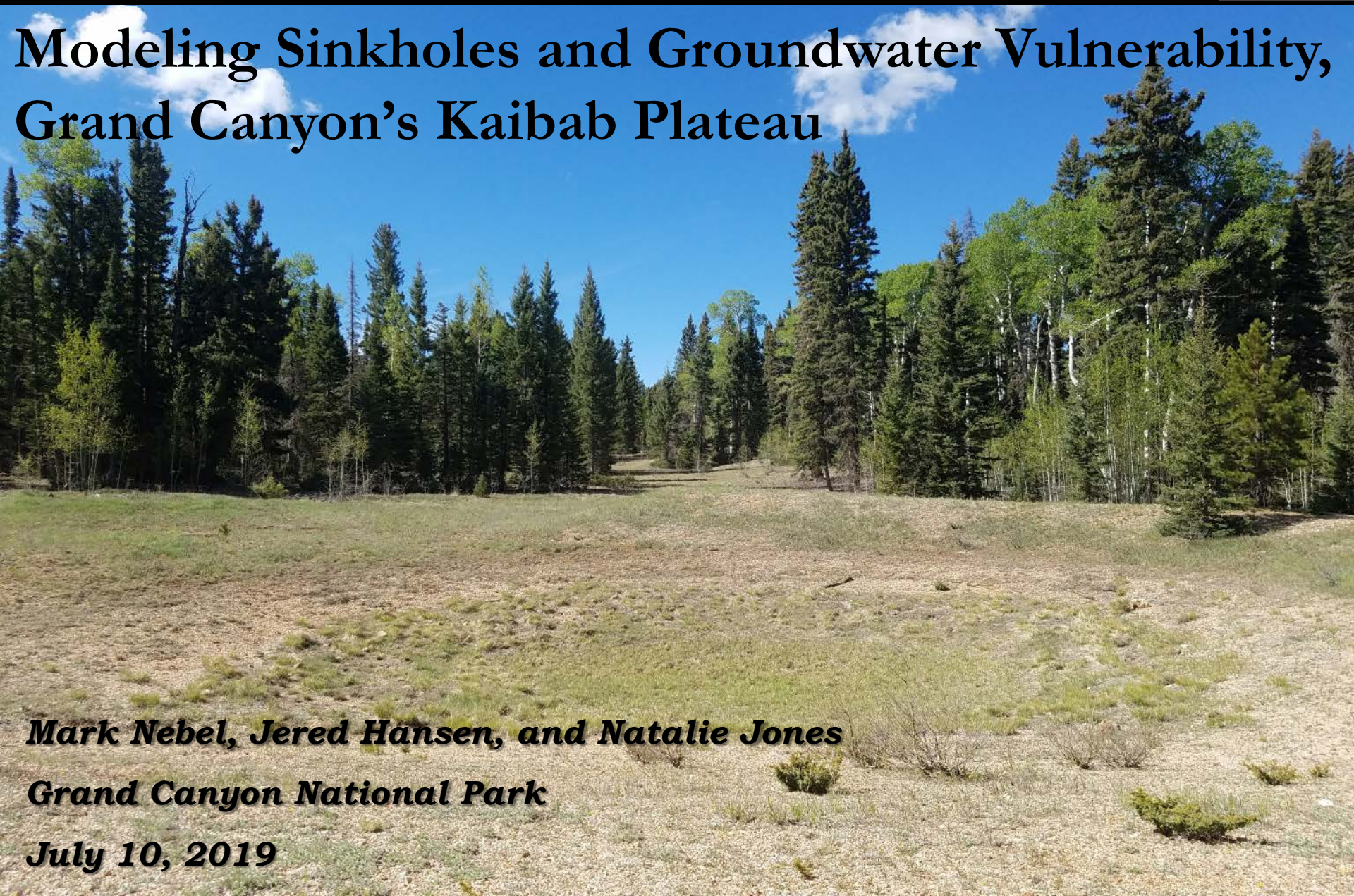
Modeling Sinkholes and Groundwater Vulnerability, Grand Canyon's Kaibab Plateau



Mark Nebel, Jered Hansen, and Natalie Jones

Grand Canyon National Park

July 10, 2019

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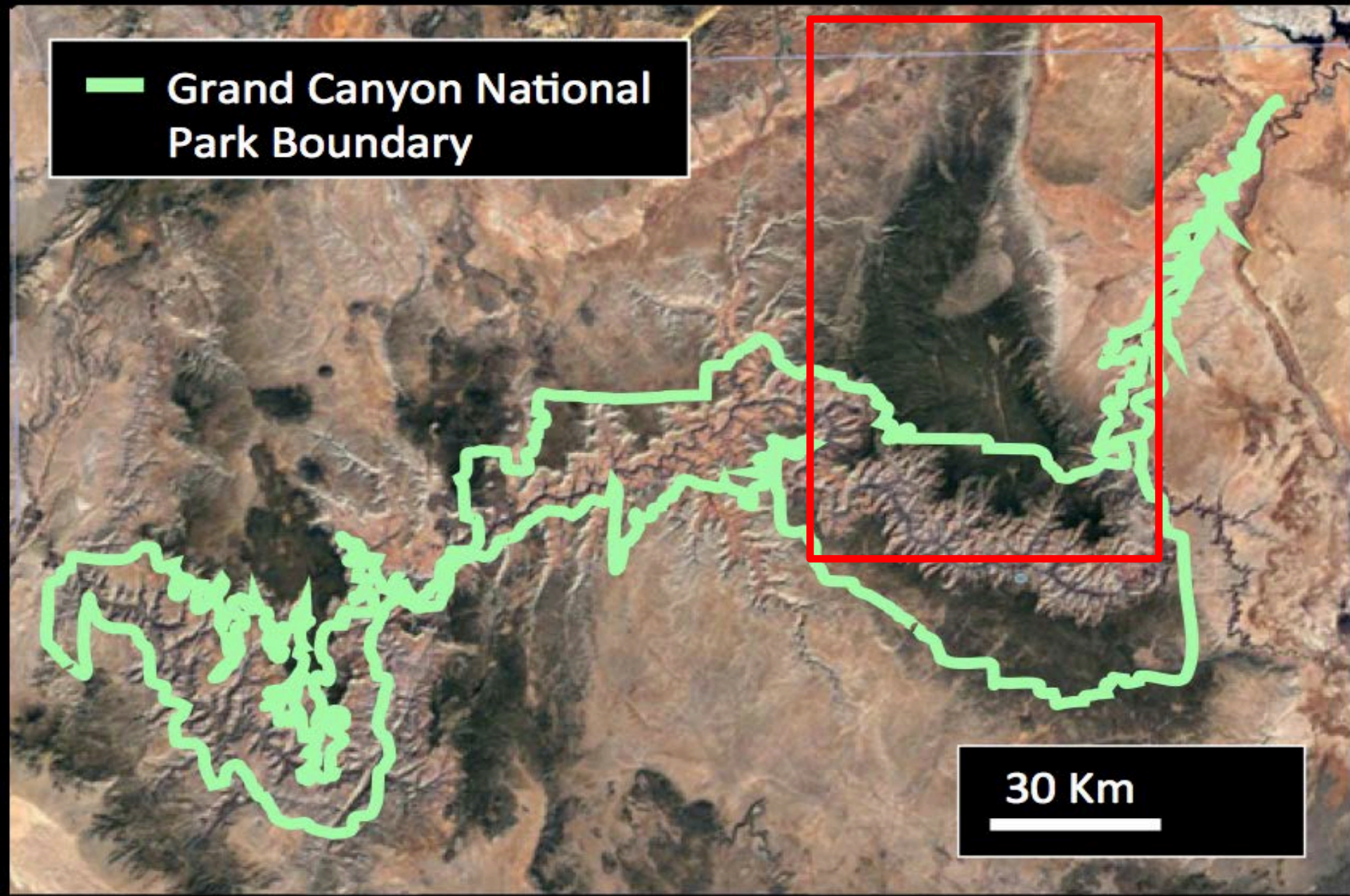
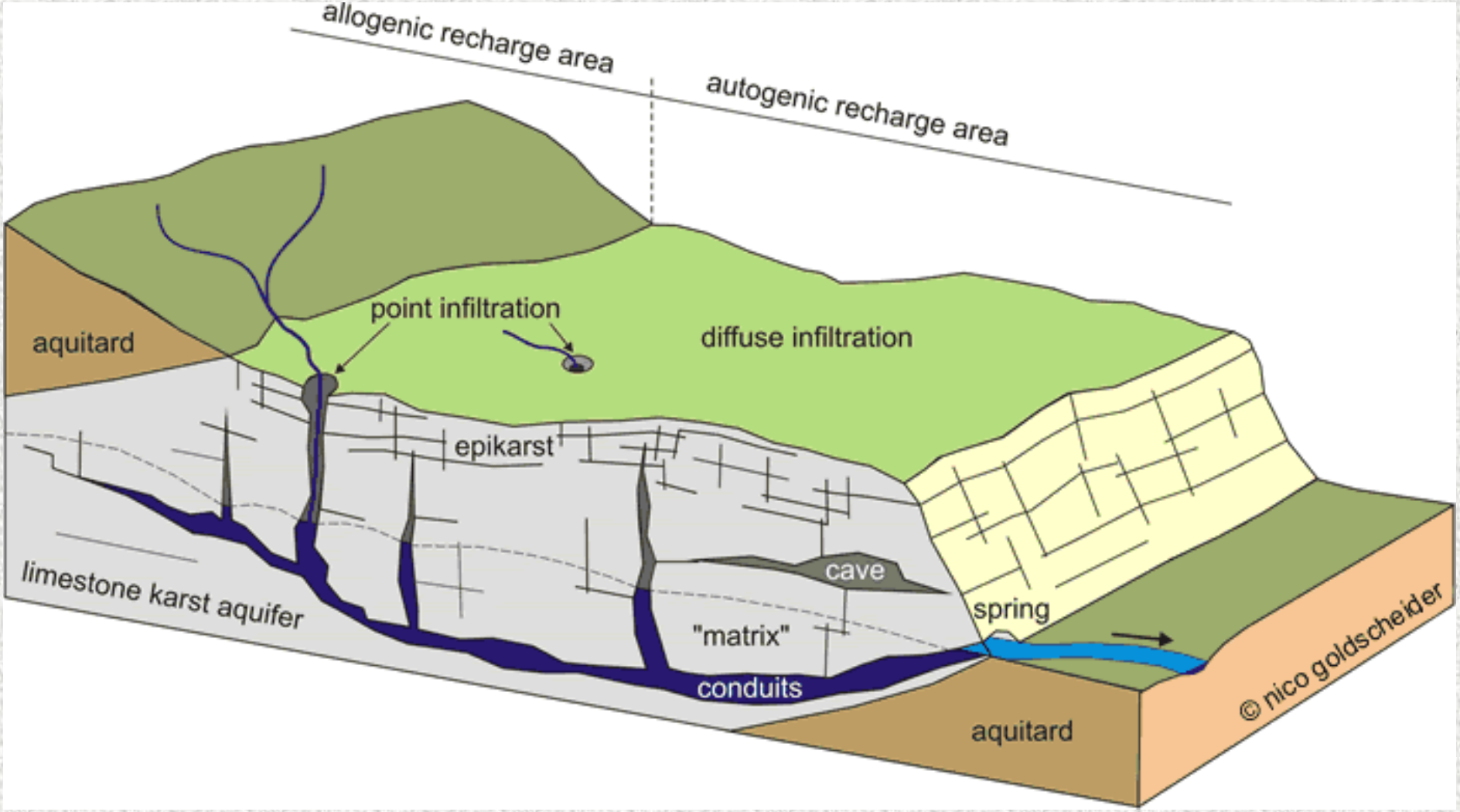


Kaibab Plateau

- 9200 ft (2817m) elevation
- Precipitation: 652 mm/yr
- Winter Snow, Summer Monsoon
- 90-100m of Limestone Bedrock
- Karst Environment

KARST ENVIRONMENTS



Thanks to BGR and UNESCO for block diagram

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Grand Canyon Aquifers and Drinking Water

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Roaring Springs

~1200 meters

Trans-Canyon Pipeline (>23 km)

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Groundwater Vulnerability

- Evaluate Risks to Grand Canyon Groundwater and Drinking Water

- Sinkholes as Vulnerability Indicators
  - Direct Conduit to Groundwater
  - Higher Density Near Faults

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Kaibab Plateau >1,630 square km

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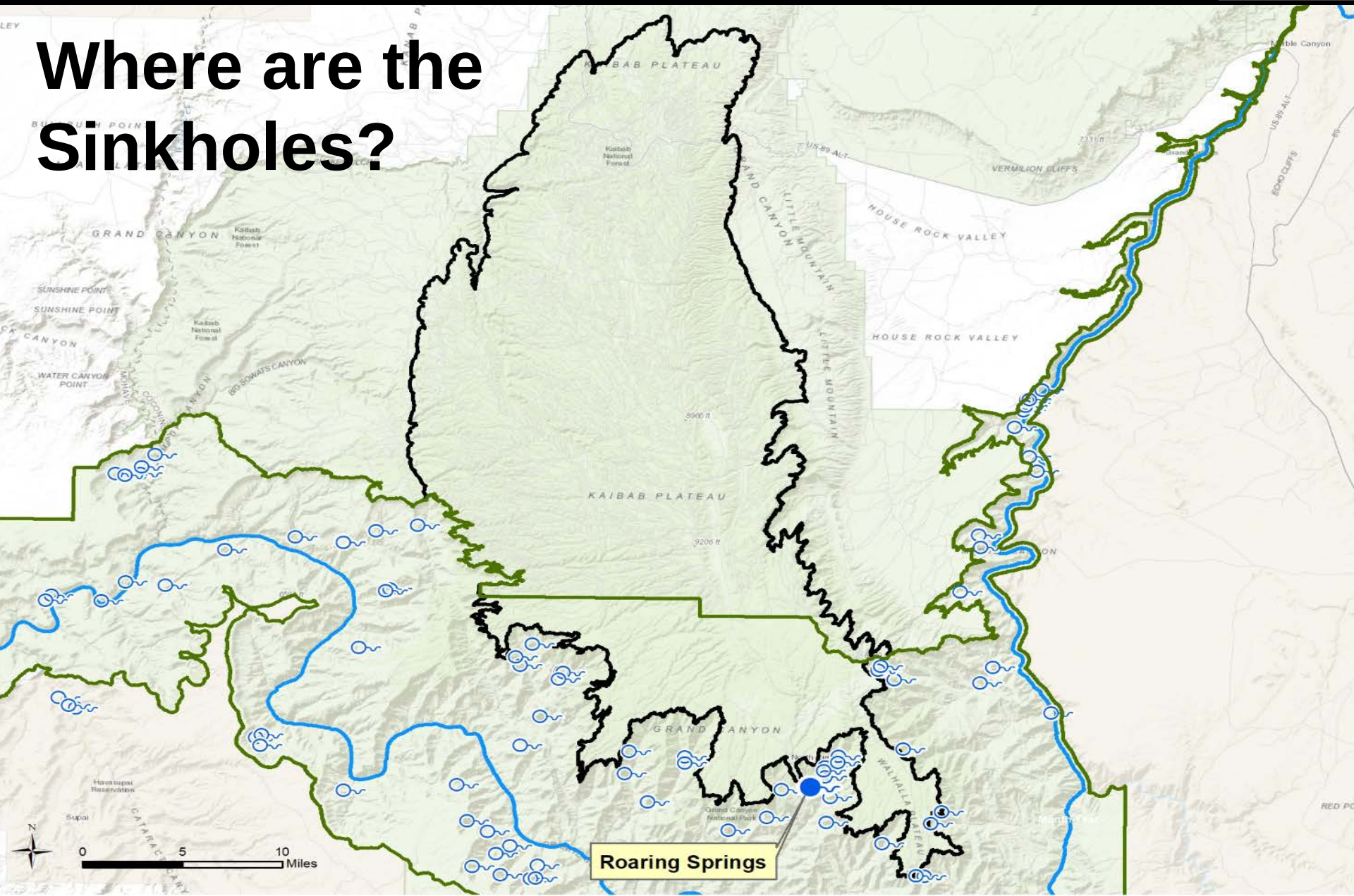
Where are the Sinkholes?



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Tiyo Point Trail Area—NAIP Imagery

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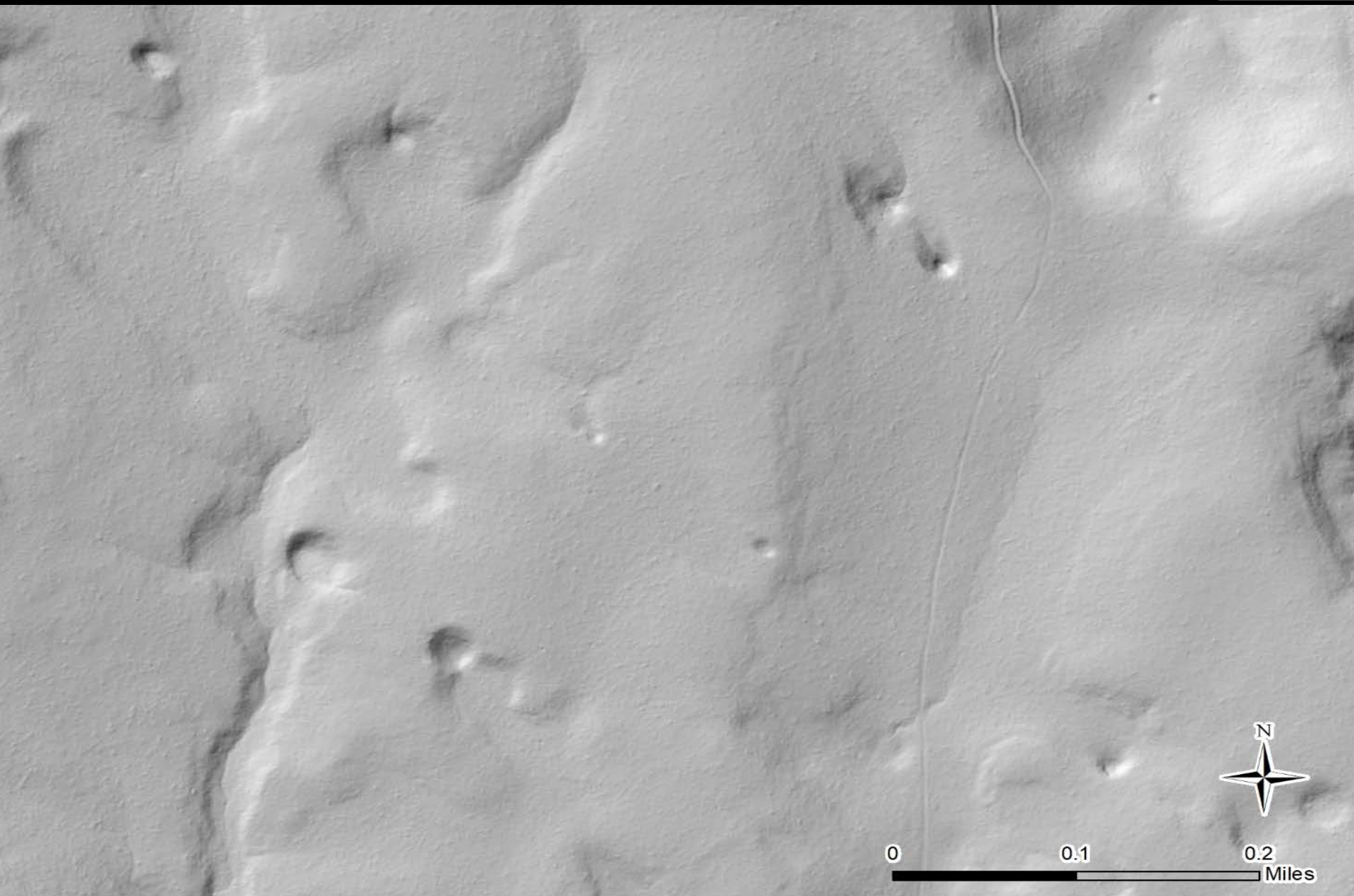
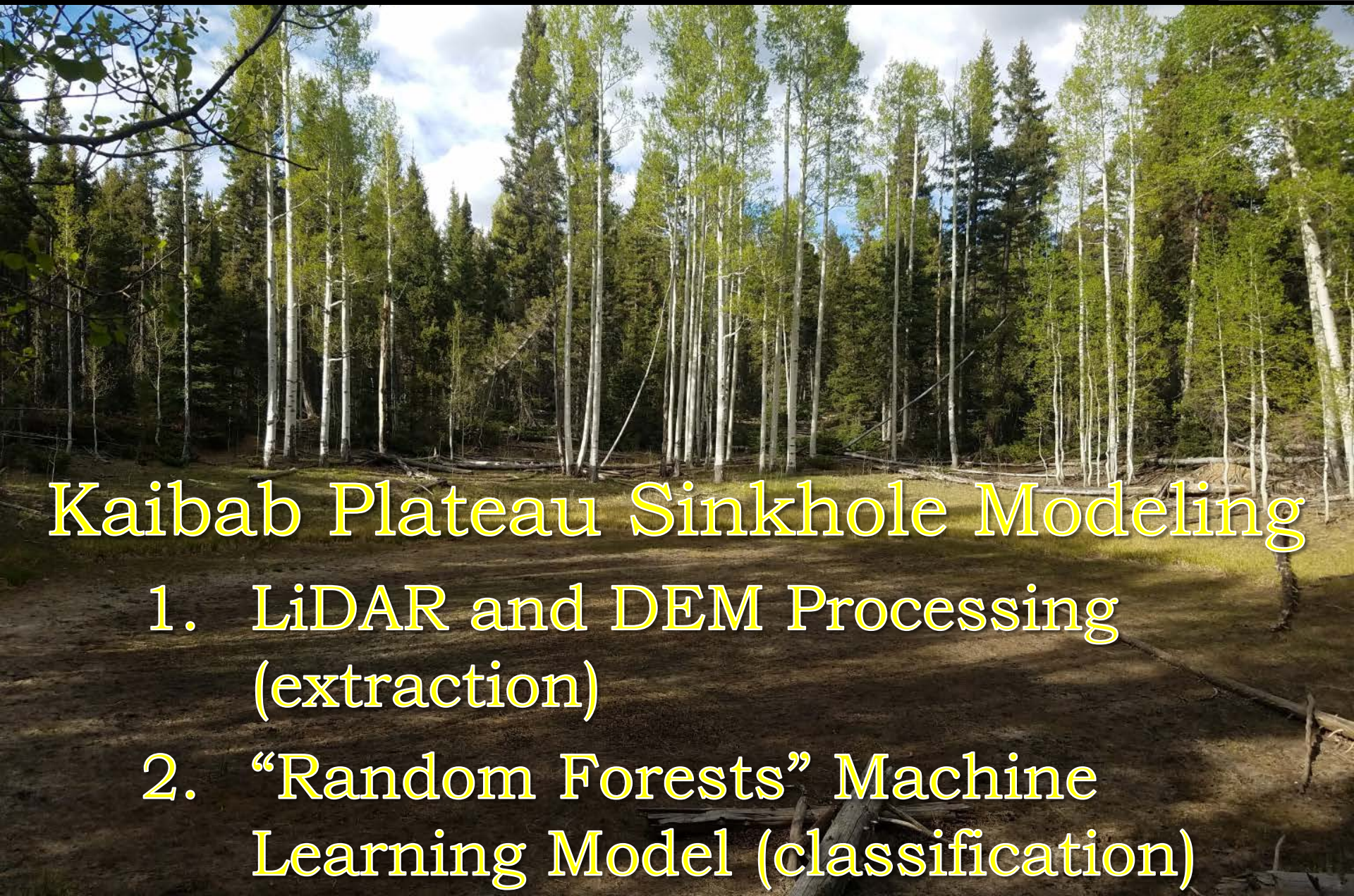
Tiyo Point Trail Area—LiDAR ”Bare Earth” Hillshade





Kaibab Plateau Sinkhole Modeling

1. LiDAR and DEM Processing (extraction)
2. “Random Forests” Machine Learning Model (classification)

Extract "Depressions" from 1-meter DEM

1. "Smooth" DEM (3x3 cells)
2. "Fill" Depressions to Pour Points
3. "Calculate" Difference Raster (Representing Depressions)
4. Convert Raster to Polygons
5. Remove Small (<3 m^2) Polygons
6. "Smooth" Remaining Polygons

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Tiyo Point Trail Area—"Depressions"

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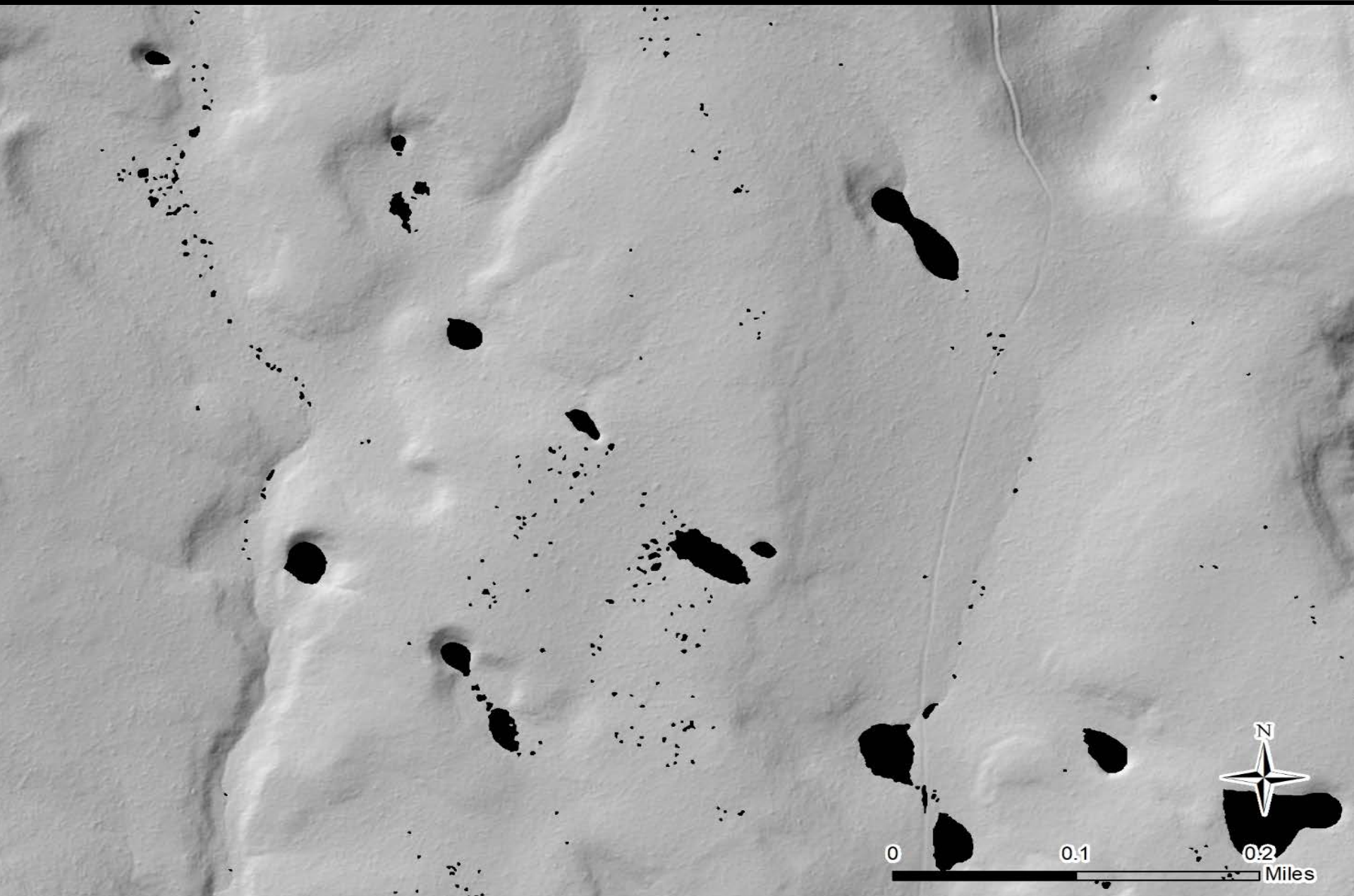

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Kaibab Plateau

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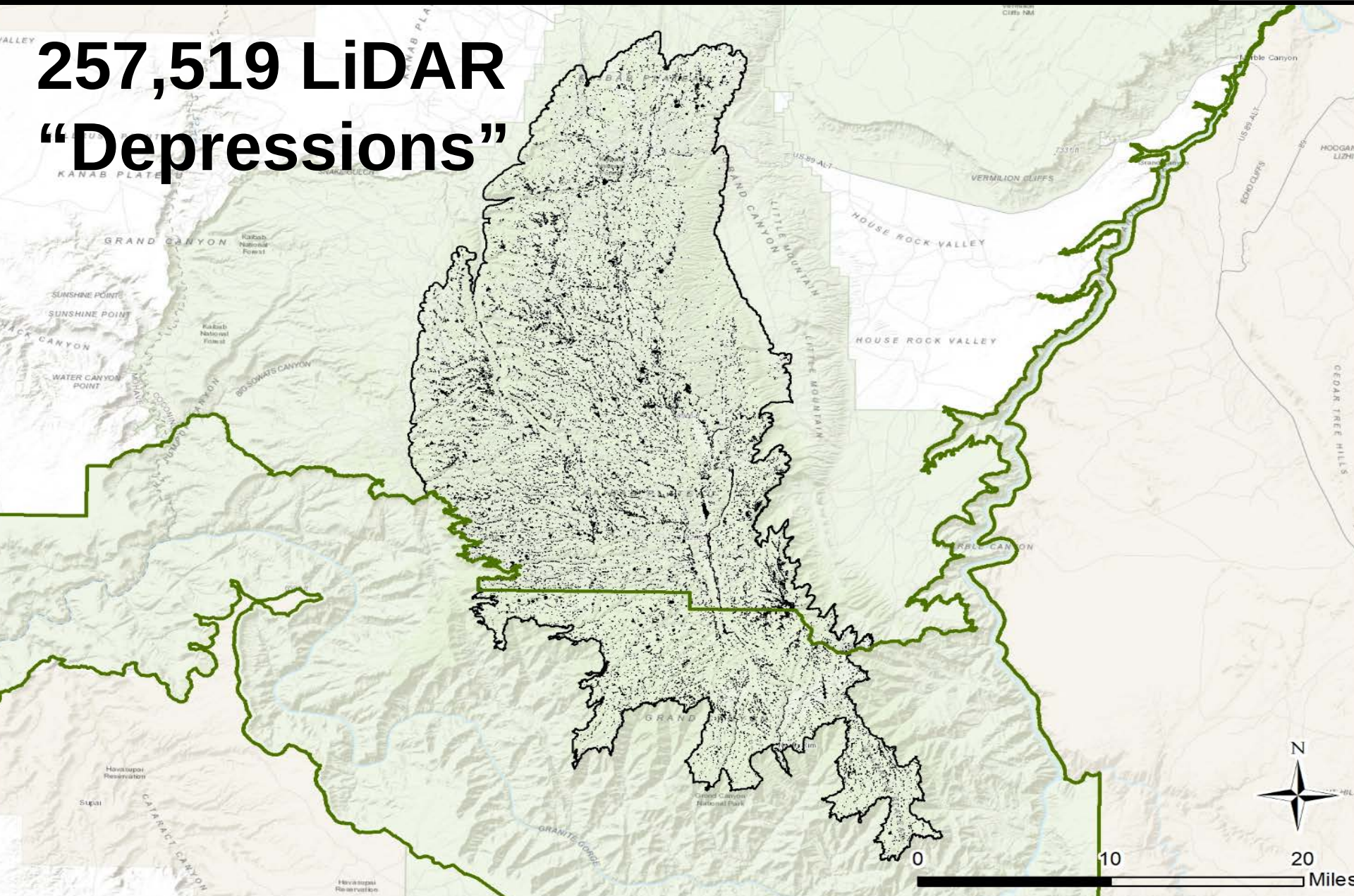


Delineate "True" Sinkhole Features

1. Develop Training Dataset
2. Characterize Depressions as Sinkholes (presence) or Non-Sinkholes (absence)
3. Develop Independent Variables
4. Classify Depressions via ITERATIVE Correlation Modeling ("Machine Learning")
5. Field Validate Models

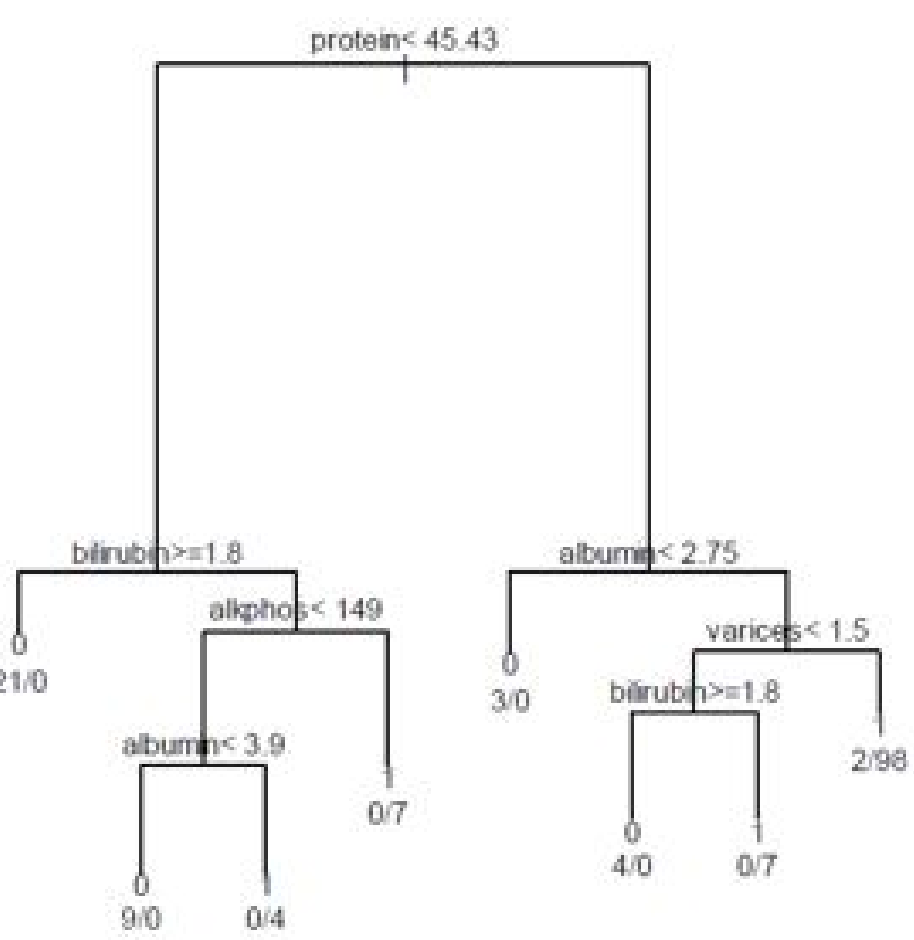
Training Dataset

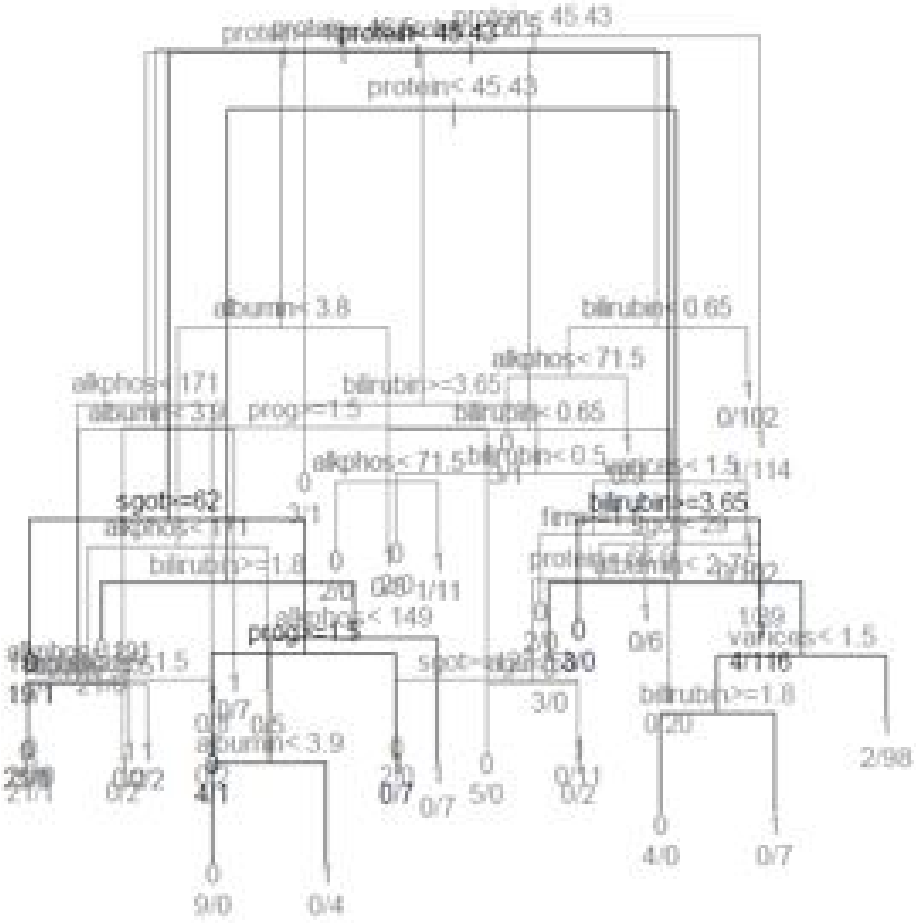
- Ten Randomly Generated 1 km^2 Training Areas
- 3,057 Depression Features (~1%)
- Three Reviewers per Depression Feature (Visual Inspection of Hillshade)
- Classification as “Sinkhole” or “Non-Sinkhole”

Sinkhole Independent Variables

1. Depth Related
   - Mean and Maximum Depth
   - Volume
   - Depth Index (~Slope)
2. Surface Shape
   - Area, Perimeter, Length, Width
   - Elongation, Circularity Index, Compactness
3. Orientation
4. Concavity (Curvature)

Random Forests Machine Learning





Model Iteration

- Dependent Variable Weight
  - Sinkhole (2)
  - Non-Sinkhole (1)
- Presence/Absence Training Data
  - 1, 2, 3 Reviewer Classifications

✓ Model Internal Performance Metrics
✓ Visual Inspection of Outcomes

Field Validation of Models

- 2.5 mile^2 Validation Survey Area
- 64 Randomly Selected Depressions (multiple size classes) Field Inspected
  - 23 Sinkholes
  - 41 Non-Sinkholes

Sinkhole Modeling Results

- 257,519 LiDAR “depressions” within 1,634 square km (Kaibab Plateau)
- 6,973 (2.7%) of “depressions” are Sinkholes
- 79% Overall Internal Model Accuracy
- 87.5% Overall Field Validation Accuracy
  - 78.3% of Sinkholes Correctly Classified
  - 92.3% of Non-Sinkholes Correct

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Tiyo Point Trail Area—"True" Sinkholes

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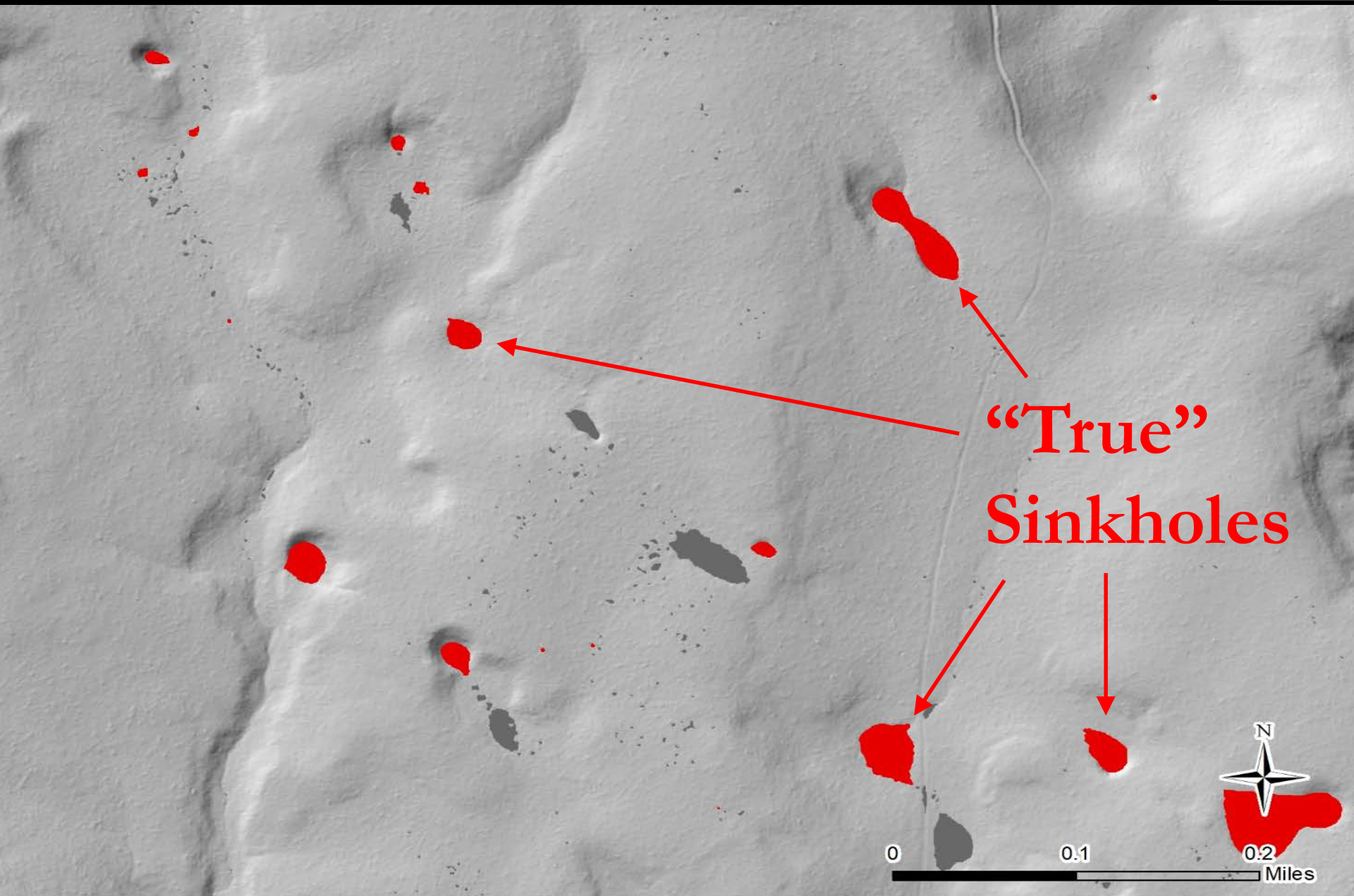

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Kaibab Plateau Sinkholes

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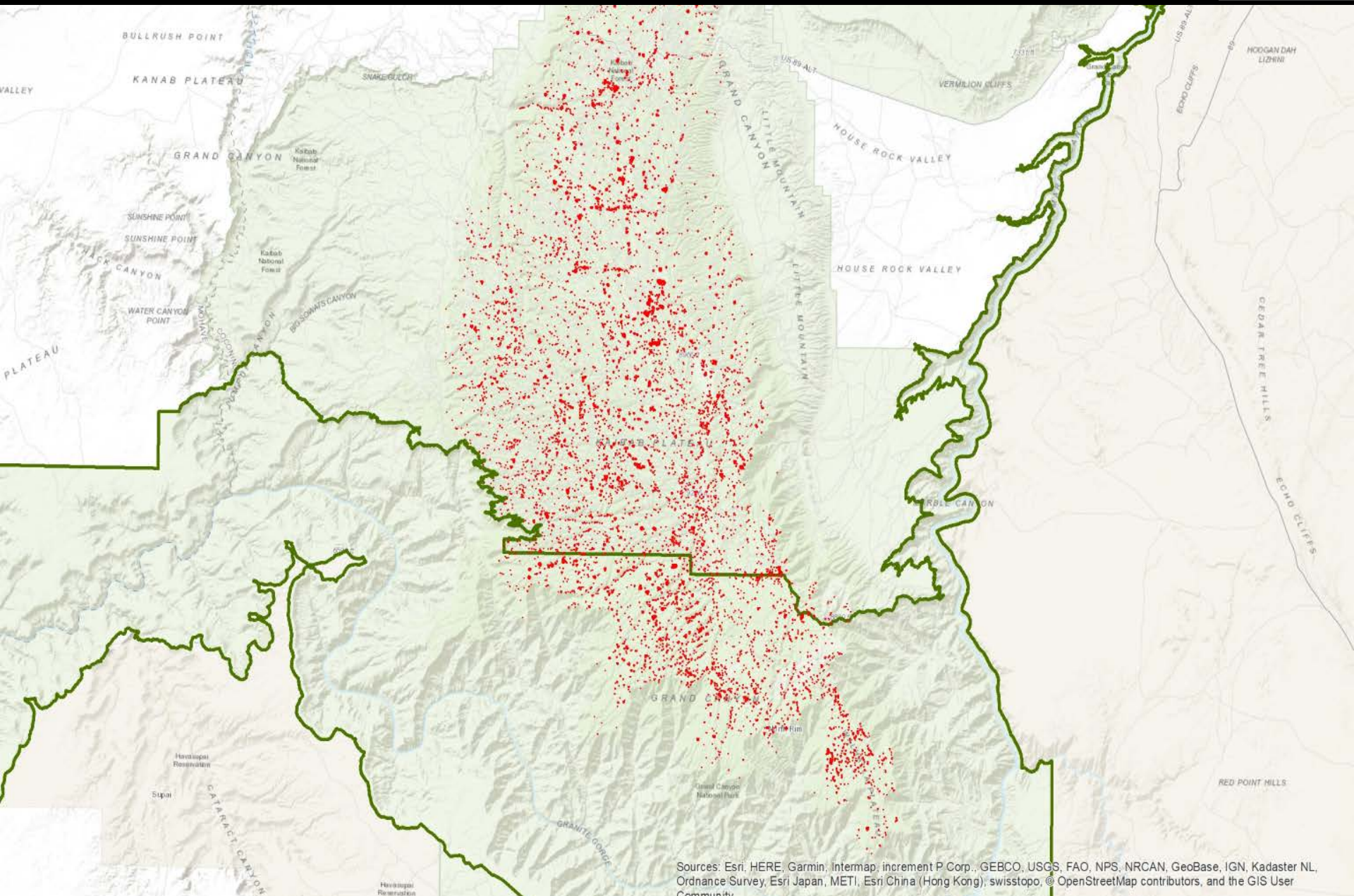

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Kaibab Plateau Sinkhole Density

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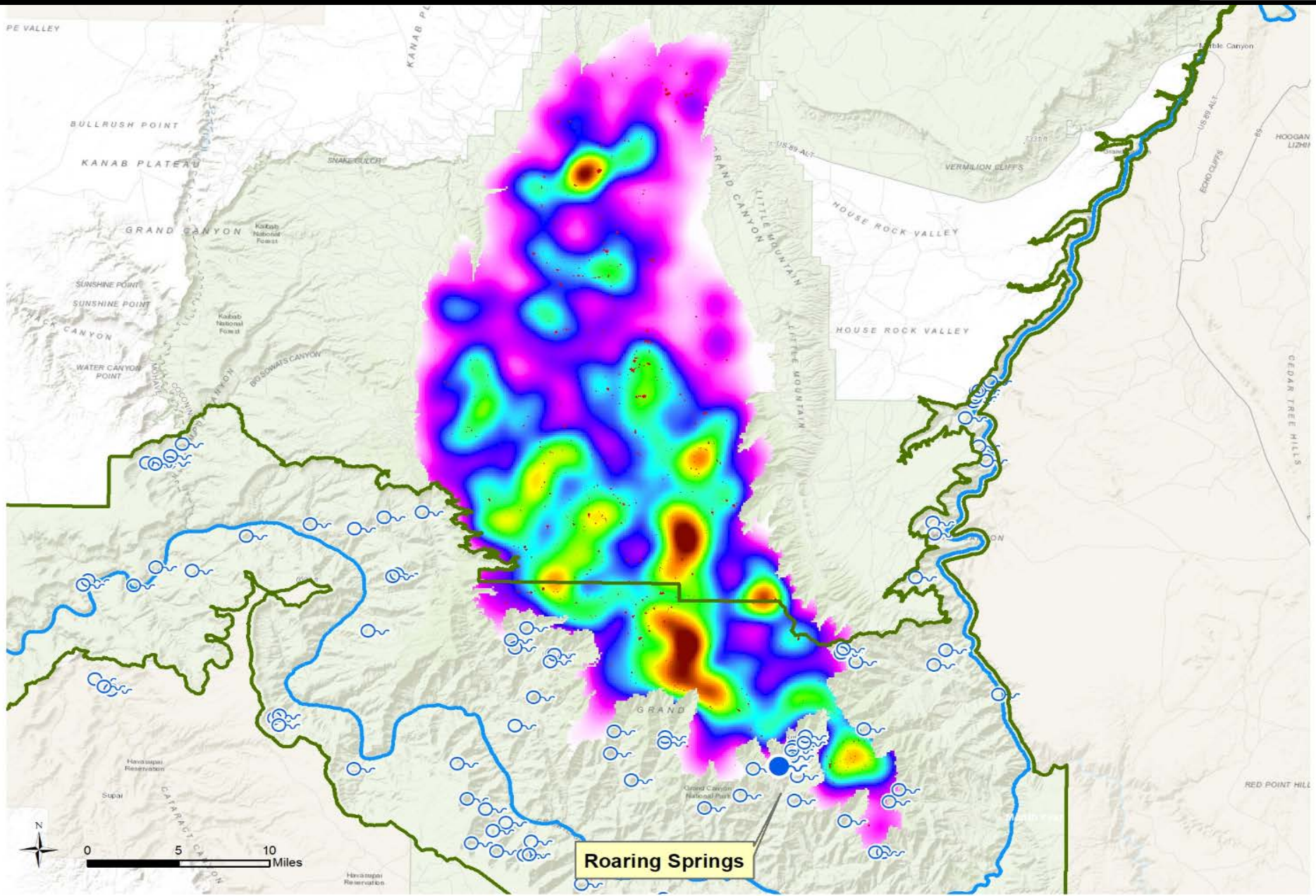

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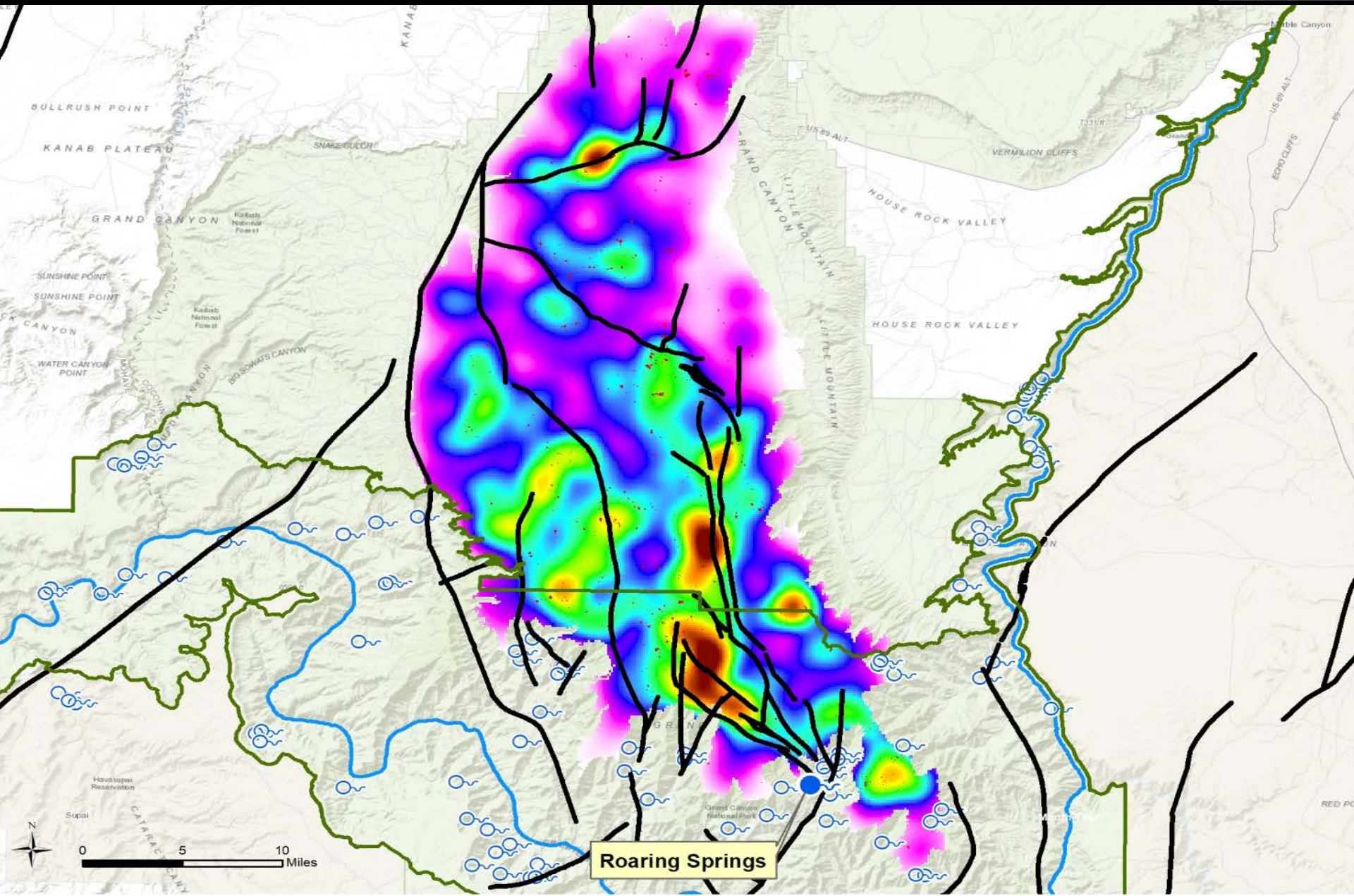
Kaibab Plateau Sinkhole Density and Mapped Faults



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Dye Trace Studies Area

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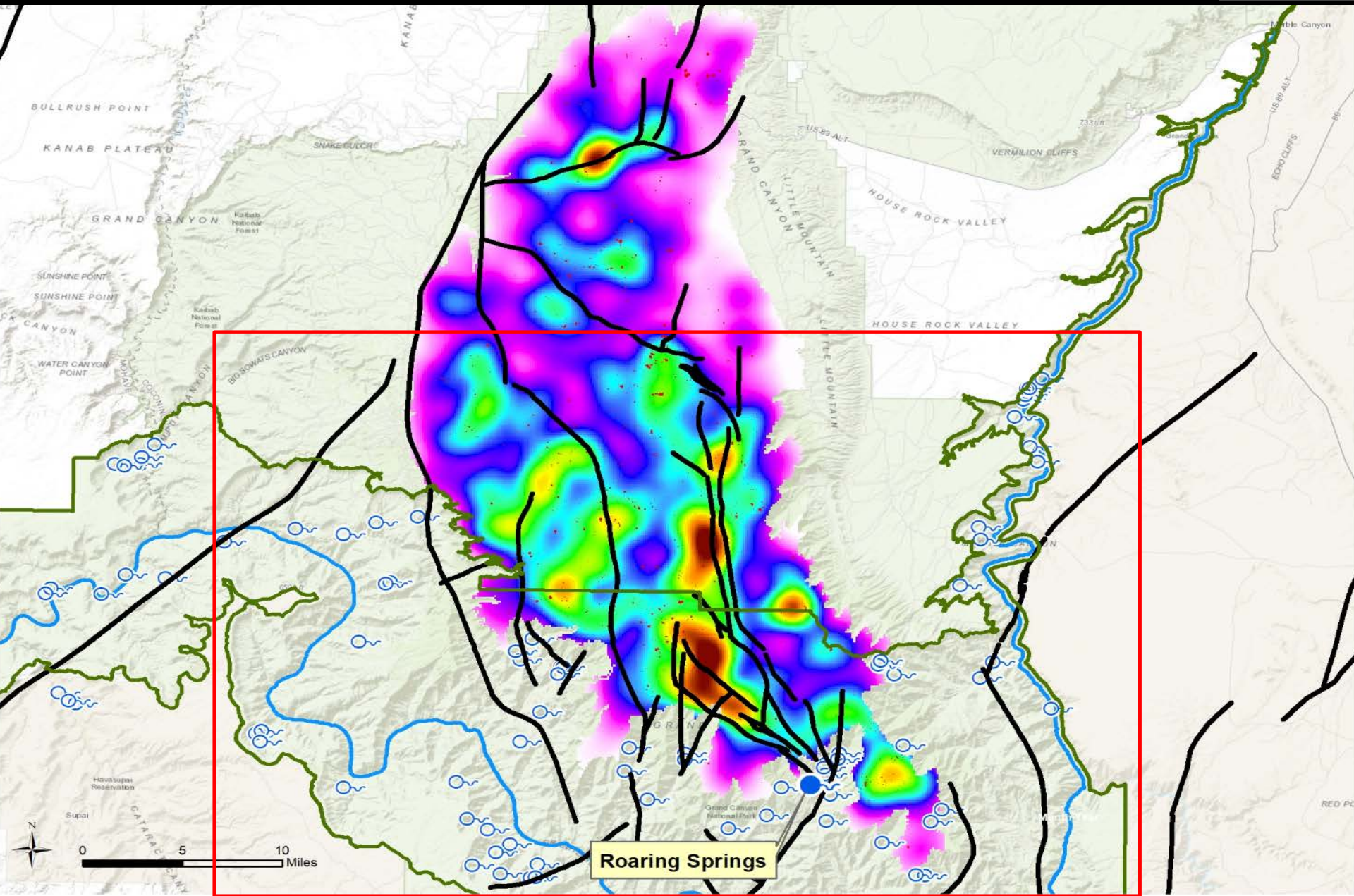
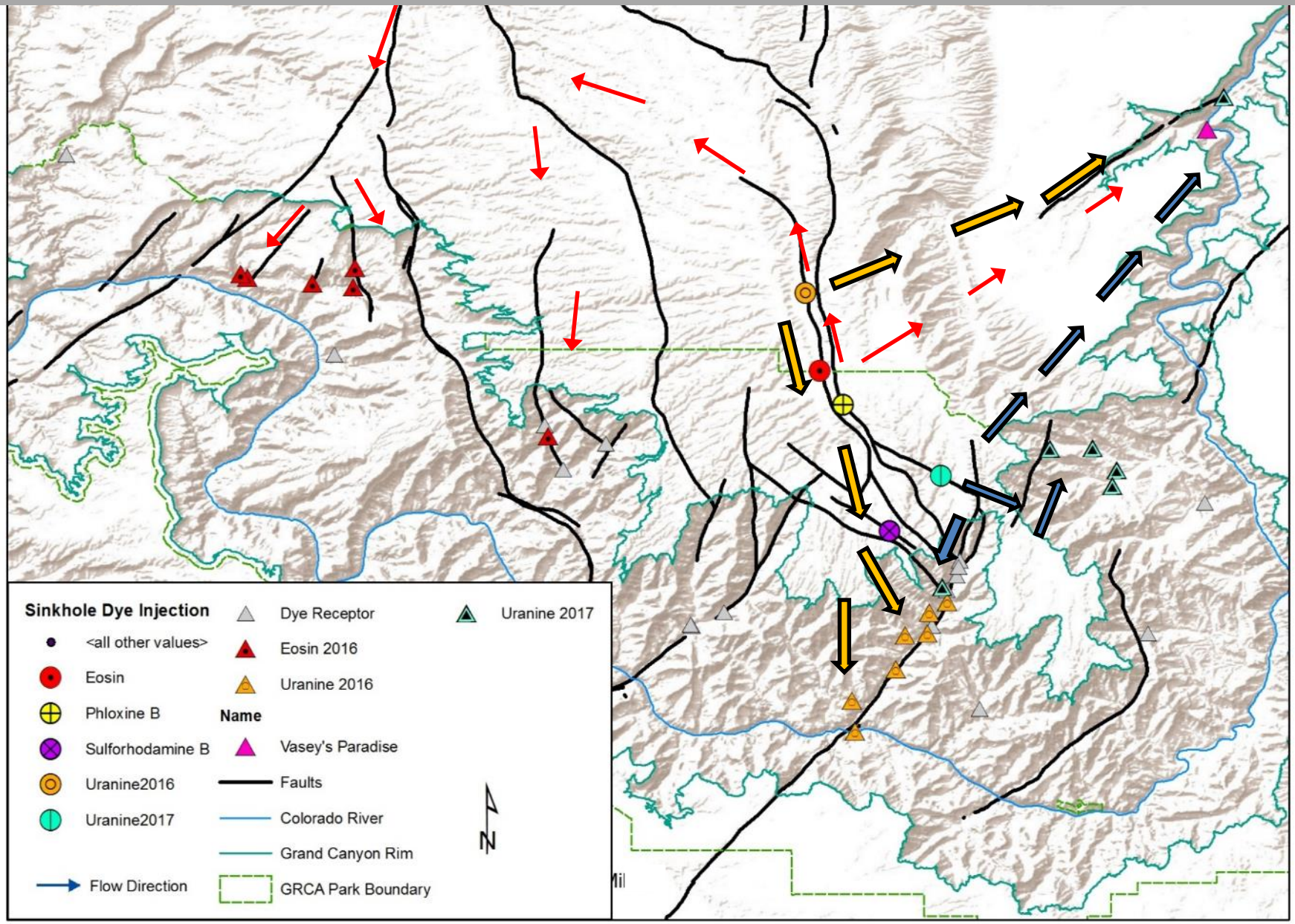


2016 - 2017 Dye Detections



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Grand Canyon Aquifers

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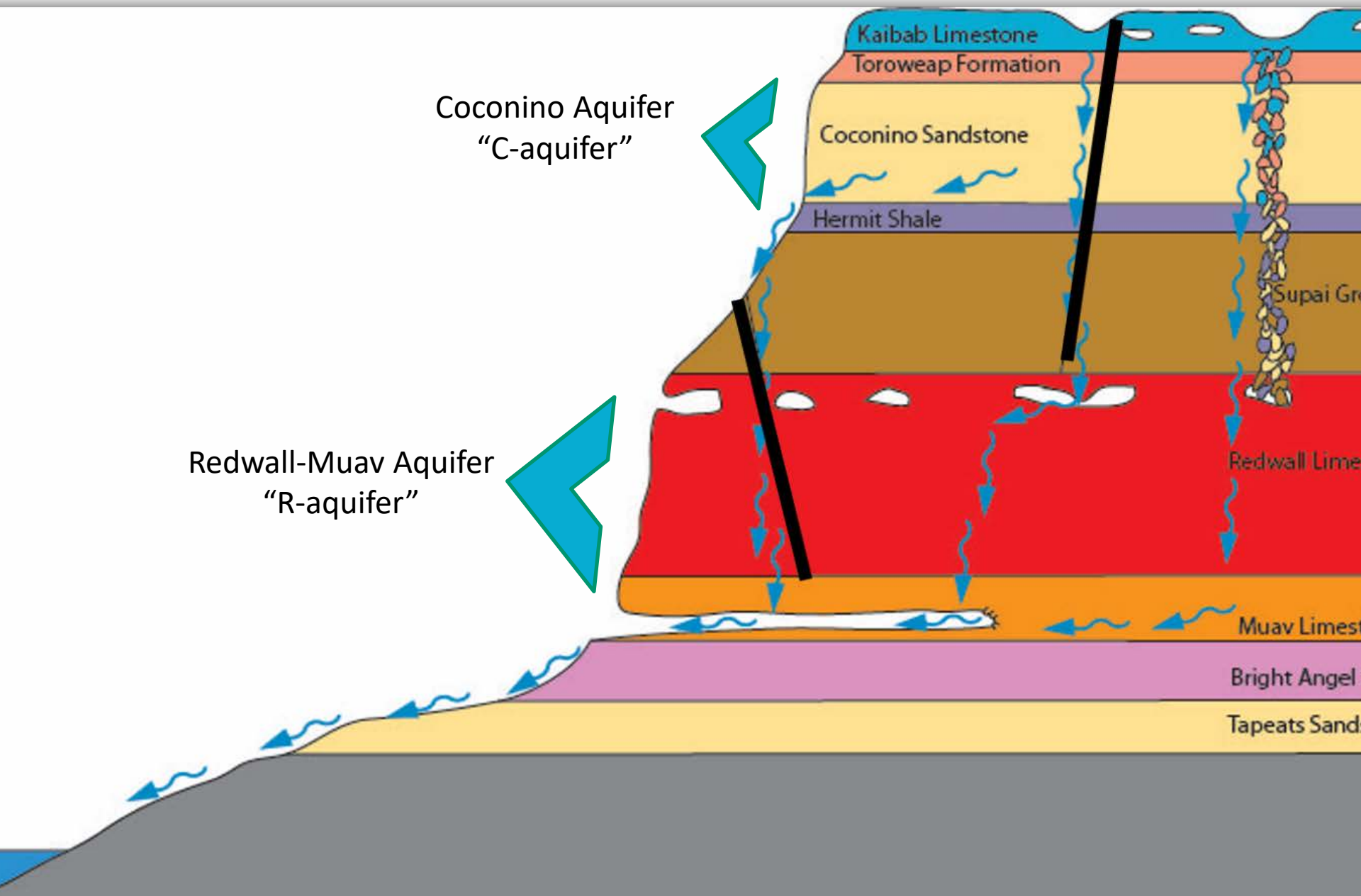

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Modified COP Aquifer Vulnerability

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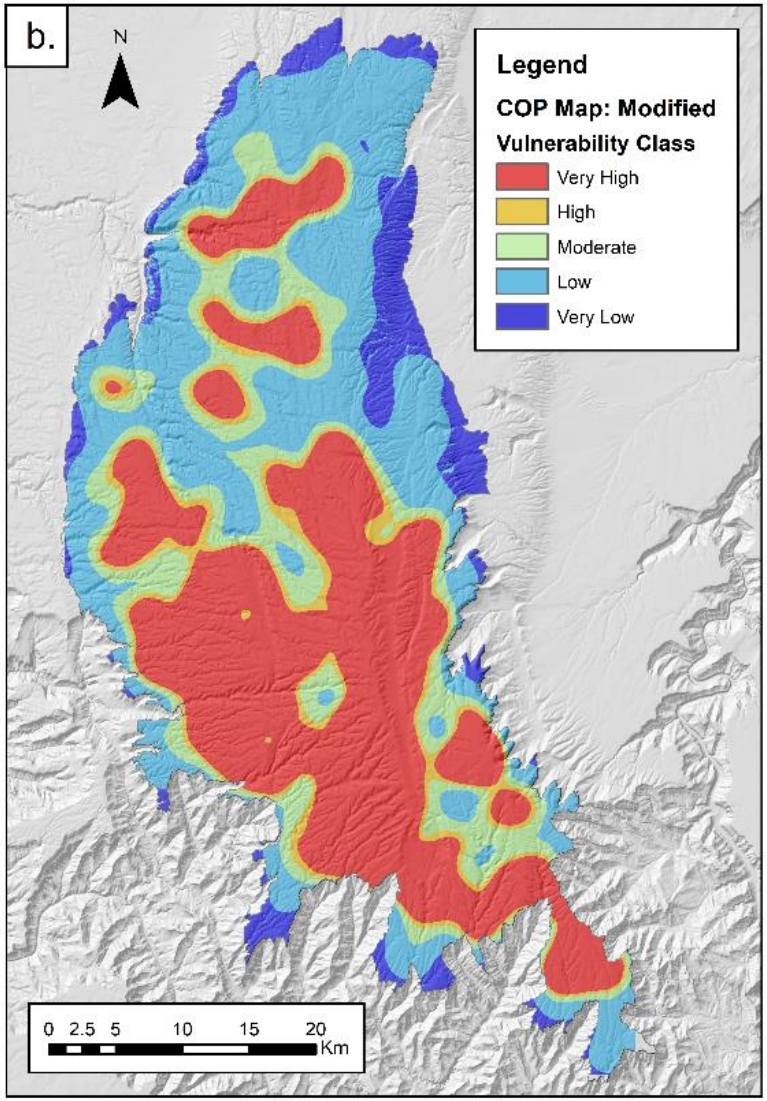
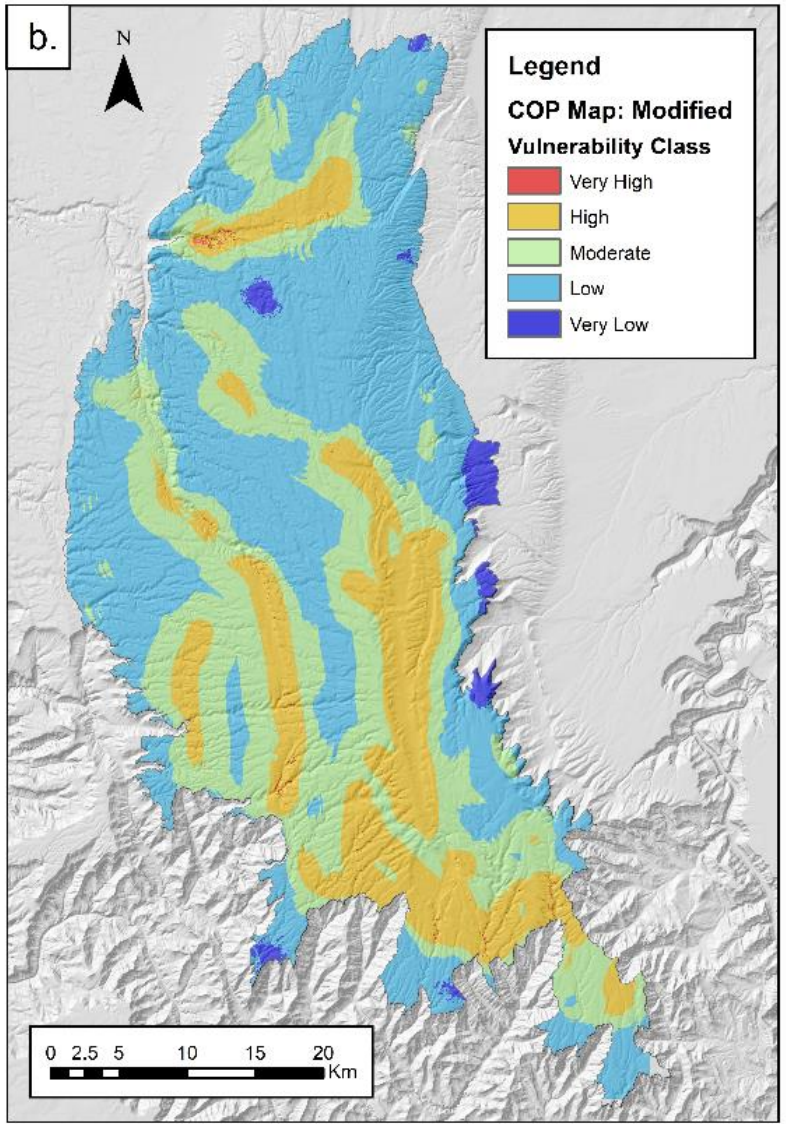
Shallow, C Aquifer



Deep, R Aquifer



Thank You!