Mapping Sinkholes and Areas of Surface Water-Groundwater Interaction in Relation to Geologic Structure

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Eastern Earth Surface Processes Team, Reston, VA

Acknowledgments:

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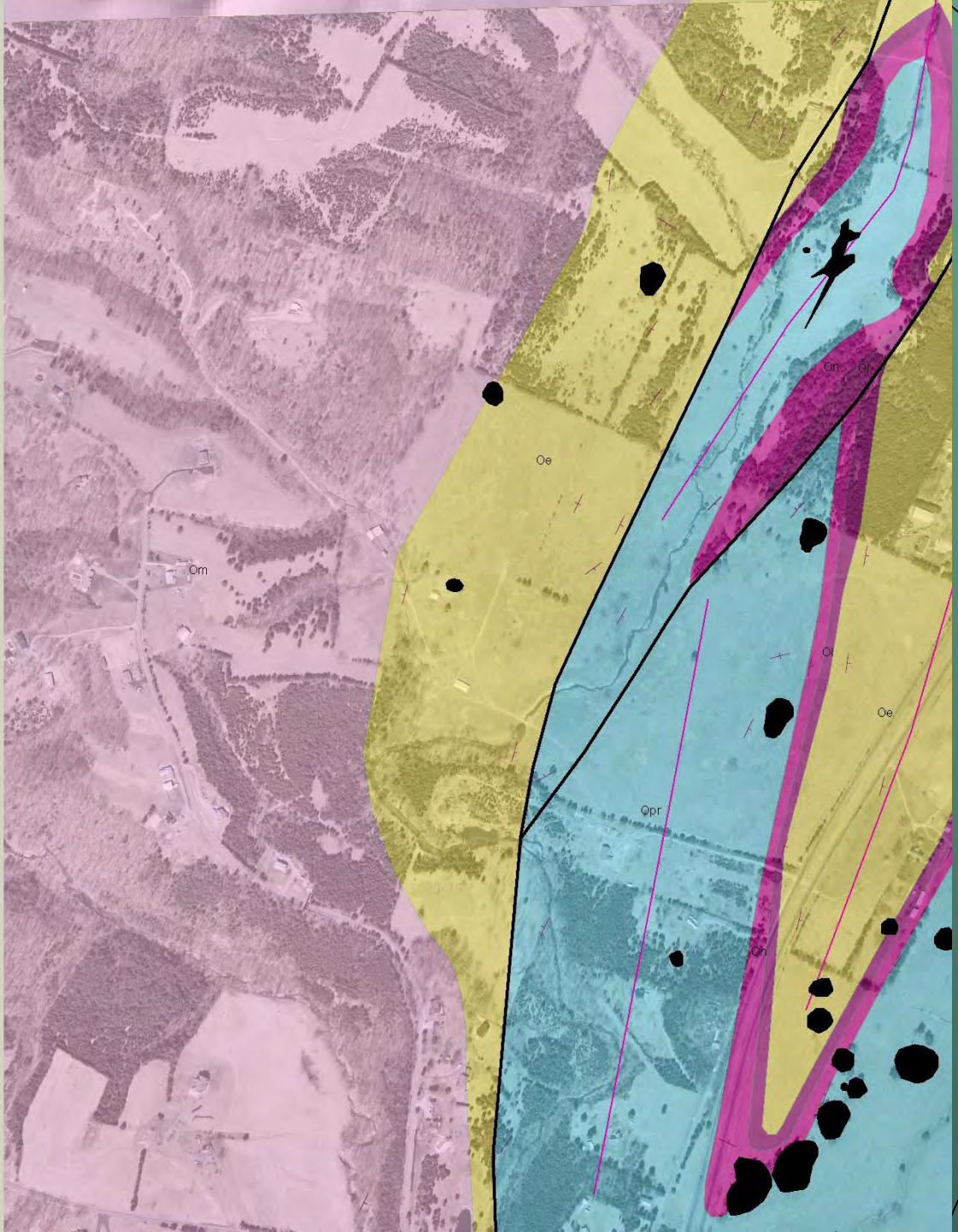
David Nelms, George Harlow, Kurt McCoy, Mark Kozar (USGS-WRD)
David Weary and Randall Orndorff (USGS-GD)

Sinkholes in the Northern Great Valley Karst

METHODS for MAPPING SINKHOLES

- Topographic Maps
  - Identify closed, hatchured contours as large depressions
  - Low resolution, >3m
- Aerial photo imagery (VGIN, Google Earth)
  - Quick reconnaissance
  - Historical information
  - Fast digital data acquisition
- Digital Elevation Model (DEM)
  - 30m/10m National Elevation Dataset
  - LiDAR (Light Detection and Ranging)
    - High-resolution (<1m), multipurpose surface elevation data
- Kung-Fu style
  - Walk the Earth, like Caine

USGS


Om
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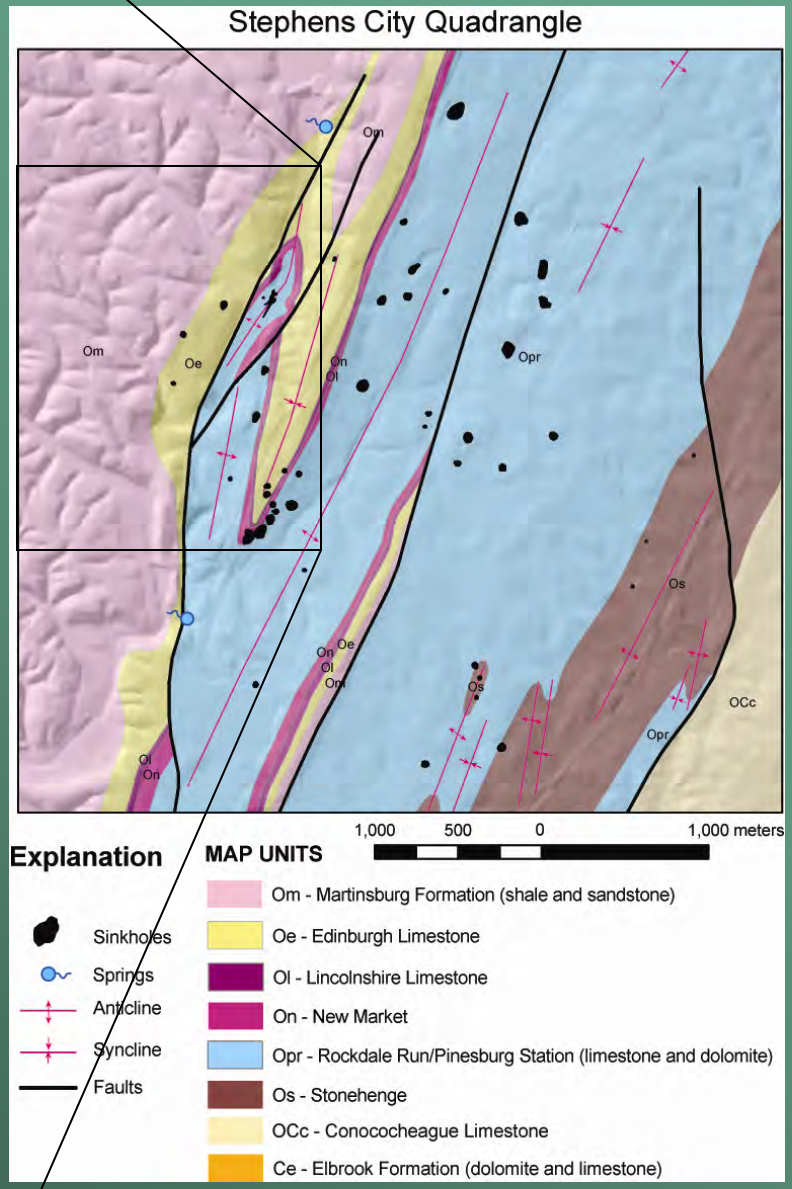
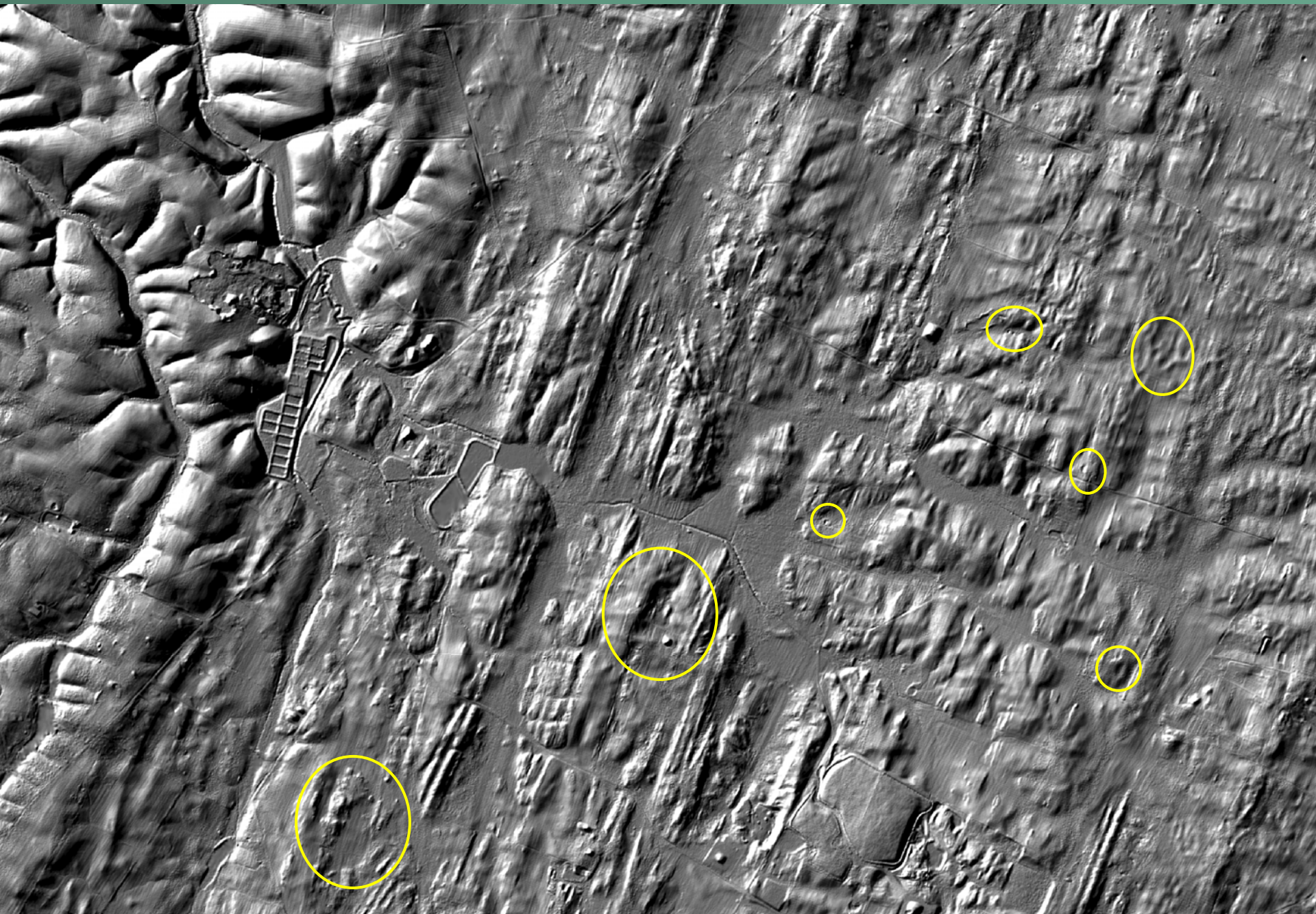
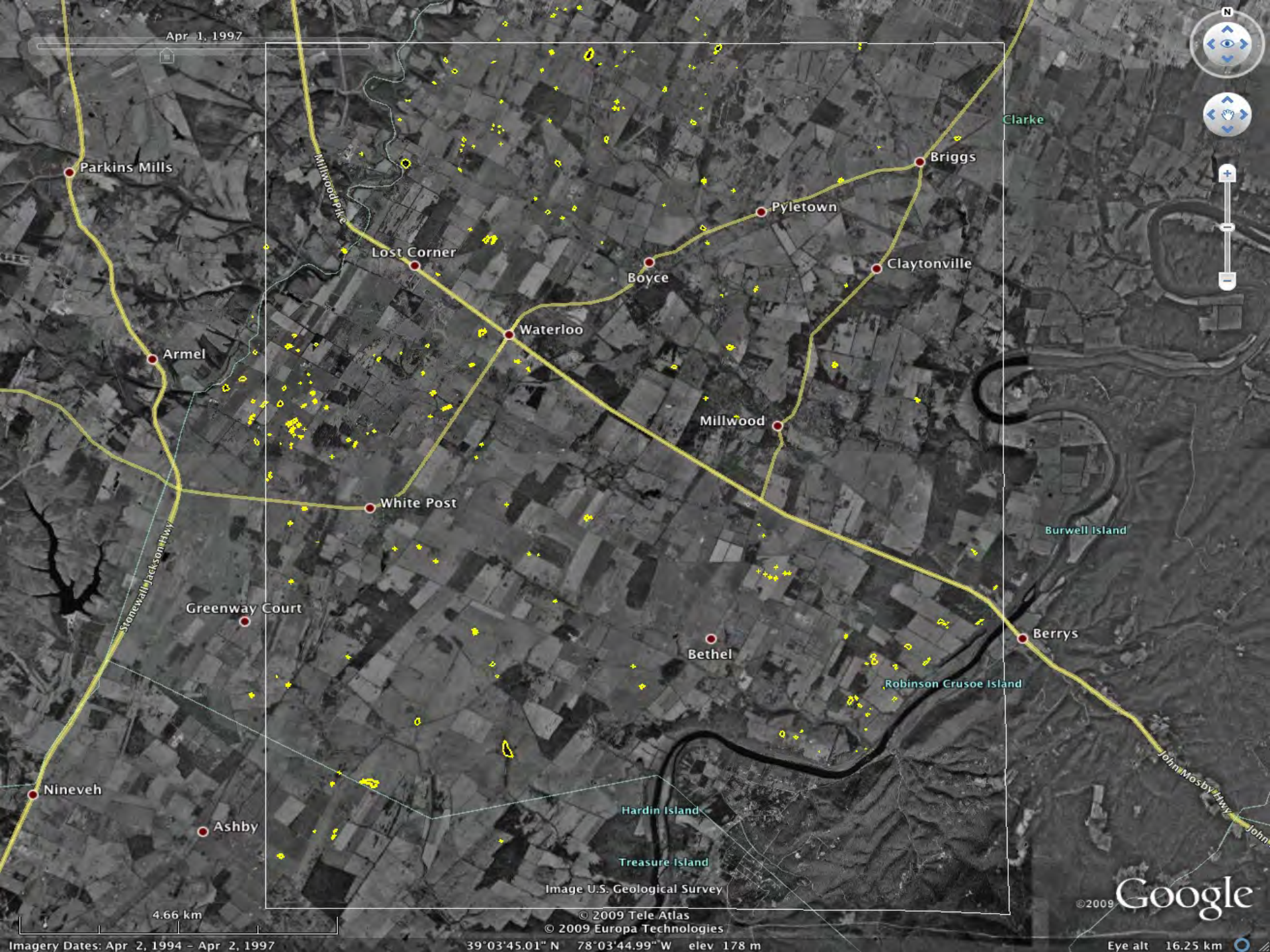
On
Ol
Opr


Stephens City Quadrangle
Om
Oe
On
Ol
Opr
Os
OCc
1,000
500
0
1,000 meters
Explanation
Sinkholes
Springs
Anticline
Syncline
Faults
MAP UNITS
Om - Martinsburg Formation (shale and sandstone)
Oe - Edinburgh Limestone
Ol - Lincolnshire Limestone
On - New Market
Opr - Rockdale Run/Pinesburg Station (limestone and dolomite)
Os - Stonehenge
OCc - Conococheague Limestone
Ce - Elbrook Formation (dolomite and limestone)

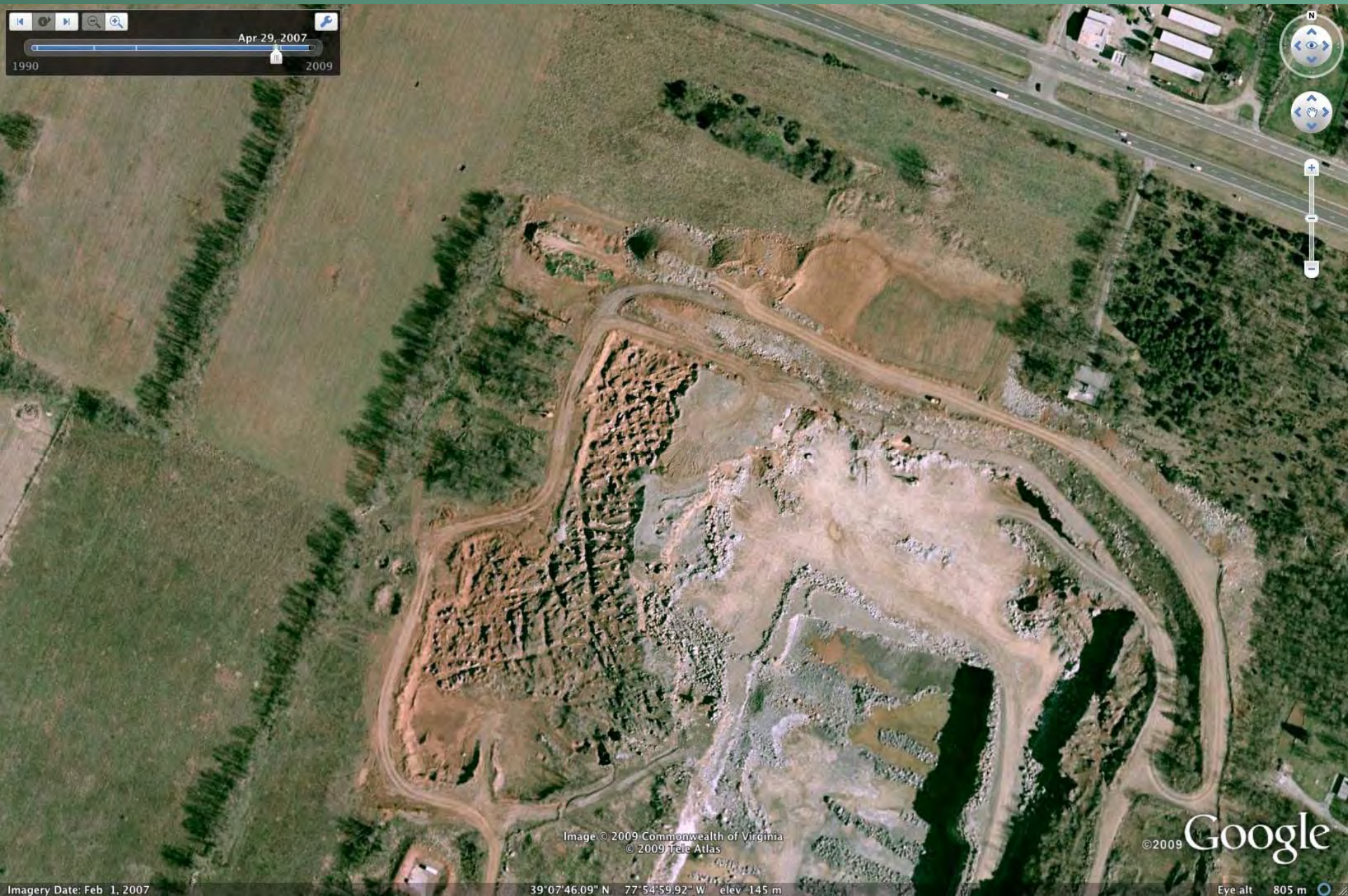
LiDAR IMAGE - John Young, Leetown Science Center




Apr 1, 1997
Parkins Mills
Millwood Pike
Lost Corner
Boyce
Pyletown
Briggs
Clarke
Claytonville
Waterloo
Armel
Millwood
White Post
Burwell Island
Stonewall Jackson Hwy
Greenway Court
Bethel
Berrys
Robinson Crusoe Island
John Mosby Hwy
Nineveh
Ashby
Hardin Island
Treasure Island
Image U.S. Geological Survey
4.66 km
© 2009 Tele Atlas
© 2009 Europa Technologies
©2009 Google
Imagery Dates: Apr 2, 1994 - Apr 2, 1997
39°03'45.01" N 78°03'44.99" W elev 178 m
Eye alt 16.25 km

BERRYVILLE, VA – Perry Quarry, 1990

BERRYVILLE, VA – Perry Quarry, 2007



BERRYVILLE, VA – Perry Quarry, 2007

Aug 24, 2007
Misty Hollow
Swimley Rd
672
Image USDA Farm Service Agency
© 2009 Tele Atlas
288 m
©2009 Google
Imagery Date: Aug 25, 2007
39°15'06.42" N 78°01'05.21" W elev 168 m
Eye alt 1.16 km

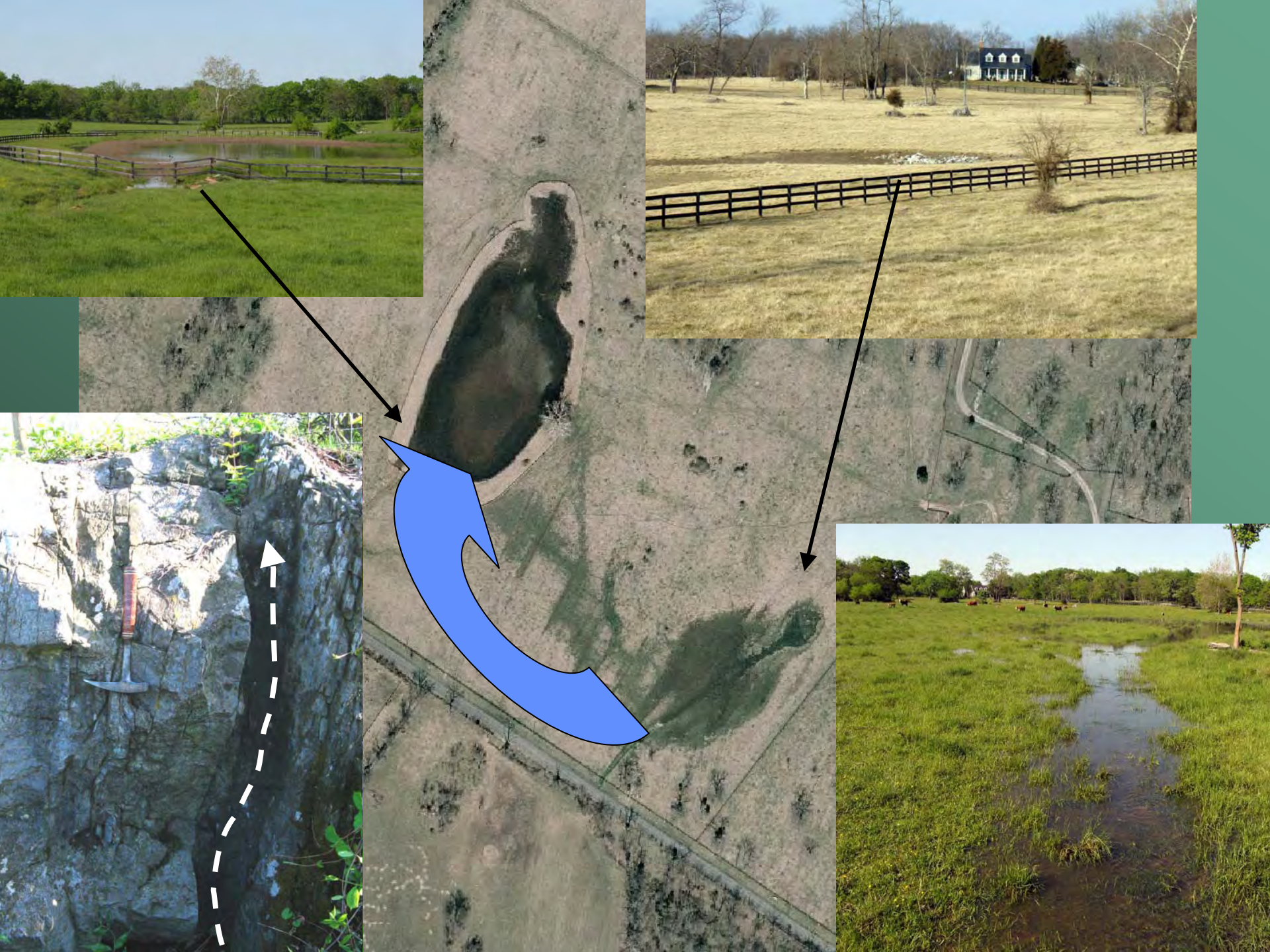
Aug 24, 2007
Misty Hollow
Swimley Rd
672
Image USDA Farm Service Agency
©2009 Tele Atlas
©2009 Google
288 m
Imagery Date: Aug 25, 2007
39°15'06.42" N 78°01'05.21" W elev 168 m
Eye alt 1.16 km

Apr 29, 2007
Misty Hill Rd
Swimley Rd
672
Image © 2009 Commonwealth of Virginia
© 2009 Tele Atlas
288 m
©2009 Google
Imagery Date: Feb 1, 2007
39°15'06.42" N 78°01'05.21" W elev 168 m
Eye alt 1.16 km

Apr 2, 1991
Misty Hill Ln
Swimley Rd
672
288 m
Image U.S. Geological Survey
© 2009 Tele Atlas
©2009 Google
Imagery Date: Apr 3, 1991
39°15'06.42" N 78°01'05.21" W elev 168 m
Eye alt 1.16 km

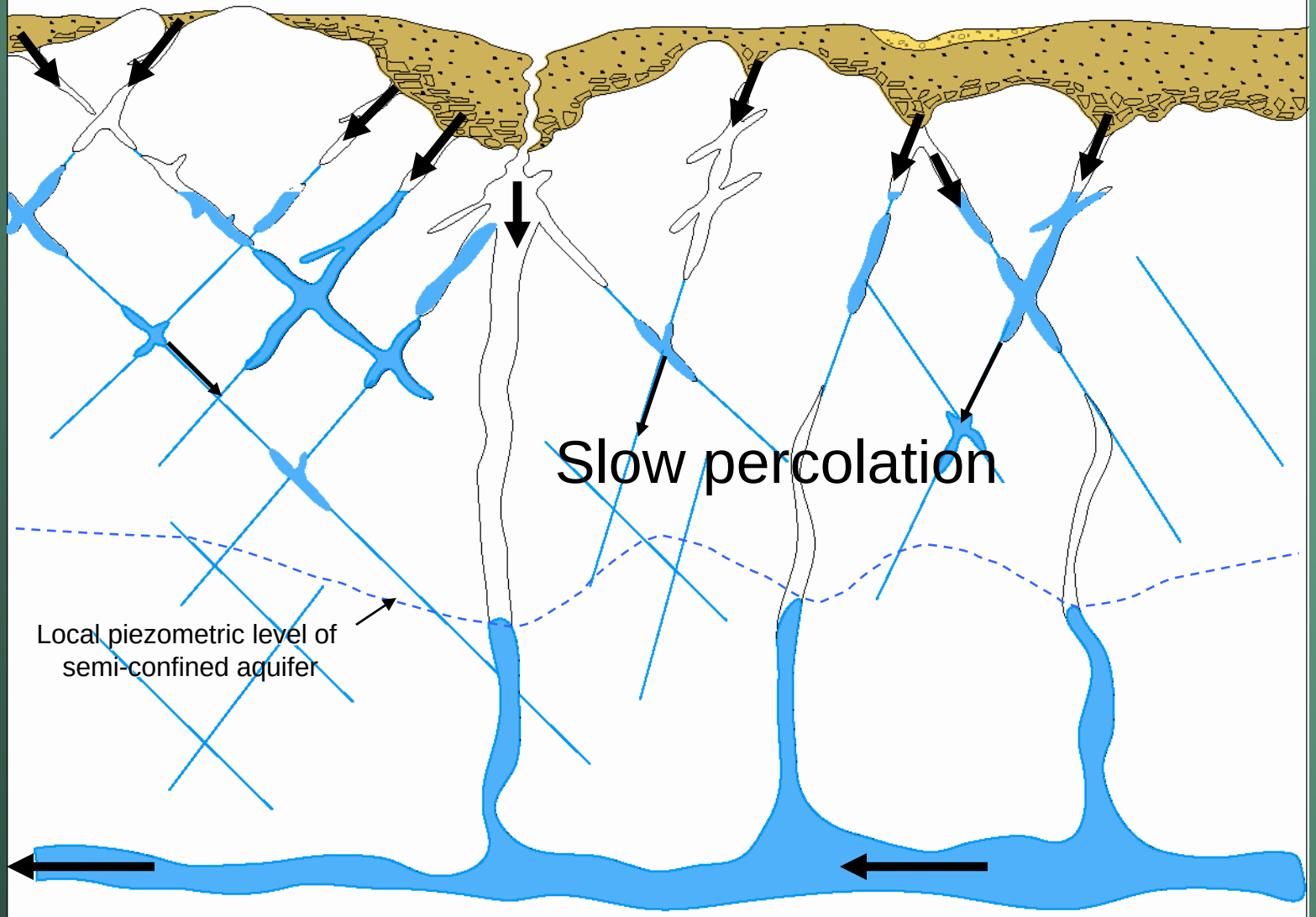
Mar 31, 1997
Misty Hill Ln
Swimley Rd
672
Image U.S. Geological Survey
© 2009 Tele Atlas
288 m
©2009 Google
Imagery Date: Apr 1, 1997
39°15'06.42" N 78°01'05.21" W elev 168 m
Eye alt 1.16 km

Mar 31, 1997
Berryville Sinkhole
From Boyce
Directions: To here - From here
Berryville Sinkhole
Misty Hill Ln
Swimley Rd
672
Image U.S. Geological Survey
© 2009 Tele Atlas
288 m
Google
Imagery Date: Apr 1, 1997
39°15'06.42" N 78°01'04.85" W elev 167 m
Eye alt 1.16 km



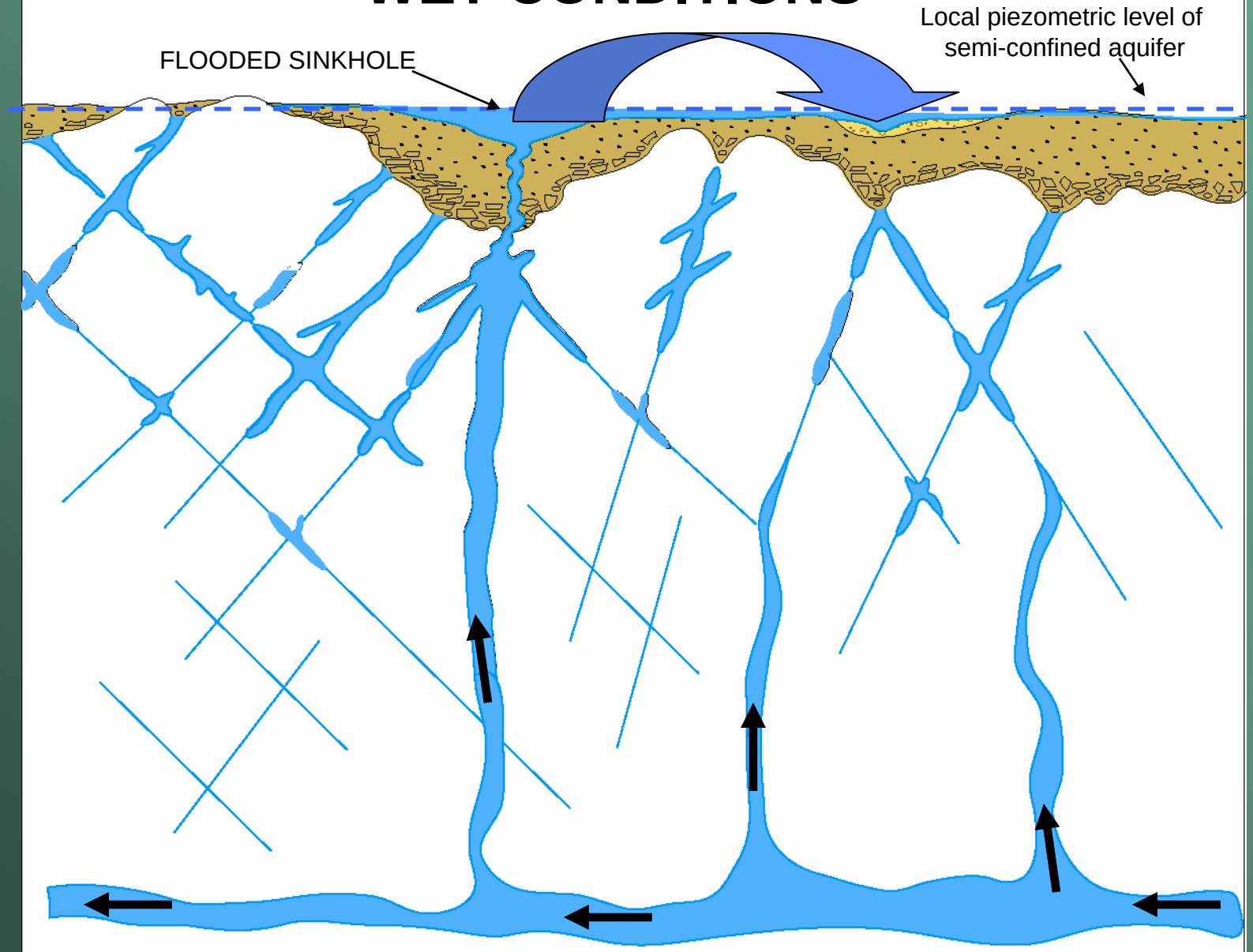
DRY CONDITIONS

Rapid surface drainage

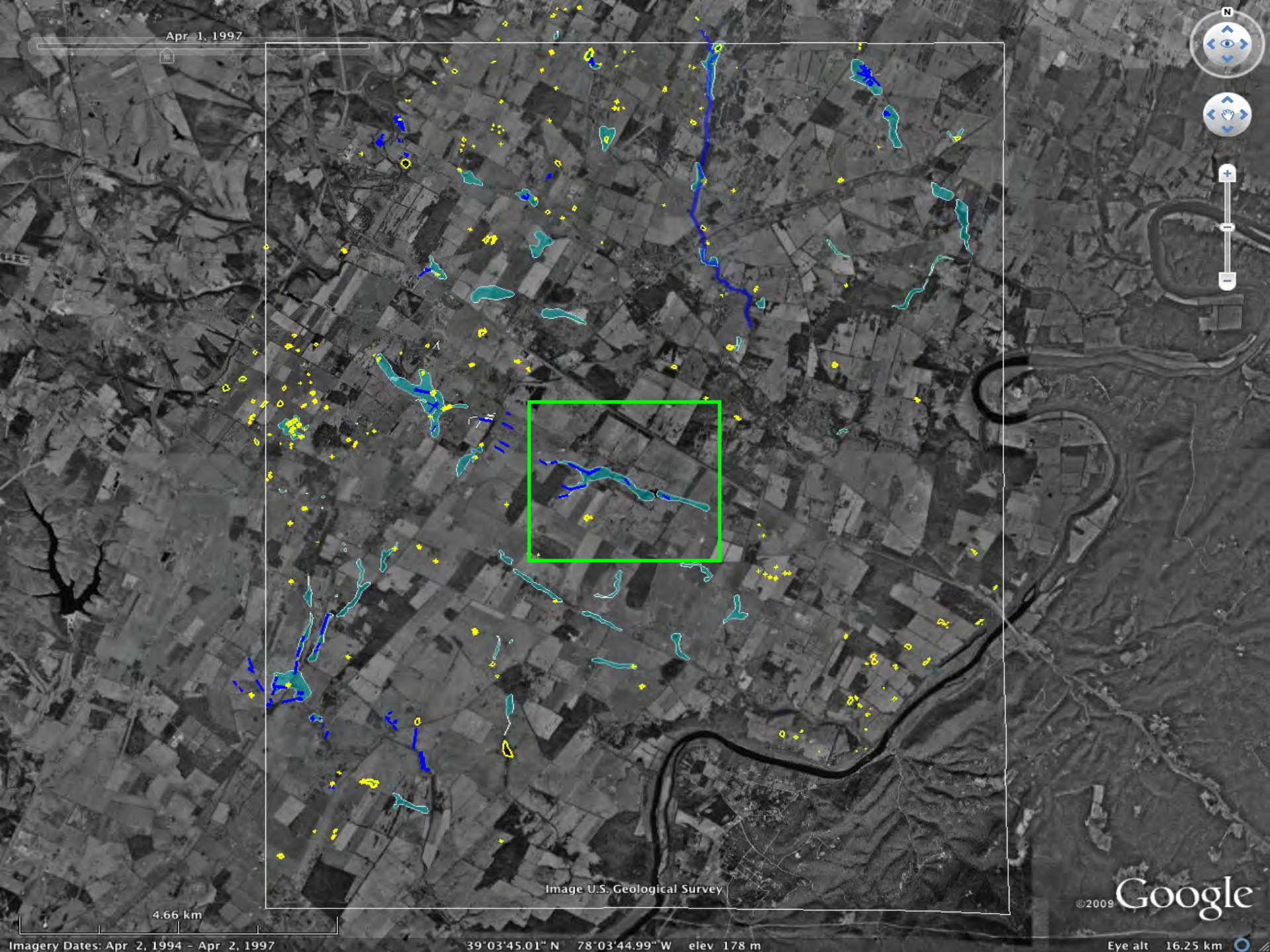


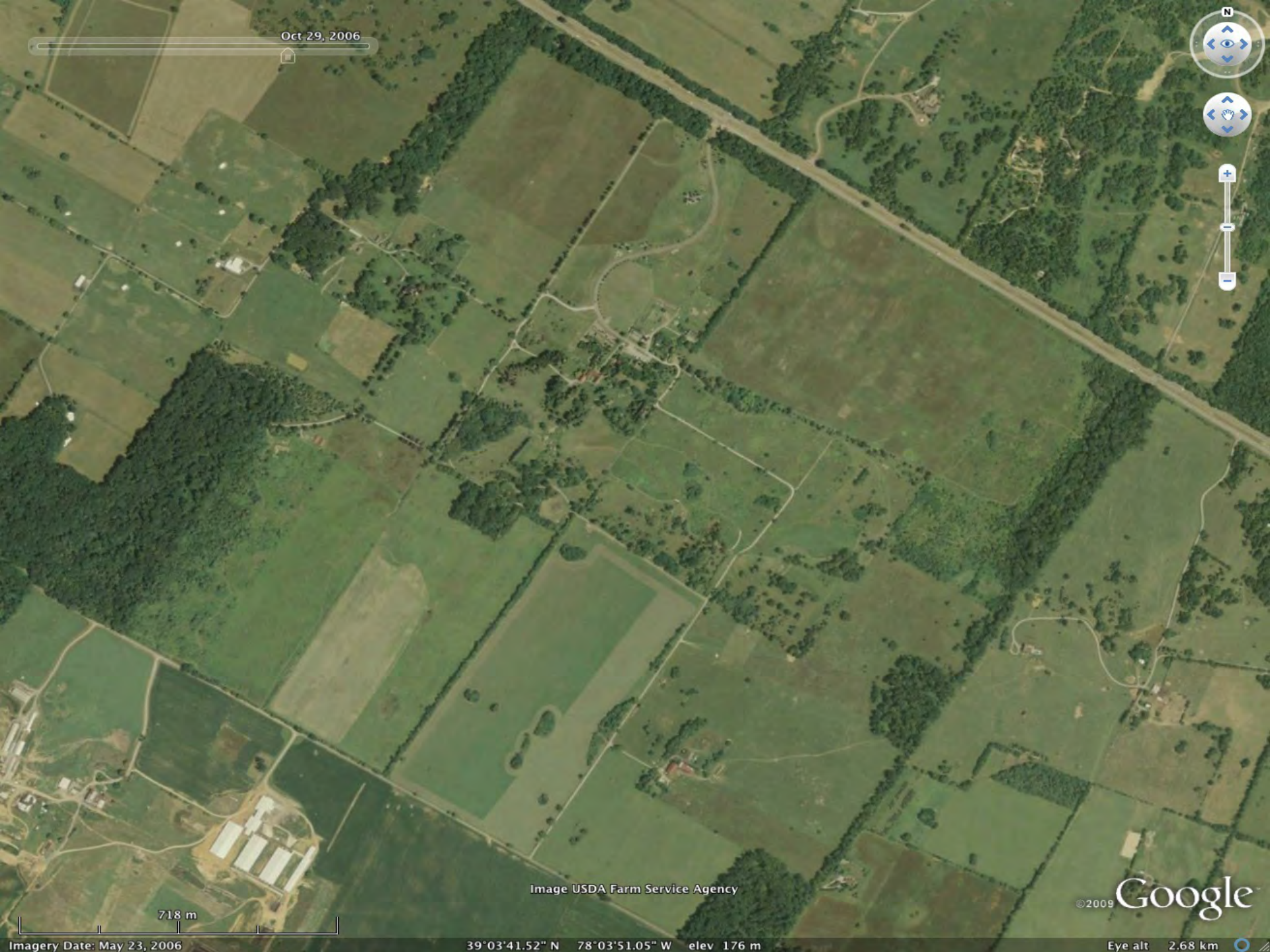
Slow groundwater flow to perennial spring

WET CONDITIONS



Rising deep groundwater flow


Apr 1, 1997
Image U.S. Geological Survey
©2009 Google
4.66 km
Imagery Dates: Apr 2, 1994 - Apr 2, 1997
39°03'45.01" N 78°03'44.99" W elev 178 m
Eye alt 16.25 km


Oct 29, 2006
Image USDA Farm Service Agency
©2009 Google
718 m
Imagery Date: May 23, 2006
39°03'41.52" N 78°03'51.05" W elev 176 m
Eye alt 2.68 km

Apr 1, 1997
Image U.S. Geological Survey
©2009 Google
718 m
Imagery Date: Apr 2, 1997
39°03'41.52" N 78°03'51.05" W elev 176 m
Eye alt 2.68 km

Apr 1, 1997
Image U.S. Geological Survey
©2009 Google
718 m
Imagery Date: Apr 2, 1997
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Apr 1, 1997
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©2009 Google
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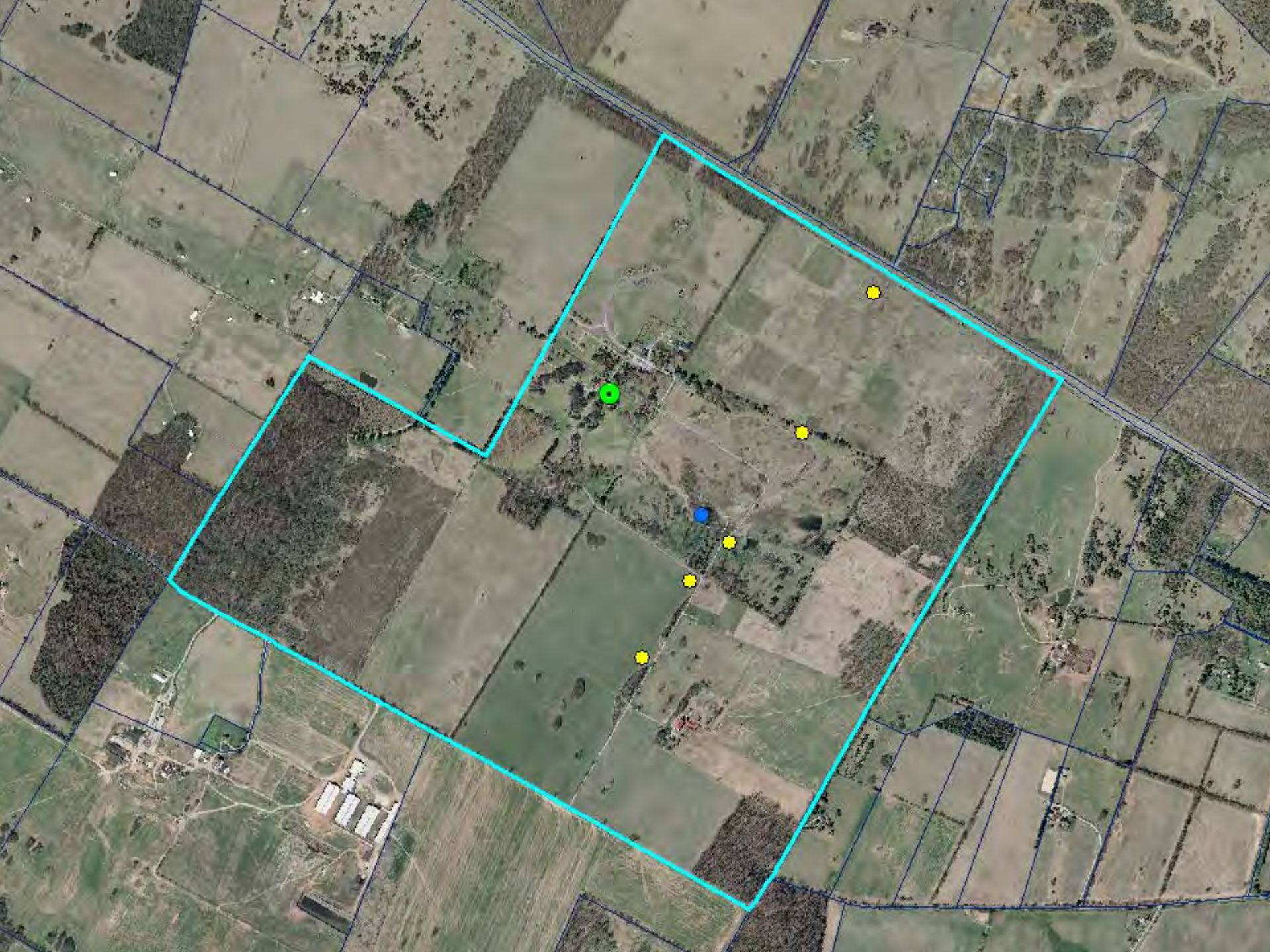

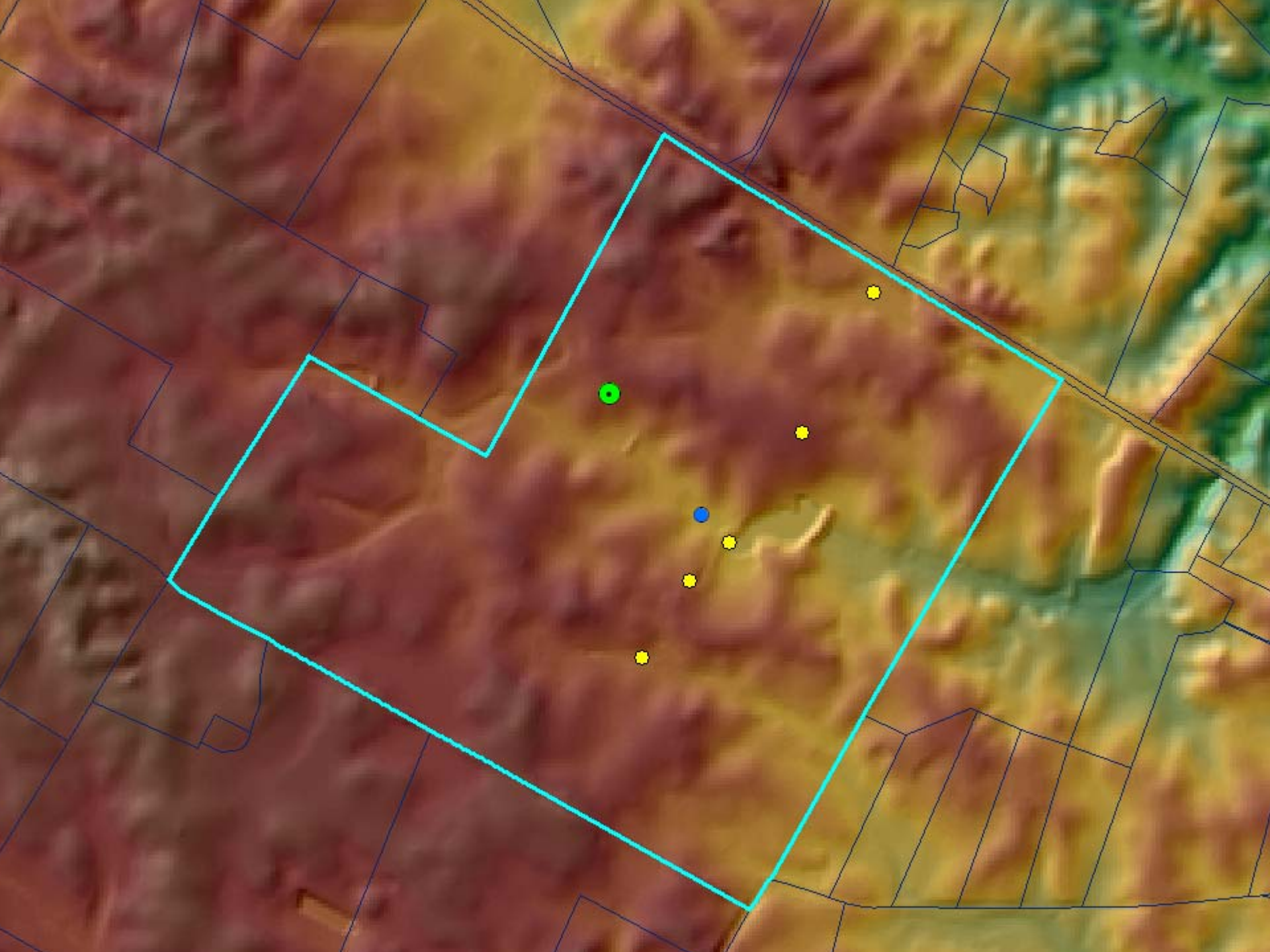

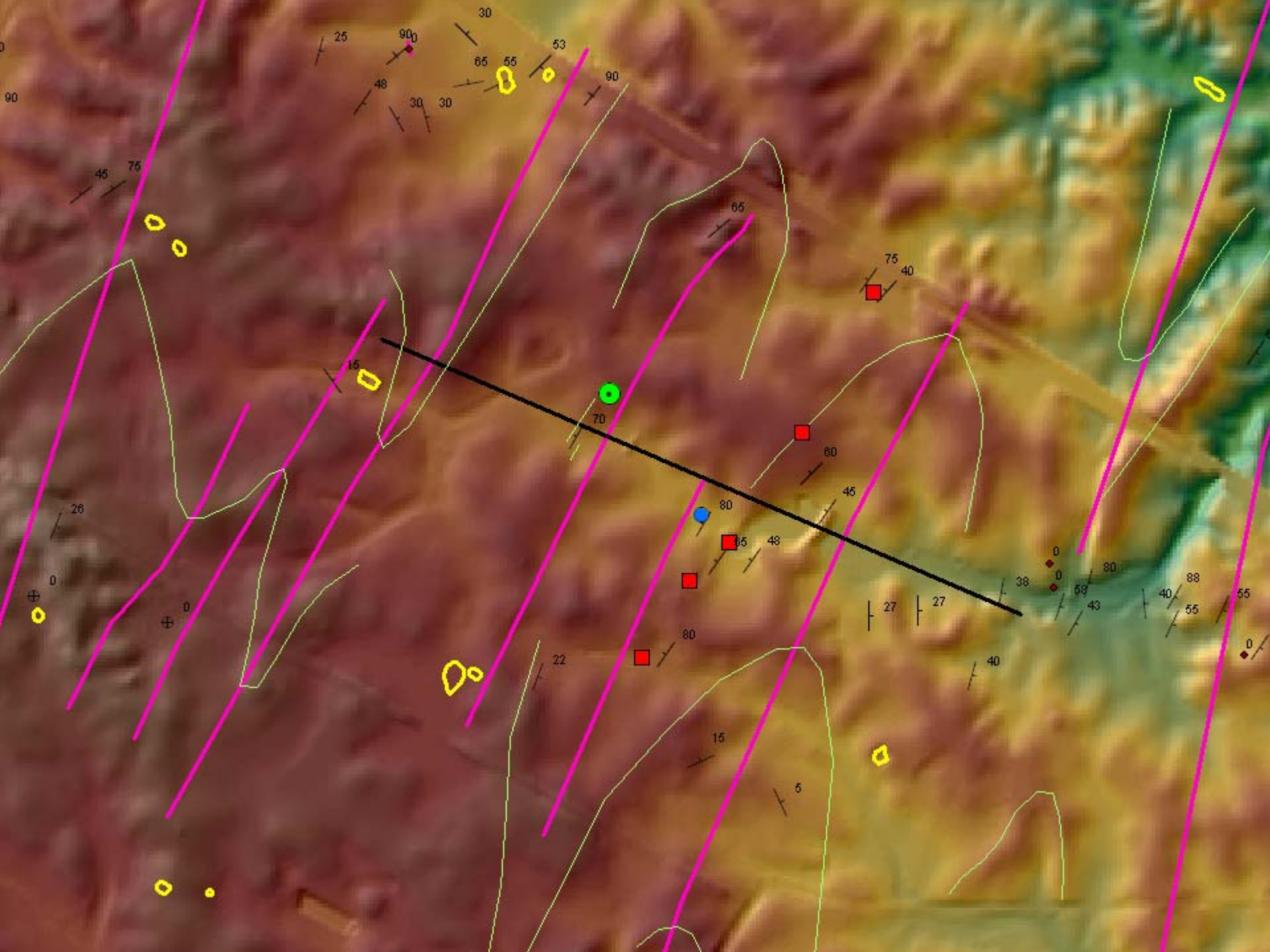

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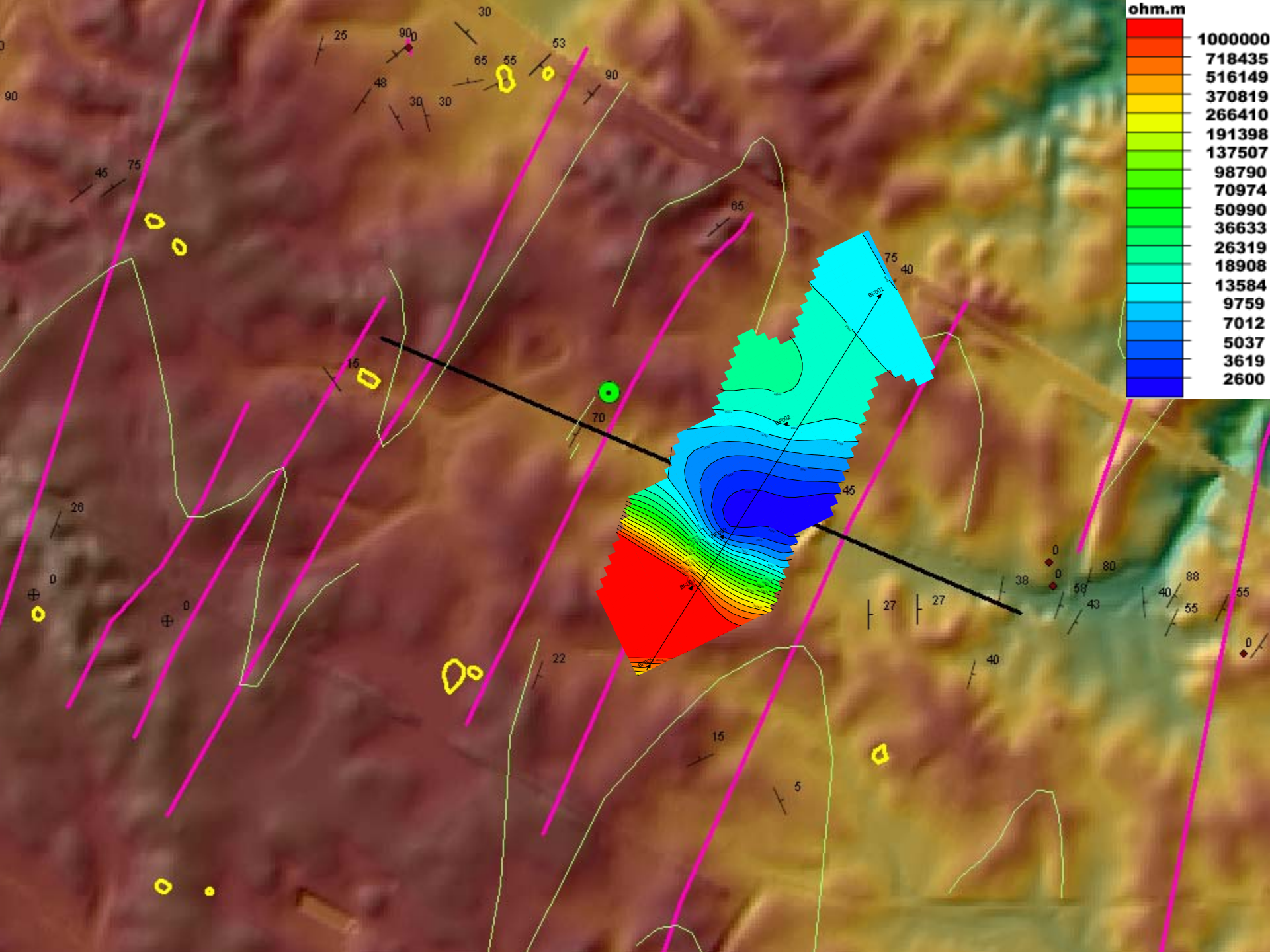
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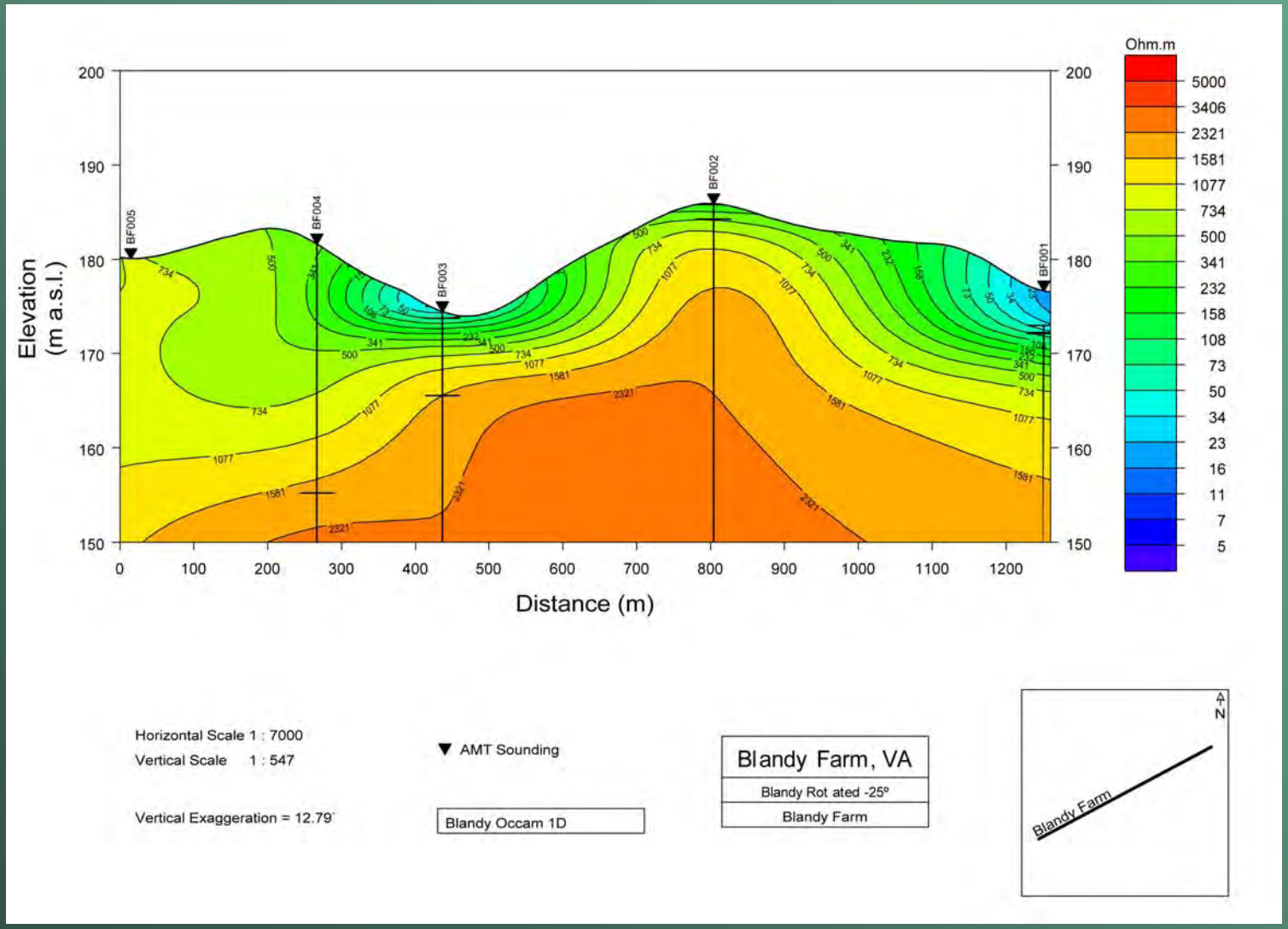
Blandy Farm AMT Cross section

30 m



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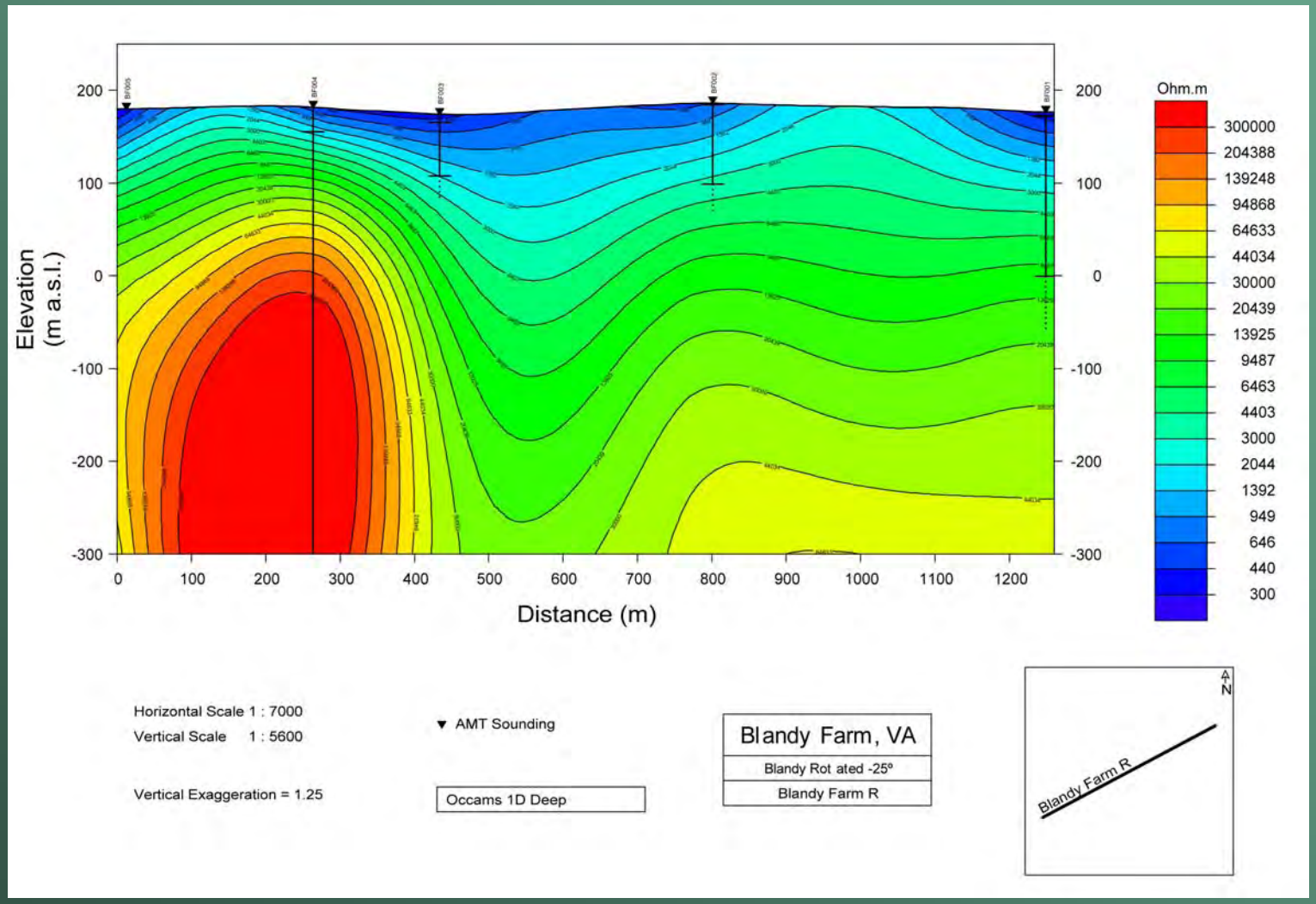
Blandy Farm AMT Cross section

500 m



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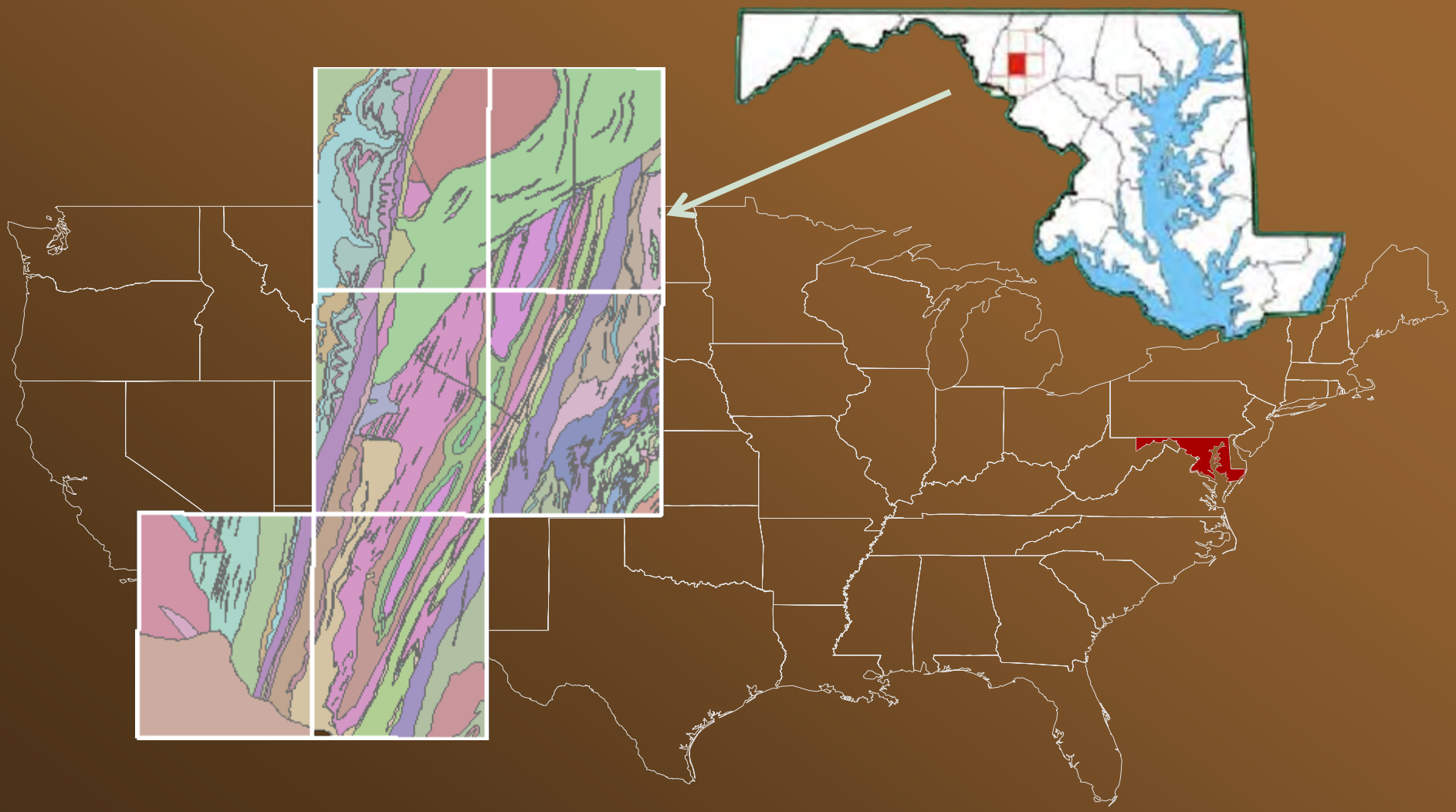
What factors influence sinkhole formation?

- Bedrock geologic structure
  - Fractures → bedding of strata, folds, faults
  - Lineaments (deep fractures)
- Water level fluctuation
- Anthropogenic influences
  - altered drainage
  - groundwater pumping

USGS

Study Area: Frederick Valley, Maryland, US



USGS

Frederick, MD - 1988

Frederick, MD - 2007

Photos: Dan Doctor

Problem statement:
How do the following anthropogenic, geologic and hydrologic factors influence new sinkhole development?

Distance to

1. quarries
2. roads
3. water-bodies
4. streams
5. depth to groundwater
6. fault lines
7. fold axis of synclines or anticlines

Anthropogenic factors

Hydrologic factors

Geologic (structural) factors

USGS

Multivariate Regression Analysis

Independent variables

Distance to

1. quarry
2. water-body
3. stream
4. roads
5. fault lines
6. fold axis
7. groundwater table

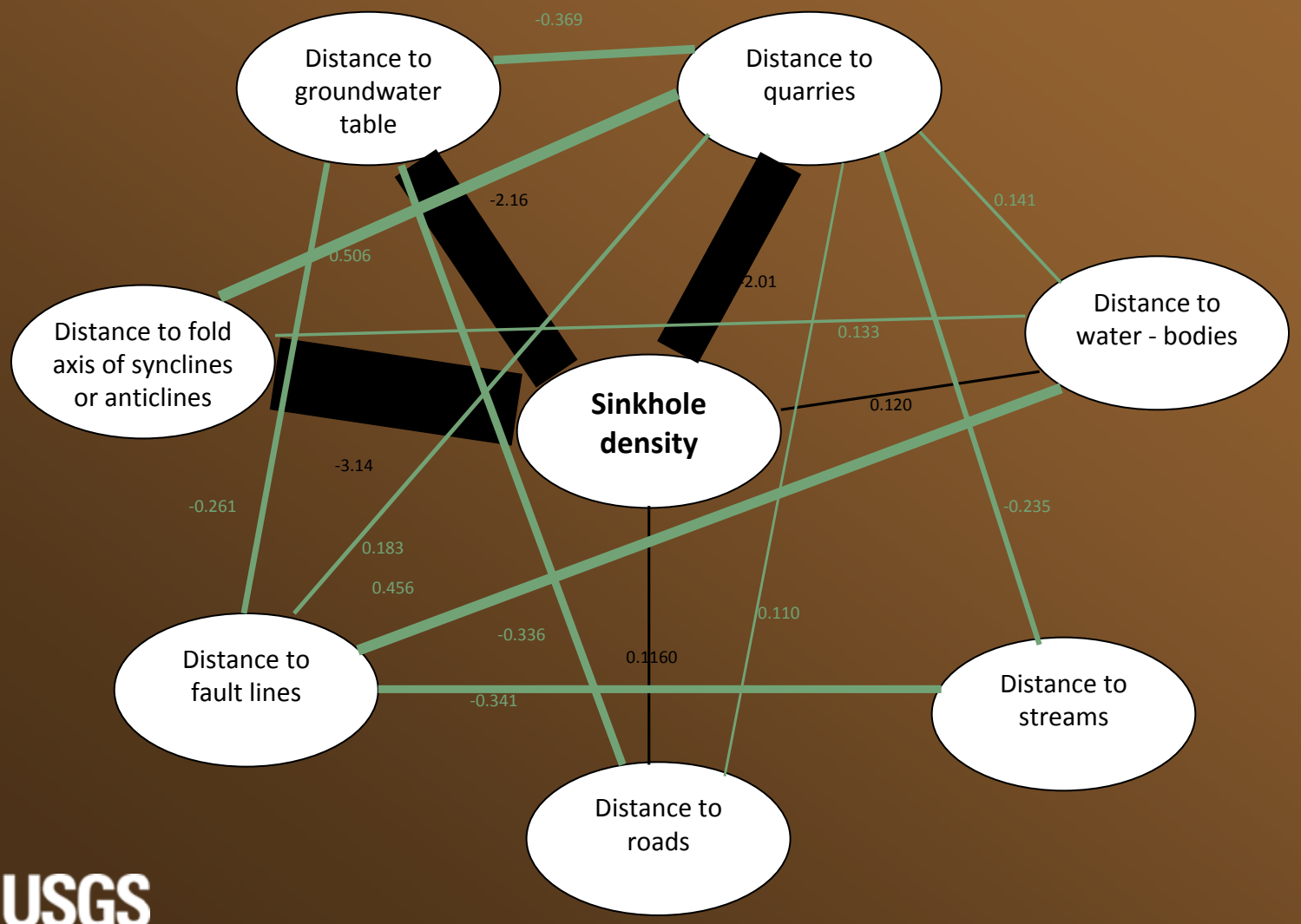
Dependent variable

Sinkhole density

USGS

Multivariate Regression Analysis Results

Correlation Matrix



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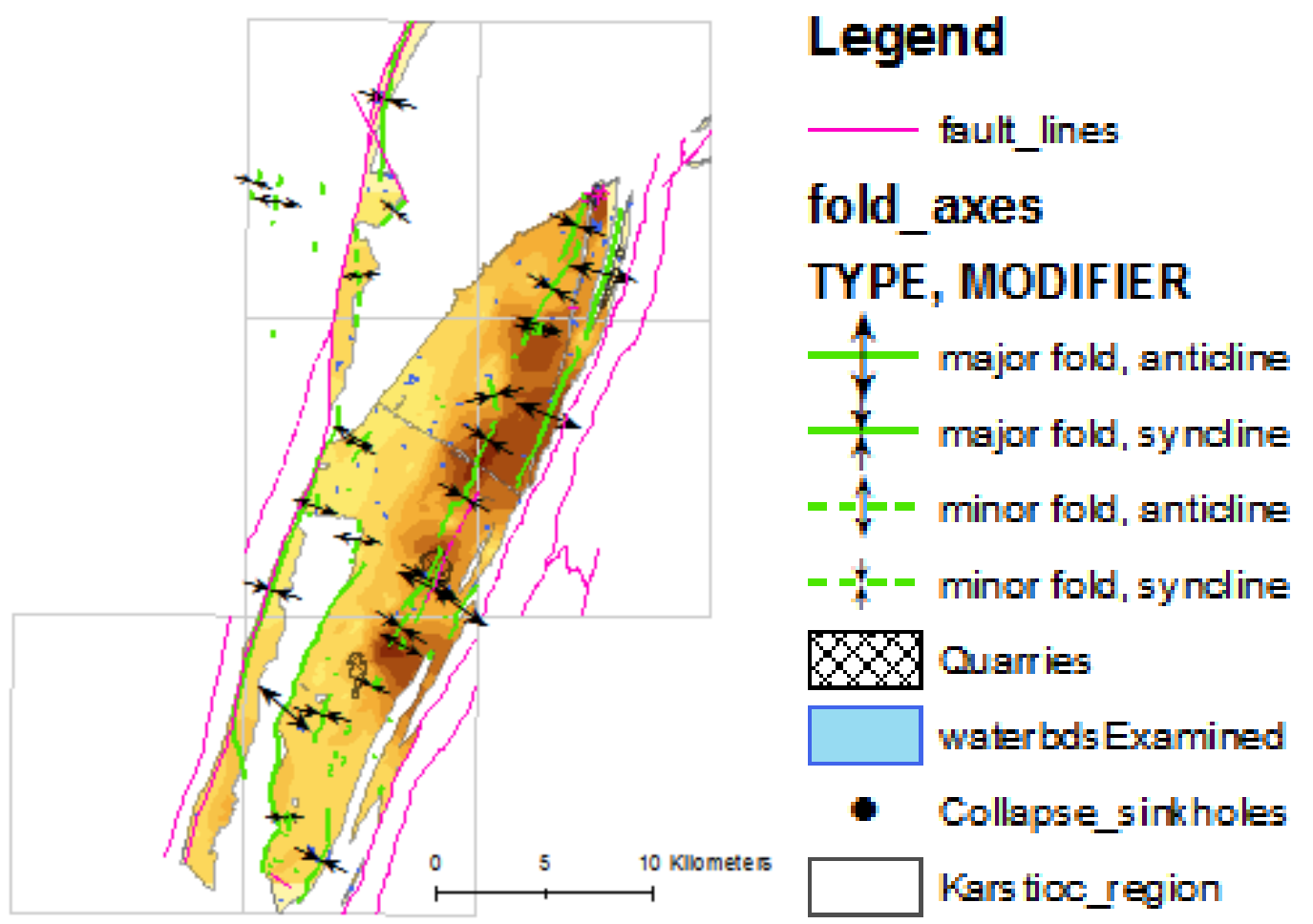
SINKHOLE SUSCEPTIBILITY MAP:



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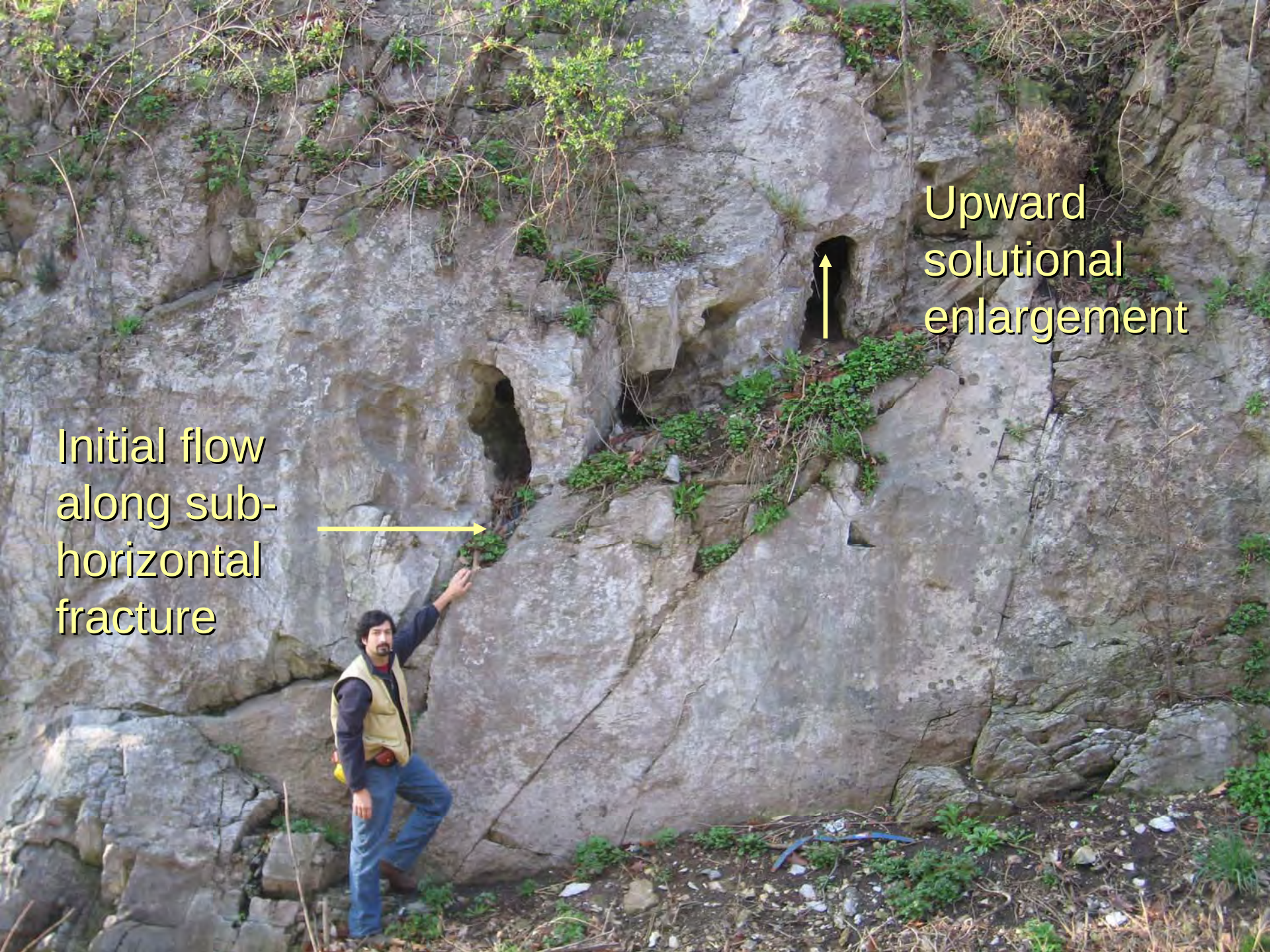
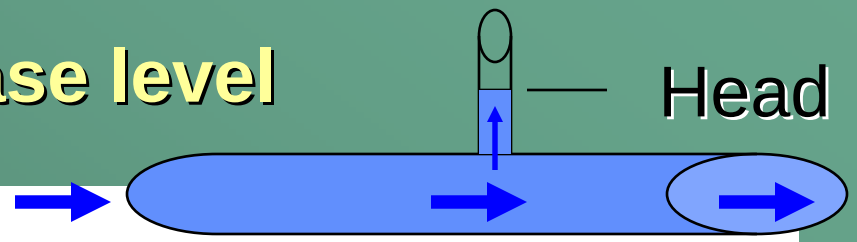
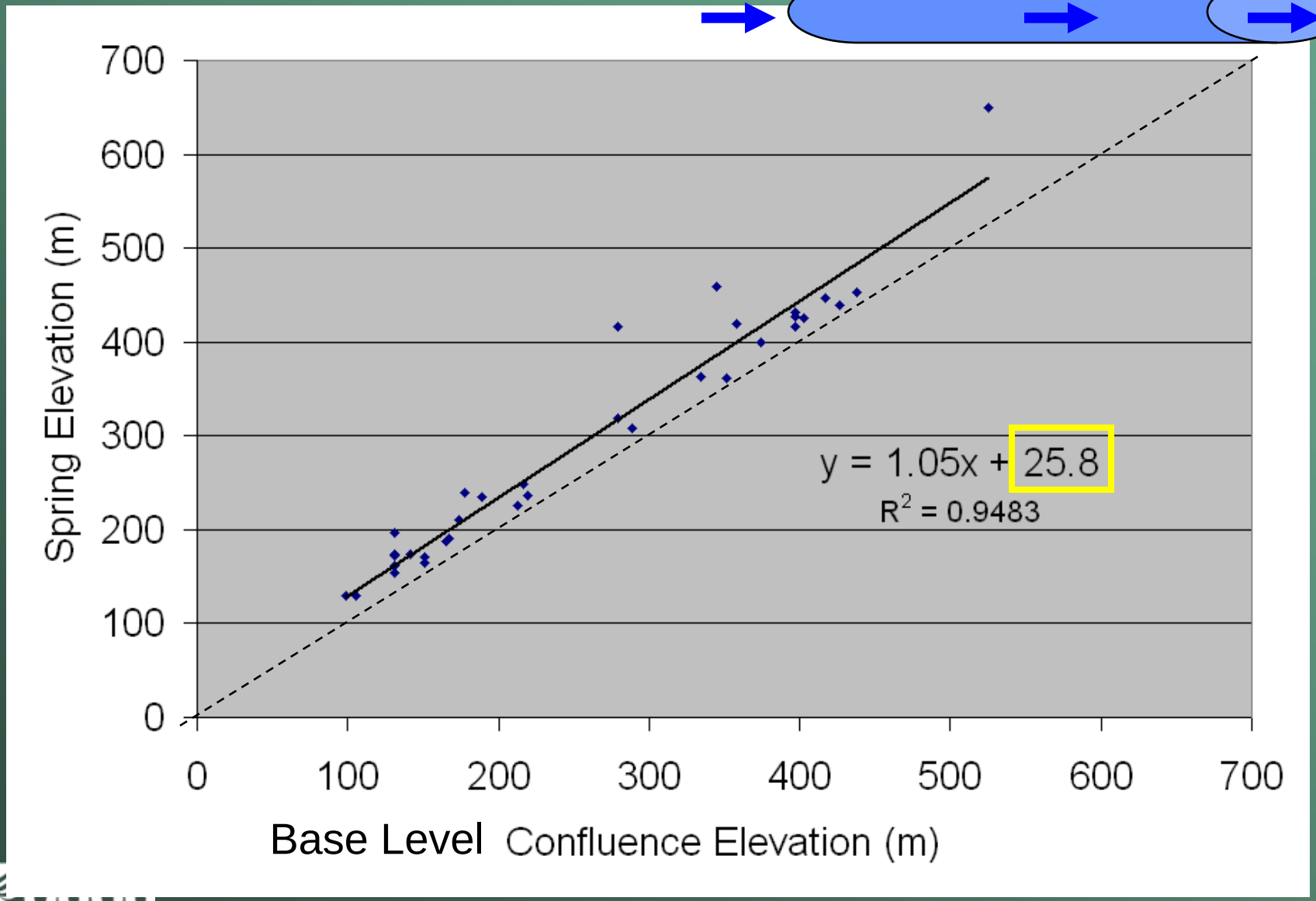
THANK YOU!


Upward solutional enlargement
Initial flow along sub-horizontal fracture

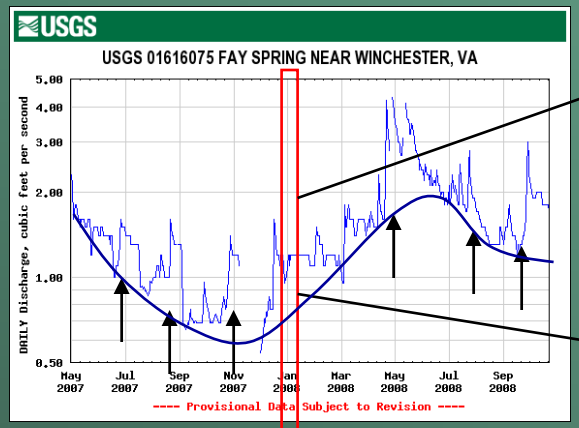
Valley springs above base level

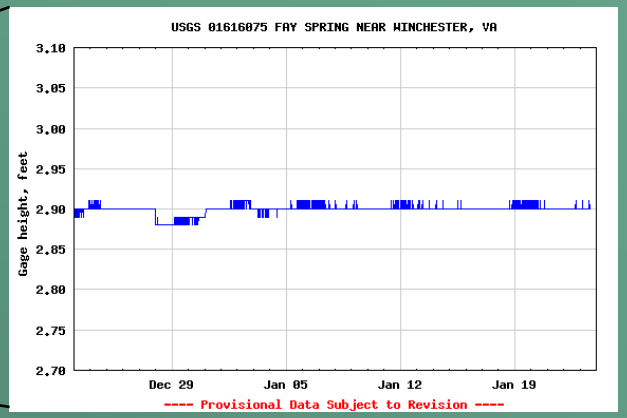




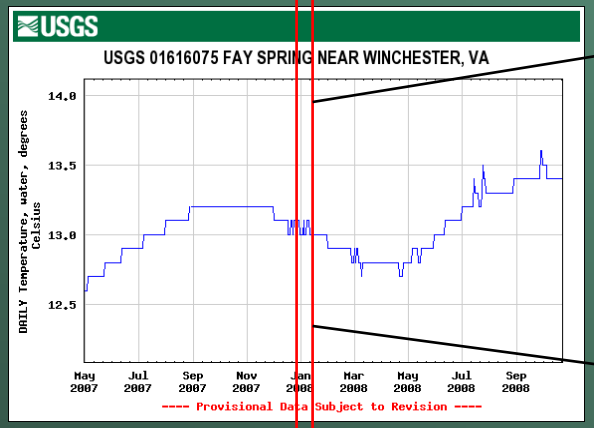
Fay Spring, Winchester – Continuous Monitoring

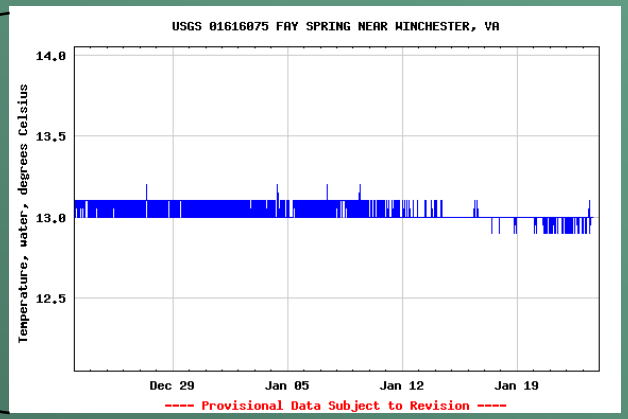
FLOW



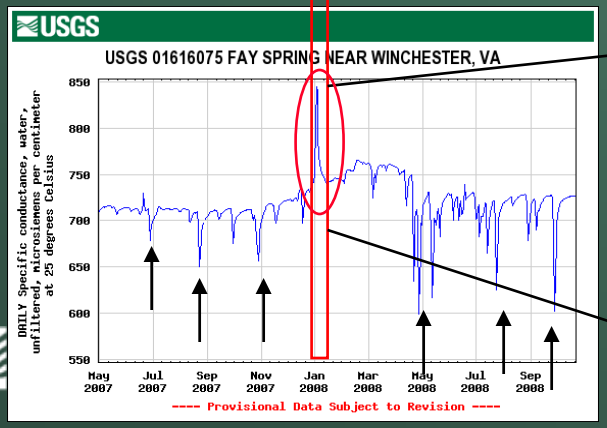


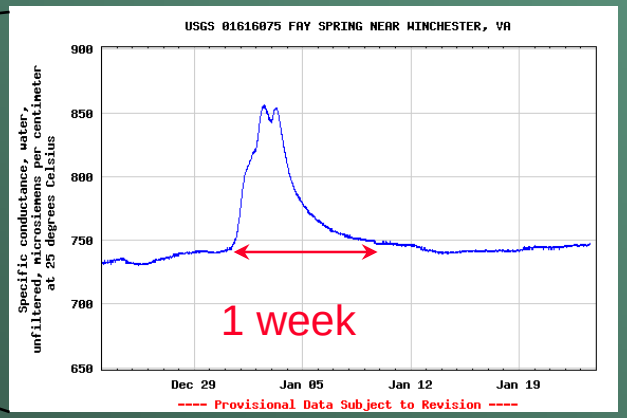
TEMP



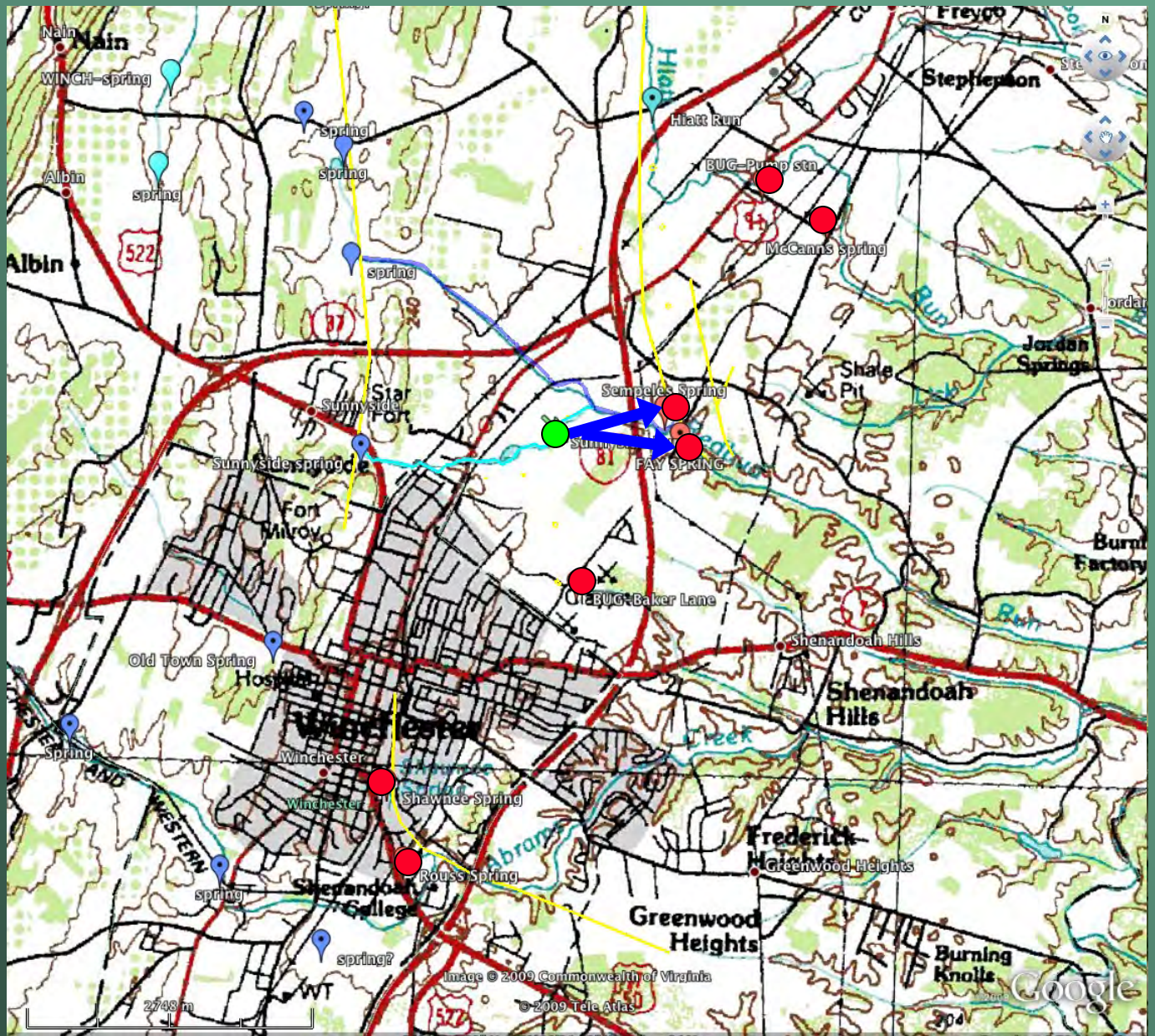


COND

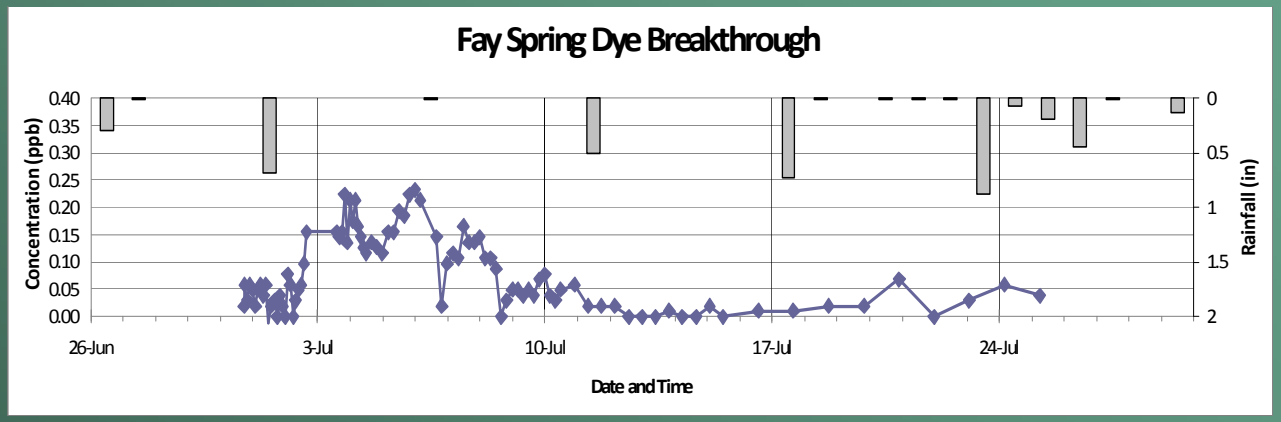


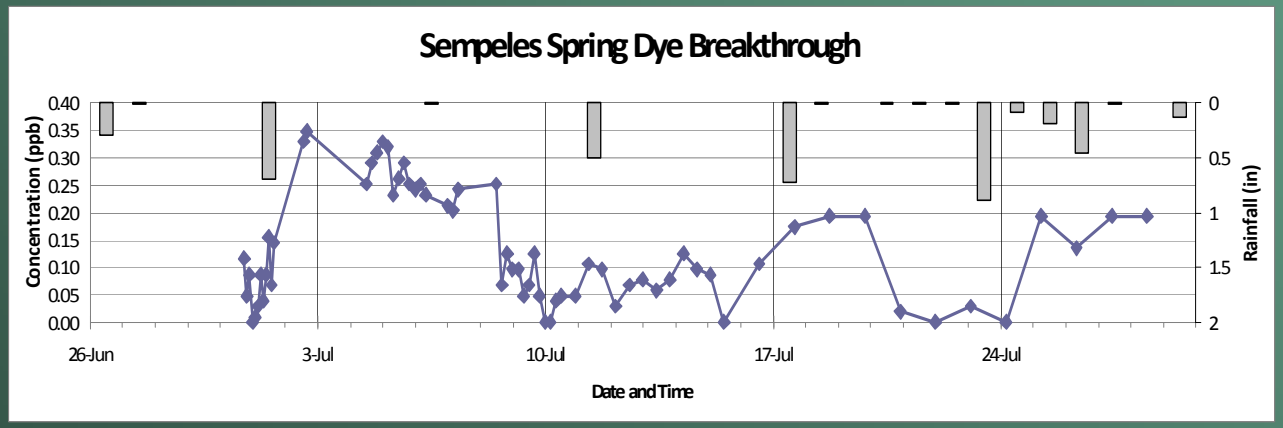


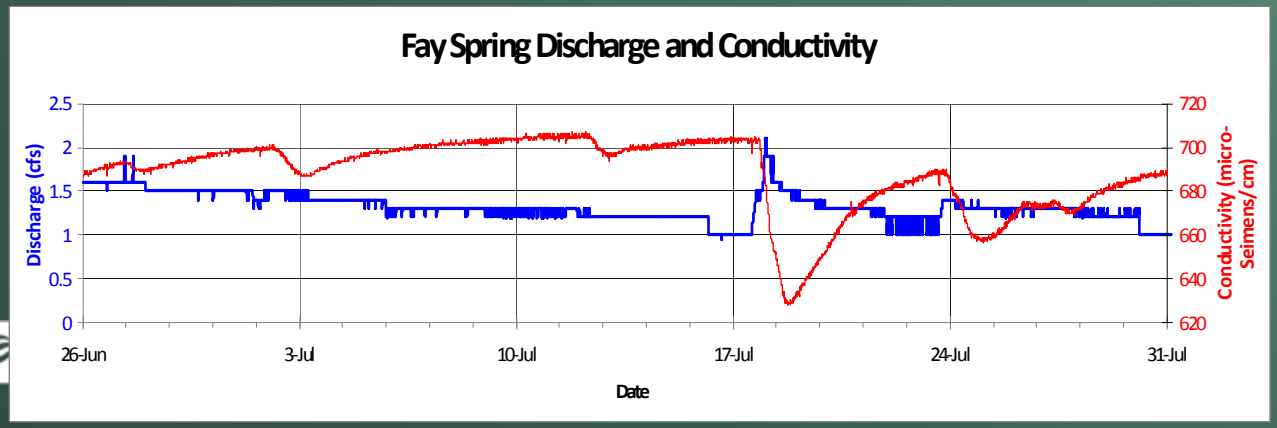
DYE TRACE TO FAY SPRING



Fay Spring, Winchester – Dye Tracing







TOTAL DYE RECOVERED AFTER ONE MONTH:

1.7%