AIRBORNE TOPOGRAPHIC LIDAR REPORT

SHENANDOAH

Contract No. G10PC00026
Requisition No. 0040080347
Task Order No. G13PD00377

November 26, 2014

Completed by Photo Science, Inc.

PHOTO SCIENCE
Geospatial Solutions

Submitted by:
Michael Shillenn, Program Manager
523 Wellington Way
Lexington, KY 40503
Phone: (859) 277-8700 | Email: mshillenn@quantumspatial.com

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1. Summary / Scope

1.1. Summary

This report contains a summary of the Shenandoah LiDAR acquisition task order, issued by the USGS National Geospatial Technical Operations Center (NGTOC), under their Geospatial Products and Services Contract (GPSC) on April 2, 2013. The combined task orders yielded one study area covering the Shenandoah Valley. The intent of this document is to only provide specific validation information for the LiDAR data acquisition/collection work completed for the USGS project.

1.2. Scope

The scope of the Shenandoah 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 Shenandoah Valley. The aerial data collection was designed with the following specifications listed in Table 1 below.

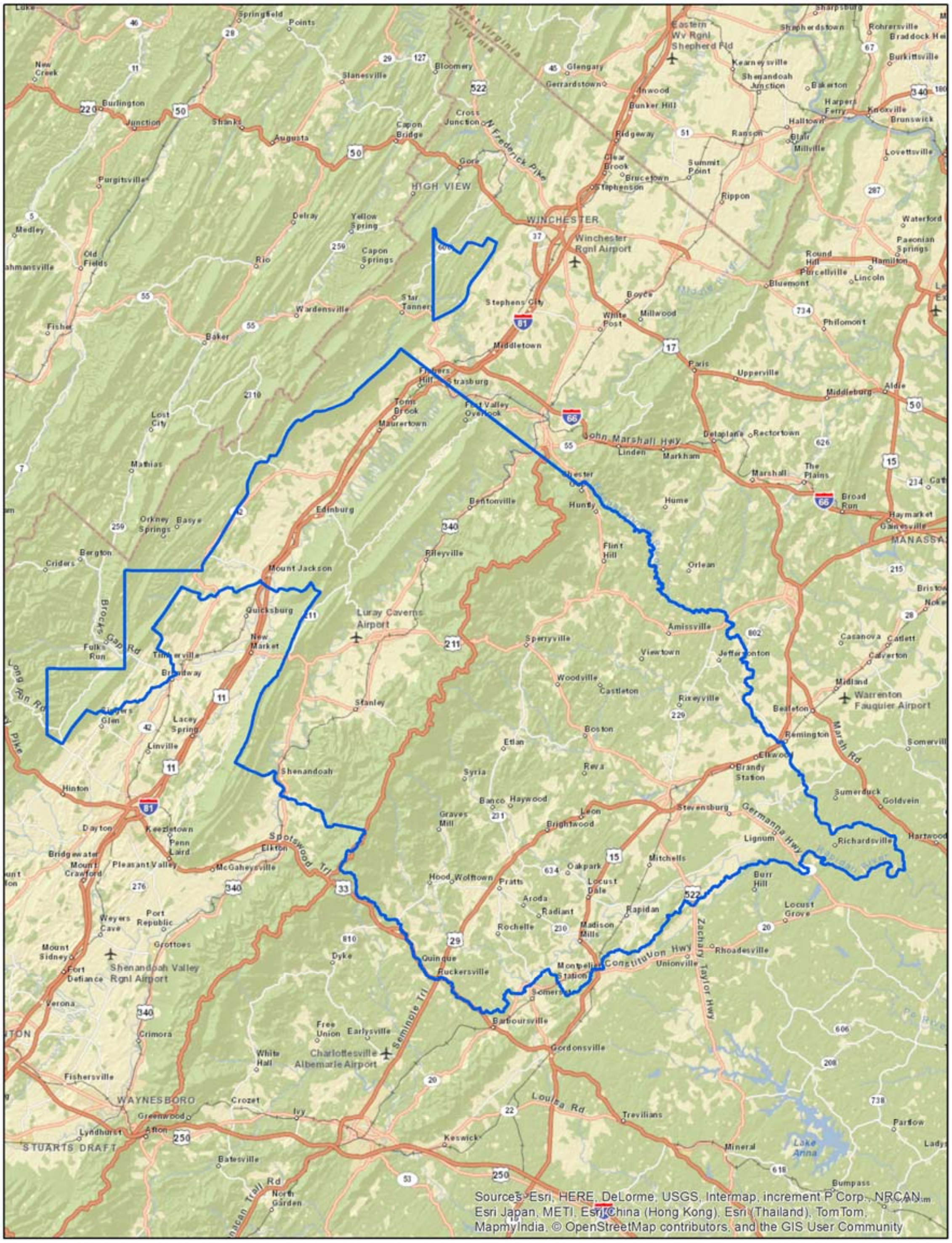
Table 1. Originally Planned LiDAR Specifications

LiDAR				
Average Point Density	Flight Altitude (AGL)	Field of View	Minimum Side Overlap	RMSEz
2.30 pts / m^2	7,001 ft	40.0 degrees	10%	9.25 cm or better

1.3. Location / Coverage

The Shenandoah LiDAR project boundary consists of an area in northwest Virginia. The project area totals approximately 1,512 square miles as shown in Figure 1 on the following page.

Figure 1. Shenandoah LiDAR Project Boundary



1.4. DURATION

The first mission was flown on January 18, 2014 and it took twenty-one total lifts to complete coverage of the area. See section 2.4 for more details.

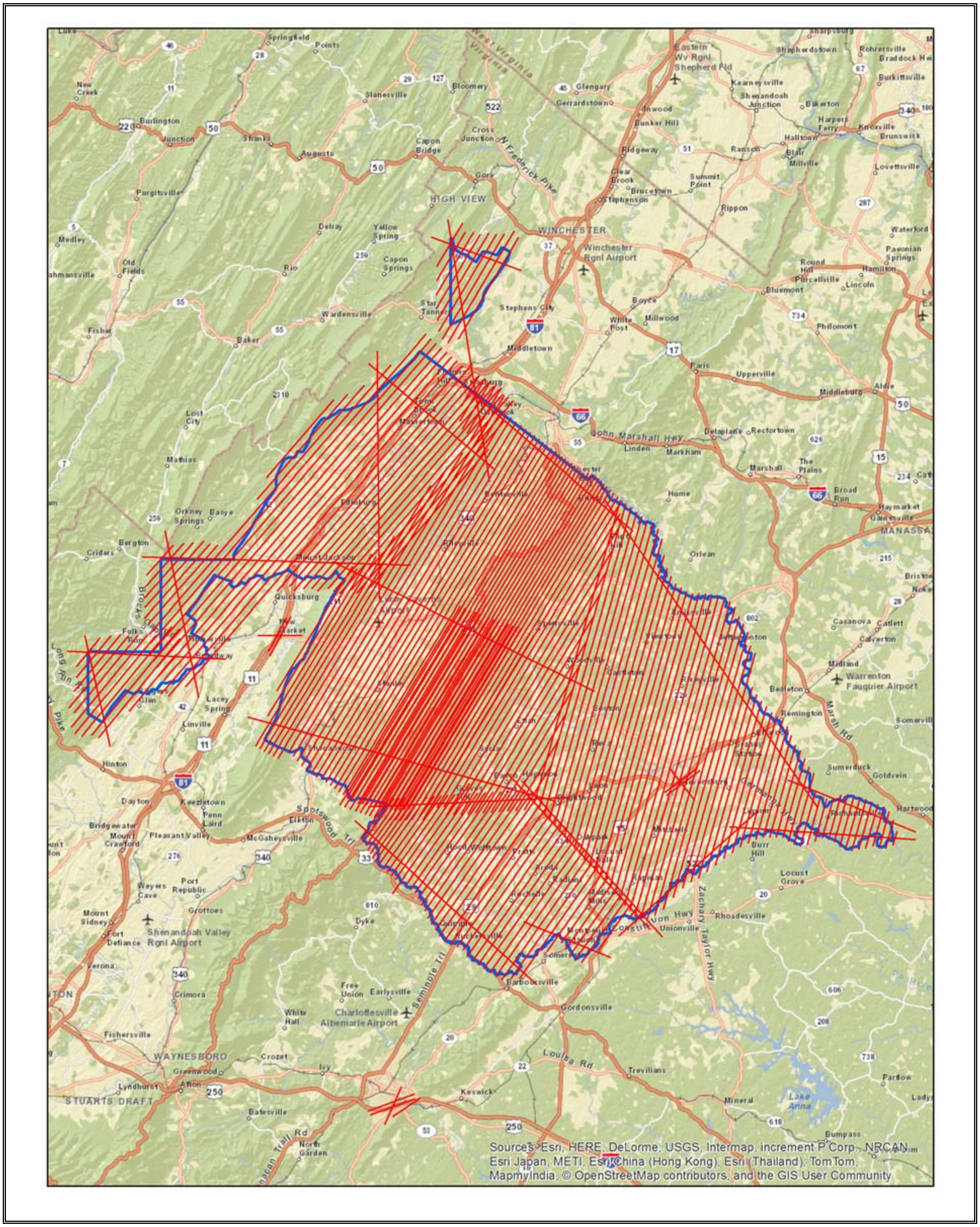
1.5. ISSUES

There is one known gap in coverage in the southwest portion of the project, where one flightline was erroneously stopped short. This issue was discussed with USGS and it was confirmed by USGS in an email dated 07/21/2014 that no re-flight would be required due to the existence of data from a neighboring project.

2. PLANNING / EQUIPMENT

The entire target area was comprised of 259 planned flight lines and approximately 7937 flight line kilometers. Please refer to Figure 2 on the following pages.

Figure 2. Shenandoah Originally Planned Flight Lines



Detailed project flight planning calculations were performed for the Shenandoah project using Optech ALTM Nav planning software and the 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. Please note that certain values in the table below are listed as "Variable" due to the various flight plans used, as described in Section 1.5 of this document. 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: 7001 ft
	Recommended Ground Speed (GS): 140 kts
Scanner	Field of View (FOV): 40º
	Scan Rate Setting used (SR): 31.3 Hz
Laser	Laser Pulse Rate used: 256,800 Hz
	Multi Pulse in Air Mode: Enabled
Coverage	Full Swath Width: 1553.42 meters
	Line Spacing: 1402.37 meters
Point Spacing and Density	Maximum Point Spacing Across Track: 1.15 m
	Maximum Point Spacing Along Track: 1.15 m
	Average Point Density: 2.3 pts / m^2

2.1. EQUIPMENT: AIRCRAFT

All flights for the Shenandoah project were accomplished through the use of a customized twin-engine Piper PA-31 Navajo (Tail # N262AS) and single-engine Cessna 206 (Tail # N2448G).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 Optech LiDAR system.

2.2. LIDAR SENSOR

Photo Science utilized a Leica LiDAR sensor, serial number 7178, 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.

Photo Science also utilized an Optech LiDAR sensor, serial number 247 during the project. This system is capable of collecting data at a maximum frequency of 167kHz, which affords elevation data collection of up to 167,000 points per second. 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 Shenandoah project the LiDAR operator monitored point density and swath to ensure data integrity and desired coverage were obtained.

Figure 3. Leica ALS70 LiDAR System

Figure 4. Optech Gemini LiDAR System

2.3. BASE STATION INFORMATION

GPS base stations were utilized during all phases of flight. The base station locations were verified using NGS OPUS service and subsequent surveys. Data sheets, graphical depiction of base station locations and log sheets used during station occupation are available in Appendix A.

Table 3. Base Station Locations

Base Station	Latitude	Longitude	Ellipsoid Height (m)
LOYI	38 01 59.42544	78 30 42.4090682	156.276
LOYJ	38 28 20.89290	-78 00 36.1468282	105.155
LOYY	38 53 18.54718	-78 29 56.9434506	222.190
LOYA	38 25 33.90025	-78 53 21.7744911	365.215
LOYC	39 07 12.54600	-78 12 02.6089611	203.089
WVMF	39 04 32.34433	-78 55 56.9981111	313.550
VAST	38 09 37.76322	-79 02 51.2049797	395.054

2.4. TIME PERIOD

Project specific flights were conducted over several months. Twenty-one sorties, or aircraft lifts were completed. Accomplished sorties are listed below:

- 140118A_7178
- 140324A_7178
- 140324B_7178
- 140331A_7178
- 140331B_7178
- 140331C_7178
- 140401A_7178
- 140401B_7178
- 140402A_7178
- 140402B_7178
- 140403A_7178
- 140405A_7178
- 140406B_7178
- 140406C_7178
- 140409A_7178
- 140410A_7178
- 140410B_7178
- 140410C_7178
- 140410D_7178
- 140411A_7178
- 140523B_247

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. All relevant graphs produced in the POSPac processing environment for each sortie during the Photo Science Shenandoah project mobilization are available in Appendix B.

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 and the Optech DashMap 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.

Metadata was generated for the project on a deliverable level.

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 C.

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 features such as vegetation, cars, etc.
- Class 2 – Bare earth ground – This is the bare earth surface
- Class 6 – Buildings and Bridges – Points occurring on building roofs and bridge decks.
- Class 7 – Noise – Low or high 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 – 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 3 feet 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 100 foot nominal width and Inland Ponds and Lakes of 2 acres or greater surface area.

Elevation values were assigned to all Inland Ponds and Lakes, Inland Pond and Lake Islands, Inland Streams and Rivers and Inland Stream and River 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 3 feet 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 2.5 foot 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.

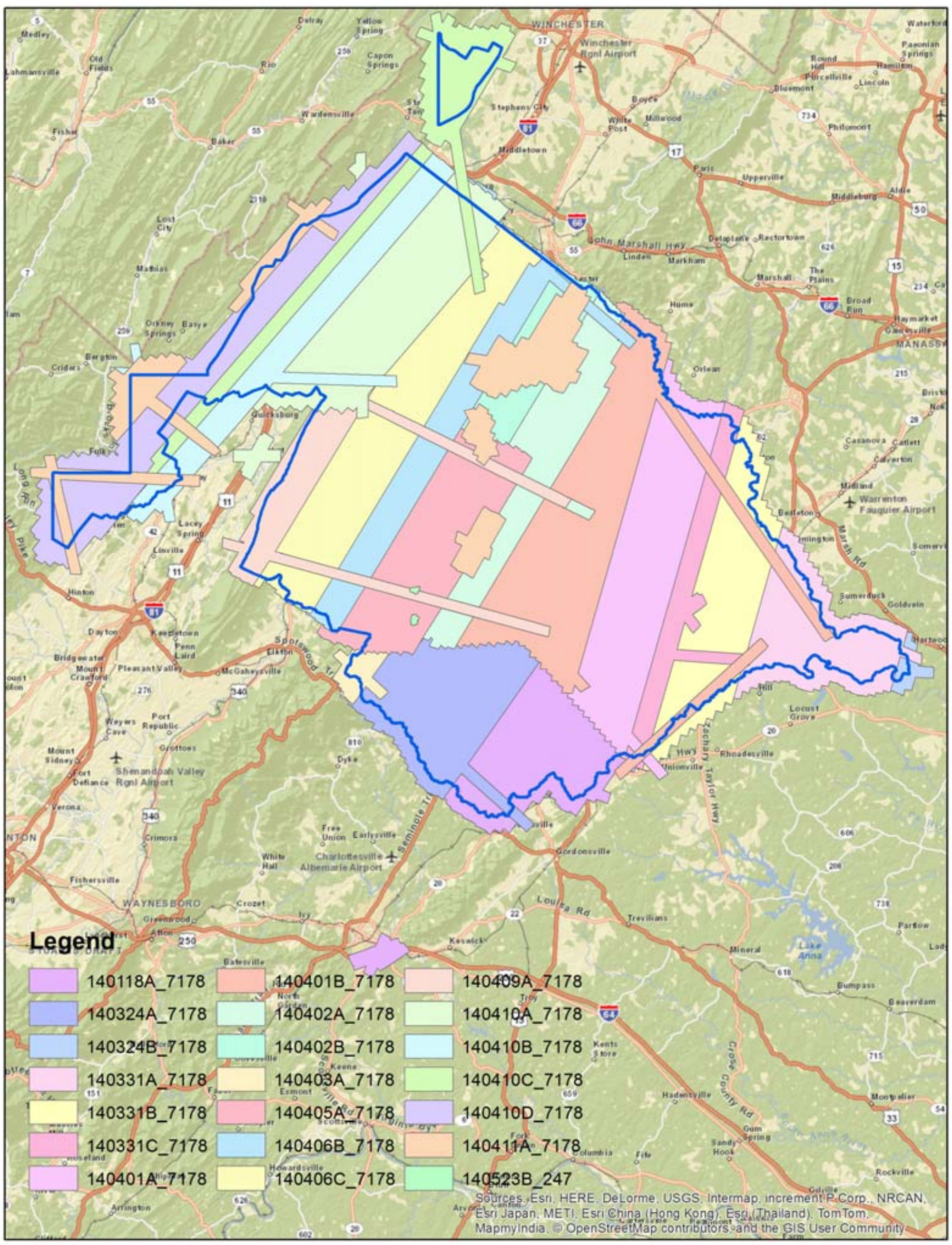
4. Deliverables

- Uncalibrated, unclassified raw point cloud swath LAS in version 1.2 format
- Calibrated, unclassified tiled LAS in version 1.2 format
- Classified point cloud tiled LAS in version 1.2 format
- Hydro flattened raster DEM in ERDAS .IMG format
- Hydro flattened breaklines in shape file format
- Ground control points in shape file format
- As-flown flightlines in shape file format
- Tile index in shape file format
- Project and deliverable level metadata in XML format
- Accuracy Assessment in XLS format

5. Project Coverage Verification

The Shenandoah 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 5.

Figure 5. Shenandoah Flightline Swath LAS File Coverage



6. GROUND CONTROL AND CHECK POINT COLLECTION

The Photo Science, Inc. completed a GPS survey of variously selected ground control points for LiDAR accuracy validation. Figure 6 shows final control point locations across the project area. Table 4 depicts the Final Control Reports for Shenandoah as computed in TerraScan as a quality assurance check.

Figure 6. Shenandoah Control Point Locations

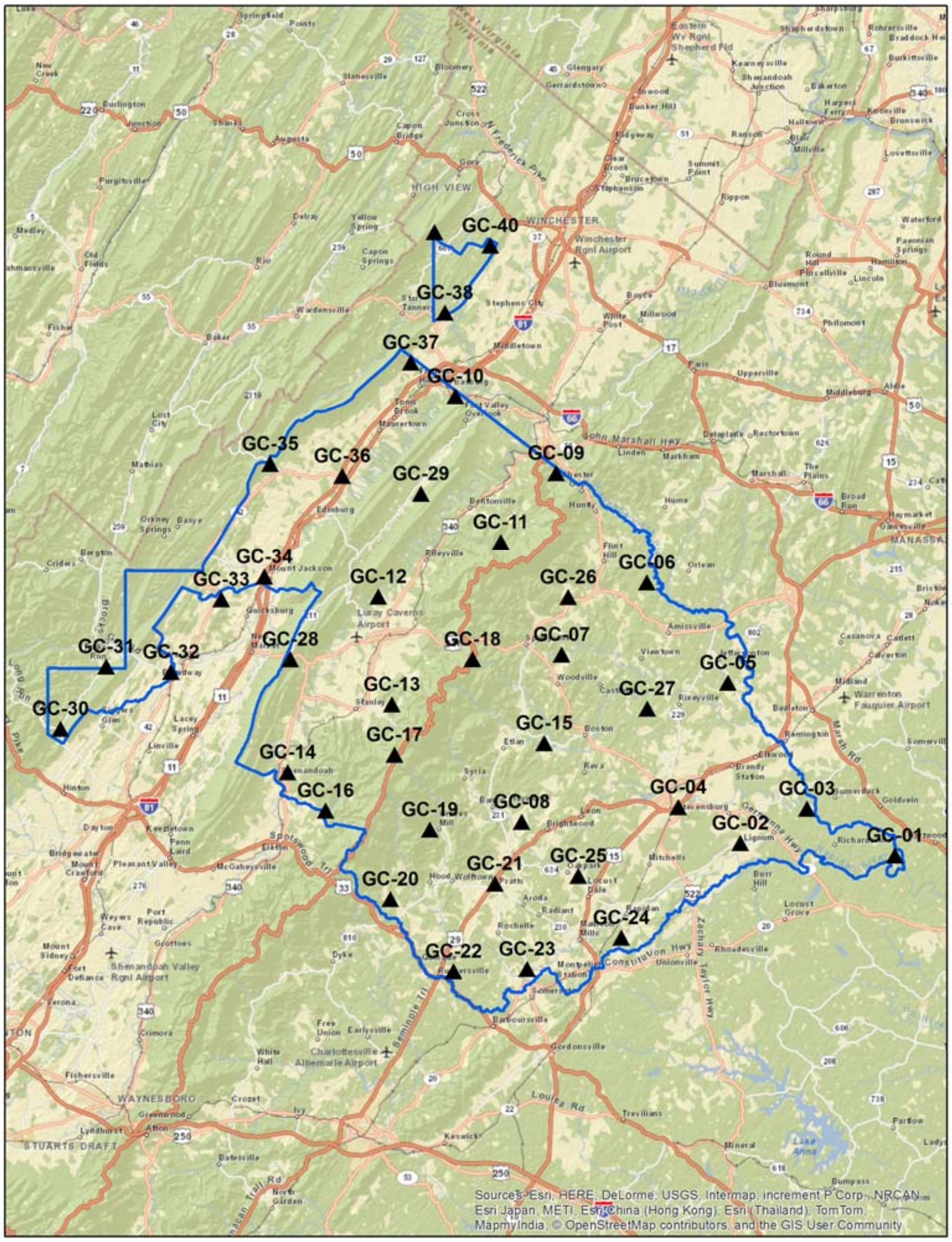


Table 4. Shenandoah Control Point Report (Units =Survey Feet)

Number	Easting	Northing	Known Z	Laser Z	Dz
1	11731730.68	6824593.7	270.55	270.94	0.39
2	11660084.84	6830329.07	278.97	278.94	-0.03
3	11691048.18	6846272.18	326.02	326.18	0.16
4	11631371.61	6846900.1	426.29	426.27	-0.02
5	11654411.69	6904478.82	447.75	447.7	-0.05
6	11616919.74	6951141.25	523.44	523.23	-0.21
7	11577367.19	6917630.3	552.71	552.73	0.02
8	11558990.03	6840193.15	469.73	469.73	0
9	11574871.35	7001764.95	885.8	885.76	-0.04
10	11528260.3	7037493.33	582.17	582.22	0.05
11	11549279.94	6969810.52	1206.18	1206.22	0.04
12	11492521.96	6944517.82	716.31	716.21	-0.1
13	11498876.82	6894460.28	1110.21	1110.1	-0.11
14	11450654.5	6863180.42	1083.16	1082.91	-0.25
15	11569408.5	6876499.73	542.7	542.75	0.05
16	11468088.52	6845357.74	1094.57	1094.53	-0.04
17	11500025.89	6871174.59	3493.44	3493.47	0.03
18	11536139.54	6915584.14	2838.8	2838.59	-0.21
19	11516456.79	6836651.91	959.16	959.19	0.03
20	11498175.11	6804267.85	707.84	707.76	-0.08
21	11546627.75	6811361.26	617.55	617.63	0.08
22	11527407.3	6770643.65	527.01	527.08	0.07
23	11561403.13	6771885.68	413.85	413.77	-0.08
24	11605083.44	6786256.35	467.23	467.24	0.01
25	11585133.43	6814956.83	426.77	426.66	-0.11
26	11580488.44	6944471.79	659.85	660.12	0.27
27	11617053.58	6892511.82	540.49	540.46	-0.03
28	11451901.57	6915535.15	1562.21	1562.15	-0.06
29	11512275.53	6992227.5	857.39	857.35	-0.04
30	11345469.46	6883144.96	1762.84	1762.9	0.06
31	11366538.79	6912154.39	1169.98	1169.93	-0.05
32	11396588.72	6909584.92	1029.71	1029.52	-0.19
33	11419832.26	6943382.86	1107.72	1107.49	-0.23
34	11439859.2	6953944.5	929.08	929.26	0.18
35	11442447.11	7006141.19	984.27	984.34	0.07
36	11475862.71	7000494.3	906.95	906.8	-0.15
37	11507656.46	7053114.01	875.78	875.85	0.07
38	11523373.66	7076198.77	720.57	720.98	0.41
39	11518613.16	7113792.24	1950.19	1950.15	-0.04
40	11544498.93	7107434.31	1046.54	1046.48	-0.06

Average dz	-0.005 ft
Minimum dz	-0.250 ft
Maximum dz	0.410 ft
Average Magnitude	0.104 ft
Root Mean Square	0.143 ft
Std Deviation	0.144 ft