Geophysical Evaluation of Dam Seepage to Support Rehabilitation Efforts

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Presentation Outline

- Dam and Lake History
- Geophysical Survey Methods
- Chacterization Results
- Rehabilitation Efforts
- Lessons Learned

Luzerne Lake Dam
Greenville, Muhlenberg County, Kentucky

Luzerne Lake Dam

Greenville, Muhlenberg County, Kentucky

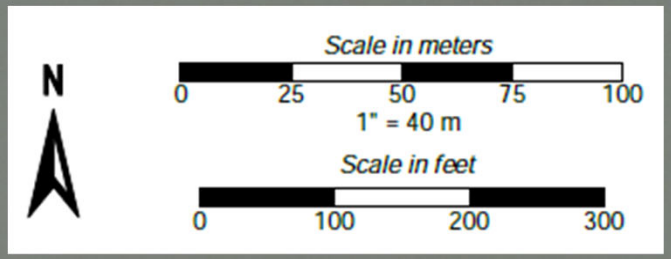
Grout Injection
10 Holes at
3' Spacing
9' Deep

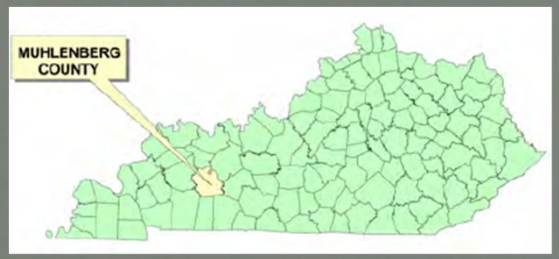
Grout Injection
10 Holes at
3' Spacing
10' Deep

Grout Injection
10 Holes at
3' Spacing
20' Deep

Historical Factoids

- Constructed in the 1920s
- 1200 ft long, 20 ft height
- Excessive seepage on dry side face
- Series of grouting programs at 3 locations
- Continued seepage post grouting
- No site investigation/borings
- Geophysical surveys proposed to locate preferential flow pathways





Dam Erosion and Seepage

Regional Geology

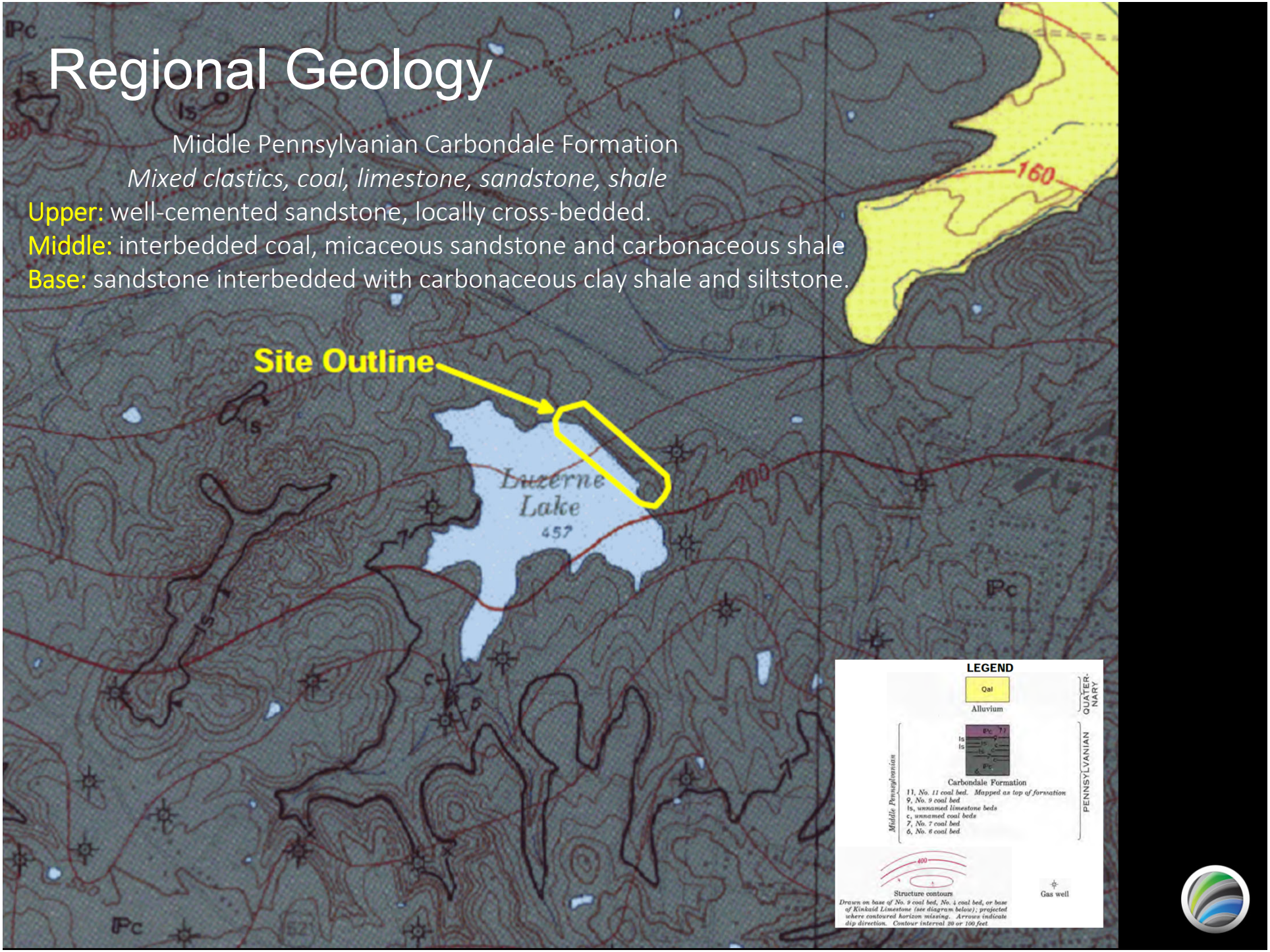
Middle Pennsylvanian Carbondale Formation

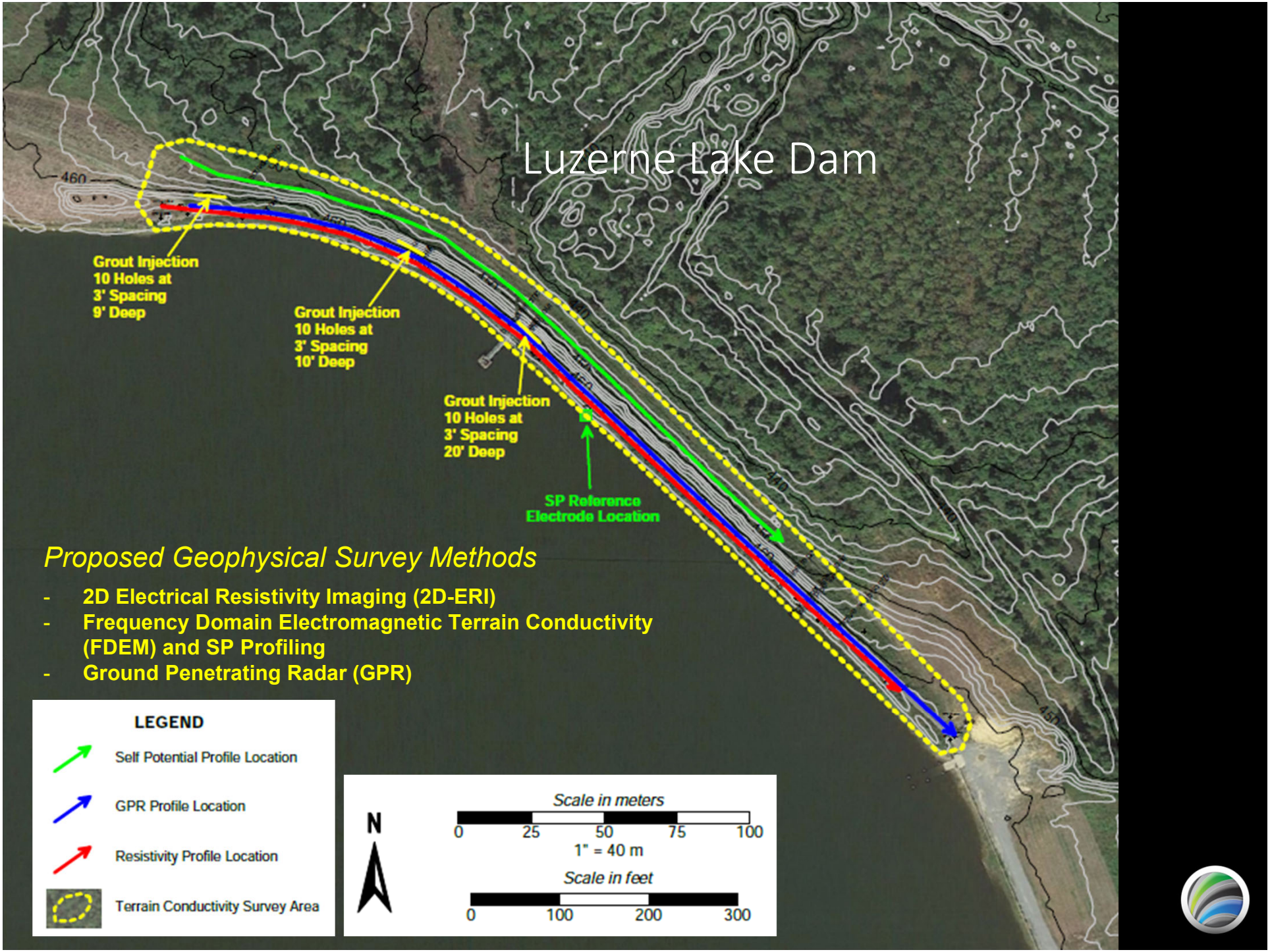
Mixed clastics, coal, limestone, sandstone, shale

Upper: well-cemented sandstone, locally cross-bedded.

Middle: interbedded coal, micaceous sandstone and carbonaceous shale

Base: sandstone interbedded with carbonaceous clay shale and siltstone.




Luzerne Lake Dam
Grout Injection
10 Holes at
3' Spacing
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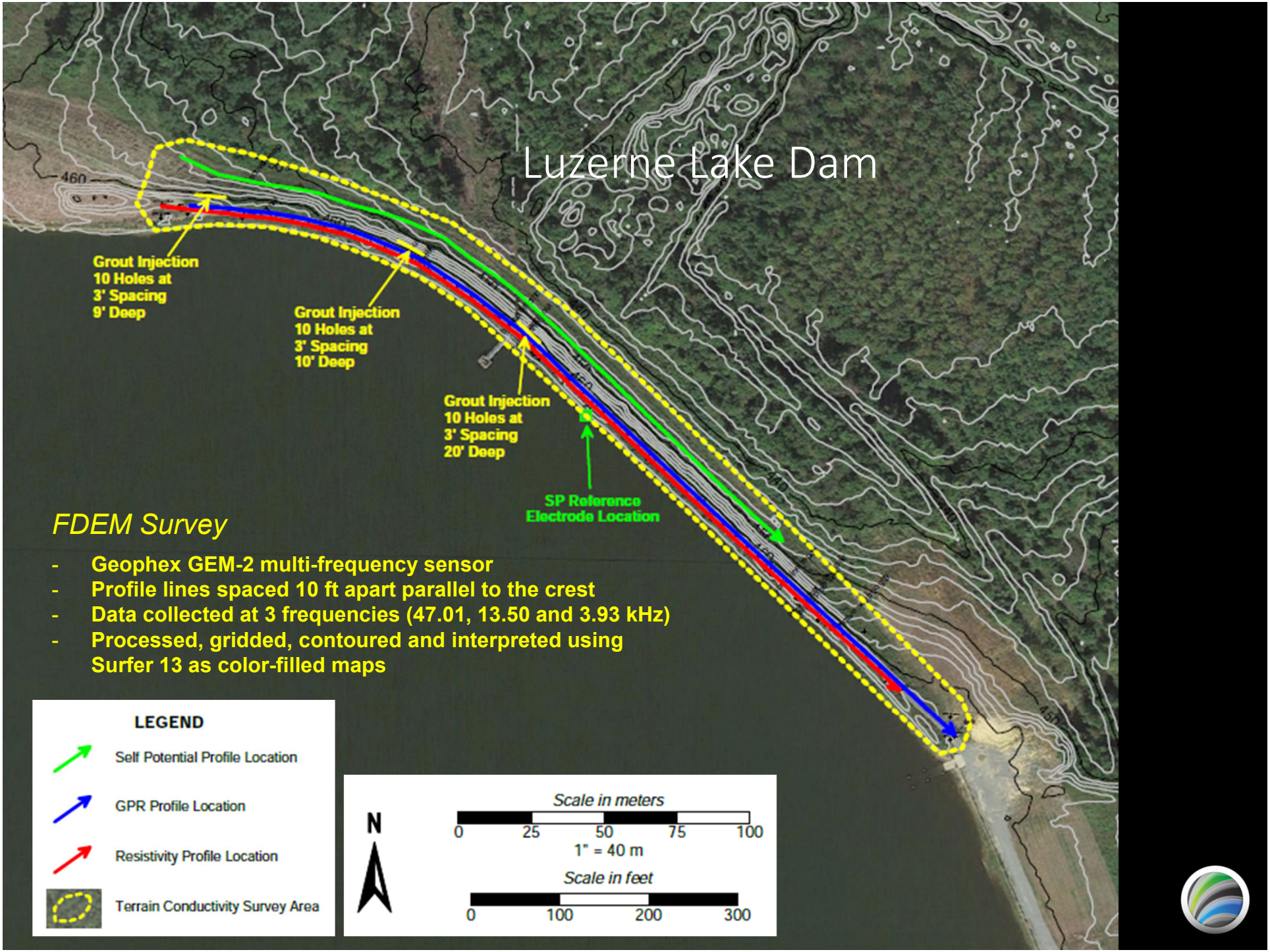
10' Deep
Grout Injection
10 Holes at
3' Spacing
20' Deep
SP Reference
Electrode Location
Proposed Geophysical Survey Methods
- 2D Electrical Resistivity Imaging (2D-ERI)
- Frequency Domain Electromagnetic Terrain Conductivity (FDEM) and SP Profiling
- Ground Penetrating Radar (GPR)
LEGEND
Self Potential Profile Location
GPR Profile Location
Resistivity Profile Location
Terrain Conductivity Survey Area
N
Scale in meters
0 25 50 75 100
1" = 40 m
Scale in feet
0 100 200 300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3' Spacing
10' Deep
Grout Injection
10 Holes at
3' Spacing
20' Deep
SP Reference
Electrode Location
FDEM Survey
- Geophex GEM-2 multi-frequency sensor
- Profile lines spaced 10 ft apart parallel to the crest
- Data collected at 3 frequencies (47.01, 13.50 and 3.93 kHz)
- Processed, gridded, contoured and interpreted using Surfer 13 as color-filled maps
LEGEND
Self Potential Profile Location
GPR Profile Location
Resistivity Profile Location
Terrain Conductivity Survey Area
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Scale in meters
0 25 50 75 100
1" = 40 m
Scale in feet
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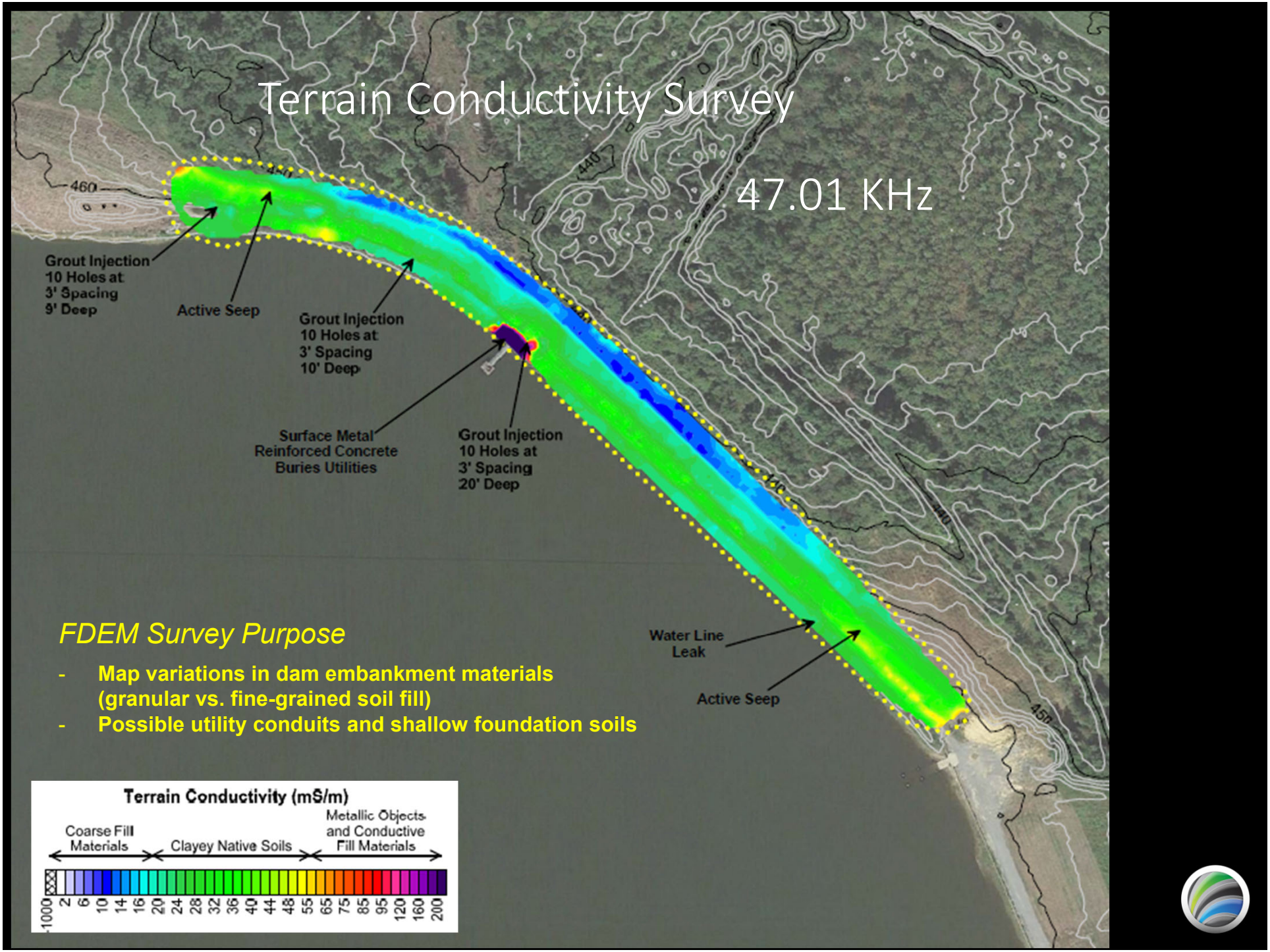
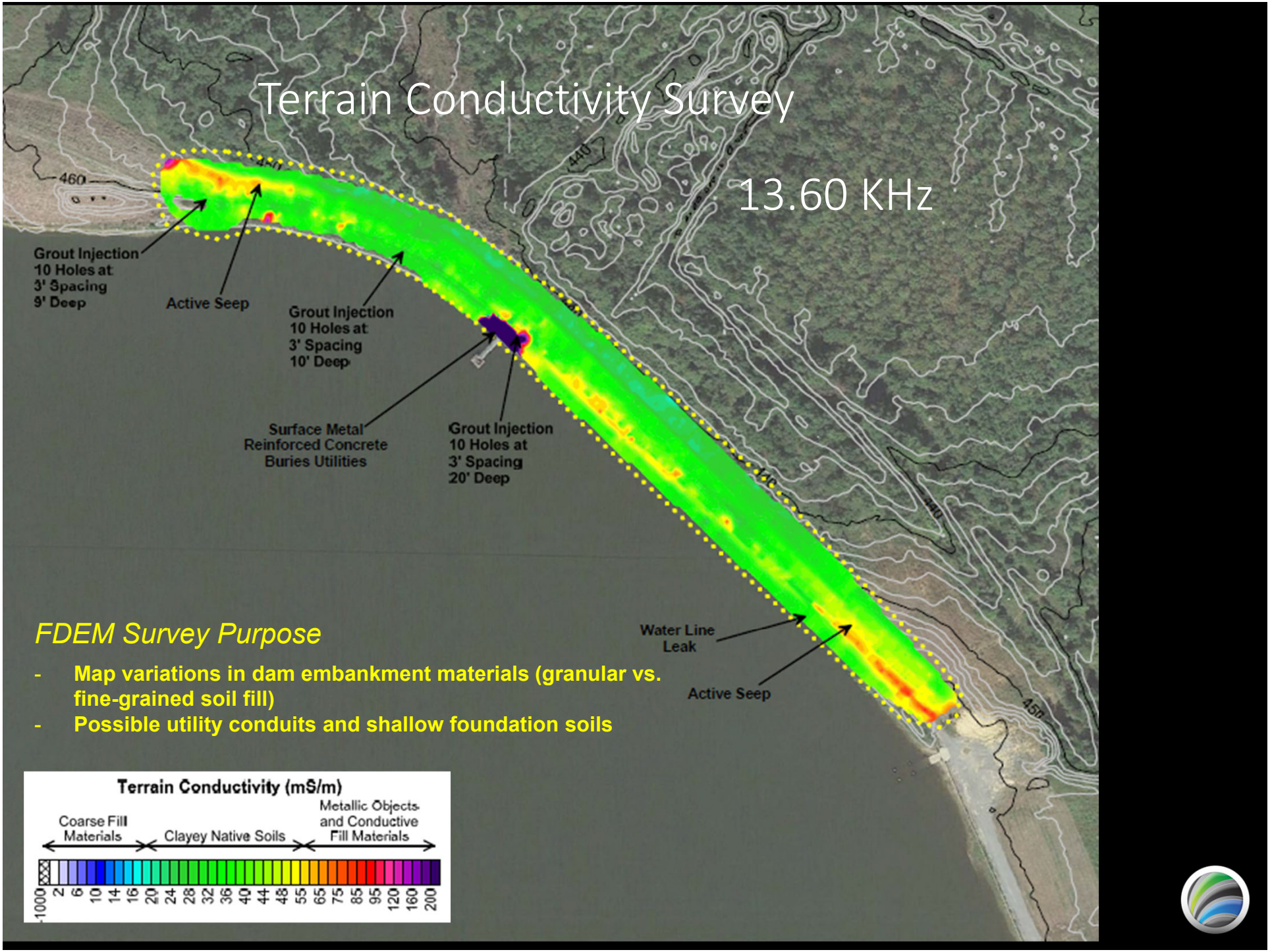
Terrain Conductivity Survey

47.01 KHz



FDEM Survey Purpose

- **Map variations in dam embankment materials (granular vs. fine-grained soil fill)**
- **Possible utility conduits and shallow foundation soils**


Terrain Conductivity Survey
13.60 KHz
Grout Injection
10 Holes at
3' Spacing
9' Deep
Active Seep
Grout Injection
10 Holes at
3' Spacing
10' Deep
Surface Metal
Reinforced Concrete
Buries Utilities
Grout Injection
10 Holes at
3' Spacing
20' Deep
Water Line
Leak
Active Seep
FDEM Survey Purpose
- Map variations in dam embankment materials (granular vs. fine-grained soil fill)
- Possible utility conduits and shallow foundation soils
Terrain Conductivity (mS/m)
Coarse Fill Materials
Clayey Native Soils
Metallic Objects and Conductive Fill Materials
-1000
2
6
10
14
16
20
24
28
32
36
40
44
48
55
65
75
85
95
120
160
200

Luzerne Lake Dam

Nonpolarizable Electrode

Grout Injection
10 Holes at
3' Spacing
9' Deep

Grout Injection
10 Holes at
3' Spacing
10' Deep

Grout Injection
10 Holes at
3' Spacing
20' Deep

SP Reference
Electrode Location

Spontaneous Potential (SP) Survey

- **Nonpolarizable Electrodes**
- **Reference electrode on wetside at water line**
- **Moving electrodes along dryside toe at 2 ft intervals**
- **Plot self potential values measured, observe trends and anomalies expected based on flow (inflow, outflow)**

LEGEND

- Self Potential Profile Location
- GPR Profile Location
- Resistivity Profile Location
- Terrain Conductivity Survey Area

N

Scale in meters

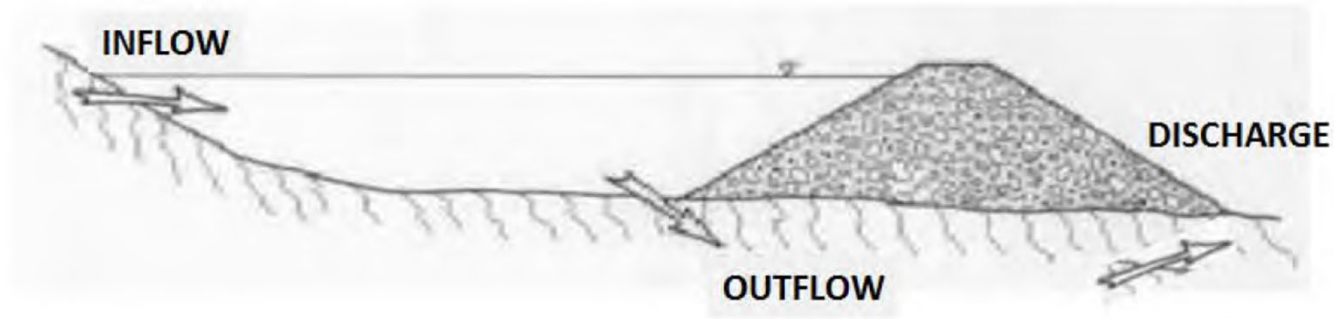
0 25 50 75 100

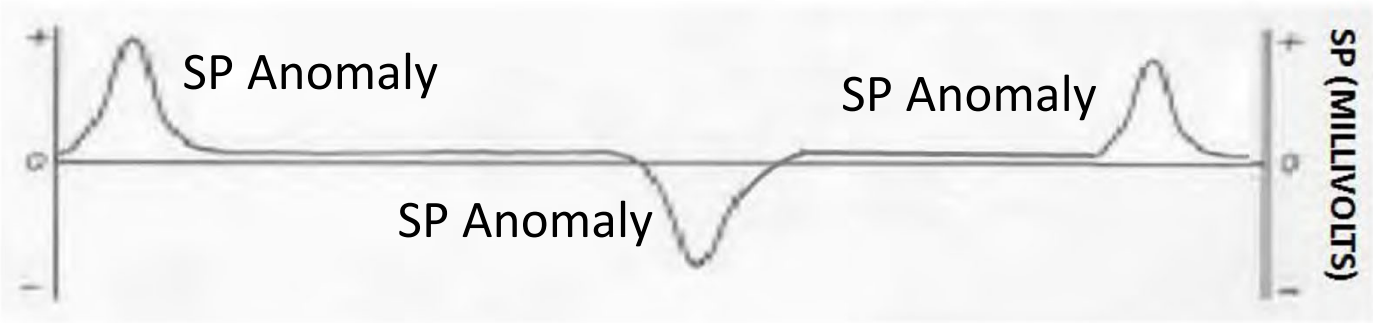
1" = 40 m

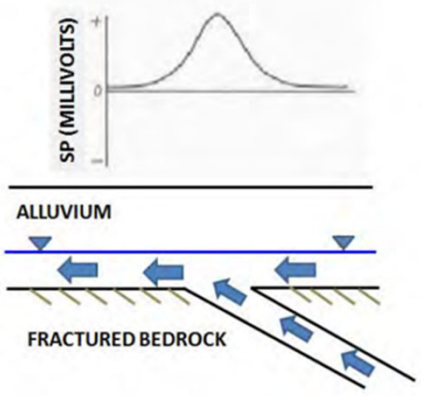
Scale in feet

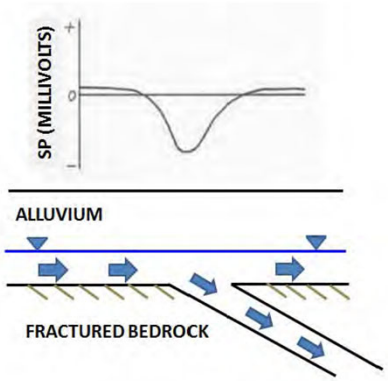
0 100 200 300

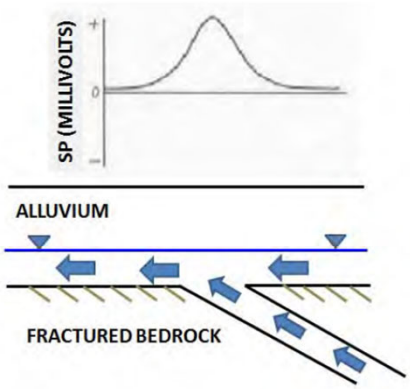
SP Response from Flows into and out of Dams











2D-ERI Survey

- Data collected with an AGI SuperSting R8 earth resistivity meter
- Dipole-dipole array of 56 electrodes at a spacing of 3 ft along one long profile line of about 1100 ft in length along the crest of the dam.
- Data downloaded and inverse-modeled using the software Advanced EarthImager2D

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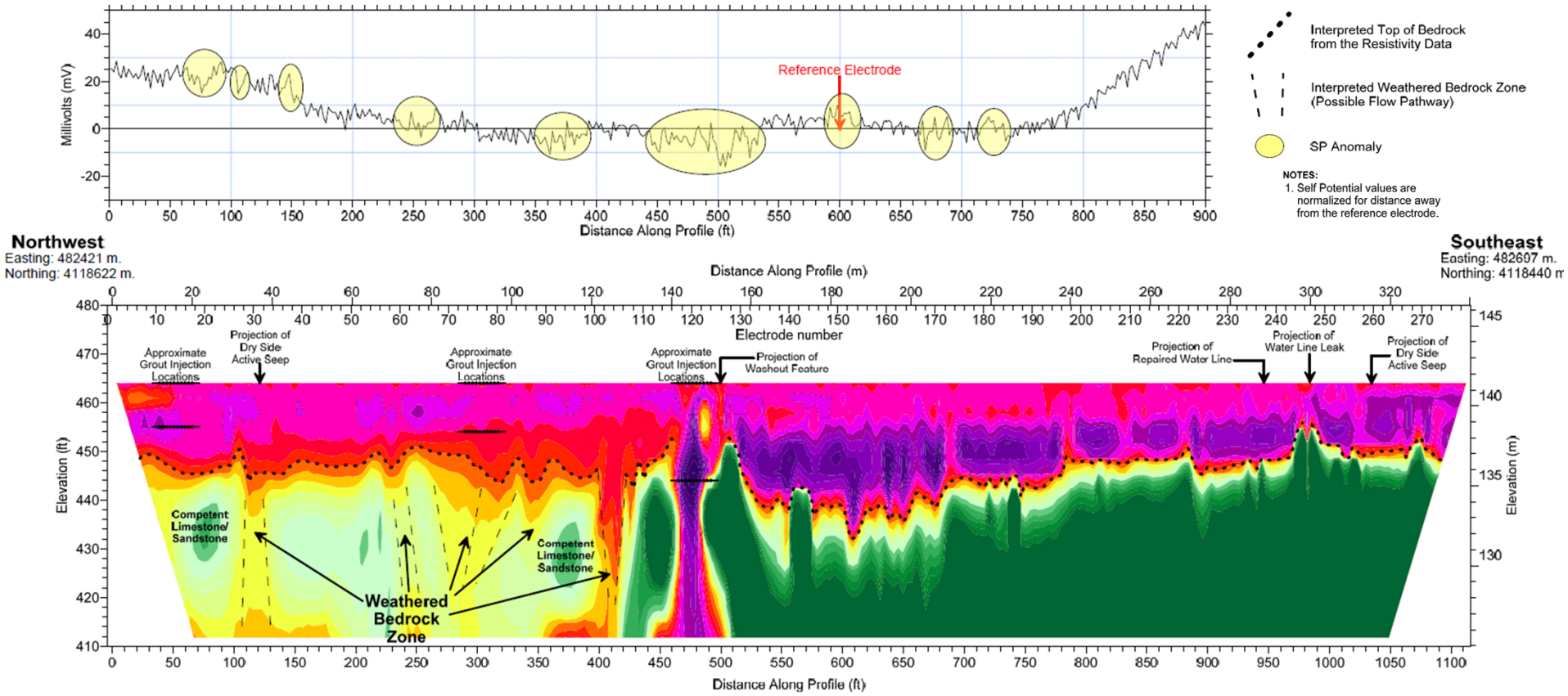
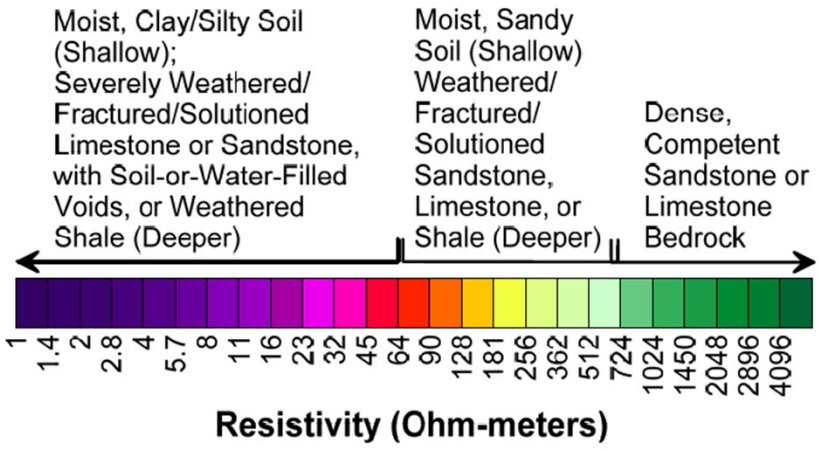
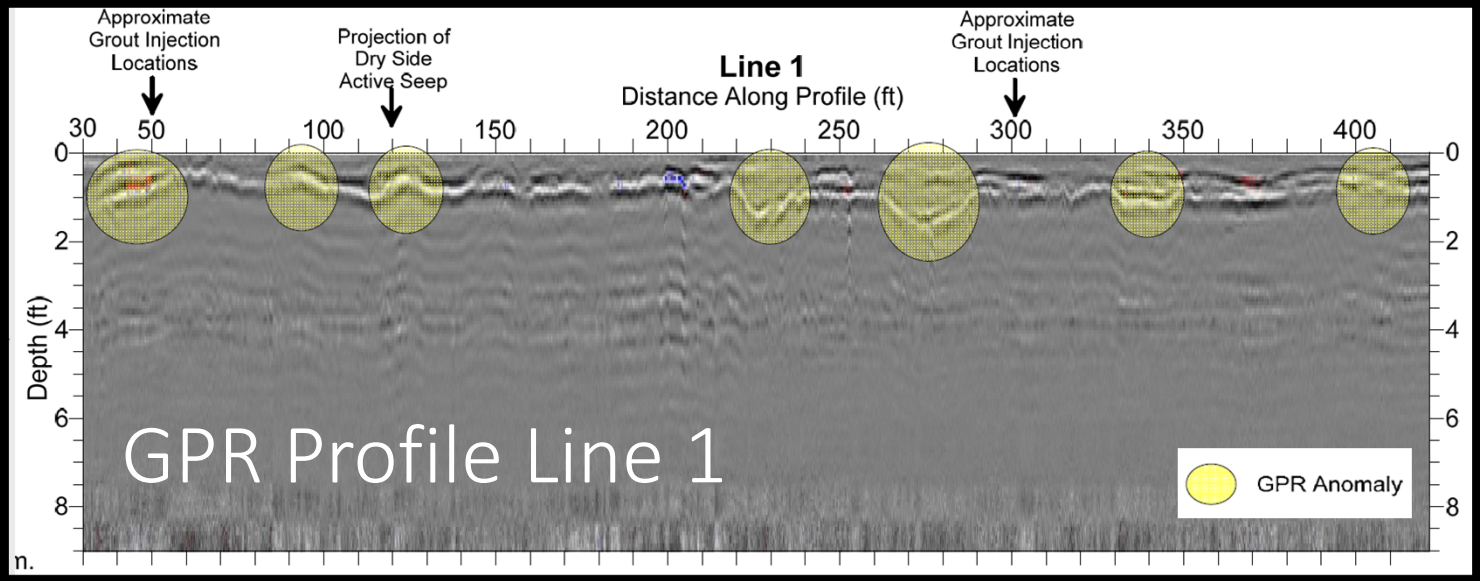
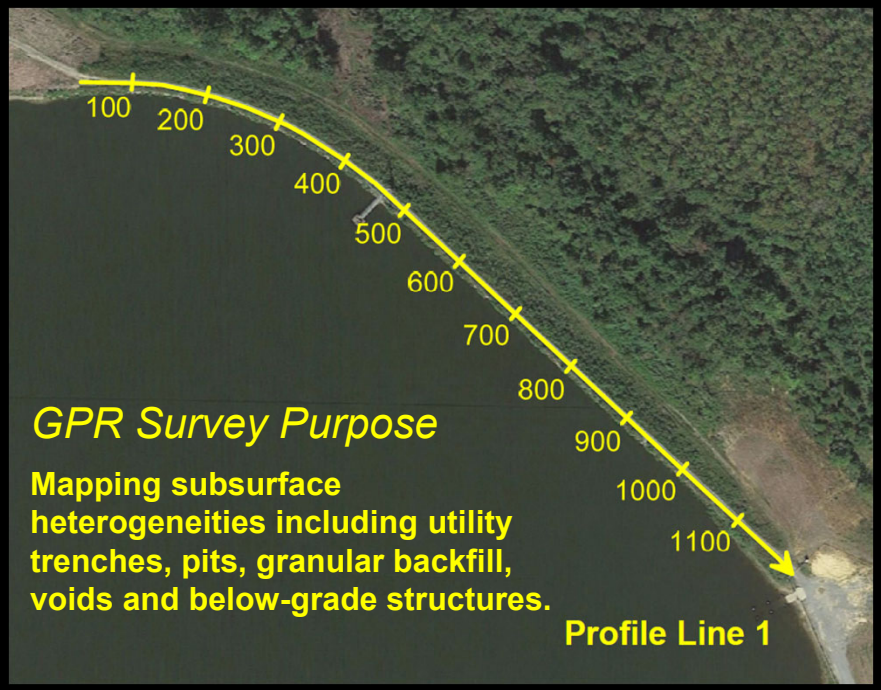




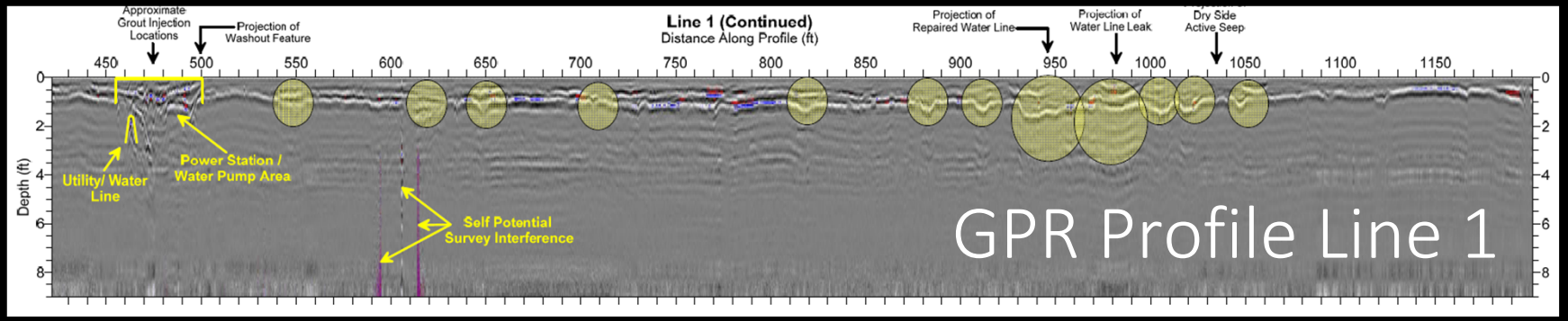
Resistivity and Self Potential Profile Line 1





GPR Survey

GSSI SIR4000 System with a shielded 400-megahertz (MHz) antenna; processed with RAdar Data Analyzer (RADAN) Version 7.4


Approximate Grout Injection Locations
Projection of Washout Feature
Line 1 (Continued)
Distance Along Profile (ft)
Projection of Repaired Water Line
Projection of Water Line Leak
Dry Side Active Seep
450
500
550
600
650
700
750
800
850
900
950
1000
1050
1100
1150
Depth (ft)
0
2
4
6
8
Utility/ Water Line
Power Station / Water Pump Area
Self Potential Survey Interference
GPR Profile Line 1

GPR Anomaly

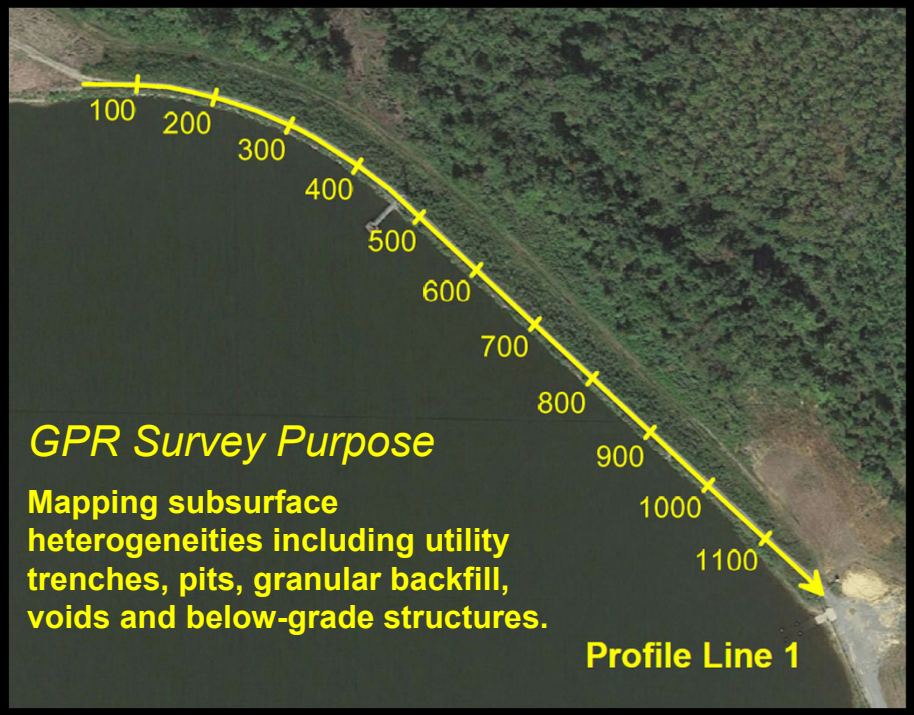

100
200
300
400
500
600
700
800
900
1000
1100
GPR Survey Purpose
Mapping subsurface heterogeneities including utility trenches, pits, granular backfill, voids and below-grade structures.
Profile Line 1

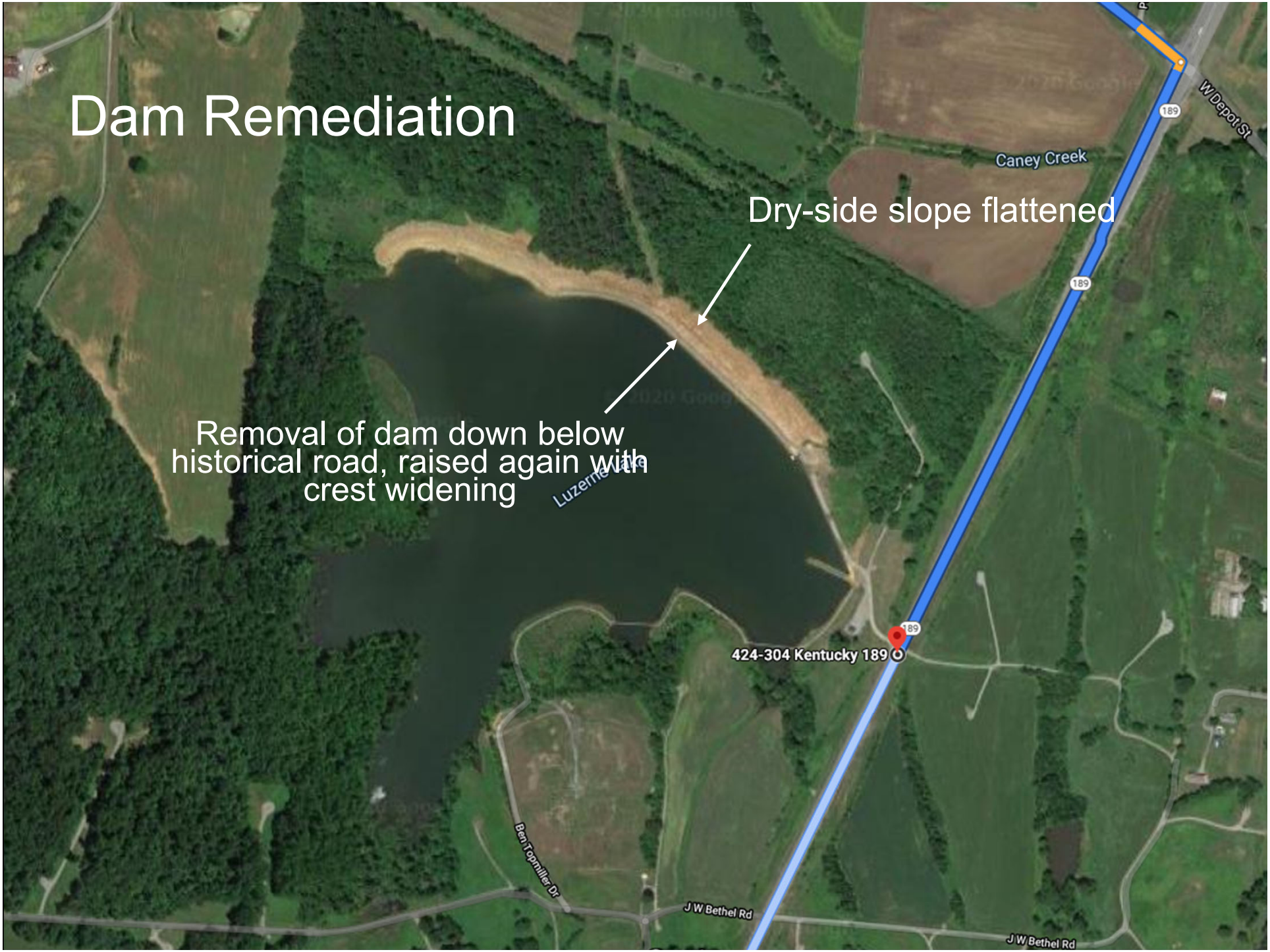
Table 1. Summary of Potential Seepage Areas from Geophysical Data Evaluatic

Distance Along Profile Line, ft	FDEM	2D-ERI Soils	2D-ERI Bedrock	SP	GPR
30 to 60	X	X	-	-	X
60 to 90	X	X	-	X	-
90 to 100	X	-	-	-	X
100 to 110	-	X	X	X	-
120 to 130	-	-	-	-	X
145 to 160	-	X	-	X	-
220 to 240	X	X	-	-	X
235 to 270	-	X	X	X	-
330 to 350	-	-	-	-	X
350 to 390	X	X	X	X	X
400 to 410	-	X	X	-	X
445 to 535	X	X	X[a]	X	X
540 to 560	-	-	-	-	X
585 to 610	-	-	X[a]	X	-
610 to 630	-	-	-	-	X
640 to 660	-	-	-	-	X
670 to 690	-	-	X[a]	X	-
715 to 740	-	-	-	X	X
810 to 820	-	-	-	-	X
880 to 890	-	-	-	-	X
910	X	-	-	-	X
930 to 1050	X	-	-	-	X

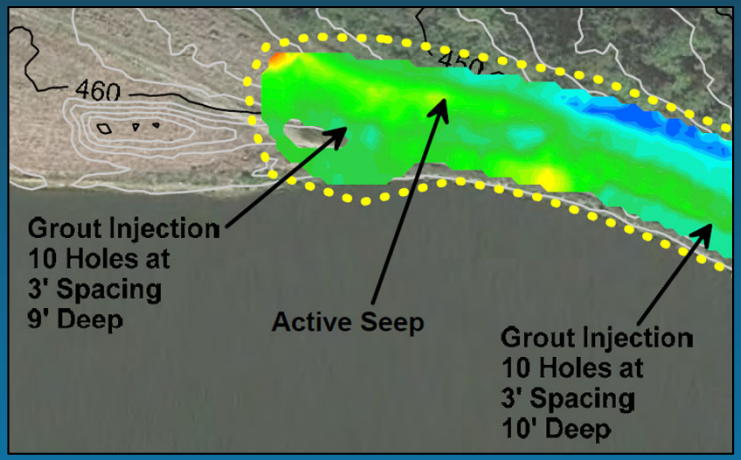
[a]Observed either as low resistivity weathered bedrock zones or greater depth to bedrock.

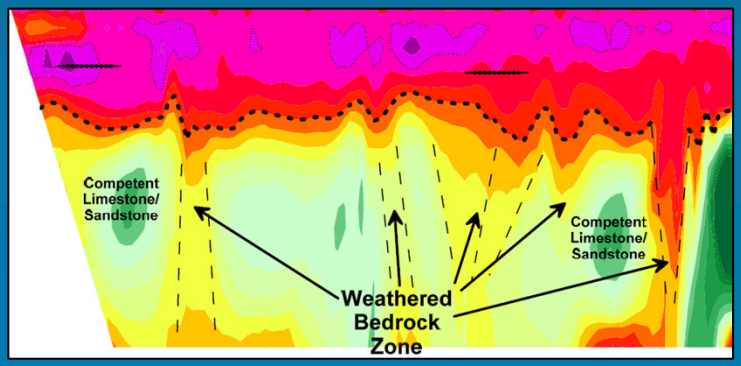
Dam Remediation Alternatives

- Embankment soils seepage
- Foundation bedrock seepage
- Shallow seepage zone removal versus additional grouting
- Removal of upper soils/historic roadway and replace soil/increase crest and flatten dam slope.


Dam Remediation
Dry-side slope flattened
Removal of dam down below historical road, raised again with crest widening
Caney Creek
W Depot St
189
424-304 Kentucky 189
Ben Toomiller Dr
J W Bethel Rd
J W Bethel Rd

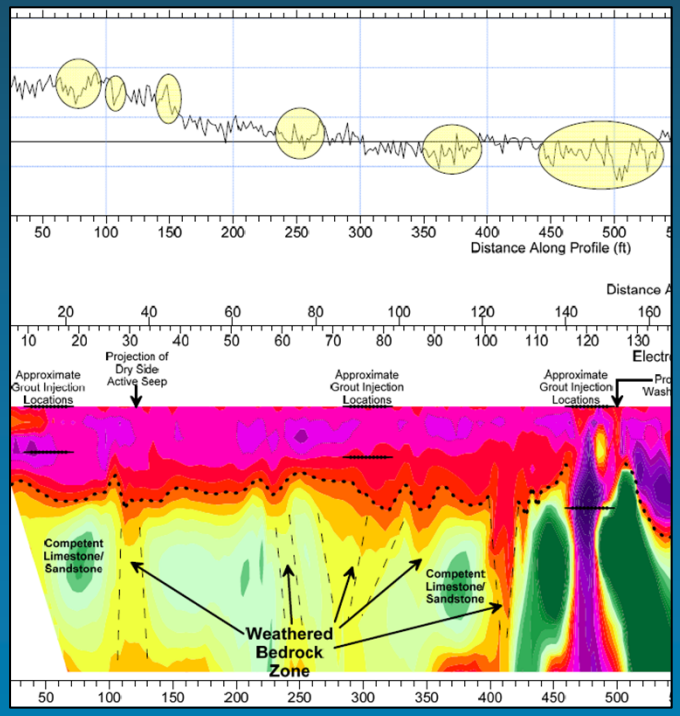
Conclusions





- Geophysical profiles were able to map an undulating variably-weathered bedrock surface beneath fine-grained clayey dam embankment materials
- Several zones of decreased resistivity present within dam embankment soils, could indicate increased soil moisture contents and seepage zones.

Conclusions



- Areas of anomalous Spontaneous Potential (SP) readings correlate well with several areas of lower resistivity within the soil and bedrock, providing another line of evidence for increased seepage.
- Some evidence that the 3 former grout areas remain locations of increased seepage.

Conclusions

- Some evidence of remaining seepage to the northwest and southeast of the water intake structure where erosion washout is currently observed.
- Geophysical surveys led to understanding of potential seepage pathways and selection of remedial alternative.