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Appendix A

GEOPHYSICAL SURVEY AND LIDAR PROCESSING TO INVESTIGATE THE REEDY ISLAND CART ROAD

SERAMUR & ASSOCIATES, PC

DECEMBER 2013

Geophysical Survey and LiDAR Processing to Investigate the Reedy Island Cart Road

Route 301, East Side of Spring Mill Branch
New Castle County, Delaware

Prepared for:

Hunter Research, Inc.
120 West State Street
Trenton, NJ 08608

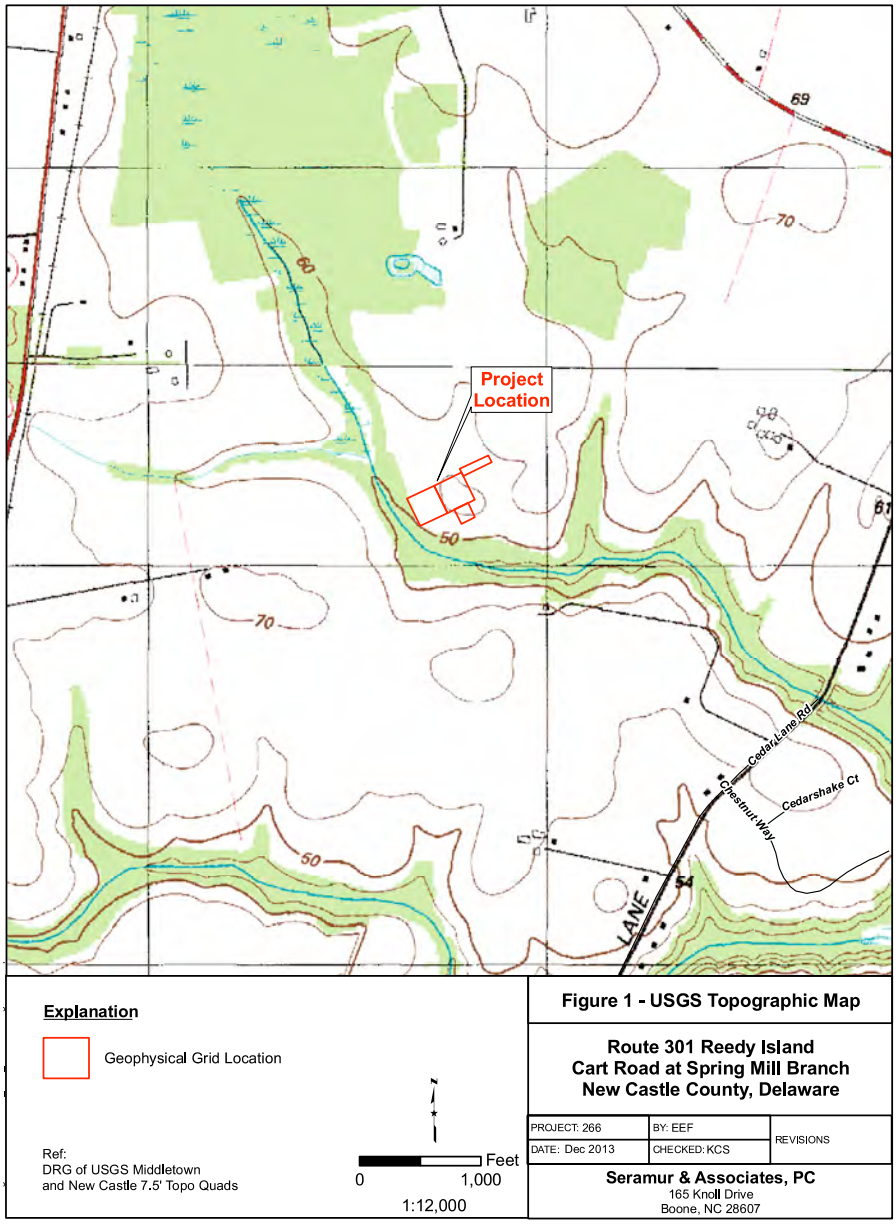
Prepared by:

Seramur & Associates, PC
165 Knoll Drive
Boone, NC 28607

December 30, 2013

Project Scope

Seramur & Associates, PC was contracted to complete a geophysical survey along a possible segment of the Reedy Island Cart Road on the east side of Spring Mill Branch in New Castle County (Figure 1). The purpose of the survey was to determine if anomalies in the geophysical data would show the location of this section of the cart road. Seramur and Associates budgeted for a total of 3.7 acres (15,000 m^2) of survey using both Ground Penetrating Radar (GPR) and Gradiometer geophysical systems.



A site meeting was conducted on October 30, 2013 with Hunter Research personnel for a reconnaissance of the survey area. A linear set of GPR and magnetometer anomalies on

the west side of Spring Branch were determined to be ditches or ruts representing the alignment of the Reedy Island Cart Road. Hunter Research marked an area approximately 250 feet square on the east side of Spring Branch that aligned with the cart road on the west side of the stream.

The study area is located in an agricultural field that was tilled and disked in preparation for running geophysical equipment across the ground surface. Seramur & Associates laid out survey grids to collect data along 0.5 meter transects. Grids 1 and 2 are each 76 square meters (249.4 ft x 249.4 ft). Each grid approximates the size of the initial target area laid out by Hunter Research. Grid 2 was added to Grid 1 along the alignment of the Reedy Island Cart Road (Figure 2). Grids 1 and 2 were divided into 4 sections (A through D) for the GPR survey. This limits the size of the data files and allows the data to be processed at different target depths across the terrain.

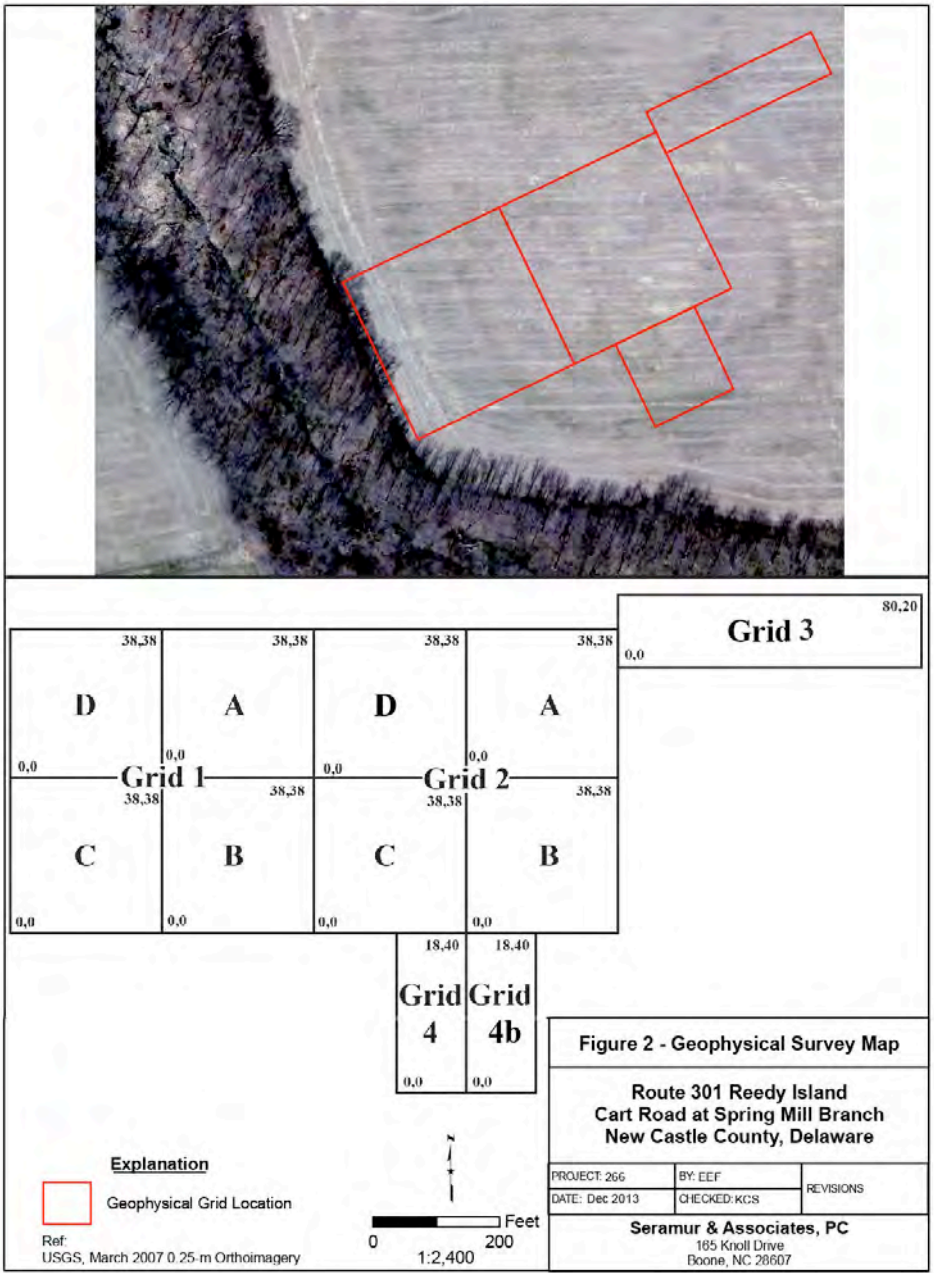
The GPR data was processed at the end of each day and evaluated. Linear anomalies were observed crossing the northern half of Grids 1 and 2. Grid 3 was added onto the northeastern corner of Grid 2 to follow these anomalies (Figure 2). Grid 4 was added to an elevated area south of Grid 2 to assess if there was a southern route for the cart road. Hunter Research had reported a possible historic site in the area of Grid 4. The GPR system was available for a few hours at the end of the budgeted field time. Grid 4b was added to widen GPR coverage of this southern survey area.

Geophysical Systems

The GPR survey was completed using the Geophysical Survey Systems, Inc. 400 MHz antenna and a SIR-3000 Single Channel GPR Data Acquisition System. Radan© software is used to produce a 3-dimensional (3-D) model of the geophysical data. GPR anomalies can be evaluated by selecting horizontal slices through the 3-D model of each grid at different depths. These horizontal slices show the radar reflections returned over a particular thickness of the 3-D model.

Magnetic field data was collected using the Geometrics Cesium Vapor G858 Magnetometer. Gradiometer data is obtained by using two vertically separated magnetometer sensors that measure changes in the earth's magnetic field along the grid transect. The gradient between the magnetometer readings from each sensor is recorded and used to map anomalies across the survey area. MagMapper© software is used to export the magnetic field gradient data into X, Y, Z ASCII columnar format files. These data files were imported into Suffer© software where they were compiled into gradiometer images. The data was process to eliminate extreme gradiometer measurements, those exceeding $\pm$15 nanoTesla.

The GPR and gradiometer grids were compiled in Adobe Illustrator© and exported as tiff files. Tiff files were then imported into ArcGIS Desktop© Geographical Information Software to georeference the compiled grids.



Geophysical data was collected along survey lines spaced 0.5 m apart. The grid layout and orientation is shown in Figure 2 with the X and Y values for the grid corners labeled.

GPR Anomalies

The GPR data is presented in Plates A-1 and A-2 of Appendix 1. The agriculture fields are plowed in a northwest-southeast orientation. The 3-D models of GPR data were sliced to depths between 0.45 to 0.65 m. The plow scars produce strong linear anomalies in the northwest-southeast direction. Some of these scars extended to a depth of 0.5 m. The slice thickness was varied from 0.1 to 1.0 m during the data processing to determine the best thickness for identifying GPR reflectors (anomalies) potentially associated with the cart road. Linear anomalies that could possibly represent the cart road appear to be best

illustrated using a slice thickness of 0.2 m or 20 cm. GPR reflections imaged in the radar data were selected at depths between 35-55 cm, 45-65 cm and 55-75 cm. Each sub-grid was evaluated separately and the appropriate depth for the grid slice was selected.

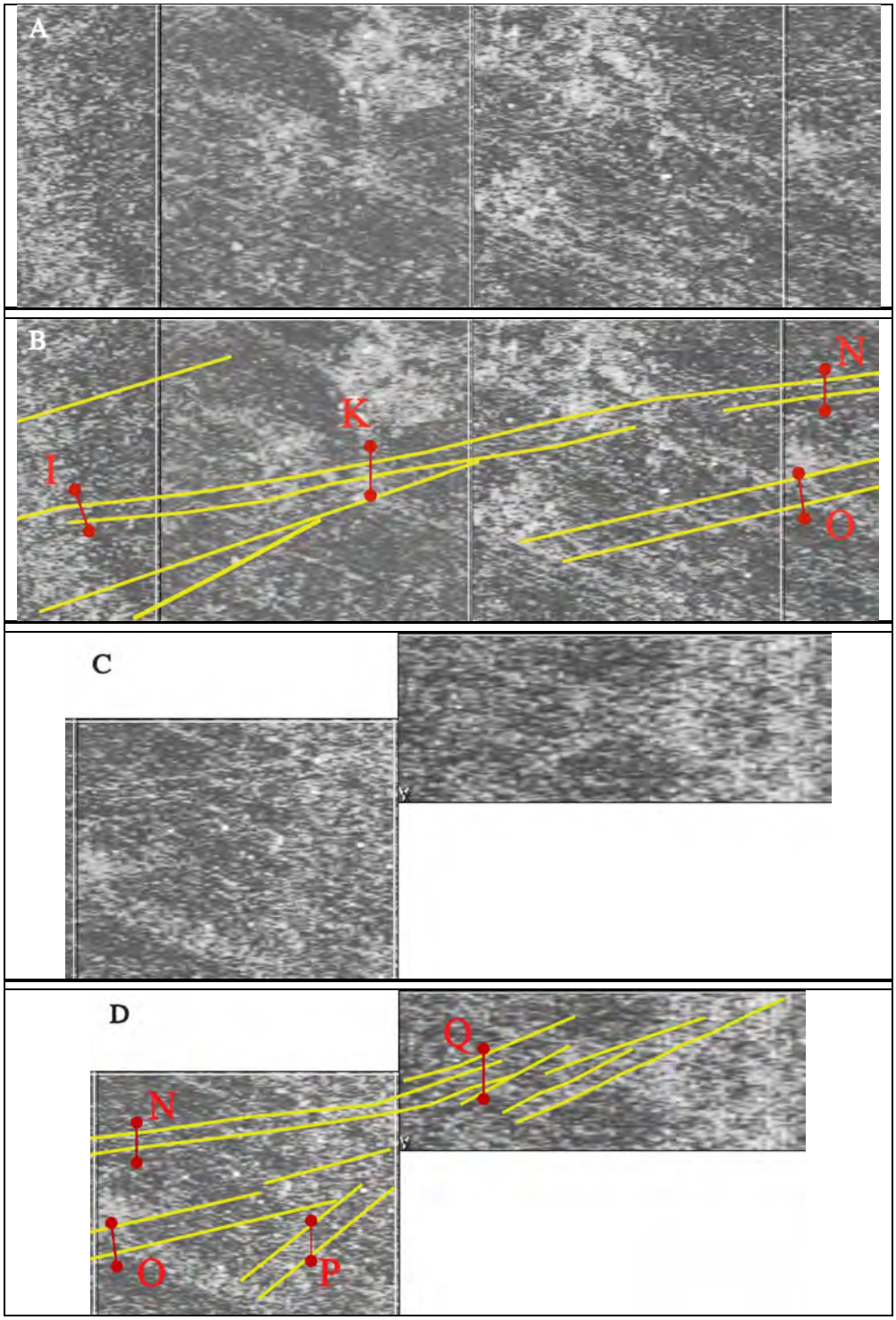


Figure 3. East-west linear GPR reflections extend across the northern portion of Grids 1 and 2 (a & b). Two additional sets of linear anomalies were observed in Grid 2, extending into Grid 3 (c & d).

The cart road orientation should range between southwest-northeast to east-west. This is an orientation perpendicular to, or oblique to the direction (north-south) that the GPR data was collected. Collecting data oblique or perpendicular to the direction of the target anomalies reduces the possibility of introducing artifacts into the GPR data.

A background of dispersed GPR reflections occurs across the west side of Grid 1 (Plate A-1). This area is on the slope up from the Spring Branch drainage. Sediment eroded off the upland surface has accumulated on this slope. Deep plow scars produce relatively strong northwest-southeast orientated reflections across the central survey area (Plate A-1). The central and eastern grids are located on the upland surface. These plow scars extend down into the B-horizon or subsoil.

Two prominent east-west linear GPR reflections extend across the northern portion of Grids 1 and 2 (Figure 3a). Proposed trench locations I, K, N and Q were located across these anomalies (Figure 3b). The spacing of these parallel anomalies is about 6 to 8 feet. Two additional sets of parallel linear anomalies were identified in Grid 2 (Figure 3c). Trenches O and P were located across these southwest-northeast trending anomalies (Figure 3d).

There is an elongate, rectangular area with a low reflection density in Grid 1 (Figure 4a). Two southwest-northeast trending linear anomalies are traced through this area and Trench J was located across these anomalies (Figure 4b).

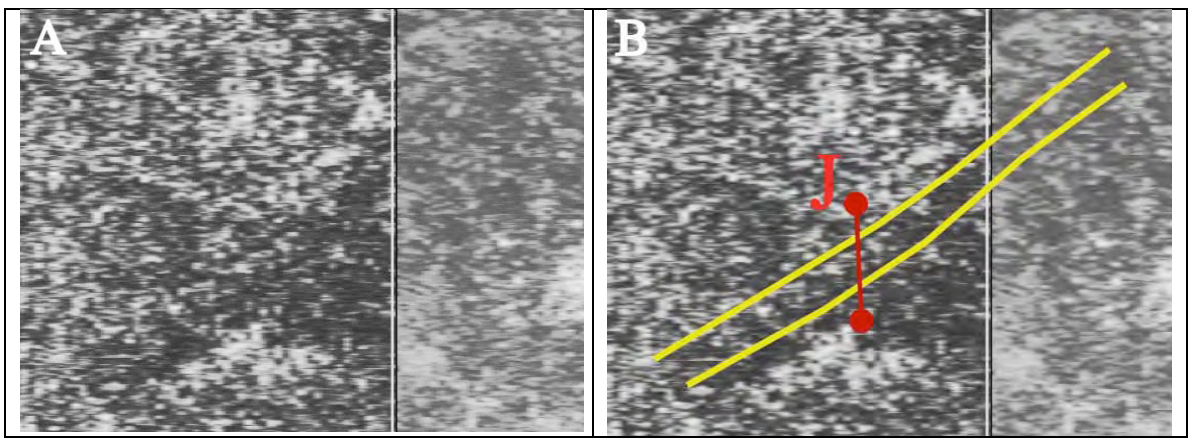


Figure 4. Elongate rectangle with low-density GPR reflections (a). Parallel linear anomalies traced through this rectangle (b).

Several east-west to southwest-northeast trending linear anomalies are located in southern Grid 2 and Grids 4 and 4b (Plate A-1). A rectangular outline of GPR reflections was noted in Grid 4b (Plate A-2). Hunter Research excavated trenches B-A-H and G-F across these anomalies (Plate A-2). Trench B-A-H was excavated along the southwest side of the rectangular anomaly. Hunter Research reported a large pit feature was recorded in the trench near point B.

Gradiometer Anomalies

The gradiometer data is presented in Plates A-3 and A-4 of Appendix 1. Three anomaly types are observed in the gradiometer data. The first are large oval features, which are

addressed in the Delmarva Bay discussion below. The second are a series of linear southwest-northeast trending anomalies showing an elevated magnetic gradient (Plates A-3 and A-4). These linear anomalies did not show up in the GPR data. They could be related to bedding or changes in iron content in the underlying fluvial and marine sediment.

The G858 magnetometer is very sensitive and metallic objects produce a strong magnetic signal in the gradiometer data. These show up on the gradiometer images as polar (white and black) anomalies (Plate A-3). These metallic anomalies are circled on Plate A-4. There is a line of these metallic anomalies that trends along the linear set of GPR anomalies in the northern portion of Grids 1 and 2 (Plates A-2 and A-4)

Several areas of interest were noted in Grids 4 and 4b on the gradiometer and GPR data. These were flagged in the field as point locations A through H. This includes a complex of circular anomalies in the vicinity of points G, H and F (Plate A-3). We were not able to conclude from our field survey whether these were pedogenic or cultural features.

Delmarva Bays

The coastal plain sediments in the project area are mapped as the Columbia Formation, sand with gravel and beds of clayey silt. Shallow deposits in the study area are silt to very fine sand. Soil is mapped as the Othello Silt Loam and the Reybold Silt Loam. The Otheelo Silt loam is mapped along the western side of the field and forms in depressions flats and swales. The Reybold Silt Loam is mapped on the upland surface and forms on interfluves. Both of these soils form in silty aeolian sediment deposited over fluviomarine sediment (USDA, 2013).

Undrained depressions formed in the Columbia Formation are commonly referred to as Delmarva Bays (Ramsey, 2005; Davias, 2012). These are also known as wet flatwood swamps and form seasonal wetlands across the Delmarva Peninsula. These wetlands occur in subtle depressions and are seasonally flooded in the spring from snowmelt and spring rains. These features are thought to be remnant Pleistocene landforms related to periglacial and aeolian processes (Newell and Clark, 2008).

A circular wooded area in the northwest corner of the farm field is not plowed because it is a seasonal wetland or Delmarva bay (See Cover Photo). The aerial photograph of the upland portion of the study area shows several round to elliptical features (Figure 2). These features are visible because of slight changes in soil moisture. These features were also observed on the GPR and magnetometer data (Figure 5a and 5b). The GPR depicts these as areas of low density reflections (Figure 5a). The GPR signal is attenuated by clay soils and the low-density reflections in the center of these circular features could indicate a higher clay content in the soil.

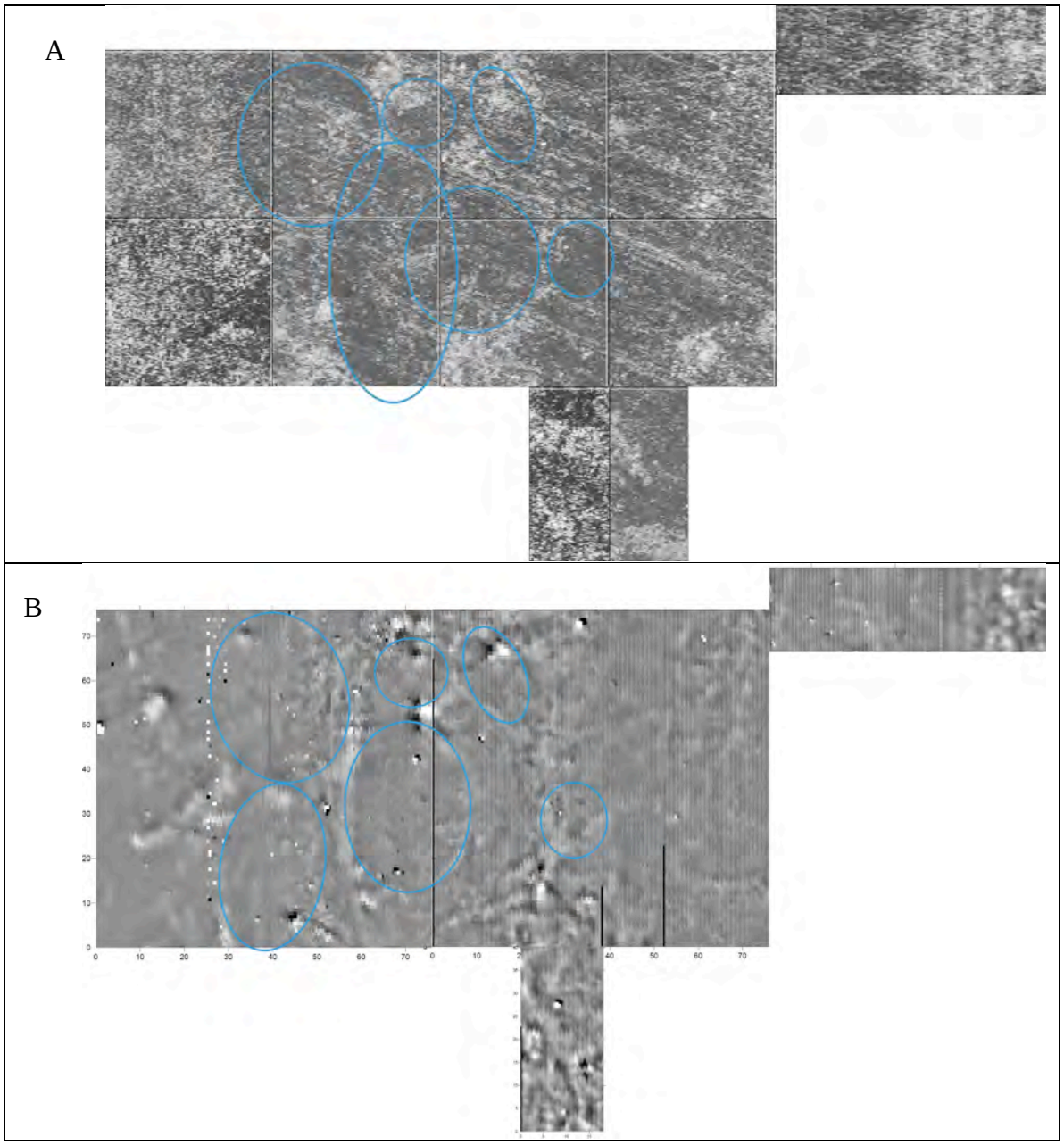


Figure 5. Geophysical survey data showing outlines of oval subsurface features. GPR shows low density reflections surrounded by oval rings or radar reflections (a). Gradiometer data shows circular to oval shaped outlines of magnetic anomalies (b).

The perimeters of these circular features are observed on the gradiometer data as areas with a high magnetic field gradient (Figure 5b). The perimeter of seasonal wetlands would experience frequent changes moisture content or wetting and drying. Iron precipitation occurs in areas along the top of the water table as a result of changes between reducing saturated conditions and oxidized aerated or drained soils. The rims of these circular features appear to be outlined by soil with a higher iron oxide concentration.

The circular features observed in the study area are former seasonal wetlands. These

remnant Pleistocene features could have been drained and plowed after European settlement.

Penetrometer Testing

A hand penetrometer was used to evaluate the compaction of soil materials associated with the cart road. Hunter Research provided penetrometer data for our review. Traffic along the road could compact soil. This soil compaction might be measured with a penetrometer and possibly mapped along the cart road. The geophysical survey west of Spring Branch identified possible ditch lines or ruts along the cart road. One possible signature for the cart road would be compacted soil in the center of the cart path with unconsolidated soil along the edges.

Visible evidence of the cart road was not observed in any of the trenches excavated east of Spring Branch. A cart road crossing the study area could have affected soil material below the roadbed. A compacted road surface would limit infiltration of surface water diverting it to the side of the road. Surface water infiltration into the deeper soil horizons could soften or reduce compaction of subsoil along the edge of the cart road. Changes in both soil compaction and soil moisture content can produce anomalies within the GPR data. The penetrometer data will be reviewed with respect to the GPR anomalies tested to assess possible trends related to the cart road.

Trenches B-A-H and G-F were excavated in an area where multiple linear and circular anomalies were observed. These anomalies were flagged in case they were structures or disturbance associated with the cart road. Hunter Research reported that a large prehistoric pit feature was recorded in the vicinity of point B. Penetrometer readings in the vicinity of point B range from 1.25 to 2.4 tons/ft^2 (Figure 6). These readings represent the compaction values for culturally disturbed soil material.

Two southwest-northeast trending linear anomalies were observed crossing line B-A (Figure 6). These anomalies could be associated with some of the large variations in penetrometer values recorded between 10 and 20 feet. The penetrometer data collected along lines B-A-H and G-F is quite variable (Figure 6). There is one area of consistently high penetrometer measurements along line G-F. The gradiometer data showed multiple anomalies in this area, possibly associated with iron oxide concentrations in the B-horizon. The variable penetrometer data along these two lines could be associated with differences in iron cementation within the B-horizon.

Proposed trench locations I, K, N and Q were located across two prominent east-west linear GPR reflections (Figure 3a & 3b). Penetrometer measurements along Trenches I and N indicated soil with the highest compaction value (4.5 tons/ft^2) with a few areas of softer soil (Figures 7 and 8). The linear anomalies along line I could be associated with the lower penetrometer measurements at 4 feet and 9 feet (Figure 7). The linear anomalies along line N could be associated with the lower penetrometer measurements at 7 feet and 13 feet (Figure 8). These lower penetrometer measurements are at a similar spacing to the linear anomalies

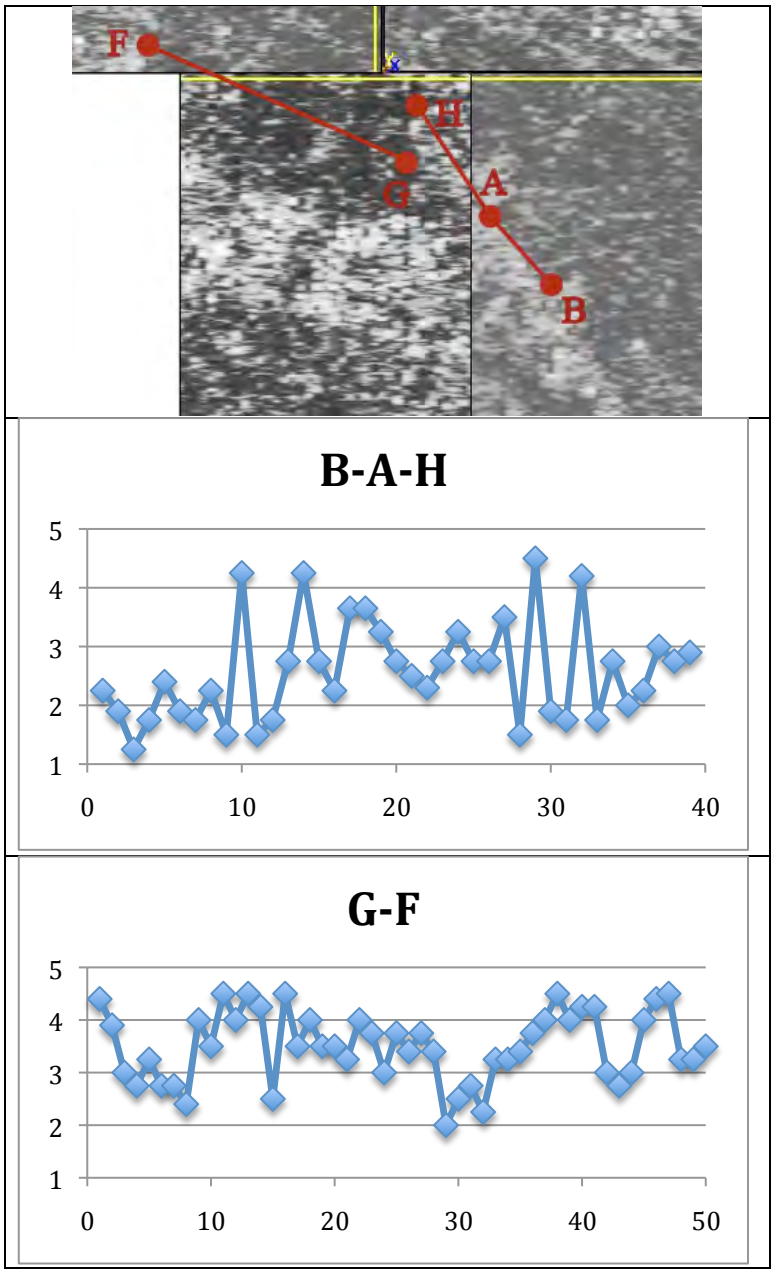


Figure 6. Location of lines B-A-H and G-F on the GPR grids and associated penetrometer data collected along those lines.

The penetrometer measurements in trenches K and Q show compacted soil in the center of the trenches and softer soil on the margins of the trenches (Figures 9 and 10). This is the expected pattern for penetrometer readings across the cart road. However, the compacted soil only extends from 13 to 17 feet in Trench K.

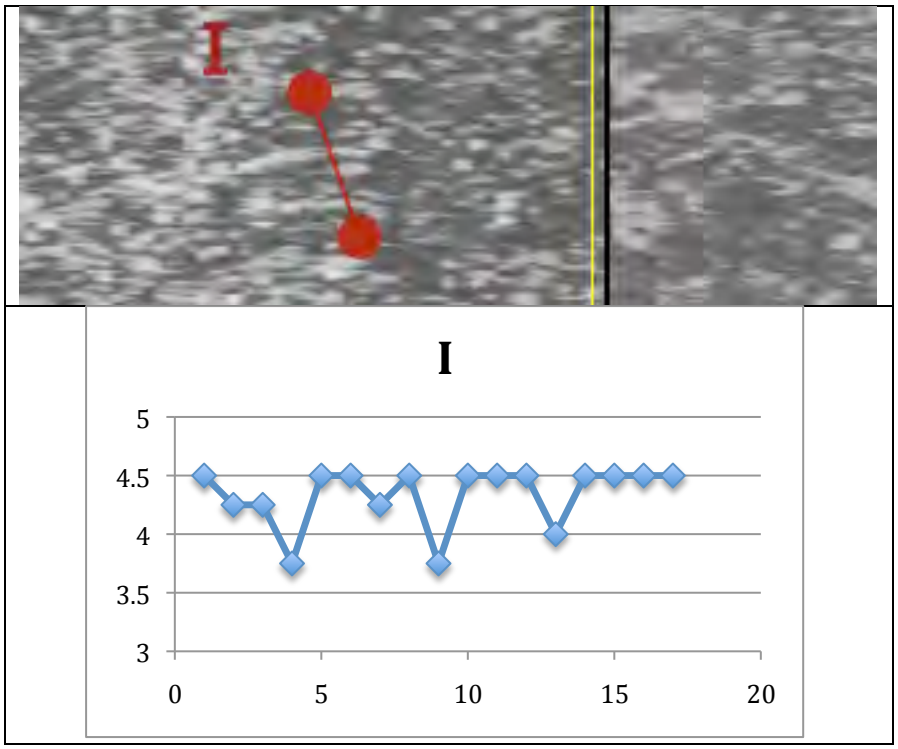


Figure 7. GPR data and penetrometer values for Trench I.

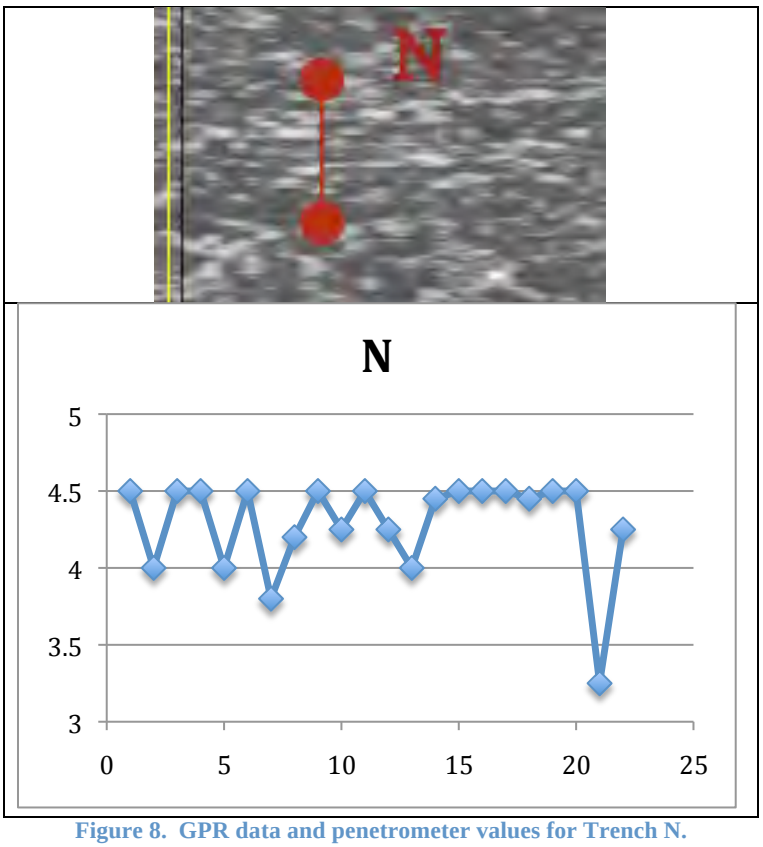


Figure 8. GPR data and penetrometer values for Trench N.

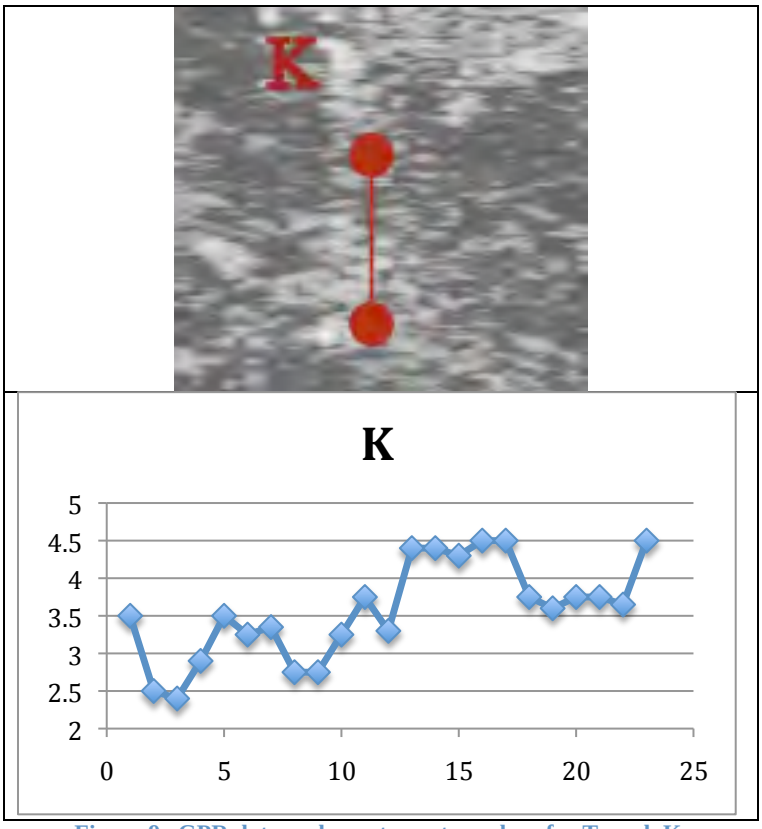


Figure 9. GPR data and penetrometer values for Trench K.

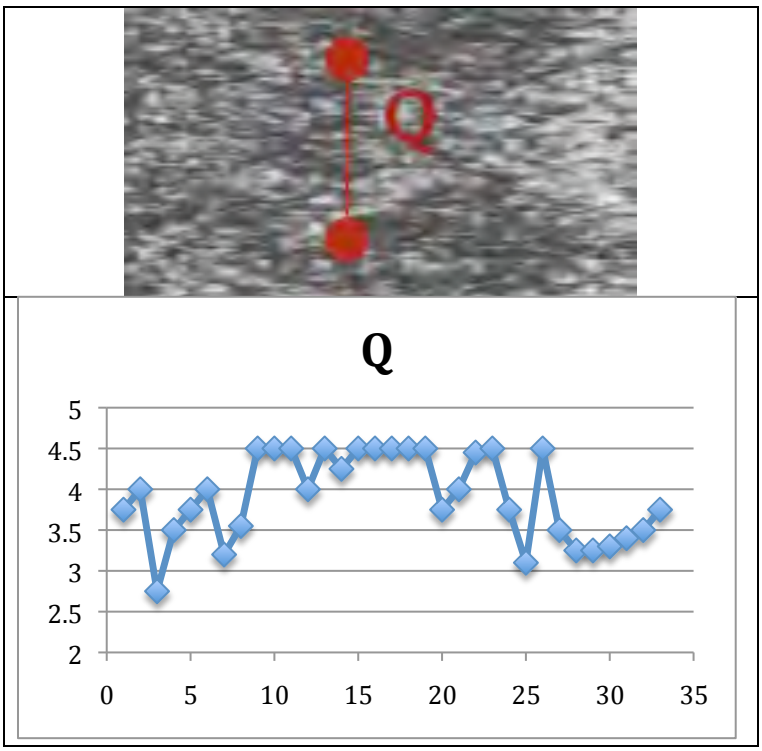


Figure 10. GPR data and penetrometer values for Trench Q.

Penetrometer testing in Trench O extended for 100 feet (Figure 11). It is uncertain exactly how these measurements align with the GPR anomalies. The penetrometer data shows variability across the trench except between 34 feet and 44 feet (Figure 11). These consistently high (4.5 tons/ft^2) penetrometer measurements could be related to soil compaction along the cart road.

The high penetrometer measurements in Trench O show that the plow zone in upland areas have been eroded down to the stiff B-horizon subsoil. Visual evidence of the cart road has been eroded from this portion of the study area.

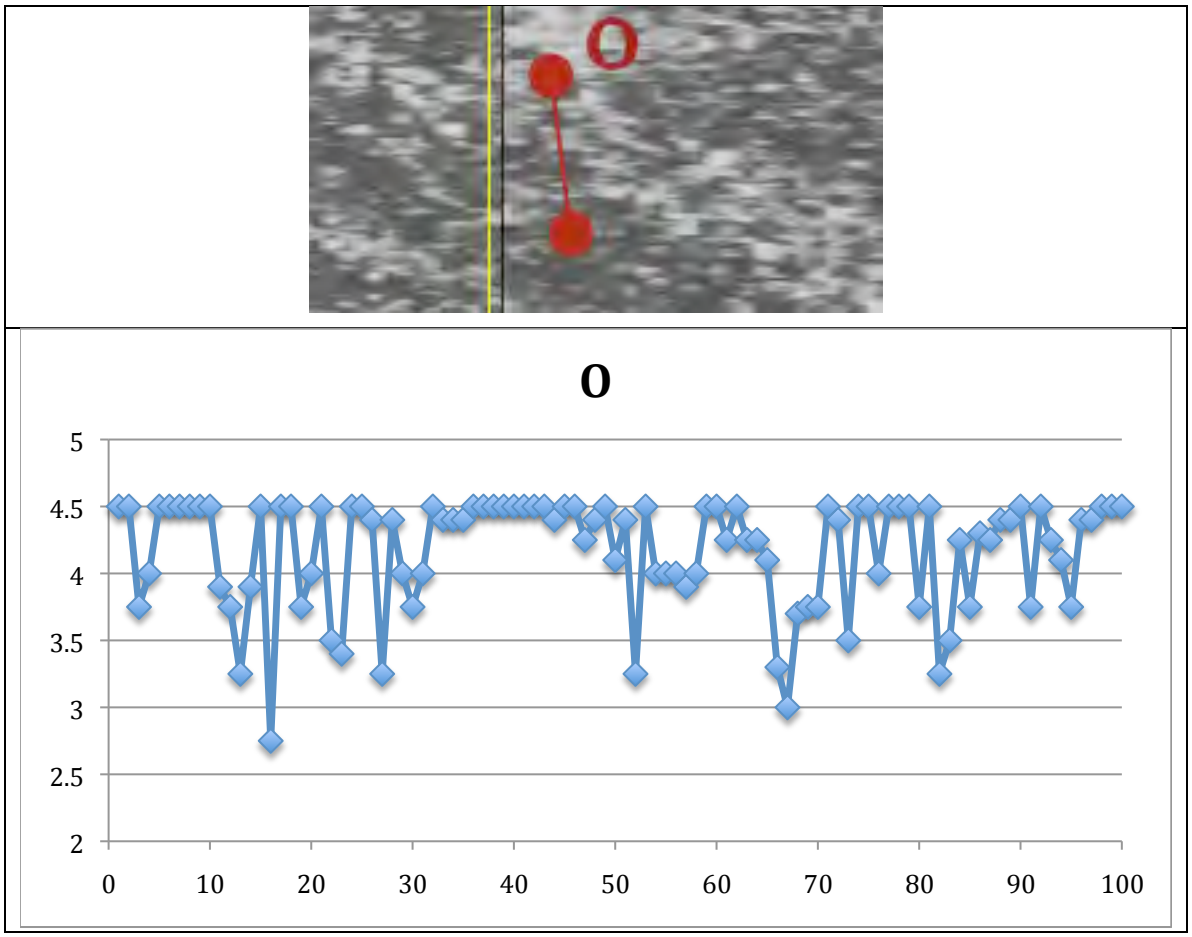


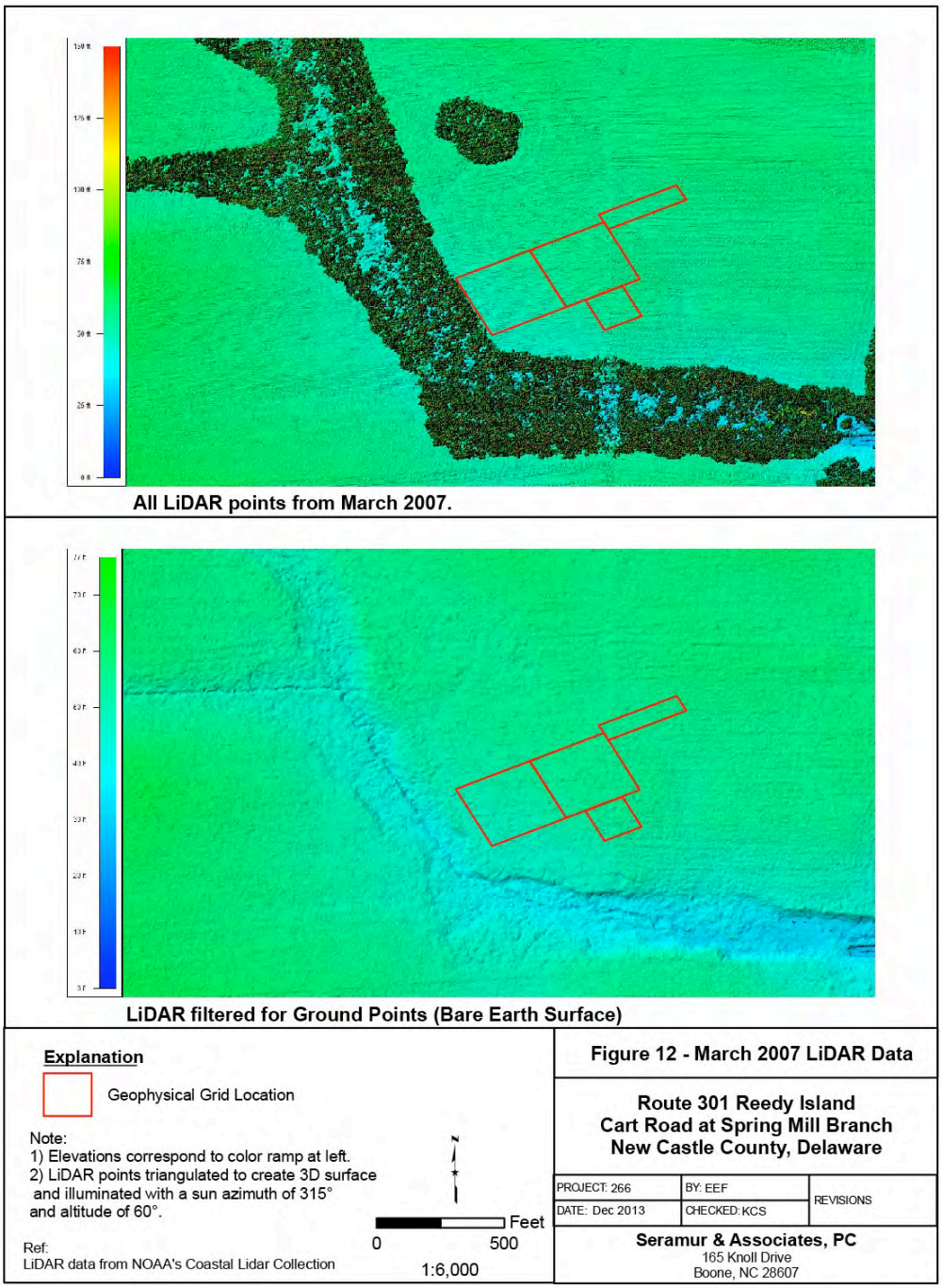
Figure 10. GPR data and penetrometer values for Trench O.

Summary of Geophysical Survey

Anomalies identified in the GPR data indicate changes in the physical properties of the soil across the survey grids. The GPR processing showed that the soil properties associated with these anomalies is only preserved over a 20 cm thick section of the subsoil. The physical properties that produce the GPR reflections are interpreted to be changes in soil moisture content and soil compaction. The linear alignment of these anomalies indicates that they are likely associated with roads or paths across the study area. This evidence of former roads and/or paths occurs along the base of the plow zone. The age of these features is not known.

Processed LiDAR Data

LiDAR data was obtained from the National Oceanographic and Atmospheric Administration's "2007 Delaware Coastal Program Lidar: Kent and New Castle Counties".



The data acquisition occurred in 7 missions between March 31 and April 5, 2007 in Kent and New Castle Counties, Delaware. The data have been classified and were flown to derive bare earth contours at 2 feet. Multiple returns were recorded for each laser pulse

along with an intensity value for each return. The points have a 1.4 m ground spacing (1.0 m ground spacing within the Wilmington Urban Area). This data set is a raster file of z values with 3712 columns and 2081 rows. The data set was extracted from a larger classified data set and only includes points classified as Ground, Model Key-point (mass point), and Bathymetric LiDAR Points within the geographic bounds.

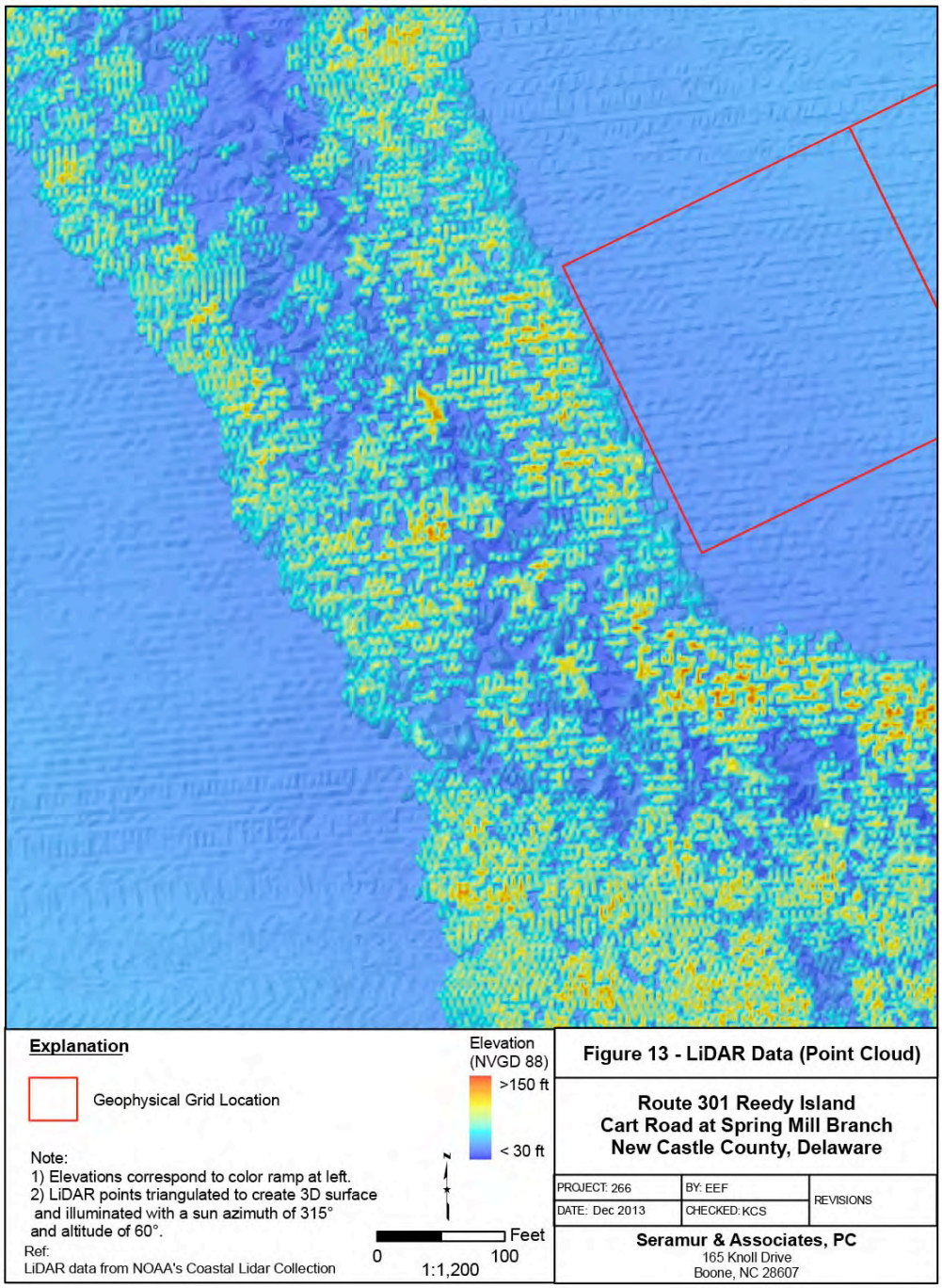
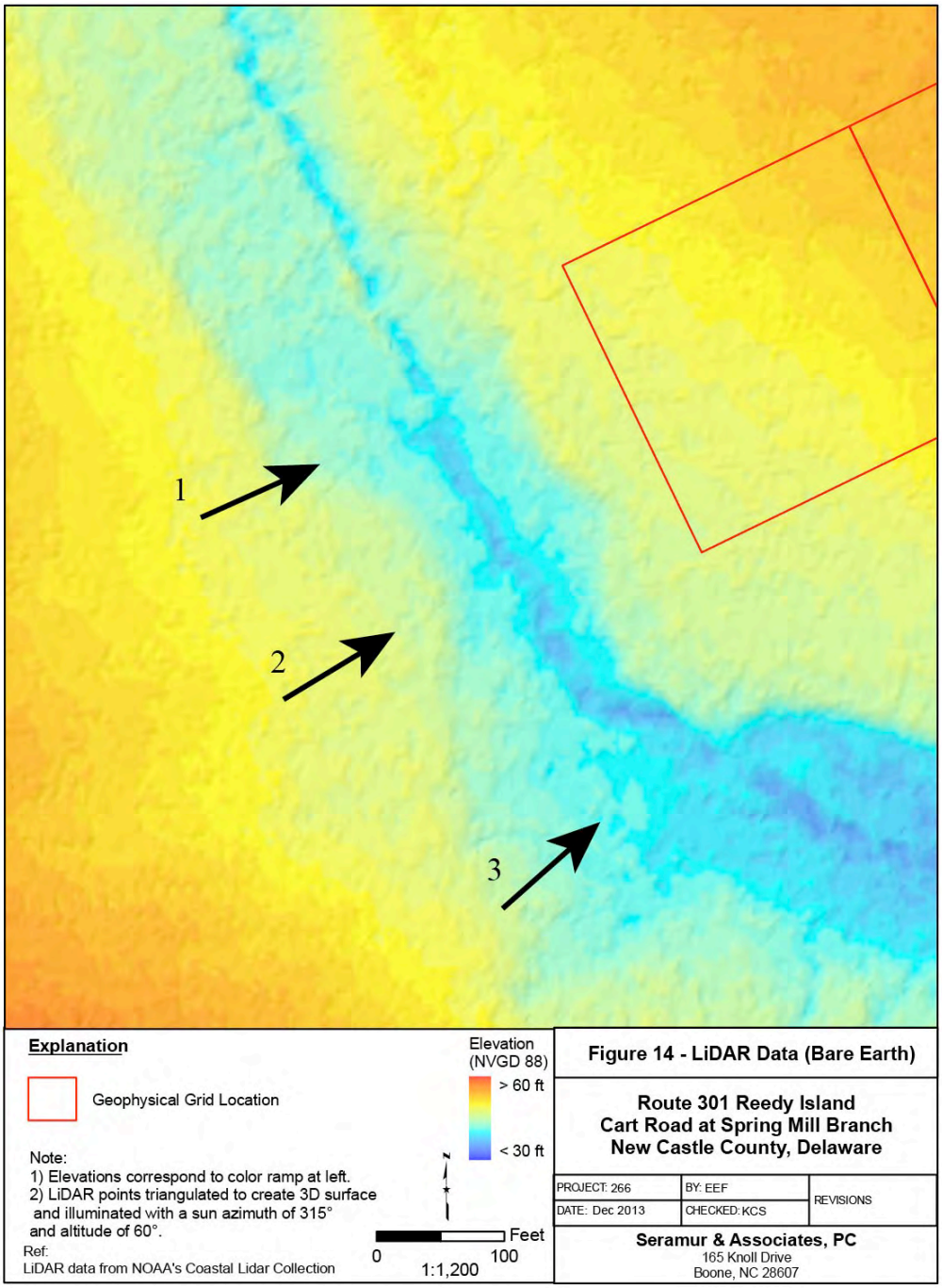


Figure 12 shows the LiDAR images with all points and with filtered ground surface points. Figure 13 is a larger scale image of all data from the LiDAR point cloud or data

set. Figure 14 shows the last LiDAR returns or bare earth model of the possible cart road crossing of Spring Branch.



Three arrows have been sketched over this last image. The first arrow shows an area where the stream channel has an unusual configuration (trending southwest-northeast). The streambed widens at this point. This could be due to springs discharging to the stream or historic modification of the channel. The second arrow points to an area where there is gentle slope down to the stream channel from the southwest. This is near one of

the shoals or riffles observed in the field. The third arrow is located at the bend in the stream channel. The stream channel morphology changes at this bend in the river. Upstream the channel is narrow and appears relatively confined. Downstream of the bend the channel appears to meander across a wide lowland area (broad dark blue area on Figure 14). A historic crossing of Spring Branch would have been more practical upstream of the bend, along the narrow confined portion of the channel.

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Ramesey, Kelvin W.
2005 Geologic Map of New Castle County, Delaware. Delaware Geologic Survey, Geologic Map Series No. 13.

U.S.D.A.
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Appendix A
Ground Penetrating Radar and Magnetometer Data

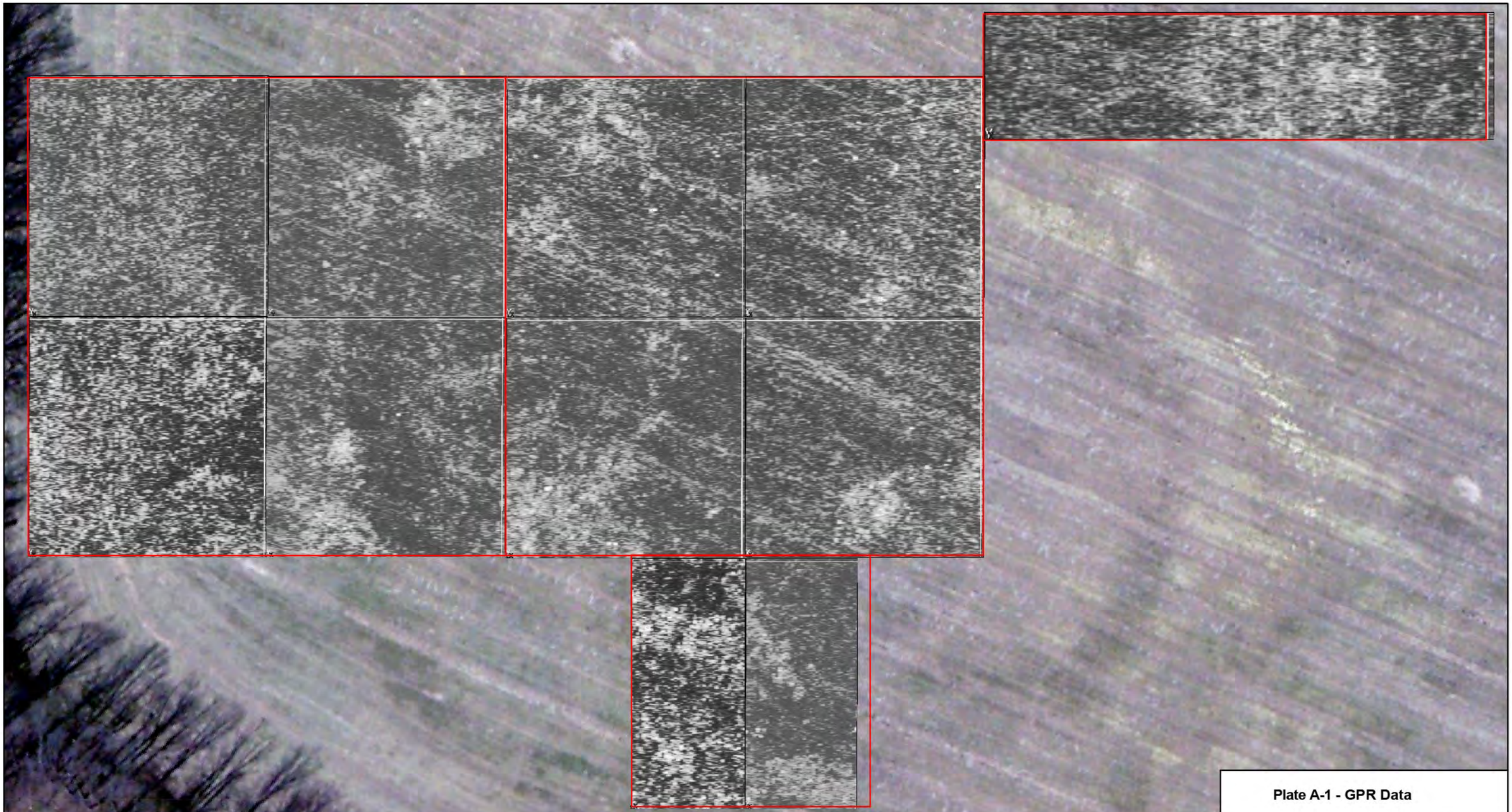


Plate A-1 - GPR Data

Route 301 Reedy Island
Cart Road at Spring Mill Branch
New Castle County, Delaware

PROJECT: 266	BY:EEF	REVISIONS
DATE: Dec 2013	CHECKED: KCS	

Seramur & Associates, PC
165 Knoll Drive
Boone, NC 28607

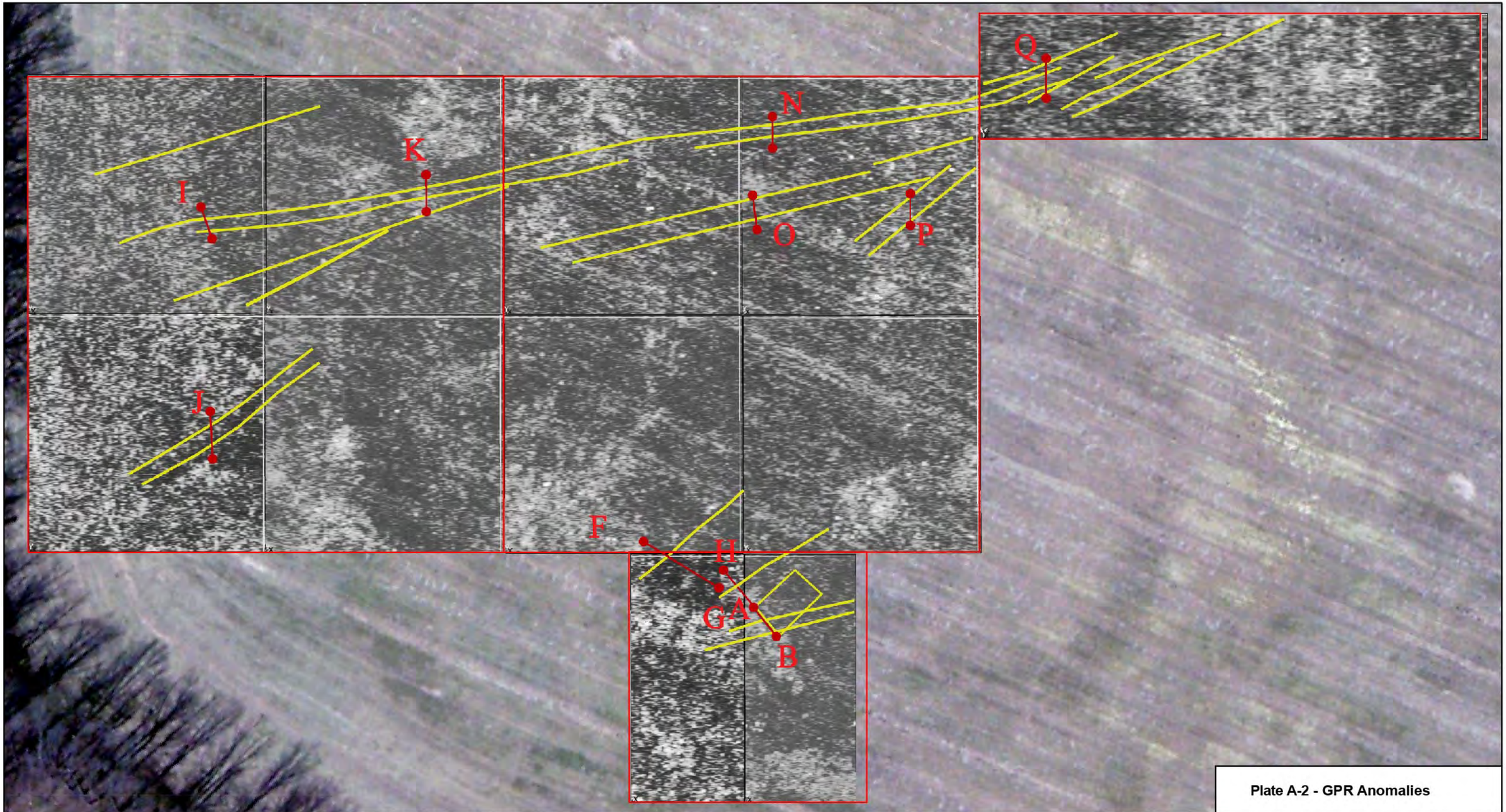
Explanation

Geophysical Grid Location

Ref:
USGS, March 2007 0.25-m Orthoimagery

N

Meters
0 20
Feet
0 100
1:600



Explanation

Geophysical Grid Location

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USGS, March 2007 0.25-m Orthoimagery

N

Meters
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Feet
0 100
1:600

Plate A-2 - GPR Anomalies

Route 301 Reedy Island
Cart Road at Spring Mill Branch
New Castle County, Delaware

PROJECT: 266	BY: EEF	REVISIONS
DATE: Dec 2013	CHECKED: KCS	

Seramur & Associates, PC
165 Knoll Drive
Boone, NC 28607

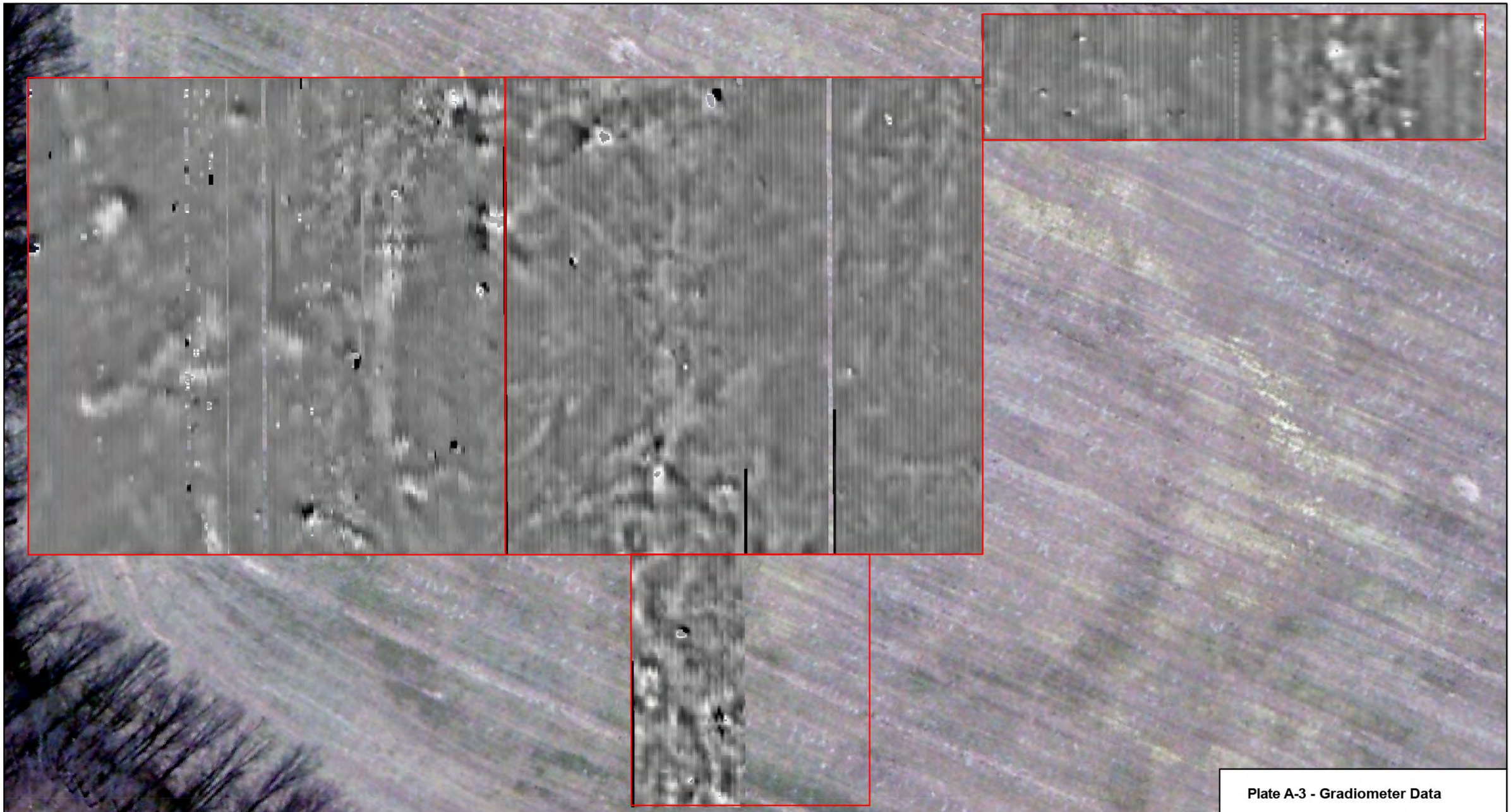

Plate A-3 - Gradiometer Data

Route 301 Reedy Island
Cart Road at Spring Mill Branch
New Castle County, Delaware

PROJECT: 266	BY:EEF	REVISIONS
DATE: Dec 2013	CHECKED: KCS	

Seramur & Associates, PC
165 Knoll Drive
Boone, NC 28607

Explanation

Magnetometer Readings
>15 nT
<-15 nT

Geophysical Grid Location

Ref:
USGS, March 2007 0.25-m Orthoimagery

N

Meters
0 20

Feet
0 100

1:600

Explanation

Magnetometer Readings
>15 nT
<-15 nT

Geophysical Grid Location

Ref:
USGS, March 2007 0.25-m Orthoimagery

N

Meters
0 20
Feet
0 100
1:600

Plate A-4 - Gradiometer Anomalies

Route 301 Reedy Island
Cart Road at Spring Mill Branch
New Castle County, Delaware

PROJECT: 266	BY:EEF	REVISIONS
DATE: Dec 2013	CHECKED: KCS	

Seramur & Associates, PC
165 Knoll Drive
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