Simulation of ground-water flow in the Shenandoah Valley using variable-direction anisotropy to represent geologic structure

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- Estimate permeability at a regional scale
- Investigate factors that control depth of active flow
- Develop a method to represent bedrock structure
- Provide a framework for future modeling studies

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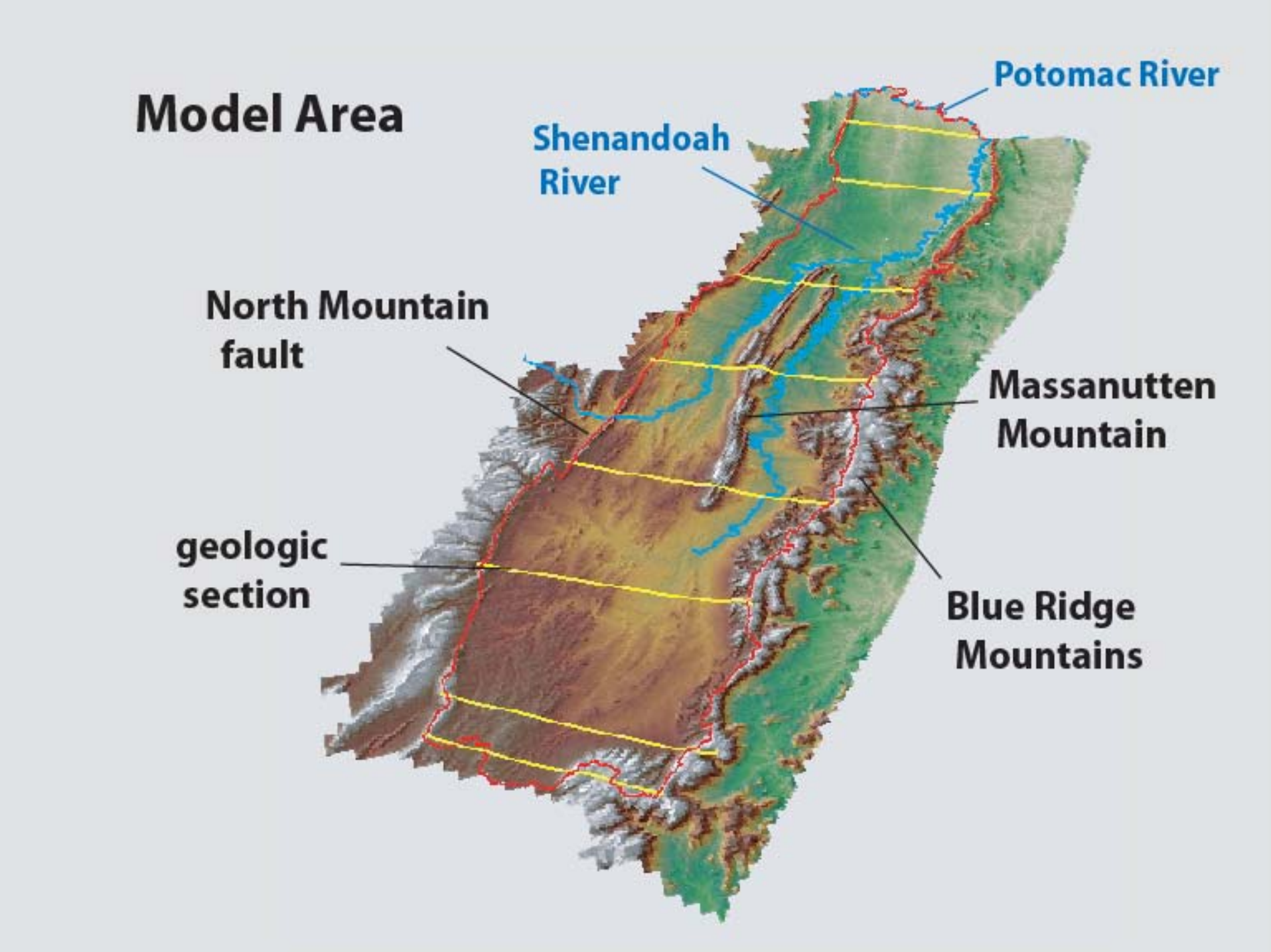
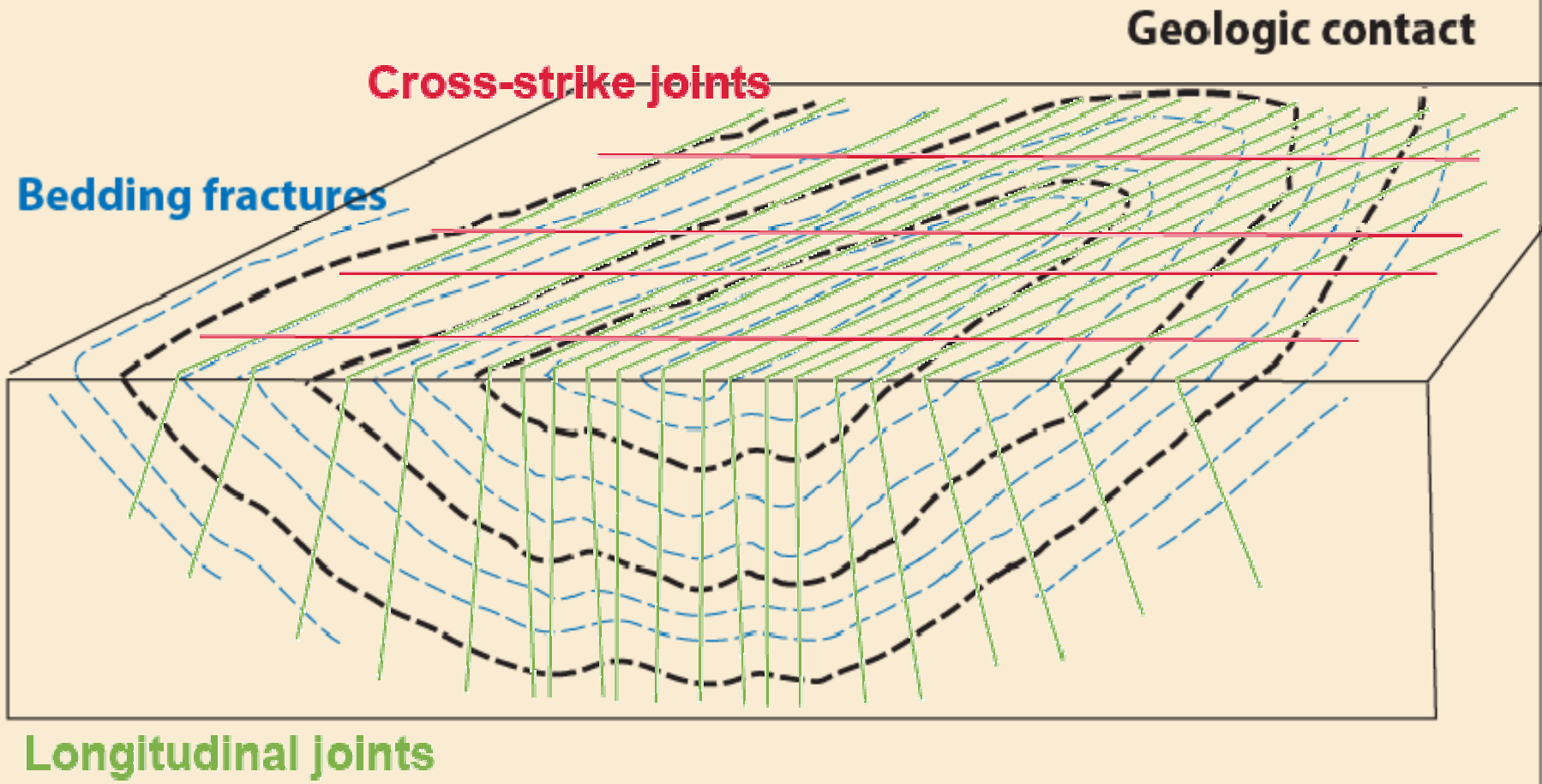
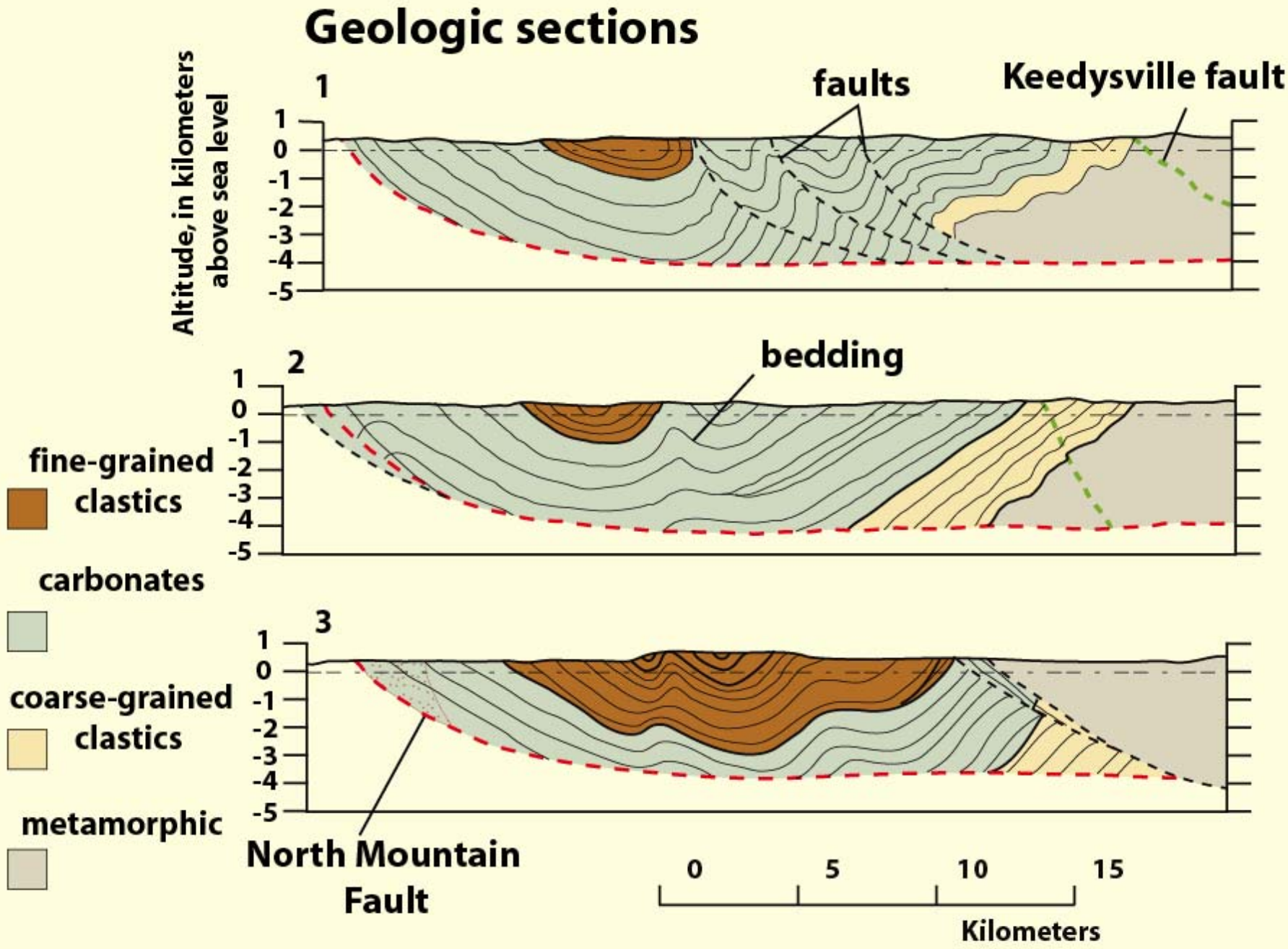
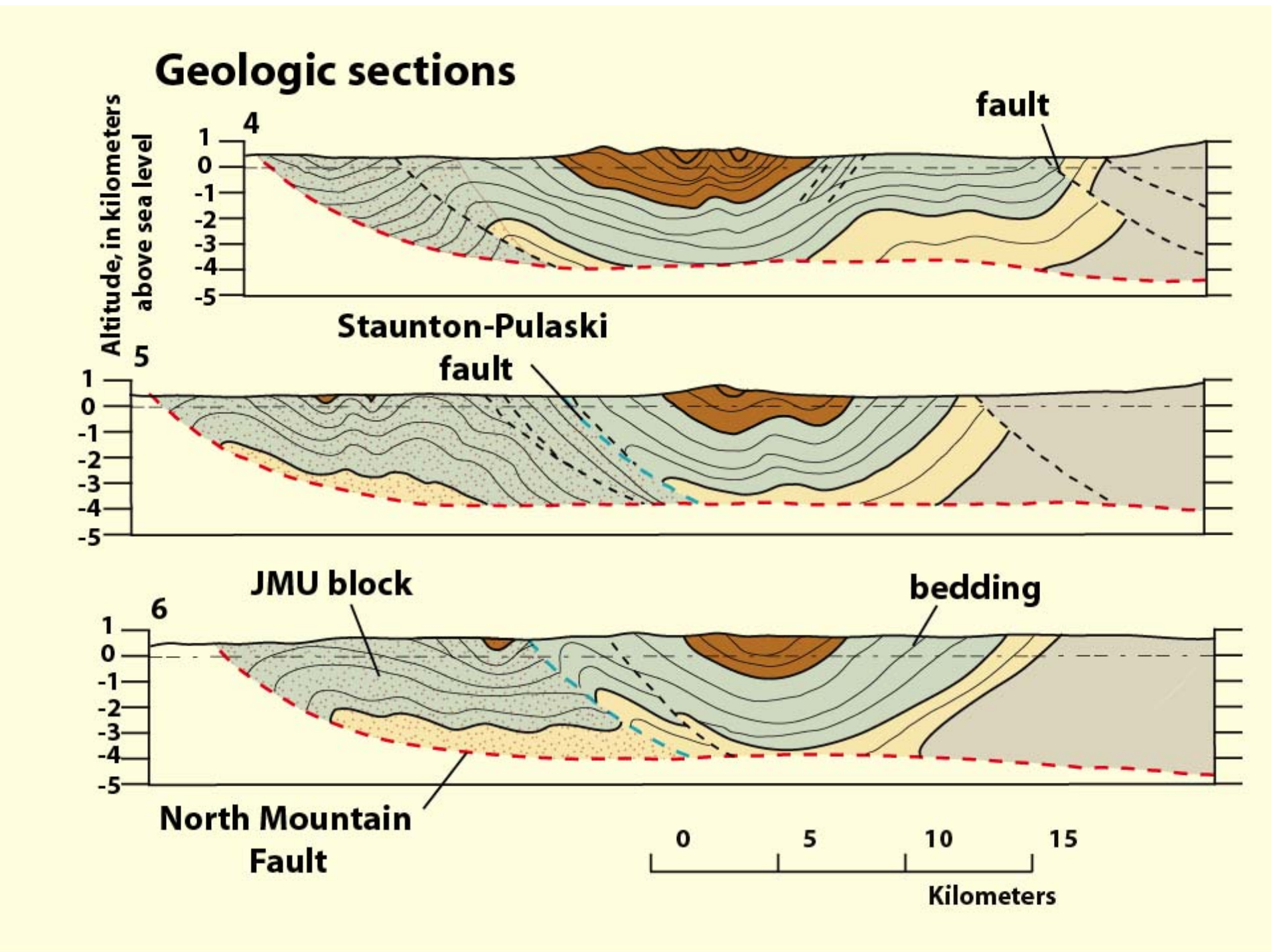

Model Area
Potomac River
Shenandoah River
North Mountain fault
Massanutten Mountain
geologic section
Blue Ridge Mountains

Conceptual fracture network for syncline

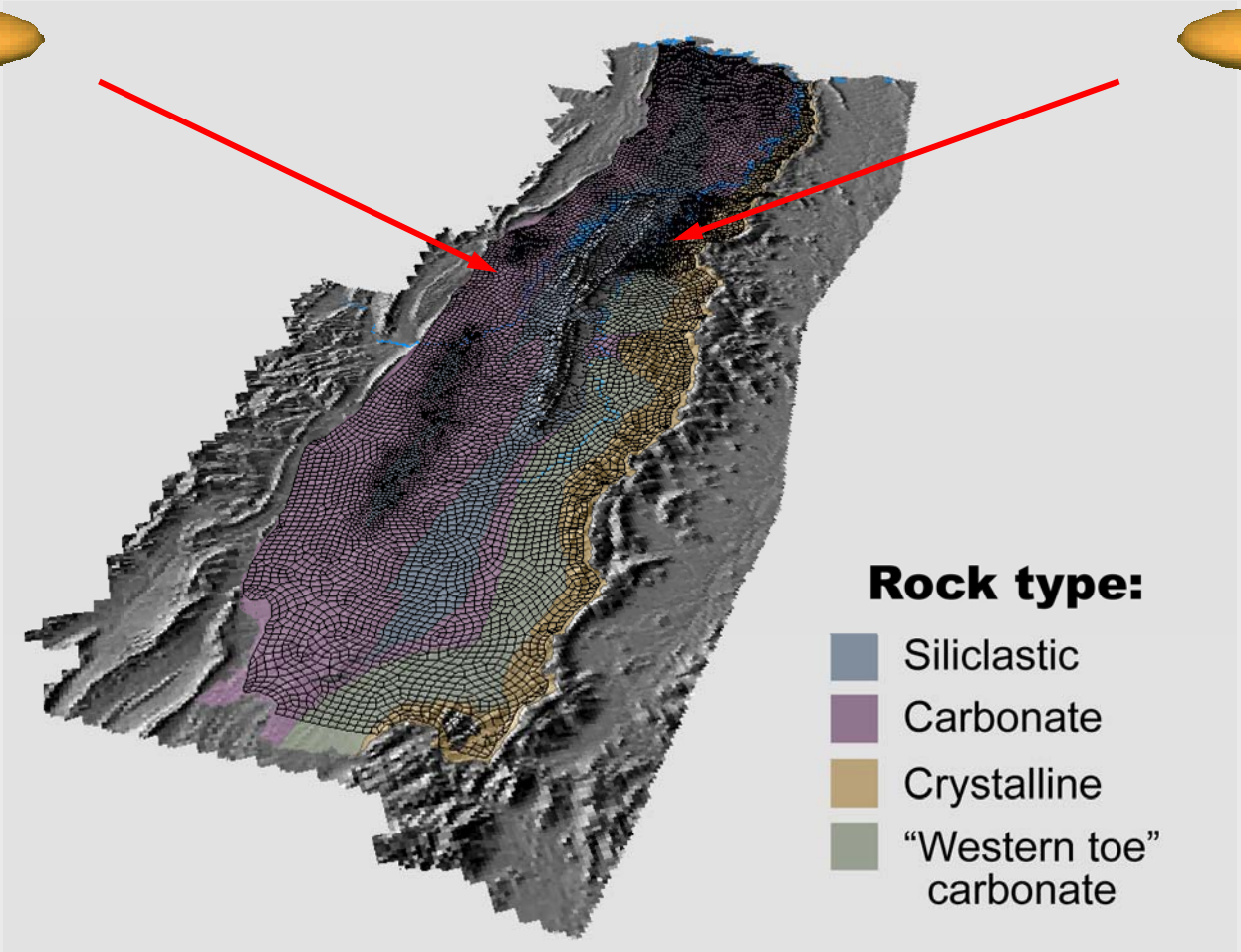
(after Burton et al)




Geologic sections
Altitude, in kilometers above sea level
1
2
3
faults
Keedysville fault
bedding
1
0
-1
-2
-3
-4
-5
fine-grained clastics
carbonates
coarse-grained clastics
metamorphic
North Mountain Fault
0
5
10
15
Kilometers


Geologic sections
Altitude, in kilometers above sea level
4
1
0
-1
-2
-3
-4
-5
fault
Staunton-Pulaski fault
5
JMU block
bedding
6
North Mountain Fault
0
5
10
15
Kilometers

Finite-element mesh & permeability tensors



Model design

- 3D representation of major rock types
  using SUTRA to specify variable-direction anisotropy

- Irregular mesh with 340,000 elements & 25 layers
  layer spacing: 30m to 1000m

- Permeability declines exponentially
  below 300 m depth

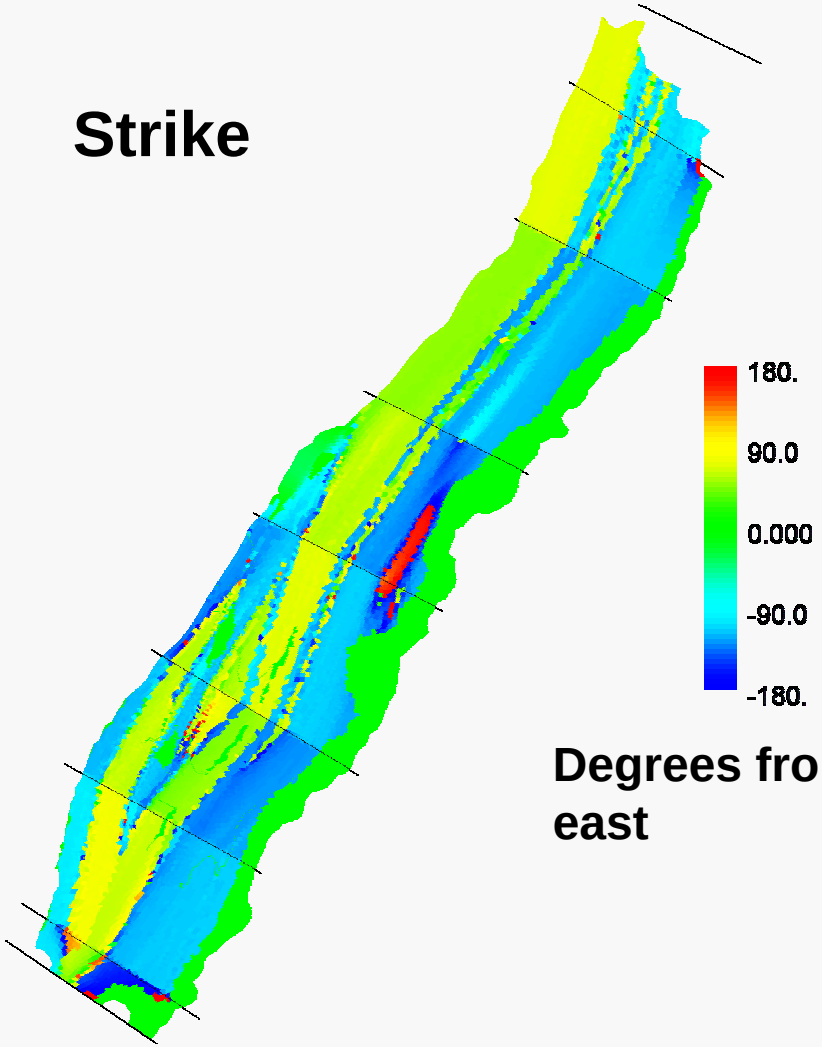
- Boundary condition:

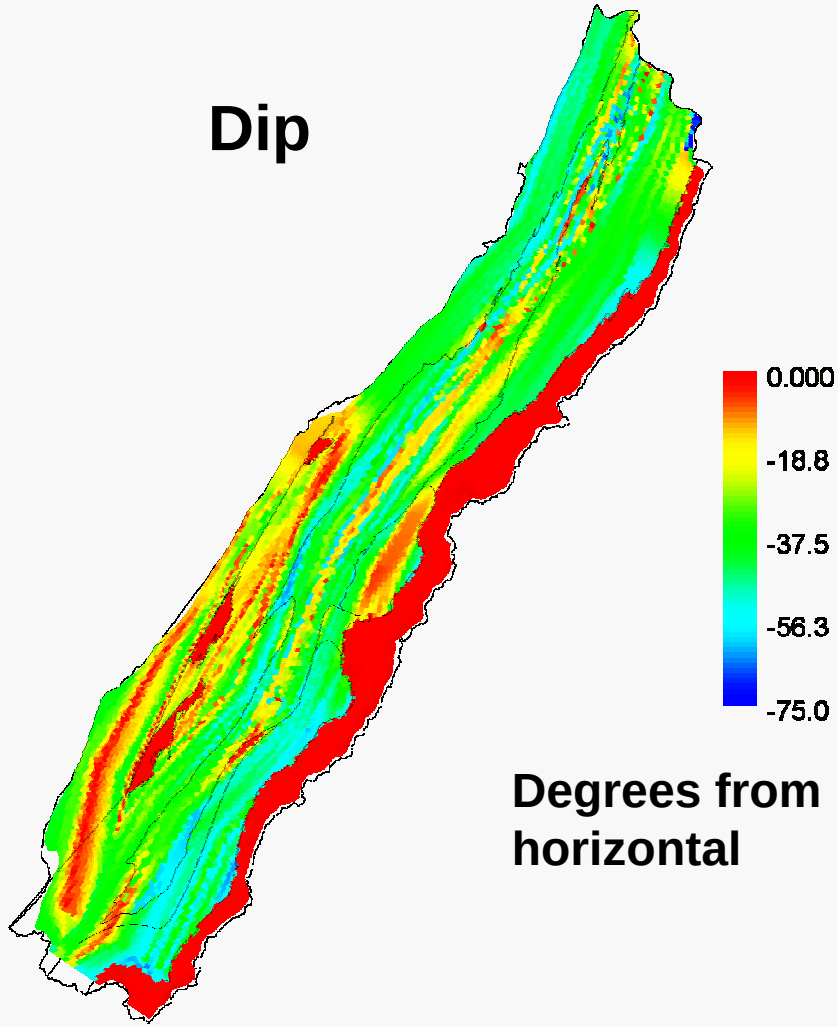
Sensitivity analysis	constant water-table
Calibration	constant flux (recharge) w/ streams

Model limitations

- Regional scale
  - generalized representation:
    - stream network
    - geology - stratigraphy & structure
- Available data
  - Missing depth profiles:
    - hydraulic head
    - geochemistry -> ground-water age
- Assumptions
  - steady state
  - diffusive flow - no karst
  - isothermal
  - constant density

Attitude of bedding



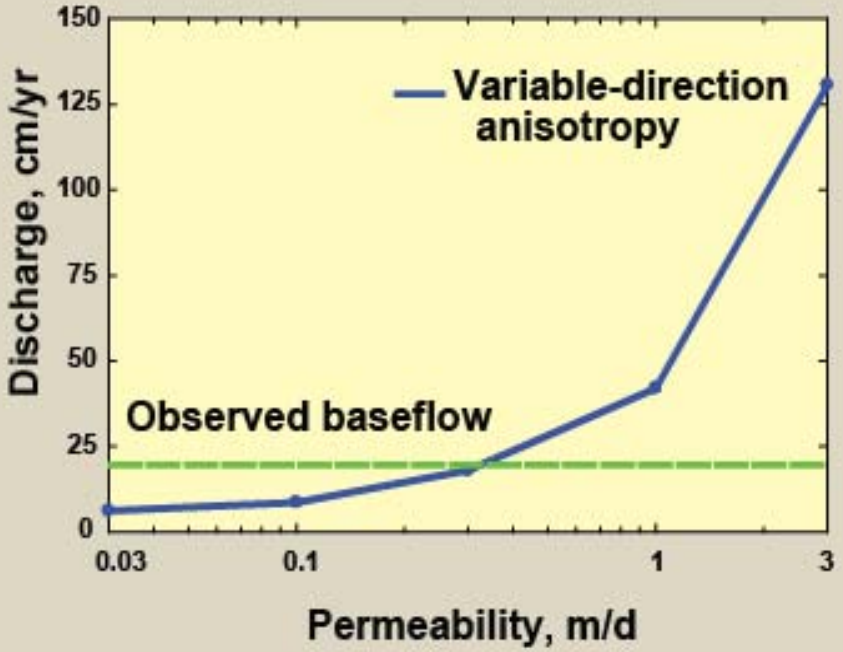


Model parameters

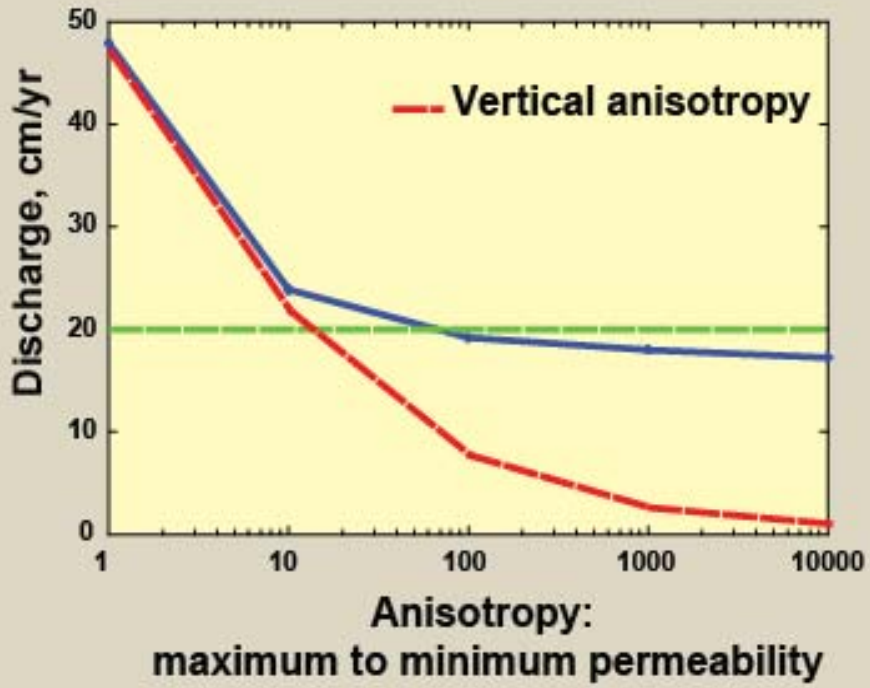
Maximum permeability, m/d	
Overburden	0.03 - 0.17
Siliclastic	0.15
Carbonate	0.03 - 3
Crystalline	0.03
"Western toe"	0.15 - 15
Cross-bedding anisotropy	1 - 1000
Depth of uniform permeabilty, m	10 - 1000
Porosity	0.01

Model sensitivity

Maximum permeability of carbonate



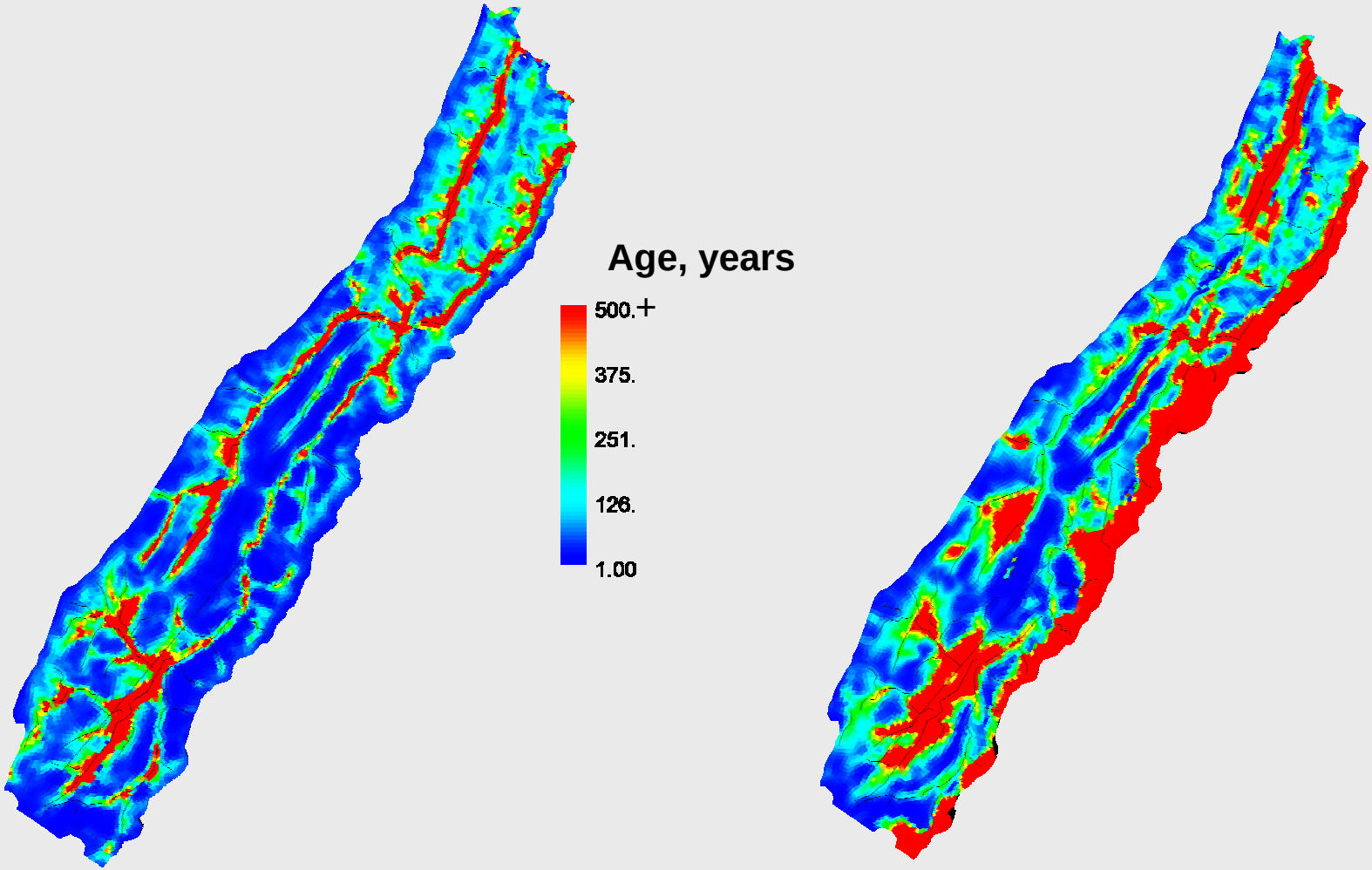
Cross-bedding anisotropy



Simulated ground-water age

Isotropic

Variable-direction anisotropy 1000:1



Simulated ground-water age

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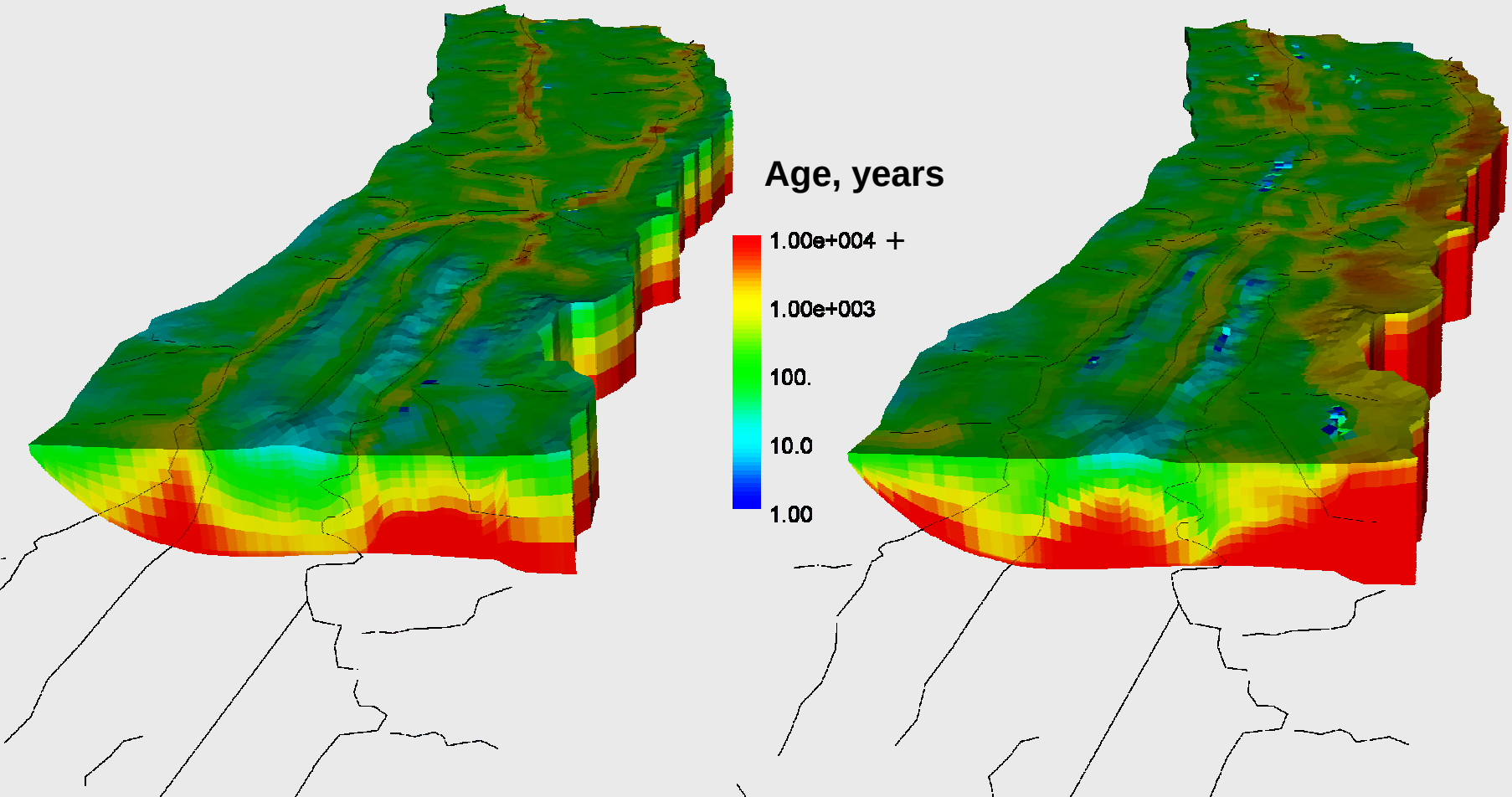
Variable-direction anisotropy 1000:1



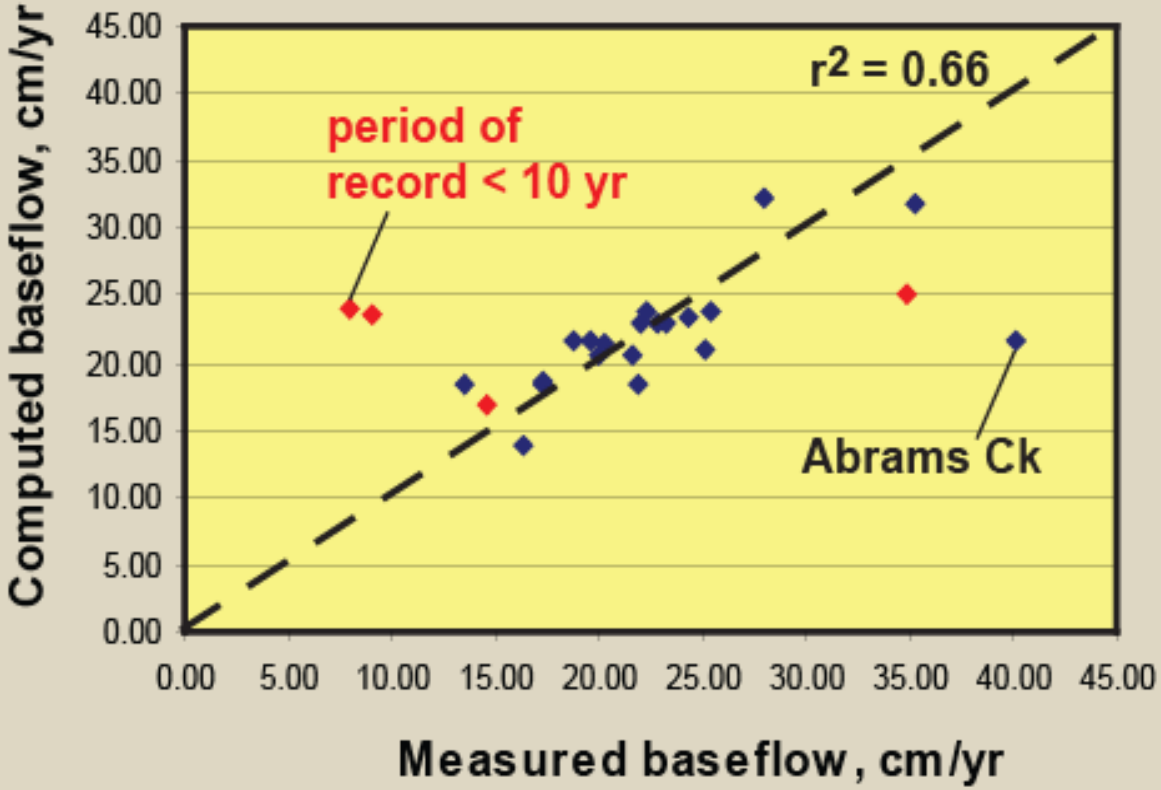
Model Calibration

- Constant flux (recharge) boundary w/ streams
  based on multivariate regression of baseflow

- Ground-water withdrawals
  49 production wells
  1.2 m^3/s (27 Mgd) -> 2.6% of baseflow

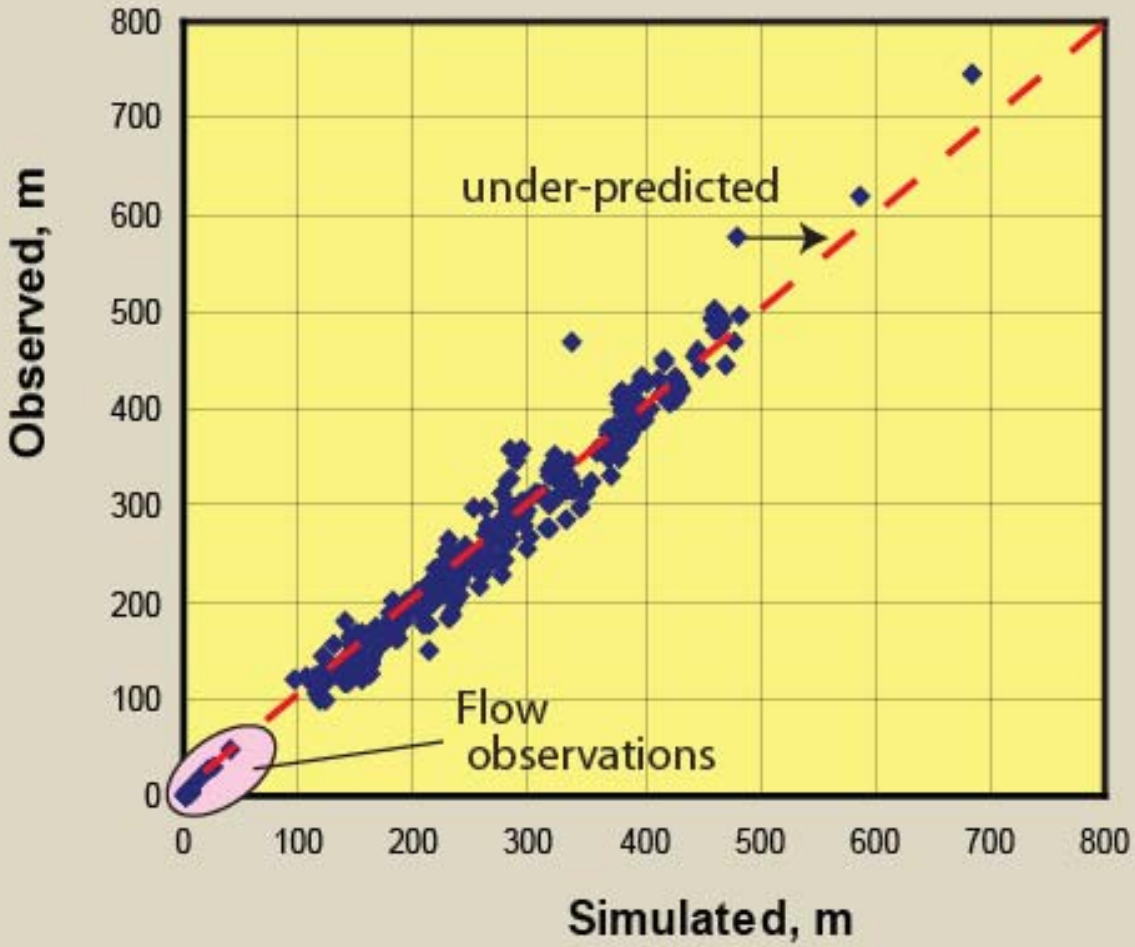
- Nonlinear regression with UCODE-2005
  observations:
  354 hydraulic heads
  24 flows

Multivariate regression of baseflow = f(rock type)



Baseflow, cm/yr	
Siliciclastic	13.9
Carbonate	24.7
Crystalline	23
Western Toe	39.5

Model Fit

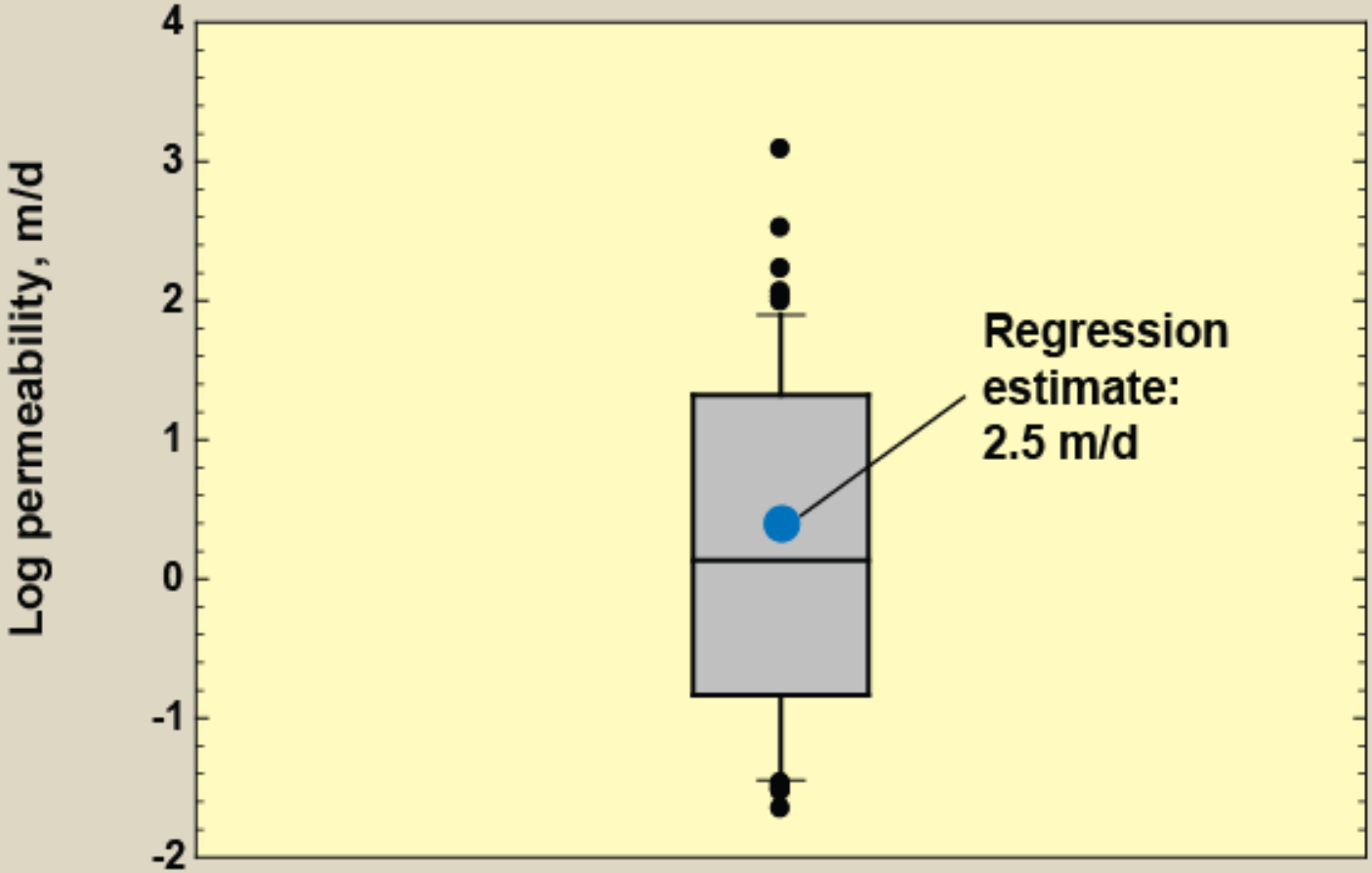


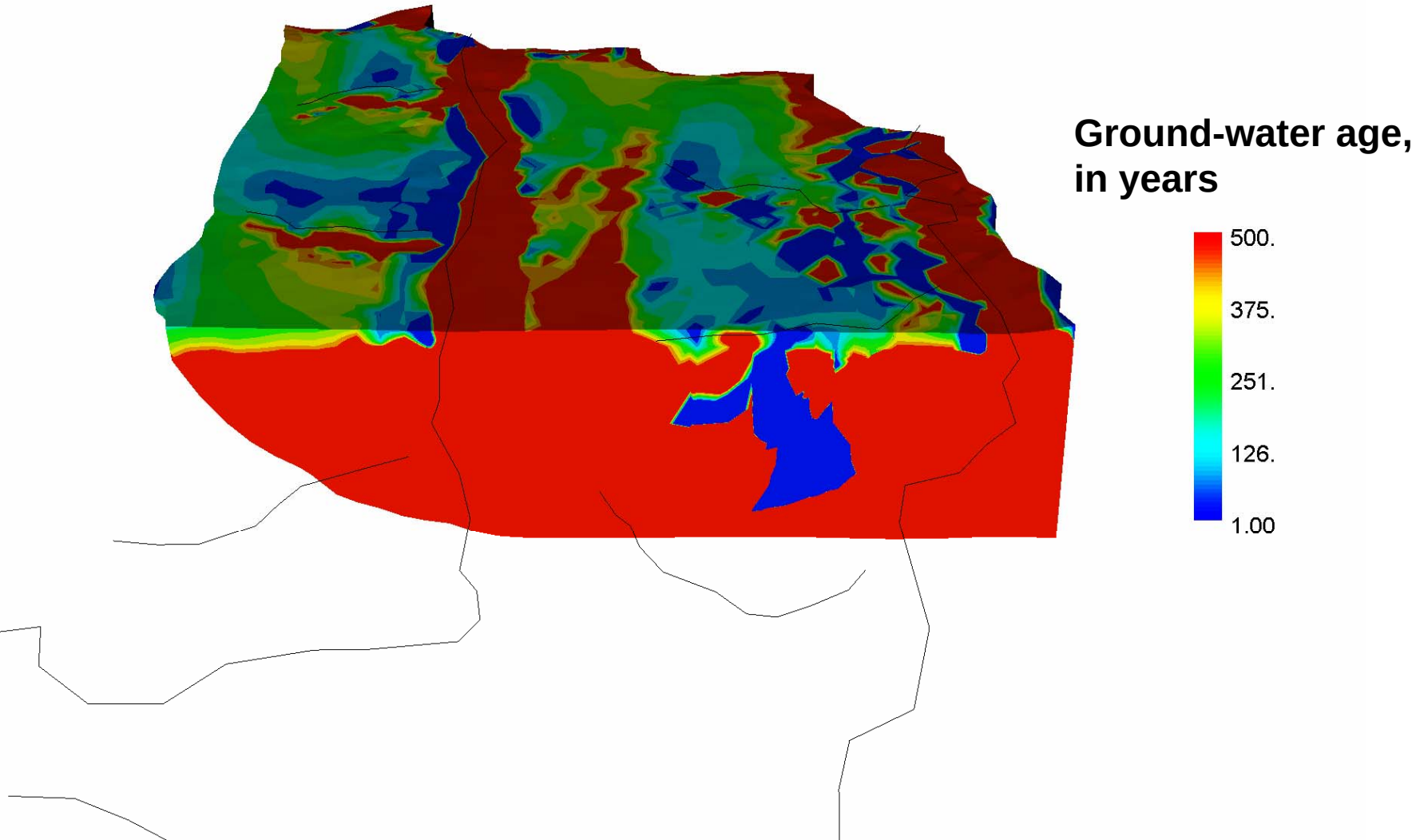
Standard error:
17 m

Parameter Estimates

Maximum permeability, m/d	Value	CV %
Siliclastic	0.08	1.7
Carbonate	2.5	1.1
Crystalline	0.58	2.1
"Western toe"	2.0	2.8
Cross-bedding anisotropy		
Siliclastic	18	32
Carbonate	66	8.3
Crystalline (vertical-no bedding)	870	5.8
"Western toe"	71	42

Permeability of carbonate from well data & regression estimate




Ground-water age,
in years
500.
375.
251.
126.
1.00

Form line map of northern Newark Basin, Rockland County NY

Conclusions

- Represent bedrock structure
  using variable-direction anisotropy

- Use smaller, watershed-scale models to better
  represent geology & hydrology

- Need geologic data at watershed scale
  form line maps
  cross-sections

- Additional ground-water data
  to delineate depth of flow:
  hydraulic head
  geochemistry

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