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An Exelon Company

# Appendix E

# Aestus ERI Survey
# Technical Memorandum

# AESTUS' GEOTRAX SURVEY™ SITE CHARACTERIZATION WORK PEPCO BENNING FACILITY WASHINGTON, D.C., USA

**PREPARED FOR:** **AECOM**

**PREPARED BY:** **Aestus, LLC**

**DATE:** **October 4, 2013**

## EXECUTIVE SUMMARY

An innovative approach to site characterization was performed by AECOM at the PEPCO Benning Facility located in Washington, D.C. Aestus, LLC (Aestus) was retained by AECOM to scan the subsurface of this site with its proprietary electrical resistivity imaging (GeoTrax Survey™) technology to map subsurface environmental impacts. This "scan first and then drill" approach has been very successful in the oil/gas and medical industries and has facilitated a very high data density site characterization effort, relative to simply installing a few monitoring wells via the conventional "drilling blind" methodology.

The project objectives of this investigation program included using Aestus' GeoTrax Survey™ technology to assist AECOM with:

1. Lateral and horizontal extent of impacts
2. Map geology/geotechnical data
3. Optimize placement of monitoring wells
4. Identify the Arundel clay and potential preferential pathways
5. Address site as a potential PCB impact to Anacostia River

A total of 10 GeoTrax Surveys™ were performed at the locations shown on Figure PV-1. Aestus employed its "Evidence-Based Geophysics" process to effectively integrate and view available data (i.e., geophysical and historical/confirmation drilling/sampling data) together on the 2-D survey images and in a 3-D visualization model, which assists AECOM in developing a robust conceptual site model (CSM). Figures 1 through 10 show GeoTrax Survey™ 2-D images, selected for detailed discussion, in one site specific resistivity color contouring scheme. Figures 12 through 16 show example 3-D perspective views (entire 3-D model is provided as Electronic Appendix E2). Please note that the various data sets combined in the 2-D Figures and 3-D visualization model are not all exactly aligned temporally or geospatially.

The following conclusions are offered at the time of this technical memo based on Aestus experience, professional judgment and our Evidence-Based Geophysics process. As with all environmental assessments, these conclusions are reached with a certain acceptable degree of uncertainty, due to the possibility that relevant subsurface conditions may exist beyond the scope of this geophysical investigation. The below conclusions are subject to revision based on any follow up drilling/sampling data from anomalous locations detected by Aestus.

1. Based on the areas surveyed, the site appears largely unimpacted.
2. Deeper electrically resistive zones do not appear to be impacted (Note: these zones may reflect naturally occurring gas pockets; methane or CO2).
3. Shallow electrically resistive zones are lightly impacted with PAHs & hydrocarbon/MTBE (location dependent). No PCBs were detected above regulatory standards (i.e., Project Screening Levels or PSLs) in confirmation borings performed along GeoTrax Survey™ transect lines.
4. The abovementioned shallow impacts appear small and isolated. Based on the proximity to electrically conductive zones these shallow impacts are likely undergoing some level of naturally occurring biodegradation.
5. GeoTrax Survey™ data can be used to delineate targets that are slightly above regulatory levels.
6. Should additional questions remain that drilling alone cannot address, additional GeoTrax Surveys™ could be performed if/as necessary.

Aestus believes that our GeoTrax Survey™ work combined with AECOM's follow up confirmation drilling/sampling work achieved the abovementioned project objectives and provided the following value added elements to the project:

- High resolution/high data density scanning left "fewer stones unturned" and focused AECOM's drilling work on potential anomalous zones detected by Aestus
- The integrated geophysical and drilling data sets provide strong integrated evidence of low impacts on site
- This approach yielded a stronger conceptual site model with increased certainty and decreased potential trailing liabilities for Pepco
- Shallow pockets of impacts were pinpointed
- Potential biodegradation zones provide data for potential MNA evaluation

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF ELECTRONIC APPENDICES

Appendix A Aestus' GeoTrax Survey™ Field Notes

Appendix B Reference - Technical Paper (The Effects of LNAPL Biodegradation Products on Electrical Conductivity Measurements)

Electronic Appendix E-1 Site Photographs

Electronic Appendix E-2 3-D Visualization Model and Free Viewer Software

Electronic Appendix E-3 XYZR GeoTrax Survey™ Data Output Files

# TABLES

# Table 1
## Electrode Spacing, Survey Line Length, and Survey Depth
## PEPCO-Benning Facility
## Washington, DC, USA

| Survey ID | Electrode Spacing (m) | Survey Line Length (ft) | Image Depth (ft) |
|---|---|---|---|
| WAS-01 | 2.00 | 361 | 72 |
| WAS-02 | 3.00 | 541 | 108 |
| WAS-03 | 3.00 | 541 | 108 |
| WAS-04 | 3.00 | 541 | 108 |
| WAS-05 | 3.00 | 541 | 108 |
| WAS-06 | 2.50 | 451 | 90 |
| WAS-07 | 3.00 | 541 | 108 |
| WAS-08 | 3.00 | 541 | 108 |
| WAS-09 | 3.00 | 541 | 108 |
| WAS-10 | 1.50 | 271 | 54 |



Aestus, LLC

# Table 2
# GeoTrax Survey™ End Electrode Land Survey Coordinates
# PEPCO-Benning Facility
# Washington, DC, USA

| Survey ID | Electrode 1 | | | Electrode 56 | | |
|---|---|---|---|---|---|---|
| | Easting (ft) | Northing (ft) | Elevation (ft) | Easting (ft) | Northing (ft) | Elevation (ft) |
| WAS-01 | 1,324,607.56 | 448,626.23 | 23.16 | 1,324,594.32 | 448,986.84 | 19.09 |
| WAS-02 | 1,324,104.88 | 448,768.20 | 19.13 | 1,324,622.88 | 448,922.28 | 17.63 |
| WAS-03 | 1,324,128.29 | 448,641.37 | 21.37 | 1,324,663.68 | 448,565.75 | 23.52 |
| WAS-04 | 1,324,400.73 | 448,603.34 | 20.45 | 1,324,935.58 | 448,526.77 | 25.91 |
| WAS-05 | 1,324,138.60 | 448,050.22 | 21.67 | 1,324,170.56 | 448,589.54 | 19.96 |
| WAS-06 | 1,324,309.41 | 448,778.50 | 19.82 | 1,324,339.94 | 449,227.44 | 18.40 |
| WAS-07 | 1,325,445.92 | 448,381.17 | 29.54 | 1,325,448.82 | 448,921.24 | 25.98 |
| WAS-08 | 1,326,175.06 | 448,366.12 | 37.46 | 1,325,636.13 | 448,322.15 | 32.46 |
| WAS-09 | 1,326,448.93 | 448,386.02 | 35.12 | 1,325,910.63 | 448,343.68 | 35.96 |
| WAS-10 | 1,326,080.97 | 447,947.60 | 32.45 | 1,325,886.83 | 447,759.36 | 34.07 |

**Notes:**

1. Coordinates provided: D.C./Maryland State Plane Coordinate System. Horizontal Datum: NAD83. Vertical Datum: MLLW.



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# Table 3
# Distance Along Survey Line from Electrode No. 1 (1.5 m Spacing)
# PEPCO-Benning Facility
# Washington, DC, USA

| *1.5 meter spacing* | | | | | |
|---|---|---|---|---|---|
| ***Electrode*** | ***Meters*** | ***Feet*** | ***Electrode*** | ***Meters*** | ***Feet*** |
| **1** | 0.00 | 0 | **29** | 42.00 | 138 |
| **2** | 1.50 | 5 | **30** | 43.50 | 143 |
| **3** | 3.00 | 10 | **31** | 45.00 | 148 |
| **4** | 4.50 | 15 | **32** | 46.50 | 153 |
| **5** | 6.00 | 20 | **33** | 48.00 | 157 |
| **6** | 7.50 | 25 | **34** | 49.50 | 162 |
| **7** | 9.00 | 30 | **35** | 51.00 | 167 |
| **8** | 10.50 | 34 | **36** | 52.50 | 172 |
| **9** | 12.00 | 39 | **37** | 54.00 | 177 |
| **10** | 13.50 | 44 | **38** | 55.50 | 182 |
| **11** | 15.00 | 49 | **39** | 57.00 | 187 |
| **12** | 16.50 | 54 | **40** | 58.50 | 192 |
| **13** | 18.00 | 59 | **41** | 60.00 | 197 |
| **14** | 19.50 | 64 | **42** | 61.50 | 202 |
| **15** | 21.00 | 69 | **43** | 63.00 | 207 |
| **16** | 22.50 | 74 | **44** | 64.50 | 212 |
| **17** | 24.00 | 79 | **45** | 66.00 | 217 |
| **18** | 25.50 | 84 | **46** | 67.50 | 221 |
| **19** | 27.00 | 89 | **47** | 69.00 | 226 |
| **20** | 28.50 | 94 | **48** | 70.50 | 231 |
| **21** | 30.00 | 98 | **49** | 72.00 | 236 |
| **22** | 31.50 | 103 | **50** | 73.50 | 241 |
| **23** | 33.00 | 108 | **51** | 75.00 | 246 |
| **24** | 34.50 | 113 | **52** | 76.50 | 251 |
| **25** | 36.00 | 118 | **53** | 78.00 | 256 |
| **26** | 37.50 | 123 | **54** | 79.50 | 261 |
| **27** | 39.00 | 128 | **55** | 81.00 | 266 |
| **28** | 40.50 | 133 | **56** | 82.50 | 271 |

* NOTE: Survey WAS-10 has a 1.5 meter electrode spacing.

# Table 4
# Distance Along Survey Line from Electrode No. 1 (2.0 m Spacing)
# PEPCO-Benning Facility
# Washington, DC, USA

| 2 meter spacing | | | | | |
|---|---|---|---|---|---|
| ***Electrode*** | ***Meters*** | ***Feet*** | ***Electrode*** | ***Meters*** | ***Feet*** |
| **1** | 0.00 | 0 | **29** | 56.00 | 184 |
| **2** | 2.00 | 7 | **30** | 58.00 | 190 |
| **3** | 4.00 | 13 | **31** | 60.00 | 197 |
| **4** | 6.00 | 20 | **32** | 62.00 | 203 |
| **5** | 8.00 | 26 | **33** | 64.00 | 210 |
| **6** | 10.00 | 33 | **34** | 66.00 | 217 |
| **7** | 12.00 | 39 | **35** | 68.00 | 223 |
| **8** | 14.00 | 46 | **36** | 70.00 | 230 |
| **9** | 16.00 | 52 | **37** | 72.00 | 236 |
| **10** | 18.00 | 59 | **38** | 74.00 | 243 |
| **11** | 20.00 | 66 | **39** | 76.00 | 249 |
| **12** | 22.00 | 72 | **40** | 78.00 | 256 |
| **13** | 24.00 | 79 | **41** | 80.00 | 262 |
| **14** | 26.00 | 85 | **42** | 82.00 | 269 |
| **15** | 28.00 | 92 | **43** | 84.00 | 276 |
| **16** | 30.00 | 98 | **44** | 86.00 | 282 |
| **17** | 32.00 | 105 | **45** | 88.00 | 289 |
| **18** | 34.00 | 112 | **46** | 90.00 | 295 |
| **19** | 36.00 | 118 | **47** | 92.00 | 302 |
| **20** | 38.00 | 125 | **48** | 94.00 | 308 |
| **21** | 40.00 | 131 | **49** | 96.00 | 315 |
| **22** | 42.00 | 138 | **50** | 98.00 | 322 |
| **23** | 44.00 | 144 | **51** | 100.00 | 328 |
| **24** | 46.00 | 151 | **52** | 102.00 | 335 |
| **25** | 48.00 | 157 | **53** | 104.00 | 341 |
| **26** | 50.00 | 164 | **54** | 106.00 | 348 |
| **27** | 52.00 | 171 | **55** | 108.00 | 354 |
| **28** | 54.00 | 177 | **56** | 110.00 | 361 |

* NOTE: Survey WAS-01 had a 2.0 meter electrode spacing.

# Table 5
# Distance Along Survey Line from Electrode No. 1 (2.5 m Spacing)
# PEPCO-Benning Facility
# Washington, DC, USA

| 2.5 meter spacing | | | | | |
|---|---|---|---|---|---|
| **Electrode** | **Meters** | **Feet** | **Electrode** | **Meters** | **Feet** |
| 1 | 0.00 | 0 | 29 | 70.00 | 230 |
| 2 | 2.50 | 8 | 30 | 72.50 | 238 |
| 3 | 5.00 | 16 | 31 | 75.00 | 246 |
| 4 | 7.50 | 25 | 32 | 77.50 | 254 |
| 5 | 10.00 | 33 | 33 | 80.00 | 262 |
| 6 | 12.50 | 41 | 34 | 82.50 | 271 |
| 7 | 15.00 | 49 | 35 | 85.00 | 279 |
| 8 | 17.50 | 57 | 36 | 87.50 | 287 |
| 9 | 20.00 | 66 | 37 | 90.00 | 295 |
| 10 | 22.50 | 74 | 38 | 92.50 | 303 |
| 11 | 25.00 | 82 | 39 | 95.00 | 312 |
| 12 | 27.50 | 90 | 40 | 97.50 | 320 |
| 13 | 30.00 | 98 | 41 | 100.00 | 328 |
| 14 | 32.50 | 107 | 42 | 102.50 | 336 |
| 15 | 35.00 | 115 | 43 | 105.00 | 344 |
| 16 | 37.50 | 123 | 44 | 107.50 | 353 |
| 17 | 40.00 | 131 | 45 | 110.00 | 361 |
| 18 | 42.50 | 139 | 46 | 112.50 | 369 |
| 19 | 45.00 | 148 | 47 | 115.00 | 377 |
| 20 | 47.50 | 156 | 48 | 117.50 | 385 |
| 21 | 50.00 | 164 | 49 | 120.00 | 394 |
| 22 | 52.50 | 172 | 50 | 122.50 | 402 |
| 23 | 55.00 | 180 | 51 | 125.00 | 410 |
| 24 | 57.50 | 189 | 52 | 127.50 | 418 |
| 25 | 60.00 | 197 | 53 | 130.00 | 427 |
| 26 | 62.50 | 205 | 54 | 132.50 | 435 |
| 27 | 65.00 | 213 | 55 | 135.00 | 443 |
| 28 | 67.50 | 221 | 56 | 137.50 | 451 |

* NOTE: Survey WAS-06 had a 2.5 meter electrode spacing.

# Table 6
# Distance Along Survey Line from Electrode No. 1 (3.0 m Spacing)
# PEPCO-Benning Facility
# Washington, DC, USA

| 3 meter spacing | | | | | |
|---|---|---|---|---|---|
| ***Electrode*** | ***Meters*** | ***Feet*** | ***Electrode*** | ***Meters*** | ***Feet*** |
| **1** | 0.00 | 0 | **29** | 84.00 | 276 |
| **2** | 3.00 | 10 | **30** | 87.00 | 285 |
| **3** | 6.00 | 20 | **31** | 90.00 | 295 |
| **4** | 9.00 | 30 | **32** | 93.00 | 305 |
| **5** | 12.00 | 39 | **33** | 96.00 | 315 |
| **6** | 15.00 | 49 | **34** | 99.00 | 325 |
| **7** | 18.00 | 59 | **35** | 102.00 | 335 |
| **8** | 21.00 | 69 | **36** | 105.00 | 344 |
| **9** | 24.00 | 79 | **37** | 108.00 | 354 |
| **10** | 27.00 | 89 | **38** | 111.00 | 364 |
| **11** | 30.00 | 98 | **39** | 114.00 | 374 |
| **12** | 33.00 | 108 | **40** | 117.00 | 384 |
| **13** | 36.00 | 118 | **41** | 120.00 | 394 |
| **14** | 39.00 | 128 | **42** | 123.00 | 404 |
| **15** | 42.00 | 138 | **43** | 126.00 | 413 |
| **16** | 45.00 | 148 | **44** | 129.00 | 423 |
| **17** | 48.00 | 157 | **45** | 132.00 | 433 |
| **18** | 51.00 | 167 | **46** | 135.00 | 443 |
| **19** | 54.00 | 177 | **47** | 138.00 | 453 |
| **20** | 57.00 | 187 | **48** | 141.00 | 463 |
| **21** | 60.00 | 197 | **49** | 144.00 | 472 |
| **22** | 63.00 | 207 | **50** | 147.00 | 482 |
| **23** | 66.00 | 217 | **51** | 150.00 | 492 |
| **24** | 69.00 | 226 | **52** | 153.00 | 502 |
| **25** | 72.00 | 236 | **53** | 156.00 | 512 |
| **26** | 75.00 | 246 | **54** | 159.00 | 522 |
| **27** | 78.00 | 256 | **55** | 162.00 | 531 |
| **28** | 81.00 | 266 | **56** | 165.00 | 541 |

* NOTE: Surveys WAS-02 through WAS-05, and WAS-07 through WAS-09 have a 3.0 meter electrode spacing.

# FIGURES

# GeoTrax Survey™ Investigation Results
# PEPCO-Benning Facility
# Washington, D.C., USA


Aestus, LLC
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7 Red Oak Road
Wilmington, DE 19806

2605 Dotsero Court
Loveland, CO 80538

6005 West 19th Avenue
Stillwater, OK 74074


| | |
|---|---|
| Scale: | NTS unless specified |
| Drawn By: | MAS |
| Approved By: | SWM |
| Date: | 10-04-13 |
| Project No.: | 12-106-10 |

**GeoTrax Survey™ Investigation Results**
**PEPCO-Benning Facility**
**Washington, D.C., USA**

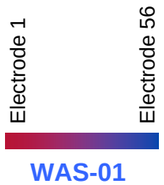
*Prepared for* AECOM

FIGURE

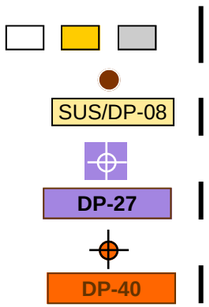
**TITLE PAGE**

# Legend and Symbols

**(for reference when reviewing all Figures)**




GeoTrax Survey™ Orientation and Designation (scale is approximate)




Indicates various site features which are labeled accordingly on the figures

Indicates surface soil sample locations

Indicates Phase I surface soil sample locations (Mar/Apr 2013; collected by AECOM)

Indicates Phase II surface soil sample locations (May-Aug 2013; collected by AECOM)

Indicates surface soil sample locations with unknown construction details

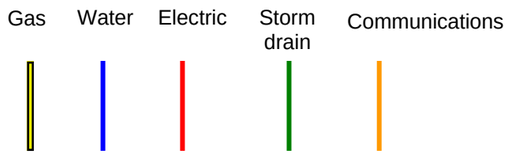

Indicates areas where GeoTrax Surveys™ intersect

Indicates a telephone pole

Indicates a manhole

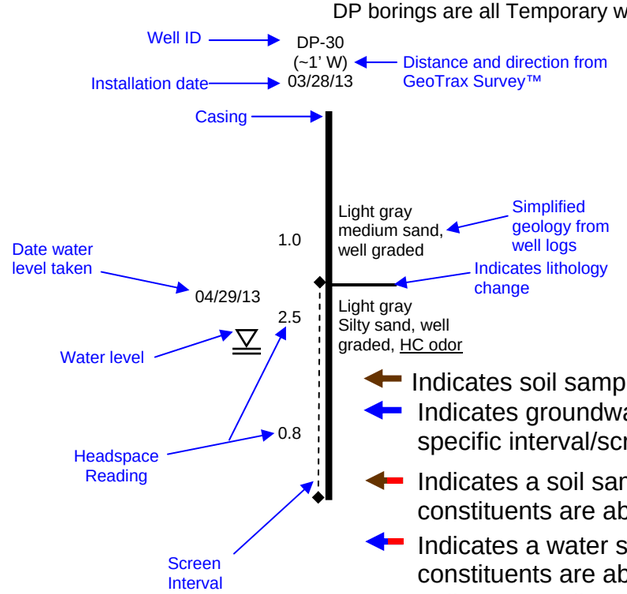
Indicates a water hydrant

## Utilities




## Well Explanation

DP borings are all Temporary wells.




**Groundwater Sample Results**

| Well | | DP-34 |
|---|---|---|
| Sample Date | | 3/29/13 |
| Parameters (µg/L) | PSL (µg/L) | |
| Arsenic | 1.4 | 1.1 |
| Manganese | 1000 | 580 B |
| Arsenic | 1.4 | 25 |
| Manganese | 1000 | 610 B |

PSL = Project Screening Level based on USEPA National Recommended Water Quality Criteria for Human Health. 2009. Values for protection of water and organisms, and organisms only. Default dilution attenuation factor of 10 applied.

**Soil Sample Results**

| Well | | DP-35 |
|---|---|---|
| Sample Date | | 3/28/13 |
| Sample Depth (feet) | | 14.5-15.5' |
| Parameters (mg/kg) | PSL (mg/kg) | |
| Arsenic | 1.6 | 0.81 |
| Chromium | 5.6 | 9.2 |
| Cobalt | 30 | 1.2 |
| Manganese | 2300 | 9.9 B |
| DRO (C10-C20) | | < 20 U |

PSL = Project Screening Level based on USEPA Regional Screening Level for Industrial Soil, May 2012. Values for noncarcinogens are divided by 10. Bold values indicate an exceedance of the PSL in some sample(s).

NS= No sample
J = The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample
U = The analyte was analyzed for, but was not detected above the reported sample quantitation limit.
B = The analyte was also detected in the method blank
H = Sample was prepped or analyzed beyond the specified holding time
Note: At time of report, analytical data marked as unvalidated.

**General Notes:**

1. *Locations of site features (e.g., utilities, wells, etc.) are approximate*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Stillwater, OK 74074


| | |
|---|---|
| Scale: | NTS unless specified |
| Drawn By: | MAS |
| Approved By: | SWM |
| Date: | 10-04-13 |
| Project No.: | 12-106-10 |

**GeoTrax Survey™ Investigation Results**
**PEPCO-Benning Facility**
**Washington, D.C., USA**

*Prepared for* AECOM

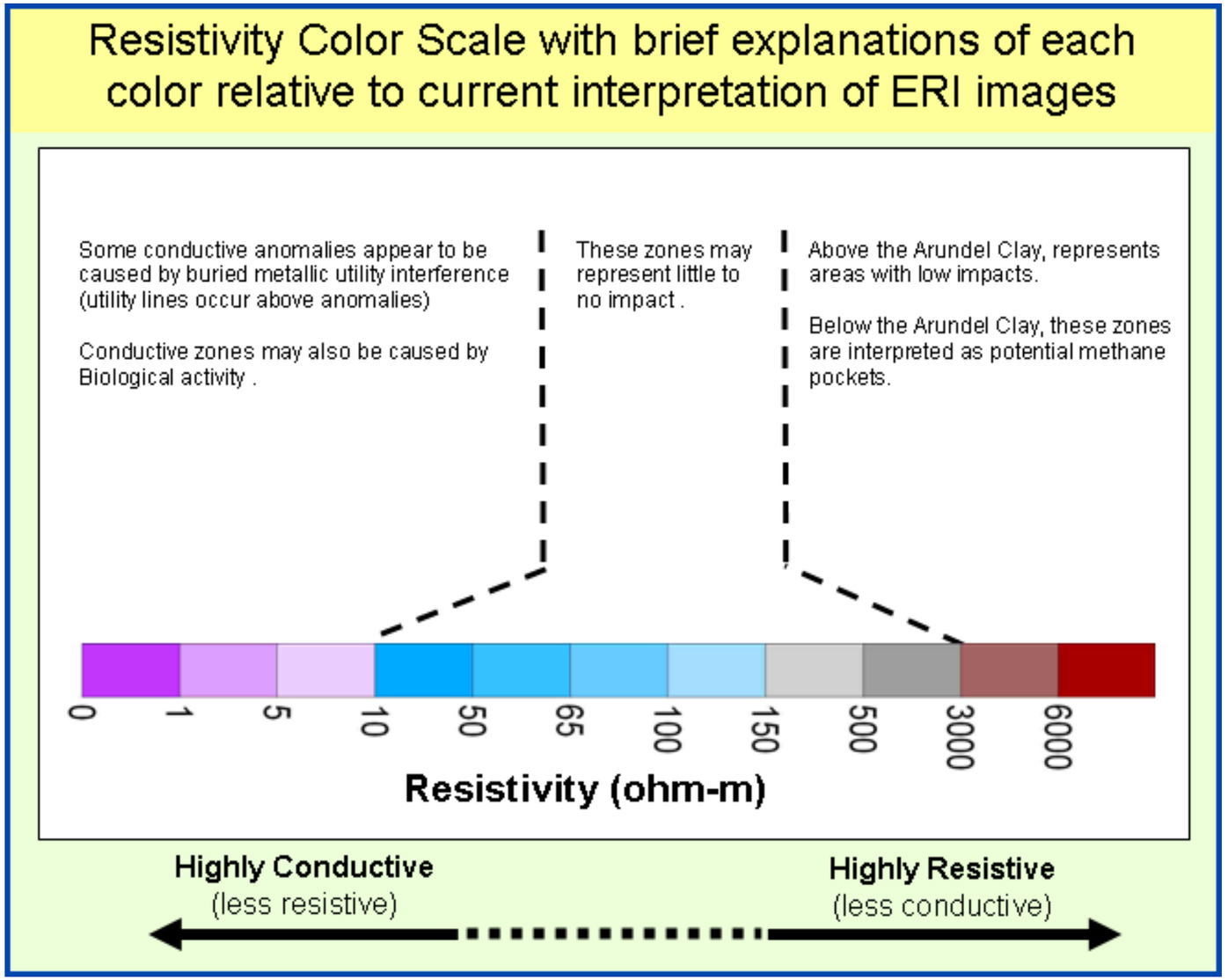
FIGURE

LS-1

# Interpretive Electrical Resistivity Scale

***(Site Specific Electrical Resistivity Scale)***

**(for reference when reviewing Figures 1 through 10)**





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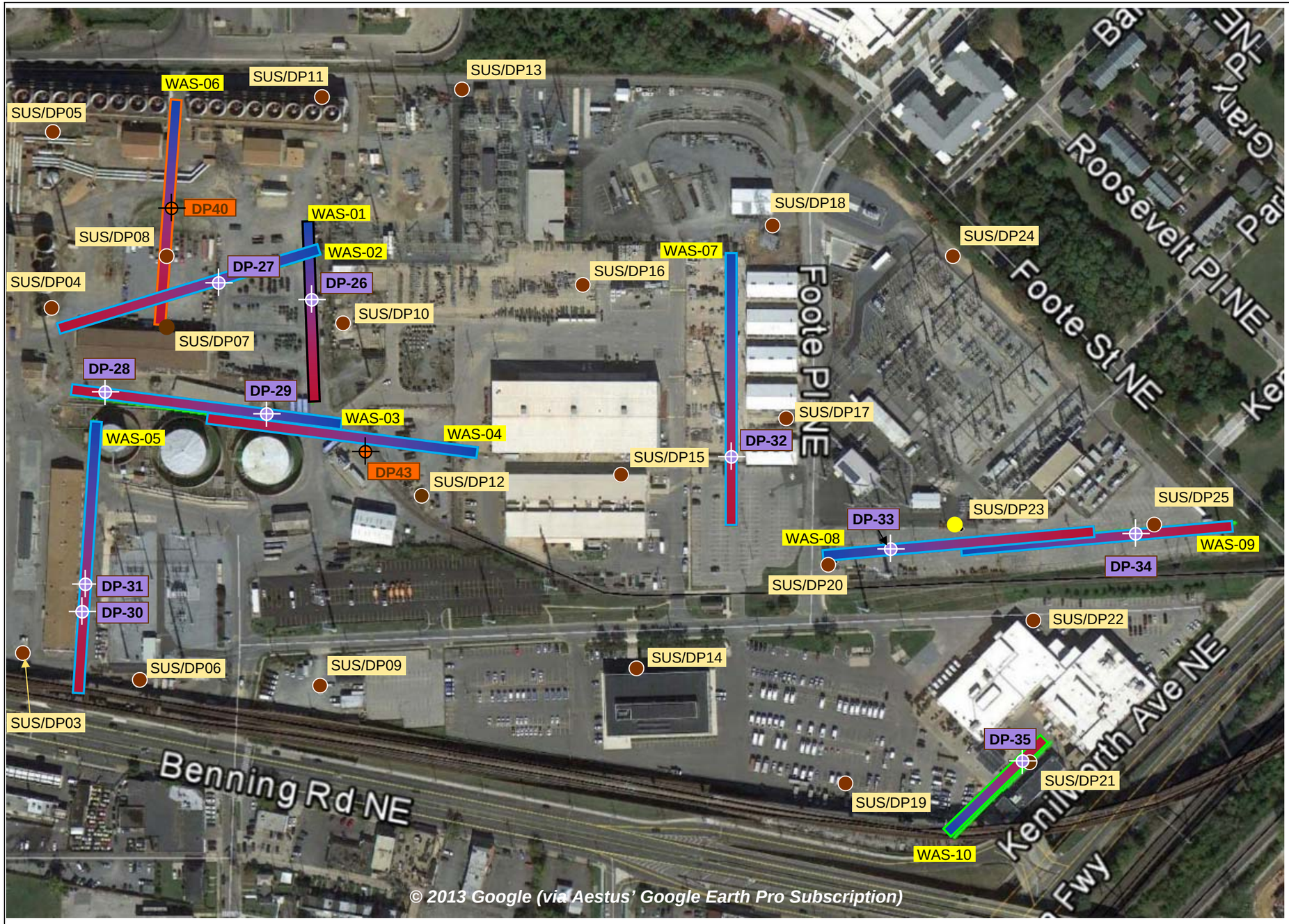
**Interpretive Resistivity Scale**
**PEPCO-Benning Facility**
**Washington, D.C., USA**

*Prepared for* AECOM

FIGURE

LS-2




## LEGEND:

**GeoTrax Survey™ Orientation and Designation**

Electrode 1 — Electrode 56

**WAS-10** — **1.50 Meter Electrode Spacing**
Survey Line ~ 271 feet long
Image Depth ~ 55 feet

**WAS-01** — **2.00 Meter Electrode Spacing**
Survey Line ~ 361 feet long
Image Depth ~ 73 feet

**WAS-06** — **2.50 Meter Electrode Spacing**
Survey Line ~ 451 feet long
Image Depth ~ 92 feet

**WAS-02** — **3.00 Meter Electrode Spacing**
Survey Line ~ 541 feet long
Image Depth ~ 110 feet

**DP-27** — Phase I borings (March/April /2013)

**DP-40** — Phase II borings (Aug/2013)

**SUS/DP15** — Surface Soil Samples (Feb 2013) Collected by AECOM

N

0 200 400
feet

**NOTE:**

**THIS MAP IS FOR REFERENCE ONLY**

**Do not use this map to determine the locations of confirmation borings. Please use Table 7 to locate confirmation borings.**

Reference: Aerial courtesy of USGS, land survey data collected by Aestus, LLC.

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| | |
|---|---|
| Scale: | NTS unless specified |
| Drawn By: | MAS |
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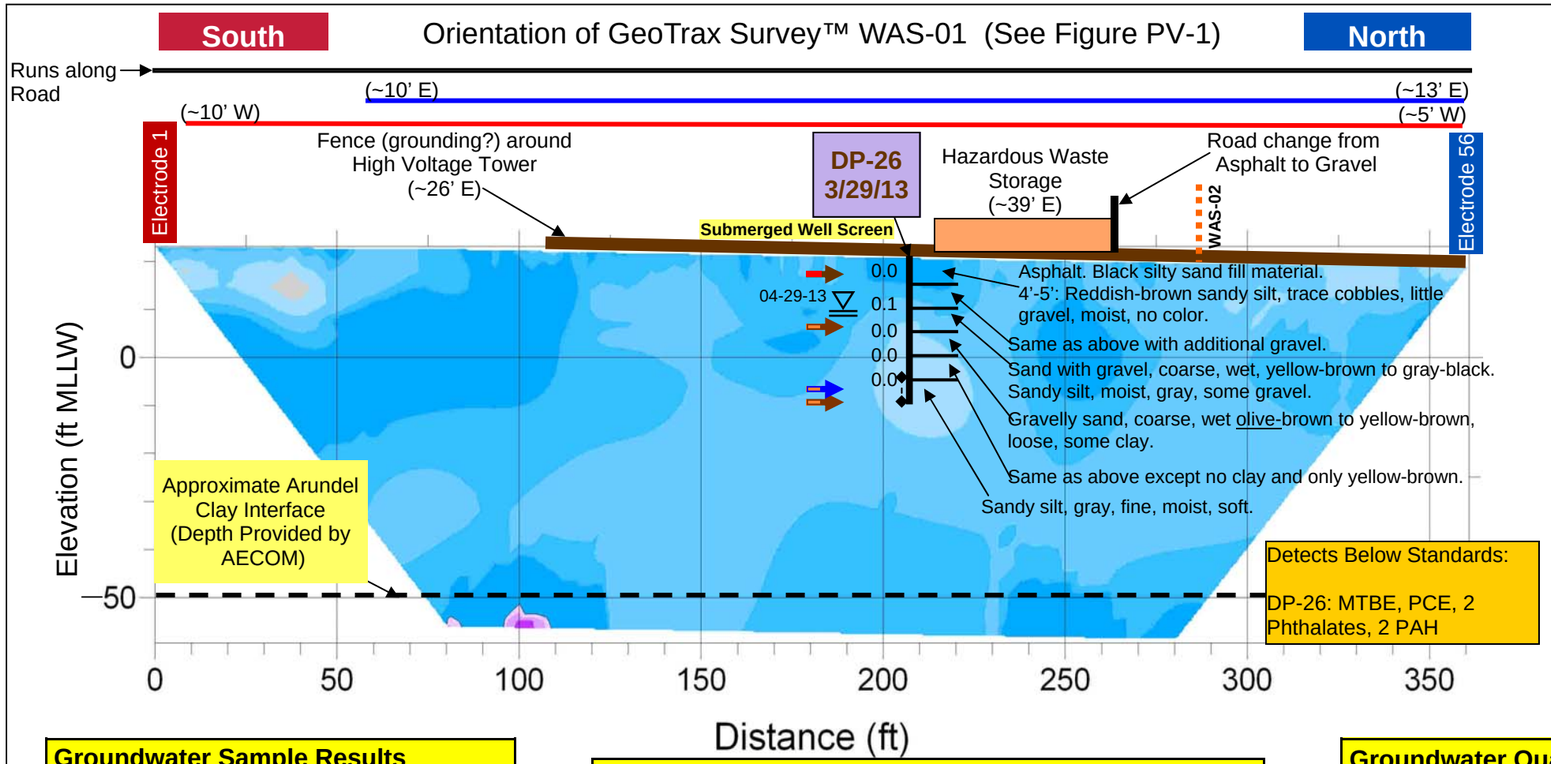
| Date: | 10-04-13 |
| Project No.: | 12-106-10 |

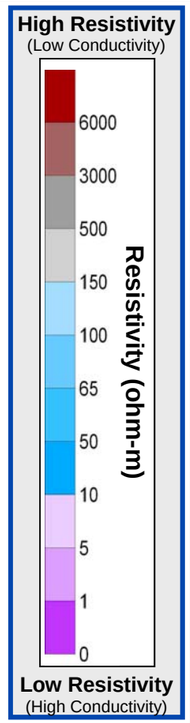
**Plan View Map Showing Site Borings, Features, & GeoTrax Survey™ Locations**
**PEPCO-Benning Facility**
**Washington, D.C., USA**

*Prepared for* AECOM

FIGURE

PV-1





**Groundwater Sample Results**

| Well | | DP-26 |
|---|---|---|
| Sample Date | | 3/29/13 |
| *Parameters (µg/L)* | PSL (µg/L) | |
| Arsenic (D) | 1.4 | 1.1 |
| Manganese (D) | 1000 | **3100 B** |
| Arsenic (T) | 1.4 | **6.4** |
| Manganese (T) | 1000 | **2800 B** |
| DRO (C10-C20) | | < 510 U |
| ORO (C20-C36) | | < 510 U |
| GRO (C6-C10) | | 76 J B |
| PCBs (Total Aroclors) | | < 0.0097 U |
| MTBE | | 2.2 |
| Benzo(a)pyrene | 0.18 | < 0.19 U |
| Indeno(1,2,3-cd)pyrene | 0.18 | < 0.19 U |

**Soil Sample Results**

| Well | | DP-26 | DP-26 | DP-26 |
|---|---|---|---|---|
| Sample Date | | 3/28/13 | 3/29/13 | 3/29/13 |
| Sample Depth (feet) | | 3.5-4.5' | 13.5-14.5' | 29.5-30.5' |
| *Parameters (mg/kg)* | *PSL (mg/kg)* | | | |
| Arsenic | 1.6 | 1.6 | **1.9** | 0.26 |
| Chromium | 5.6 | **14** | 5.6 | **14** |
| Cobalt | 30 | 4.4 | 4.5 | 6.5 |
| Manganese | 2300 | 80 B | 43 B | 290 B |
| DRO (C10-C20) | | < 19 U | < 19 U | < 21 U |
| ORO (C20-C36) | | 28 | 33 | 72 |
| GRO (C6-C10) | | 0.051 J B | < 0.085 U | 0.056 J B |
| PCBs (Total Aroclors) | 0.74 | < 0.0047 U | < 0.0047 U | < 0.0052 U |
| Benzo(a)pyrene | 0.21 | **0.24** | < 0.0076 U | < 0.0084 U |
| Indeno(1,2,3-cd)pyrene | 2.1 | 0.15 | < 0.0076 U | < 0.0084 U |
| Phenanthrene | 17000 | 0.4 | < 0.0076 U | < 0.0084 U |
| Pyrene | 1700 | 0.34 | < 0.0076 U | < 0.0084 U |

**Groundwater Quality Sample Results**

| Well | | DP-26 |
|---|---|---|
| Sample Date | | 3/29/13 |
| *Parameters* | Units | |
| Temperature | ºC | 17.45 |
| pH | S.U. | 5.6 |
| Specific Conductivity | mS/cm | 0.581 |
| DO | Mg/L | 1.37 |
| ORP | mV | 237.3 |
| Calcium, dissolved | µg/L | 24,000 |
| Iron, dissolved | µg/L | 2400 |
| Manganese, dissolved | µg/L | **3100 B** |

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Approved By: SWM
Date: 10-04-13
Project No.: 12-106-10

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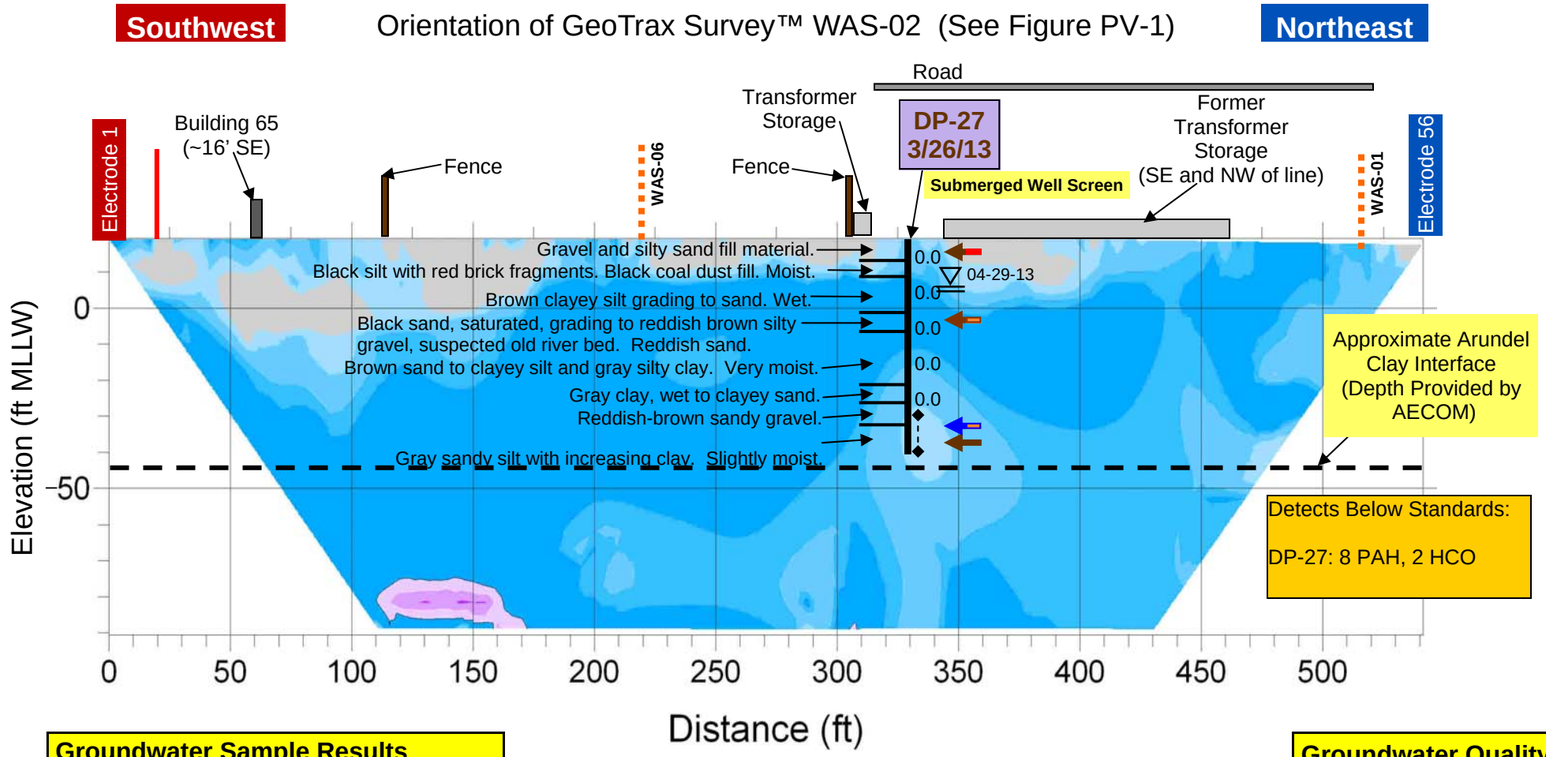
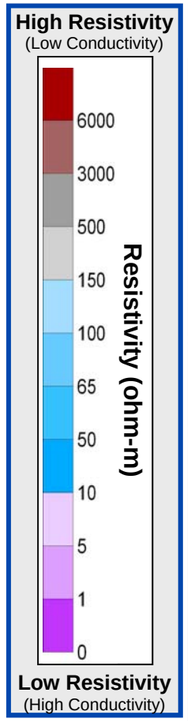
FIGURE
1

# Orientation of GeoTrax Survey™ WAS-02 (See Figure PV-1)




## GeoTrax Survey™ Line Location in Plan View


## Groundwater Sample Results

| Well | | DP-27 |
|---|---|---|
| Sample Date | | 3/26/13 |
| *Parameters (µg/L)* | PSL (µg/L) | |
| Arsenic | 1.4 | **2.3** |
| Manganese | 1000 | 870 B |
| Arsenic | 1.4 | **18** |
| Manganese | 1000 | **1800 B** |
| DRO (C10-C20) | | < 480 U |
| ORO (C20-C36) | | 490 |
| GRO (C6-C10) | | 73 J B |
| PCBs (Total Aroclors) | | 0.023 |
| MTBE | | < 1.0 U |
| Benzo(a)pyrene | 0.18 | < 0.19 U |
| Indeno(1,2,3-cd)pyrene | 0.18 | < 0.19 U |

**EVIDENCE-BASED GEOPHYSICS DATA INTEGRATION**

## Soil Sample Results

| Well | | DP-27 | DP-27 | DP-27 |
|---|---|---|---|---|
| Sample Date | | 3/26/13 | 3/26/13 | 3/26/13 |
| Sample Depth (feet) | | 6.5-7.5' | 21.5-22.5' | 57.5-58.5' |
| *Parameters (mg/kg)* | *PSL (mg/kg)* | | | |
| Arsenic | 1.6 | **9.5** | **1.9** | 0.076 J |
| Chromium | 5.6 | **16** | **12** | 4 |
| Cobalt | 30 | 6.9 | 10 | 0.52 |
| Manganese | 2300 | 150 B | 110 B | 28 B |
| DRO (C10-C20) | | 68 | < 24 U | < 20 U |
| ORO (C20-C36) | | 220 | 56 | < 20 U |
| GRO (C6-C10) | | < 0.094 U | 0.057 J B | 0.047 J B |
| PCBs (Total Aroclors) | 0.74 | 0.35 | < .0061 U | < 0.001 U |
| Benzo(a)pyrene | 0.21 | **0.330** | < 0.0098 U | < 0.0081 U |
| Indeno(1,2,3-cd)pyrene | 2.1 | 0.2 | < 0.0098 U | < 0.0081 U |
| Phenanthrene | 17000 | 0.49 | < 0.0098 U | < 0.0081 U |
| Pyrene | 1700 | 0.530 | < 0.0098 U | < 0.0081 U |

## Groundwater Quality Sample Results

| Well | | DP-27 |
|---|---|---|
| Sample Date | | 3/26/13 |
| *Parameters* | Units | |
| Temperature | ºC | 16.46 |
| pH | S.U. | 5.88 |
| Specific Conductivity | mS/cm | 0.426 |
| DO | Mg/L | 0.39 |
| ORP | mV | -25.9 |
| Calcium, dissolved | µg/L | 31,000 |
| Iron, dissolved | µg/L | 8,500 |
| Manganese, dissolved | µg/L | 870 B |


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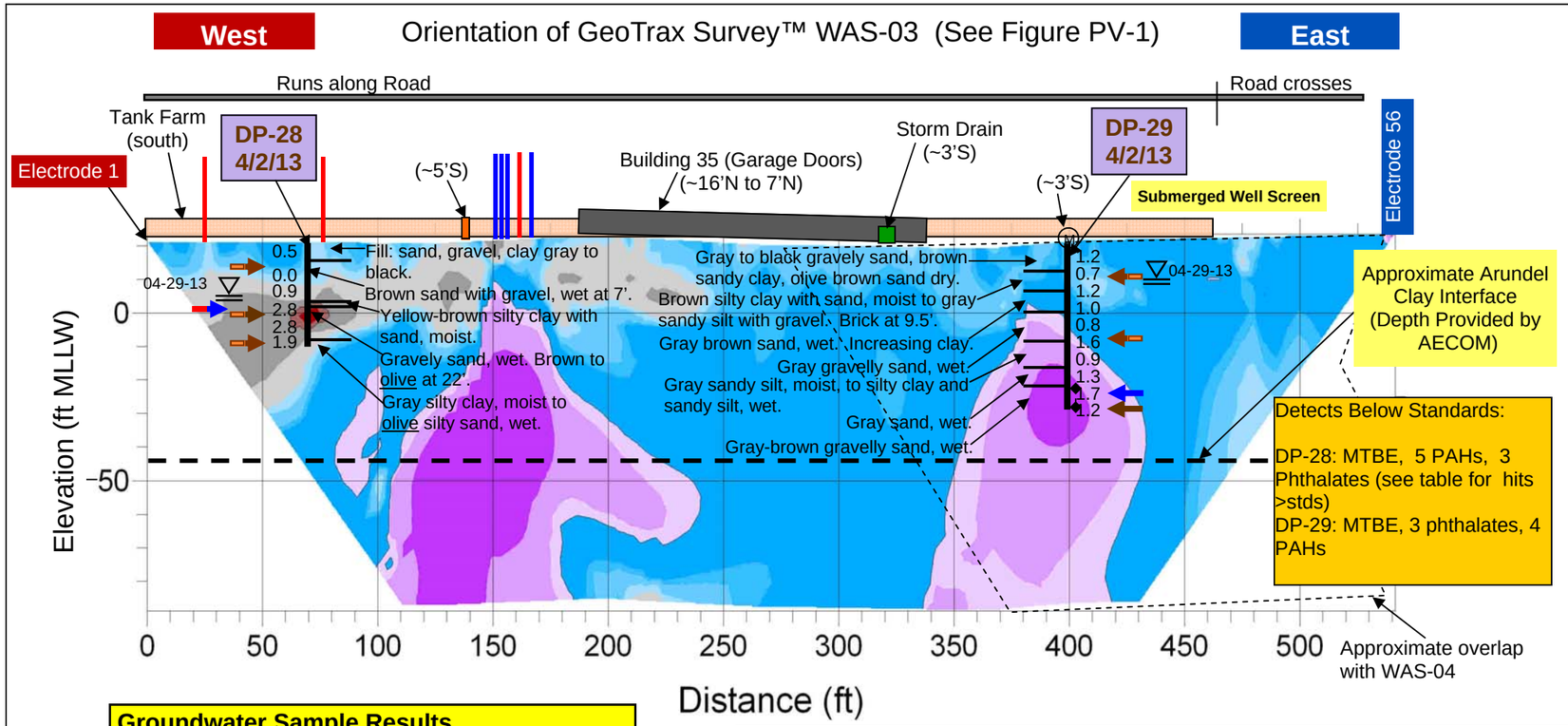
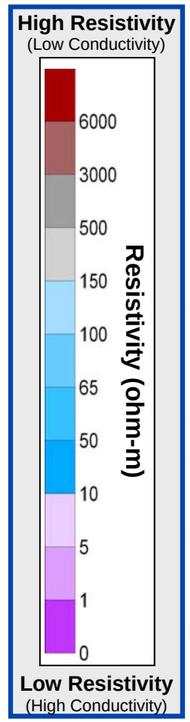
FIGURE
2





## Groundwater Sample Results

| Well | | DP-28 | DP-29 |
|---|---|---|---|
| Sample Date | | 4/2/13 | 4/2/13 |
| *Parameters (µg/L)* | PSL (µg/L) | | |
| Arsenic | 1.4 | 1.3 | < 1.0 U |
| Manganese | 1000 | 93 B | 860 B |
| Arsenic | 1.4 | **19** | < 1.0 U |
| Manganese | 1000 | 640 B | 890 B |
| DRO (C10-C20) | | < 480 U H | < 480 U H |
| ORO (C20-C36) | | 240 J H | < 480 U H |
| GRO (C6-C10) | | 31 J B | 55 J B |
| PCBs (Total Aroclors) | | < 0.0095 U | < 0.0095 U |
| MTBE | | 1.2 | 19 |
| Benzo(a)pyrene | 0.18 | **0.81** | < 0.19 U |
| Indeno(1,2,3-cd)pyrene | 0.18 | **1.2** | < 0.19 U |

**EVIDENCE-BASED GEOPHYSICS DATA INTEGRATION**

## Soil Sample Results

| Well | | DP-28 | DP-28 | DP-28 | DP-29 | DP-29 | DP-29 |
|---|---|---|---|---|---|---|---|
| Sample Date | | 4/2/13 | 4/2/13 | 4/2/13 | 4/2/13 | 4/2/13 | 4/2/13 |
| Sample Depth (feet) | | 7.5-8.5' | 20.5-21.5' | 31-33' | 9-11' | 29-31' | 49-51' |
| *Parameters (mg/kg)* | *PSL (mg/kg)* | | | | | | |
| Arsenic | 1.6 | **1.8** | 1.3 | **1.9** | **2.9** | 0.35 | 0.3 |
| Chromium | 5.6 | **9.8** | **7.8** | **21** | **16** | **6.1** | 1.7 |
| Cobalt | 30 | 7.3 B | **120 B** | 19 B | 6.8 B | 3.1 B | 2.5 B |
| Manganese | 2300 | 140 B | **3400 B** | 130 B | 160 B | 41 B | 2.1 B |
| DRO (C10-C20) | | < 18 U | < 18 U | < 24 U | 12 J | < 20 U | < 19 U |
| ORO (C20-C36) | | < 18 U | < 18 U | 45 | 59 | < 20 U | < 19 U |
| GRO (C6-C10) | | < 0.085 U | < 0.11 U | < 0.120 U | < 0.097 U | < 0.1 U | < 0.11 U |
| PCBs (Total Aroclors) | 0.74 | < 0.0009 U | < 0.00092 | < 0.0012 U | < 0.001 U | < 0.00098 U | < 0.00096 U |
| Benzo(a)pyrene | 0.21 | < 0.0073 U | < 0.0073 U | < 0.0095 U | 0.061 | 0.0054 J | < 0.0078 U |
| Indeno(1,2,3-cd)pyrene | 2.1 | < 0.0073 U | < 0.0073 U | < 0.0095 U | 0.030 | 0.0024 J | < 0.0078 U |
| Phenanthrene | 17000 | < 0.0073 U | < 0.0073 U | < 0.0095 U | 0.066 | 0.017 | < 0.0078 U |
| Pyrene | 1700 | < 0.0073 U | < 0.0073 U | < 0.0095 U | 0.100 | 0.014 | < 0.0078 U |

## Groundwater Quality Sample Results

| Well | | DP-28 | DP-29 |
|---|---|---|---|
| Sample Date | | 4/2/13 | 4/2/13 |
| *Parameters* | Units | | |
| Temperature | ºC | 15.53 | 16.19 |
| pH | S.U. | 7.02 | 5.73 |
| Specific Conductivity | mS/cm | 1.303 | 0.607 |
| DO | Mg/L | 0.28 | 0.39 |
| ORP | mV | 212.6 | 51.7 |
| Calcium, dissolved | µg/L | 83,000 B | 30,000 B |
| Iron, dissolved | µg/L | 32 J B | 6,000 B |
| Manganese, dissolved | µg/L | 93 B | 860 B |


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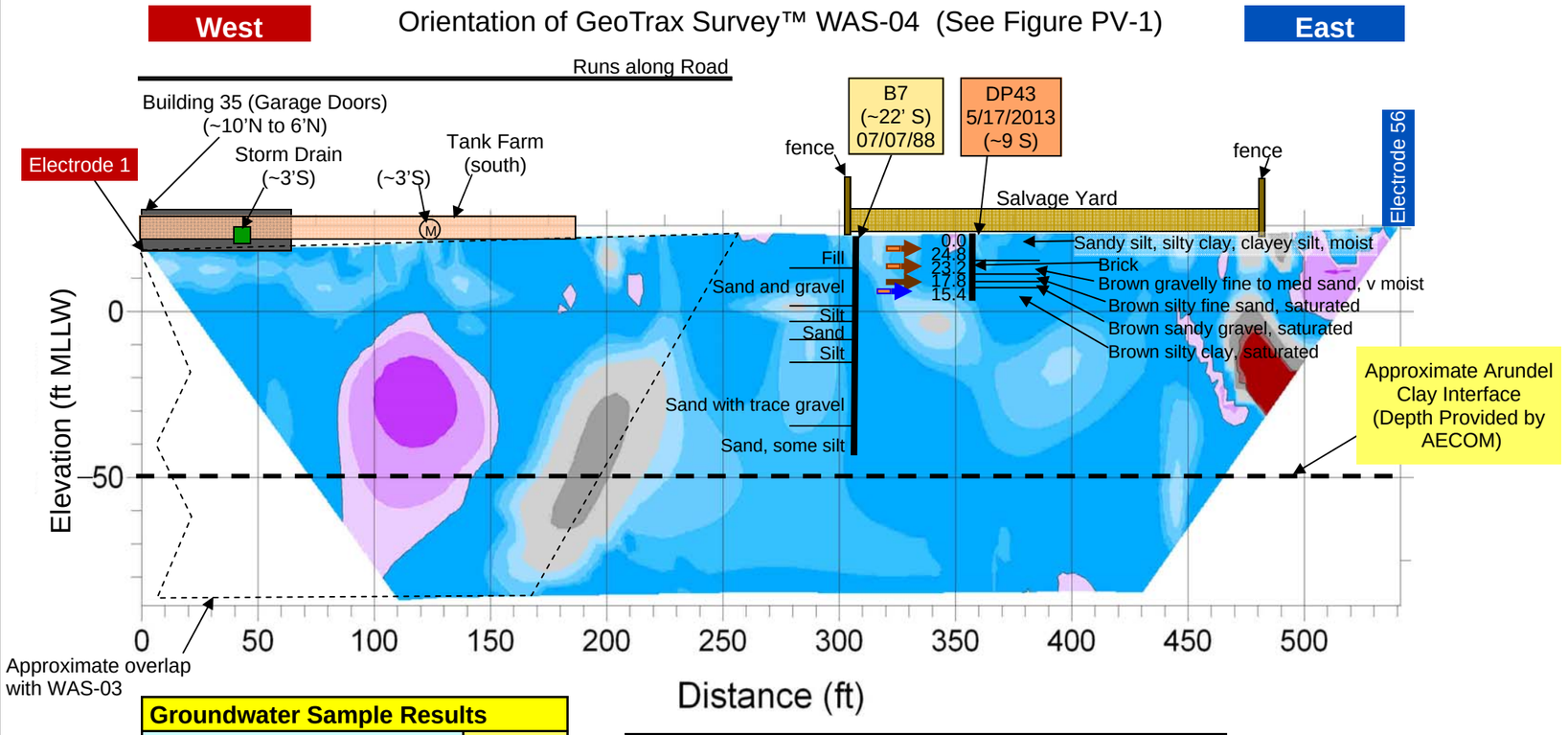
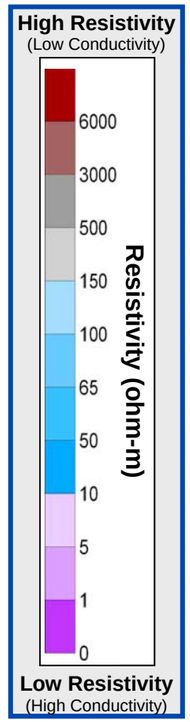
FIGURE
3

## Orientation of GeoTrax Survey™ WAS-04 (See Figure PV-1)




### GeoTrax Survey™ Line Location in Plan View


### Groundwater Sample Results

| Well | | DP-43 |
|---|---|---|
| Sample Date | | 6/6/2013 |
| *Parameters (µg/L)* | PSL (µg/L) | |
| Arsenic | 1.4 | 1.4 |
| Manganese | 1000 | 920 |
| Arsenic | 1.4 | **14** |
| Manganese | 1000 | 1000 B |
| DRO (C10-C20) | | 490 |
| ORO (C20-C36) | | 1900 |
| GRO (C6-C10) | | 57 J B |
| PCBs (Total Aroclors) | | < 0.0094 U |
| MTBE | | 0.25 J |
| Benzo(a)pyrene | 0.18 | < 0.20 U |
| Indeno(1,2,3-cd)pyrene | 0.18 | < 0.20 U |

### Soil Sample Results

| Well | | DP43 | DP43 | DP43 |
|---|---|---|---|---|
| Sample Date | | 5/17/2013 | 6/7/2013 | 6/7/2013 |
| Sample Depth (feet) | | 3.5-4.5 | 9.5-10.5 | 14.5-15.5 |
| *Parameters (mg/kg)* | *PSL (mg/kg)* | | | |
| Arsenic | 1.6 | 0.39 B | **2.9** | |
| Chromium | 5.6 | **13** | **13** | |
| Cobalt | 30 | 4.1 | 4.8 | |
| Manganese | 2300 | 53 B | 140 | |
| DRO (C10-C20) | | < 20 U | < 20 U | 150 |
| ORO (C20-C36) | | 22 | 18 J | 770 |
| GRO (C6-C10) | | 0.070 J H B | <0.0 96 U H | < 0.1 U H |
| PCBs (Total Aroclors) | 0.74 | 0.014 | 0.280 | 0.0071 |
| Benzo(a)pyrene | 0.21 | | | |
| Indeno(1,2,3-cd)pyrene | 2.1 | | | |
| Phenanthrene | 17000 | | | |
| Pyrene | 1700 | | | |

### Groundwater Quality Sample Results

| Well | | DP43 |
|---|---|---|
| Sample Date | | 6/6/13 |
| *Parameters* | Units | |
| Temperature | ºC | 16.32 |
| pH | S.U. | 7.0 |
| Specific Conductivity | mS/cm | 1.317 |
| DO | Mg/L | 2.17 |
| ORP | mV | -134.2 |
| Calcium, dissolved | µg/L | 140,000 |
| Iron, dissolved | µg/L | 14 J |
| Manganese, dissolved | µg/L | 920 |

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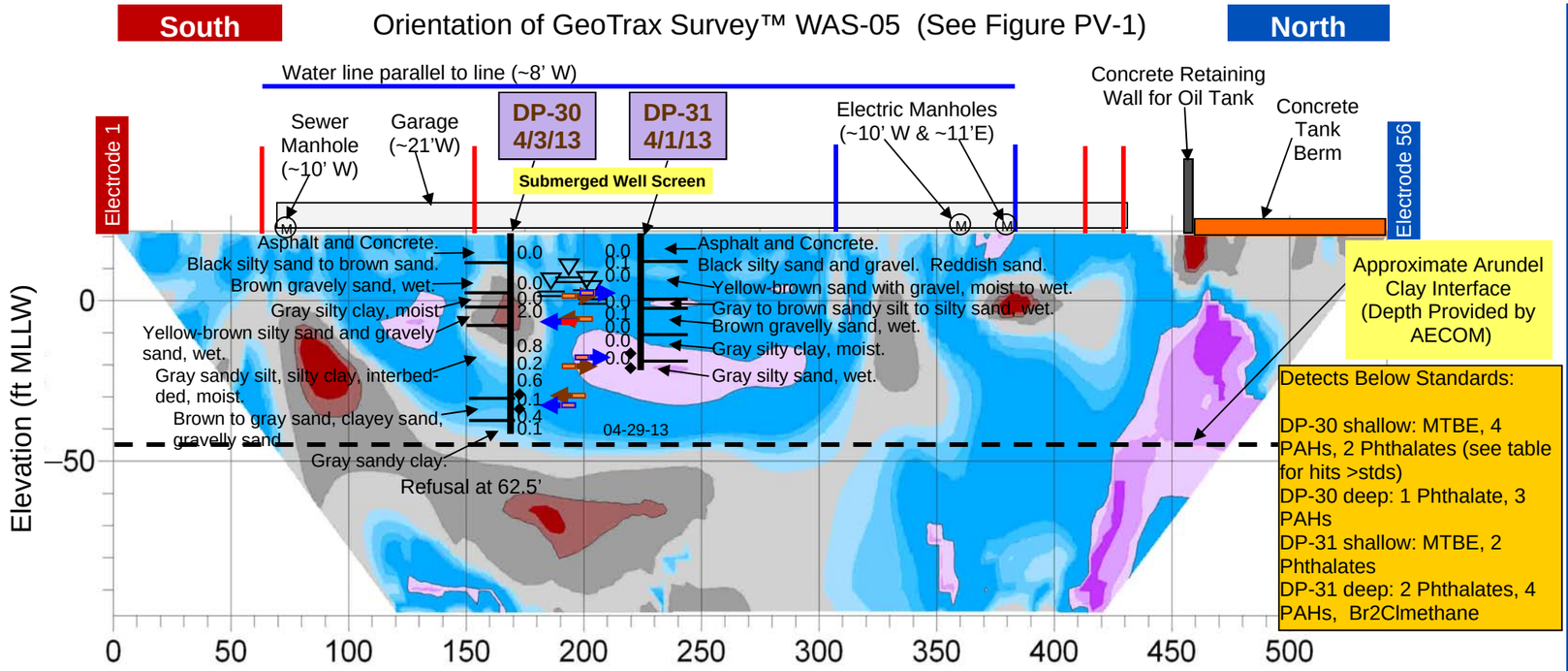
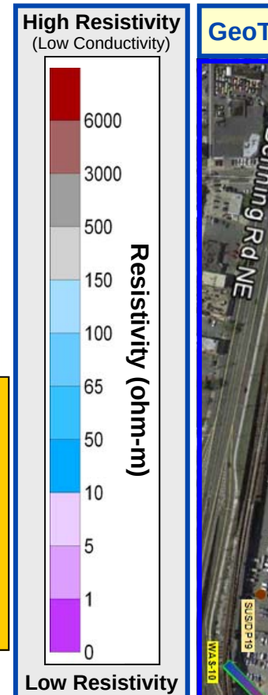
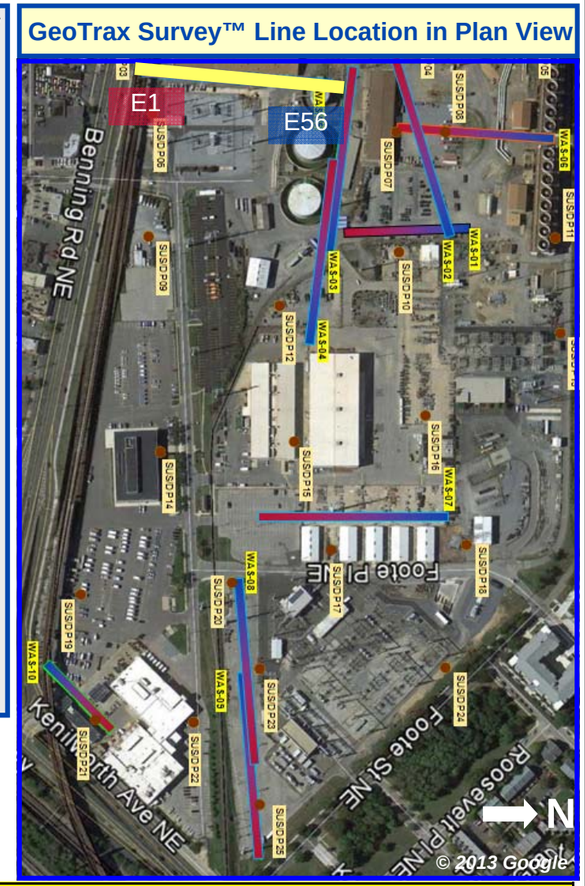
FIGURE
4




## Groundwater Sample Results

| Well | | DP-30 | DP-30 | DP-31 | DP-31 |
|---|---|---|---|---|---|
| Sample Date | | 4/3/13 | 4/3/13 | 4/1/13 | 4/1/13 |
| *Parameters (µg/L)* | PSL (µg/L) | Punch: 27-29' | Screen: 50-55' | Punch: 19-21' | Screen: 37-42' |
| Arsenic | 1.4 | < 1.0 U | < 1.0 U | < 1.0 U | < 1.0 U |
| Manganese | 1000 | **2200 B** | 980 B | **3700 B** | 530 B |
| Arsenic | 1.4 | 0.44 J | **19** | **50** | **34** |
| Manganese | 1000 | **2400 B** | **1100 B** | **4900 B** | **1700 B** |
| DRO (C10-C20) | | < 500 U | < 480 U | < 480 U | < 480 U |
| ORO (C20-C36) | | 550 | < 480 U | 590 | < 480 U |
| GRO (C6-C10) | | 31 J B | 30 J B | 49 J B | 150 B |
| PCBs (Total Aroclors) | | < 0.0094 U | < 0.0095 U | < 0.0095 U | < 0.0095 U |
| MTBE | | 0.47 J | < 1.0 U | 2.0 | < 1.0 U |
| Benzo(a)pyrene | 0.18 | **0.37** | < 0.19 U | < 0.19 U | < 0.19 U |
| Indeno(1,2,3-cd)pyrene | 0.18 | **0.51** | < 0.19 U | < 0.19 U | < 0.19 U |

**EVIDENCE-BASED GEOPHYSICS DATA INTEGRATION**

## Soil Sample Results

| Well | | DP-30 | DP-30 | DP-31 | DP-31 |
|---|---|---|---|---|---|
| Sample Date | | 4/3/13 | 4/3/13 | 4/1/13 | 4/1/13 |
| Sample Depth (feet) | | 27-29' | 49-51' | 19.5-20.5' | 41.5-42.5' |
| *Parameters (mg/kg)* | *PSL (mg/kg)* | | | | |
| Arsenic | **1.6** | **2** | **2.3** | 0.56 | 0.96 |
| Chromium | **5.6** | **9** | **15** | **12** | **13** |
| Cobalt | **30** | 2.5 B | 28 B | 2.9 B | 11 B |
| Manganese | **2300** | 33 B | 140 B | 25 B | 75 B |
| DRO (C10-C20) | | < 20 U | < 21 U | < 19 U | < 20 U |
| ORO (C20-C36) | | 22 | 16 J | < 19 U | < 20 U |
| GRO (C6-C10) | | < 0.1 U | < 0.11 U | < 0.092 U | < 0.097 U |
| PCBs (Total Aroclors) | 0.74 | < 0.00098 U | < 0.0011 U | < 0.00094 U | < 0.001 U |
| Benzo(a)pyrene | 0.21 | < 0.0078 U | < 0.0085 U | < 0.0076 U | < 0.0083 U |
| Indeno(1,2,3-cd)pyrene | 2.1 | < 0.0078 U | < 0.0085 U | < 0.0076 U | < 0.0083 U |
| Phenanthrene | 17000 | < 0.0078 U | < 0.0085 U | < 0.0076 U | < 0.0083 U |
| Pyrene | 1700 | < 0.0078 U | < 0.0085 U | < 0.0076 U | < 0.0083 U |

## Groundwater Quality Sample Results

| Well | | DP-30 | DP-30 | DP-31 | DP-31 |
|---|---|---|---|---|---|
| Depth | | 28' | 50-55' | 20' | 37'-42' |
| Sample Date | | 4/3/13 | 4/3/13 | 4/1/13 | 4/1/13 |
| *Parameters* | Units | | | | |
| Temperature | ºC | 16.02 | 17.5 | 18.05 | 18.04 |
| pH | S.U. | 6.21 | 6.12 | 6.47 | 5.96 |
| Specific Conductivity | mS/cm | 1.23 | 0.593 | 1.851 | 0.259 |
| DO | Mg/L | 0.56 | 0.21 | 0.32 | 0.2 |
| ORP | mV | 30.1 | 11.6 | -46.3 | -14.5 |
| Calcium, dissolved | µg/L | 37,000 B | 21,000 B | 57,000 B | 18,000 B |
| Iron, dissolved | µg/L | 360 B | 6,300 B | 7.8 J B | 39 J B |
| Manganese, dissolved | µg/L | **2200 B** | 980 B | **3700 B** | 530 B |


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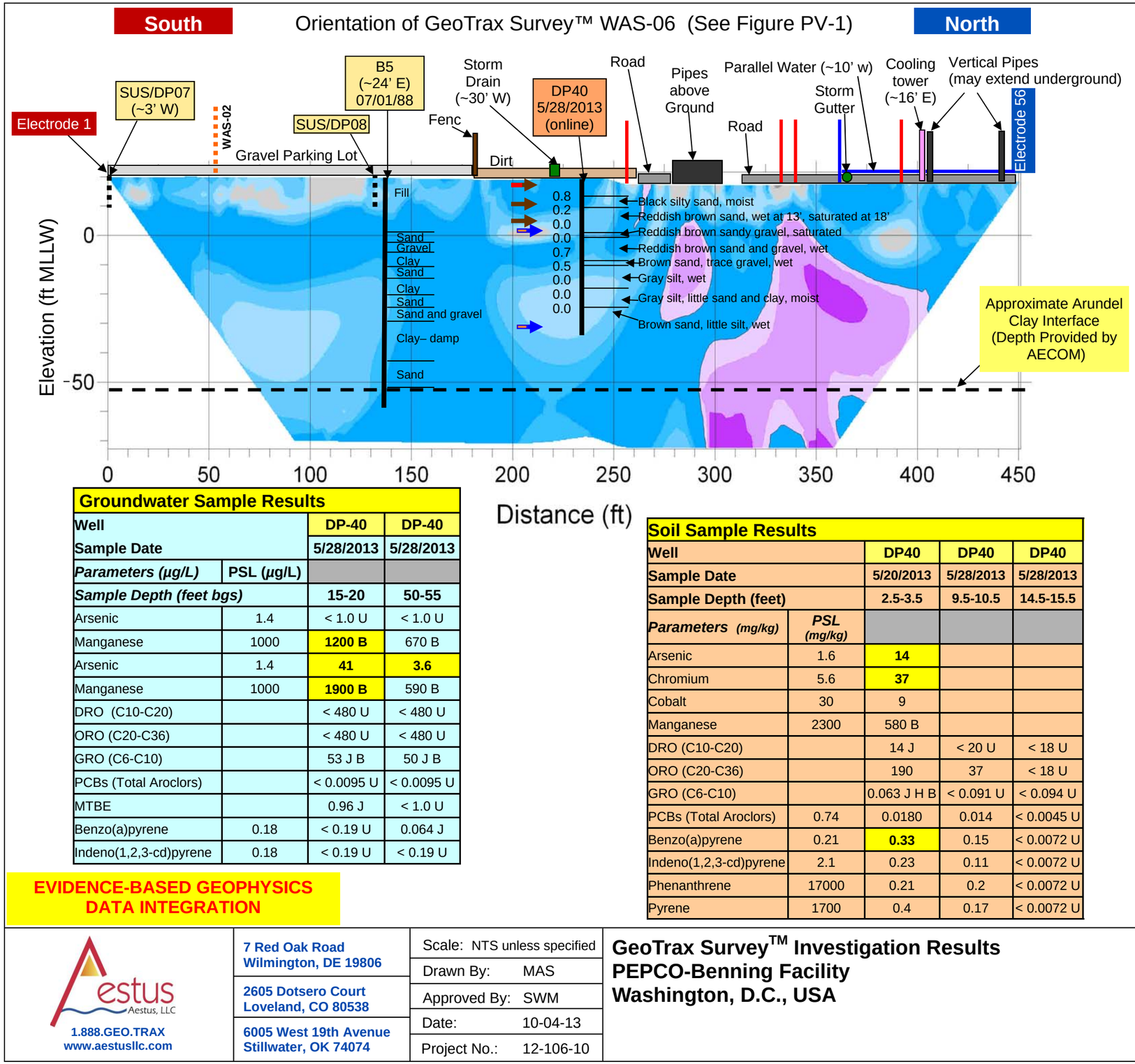
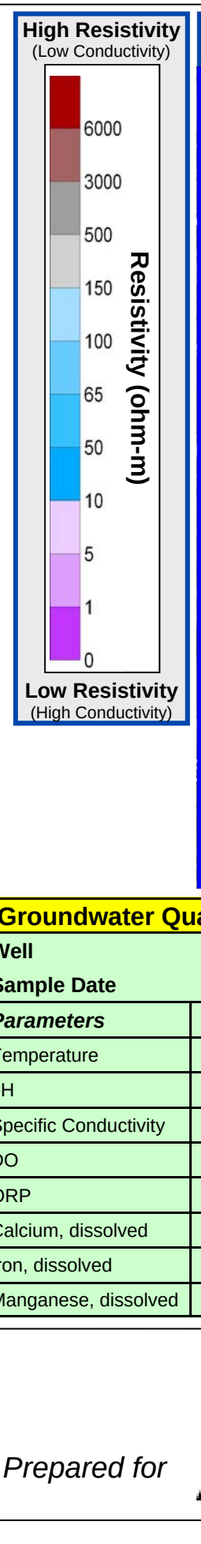
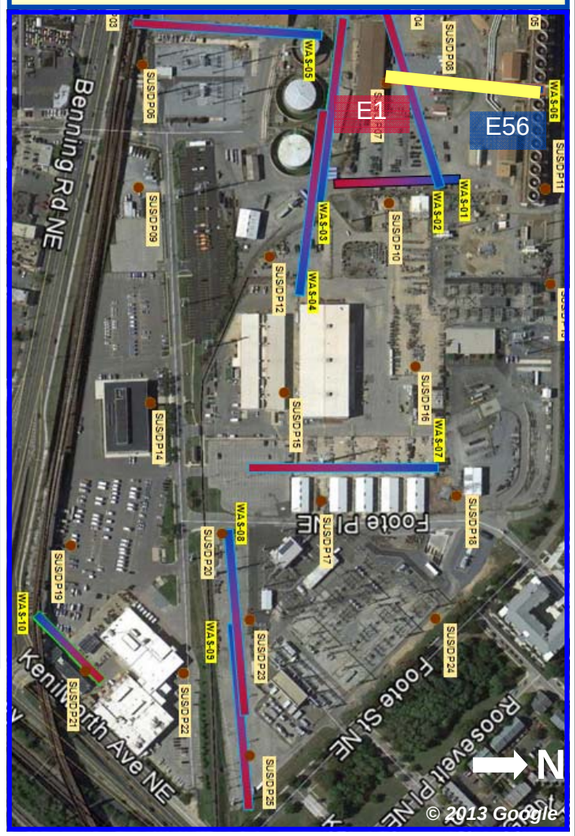
FIGURE
5

## Orientation of GeoTrax Survey™ WAS-06 (See Figure PV-1)




### GeoTrax Survey™ Line Location in Plan View




### Groundwater Sample Results

| Well | | DP-40 | DP-40 |
|---|---|---|---|
| Sample Date | | 5/28/2013 | 5/28/2013 |
| *Parameters (µg/L)* | PSL (µg/L) | | |
| *Sample Depth (feet bgs)* | | 15-20 | 50-55 |
| Arsenic | 1.4 | < 1.0 U | < 1.0 U |
| Manganese | 1000 | **1200 B** | 670 B |
| Arsenic | 1.4 | **41** | **3.6** |
| Manganese | 1000 | **1900 B** | 590 B |
| DRO (C10-C20) | | < 480 U | < 480 U |
| ORO (C20-C36) | | < 480 U | < 480 U |
| GRO (C6-C10) | | 53 J B | 50 J B |
| PCBs (Total Aroclors) | | < 0.0095 U | < 0.0095 U |
| MTBE | | 0.96 J | < 1.0 U |
| Benzo(a)pyrene | 0.18 | < 0.19 U | 0.064 J |
| Indeno(1,2,3-cd)pyrene | 0.18 | < 0.19 U | < 0.19 U |

### Soil Sample Results

| Well | | DP40 | DP40 | DP40 |
|---|---|---|---|---|
| Sample Date | | 5/20/2013 | 5/28/2013 | 5/28/2013 |
| Sample Depth (feet) | | 2.5-3.5 | 9.5-10.5 | 14.5-15.5 |
| *Parameters (mg/kg)* | *PSL (mg/kg)* | | | |
| Arsenic | 1.6 | **14** | | |
| Chromium | 5.6 | **37** | | |
| Cobalt | 30 | 9 | | |
| Manganese | 2300 | 580 B | | |
| DRO (C10-C20) | | 14 J | < 20 U | < 18 U |
| ORO (C20-C36) | | 190 | 37 | < 18 U |
| GRO (C6-C10) | | 0.063 J H B | < 0.091 U | < 0.094 U |
| PCBs (Total Aroclors) | 0.74 | 0.0180 | 0.014 | < 0.0045 U |
| Benzo(a)pyrene | 0.21 | **0.33** | 0.15 | < 0.0072 U |
| Indeno(1,2,3-cd)pyrene | 2.1 | 0.23 | 0.11 | < 0.0072 U |
| Phenanthrene | 17000 | 0.21 | 0.2 | < 0.0072 U |
| Pyrene | 1700 | 0.4 | 0.17 | < 0.0072 U |

### Groundwater Quality Sample Results

| Well | | DP40 |
|---|---|---|
| Sample Date | | 5/28/13 |
| *Parameters* | Units | 50-55' |
| Temperature | ºC | 17.67 |
| pH | S.U. | 6.26 |
| Specific Conductivity | mS/cm | 0.332 |
| DO | Mg/L | 0.86 |
| ORP | mV | -77.5 |
| Calcium, dissolved | µg/L | 14,000 B |
| Iron, dissolved | µg/L | 6,000 |
| Manganese, dissolved | µg/L | 670 B |

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| Drawn By: | MAS |
| Approved By: | SWM |
| Date: | 10-04-13 |
| Project No.: | 12-106-10 |

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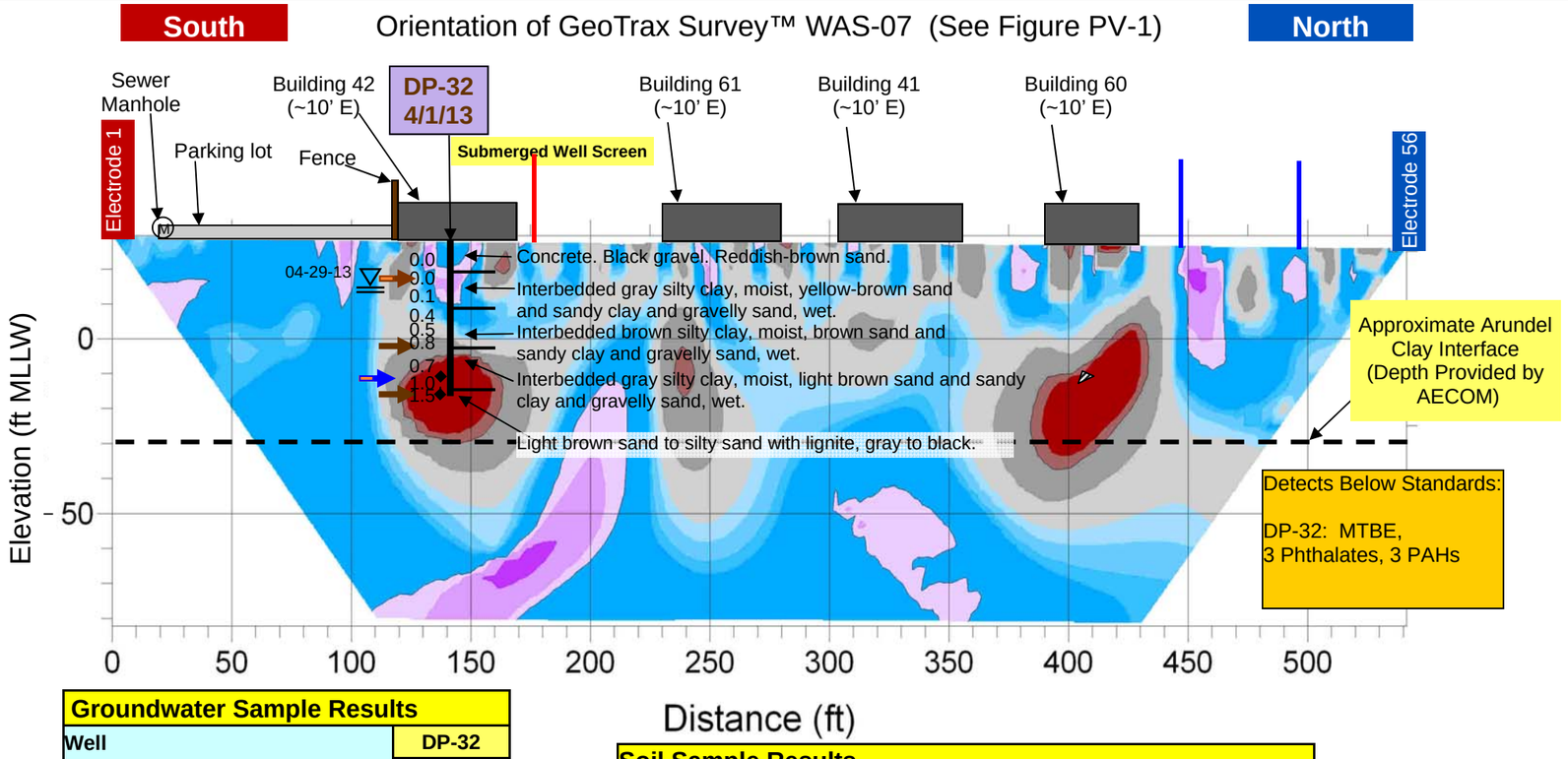
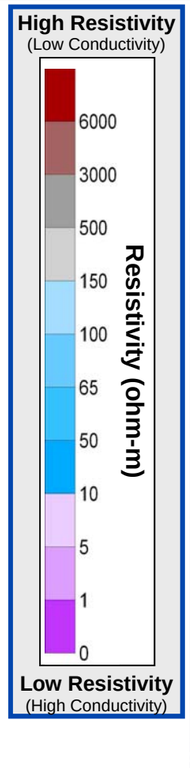
FIGURE
6





| Groundwater Sample Results | | |
|---|---|---|
| **Well** | | **DP-32** |
| **Sample Date** | | **4/1/13** |
| ***Parameters (µg/L)*** | **PSL (µg/L)** | |
| Arsenic | 1.4 | < 1.0 U |
| Manganese | 1000 | 750 B |
| Arsenic | 1.4 | **23** |
| Manganese | 1000 | 790 B |
| DRO (C10-C20) | | < 480 U |
| ORO (C20-C36) | | < 480 U |
| GRO (C6-C10) | | 880 B |
| PCBs (Total Aroclors) | | < 0.0095 U |
| MTBE | | 740 |
| Benzo(a)pyrene | 0.18 | < 0.19 U |
| Indeno(1,2,3-cd)pyrene | 0.18 | < 0.19 U |

**EVIDENCE-BASED GEOPHYSICS DATA INTEGRATION**

| Soil Sample Results | | | | |
|---|---|---|---|---|
| **Well** | | **DP-32** | **DP-32** | **DP-32** |
| **Sample Date** | | **4/1/13** | **4/1/13** | **4/1/13** |
| **Sample Depth (feet)** | | **9.5-10.5'** | **29.5-30.5** | **42.5-43.5'** |
| ***Parameters (mg/kg)*** | ***PSL (mg/kg)*** | | | |
| Arsenic | 1.6 | **2.6** | 0.37 | 0.73 |
| Chromium | 5.6 | **11** | 2.3 | 0.89 |
| Cobalt | 30 | 1.0 B | 0.27 B | 3.4 B |
| Manganese | 2300 | 13 B | 4.9 B | 0.86 B |
| DRO (C10-C20) | | < 20 U | < 19 U | < 20 U |
| ORO (C20-C36) | | < 20 U | < 19 U | 21 |
| GRO (C6-C10) | | < 0.091 U | < 0.096 U | 0.170 B |
| PCBs (Total Aroclors) | 0.74 | < 0.00099 U | < 0.00093 U | < 0.001 U |
| Benzo(a)pyrene | 0.21 | < 0.008 U | < 0.0075 U | < 0.008 U |
| Indeno(1,2,3-cd)pyrene | 2.1 | < 0.008 U | < 0.0075 U | < 0.008 U |
| Phenanthrene | 17000 | < 0.008 U | < 0.0075 U | < 0.008 U |
| Pyrene | 1700 | < 0.008 U | < 0.0075 U | < 0.008 U |

| Groundwater Quality Sample Results | | |
|---|---|---|
| **Well** | | **DP-32** |
| **Sample Date** | | **4/1/13** |
| ***Parameters*** | **Units** | |
| Temperature | ºC | 17.8 |
| pH | S.U. | 5.22 |
| Specific Conductivity | mS/cm | 0.76 |
| DO | Mg/L | 0.28 |
| ORP | mV | 263.5 |
| Calcium, dissolved | µg/L | 29,000 B |
| Iron, dissolved | µg/L | 170 B |
| Manganese, dissolved | µg/L | 750 B |


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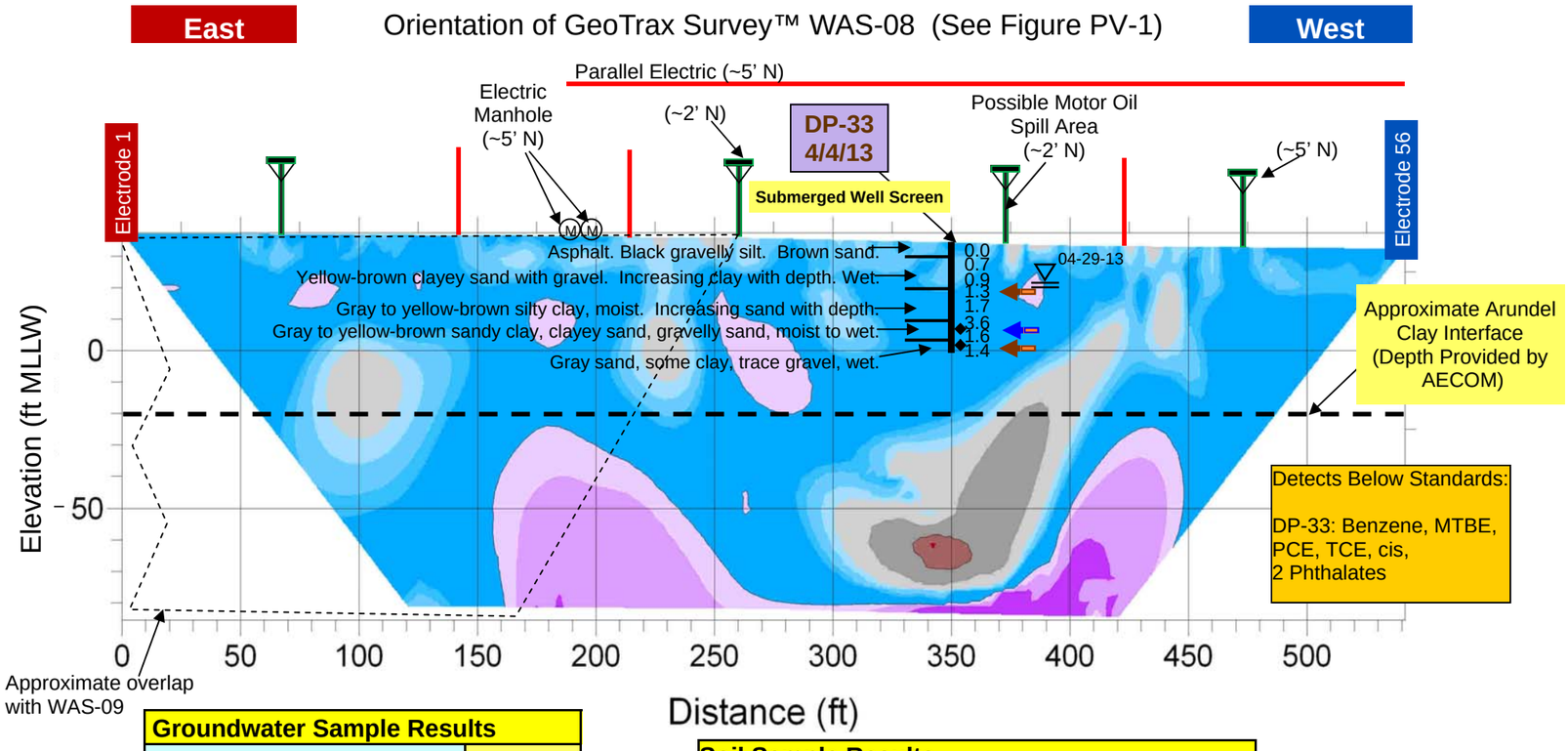
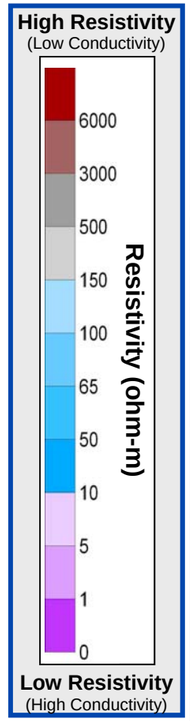
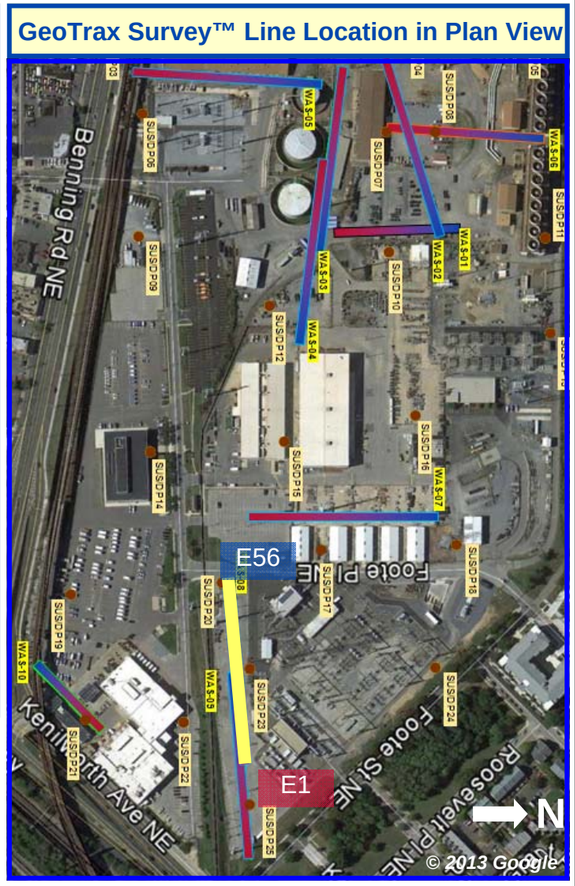
FIGURE
7




**Groundwater Sample Results**

| Well | | DP-33 |
|---|---|---|
| Sample Date | | 4/4/13 |
| *Parameters (µg/L)* | PSL (µg/L) | |
| Arsenic | 1.4 | 0.31 J |
| Manganese | 1000 | **1900 B** |
| Arsenic | 1.4 | **32** |
| Manganese | 1000 | **1800 B** |
| DRO (C10-C20) | | < 480 U |
| ORO (C20-C36) | | < 480 U |
| GRO (C6-C10) | | 60 J B |
| PCBs (Total Aroclors) | | < 0.0095 U |
| MTBE | | 21 |
| Benzo(a)pyrene | 0.18 | < 0.19 U |
| Indeno(1,2,3-cd)pyrene | 0.18 | < 0.19 U |

**Soil Sample Results**

| Well | | DP-33 | DP-33 |
|---|---|---|---|
| Sample Date | | 4/4/13 | 4/4/13 |
| Sample Depth (feet) | | 14-16' | 34-36' |
| *Parameters (mg/kg)* | *PSL (mg/kg)* | | |
| Arsenic | 1.6 | **3.7** | **5.4** |
| Chromium | 5.6 | **22** | **14** |
| Cobalt | 30 | 4.6 B | 19 B |
| Manganese | 2300 | 35 B | 14 B |
| DRO (C10-C20) | | < 20 U | < 26 U |
| ORO (C20-C36) | | < 20 U | 43 |
| GRO (C6-C10) | | 0.060 J | 0.079 J |
| PCBs (Total Aroclors) | 0.74 | < 0.00098 U | < 0.0013 U |
| Benzo(a)pyrene | 0.21 | < 0.008 U | < 0.01 U |
| Indeno(1,2,3-cd)pyrene | 2.1 | < 0.008 U | < 0.01 U |
| Phenanthrene | 17000 | < 0.008 U | < 0.01 U |
| Pyrene | 1700 | < 0.008 U | < 0.01 U |

**Groundwater Quality Sample Results**

| Well | | DP-33 |
|---|---|---|
| Sample Date | | 4/4/13 |
| *Parameters* | Units | |
| Temperature | ºC | 17.5 |
| pH | S.U. | 5.43 |
| Specific Conductivity | mS/cm | 1.705 |
| DO | Mg/L | 0.43 |
| ORP | mV | 57.3 |
| Calcium, dissolved | µg/L | 51,000 B |
| Iron, dissolved | µg/L | 1,700 B |
| Manganese, dissolved | µg/L | **1,900 B** |

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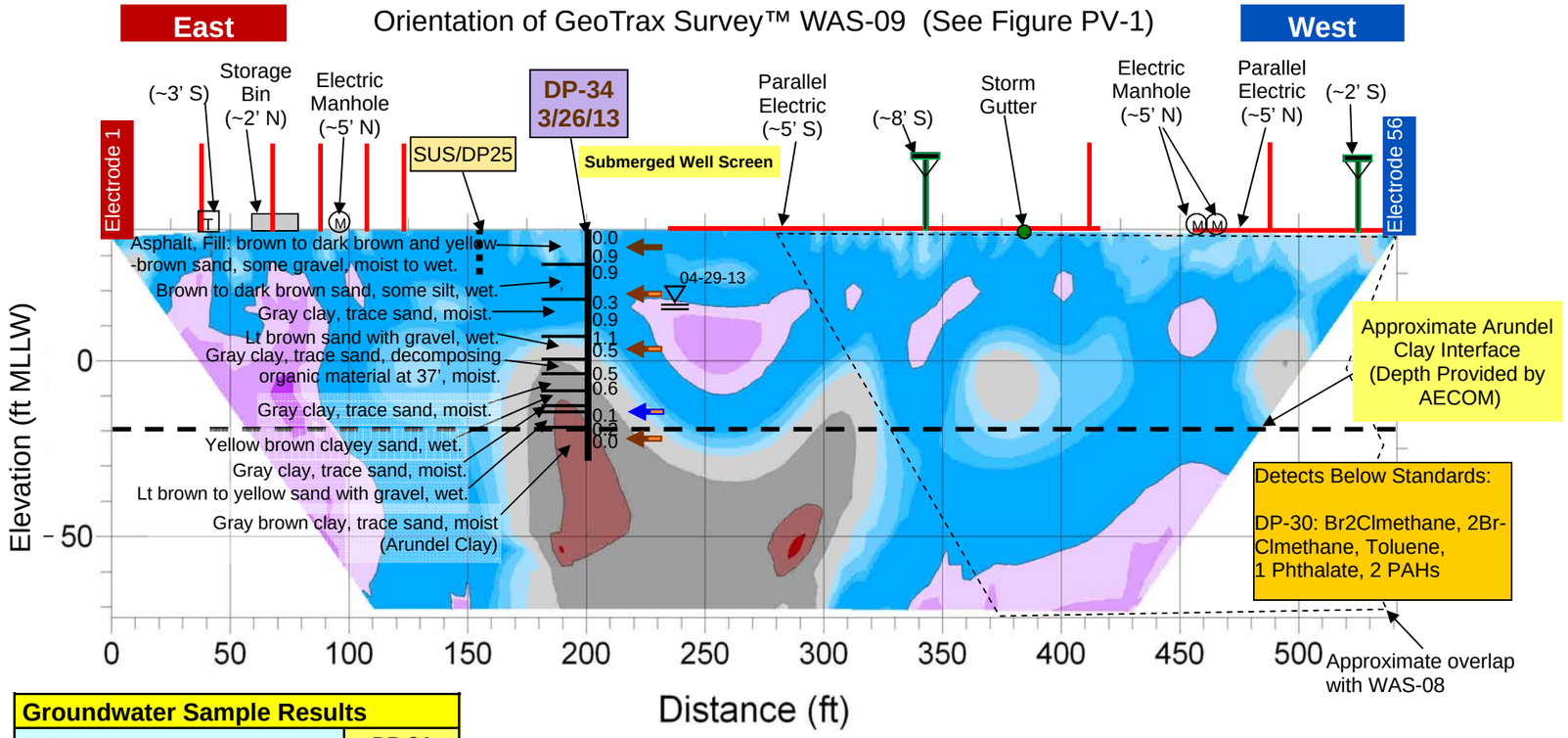
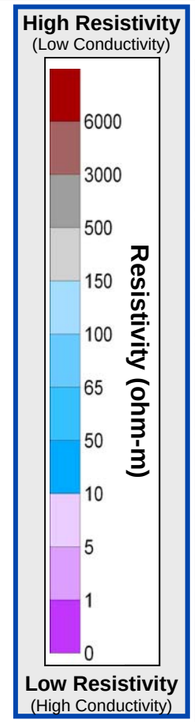
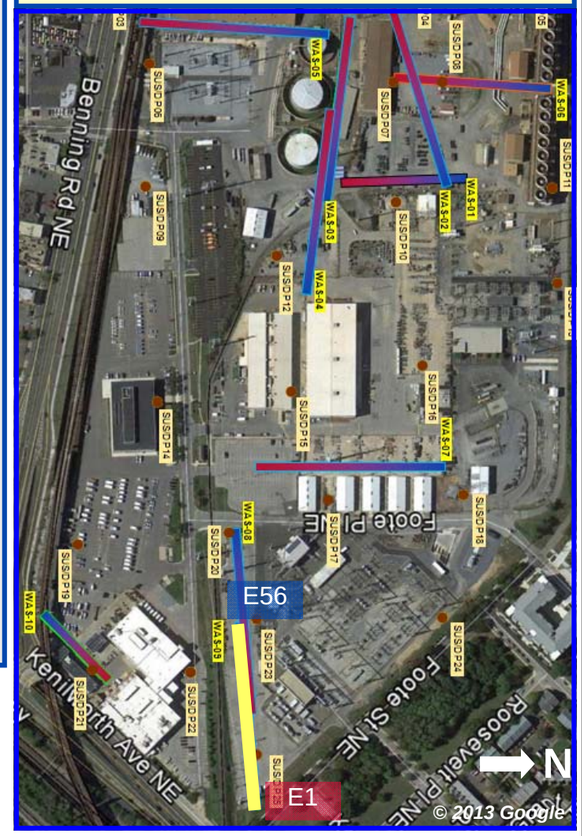
FIGURE
8




## GeoTrax Survey™ Line Location in Plan View




## Groundwater Sample Results

| Well | | DP-34 |
|---|---|---|
| Sample Date | | 3/29/13 |
| *Parameters (µg/L)* | PSL (µg/L) | |
| Arsenic | 1.4 | 1.1 |
| Manganese | 1000 | 580 B |
| Arsenic | 1.4 | **25** |
| Manganese | 1000 | 610 B |
| DRO (C10-C20) | | < 480 U |
| ORO (C20-C36) | | < 480 U |
| GRO (C6-C10) | | 75 J B |
| PCBs (Total Aroclors) | | < 0.0095 U |
| MTBE | | < 1.0 U |
| Benzo(a)pyrene | 0.18 | < 0.19 U |
| Indeno(1,2,3-cd)pyrene | 0.18 | < 0.19 U |

**EVIDENCE-BASED GEOPHYSICS DATA INTEGRATION**

## Soil Sample Results

| Well | | DP-34 | DP-34 | DP-34 | DP-34 |
|---|---|---|---|---|---|
| Sample Date | | 3/29/13 | 3/29/13 | 3/29/13 | 3/29/13 |
| Sample Depth (feet) | | 4.5-5.5' | 17.5-18.5' | 44.5-45.5' | 59.5-60.5' |
| *Parameters (mg/kg)* | *PSL (mg/kg)* | | | | |
| Arsenic | 1.6 | 1.5 | 1.2 | 0.58 | 0.93 |
| Chromium | 5.6 | 4.8 | **11** | **15** | **11** |
| Cobalt | 30 | 1.8 | 3.9 | 3.8 | 2 |
| Manganese | 2300 | 32 | 180 B | 83 B | 48 B |
| DRO (C10-C20) | | < 20 U | < 22 U | < 20 U | < 45 U |
| ORO (C20-C36) | | < 20 U | 17 J | < 20 U | < 45 U |
| GRO (C6-C10) | | < 0.11 U | < 0.1 U | < 0.091 U | 0.048 J B |
| PCBs (Total Aroclors) | 0.74 | < 0.00098 U | < 0.0055 U | < 0.0049 U | < 0.005 U |
| Benzo(a)pyrene | 0.21 | < 0.0079 U | < 0.0089 U | < 0.008 U | < 0.008 U |
| Indeno(1,2,3-cd)pyrene | 2.1 | < 0.0079 U | < 0.0089 U | < 0.008 U | < 0.008 U |
| Phenanthrene | 17000 | < 0.0079 U | < 0.0089 U | < 0.008 U | < 0.008 U |
| Pyrene | 1700 | < 0.0079 U | < 0.0089 U | < 0.008 U | < 0.008 U |

## Groundwater Quality Sample Results

| Well | | DP-34 |
|---|---|---|
| Sample Date | | 3/29/13 |
| *Parameters* | Units | |
| Temperature | ºC | 17.27 |
| pH | S.U. | 5.97 |
| Specific Conductivity | mS/cm | 0.357 |
| DO | Mg/L | 0.45 |
| ORP | mV | 16.5 |
| Calcium, dissolved | µg/L | 20,000 B |
| Iron, dissolved | µg/L | 4,600 B |
| Manganese, dissolved | µg/L | 580 B |


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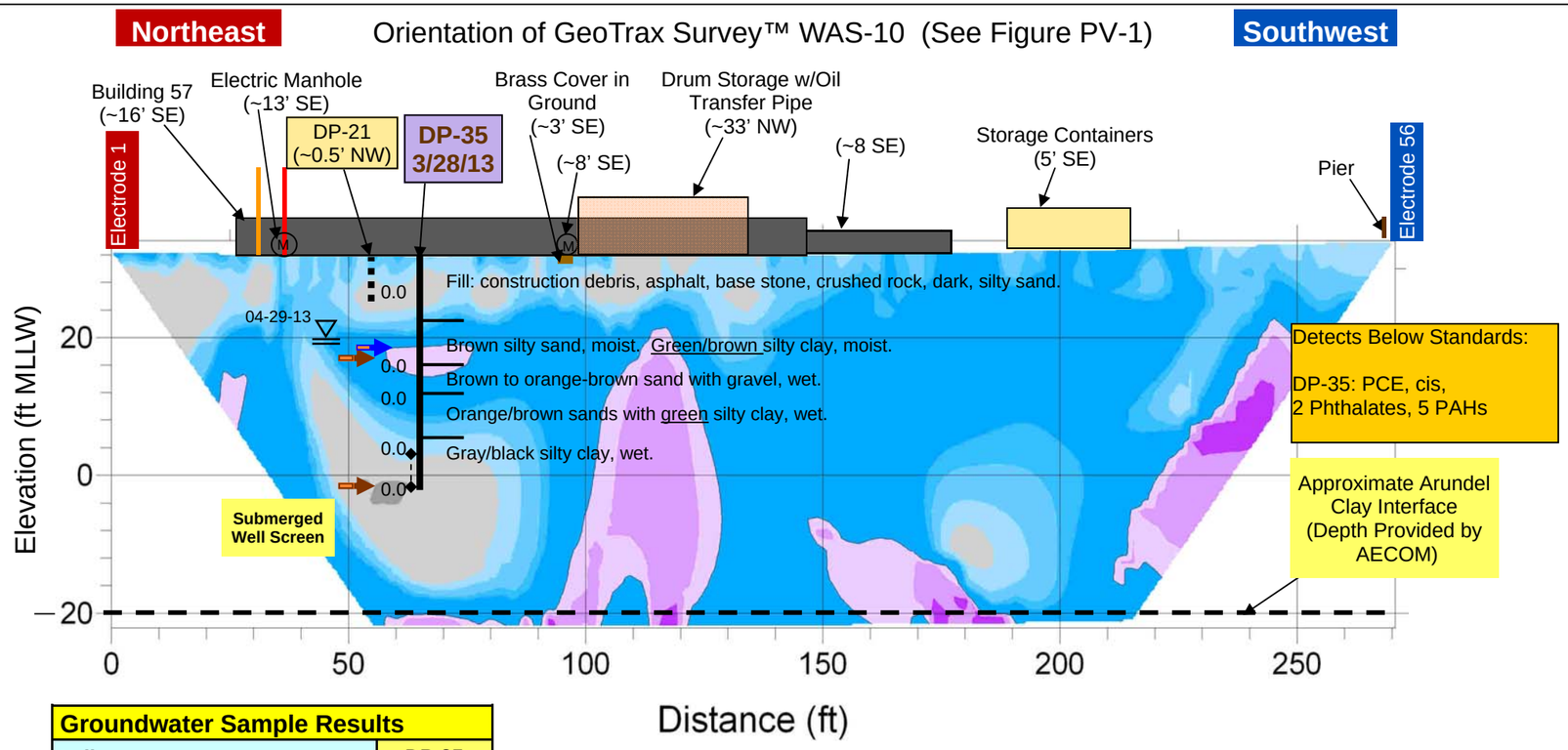
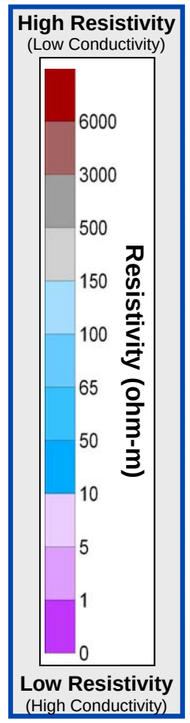
FIGURE
9





| Groundwater Sample Results | | |
|---|---|---|
| **Well** | | **DP-35** |
| **Sample Date** | | **3/28/13** |
| ***Parameters (µg/L)*** | **PSL (µg/L)** | |
| Arsenic | 1.4 | **2.7** |
| Manganese | 1000 | **2500 B** |
| Arsenic | 1.4 | **4.0** |
| Manganese | 1000 | **2000 B** |
| DRO (C10-C20) | | < 480 U |
| ORO (C20-C36) | | < 480 U |
| GRO (C6-C10) | | 68 J B |
| PCBs (Total Aroclors) | | < 0.0095 U |
| MTBE | | < 1.0 U |
| Benzo(a)pyrene | 0.18 | < 0.19 U |
| Indeno(1,2,3-cd)pyrene | 0.18 | < 0.19 U |

| Soil Sample Results | | | |
|---|---|---|---|
| **Well** | | **DP-35** | **DP-35** |
| **Sample Date** | | **3/28/13** | **3/28/13** |
| **Sample Depth (feet)** | | **14.5-15.5'** | **33.5-34.5** |
| ***Parameters (mg/kg)*** | ***PSL (mg/kg)*** | | |
| Arsenic | 1.6 | 0.81 | 0.2 |
| Chromium | 5.6 | **9.2** | **15** |
| Cobalt | 30 | 1.2 | 3.6 |
| Manganese | 2300 | 9.9 B | 96 B |
| DRO (C10-C20) | | < 20 U | < 20 U |
| ORO (C20-C36) | | < 20 U | < 20 U |
| GRO (C6-C10) | | 0.048 J B | 0.070 J B |
| PCBs (Total Aroclors) | 0.74 | < 0.0049 U | < 0.0051 U |
| Benzo(a)pyrene | 0.21 | < 0.0079 U | < 0.0083 U |
| Indeno(1,2,3-cd)pyrene | 2.1 | < 0.0079 U | < 0.0083 U |
| Phenanthrene | 17000 | < 0.0079 U | < 0.0083 U |
| Pyrene | 1700 | < 0.0079 U | < 0.0083 U |

| Groundwater Quality Sample Results | | |
|---|---|---|
| **Well** | | **DP-35** |
| **Sample Date** | | **3/28/13** |
| ***Parameters*** | **Units** | |
| Temperature | ºC | 15.85 |
| pH | S.U. | 4.34 |
| Specific Conductivity | mS/cm | 1.698 |
| DO | Mg/L | 0.61 |
| ORP | mV | 263.9 |
| Calcium, dissolved | µg/L | 65,000 B |
| Iron, dissolved | µg/L | 1,100 B |
| Manganese, dissolved | µg/L | **2,500 B** |

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FIGURE
10

# Representative Site Photos*


*** All site photos included as an electronic appendix to this report**

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**Photos of GeoTrax Survey™ Locations**
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FIGURE

11

# 3-D Visualization Model Perspective View
# Images with Transparent Aerial Photo; Custom Color Scheme

**General Note:**

Because this perspective view is rotated at an arbitrary angle away from plan view, the locations of survey images, site features, and text may appear slightly different or inaccurate relative to actual conditions. To ascertain actual locations of data points/features shown in this 3-D perspective view, please refer to electronic 3-D model files included with this report.

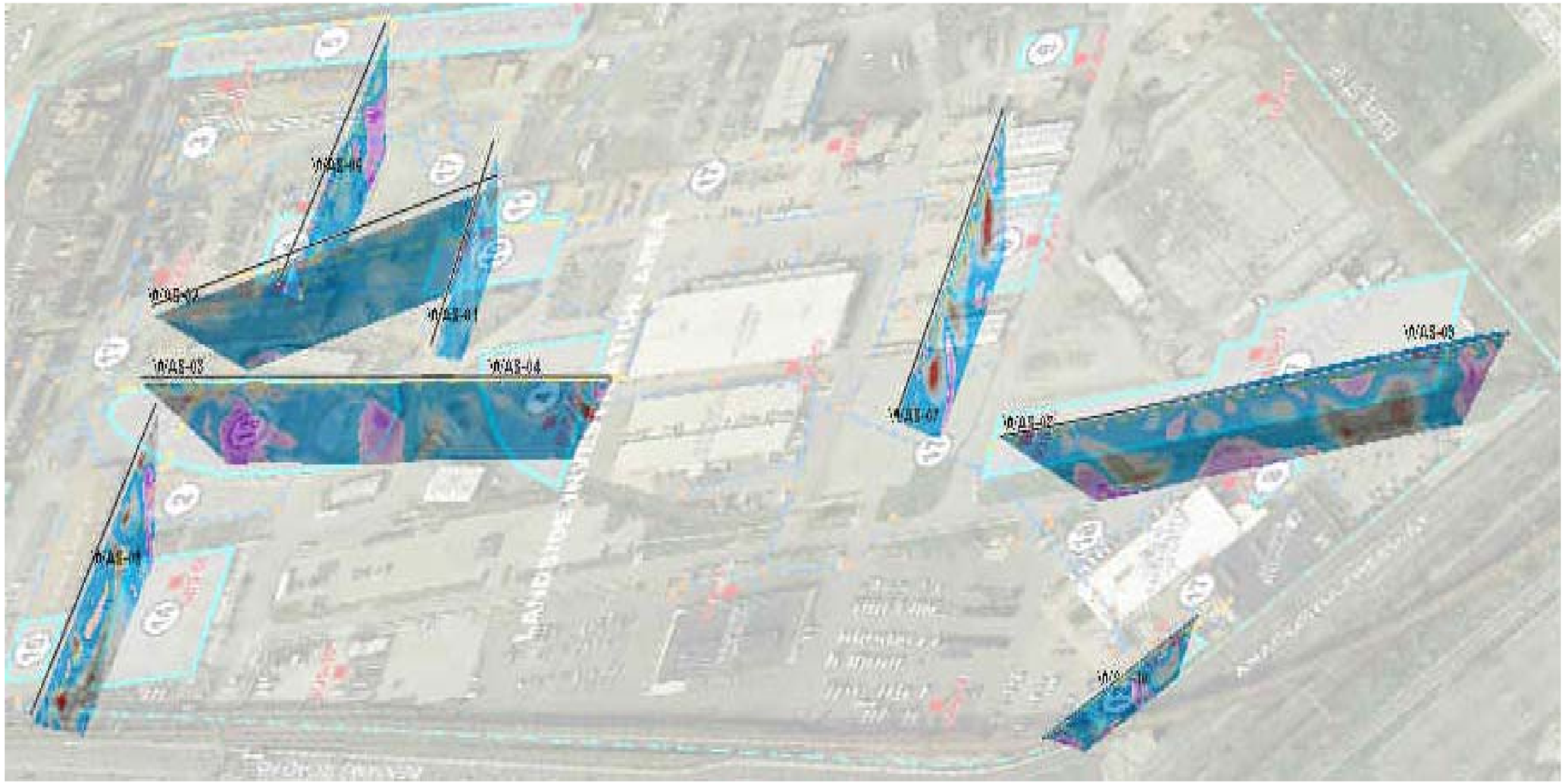



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FIGURE

12

# 3-D Visualization Model Perspective View
# Images with Aerial Photo; Custom Color Scheme

**General Note:**

Because this perspective view is rotated at an arbitrary angle away from plan view, the locations of survey images, site features, and text may appear slightly different or inaccurate relative to actual conditions. To ascertain actual locations of data points/features shown in this 3-D perspective view, please refer to electronic 3-D model files included with this report.


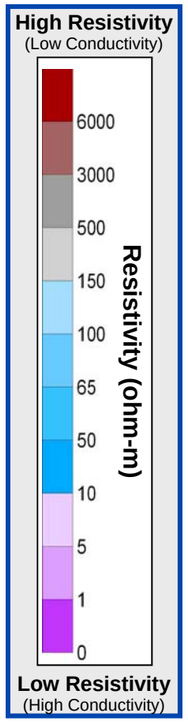



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FIGURE

13

# 3-D Visualization Model Perspective View
# Images only; Custom Color Scheme

**General Note:**

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FIGURE

14

# 3-D Visualization Model Perspective View
# Images only; Conductive Only Color Scheme

**General Note:**

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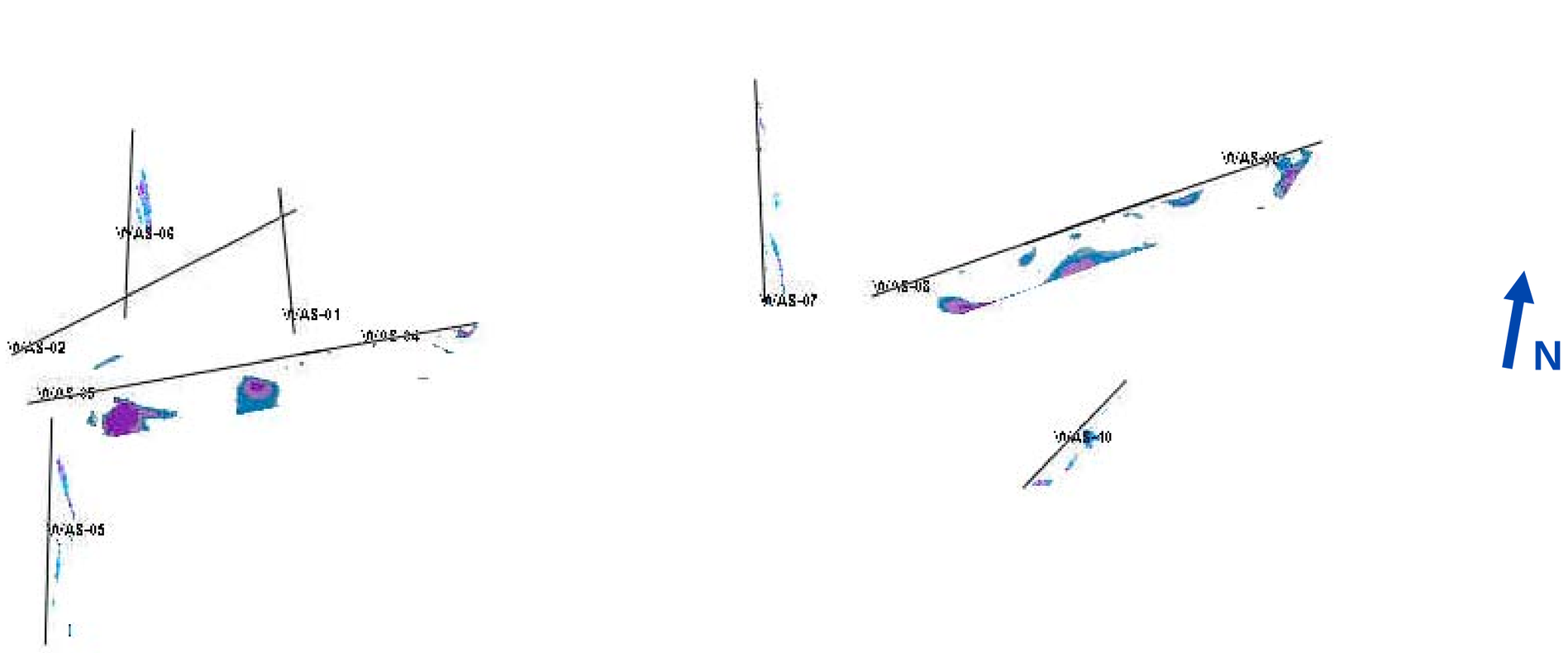



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FIGURE

15

# 3-D Visualization Model Perspective View
# Images only; Resistive Only Color Scheme

**General Note:**

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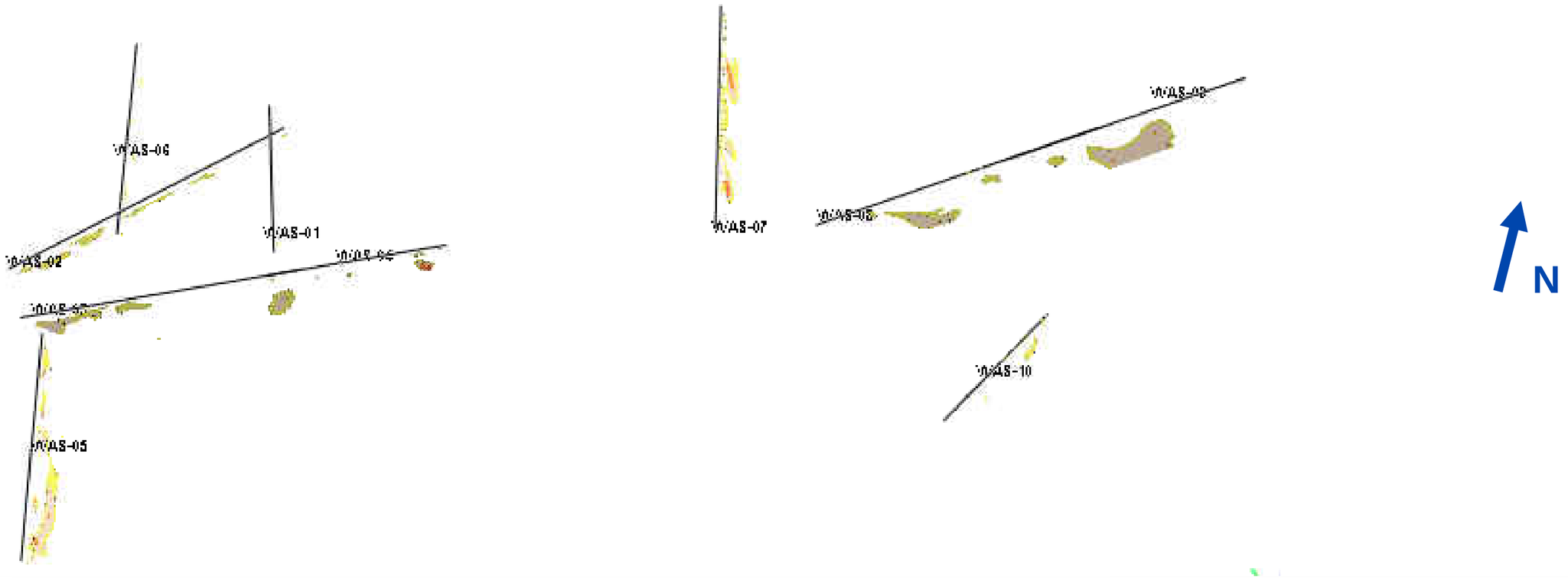



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FIGURE

16

# APPENDICES

# Appendix A

# Aestus' GeoTrax Survey™ Field Notes

**File Name** W A S 0 1 JQ

Project Name PEPCO-Benning Facility

**Relative to North arrow on Sketch Page (reference point is looking from E-01 towards E-56):**

**"Left" of Survey Line = _____ (specify direction)  "Right" of Survey Line = _____(specify direction)**

| Electrode # | Notes | Electrode # | Notes |
|---|---|---|---|
| 1 | 1.5m E of road edge | 29 | |
| 2 | @ end of curve in road | 30 | |
| 3 | | 31 | |
| 4 | | 32 | |
| 5 | | 33 | |
| 6 | | 34 | end asphalt road begin gravel |
| 7 | | 35 | Hazardous waste storage |
| 8 | | 36 | bldg 12m E |
| 9 | | 37 | |
| 10 | #10 3m E parallel | 38 | |
| 11 | | 39 | |
| 12 | | 40 | |
| 13 | | 41 | end asphalt road |
| 14 | | 42 | begin gravel |
| 15 | | 43 | |
| 16 | | 44 | |
| 17 | begin fence around Hi Voltage | 45 | |
| 18 | tower (prob grounding) | 46 | |
| 19 | | 47 | |
| 20 | | 48 | |
| 21 | | 49 | |
| 22 | | 50 | |
| 23 | | 51 | |
| 24 | | 52 | |
| 25 | | 53 | |
| 26 | | 54 | |
| 27 | | 55 | fence 9m E |
| 28 | | 56 | 9m W of fence @ 8th fence pole from corner |

3mW E parallel

fence

fence

#20 3m E

E 1.5m W

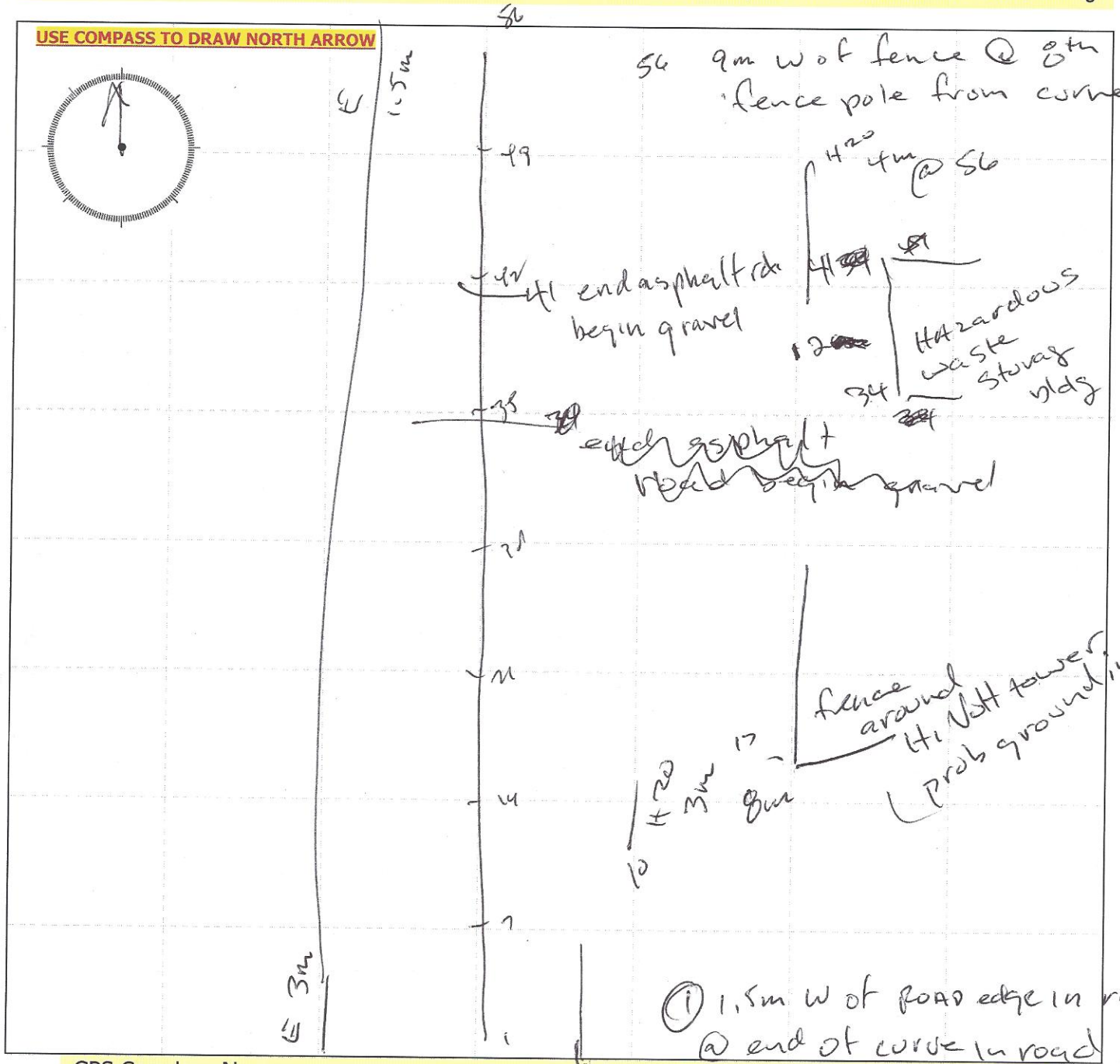
**File Name** W A S 01 V2

Project Name PEPCO-Benning Facility

~20m

**Checklist - Site Features to Sketch/Note:**

- ☐ Monitoring Wells (ID and distance away)
- ☐ Underground Utilities (Location and Type)
- ☐ Metallic Light Poles
- ☐ Streets (w/ street names)
- ☐ Potential contamination source areas (tanks, etc.)
- ☐ Buildings (w/ address if known)
- ☐ Other site features within ~15 feet of survey line
- ☐ Add Legend (if using abbreviations)
- ☐ Overhead power lines/obstacles for future drilling



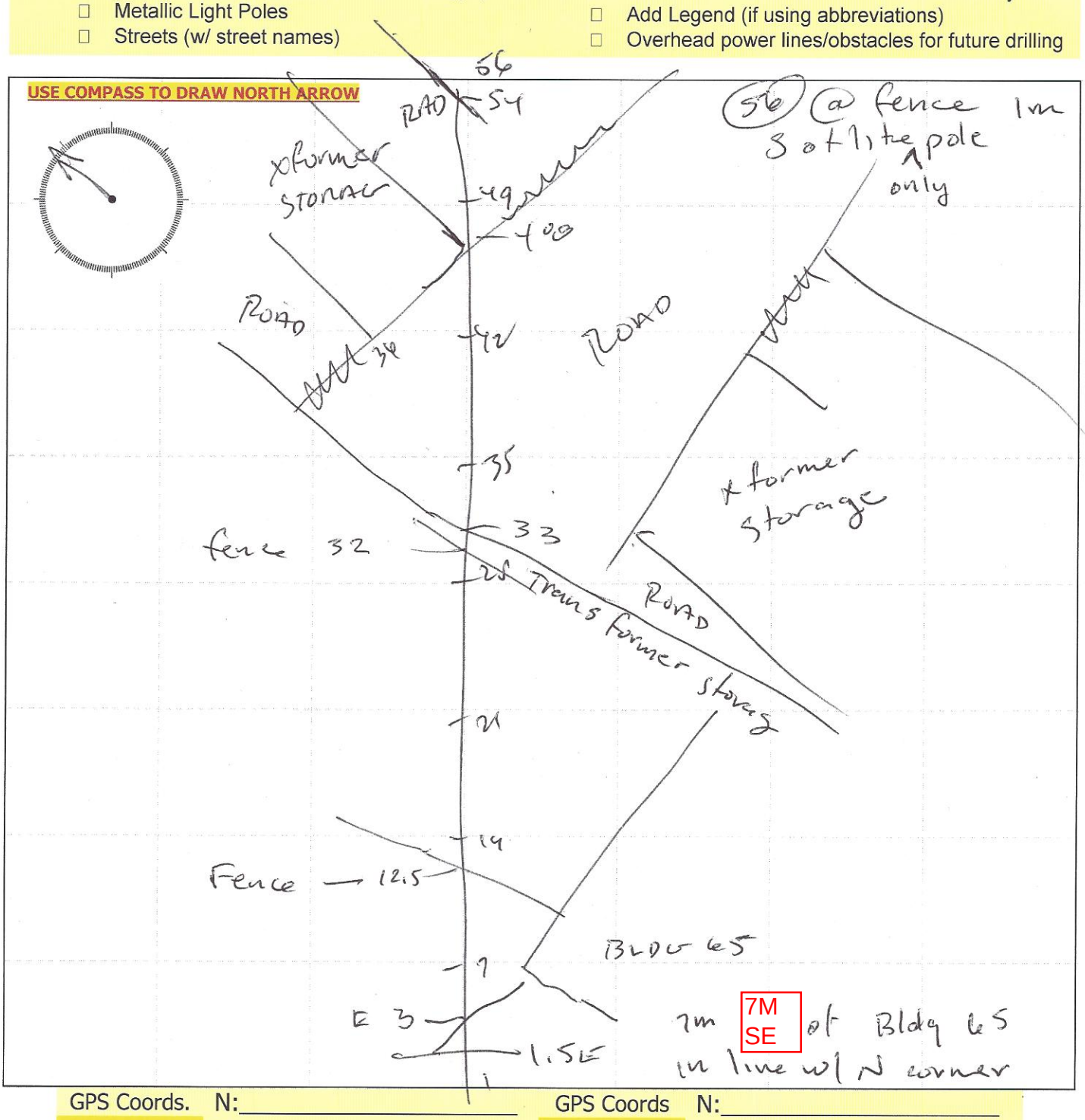

| GPS Coords. Electrode #1 | N: | W: | Accuracy: | GPS Coords Electrode #56 | N: | W: | Accuracy: |
|---|---|---|---|---|---|---|---|
| | | | | | | | |

**File Name** W A S 0 2 VQ

Project Name PEPCO-Benning Facility 3.0.

**Checklist - Site Features to Sketch/Note:**

- ☐ Monitoring Wells (ID and distance away)
- ☐ Underground Utilities (Location and Type)
- ☐ Metallic Light Poles
- ☐ Streets (w/ street names)
- ☐ Potential contamination source areas (tanks, etc.)
- ☐ Buildings (w/ address if known)
- ☐ Other site features within ~15 feet of survey line
- ☐ Add Legend (if using abbreviations)
- ☐ Overhead power lines/obstacles for future drilling




| GPS Coords. | N: | GPS Coords | N: |
|---|---|---|---|
| Electrode #1 | W: | Electrode #56 | W: |
| | Accuracy: | | Accuracy: |

**File Name** W A S 0 2 VG

Project Name PEPCO-Benning Facility

**Relative to North arrow on Sketch Page (reference point is looking from E-01 towards E-56):**

**"Left" of Survey Line = _____ (specify direction)  "Right" of Survey Line = _____(specify direction)**

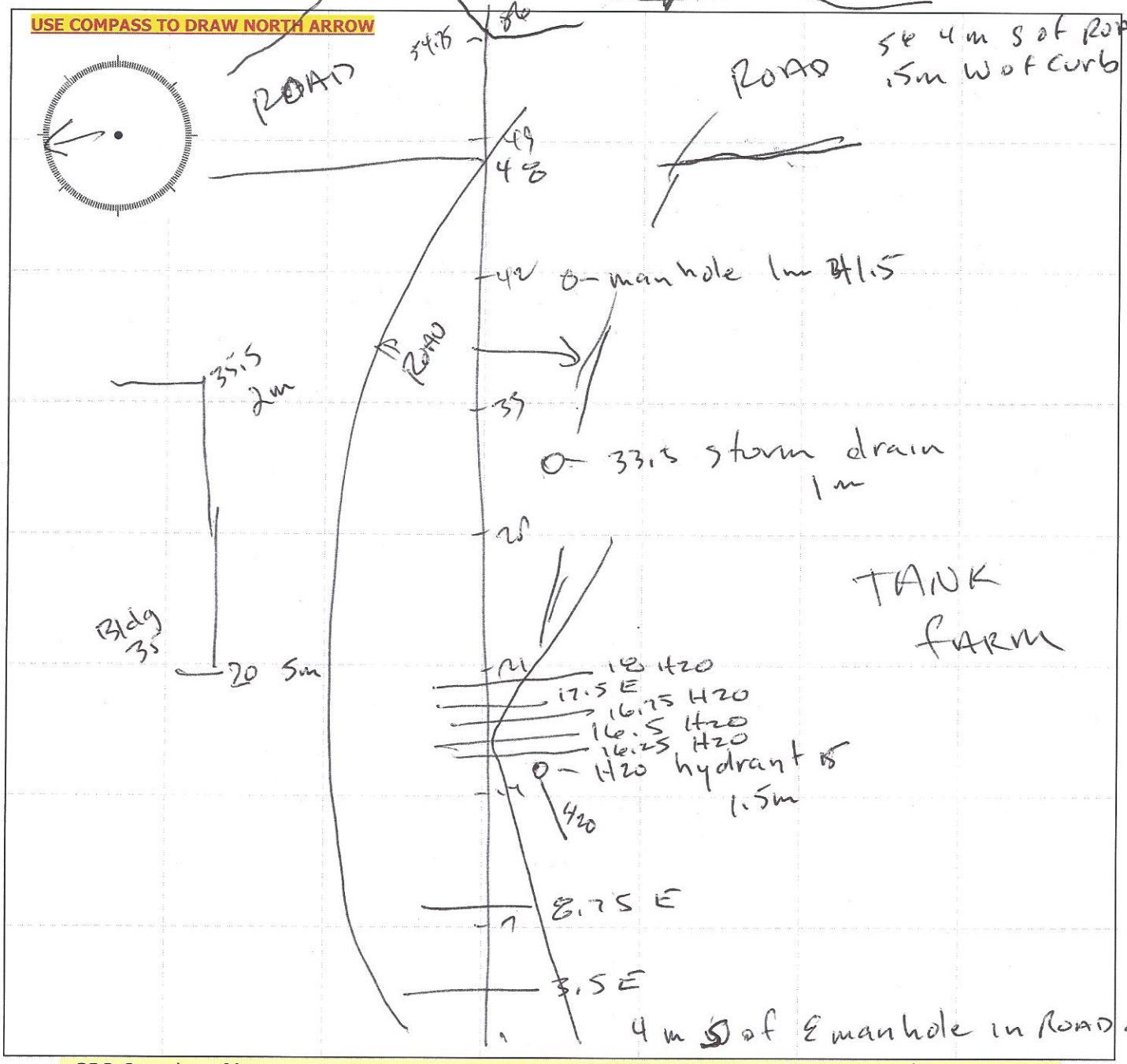
| Electrode # | Notes | Electrode # | Notes |
|---|---|---|---|
| 1 | 7m W of Bldg 65 in Line | 29 | |
| 2 | w/ N. Corner | 30 | |
| 3 | 1.5 E | 31 | |
| 4 | 3 E | 32 | fence, trans former Storage |
| 5 | | 33 | ROAD |
| 6 | | 34 | |
| 7 | BLDG 65 -approx 5m SE | 35 | |
| 8 | | 36 | x former storage areas |
| 9 | | 37 | to Right & LEFT of line |
| 10 | | 38 | |
| 11 | | 39 | |
| 12 | 5 fence | 40 | |
| 13 | | 41 | |
| 14 | | 42 | |
| 15 | | 43 | |
| 16 | | 44 | |
| 17 | | 45 | |
| 18 | | 46 | |
| 19 | | 47 | |
| 20 | | 48 | |
| 21 | | 49 | |
| 22 | | 50 | |
| 23 | | 51 | |
| 24 | | 52 | |
| 25 | | 53 | |
| 26 | | 54 | |
| 27 | | 55 | |
| 28 | | 56 | @ fence 1m S of only lite pole |

**File Name** W A S 0 3 V0

Project Name PEPCO-Benning Facility

**Checklist - Site Features to Sketch/Note:**

- ☐ Monitoring Wells (ID and distance away)
- ☐ Underground Utilities (Location and Type)
- ☐ Metallic Light Poles
- ☐ Streets (w/ street names)
- ☐ Potential contamination source areas (tanks, etc.)
- ☐ Buildings (w/ address if known)
- ☐ Other site features within ~15 feet of survey line
- ☐ Add Legend (if using abbreviations)
- ☐ Overhead power lines/obstacles for future drilling




| GPS Coords. Electrode #1 | N: | W: | Accuracy: | GPS Coords Electrode #56 | N: 2m W | W: | Accuracy: |
|---|---|---|---|---|---|---|---|

**File Name** W A S 0 3 VQ

Project Name PEPCO-Benning Facility

**Relative to North arrow on Sketch Page (reference point is looking from E-01 towards E-56):**

**"Left" of Survey Line = _____ (specify direction)** **"Right" of Survey Line = _____(specify direction)**

| Electrode # | Notes | Electrode # | Notes |
|---|---|---|---|
| 1 | 4m S of E manhole in Road | 29 | |
| 2 | 2m W | 30 | |
| 3 .5 | E | 31 | |
| 4 | | 32 | |
| 5 | | 33 .5 | Storm drain 1m S |
| 6 | | 34 | |
| 7 | | 35 35.5 | Bldg 35 2m N |
| 8 .75 | E | 36 | |
| 9 | | 37 | |
| 10 | | 38 | |
| 11 | | 39 | |
| 12 | | 40 | |
| 13 | | 41 | 41.5 manhole 1m South |
| 14 | | 42 | |
| 15 | H20 Hydrant 1.5m S | 43 | |
| 16 .25, | 16.5, 16.75 H20 | 44 | |
| 17 .5 | E | 45 | |
| 18 | H20 | 46 | |
| 19 | | 47 | |
| 20 | Bldg 35 5m N | 48 | Corner intersection Road |
| 21 | | 49 | |
| 22 | | 50 | |
| 23 | | 51 | |
| 24 | | 52 | |
| 25 | | 53 | |
| 26 | | 54 54.75 | edge Road |
| 27 | | 55 | |
| 28 | | 56 | 4m S of Road .5m W of Curb |

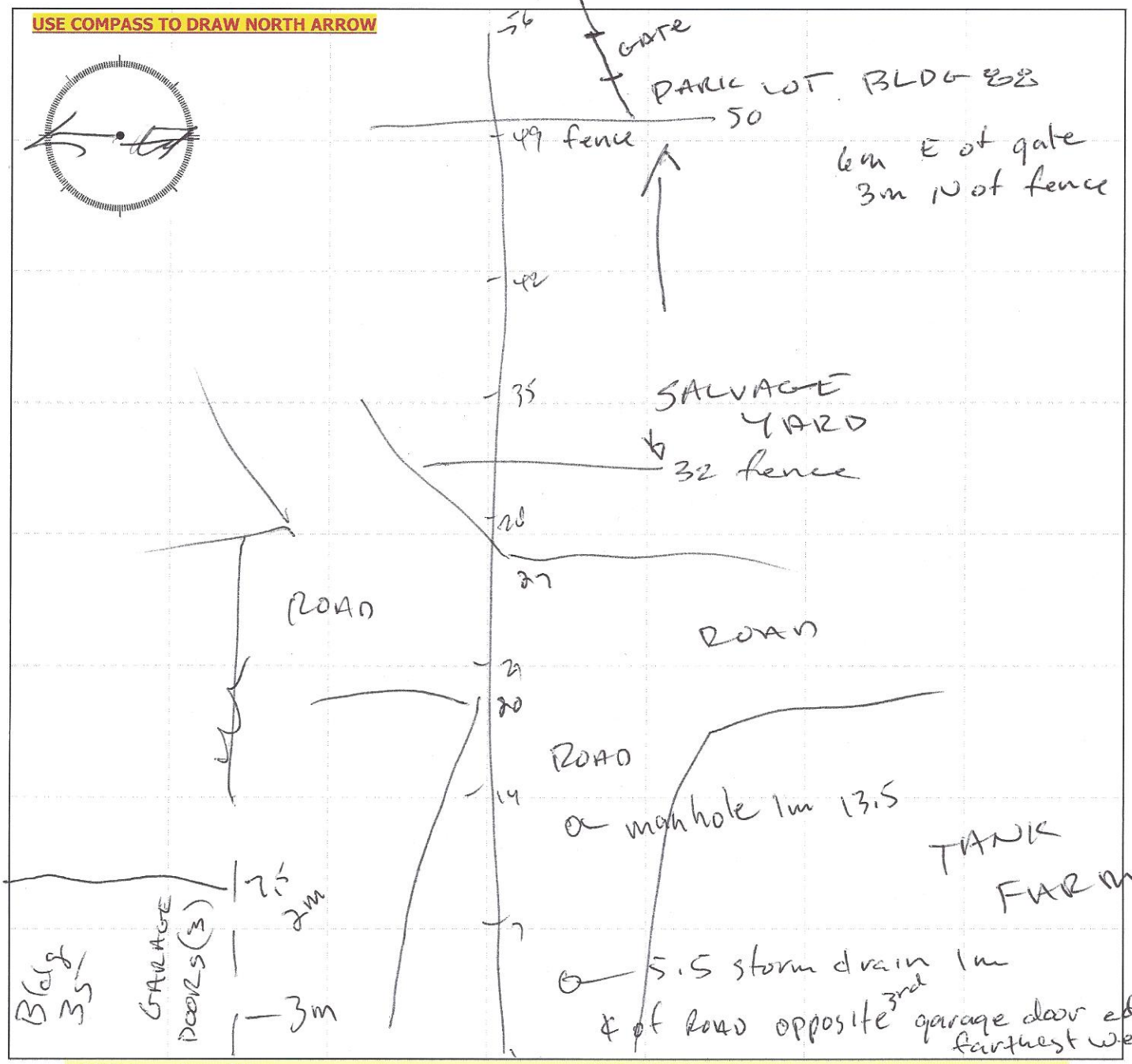
TANK farm South

**File Name** | W | A | S | 6 | ~~4~~ | √0 |

Project Name PEPCO-Benning Facility

**Checklist - Site Features to Sketch/Note:**

- ☐ Monitoring Wells (ID and distance away)
- ☐ Underground Utilities (Location and Type)
- ☐ Metallic Light Poles
- ☐ Streets (w/ street names)
- ☐ Potential contamination source areas (tanks, etc.)
- ☐ Buildings (w/ address if known)
- ☐ Other site features within ~15 feet of survey line
- ☐ Add Legend (if using abbreviations)
- ☐ Overhead power lines/obstacles for future drilling




| GPS Coords. Electrode #1 | N: | W: | Accuracy: | GPS Coords Electrode #56 | N: | W: | Accuracy: |
|---|---|---|---|---|---|---|---|

**File Name** W A S 0 4 NR

Project Name PEPCO-Benning Facility

**Relative to North arrow on Sketch Page (reference point is looking from E-01 towards E-56):**

**"Left" of Survey Line = _____ (specify direction)** **"Right" of Survey Line = _____(specify direction)**

| Electrode # | Notes | Electrode # | Notes |
|---|---|---|---|
| 1 | E of ROAD opposite 3rd garage edge | 29 | |
| 2 | door farthest west | 30 | |
| 3 | | 31 | |
| 4 | | 32 | fence salvage yard |
| 5.5 | storm drain 1m S | 33 | |
| 6 | | 34 | |
| 7 | | 35 | |
| 8 | | 36 | |
| 9 | | 37 | |
| 10 | | 38 | |
| 11 | | 39 | |
| 12 | | 40 | |
| 13.5 | manhole 1m S | 41 | |
| 14 | | 42 | |
| 15 | | 43 | |
| 16 | | 44 | |
| 17 | | 45 | |
| 18 | | 46 | |
| 19 | | 47 | |
| 20 | corner intersection ROAD | 48 | |
| 21 | | 49 | |
| 22 | | 50 | fence |
| 23 | | 51 | park lot Bldg 88 |
| 24 | | 52 | |
| 25 | | 53 | |
| 26 | | 54 | |
| 27 | | 55 | |
| 28 | | 56 | 6m E of gate 3m N of fence |

Bldg 3m

35

Bldg 35 North

2m 7.5

tank farm SOUTH

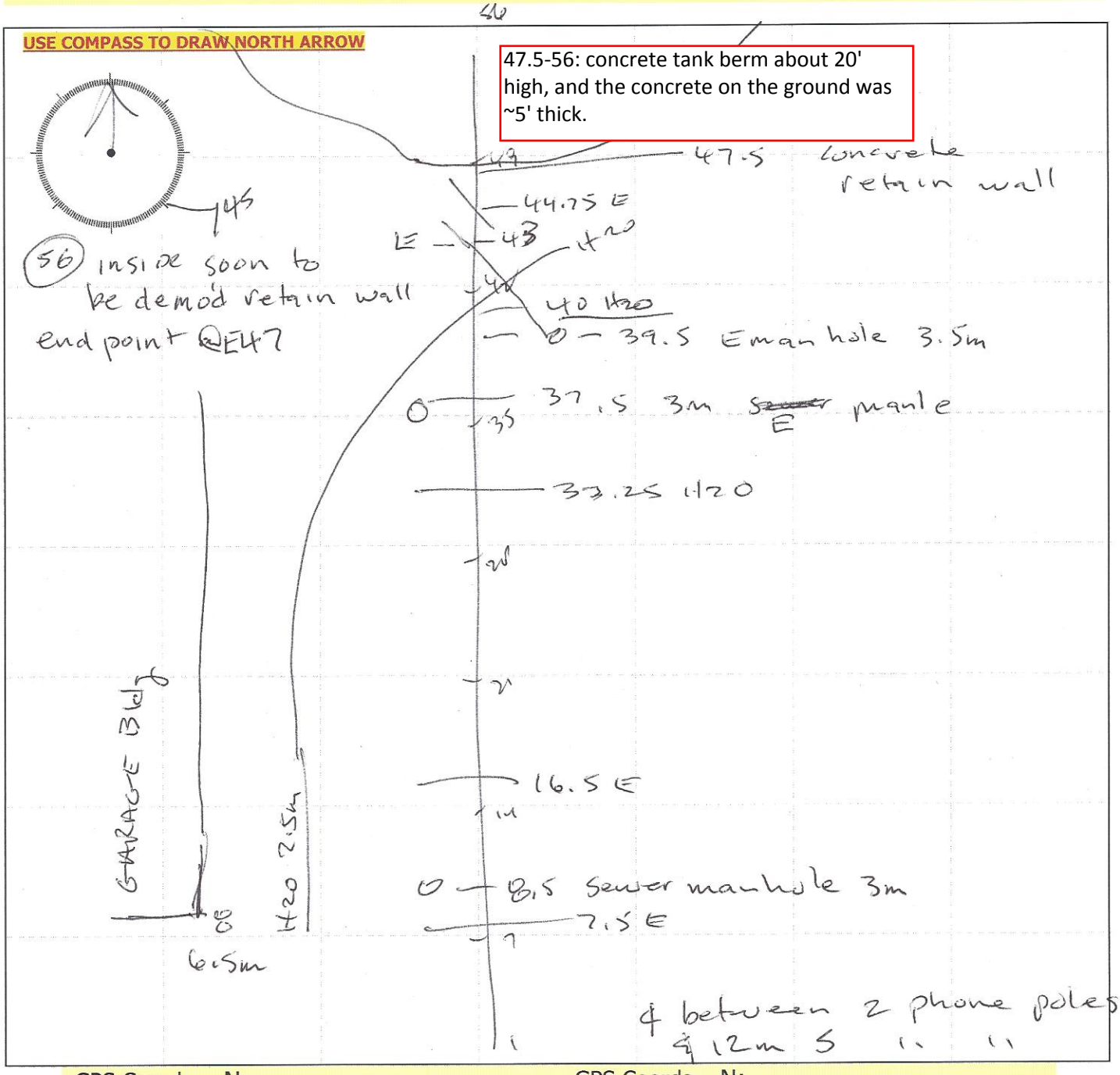
**File Name** W A S 0 5 VQ

Project Name PEPCO-Benning Facility

3.0m

**Checklist - Site Features to Sketch/Note:**

- ☐ Monitoring Wells (ID and distance away)
- ☐ Underground Utilities (Location and Type)
- ☐ Metallic Light Poles
- ☐ Streets (w/ street names)
- ☐ Potential contamination source areas (tanks, etc.)
- ☐ Buildings (w/ address if known)
- ☐ Other site features within ~15 feet of survey line
- ☐ Add Legend (if using abbreviations)
- ☐ Overhead power lines/obstacles for future drilling




| GPS Coords. | N:_____ | GPS Coords | N:_____ |
|---|---|---|---|
| Electrode #1 | W:_____ | Electrode #56 | W:_____ |
| | Accuracy:_____ | | Accuracy:_____ |

**File Name** W A S

Project Name PEPCO-Benning Facility

**Relative to North arrow on Sketch Page (reference point is looking from E-01 towards E-56):**

**"Left" of Survey Line = _____ (specify direction)** **"Right" of Survey Line = _____(specify direction)**

| Electrode # | Notes | Electrode # | Notes |
|---|---|---|---|
| 1 | & between 2 phone poles and | 29 | |
| 2 | centered between " " | 30 | |
| 3 | | 31 | |
| 4 | | 32.25 | H2O |
| 5 | | 33 | |
| 6 | | 34 | |
| 7 | .5 E | 35 | |
| 8 | GARAG 6.5M W, 8.5 Sewer manhole | 36 | |
| 9 | 3m W | 37.5 | E manhole 3m west |
| 10 | | 38 | |
| 11 | | 39.5 | E manhole 3/5 m east |
| 12 | | 40 | H2O |
| 13 | | 41 | |
| 14 | | 42 | |
| 15 | | 43 | E |
| 16 | .5 E | 44 | .75 E |
| 17 | | 45 | |
| 18 | | 46 | |
| 19 | | 47.5 | Concrete retain wall for demoid oil tank |
| 20 | | 48 | |
| 21 | | 49 | 47.5-56: concrete tank berm about 20' high, and the concrete on the ground was ~5' thick. |
| 22 | | 50 | |
| 23 | | 51 | |
| 24 | | 52 | |
| 25 | | 53 | |
| 26 | | 54 | |
| 27 | | 55 | |
| 28 | | 56 | inside soon to be demoid retain wall - end point @ E47 |

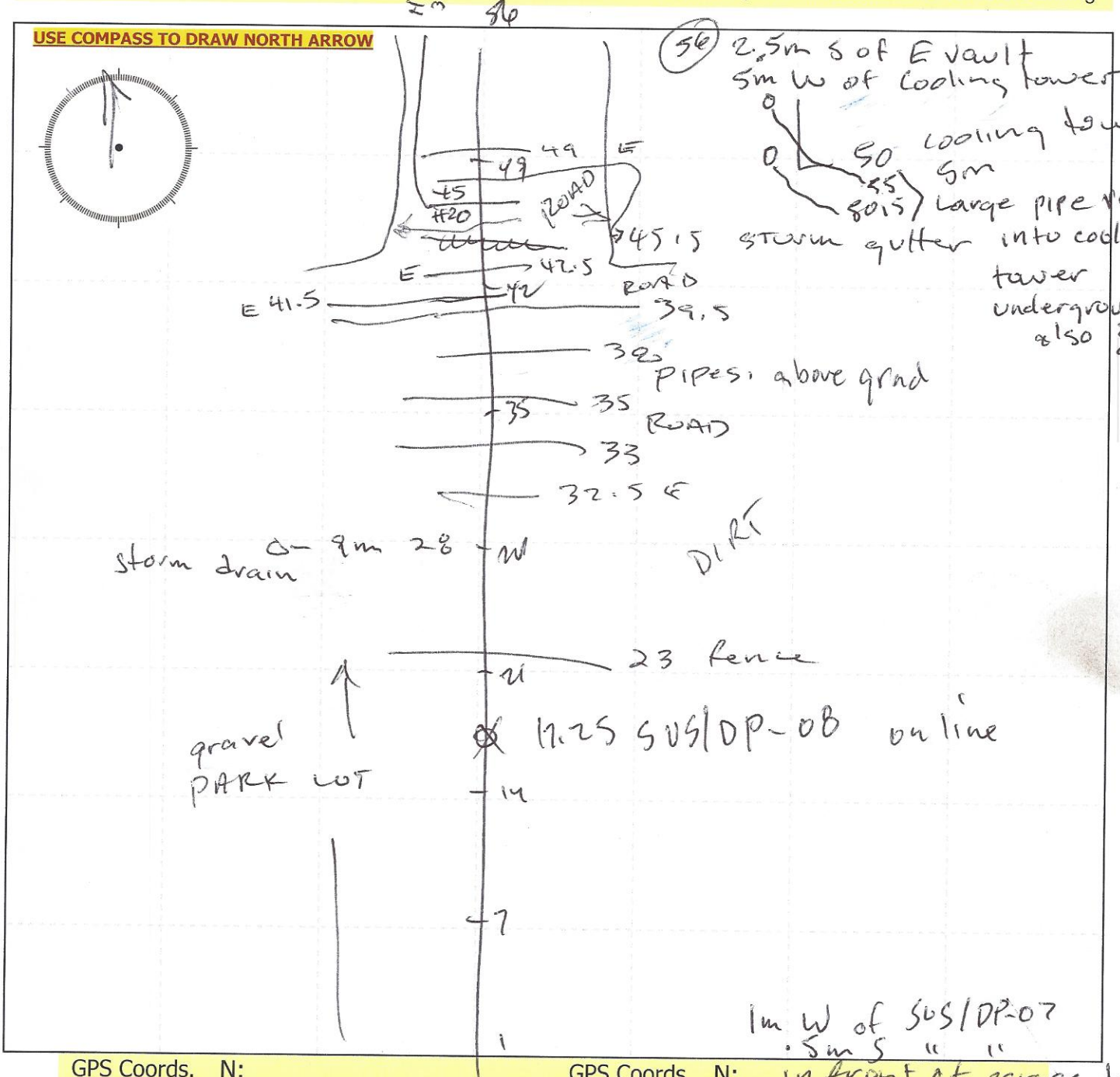
H2O parallel 2.5m W

**File Name** W A S 0 6 v2

Project Name PEPCO-Benning Facility

**Checklist - Site Features to Sketch/Note:**

- ☐ Monitoring Wells (ID and distance away)
- ☐ Underground Utilities (Location and Type)
- ☐ Metallic Light Poles
- ☐ Streets (w/ street names)
- ☐ Potential contamination source areas (tanks, etc.)
- ☐ Buildings (w/ address if known)
- ☐ Other site features within ~15 feet of survey line
- ☐ Add Legend (if using abbreviations)
- ☐ Overhead power lines/obstacles for future drilling




| | | | |
|---|---|---|---|
| GPS Coords. Electrode #1 | N: | GPS Coords Electrode #56 | N: |
| | W: | | W: |
| | Accuracy: | | Accuracy: |

File Name W A S 0 6 VR

Project Name PEPCO-Benning Facility

**Relative to North arrow on Sketch Page (reference point is looking from E-01 towards E-56):**

"Left" of Survey Line = _____ (specify direction) "Right" of Survey Line = _____(specify direction)

| Electrode # | Notes | Electrode # | Notes |
|---|---|---|---|
| 1 | 1m W of SUS/DP-07 | 29 | |
| 2 | 1.5m S of SUS/DP-07 | 30 | |
| 3 | | 31 | |
| 4 | | 32 | 32.5 E |
| 5 | | 33 | Road |
| 6 | | 34 | |
| 7 | | 35 | Pipes above ground |
| 8 | | 36 | |
| 9 | | 37 | |
| 10 | | 38 | |
| 11 | | 39 | 39.5 Road 39.5 - 56?Road |
| 12 | | 40 | |
| 13 | | 41 | 41.5 E |
| 14 | | 42 | 42.5 E |
| 15 | | 43 | |
| 16 | | 44 | |
| 17 | 17.25 SUS/DP-08 online | 45 | H2O 45-56 Water line \|\| to line e at 3 m west |
| 18 | | 46 | 45.5 Storm Gutter |
| 19 | | 47 | |
| 20 | | 48 | |
| 21 | | 49 | E |
| 22 | | 50 | Cooling tower 5m E |
| 23 | fence | 51 | 50.5 Pipe (vertical into cooling |
| 24 | | 52 | tower underground also ? |
| 25 | | 53 | |
| 26 | | 54 | |
| 27 | | 55 | 55 Vertical pipe into cooling tower |
| 28 | 28 Storm Drain 9m west | 56 | underground also ? |
| | | 56 | 2.5m S of E. Vault |

PARKING LOT

gravel

DIRT

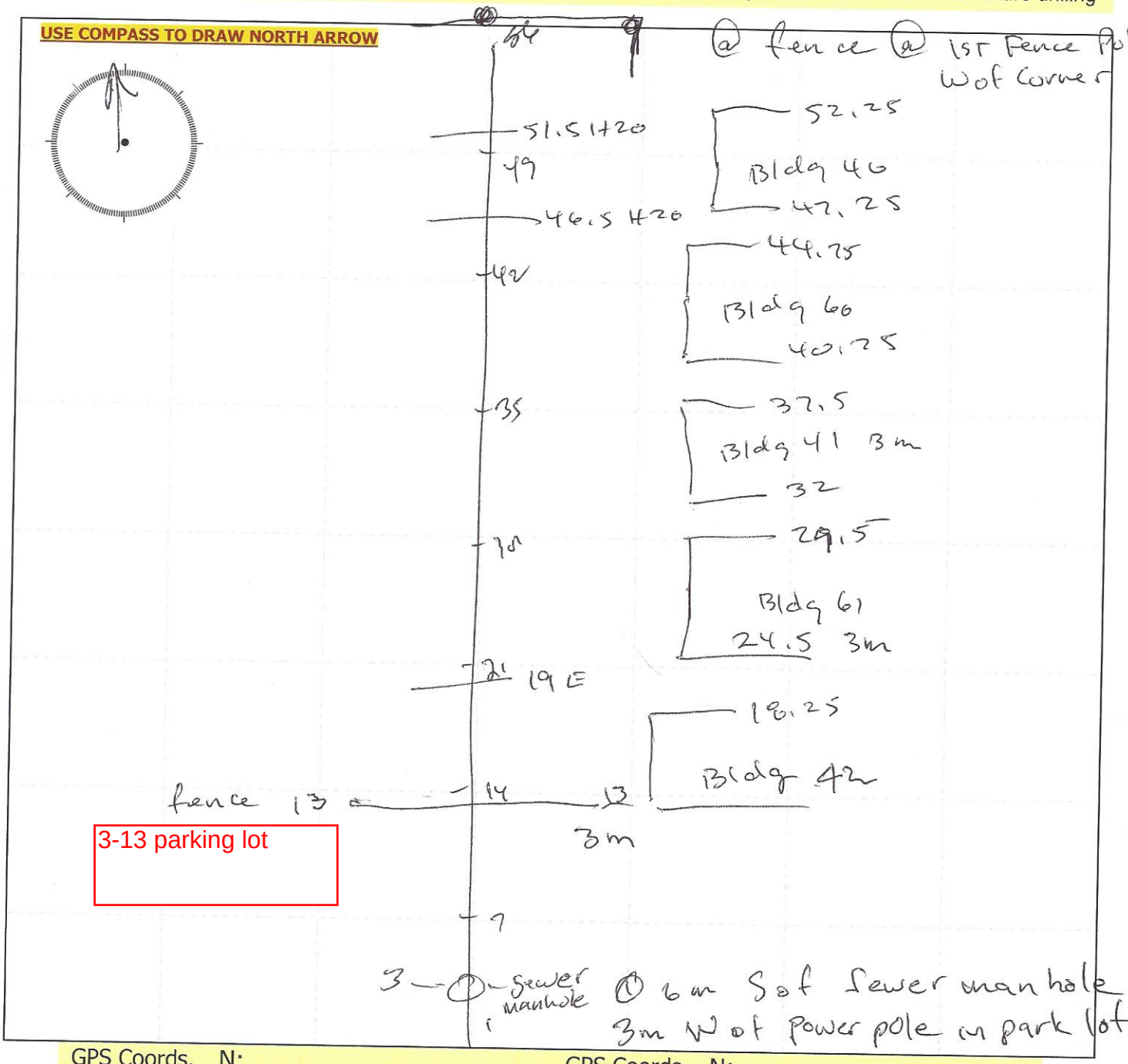
5m W of cooling tower

**File Name** W A S 0 7 NG

Project Name PEPCO-Benning Facility

**Checklist - Site Features to Sketch/Note:**

- ☐ Monitoring Wells (ID and distance away)
- ☐ Underground Utilities (Location and Type)
- ☐ Metallic Light Poles
- ☐ Streets (w/ street names)
- ☐ Potential contamination source areas (tanks, etc.)
- ☐ Buildings (w/ address if known)
- ☐ Other site features within ~15 feet of survey line
- ☐ Add Legend (if using abbreviations)
- ☐ Overhead power lines/obstacles for future drilling




| | | | |
|---|---|---|---|
| GPS Coords. Electrode #1 | N:_____ W:_____ Accuracy:_____ | GPS Coords Electrode #56 | N:_____ W:_____ Accuracy:_____ |

**File Name** W A S 0 7 V2

Project Name PEPCO-Benning Facility

**Relative to North arrow on Sketch Page (reference point is looking from E-01 towards E-56):**

**"Left" of Survey Line = _____ (specify direction)** **"Right" of Survey Line = _____(specify direction)**

| Electrode # | Notes | Electrode # | Notes |
|---|---|---|---|
| 1 | 6m S of Sewer manhole | 29 | ↓ 29.5 |
| 2 | 3m W of power pole in park lot | 30 | |
| 3 | Sewer manhole on line | 31 | |
| 4 | | 32 | Bldg 41 3m E |
| 5 | | 33 | |
| 6 | | 34 | |
| 7 | | 35 | |
| 8 | | 36 | |
| 9 | | 37 | ↓ 37.5 |
| 10 | | 38 | |
| 11 | | 39 | |
| 12 | | 40 | .75 Bldg 60 3m E |
| 13 | fence, Bldg 42 3m E | 41 | |
| 14 | | 42 | |
| 15 | | 43 | |
| 16 | | 44 | ↓ 44.75 |
| 17 | | 45 | |
| 18 | ↓ 18.25 | 46 | .5 H2O |
| 19 | E | 47 | .25 Bldg 46 3m E |
| 20 | | 48 | |
| 21 | | 49 | |
| 22 | | 50 | |
| 23 | | 51 | .5 H2O |
| 24 | .5 Bldg 61 3m E | 52 | ↓ 52.25 |
| 25 | | 53 | |
| 26 | | 54 | |
| 27 | | 55 | |
| 28 | | 56 | @ fence, @ 1st fence pole W of Corner |

park lot

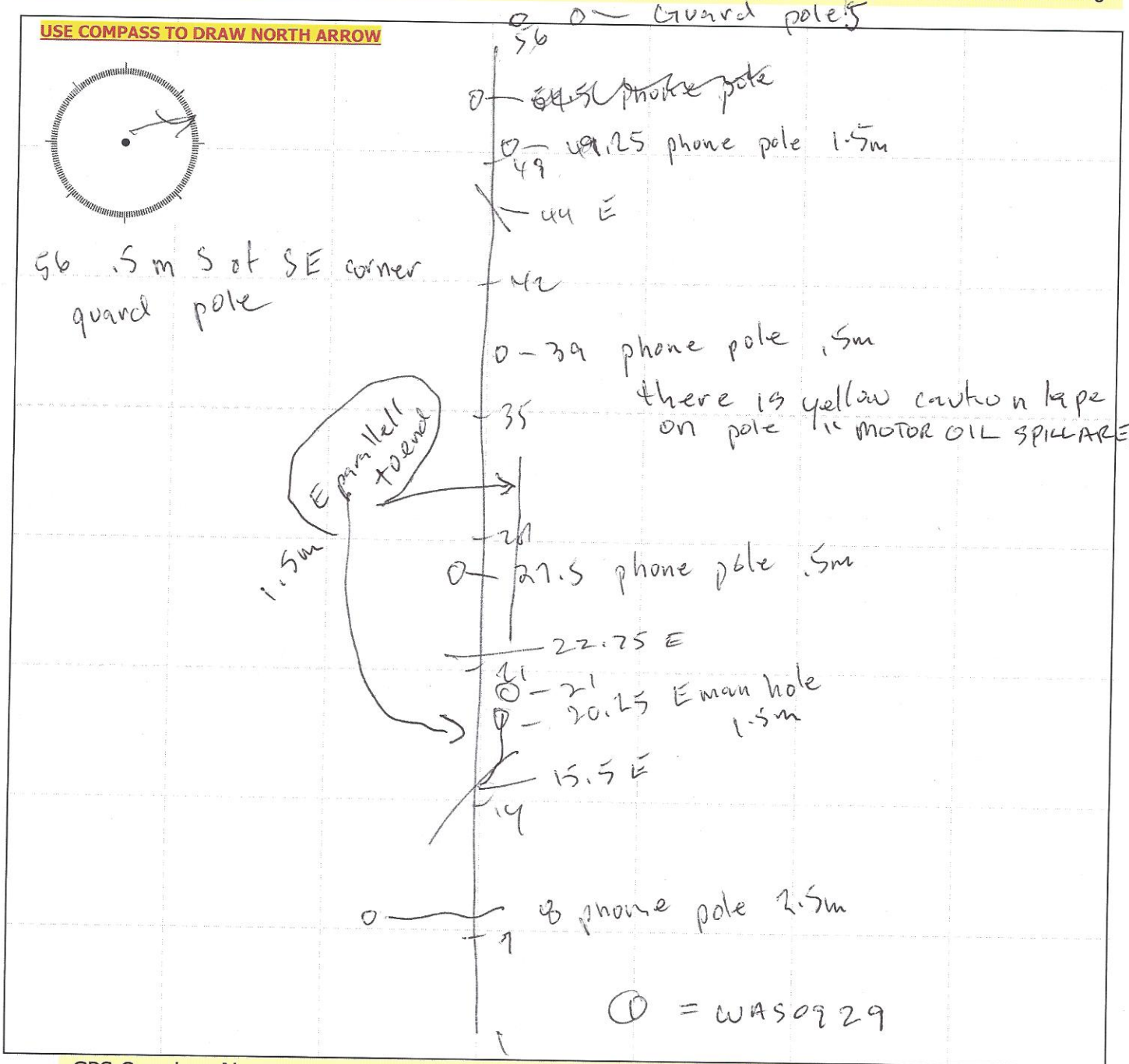
**File Name** W A S 0 8 VQ

Project Name PEPCO-Benning Facility

phone pole 3.0m

**Checklist - Site Features to Sketch/Note:**

- ☐ Monitoring Wells (ID and distance away)
- ☐ Underground Utilities (Location and Type)
- ☐ Metallic Light Poles
- ☐ Streets (w/ street names)
- ☐ Potential contamination source areas (tanks, etc.)
- ☐ Buildings (w/ address if known)
- ☐ Other site features within ~15 feet of survey line
- ☐ Add Legend (if using abbreviations)
- ☐ Overhead power lines/obstacles for future drilling




| GPS Coords. Electrode #1 | N: | W: | Accuracy: | GPS Coords Electrode #56 | N: | W: | Accuracy: |
|---|---|---|---|---|---|---|---|

File Name W A S 0 8 V2

Project Name PEPCO-Benning Facility

**Relative to North arrow on Sketch Page (reference point is looking from E-01 towards E-56):**

**"Left" of Survey Line = _____ (specify direction)  "Right" of Survey Line = _____(specify direction)**

| Electrode # | Notes | Electrode # | Notes |
|---|---|---|---|
| 1 | WAS09-29 | 29 | |
| 2 | | 30 | |
| 3 | | 31 | |
| 4 | | 32 | |
| 5 | | 33 | |
| 6 | | 34 | |
| 7 | | 35 | |
| 8 | Phone pole 2.5m S | 36 | |
| 9 | | 37 | |
| 10 | | 38 | |
| 11 | | 39 | Phone Pole .5m N - there |
| 12 | | 40 | is yellow caution tape on pole |
| 13 | | 41 | "motor oil spill area" Z |
| 14 | | 42 | |
| 15 .5 | E | 43 | |
| 16 | | 44 | E |
| 17 | | 45 | |
| 18 | | 46 | |
| 19 | | 47 | |
| 20 .25 | E man hole | 48 | |
| 21 | E. man hole | 49 .25 | Phone Pole 1.5m N |
| 22 | | 50 | |
| 23 | | 51 | |
| 24 | | 52 | |
| 25 | | 53 | |
| 26 | | 54 | |
| 27 .5 | Phone Pole .5m S N | 55 | |
| 28 | | 56 | .5m S of S.E corner guard pole |

20.25 & 21
E Manhole
1.5 m north

E parallel 1.5m N to 56

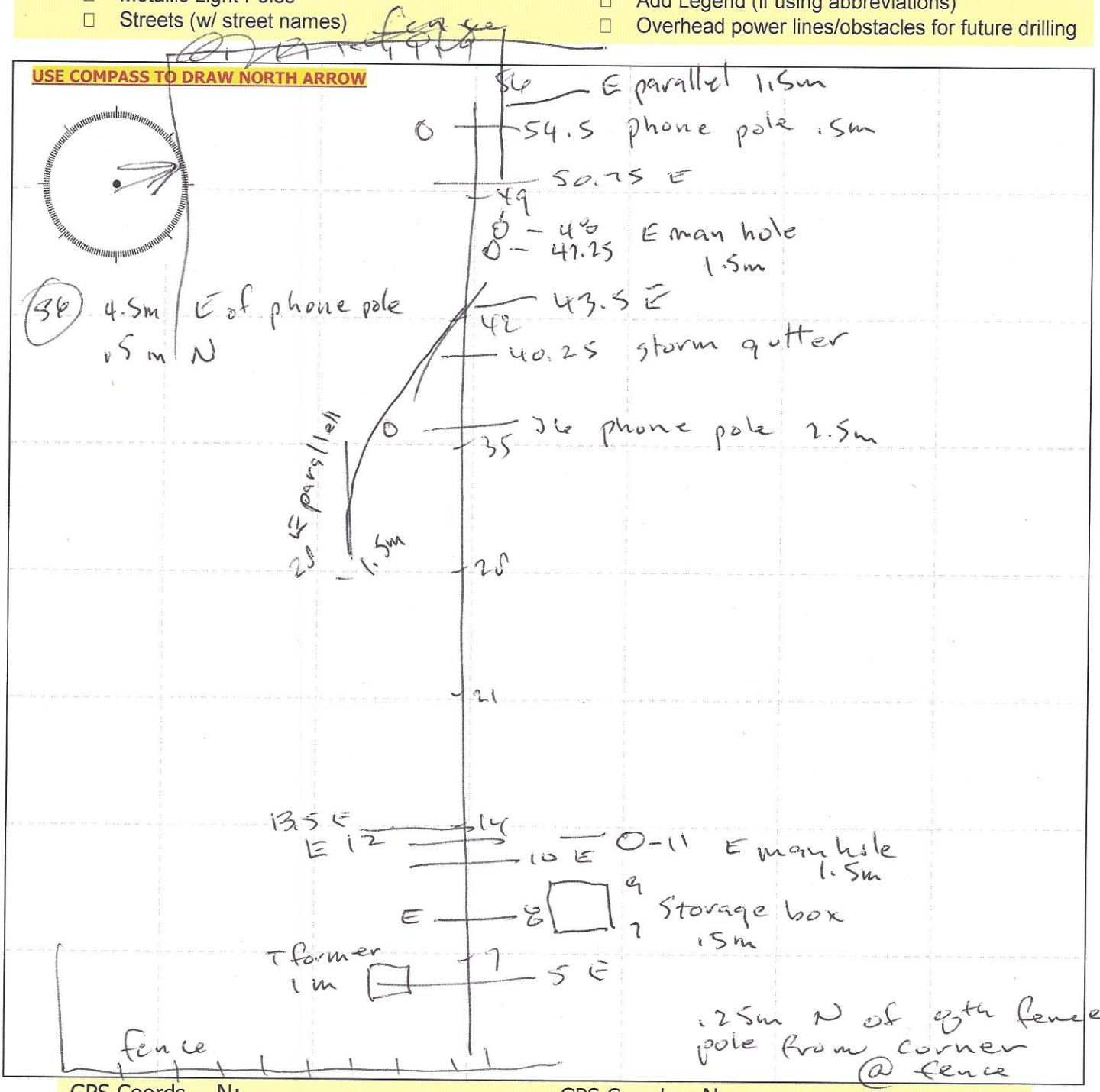
**File Name** W A S 0 9 V2

Project Name PEPCO-Benning Facility

3.0 m

**Checklist - Site Features to Sketch/Note:**

- ☐ Monitoring Wells (ID and distance away)
- ☐ Underground Utilities (Location and Type)
- ☐ Metallic Light Poles
- ☐ Streets (w/ street names)
- ☐ Potential contamination source areas (tanks, etc.)
- ☐ Buildings (w/ address if known)
- ☐ Other site features within ~15 feet of survey line
- ☐ Add Legend (if using abbreviations)
- ☐ Overhead power lines/obstacles for future drilling




| GPS Coords. Electrode #1 | N: | GPS Coords Electrode #56 | N: |
|---|---|---|---|
| | W: | | W: |
| | Accuracy: | | Accuracy: |

**File Name** W A S 09 V2

Project Name PEPCO-Benning Facility

**Relative to North arrow on Sketch Page (reference point is looking from E-01 towards E-56):**

**"Left" of Survey Line = _____ (specify direction)** **"Right" of Survey Line = _____(specify direction)**

| Electrode # | Notes | Electrode # | Notes |
|---|---|---|---|
| 1 | .25m N of 8th fence pole | 29 | |
| 2 | from corner @ fence | 30 | 25-43.5 Electric parallel |
| 3 | | 31 | |
| 4 | | 32 | |
| 5 | E, Tformer 1m S | 33 | |
| 6 | | 34 | |
| 7 | Storage bin .5m N | 35 | |
| 8 | E | 36 | Phone pole 2.5m S |
| 9 | | 37 | |
| 10 | E | 38 | |
| 11 | E manhole 1.5m N | 39 | |
| 12 | E | 40 | .25 Storm gutter |
| 13 | .5 E | 41 | |
| 14 | | 42 | E |
| 15 | | 43.5 | E |
| 16 | | 44 | |
| 17 | | 45 | |
| 18 | | 46 | |
| 19 | | 47 | .25 E. manhole (.5m N) |
| 20 | | 48 | E manhole (.5m N) |
| 21 | | 49 | |
| 22 | | 50 | .75 E |
| 23 | | 51 | |
| 24 | | 52 | |
| 25 | | 53 | |
| 26 | | 54 | .5 Phone pole .5m S |
| 27 | | 55 | |
| 28 | | 56 | |

E parallel 1.5m S

down 43.5

E parallel 1.5m N

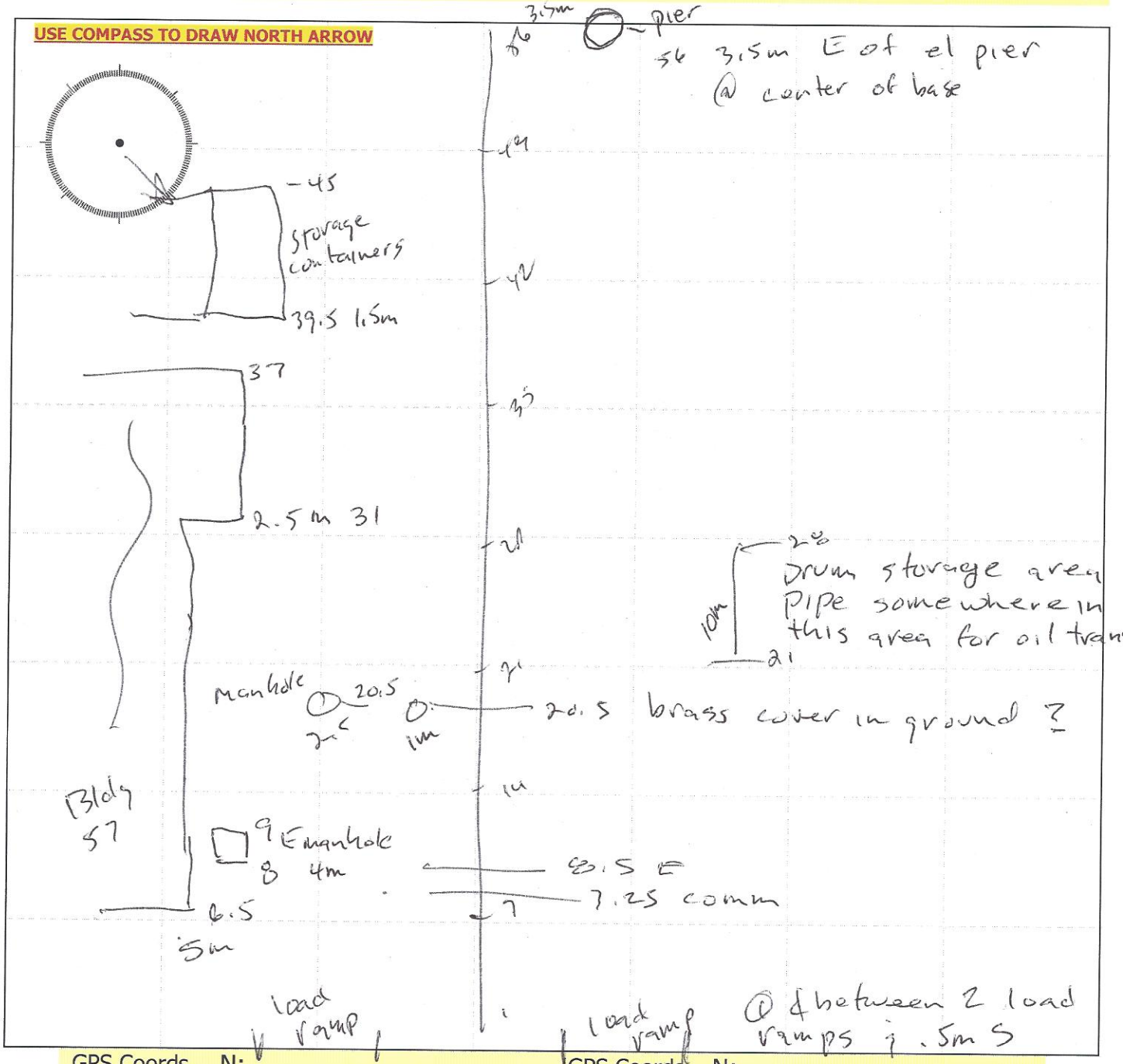
**File Name** W A S 1 0 v2

Project Name PEPCO-Benning Facility

1.5m

**Checklist - Site Features to Sketch/Note:**

- ☐ Monitoring Wells (ID and distance away)
- ☐ Underground Utilities (Location and Type)
- ☐ Metallic Light Poles
- ☐ Streets (w/ street names)
- ☐ Potential contamination source areas (tanks, etc.)
- ☐ Buildings (w/ address if known)
- ☐ Other site features within ~15 feet of survey line
- ☐ Add Legend (if using abbreviations)
- ☐ Overhead power lines/obstacles for future drilling




| | | | |
|---|---|---|---|
| GPS Coords. Electrode #1 | N: _____ W: _____ Accuracy: _____ | GPS Coords Electrode #56 | N: _____ W: _____ Accuracy: _____ |

File Name W A S ? 0 VQ

Project Name PEPCO-Benning Facility

**Relative to North arrow on Sketch Page (reference point is looking from E-01 towards E-56):**

**"Left" of Survey Line = _____ (specify direction)  "Right" of Survey Line = _____(specify direction)**

| Electrode # | Notes | Electrode # | Notes |
|---|---|---|---|
| 1 | & between two load ramps | 29 | |
| 2 | ? .5m S | 30 | |
| 3 | | 31 | Bldg 57 Seq 2.5m L |
| 4 | | 32 | |
| 5 | | 33 | |
| 6 | S Bldg 57 5m LEFT | 34 | |
| 7 | 7.25 util Communication | 35 | |
| 8 | E man hole 4m L 8.25E | 36 | |
| 9 | 8.5 util Electric | 37 | |
| 10 | | 38 | |
| 11 | | 39 | S Storage Containers 1.5m L |
| 12 | | 40 | |
| 13 | | 41 | |
| 14 | | 42 | |
| 15 | | 43 | |
| 16 | | 44 | |
| 17 | | 45 | |
| 18 | | 46 | |
| 19 | | 47 | |
| 20 | S man hole 2.5 m L brass cover? | 48 | |
| 21 | Drum storage area 1m L | 49 | |
| 22 | pipe some where in this | 50 | |
| 23 | area for oil transfer | 51 | |
| 24 | 10m R | 52 | |
| 25 | | 53 | |
| 26 | | 54 | |
| 27 | | 55 | |
| 28 | | 56 | 3.5m E of El pier @ center of base |

# Appendix B

# REFERENCE - TECHNICAL PAPER

# The Effects of LNAPL Biodegradation Products on Electrical Conductivity Measurements

# The Effects of LNAPL Biodegradation Products on Electrical Conductivity Measurements

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ABSTRACT

Field geophysical Studies have identified anomalously high conductivities in and below the free product Tone at many sites with aged contamination by light. non-aqueous phase liquid\ (LNAPL). Laboratory experiments were conducted to test the hypotheses that these anomalously high conductivities can result from products of LNAPL biodegradation. Soil from a hydrocarbon-impacted site with anomalously high conductivities was washed repeatedly IO remove soluble constituents, re-contaminated with diesel fuel (DF), and the port\ tilled with water to simulate a saturated smear Tone. Nutrients were provided at level? observed at the site. which resulted in anaerobic conditions due to DF biodegradation. Within 121) days. the increase in specific conductivity from microbial activity was 2, 100 $\mu$S/cm. caused by an increase in total dissolved solids (DS) of over 1,700 *mg/L*. The increase in DS was due to mineral (mostly carbonate) dissolution and to the production of organic acids and biosurfactants. Under aerobic conditions (i.e., without added nutrients) products of DF biodegradation increased the total DS and conductivity by 340 mg/L and 440 $\mu$S/cm. respectively. The results show that products of LNAPL biodegradation can drastically increase the conductivity at impacted sites.

## Introduction

The collection. preparation. and analysis of ground water samples at contaminated sites constitute a major portion of the total cost for remediation (Granato and Smith, 1999) Geophysical surveys using resistivity and ground penetrating radar (GPR) are convenient, non-invasive tools 10 detect and map subsurface contamination with light, nonaqueous phase liquid\ (LNAPL). Recent reports suggest that LNAPL biodegradation can change biogeochemical properties sufficiently to have a significant impact on resistively and GPR measurements (Sauck, 2000, Werkema *et al.* 2000: Atekwana *et al.* 1998, 1999). If the geophysical responses caused by these Microbially-induced changes in pore water biogeochemistry can be better understood geophysical measurements could possibly be used to monitor contaminants and their breakdown products in the subsurface. This could allow resistivity techniques to be used as a surrogate or ground-water sampling and analysis to achieve lower cleanup costs.

Typical products of LNAPL biodegradation ale acids and biosurfactants. Carbonic and organic acids are produced during LNAPL biodegradation (Cozzarelli *et al.* 1990, 1994 1995; Eaganhouse *et al.* 1993; Hiebert *et al.* 1995: Baedecker *et al.* 1993; McMahon *et al.* 1995). These products increase conductivity directly by increasing the dissolved solids (DS) concentration, and indirectly by promoting mineral dissolution (Hiebert *et al.* 1995; McMahon *et al.* 1995). High DS concentrations in LNAPL-impacted zones have been invoked to explain anomalously low bulk electrical resistivity (Sauck *et al.* 1998; Bermejo *et al.* 1997). However. it has not yet been shown that temporal changes in geoelectrical properties of pore water occur due to LNAPL biodegradation.

Biosurfactants are produced by many genera of soil micro-organisms during growth on NAPL (Alexander. 1994; Miller. 1995: Desai and Banat. 1997). When present at concentration above the critical micelle concentration (CMC). Surfactants product microemulsions of NAPL m water. Biosurfactant are produced by aerobic and anaerobic microorganisms (Desai and Banat. 1997: Cooper *et al.* 1980; Mclnerney *et al.* 1990). Biosurfactants increase DS concentrations. Perhaps more importantly. emulsion of NAPL resulting from biosurfactants could promote a change in conditions from LNAPL-wetted to water-wetted. This can increase the contact area between water and solids. providing more nutrients and promoting further biogeochemical changes. Hence, biosurfactant production he> the potential to impact both resistivity and GPR measurements tremendously. While biosurfactants have been linked with NAPL biodegradation in mixed soil reactors (Cassidy, in press). in situ biosurfactant production and NAPL emulsification have not been demonstrated.

The efficacy of resistivity surveys rests in a high electrical resistivity of LNAPL relative to subsurface materials. This "insulating layer" model has been verified in short-term laboratory and controlled spill experiments (Schneider and Greenhouse. 1992). However, investigations at numer-

ous sites with aged contamination show that the LNAPL smear zone has a lower resistivity (higher conductivity) than the bulk formation (Atekwana *et al.*, 1998, 1999; Benson and Stubben, 1995; Gajdos and Kral, 1995; Sauck. 1998). It has been hypothesized that anomalously low apparent resistivities are the result of LNAPL biodegradation (Atekwana *et al.* 1999: Sauck, 2000). However, to confirm this hypothesis changes in geoelectrical properties must be co! related with biodegradation products over time. This paper describes laboratory experiments designed to correlate temporal changes in the concentrations of diesel fuel (DF) degradation products with changes in specific electrical conductivity. under aerobic and anaerobic conditions. The production of biosurfactants and the resulting emulsification of DF were also monitored.

## Materials and Methods

The soil was obtained from a hydrocarbon-impacted site described by Atekwana *et al.*. (1999) and Werkema *et al.*. (2000). The contaminated soil was washed five times with deionized water to remove soluble constituents. Fresh, no. 2 diesel fuel (DF) was mixed into the soil. The reactor-x consisted of 20-L plastic vessels. Approximately 18 L of soil was packed into each reactor, and deionized water was added to bring the water level up to the surface of the soil. A visible NAPL layer was present after adding water. The reactor setup was designed to simulate conditions in the saturated smear zone. A slotted, fully-penetrating PVC tube allowed composite pore water samples to be drawn and probes to be inserted into the saturated zone.

Duplicate reactors of three types were maintained for 120 days; one with added nutrients, one without added nutrients. and one "killed" (autoclaved) control without nutrients. Nutrients (4 mg/L $NO_3$-$N_{,4}$ mg/L $NH_{,}$-N. and I mg/L $PO_{,}$-P) were added to the reactors with the deionized fill water. These nutrient concentrations arc similar- to those observed at the site. Addition of nutrients resulted in anaerobic conditions within 10 days. The reactor with added nutrients was labeled "anaerobic." Anaerobic conditions also predominate at the bite. The reactor without added nutrients maintained aerobic conditions and was labeled "aerobic."

Dissolved oxygen (DO), pH. and conductivity were measured in situ. Pore water samples were drawn to quantify volatile organic acids (VOA), aqueous DF concentration. surface tension (ST), biosurfactant concentration, and $C^{2-}$ concentrations. The samples were first passed through a 0.45-$\mu$m Whatman filter paper to remove suspended solids and non-emulsified DE Emulsified DF passes through this filter and is measured as aqueous DE Volatile organic acids (VOA) and $Ca^{2-}$ concentrations were quantified with *Standard Methods* 5560-B and 35000 D. respectively (Eaton *et al*. 1995). ST and concentrations of aqueous DF and biosurfactants. were measured according to Cassidy (in press). Biosurfactant concentration was measured using critical micelle dilution, which provides units of "times the critical micelle concentration" (x CMC). Dissolved solids (DS) were measured on filtrate at the end of I20 days. Total. inorganic. and organic DS were measured using Standard Methods 2540-B & C (Eaton *et al.*, 1995). The concentration of DF-degrading microbes was quantified as described by Werkema *et al.* [2000].

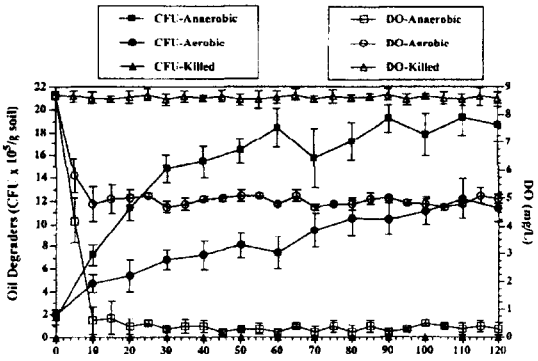


**Figure 1. Average concentrations of oil degrading mi croorganisms and DO with time.**

## Results and Discussion

Figure 1 shows the average measurements of oil-degrading microorganisms and DO with time. The killed controls showed no decrease in DO from the saturation concentration of 8.5 mg/L throughout the entire experiment. The killed reactors also had microbial concentrations that were essentially zero throughout the experiment. This shows that autoclaving was successful ill killing the micro organisms. In contrast, the biologically active reactors showed significant increases in microbial concentrations and decreases in DO within the first 5 to 10 days. These results show that there was considerable aerobic microbial activity in the biologically active systems. It can be concluded that this microbial activity was driven by DF biodegradation, since DF was the only major food source available. The greatest increase in CFU and decrease in DO was observed in the anaerobic systems, because adding nutrients promoted more biological activity than was possible in the aerobic systems. The anaerobic reactors showed an increase in the number of oil-degrading microbes from roughly 2 $X10^5$ CFU/g to 1.9 X $10^6$ CFU/g after 120 days. This represents an increase of nearly an order of magnitude. DO in the anaerobic reactors decreased to less than 0.5 mg/ L within 10 days, and remained at this concentration thereafter. The aerobic reactors showed an increase in the number of oil degrades from roughly 2 x $10^5$ CFU/g to

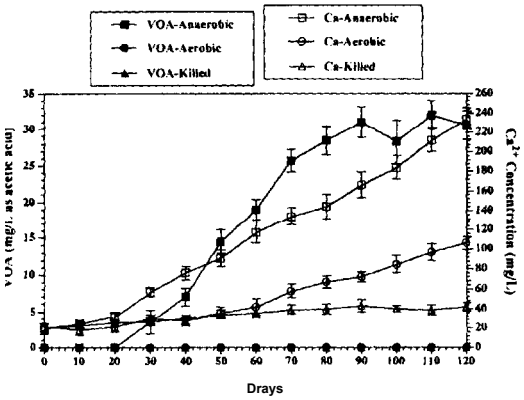


**Figure 2. Average concentrations of VOA and $Ca^{2+}$ with time.**

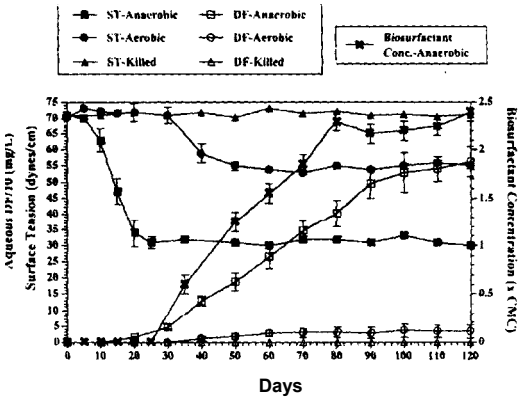


**Figure 3. Average values of surface tension, aqueous DF concentration, and biosurfactant concentration with time.**

to 1.3 X 106 CFU/g during the experiment. The DO in the reactors without added nutrients reached a steady state concentration of approximately 5 mg/L, which is considered aerobic.

The anaerobic reactors were designed to simulate conditions observed in the subsurface at the hydrocarbon impacted site from whence the soil was obtained (Werkema *et al.*, 2000) and at many such sites. Nutrients were provided at concentrations observed at the site, where the presence of sufficient nutrients and hydrocarbons have resulted in anaerobic conditions (*i.e.*. DO < 0.5 mg/L) caused by microbial activity (Werkema PI al., 2000). Anaerobic conditions exist in the saturated zone at nearly all LNAPL impacted site& (Alexander, 1994). Nitrate ($NO^{3-}$), which is present at the site and was added to the anaerobic systems. promotes the growth of denitrifying bacteria that degrade DF by providing a necessary electron acceptor. It is important to remember that aerobic reactions occur in anaerobic systems along with anaerobic reactions. which is what continually consumes oxygen and maintains anaerobic conditions. Therefore, both aerobic and anaerobic reactions took place in the anaerobic systems. The aerobic reactors were maintained as a control to observe the effects of nutrients at the site on biogeochemistry and conductivity. and to simulate a nutrient-starved, aerobic site. Killed reactors provided an abiotic system for comparison with the biologically active reactors.

The average values for measurements of VOA and $Ca^{2+}$ concentrations are plotted in Fig. 2. VOA levels were zero throughout the experiment in the killed and aerobic systems. However, VOA concentrations in the anaerobic systems began to increase on day 20 and stabilized at values between 30-35 mg/L as acetic acid between days 90 and 120. Since VOAs are biodegradable, an accumulation of VOA indicates that rates of production exceed rates of degradation during that time. Concentrations of Ca" started at a background value of approximately 25 mg/L and increased with time in all the reactors. Increases in Ca" concentrations with time were probably to due to dissolution of carbonates, which comprised approximately 2% (by weight) of the soil. The lowest levels of $Ca^{2+}$ at the end of the experiment (40 mg/L) were observed in the killed reactors, which represent\ $Ca^{2+}$ concentrations achieved by carbonate dissolution in the absence of microbial activity. In contrast. the $Ca^{2+}$ concentration in the aerobic and anaerobic systems reached levels of 105 mg/L and 235 mg/ L, respectively.

The results in Fig. 2 show that microbial activity promoted the dissolution of carbonates, most pronounced under anaerobic conditions. The greater dissolution of carbonates achieved in the anaerobic systems is consistent with the accumulation of VOA and the overall enhanced microbial activity in these reactors compared with the aerobic reactors. While VOA was not detected in the aerobic reactors, it may have been present in low levels. $CO_2$ is another common product of microbial activity (not measured in this study), and its production is proportional to overall microbial activity (aerobic and anaerobic). Considering that more microbial activity was observed in the anaerobic systems than the aerobic ones, and that both aerobic and anaerobic reactions took place in the anaerobic systems, it is likely that more $CO_2$ was produced in the anaerobic systems than the aerobic ones. $CO_2$ and organic acid production has been demonstrated at LNAPL-impacted sites (Cozzarelli *et al.* 1990, 1994, 1995; Eaganhouse *et al.*, 1993; Hiebert *et al.* 1995: Baedecker *et al.* 1993; McMahon *et al.* 1995) and is known co enhance the dissolution of carbonate\ and other minerals.

Figure 3 shows the average values of biosurfactant

related measurements: ST and concentrations of aqueous DF and biosurfactants. Killed controls showed no significant decrease in surface tension from 72 dynes/cm (the value for distilled water al 25 C) throughout the entire experiment. In contrast. ST measurements in the anaerobic reactors decreased from 72 dynes/cm to approximately 30 dynes/cm after 20 days. and remained al these levels until the end of the experiment. ST in the aerobic systems decreased after day 30 IO values between SO and 55 dynes/ cm, where they remained for the remainder of the experiment. Aqueous DF concentrations were zero for the first 20-X) days in all the reactors, and remained zero throughout the experiment in the killed reactors. The aqueous concentration of DF is roughly 5 mg/L (Testa and Winegardner, 1991). hut DF sorbs readily to soil, which explains the initial absence of DF in the aqueous phase. Aqueous DF concentration\ in the aerobic systems increased after day 30 to final values of nearly 5 mg/L. Aqueous DF concentrations in the anaerobic systems increased dramatically after day 20. reaching values of 550 mg/L (over 100 times the aqueous solubility). Biosurfactant concentrations in the killed and aerobic systems (not shown) were below the CMC throughout the experiment. However, biosurfactant concentrations in the anaerobic reactors increased after day 20 to levels over 2 times the CMC during the last 40 days of the experiments.

The results in Fig. 3 show that biosurfactants were produced in the anaerobic systems to levels over twice the CMC. The drop in ST to 30 dynes/cm observed in the anaerobic reactors coincided with biosurfactant concentrations above the CMC. and is a clear indication of surfactant concentrations above the CMC (Zajic and Seffens, 1984; Desai and Banat. 1907). Common metabolic products (e.g., organic acids) are not able to reduce ST to 30 dynes/cm. even at concentrations above 10% (Zajic and Seffens. 1984). indicating that the low ST reached in the anaerobic systems was not due to the accumulation of such products. Another unmistakable sign of biosurfactant concentration observed in the anaerobic systems was the increase in aqueous; DF concentrations coinciding with increasing biosurfactant concentrations after day 20. Aqueous DF measurements two orders of magnitude greater than the solubility limit is explained by emulsification of DE Emulsified NAPL droplets are le\s than 0.1 +m in diameter (Miller, 1995). and can pass through the 0.4%-$\mu$m filter, whereas non-emulsified NAPL cannot. Biosurfactant are biodegradable and sorb readily to soil (Miller, 1995: Desai and Banat. 1997). so the accumulation of biosurfactants in the anaerobic systems indicates that the rate of production exceeded rates of biodegradation and sorption. While biosurfactant concentrations above the CMC were not measured in the aerobic systems. ST values decreased and aqueous DF concentrations increased noticeably. This suggests that biosurfactants may have been in excess of the CMC in some pores. but that the concentrations dropped to below the CMC by dilution during sampling. Increasing aqueous DF concentrations with time in the aerobic systems support this. Numerous aerobic and anaerobic species produce biosurfactants (Zajic and Seffens, 1984: Desai and Banat, 1997). However. this study is the first to demonstrate in situ biosurfactant production accompanying microbial growth on NAPL.

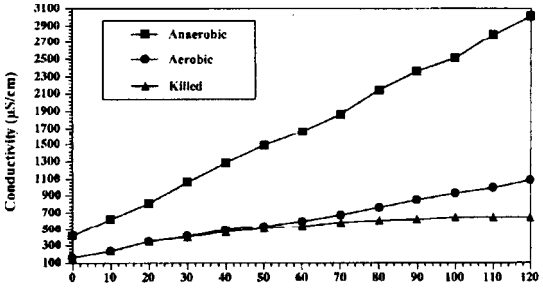


**Figure 4. Average values of specific electrical conductivity with time.**

Figure 4 shows the average values of specific conductivity measurements in pore water r:Imple\ over time. Conductivity increased in all reactors, hut the increase was by far the greatest in anaerobic systems. The initial conductivity of the anaerobic systems began at approximately 420 $\mu$S/cm. which was considerably higher than m the killed and aerobic reactors because of the added nutrients. Conductivity then increased in the anaerobic systems to over 3,000 $\mu$S/cm after 120 days. The initial conductivity in the killed and aerobic reactors was approximately 150 $\mu$S/cm. Conductivity increased to final values of roughly 650 $\mu$S/cm and I.100 $\mu$S/cm in the killed and aerobic systems. respectively. Since conductivity increases in the killed reactors are strictly from abiotic processes. subtracting these values from those observed in the biologically active systems gives an estimate of the increases in conductivity due to DF biodegradation processes in those systems. After 120 days in the killed reactors, conductivity increased 500 $\mu$S/cm (650 $\mu$S/cm- 150 $\mu$S/cm). Subtracting this value from the conductivity increases observed after 120 days in the aerobic systems (2,600 $\mu$S/cm) and anaerobic systems (950 $\mu$S/cm). yields an increase in conductivity of the aerobic and anaerobic systems of approximately 2,100 $\mu$S/cm and 450 $\mu$S/cm, respectively. From this analysis it is clear that specific conductivity increased roughly 4.5 times more in the anaerobic reactors than in the aerobic ones. This IS consistent with enhanced microbial activity, greater VOA production and carbonate dissolution. and enhanced production of biosurfactants in the anaerobic systems relative to the aerobic ones (Figs. 1-3).

**Table 1. Measurements of dissolved solids in the pore waters from the three systems at the conclusion of the 120-day experiment.**

| Measurement | Anaerobic | Aerobic | Killed |
|---|---|---|---|
| Total DS (mg/L) | 2130 ± 64 (8)[a] | 758 ± 46 (8) | 416 ± 28 (8) |
| Inorganic DS (mg/L) | 1518 ± 54 (8) | 602 ± 35 (8) | 416 ± 28 (8) |
| Organic DS (mg/L) | 612 ± 36 (8) | 156 ± 31 (8) | 0 |
| Inorganic DS/Organic DS | 2.5 | 3.9 | NA |
| Total DS/Conductivity | 0.72 | 0.69 | 0.64 |

[a] mean ± standard deviation (number of measurements). NA = not applicable.

Bulk conductivity was not measured in the reactors. However, specific conductivity is the major variable affecting bulk conductivity measurements, as described by Archie's Law. Using a soil porosity of 0.4 (common for unconsolidated sands) and other commonly used values for Archie's Law the ratio of specific conductivity to bulk conductivity is 10 (Telford *et al.*, 1990). This means that the increase in specific conductivity observed in the anaerobic systems due to DF biodegradation processes was 210 μS/cm (2,100 S/cm/10). This represents a significant increase in bulk conductivity measured in the field. Furthermore, the reactors in this study were only operated for 120 days. These results clearly show that biodegradation of DF can have a significant effect on bulk conductivity measurements at NAPL-impacted sites.

Table 1 lists results from the dissolved solids (DS) measurements of pore waters from the three systems at the end of the 120-day experiment. Total DS concentrations ranged from 416 mg/L in the killed controls to 2,130 mg/L in the anaerobic reactors. The value in the killed control (416 mg/L) was strictly due to abiotic processes, and subtracting this value from the total DS concentration in the anaerobic and aerobic systems gives an indication of the increase in those system due to DF biodegradation processes. This analysis yields an increase in total DS due to DF biodegradation in the anaerobic and aerobic systems of 1,714 mg/L and 342 mg/L, respectively. The organic DS concentration in the killed controls was zero, which is supported by the lack of microbial activity and lack of associated products (Figs. 1–3). The ratios of inorganic DS to organic DS concentrations in the anaerobic and aerobic reactors were 2.5 and 3.9, respectively. The lower ratio for the anaerobic system is explained by the greater concentrations of biosurfactants and emulsified DF (Fig. 3). The ratio of total DS concentrations to conductivity in the reactors on day 120 ranged from 0.64 to 0.72. These ratios are within the range of 0.55–0.75 reported for a survey of natural groundwaters (Hem, 1970).

The results clearly show that products of DF biodegradation in the reactors increased with increasing microbial activity and were greater for the anaerobic systems (with added nutrients) than for the aerobic ones (without added nutrients). DF biodegradation resulted in an increase in inorganic DS due to mineral dissolution and in organic DS due to organic acid and biosurfactant production. The increase in DS resulted in increases in conductivity. The anaerobic reactors simulated subsurface conditions at a LNAPL-impacted site with anomalously high conductivities (Atekwana *et al.*, 1999; Werkema *et al.*, 2000). The results from this study show that products of LNAPL biodegradation can explain those anomalous resistivities.

## Conclusions

The results show that LNAPL biodegradation, under aerobic and anaerobic conditions, can substantially change pore water biogeochemistry, producing dramatic increases in electrical conductivity. These results help explain anomalously high conductivities reported in recent geophysical investigations at several LNAPL-contaminated sites. It has been known for some time that LNAPL biodegradation produces $CO_2$ and can produce organic acids, which enhance mineral dissolution. However, this study is the first to link these biogeochemical processes to enhanced pore water conductivity. This is also the first study demonstrating in situ biosurfactant production and LNAPL emulsification. The results suggest that biosurfactant production can accelerate a change in conditions from NAPL-wetted to water-wetted solids over time. The resulting increase in water/solids contact area could affect resistivity and GPR measurements.

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