AIRBORNE TOPOGRAPHIC LIDAR REPORT

ADDISON, VERMONT

Contract No. G10PC00026
Requisition No. 0040057101
Task Order No. G12PD01111

December 2, 2013

Completed by Photo Science, Inc.

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

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

1. SUMMARY / SCOPE

1.1. SUMMARY

This report contains a summary of the Addison, Vermont LiDAR acquisition, processing and accuracy validation processes completed for the U.S. Geological Survey (USGS) (Photo Science Contract No. G10PC00026, Requisition No. 0040057101, Task Order No. G12PD01111). The intent of this document is to provide specific parameter information associated with the Task Order's LiDAR data acquisition, processing and accuracy validation. The following Report contains four (4) sections, Summary/Scope, Planning/Equipment, Processing Summary, and Project Coverage Verification along with associated figures, tables and appendices. Of particular note, Appendix D: Ground Control Survey Report and Appendix E: LiDAR Accuracy Assessment Report describes Photo Science's approach and results to establishing both supplemental and quality assurance control survey points and the results of the vertical accuracy testing per Task Order specifications.

1.2. SCOPE

The scope of the 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 Addison, Vermont and surrounding areas. The aerial data collection was designed with the following specifications listed in Table 1 below.

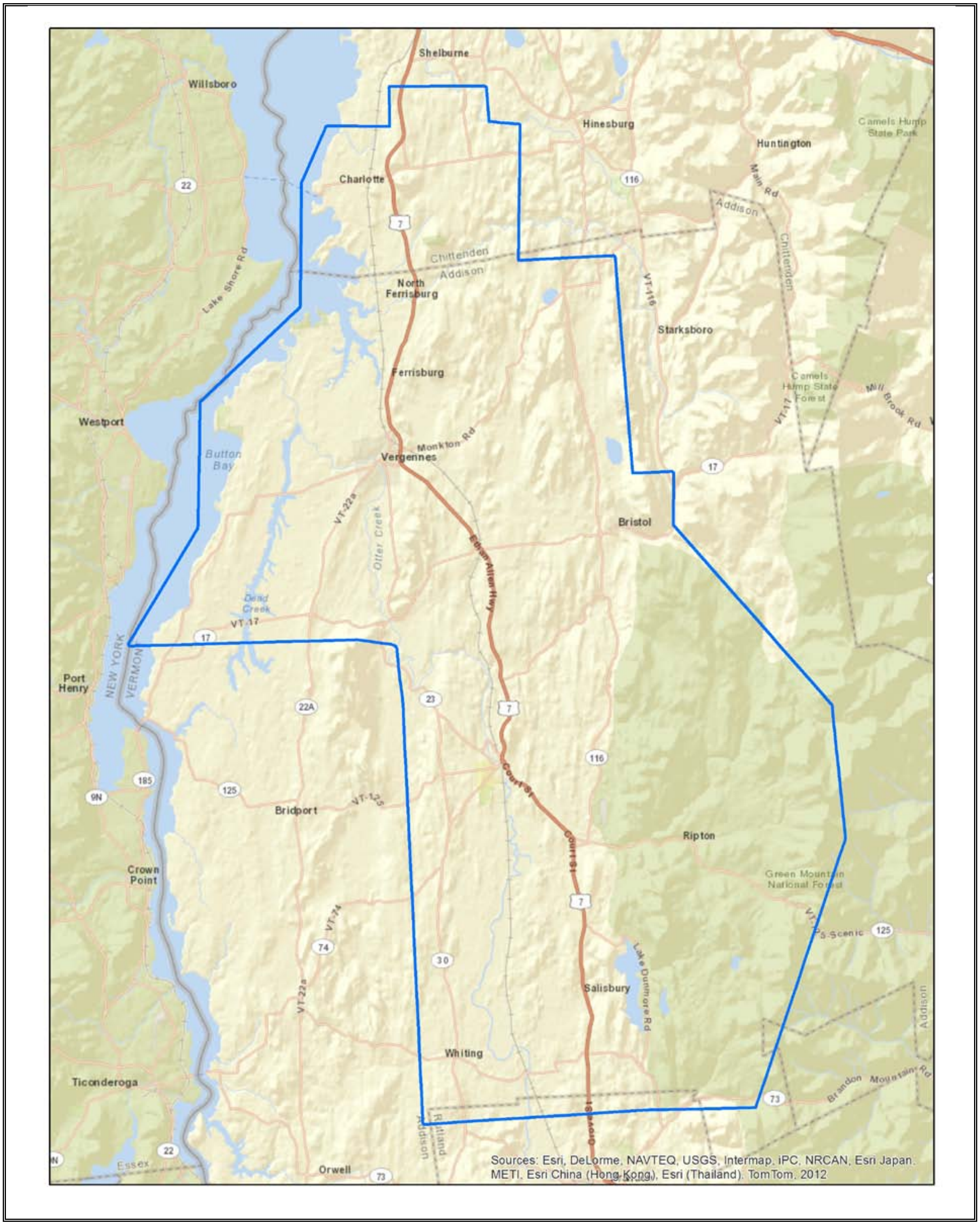
Table 1. Planned LiDAR Specifications

LiDAR				
Average Point Density	Flight Altitude (AGL)	Field of View	Side Overlap	RMSEz
4.3 pts / m^2	6,000 ft	35.0 degrees	11.68%	12.5 cm or better

1.3. LOCATION / COVERAGE

The LiDAR project boundary consists of approximately 478 square miles as shown in Figure 1 on the following page.

Figure 1. LiDAR Project Boundary



1.4. DURATION

The first mission was flown on December 6, 2012 and it took four different lifts to complete coverage of the area. See section 2.4 for more details.

1.5. ISSUES

The primary issues of concern with this task order were the weather encountered during collection and sensor issues during our initial collection of the project area.

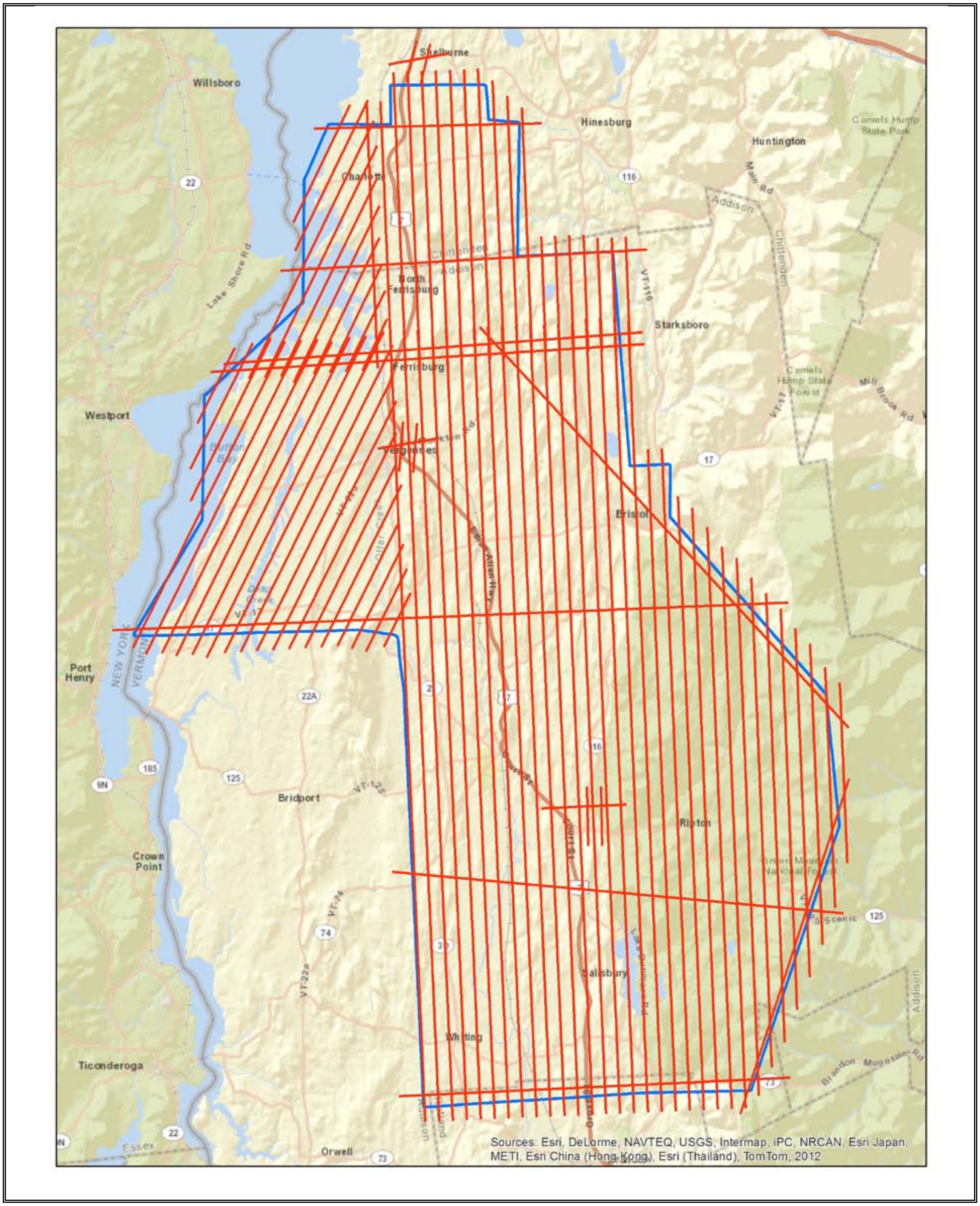
Original data was collected for the project over a 5 day window in November, 2012. However, internal issues with the Leica sensor were discovered during initial office processing. These issues were discussed with Leica, and the data was found to be unfixable in the office environment. Because of this, the LiDAR unit was serviced in Danbury, CT and the project area was reflown in December, 2012.

During the collection of the first mission on December 6, 2012, the base station was found to have stopped collecting at some point during the flight. The surrounding CORS stations were used to assist in the creation of the final trajectory for this mission.

2. PLANNING / EQUIPMENT

The entire target area was comprised of 115 planned flight lines and approximately 1545 flight line miles. Please refer to Figure 2 on the following page.

Figure 2. Planned Flight Lines



Detailed project flight planning calculations were performed for the project using Leica Mission Pro ALTM Nav 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:	1828 m; 6000 feet
	Recommended Ground Speed (GS): 120 kts	
Scanner	Field of View (FOV): 35 degrees	
	Scan Rate Setting used (SR): 36.6 Hz	
Laser	Laser Pulse Rate used: 303400 Hz	
	Multi Pulse in Air Mode: Enabled	
Coverage	Full Swath Width: 1152.73 m	
	Line Spacing (No DTM): 1018.15 m	
Point Spacing and Density	Maximum Point Spacing Across Track: 0.85 m	
	Maximum Point Spacing Along Track: 0.85m	
	Average Point Density: 4.3 pts / m^2	

2.1. Equipment: Aircraft

Flights for the project were accomplished through the use of a customized Piper Navajo (Tail Number N22GE).This aircraft, depicted on the cover of the report, 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 LiDAR sensor, serial number 7170, 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.

Figure 3. Leica ALS70 LiDAR System

Figure 4. Unit Installed in Plane.

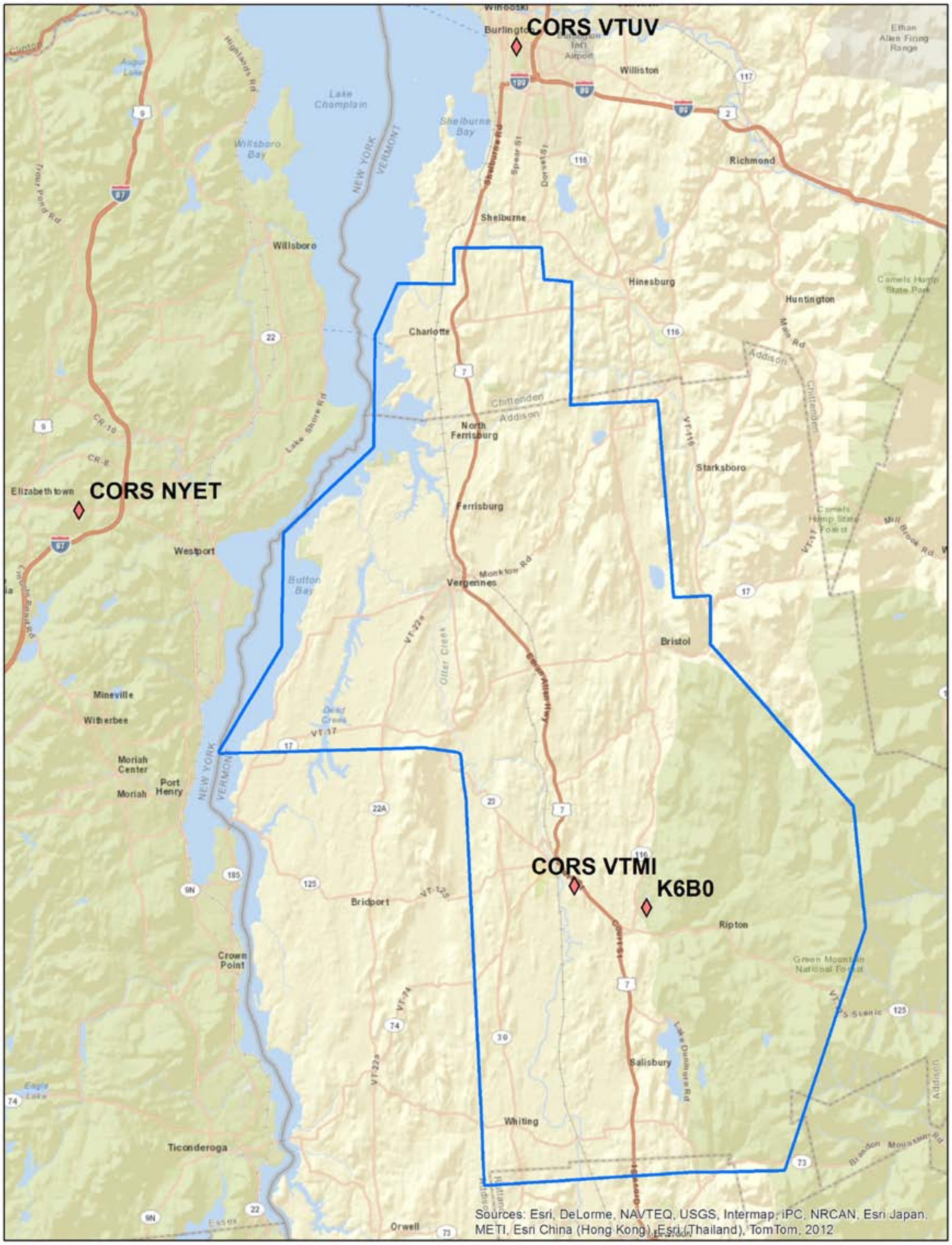
2.3. BASE STATION INFORMATION

GPS base stations were utilized during all phases of flight. Base station at, K6B0 was occupied with a R7 GNSS and a Trimble Zephyr Geodetic Antenna during airborne operations of the project. Both base station locations were verified using NGS OPUS service and subsequent surveys. The table below, Table 3, lists the location values and the figure on the following page, Figure 5, shows a map of the locations in relation to the area of interest. 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 by Lift

CORS / Base Station	Latitude	Longitude	Ellipsoid Height (m)
K6B0	43 59 10.43224	-73 05 45.5532121	122.378
CORS NYET	44 12 34.85080	-73 32 25.85231	174.246
CORS VTMI	43 59 55.02507	-73 09 09.38024	96.027
CORS VTUV	44 28 09.21279	-73 11 52.37575	112.41

Figure 5. Base Station and CORS location



2.4. Time Period

Project specific flights were conducted over three (3) days. Four Sorties, or aircraft lifts, were completed. Accomplished sorties are listed below:

- 20121206A_7170
- 20121207B_7170
- 20121209A_7170
- 20121209B_7170

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 Addison 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 Processing 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.

All data will be manually reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler. Hydro Breaklines meeting the USGS Version 1 specification are collected through heads-up digitization off the bare earth surface model and then dropped to the LIDAR surface. Bare earth raster DEM files are created using proprietary python scripting algorithms created in ESRI Arc Map. These deliverable surfaces are then reviewed in Global Mapper. This surface also is used as a final check of the bare earth dataset. GeoCue will then be used to create the deliverable industry-standard LAS files for the Calibrated Classified Point Cloud as well as intensity images of the project area. 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 this Final Report as well as a FOCUS report.

3.1. Flight Logs

Flight logs were completed by LIDAR sensor technicians for each mission during acquisition. These logs depict various 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, dewpoint, 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 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 – In-land 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 11 – Withheld – Points found to be noise during automated processing.
- Class 13 – Hydro-Enforcement Ground (Unclassified) – Ground points found inside of the hydro-enforcement breaklines. These points were classified through automated processing methods and were used as part of the hydro-flattening process.
- 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 In-land Water – Points found in the overlap between flight lines that are located inside of inland lake/ponds. 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 and Inland Ponds and Lakes of 8,000 sq. meters or greater surface area.

Elevation values were assigned to all Inland Ponds and Lakes, Inland Pond and Lake Islands, 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 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).

Hydro enforcement was also a requirement of this task order. This was accomplished by connecting any collected hydro feature that met the collection parameters. Any ground (ASPRS Class 2) LiDAR data inside of this collected feature was then moved to Class 13. A mutually agreed upon class between USGS and Photo Science.

The breakline files were then translated to ESRI Shapefile format using ESRI conversion tools.

3.5. Hydro Flattening/Enforcement Raster DEM Process

Class 2 LiDAR in conjunction with the hydro breaklines were used to create a 1.6 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.

Class 2 LiDAR in conjunction with the hydro breaklines and any collected enforcement lines were used to create a 1.6 meter Hydro Enforcement 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.

3.6. Contour Generation Process

Using automated scripting routines within ArcMap, a terrain surface was created using the ground (ASPRS Class 2) LiDAR data as well as the hydro-flattening breaklines. This surface was then used to generate the final 0.5 meter contour dataset in ESRI GeoDatabase format. The contours were initially created in UTM Zone 18 meters and then reprojected to Vermont State Plane coordinates for a match between the final contour datasets.

3.7. Intensity Image Generation Process

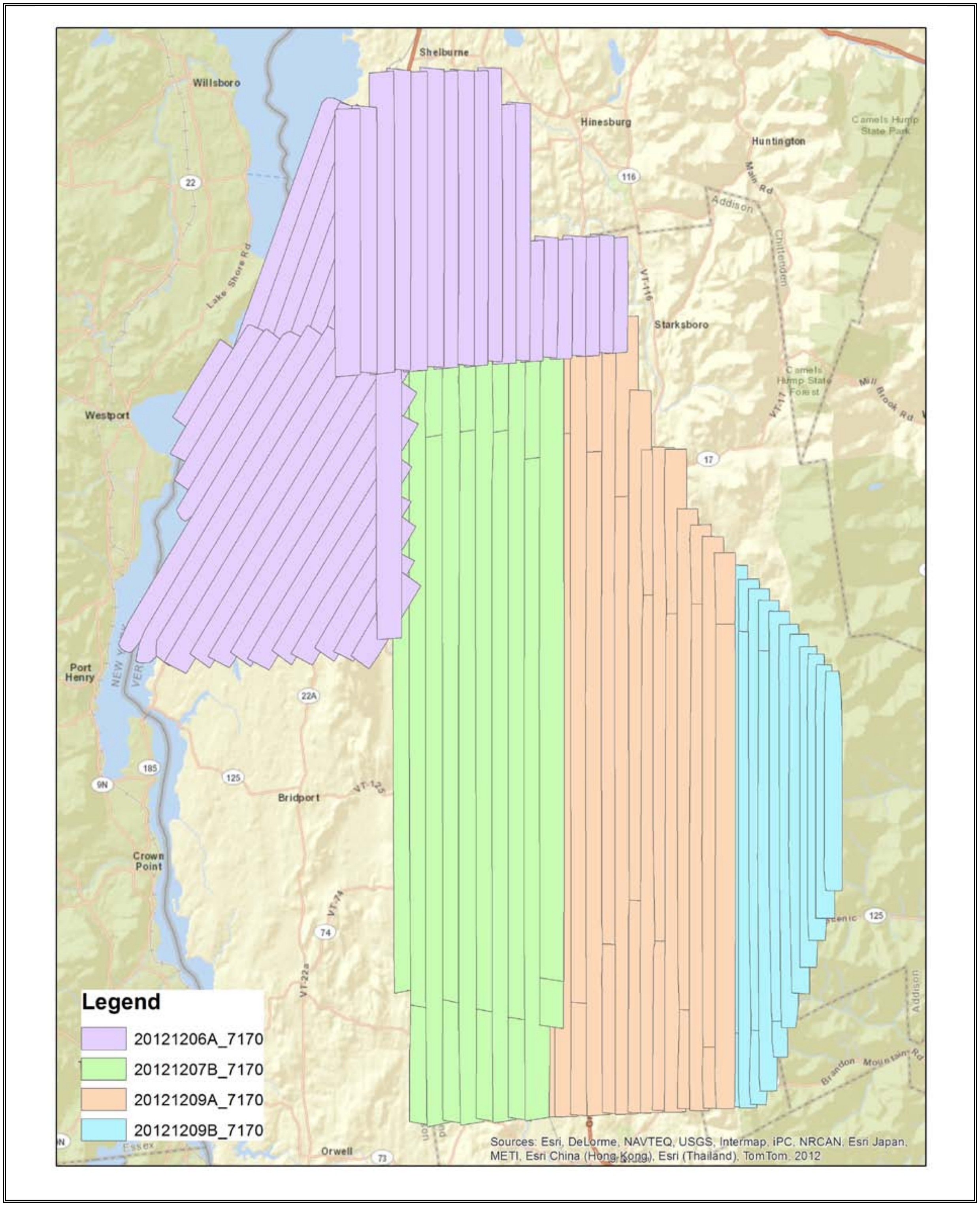
GeoCue software was used to create the deliverable Intensity Images. All overlap classes (ASPRS class 17/18/25) were ignored during this process. This helps to ensure a more aesthetically pleasing image.

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

The Addison project area coverage verification was performed by comparing coverage of processed .LAS files captured during project collection to generated project shape files depicting boundaries of specified project areas. The project area has 100% .LAS coverage. Please refer to Figure 8 on the following page.

Figure 6. LAS File Coverage



5. Ground Control Surveys & Vertical Accuracy Testing

Photo Science completed a GPS control survey of selected ground control points for use in calibrating (supplemental control) the individual/combined LiDAR missions as well as Quality Assurance control points to independently validate the Fundamental (FVA), Supplemental (SVA) and Consolidated (CVA) vertical accuracies of the final LiDAR datasets per Task Order requirements. Appendix D contains the Ground Control Survey Report that outlines Photo Science's survey activities to establish both supplemental and quality assurance control points. Appendix E describes Photo Science testing approach and results to validate FVA, SVA and CVA.