Western Vermont
2017 QL2 LiDAR Project Report

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Requisition # 0040356007
Task Order # G17PD01130

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Contents

List of Figures

List of Tables

List of Appendices

1. Summary / Scope

1.1. Summary

This report contains a summary of the Western Vermont 2017 QL2 LiDAR acquisition task order, issued by USGS OAG Denver Acquisition Branch under their Geospatial Product and Services Contract v.3 (GPSC3) on August 24, 2017. The task order yielded a project area covering approximately 1,910 square miles over three AOIs in Western Vermont that were previously acquired at QL3. The intent of this document is only to provide specific validation information for the data acquisition/collection, processing, and production of deliverables 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	Side Overlap	RMSEz
2.22 pts / m^2	2,100 m	40°	30%	≤ 10 cm

1.3. Coverage

The project boundary covers approximately 1,190 square miles and encompasses three AOIs in Western Vermont. The northern AOI encompasses portions of Grand Isle, Franklin, Orleans, and Lamoille Counties. The central AOI includes a portion of Addison County. The southern AOI contains most of Bennington County and portions of Rutland and Windham Counties. A buffer of 100 meters was created to meet task order specifications. Project extents are shown in Figure 1.

1.4. Duration

LiDAR data was acquired from November 5th, 2017 to November 21st, 2017 in 17 total lifts. See “Section: 2.5. Time Period” for more details.

1.5. Issues

There were no issues to report for this project.

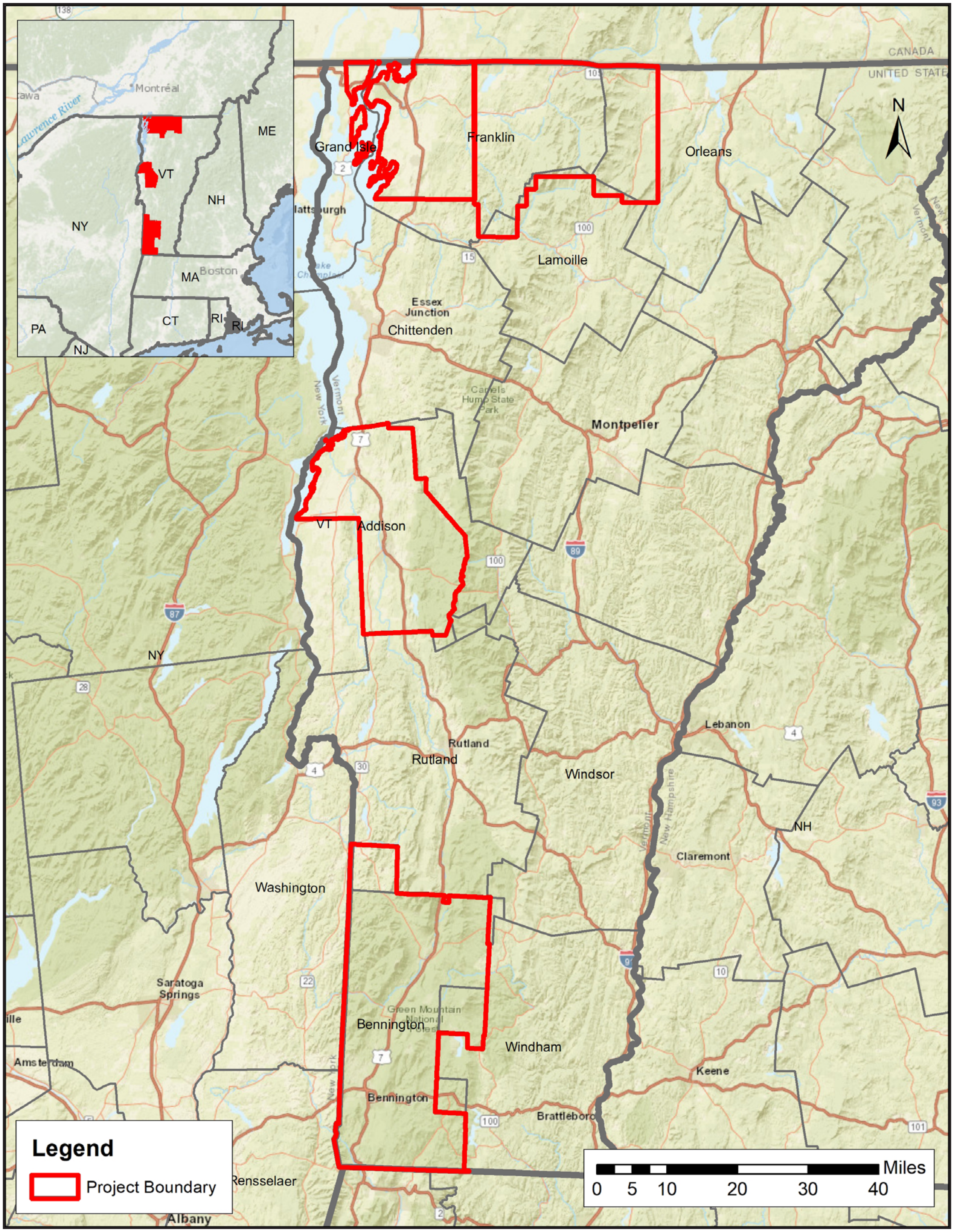
1.6. Deliverables

The following products were produced and delivered:

- Classified LiDAR point cloud data tiles in .LAS 1.4 format
- Continuous hydro-flattened breaklines in Esri file geodatabase format
- 0.7-meter hydro-flattened bare earth digital elevation model (DEM) tiles in ERDAS .IMG format
- 0.7-meter hydro-enforced bare earth digital elevation model (DEM) tiles in ERDAS .IMG format
- 0.7-meter first return digital surface model (DSM) tiles in ERDAS .IMG format
- 0.7-meter intensity imagery tiles in ERDAS .IMG format
- 1-foot contour tiles in Esri file geodatabase format
- Processing boundary in Esri shapefile format
- Calibration and QC checkpoints (NVA/VVA) in Esri shapefile format
- GPS/IMU statistics and flight logs in .PDF format
- Survey report in .PDF format
- FOCUS report in .PDF format
- FOCUS on Deliverables report in .PDF format
- FOCUS on Accuracy report in .PDF format
- Project and deliverable metadata in .XML format

All geospatial deliverables were produced with a horizontal datum/projection of NAD83 (2011), Vermont FIPS 4400, meters and a vertical datum/projection of NAVD88 (GEOID12B), meters. All tiled deliverables have a tile size of 1,400-meters x 1,400-meters. Tile names are derived from the US National Grid.

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 MissionPro and Riegl RiPARAMETER planning software. The entire target area was comprised of 194 planned flight lines (Figure 2).

2.2. LiDAR Sensor

Quantum Spatial utilized a Leica ALS 70 LiDAR sensor (Figure 3), serial number 7161 and a Riegl LMS Q1560 sensor, serial numbers 175 and 1256, during the project.

The Leica ALS 70 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.

The Riegl LMS-Q1560 system is capable of collecting data at a maximum pulse repetition rate of 800 kHz, affording an effective rate of 532,000 measurements on the ground. The sensor's multiple time around processing software automatically resolves range ambiguities and handles more than 10 simultaneous pulses in the air.

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

Figure 2. Planned Flight Lines

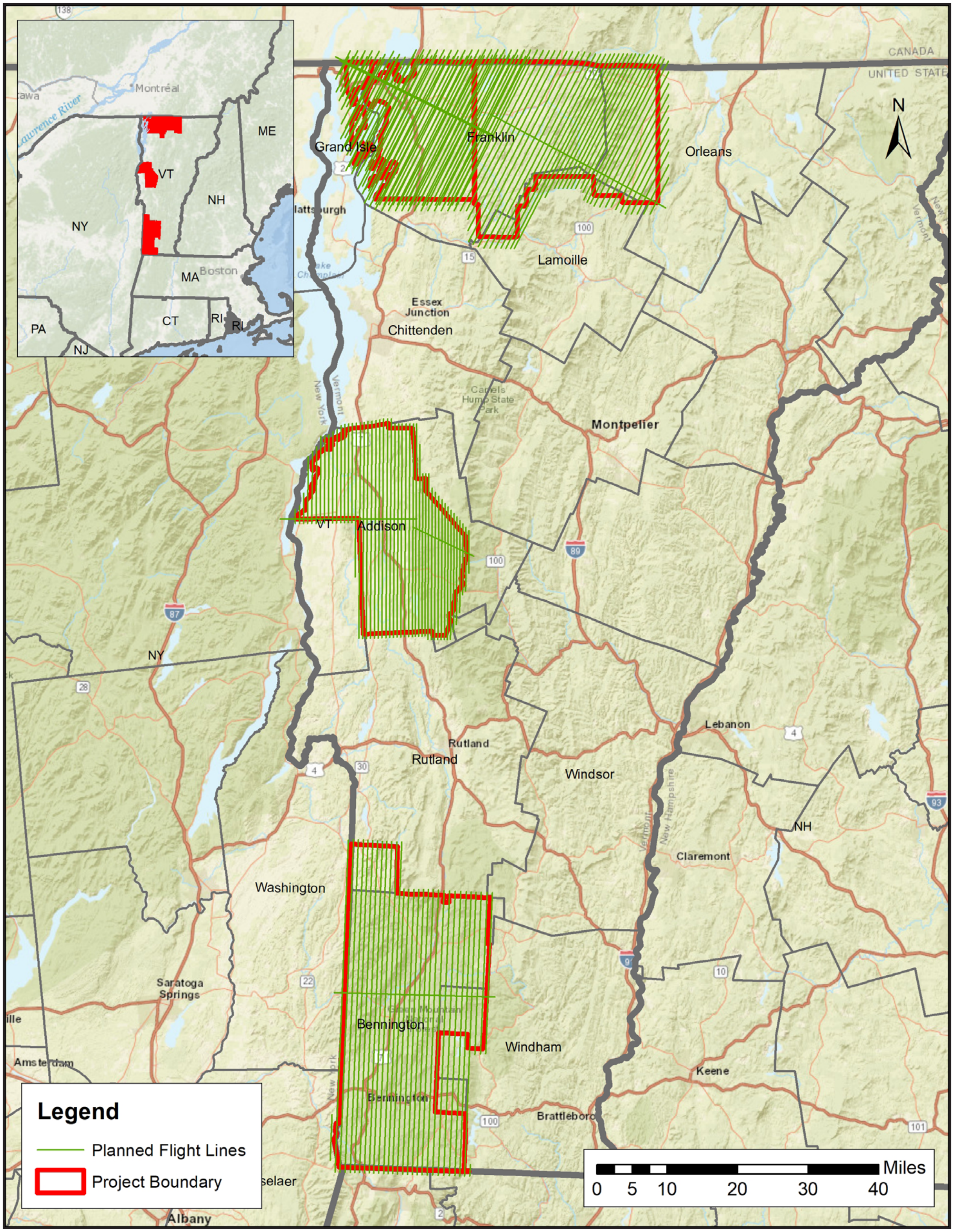
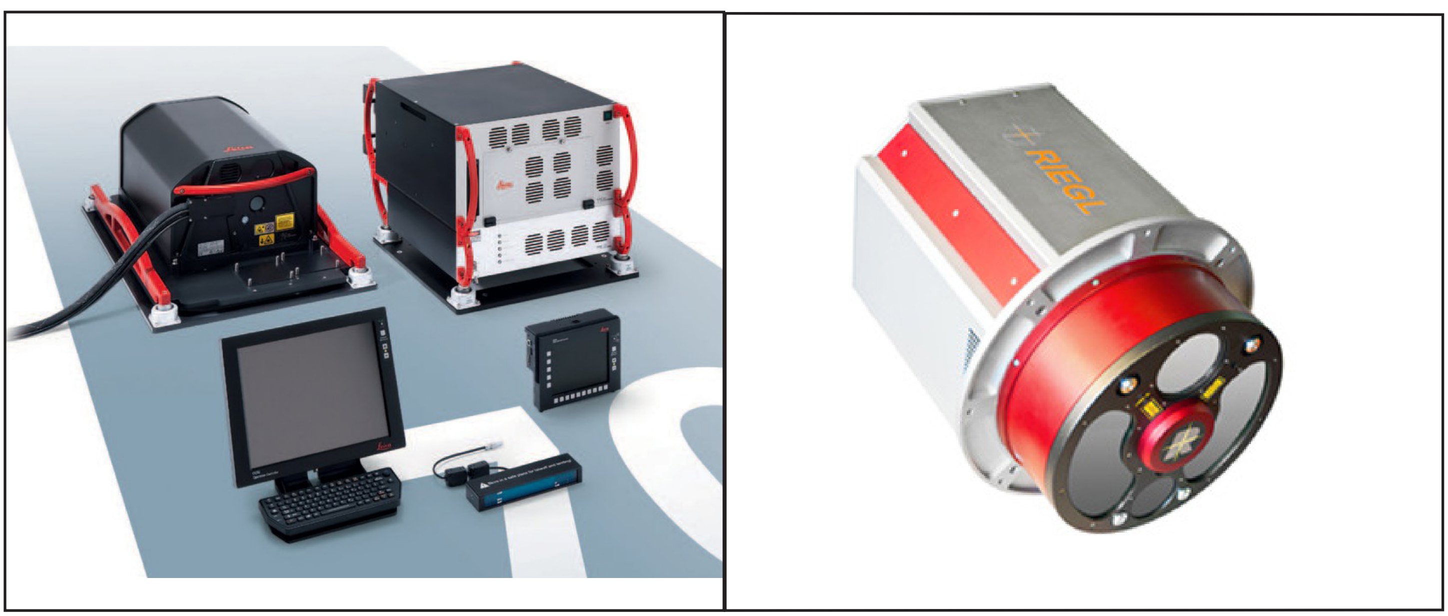


Table 2. LiDAR System Specifications

		Leica ALS 70	Riegl LMS Q1560
Terrain and Aircraft Scanner	Flying Height	2100 m	1900 m
	Recommended Ground Speed	135 kts	150 kts
Scanner	Field of View	36°	58.5°
	Scan Rate Setting Used	55 Hz	180 Hz
Laser	Laser Pulse Rate Used	265.2 kHz	700 kHz
	Multi Pulse in Air Mode	Enabled	Enabled
Coverage	Full Swath Width	1364.66 m	2128.1 m
	Line Spacing	552.46m	764.93 m
Point Spacing and Density	Average Point Spacing	0.6 m	0.84 m
	Average Point Density	2.8 pts/m²	2.84 pts/m²

Figure 3. Leica ALS 70 (Left) and Riegl LMS Q1560 (Right) LiDAR Sensors



2.3. Aircraft

All flights for the project were accomplished through the use of customized planes. Plane type and tail numbers are listed below.

LiDAR Collection Planes
- Piper Navajo (twin-piston), Tail Numbers: N73TM, N812TB
- Cessna 310 (twin-piston), Tail Number: N1107Q

These aircraft provided an ideal, stable aerial base for LiDAR and orthoimagery acquisition. These aerial platforms 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 state-of-the-art Riegl and Leica LiDAR systems. Some of Quantum Spatial's operating aircraft can be seen in Figure 4 below.

Figure 4. Some of Quantum Spatial's Planes

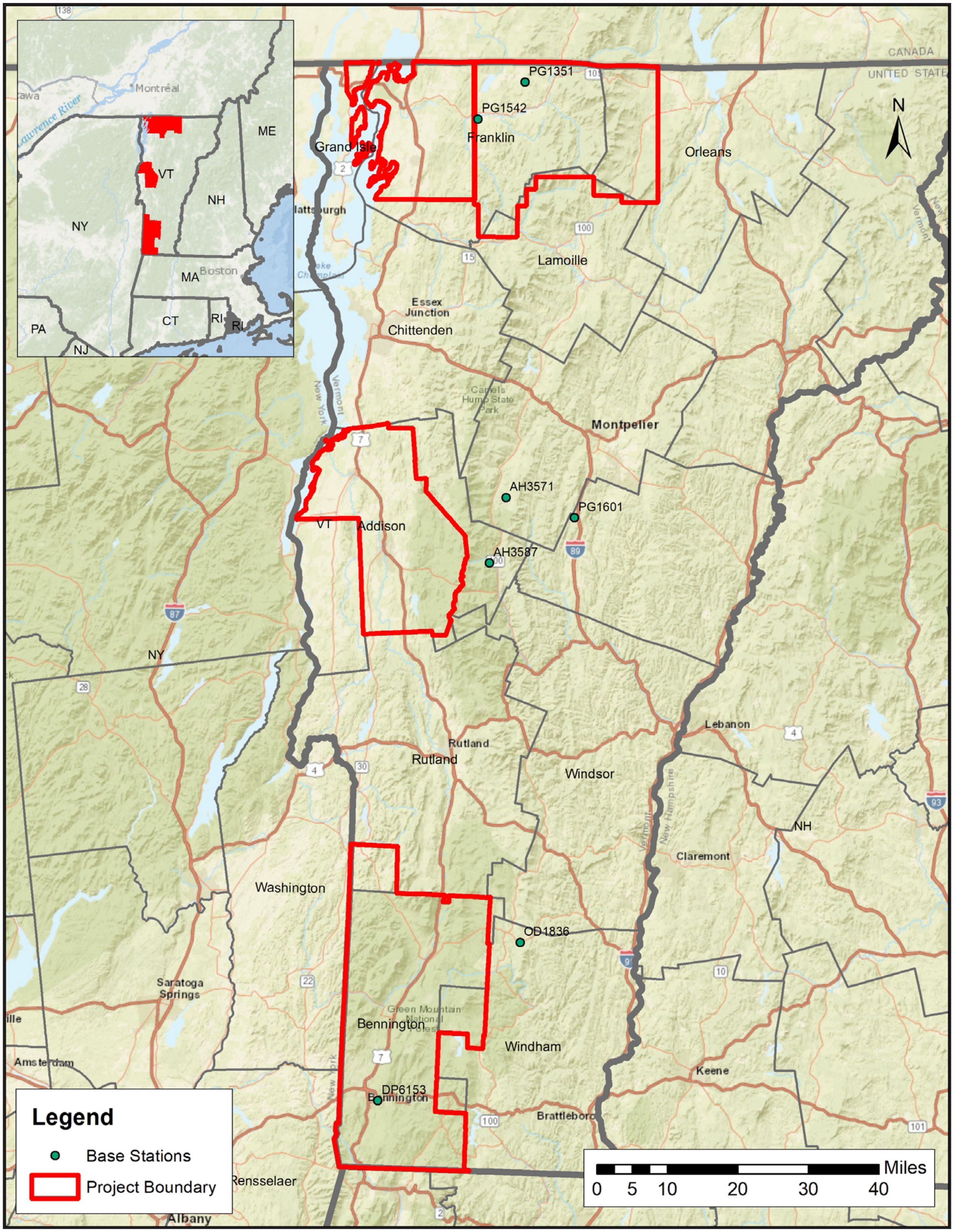
2.4. Base Station Information

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	Longitude	Latitude	Ellipsoid Height (m)
PG1601	-73° 22' 32''	44° 4' 52''	43.03
AH3571	-73° 10' 50''	44° 7' 20''	86.67
AH3587	-73° 8' 4''	43° 59' 16''	132.41
PG1351	-73° 13' 51''	44° 58' 32''	35.92
PG1542	-73° 5' 44''	44° 53' 57''	52.58
OD1836	-72° 46' 30''	43° 12' 32''	376.27
DP6153	-73° 10' 16''	42° 52' 54''	254.73

Figure 5. Base Station Locations



2.5. Time Period

Project specific flights were conducted over one month. Seventeen aircraft lifts were completed. Accomplished lifts are listed below.

- November 5, 2017-A (N73TM, SN175)
- November 8, 2017-A (N812TB, SN7161)
- November 8, 2017-B (N812TB, SN7161)
- November 8, 2017-A (N73TM, SN175)
- November 9, 2017-A (N812TB, SN7161)
- November 9, 2017-B (N812TB, SN7161)
- November 9, 2017-A (N73TM, SN175)
- November 12, 2017-A (N812TB, SN7161)
- November 15, 2017-A (N812TB, SN7161)
- November 15, 2017-A (N73TM, SN175)
- November 15, 2017-A (N1107Q, SN1256)
- November 18, 2017-A (N812TM, SN7161)
- November 18, 2017-B (N812TM, SN7161)
- November 18, 2017-A (N73TM, SN175)
- November 18, 2017-A (N1107Q, SN1256)
- November 21, 2017-A (N1107Q, SN1256)
- November 21, 2017-B (N1107Q, SN1256)

3. Processing Summary

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 A.

3.2. LiDAR Processing

Inertial Explorer/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. Inertial Explorer/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 Inertial Explorer/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 Inertial Explorer/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 CloudPro and Riegl RiPROCESS software packages. 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 was manually reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler. Global Mapper was 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 was 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 3 – Low Vegetation (Automated)
- Class 4 – Medium Vegetation (Automated)
- Class 5 – High Vegetation (Automated)
- Class 7 – Low Noise – Low points, manually identified 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 moved to this class from the Class 2 dataset. This class is ignored during the DEM creation process to provide smooth transition between the ground surface and hydro flattened surface.
- Class 13 – Hydro-Enforced Ground Points – Points removed during hydro-enforcement.
- Class 17 – Bridge Decks – Points falling on bridge decks.
- Class 18 – High Noise – High points, manually identified above 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 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 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 is used as a final check of the bare earth dataset.

GeoCue was then used to create the deliverable industry-standard LAS files for all point cloud data. Quantum Spatial's 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. Hydro-Flattened/Hydro-Enforced Breakline Processing

Class 2 (ground) LiDAR points were 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 Stream and River Islands, and Inland Streams and Rivers using TerraModeler functionality.

Elevation values were assigned to all inland streams and rivers using Quantum Spatial's 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).

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 Quantum Spatial.

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

Breaklines are reviewed against LiDAR intensity imagery to verify completeness of capture. All breaklines are then compared to TINs (triangular irregular networks) created from ground only points prior to water classification. The horizontal placement of breaklines is compared to terrain features and the breakline elevations are compared to LiDAR elevations to ensure all breaklines match the lidar within acceptable tolerances. Some deviation is expected between breakline and LiDAR elevations due to monotonicity, connectivity, and flattening rules that are enforced on the breaklines. Once completeness, horizontal placement, and vertical variance is reviewed, all breaklines are reviewed for topological consistency and data integrity using a combination of Esri Data Reviewer tools and proprietary tools.

3.6. Hydro-Flattened Raster DEM Processing

Class 2 LiDAR in conjunction with the hydro breaklines were used to create a 0.7-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.

3.7. Hydro-Enforced Raster DEM Processing

Class 2 (Ground) LiDAR in conjunction with the hydro-breaklines and any collected enforcement lines were used to create a 0.7-meter hydro-enforced raster DEM. Using automated scripting routines within ArcMap, an ERDAS Imagine .IMG file was created for each tile. Each surface was reviewed using Global Mapper to check for any surface anomalies or incorrect elevations found within the surface.

3.8. Intensity Image Processing

GeoCue software was used to create the deliverable intensity images. 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. ERDAS .IMG files with a cell size of 0.7-meters were then provided as the deliverable for this dataset requirement.

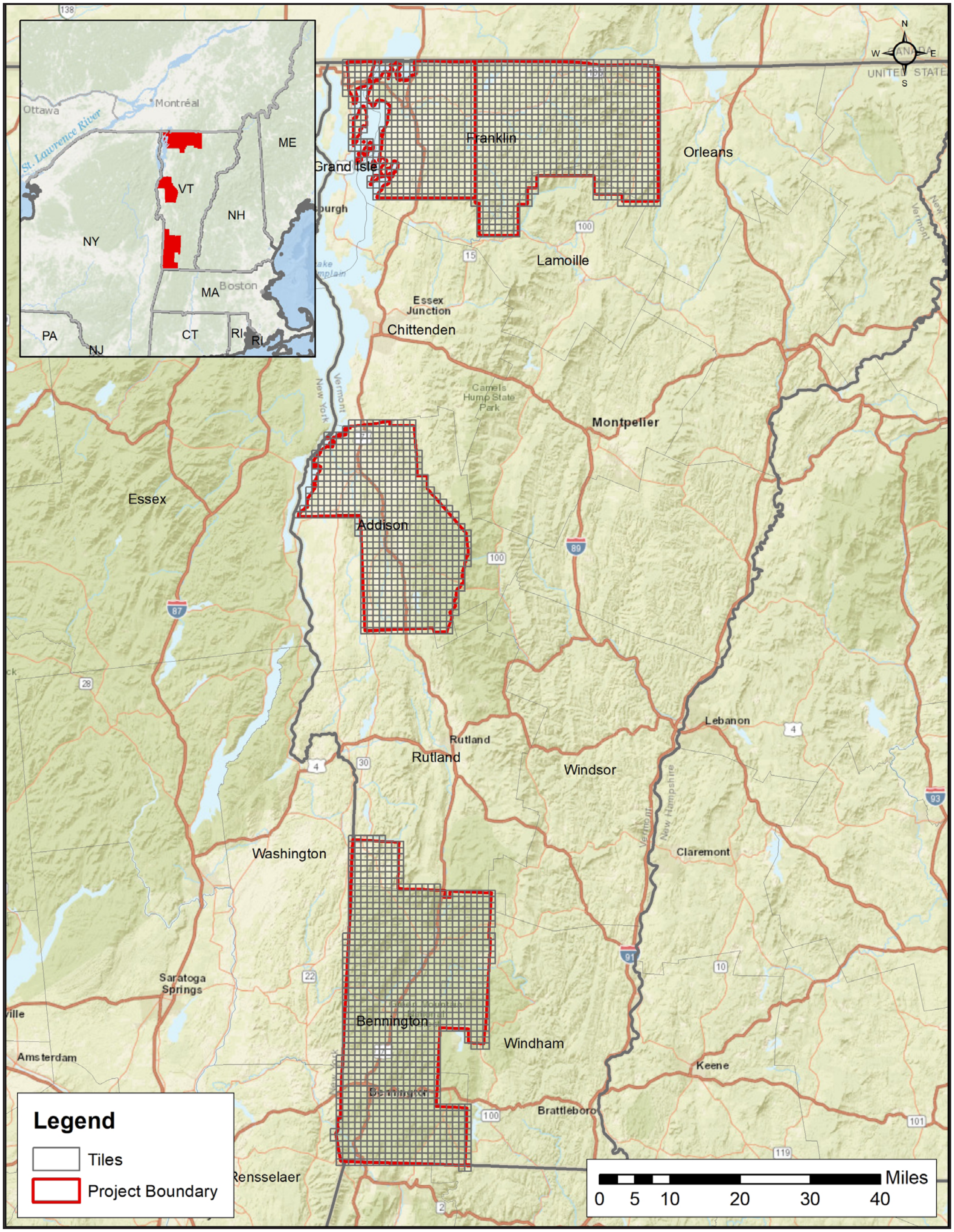
3.9. Contour Processing

Using automated scripting routines within ArcMap, a terrain surface was created using the ground (ASPRS Class 2) LiDAR data as well as the hydro-flattened breaklines. This surface was then used to generate the final 1-foot contour dataset in Esri File Geodatabase format.

3.10. First Return DSM Processing

First return and non-noise LAS points were used to create a 0.7-meter raster DSM in ERDAS .img format.

Figure 6. LiDAR Tile Layout



4. Ground Control and Checkpoint Collection

Quantum Spatial completed a field survey of 48 ground control (calibration) points along with 210 blind QA points in Non-Vegetated and Vegetated land cover classifications (total of 258 points) as an independent test of the accuracy of this project.

A combination of precise GPS surveying methods, including static and RTK observations were used to establish the 3D position of ground calibration points and QA points for the point classes above. GPS was not an appropriate methodology for surveying in the forested areas during the leaf-on conditions for the actual field survey (which was accomplished after the LiDAR acquisition). Therefore the 3D positions for the forested points were acquired using a GPS-derived offset point located out in the open near the forested area, and using precise offset surveying techniques to derive the 3D position of the forested point from the open control point. The explicit goal for these surveys was to develop 3D positions that were three times greater than the accuracy requirement for the elevation surface. In this case of the blind QA points the goal was a positional accuracy of 5 cm in terms of the RMSE.

For more information, see the Survey Report in Appendix B.

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).

4.1. Calibration Control Point Testing

Figure 7 shows the location of each bare earth calibration point for the project area. TerraScan was used to perform a quality assurance check using the LiDAR bare earth calibration points. The 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.

4.2. Point Cloud Testing

The project specifications require that only Non-Vegetated Vertical Accuracy (NVA) be computed for raw lidar point cloud swath files. The required accuracy (ACCz) is: 19.6 cm at a 95% confidence level, derived according to NSSDA, i.e., based on RMSE of 10 cm in the "bare earth" and "urban" land cover classes. The NVA was tested with 122 checkpoints located in bare earth and urban (non-vegetated) areas. These check points were not used in the calibration or post processing of the lidar point cloud data. The checkpoints were distributed throughout the project area and were surveyed using GPS techniques. See survey report for additional survey methodologies.

Elevations from the unclassified lidar surface were measured for the x,y location of each check point. Elevations interpolated from the lidar surface were then compared to the elevation values of the surveyed control points. AccuracyZ has been tested to meet 19.6 cm or better Non-Vegetated Vertical Accuracy at 95% confidence level using RMSE(z) x 1.9600 as defined by the

National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASRPS Guidelines. See Figure 8.

4.3. Digital Elevation Model (DEM) Testing

The project specifications require the accuracy (ACCz) of the derived DEM be calculated and reported in two ways:

1. The required NVA is: 19.6 cm at a 95% confidence level, derived according to NSSDA, i.e., based on RMSE of 10 cm in the "bare earth" and "urban" land cover classes. This is a required accuracy. The NVA was tested with 122 checkpoints located in bare earth and urban (non-vegetated) areas. See Figure 8.

2. Vegetated Vertical Accuracy (VVA): VVA shall be reported for "forests", "tall weeds", and "shrubs" land cover classes. The target VVA is: 29.4 cm at the 95th percentile, derived according to ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data, i.e., based on the 95th percentile error in all vegetated land cover classes combined. This is a target accuracy. The VVA was tested with 88 checkpoints located in forest, tall weeds, and shrubs (vegetated) areas. The checkpoints were distributed throughout the project area and were surveyed using GPS techniques. See Figure 9.

AccuracyZ has been tested to meet 19.6 cm or better Non-Vegetated Vertical Accuracy at 95% confidence level using RMSE(z) x 1.9600 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASRPS Guidelines.

A brief summary of results are listed below. For more information, See the FOCUS on Accuracy report.

	Target	Measured	Point Count
Raw NVA	0.196 m	0.093 m	122
NVA	0.196 m	0.095 m	122
VVA	0.294 m	0.267 m	88

Figure 7. Calibration Control Point Locations

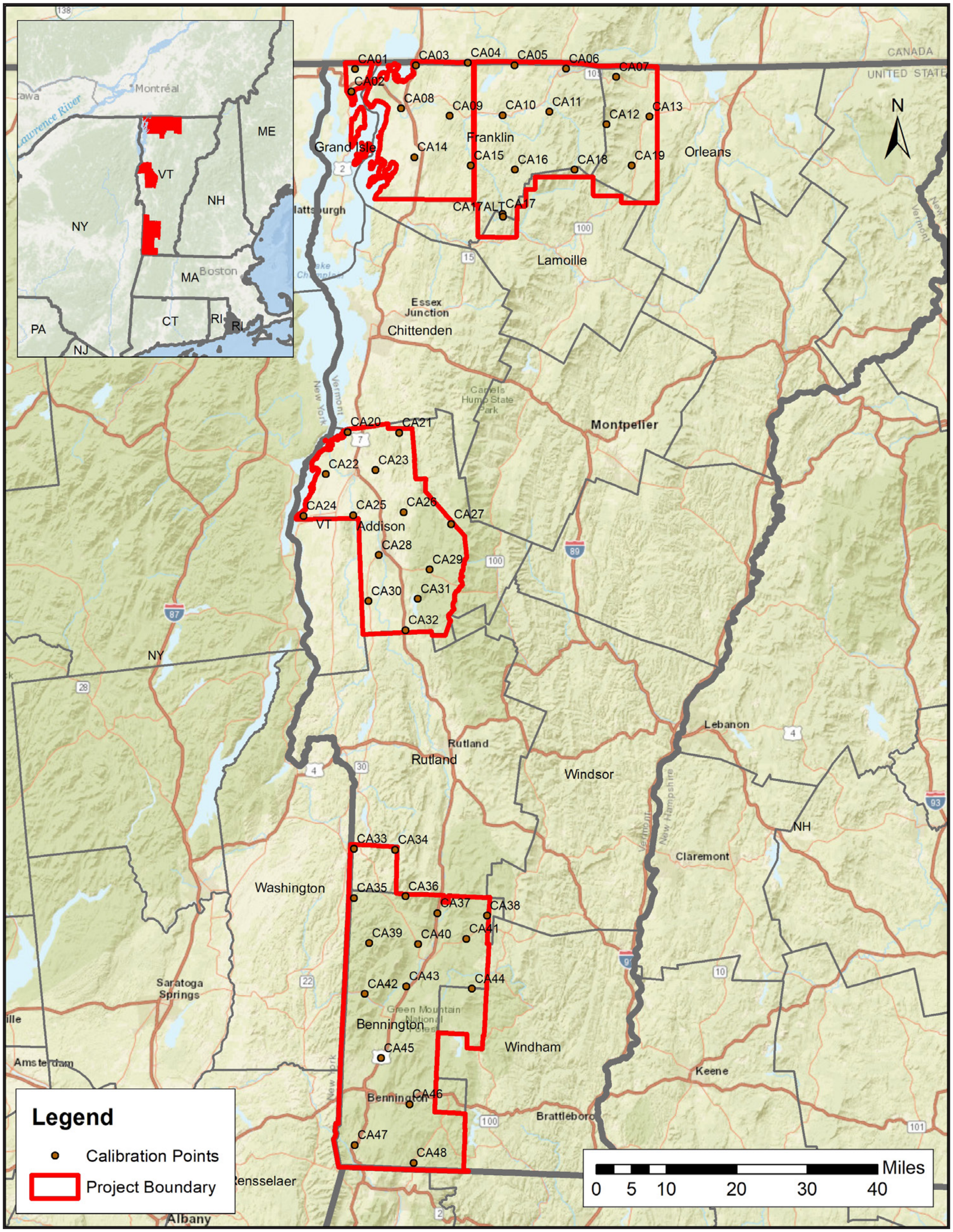


Figure 8. QC Checkpoint Locations - NVA

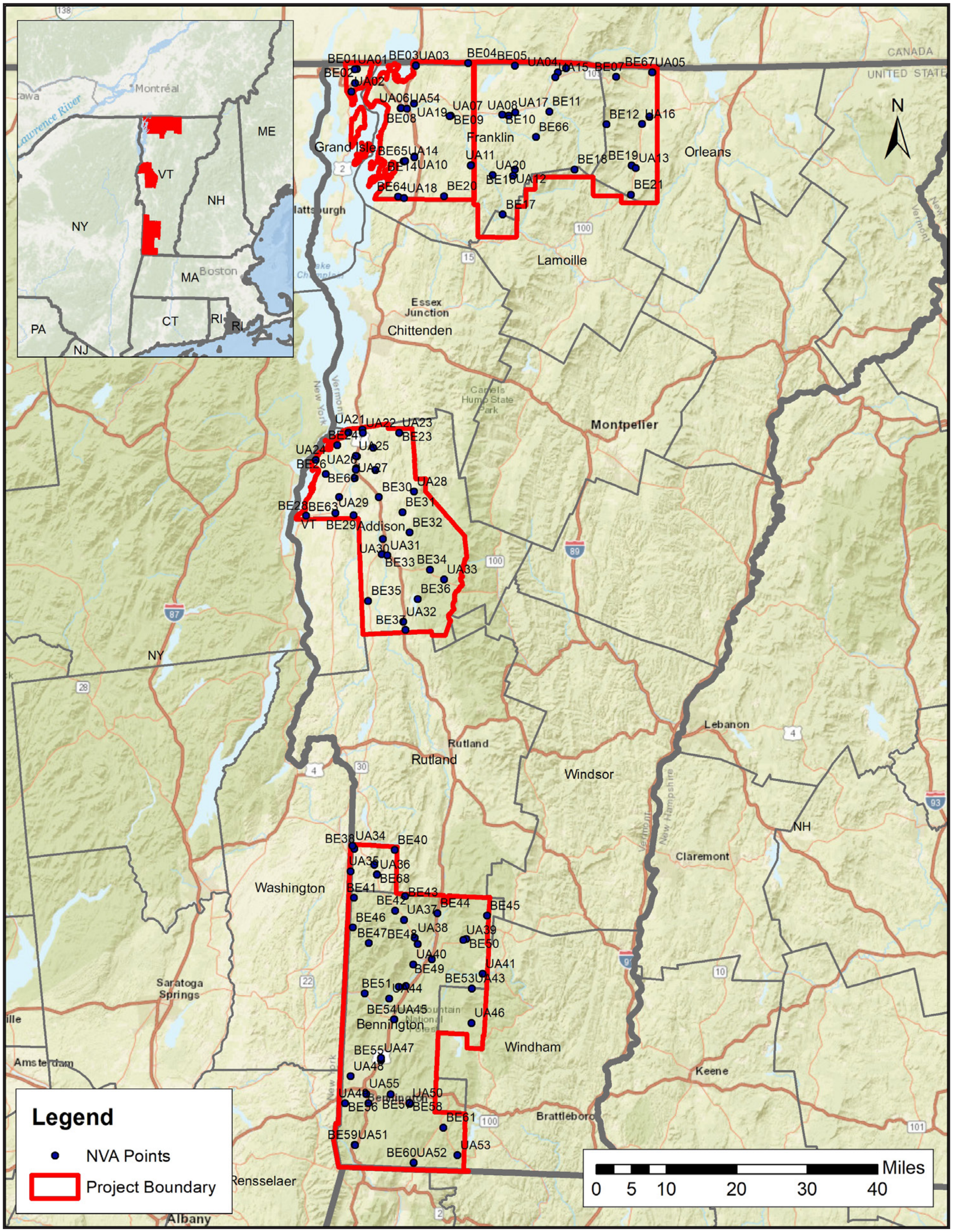


Figure 9. QC Checkpoint Locations - VVA