United States Virgin Islands LiDAR Data Acquisition and Processing

Post-Flight Aerial Acquisition and Calibration Report

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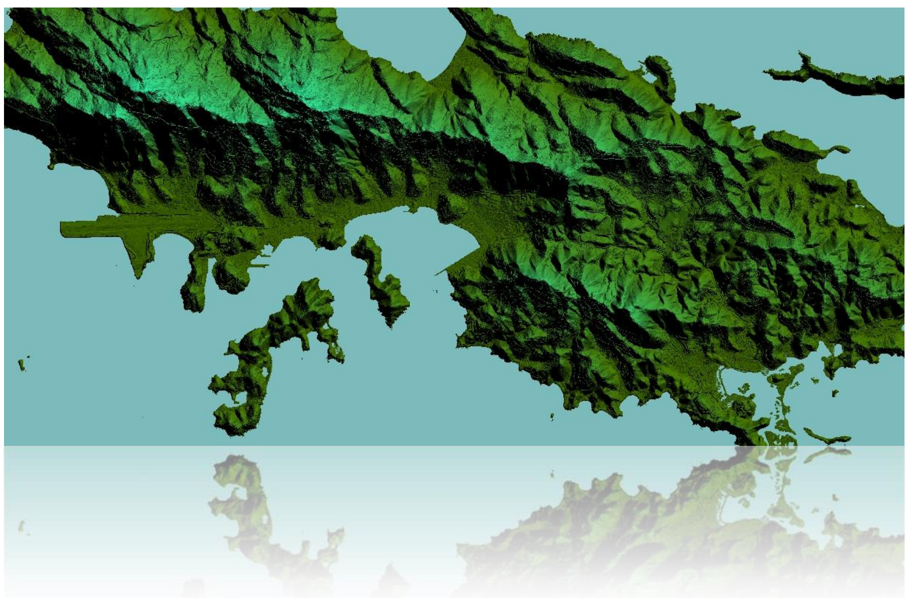

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1. SUMMARY / SCOPE

1.1. SUMMARY

This report contains a summary of the United States Virgin Islands (USVI) Topographic LiDAR acquisition task order, issued by the NOAA Coastal Services Center. A separate but related task order was issued by the NOAA Coastal Services Center and the National Geodetic Survey for topographic and bathymetric LiDAR data in coastal areas of Rhode Island and Massachusetts. The intent of this document is to only provide specific validation information for the LiDAR data acquisition/collection work completed for the United States Virgin Islands portion of the project.

1.2. SCOPE

The scope of the United States Virgin Islands LiDAR task order included the acquisition of aerial topographic LiDAR using state of the art technology, along with necessary surveyed ground control points (GCPs) and airborne GPS and inertial navigation systems, for the islands of Saint Thomas, Saint John, Saint Croix and various smaller outlying islands and islets. The aerial data collection was designed with the following specifications listed in Table 1 below.

Table 1. Originally Planned LiDAR Specifications

LiDAR				
Average Point Density	**Flight Altitude (AGL)**	**Field of View**	**Side Overlap**	**RMSEz**
2.0 pts / m^2	3,800 ft	40.0 degrees	25%	9.25 cm or better

1.3. LOCATION / COVERAGE

The United States Virgin Islands LiDAR project boundary consists of two main areas of interest, one encompassing the islands of Saint Thomas and Saint John and the other encompassing the island of Saint Croix. The project area totals approximately 140 square miles as shown in Figures 1 and 2 on the following page.

Figure 1. Saint Thomas and Saint John LiDAR Project Boundary

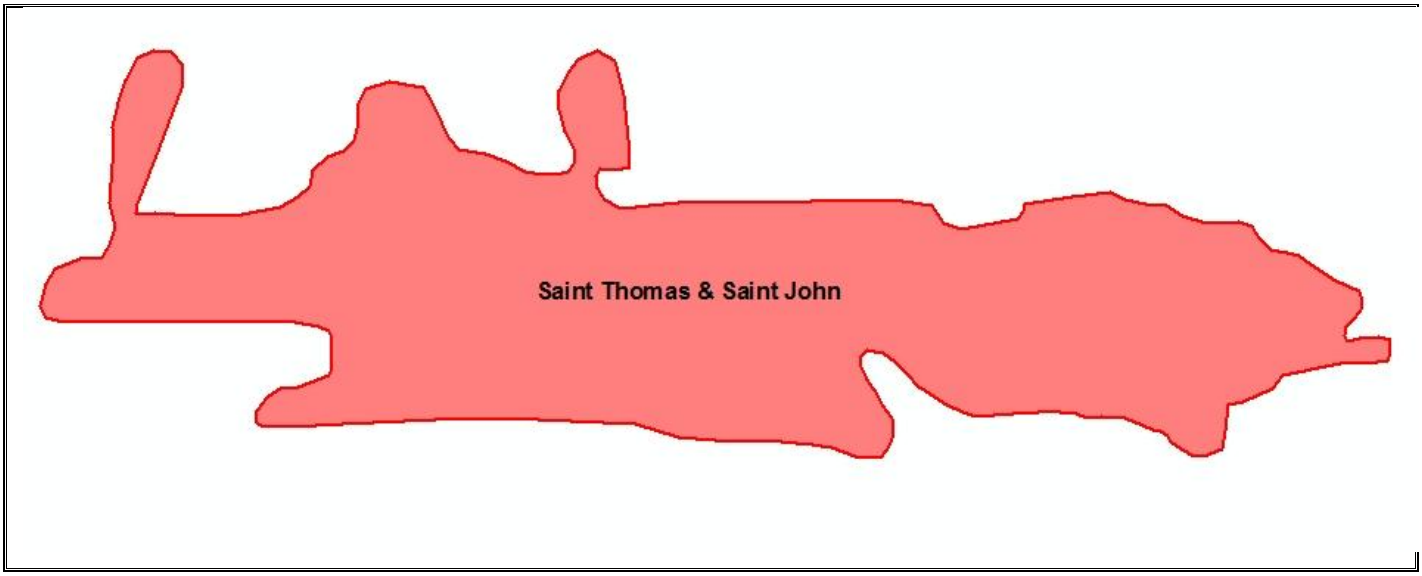
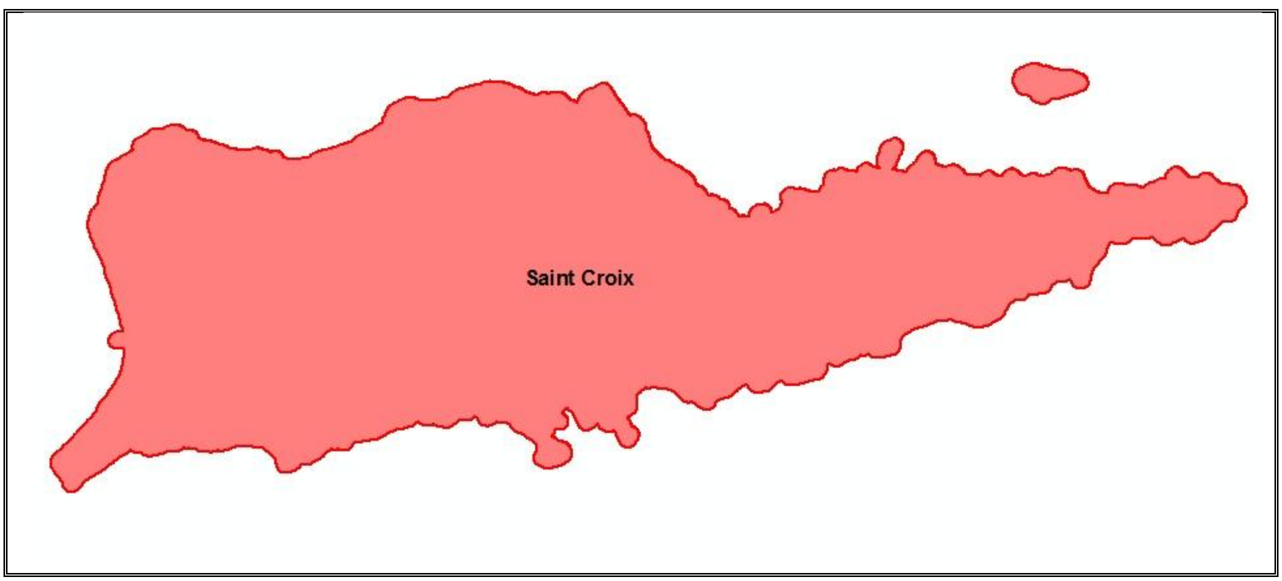


Figure 2. Saint Croix LiDAR Project Boundary



1.4. DURATION

The data was acquired over a span of about a month from November 9th, 2013 to December 10th, 2013. The islands of Saint Thomas and Saint John were acquired between November 9th, 2013 and November 19th, 2013. The island of Saint Croix was acquired between November 27th, 2013 and December 10th, 2013.

1.5. ISSUES

The primary issue of concern with this task order was the overall weather conditions during the time Photo Science was on-site in the United States Virgin Islands. Clouds and rain were a frequent occurrence and numerous lines required a re-flight due to clouds being present.

2. PLANNING / EQUIPMENT

The entire target area was comprised of 88 planned flight lines and approximately 1,669 flight line kilometers. Please refer to Figures 3 and 4 below and on the following page.

Figure 3. Saint Thomas & Saint John Planned Flight Lines

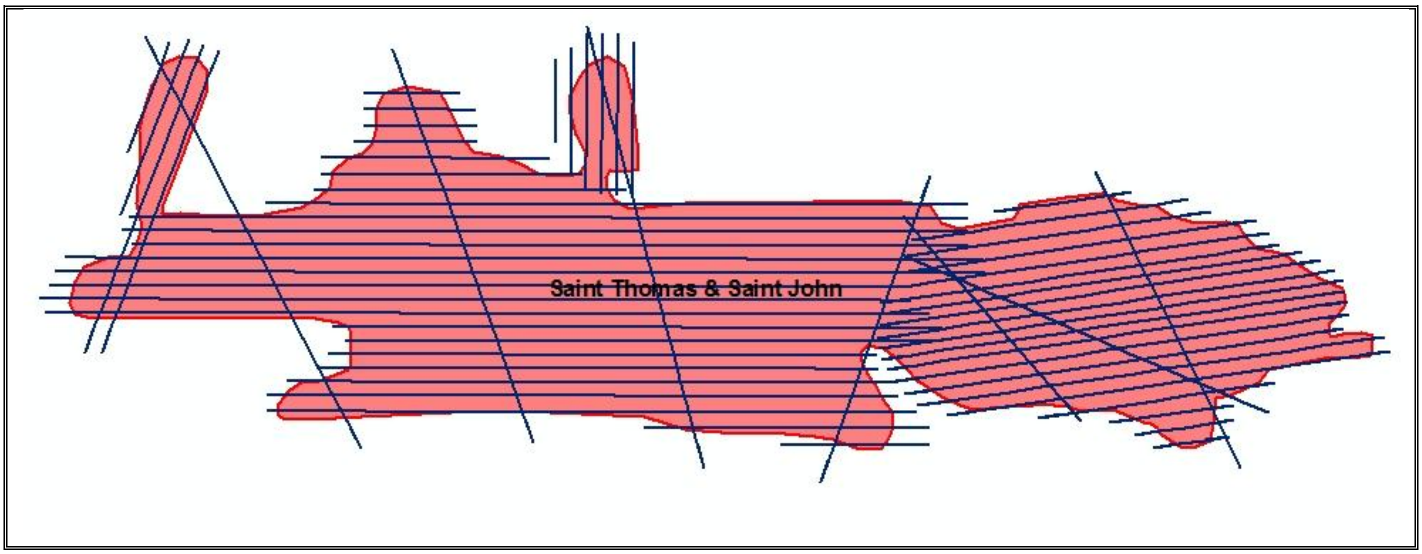
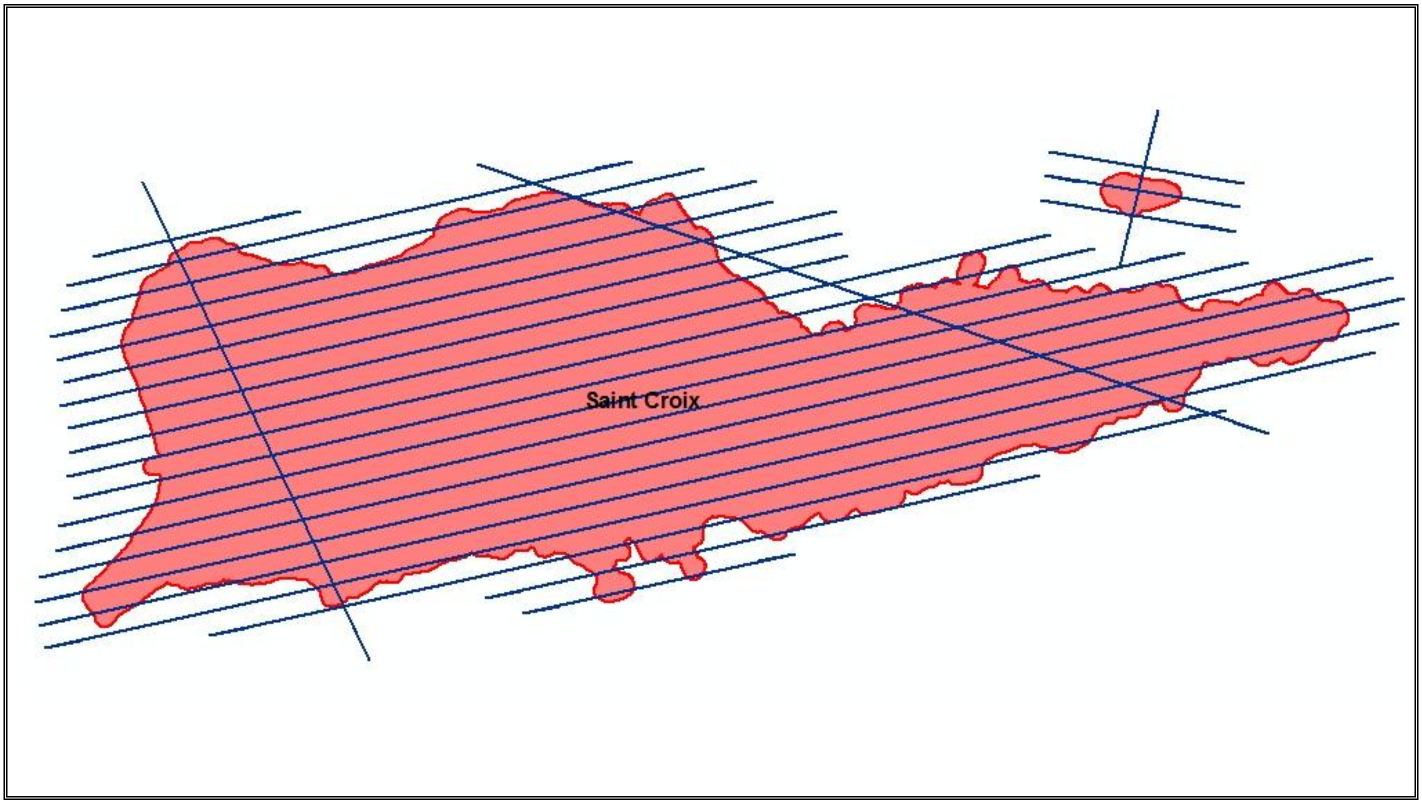


Figure 4. Saint Croix Planned Flight Lines



Detailed project flight planning calculations were performed for the United States Virgin Islands project using Leica Mission Pro planning software. 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. A brief summary of the aerial acquisition parameters for the project are shown in the LiDAR System Specification Table 2 below:

Table 2. LiDAR System Specifications

LiDAR System Specifications	
Terrain and Aircraft	**Flying Height AGL:** 3800 feet
	Recommended Ground Speed (GS): 140 kts
Scanner	**Field of View (FOV):** 40 degrees
	Scan Rate Setting used (SR): 56.8 Hz
Laser	**Laser Pulse Rate used:** 465,400 Hz
	Multi Pulse in Air Mode: Enabled
Coverage	**Full Swath Width:** 842.96 meters
	Line Spacing (No DTM): 730.25 meters
Point Spacing and Density	**Maximum Point Spacing Across Track:** 0.63 m
	Maximum Point Spacing Along Track: 0.63 m
	Average Point Density: 7.67 pts / m^2

2.1. EQUIPMENT: AIRCRAFT

All flights for the United States Virgin Islands project were accomplished through the use of a customized twin-engine Cesna U206G (Tail # N799AC).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 Leica LiDAR system.

2.2. LIDAR SENSOR

Photo Science utilized a Leica ALS70 LiDAR sensor, serial number 7169 during the project. The system utilizes a Multi-Pulse in the Air option (MPIA). This sensor is also equipped with the ability to measure up to 5 returns per outgoing pulse from the laser and these come in the form of 1st, 2nd, 3rd, 4th, and last returns. The intensity of the first four returns is also captured during aerial acquisition. During mission collection of the United States Virgin Islands project the LiDAR operator monitored point density and swath to ensure data integrity and desired coverage were obtained.

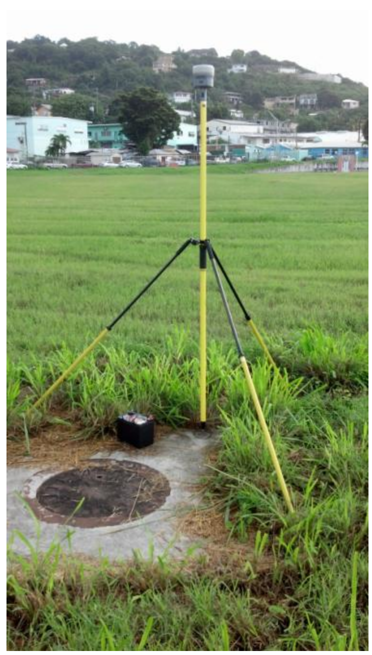
Figure 5. Leica ALS70 LiDAR System

2.3. BASE STATION INFORMATION

A GPS base station was utilized during all phases of flight. Base station “STX C” was occupied during airborne operations of the Saint Croix portion of the project. Base station “STT F” was occupied during airborne operations of the Saint Thomas/Saint John portion of the project. The base station location was verified using NGS OPUS service and subsequent surveys. Please refer to Figures 6 and 7 on the following page for images of each base station. Data sheets, graphical depiction of base station locations and log sheets used during station occupation are available in Appendix A.

Figure 6. **STC X Base Station**

Figure 7. STT F Base Station



2.4. TIME PERIOD

Project specific flights were conducted over (30) days. Fifteen sorties, or aircraft lifts were completed. Accomplished sorties are listed below:

- M1_20131110A
- M2_20131110B
- M3_20131111
- M4_20131114
- M5_20131115
- M6_20131116
- M9_20131119A
- M10_20131119B
- M1_20131127A
- M2_20131127B
- M3_20131129
- M4_20131203
- M5_20131209A
- M6_20131209B
- M7_20131210

3. PROCESSING SUMMARY

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.

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 will then be 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. All graphic statistical analysis will be provided within the Final Report.

3.1. FLIGHT LOGS

Flight logs were 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 B.

3.2. LAS CLASSIFICATION SCHEME

The classification classes are determined by the USGS Version 1.0 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 things like vegetation, buildings, cars, bridges, etc.
- Class 2 – Bare earth ground – This is the bare earth surface
- Class 7 – Noise – Low or high points, manually identified above or below the surface that could be noise points in point cloud.
- Class 9 – Water – Points found inside of inland lake/ponds
- Class 10 – Ignored Ground – Points found to be close to breakline features. Points are typically moved to this class from Class 2. This class is ignored during the DEM creation.
- Class 17 – Overlap Default (Unclassified) – Points found in the overlap between flight lines. These points are created through automated processing methods and not cleaned up during processing.
- Class 18 – Overlap Bare-earth ground – Points found in the overlap between flight lines. These points are created through automated processing, matching the specifications determined during the automated process, that are close to the Class 2 dataset (when analyzed using height from ground analysis)
- Class 25 – Overlap Water – Points found in the overlap between flight lines that are located inside hydro features. These points are created through automated processing methods and not cleaned up during processing.

3.3. 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 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 classified to Class 17 (Overlap Default) and Class 18 (Overlap Ground). These classes were created through automated processes only and were not verified for classification accuracy. Due to software limitations within TerraScan, these classes were used to trip the withheld bit within various software packages. These processes were reviewed and accepted by USGS through numerous conference calls and pilot study areas.

All data was manually reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler. Global Mapper is 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. Photo Science 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.

3.4. Hydro Flattening Breakline Process

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, Inland Ponds and Lakes of 8,000 sq. meters or greater surface area as well as Coastal Shorelines and Coastal Islands.

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

Elevation values were assigned to all Inland streams and rivers using Photo Science 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 Shapefile format using ESRI conversion tools.

3.5. Hydro Flattening Raster DEM Process

Class 2 LiDAR in conjunction with the hydro breaklines were used to create a 1.0 meter Raster DEM. Using automated scripting routines within ArcMap, an ERDAS Imagine 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.

4. PROJECT COVERAGE VERIFICATION

The United States Virgin Islands project area 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 8 on the following pages.

Figure 8. Saint Thomas and Saint John Flightline Swath LAS Coverage

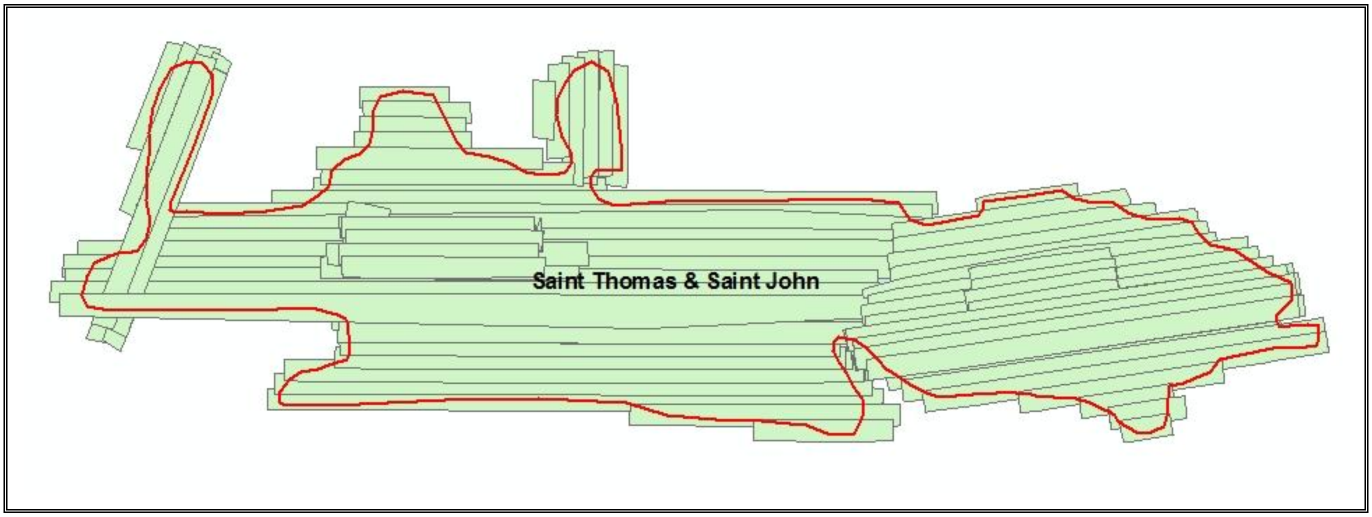
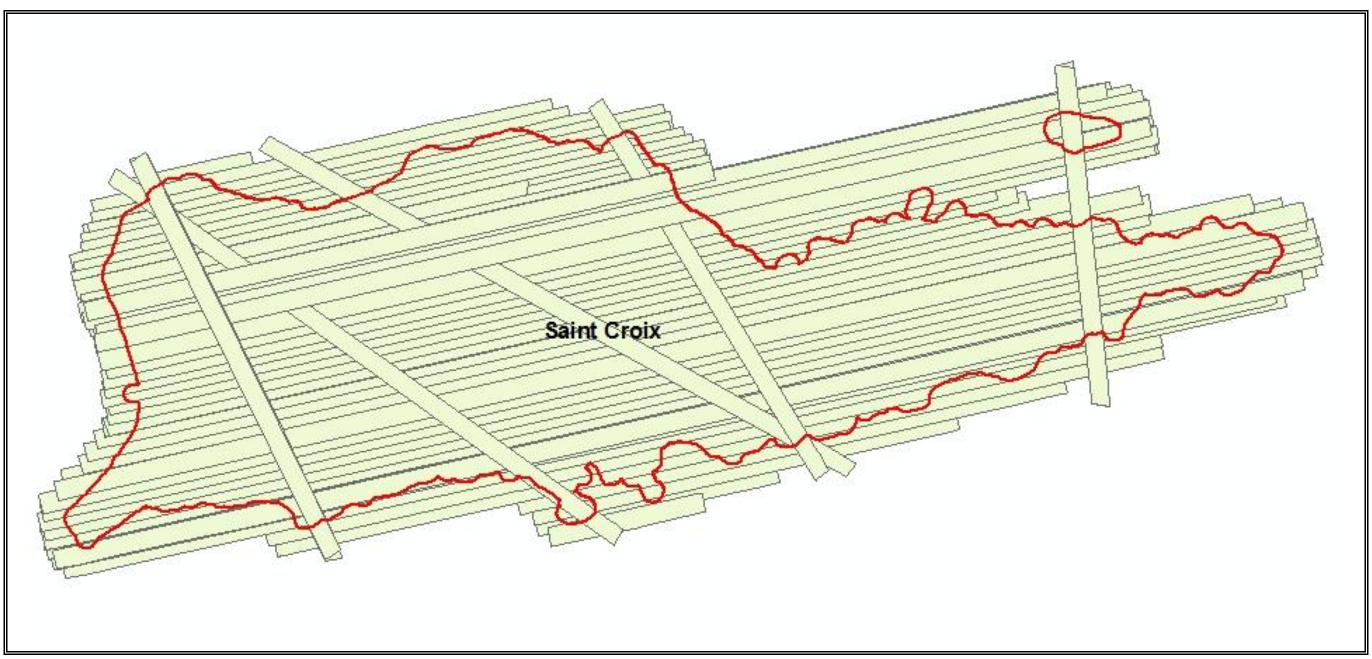


Figure 9. Saint Croix Flightline Swath LAS Coverage



5. Ground Control and Check Point Collection

The Photo Science, Inc. surveying team completed a GPS survey of variously selected ground control points for LiDAR accuracy validation. Figure 10 shows control point locations across the Saint Croix project area and Figure 11 shows the control point locations across the Saint Thomas and Saint John project areas. Table 3 depicts the Final Control Reports for all three islands as computed in TerraScan as a quality assurance check.

Figure 10. Saint Croix Control Point Locations

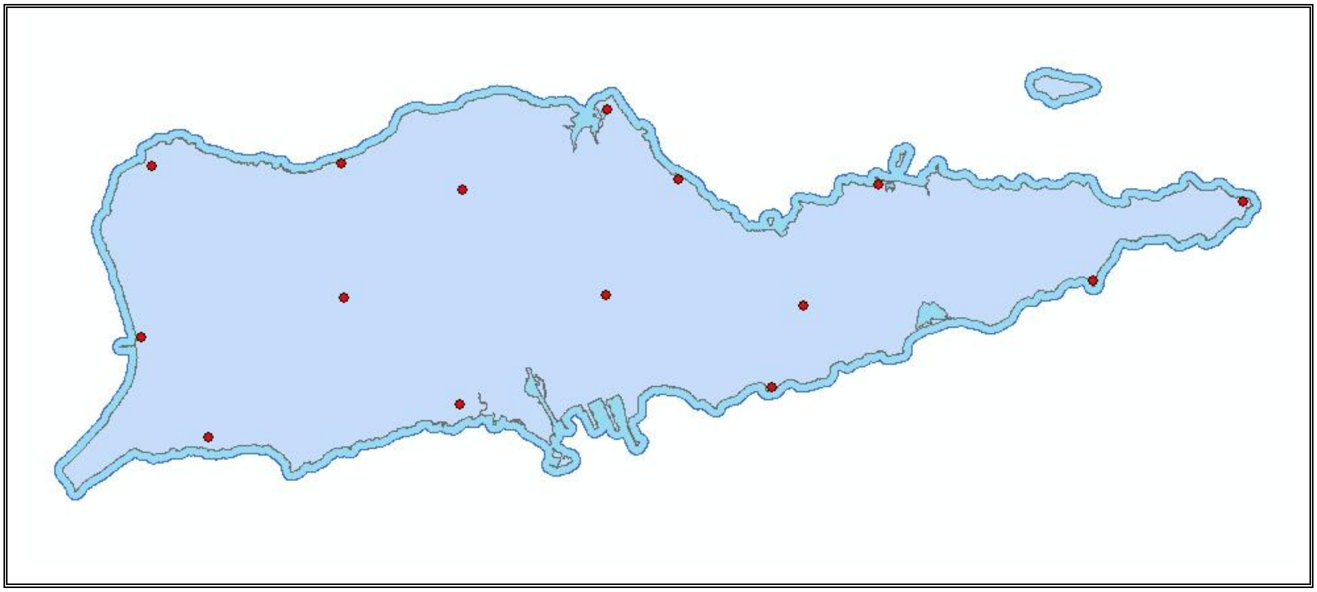


Figure 11. Saint Thomas and Saint John Control Point Locations

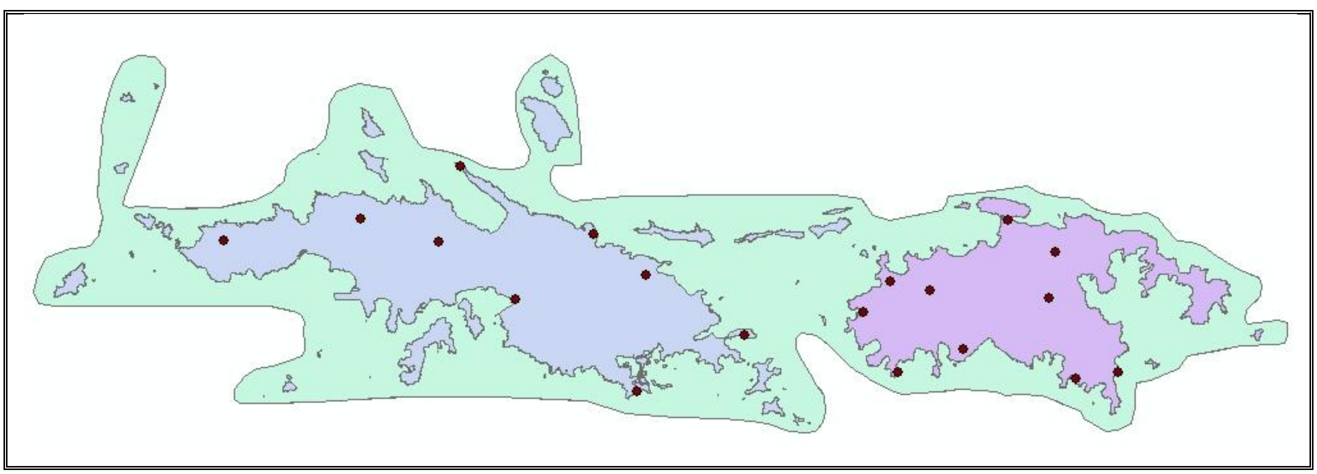


Table 3. United States Virgin Islands Final Control Report (units = meters)

United States Virgin Islands Final Control Report					
Number	**Easting**	**Northing**	**Known Z**	**Laser Z**	**Dz**
C1_131123	302439.68	1956756.16	7.00	6.97	-0.03
C2_131124	300731.61	1964989.11	7.25	7.16	-0.09
C3_131123	300381.53	1959766.18	0.79	0.83	0.04
C4_131123	310071.24	1957753.23	3.64	3.71	0.08
C5_131124	306562.33	1960967.56	61.57	61.63	0.06
C6_131124	306484.46	1965055.46	23.31	23.39	0.08
C7_2_131124	319505.41	1958268.28	1.80	1.78	-0.02
C8_131124	314482.97	1961062.10	37.12	37.07	-0.05
C9_131122	314542.02	1966679.35	8.73	8.67	-0.06
C10_131123	316679.72	1964585.52	1.91	2.09	0.18
C11_131123	322744.63	1964402.50	2.29	2.25	-0.04
C12_131123	329242.56	1961497.39	3.57	3.44	-0.13
C13_131123	333818.39	1963879.84	67.93	67.82	-0.11
C15_131123	320487.17	1960733.64	134.71	134.71	0.00
C16_131124	310126.05	1964248.82	140.27	140.30	0.03
T10_131109_Tom	291346.33	2031539.14	255.04	255.05	0.007
T1-131109-Tom	295143.50	2033528.75	18.03	18.01	-0.019
T12_131109_Tom	286106.90	2030689.77	191.92	191.90	-0.020
T19_131109_Tom	300220.07	2030942.55	55.21	55.23	0.022
T3_13110_Tom	297251.91	2028451.13	3.23	3.14	-0.089
T4_131110_Tom	301863.51	2024913.14	2.50	2.60	0.105
T5_131110_Tom	306002.74	2027061.40	10.02	10.08	0.064
T7_131110_Tom	302217.82	2029381.51	3.30	3.27	-0.027
T9_131109_Tom	294294.27	2030614.85	452.54	452.41	-0.125
J1_131121	311820.96	2025647.18	44.21	44.14	-0.071
J2_131120	310531.49	2027956.71	1.48	1.49	0.014
J3_2_1131120	311552.05	2029113.17	15.15	15.23	0.085
J4_131121	316044.75	2031459.94	7.62	7.65	0.031
J5_2_131120	313081.37	2028773.16	176.66	176.63	-0.029
J6_131121	314350.43	2026541.60	47.24	47.27	0.029
J7_131120	317594.30	2028477.86	289.08	289.02	-0.057
J8_131121	318639.47	2025399.64	1.79	1.92	0.129
J9_131121	320238.19	2025678.44	7.63	7.72	0.088
J10_131121	317839.74	2030230.72	152.93	152.88	-0.052
Average dz	**0.001 m**				
Minimum dz	**-0.131 m**				
Maximum dz	**+0.183 m**				
Root Mean Square	**0.074 m**				
Std Deviation	**0.075 m**				