Hurricane Joaquin - Maryland Islands 2015 QL2 LiDAR Project Report

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1. Summary / Scope

1.1. Summary

This report contains a summary of the Hurricane Joaquin - Maryland Islands 2015 QL2 LiDAR acquisition task order, issued by USGS National Geospatial Technical Operations Center (NGTOC) under their Geospatial Products and Services Contract on November 6, 2015. The task order yielded a project area covering 80 square miles over the barrier islands along the coast of Maryland and Virginia. The intent of this document is only to provide specific validation information for the data acquisition/collection work completed as specified in the task order.

1.2. Scope

Aerial topographic LiDAR was acquired using state of the art technology along with the necessary surveyed ground control points (GCPs) and airborne GPS and inertial navigation systems. The aerial data collection was designed with the following specifications listed in Table 1 below.

Table 1. Originally Planned LiDAR Specifications

Average Point Density	Flight Altitude (AGL)	Field of View	Minimum Side Overlap	RMSEz
2.12 pts / m^2	2,051 - 2,075 m	40.0°	10.80%	≤ 10 cm

1.3. Coverage

The LiDAR project boundary covers 80 square miles and encompasses barrier islands along the coast of Worcester County, Maryland and Accomack County, Virginia. LiDAR extents are shown in Figure 1 on the following page. A buffer of 100-meters was created for this project.

1.4. Duration

LiDAR data was acquired from in one lift on November 26, 2015.

1.5. Issues

There were no issues with this project.

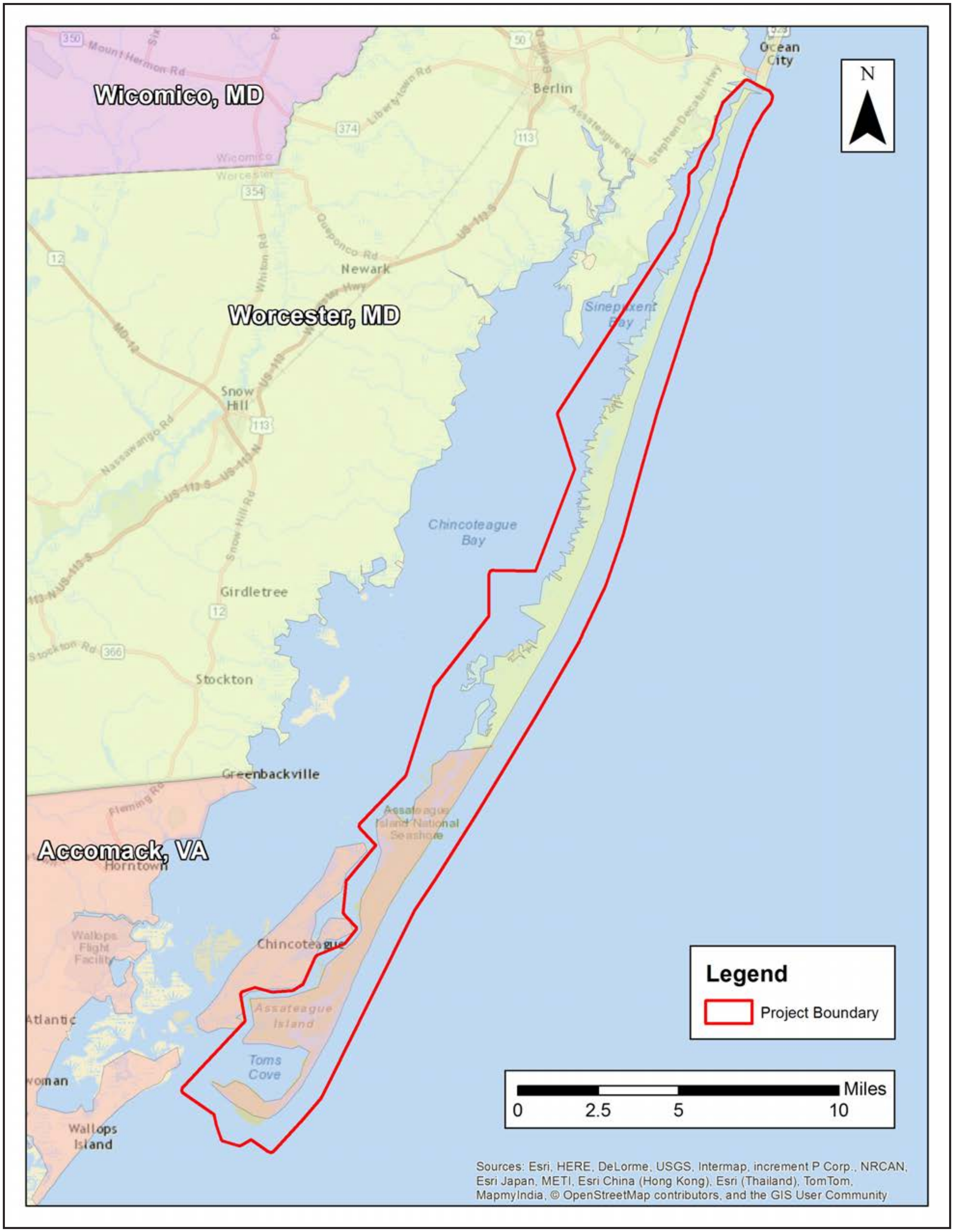
1.6. Deliverables

The following products were produced and delivered:

- Raw point cloud data in LAS 1.4 format
- Classified point cloud data in LAS 1.4 format
- 1-meter bare-earth raster DEM in ERDAS .IMG format
- Breaklines in Esri file geodatabase format
- 1-meter intensity images in GeoTIFF format
- Processing boundary in Esri shapefile format
- Tile index in Esri shapefile format

All geospatial deliverables were produced in NAD83 (2011) UTM Zone 18, meters; NAVD88 (Geoid 12A), meters). All tiled deliverables have a tile size of 1,500 meters x 1,500 meters, edge-match seamlessly in the horizontal and vertical without added overlap, and are named according to the US National Grid conventions.

Figure 1. Project Boundary



2. Planning / Equipment

2.1. Flight Planning

Flight planning was based on the unique project requirements and characteristics of the project site. The basis of planning included: required accuracies, type of development, amount / type of vegetation within project area, required data posting, and potential altitude restrictions for flights in project vicinity.

Detailed project flight planning calculations were performed for the project using Leica Mission Pro planning software. The entire target area was comprised of 20 planned flight lines measuring approximately 338.6 total flight line miles (Figure 2).

2.2. LiDAR Sensor

Quantum Spatial utilized a Leica ALS 70 LiDAR sensor (Figure 3), serial number 7161, during the project. The system is capable of collecting data at a maximum frequency of 500 kHz, which affords elevation data collection of up to 500,000 points per second. The system utilizes a Multi-Pulse in the Air option (MPIA). The 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 returns is also captured during aerial acquisition.

A brief summary of the aerial acquisition parameters for the project are shown in the LiDAR System Specifications in Table 2.

Figure 2. Planned LiDAR Flight Lines

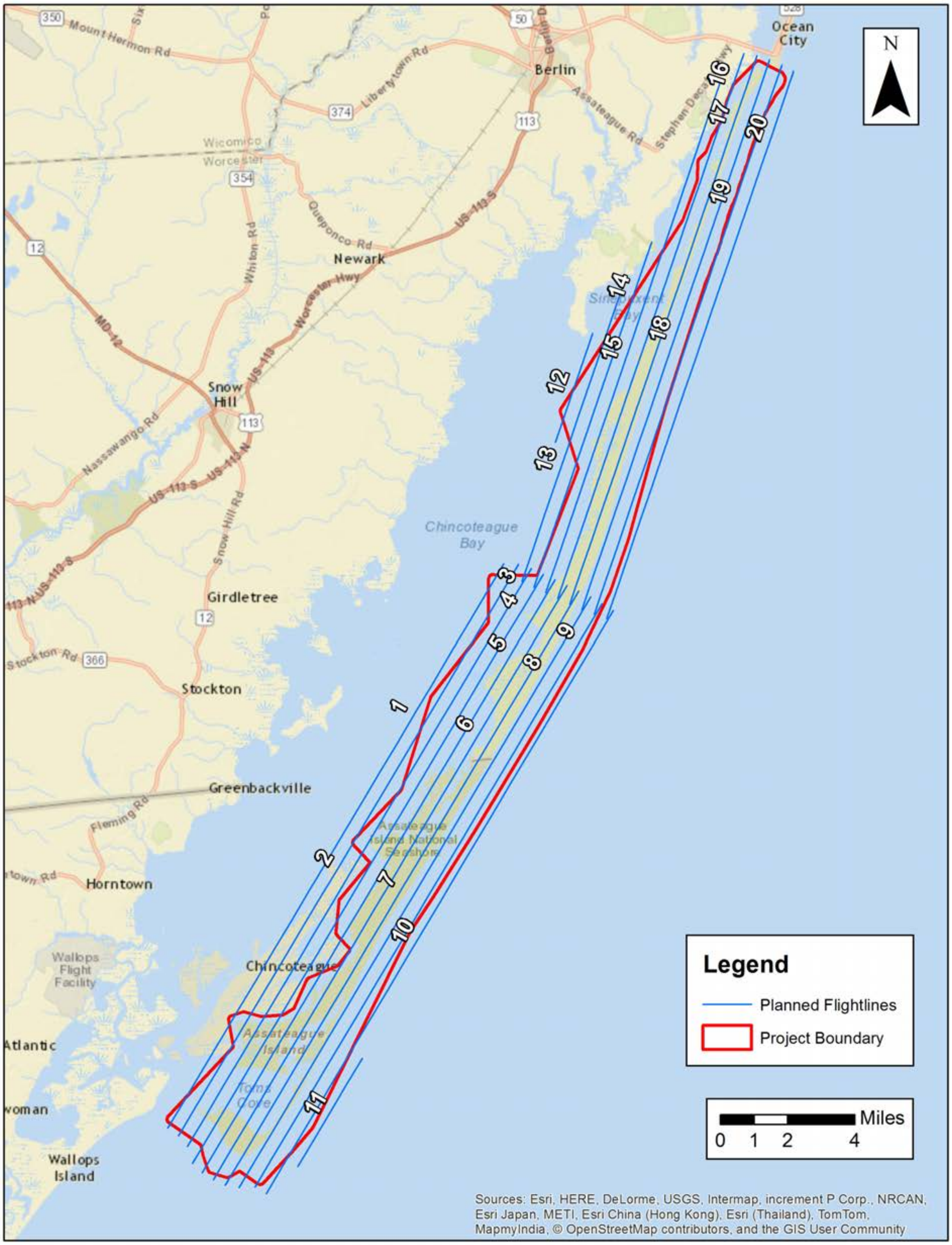


Figure 3. Leica ALS 70 LiDAR Sensor

Table 2. Lidar System Specifications

Terrain and Aircraft Scanner	Flying Height	2,051 m
	Recommended Ground Speed	160 kts
Scanner	Field of View	40°
	Scan Rate Setting Used	53.4 Hz
Laser	Laser Pulse Rate Used	263.4 kHz
	Multi Pulse in Air Mode	Enabled
Coverage	Full Swath Width	1,510.48 m
	Line Spacing	1,131.77 m
Point Spacing and Density	Maximum Point Spacing Along Track	1.33 m
	Maximum Point Spacing Along Track	1.54 m
	Average Point Density	2.12 pts / m^2

2.4. Aircraft

All flights for the project were accomplished through the use of a customized Piper Navajo (twin-piston), Tail # N6GR. This aircraft provided an ideal, stable aerial base for LiDAR acquisition. This aerial platform has relatively fast cruise speeds which are beneficial for project mobilization / demobilization, while maintaining relatively slow stall speeds which proved ideal for collection of high-density, consistent data posting using a state-of-the-art LiDAR system. Some of Quantum Spatial's operating aircraft can be seen in Figure 4 below.

Figure 4. Some of Quantum Spatial's Planes

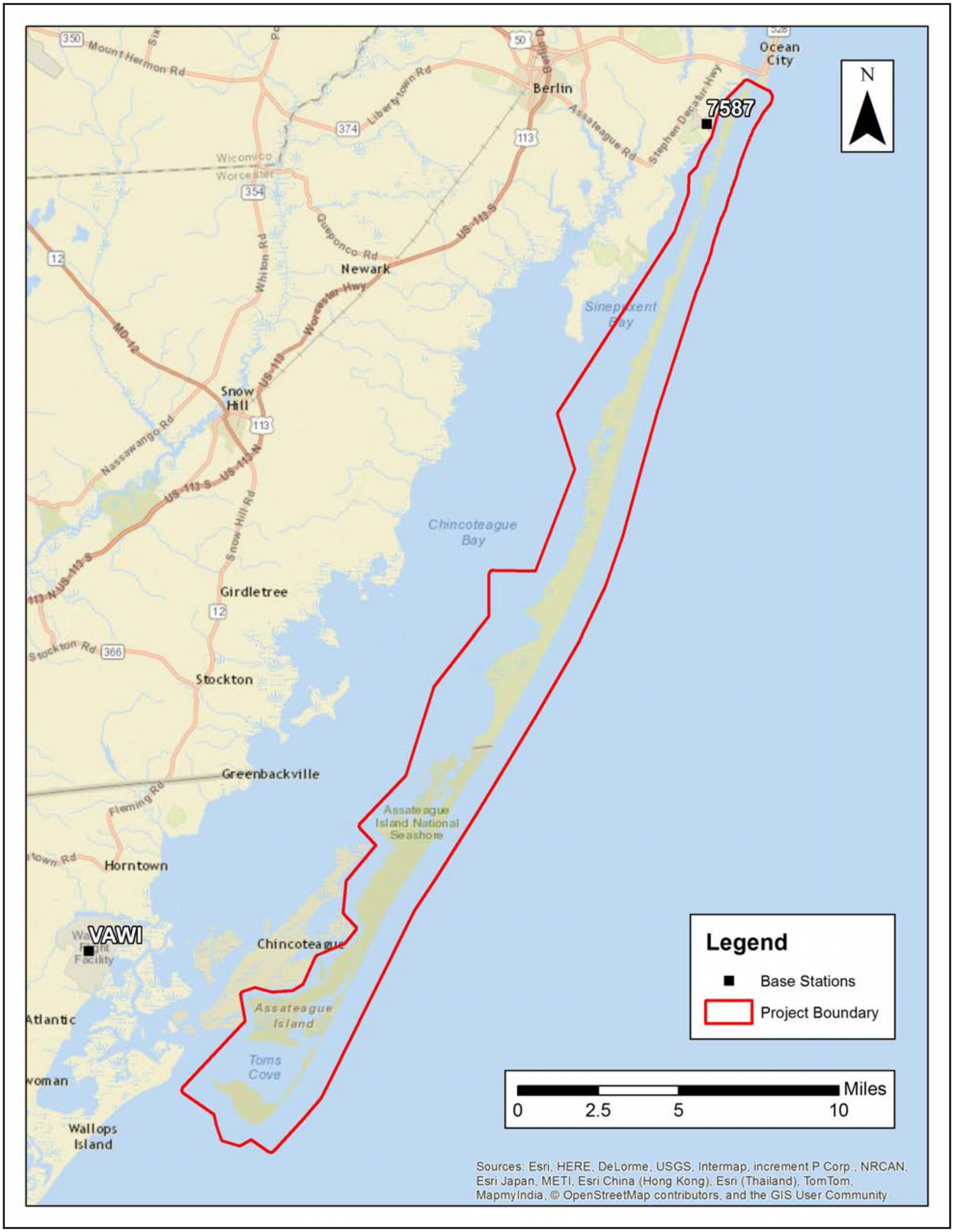
2.4. Base Station Information

GPS base stations were utilized during all phases of flight (Table 3). The base station locations were verified using NGS OPUS service and subsequent surveys. Base station locations are depicted in Figure 5. Data sheets, graphical depiction of base station locations or log sheets used during station occupation are available in Appendix A.

Table 3. Base Station Locations

Base Station	Latitude	Longitude	Ellipsoid Height (m)
7587	38° 18’ 33.16170”	75° 7’ 8.73333”	-33.967
VAWI	37° 56’ 3.49970”	75° 28’ 15.94918”	-22.324

Figure 5. Base Station Locations



3. Processing Summary

3.1. Flight Logs

Flight logs are completed by LIDAR sensor technicians for each mission during acquisition. These logs depict a variety of information, including:

- Job / Project #
- Flight Date / Lift Number
- FOV (Field of View)
- Scan Rate (HZ)
- Pulse Rate Frequency (Hz)
- Ground Speed
- Altitude
- Base Station
- PDOP avoidance times
- Flight Line #
- Flight Line Start and Stop Times
- Flight Line Altitude (AMSL)
- Heading
- Speed
- Returns
- Crab

Notes: (Visibility, winds, ride, weather, temperature, dew point, pressure, etc). Project specific flight logs for each sortie are available in Appendix A.

3.2. LiDAR Processing

Applanix + POSPac Mobile Mapping Suite software was used for post-processing of airborne GPS and inertial data (IMU), which is critical to the positioning and orientation of the LiDAR sensor during all flights. POSPac combines aircraft raw trajectory data with stationary GPS base station data yielding a "Smoothed Best Estimate Trajectory (SBET) necessary for additional post processing software to develop the resulting geo-referenced point cloud from the LiDAR missions.

During the sensor trajectory processing (combining GPS & IMU datasets) certain statistical graphs and tables are generated within the Applanix POSPac processing environment which are commonly used as indicators of processing stability and accuracy. This data for analysis include: Max horizontal / vertical GPS variance, separation plot, altitude plot, PDOP plot, base station baseline length, processing mode, number of satellite vehicles, and mission trajectory. All relevant graphs produced in the POSPac processing environment for each sortie during the project mobilization are available in Appendix A.

The generated point cloud is the mathematical three dimensional composite of all returns from all laser pulses as determined from the aerial mission. Laser point data are imported into TerraScan and a manual calibration is performed to assess the system offsets for pitch, roll, heading and scale. 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. Point clouds were created using the Leica ALS Post Processor software. GeoCue distributive processing software was used in the creation of some files needed in downstream processing, as well as in the tiling of the dataset into more manageable file sizes. TerraScan and TerraModeler software packages were then used for the automated data classification, manual cleanup, and bare earth generation. Project specific macros were developed to classify the ground and remove side overlap between parallel flight lines.

All data will manually be reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler. Global Mapper will be used as a final check of the bare earth dataset. GeoCue was used to create the deliverable industry-standard LAS files for both the All Point Cloud Data and the Bare Earth. In-house software will then used to perform final statistical analysis of the classes in the LAS files.

3.3. LAS Classification Scheme

The classification classes are determined by the USGS Version 1.2 specifications and are an industry standard for the classification of LIDAR point clouds. All data starts the process as Class 1 (Unclassified), and then through automated classification routines, the classifications are determined using TerraScan macro processing.

The classes used in the dataset are as follows and have the following descriptions:

- Class 1 – Processed, but Unclassified – These points would be the catch all for points that do not fit any of the other deliverable classes. This would cover features such as vegetation, cars, etc.
- Class 2 – Bare earth ground – This is the bare earth surface
- Class 7 – Low Noise – Low points, manually identified above or below the surface that could be noise points in point cloud.
- Class 9 – In-land Water – Points found inside of inland lake/ponds
- Class 10 – Ignored Ground – Points found to be close to breakline features. Points are moved to this class from the Class 2 dataset. This class is ignored during the DEM creation process in order to provide smooth transition between the ground surface and hydro flattened surface.
- Class 17 – Bridge Decks – Points falling on bridge decks.
- Class 18 – High noise – High points, manually identified above or below the surface that could be noise points in point cloud.

3.4. Classified LAS Processing

The bare earth surface is then manually reviewed to ensure correct classification on the Class 2 (Ground) points. After the bare-earth surface is finalized, it is then used to generate all hydro-breaklines through heads-up digitization.

All ground (ASPRS Class 2) LiDAR data inside of the Lake Pond and Double Line Drain hydro flattening breaklines were then classified to water (ASPRS Class 9) using TerraScan macro functionality. A buffer of 1 meter was also used around each hydro-flattened feature to classify these ground (ASPRS Class 2) points to Ignored ground (ASPRS Class 10). All Lake Pond Island and Double Line Drain Island features were checked to ensure that the ground (ASPRS Class 2) points were reclassified to the correct classification after the automated classification was completed. All bridge decks were classified to Class 17.

All overlap data was processed through automated functionality provided by TerraScan to classify the overlapping flight line data to approved classes by USGS. The overlap data was identified using the Overlap Flag, per LAS 1.4 specifications.

All data was manually reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler. Global Mapper us used as a final check of the bare earth dataset. GeoCue was then used to create the deliverable industry-standard LAS files for both the All Point Cloud Data and the Bare Earth. Quantum Spatial proprietary software was used to perform final statistical analysis of the classes in the LAS files, on a per tile level to verify final classification metrics and full LAS header information.

3.5. Breakline Creation

Class 2 LiDAR was used to create a bare earth surface model. The surface model was then used to heads-up digitize 2D breaklines of inland streams and rivers with a 30 meter nominal width and Inland Ponds and Lakes of 2 acres or greater surface area, as well as the ocean shoreline.

Elevation values were assigned to all Inland Ponds and Lakes, Inland Pond and Lake Islands, Inland Stream and River Islands and Ocean Shorelines using TerraModeler functionality.

Elevation values were assigned to all Inland streams and rivers using Quantum Spatial proprietary software.

All ground (ASPRS Class 2) LiDAR data inside of the collected inland breaklines were then classified to water (ASPRS Class 9) using TerraScan macro functionality. A buffer of 1 meter was also used around each hydro-flattened feature. These points were moved from ground (ASPRS Class 2) to Ignored Ground (ASPRS Class 10).

The breakline files were then translated to Esri file geodatabase format using Esri conversion tools.

3.6. Bare-Earth Raster DEM Creation

Class 2 LiDAR was used to create a 1-meter Bare Earth Raster DEM. Using automated scripting routines within ArcMap, an ERDAS .IMG file was created for each tile. Each surface is reviewed using Global Mapper to check for any surface anomalies or incorrect elevations found within the surface.

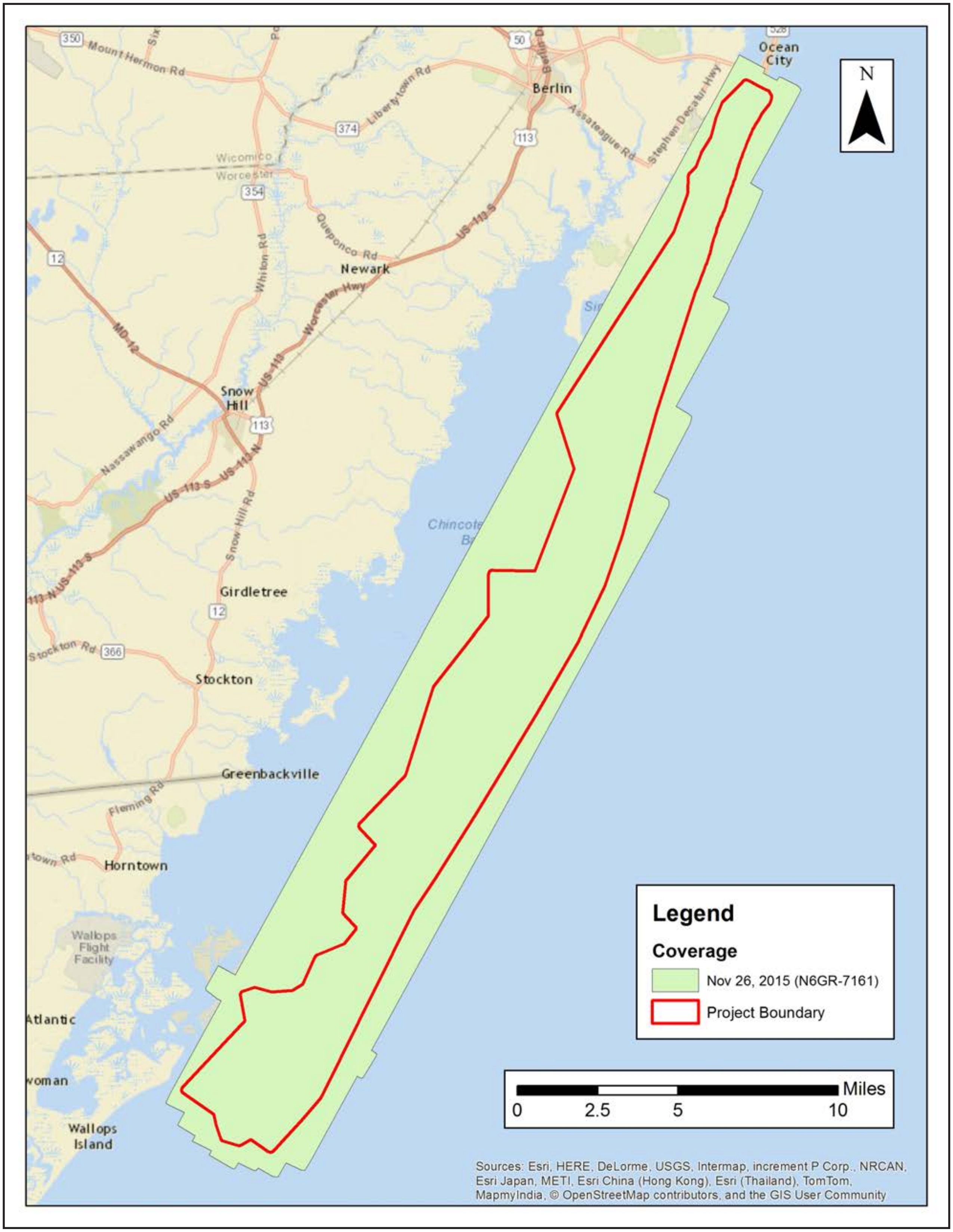
3.7. Intensity Image Creation

GeoCue software was used to create the deliverable Intensity Images with a 1 meter cell size. All overlap classes were ignored during this process. This helps to ensure a more aesthetically pleasing image. The GeoCue software was then used to verify full project coverage as well. TIF/TWF files were then provided as the deliverable for this dataset requirement.

4. Project Coverage Verification

Coverage verification was performed by comparing coverage of processed .LAS files captured during project collection to generate project shape files depicting boundaries of specified project areas. Please refer to Figure 6.

Figure 6. Flightline Swath LAS File Coverage



5. Ground Control and Check Point Collection

A total of 33 control points, 8 ground control (calibration) points and 25 QA points in Vegetated and Non-Vegetated land cover classifications were used as an independent test of the accuracy of this project. Control points were provided by the client.

Figure 7 shows the location of each bare earth calibration point for the project area. Table 4 depicts the Control Report for the LiDAR bare earth calibration points, as computed in TerraScan as a quality assurance check. Note that these results of the surface calibration are not an independent assessment of the accuracy of these project deliverables, but the statistical results do provide additional feedback as to the overall quality of the elevation surface.

In this document, horizontal coordinates for ground control and QA points for all LiDAR classes are reported in NAD83 (2011) UTM Zone 18, meters; NAVD88 (Geoid 12A), meters.

The required accuracy testing was performed on the LiDAR dataset (both the LiDAR point cloud and derived DEM's) according to the USGS LiDAR Base Specification Version 1.2 (2014). The summary below provides the results of this testing.

5.1. Point Cloud Testing

Raw Nonvegetated Vertical Accuracy (Raw NVA): The tested Raw NVA for the dataset was found to be 4.1 cm in terms of the RMSEz. The resulting NVA stated as the 95% confidence level (RMSEz x 1.96) is 8.0 cm. This dataset meets the required FVA of ≤ 19.6 cm at the 95% confidence level (according to the National Standard for Spatial Database Accuracy (NSSDA)), based on TINs derived from the final calibrated and controlled LiDAR swath data. See Figure 8 and Table 5.

5.2. Digital Elevation Model (DEM) Testing

The tested Non-Vegetated Vertical Accuracy (NVA) for the dataset captured from the DEM using bi-linear interpolation to derive the DEM elevations was found to be 0.042 meters in terms of the RMSEz. The resulting accuracy stated as the 95% confidence level (RMSEz x 1.96) is 8.2 cm. This dataset meets the required NVA of ≤ 19.6 cm at the 95% confidence level (based on NSSDA). See Figure 8 and Table 6.

The tested Vegetated Vertical Accuracy (VVA) for the dataset captured from the DEM using bi-linear interpolation for all classes (including the bare earth class) was found to be 18.5 cm, which is stated in terms of the 95th percentile error. Therefore the data meets the required VVA of ≤ 29.4 cm. This test was based on the 95th percentile error (based on ASPRS guidelines) across all land cover categories. See Figure 9 and Table 7.

Figure 7. Calibration Point Locations

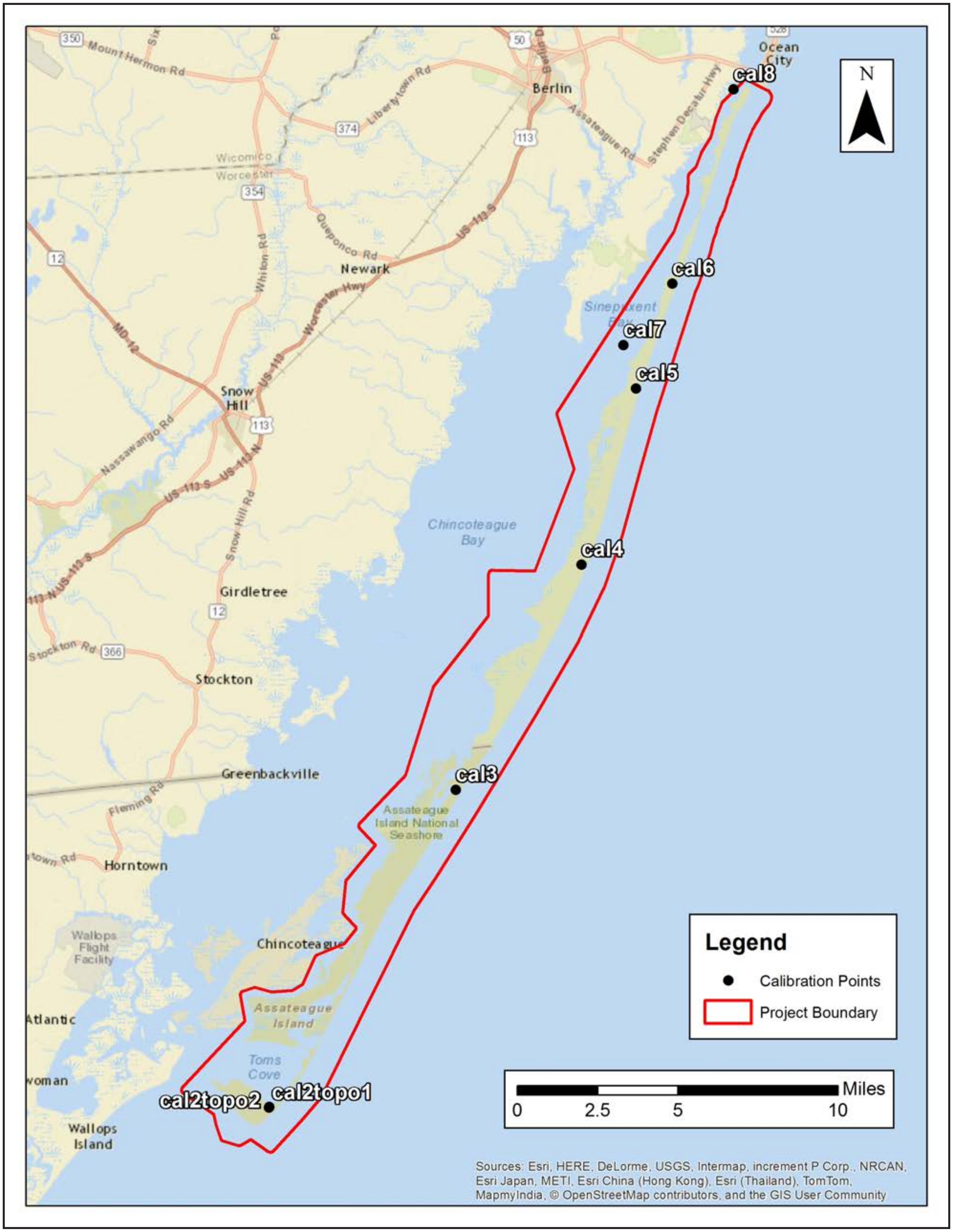


Figure 8. NVA Point Locations

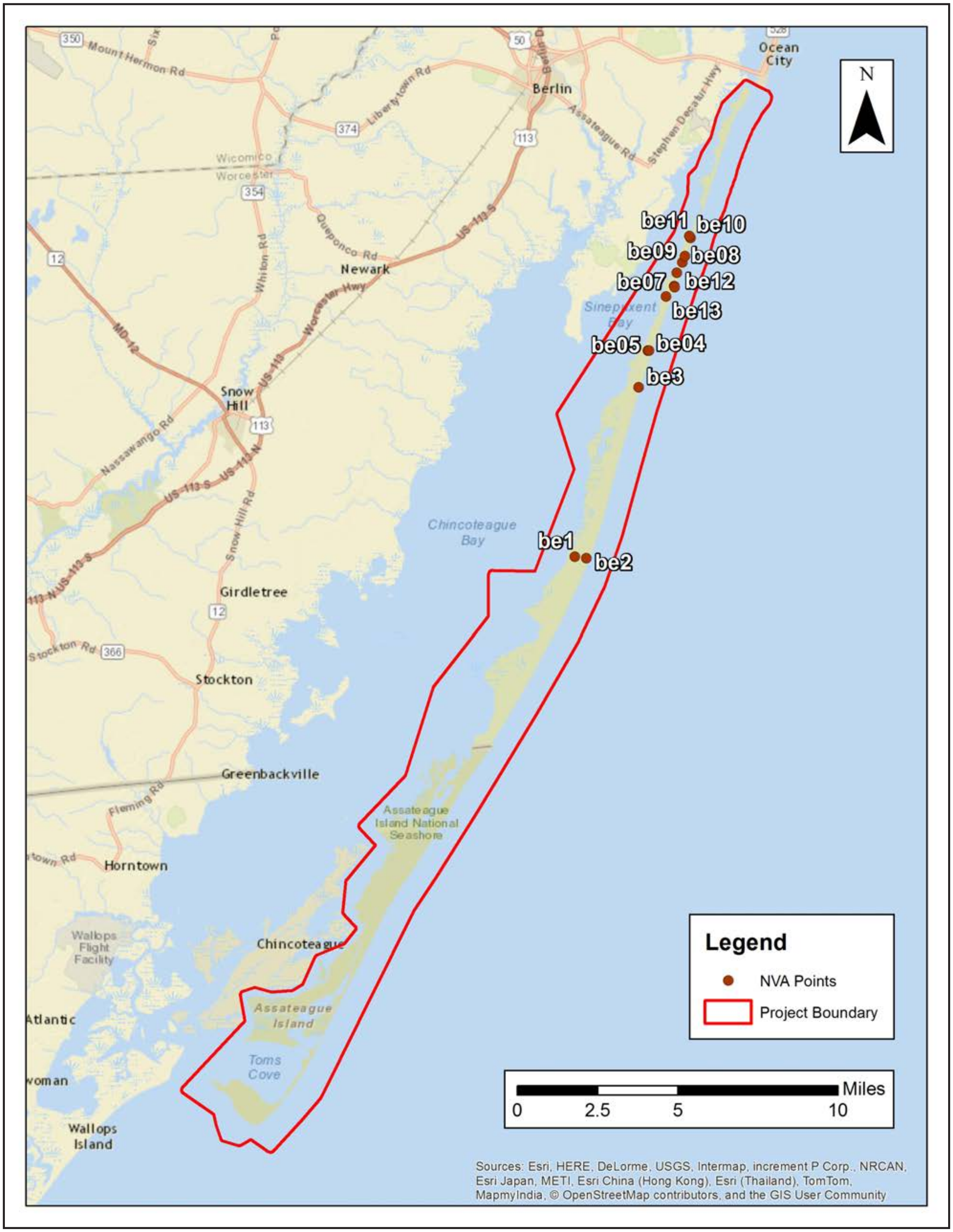


Figure 9. VVA Point Locations

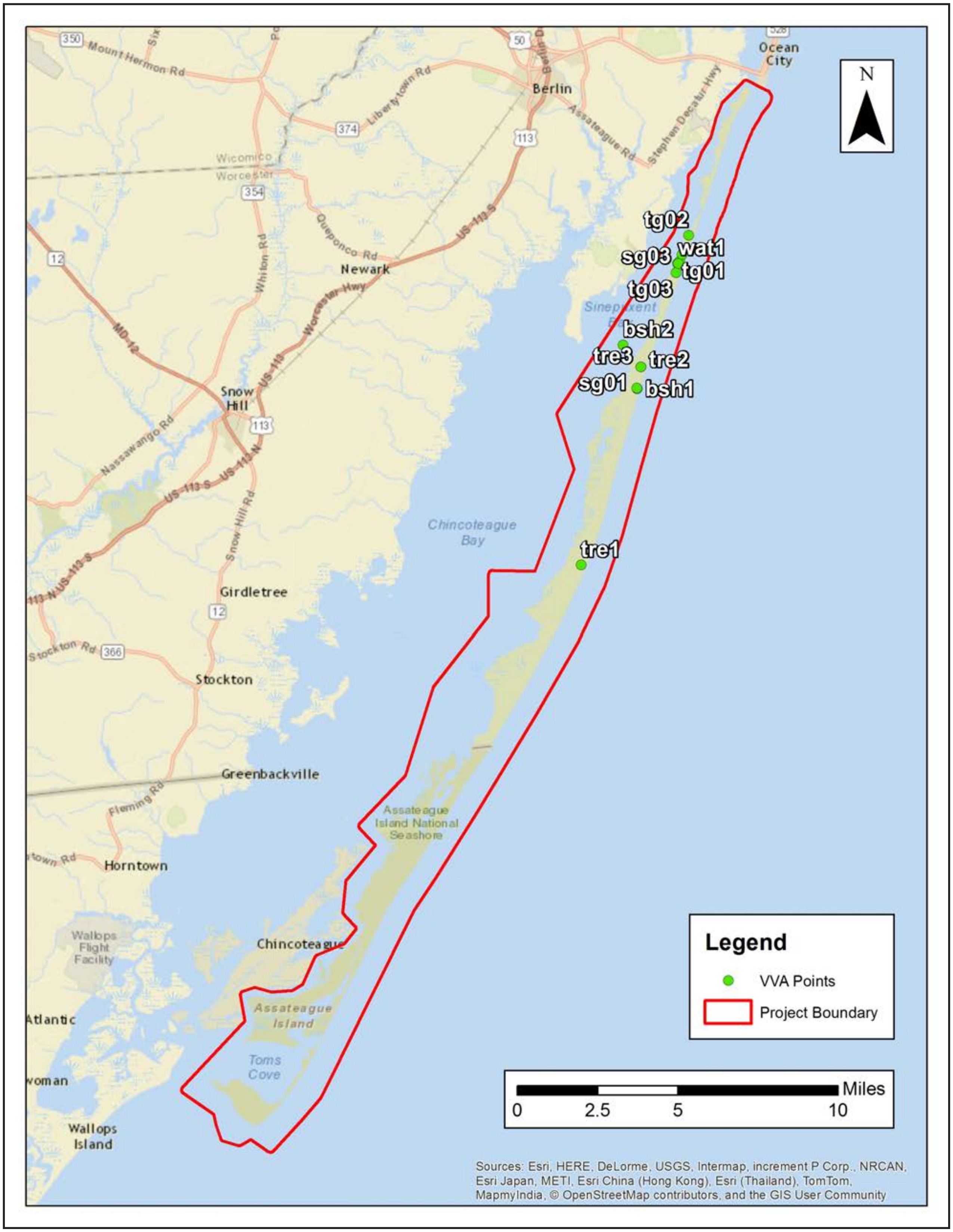


Table 4. Calibration Point Report

Units = meters

Number	Easting	Northing	Known Z	Laser Z	Dz
cal2topo1	467637.273	4190754.007	1.39	1.35	-0.04
cal2topo2	467664.816	4190794.837	1.39	1.35	-0.04
cal3	477030.552	4206716.210	1.05	0.92	-0.13
cal4	483342.509	4217988.771	1.07	1.07	0.00
cal5	486072.644	4226828.877	1.47	1.58	0.11
cal6	487894.474	4232104.434	1.54	1.52	-0.01
cal7	485448.477	4229014.286	1.29	1.30	0.01
cal8	490971.050	4241855.860	2.35	2.46	0.11
	Average Dz	0.00 m			
	Minimum Dz	-0.132 m			
	Maximum Dz	0.114 m			
	Root Mean Square	0.076 m			
	Std. Deviation	0.081 m			

Table 5. Raw NVA Point Report

Units = meters

Number	Easting	Northing	Known Z	Laser Z	Dz
be1	483007.037	4218395.047	0.37	0.35	-0.022
be2	483586.238	4218330.303	1.16	1.14	-0.02
be3	486197.164	4226907.636	2.34	2.34	-0.001
be04	486676.600	4228746.856	2.56	2.62	0.063
be05	486719.994	4228749.287	2.71	2.7	-0.008
be06	487986.787	4231995.362	1.55	1.49	-0.058
be07	488007.258	4231937.842	4.69	4.66	-0.029
be08	488408.332	4233182.337	1.59	1.57	-0.021
be09	488536.337	4233489.933	1.75	1.66	-0.092
be10	488811.537	4234402.467	2.07	2.04	-0.034
be11	488755.205	4234499.019	0.79	0.77	-0.023
be12	488114.134	4232663.279	1.44	1.4	-0.041
be13	487588.173	4231474.128	0.98	0.96	-0.019

Average Dz	-0.02 m
Minimum Dz	-0.092 m
Maximum Dz	0.063 m
Root Mean Square	0.041 m
95% Confidence	0.080 m

Table 6. NVA Point Report

Units = meters

Number	Easting	Northing	Known Z	Laser Z	Dz
be1	483007.037	4218395.047	0.37	0.33	-0.04
be2	483586.238	4218330.303	1.16	1.21	0.05
be3	486197.164	4226907.636	2.34	2.35	0.01
be04	486676.600	4228746.856	2.56	2.63	0.07
be05	486719.994	4228749.287	2.71	2.69	-0.01
be06	487986.787	4231995.362	1.55	1.49	-0.06
be07	488007.258	4231937.842	4.69	4.66	-0.03
be08	488408.332	4233182.337	1.59	1.55	-0.04
be09	488536.337	4233489.933	1.75	1.68	-0.07
be10	488811.538	4234402.467	2.07	2.05	-0.02
be11	488755.205	4234499.019	0.79	0.78	-0.02
be12	488114.134	4232663.279	1.44	1.40	-0.04
be13	487588.173	4231474.128	0.98	0.96	-0.02

Average Dz	-0.02 m
Minimum Dz	-0.070 m
Maximum Dz	0.072 m
Root Mean Square	0.042 m
95% Confidence	0.082 m

Table 7. VVA Point Report

Units = meters

Number	Easting	Northing	Known Z	Laser Z	Dz
bsh1	486121.447	4226839.358	0.95	1.08	0.13
bsh2	485424.990	4229024.048	0.80	0.96	0.16
sg01	486106.380	4226872.161	0.91	1.01	0.10
sg02	488154.794	4233124.008	0.21	0.31	0.11
sg03	488263.027	4233231.747	0.81	0.92	0.11
tg01	488390.525	4233578.941	0.27	0.38	0.11
tg02	488710.918	4234540.828	0.35	0.48	0.13
tg03	488083.360	4232662.956	1.27	1.28	0.00
tre1	483322.108	4217980.708	0.73	0.92	0.19
tre2	486316.711	4227937.105	1.02	1.17	0.15
tre3	486316.765	4227937.178	1.05	1.17	0.12
wat1	488193.669	4233128.545	-0.08	0.10	0.18

Average Dz	0.12 m
Minimum Dz	0.002 m
Maximum Dz	0.193 m
Root Mean Square	0.133 m
95th Percentile	0.185 m