Applied Geophysics for Environmental Site Characterization and Remediation

MSECA Webinar
September 24, 2015

John Mundell, P.E., L.P.G.
Ryan Brumbaugh, L.P.G.
MUNDELL & ASSOCIATES, INC.

Webinar Objective

Introduce the use of geophysical survey methods to enhance standard environmental site characterization practices and improve the design of remedial alternatives for complex site and geologic conditions.

Overview

- Who are we?
- What environmental consultants do?
- Geophysical Survey Methods
- Practical Applications
- Conclusion/Questions

Who Are We?

- Consulting professionals with geologic, geochemical, geophysical, and engineering backgrounds
- Focused on the use of geophysics integrated into environmental, engineering, water resources, and construction projects
- Personnel have performed geophysical surveys since 1976.

Ryan Brumbaugh

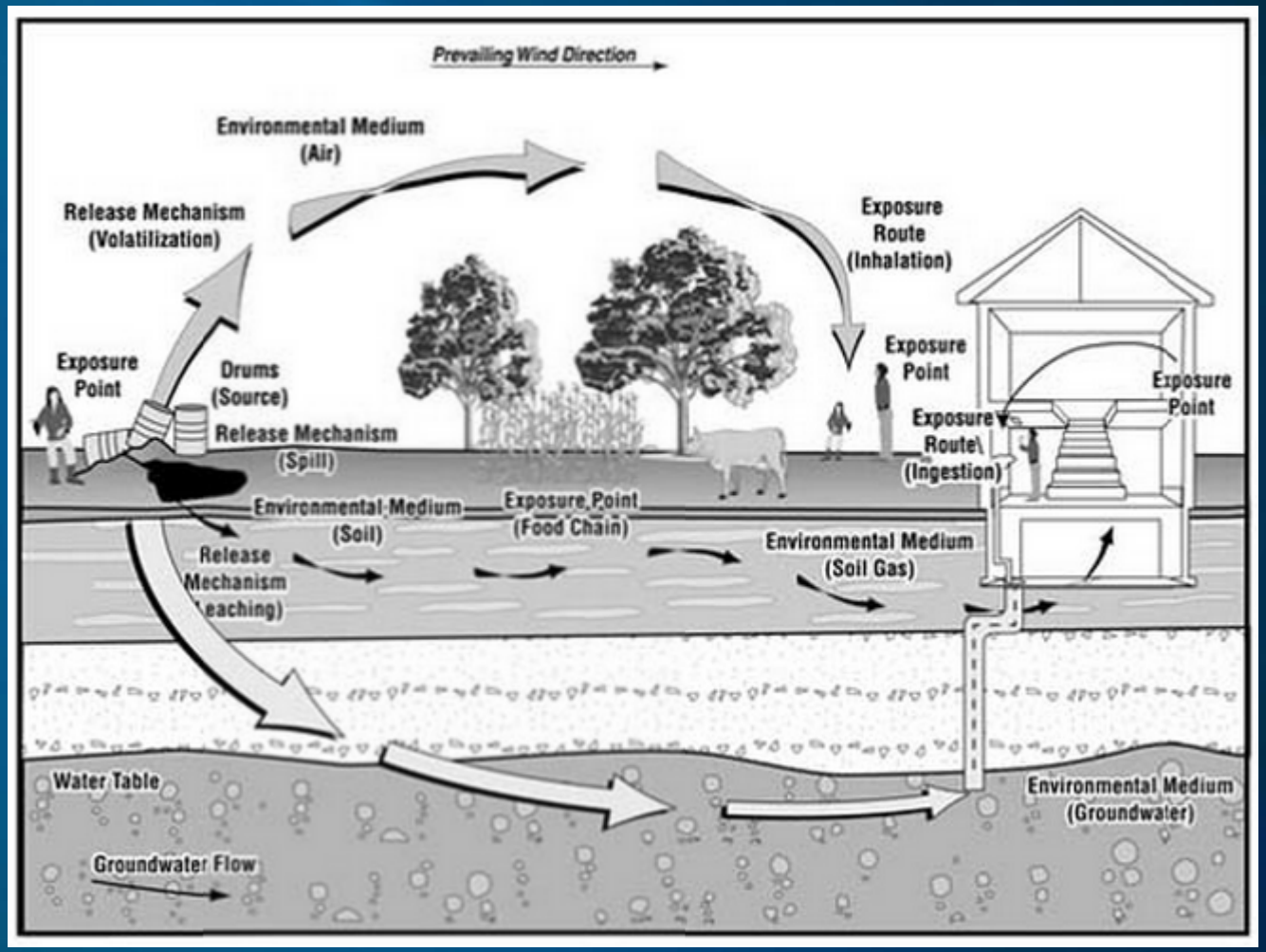
John Mundell

What environmental consultants do?

Geophysics - Environmental

- Environmental Site Assessments
- Phase I ESAs
- Phase II ESAs
  - Reconstruction of Site Development History
  - UST Search/Old Tank Pits/Fill Materials
  - Piping Systems and Utilities
  - Disposal Areas (Drums, Waste, Debris)
  - Conceptual Site Model Development and Refinement with Complex Geology

Conceptual Site Model



What environmental consultants do?

Geophysics - Environmental

- Industrial Contamination Projects
  - Source Areas, Contamination Type/Severity/Extent
  - Migration Pathway Analysis
    - Product/Vent/Utility Lines
    - Aquifer (Sand/Gravel/Bedrock) Distribution
    - Preferential Pathways – Fractures, Faults, Karst Features

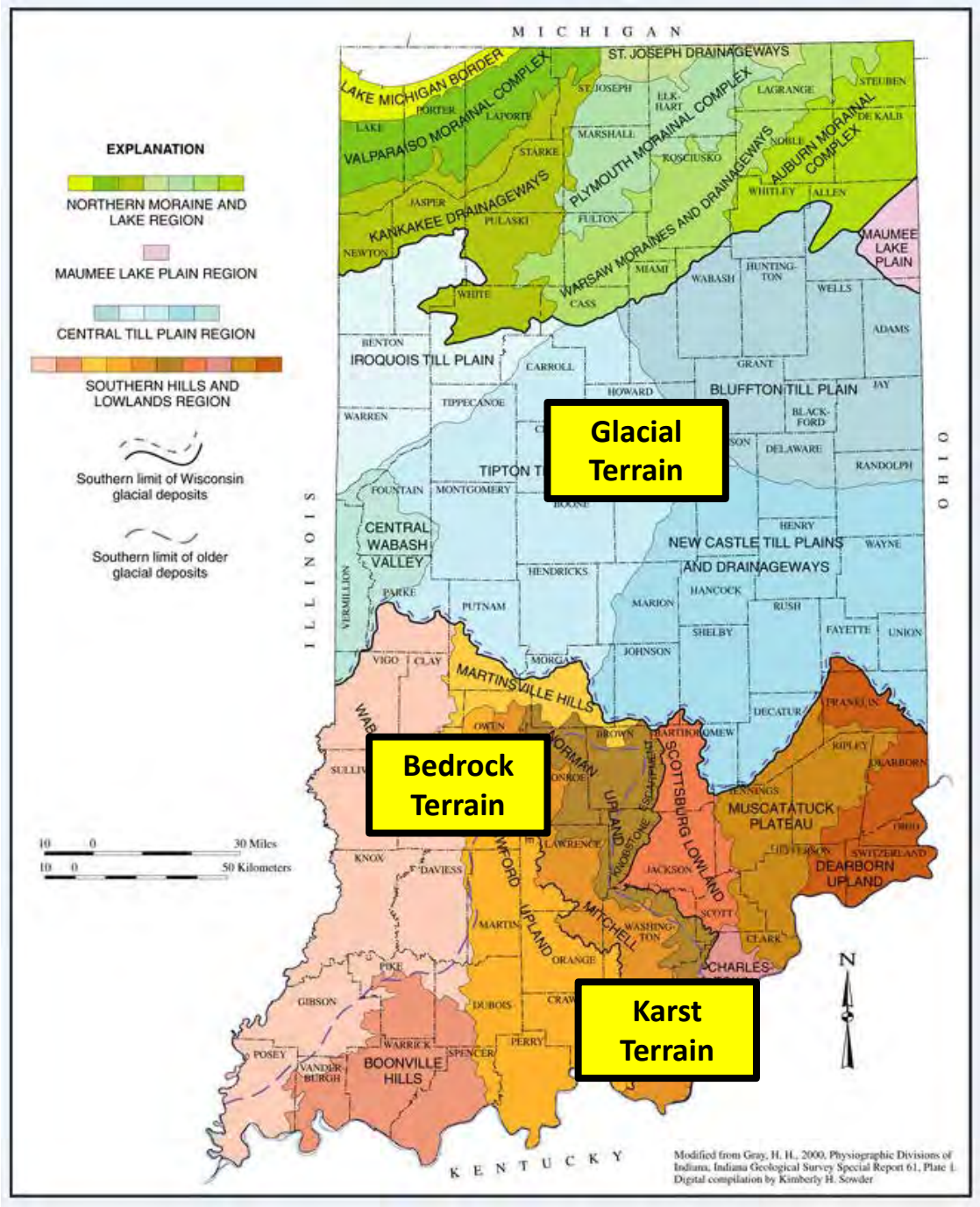
What environmental consultants do?

Geophysics - Environmental

- Groundwater Investigations/Remediation
  - Aquifer/Sand/Gravel Unit Mapping
  - Fracture/fault/karst delineation
  - Placement of Wells (Monitoring/Production)
  - Enhanced Design of In-situ Treatment
  - Monitoring of Remediation Progress

Groundwater Remediation 101

- To be effective, you must know
  - Where the source of the plume impacts are
  - Where the chemical impacts have gone
  - How significant are the impacts
- If these remain unknown, it is highly likely you will fail to be able to successfully cleanup a contaminant plume!


MICHIGAN
ST. JOSEPH DRAINAGEWAYS
LAKE MICHIGAN BORDER
VALPARAISO MORAINAL COMPLEX
PLYMOUTH MORAINAL COMPLEX
AUBURN MORAINAL COMPLEX
KANKAKEE DRAINAGEWAYS
WARSAW MORAINES AND DRAINAGEWAYS
MAUMEE LAKE PLAIN
IROQUOIS TILL PLAIN
BLUFFTON TILL PLAIN
TIPTON T
CENTRAL WABASH VALLEY
NEW CASTLE TILL PLAINS AND DRAINAGEWAYS
MARTINSVILLE HILLS
SCOTTSBURG LOWLAND
MUSCATATUCK PLATEAU
DEARBORN UPLAND
MITCHELL KARST UPLAND
BOONVILLE HILLS
ILLINOIS
OHIO
KENTUCKY
EXPLANATION
NORTHERN MORAINE AND LAKE REGION
MAUMEE LAKE PLAIN REGION
CENTRAL TILL PLAIN REGION
SOUTHERN HILLS AND LOWLANDS REGION
Southern limit of Wisconsin glacial deposits
Southern limit of older glacial deposits
30 Miles
50 Kilometers
N
Glacial Terrain
Bedrock Terrain
Karst Terrain
Modified from Gray, H. H., 2000, Physiographic Divisions of Indiana, Indiana Geological Survey Special Report 61, Plate 1. Digital compilation by Kimberly H. Sowder

Geologic Complexity

- Can cause plume movement in directions not expected by subsurface conditions only described by a classic ‘widely-spaced’ soil boring and monitoring well-based subsurface exploration program
- Subsurface data density limits the development of an accurate Conceptual Site Model that can adequately describe groundwater movement and plume progression.

Midwestern Geologic Complexity

What is Applied Geophysics?

- Technologies used **to quantify properties** of soils, bedrock and groundwater in an understandable manner.
- Technologies providing subsurface information **without** direct samling.
- Technologies that can **reduce** time to collect information, drilling and cost.

What is Surface Geophysics?

A way of measuring the Earth's 'natural' or 'induced' properties for the purpose of characterizing its variability. Contrasts in surface or subsurface materials cause 'changes' to these properties, and allow us to locate their position and depth.

The Typically Used Tools…

The Commonly Applied Technologies

- Potential Field Methods - gravity & magnetics
- Transmitted Energy Source Methods - seismic & ground penetrating radar
- Electromagnetic Methods - conductivity, TEM, VLF
- Electrical Methods - resistivity & IP

Geophysical Methods

- Electromagnetic Metal Detection
- Electromagnetic Conductivity
- Electrical Resistivity Imaging
- Seismic (Refraction, Surface Wave)
- Microgravity
- Ground Penetrating Radar (GPR)
- Downhole Logging

EM61 Electromagnetic Metal Detection System

This electromagnetic instrument is specifically designed to detect conductive metallic objects buried within the upper 10 feet of the subsurface

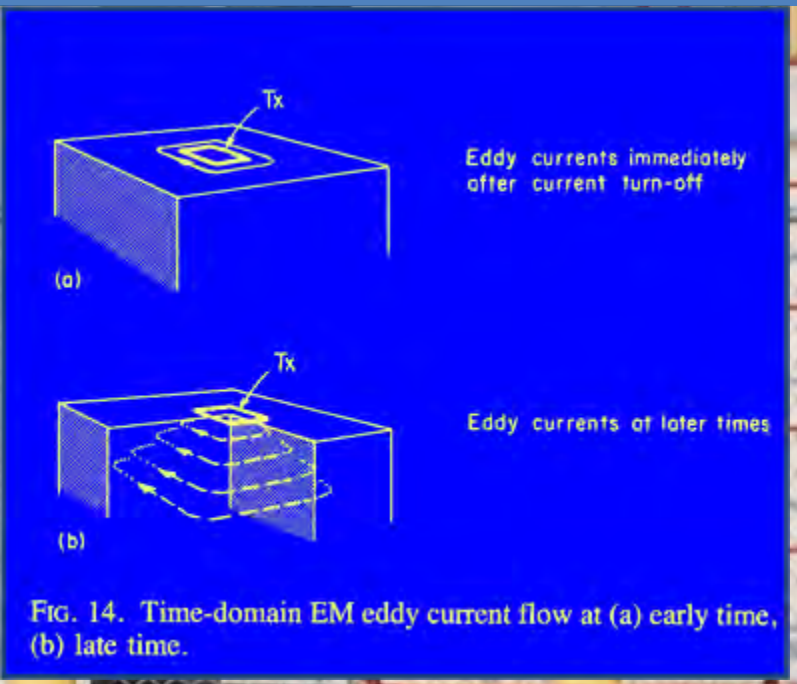
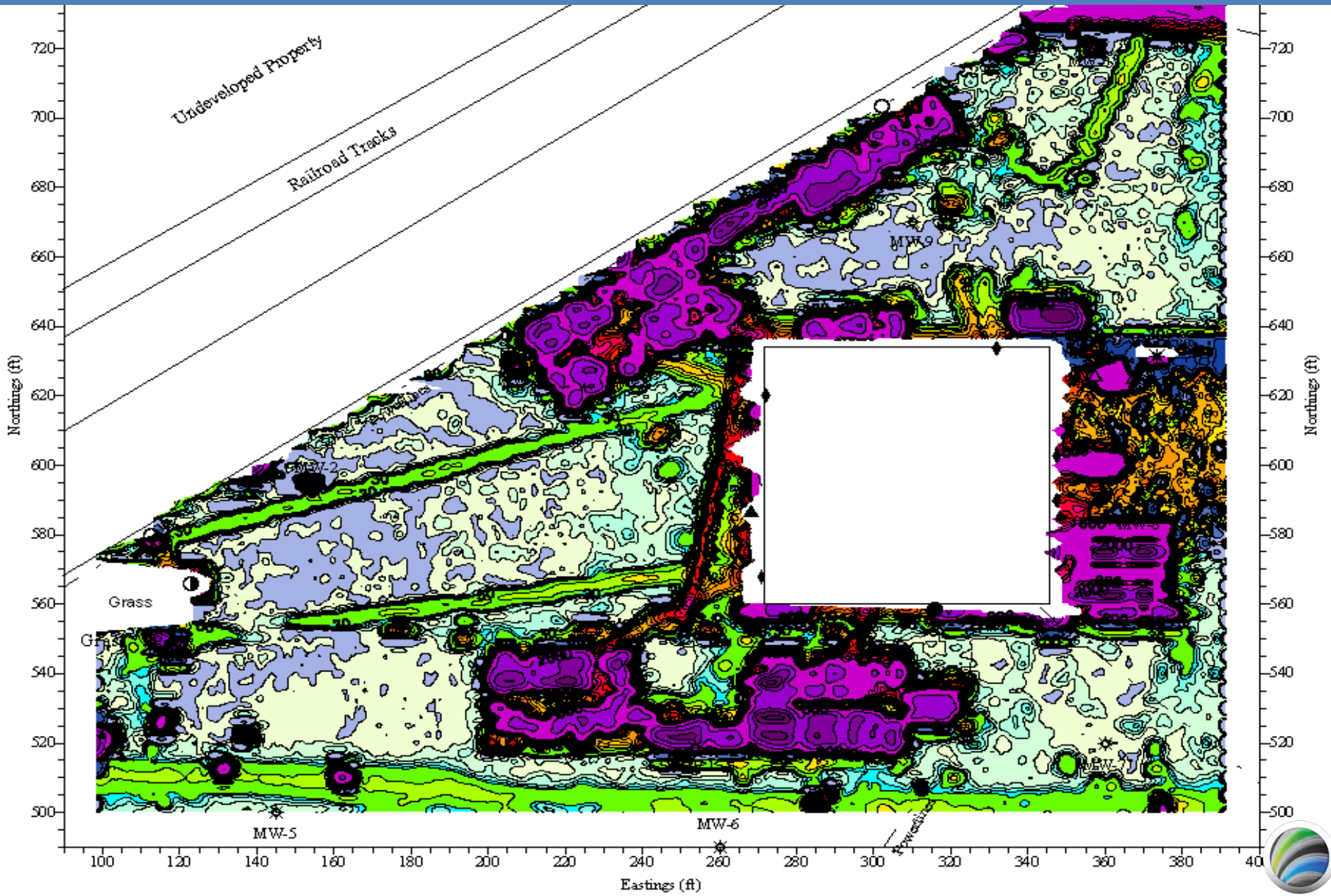


FIG. 14. Time-domain EM eddy current flow at (a) early time, (b) late time.

EM61 is Useful for Locating Product Storage (tanks, drums), Product Piping, Waste Materials, and All Metallic Utilities



Electromagnetic Conductivity Meters

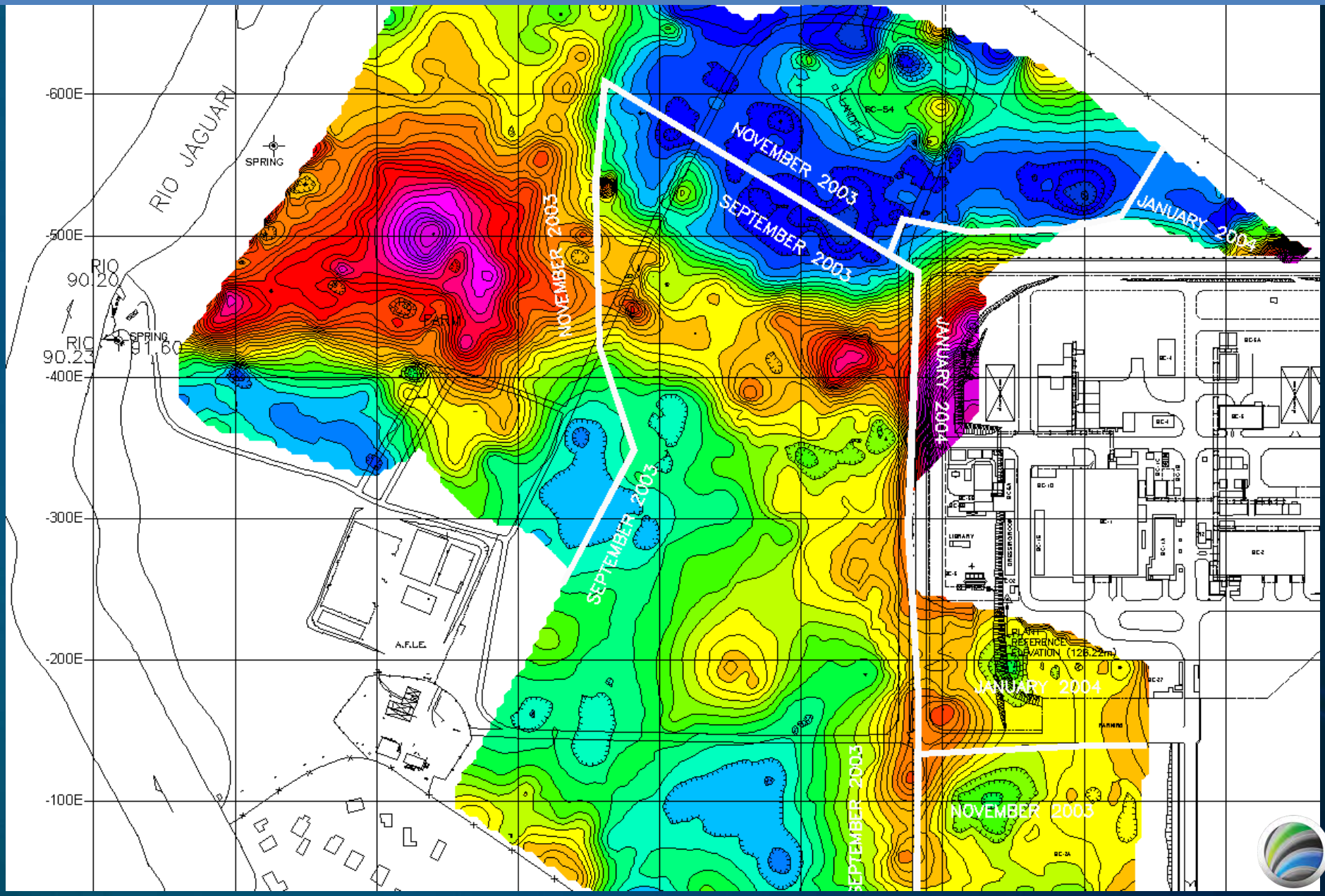
EM34: Deepest Conductivity Meter

EM31: Moderate Depth Conductivity Meter

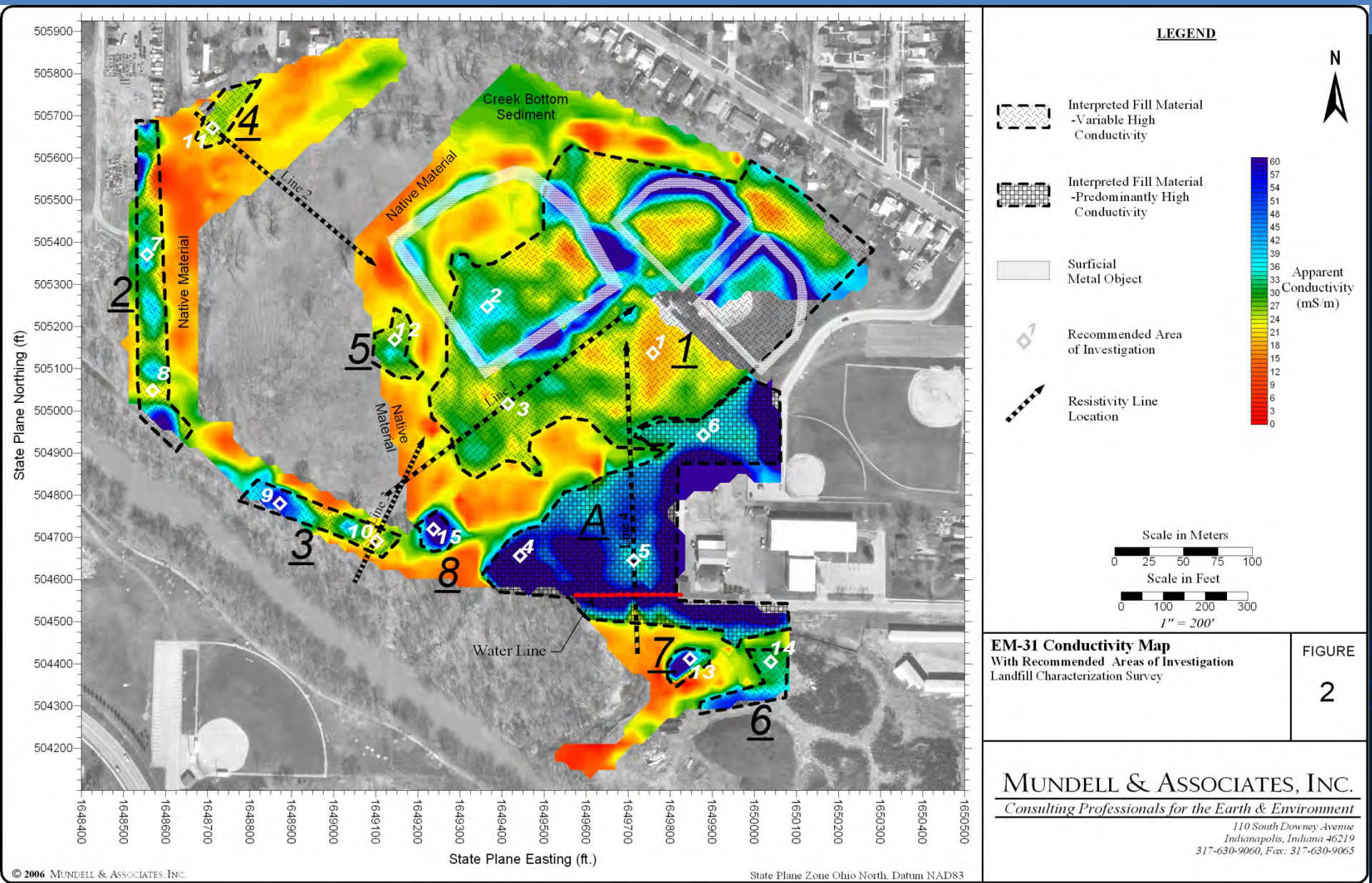
EM38: High Res, Shallow Conductivity Meter

GEM2: Multi-frequency Conductivity Meter

EM34 Maps Can be Used to Delineate Plumes, Define Geology, and Find Preferential Pathways



EM31 Used to Delineate Fill/Waste Areas and Give Insight into Historical Site Development



EM-31 Conductivity Map
With Recommended Areas of Investigation
Landfill Characterization Survey

FIGURE 2

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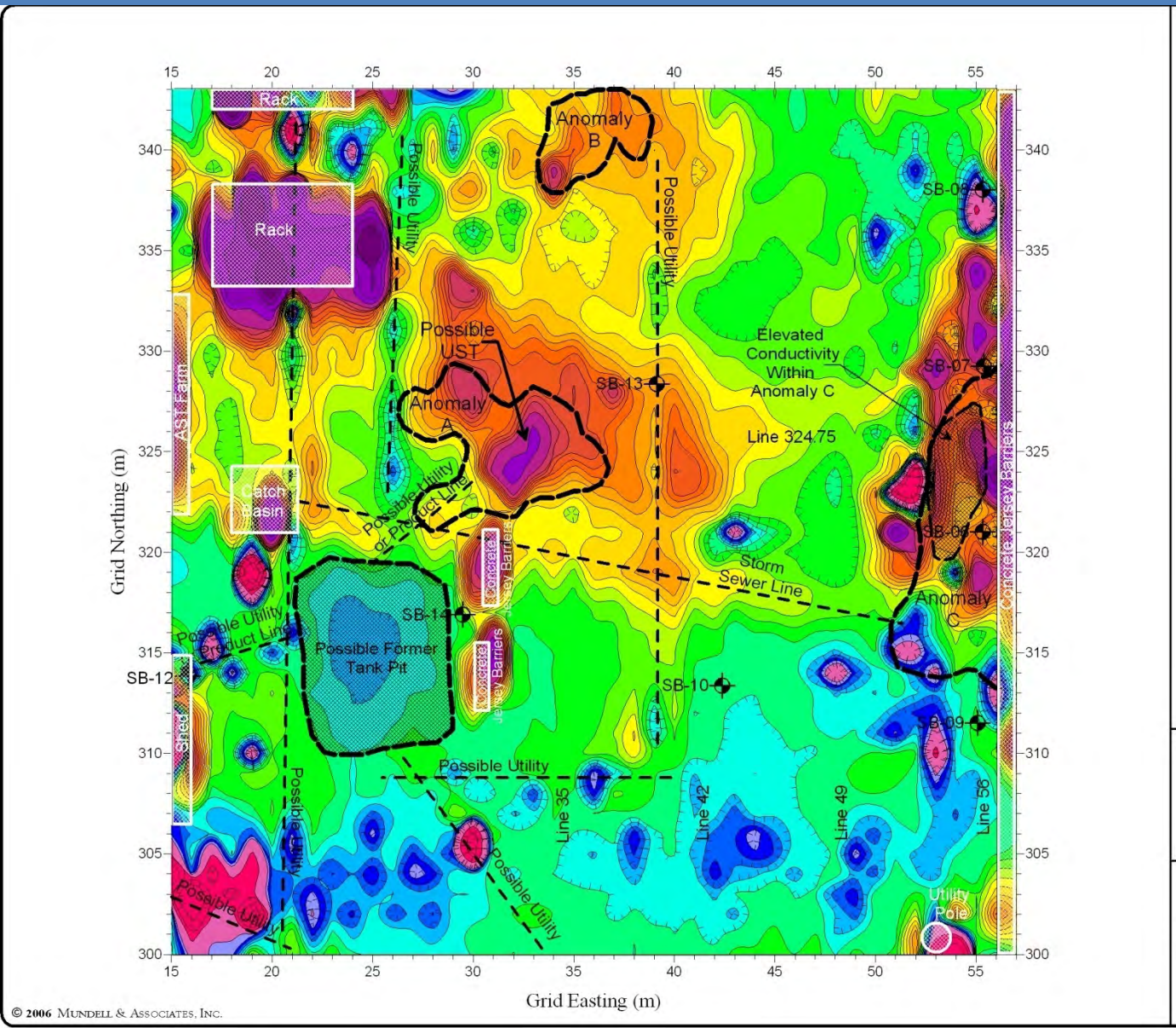
Consulting Professionals for the Earth & Environment
110 South Downey Avenue
Indianapolis, Indiana 46219
317-630-9060, Fax: 317-630-9065

EM38 Used to Located Shallow Preferential Pathways and Impacted Soils



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LEGEND

Apparent Conductivity (mS/m)

250 200 150 125 100 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0 -25 -50 -100 -200

Grid North / True North (18°)

Linear Anomaly

Surficial Features

Scale in Feet: 0 5 10 15 20 25 30

Scale in Meters: 0 2 4 6 8 10

1 : 200

EM-38 Terrain Conductivity Map

FIGURE 4

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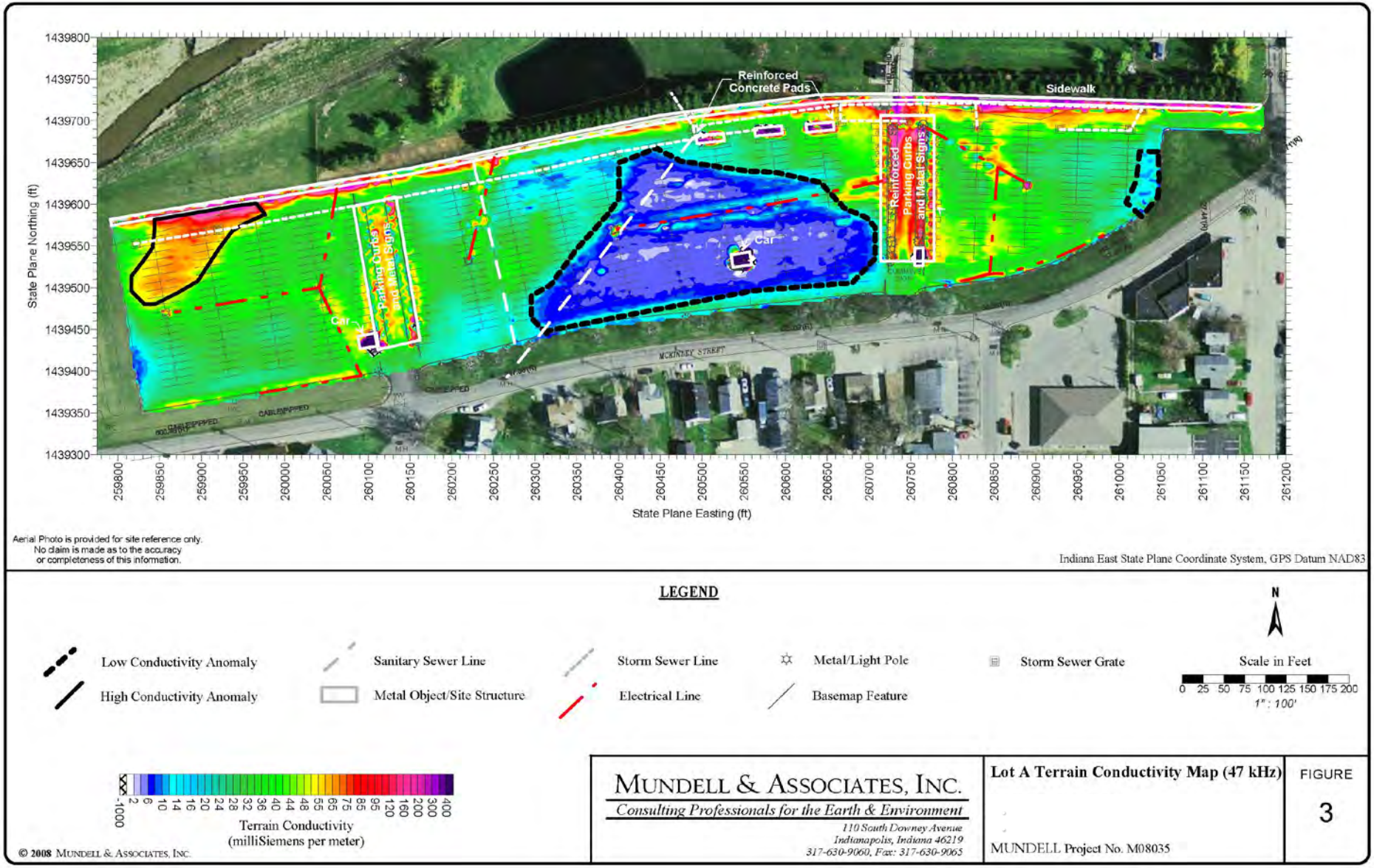
Consulting Professionals for the Earth & Environment
429 East Vermont Street, Suite 200
Indianapolis, Indiana 46202-3688
317-630-9060, Fax: 317-630-9065

GEM2 Terrain Conductivity Map – Looking for Areas Prone to Subsidence

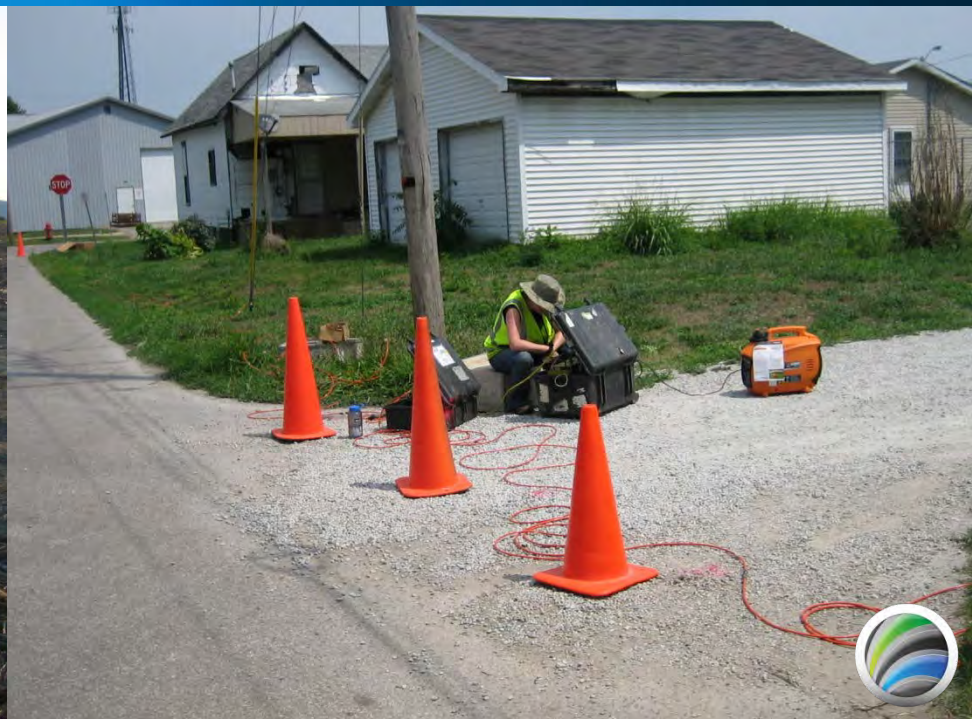


2D Electrical Resistivity Imaging System

High Detail Method for Characterizing Subtle
Variations in Both Shallow and Deeper Subsurface Resistivity

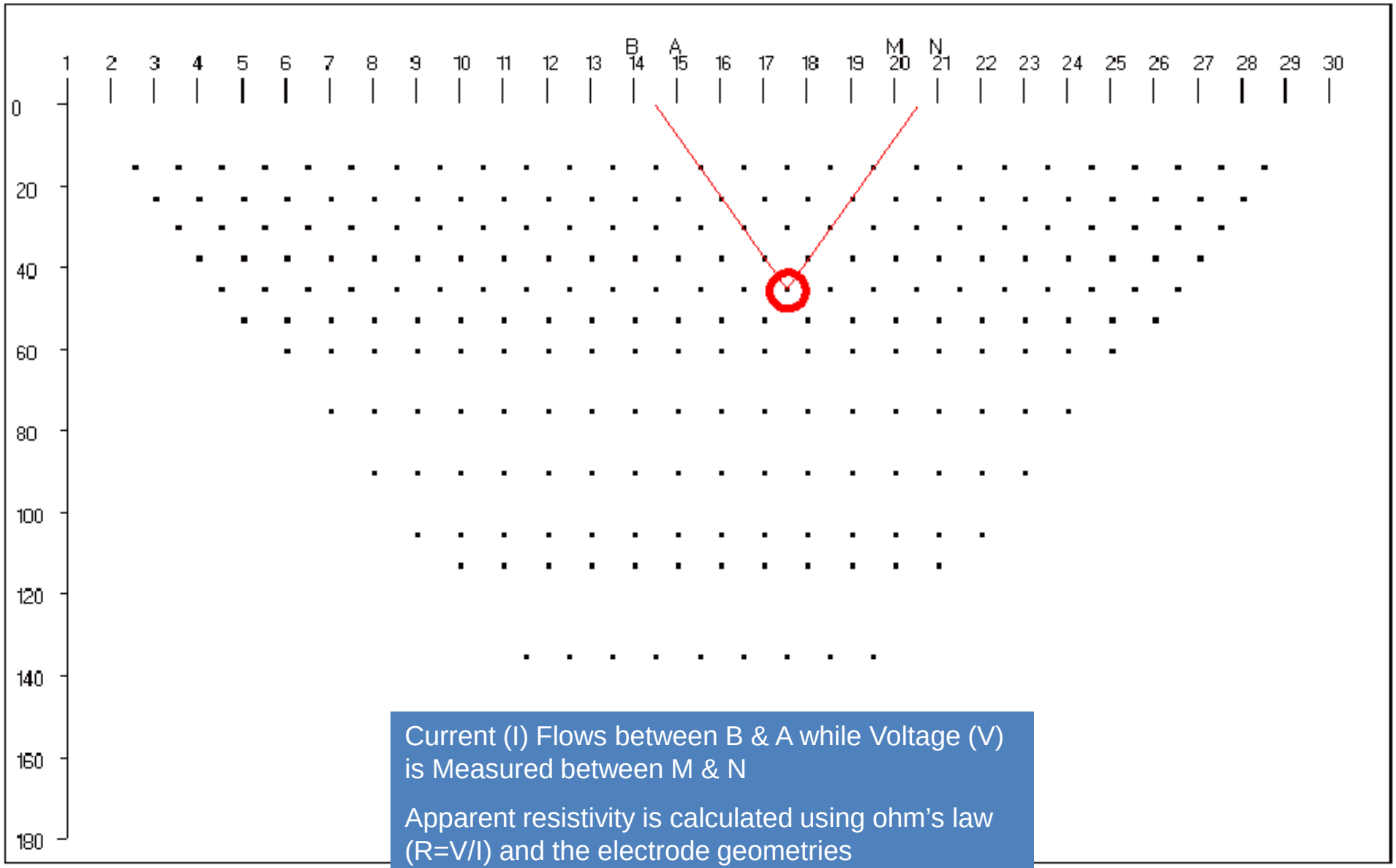
Often used in conjunction with surface mapping techniques such as EM31 or GEM2

Works in both rural and urban environments



2D Electrical Resistivity Imaging System

Here's an example of the subsurface coverage from a dipole-dipole array with one specific data point location shown:

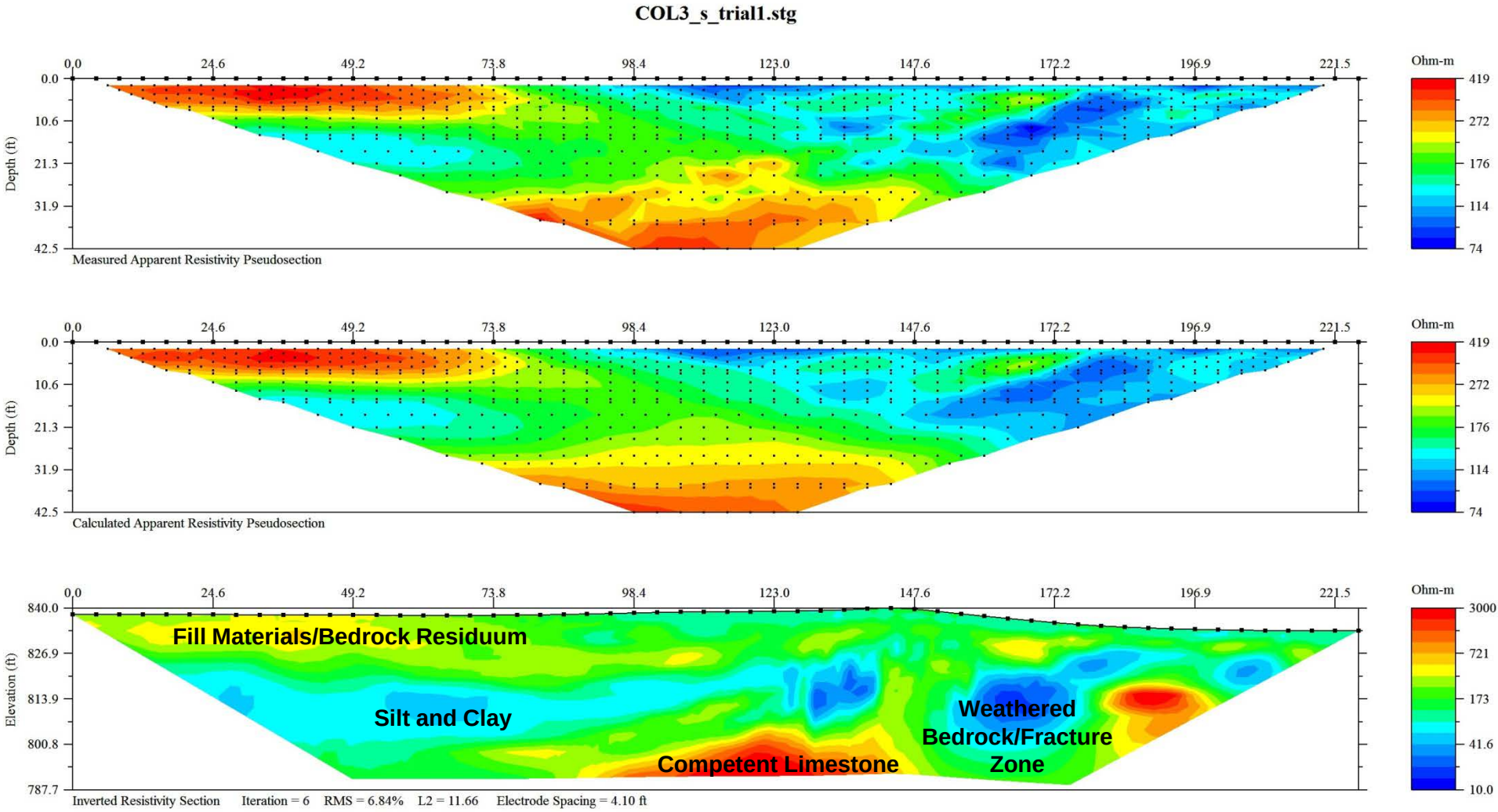


Current (I) Flows between B & A while Voltage (V) is Measured between M & N

Apparent resistivity is calculated using ohm's law (R=V/I) and the electrode geometries

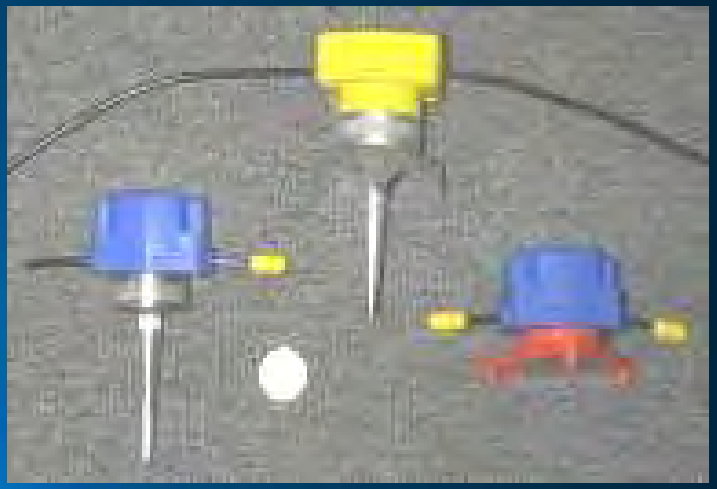
2D Electrical Resistivity Imaging System

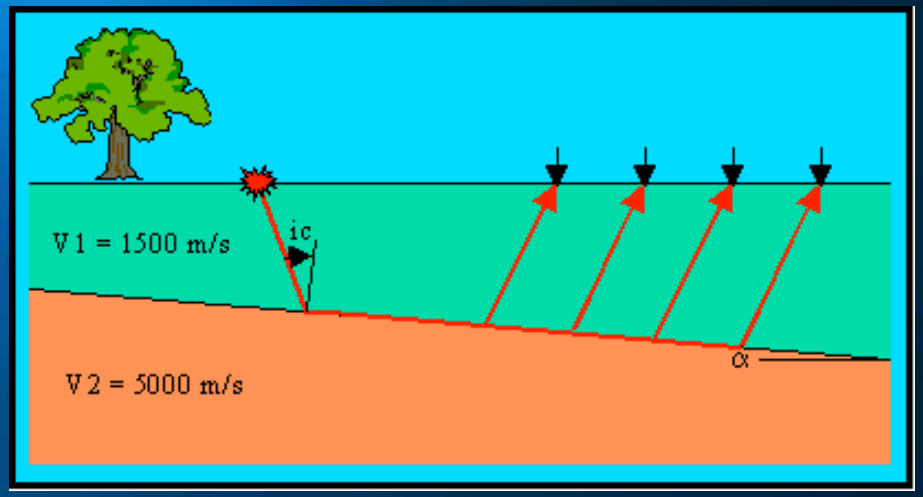
Once the apparent resistivity data is collected, it is modeled using an inversion technique which creates a “true” resistivity cross section



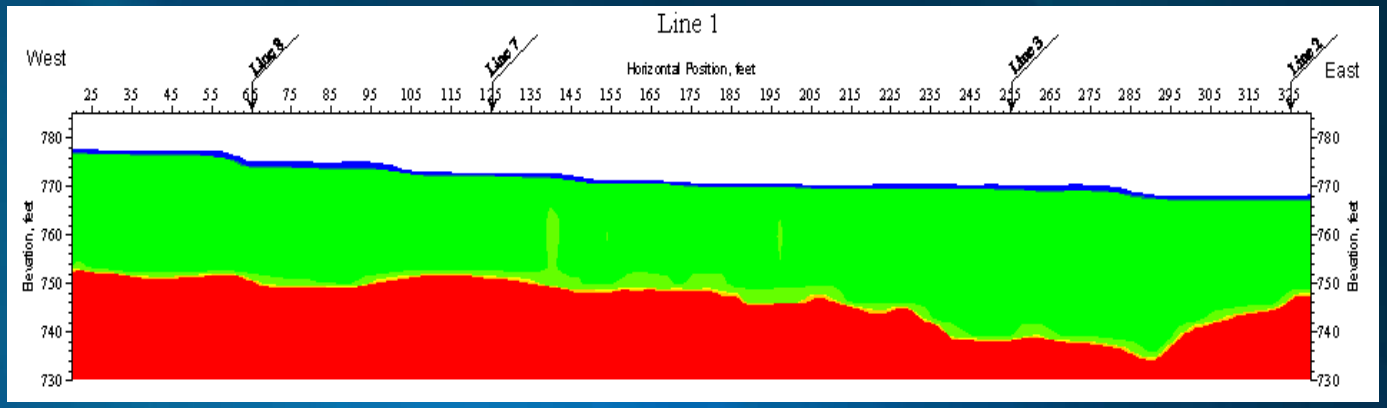
Seismic Refraction and Surface Wave Methods

Useful for mapping the top of bedrock, locating fracture zones and preferential pathways, and determining Vs30



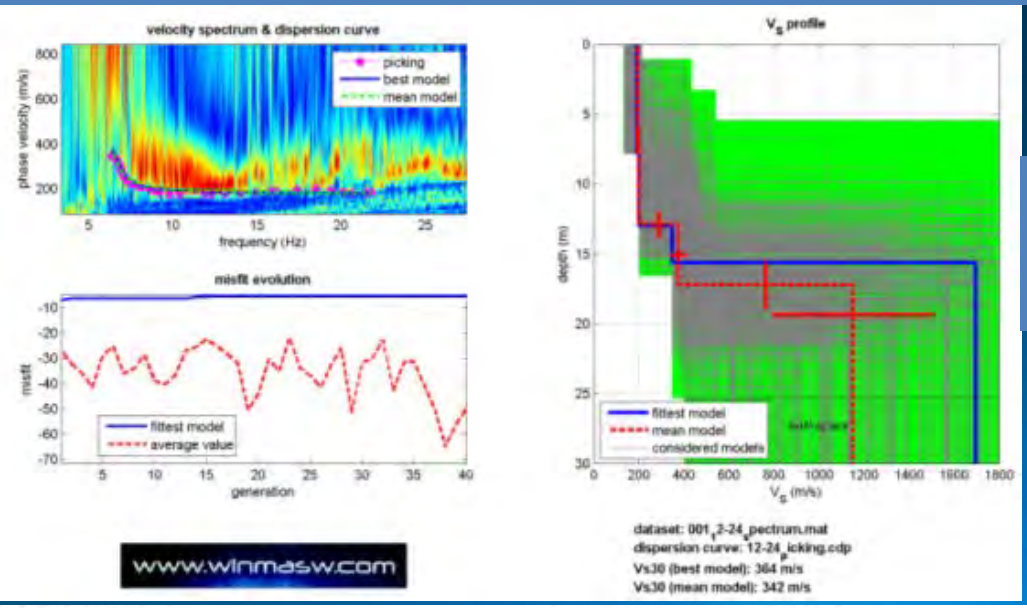


Can Be Used in 2-D

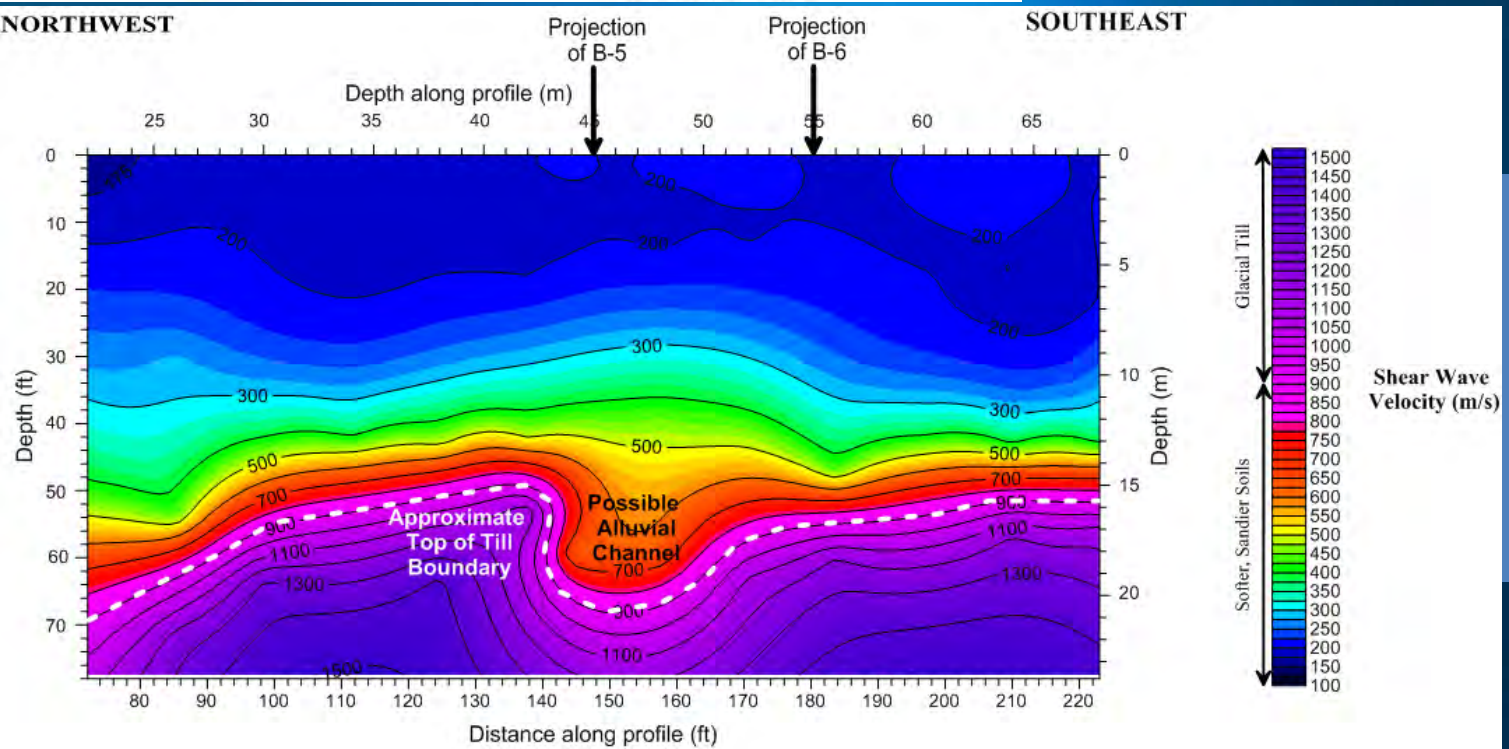


Or in 3-D

Shear Wave Velocity Studies



1-D Graphs for Determining Vs 30

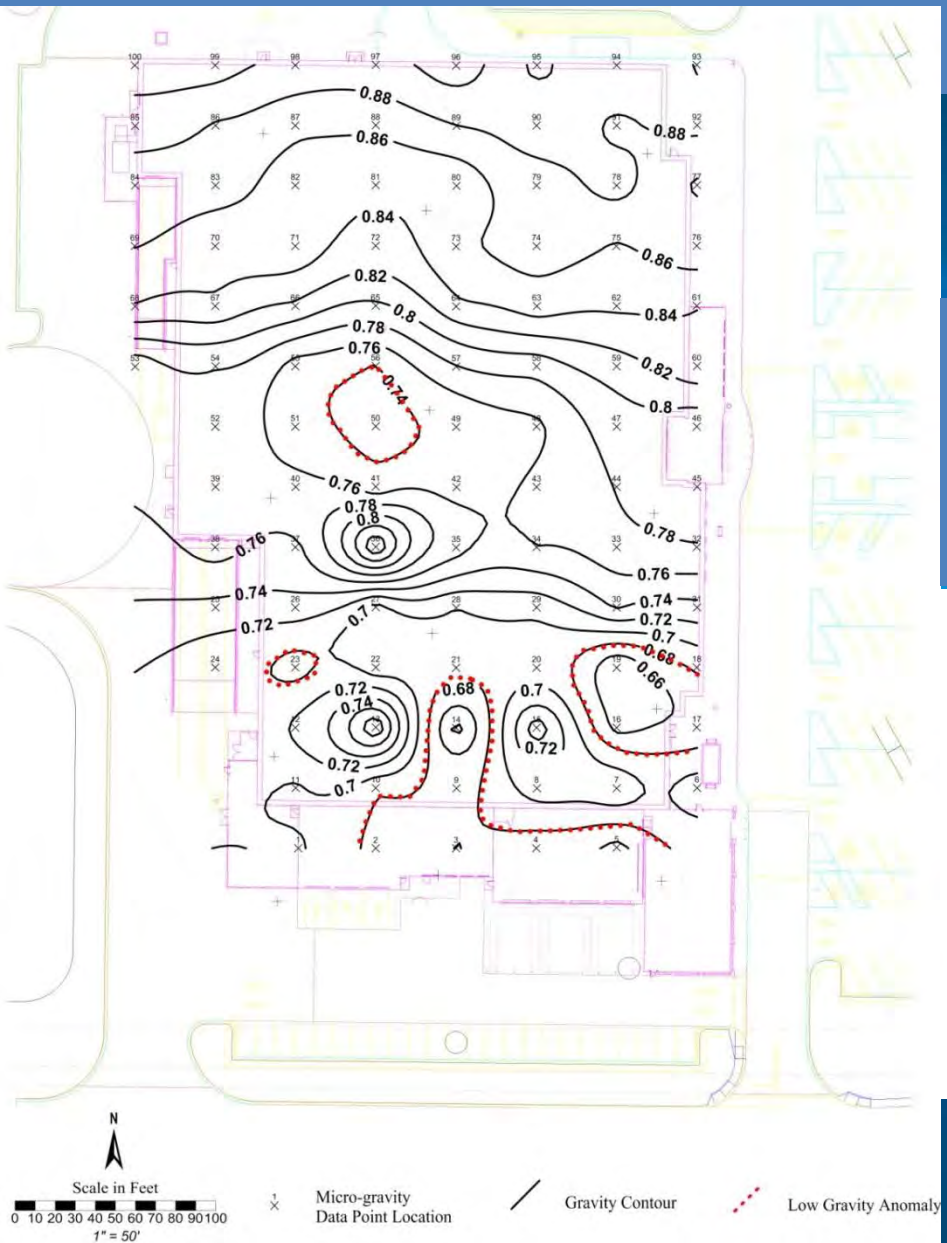


2-D Profiles For Mapping Site Variability

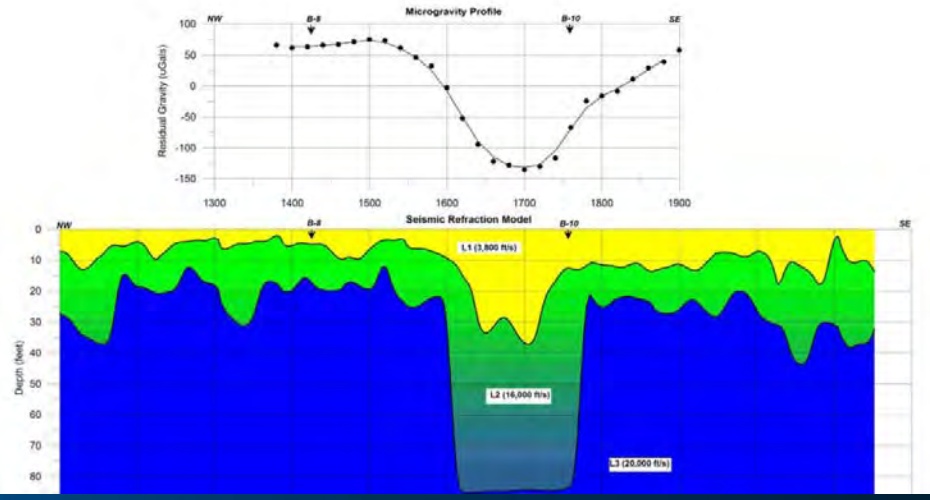
Microgravity

For mapping voids and severe fracture zones within bedrock. Very useful for locating mined areas within the upper 200 feet of the subsurface.

Microgravity Mapping Locates Missing Mass – Such as From Mined Coal Seam



Or From a Fractured/Weathered Zone in the Bedrock



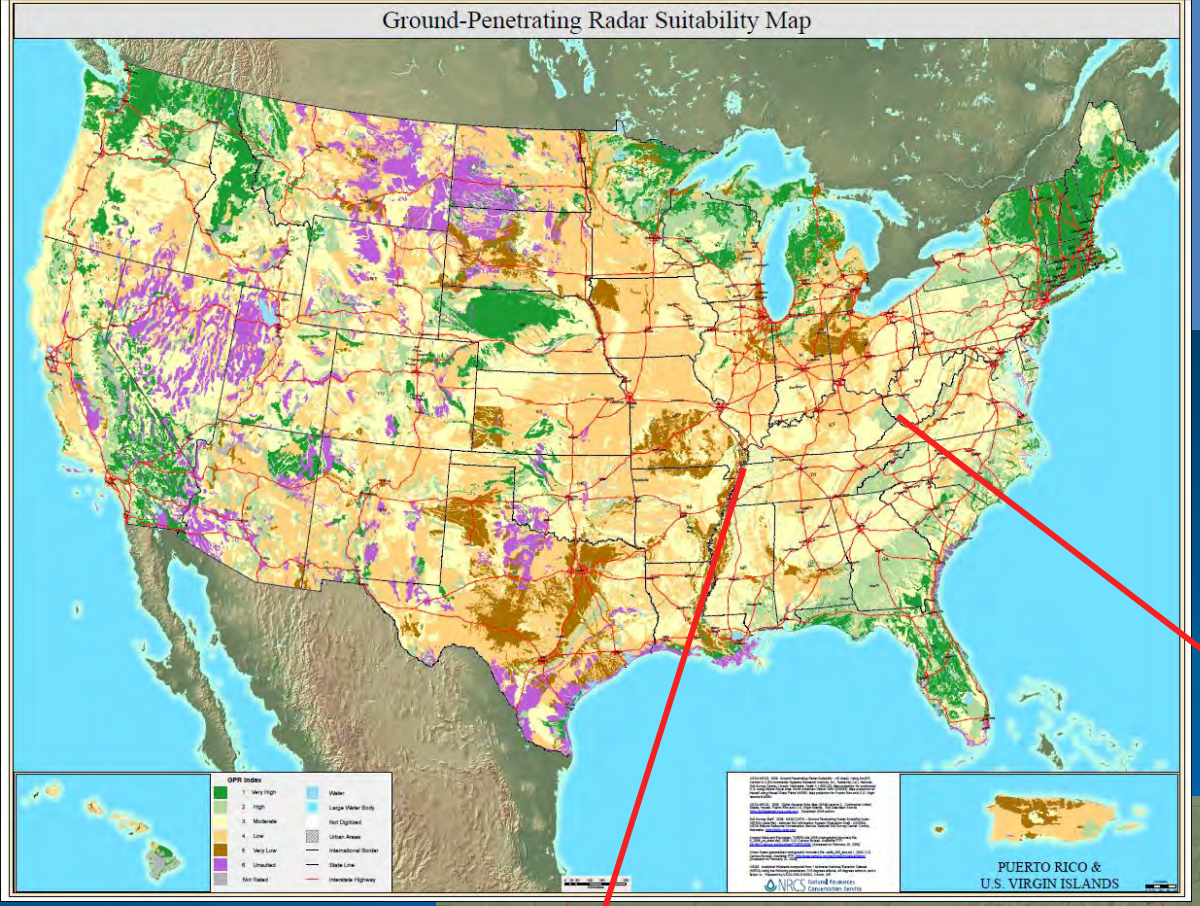
Ground Penetrating Radar (GPR)

Generally most applicable in coarse grained soils

Excellent at imaging shallow metallic objects, structures, and geologic features

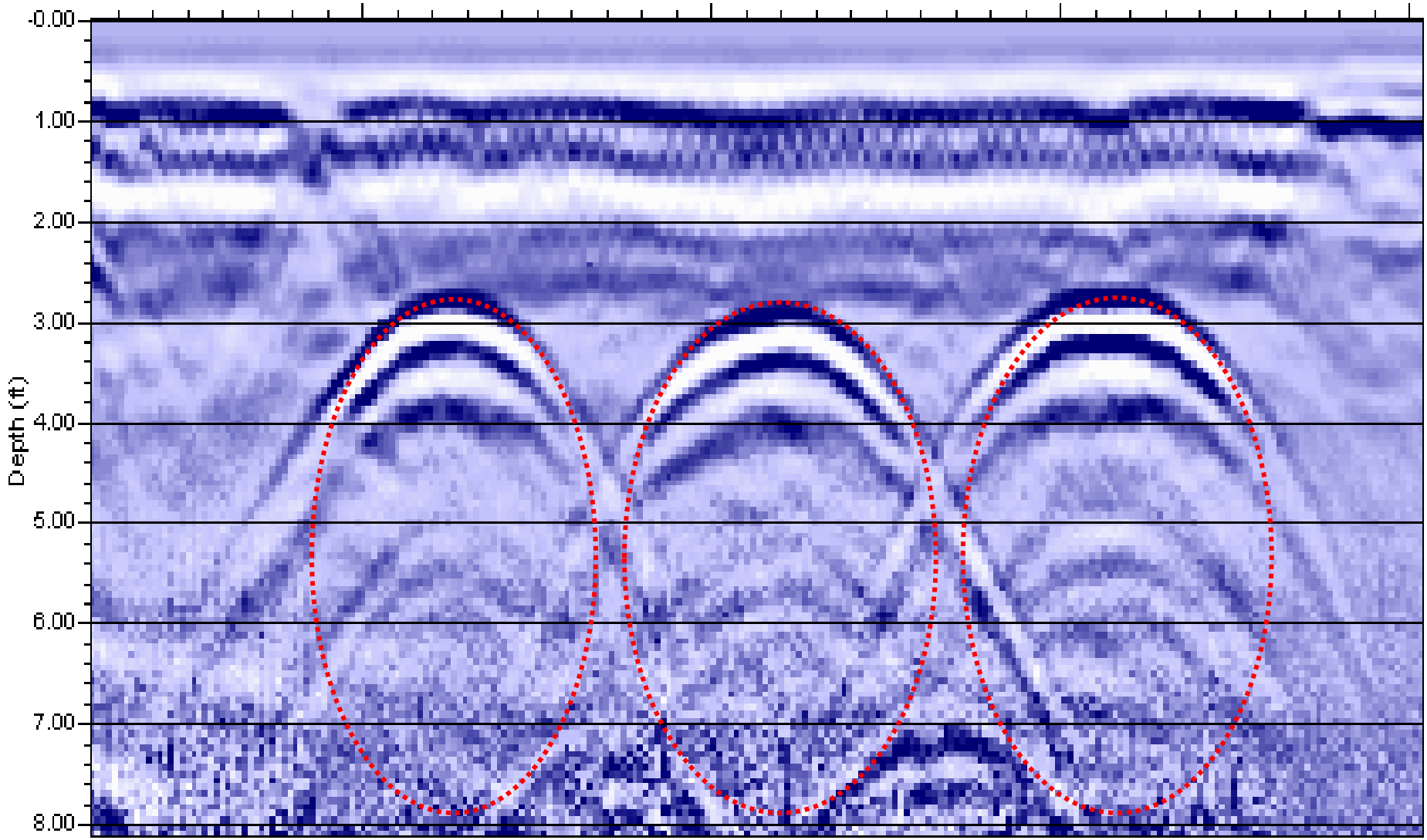
Recent technical advances make rapid data collection possible

GPR Suitability Maps Show That GPR Isn't Always the Best Tool in the Toolbox



Individual GPR Profile

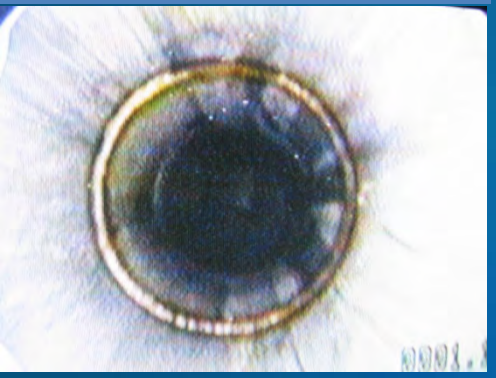
This profile shows three UST's beneath reinforced concrete



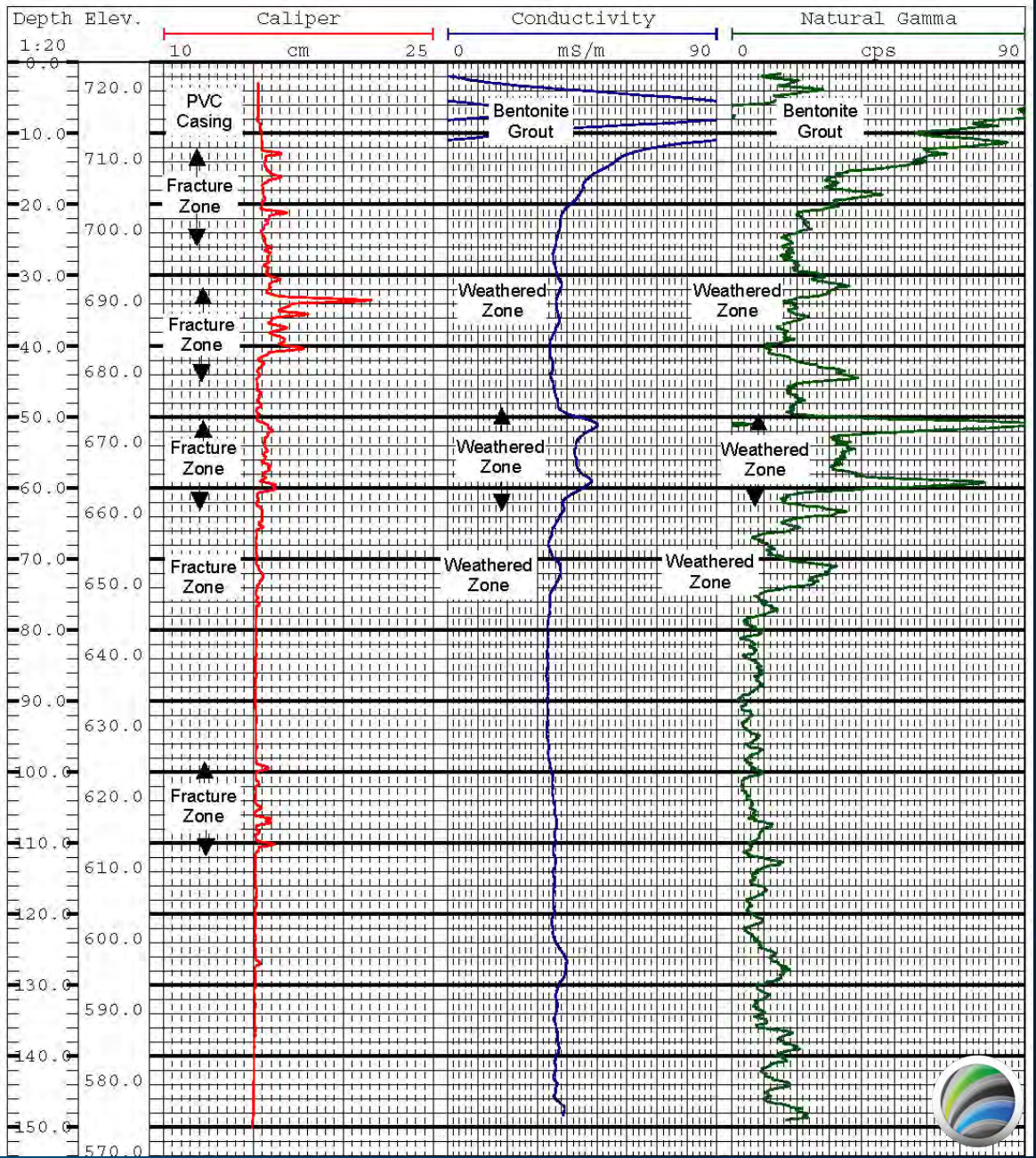
Downhole Logging

Commonly used to determine site geology and structural integrity of site wells

Downhole view of casing

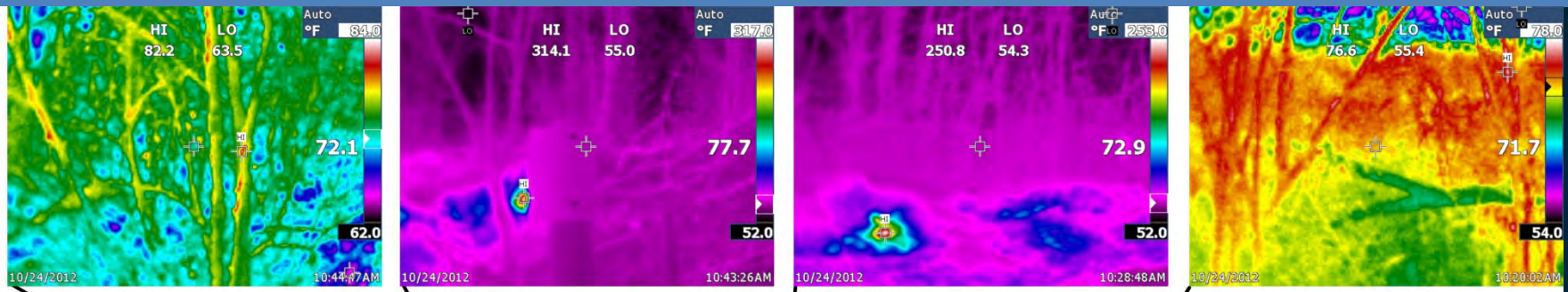


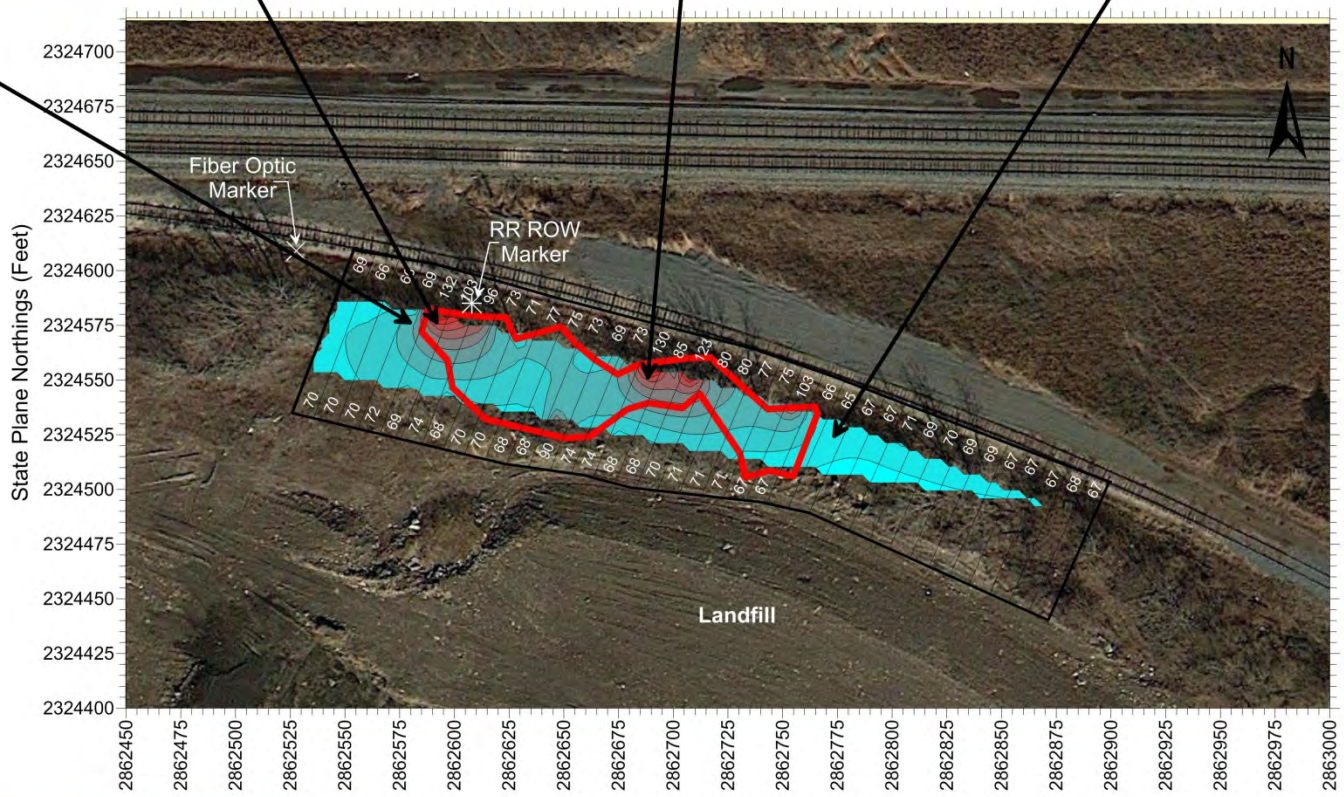
Side view of wire wrapped screen

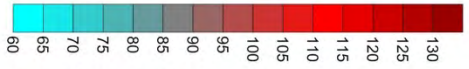


Thermal Imaging

Used for mapping thermal variations due to burning or exothermic reactions







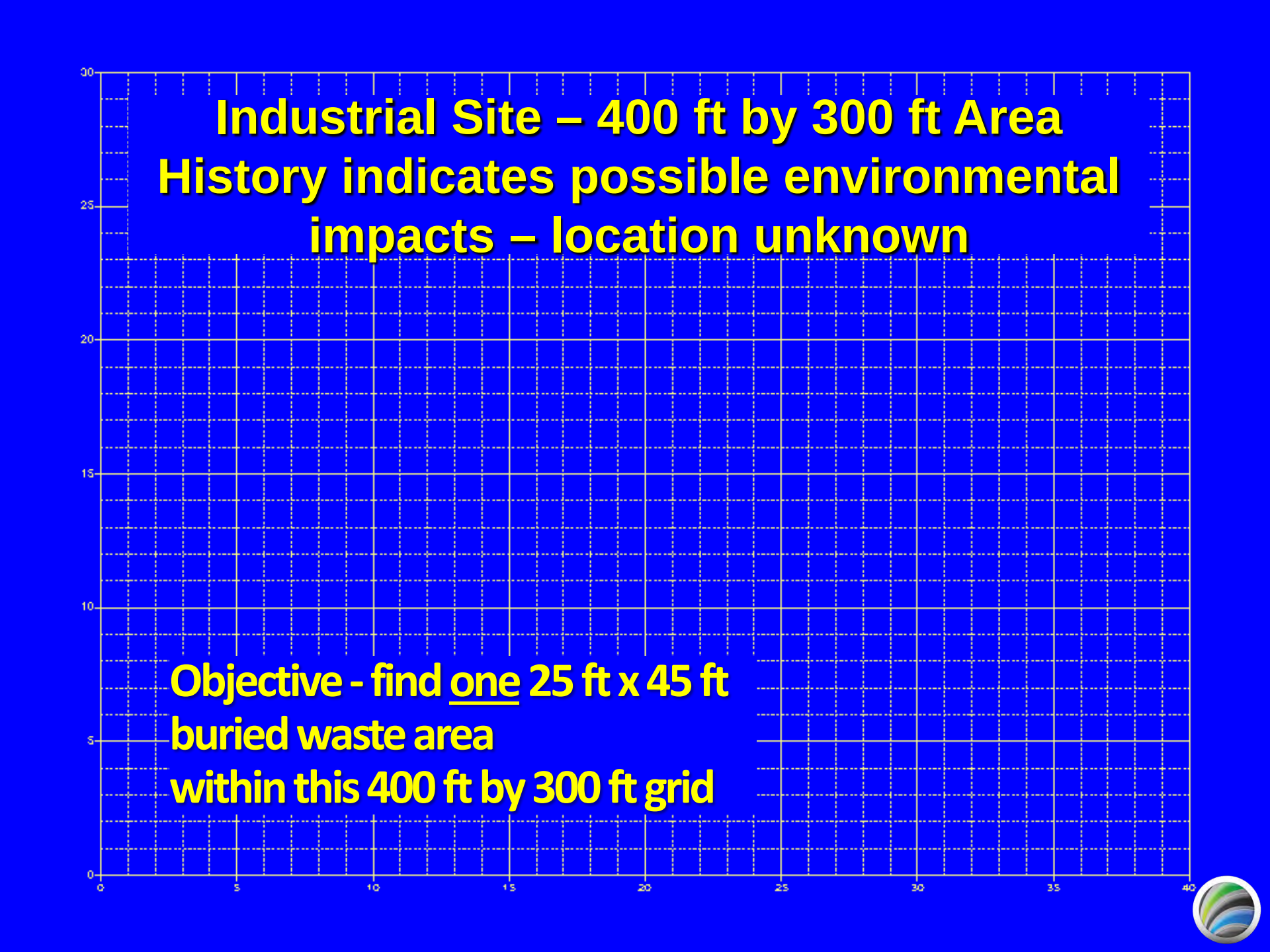
67 Maximum Surface Temperature from Thermometer (deg F)

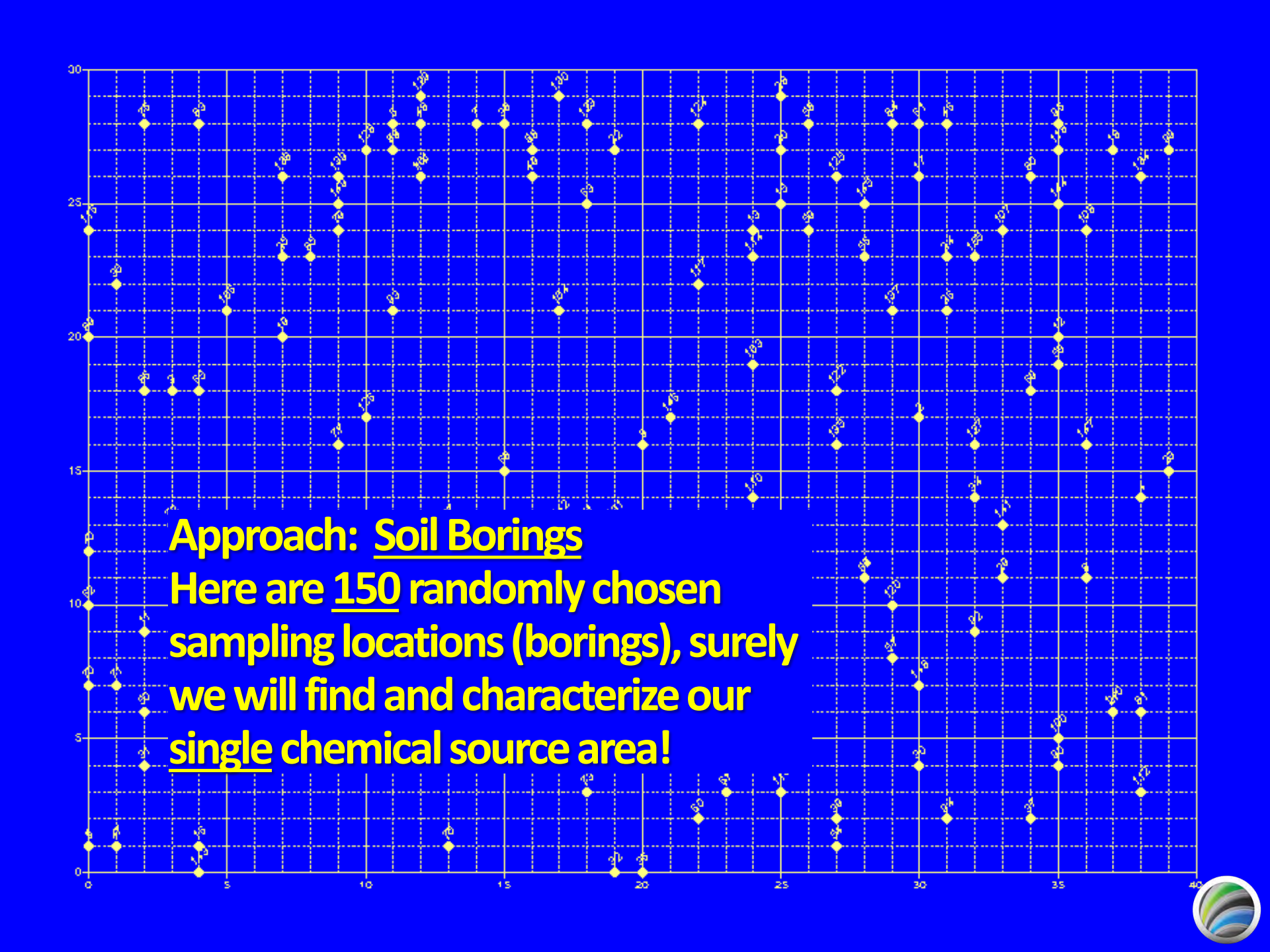
Survey Boundary

Extent of Surface Thermal Anomalies as Mapped with the Thermometer and Infrared Camera

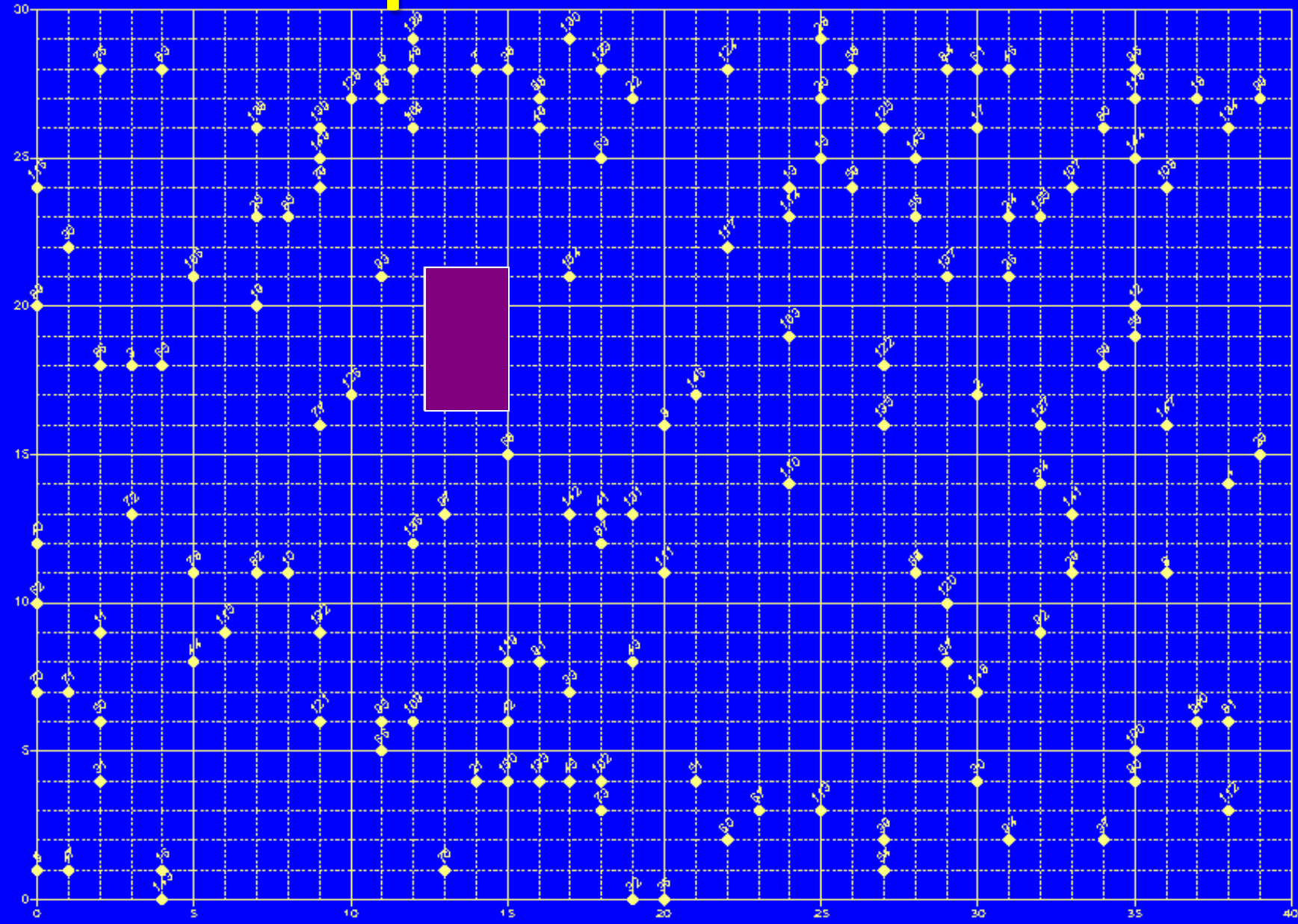
Practical Applications

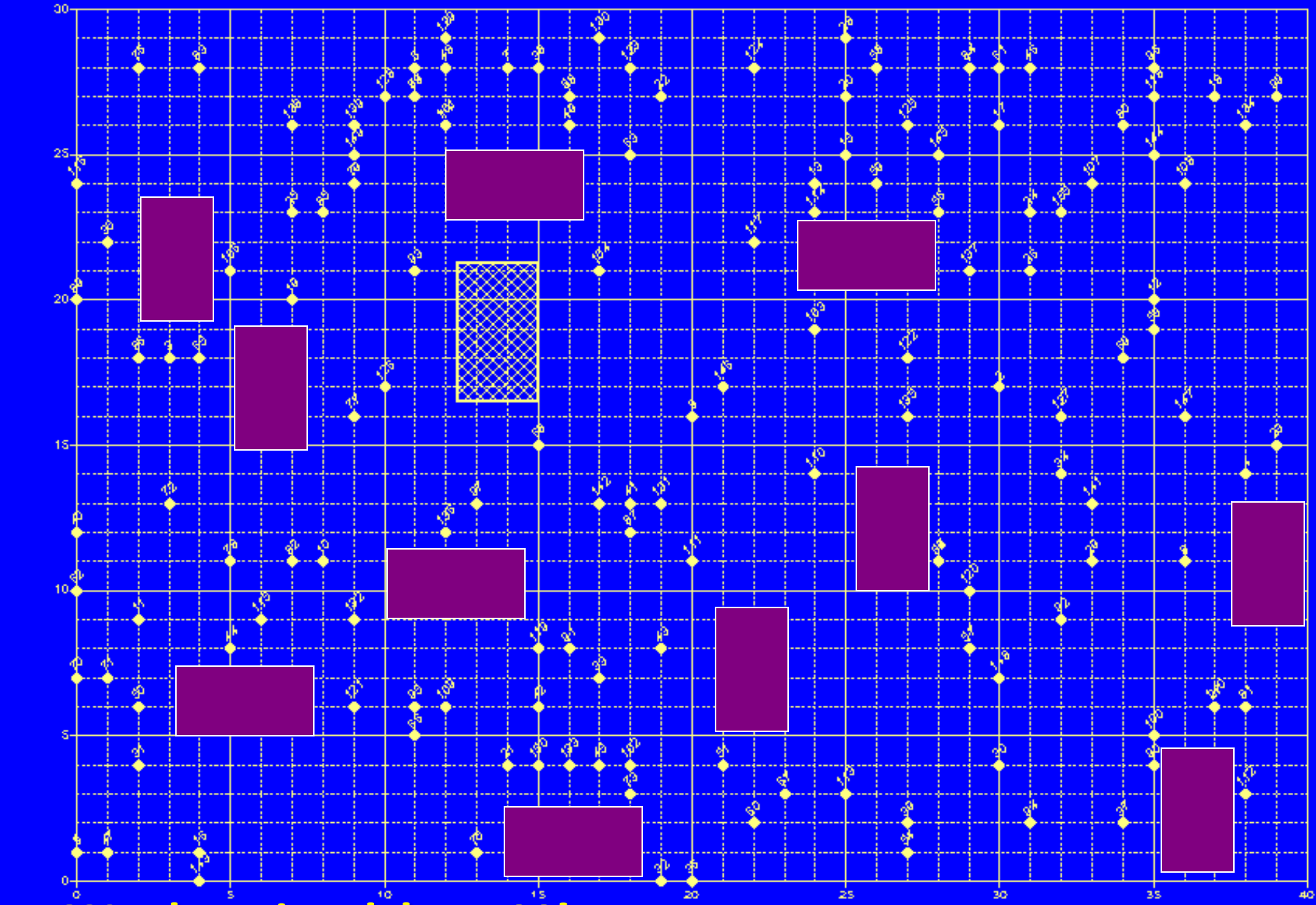
- Environmental Site Assessments
  - UST Search/Old Tank Pits
  - Pipes and Utilities
  - Site History/Fills
  - Drum Disposal Areas


Industrial Site – 400 ft by 300 ft Area
History indicates possible environmental impacts – location unknown
Objective - find one 25 ft x 45 ft buried waste area within this 400 ft by 300 ft grid
0
5
10
15
20
25
30
35
40

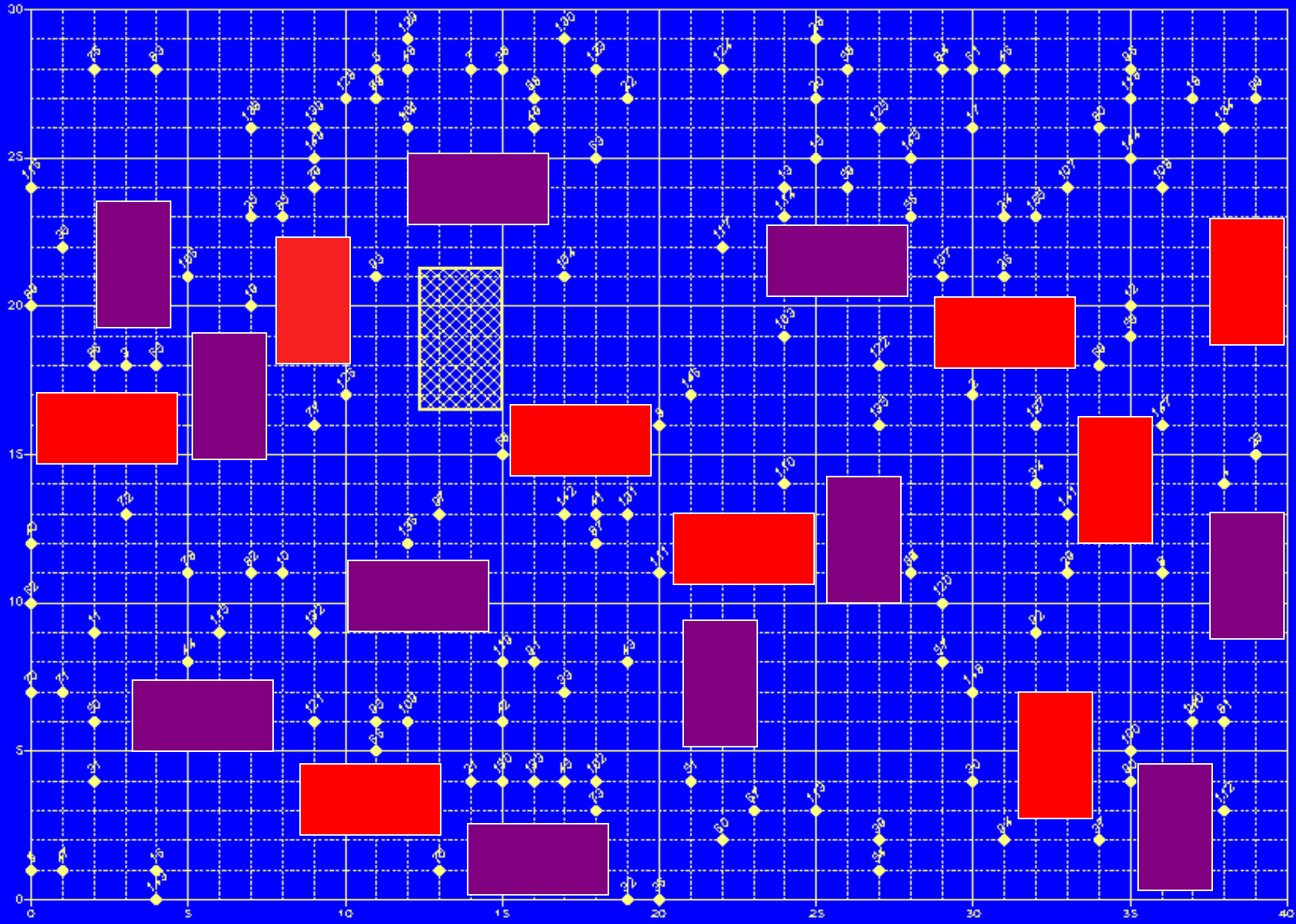

Approach: Soil Borings
Here are 150 randomly chosen sampling locations (borings), surely we will find and characterize our single chemical source area!

Oops! We missed!

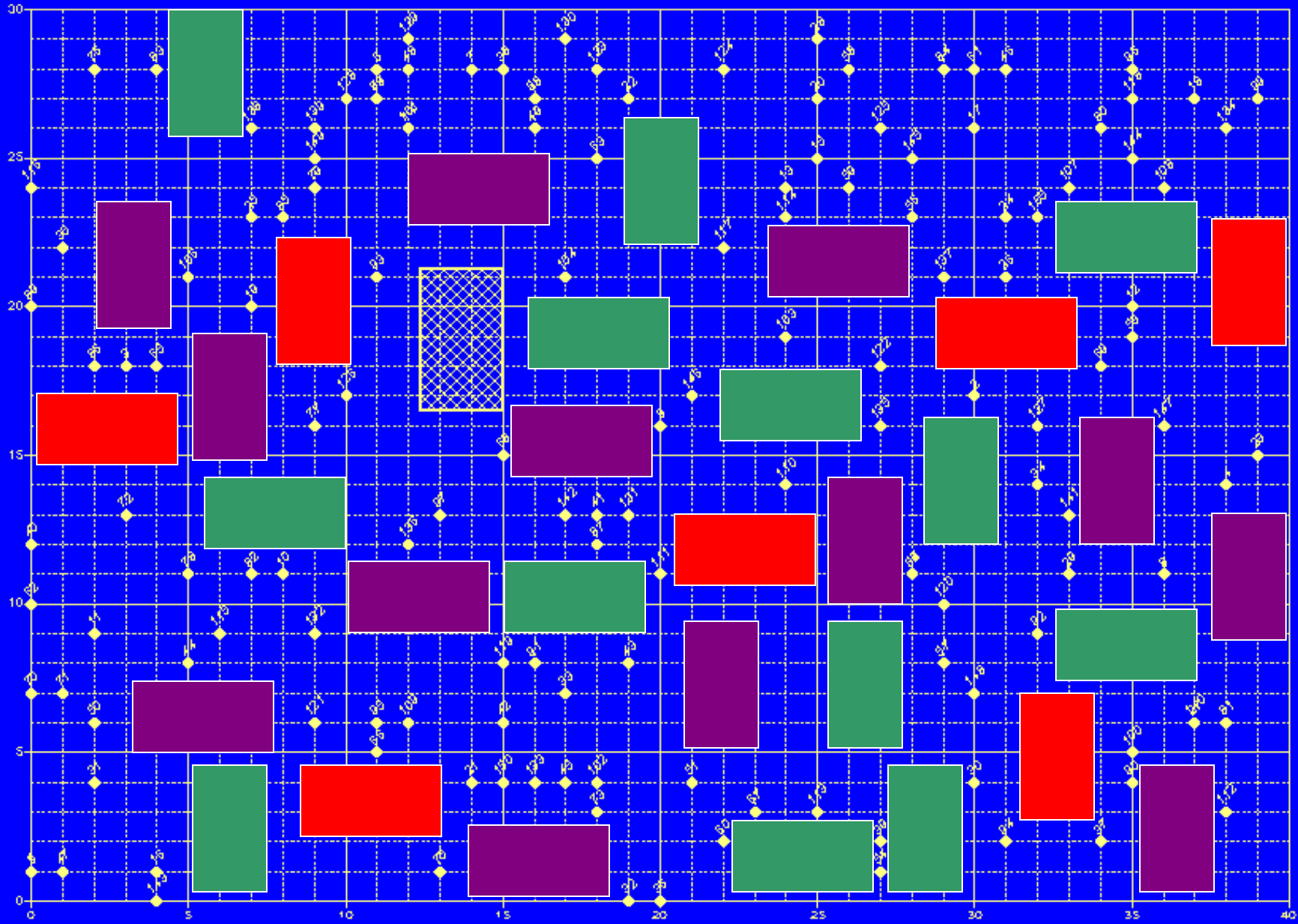




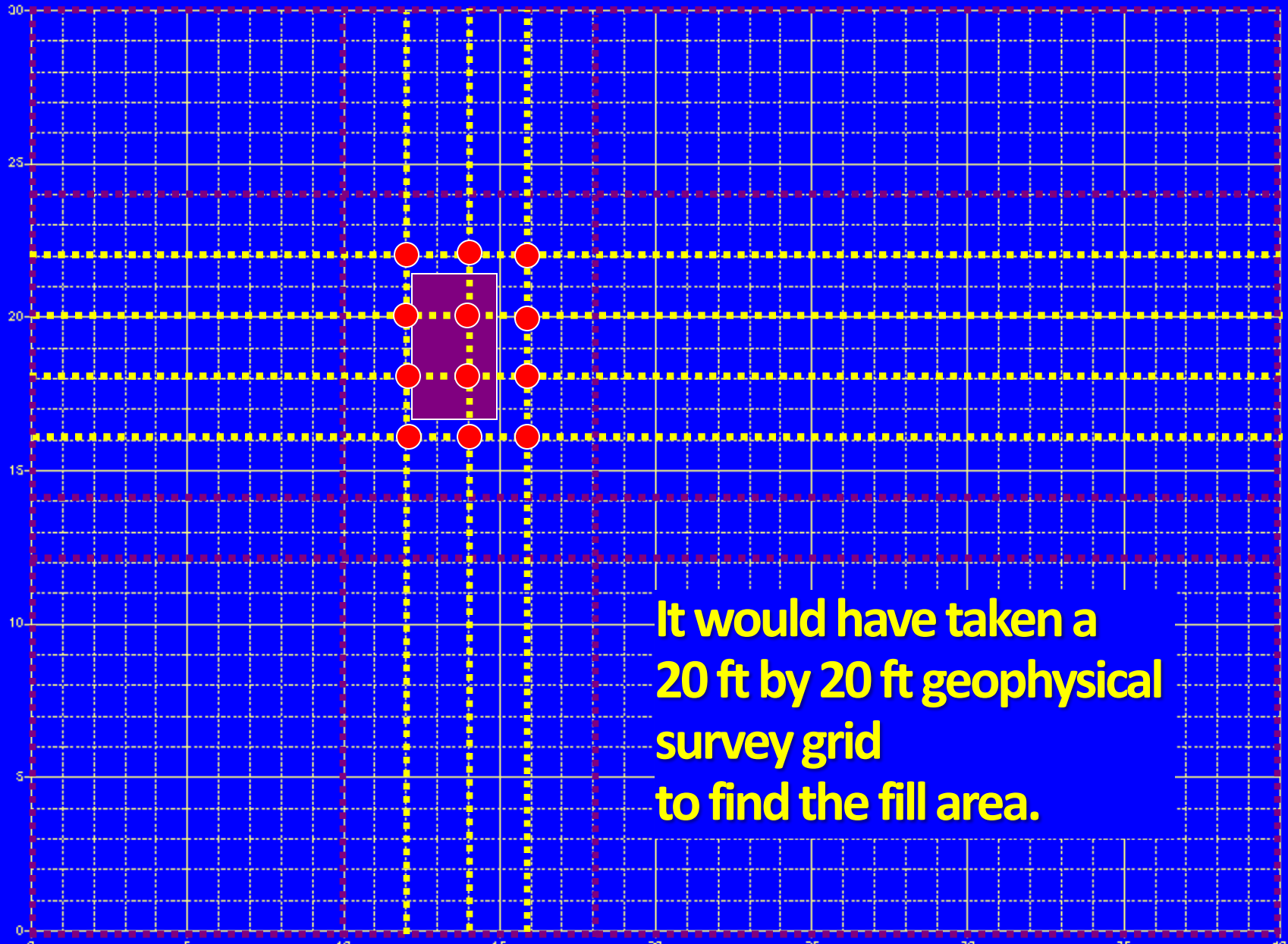
We also missed these 11!



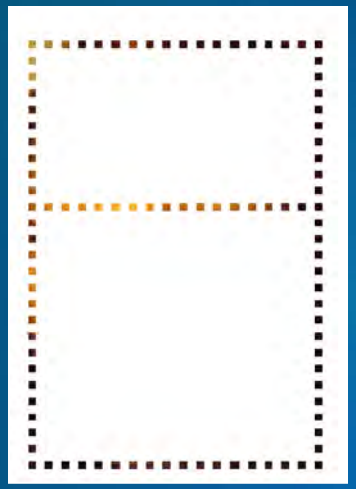
And these 9!



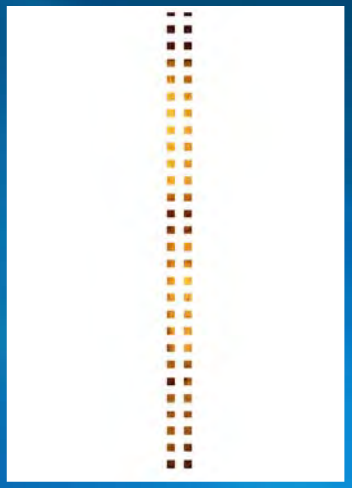
And these 13 too!


30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
It would have taken a
20 ft by 20 ft geophysical
survey grid
to find the fill area.

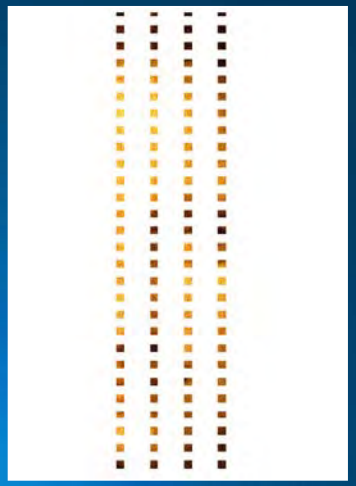
DATA ACQUISITION DENSITY AND ITS RELATIONSHIP TO MEETING DELINEATION OBJECTIVES



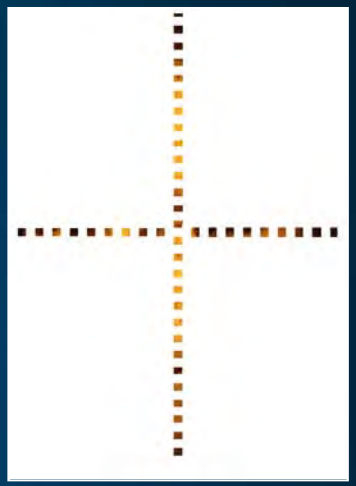
Single row, Perimeter



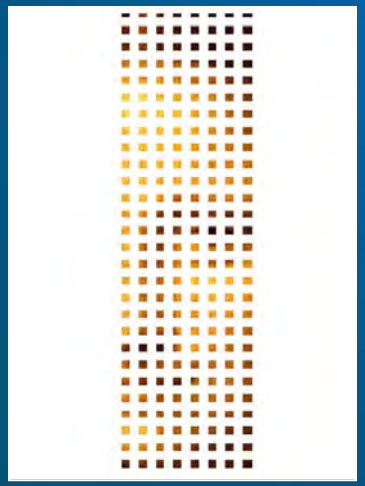
Medium Density, Double



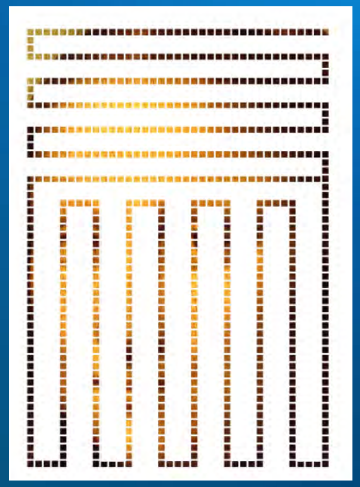
Low Density, Center



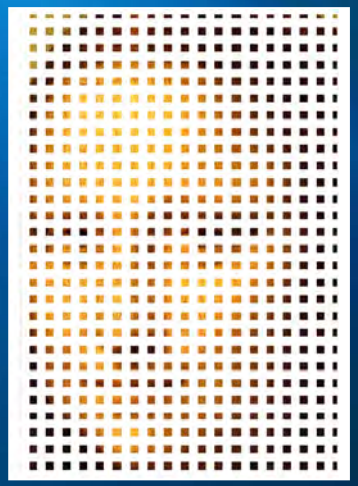
Single Row Cross



Medium density, Center



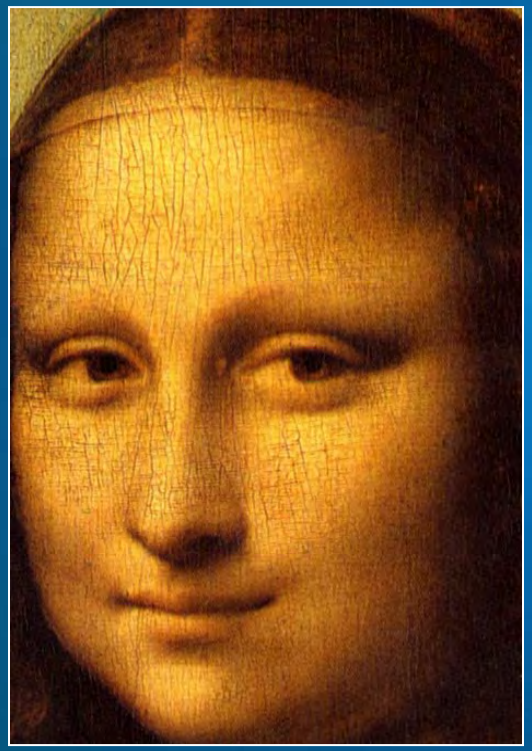
Low density, Meandering



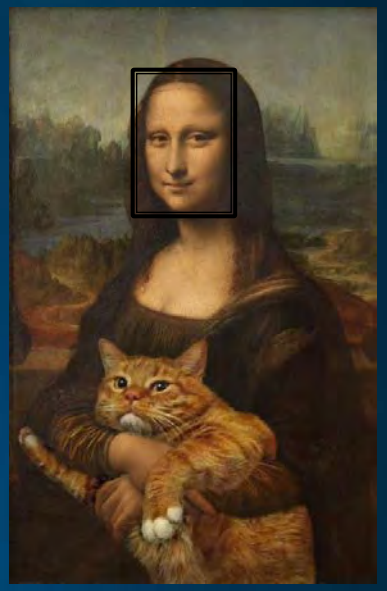
Medium density, target

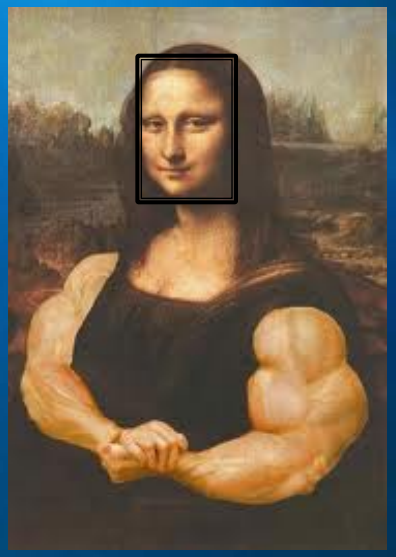
High density, target

LIMITING DATA DENSITY TO TARGET AREA ONLY



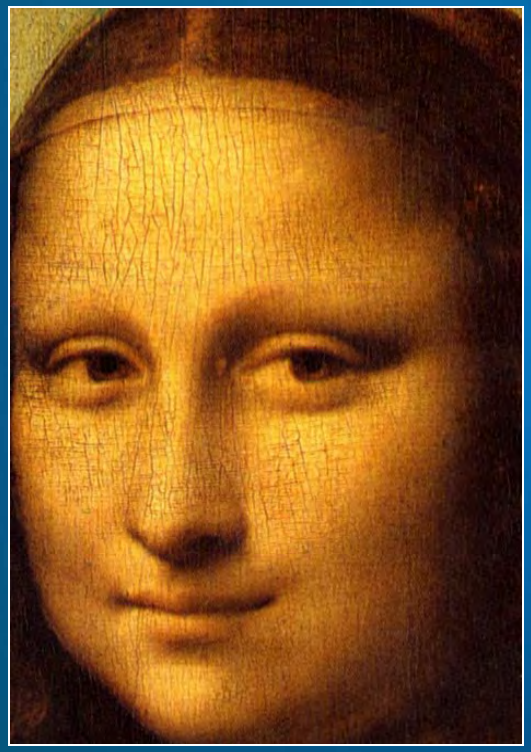
High density, target



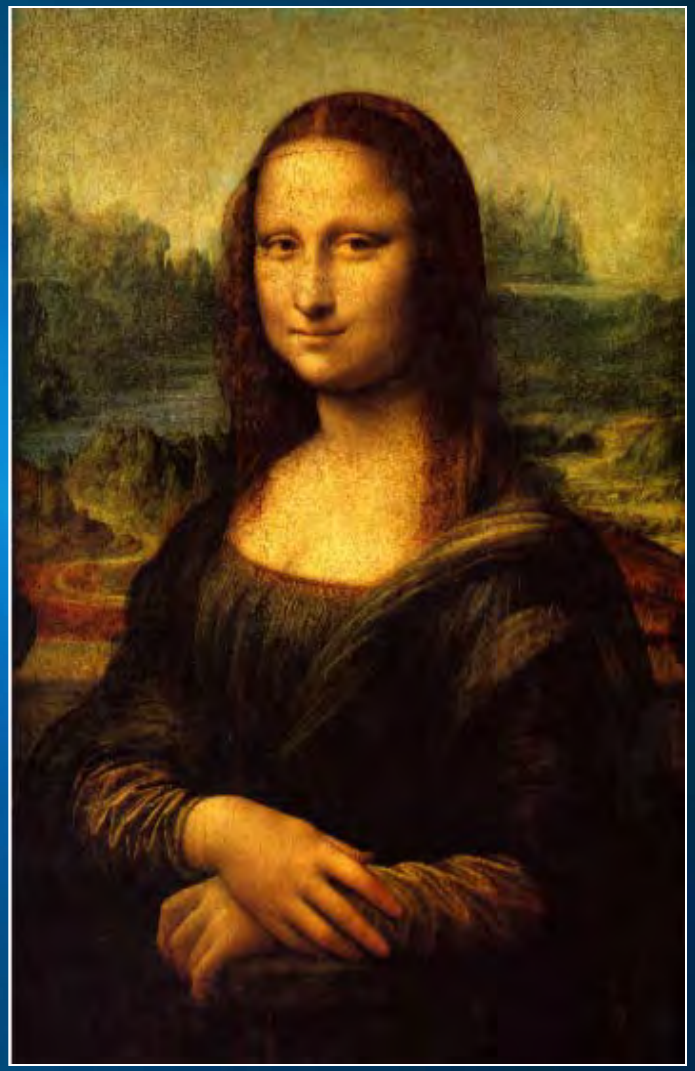


High density, complete

HIGH DENSITY DATA ACQUISITION OVER ENTIRE AREA SUCCEEDS IN MEETING DELINEATION OBJECTIVES

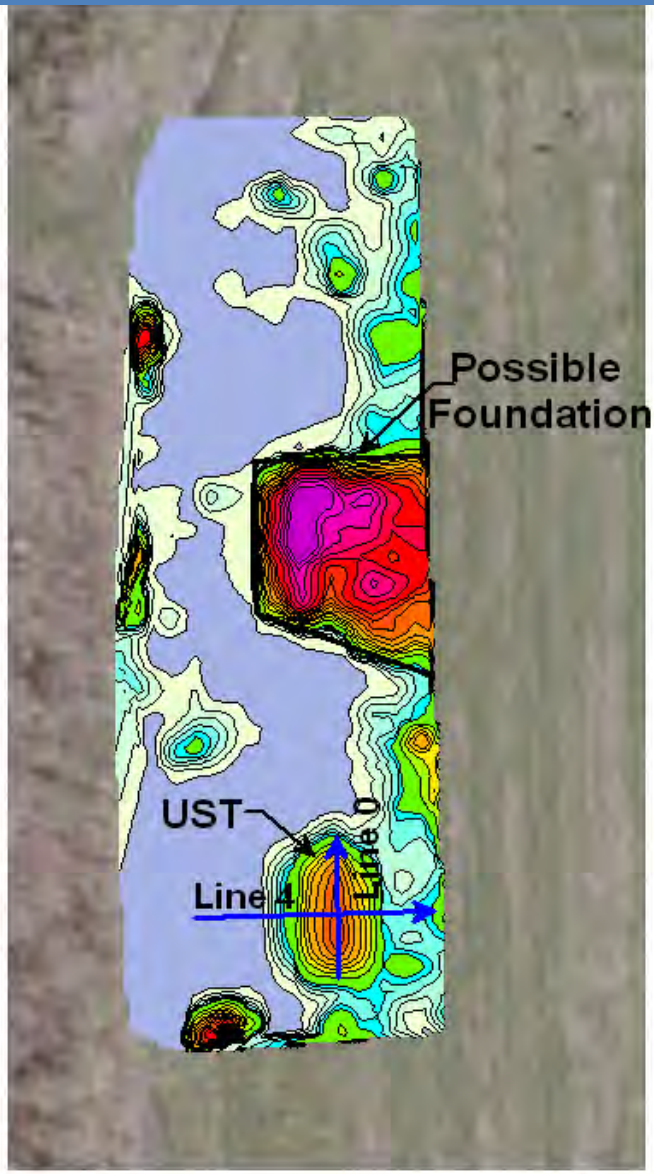


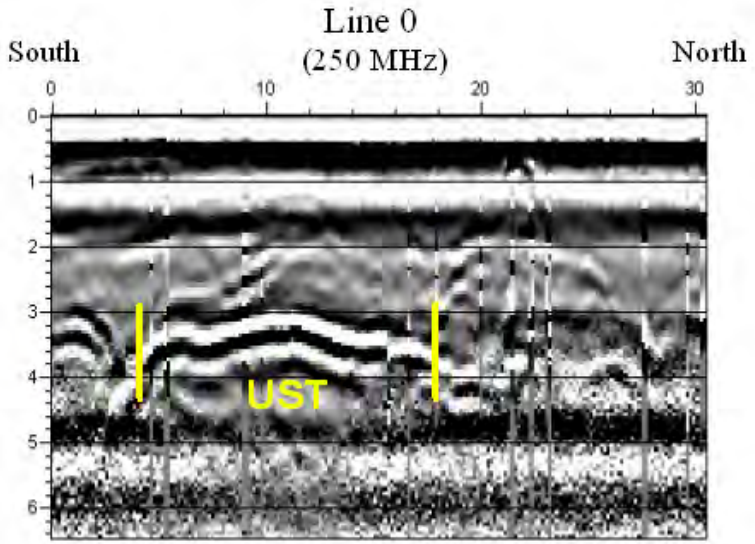
High density, target

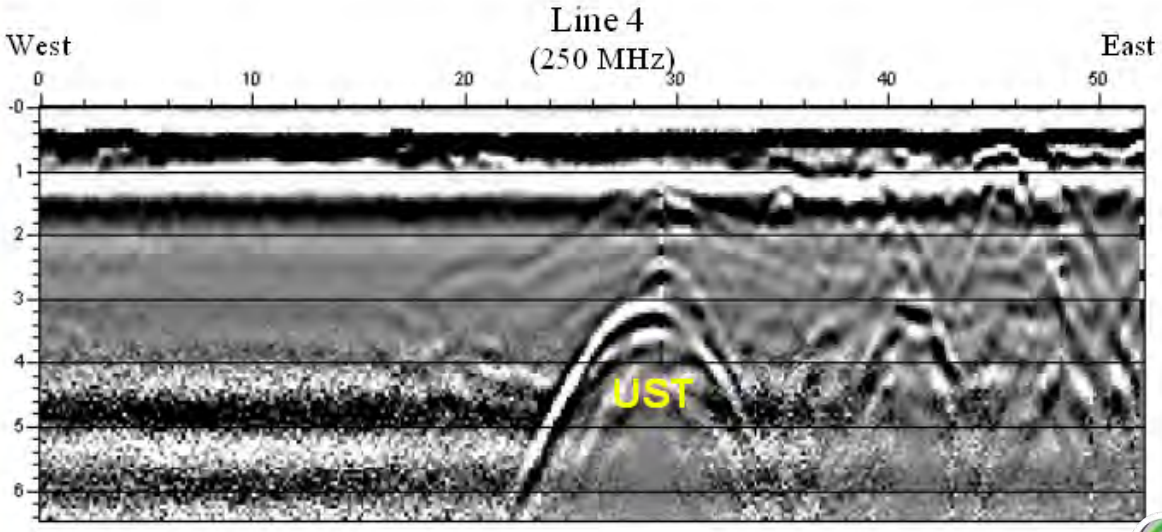


High density, complete and accurate delineation

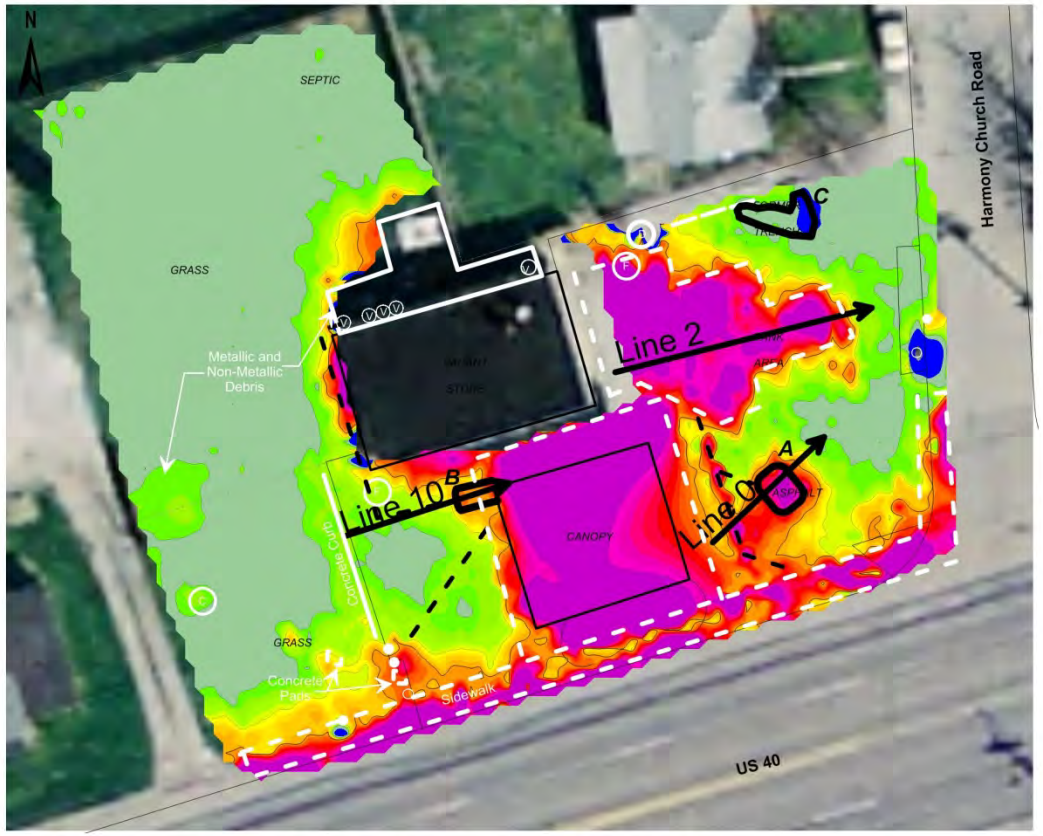
UST Search
(EM-61 Channel Difference Map with GPR)

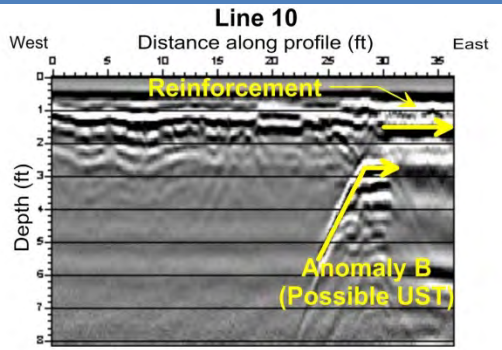


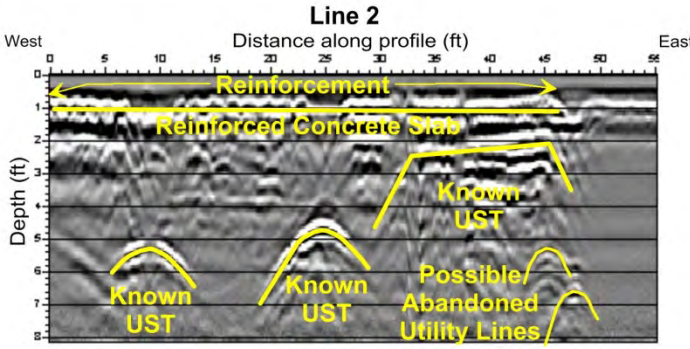


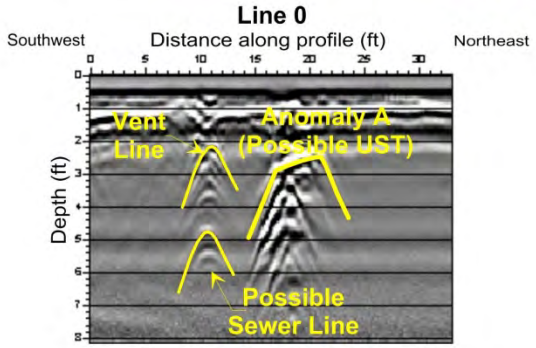


UST Search
(EM-61 Channel Difference Map with GPR)

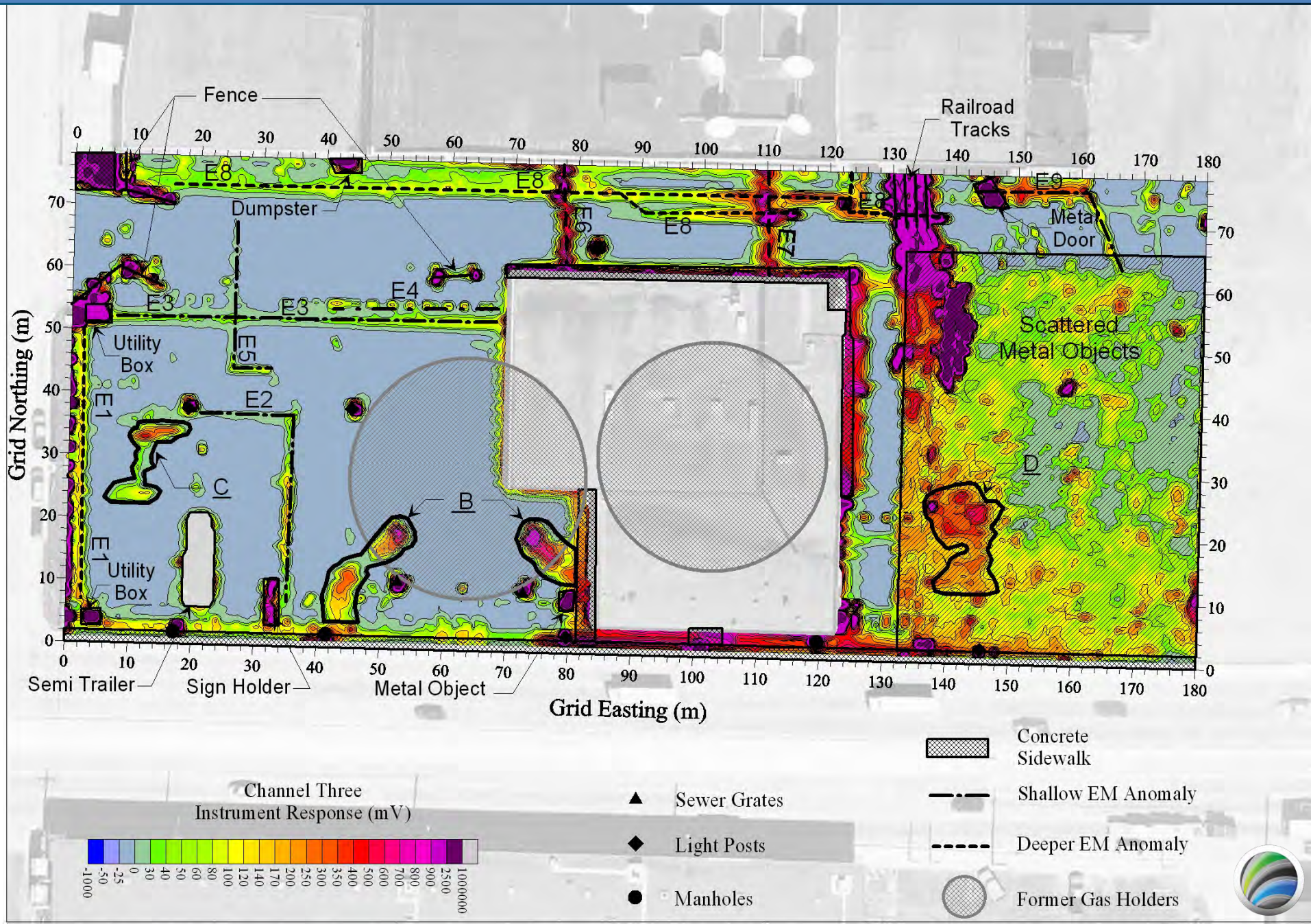




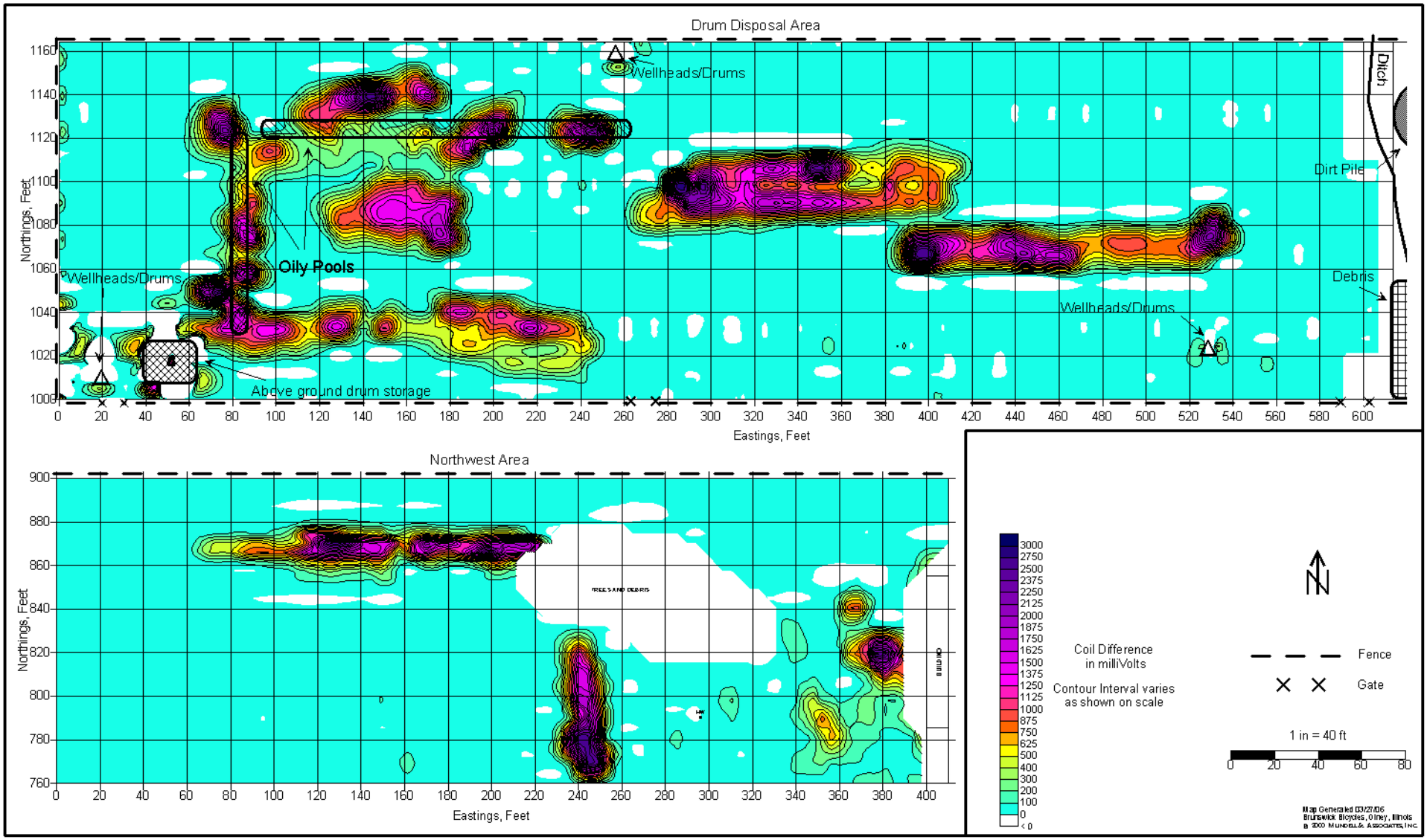




Site Mapping a Former MGP Site with EM-61

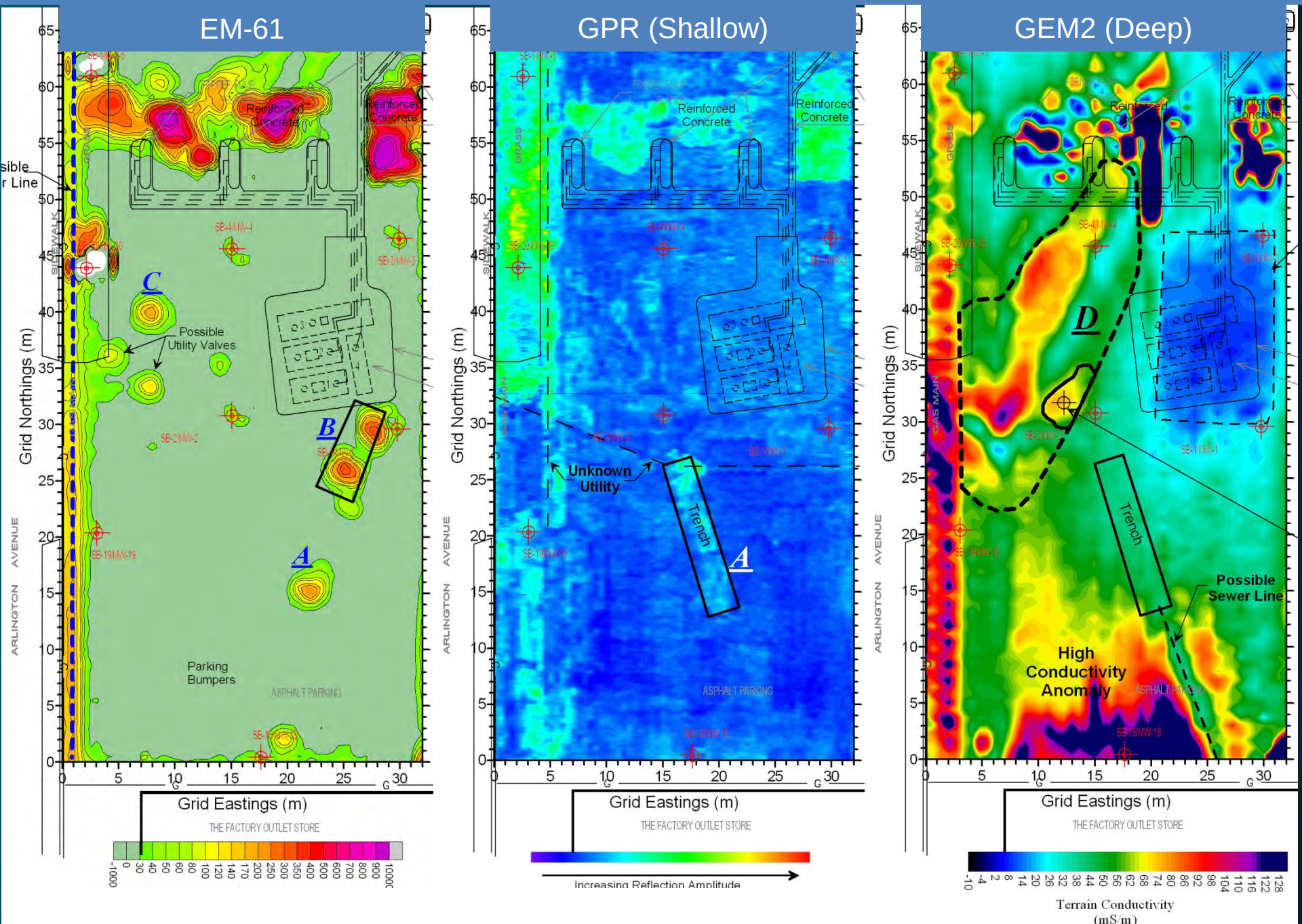


Drum Search with EM-61

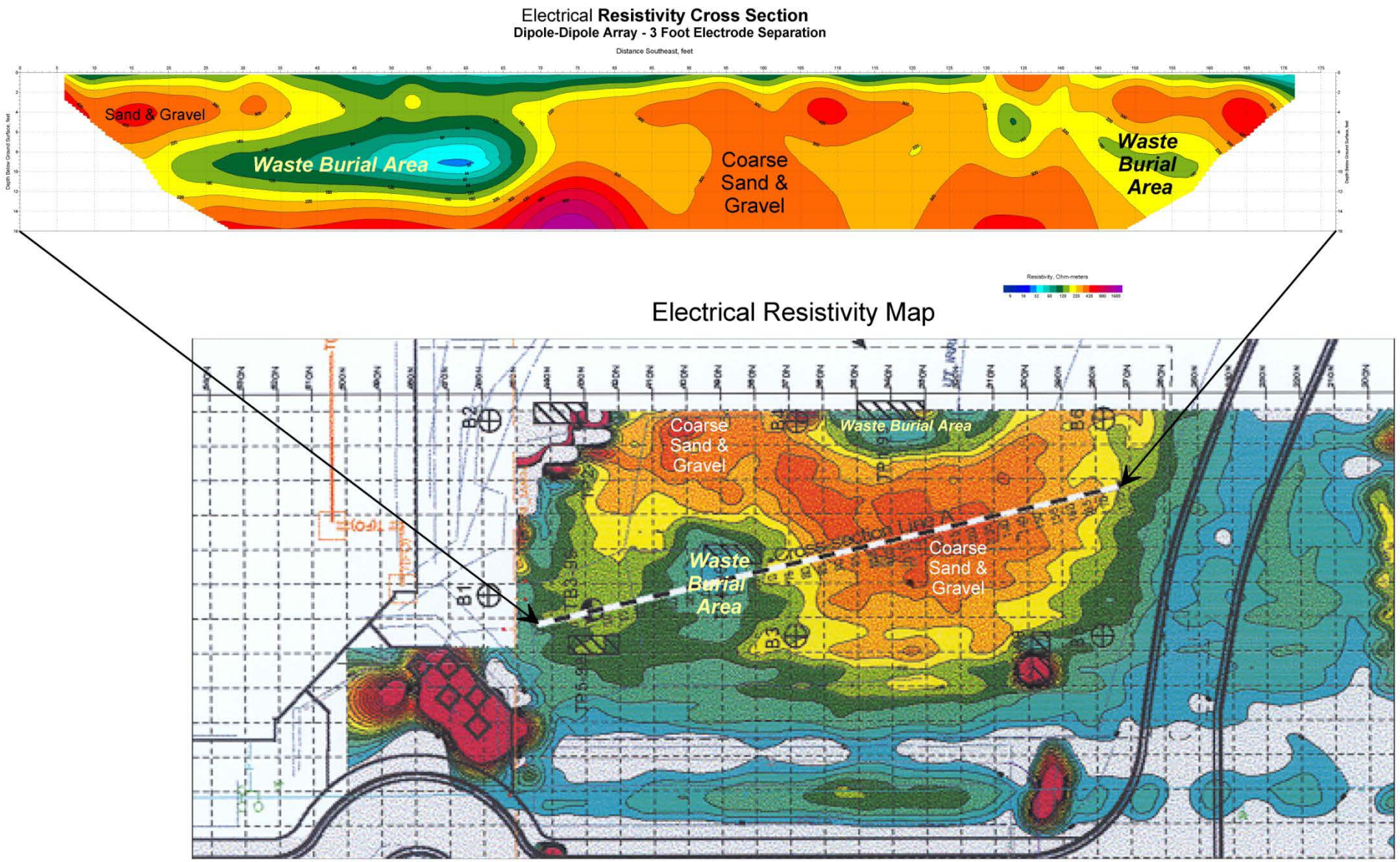


In The End, 4,000 Drums Were Discovered!

Site Mapping with Multiple Techniques



Delineating Fill Materials with EM Methods

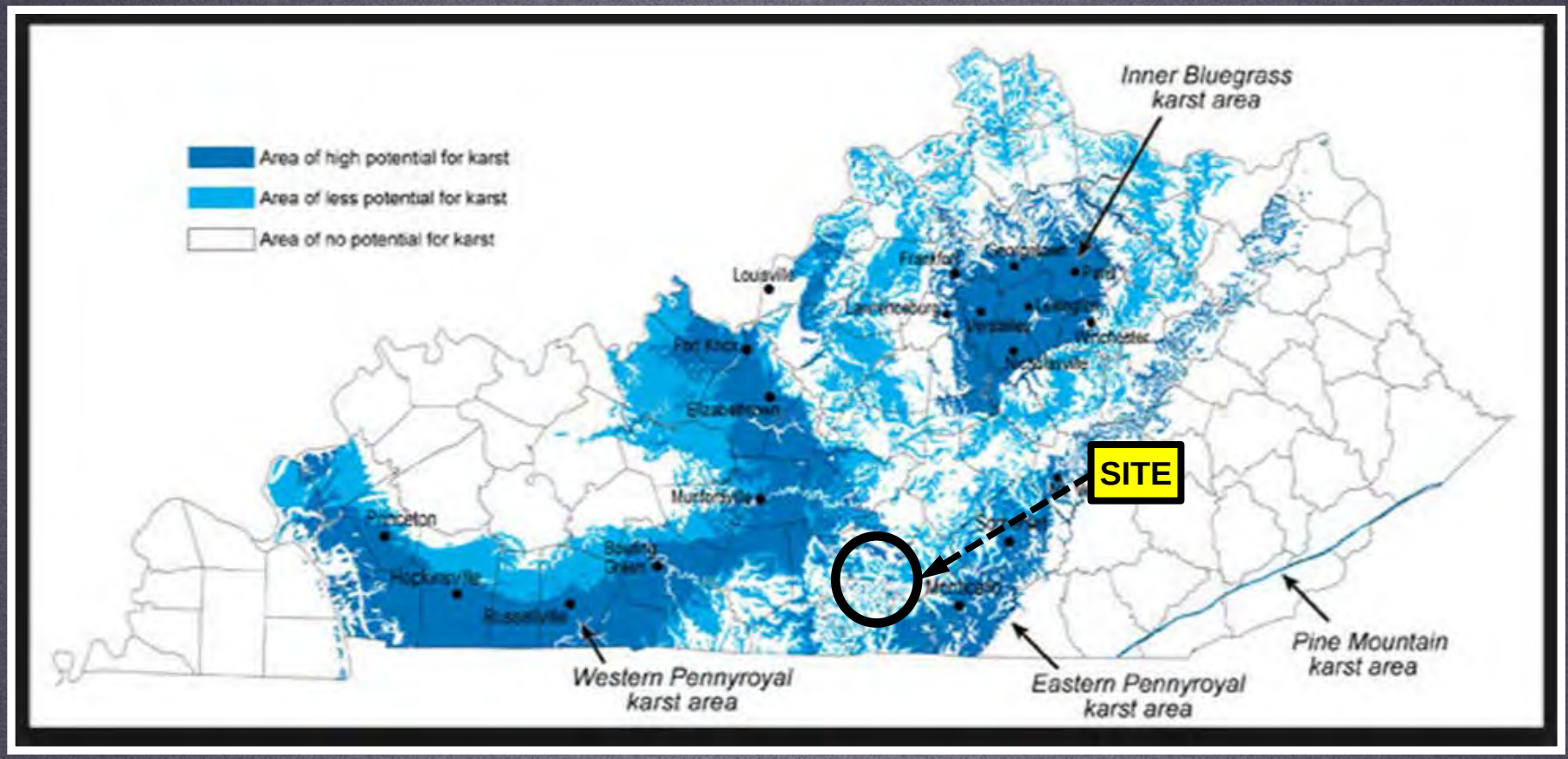


Practical Applications

Environmental Cont.

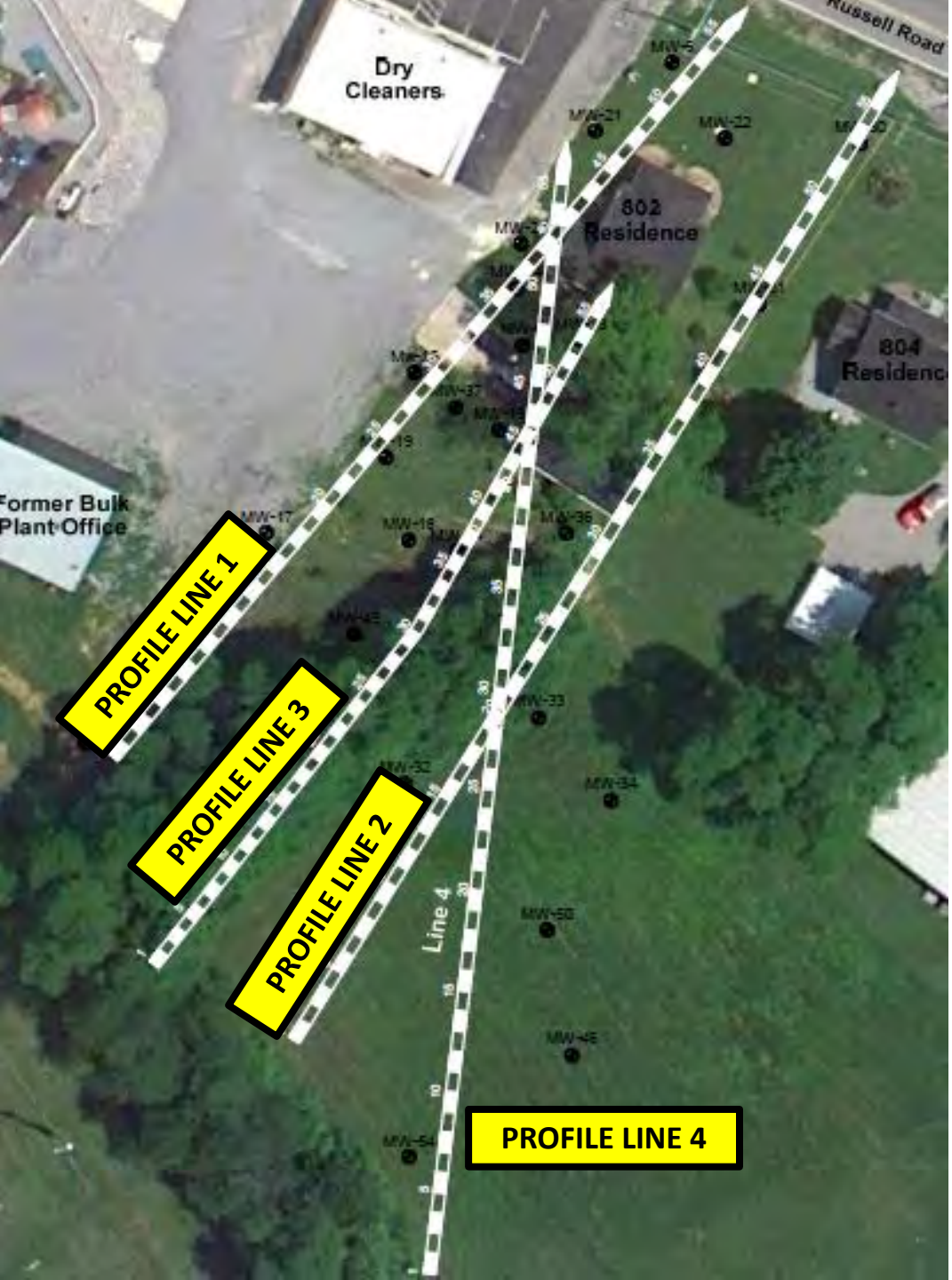
- Site Remediation
  - Preferential Pathways
  - Karst Mapping

Environmental Project in Kentucky



- **92/120 counties contain some areas of karst**
- **40 % of State is underlain by rocks with potential for karst**
- **20 % has well-developed karst features**
- **Occurs in 4 principal regions**

- Gasoline impacts on/off site
- Free product random
- Variable depth to bedrock (10 to 40 ft)
- Offsite impacts



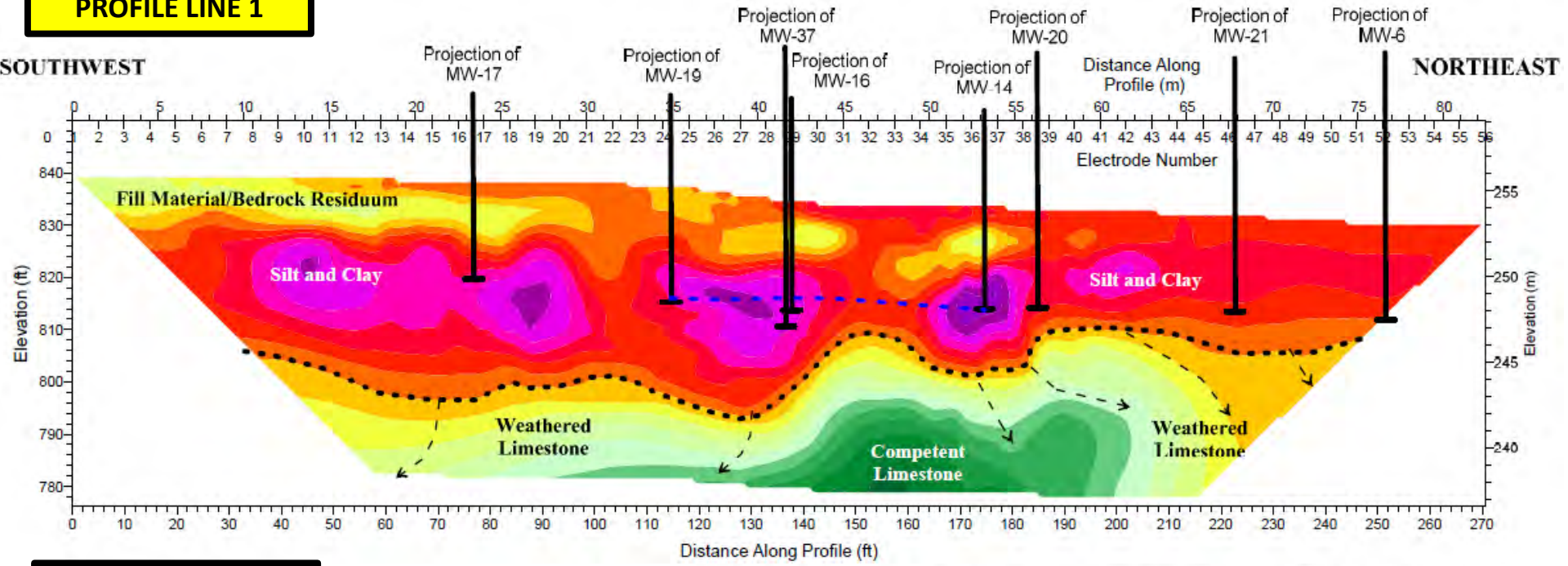
Geophysical Survey
2D Electrical Resistivity

Phase I – 4 Profile Lines

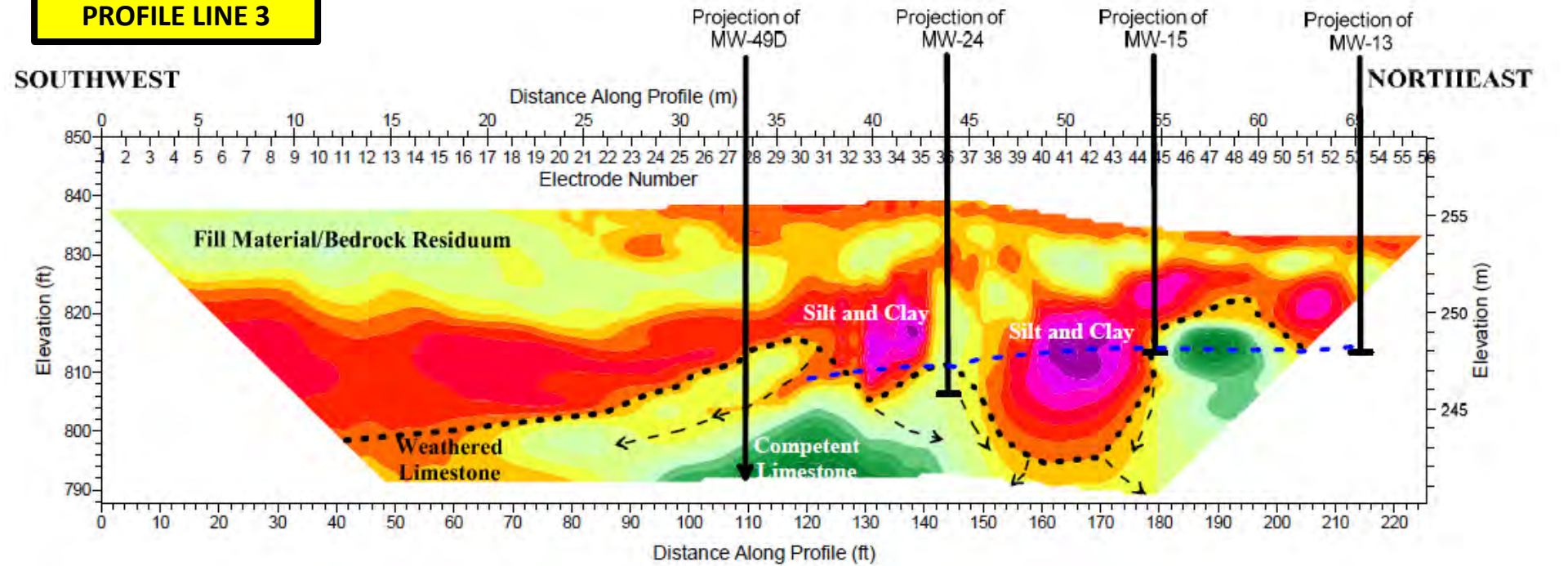
● Monitoring Well Location

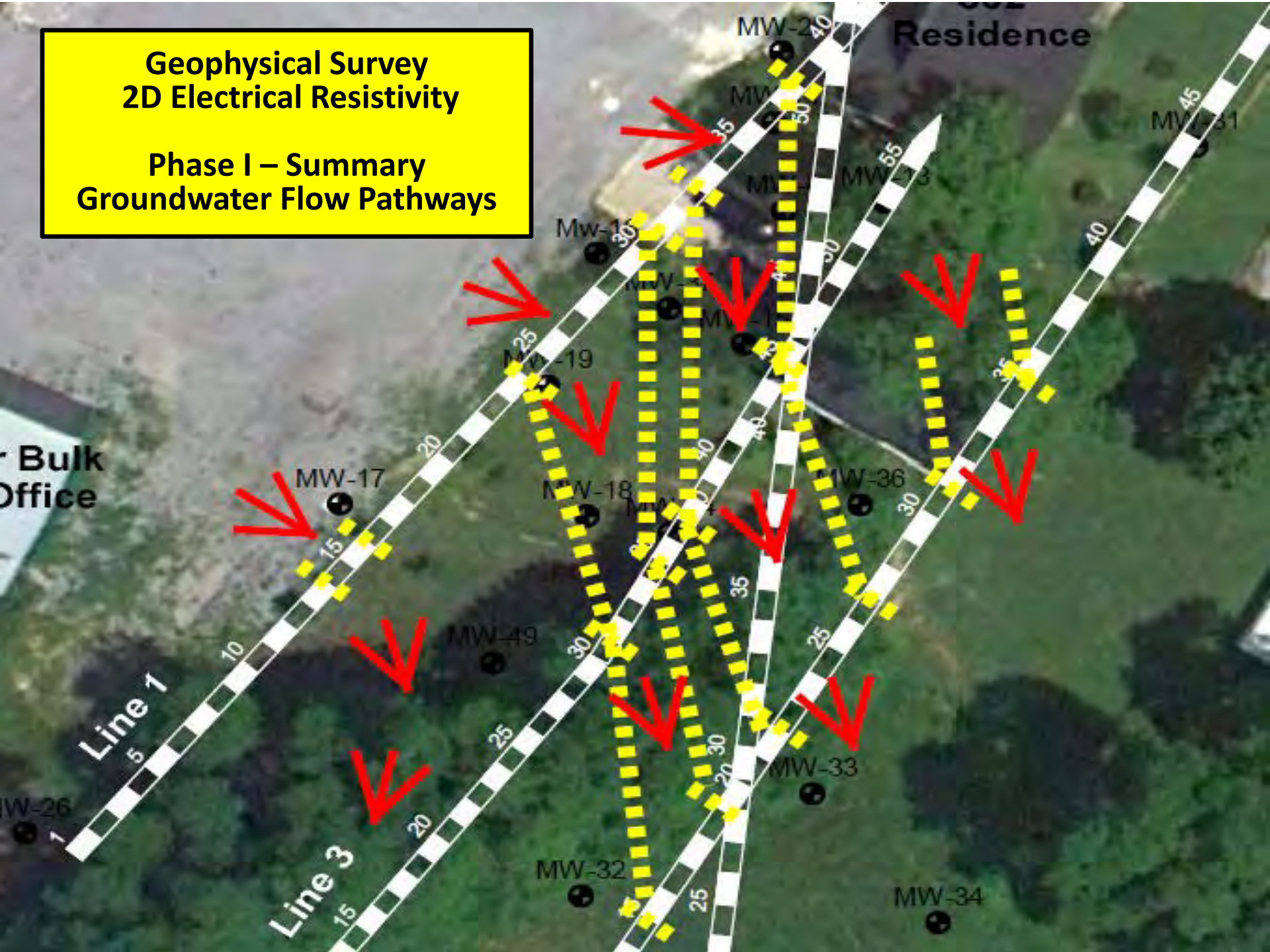
Resistivity Profile Location

PROFILE LINE 1



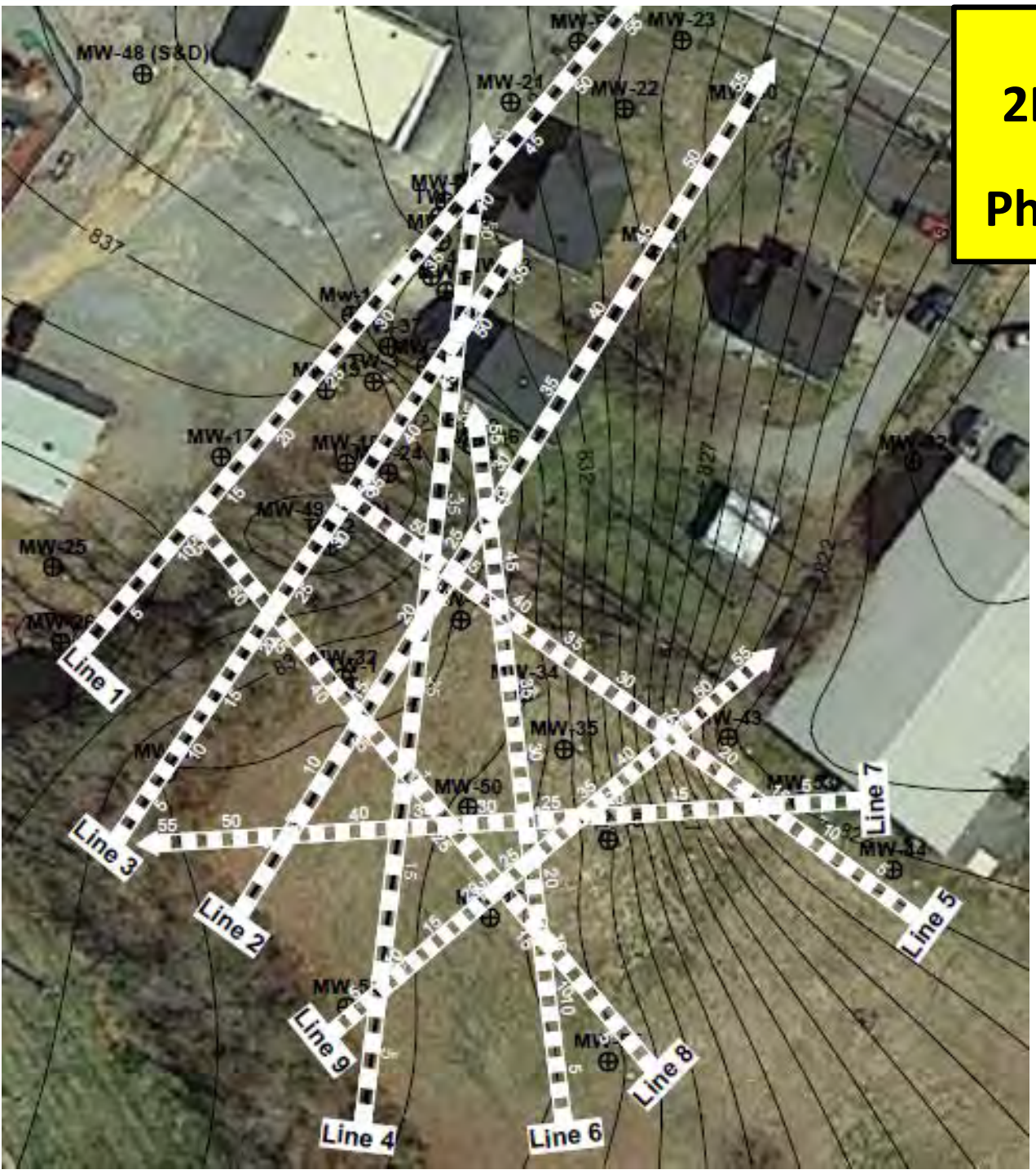
PROFILE LINE 3




Geophysical Survey
2D Electrical Resistivity
Phase I – Summary
Groundwater Flow Pathways
Residence
Bulk
Office
Line 1
Line 3
MW-17
MW-18
MW-19
MW-36
MW-49
MW-33
MW-32
MW-34
MW-26
MW-31
MW-13
MW-15

Geophysical Survey
2D Electrical Resistivity

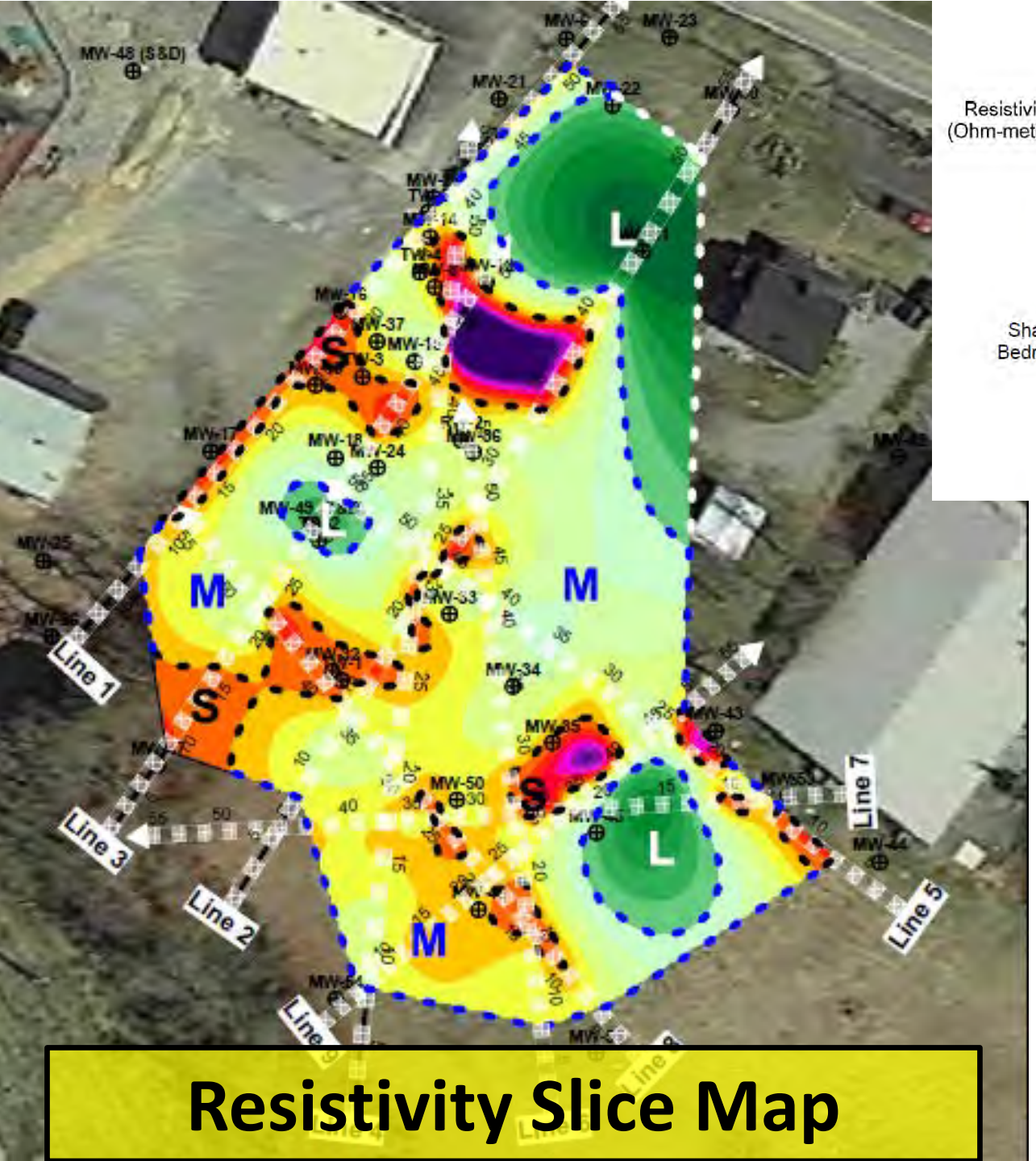
Phase II – 5 Profile Lines



LEGEND

Resistivity Line Location

⊕ Monitoring Well Location



Resistivity Slice Map

LEGEND

Resistivity (Ohm-meters)

4096
2896
2048
1450
1024
724
512
362
256
181
128
90
64
45
32
23
16
11
8
5.7
4
2.8
2
1.4

Dense, Competent Limestone Bedrock

Coarse Soils, Fill, and Residuum (Shallow)

Moderate to Severely Weathered, Fractured, or Solutioned Limestone with Soil-or-Water-Filled Voids (Deeper)

Shale Bedrock

Moist, Clayey Soil (Shallow) Shale Bedrock/Soil-or-Water-Filled Voids (Deeper)

Slice at 800 Ft. Elevation

Resistivity Line Location

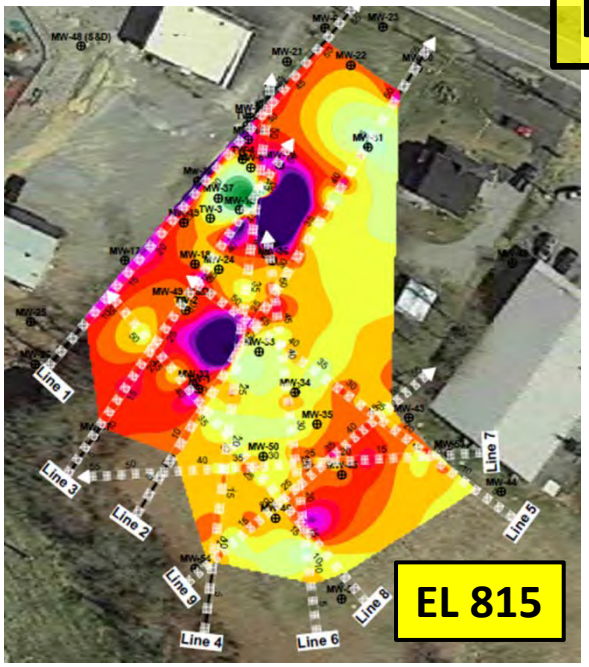
⊕ Monitoring Well Location

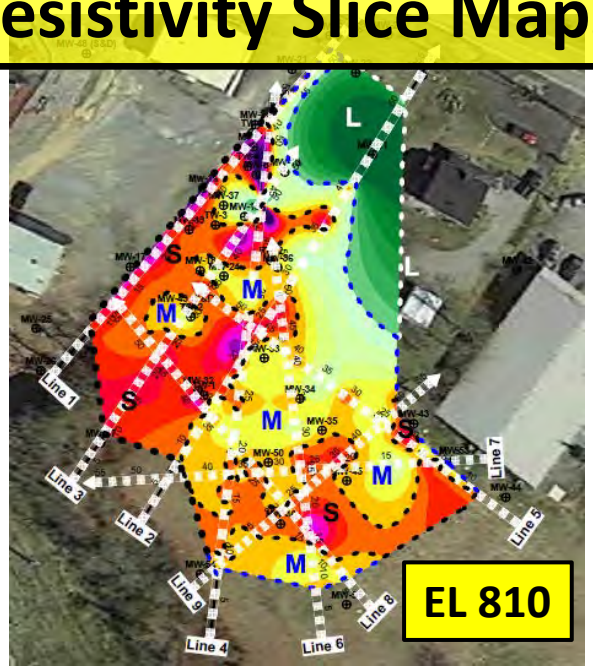
S Zone of Severe Weathering

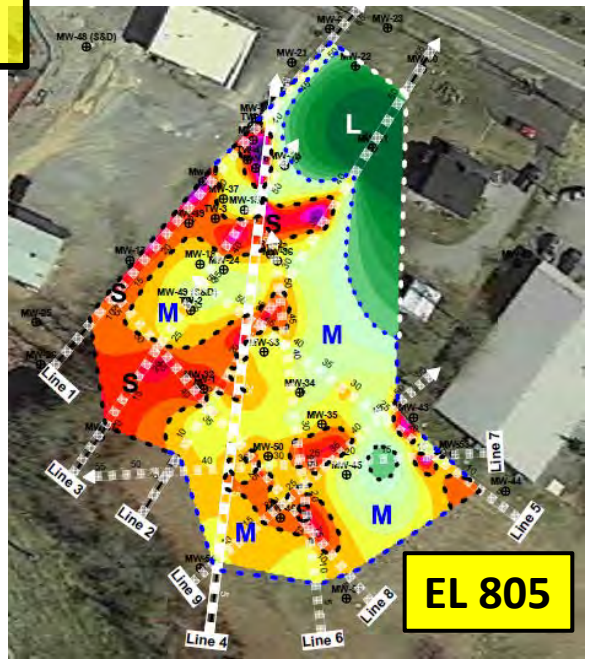
M Zone of Moderate Weathering

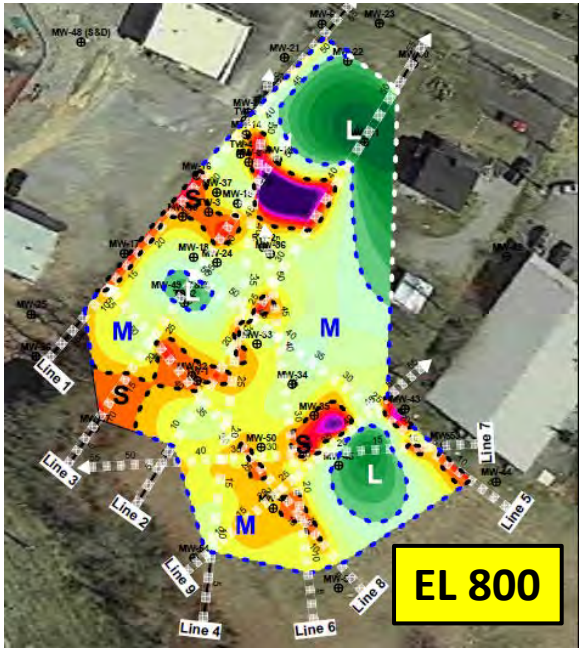
L Zone of Low Weathering

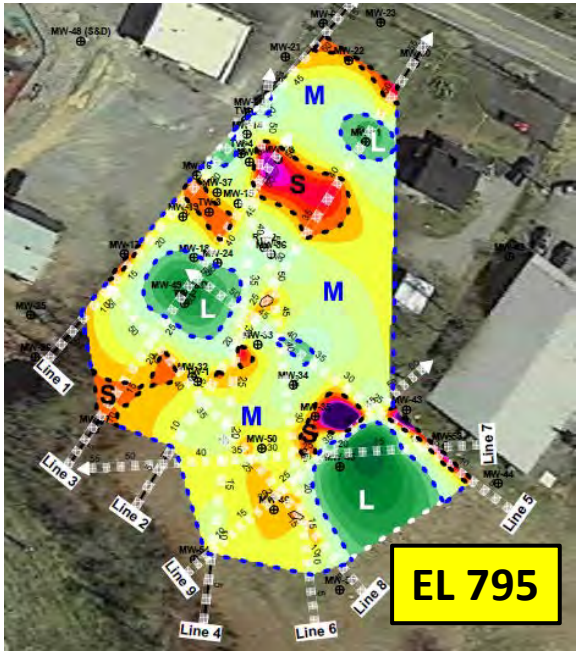
Resistivity Slice Maps

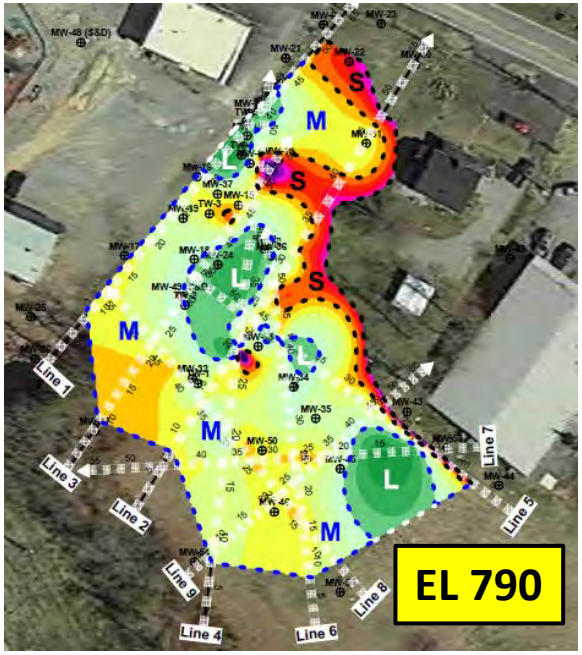




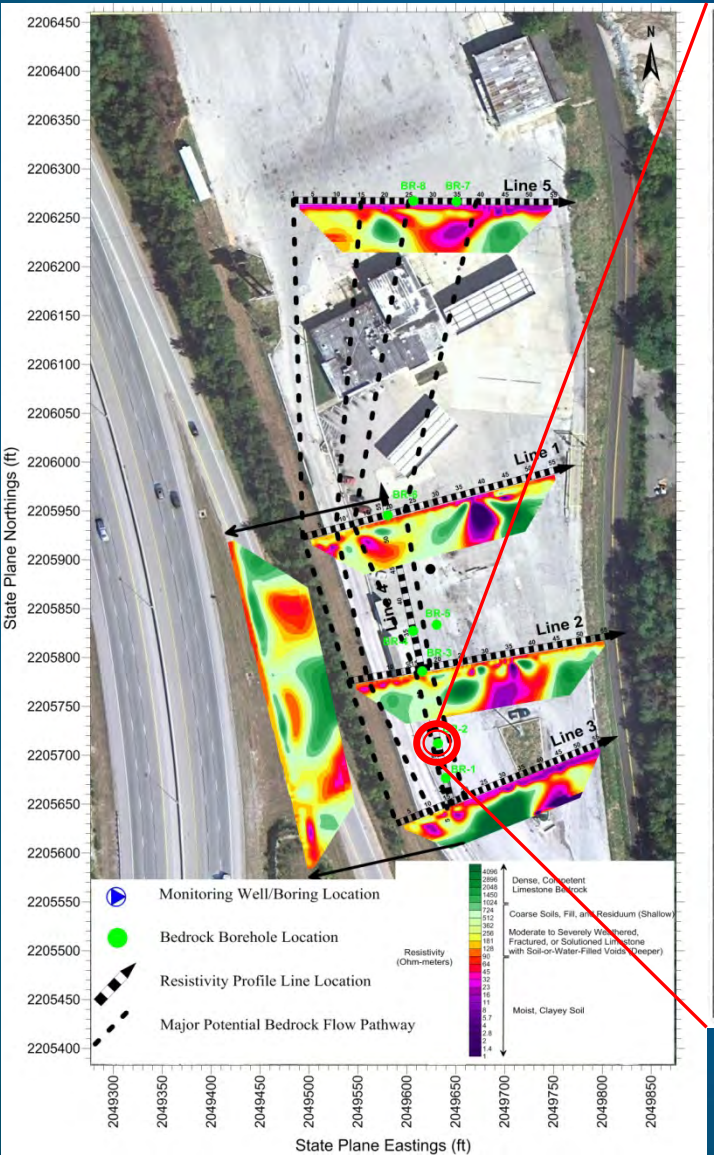


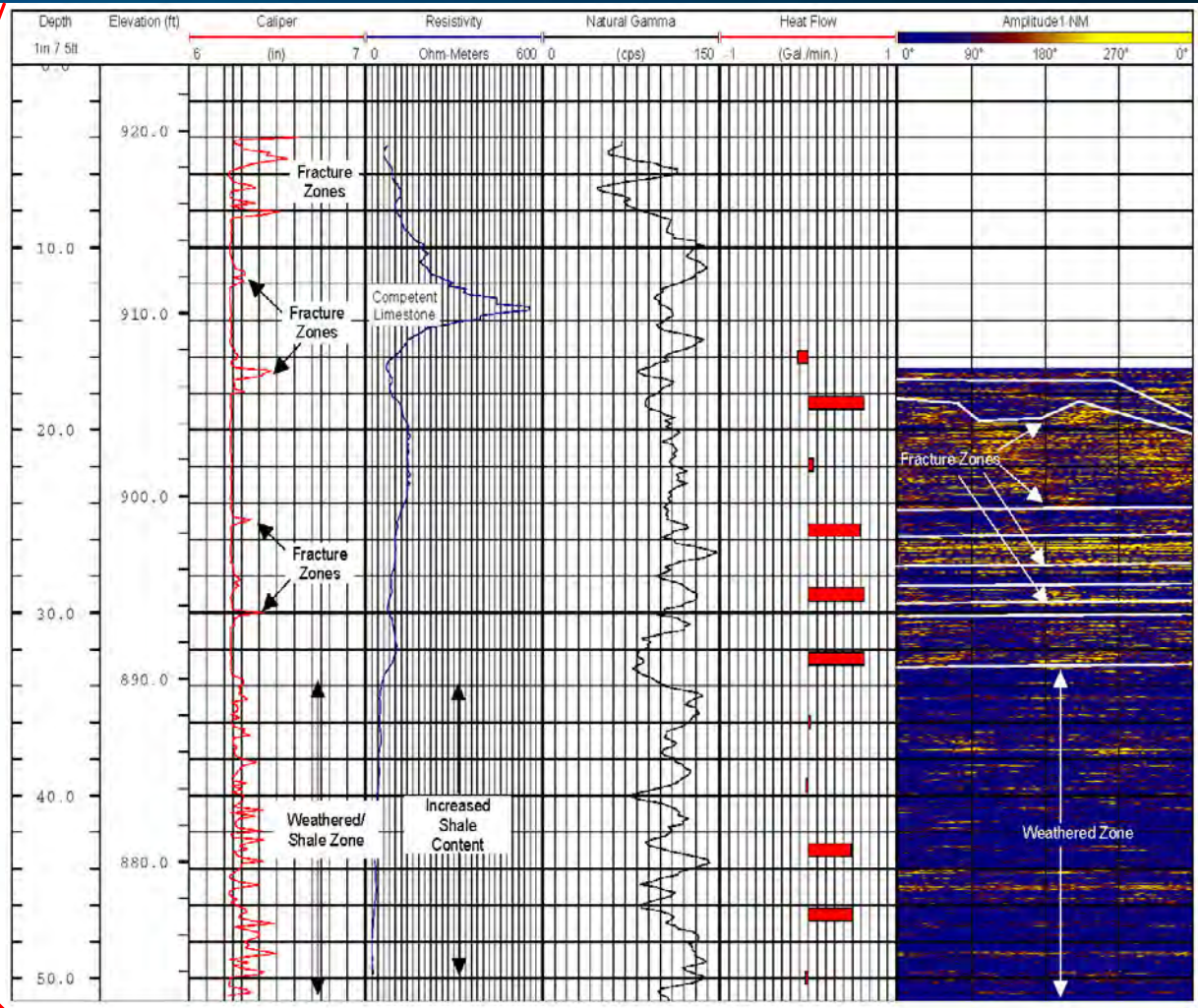




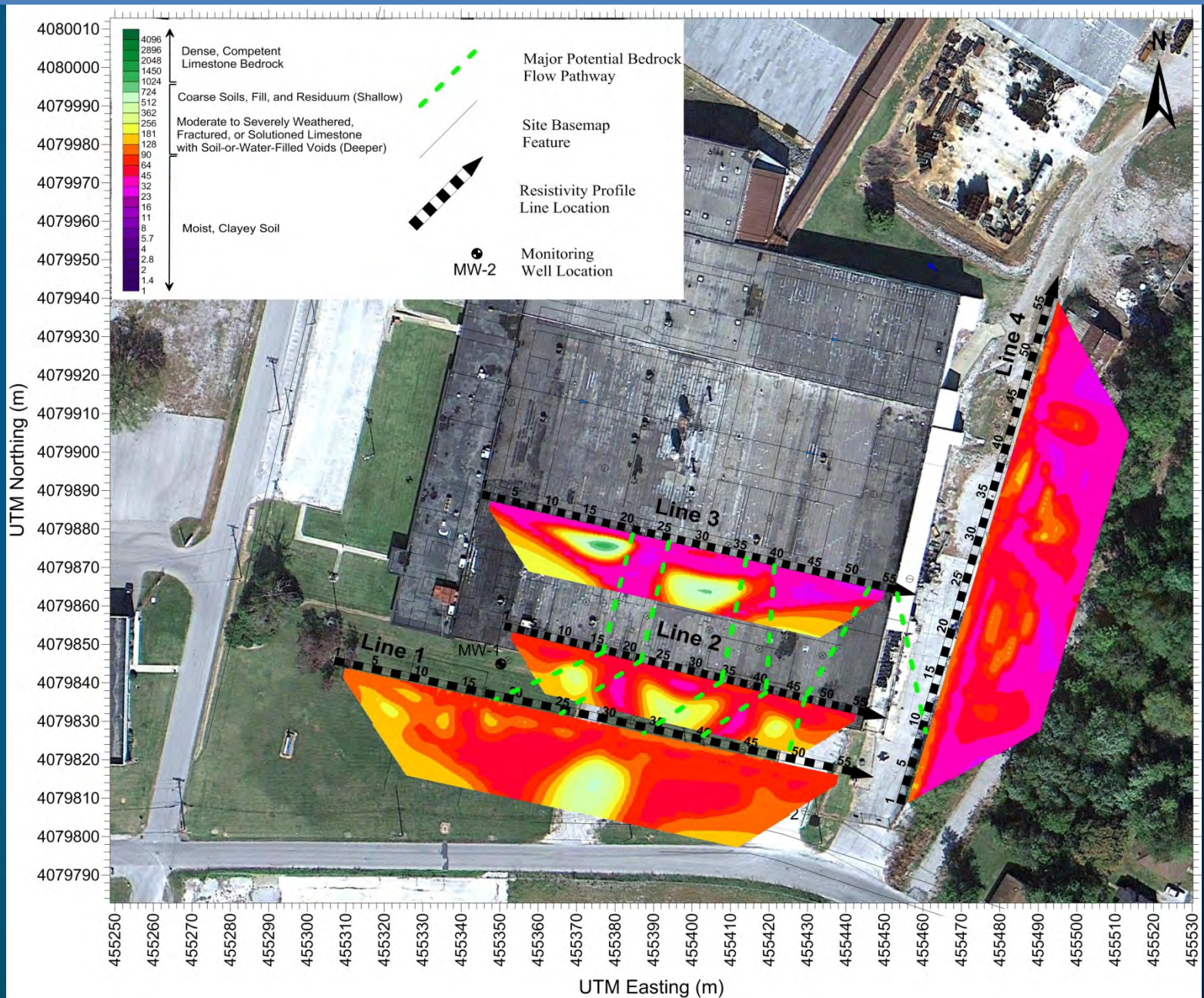


Resistivity Mapping Used to Locate Preferential Pathways and Guide the Placement of Bedrock Cores, Borehole Imaging, and Remedial Injections



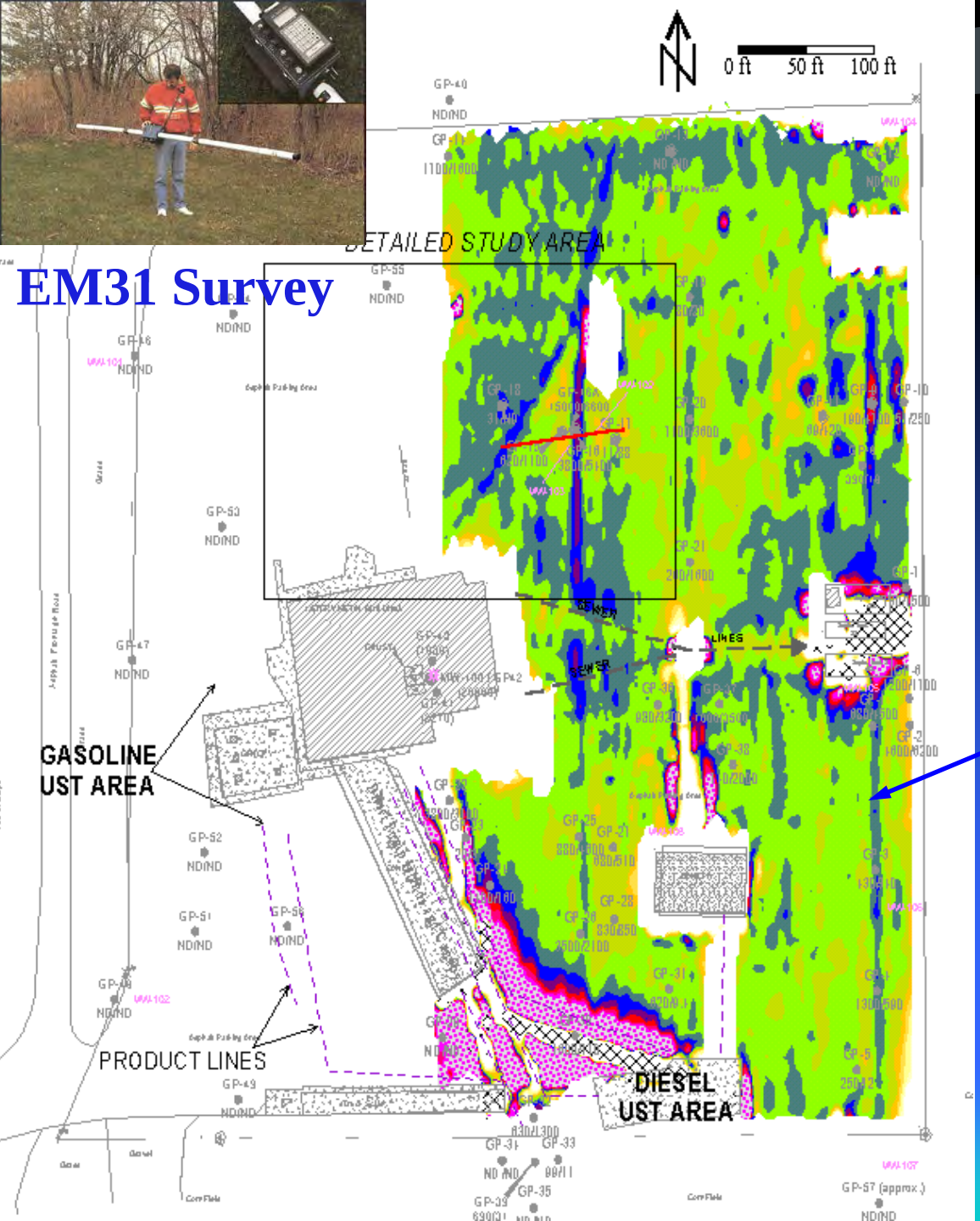


Resistivity Mapping Used to Locate Preferential Pathways and Guide Remedial Injections



Non-Metallic Field Tiles Detected Using Conductivity Mapping

EM31 Survey



11-acre Plume Impacted with Gasoline and Diesel Fuel

Flow pathways along agricultural drainage tiles cut through clay soils within 10 ft of ground surface distributed gasoline across site.

Closing Remarks

- Numerous geophysical techniques available to help on any project
- Geophysical surveys yield increased confidence in finding buried targets and improving Conceptual Site Model
- Complimentary techniques allow for better overall characterization
- Remediation effectiveness improved to allow successful cleanups.

THANKS!

Questions?

Mundell
Consulting Professionals
for the Earth and the Environment

John A. Mundell, P.E., L.P.G
President/Director of Geophysical Services
jmundell@mundellassociates.com

Ryan P. Brumbaugh, L.P.G.
Project Geophysicist
rbrumbaugh@mundellassociates.com

www.mundellassociates.com
317-630-9060