FRACTURED BEDROCK CHARACTERISATION AND EFFECTIVE REMEDY SELECTION IN REGION 4

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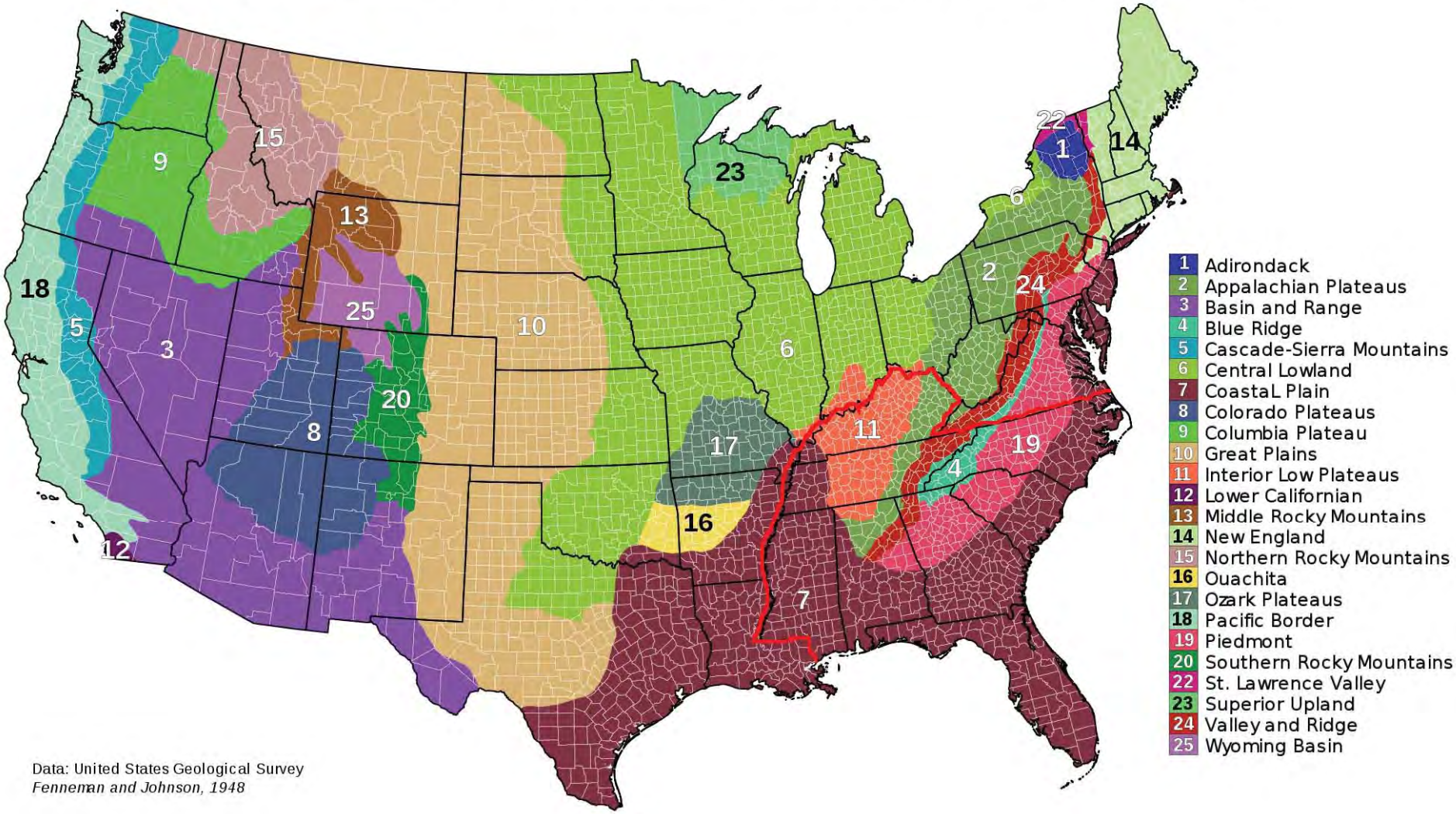
EPA REGION 4

Presentation Outline

- Region 4's area with Fractured Bedrock Aquifers
- Examples of three kinds of aquifers
  - Fractured Metamorphic
  - Fractured Igneous
  - Fractured Sedimentary
- Characterization and Remediation
  - Five Federal Facilities
  - Four Non-Federal Facilities
- Summary and Conclusions

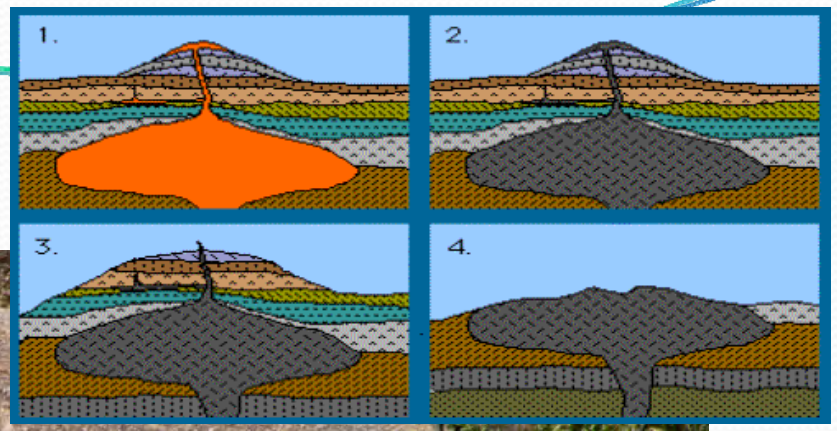
Geophysical Provinces of the Conterminous United States



Fractured Metamorphic Rock

Lawrenceville, GA

Fractured Igneous Rock

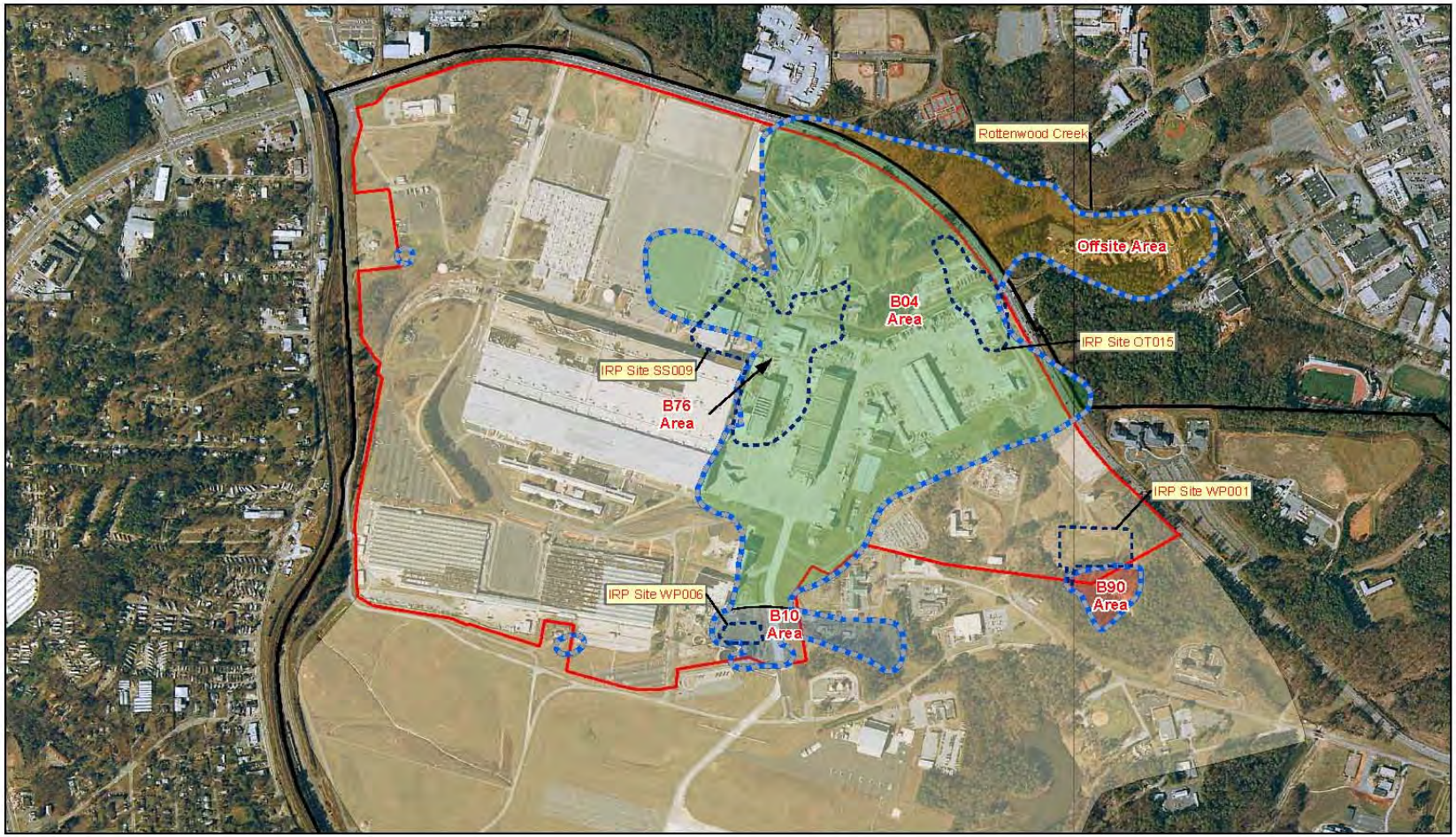


Fractured Sedimentary Rock

Manchester, TN

West Trenton, NJ

Air Force Plant No. 6 - Marietta, GA
Fractured Metamorphic Rock - Piedmont



Site Map

Air Force Plant No. 6 - Marietta, GA
Fractured Metamorphic Rock - Piedmont

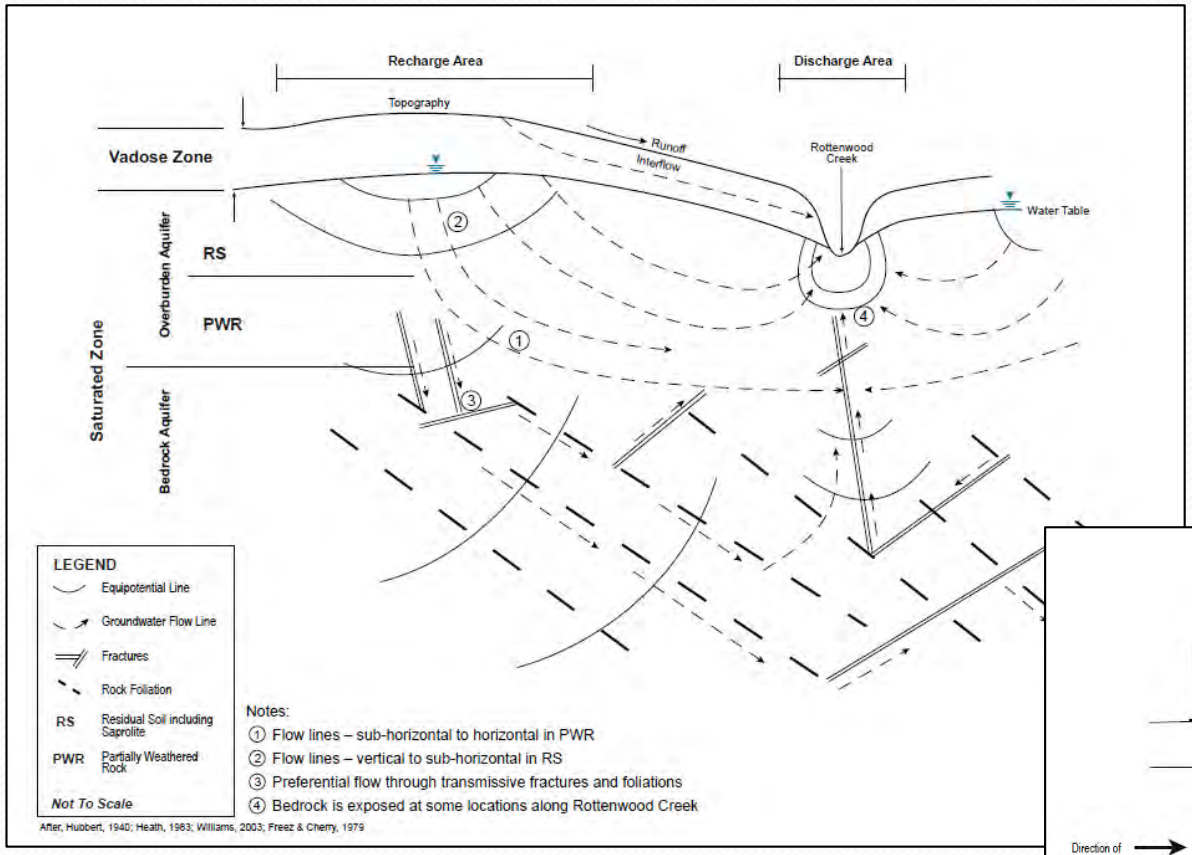
- Airplane Assembly since WWII
- Multiple Solvent Releases
- Detailed Characterization
- Groundwater contamination in saprolite, partially weathered rock (PWR) (together considered the overburden aquifer) and bedrock (BR)
  - Dissolved Phase and DNAPL
- Most recent report – (third) Annual Corrective Action Effectiveness Report - RCRA

Air Force Plant No. 6 - Marietta, GA
Fractured Metamorphic Rock - Piedmont

Characterization included:

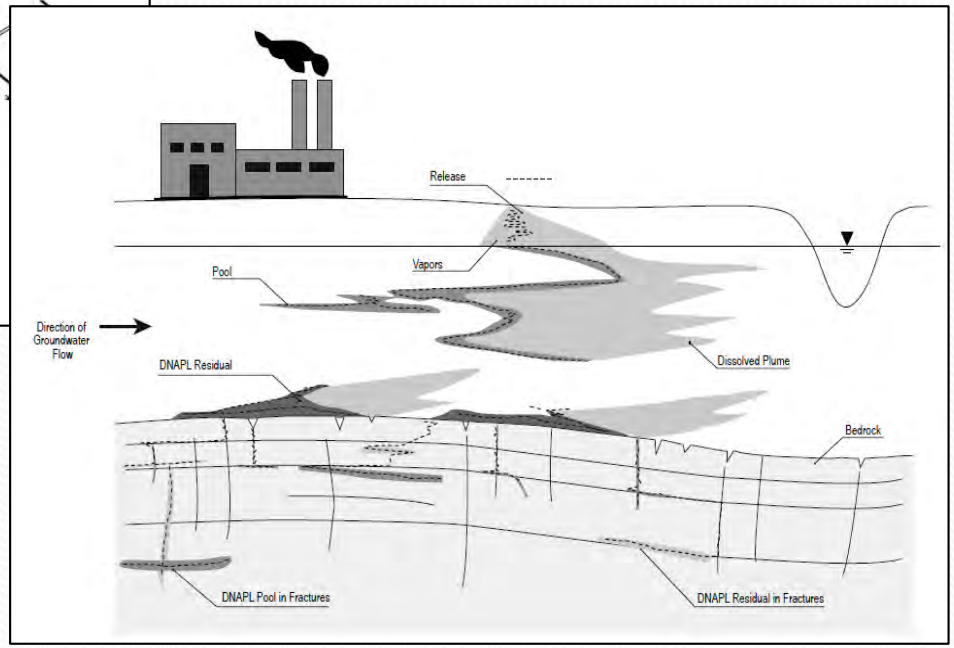
- Bedrock cores and thin section analysis (gneiss v. schist)
- Borehole geophysics
- PWR aquifer test - one connected anisotropic aquifer but with differing properties
- Site-wide water level gauging and gradient analysis suggesting less flow in BR
- Extensive soil and groundwater sampling
- Conceptual Site Model development

Air Force Plant No. 6 - Marietta, GA
Fractured Metamorphic Rock - Piedmont



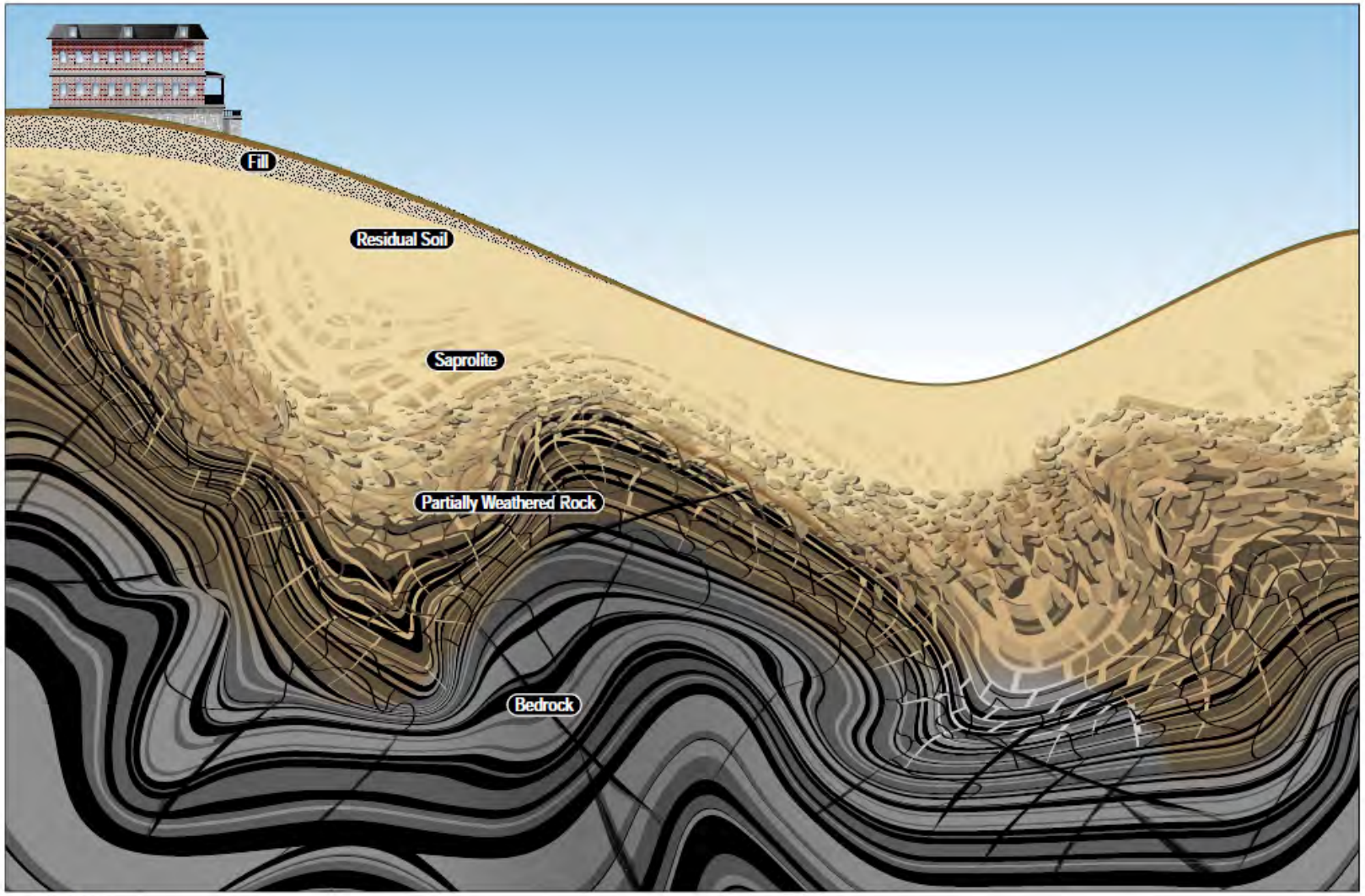
Hydrogeology
Conceptual Site Model

DNAPL Conceptual
Site Model



Air Force Plant No. 6 - Marietta, GA
Fractured Metamorphic Rock - Piedmont

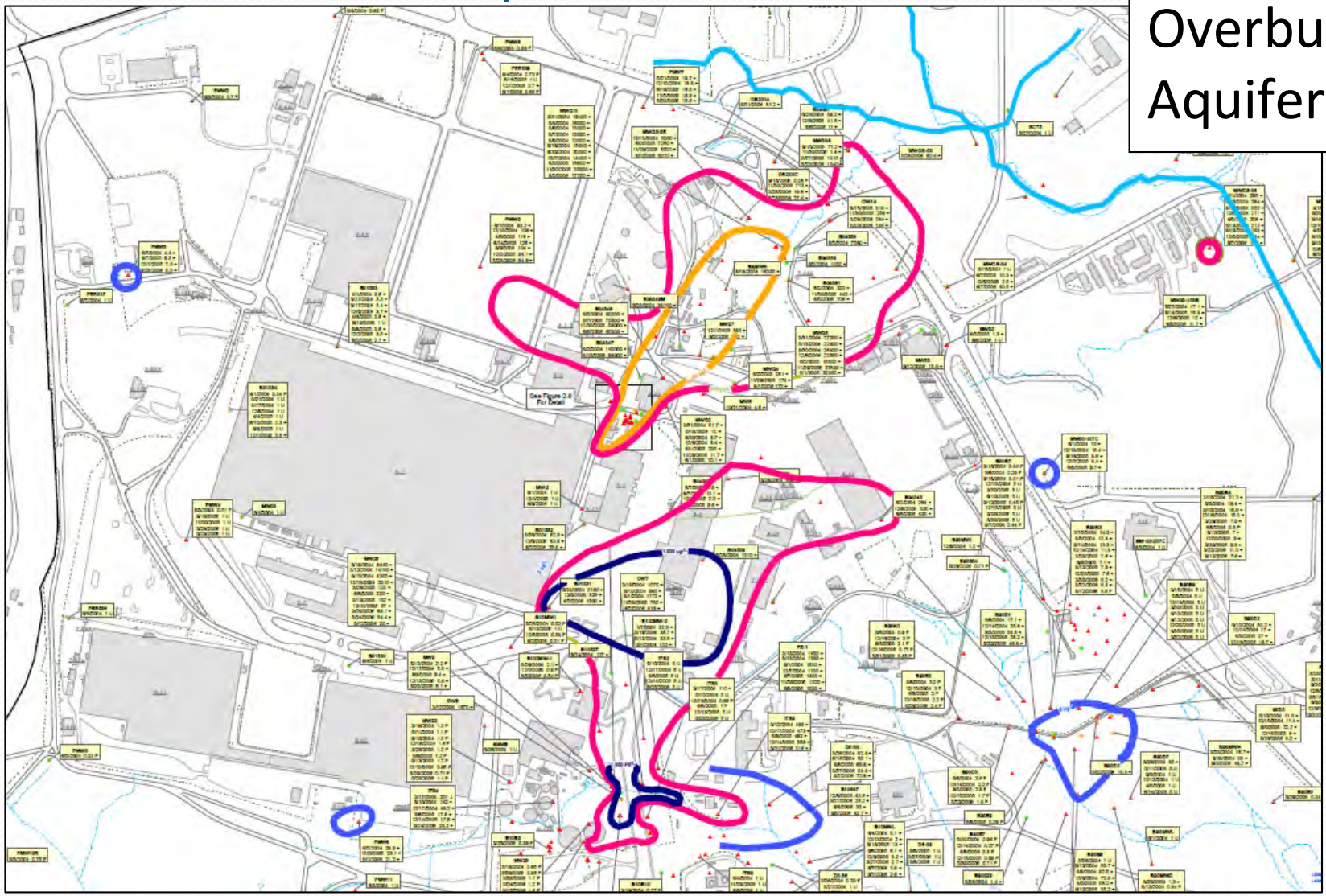
Conceptual Site Model



Drawing Not To Scale

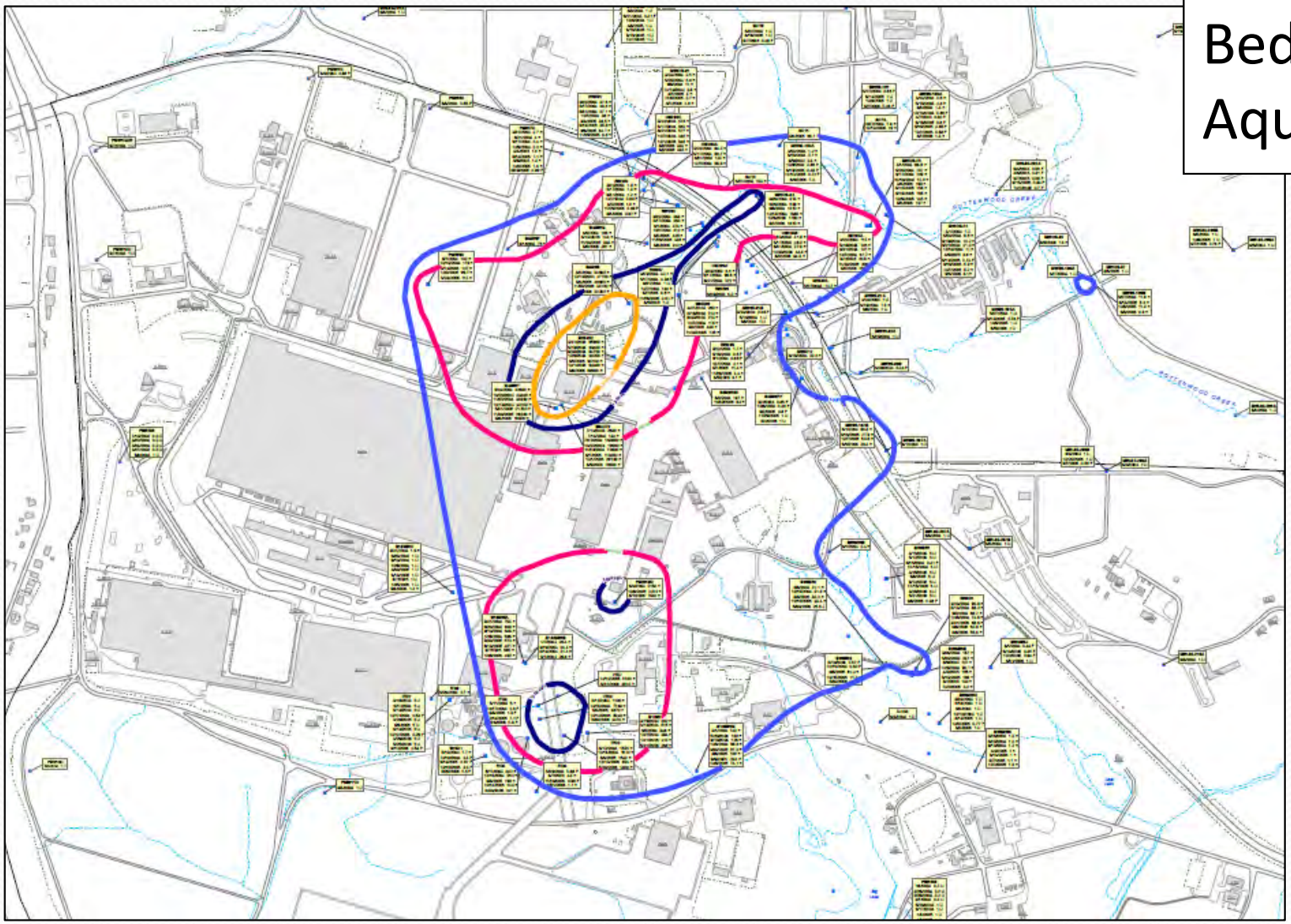
Air Force Plant No. 6 - Marietta, GA
Fractured Metamorphic Rock - Piedmont

TCE in the Overburden Aquifer



Air Force Plant No. 6 - Marietta, GA
Fractured Metamorphic Rock - Piedmont

TCE in the Bedrock Aquifer



Air Force Plant No. 6 - Marietta, GA
Fractured Metamorphic Rock - Piedmont

REMEDIAL TECHNOLOGIES SELECTED

Air Sparge/Soil Vapor Extraction in Overburden Aquifer and Vadose Zone

In-Situ Chemical Oxidation in Overburden Aquifer

Microbiological Enhancement with Microbes

Permeable Reactive Barrier

Monitored Natural Attenuation

Land Use Controls

Air Force Plant No. 6 - Marietta, GA
Fractured Metamorphic Rock - Piedmont

GOALS: Reduce Mass Flux and Offsite Migration & Facilitate MNA

This is happening but offsite investigation handled by different contractor

TIMEFRAME: Estimated for Overburden, not for Bedrock aquifer

NOTE: No treatment of DNAPL in the fractured bedrock

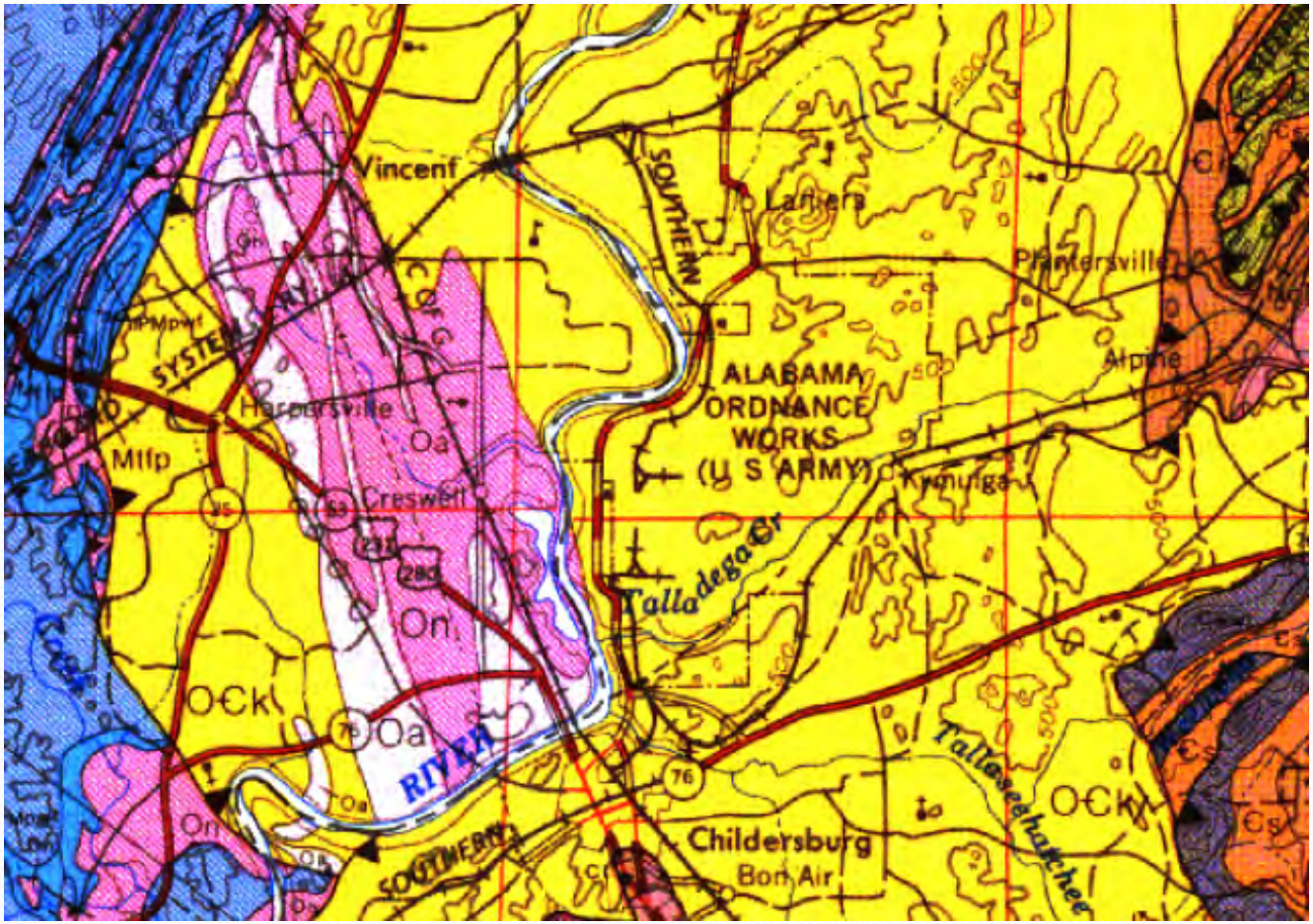
"It is important to emphasize that the presence of residual DNAPL does not impact the conclusions of the RA (risk assessment) and the recommendations for site risk management."

Final Corrective Action Plan, p. 2-5

Alabama Army Ammunition Plant - Childersburg, AL
Fractured Sedimentary Rock

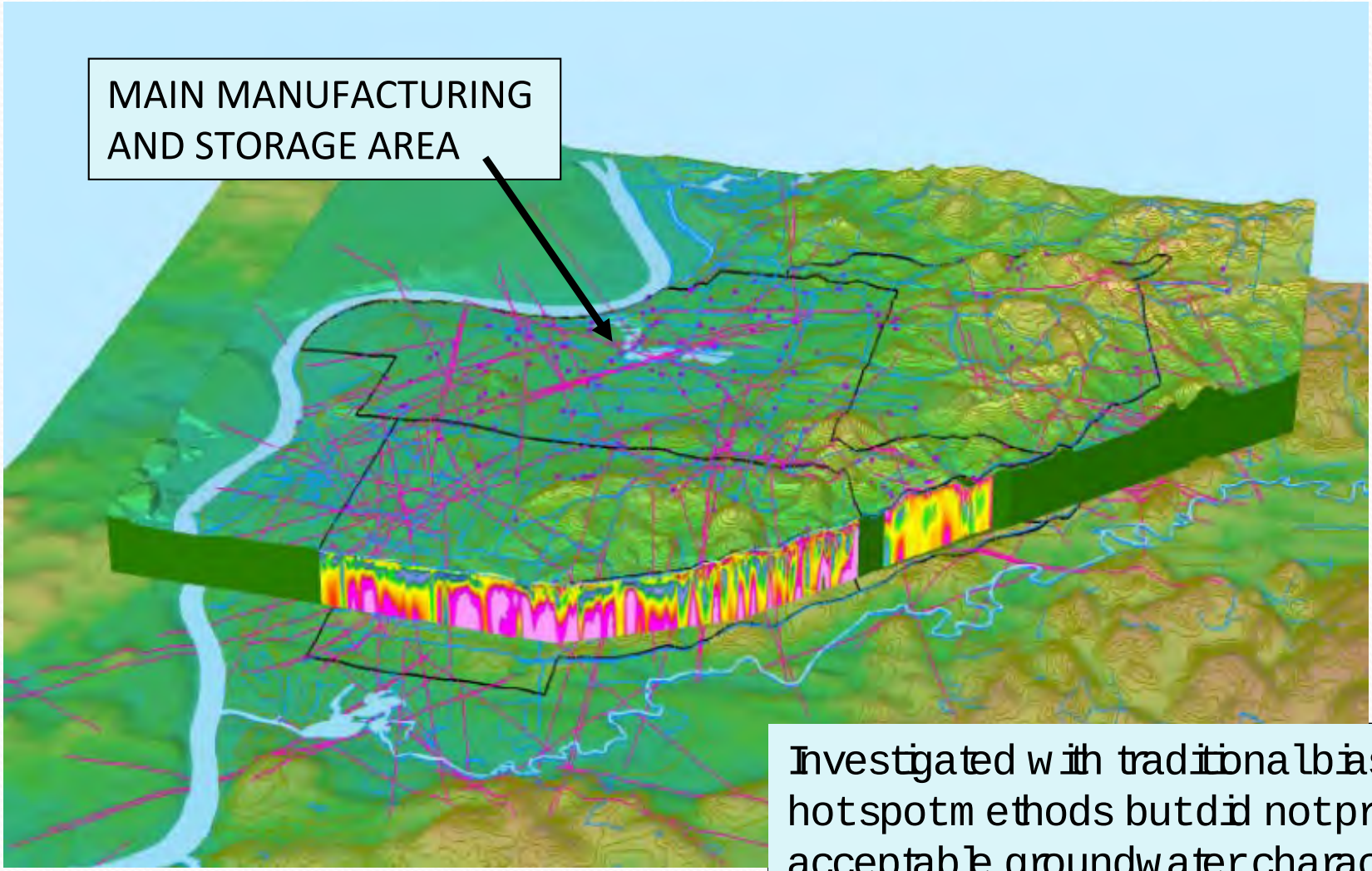
- Located 40 miles southeast of Birmingham, AL
- Operated 1941 -1945 manufacturing TNT, DNT
- Approximately 5,000 acres
- Standby 1946 – 1973 and declared excess
- Property no longer owned by Army
- CERCLA investigations started in the 1980s
- Source Control - 120,000 cubic yard soil incineration 1994-97
- 2010 - Final Soils ROD
- Groundwater RI completed 2010

Alabama Army Ammunition Plant - Childersburg, AL
Fractured Sedimentary Rock



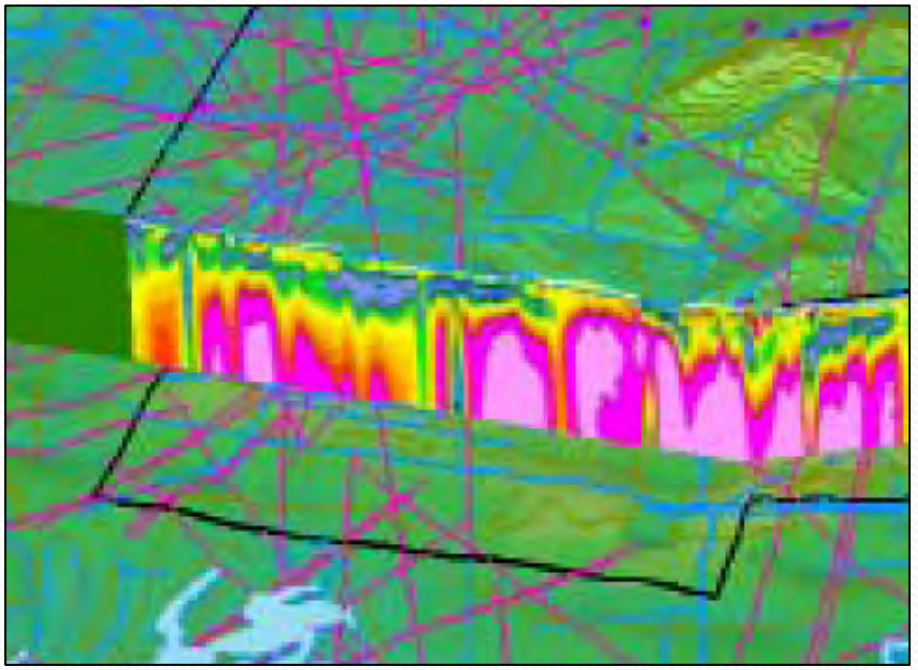
- Broad expanse of Knox Formation, carbonates
- Thrust sheets evidence tectonic activity resulting in significant fractures
- Adjacent to Coosa River whose course is fracture controlled

Alabama Army Ammunition Plant - Childersburg, AL
Fractured Sedimentary Rock



Investigated with traditional biased/ hotspot methods but did not provide acceptable groundwater characterization

Alabama Army Ammunition Plant - Childersburg, AL
Fractured Sedimentary Rock



2003 - 2009 GW Investigation

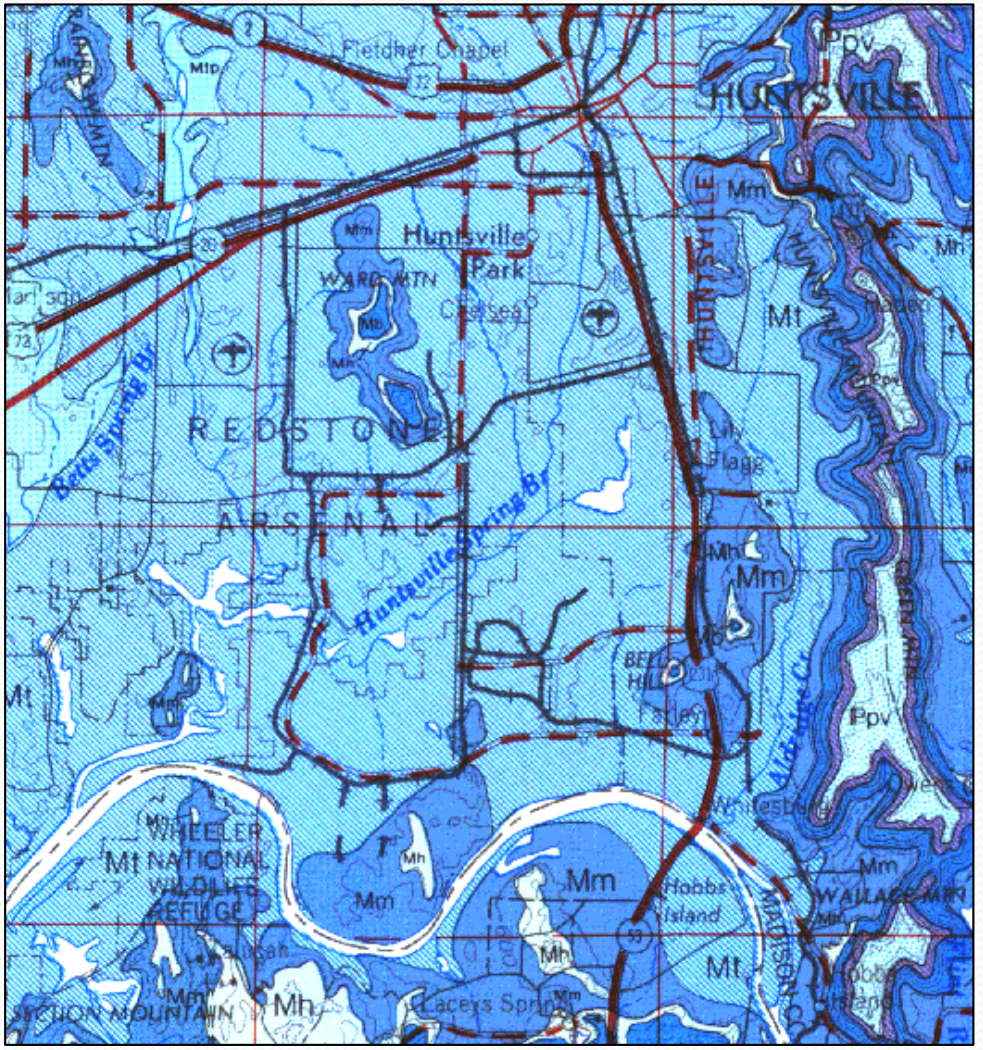
- Bedrock Focus
- Fracture Trace Analysis
- Resistivity Surveys
- Focused Drilling for bedrock wells on fractures/conduits
  - 18 of 19 drilled on fractures
- Central facility v. exit pathway wells
- Thermal survey along river confirmed exit points
- To complete RI, characterization approach required focus on the fractured nature bedrock
- With source removed, bedrock GW now demonstrated to be relatively minor problem

Redstone Arsenal - Huntsville, AL
Fractured Sedimentary Rock

- 38,300 acres just west of Huntsville, AL
- 1,841 acre Marshall Space Flight Center within Redstone Arsenal property
- 158 active IRP sites, 20 surface media OUs, 13 GW investigation areas
- Finalized on NPL in 1994
- COCs – solvents, metals, pesticides, perchlorate & chemical weapons material
- Karst hydrogeology with fractured bedrock influence

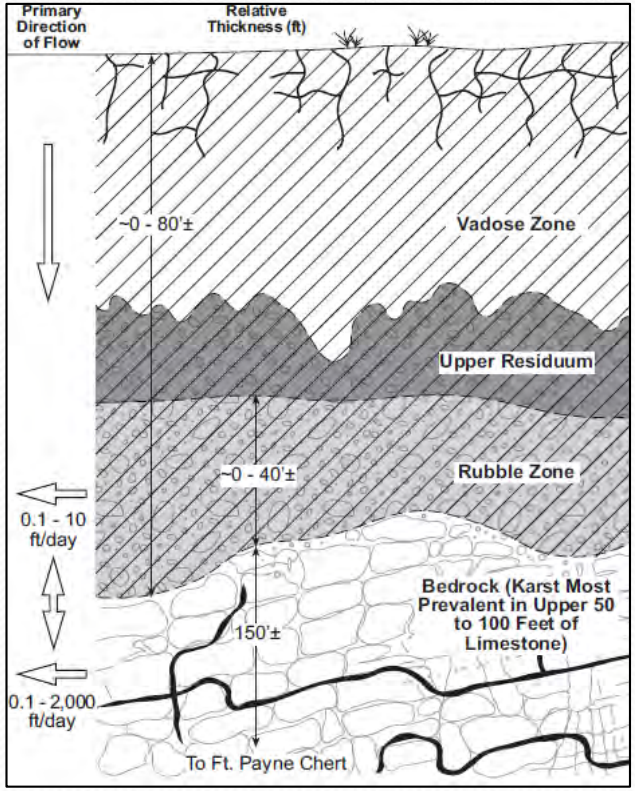
Redstone Arsenal - Huntsville, AL
Fractured Sedimentary Rock

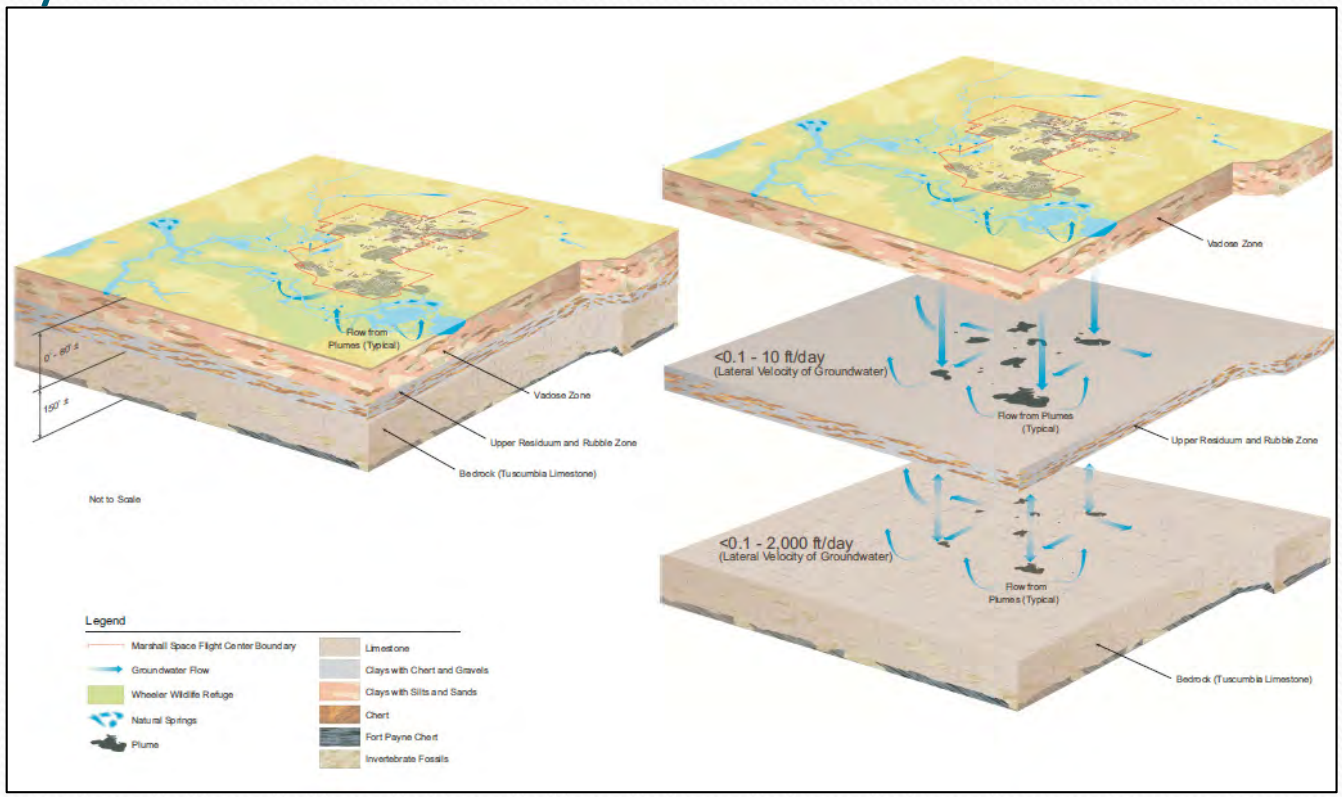
- Structural setting –horst and graben
- Dipping limestones
- Thermal imaging of springs
- Coring, hydro-physics, flute wells
- Complicated groundwater chemistry with salt water and natural oil at depth



Redstone Arsenal - Huntsville, AL
Fractured Sedimentary Rock

Local Conceptual Hydrogeologic Model

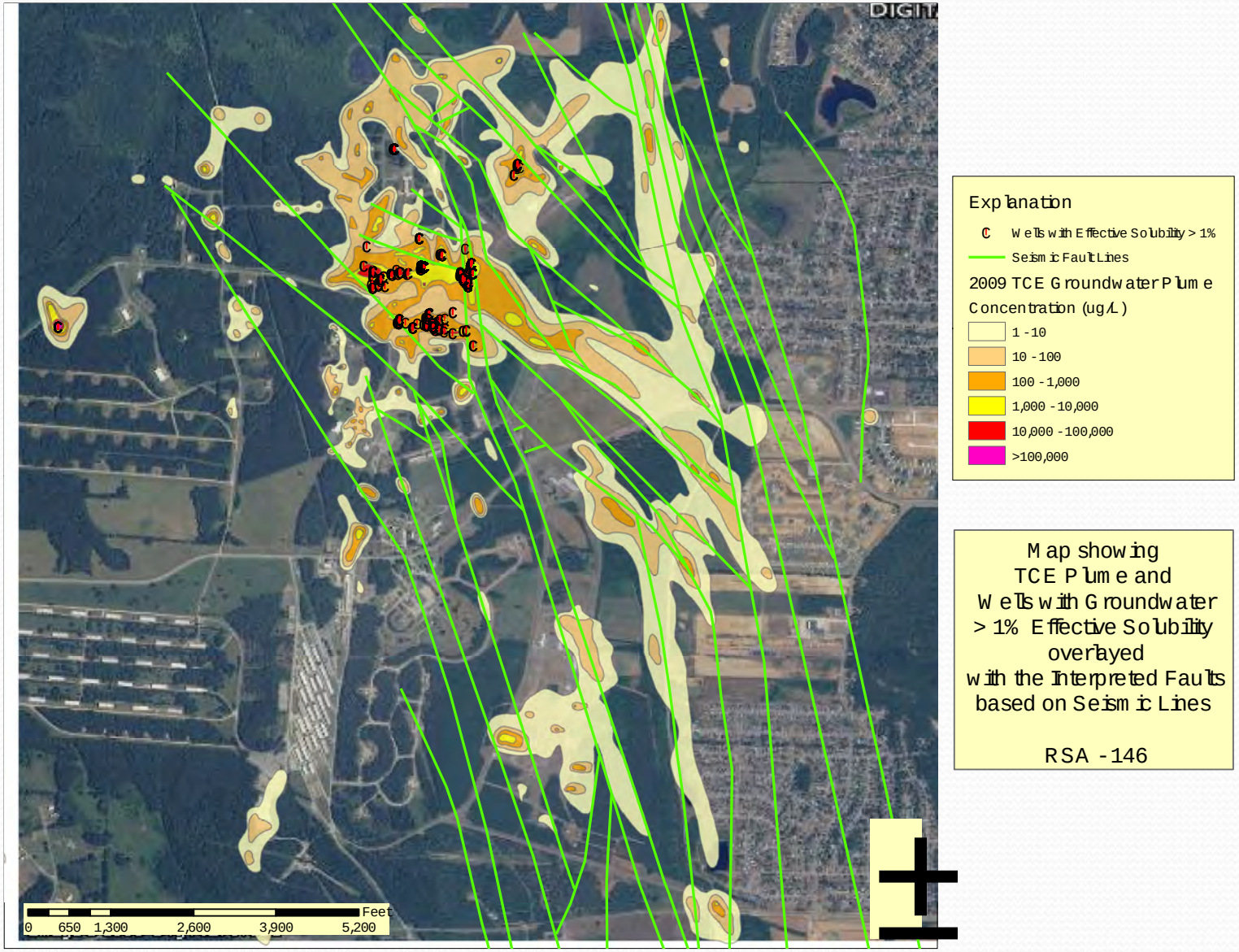




Area-wide Conceptual Hydrogeological Model

Figures from MSFC reports

Redstone Arsenal - Huntsville, AL
Fractured Sedimentary Rock



Map showing TCE Plume and Wells with Groundwater > 1% Effective Solubility overlayed with the Interpreted Faults based on Seismic Lines

RSA - 146

Map by Kay Wischkaemper, October, 2010

Oak Ridge Reservation, Oak Ridge, TN
Anniston Army Depot, Anniston, AL
Fractured Sedimentary Rock

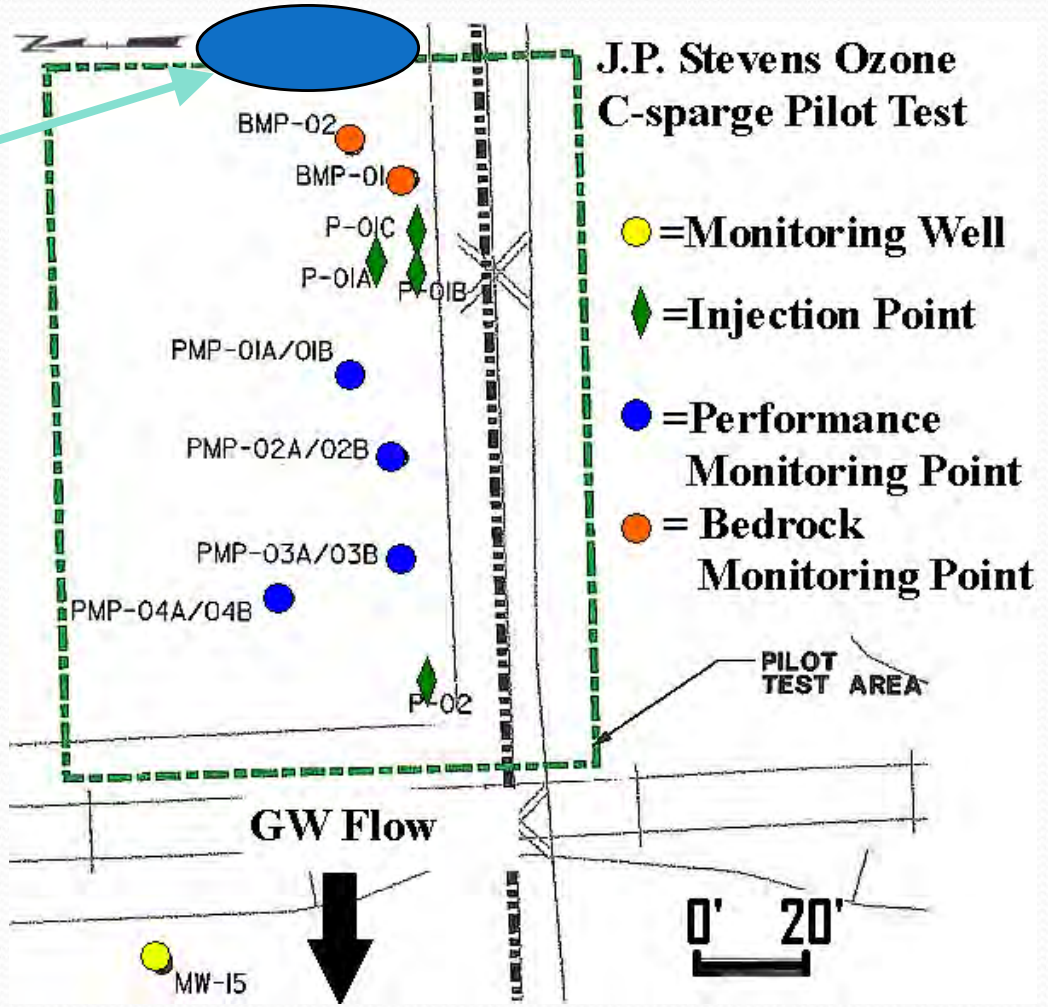
- Very large, very complex sites in Valley and Ridge
- Hydrogeology is a blend of fractured due to tectonic activity and karst due to carbonates
- Both facilities have performed source control/removals and interim actions for receptor protection
- Neither have final groundwater remedies for their largest releases

J. P. Stevens Facility- Upstate South Carolina
Fractured Metamorphic Rock – Piedmont with Igneous Intrusions

Source Area (Tank Farm)

COCs – Benzene, Chlorobenzene
Cis-1,2-DCE, Vinyl Chloride

Overall, much smaller scale of release & remedial action *BUT* uses broad range of characterization techniques



J. P. Stevens Facility- Upstate South Carolina
Fractured Metamorphic Rock – Piedmont with Igneous Intrusions

CHARACTERIZATION and FINDINGS

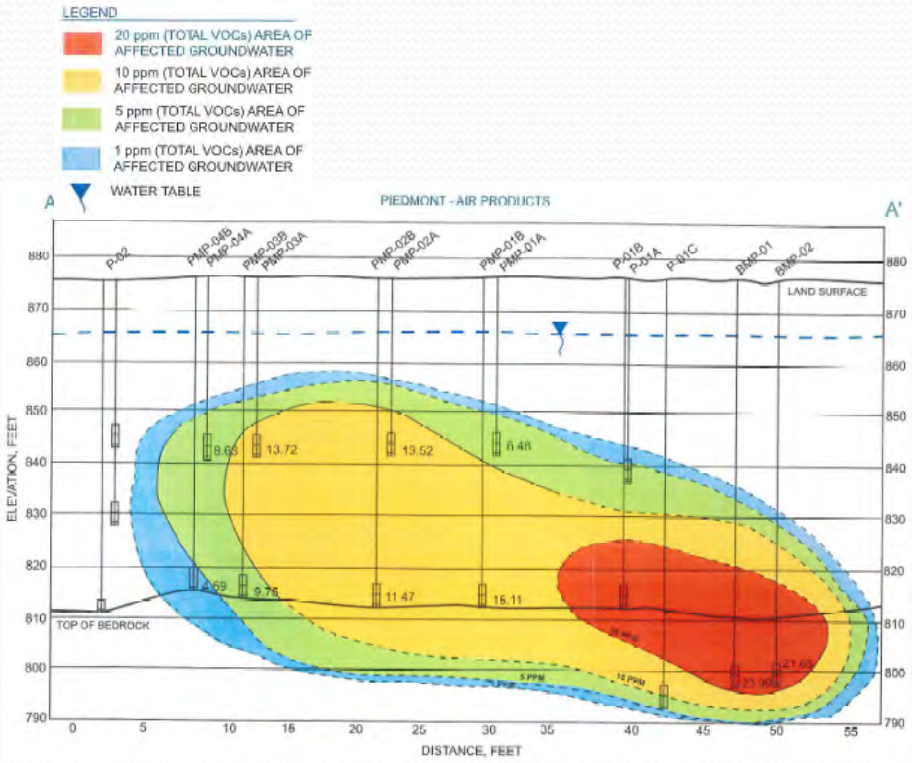
- Regional recon and outcrop mapping – site at edge of thrust sheet
- Lineament studies and rose diagrams
- Trenching perpendicular to creek and structural dip – detailed logging
  - Found series of intrusive dikes in soil/saprolite
  - Used structural information to predict anisotropy and design aquifer characterization

J. P. Stevens Facility- Upstate South Carolina
Fractured Metamorphic Rock – Piedmont with Igneous Intrusions

- Membrane Interface Probe used in Source Areas
- Cored bedrock with packer and analytical tests on fracture features
- Bedrock aquifer test – 60 GPM with minimal drawdown (14 GPM Steady State P&T)
- Capture zone analysis using simplified three layer model
- Ozone sparging source control/treatment
- Groundwater recovery system – plume migration control

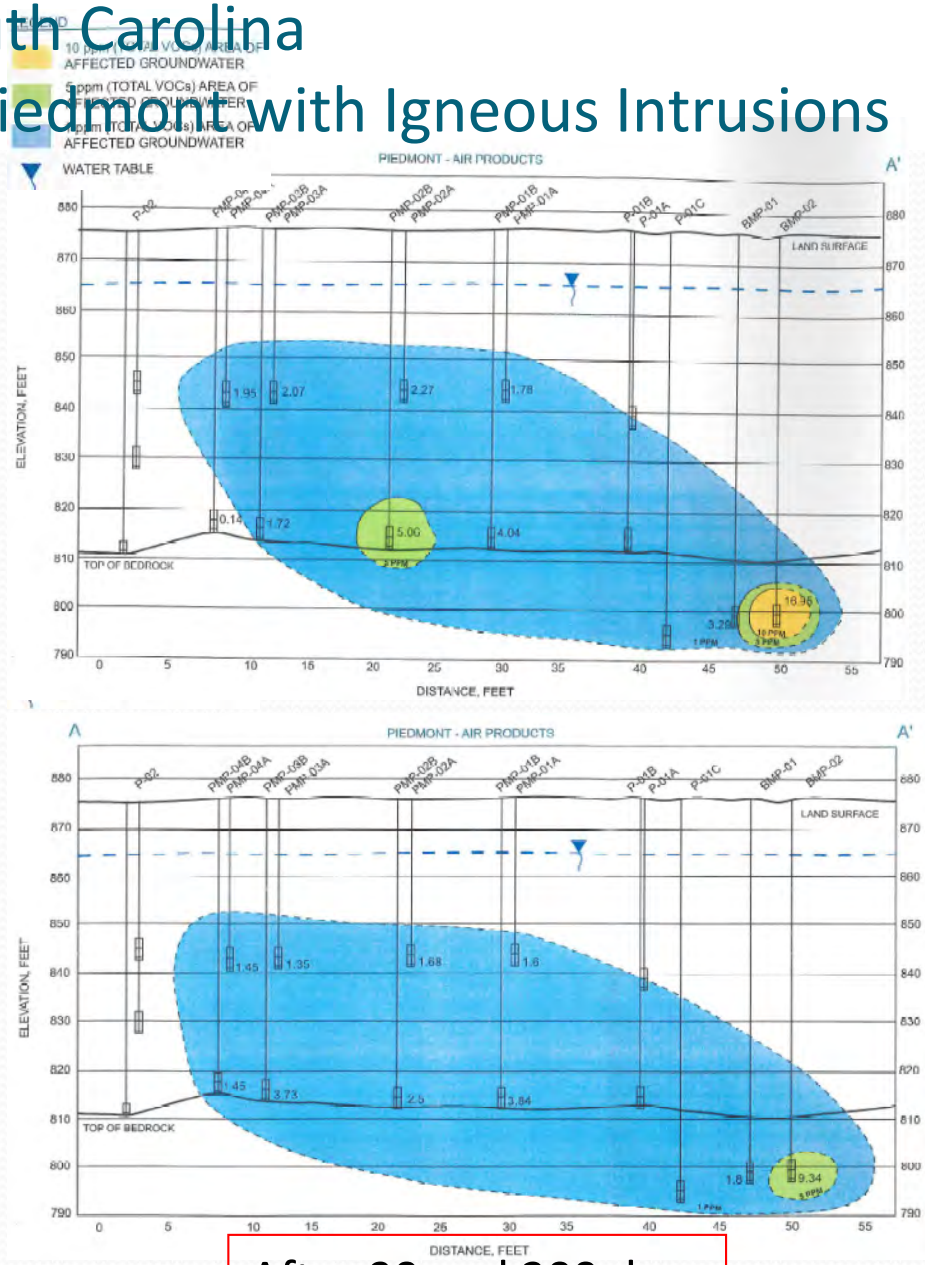
J. P. Stevens Facility- Upstate South Carolina
Fractured Metamorphic Rock – Piedmont with Igneous Intrusions

Ozone Air Sparge Progress



GW Flow direction

Baseline conditions



After 90 and 200 days

J. P. Stevens Facility- Upstate South Carolina
Fractured Metamorphic Rock – Piedmont with Igneous Intrusions

Why was Ozone Sparging Successful at J.P. Stevens?

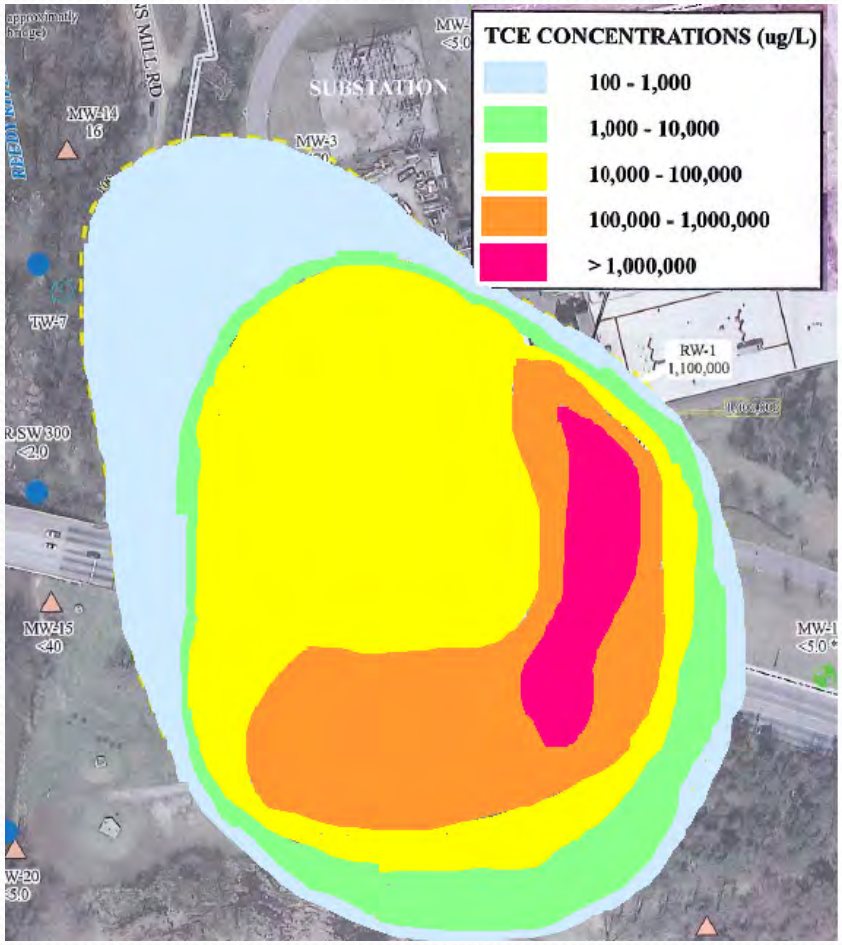
- Sparge and multi-level injection points enhance shape of area of influence
- Monitoring of indicator parameters (ORP, DO) substantiated ozone was impacting groundwater
- Good interconnection between saprolite and bedrock
- Multiple depths of injection and monitoring
- Well-designed pilot study
  - Length of monitoring before, during, and after
  - Spacing of monitoring points

Hitachai - Greenville, SC
Fractured Metamorphic Rock

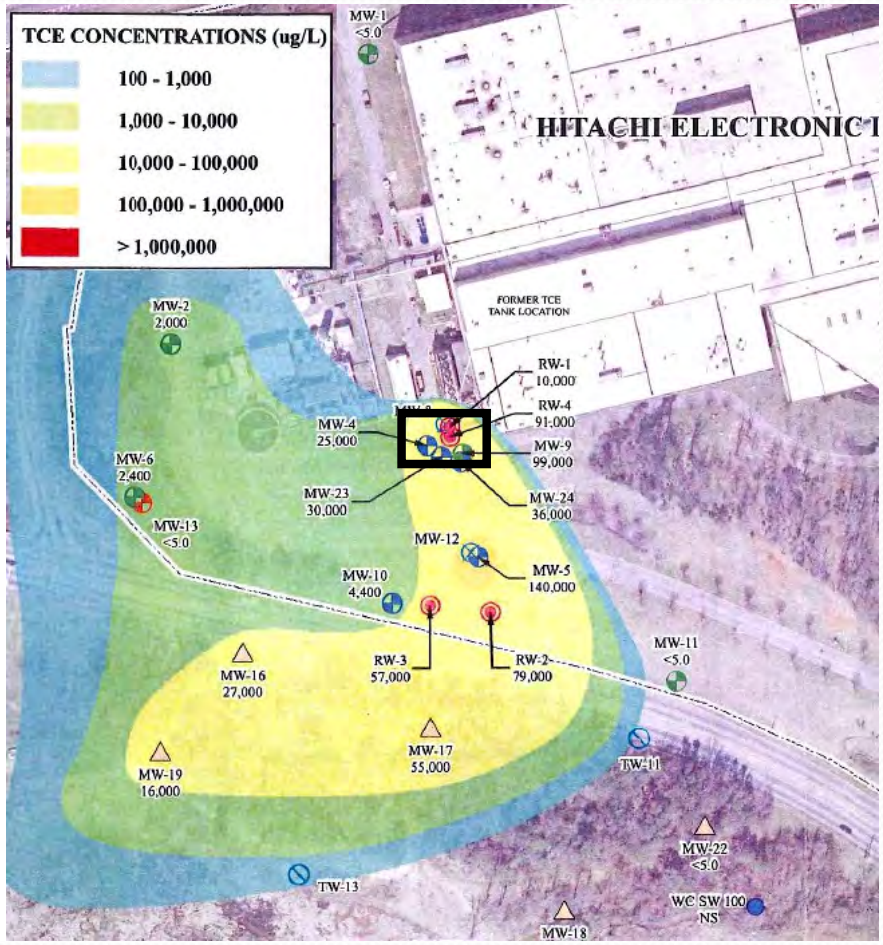
- Release of 12,000+ lbs of TCE
- This remedial action employed In-Situ Thermal Desorption in soils and shallow bedrock
- 14 Heater wells (~90' bls)
- 10 Heater vacuum points (~95' bls)
- 2 Recovery wells (~45-76' bls)
  - recovered 72,000 gallons of water during operation before water became steam

Thermal Treatment Area
33'x76'x90' deep
PW R at 55'

Hitachai Greenville, SC
Fractured Metamorphic Rock



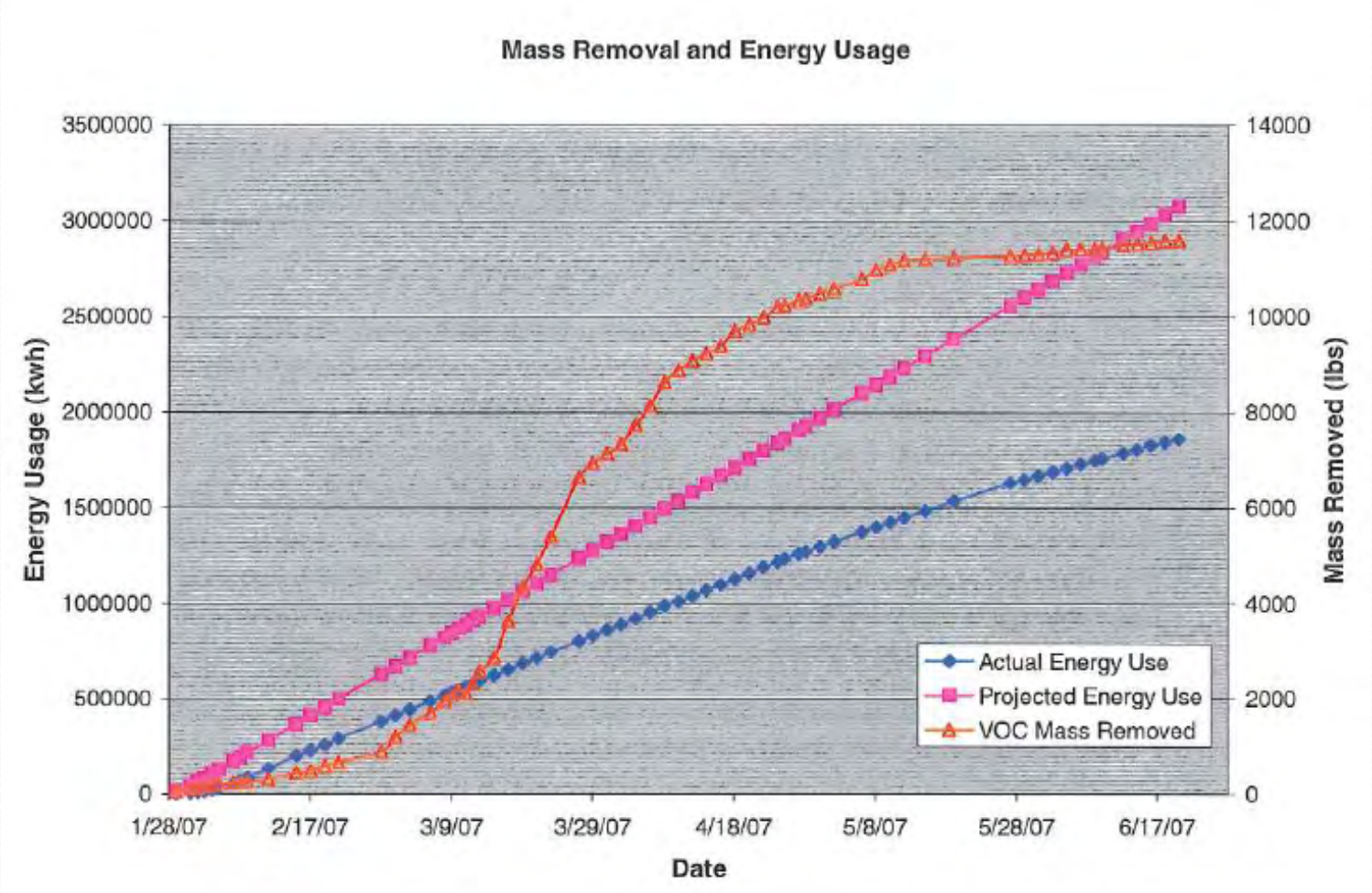
BEFORE



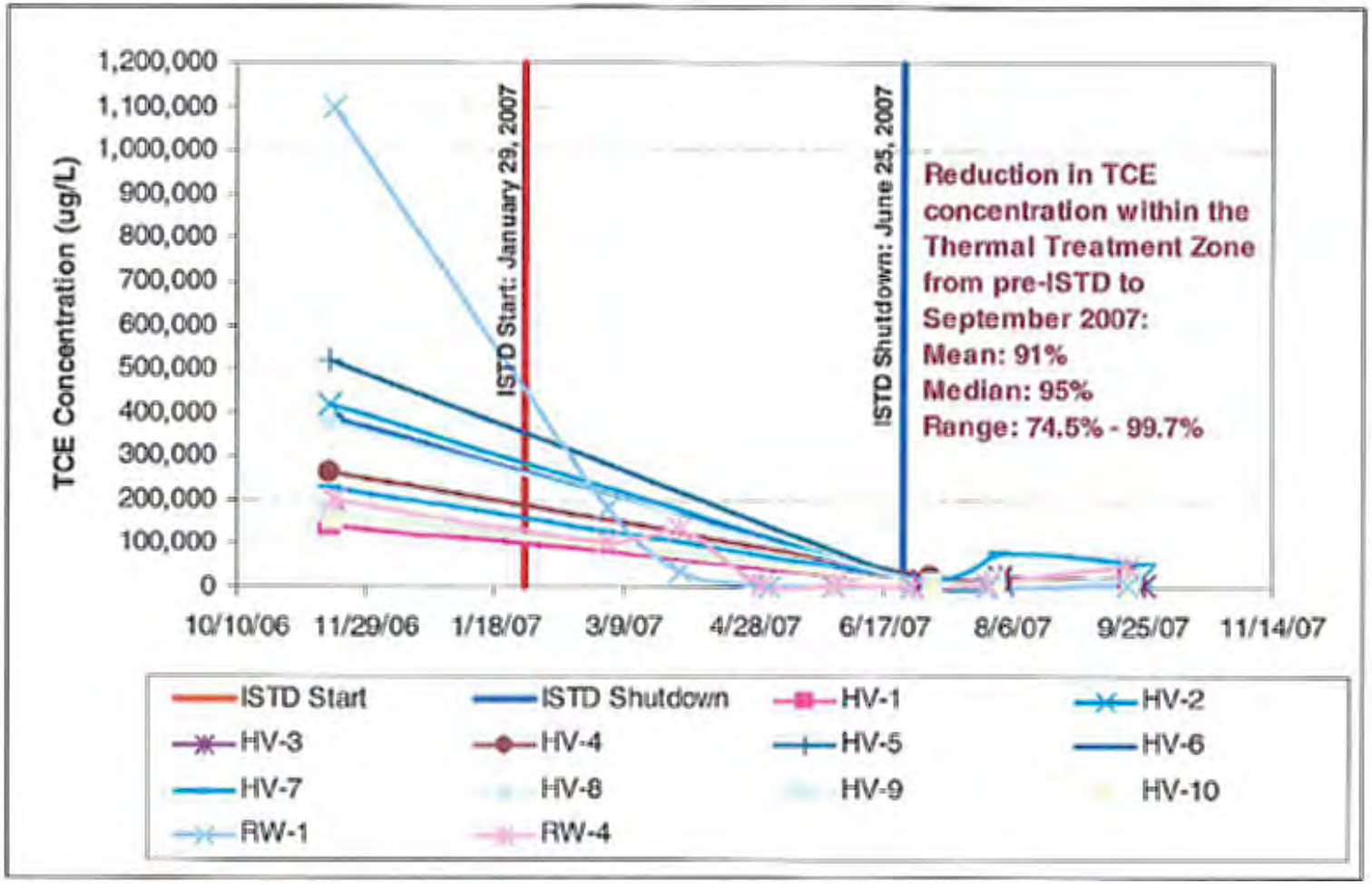
AFTER

Note: treatment zone only 2,500 ft^2

Hitachai Greenville, SC
Fractured Metamorphic Rock



Hitachai Greenville, SC
Fractured Metamorphic Rock



Hitachai Greenville, SC
Fractured Metamorphic Rock

- Removed about 12,000 lbs TCE (~5 months operation)
- Met treatment goals for vadose zone soil
  - Goal was 60 ug/kg TCE
  - Attained 13.41 ug/kg TCE (UCL)
  - Overall soil (vadose and subaqueous) 17.05 ug/kg TCE
- Initial reductions of 75% to 99% of TCE in groundwater
- Rebound noted (DNAPL; Fractures, Relic Fractures, Back-Diffusion)
- Longer treatment period required for more bedrock improvement
- Progress towards but not the Final Remedy

Fractured Metamorphic Bedrock

- Historical solvent release managed with shallow SVE and ozone treatment in nearby springs – interim remedy
- Ongoing investigation focused on facility and generally shallower portions of bedrock aquifer
- Private deep bedrock drinking water supply wells contaminated up to 1 mile away
- Detailed geological mapping by State Geologic Survey
- Detailed hydrogeological characterization by USGS

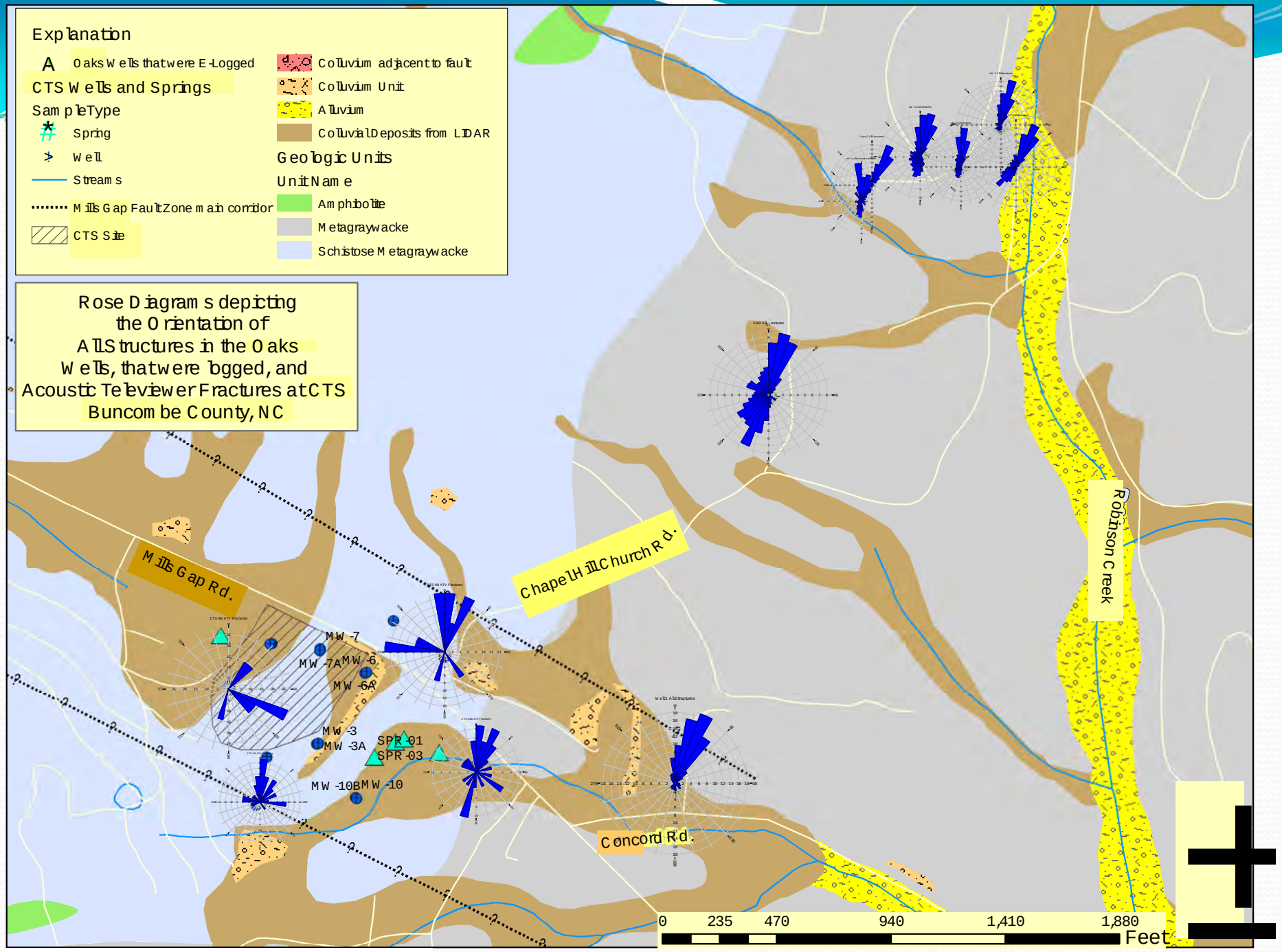
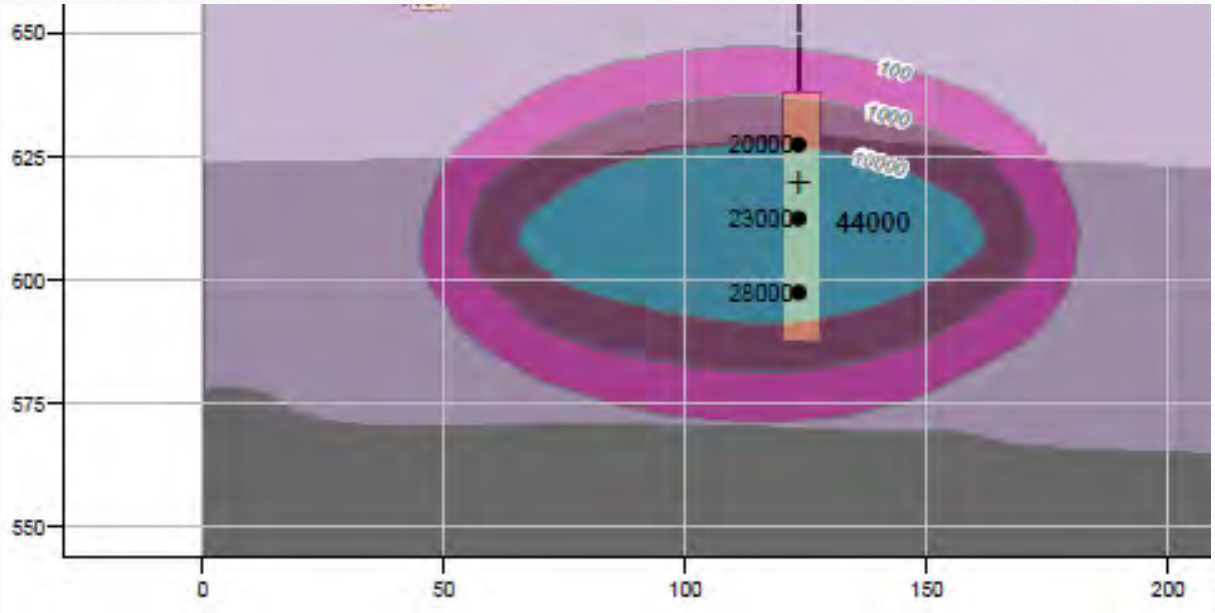


Figure by Kay Wischkaemper, October, 201, Mills Gap Rd.

Fractured Metamorphic Bedrock

- Historical site understanding focused investigation topographically downgradient and shallower
- Employed sophisticated characterization techniques to understand possible connections between solvent releases and contaminated private drinking wells
- Deepest contaminated well discovered to date - 700’ deep
- Recent characterization work will guide future work with a much improved conceptual site model. However, it does not represent an easy path forward.

Actual Example of Poor Characterization
Fractured Rock – North Carolina Piedmont



- One well with 50’ open hole completion in bedrock with DNAPL solvents
- Two analytical data points -1 set of three diffusion bag samplers and 1 sample collected 6 months later by low flow purge
- Proposed one well pilot study - Enhanced Reductive Dechlorination

Actual Example of Poor Characterization
Fractured Rock – North Carolina Piedmont

Just a Few of the Problems with This Approach

- Contamination not delineated
- No surveys to identify fractured zones
- No other proposed monitoring wells
- Pilot Study would invalidate the use of this one well as a monitoring location
- No demonstration of how this well relates to the rest of the site or how this test would benefit the rest of the site

SUMMARY
EPA Region 4 Perspective

FEDERAL FACILITIES

- Large facilities, Large number of releases, Large volume of releases
- Applying a wide range of increasingly sophisticated characterization technologies
- Performing source removal, source control and receptor protection
- Final groundwater remedies - uncommon
- Deep fractured bedrock remediation - no final answer YET

SUMMARY
EPA Region 4 Perspective

Non-Federal Facilities

- Smaller facilities and smaller releases
- Also applying a wide range of increasingly sophisticated characterization technologies
- Appear to have made more progress
  - Smaller problems, smaller solutions
  - different motivation - Industry v. Federal
- Deep fractured bedrock remediation – no final answer YET

CONCLUSIONS
This Hydrogeologist's Perspective

Last 20 years have made great advances in types and sophistication of characterization.

- Focus on flow zones and geophysics/sensors

Biggest number of unresolved sites have dissolved or DNAPL solvents in fractured bedrock.

At a basic level, it still a question of really understanding the nature and extent of the contamination and how that affects the selection of an effective remedy.

CONCLUSIONS
This Hydrogeologist's Perspective

- Good progress on remediating saprolite and partially weathered bedrock
- Fractured Bedrock and Solvents
  - No cure for this problem yet
  - Difficult and expensive to characterize flow pathways at depth
  - Back diffusion and time (cost) to remediate – biggest impediments