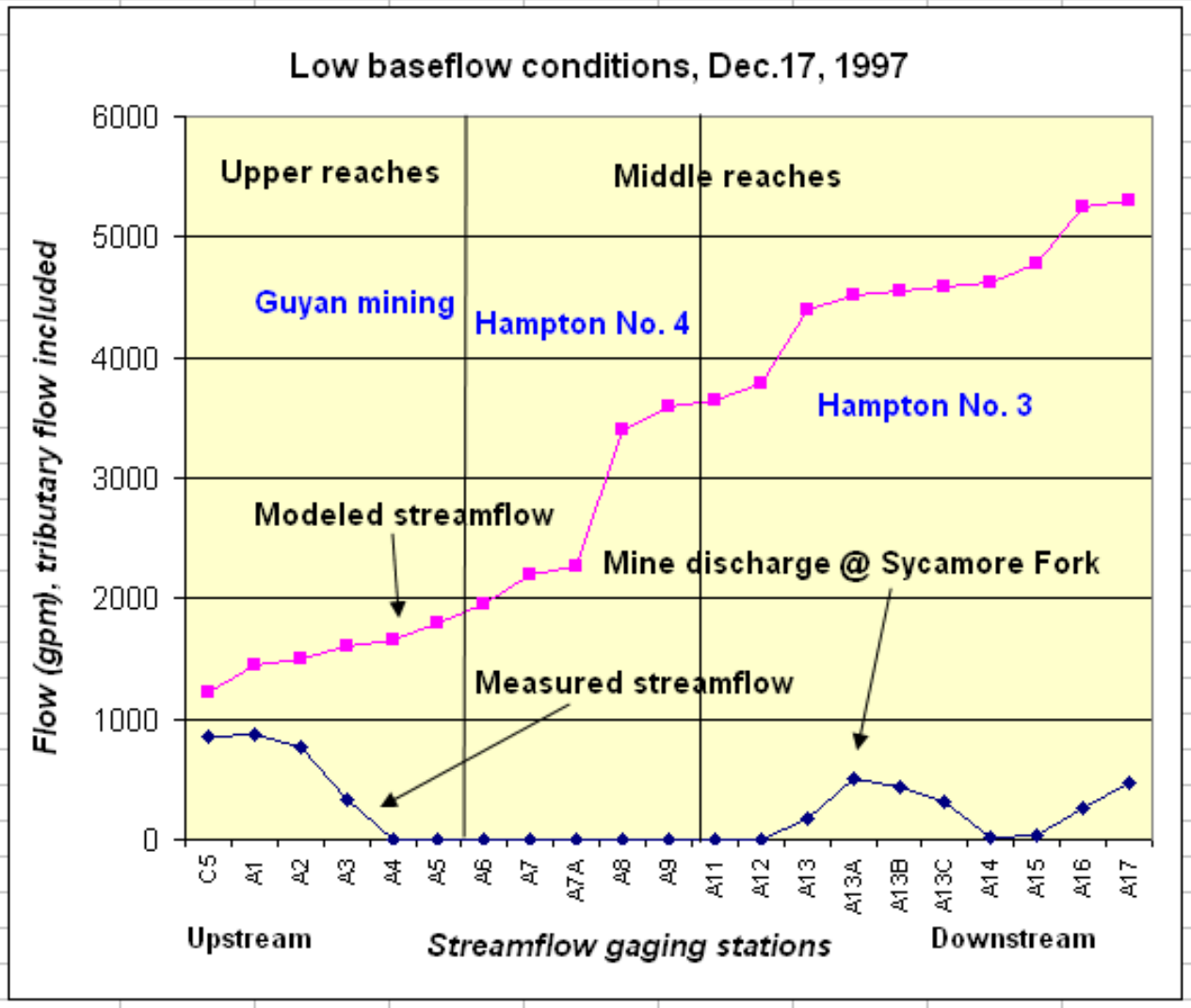
Measured Streamflow v. WVU-WCMS 30–Year Flow Average Model

Stations	Reed (1998) 25-Jan-98 gpm	WCMS model January-98 gpm
C5	6283	7316
A1	5939	8666
A2	6706	8904
A3	6826	9546
A4	4913	9883
A5	4441	10731
A6	4918	11655
A7	4950	13105
A7A	6510	13495
A8	7781	20483
A9	6777	21358
A11	7127	21695
A12	6510	22525
A13	7770	26156
A13A	10146	26906
A13B	9569	27157
A13C	8997	27283
A14	9023	27547
A15	10198	28440
A16	10258	31304
A17	11592	31587

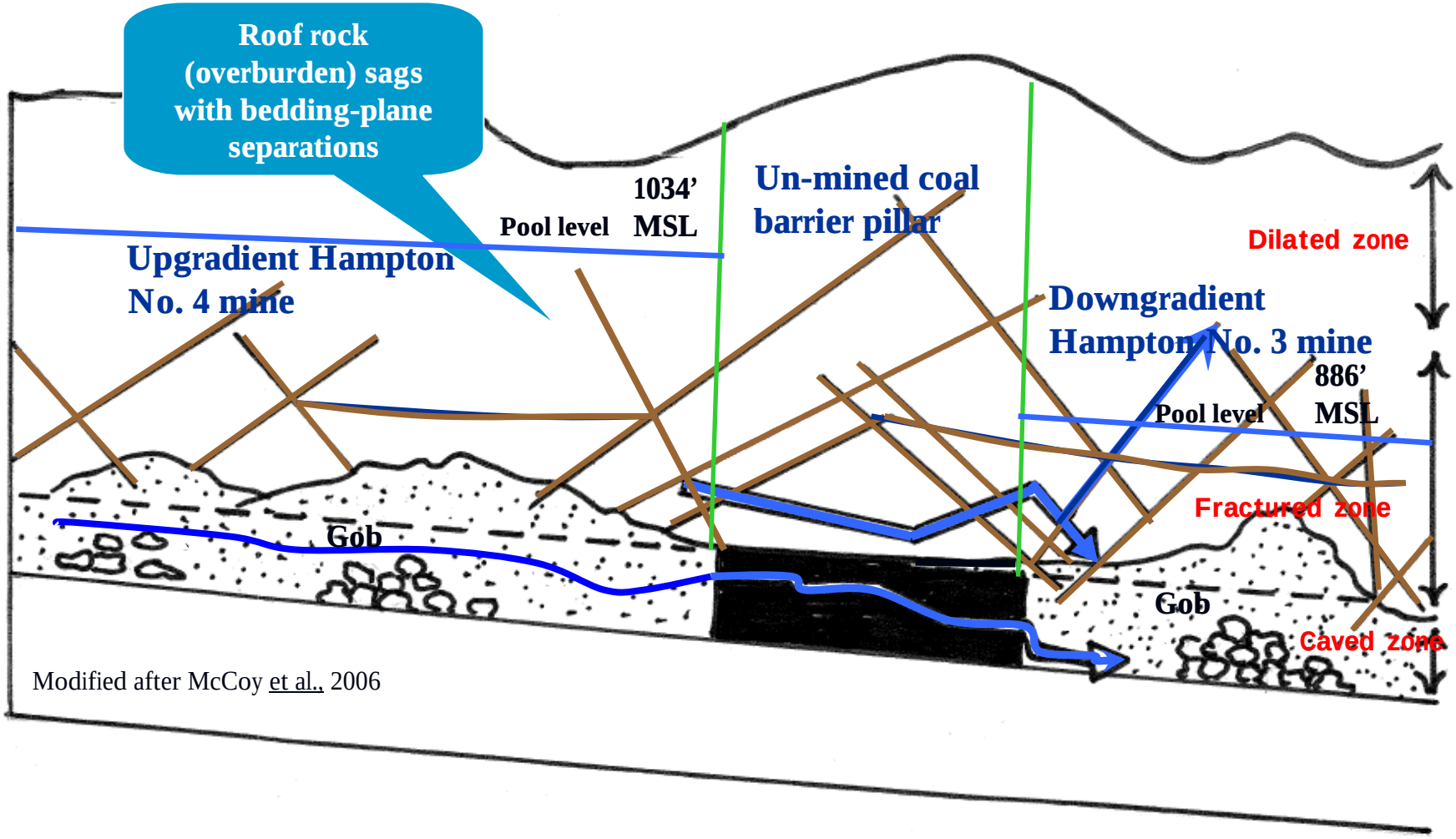


Measured Streamflow v. WVU-WCMS 7Q10 Flow Model

tations	Reed (1998) 012/17/1997 Flow (gpm)	WCMS model 012/17/1997 Flow (gpm)
C5	849	1228
A1	868	1455
A2	776	1495
A3	324	1603
A4	0	1659
A5	0	1801
A6	0	1957
A7	0	2201
A7A	0	2266
A8	0	3397
A9	0	3588
A11	0	3642
A12	0	3782
A13	179	4393
A13A	510	4520
A13B	428	4558
A13C	319	4580
A14	16	4628
A15	43	4776
A16	266	5256
A17	466	5301



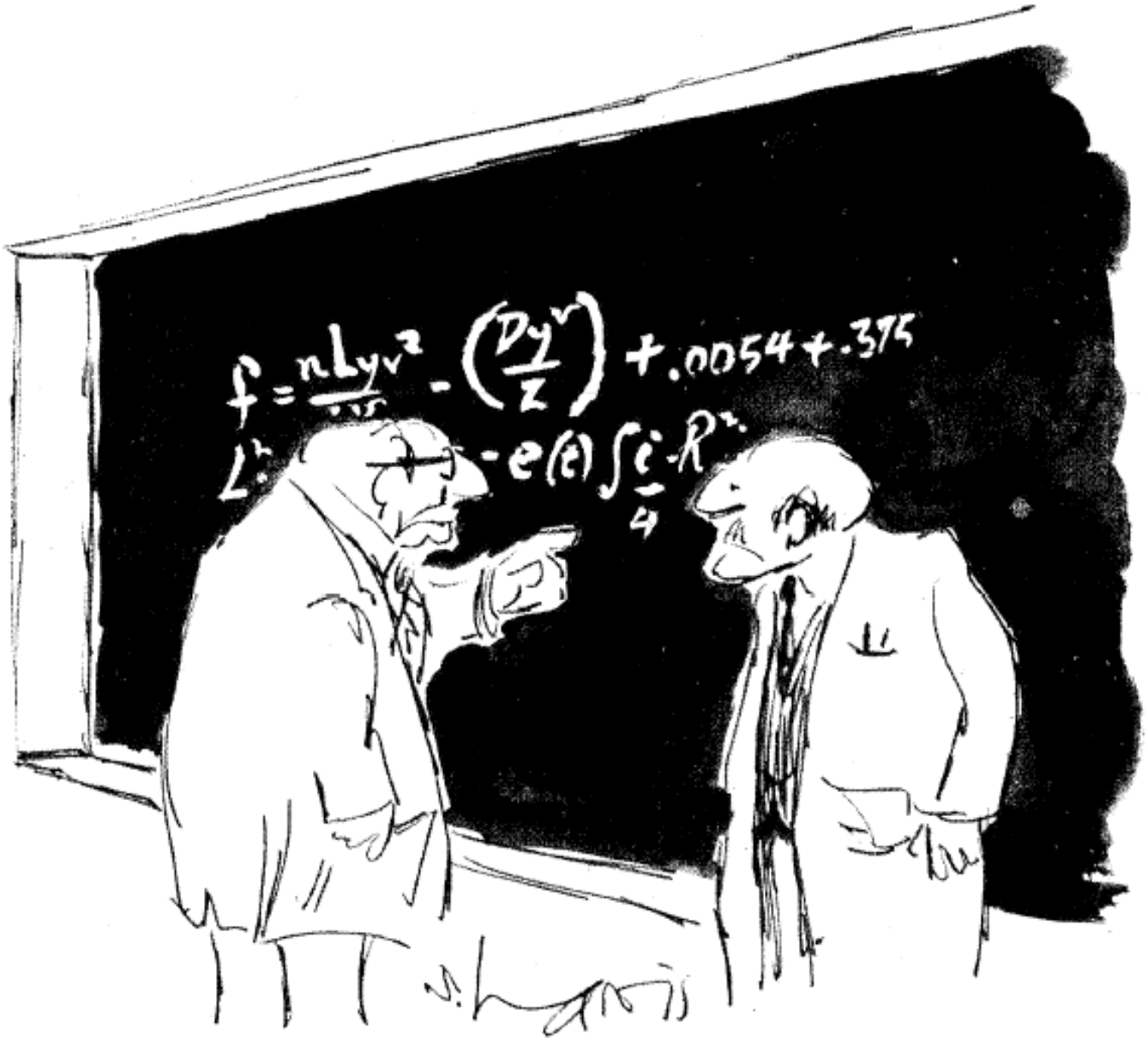
Conceptual Hydrologic Model



Modified after McCoy et al., 2006

Using GMS to Model Ground Water

Darcian Flow Assumptions



"Does this apply always, sometimes, or never?"

Darcian Assumptions

- Mines are fully flooded and at equilibrium
- Ground water flow is laminar and follows the downgradient direction
- Ground water flow is horizontal

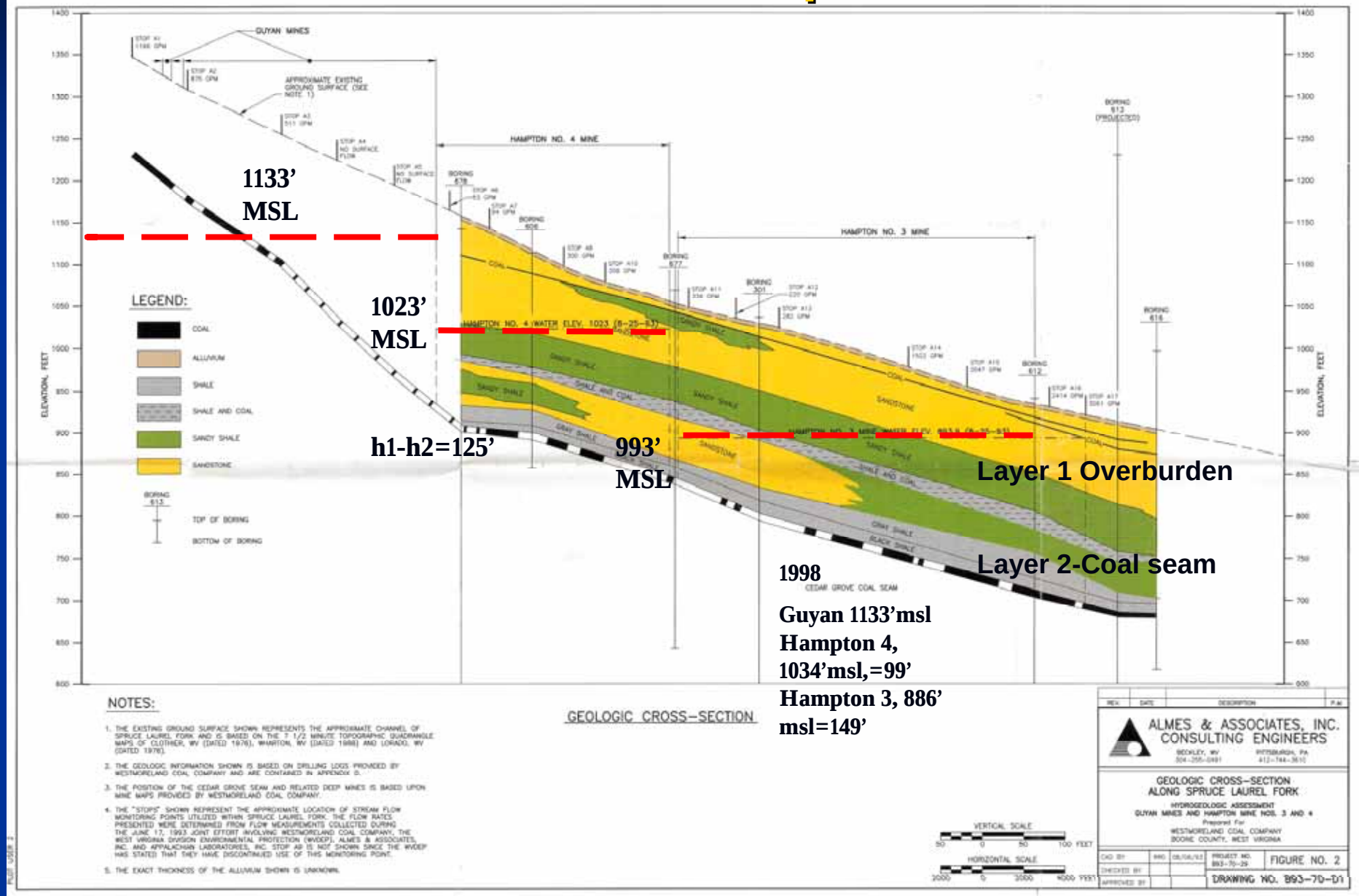
  - Flow may extend into overburden from the coal barrier that separates adjacent mines
- Aquifer is homogenous and isotropic
- Seepage flow from mine pools follows the coal seam cleat systems

MODFLOW Packages Used in SLF Modeling

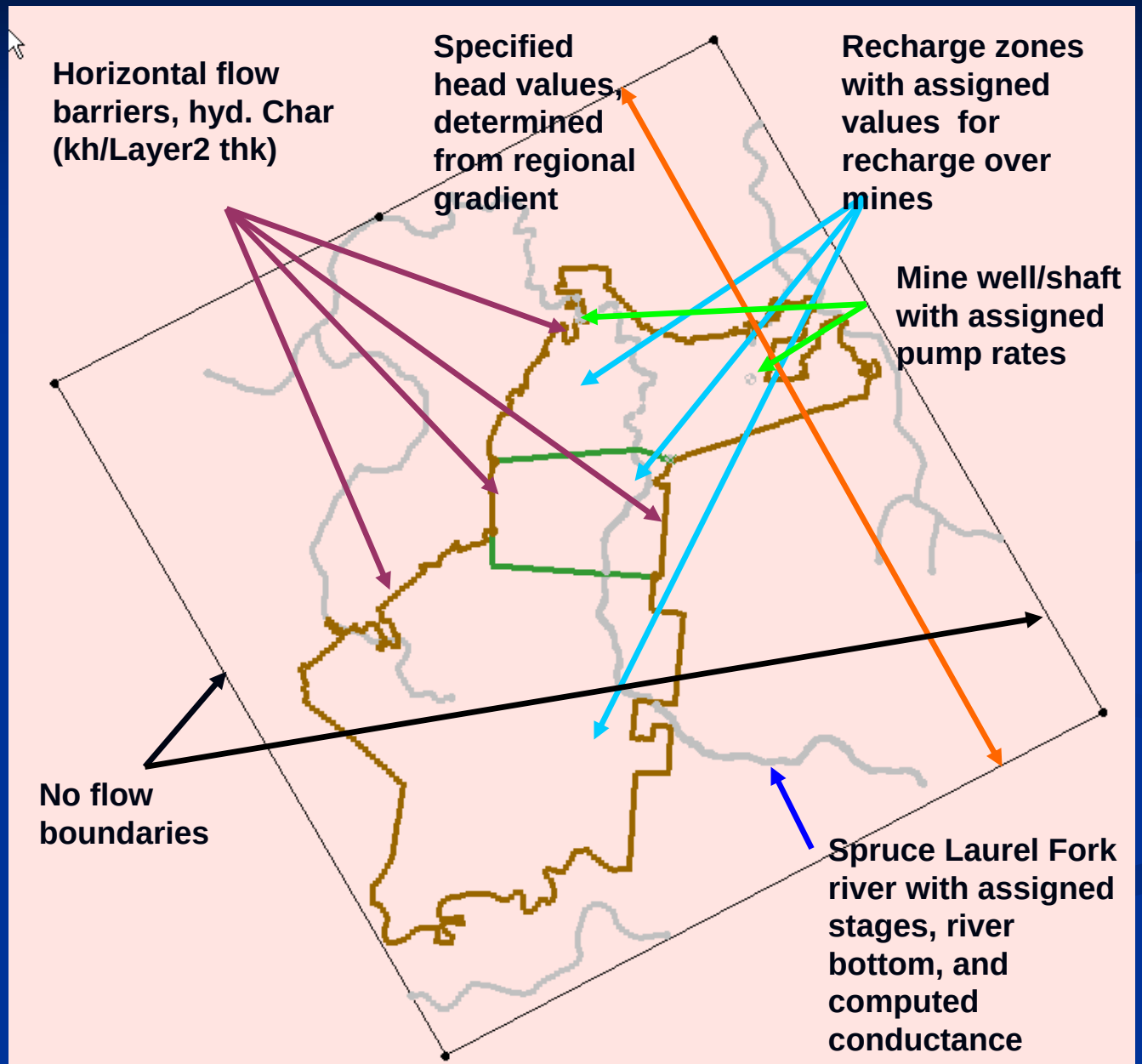
- River
- Well
- Horizontal Flow Barrier
- Specific Heads
- Recharge
- Drain-Seepage Faces
- Flow-LPF (Layer Property Flow)

  - Two layer model; both non-confining
    - + Overburden
    - + Mined coal seam in Hampton, Guyan mines

Pirated" SLF enters into mines and creates mine pools



GMS Model Boundary Conditions

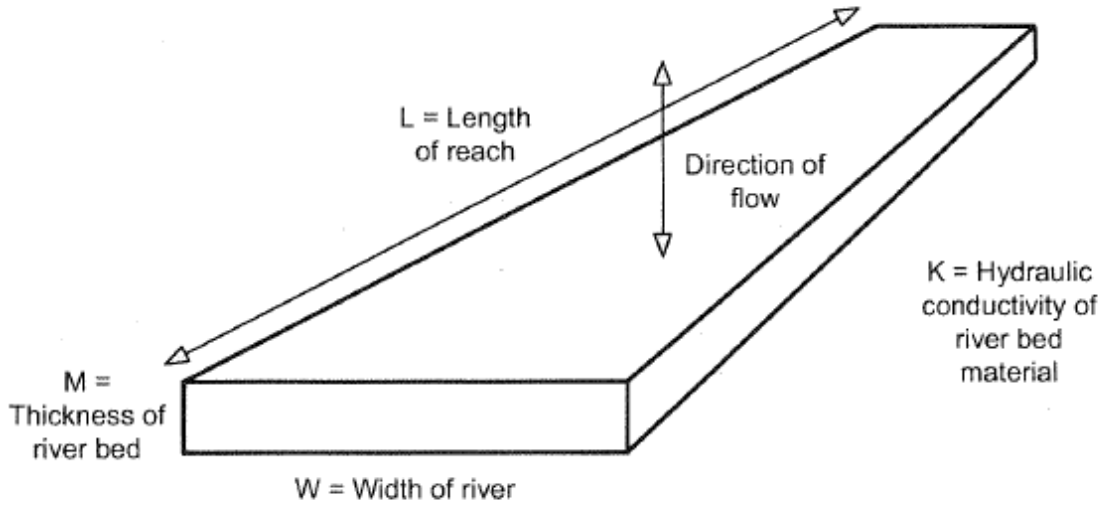


River Package

- Stream-Aquifer System
  - If Head is above River Stage, Flow is from Aquifer to River
  - If Head is below River Stage, Flow is from River to Aquifer
- Reach Attributes, Required Parameters
  - Elevation of the Top of the Streambed
  - Elevation of the Bottom of the Streambed
  - Conductance

River Package - SLF Conductance

River Conductance



$$\text{Cond} = \frac{K * (\text{area of flow})}{(\text{length of flow})} = \frac{KLW}{M}$$

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Computed SLF River Conductance

Station	Stream Elev.	Stream Bottom
	(m)	(m)
Bottom	442.0	441.7
C1	428.2	427.9
C2	424.0	423.7
C3	422.1	421.8
C4	419.1	418.8
C5	416.1	415.7
A1	399.9	399.6
A2	393.2	392.9
A3	379.5	379.2
A4	373.4	373.1
A5	363.9	363.6
A6	350.2	349.9
A7	347.8	347.5
A7a	340.2	339.9
A8	338.3	338.0
A9	322.2	321.9
A11	321.3	321.0
A12	314.6	314.2
A13	310.9	310.6
A13a	308.2	307.8
A13b	305.4	305.1
A13c	302.7	302.4
A14	297.2	296.9
A15	289.6	289.3
A16	285.9	285.6
A17	278.9	278.6
Top	244.8	244.4

Station	Conductance
	(m^2/d)/(m)
Bottom	1987.2
C1	1589.8
C2	1189.9
C3	1135.5
C4	1399.4
C5	518.9
A1	50000.0
A2	2394.2
A3	482.3
A4	596.8
A5	445.6
A6	2394.2
A7	1987.2
A7a	596.8
A8	1122.7
A9	794.9
A11	807.8
A12	1494.1
A13	3312.0
A13a	4968.0
A13b	3312.0
A13c	3974.4
A14	5677.7
A15	5229.5
A16	4968.0
A17	6021.8
Top	6624.0

Data for GMS Modeling

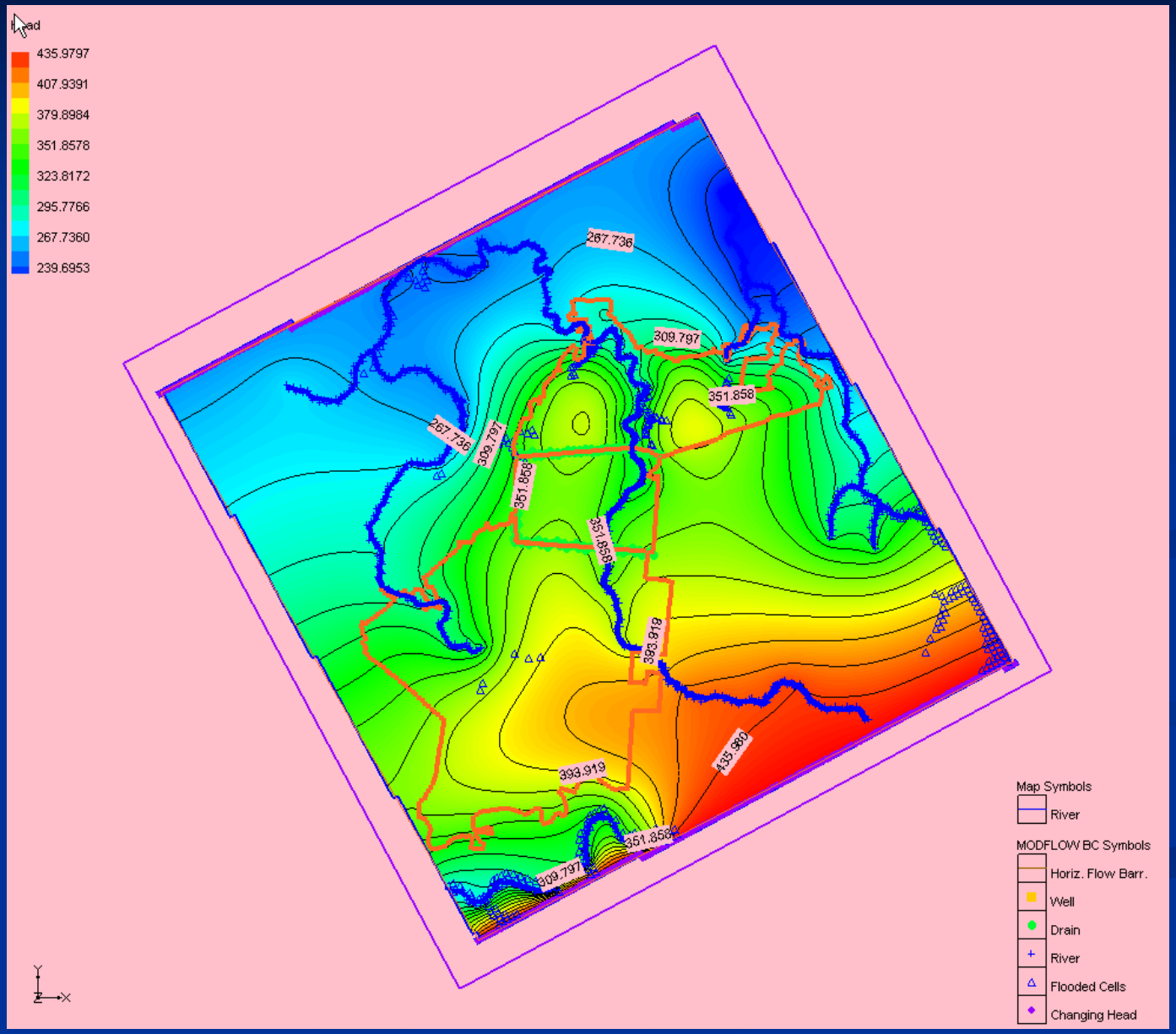
- Literature Values
  - Recharge
  - Horizontal and Vertical Hydraulic Conductivity
- Back-calculating Hydraulic Values from SLF Mining History
  - Recharge
  - Hydraulic Conductivity
- Spruce Laurel Fork data
  - River Conductance
  - Seepage Faces

Ground Water Model Runs

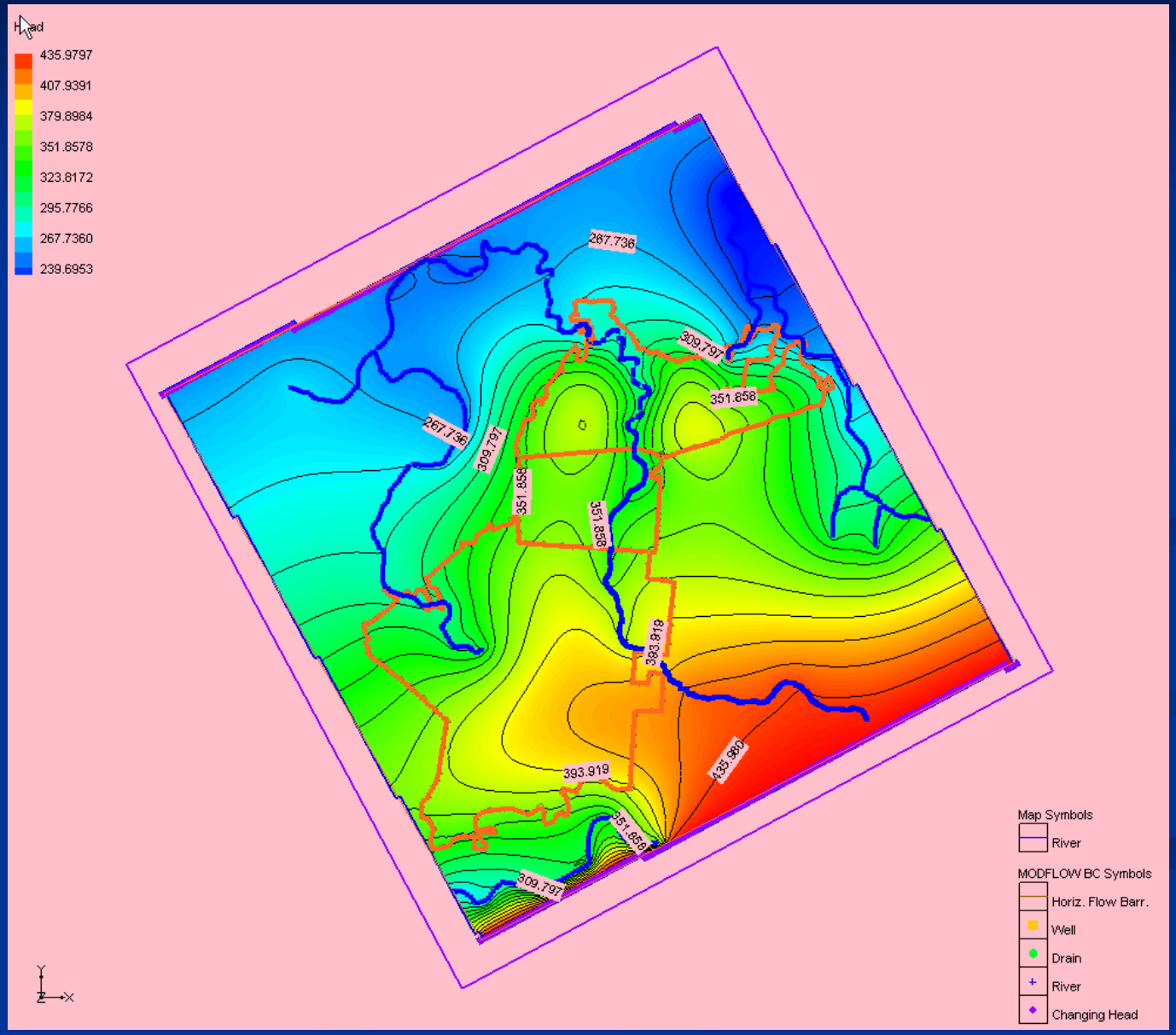
Low Pumping Rates

High Pumpimg Rates

Low Pumping Rate-Layer 1



Low Pumping Rate-Layer 2



Low Pumping Rate-Flow Budget

Flow Budget

Cells | Zones

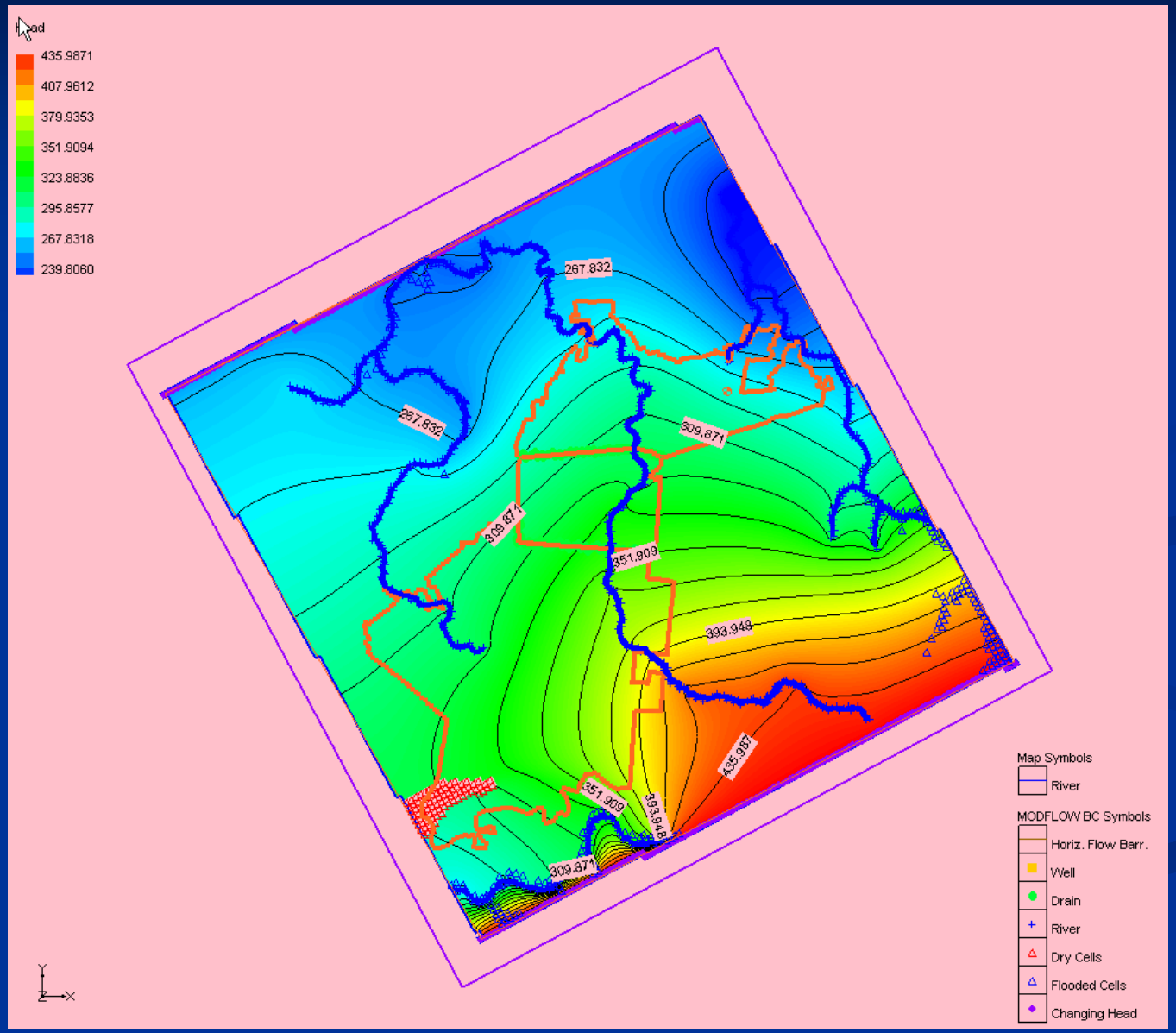
Number of selected cells: 0 (data for all cells is displayed below)

	Flow In	Flow Out
Sources/Sinks		
Storage		
Constant heads	152577.74043371	-2902.940951526
Drains	0.0	-366.0845336914
General heads		
Rivers	750067.52403242	-1091966.260546
Streams		
Wells	0.0	-7122.0
Recharge	199846.28385806	0.0
Evapotranspiration		
Lake		
Total Source/Sink	**1102491.5483242**	**-1102357.286031**
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	**1102491.5483242**	**-1102357.286031**
Summary	**In - Out**	**% difference**
Sources/Sinks	**134.26229307614**	**0.0121780791227**
Cell To Cell	**0.0**	**0.0**
Total	**134.26229307614**	**0.0121780791227**

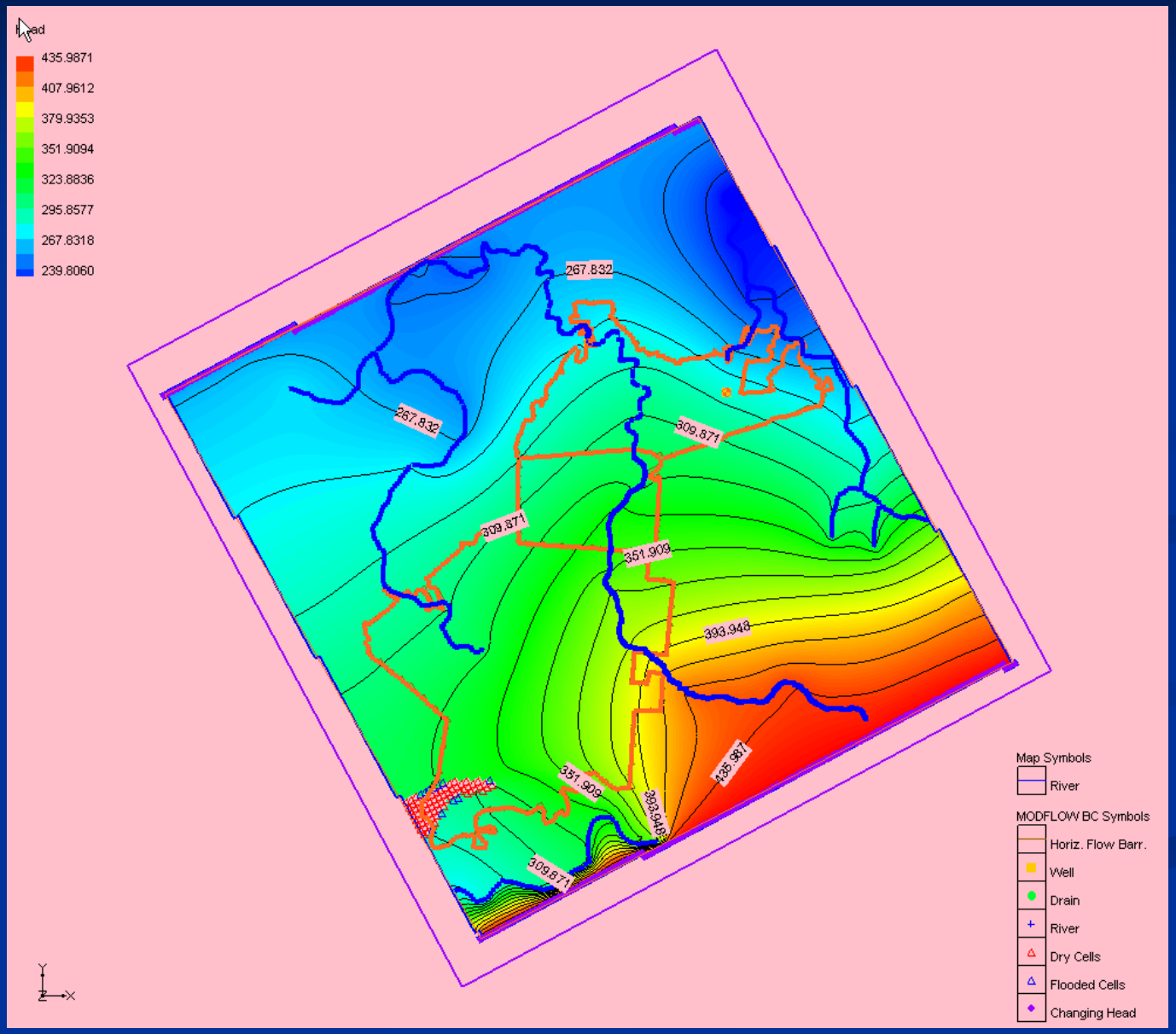
Help... OK

- **Flow In Contributions**
  - Rivers=68 %
  - Recharge=18 %
  - Constant heads=14 %
- **Flow Out Contributions**
  - Well=0.6 %
  - Rivers=99 %
    - + Losing stream

High Pump Rate-Layer 1



High pump Rate-Layer 2



High Pump Rate-Flow Budget

Flow Budget

Cells | Zones

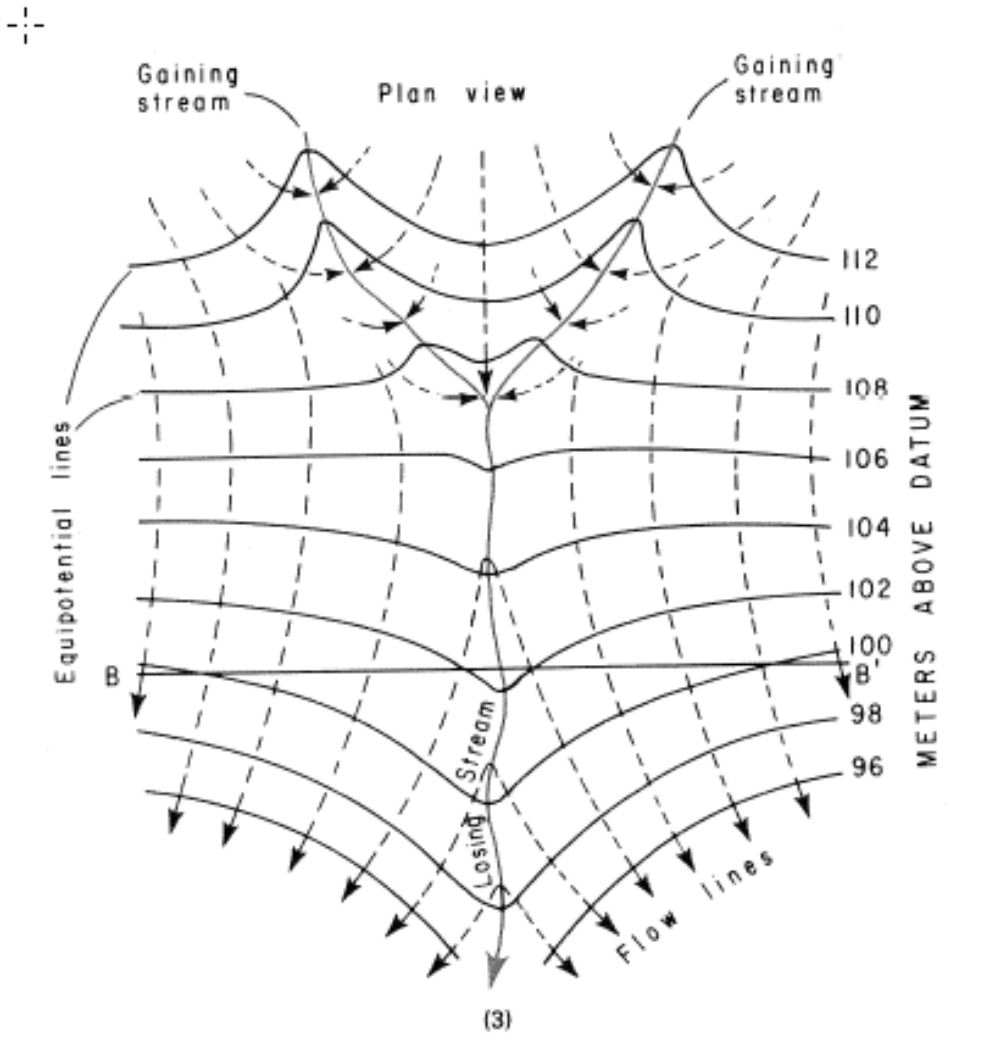
Number of selected cells: 0 (data for all cells is displayed below)

	Flow In	Flow Out
Storage		
Constant heads	5629369.929504	-70692.99914163
Drains	0.0	0.0
General heads		
Rivers	1696023.4900534	-7446393.474535
Streams		
Wells	0.0	-7122.0
Recharge	198949.27643085	0.0
Evapotranspiration		
Lake		
Total Source/Sink	**7524342.6959882**	**-7524208.473677**
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	**7524342.6959882**	**-7524208.473677**
Summary	**In - Out**	**% difference**
Sources/Sinks	**134.22231113724**	**0.0017838410152**
Cell To Cell	**0.0**	**0.0**
Total	**134.22231113724**	**0.0017838410152**

Help... OK

- **Flow In Contributions**
  - Rivers=23 %
  - Recharge=3 %
  - Constant heads=74 %
- **Flow Out Contributions**
  - Rivers=99 %
    - + Losing stream

GMS SLF Models Show



- In gaining reaches, the equipotential lines form "V"s pointing upstream
- In losing reaches, the equipotenital lines form "V"s pointing downstream

Conclusions and Recommendations

- The results of this project illustrate how the WCMS-HSPF and GMS applications modeled surface and ground water
- WCMS-HSPF application successfully modeled the hydrology of the Spruce Laurel Fork watershed
- GMS application model still needs considerable refinement

  - Requires much more site-specific data

    + Hydraulic parameters, i.e., Kh, Kv, recharge

  - Boundary conditions, regional constant (specific) heads
- OSM business practices need predictive models that more accurately simulates potential or consequences of underground mining
- Models must accurately simulate dewatered stream reaches, mine pool development, and potential artesian conditions and likely breakout locations

The End