LiDAR Project Report
South New Jersey
2008

Submitted to:
USGS
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Fairfax, VA

EXECUTIVE SUMMARY

This South New Jersey County LiDAR project ordered by USGS provides precise elevations acquired by airborne LiDAR sensor. High accuracy multiple returns LiDAR data separated in several classes are provided in addition to 2 meter hydro enforced DEMs in ArcGrid format. The project covers approximately 874 square miles over the three New Jersey counties of Cape May, Cumberland, and part of Salem that is south and west of the CAFRA line. The LiDAR data were acquired and processed by Dewberry's sub-consultant Photo Science. Dewberry's role is to provide overall project management as well as quality management. The product is a high density mass point dataset with an average point spacing of 0.8m. The data is tiled (5000ft by 5000ft tiles), stored in LAS format 1.1, and LiDAR returns are classified in four ASPRS classes: non-ground (1), ground (2), water (9) and overlap (12). Hydro-enforced DEMs are also delivered. The horizontal coordinate system is New Jersey State Plane South, NAD83, US survey feet with elevation in meters (NAVD88). Derived DEMs are also in New Jersey State Plane South, NAD83, US survey feet (pixel size 6.5616798ft ~2m) with elevations in meters.

Dewberry performed a quantitative accuracy testing and a qualitative assessment of these data including a completeness check and a micro qualitative review.

Based on Dewberry's independent survey data, the elevation meets and exceeds the fundamental vertical accuracy required for this project. This LiDAR dataset was tested 0.13m vertical accuracy at 95 percent confidence level, based on consolidated $RMSE_z$ x 1.9600. The survey and methodology complies with the NSSDA standard.

Dewberry inventoried the files and confirmed that all tiles were delivered in the specified format and projected geographically correct. We visually inspected 100% of the data; no remote-sensing data void was found and the data are free of major systematic errors. The cleanliness of the bare earth model meets expectations. Minor errors were found (such as vegetation artifacts and poor LiDAR penetration) but are not representative of the majority of the data.

In essence, this LiDAR dataset is of good quality and should meet the user's needs.

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QAQC REPORT

1 Introduction

LiDAR technology data gives access to precise elevation measurements at a very high resolution, resulting in a detailed definition of the earth's surface topography. Dewberry's role is to provide overall project management as well as quality management that includes verification of the data using a vertical accuracy assessment, a completeness validation of the LiDAR mass points, and a qualitative review of the derived bare earth surface.

First, the completeness verification is conducted at a project scale (files are considered as the entities). It consists of a file inventory and a validation of conformity to format, projection, and georeference specifications. General statistics over all fields are computed per file and analyzed to identify anomalies, especially in elevations and LAS classes.

Then, the quantitative analysis addresses the quality of the data based on absolute accuracy of a limited collection of discrete checkpoint survey measurements. Although only a small amount of points are actually tested through the quantitative assessment, there is an increased level of confidence with LiDAR data due to the relative accuracy. This relative accuracy in turn is based on how well one LiDAR point "fits" in comparison to the next contiguous LiDAR measurement as acquisition conditions remain similar from one point to the next.

Finally, to fully address the data for overall accuracy and quality, a qualitative review for anomalies and artifacts is conducted at the data level. As no automatic method exists yet, we perform a manual visualization process based on the knowledge of Dewberry's analysts. This includes creating pseudo image products such as 3-dimensional models. By creating multiple images and using overlay techniques, not only can potential errors be found, but we can also find where the data meets and exceeds expectations.

Within this Quality Assurance/Quality Control process, three fundamental questions were addressed:

- Did the LiDAR system perform to specifications?
- Was the data complete?
- Did the ground classification process yield desirable results for the intended bare-earth terrain product?

This is a LiDAR project for USGS covering South New Jersey counties. Data were acquired over the 3 New Jersey counties of Cape May, Cumberland, and part of Salem that is south and west of the CAFRA line. A detailed description of the project acquisition conditions and of the data processing steps can be found in the metadata delivered with the data. Additionally PhotoScience's acquisition report is provided as Appendix C. All quality assurance processes and results are given in the following sections.

2 Quality Assurance

2.1 *Completeness of deliverables*

The first step in our review is to inventory the data delivered, to validate the format, projection, georeferencing and verify the range of elevations.

2.1.1 LAS data

The project area for lot 1 - Salem is approximately 76 square miles south and west of the CAFRA line, lot 2 - Cumberland is approximately 502 square miles and lot 3 – Cape May is 285 square miles. The delivered data footprints are mapped in Figure 1.

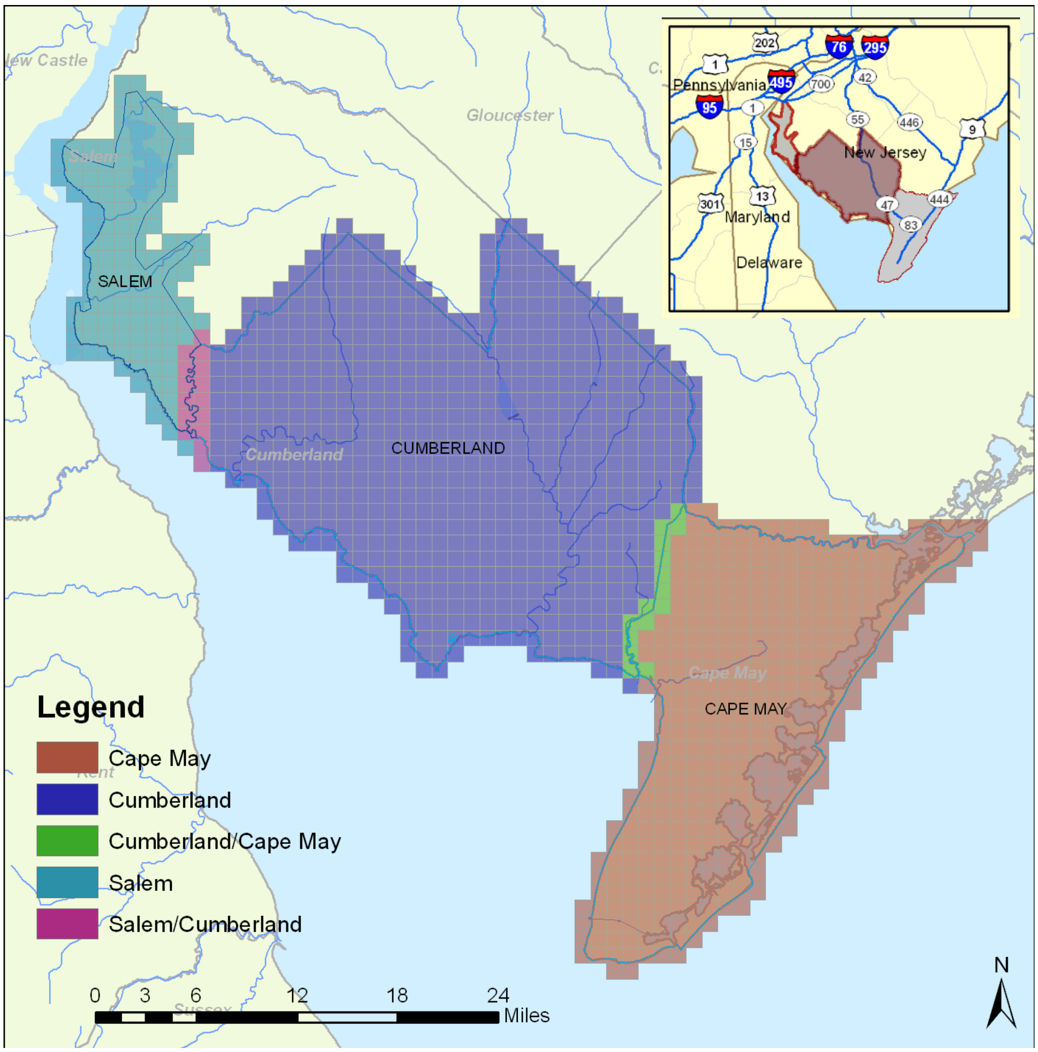


Figure 1 - Delivered LiDAR. Tiles highlighted at the boundary will be delivered twice

The LiDAR data were delivered in LAS format.
Las version: 1.1

- Point data format: 1
- Projection set in the header:
    - NAD_1983_StatePlane_New_Jersey_FIPS_2900_Feet;
    - Linear Foot US Survey,
    - Elevation in meters

Data were delivered tiled, adhering to the State of New Jersey's 5000x5000ft tile scheme (see Figure 2). A modification was added to the naming convention though in order to differentiate points that were acquired across two GPS week. Indeed, the LAS format allows the storage of GPS time associated with each point, however this GPS time resets to zero every week (Saturday at midnight); as a consequence two points acquired a week apart would have the same GPS time. To avoid this, all files have the GPS week code added to the filename and when an area includes data from flightlines acquired over two different GPS weeks, separate files for the data captured in each of the weeks are delivered. For example sheet B18D14 will have data from both weeks; therefore there will be two separate files: B18D14_1474.LAS & B18D14_1475.LAS. All data were compiled over the 2 following GPS weeks: 1474 = week starting 04/6/2008; 1475 = week starting 04/13/2008. For Cape May however all the tiles were acquired during week 1475.

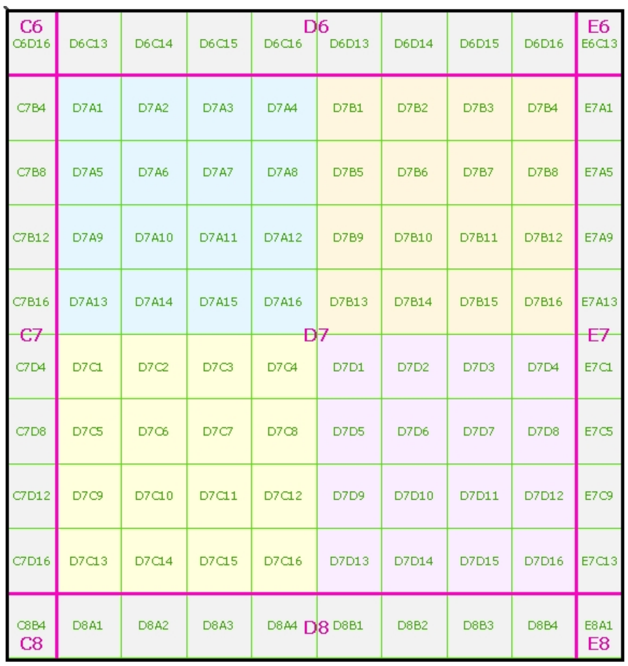
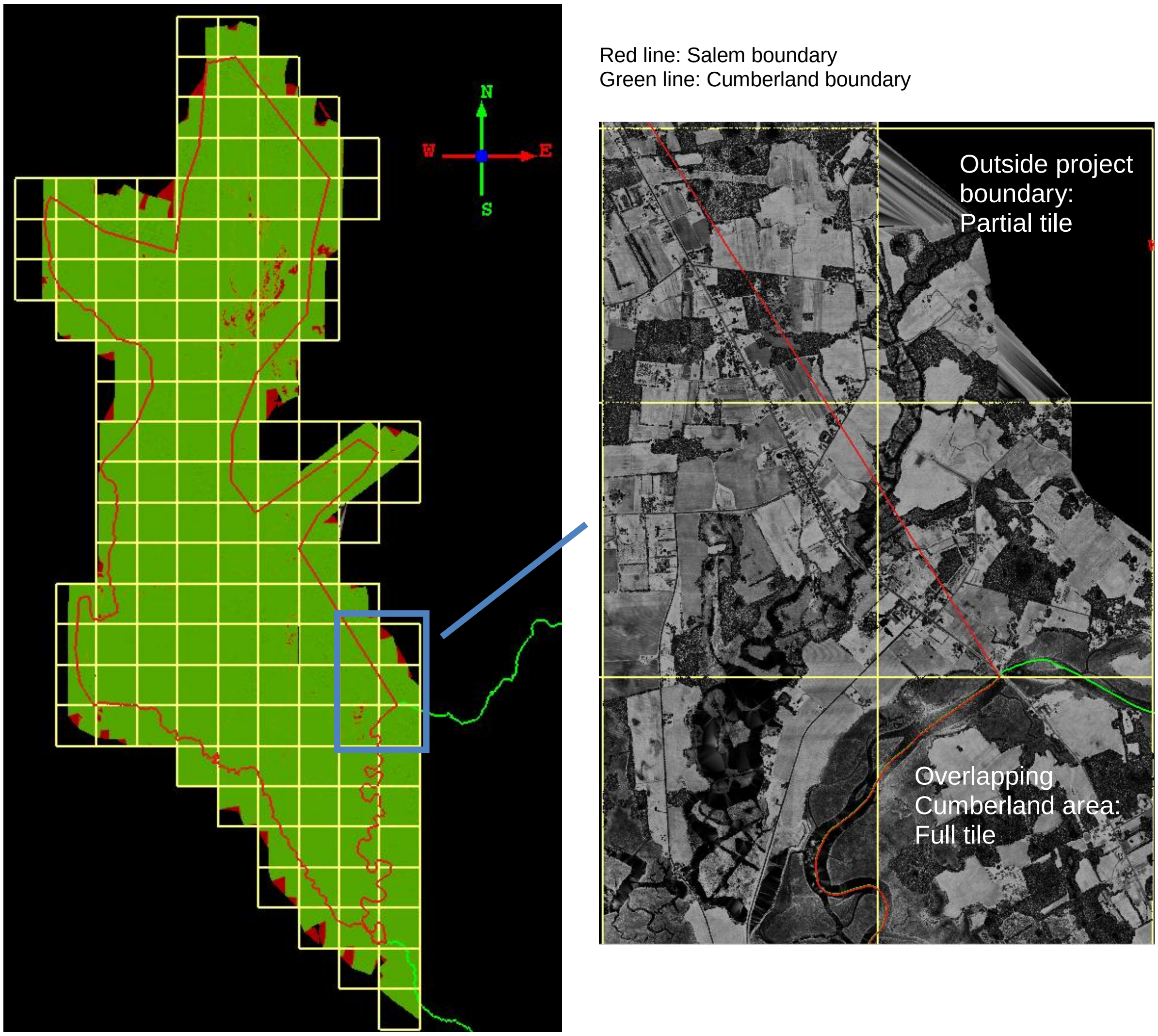


Figure 2 – Tiling scheme naming convention example; LiDAR tiles would follow the green outlines (5000x5000ft)

We delivered 144 LiDAR LAS files covering Salem area, 650 LAS files covering Cumberland and 385 LAS files covering Cape May.

We verified that the entire project area was covered by data using a decimated surface model built from the files. One should note that the actual LiDAR coverage extends outside the project boundary and stops irregularly where flightlines were clipped, consequently the tiles intersecting the outer boundary are partial but to reiterate the section inside the project area is covered. Moreover, tiles intersecting the limit between Salem and Cumberland for example are full because Cumberland is part of the project, but as a second delivery. See illustration at Figure 3.



Full point cloud surface model with density (red = no data)

Full point cloud model with intensity

Figure 3 – Salem – Cumberland boundary: tiles between Salem and Cumberland are full and delivered in Lot 1; tiles intersecting boundary are partial (accepted)

The point spacing exceeds the requirement of 1 point per square meter (1.58 points per square meter, average point spacing is 0.8 meters).

Each record includes the following fields:

- XYZ coordinates
- Flightline
- Intensity
- Return number, Number of return, scan direction, edge of a flight line and scan angle
- Classification:
    - code 1 for non-ground,

  - code 2 for ground
  - code 9 for water
  - code 12 for overlap
- GPS time

2.1.2 Statistical analysis of tile content

To verify the content of the data and to validate the data integrity, a statistical analysis was performed on all the data. This process allows Dewberry to statistically review 100% of the data to identify any gross outliers. This statistical analysis consists of:

1. Extract the header information
2. Read the actual records and compute the number of points, minimum, maximum and mean elevation for each class. Minimum and maximum for other relevant variables are also evaluated.

Each tile was queried to extract the number of LiDAR points. With a nominal point density of 1 point per square meter, the number of point per tile should be around 2.3 million. The means over the different county tiles are between 3 and 5 million and all tiles are within the anticipated size range except for where fewer points are expected (near the project boundary or over large rivers and lakes) as illustrated in Figure 4.

To first identify incorrect elevations, the z-minimum and z-maximum values for the ground class were reviewed. No noticeable anomalies were identified taking into account that those counties are for the most part close to sea level. Figure 5 (right) shows the spatial distribution of these elevations, following the anticipated terrain topography. Higher points were legitimate elevation on top of cliffs.

Lower elevations are negative which is still possible since the area is close to water level, and the acquisition was done at low tide which may uncover lower areas.

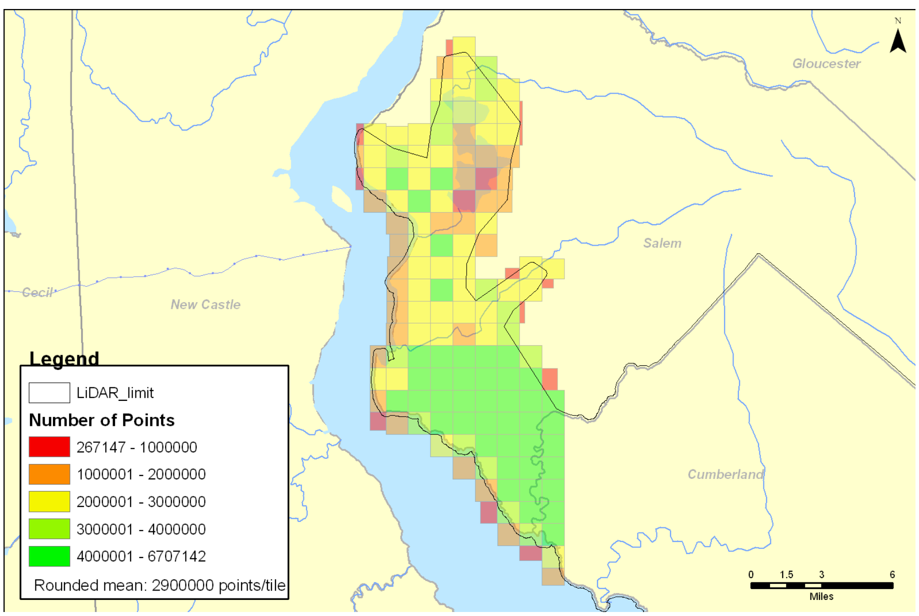


Figure 4 – Number of point per tile - Salem

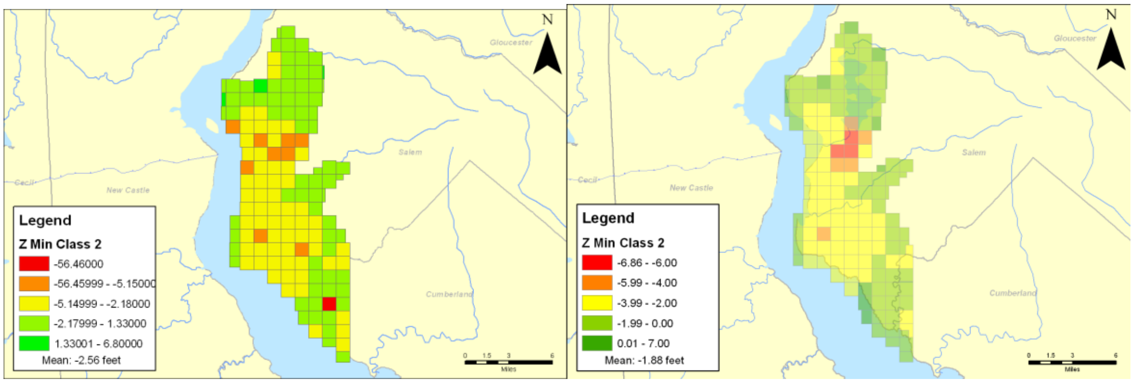


Figure 5 – Min and max Z (Class 2) - Salem

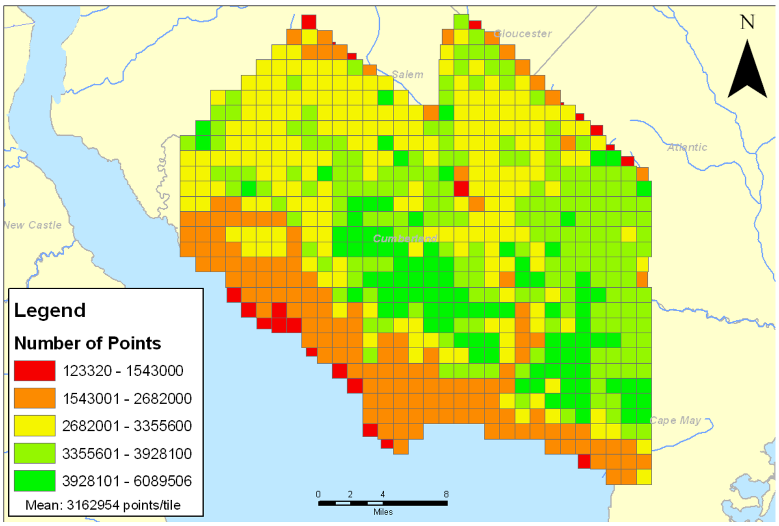


Figure 6 – Number of point per tile - Cumberland

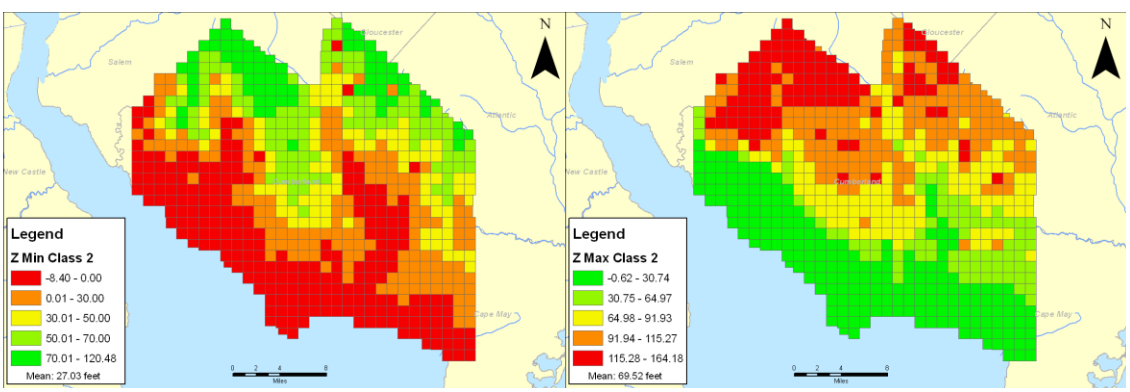


Figure 7 – Min and max Z (Class 2) - Cumberland

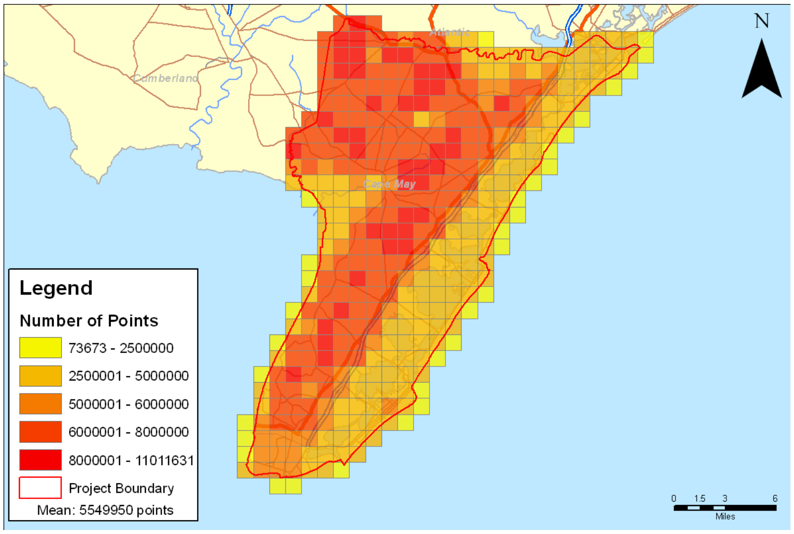


Figure 8 - Number of point per tile - Cape May

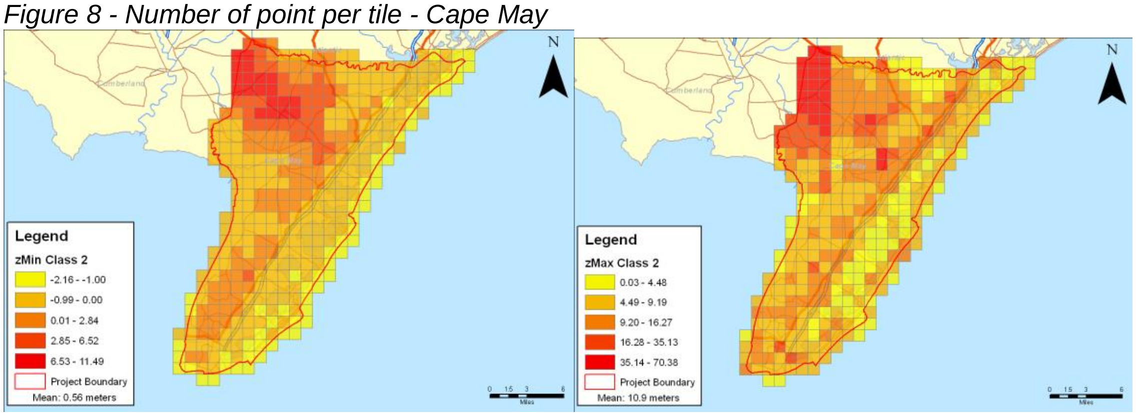


Figure 9 - Min and max Z (Class 2) – Cape May

2.1.3 DEMs

DEMs corresponding to the LiDAR tiles are also delivered. These DEMs are hydro- enforced using breaklines compiled by LiDARgrammetry techniques from LiDAR intensity stereopairs:

- Waterbodies and coastal shoreline were flattened
- 3D Double Line Hydro flowing downhill replaced the LiDAR elevations (LiDAR points inside the rivers were removed)
- 3D Single Line Hydro flowing downhill were burnt into the terrain

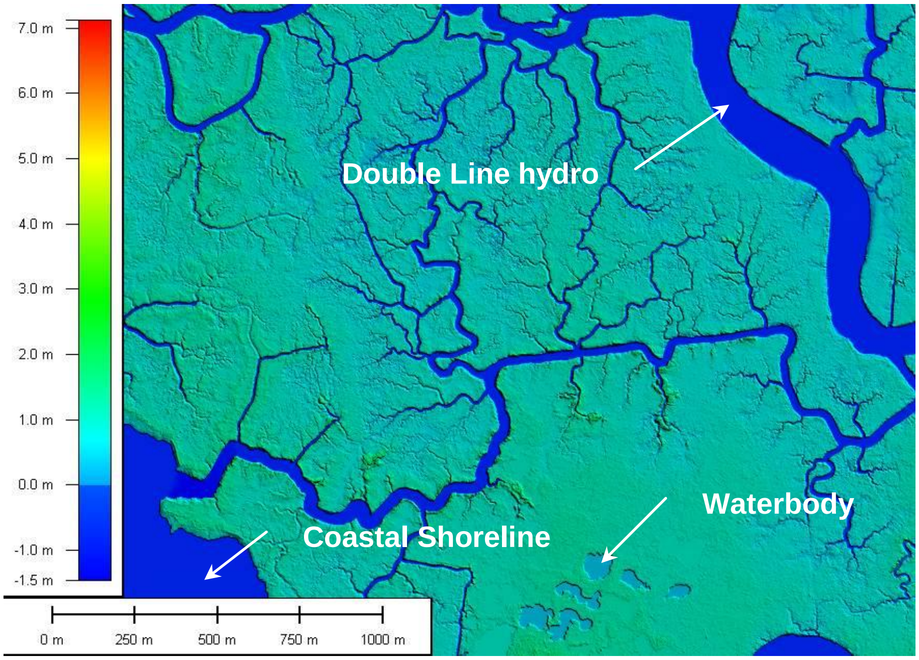
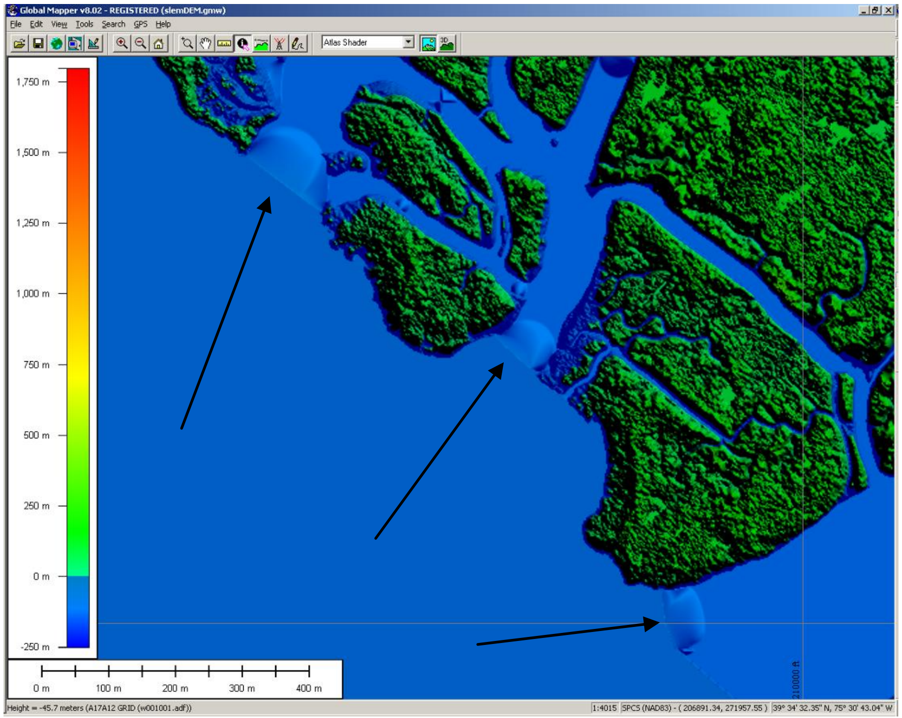


Figure 10 – Hydroenforced DTM

They are in ArcGRID format and match the tile scheme. Pixels have a resolution of 2m (or equivalent in feet). Elevations are in meters. DEMs intersecting the outside boundary are partial and areas outside a buffered project boundary are set to NoData.

After initial delivery of the Salem and Cumberland DEM products some irregular elevations along double line hydrographic features and the coast were noticed causing bumps to appear on the water surface. Dewberry analyzed the issue, including our production methods that resulted in these occurrences as well as acceptable ways to correct the issue.

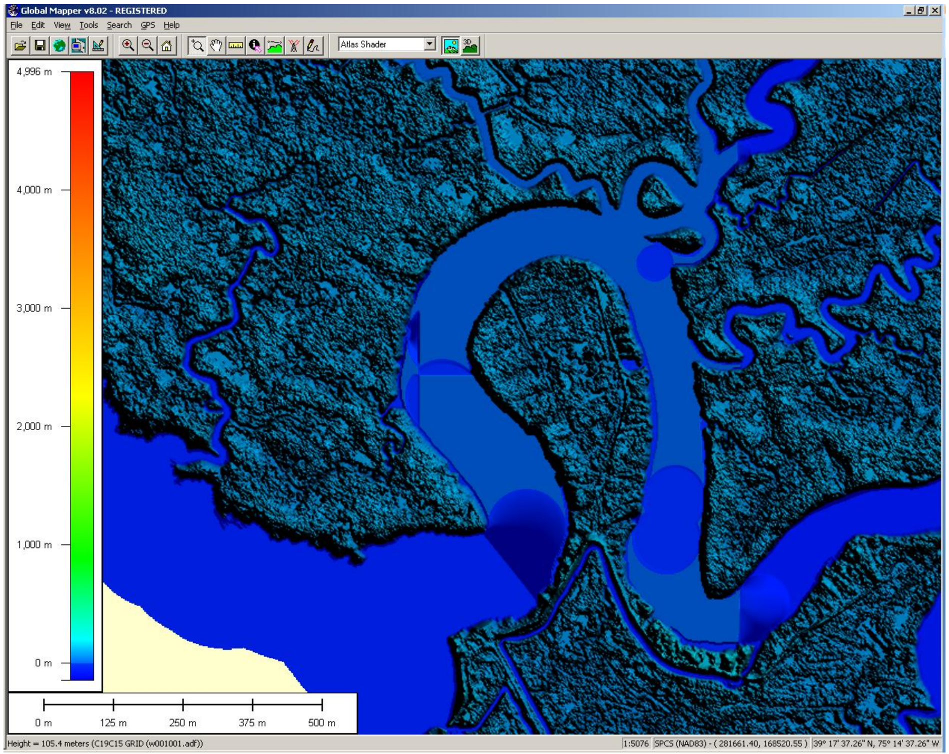
The DEM's are created from hydro-enforced terrains. The coastline is used to build the terrain as a hard replace, assigning one averaged elevation to each polygon in the coastal shoreline even though the breaklines along the coastline have varying elevation. A hard replace was used for the coastal shoreline so that it would be flat. However, because each coastal polygon could potentially have a different averaged elevation, there could be "steps" or "bumps" between the coastal polygons as well as between the coast and hydrographic features. In some cases this caused the sea to flow into a river in some estuaries.



An example of “bumps” along the coast resulting from the averaged elevations of individual coastal polygons

Waterbodies were also used as hard replaces in the terrain to create DEM’s. However, since waterbodies are collected at a constant elevation, using them as a hard replace flattens the features without causing any “steps” or “bumps.”

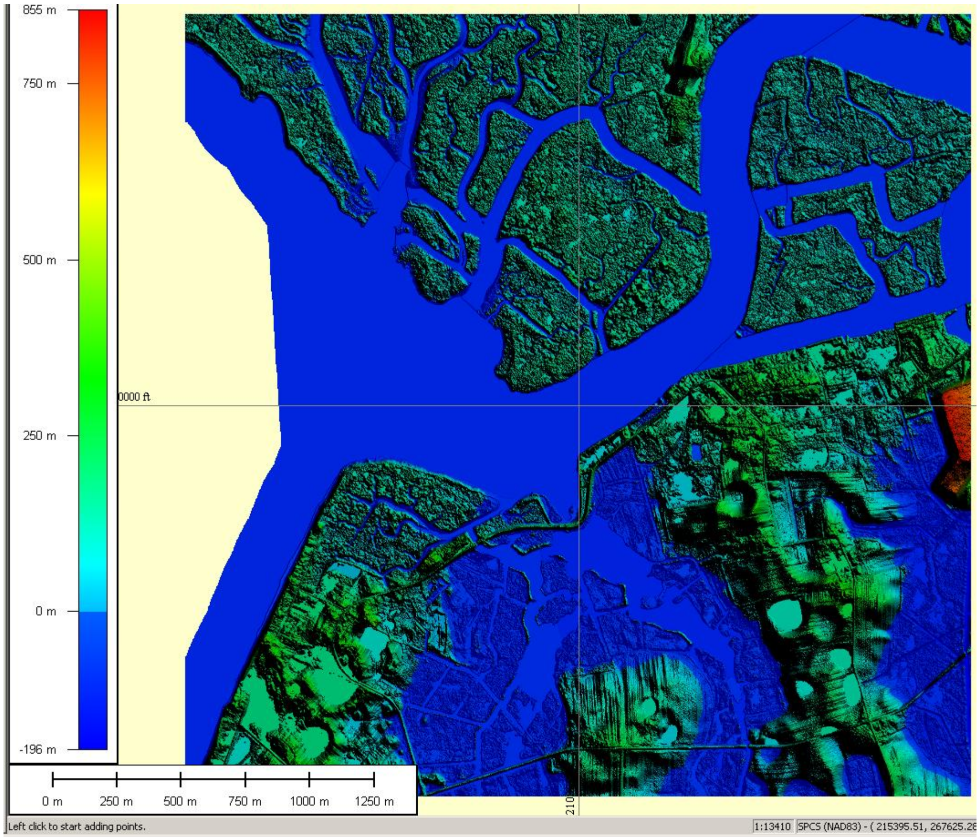
Linear hydrographic features (single and dual line drains) were used as hard lines in the terrain used to create DEM’s. As single line drains are a single line, they posed no problem. However, “bumps” could easily be seen in the dual line drain features. Linear hydrographic features are used as a hard line in the terrain to force the terrain to the breaklines elevation while still allowing the varying elevations of the feature to be correctly modeled. This is especially important to show the downhill flow of rivers. Because only the banks are enforced using this method, slight elevation differences between the banks will cause a “bump” as the surface of the river is interpolated between the breaklines. This occurred within dual line features as well as confluences where two dual line features merged.



An example of "bumps" in dual line hydrographic features, resulting from slight variations of elevations along the bank breaklines.

The original hydro-enforced DEM's were delivered with elevation in centimeters. As the breaklines were captured with elevations in meters, this conversion was determined to exaggerate the issue, as many of these "bumps" were only a few centimeters in variation.

In order to correct the issue Dewberry reprocessed all of the DEMs. Elevations were converted from centimeters to meters; polygons were created around the "bumps" and the lowest surrounding elevation was applied to each polygon. These polygons were then used to mask the "bumps" in the DEM. This process eliminated the "bumps" and smoothed the surfaces of the hydrographic features and coastal shoreline to create a more visually pleasing DEM.



An example of the coastal shoreline and hydrographic features that have been re-processed to remove “bumps” and inconsistencies within the DEM’s.

Quantitative assessment

2.1.4 Checkpoint inventory

Typically for this type of data collection, a ground truth survey is conducted following the *FEMA Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix A: Guidance for Aerial Mapping and Surveying,* which is based on the National Standard for Spatial Data Accuracy (NSSDA). This methodology collects a minimum of 20 test points for each of the predominant land cover types (i.e. bare-earth, weeds and crops, forest, urban, etc.). By verifying the data in these different classes, the data accuracy is tested but it also tests whether the classification of the LiDAR has been performed correctly at those test point locations. In this project the predominant land cover categories selected are bare-earth, urban and mixed vegetation.

The field survey was conducted in April 2008. A total of 80 checkpoints (test points) were captured throughout the South New Jersey Project Area; 60 checkpoints were collected to be used for Dewberry’s LiDAR QA/QC in different land covers: 20 points in Urban Areas, 20 points in Open Terrain, and 20 points divided equally in Medium Vegetation and Forested Areas. Checkpoints used in Dewberry’s QAQC are listed in Appendix A. Additionally 20 points were sent to USGS for their internal QAQC; these were not used in Dewberry’s QAQC and are listed in Appendix D.

Figure 11 shows the even distribution of the checkpoints throughout the project.

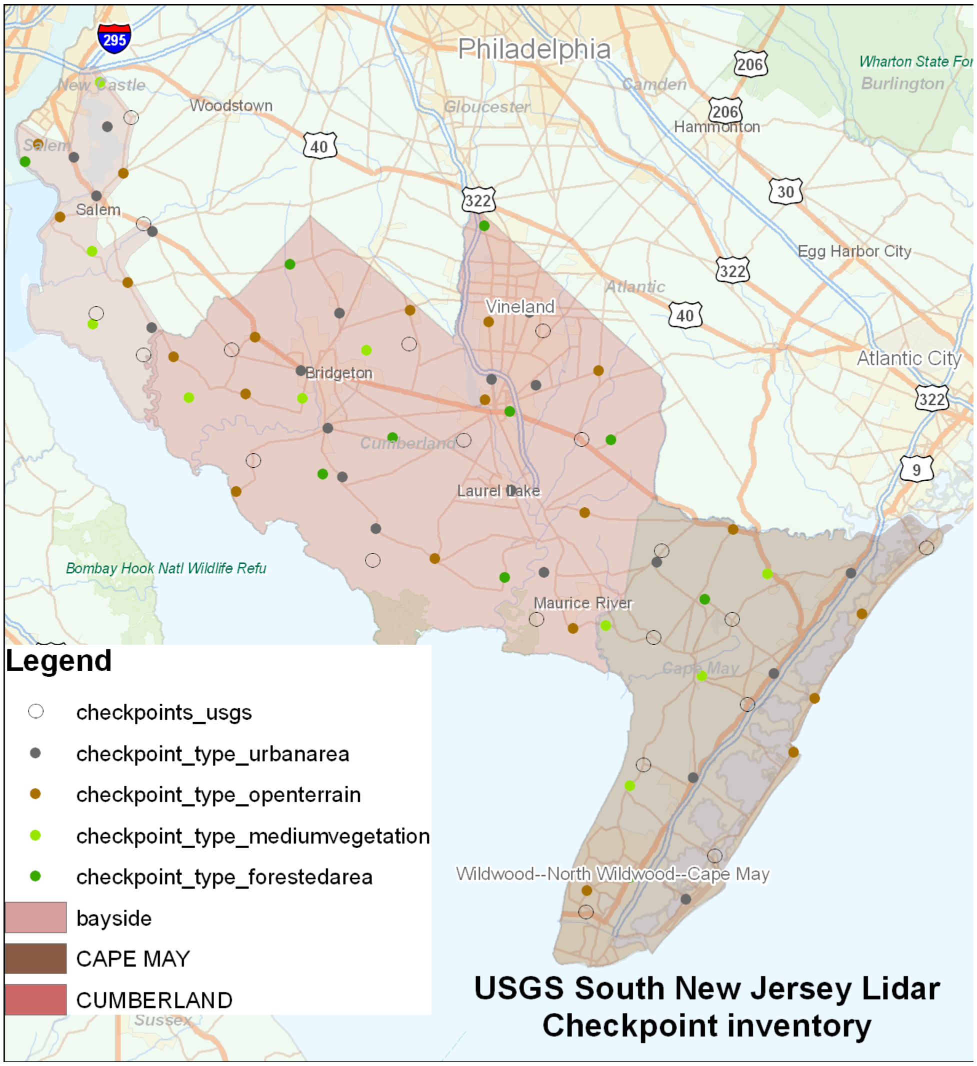


Figure 11 – Check Points.

2.1.5 Vertical Accuracy Assessment Using the RMSE Methodology

The method of testing vertical accuracy used the FEMA specifications which essentially follows the National Standard for Spatial Data Accuracy (NSSDA) procedures. The accuracy is reported at the 95% confidence level using the Root Mean Square Error (RMSE) which is valid when errors follow a normal distribution. This methodology measures the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points. The vertical accuracy assessment compares the measured survey checkpoint elevations with those of the TIN as generated from the bare-earth LiDAR. The survey checkpoint's X/Y location is overlaid on the TIN and the interpolated Z value is recorded. This interpolated Z value is then compared to the survey checkpoint Z value and this difference represents the amount of error between the measurements. For the panel center points, however, we used the full point cloud instead of only the ground to build the TIN as the elevated surfaces were removed from the ground class. The following tables and graphs outline the vertical accuracy and the statistics of the associated errors.

Table 1 shows the complete results from the Dewberry RMSE process. The individual and consolidated RMSE values well exceed the specifications for 2 ft. contours (RMSE of 0.09m compared to the 0.185m specification). Similarly, Table 2 shows that the Fundamental Vertical Accuracy (FVA), Consolidated Vertical Accuracy (CVA) and Supplemental Vertical Accuracy (SVA) for each land cover category easily satisfy the criteria for 2 ft. contours based on LiDAR testing methodology endorsed by the National Digital Elevation Program (NDEP) and the American Society for Photogrammetry and Remote Sensing (ASPRS).

Table 1 – Accuracy report based on FEMA and NSSDA methodology using RMSE

Land Cover Category	RMSE (m) Spec=0.185m	Mean (m)	Median (m)	Skew	Std Dev (m)	# of Points	Min (m)	Max (m)
Consolidated	0.09	0.04	0.04	0.58	0.07	60	-0.10	0.31
Open Terrain	0.07	0.01	0.01	0.18	0.07	20	-0.10	0.16
Med Vegetation	0.11	0.09	0.09	1.36	0.08	20	-0.03	0.31
Urban Area	0.07	0.04	0.03	0.06	0.06	20	-0.09	0.15

Table 2 – Accuracy report based on NDEP and ASPRS methodology using 95th percentile

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy ($RMSE_Z$ x 1.9600) Spec=0.363 m	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=0.363 m	SVA — Supplemental Vertical Accuracy (95th Percentile) Target=0.363 m
Consolidated	60		0.16 m	
Open Terrain	20	0.13 m		0.11 m
Med Vegetation	20			0.18 m
Urban Area	20			0.12 m

Figure 12 illustrates the distribution of the elevation differences between the LiDAR data and the surveyed points. The points are almost all above zero indicating a slightly positive Z bias which remains acceptable.

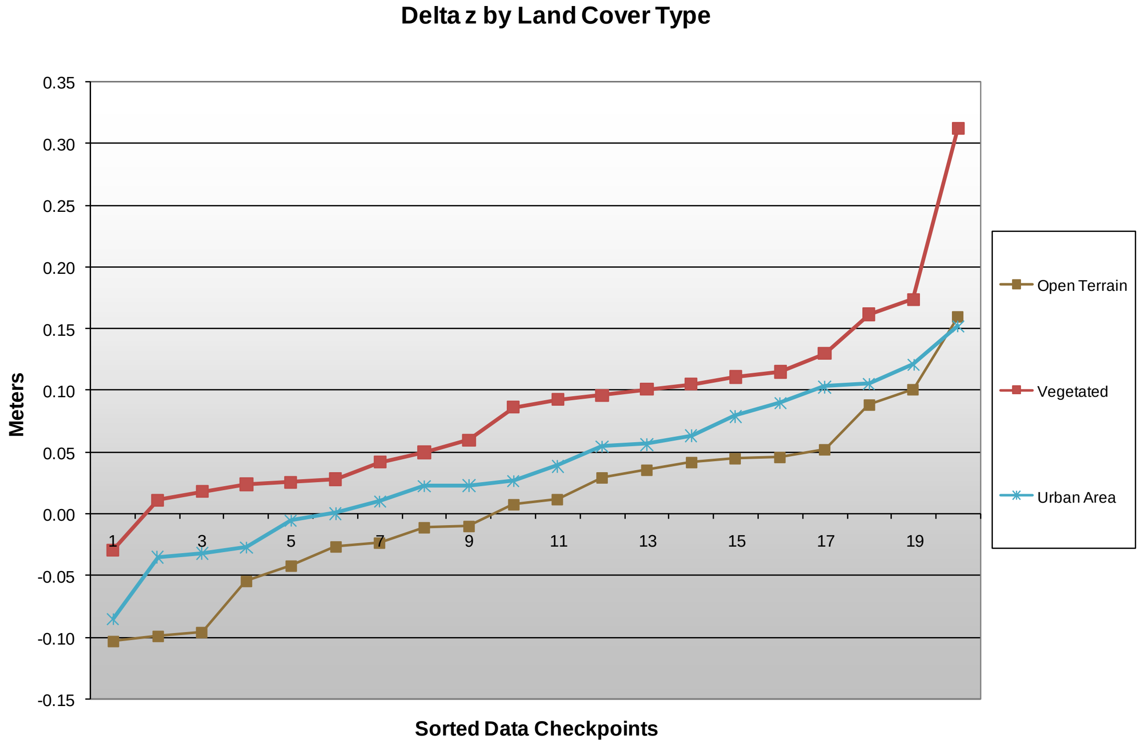


Figure 12 – Sorted checkpoint errors

2.1.6 Horizontal assessment

Typically, horizontal accuracy in LiDAR is implied since it is not explicitly tested. It is however tested during the calibration of the LiDAR system and is verified in the daily check flights by comparing parallel and perpendicular flights over a test area. To ensure no gross horizontal errors occur, we tested the data by comparing the LiDAR data to orthophotos. Of course, this will only inform us about the relative accuracy of the LiDAR, any discrepancy between these two sources will not give an accurate value of the hypothetical horizontal displacement.

For the review, 2002 orthophotos were downloaded from the State of New Jersey Office of Information Technology, Office of Geographic Information Systems[1]. Their Horizontal Positional Accuracy Report is:

" Horizontal_Positional_Accuracy_Report: Orthophotography has a +/- 4.0 ft. horizontal accuracy at 95% confidence level, National Standard for Spatial Data Accuracy (NSSDA), for a 1.0 foot Ground Resolution Distance (GRD). Horizontal accuracy determined as 1.7308 times the RMSE circular error. This requirement will not be applicable in areas where the ground is obscured on the aerial photography by foliage, prevalent smoke, or dense shadow."

Using these aerial orthophotos, analysts digitized road intersections and other objects easily seen in the LiDAR intensity in 2 locations in each tile. The vector lines were then overlaid on the masspoints displayed with the intensity.

[1] http://njgin.nj.gov/OIT_IW/index.jsp

By visual interpretation we were able to determine that the LiDAR points match the orthophotos, which comforts our judgment that the horizontal accuracy shall meet 1m RMSE. To reiterate this is not a valid statistical test but an indirect verification of the horizontal accuracy of the data.

Finally, we noticed a horizontal shift at the edge of the flightlines which does not prevent the dataset from passing the horizontal requirements. This relative shift reportedly caused at the preprocessing level by a slightly inaccurate modeling of the torsion correction was only measurable because of a minor sensor malfunction (an unequal swing of the scan mirror resulted in a “large” overlap on one side and a “small” overlap on the other side which did not impact the accuracy of the data in itself but in this case enhanced the relative shift). This matter is discussed and illustrated in detail in the Photo Science’s acquisition report, Appendix C in this document. To summarize, the maximum absolute shift measurable in the bare earth is of 1.5 feet along the cutline of the small overlap sections. After carefully analyzing the limited extent and impact of this issue on the derived products and taking into account that the breaklines were compiled on a 3ft resolution intensity stereopairs and that the final DEM have a 6.56ft cell size, it was decided that the two lots already at the end of the processing flow (Salem and Cumberland) would not need to be reprocessed because they still met the accuracy specifications. Cape May editing, however, was in progress; therefore the whole dataset was corrected.

2.1.7 Quantitative Accuracy Conclusion

The LiDAR data meets all vertical accuracy specifications. The LiDAR horizontal coordinates perfectly agree with reference orthophotos.

2.2 Qualitative assessment

2.2.1 Protocol

The goal of this qualitative review is to assess the continuity and the level of cleanliness of the bare earth product. The acceptance criteria we have reviewed are the following:

- If the density of points is homogeneous, correctly supported by flightline overlap and sufficient to meet the user needs.
- If the ground points have been correctly classified (no manmade structures and vegetation remains, no gap except over water bodies),
- If the ground surface model exhibits a correct definition (no aggressive classification, no over-smoothing, no inconsistency in the post-processing),
- If no obvious anomalies due to sensor malfunction or systematic processing artifact is present (data holidays, spikes, divots, ridges between tiles, cornrows…).

Dewberry analysts, experienced in evaluating LIDAR data, performed a visual inspection of the bare-earth digital elevation model (bare-earth DEM). LiDAR mass points were first gridded with a grid distance of 2x the full point cloud resolution. Then, a triangulated irregular network (TIN) was built based on this gridded DEM and displayed as a 3D surface. A shaded relief effect was applied which enhances 3D rendering. The software used for visualization allows the user to navigate, zoom and rotate models and to display elevation information with an adaptive color coding in order to better identify anomalies.

One of the variables established, when creating the models, is the threshold for missing data. For each individual triangle, the point density information is stored; if it meets the threshold, the corresponding surface will be displayed in green, if not it will be displayed in red (see Figure 13). It should also be noted that if this density model is created with the ground points only, it is expected to have void areas where buildings were reclassified, or in water; vegetation can also reduce the number of points hitting the ground resulting in more distanced points.

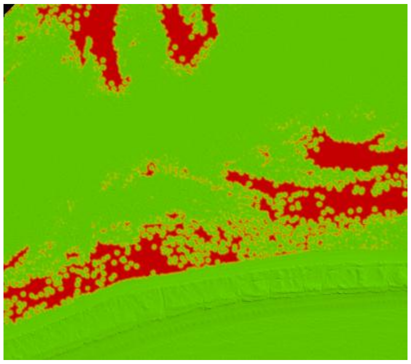


Figure 13 – Ground model with density information (red means no data)

The first step of Dewberry's qualitative workflow was to verify the point distribution by systematically loading a percentage of the tiles as mass points colored by class or by flightline. This particular type of display helps us visualize and better understand the scan pattern, the flight line orientation, flight coverage, and gives an additional confirmation that all classes are present and seem to logically represent the terrain.

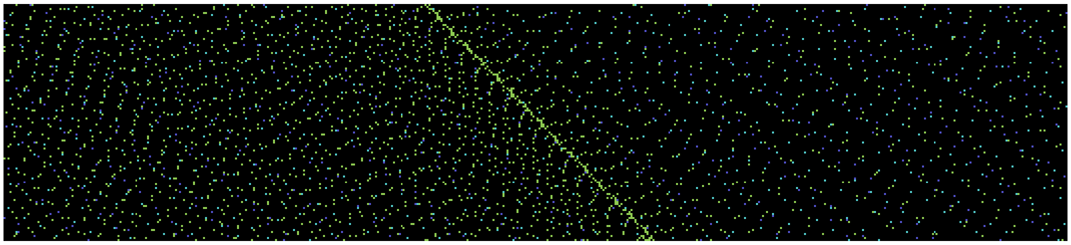


Figure 14 – LiDAR points colored by flightline. Detail of the point distribution. Note the variations in the scan pattern

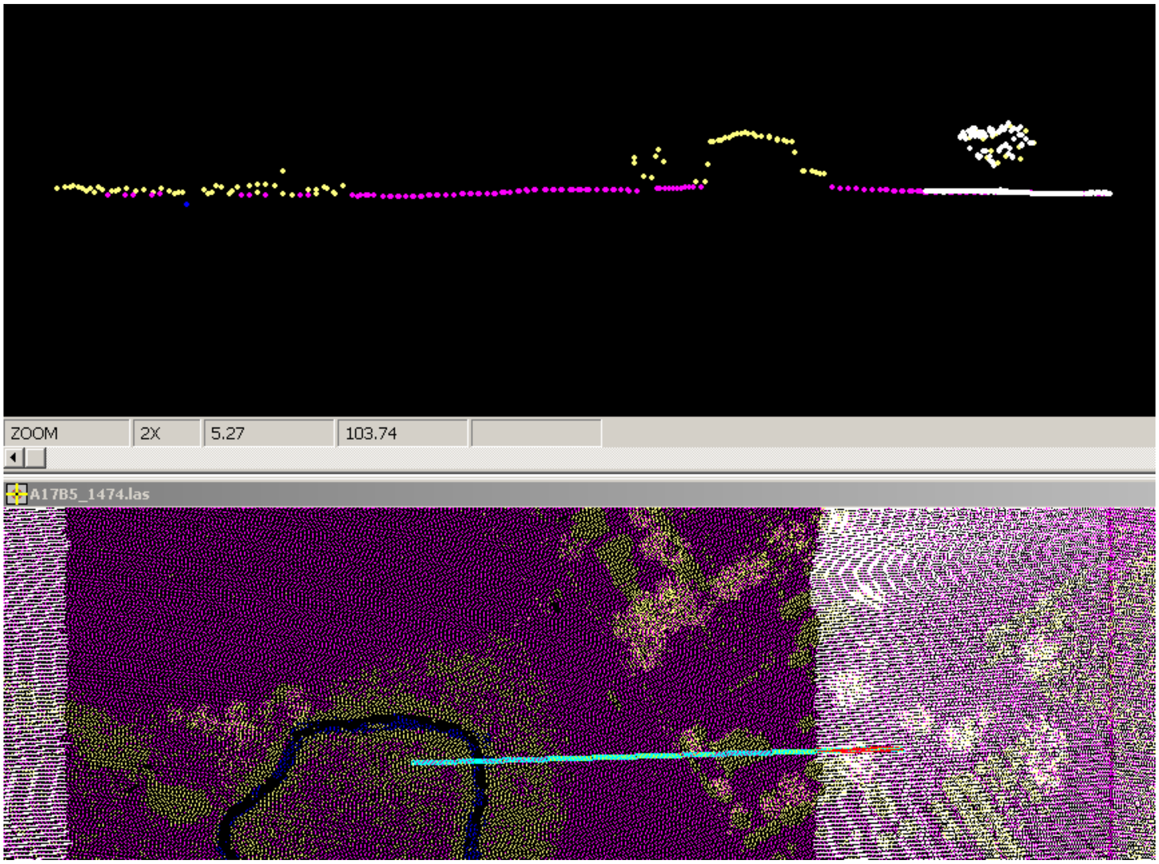


Figure 15 – Full point cloud colored by class (white: overlap, pink: ground, yellow: non-ground, blue: water)

The second step was to verify data completeness and continuity using the bare-earth DEM with density information, displayed at a macro level. If, during this macro review of the ground models, we find potential artifacts or large voids, we use the digital surface model (DSM) based on the full point cloud including vegetation and buildings to help us better pinpoint the extent and the cause of the issue. Moreover, the intensity information stored in the LiDAR data can be visualized over this surface model, helping in interpretation of the terrain. Finally, in case the analyst suspects a systematic error relating to data collection, a visualization of the 3D raw mass points is performed, rather than visualizing as a surface.

The process of importing, comparing and analyzing these two later types of models (DSM with intensity and raw mass points), along with cross section extraction, surface measurements, density evaluation, constitutes our micro level of review.

2.2.2 Quality report

Our Qualitative review was to perform a macro visual inspection of all the tiles.

Our professional judgment is that the bare earth model is of acceptable quality (see Figure 16). The cleanliness of artifacts is of high level. Dewberry found very few errors in the data as outlined in the text and images below. The majority of the calls are due to some vegetation artifacts, poor LiDAR penetration in marsh and minor inconsistencies for some structure removal. However, these issues have a minimal impact on the data usability.

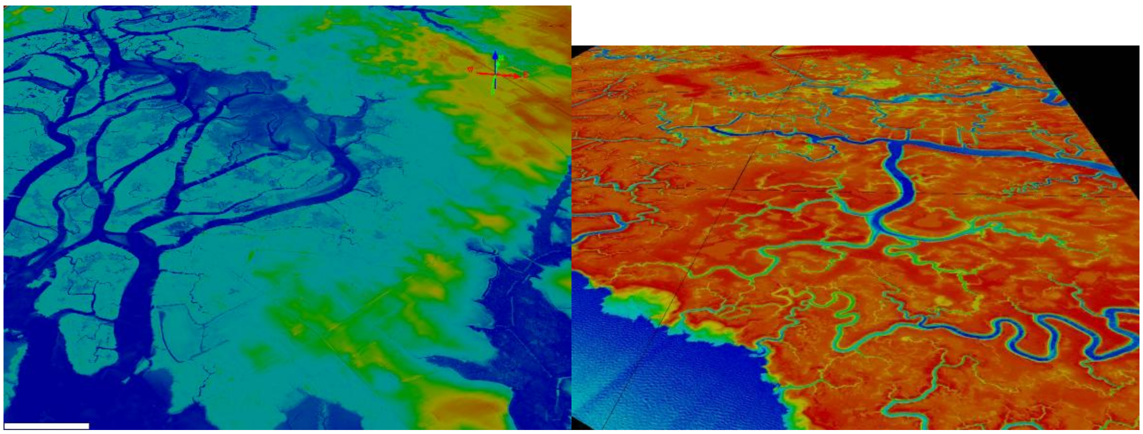
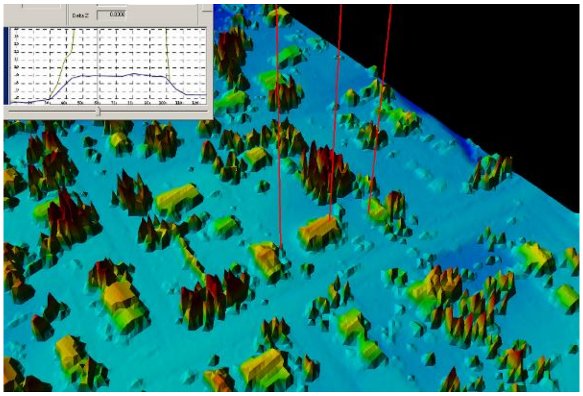


Figure 16 – Good examples of the quality of the data

Please note that the following screen shots were taken on a temporary version of the data created for the QAQC with elevation in feet (hence the scale of the cross sections is in feet), but the final dataset is actually in meters.

Misclassifications

Due to the vast amounts of data and geographic phenomena, the classification algorithms can sometimes erroneously classify data. This misclassification results in artifacts which can be remnants of vegetation or manmade structures that do not represent the bare-earth terrain. Figure 17 shows an example of some building remains; the building is removed but some elevated points at its perimeter are left and create a 1m high section. This type of issue is minor however.


Full point cloud surface model

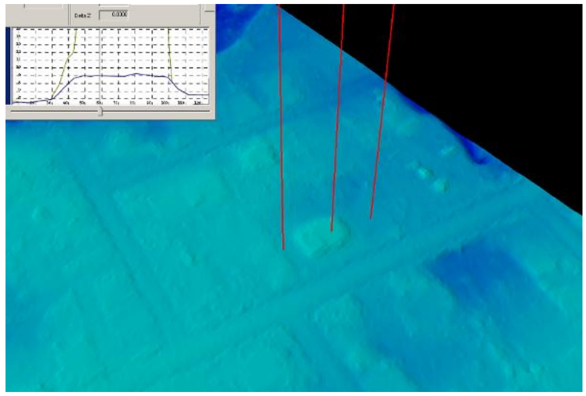
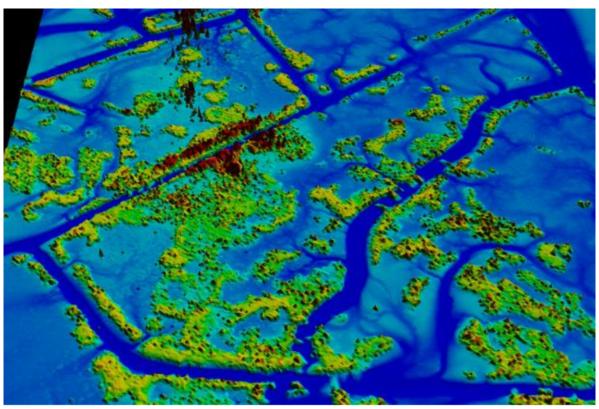

Bare earth model

Figure 17 – Tile A16B13: Possible building artifact

Figure 18 and Figure 19 illustrate potential vegetation artifacts based on the visual inspections of the bare-earth terrain. However, there is a good chance that the ground actually exhibits these irregular mounds. None of these tiles have been ground-truthed and therefore are identified only as potential issues. Moreover, it is evident that these potential areas are relatively small and easily within the specification of being 95% cleaned of vegetation artifacts.


Full point cloud surface model

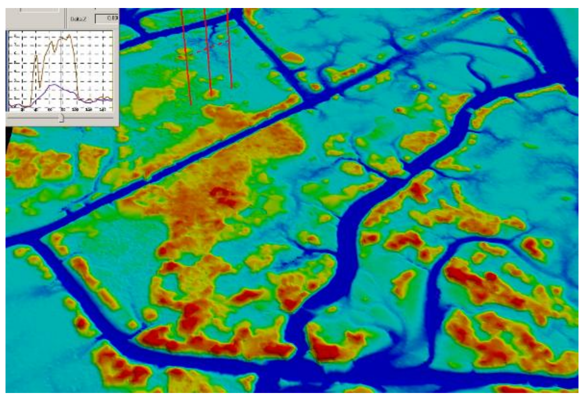

Bare earth model

Figure 18 – Tile A17D9: Possible vegetation artifacts

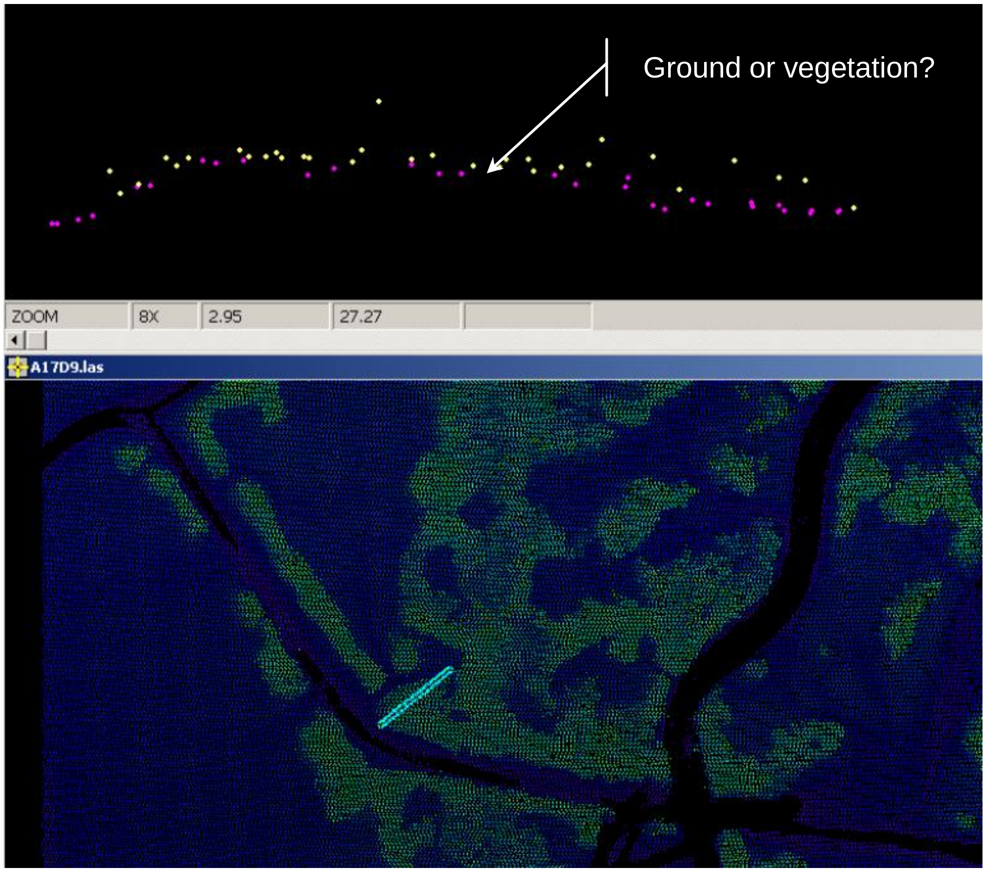
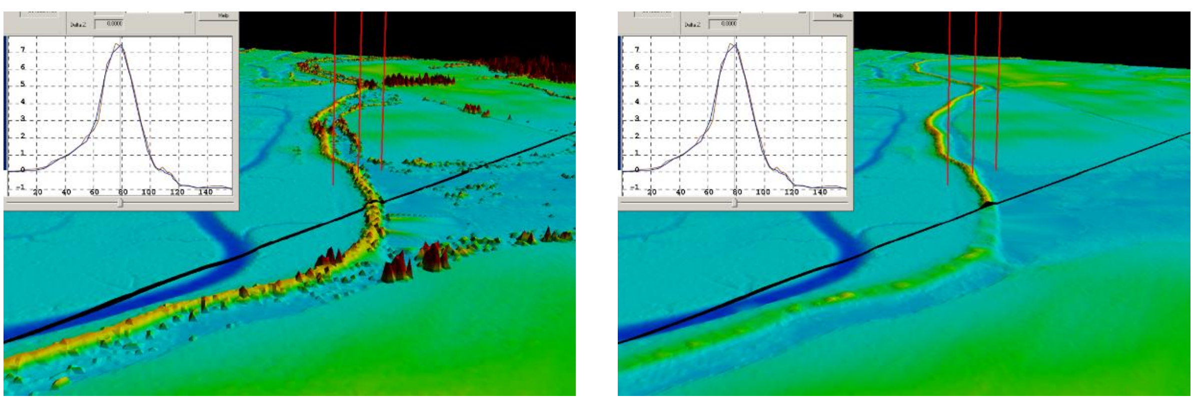


Figure 19 – Tile A17D9: Possible vegetation artifacts. Same area as Figure 18. Bottom: full point cloud displayed by elevation. Top: cross section, points colored by class (pink=2 ground; yellow=1 unclassed). Ground points elevated compared to adjacent areas are these vegetation remains?

We also noticed that sections of narrow elevated ground (some sort of levee) were sometimes inconsistently removed (Figure 20). Since they are likely not to be manmade structures, one could argue that they should be kept in the bare earth model. However, it's more the consistency along the same structure that we assessed here.

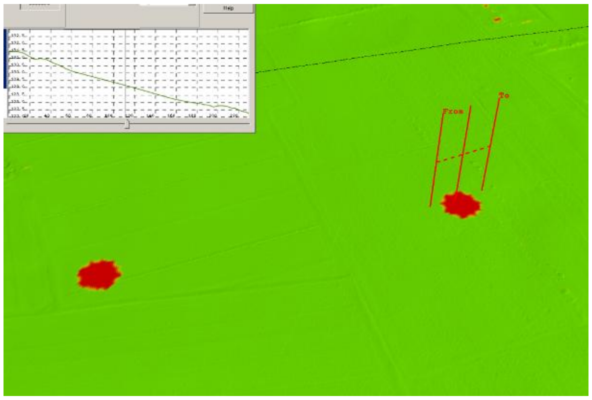


Full point cloud surface model | Bare earth model

Figure 20 - A18B1 to A18B2: Inconsistent editing across tiles

In the same train of thought, one minor issue for the bare-earth terrain is the classification of bridges. Some users may require bridges to be removed (classified to non-ground) while others may require them classified as ground. For the user community if this is an issue this is easily remedied because it is clearly identifiable and the data can be reclassified. In this dataset, the majority of them are removed from the ground but some instances of bridges partially removed or left were found.

Another type of misclassification was encountered. We found a section of points creating shapes that very unlikely correspond to natural features and are completely removed from the ground (in class 1). The reason for such discrepancies is difficult to explain but since they occur in homogeneous terrain, we do not think they require any correction. See Figure 21.

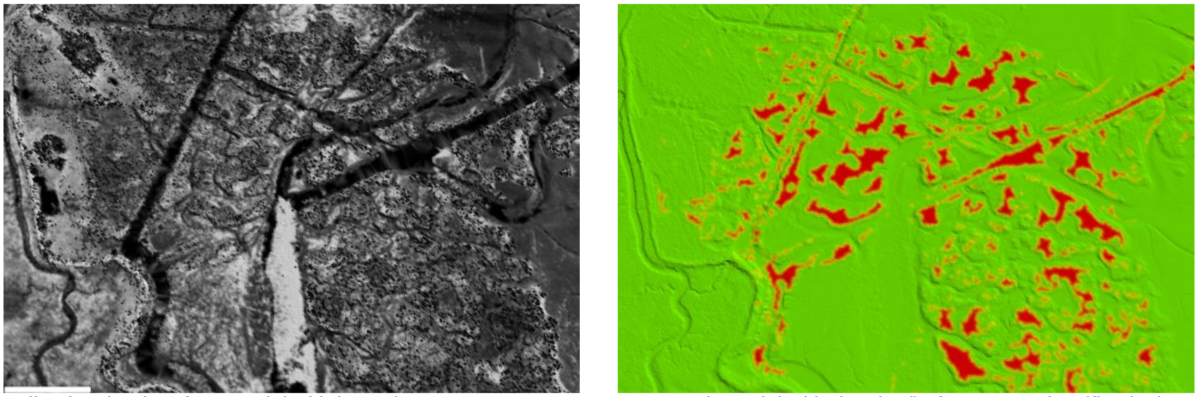


Bare earth model

Figure 21 – Tile B17D16: misclassification

Poor LiDAR penetration in swamps

A problem that we often found is patches with lower density of ground points. When the vegetation is very dense, the LiDAR may not penetrate the canopy all the way to the ground; another possibility is that when the soil is really wet no reflection occurs since except at angles close to nadir, the Near Infrared LiDAR beam is usually not reflected by water. Therefore in both cases only a few ground points remain after classification of the vegetation. Nevertheless, as soon as a few points are present, a 3D model can be built with an acceptable reliability, especially in flat areas. However, the definition of the surface is often of poorer quality; this is illustrated in Figure 22.



Full point cloud surface model with intensity

Bare earth model with density (before water classification)

Figure 22 – Tile A17C12: Poor LiDAR penetration in marshy area

Negligible Flightline ridges

We noticed ridges at seamlines caused by a vertical mismatch between 2 adjacent flightlines. Since the overlap is stored in a different class, no real blending of flightlines is done. A seamline is used to cut the data from one line to the next so when two flightlines do not perfectly match vertically a false edge is visible. Although they are easily visible in the shaded ground model, these ridges are below the commonly accepted threshold of 20cm and are therefore negligible.

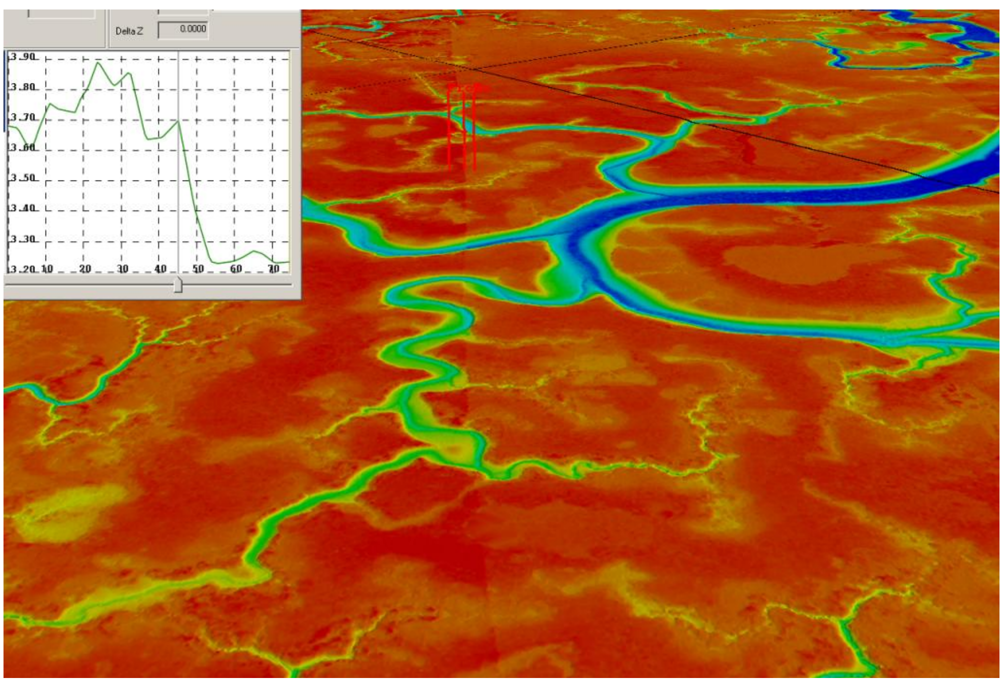


Figure 23 – Tile B19D12: Ridge between 2 adjacent flightlines (0.5ft)

Additional comments

Another anomaly detected in the data is the lack of returns on certain type of roads and buildings (parking lot and roof tops), see Figure 24.

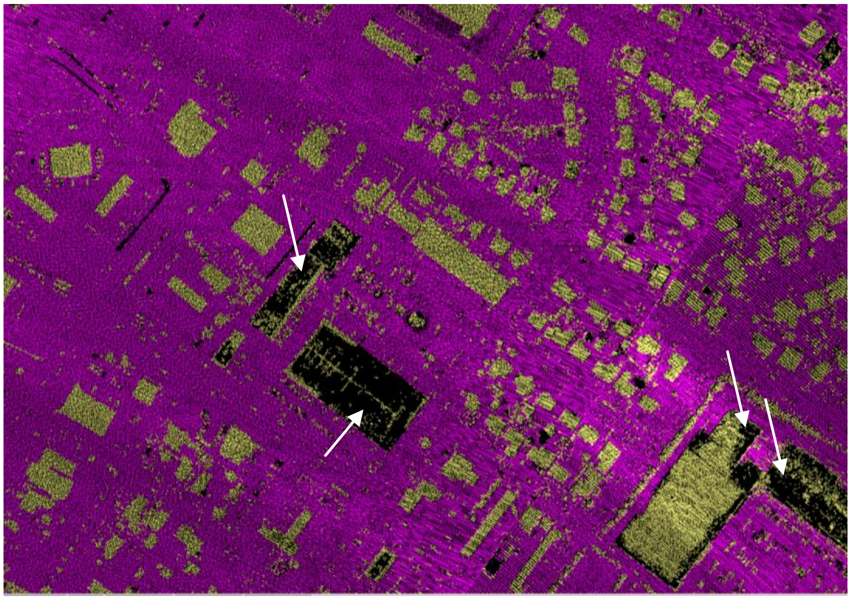
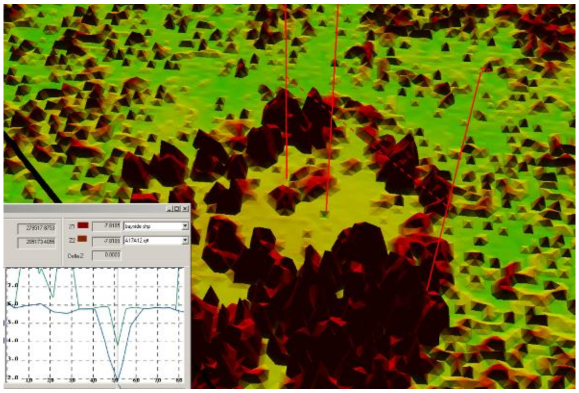


Figure 24 - Tile E22B16: no reflection on asphalt parking lot (colored by class, pink=ground, yellow=extracted features; black = no point)

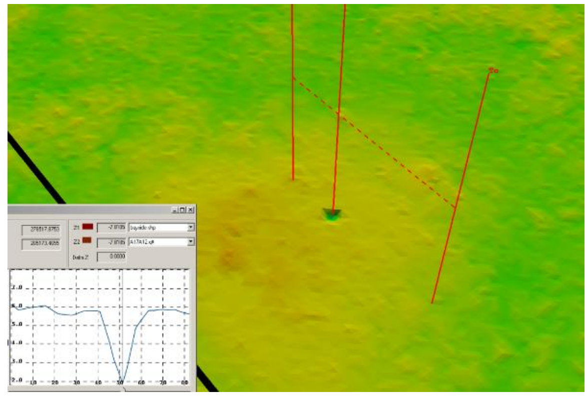
Among the possible explanations for this anomaly is a low gain setting or a low emission power, both resulting in a non-detection of a weak reflected signal. A weak reflected signal can occur on certain types of asphalt that absorbs the near infrared wavelength.

The data user should be aware that this issue has almost no impact on the ground integrity: buildings are removed regardless and roads centerlines are present allowing a proper definition of the terrain (the roads are expected to be linear from the center to the edges). However, the lack of reflection on buildings will have a minor quality impact if the data are utilized for a surface model (where all points are considered), because some buildings will be partially or completely missing. Moreover, this kind of acquisition "drop-off" had a limited occurrence in this dataset.

There were few instances of divots visible in the bare earth models. They were minor however, less than 4 feet.



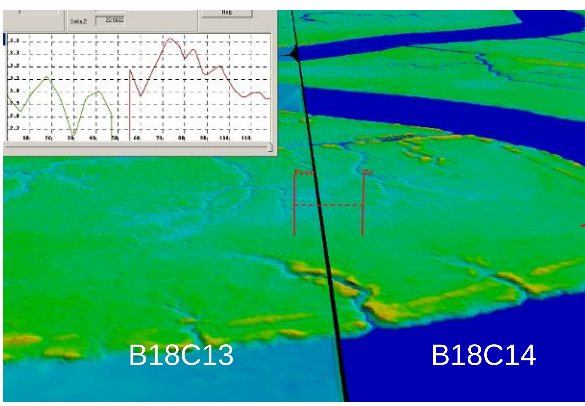
Full point cloud surface model



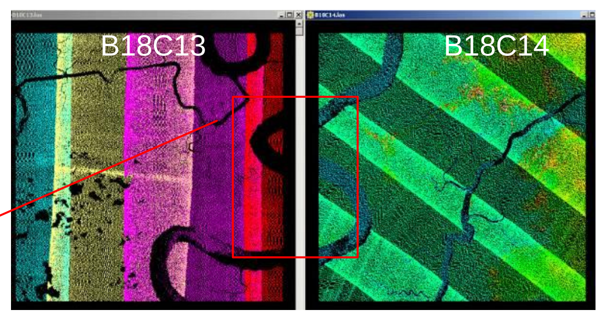
Bare earth model

Figure 25 – Tile A17A8: Divot (4 feet deep)

The acquisition specifications required the dataset to be flown at low tide which was actually the case. Nevertheless it is still possible that between two adjacent flightlines acquired at two different dates there was a discrepancy of water level. This is illustrated at Figure 26. In this case, the two tiles are from distinct missions because the flightline orientation changes from one tile to the other. For each instance, we checked the relative accuracy on the ground at the flightline edge or the tile which was always within the 20cm tolerance commonly accepted.



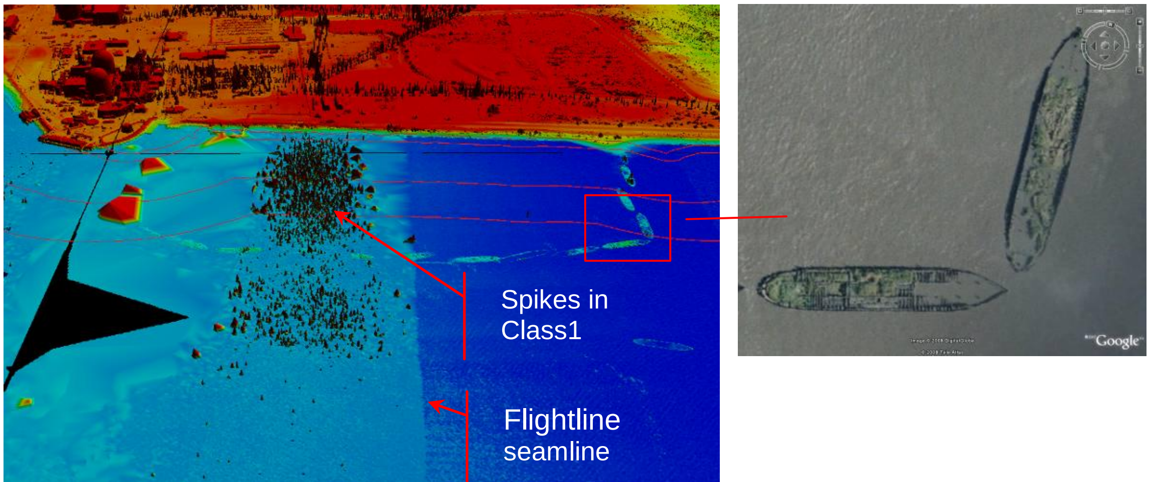
Bare earth model (detail)



Full point cloud colored by flightline (left) and elevation (right)

Figure 26 - Tile edge between B18C13and B18C14: note the water level discrepancy (two different acquisition times); the ground matches within 20cm.

When inspecting some of the full point cloud surface models we noticed that spikes in water were recurrent and always situated in the center of a flightline. These are not natural features (sometimes the power lines may create false impressions of spikes) but rather artifacts caused by the sensor over highly reflective water at nadir. These error points are correctly classed in class 1 and are not visible in the bare earth model, therefore they do not impact the usability of the data.



Surface model colored by elevation Google Map Aerial photography

Figure 27 – Tile A18A15: different water levels explained by flightline acquisition time differences, spikes in water due to potential sensor malfunction or saturation and legitimate ship wrecks

3 Conclusion

Overall the data are of good quality and meet both the absolute and relative accuracy.

The level of cleanliness for the bare-earth terrain easily meets the specifications and no major anomalies were found. A minor processing anomaly with minimal impact on the dataset was found but was not serious enough to render the data unusable. The processing performed exceptionally well given the low relief and swampy terrain. The figures highlighted above are a sample of the minor issues that were encountered and are not representative of the majority of the data, which is of good quality.

Appendix A Checkpoints

New Jersey State Plane, NAD83 (Feet)
Elevations: orthometric heights NAVD88 (Meters)

pointNo	easting	northing	elevation	zLiDAR	LandCoverType	DeltaZ	AbsDeltaZ
G6	263983.56	210745.09	10.65	10.55	Open Terrain	-0.104	0.104
G14	367919.59	174331.47	11.22	11.12	Open Terrain	-0.099	0.099
G9	260935.02	180727.04	1.23	1.13	Open Terrain	-0.096	0.096
G7	266902.66	228127.03	34.84	34.78	Open Terrain	-0.055	0.055
G5	241811.46	222096.59	11.92	11.88	Open Terrain	-0.043	0.043
G1	226546.99	278272.76	6.45	6.43	Open Terrain	-0.027	0.027
G17	452869.13	143202.27	1.41	1.39	Open Terrain	-0.024	0.024
G8	314238.20	236329.42	30.24	30.23	Open Terrain	-0.011	0.011
G10	321831.60	160179.20	3.32	3.31	Open Terrain	-0.010	0.010
G16	413312.66	169159.75	2.97	2.97	Open Terrain	0.007	0.007
G20	368430.30	58604.52	4.74	4.75	Open Terrain	0.012	0.012
G3	207002.21	264843.87	3.38	3.41	Open Terrain	0.030	0.030
G13	372101.84	217723.97	24.21	24.24	Open Terrain	0.036	0.036
G18	438291.46	117423.81	1.56	1.60	Open Terrain	0.042	0.042
G19	431883.78	101026.91	1.23	1.28	Open Terrain	0.045	0.045
G2	200342.55	287255.71	2.44	2.49	Open Terrain	0.046	0.046
G4	227778.09	244781.64	4.78	4.84	Open Terrain	0.052	0.052
G12	338348.51	232751.81	20.41	20.50	Open Terrain	0.089	0.089
G15	364390.18	138903.77	3.04	3.14	Open Terrain	0.101	0.101
G11	337277.53	208781.18	9.27	9.43	Open Terrain	0.160	0.160
W5	246593.31	209573.52	5.93	5.90	Med Vegetation	-0.029	0.029
W15	374268.22	139746.51	4.02	4.03	Med Vegetation	0.011	0.011
WF2	196313.61	281692.37	2.38	2.40	Med Vegetation	0.018	0.018
WF16	404613.06	147702.10	12.06	12.09	Med Vegetation	0.024	0.024
W8	300982.13	223923.90	24.04	24.06	Med Vegetation	0.025	0.025
WF10	308974.38	197215.84	27.18	27.21	Med Vegetation	0.028	0.028
WF20	381633.94	62490.29	5.35	5.39	Med Vegetation	0.042	0.042
W19	381608.58	90620.21	4.52	4.57	Med Vegetation	0.050	0.050
W4	217195.09	231974.33	0.98	1.04	Med Vegetation	0.060	0.060
W1	219241.00	306006.78	1.58	1.67	Med Vegetation	0.086	0.086
WF9	287599.84	186175.89	2.23	2.32	Med Vegetation	0.093	0.093
WF13	375930.02	196598.17	19.77	19.87	Med Vegetation	0.096	0.096
W18	403699.93	124429.43	3.76	3.86	Med Vegetation	0.101	0.101
WF7	277419.24	250431.79	23.83	23.94	Med Vegetation	0.105	0.105
WF11	344879.06	205337.00	12.19	12.30	Med Vegetation	0.111	0.111
W6	281418.31	209371.89	15.40	15.52	Med Vegetation	0.115	0.115
WF14	343347.76	154545.76	3.49	3.62	Med Vegetation	0.130	0.130
W3	216868.38	254424.55	2.21	2.37	Med Vegetation	0.162	0.162
WF12	337163.15	262208.56	33.43	33.61	Med Vegetation	0.174	0.174
W17	423799.65	155528.27	8.17	8.48	Med Vegetation	0.312	0.312
U10	303896.28	169375.92	3.48	3.39	Urban Area	-0.085	0.085

USGS: South New Jersey
02/20/2009

pointNo	easting	northing	elevation	zLiDAR	LandCoverType	DeltaZ	AbsDeltaZ
U4	235338.49	260395.87	5.87	5.83	Urban Area	-0.035	0.035
U15	355394.13	155999.92	6.66	6.63	Urban Area	-0.032	0.032
U6	280764.79	217757.89	23.07	23.04	Urban Area	-0.027	0.027
U7	292652.25	235323.47	30.85	30.85	Urban Area	-0.006	0.006
U2	211344.98	283028.84	3.11	3.11	Urban Area	0.000	0.000
U3	218096.57	271411.36	2.69	2.70	Urban Area	0.010	0.010
U8	289237.64	200279.96	9.67	9.70	Urban Area	0.022	0.022
U16	389984.63	159105.28	13.68	13.70	Urban Area	0.023	0.023
U14	345416.23	181264.11	7.47	7.49	Urban Area	0.026	0.026
U1	221620.69	292460.17	2.49	2.53	Urban Area	0.039	0.039
U5	235089.20	230933.37	3.27	3.33	Urban Area	0.055	0.055
U9	293646.37	185128.80	8.95	9.01	Urban Area	0.056	0.056
U11	339268.38	215128.00	15.40	15.47	Urban Area	0.063	0.063
U19	401162.55	93098.79	3.96	4.04	Urban Area	0.079	0.079
U17	449523.09	155683.33	8.98	9.07	Urban Area	0.089	0.089
U20	398939.73	55859.31	1.79	1.90	Urban Area	0.103	0.103
U18	425769.90	125022.99	6.53	6.63	Urban Area	0.106	0.106
U12	350945.16	235683.89	30.03	30.15	Urban Area	0.121	0.121
U13	352841.89	213264.58	20.38	20.53	Urban Area	0.152	0.152

Appendix B LiDAR Acquisition Report

Lidar Report

for

South New Jersey
Cape May, Cumberland & Part of Salem (Bayside)

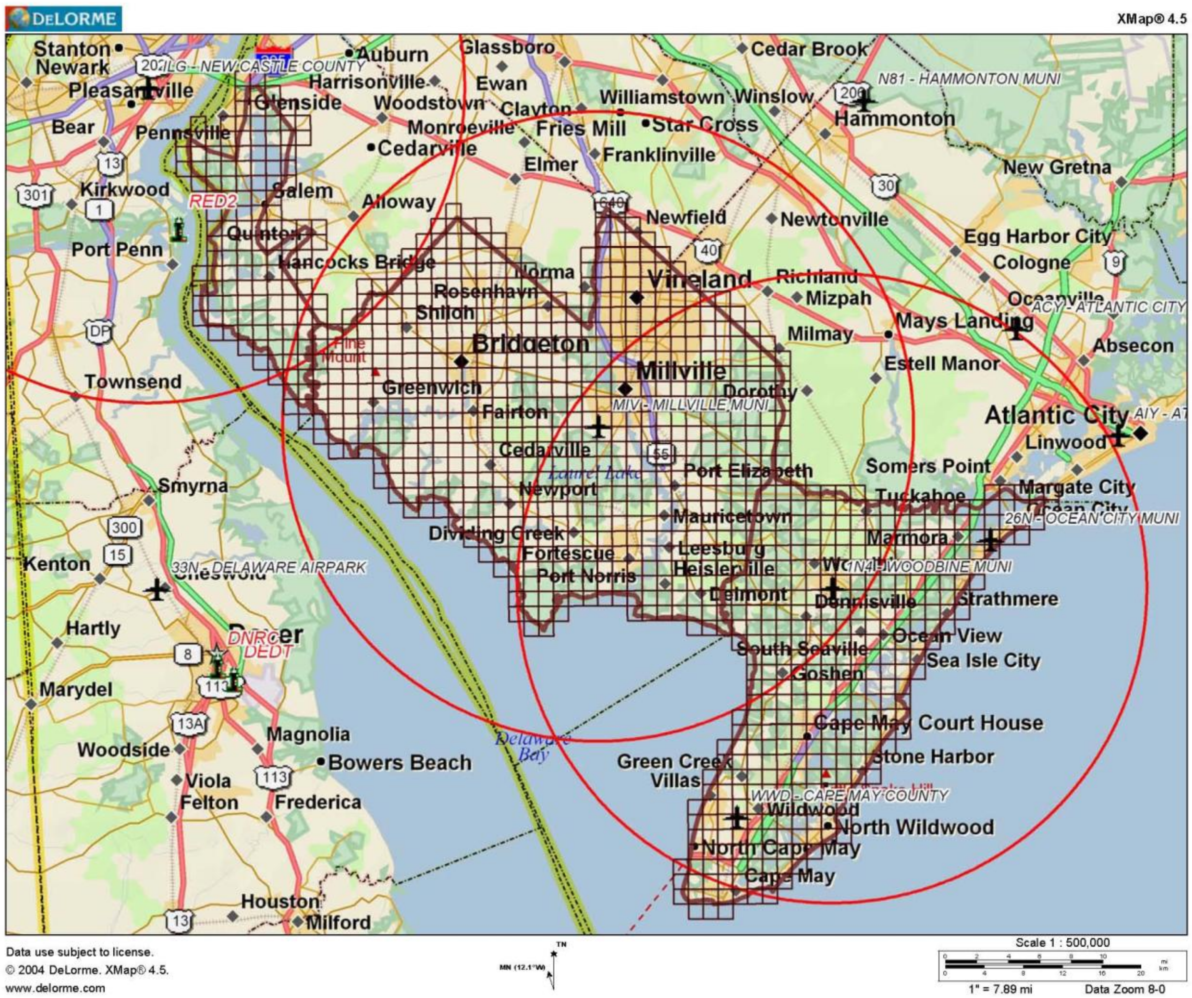
PHOTO SCIENCE
Geospatial Solutions

September 12, 2008

Table of Contents

Project Description

This project includes Lidar collection, processing, and deliverable production for a portion of South New Jersey for the New Jersey Department of Environmental Protection (NJ-DEP). This project includes the acquisition and production of high accuracy bare-earth processed Lidar data in LAS x-y-z-i format and 2.0-meter Digital Elevation Models (DEMs) in ArcGrid format for approximately 874 square miles covering the 3 New Jersey counties of Cape May, Cumberland, and part of Salem as shown in the exhibit below:



Aerial Platform / Lidar Sensor

All flights for the project were accomplished with one of our customized single-engine Cessna 206s which provide an ideal, stable aerial base for Lidar acquisition. This platform has relatively fast cruise speeds that are beneficial for project mobilization / demobilization while maintaining relatively slow stall speeds which can prove ideal for collection of a high-density, consistent data posting.

The Lidar sensor used for this project was one of our two Leica ALS-50 sensors, specifically SN019. This system is capable of collecting data at a maximum frequency of 150 kHz, which affords elevation data collection of up to 150,000 points per second. This sensor is also equipped with the ability to measure up to 4 returns per outgoing pulse from the laser and these come in the form of 1st, 2nd, 3rd, and last returns. The intensity of the first three returns is also captured during the aerial acquisition.

Flight Parameters

Detailed project planning was performed for this project. This planning was based on project specific requirements and the characteristics of the project site. The basis of this planning included the required accuracies, type of development, amount and type of vegetation within the project area, the required data posting, and potential altitude restrictions for flights in the general area. A brief summary of the aerial acquisition parameters for this project are shown in the table below:

Parameter	Value
Flying Height (AMT)	5000 feet
Nominal ground speed	115 knots
Field of View	29˚
Laser Rate	73.5 kHz
Scan Rate	42 Hz
Maximum Cross Track Posting	1.4 meters
Maximum Along Track Posting	1.4 meters
Nominal Sidelap	30%

These collection parameters resulted in a swath width of 2,360 feet and an average point distribution of 1.58 points per square meter (or on average 1 point per 0.63 square meters).

Dates Flown

Collection occurred as weather permitted between April 9th and 17th, 2008. The collection was tide coordinated, taking place at or near low tides.

Base Stations Used

ABGPS stations were Trimble 5700 data collection units, logging at 2 hertz, paired with Trimble Zephyr Geodetic antennas, which were mounted on variable height tripods with the H.I. measured at the beginning and end of each logging session.

The overall study area was broken into 3 sub-areas, shown in the Appendix to this report, each flown in relation to at least one GPS base station. Base stations at airport locations were used to control the flights.

Flight lines within each sub-area were planned for direction of flight to coincide with the prevailing topography and to provide the best configuration for flying flight lines with the local tides. We also took into consideration our impact on the busy local airspace.

GPS Collection Parameters

Collection parameters for this project included the following:

Parameter	Value
Maximum PDOP	3.5
Minimum number of SVs	6
Ground collection epoch	2 Hz (0.5 sec)

Projection / Datum

All data for this project was reduced to New Jersey State Plane Coordinates, using NAD 83 and NAVD 88. Geoid03 was used in the translation of elevations from ellipsoidal to orthometric heights. Horizontal and vertical units were U.S. Survey Feet.

Data Processing

Leica software was used in the post-processing of the airborne GPS and inertial data that is critical to the positioning of the sensor during all flights. This software suite includes Applanix's PosPac and Waypoint's GrafNav solutions. PosPac provides the smoothed best estimate of trajectory (SBET) that is necessary for Leica's post processor to develop the point cloud from the Lidar missions. The point cloud is the mathematical three dimensional collection of all returns from all laser pulses as determined from the aerial mission. At this point this data is ready for analysis, classification, and filtering to generate a bare earth surface model in which the above ground features are removed from the data set.

The point cloud was manipulated within the Leica software, GeoCue, TerraScan, and TerraModeler software was used for the automated data classification, manual cleanup, and bare earth generation from this data. Project specific macros were used to classify the ground and to remove the side overlap between parallel flight lines. All data was manually reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler.

QA/QC Analysis

A total of 20 points were established in the field by Rettew (Lancaster, PA) for check points of the Lidar surface. Points in open areas were established using double fast-static GPS procedures. All of these points were established with two independent observations and were checked to ensure that the positions did not vary by more than 5 cm. The table below lists the statistics of this accuracy analysis:

Parameter	Value
Number of QA/QC Points	20
Minimum difference	-0.26 feet
Maximum difference	+0.32 feet
Average difference	-0.01 feet
RMSE	0.16 feet

The RMSE of 0.16 feet (4.9 cm) is well within the project requirements for a vertical RMSE of 15 cm.

Problems Encountered

After completing the processing of two of the three areas, a small amount of horizontal shift was noticed in some of the overlap zones for this project. After significant analysis, we determined there were two things going on in this data that resulted in the small amount of shift.

The first is an unequal swing of the scan mirror about nadir, which resulted in a “large” side overlap on one side, and a “small” side overlap on the other when adjacent flight lines were flown opposing one another. As a general statement, the larger of the side overlaps measures 900 feet while the small measures 500 feet. The swath of the Lidar was approximately 1,150 feet on one side of nadir and 1,320 feet on the other. That geometry equates to a swing of 13 degrees and 15 degrees, respectively at a flight altitude of 5,000 feet. It should be noted that flight planning was for a full-angle field of view of 29 degrees, which should have equated to 14.5 degrees each side of nadir.

Leica carefully reviewed the mission data and provided the following explanation: “The unequal sides could be due to a problem with the scan interface board. This is the board that takes inputs from Trac GUI and produces the signal for the current to drive the scan motor. Normally the mirror is adjusted to be at least within 1/2 degree side to side. If this is still a problem then some board replacement or adjustment/tuning may be required. Please monitor left side / right side on future flights and advise if action is required.”

Secondly, a horizontal shift in the laser returns that fall very near the edge of the field of view was noticed in the processed data. This generally occurs only in the small overlap area (comparisons in the large overlap zone are made with points closer to nadir). Buildings that fall in this overlap have a total shift of approximately 6 feet when one flight line is compared to the adjacent opposing flight line. Because of the opposing direction of the flight lines, the actual error in each flight line would be doubled in the visual comparison of one flight line to the next; in general terms, 3 feet of shift to the east in one and 3 feet of shift to the west in the next (the lines were flown north-south). This error is only apparent very near the extremes of the swath, then very quickly disappears as you analyze data nearer nadir. The error we are seeing near the field of view edge is about 3 feet in each line and at the cutline of the overlap it is about half that at the extreme or about 1.5 feet in each line. By moving another two to three hundred feet toward nadir, no horizontal shift is generally visible.

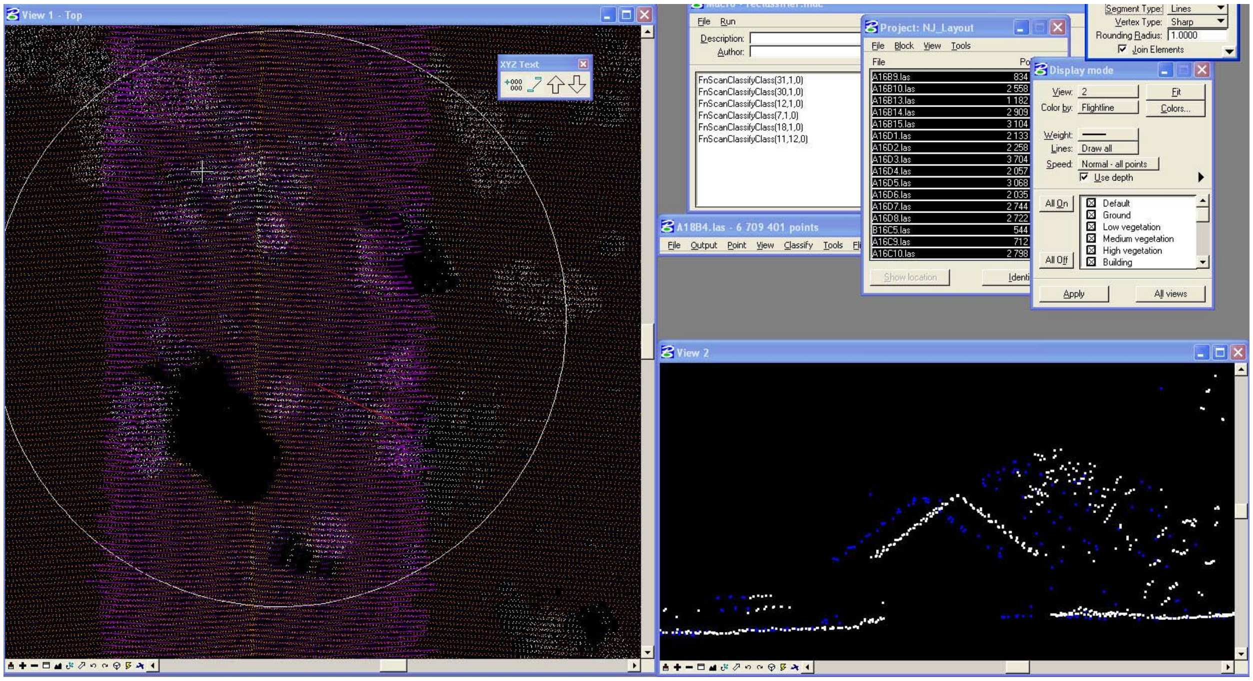


*Figure 28 – **The section cut through the house on the extreme edge of the small overlap zone exhibits approximately 6 feet of relative shift from one flightline to the adjacent flightline.***

Because this error only occurs at the extremes of the field of view, our first suspicion was an inaccurate modeling of the torsion correction in the boresight data. This was verified by Leica after their analysis of the mission data. And this makes perfect sense given the nature of error only showing up at the extremes of the mirror swing, then very quickly disappearing.

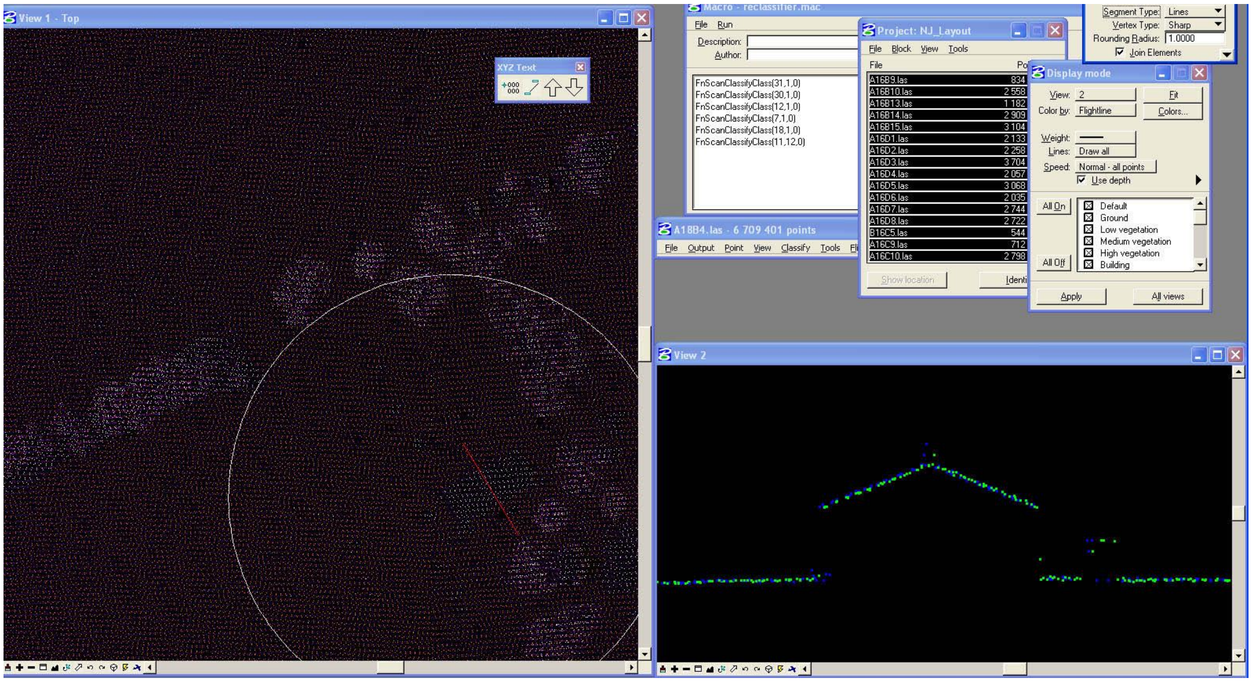
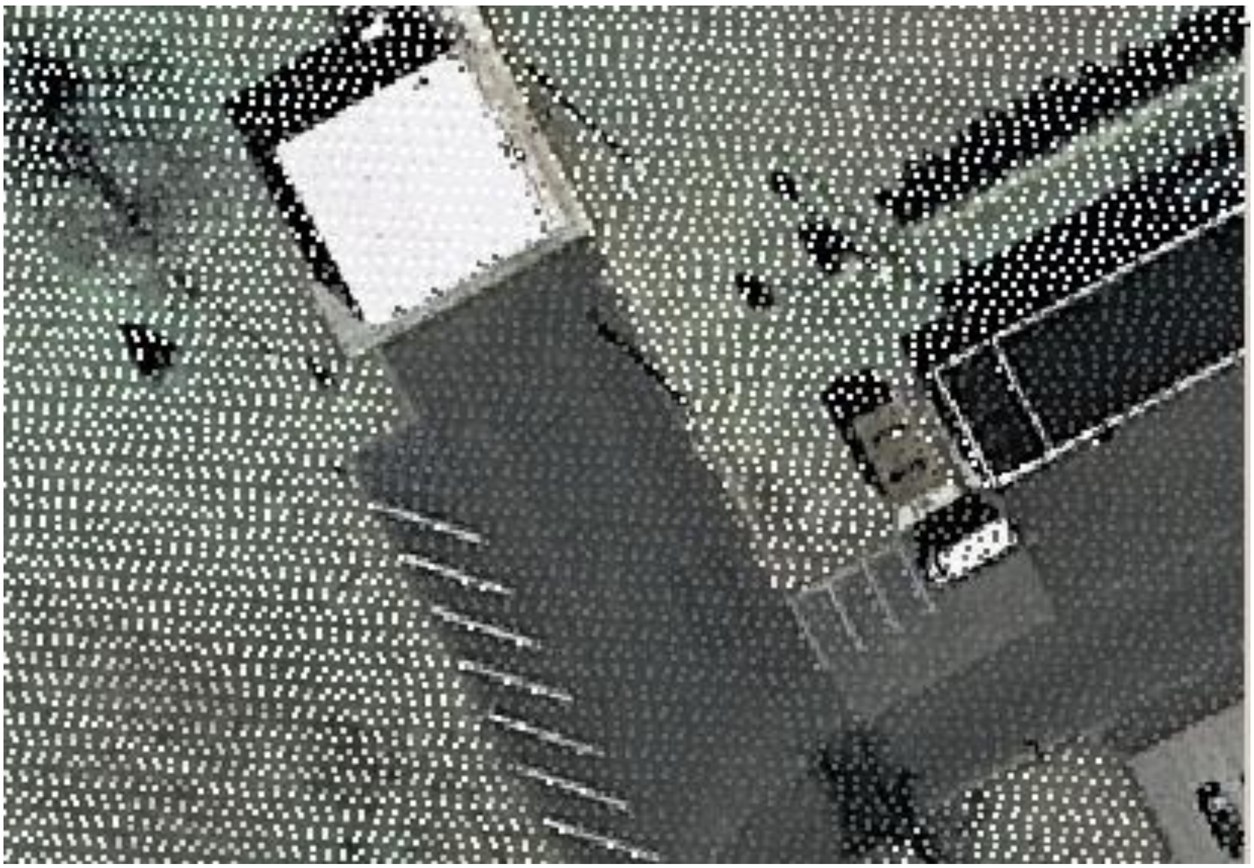


Figure 29 – ***The section cut through another home in the large overlap zone shows almost perfect relative alignment. This section would be more closely located to nadir by a few hundred feet.***

Given the notice of this shift, we took considerable effort to verify the accuracy of the horizontal placement of the Lidar points throughout all areas within a swath to ensure there were not errors in other areas within the data. Firstly, we produced digital orthophotos for this same area not too long ago. We have brought quite a few orthophotos in and back draped them behind the intensity images from the Lidar. The graphic below is an overall view of one of the smaller overlap areas. You should notice the cutline, lake, and structure in the left center portion of the graphic. This is the same structure shown in Figure 1 above. Mainly we are looking at paint striping on roadways and parking lots in the verification of the horizontal accuracy of the Lidar. And we were careful to look at different roadway orientations to make sure that a horizontal shift in the Lidar data parallel to the roadway is not providing false reassurance of the data. The most horizontal shift we were able to find between the intensity and the orthophotos is about 1.5 feet, occurring near the edge of the field of view.

This magnitude is consistent with what we saw in comparing building profiles in digital surface model cross sections. Actually most of the high intensity returns (that would be expected on paint striping) are perfectly coincident with the paint striping in the orthophotos. One of the houses visible in the image above showed significant shift in adjacent Lidar flight lines. This house was very near the field of view edge (not along the sidelap cutline) and had about 6 feet of shift (again taken as 3 feet in one flight line and 3 in the opposing, making the error double what it is in a single flight line). 250 feet away on the roadway, the intensity and orthophotos line up with a 1.0 to 1.5 foot horizontal shift. The paint stripes in the parking lot in the northeast quadrant of the image line up nearly perfectly, as shown in the orthophoto-Lidar intensity composite below.



It should be noted that the cutline or seamline discussed in the text above refers to the line that is drawn in the nominal center of the side overlap area. With our production workflow, that cutline is automatically determined by the TerraScan software. The points that fall outside of that cutline (the points nearest the field of view edge) for each of the two adjacent parallel flight lines are moved to an overlap classification, Class 12. This results in a bare earth class with a nominal point density equal throughout the project coverage, not a bare earth class with double the nominal density within the side overlap area. And this helps increase the accuracy of the elevation model as the accuracy of Lidar data decreases as you move from nadir to the field of view edge. By removing all points outside of the cutline, in effect the points with the least accuracy are removed from the bare earth class.

Secondly, we brought in six photo identifiable control points that were used in the aerotriangulation process for the orthophoto project. These control points include corners of sidewalks, corners of parking lots, etc. There was little discernable difference in these control points and the intensity images. In fact, the control points generally fit within the nominal posting of the Lidar data, ranging from 1.2 to 1.8 feet with an RMSE of 1.5 feet. These control points fell both very close to nadir and in the smaller of the sidelap areas. The table below lists the summary of the photo identifiable control points that were checked in the intensity images.

Point Name	X	Y	Error (ft)	Description	Tile
303	292738.24	229039.52	1.5	SE Corner of Parking Lot (Base of Curb) on West Side of Road	C18B13
SNJ-04	221018.07	249407.76	1.7	SW Corner of Concrete Landing at South End of Stairs	A17D15
130	205353.34	263332.79	1.3	NE Corner of Concrete Sidewalk leading from Parking Lot to Bldg	A17C4
SNJ-02	195995.38	282121.58	1.8	SE Corner of Concrete Sidewalk	A17A2
SNJ-05	227092.43	288610.39	1.4	West end of Concrete Curbing in NW Quad of Intersection	A16D16
126	313682.25	150938.59	1.2	NW Corner of Concrete Landing	D20A9
		RMSE (ft)	**1.5**		

Considerations Regarding Accuracy Requirements

An important question that needs to be answered is does this data meet the accuracy requirements written in the specifications. In terms of the vertical accuracy, our internal QA analysis produced a vertical RMSE of 0.16 feet (4.9 cm) using 20 control points geometrically dispersed throughout the project area as noted earlier. This easily satisfies the requirements in the specifications, which provided a requirement for an RMSE of 0.49 feet (15 cm).

The horizontal accuracy requirements for this project as provided in the specifications were for an RMSE error of 1 meter. This would generally be equal to a confidence interval for 68 percent of the points at that level. The 95 percent confidence interval also referred to as the horizontal accuracy defined by NSSDA, would be a multiple of 1.7308 times the RMSE, which would equate to 5.7 feet.

Even with a slightly inaccurate modeling of the torsion of the sensor, the horizontal accuracy requirements are easily met. I make this statement based on the following facts gathered from the actual data.

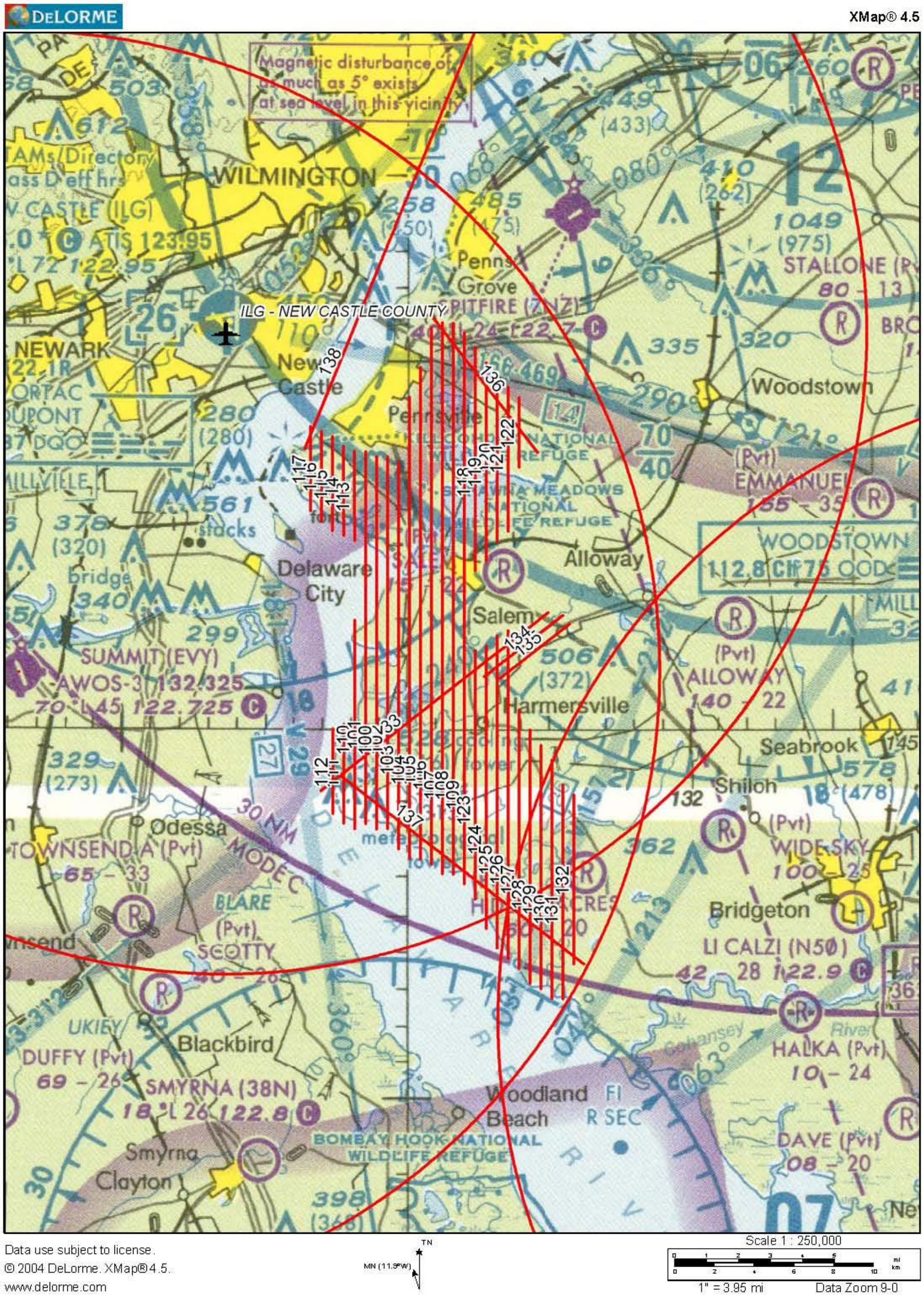
1. Only a small percentage of the Lidar points are affected by the torsion model, generally in the 5 percent range.

2. The *maximum* horizontal error that we are seeing for these points is approximately 3 feet.
3. The *maximum* horizontal error found at the cutline of the sidelap is approximately 1.5 feet.
4. The horizontal accuracy requirements for this project are for a horizontal RMSE of 1 meter, or 3.28 feet.
5. Working backward using the NSSDA constant of 1.7308 for the 95% confidence interval and the shift of 3 feet affecting 5 percent of the points, the indicated horizontal RMSE would be 1.7 feet (3 feet / 1.7308), which is significantly better than the 3.3 feet (1 meter) requirement of the specifications. This is consistent with the comparisons of the orthophoto ground control point assessment. In fact the horizontal accuracy is approximately *two times better* than that required by specification.
6. Most points affected by the torsion correction are found in Class 12 (overlap), not in bare earth Class 2, or other classes in the LAS data. The maximum error in the bare earth class (as mentioned in bullet 3 above) is at the cutline and generally one half that found in the overlap. Therefore the horizontal accuracy of the bare earth class is approximately *four times better* than that required by specification.
7. There is little effect on this shift on the bare earth class. In general, the only place the shift is visible is in buildings found in the overlap class.

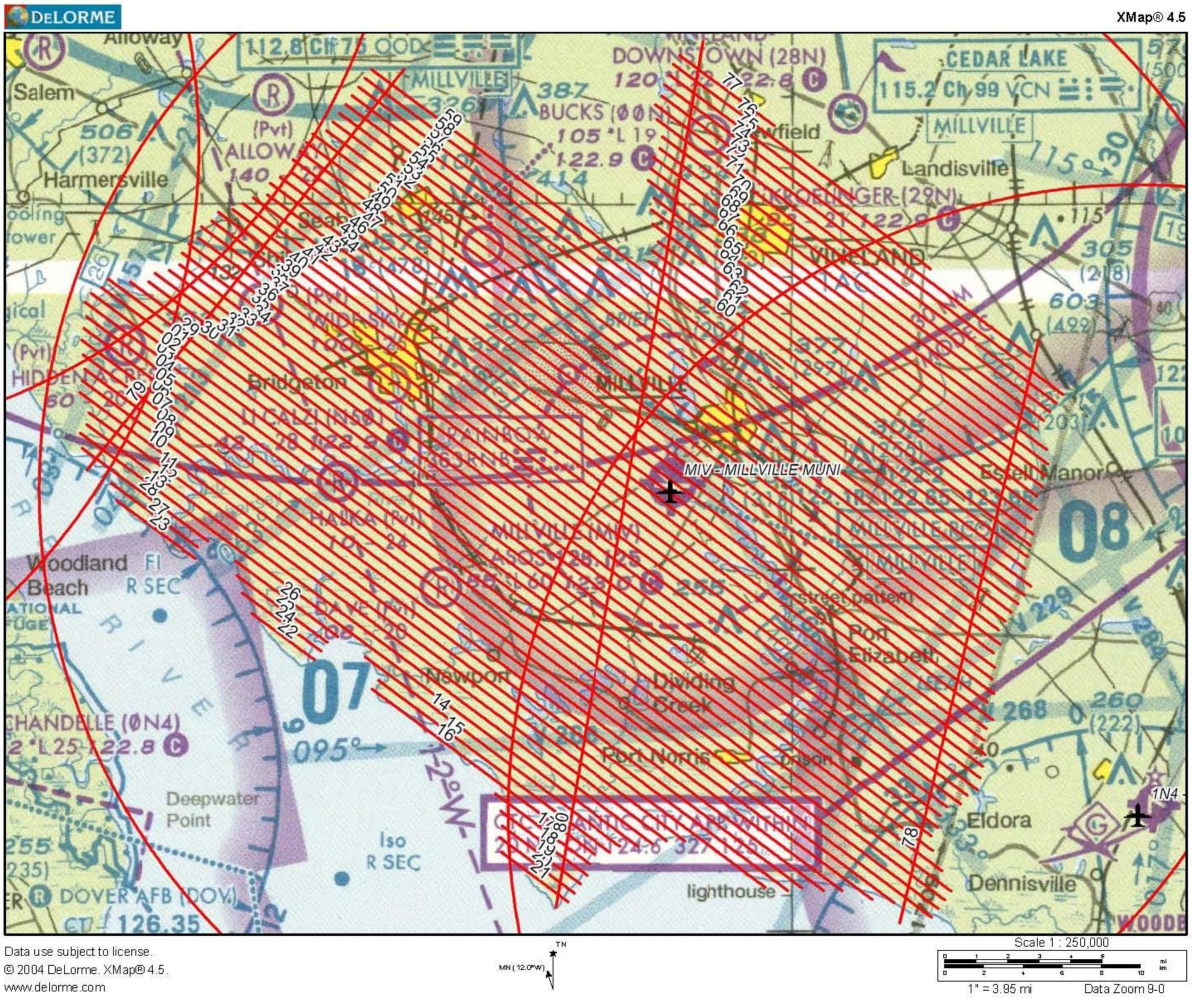
Because Cape May had not been fully processed and hydro enforced at the time of the shift discovery, it was re-processed with the new torsion correction to correct the issue. Cumberland and Salem were too far along in the edit and hydro enforcement process to start over. It was determined that the data still met the accuracy requirements as supported in this section.

Flight Line Layouts

USGS: South New Jersey
02/20/2009



USGS: South New Jersey
02/20/2009



USGS: South New Jersey
02/20/2009

Appendix C Ground Control Survey Report

Ground Control Survey Report
South New Jersey
April, 2008

Prepared by Dewberry and Davis, LLC.

Prepared By:
Dewberry

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Fairfax, Virginia 22031-4666
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TABLE OF CONTENTS

1. INTRODUCTION

1.1 *Project Summary*

Dewberry & Davis, LLC has provided a total of 80 quality control / quality assurance checkpoints within a portion of South, NJ. Sixty of the 80 checkpoints are to be used to check the vertical accuracy of the LiDAR digital terrain model. The remaining 20 checkpoints are to be used by the USGS to check the fundamental vertical accuracy. The points for the USGS are numbered 101 to 120 and have a red circle on the survey plot.

The project covered the following Counties: Cape May, Cumberland, and a portion of Salem. The project area is approximately 850 square miles.

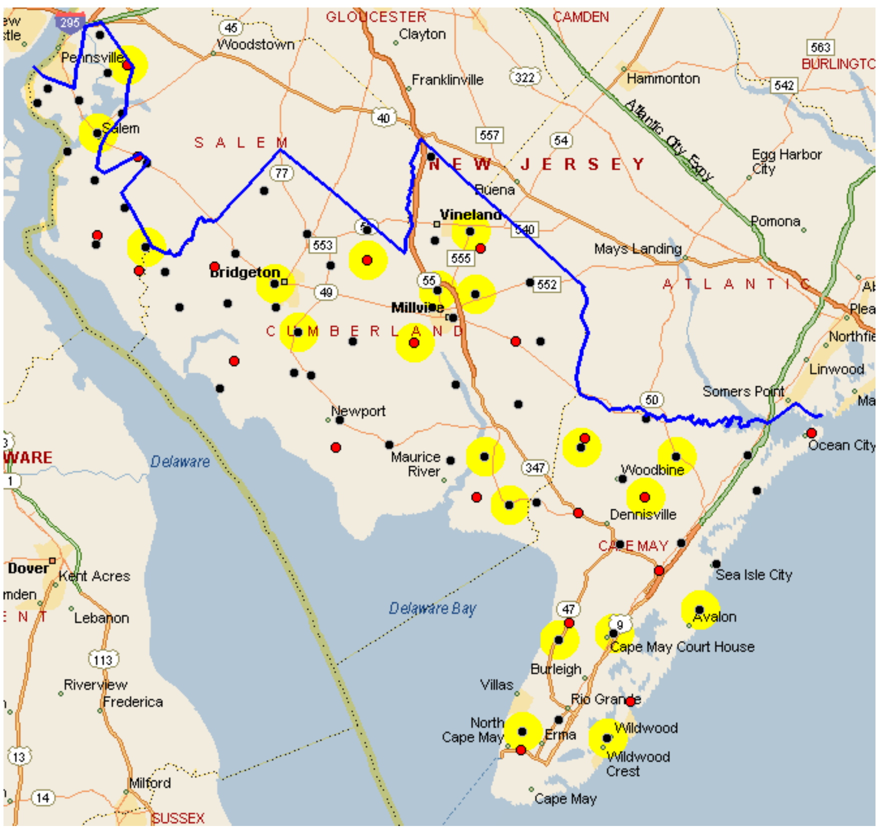
Final horizontal coordinates are published on the New Jersey State Plane Coordinate System, NAD83, feet. Final orthometric elevations are published in NAVD88, meters.

1.2 *Points of Contact*

Questions regarding the technical aspects of this report should be addressed to:

Dewberry & Davis, LLC
8401 Arlington Blvd
Fairfax, Virginia 22031
Attention: Dave Maune, or Tim Blak
Telephone: (703) 849-0100
Fax: (703) 849-0182

1.3 *Project Area*



*** Highlighted points were re-observed on a different day ***

2. Project Details

2.1 *Survey Equipment*

One Trimble R-8 receiver/antenna attached to a two meter pole with a quick release was used for GPS Observations.

For conventional observations a Topcon GPT-3005 LW total station with a Trimble TSC2 data collector was used.

2.2 *Survey Point Details*

Sixty checkpoints were divided into four categories, 20 points in Urban Areas, 20 points in Open Terrain, and 20 points divided equally in Medium Vegetation and Forested Areas. The 20 checkpoints for the USGS were in Open Terrain. The features that made up each category was: Open Terrain (bare earth, short grass, sand, rock), Medium Vegetation (tall grass, weeds, crops, scrub), Urban Areas (asphalt roads, parking lots), Forested Areas (fully covered by trees, dense bushes). No set locations were designated for the checkpoints; they are generally interspersed throughout the surveyed area.

A sketch was made for each location and a 6” nail or PK nail was set at the point. The locations are detailed in the field notes.

2.3 *Network Design*

The GPS survey performed by Dewberry was tied to the KeyNet GPS Network. KeyNet GPS is a series of continuously operating, high precision GPS reference stations.

2.4 *Field Survey Procedures and Analysis*

Dewberry used a Trimble R-8 receiver, which is a geodetic quality dual frequency GPS receiver, to collect data at each station. All stations were occupied twice (100% redundancy), additionally, 25% of the stations were re-observed on a different day. All re-observations matched the initially derived station positions within the allowable of ± 5cm. Each occupation was between two to five minutes in duration, depending on the number of satellites being tracked. Field GPS observations are detailed in the field notes.

The points located in the forested areas were tied in using conventional methods. An intervisible pair was set using GPS near the forested point location and then occupied with a total station to shoot in the point.

Six existing monuments listed in the NSRS database were tied to check the accuracy of the KeyNet network. The results are as follows:

Name	Published			Surveyed			Differences		
	Northing	Easting	Elev.	Northing	Easting	Elev.	ΔNorth	ΔEast	ΔElev
17 A 1	81692.550	66889.199	0.888	81692.531	66889.186	0.862	0.019	0.013	0.026
A 100	93624.378	64012.718	4.050	93624.383	64012.712	4.012	-0.005	0.006	0.038
MIDDLE 1	22680.082	119796.130	4.055	22680.069	119796.144	4.008	0.013	-0.014	0.047
MIV A	59304.112	100771.530	21.7	59304.107	100771.527	21.651	0.005	0.003	0.05
S 82	65735.901	89236.444	23.676	65735.894	89236.433	23.677	0.007	0.011	-0.001
WOODBINE PRIMARY PAIR 1	43162.462	124438.074	11.06	43162.461	124438.080	11.041	0.001	-0.006	0.02

The above results indicate that the KeyNet network is providing positional values within the 5cm parameters of this survey.

2.5 Adjustment

The survey data was collected using Real Time Kinematic (RTK) methodology within a Real Time Network (RTN). Therefore, corrections were applied to the points as they were being collected, thus negating the need for an adjustment.

The final coordinates are in the New Jersey State Plane Coordinate System, NAD83 horizontal datum and NAVD88 vertical datum. The Geoid03 model was used. Coordinates and elevations were calculated the U.S. survey foot and the elevations are in meters.

3. FINAL ADJUSTED COORDINATES

Final Adjusted Coordinates, April 22/08					
New Jersey State Plane, NAD83 (Feet) / NAVD88 (Meters)					
Name	Northing	Easting	Elevation	Description	Land Type
2A	281833.71	196430.65	2.310	PK Nail	Forest Pair
2B	281934.70	196305.04	2.573	PK Nail	Forest Pair
7A	250298.71	277353.15	24.237	6” nail	Forest Pair
7B	250306.98	277554.29	25.294	6” nail	Forest Pair
9A	186113.77	287452.40	3.120	6” nail	Forest Pair
9B	186115.20	287350.10	3.186	6” nail	Forest Pair
10A	197177.95	309063.73	27.028	6” nail	Forest Pair
10B	197089.62	309027.49	27.112	6” nail	Forest Pair
11A	205380.74	344817.92	12.492	PK Nail	Forest Pair
11B	205260.78	344819.71	12.148	6” nail	Forest Pair
12A	262180.93	337048.00	33.183	6” nail	Forest Pair
12B	262248.16	336887.27	33.997	6” nail	Forest Pair
13A	196658.18	375976.64	19.672	6” nail	Forest Pair
13B	196582.94	376075.34	20.399	6” nail	Forest Pair
14A	154507.32	343280.40	3.925	6” nail	Forest Pair
14B	154382.56	343199.09	4.119	6” nail	Forest Pair
16A	147585.04	404682.45	12.134	PK Nail	Forest Pair
16B	147644.77	404562.33	12.330	6” nail	Forest Pair
20A	62380.93	381627.06	5.647	6” nail	Forest Pair
20B	62260.90	381485.54	5.684	6” nail	Forest Pair
F2	281692.37	196313.61	2.383	6” nail	Forested Area
F7	250431.79	277419.24	23.831	6” nail	Forested Area
F9	186175.89	287599.84	2.228	6” nail	Forested Area
F10	197215.84	308974.38	27.184	6” nail	Forested Area
F11	205337.00	344879.06	12.188	6” nail	Forested Area
F12	262208.56	337163.15	33.432	6” nail	Forested Area
F13	196598.17	375930.02	19.773	6” nail	Forested Area
F14	154545.76	343347.76	3.493	6” nail	Forested Area
F16	147702.10	404613.06	12.065	6” nail	Forested Area
F20	62490.29	381633.94	5.352	6” nail	Forested Area
G1	278272.76	226546.99	6.452	6” nail	Open Terrain
G2	287255.71	200342.55	2.442	6” nail	Open Terrain

G3	264843.87	207002.21	3.376	6” nail	Open Terrain
G4	244781.64	227778.08	4.783	6” nail	Open Terrain
G5	222096.59	241811.46	11.925	6” nail	Open Terrain
G6	210745.09	263983.56	10.651	6” nail	Open Terrain
G7	228127.03	266902.66	34.237	6” nail	Open Terrain
G8	236329.42	314238.20	30.241	6” nail	Open Terrain
G9	180727.04	260935.02	1.228	6” nail	Open Terrain
G10	160179.20	321831.60	3.319	6” nail	Open Terrain
G11	208781.18	337277.53	9.274	6” nail	Open Terrain
G12	232751.81	338348.51	20.411	6” nail	Open Terrain
G13	217723.97	372101.84	24.207	6” nail	Open Terrain
G14	174331.47	367919.59	11.221	6” nail	Open Terrain
G15	138903.77	364390.18	3.040	6” nail	Open Terrain
G16	169159.75	413312.66	2.965	6” nail	Open Terrain
G17	143202.27	452869.13	1.411	6” nail	Open Terrain
G18	117423.81	438291.46	1.563	6” nail	Open Terrain
G19	101026.91	431883.78	1.232	6” nail	Open Terrain
G20	58604.52	368430.30	4.738	6” nail	Open Terrain
U1	292460.17	221620.69	2.494	PK Nail	Urban Area
U2	283028.84	211344.98	3.114	PK Nail	Urban Area
U3	271411.36	218096.57	2.689	PK Nail	Urban Area
U4	260395.87	235338.49	5.870	PK Nail	Urban Area
U5	230933.37	235089.20	3.274	PK Nail	Urban Area
U6	217757.89	280764.79	23.071	PK Nail	Urban Area
U7	235323.47	292652.25	30.855	PK Nail	Urban Area
U8	200279.96	289237.64	9.674	PK Nail	Urban Area
U9	185128.80	293646.37	8.954	PK Nail	Urban Area
U10	169375.92	303896.28	3.480	PK Nail	Urban Area
U11	215128.00	339268.38	15.405	PK Nail	Urban Area
U12	235683.89	350945.16	30.033	PK Nail	Urban Area
U13	213264.58	352841.89	20.383	PK Nail	Urban Area
U14	181264.11	345416.22	7.468	PK Nail	Urban Area
U15	155999.92	355394.13	6.661	PK Nail	Urban Area
U16	159105.28	389984.63	13.676	PK Nail	Urban Area
U17	155683.33	449523.09	8.980	PK Nail	Urban Area
U18	125022.99	425769.90	6.527	PK Nail	Urban Area
U19	93098.79	401162.55	3.957	PK Nail	Urban Area
U20	55859.31	398939.73	1.795	PK Nail	Urban Area

W1	306006.78	219241.00	1.583	6” nail	Medium Vegetation
W3	254424.55	216868.38	2.208	6” nail	Medium Vegetation
W4	231974.33	217195.09	0.983	6” nail	Medium Vegetation
W5	209573.52	246593.31	5.927	6” nail	Medium Vegetation
W6	209371.89	281418.31	15.400	6” nail	Medium Vegetation
W8	223923.90	300982.13	24.037	6” nail	Forest Pair
W15	139746.51	374268.22	4.023	6” nail	Medium Vegetation
W17	155528.27	423799.65	8.171	6” nail	Medium Vegetation
W18	124429.43	403699.93	3.755	6” nail	Medium Vegetation
W19	90620.21	381608.58	4.518	6” nail	Medium Vegetation
101	295132.50	228722.65	4.851	6” nail	Open Terrain
102	262587.30	232397.22	5.830	6” nail	Open Terrain
103	235217.68	217944.34	3.431	6” nail	Open Terrain
104	222520.20	232461.98	1.592	6” nail	Open Terrain
105	223925.11	259491.08	36.477	6” nail	Open Terrain
106	190106.44	266174.91	1.885	6” nail	Open Terrain
107	225902.78	313947.05	25.168	6” nail	Open Terrain
108	229777.61	354809.68	27.427	6” nail	Open Terrain
109	196478.65	330532.12	20.293	PK Nail	Open Terrain
110	159525.15	302630.55	2.667	6” nail	Open Terrain
111	141530.25	352891.36	2.268	6” nail	Open Terrain
112	196545.28	366832.68	10.371	6” nail	Open Terrain
113	162411.41	391360.95	13.126	6” nail	Open Terrain
114	163337.70	472502.95	1.885	6” nail	Open Terrain
115	141413.65	412810.82	10.660	6” nail	Open Terrain
116	135987.82	388775.65	3.419	6” nail	Open Terrain
117	115378.06	417509.70	5.817	6” nail	Open Terrain
118	96857.56	385639.33	4.453	6” nail	Open Terrain
119	68931.62	407485.28	2.736	6” nail	Open Terrain
120	51853.16	368134.42	4.127	PK Nail	Open Terrain

4. GPS OBSERVATION SCHEDULE

			Session 1		Session 2	
Station	Date	Julian Date	Start Time	End Time	Start Time	End Time
11A	4-14-08	105	15:19	15:22	15:32	15:34
11B	4-14-08	105	15:36	15:38	15:46	15:48
109	4-14-08	105	16:32	16:35	16:35	16:38
G11	4-14-08	105	14:39	14:41	14:49	14:51
U11	4-14-08	105	13:49	13:52	13:52	13:56
MIDDLE 1	4-15-08	106	11:37	11:39	11:44	11:46
MIV A	4-15-08	106	17:08	17:10	17:10	17:12
WOODBINE PRIMARY PAIR 1	4-15-08	106	16:02	16:04	16:04	16:06
16A	4-15-08	106	15:26	15:28	15:28	15:30
16B	4-15-08	106	15:33	15:35	15:39	15:41
G19	4-15-08	106	13:48	13:51	13:51	13:53
U19	4-15-08	106	13:16	13:19	13:19	13:21
W19	4-15-08	106	12:11	12:14	12:14	12:16
G20	4-15-08	106	8:42	8:46	8:46	8:49
U20	4-15-08	106	10:26	10:28	10:28	10:30
20A	4-15-08	106	9:38	9:40	9:40	9:42
20B	4-15-08	106	9:51	9:53	9:55	9:57
115	4-15-08	106	15:04	15:06	15:06	15:08
117	4-15-08	106	14:14	14:16	14:16	14:18
118	4-15-08	106	12:53	12:55	12:55	12:57
119	4-15-08	106	11:01	11:03	11:10	11:12
120	4-15-08	106	8:11	8:14	8:14	8:17
14A	4-16-08	107	17:13	17:15	17:15	17:18
14B	4-16-08	107	17:26	17:28	17:28	17:30
G15	4-16-08	107	15:50	15:52	15:54	15:56
U15	4-16-08	107	16:27	16:29	16:30	16:32
W15	4-16-08	107	15:34	15:37	15:37	15:39
G16	4-16-08	107	13:52	13:54	13:54	13:56
U16	4-16-08	107	14:47	14:50	14:50	14:52
G17	4-16-08	107	12:41	12:43	12:44	12:46
U17	4-16-08	107	12:14	12:16	12:16	12:18
W17	4-16-08	107	11:31	11:34	11:34	11:36
G18	4-16-08	107	9:59	10:01	10:01	10:03
U18	4-16-08	107	10:19	10:21	10:21	10:23
W18	4-16-08	107	10:45	10:47	10:47	10:50

111	4-16-08	107	16:08	16:10	16:11	16:13
113	4-16-08	107	14:11	14:13	14:13	14:15
114	4-16-08	107	13:06	13:08	13:08	13:10
116	4-16-08	107	15:15	15:17	15:17	15:19
G8	4-17-08	108	15:53	15:55	15:56	15:58
U8	4-17-08	108	16:48	16:51	16:51	16:53
W8	4-17-08	108	16:14	16:16	16:16	16:18
G12	4-17-08	108	15:09	15:12	15:12	15:14
U12	4-17-08	108	13:44	13:47	13:47	13:49
12A	4-17-08	108	14:17	14:19	14:20	14:22
12B	4-17-08	108	14:28	14:30	14:30	14:32
G13	4-17-08	108	11:53	11:55	11:55	11:57
U13	4-17-08	108	12:13	12:15	12:15	12:17
13A	4-17-08	108	11:07	11:10	11:10	11:12
13B	4-17-08	108	11:19	11:21	11:21	11:23
G14	4-17-08	108	10:30	10:32	10:33	10:35
U14	4-17-08	108	9:58	10:00	10:00	10:02
107	4-17-08	108	15:37	15:39	15:39	15:41
108	4-17-08	108	13:22	13:25	13:25	13:27
112	4-17-08	108	7:39	7:41	7:41	7:43
17 A 1	4-18-08	109	11:48	11:51	11:52	11:54
A 100	4-18-08	109	8:24	8:26	8:27	8:29
G1	4-18-08	109	10:01	10:03	10:03	10:05
U1	4-18-08	109	9:33	9:36	9:36	9:38
W1	4-18-08	109	9:11	9:13	9:13	9:15
G2	4-18-08	109	11:02	11:04	11:04	11:06
U2	4-18-08	109	11:21	11:24	11:24	11:26
2A	4-18-08	109	10:28	10:30	10:30	10:32
2B	4-18-08	109	10:35	10:37	10:40	10:42
G3	4-18-08	109	13:42	13:45	13:45	13:47
U3	4-18-08	109	13:05	13:07	13:08	13:10
W3	4-18-08	109	14:02	14:05	14:05	14:07
G4	4-18-08	109	15:11	15:14	15:14	15:16
U4	4-18-08	109	14:50	14:52	14:52	14:54
W4	4-18-08	109	15:44	15:46	15:53	15:55
U5	4-18-08	109	16:31	16:34	16:34	16:36
101	4-18-08	109	8:54	8:56	8:56	8:58
102	4-18-08	109	14:27	14:29	14:29	14:31
103	4-18-08	109	16:07	16:10	16:10	16:12
U6	4-19-08	110	16:44	16:47	16:47	16:49
G9	4-19-08	110	15:59	16:02	16:02	16:04

U9	4-19-08	110	14:38	14:41	14:41	14:43
9A	4-19-08	110	15:11	15:14	15:14	15:16
9B	4-19-08	110	15:19	15:22	15:22	15:24
G10	4-19-08	110	14:15	14:17	14:17	14:19
U10	4-19-08	110	13:56	13:58	13:58	14:00
10A	4-19-08	110	12:41	12:43	12:43	12:45
10B	4-19-08	110	12:49	12:51	12:51	12:53
106	4-19-08	110	16:15	16:17	16:17	16:19
110	4-19-08	110	13:33	13:36	13:36	13:38
S 82	4-20-08	111	11:28	11:32	11:32	11:34
G5	4-20-08	111	14:10	14:13	14:13	14:15
W5	4-20-08	111	13:53	13:55	13:55	13:57
G6	4-20-08	111	13:34	13:37	13:37	13:39
W6	4-20-08	111	13:08	13:11	13:11	13:13
G7	4-20-08	111	12:10	12:13	12:13	12:15
U7	4-20-08	111	11:01	11:03	11:03	11:05
7A	4-20-08	111	10:20	10:22	10:22	10:24
7B	4-20-08	111	10:33	10:35	10:35	10:37
104	4-20-08	111	14:52	14:54	14:54	14:56
105	4-20-08	111	12:31	12:33	12:33	12:35

RE-OBSERVATIONS						
109	4-15-08	106	16:58	17:00		
G19	4-16-08	107	9:28	9:30		
U19	4-16-08	107	7:53	7:55		
W19	4-16-08	107	8:10	8:12		
G20	4-16-08	107	8:34	8:36		
U20	4-16-08	107	8:56	8:58		
U11	4-17-08	108	13:02	13:04		
G15	4-17-08	108	9:16	9:18		
U15	4-17-08	108	9:32	9:34		
U16	4-17-08	108	8:55	8:58		
W17	4-17-08	108	8:19	8:21		
115	4-17-08	108	8:37	8:40		
U8	4-19-08	110	12:19	12:21		
U12	4-19-08	110	11:22	11:24		
U13	4-19-08	110	10:58	11:00		
107	4-19-08	110	11:53	11:55		
U3	4-20-08	111	15:34	15:36		
U5	4-20-08	111	15:05	15:07		
U6	4-20-08	111	11:50	11:52		
101	4-20-08	111	15:56	15:58		

Appendix D Additional Control Points

Final Adjusted Coordinates, April 22/08					
New Jersey State Plane, NAD83 (Feet) / NAVD88 (Meters)					
Name	Northing (Ft)	Easting (Ft)	Elevation (M)	Description	Land Type
101	295132.51	228722.65	4.851	6" Nail	Open Terrain
102	262587.30	232397.22	5.830	6" Nail	Open Terrain
103	235217.68	217944.34	3.431	6" Nail	Open Terrain
104	222520.20	232461.98	1.592	6" Nail	Open Terrain
105	223925.11	259491.08	36.477	6" Nail	Open Terrain
106	190106.44	266174.91	1.885	6" Nail	Open Terrain
107	225902.78	313947.05	25.168	6" Nail	Open Terrain
108	229777.61	354809.68	27.427	6" Nail	Open Terrain
109	196478.65	330532.12	20.293	PK Nail	Open Terrain
110	159525.15	302630.55	2.667	6" Nail	Open Terrain
111	141530.25	352891.36	2.268	6" Nail	Open Terrain
112	196545.28	366832.68	10.371	6" Nail	Open Terrain
113	162411.41	391360.95	13.126	6" Nail	Open Terrain
114	163337.70	472502.95	1.885	6" Nail	Open Terrain
115	141413.65	412810.82	10.660	6" Nail	Open Terrain
116	135987.83	388775.65	3.419	6" Nail	Open Terrain
117	115378.07	417509.70	5.817	6" Nail	Open Terrain
118	96857.56	385639.33	4.453	6" Nail	Open Terrain
119	68931.62	407485.28	2.736	6" Nail	Open Terrain
120	51853.16	368134.43	4.127	PK Nail	Open Terrain