Proposed Cumulative Hydrologic Impact Assessment (CHIA) Regional Decision Support Tool

U.S. Department of the Interior
U.S. Geological Survey
Kentucky Water Science Center

CHIA Decision Support Tool: What is Needed Regarding Probable Hydrologic Consequences?

- **Enable mine permit officials to accurately simulate streamflows and hydrograph characteristics under pre- and post-mined conditions.**
- **Determine or predict changes in streamflow characteristics—including storm-runoff response and baseflow—due to mining-related surface disturbances.**
- **Assess the potential cumulative hydrologic impacts of all mining-related surface disturbances within an impacted watershed.**
- **Provide a means of quantitatively identifying the point-of-inception of flows and defining stream reaches as perennial, intermittent, or ephemeral, according to SMCRA-established regulatory definitions.**

Proposed Application of WATER as a CHIA Regional Decision-Support Tool

WATER

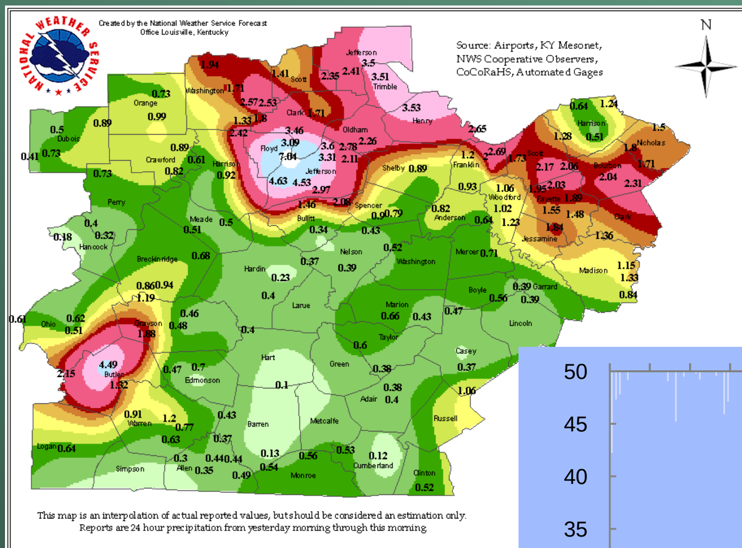
Water Availability Tool for Environmental Resources

- **Quantify water availability where there are no long-term monitoring data**
- **Builds on geospatial data**
  - **Topography**
  - **Precipitation and temperature**
  - **Soils**
  - **Land management**
- **Uniform approach without need for site-specific optimization**
- **Accurate and precise estimates of streamflow**

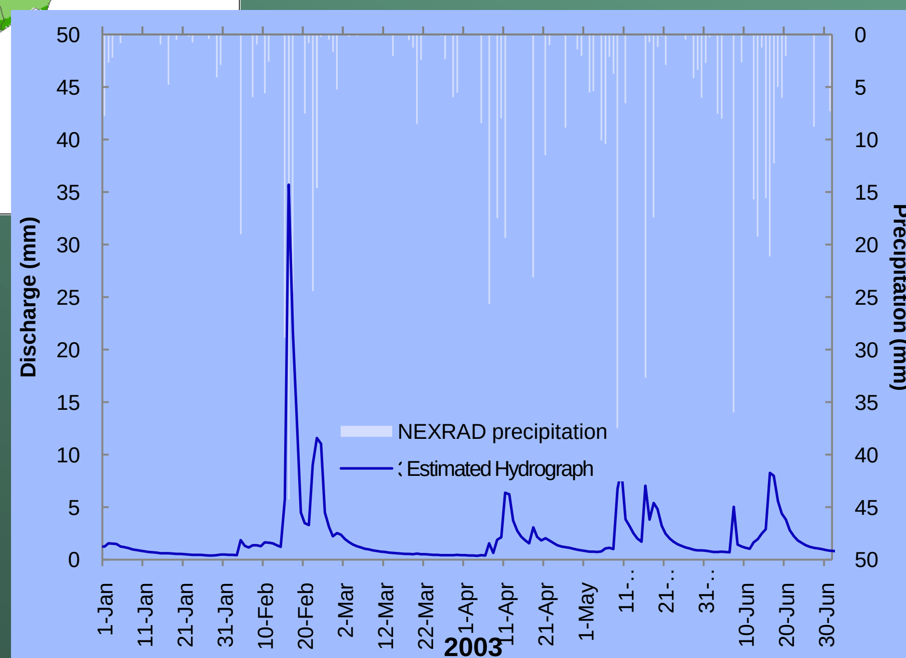
USGS

The value of WATER

Precipitation Record or Forecast



Hydrograph



Long-term Flow Record

Historic Baseline

Impact of Planned Reclamation

Identification of Perennial Stream Reaches

Water Budget

Water Allocation Decisions

Flood Forecast

Disaster Preparedness

Current Ability - WATER

Estimate of surface-water hydrology

- Daily streamflow estimated
  - Historic climate record
  - Natural landscape characteristics
- Identification of saturated stream cells (flow)
  - Stream delineation
  - Ecological implications
- Changes due to land management
  - Topographic Wetness Index
  - Saturated hydraulic conductivity
  - Impervious surface

WATER's Hydrologic Modeling Approach

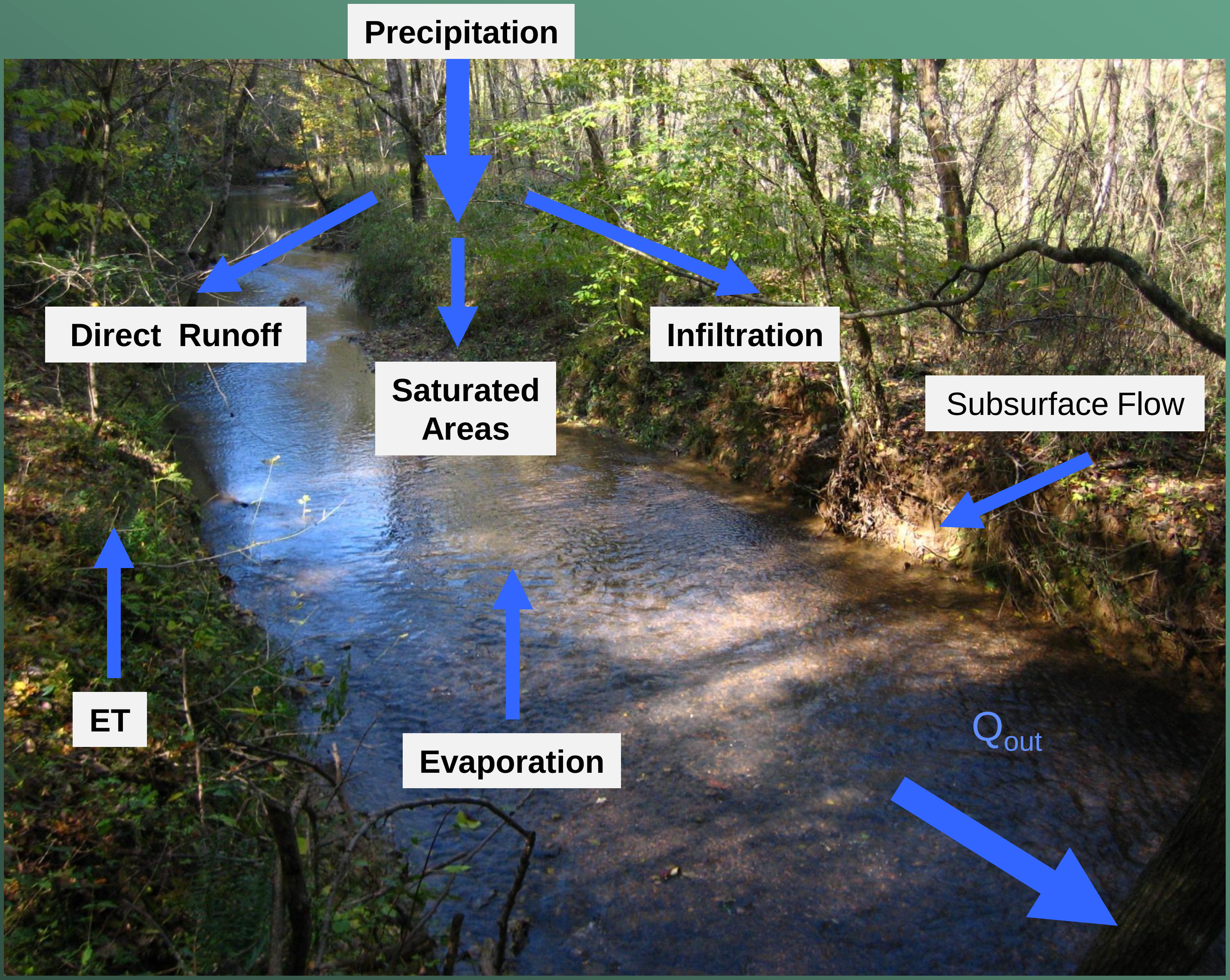
- **TOPography-based hydrological MODEL based**
- **Developed by Beven and Kirkby, 1979**
- **"Physically-based watershed model that simulates the variable-source-area concept of streamflow generation." (Wolock, 1993)**
- **Quasi-distributed approach – breaks the watershed up into landscape components that are identified by the topographic wetness index**

USGS

Beven, K.J. and M.J. Kirkby. 1979. A physically based, variable contributing area model of basin hydrology. *Hydrological Sciences Bulletin*, v. 24, pp. 43-69.
Wolock, David M. 1993. Simulating the variable-source-area concept of streamflow generation with the watershed model TOPMODEL. *USGS WRI 93-4124.*

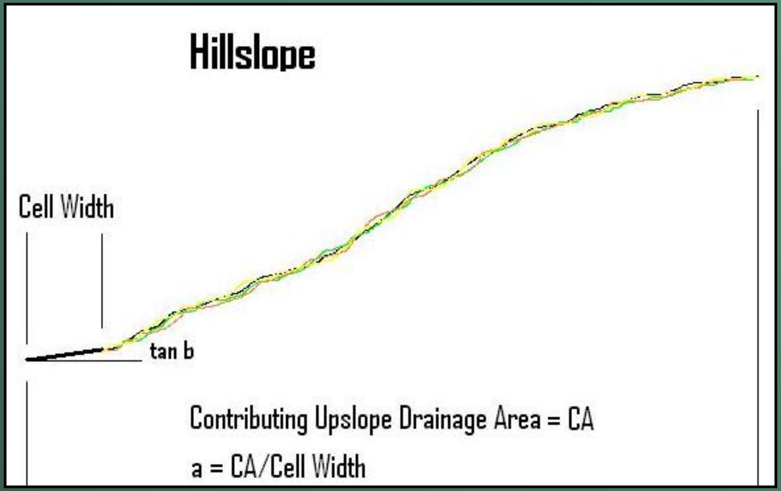
TOPMODEL Water Budget Components

Water Cycle



TOPMODEL topographic wetness index

$$TWI = \ln\left(\frac{upslope\ contributing\ area}{\tan\ slope}\right)$$



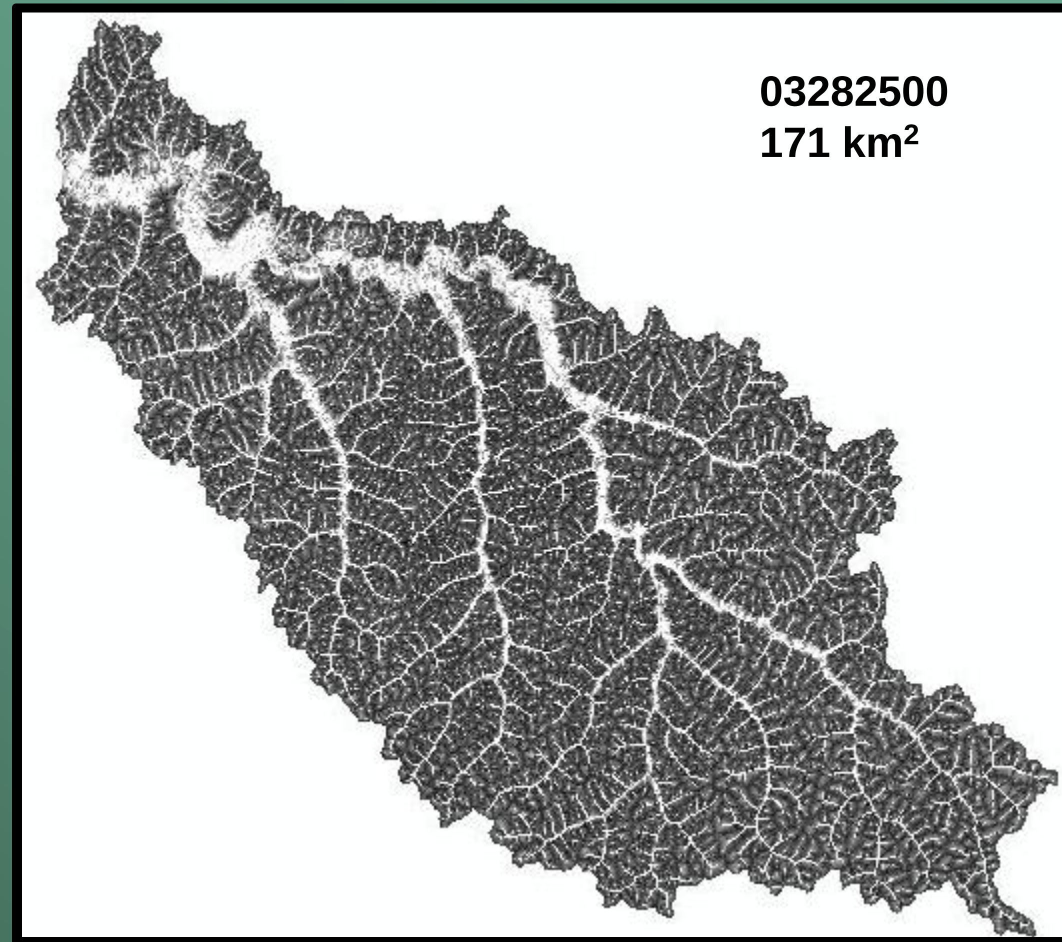
Grid cells with the same TWI are hydrologically similar

Calculations need not be performed on every single grid cell.

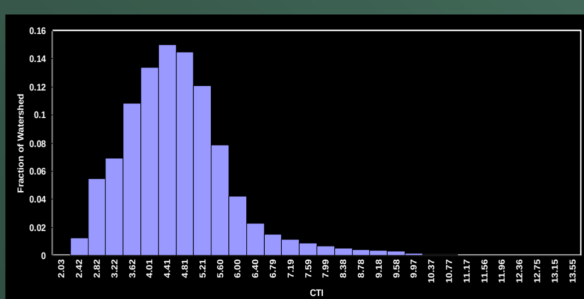
High values of TWI → High potential for saturation
Low values of TWI → Low potential for saturation

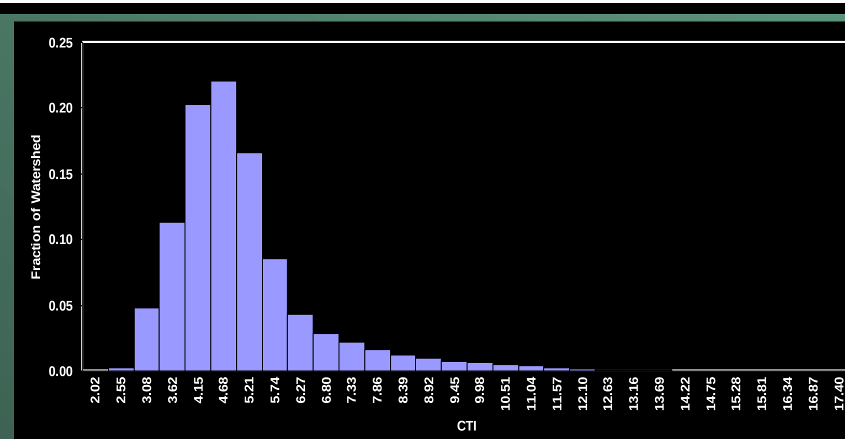
Quasi-distributed Approach

03207965
17 km^2



03282500
171 km^2





Data Library

Historical Climate and gridded NEXRAD data

Precipitation and Temperature Estimates for Each Basin

Topographic Wetness Index

Histogram

DEM

Streams (synthetic)

From Spatial Layers

Site ID

Area

Total cells

Lake area

Uplake Area

Soil Characteristics

Root Zone

Stream cells

Latitude

Impervious areas

Withdrawals

Discharges

WATER

- **Estimated hydrograph**
- **Time series**
  - **Saturated areas**
  - **Stream length**

DATA SOURCES

- **KY Dam Safety Commission**
- **Soil Survey Geographic Data**
- **TR-55 Impervious Erosion Curve**
- **National Land Cover Data 2001**
- **KY Pollutant Discharge Elimination System**
- **KY Division of Water**
- **NOAA NWS**

Statistical Validation of WATER Output

Bias

$$\frac{\sum (x_i - y_i)}{n}$$

Root Mean Square Error

$$\sqrt{\frac{\sum (y_i - x_i)^2}{n}}$$

Correlation

$$\frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}}$$

Nash-Sutcliffe Efficiency

$$1 - \frac{\sum (y_i - x_i)^2}{\sum (x_i - \bar{x})^2}$$

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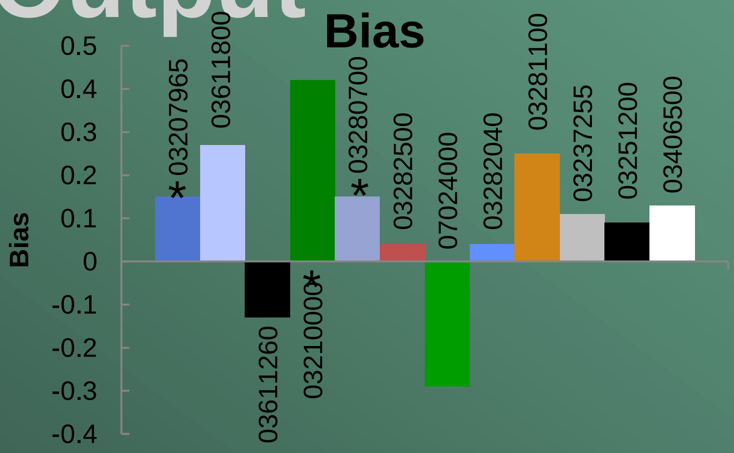
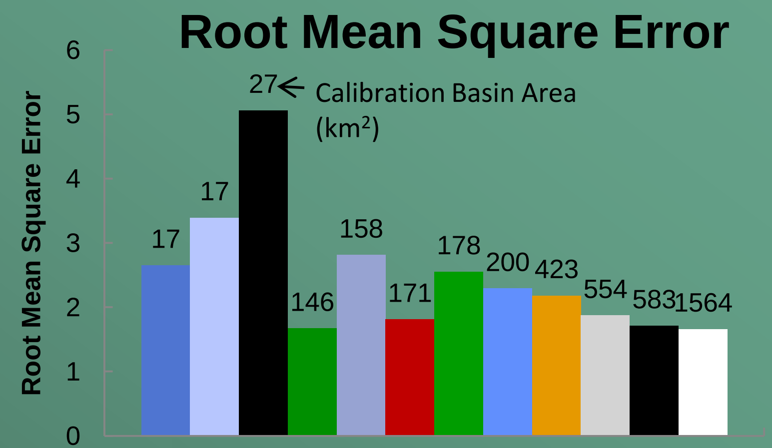
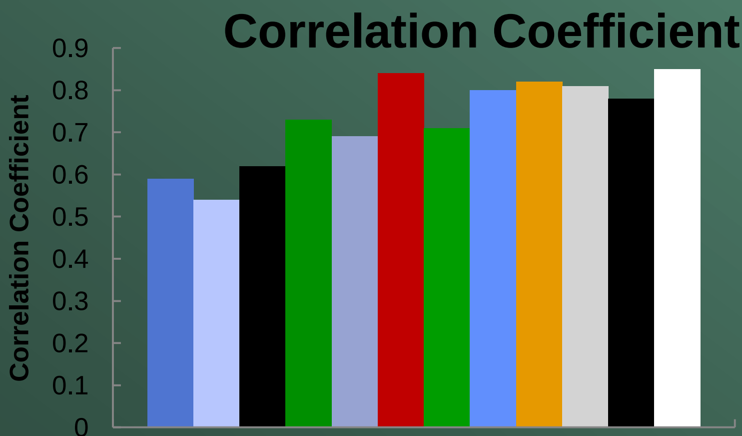
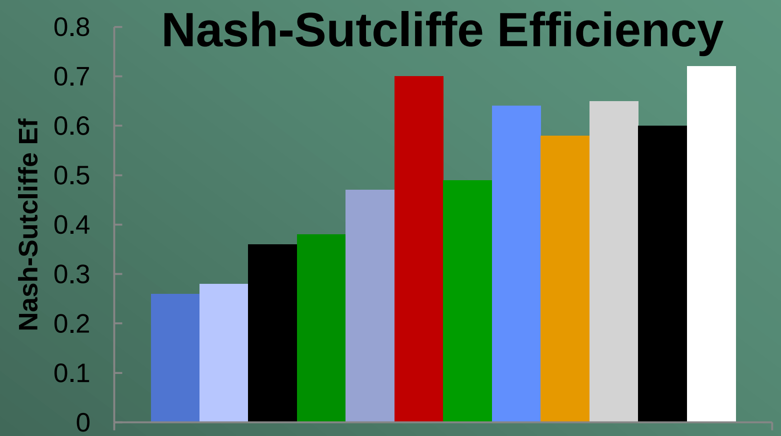
Statistical Validation of WATER Output

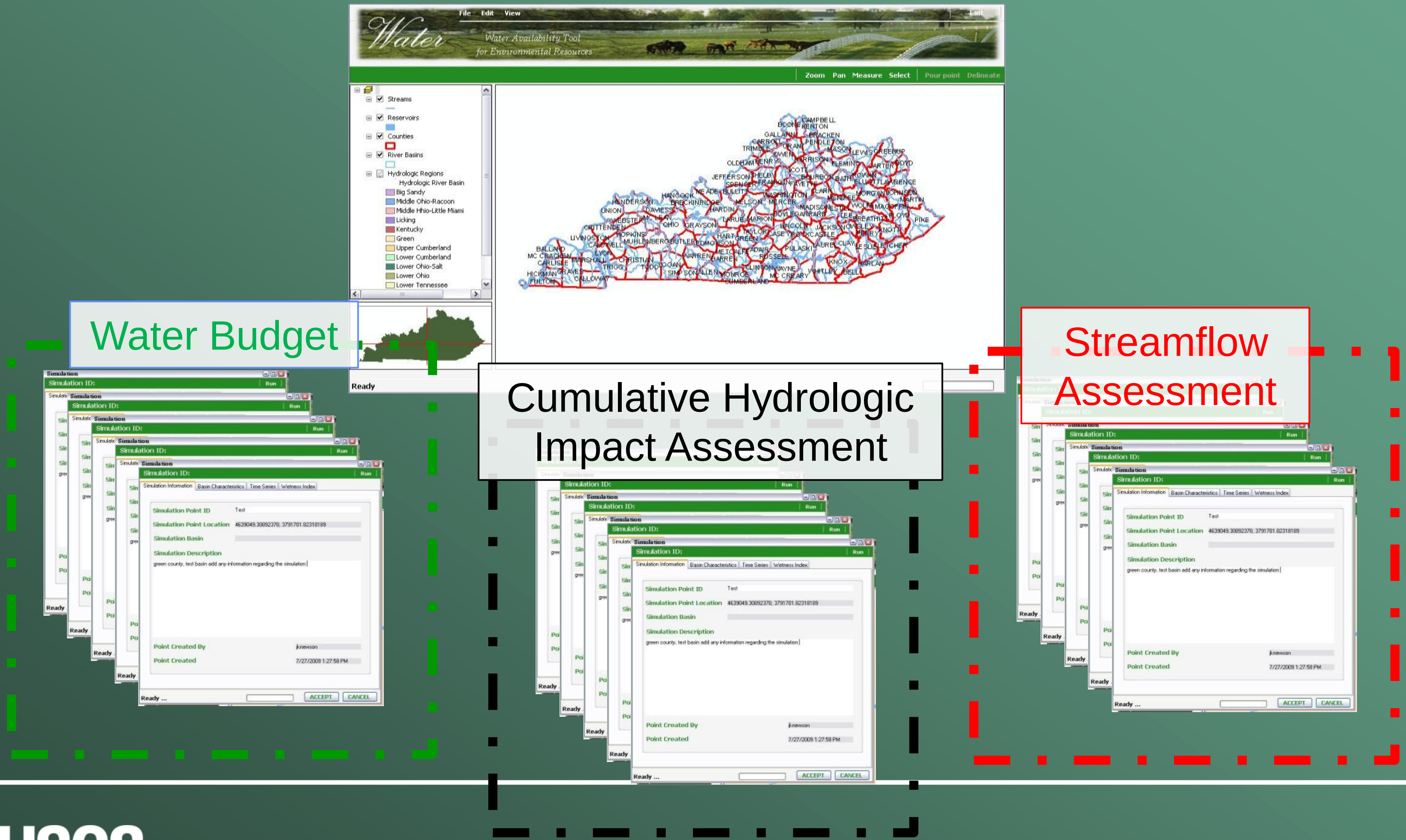




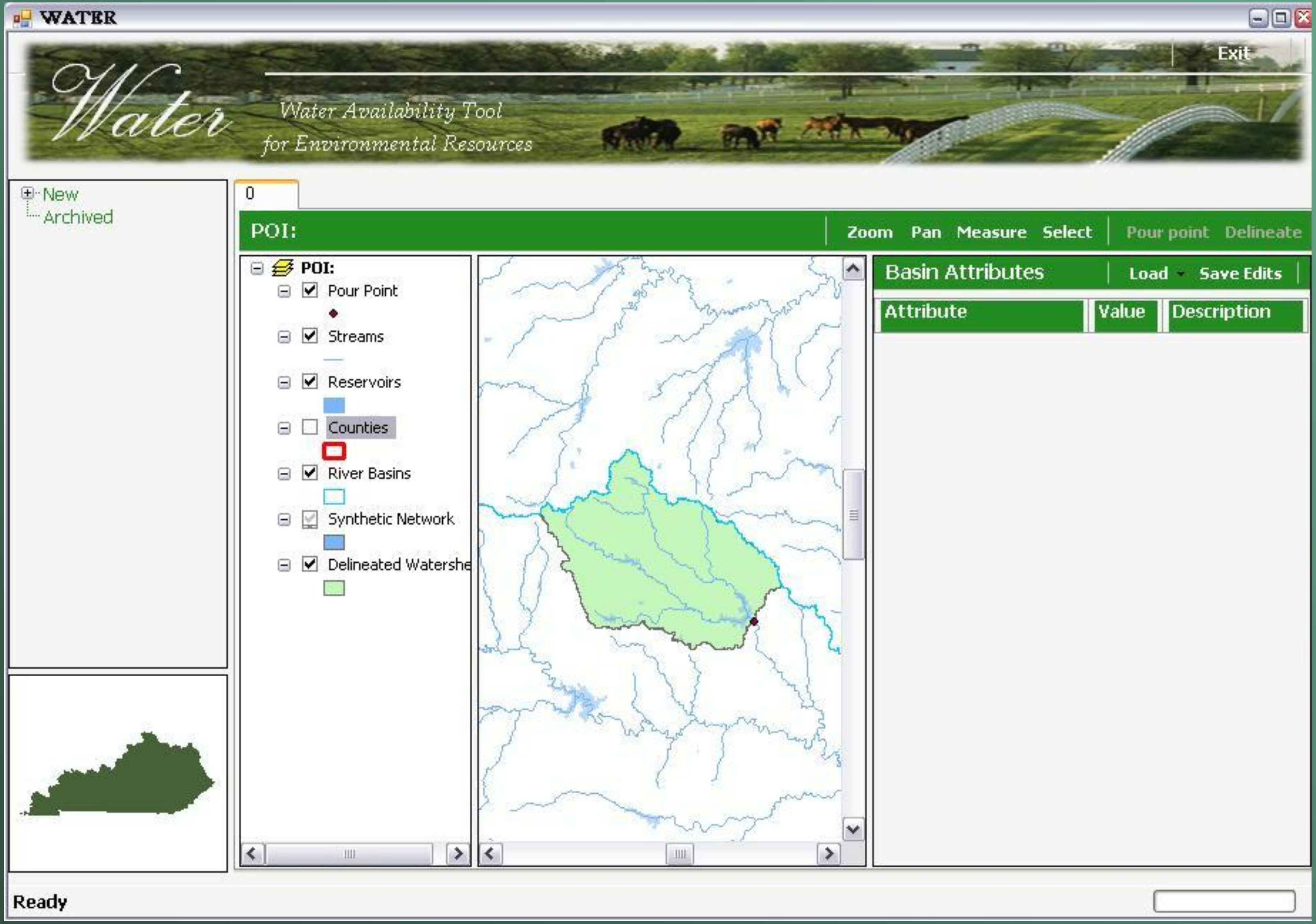




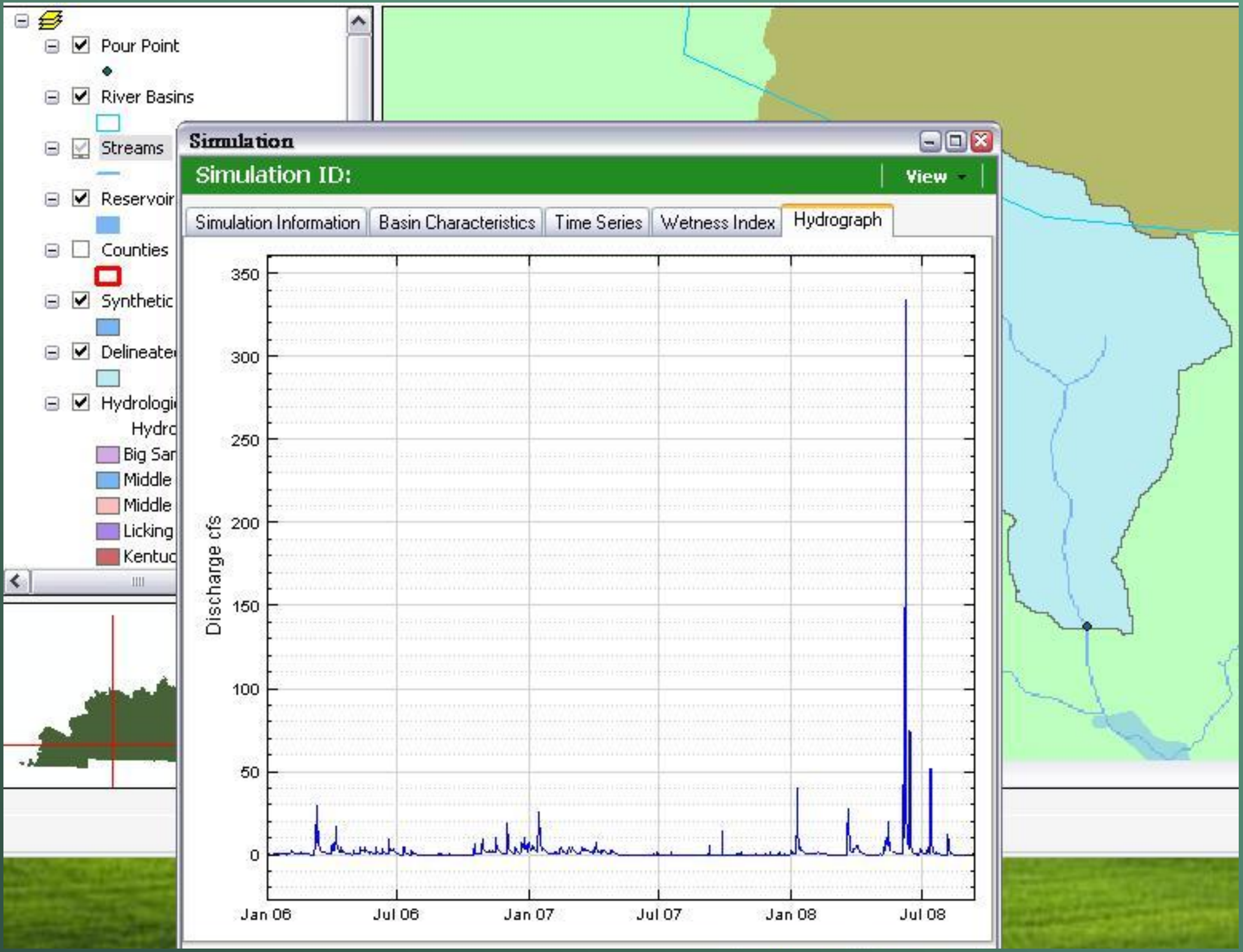
WATER's Present Applicability to Hydrologic Problems



CHIA-Related Needs –
Cumulative Impact Area



CHIA-Related Needs –
Quantification of streamflow "baseline" responses



CHIA-Related Needs – Impact of individual sites

Simulation ID: _03BothfromFile | Run

Simulation Information | Basin Characteristics | Wetness Index | Time Series

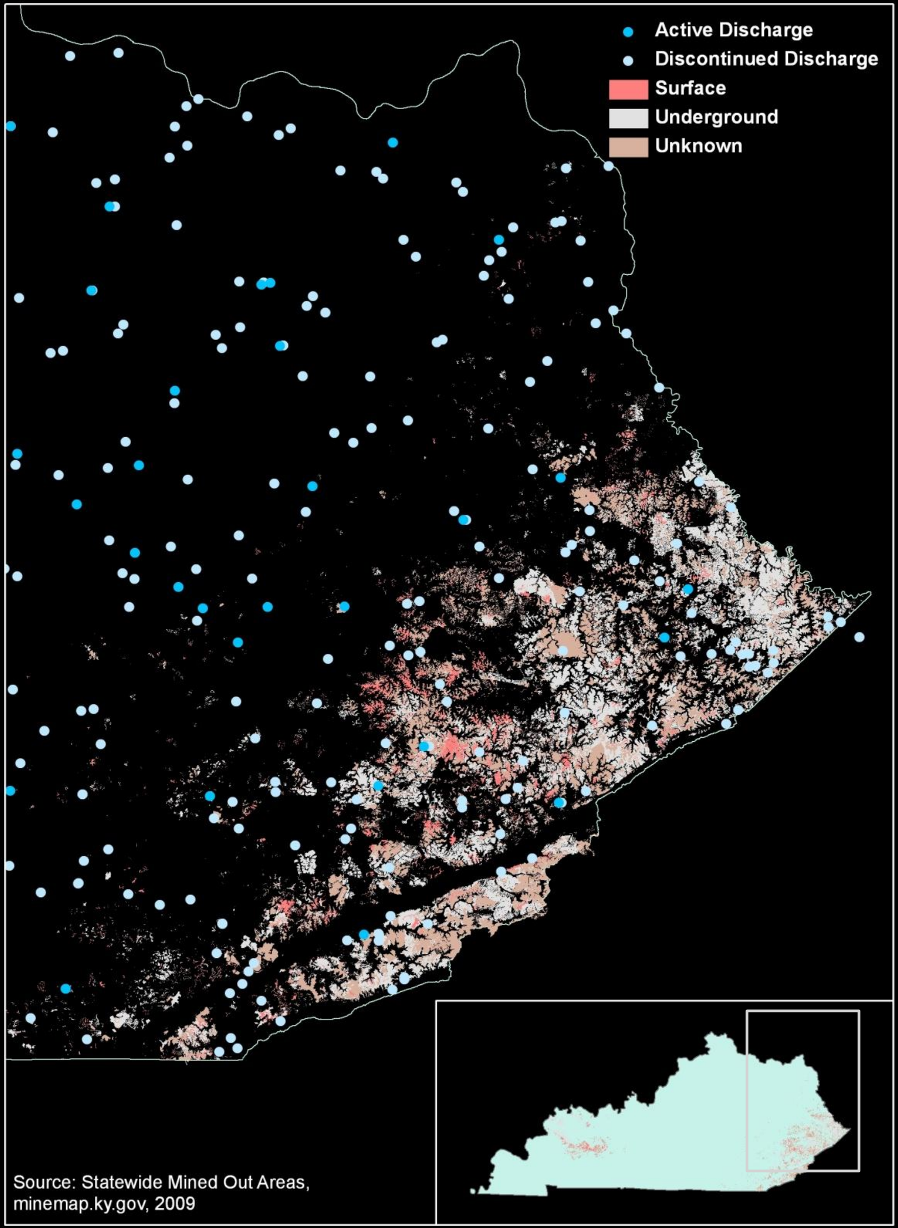
Property	Value	Units	Description
Simulation ID	_03BothfromFile		Simulation id...
Total Area	399.142548648532	square Kilometer	Simulation b...
Total Lake Area	1.8796	square Kilometer	Upstream c...
Saturated Hydraulic Conductivity	790.1959379184	millimeter/day	Saturated h...
Soil Depth	1732.9	millimeter	Depth of soil
Field Capacity	0.283178	unitless	
Water Holding Capacity	0.159403	unitless	Water holdi...
Porosity	0.383718	unitless	Porosity of soil
Percent Impervious	2.04131	%	Percent imp...
Percent Road Impervious	0.767953	%	Percent roa...
Latitude	36.48	Decimal Degrees	Latitude
Site ID	03438000		Site ID
Effective Impervious	0.7	%	Effective im...
Conductivity Multiplier	4.78896	unitless	Soil conduct...
Percent Macropore	0.2		
Scaling Factor M	19.782	millimeter	Soil scaling f...
Ground Water Withdrawal	0	million gal/year	Ground wat...
Surface Water Withdrawal	3556.63868613139	million gal/year	Surface wat...
Surface Water Discharge	2842.90875912409	million gal/year	Surface wat...
Impervious Surface History_Flag	False	True/False	Is there a hi...
Wettness Index_Adjustment	1	unitless	Topographi...
Depth of Root Zone	300	millimeter	Depth of roo...
Impervious Run off Delay	0.1	unitless	Factor relati...
Impervious Curve Number	98	unitless	curve number
Uplake Area	68.71240817	square Kilometer	Contributing ...
Lake Decay	1.5	unitless	Coefficient f...
Evapotranspiration Exponent	0	unitless	Evapotrans...
Return Flow Flag	True	True/False	Indicates ap...
Impervious Flag	False	True/False	Indicates ap...

Karst Characteristics

Property	Value	Units	Description
Simulation ID	_03BothfromFile		Simulation i...
Total Area	232.67459529504	square Kilometer	Simulation ...
Total Lake Area	0	square Kilometer	Upstream c...
Saturated Hydraulic Conductivity	710.944374327128	millimeter/day	Saturated ...
Soil Depth	2008.53807718908	millimeter	Depth of soil
Field Capacity	0.295608833351692	unitless	
Water Holding Capacity	0.161194825409953	unitless	Water holdi...
Porosity	0.389047041927975	unitless	Porosity of ...
Percent Impervious	1.13000019764515	%	Percent im...
Percent Road Impervious	0.433436528057526	%	Percent ro...
Latitude	36.7656375280967	Decimal Degrees	Latitude
Site ID	03438000		Site ID
Effective Impervious	0.7	%	Effective i...
Conductivity Multiplier	3.51024892782913	unitless	Soil condu...
Percent Macropore	0.2		
Scaling Factor M	23.6244307246701	millimeter	Soil scaling...
Ground Water Withdrawal	0	million gal/year	Ground wa...
Surface Water Withdrawal	971.6197875	million gal/year	Surface wa...
Surface Water Discharge	1.461	million gal/year	Surface wa...
Impervious Surface History_Flag	False	True/False	Is there a h...
Wettness Index_Adjustment	1	unitless	Topographi...
Depth of Root Zone	300	millimeter	Depth of ro...
Impervious Run off Delay	0.1	unitless	Factor relat...
Impervious Curve Number	98	unitless	curve num...
Uplake Area	0	square Kilometer	Contributin...
Lake Decay	1.5	unitless	Coefficient ...
Evapotranspiration Exponent	0	unitless	Evapotrans...
Return Flow Flag	True	True/False	Indicates a...
Impervious Flag	False	True/False	Indicates a...

Proposed application of WATER to CHIA

- Apply WATER to unmined watersheds in Eastern Appalachian Coalfield regions
  - baseline hydrologic response
  - compare various settings
    - hydrogeologic
    - climatic
- Apply WATER to mined watersheds in Eastern Appalachian Coalfield regions
  - ≥ 30% surface disturbance
  - simulate mining impact
- Characterize changes in hydrologic response of the test watersheds
  - statistically evaluate changes in basin hydrology with time
  - compare responses between unmined and mined watersheds
  - determine whether relation between percent mining-disturbance and hydrologic change is quantifiable
    - stormwater-runoff response
    - baseflow or ground-water recharge



Future Capabilities of WATER – mining-related impacts on stream-water quality

- Investigating pairing WATER with geochemical modeling
  - PHREEQC
  - MINTEQ
- Identify water-quality constituents
  - Most important to water quality
  - Best indicators of potential impacts
- Considerable data mining/preparation effort would be needed

Future Capabilities for WATER –
Assess potential impacts to Ground Water

- Significant technical-conceptual and data availability difficulties to overcome.
- The TOPMODEL approach is not an appropriate tool.
- Other gw-numerical models (e.g. MODFLOW) might be useful for certain site-specific or sub-regional evaluations.
- In general, application of numerical gw-flow models is technically difficult and subject to large potential errors given complexities of Eastern Appalachian Coalfield hydrogeology.
- Relative lack of availability of suitable quantitative data about aquifer characteristics is a problem. “Scale problems” are also significant.
- A spatial statistical methodology (logistical regression model) might be the most beneficial approach.

USGS