Appendix B

Location of Codorus Creek

Levee Wells on Conduit Features

Appendix B – Location Of Codorus Creek Levee Wells on Conduit Features

1 Introduction

An important component of the Supplemental RI was to investigate the relationship of Codorus Creek to the groundwater at the Site. Four sets of multi-level wells were placed on the eastern bank (flood control levee) of Codorus Creek. These wells were placed in locations that would increase the potential that they would intersect karst weathering features that are preferential groundwater flow paths. The wells were located using information gathered from fracture trace analysis, a thermal survey of water in the Codorus Creek, and Electrical Imaging, a geophysical methodology that can differentiate subsurface conditions.

2 Fracture Trace Analysis

Information from a fracture trace analysis was used to assist in locating the levee wells. An aerial photograph fracture trace analysis was completed a number of years ago for the fYNOP Site to identify likely fracture zone locations and their orientation in the carbonate limestone aquifer, and to correlate them, where possible, with karst weathering features in the bedrock. A photogeologic fracture trace is defined by Lattman (1958) as a "natural linear feature consisting of topographic (including straight stream segments), vegetal, or soil tonal alignments, visible primarily on aerial photographs, and expressed continuously for less than one mile. Only natural linear features not obviously related to outcrop pattern or tilted beds, lineation and foliation, and stratigraphic contacts are classified as fracture traces."

Black and white 10- by 10-inch contact prints of aerial photographs taken in September 1937 were obtained at a scale of 1:20,000. The historical aerial photographs were used to map fracture traces and lineaments to allow these features to be observed with minimal disturbance by Site development that reportedly began in 1941. The photographs were viewed obliquely and in stereo at various magnifications. Fracture traces were mapped and marked directly on the photographs. The photographs were digitally scanned, imported into the Arcview®, and superimposed on the Site topographic base map, rotated, and scaled for best-fit. Straight line segments were aligned with the mapped fractures on the photographs and saved as an Arcview® shape file. A total number of 16 fracture traces were identified from the aerial photographs.

Mapped fracture trace locations and orientations overlying the Site base map are illustrated in Figure B2-1. Because of the registration and distortion associated with the aerial photographs, compounded by the paucity of useful features that survived since 1937, the accuracy of the fracture trace locations is approximately ±100 feet. The error was estimated for this and similar projects by comparing fracture trace positions with the positions of topographic features, such as breaks in the ridges, which were caused by fracture traces, and the difference in the position of a single fracture trace mapped on two different photographs.

The fracture traces showed two sets of orientations, trending North 50-70º East (9 fracture traces) and trending North 35-55º West (6 fracture traces). A single fracture trace was oriented North 22º East. When fracture sets are tightly grouped into a few orientations, as these are, it is reasonable to expect that the fracture traces reflect a structural fabric within bedrock and beneath the Site. As such, unmapped fractures and discontinuities may be present in the bedrock and residual structures may be present in the residual soil parallel to these fracture trace orientations.

3 Thermal Survey of Codorus Creek

A thermal surface water study was conducted on the Codorus Creek in August 2007 to delineate groundwater discharge points associated with subsurface conduits in the karst limestone bedrock (carbonate aquifer) that underlies the area of the creek and the flat lowland (western) portion of the Site. The survey covered a 2,500-foot length of the creek immediately west of the Site, as shown on Figure B2-1. Due to the karst nature of the carbonate aquifer beneath the project area, groundwater may discharge to the creek downgradient of the Site from discrete conduits (the nature of the karst conduits in the carbonate aquifer is described in Section 3.3 of this report). Temperature differentials identified near the bottom of the creek may indicate the location of the discharge of groundwater from a karst conduit.

Two water quality probes (YSI Model 600XLM) were integrated with a Trimble PR-XRS global positioning system (GPS), utilizing a satellite-based Omnistar differential correction service to yield submeter accuracy. Hydrosoftware® **(**made by Trimble) was used to collect water quality parameters, thermal, and GPS coordinate data simultaneously from the YSI probes. The probes were mounted on the front left and right sides of a small boat that was propelled by an electric trolling motor, and the offsets of each probe from the GPS antenna programmed into the software. All data were geographically referenced to the Pennsylvania State Plane Coordinate System (South). The survey accuracy of the data collection points was approximately ± 3 feet. The survey simultaneously recorded temperature, pH, dissolved oxygen, conductivity, and creek depth/ probe depth. The data obtained from the thermal study are provided in this Appendix.

The boat was maneuvered up and down the creek in a pattern to cover the entire stream. Readings were collected on one second intervals, and the distance between sequential points ranged from 0.2 to 0.4 feet. Distance between "parallel" traverses ranged up to 10 feet. Due to the nature of the survey and the inability to stay on an exact course, some areas were traversed more than one time, which increased the density of the readings. Readings were taken at 182,068 locations. Figure B3-1 shows each individual point location as a red dot. On the scale of the map, the sequential points run together and form a line that represents the course of the instrument.

The survey was conducted during the summer months when surface water temperatures were approximately 15 degrees Celsius (°C) warmer (ranged from 11 to 27 ºC) than groundwater temperatures (expected to be approximately 10.5 ºC). During the course of the day, stream temperatures increased significantly, due to the sun warming the water, which was enhanced by the urban nature of the stream course up gradient of the survey location. As a result of this change in ambient conditions, absolute temperatures could not be used to indicate a change in temperature caused by a discrete groundwater discharge. Therefore temperature measurements were plotted in the order they were collected, and temperature anomalies representing a differential of approximately 0.5 ºC or more were selected from the resulting graph. Judgment was used in selecting anomalies that appeared to represent discrete changes. Some areas of the survey were "noisy" and the smaller anomalies were not selected in these areas. The lowest reading of the anomaly was selected as representing the location of the low temperature anomaly. In all, 100 low temperature anomalies were selected from the data points. These selected points were plotted on top of the complete database in map view, using ArcView GIS. The locations of the anomalies are shown on Figure B3-1 as blue dots superimposed over the rest of the data. The thermal survey data has been subdivided into three sections designated Section A through Section C, based on the characteristics of the data. A discussion of the distribution of temperature anomalies for each of these segments shown on Figure B3-1 is provided below:

- Section A - Most of the rock outcrops that appear in the stream (identified by gray squares on Figure B3-1) occur in the southern 700 feet of the surveyed length. Low temperature anomalies were fairly evenly distributed throughout this area. A mapped fracture trace also cuts at an angle through this area. A blue triangle located near the northern limit of the area of rock outcrops denotes the location of a 6" diameter hole near the eastern bank of the stream, similar to a muskrat hole. A technician observed the submerged hole and placed his hand inside. He could physically detect a significantly cooler temperature to the water in the hole. The location was established by GPS, but the temperature was not measured with an instrument.

- Section B - Low temperature anomalies are fairly evenly distributed along the western side of the creek, while on the east side they are clustered in two areas. A possible explanation could be that discharges of groundwater from the east side of the creek are fed by the limited recharge in the area west of the groundwater divide due to the effects of the groundwater extraction system operating in the WPL, while discharges from the west reflect a larger recharge area. Low temperature anomalies on the east side of the creek occur in two clusters, which may indicate groundwater discharges from preferential flow paths.

- Section C - The northern portion of the surveyed creek is characterized by two segments of the creek where no low temperature anomalies occur for hundreds of feet. Just to the south of the intersection of a fracture trace with the creek, which runs through the center of Section C, there is a cluster of anomalies on both sides of the creek. The cluster could indicate a high permeability zone within the bedrock, from which groundwater discharges to the creek. However, small streams enter the Codorus Creek on both sides of the creek, and could be providing cooler water. The slight bend in the stream to the west (marked on Figure B3-1) is the location where the fault contact between the Harpers Phyllite and the Vintage Limestone is mapped. The position of the fault and the change in rock type is the likely cause for the location of these small streams, pushing carbonate groundwater to the surface, as its northward migration is resisted by the less permeable phyllite.

4 Electrical Imaging Survey

The objective of the electrical imaging survey was to provide data on potential preferred groundwater flow pathways to support selection of locations for groundwater characterization well pairs. The results of this survey were used in conjunction with the fracture trace analysis results and the thermal survey of Codorus Creek to assist in the site selection of monitoring well pair locations along the east bank of Codorus Creek.

Electrical imaging (EI) is a computer-controlled version of the classic electrical resistivity survey that has been used in geophysical investigations for many decades. It was chosen for this investigation because of its proven success in detecting geologic materials or conditions that represent potential pathways for groundwater flow in Karst terrain. It is based on inducing an electrical current into the earth at a pair of electrodes and measuring the amount of current that reaches a second pair of electrodes at a certain distance away. The depth of penetration of the induced electrical current can be adjusted by varying the electrode spacing. The amount of current detected at the second set of electrodes depends, in part on the resistivity of the subsurface material

through which it passes. Dry granular material like sand is relatively more resistant to electrical current flow. On the other hand, moist fine-grained soils like clay are relatively more conductive (i.e. less resistive).

In solution-prone carbonate rocks where karst weathering has developed in the aquifer, low resistivity anomalies can indicate discontinuities such as fractures, water- or sediment-filled solution cavities, and zones of greater depth to bedrock. These conditions often represent preferential pathways for groundwater flow in solution-prone carbonate rock. Dense, competent bedrock would be expected to have a relatively high resistivity. Significantly large and/or solution enhanced zones tend to have lower resistivity since they are generally filled with water and fine-grained weathered bedrock residuum. Zones of greater depth to bedrock tend to have karst weathering features at depth below them.

SAIC conducted the EI survey in September of 2008. Five EI survey lines were laid out parallel to the creek and the west property line of the Site. Traverse lines 1 through 5 were laid out as shown on Figure B4-1. Traverse 1 was run along the eastern edge and parallel to the flood control levee constructed on the east side of Codorus Creek. Traverse 5 was run parallel to and east of the Harley-Davidson property line and west of Eden Road. Traverses 2, 3, and 4 were spaced as evenly as possible between Lines 1 and 5, while attempting to avoid areas of standing water in the wetland area. A total of 7,300 feet of EI surveying was conducted, with Traverse 1 being 3,100 feet, and Traverses 2 through 5 being 1,050 feet in length.

Individual traverses were staked with push flags by the field crew with their locations measured and plotted on a Site map relative to road intersections and interpreted fracture traces of interest indicated in aerial photographs. The proposed stake locations were examined for any surface indications of cultural interferences. Shortly following the installation of the stakes, the soil surface immediately surrounding each stake was soaked with a salt water solution to enhance electrical contact between the stake and soil.

The location of every fifth electrode was measured using a real-time differential global positioning system (DGPS) to establish reference coordinates along each traverse and at the locations of key electrodes. DGPS data were recorded on a Trimble Pro-XRS system to establish the location of the geophysical data. Relative elevations of the electrode locations were established using an auto level and stadia rod to gather relative ground surface elevations.

The EI equipment used for this survey was comprised of two primary components. The first is the SuperSting® resistivity meter with data storage capability manufactured by Advanced Geosciences Inc. (AGI) of Austin, TX. Second, the SuperSting® cables contain fixed cylindrical stainless steel switches that attach to the stainless steel electrode stakes placed into the ground. The SuperSting® system, a multi-electrode switching system, passes an electrical current automatically along multiple paths at various depths and measures the resulting associated voltages. Electrodes were attached to the electrode stakes to complete the electrical circuits between the electrical switching box and the earth.

The data were collected with a dipole-dipole electrode arrangement. With this survey method, two electrodes were used to provide current to the subsurface in one location, while two other electrodes some distance away were used to measure the voltage. The dipole-dipole array is useful for deeper investigations where a long layout of electrodes may be difficult. For the purpose of this EI survey and the desired depth of approximately 150 ft. bgs, individual stainless steel electrode stakes were placed into the ground at a spacing of 9.8 feet (4 meters) along each traverse. A minimum of 30 resistivity measurements was made at one second intervals at each location that was surveyed.

4.1.1.1.1 Data Processing

Modeling of the data was performed using RES2DINV® commercially available from GeoTomo Software of Penang, Malaysia. At the conclusion of modeling, data files were exported in Surfer® format for final data processing and generation of figures for presentation. Final data processing involved the generation of color-enhanced contour cross-sections of the data using Surfer® mapping and processing system, commercially available from Golden Software, of Golden Colorado. Surfer® was used to grid the data using a kriging grid method with a 1.6 foot (0.5 meter) grid. Finally, Surfer® was used as an annotation tool to convey interpretation information.

4.1.1.1.2 EI Data Analysis

The contoured results of Traverse 1 are shown on Figures B4-2 and B4-3. The figures show a vertical slice of the subsurface running from south (on the left) to north to a depth of approximately 200 feet. Note that the vertical scale is shown in feet above Mean Sea Level (msl), but this discussion refers to depth below the ground surface. Confidence in the data diminishes considerably below a depth of 150 feet. Modeled resistivities are contoured and color coded, with blues and greens representing low resistivities, yellow to orange representing medium resistivities, and red and brown (maroon on screen) representing the highest resistivities.

A good example of how the profile is interpreted can be described using Figures B4-2 and B4-3 as follows:

- Starting with in-line distance 800 through 1,400 on Figure B4-2, there is a discontinuous layer of yellow to orange contours at a depth of 20 to 40 feet. The top of this layer is interpreted to indicate unsaturated moderately resistant materials, probably bedrock blocks or pinnacles sticking above the water table.

- At a depth of approximately 100 feet, from in-line distance 1,000 to 1,700 (starting on Figure B4-2 and continuing on to Figure B4-3) is a moderately resistant layer (yellow) which increases in resistivity with depth. This layer is interpreted to indicate competent bedrock with few very small zones of concentrated weathering.

- At mid depths (averaging from 50 to 100 feet in the section from in-line distance 1,000 to 1,700) are low resistivities shown as greens and blues. This layer is interpreted to indicate a generally deeply weathered limestone layer (the term epikarst layer will be defined in Section 3 to describe the weathered layer of the limestone bedrock). It can be made up of blocks of competent bedrock with frequently spaced discontinuities (joints, bedding planes, and fractures) or a series of blocks of hard unfractured pinnacles of rock with in-filled unconsolidated materials (silt, sand and clay) between the pinnacles.

- Candidate areas for drilling (called Features of Interest and marked with a blue asterick on the cross sections) are areas where:
  - There is a break in the shallow (20 to 40 feet) moderately resistant layer;
  - The middle layer (down to 100 feet) of low resistivity materials indicate an increased degree of lower resistivity (such as the blue zone at a depth of 50-75 feet of depth at in-line distance 1,050); and
  - There is a deepening or break in the top of the lower high resistivity layer (such as in-line distance locations 900 and 1,900).

Interference caused by cultural features was an issue for portions of the EI traverses. The vertically oriented very low resistivity zone which appears at in-line distance 560 was produced by an abandoned pipeline. The blocks of very high resistivities on either side of this feature, stretching 150 feet in each direction and to the total depth of the profile, are also a result of the pipeline interference. A similar configuration was encountered at in-line distance 2,580, where the traverse crosses the Sun Oil pipeline.

Features of interest, cultural interference features and surface features of interest (like the surface depression which may indicate sinkhole activity) were marked on the profiles, along with points where fracture traces intersect the traverse.

Traverses 2 through 5 were positioned west of the stacked caverns and solution channels in the southwest corner of the WPL, near well CW-20. This is a zone of stacked sediment-filled solution channels in the bedrock. It is also an area where chlorinated volatile organic compounds (CVOCs) are highly concentrated and represent a source of groundwater contamination. The traverses were placed to examine the potential for tracing preferred groundwater pathways between the WPL and the Codorus Creek.

The contoured results of Traverses 2 through 4 are shown on Figures B4-4 through B4-6. Data from Traverse 5 could not be interpreted due to cultural interferences from numerous underground utilities and the proximity to the rail line, which paralleled the traverse, and interfered with the electrical fields. For Traverses 2 through 4, the abandoned pipeline interfered with the southern end of each line, as it did for Traverse 1. A number of features of interest are noted on the traverses. These are low resistivity zones which could indicate concentrated karst weathering activity, and may be zones of preferential groundwater flow. Figure B4-1 shows the lateral distribution of the features of interest as green dots.

5 Well Location Selection

Figure B5-1 shows the results of the fracture trace analysis, the Codorus Creek thermal survey, and the EI survey. All three studies are indirect methods of identifying locations of preferential groundwater flow features. As shown on Figure B5-1, results of these three methods identified three areas, designated as segments A, B and C along the west side of Codorus Creek, for possible monitoring well locations as follows:

- Segment A - This area hosts a cluster of thermal anomalies scattered among the bedrock outcrops through which a fracture trace runs. An EI anomaly occurs approximately 120 feet to the south of the fracture trace. If the fracture trace were shifted southeastward 75 feet (the accuracy of the fracture trace location is approximately 100’) the trace would cross the EI anomaly and would line up the EI anomaly with the denser cluster of thermal anomalies.

- Segment B - The high density of thermal anomalies in the creek is coincident with a high frequency of EI anomalies in EI Traverse 1 closest to the creek. Linear trends between EI anomalies on Traverses 1 through 4 and clusters of thermal anomalies suggest the subsurface presence of groundwater conduits.

- Segment C - A cluster of thermal anomalies immediately adjacent to a broad EI anomaly (in-line distance 2200, See Figure B4-3) ties closely with the fracture trace mapped through the area. If the fracture trace position is shifted approximately 100 feet to the southwest, it would reasonably coincide with the EI and thermal anomalies.

Four well pair/cluster locations as shown on Figure B5-1 were selected based on these the EI results, and are denoted on the EI Traverse 1 profile. The locations were distributed across the 2500 foot reach of the east side of Codorus Creek, using the flood control levee as access. The wells targeted EI anomalies that were believed to indicate well-developed karst weathering features and had good potential to be connected to preferential flow pathways that extend to the west from the fYNOP Site.

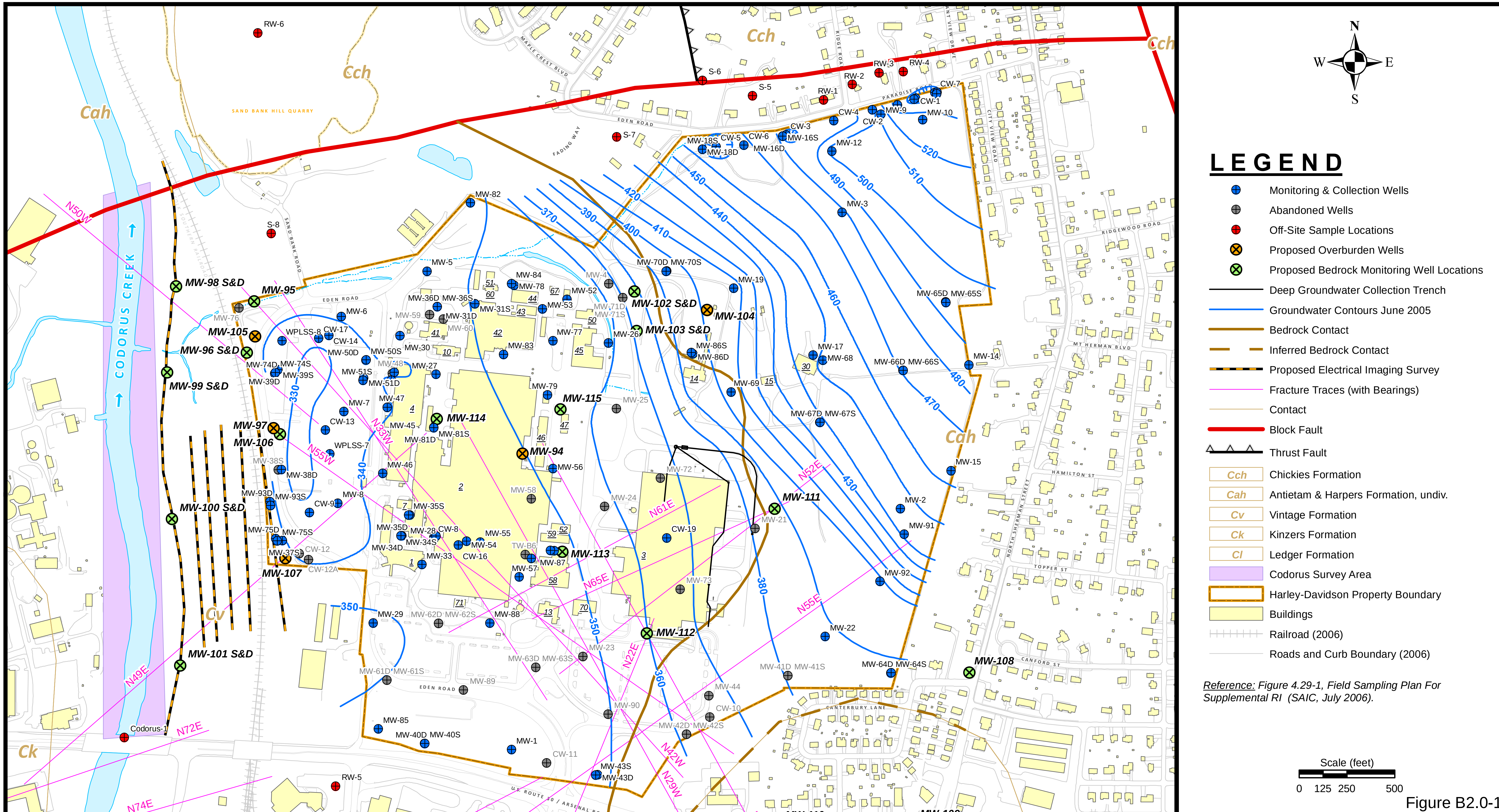

Figure B2.0-1

Former York Naval Ordnance Plant

1425 Eden Road, York, PA 17402

Proposed Supplemental RI
Groundwater Investigations - July 2006

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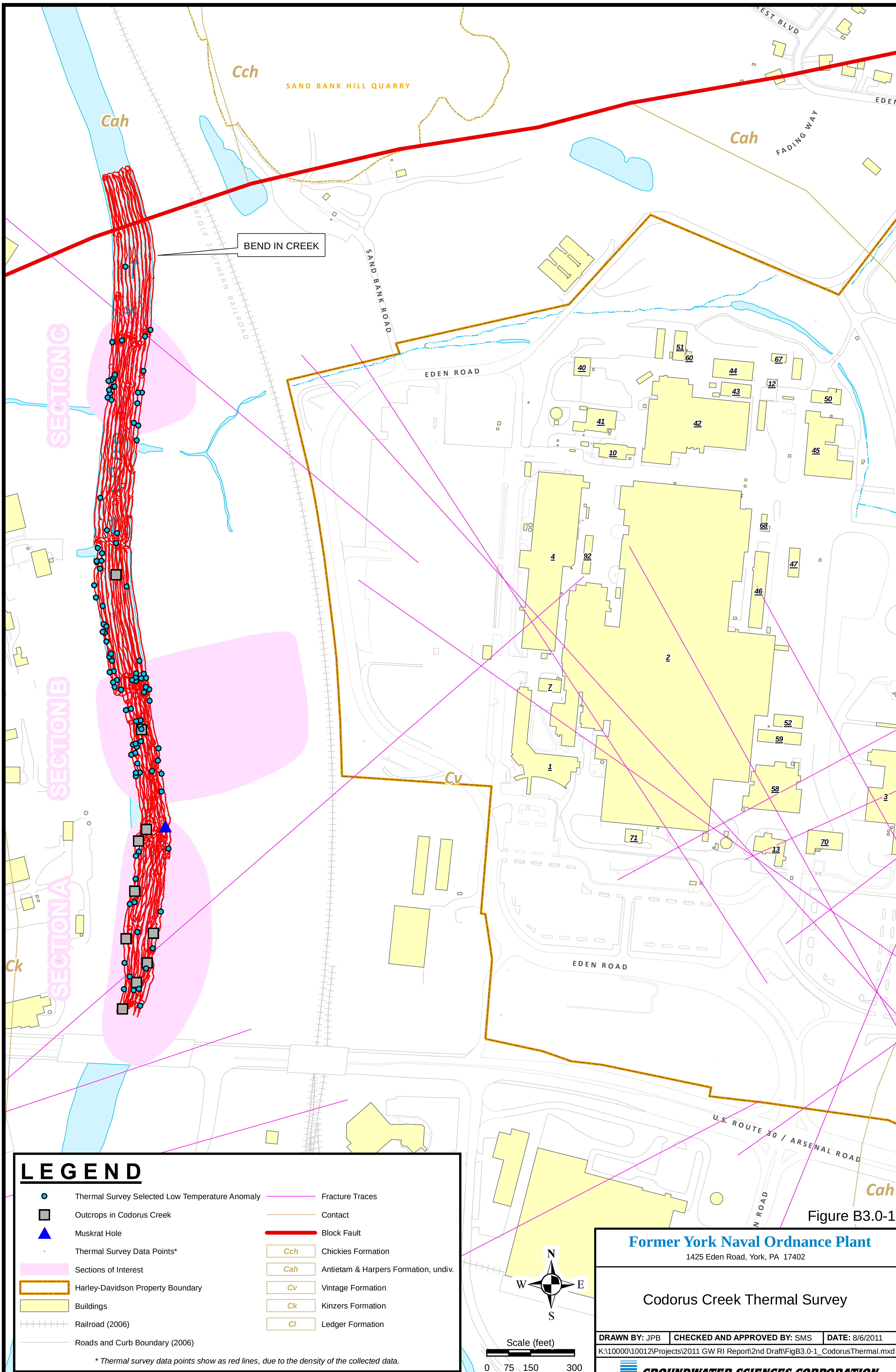

Cch
SAND BANK HILL QUARRY
Cah
BEND IN CREEK
NORFOLK SOUTHERN RAILROAD
SAND BANK ROAD
EDEN ROAD
FADING WAY
SECTION C
SECTION B
SECTION A
Cv
Ck
U.S. ROUTE 30 / ARSENAL ROAD
LEGEND
Thermal Survey Selected Low Temperature Anomaly
Outcrops in Codorus Creek
Muskrat Hole
Thermal Survey Data Points*
Sections of Interest
Harley-Davidson Property Boundary
Buildings
Railroad (2006)
Roads and Curb Boundary (2006)
Fracture Traces
Contact
Block Fault
Cch Chickies Formation
Cah Antietam & Harpers Formation, undiv.
Cv Vintage Formation
Ck Kinzers Formation
Cl Ledger Formation
* Thermal survey data points show as red lines, due to the density of the collected data.
N
W E
S
Scale (feet)
0 75 150 300
Former York Naval Ordnance Plant
1425 Eden Road, York, PA 17402
Codorus Creek Thermal Survey
DRAWN BY: JPB
CHECKED AND APPROVED BY: SMS
DATE: 8/6/2011
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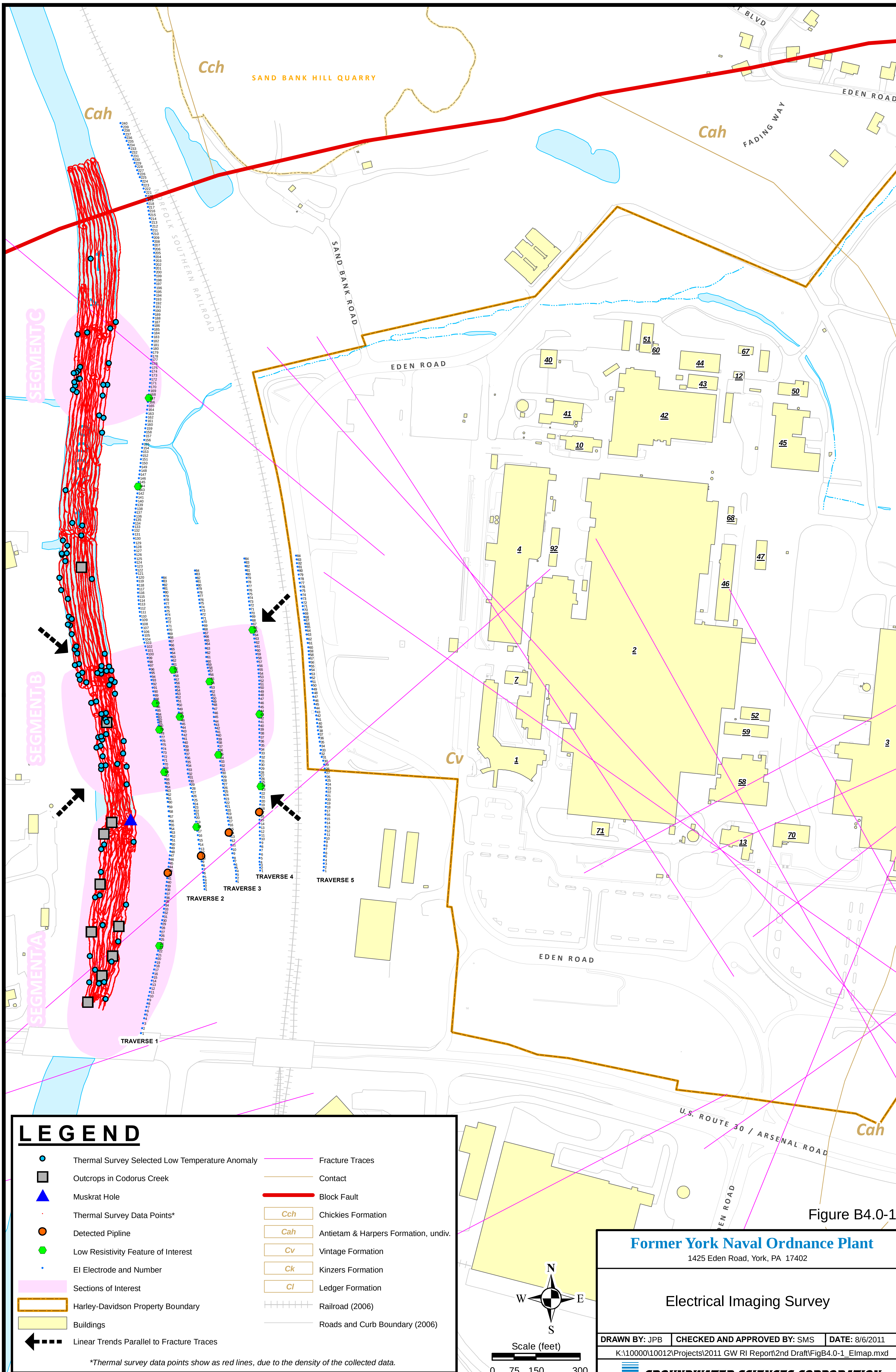
Figure B3.0-1



LEGEND

	Thermal Survey Selected Low Temperature Anomaly		Fracture Traces
	Outcrops in Codorus Creek		Contact
	Muskrat Hole		Block Fault
	Thermal Survey Data Points*	Cch	Chickies Formation
	Detected Pipline	Cah	Antietam & Harpers Formation, undiv.
	Low Resistivity Feature of Interest	Cv	Vintage Formation
	EI Electrode and Number	Ck	Kinzers Formation
	Sections of Interest	Cl	Ledger Formation
	Harley-Davidson Property Boundary		Railroad (2006)
	Buildings		Roads and Curb Boundary (2006)
	Linear Trends Parallel to Fracture Traces		

**Thermal survey data points show as red lines, due to the density of the collected data.*

Figure B4.0-1

Former York Naval Ordnance Plant

1425 Eden Road, York, PA 17402

Electrical Imaging Survey

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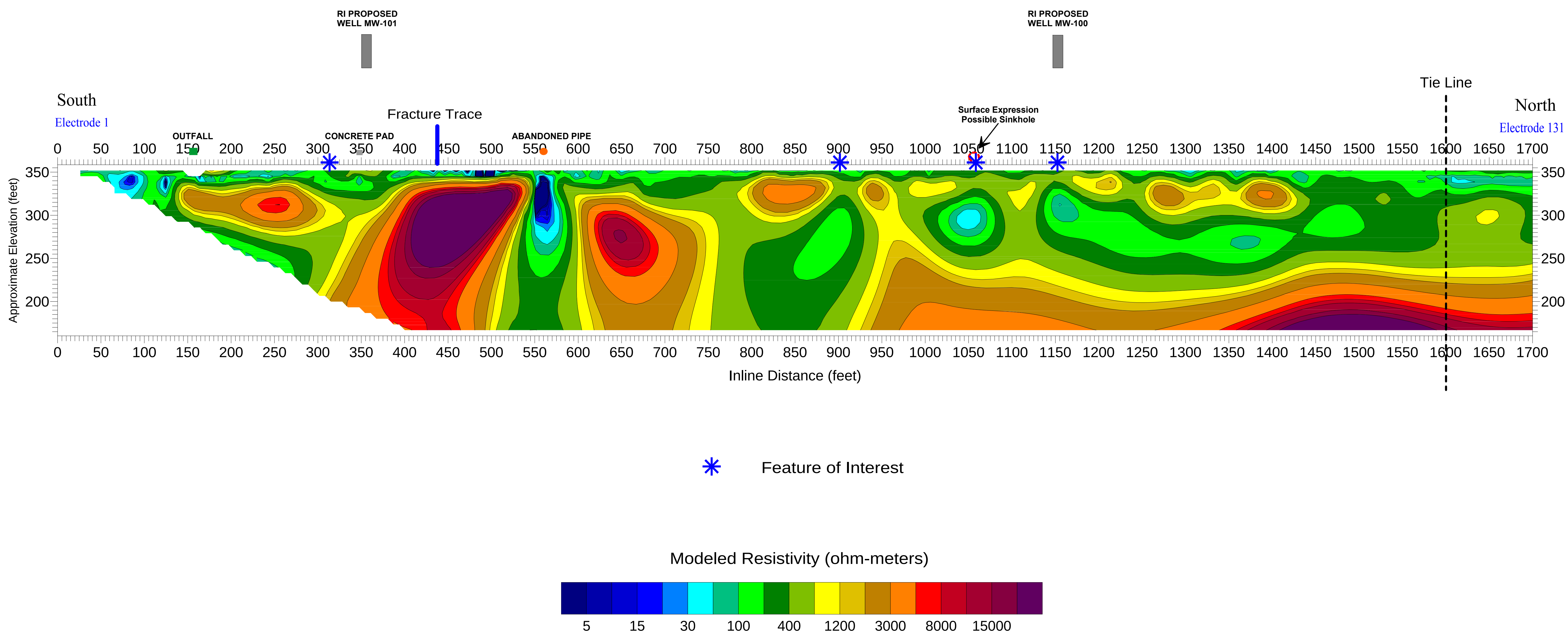
Electrical Imaging Traverse 1 (Section A)



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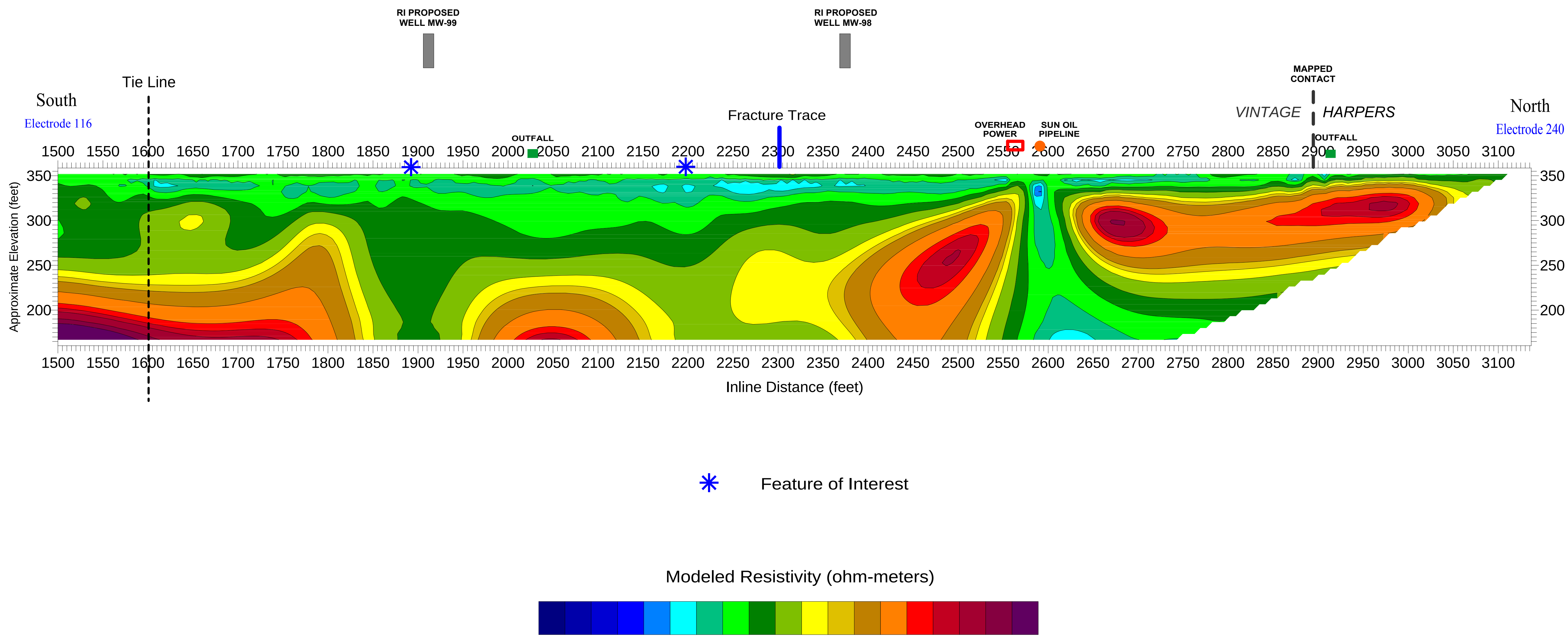
Electrical Imaging Traverse 1 (Section B)



Harley-Davidson

York Facility - Condorus Creek

Electrical Imaging Line 1 North

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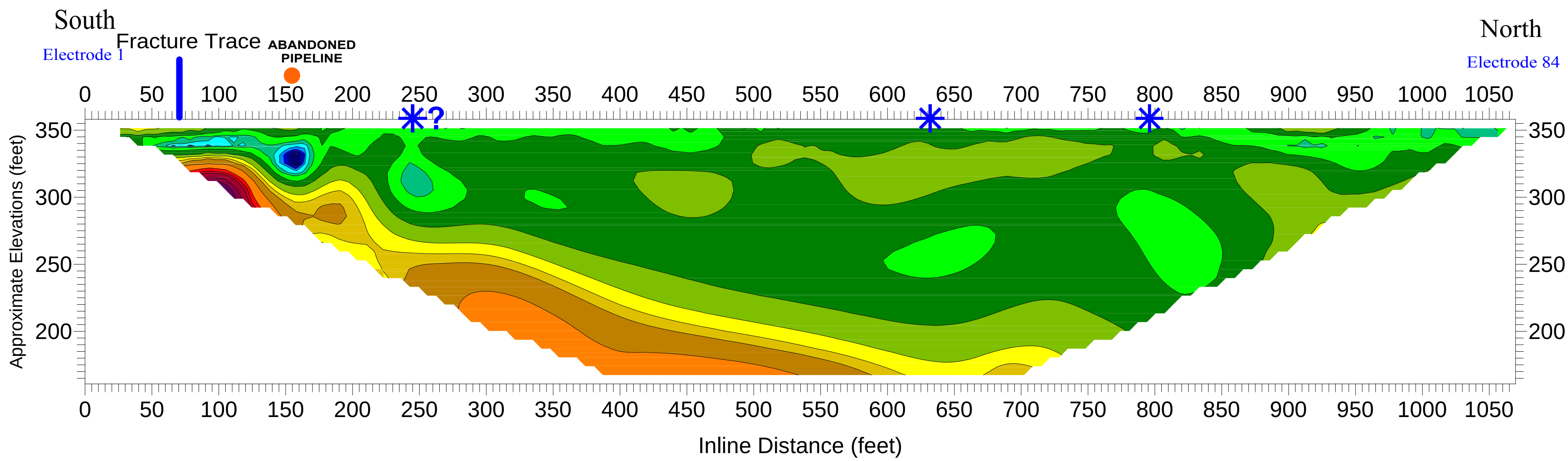
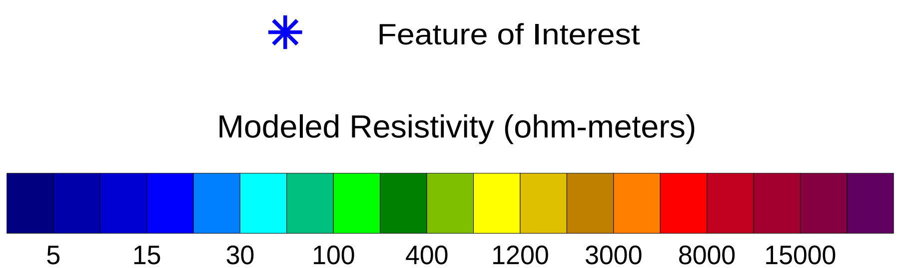
Electrical Imaging Traverse 2





Harley-Davidson York Facility - Condorus Creek			
Electrical Imaging Line 2			
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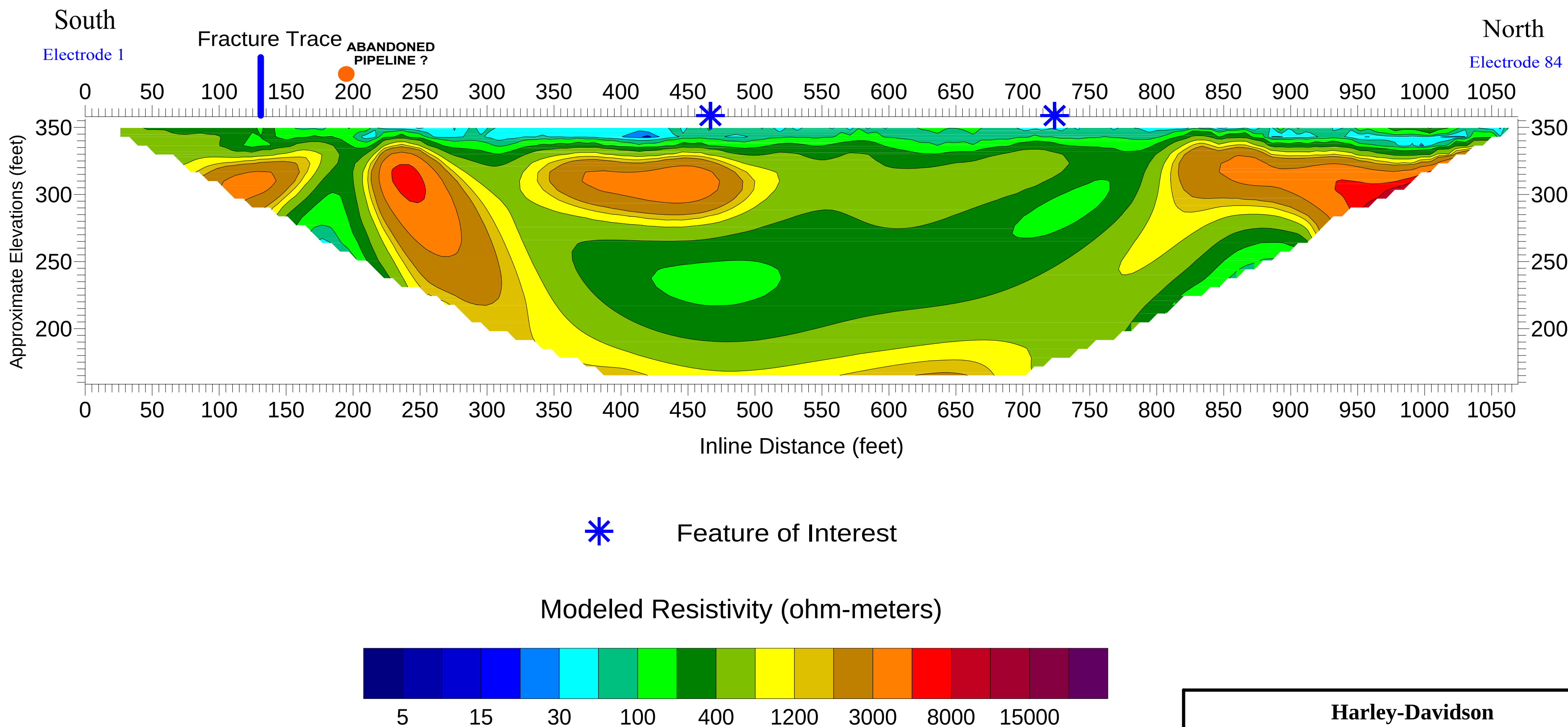
Electrical Imaging Traverse 3



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Electrical Imaging Line 3			
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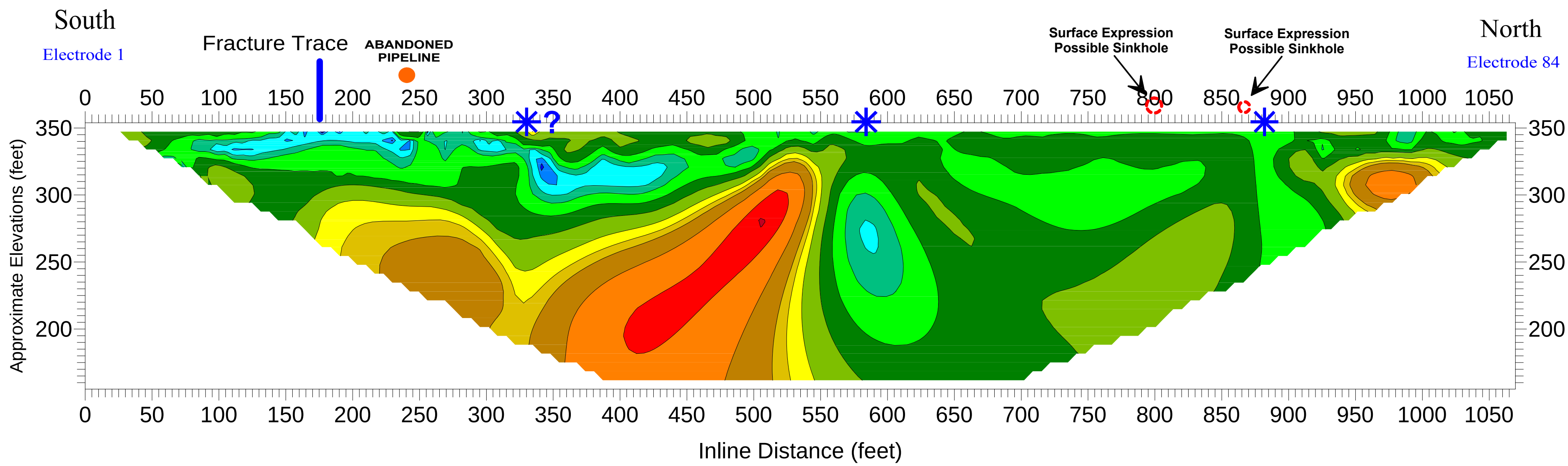
Electrical Imaging Traverse 4



Feature of Interest

Modeled Resistivity (ohm-meters)

Harley-Davidson York Facility - Condorus Creek			
Electrical Imaging Line 4			
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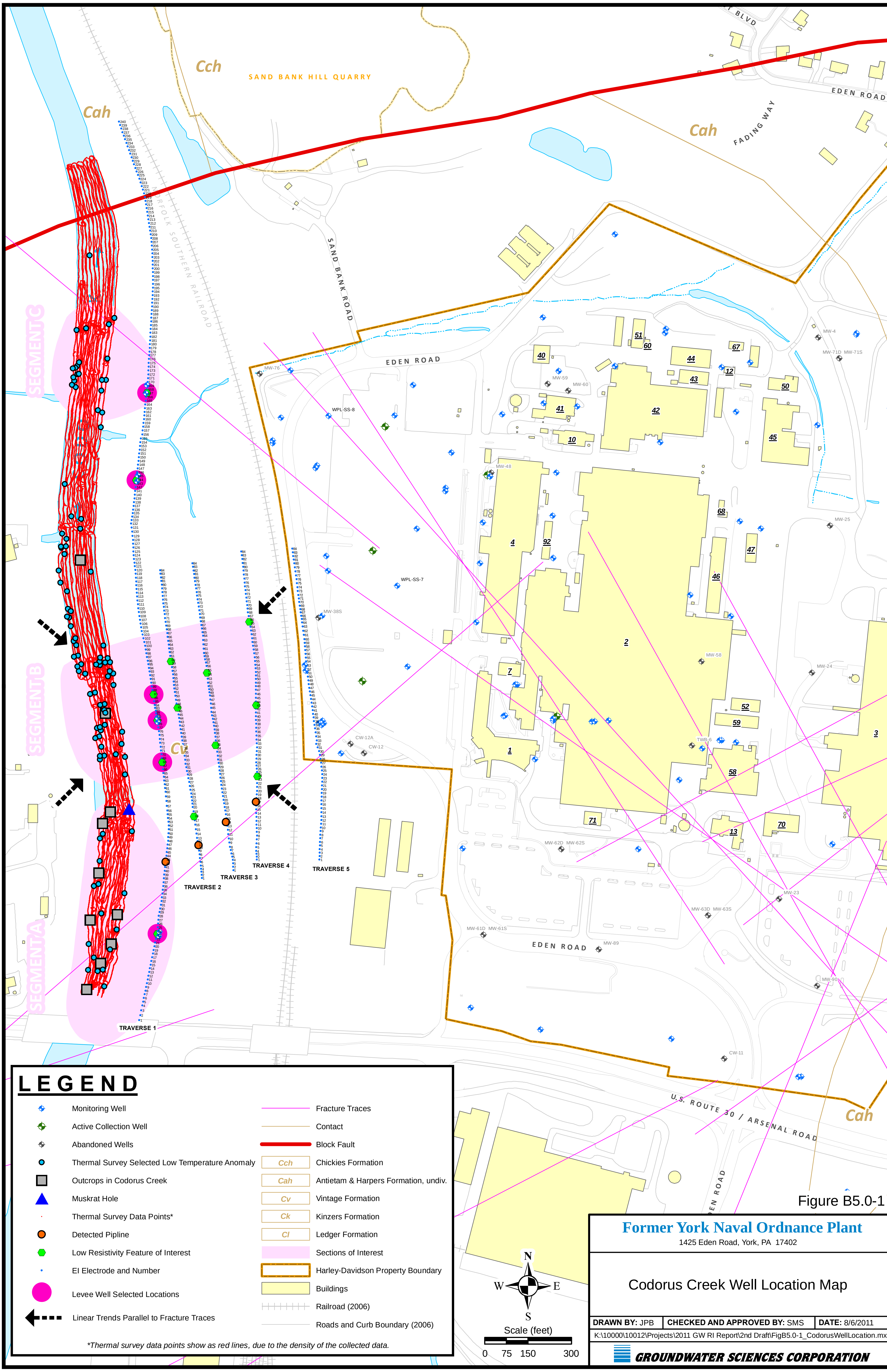

Cch
SAND BANK HILL QUARRY
Cah
EDEN ROAD
FADING WAY
SAND BANK ROAD
NORFOLK SOUTHERN RAILROAD
SEGMENT C
SEGMENT B
SEGMENT A
TRAVERSE 1
TRAVERSE 2
TRAVERSE 3
TRAVERSE 4
TRAVERSE 5
WPL-SS-8
WPL-SS-7
MW-76
MW-38S
CW-12A
CW-12
MW-59
MW-60
MW-48
MW-58
MW-4
MW-71D MW-71S
MW-25
MW-24
TWB-6
MW-62D MW-62S
MW-63D MW-63S
MW-61D MW-61S
MW-89
MW-23
MW-90
CW-11
U.S. ROUTE 30 / ARSENAL ROAD
LEGEND
Monitoring Well
Active Collection Well
Abandoned Wells
Thermal Survey Selected Low Temperature Anomaly
Outcrops in Codorus Creek
Muskrat Hole
Thermal Survey Data Points*
Detected Pipline
Low Resistivity Feature of Interest
EI Electrode and Number
Levee Well Selected Locations
Linear Trends Parallel to Fracture Traces
Fracture Traces
Contact
Block Fault
Cch Chickies Formation
Cah Antietam & Harpers Formation, undiv.
Cv Vintage Formation
Ck Kinzers Formation
Cl Ledger Formation
Sections of Interest
Harley-Davidson Property Boundary
Buildings
Railroad (2006)
Roads and Curb Boundary (2006)
*Thermal survey data points show as red lines, due to the density of the collected data.
N
W
E
S
Scale (feet)
0 75 150 300
Figure B5.0-1
Former York Naval Ordnance Plant
1425 Eden Road, York, PA 17402
Codorus Creek Well Location Map
DRAWN BY: JPB
CHECKED AND APPROVED BY: SMS
DATE: 8/6/2011
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