# Eating the Elephant

## Development of a Remedial Strategy in a Complex Karst Bedrock Setting

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# Introduction

- Complexities with storage and transport of contaminants in karst can lead professionals to think remediation is impracticable
- Meaningful progress can be achieved by systematically attacking mass in residuum and epikarst in source areas
- The scale and complexity of the case study to be presented required a systematic approach

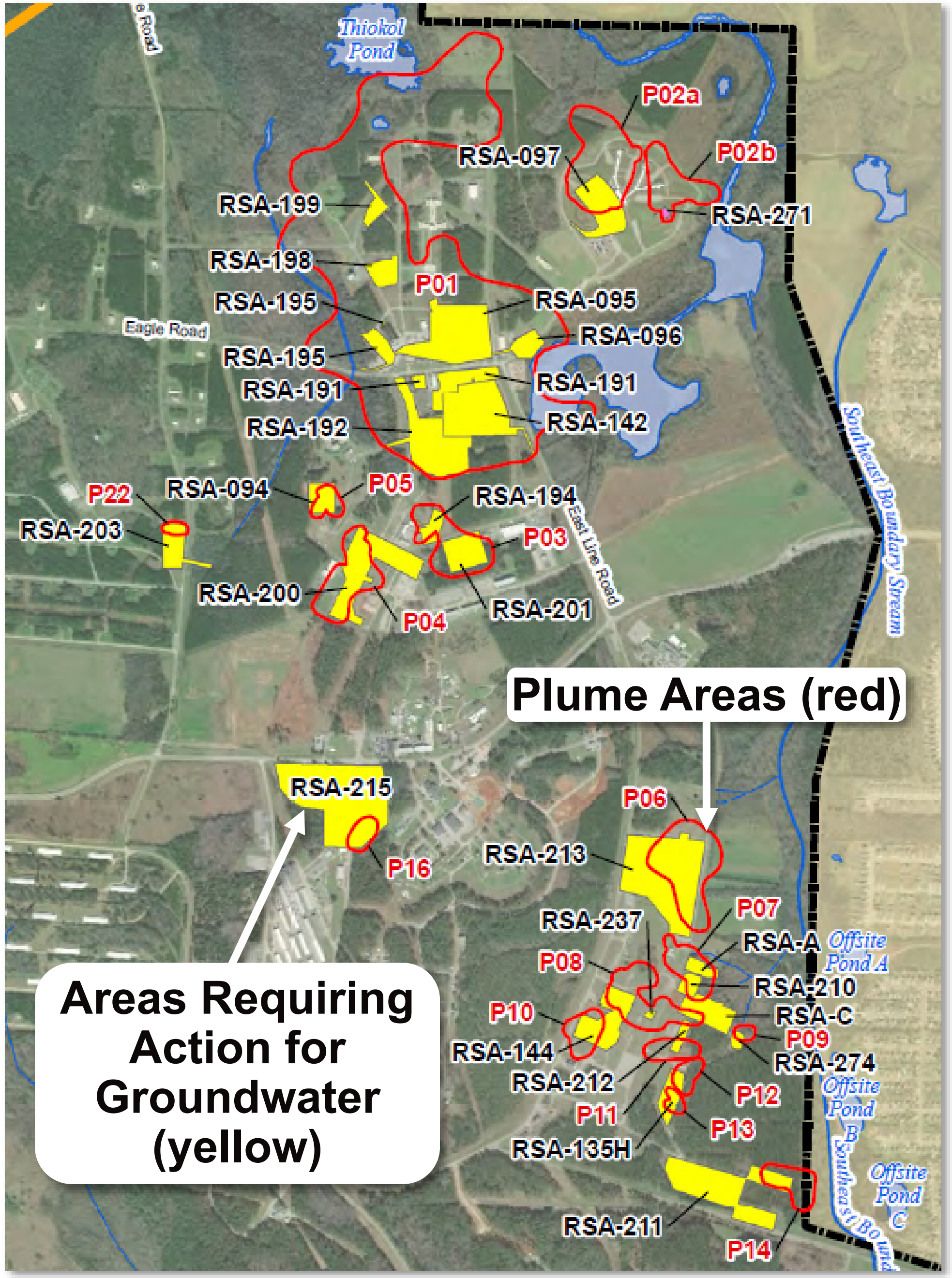
# Objective of the Approach

**Due to the large size and complex nature of RSA-146, the Army recognizes that *no single corrective measure* can likely be developed that is technically or economically feasible; therefore, the objective is to:**

- **WHERE:** Identify areas that pose the highest risk to human health and/or the environment
- **WHAT:** Recommend a preferred corrective measure for each area
- **WHEN:** Develop criteria to prioritize these areas for potential corrective measures
- **HOW:** Implement field-scale pilot testing

# RSA-146 Groundwater Unit

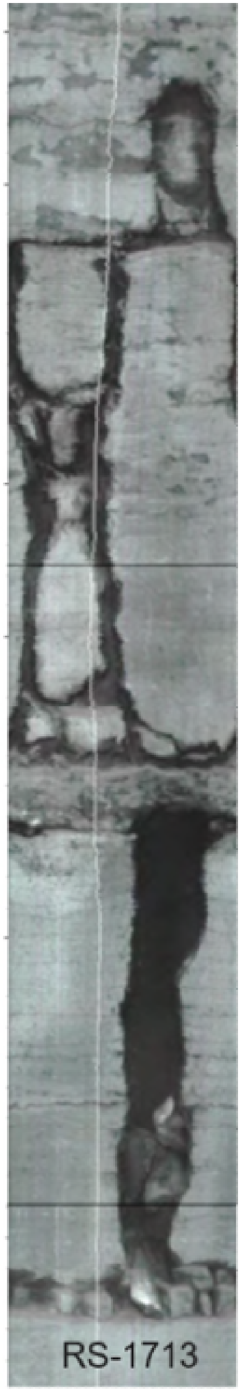
- RSA-146 includes a 10.3 $mi^2$ area
  - Karst aquifer
  - Tennessee River discharge
- 23 source areas where corrective measures are required for groundwater, 17 separate plume areas
- Primary sources are chlorinated solvents and perchlorate from former rocket engine manufacturing, and explosives from an ordnance plant



ARCADIS

# Conceptual Site Model

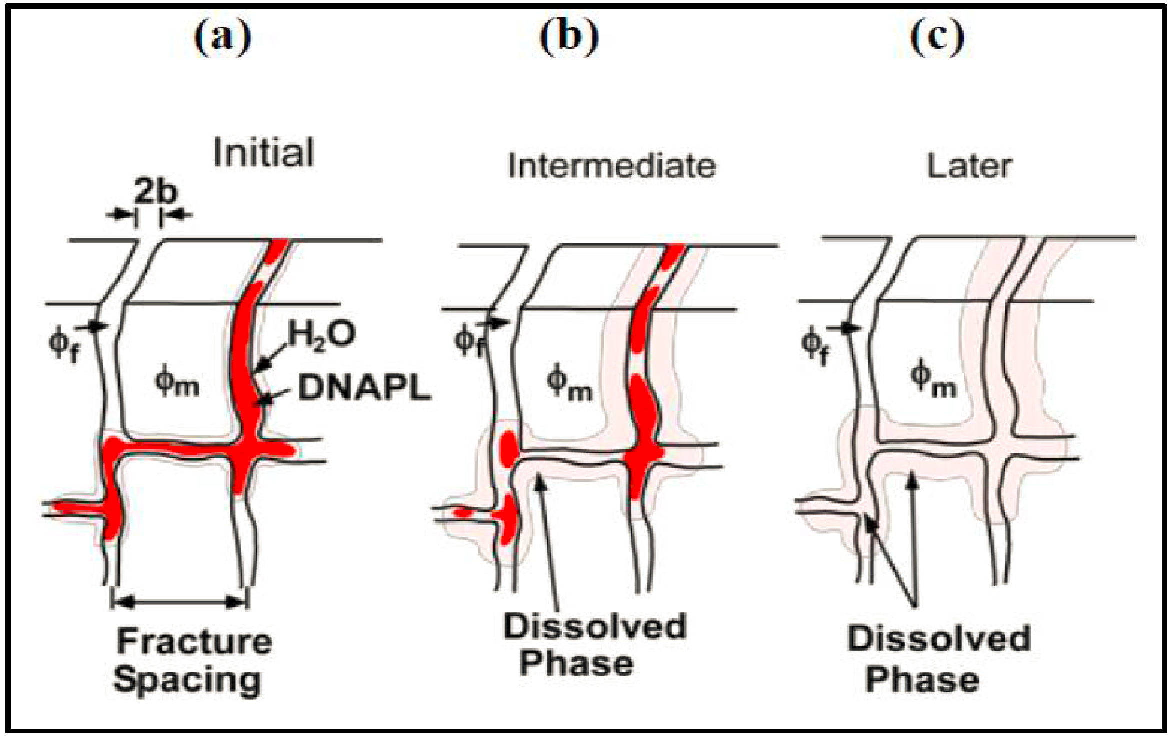
- **Overburden (Residuum):** Low perm silty clay, water table typically occurs here, ~6-60’ thick
- **Limestone Bedrock**
  - Epikarst: Upper highly weathered limestone, avg. ~30’ thick
  - Tuscumbia limestone & Fort Payne chert, total of 205-250’ thick
- **Shale:** Maury Formation & Chattanooga shale, base of materials of interest for cleanup




**Optical televiewer image of Tuscumbia Limestone**

# Conceptual Site Model

- DNAPL identified at 4 of 23 source areas
  - DNAPL present in the overburden (and some in epikarst) was thermally treated
- Likely that DNAPL has reached its final distribution
- DNAPL can act as a continuing source

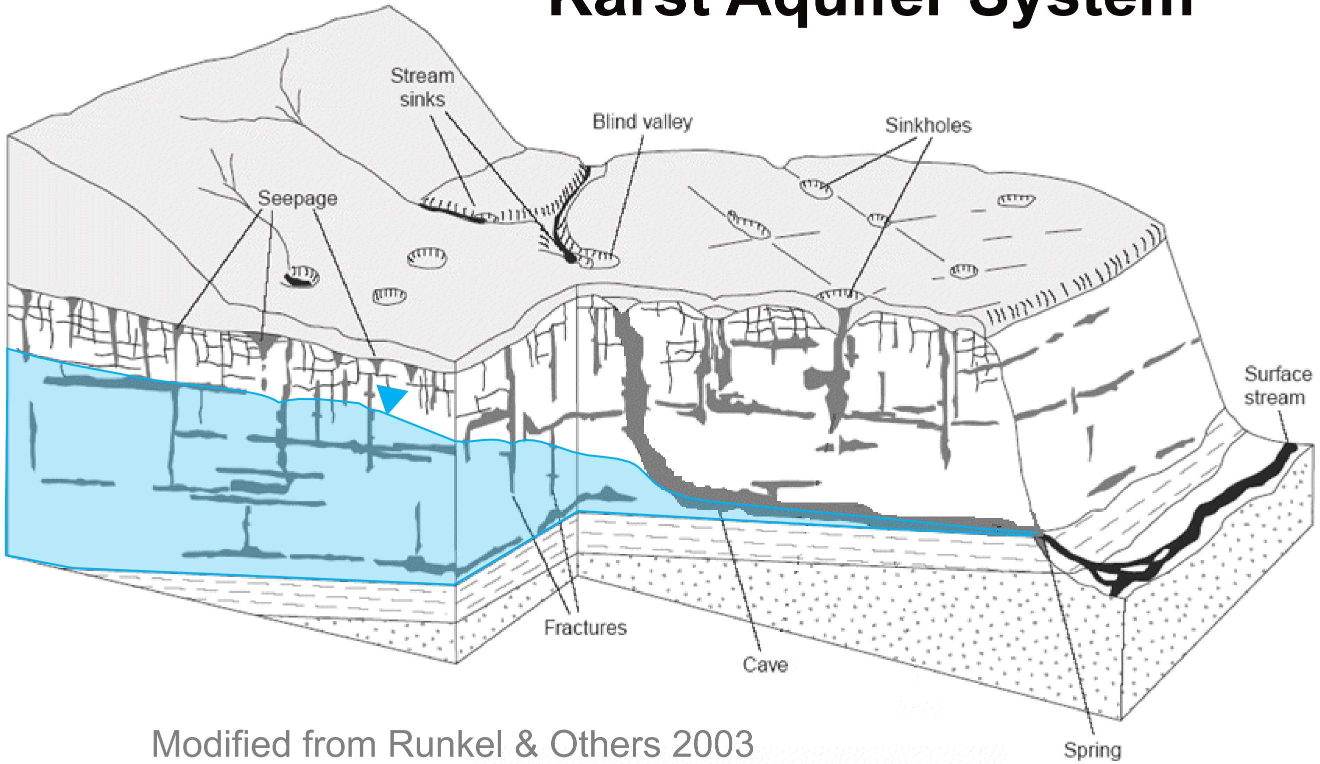



Beth Parker et al. 2011

# Conceptual Site Model

- 19 source areas have primarily dissolved phase contamination
- Groundwater plumes in karst are unique: water seeps into and is largely confined to tertiary porosity networks, which are not frequently intercepted by MWs
- Velocities of hundreds of ft/day have been documented at RSA-146

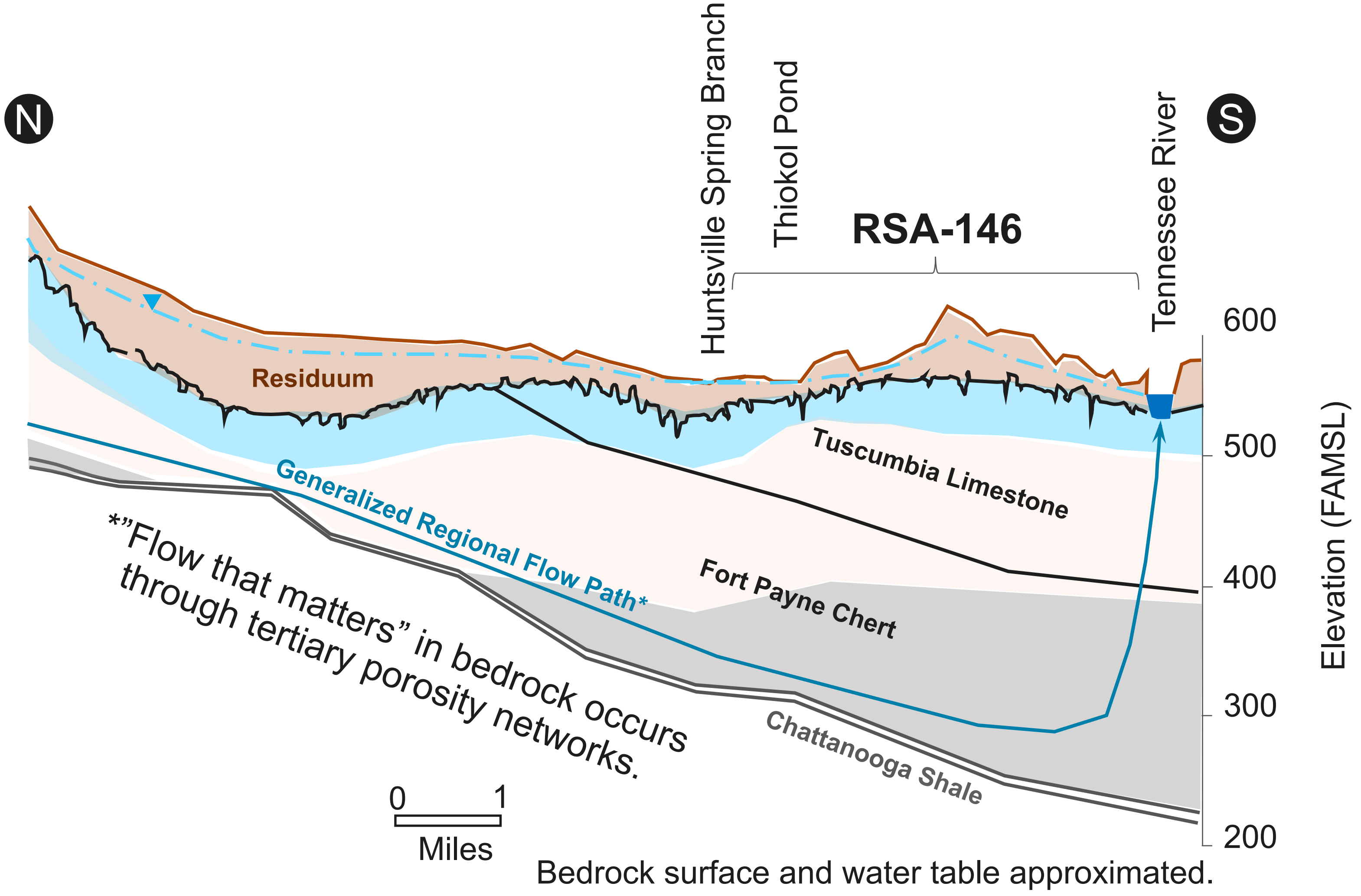
**Karst Aquifer System**




Modified from Runkel & Others 2003

# Conceptual Site Model

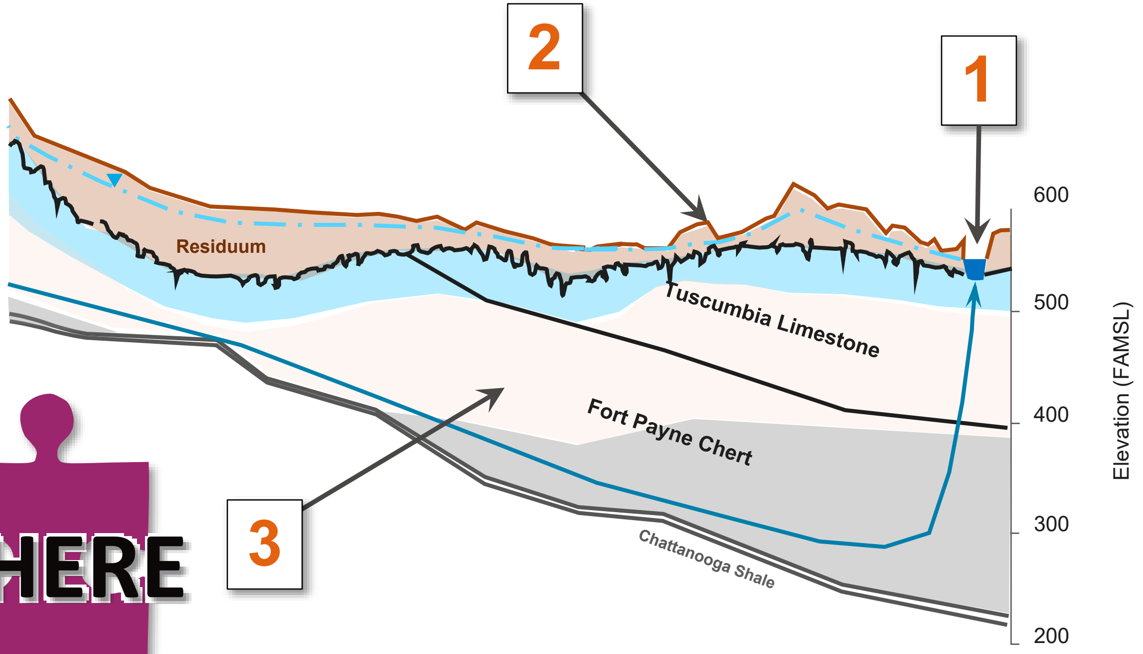
| Groundwater Flux | Ability to Successfully Remediate |
| --- | --- |
| Low | High |
| Very High | Moderate/Low |
| High | Low |
| Moderate | Very Low |



# Cleanup Approach

1. Eliminate exposure pathways
   - Restrict use of surface water & groundwater
2. Focus on the source areas
   - Reduce contaminant mass & flux to receptors
3. Manage contamination in bedrock
   - Monitor for reductions due to source area cleanup
   - Establish a framework for long-term trend assessment and adaptive management

WHERE




| Groundwater Flux | Ability to Successfully Remediate |
|---|---|
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# Corrective Measure Objectives

| Media | ICM Objective |
| --- | --- |
| DNAPL | • Reduce source mass in overburden and epikarst |
| Dissolved COCs | • High concentration: Expedite treatment<br>• Low concentration: Collect data required to proposed MNA |
| Surface Water | • Where there is potential to contribute to surface water, achieve meaningful reductions in mass discharge |

# Corrective Measure Evaluation

## Grouping of Apparent Sources

| Group | Plume Area | Site | Primary COC(s) | Max. Conc. (µg/L) | ICM Zones |
|---|---|---|---|---|---|
| Apparent or Suspected DNAPL | P01 | RSA-095 | TCE | 198,000 | OVB & epikarst |
| | P01 | RSA-096 | TCE | 70,700 | OVB & epikarst |
| | P01 | RSA-142 | TCE, perchlorate | 21,900 | OVB & epikarst |
| | P01 | RSA-195 | TCE | 63,100 | OVB & epikarst |
| High-Conc. Perchlorate & TCE | P01 | RSA-198 | Perchlorate, TCE | 18,000 | OVB & epikarst |
| | P01 | RSA-199 | Perchlorate, TCE | 2,000 | OVB & epikarst |
| | P02a | RSA-097 | TCE, Perchlorate | 8,400 | OVB & epikarst |
| High-Conc. Perchlorate | P03 | RSA-194 | Perchlorate | 47,300 | OVB & epikarst |
| | P03 | RSA-201 | Perchlorate | 1,160 | OVB |
| | P04 | RSA-200 | Perchlorate, TCE | 3,500 | OVB |
| Low-Conc. Perchlorate | P05 | RSA-094 | Perchlorate | 220 | OVB & epikarst |
| | P12/P13 | RSA-135H | Perchlorate, RDX, TCE | 103 | OVB |

Continues through P22

# Preferred ICM Alternatives – North Plant

WHAT

| Plume Area | Source Area | Preferred ICM Alternative |
|---|---|---|
| P01 | RSA-095 | In situ bioremediation (ISB) for DNAPL / in situ biogeochemical reduction (ISBGR) for dissolved groundwater |
| | RSA-096 | ISB for DNAPL and ISB for dissolved groundwater |
| | RSA-142 | ISB for DNAPL and ISB for dissolved groundwater |
| | RSA-195 | ISB for DNAPL and ISB for dissolved groundwater |
| | RSA-198 | ISB |
| | RSA-199 | ISB |
| P02a | RSA-097 | ISB |
| P03 | RSA-194 | ISB |
| | RSA-201 | ISB |
| P04 | RSA-200 | ISB |
| P05 | RSA-094 | Monitored natural attenuation (MNA) |

# Remedy Prioritization Decision Framework

- Developed evaluation criteria. Each was assigned a value designating how crucial it was as a driver. These were multiplied by the score that each source received for that criteria.
- Evaluation Criteria:
  - Contribution to Off-Post Migration (Yes or No)
  - Potential Contribution to Surface Water Risk (Yes or No)
  - Presence of a Continuing Source to Groundwater (Yes or No)
  - Maximum Concentration (< 100 to > 10,000 µg/L)
  - Contribution to Larger Groundwater Issue (Isolated/Commingled, Scale)

# Prioritization Results

## Tier 1: High Priority (≥ 20)

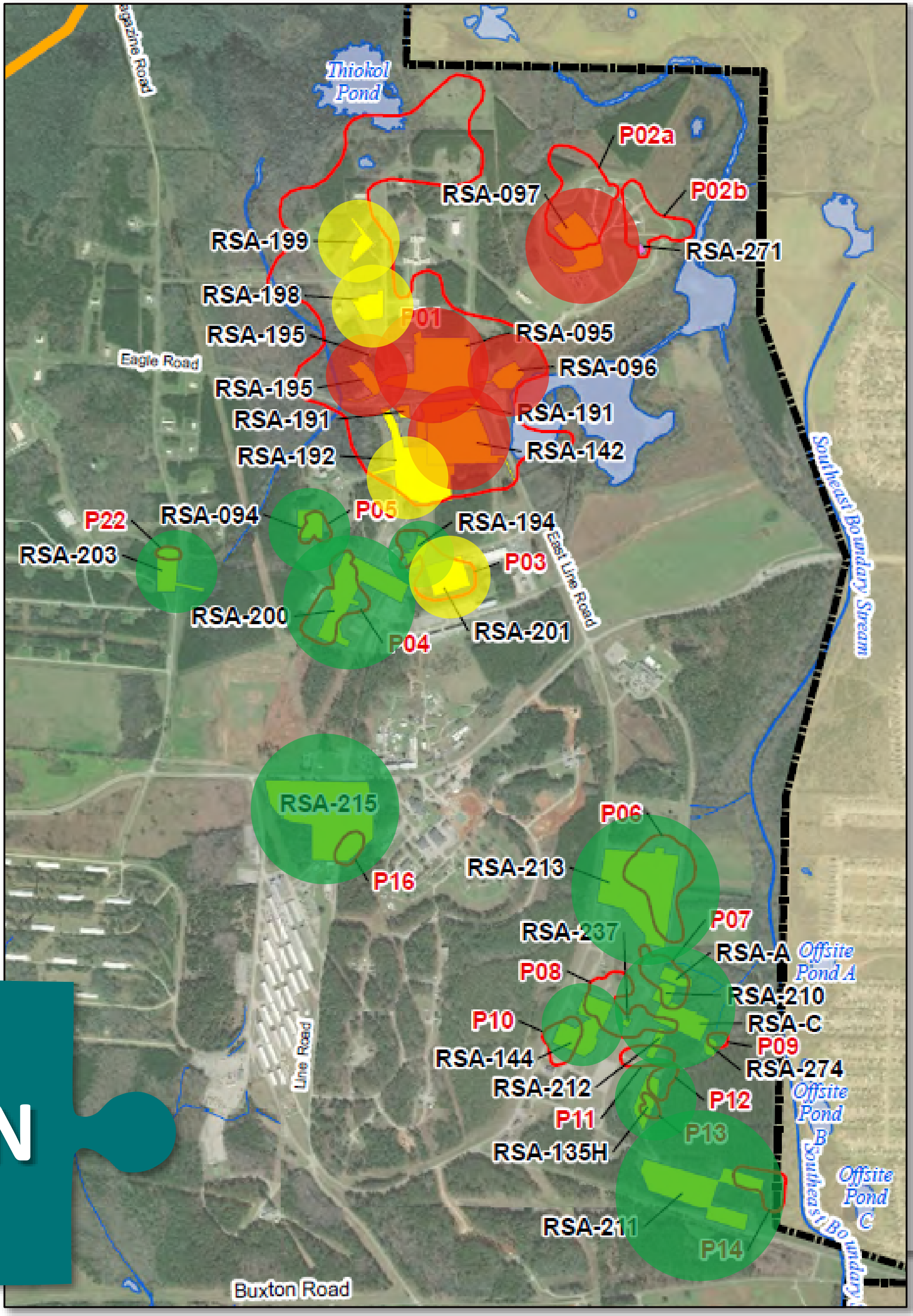
- Source mass remains, highest risk to surface water and off-post impacts

## Tier 2: Moderate Priority (10 – 19)

- Low to no risk to receptors, moderate to high concentrations in groundwater

## Tier 3: Low Priority (< 10)

- No apparent risk to receptors, smaller scale, low concentration

# Implementation at Tier 1 Sites

- Pilot study injections at RSA-095 and RSA-195 in March 2024
- Overburden: Rhodamine WT with ABC-Ole at RSA-195 and EHC at RSA-095 injected via DPT
- Epikarst: Fluorescein with ABC-Ole injected using injection wells

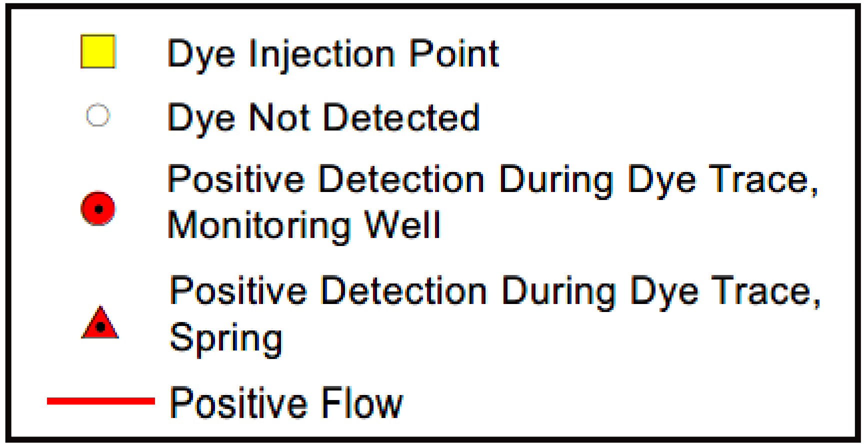
*Note: Work has also begun at the other 21 source areas – pre-design for active remedies and monitoring for MNA*

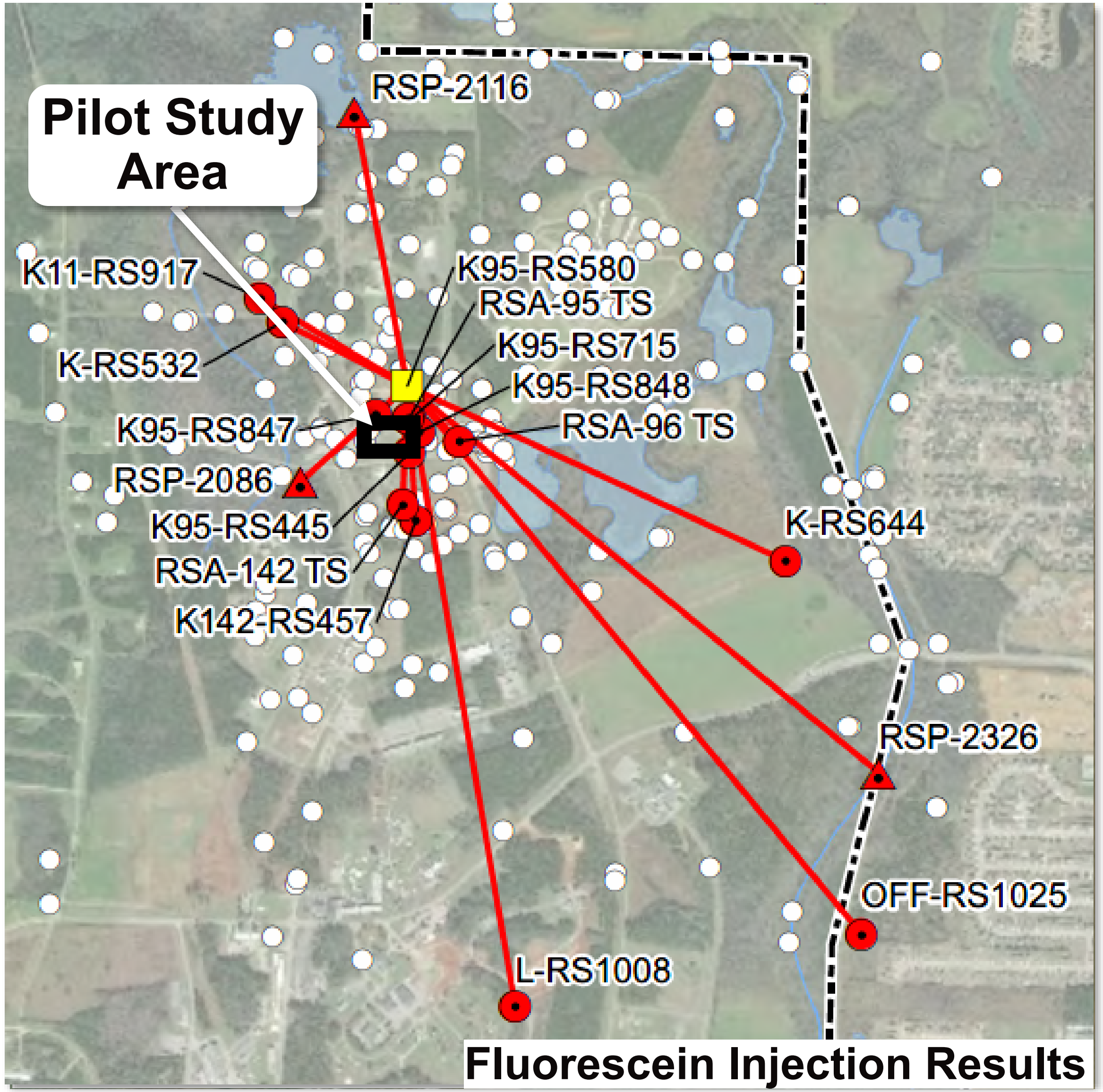
Tracer Dye in Residuum

Epikarst Injection Well

# Qualitative Tracer Study

- Charcoal samplers in place to collect tracer dye while deployed
- Objective is to assess if a “signal” of the injections reaches these locations
- Spring and surface water monitoring locations selected based on available data, including results of tracer studies

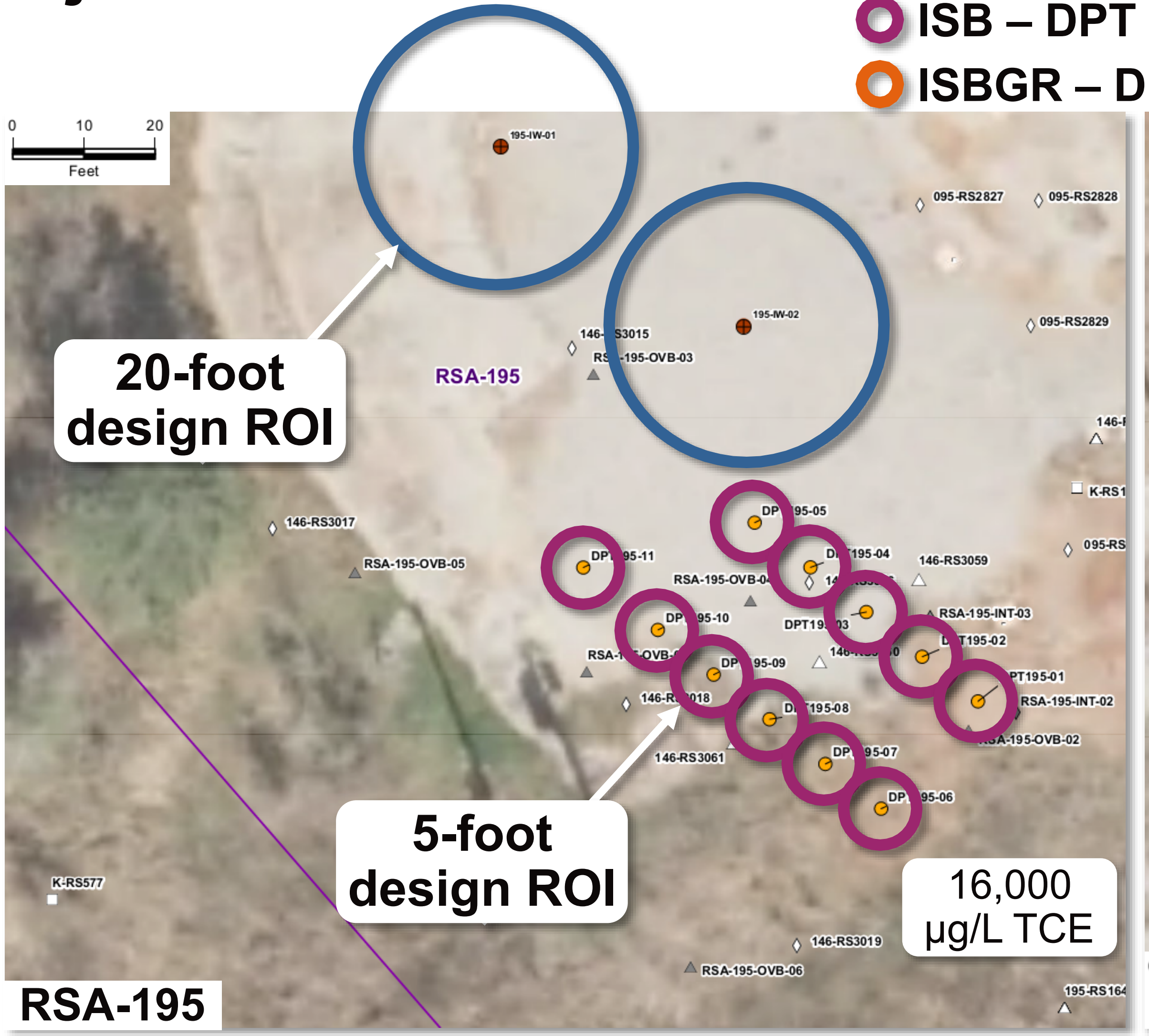


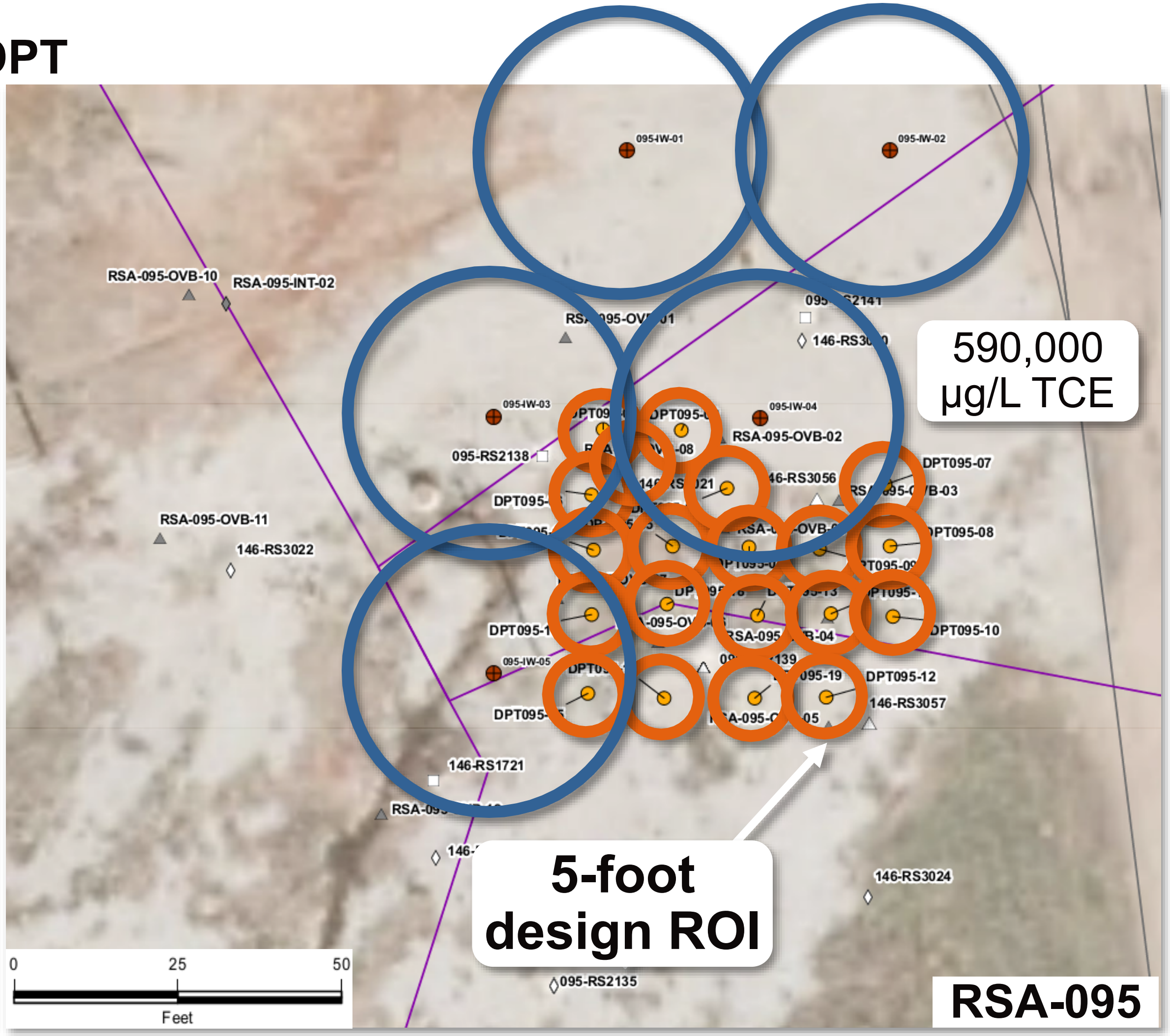




Fluorescein Injection Results

# Injection Locations

ISB – Epikarst Injection Wells
ISB – DPT
ISBGR – DPT

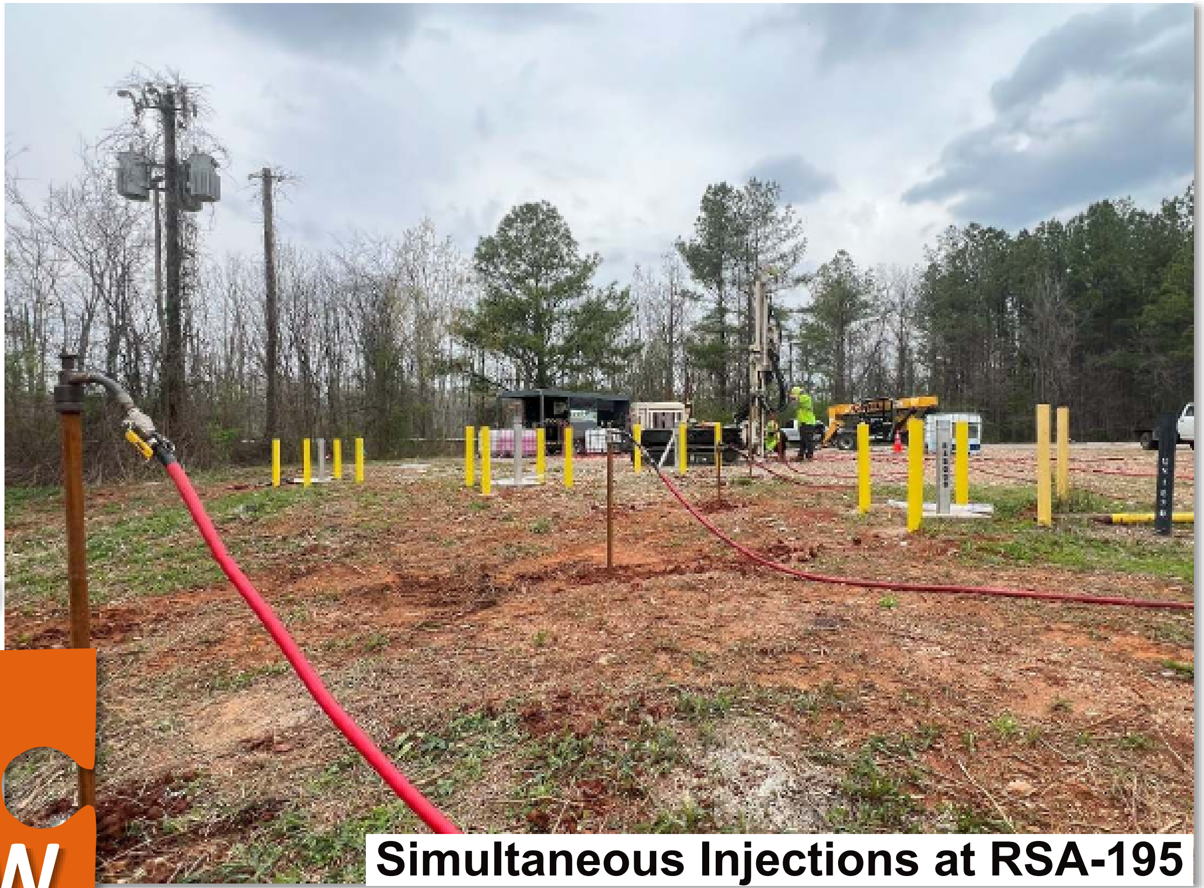


# Early Observations & Lessons Learned

- Hydraulic testing of boreholes in epikarst results in better connectivity
- Delivered target volumes to injection wells at 6 of 7 locations, dye 23’ away
- Low pressure injection for ISB (5 to 20 psi, ~1.5 gpm) worked well, dye 13' away
- EHC injections at higher pressures (100 to 180 psi, 7 to 12 gpm), required for slurry in tight residuum, also went as planned (no daylighting, dye observed 7.5' away)

HOW



Simultaneous Injections at RSA-195


# Thank you!

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# Extra Slides

# Pilot Study Components

- **Baseline Sampling:** COCs, biogeochemical parameters, tracer dye
- **RSA-095:**
  - ISBGR in OVB: EHC & Rhodamine WT, 19 pts
  - ISB in Epikarst: ABC Ole & Fluorescein, 5 IWs
- **RSA-195:**
  - ISB in OVB: ABC-Ole & Rhodamine WT, 10 pts
  - ISB in Epikarst: ABC Ole & Fluorescein, 2 IWs
- **Performance Monitoring:**
  - Weeks 1, 3, 6, then quarterly: Tracer dye at springs, surface water, porewater, select MWs
  - Quarterly: COCs, biogeochemical parameters, UIC permit required parameters

**Epikarst Injection Solution**