Windham County, Vermont 2015
QL2 LiDAR Project Report

USGS Contract # G10PC00026
Requisition # 0040236244
Task Order # G15PD00865

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1. Summary / Scope

1.1. Summary

This report contains a summary of the Windham County, Vermont 2015 QL2 LiDAR acquisition task order, issued by USGS National Geospatial Technical Operations Center (NGTOC) under their Geospatial Product and Services Contract on August 22, 2015. The task order yielded a project area covering 661 square miles over Windham County, Vermont. 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 pts / m^2	2,075 m	40.0°	30%	≤ 10 cm

1.3. Coverage

The LiDAR project boundary covers 661 square miles and encompasses most of Windham County in southern Vermont. A buffer of 100-meters was created for the area. LiDAR extents are shown in Figure 1 on the following page.

1.4. Duration

LiDAR data was acquired from November 9, 2015 to November 15, 2015 in four total lifts. See "Section: 2.5. Time Period" for more details.

1.5. Issues

There were no issues to report with this project.

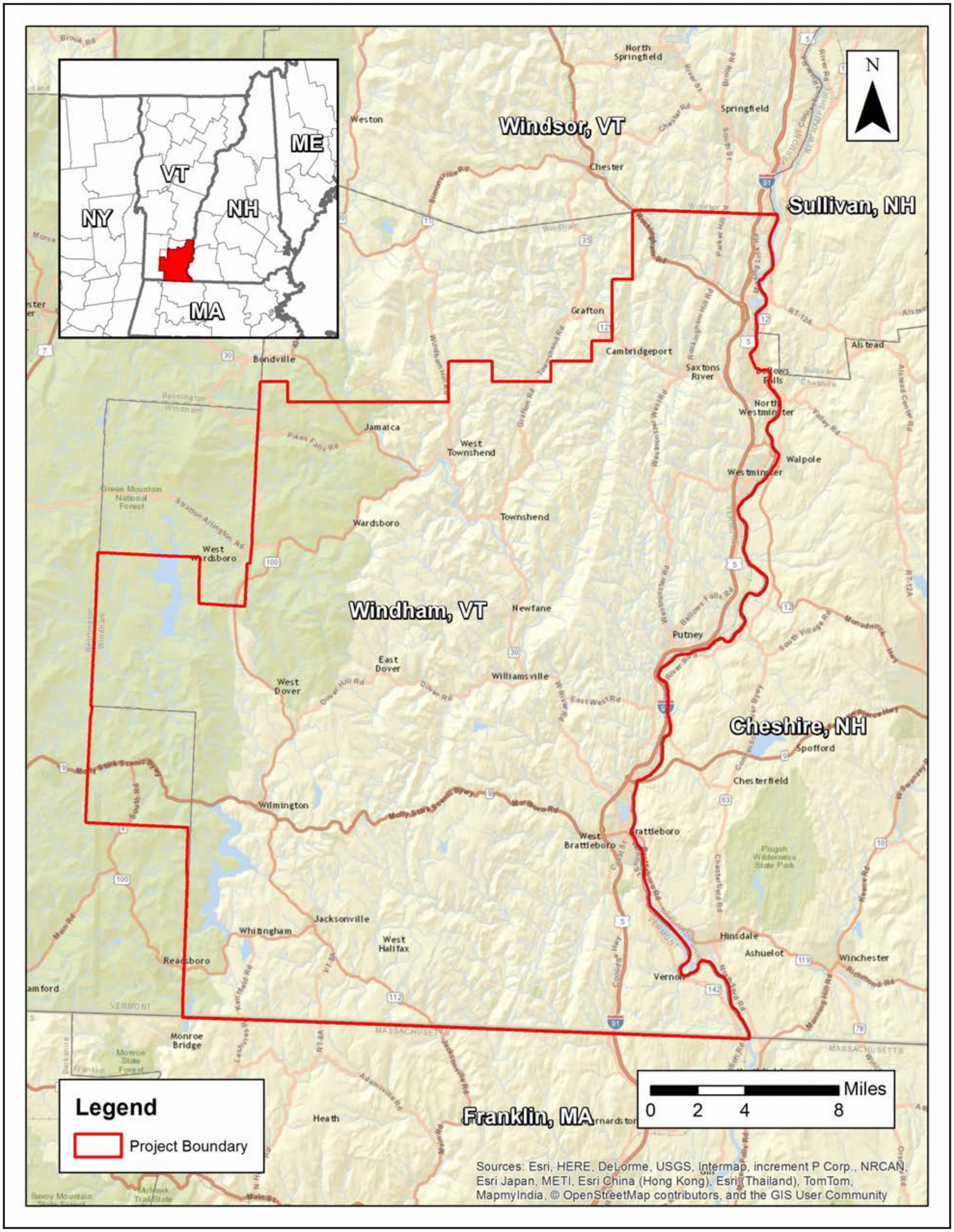
1.6. Deliverables

The following products were produced and delivered:

- Raw point cloud data, swath, in LAS 1.4 format
- Classified point cloud data, tiled, in LAS 1.4 format
- 0.7-meter hydro-flattened bare-earth raster DEM, tiled, in ERDAS .IMG format
- 0.7-meter hydro-enforced bare earth raster DEM, tiled, in Esri Grid format
  0.7-meter hydro-enforced bare earth raster mosaic, in ERDAS .IMG format
- 0.7-meter intensity images, tiled, in GeoTIFF format
- Continuous 1-foot contours, in Esri shapefile format
- Combination hydro-flattened and hydro-enforced breaklines in Esri shapefile format
- Accuracy Assessment, in .XLS format
- FOCUS report, in .PDF format
- Calibration control and QC checkpoints, in Esri shapefile format
- Processing boundary, in Esri shapefile format
- Tile index, in Esri shapefile format
- Project-, deliverable-, and lift-level metadata in XML format

All geospatial deliverables were produced in NAD83 (NSRS 2007) Vermont State Plane, meters; NAVD88, meters. All tiled deliverables have a tile size of 1,400 meters x 1,400 meters and follow the US National Grid naming schema.

Figure 1. LiDAR Project Boundary



Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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. 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. Issues” of this document.

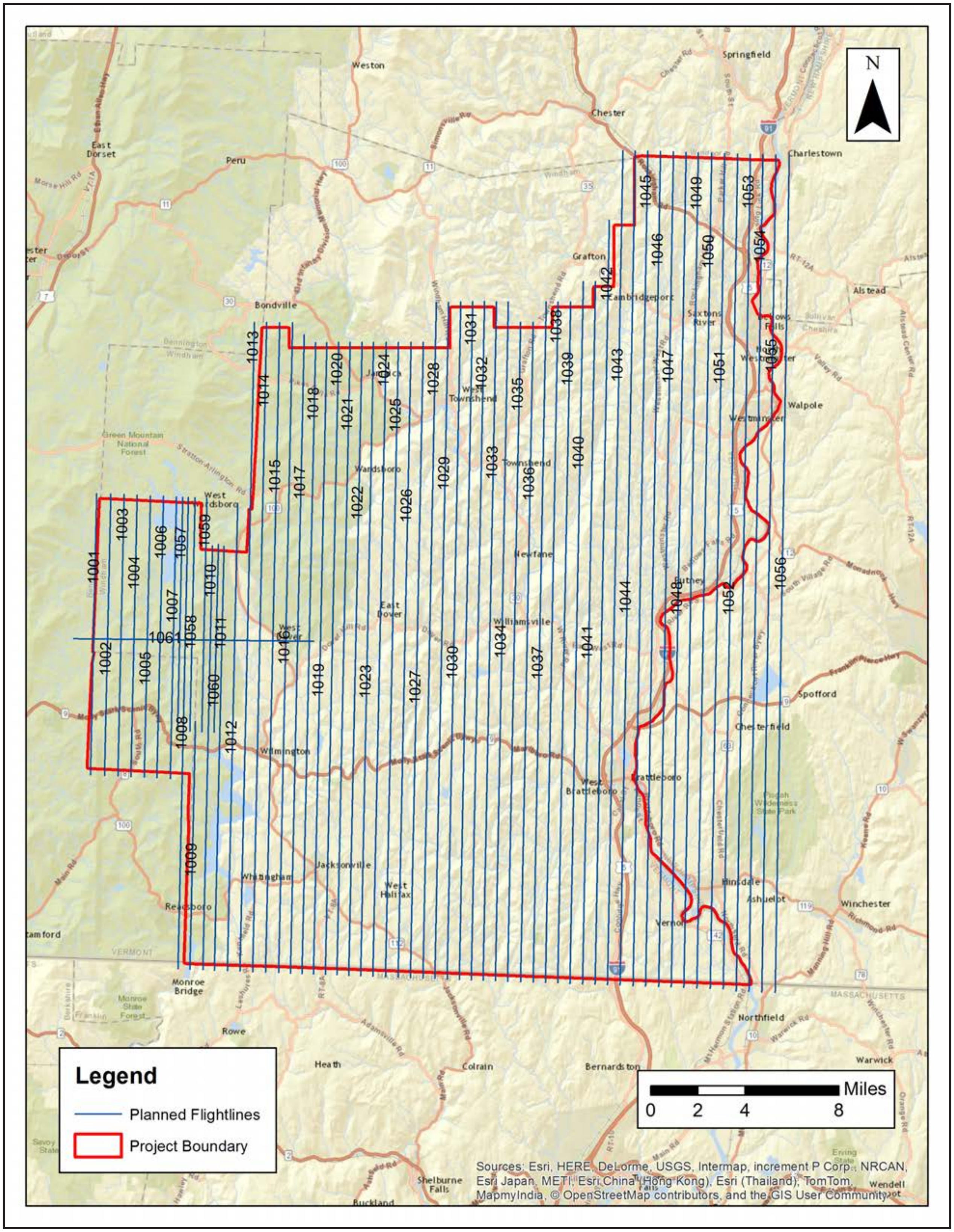
Detailed project flight planning calculations were performed for the project using Leica Mission Pro planning software. The entire target area was comprised of 61 planned flight lines measuring approximately total 1,357.98 flight line miles (Figure 2).

2.2. LiDAR Sensor

Quantum Spatial utilized a Leica ALS 70 LiDAR sensor (Figure 3), serial number 7108, 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



Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Table 2. Lidar System Specifications

		7178
Terrain and Aircraft Scanner	Flying Height	1,179 - 2,075 m
	Recommended Ground Speed	160 kts
Scanner	Field of View	40.0°
	Scan Rate Setting Used	40.7 Hz
Laser	Laser Pulse Rate Used	264.0 kHz
	Multi Pulse in Air Mode	Enabled
Coverage	Full Swath Width	1,510.48 m
	Line Spacing	744.71 m
Point Spacing and Density	Maximum Point Spacing Along Track	1.01 m
	Maximum Point Spacing Along Track	1.01 m
	Average Point Density	2.12 pts / m^2

Figure 3. Leica ALS 70 LiDAR Sensor

2.3. Aircraft

All flights for the project were accomplished through the use of a customized Cessna 310 twin-piston, (Tail # N1107Q). 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.

2.4. 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 4. 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

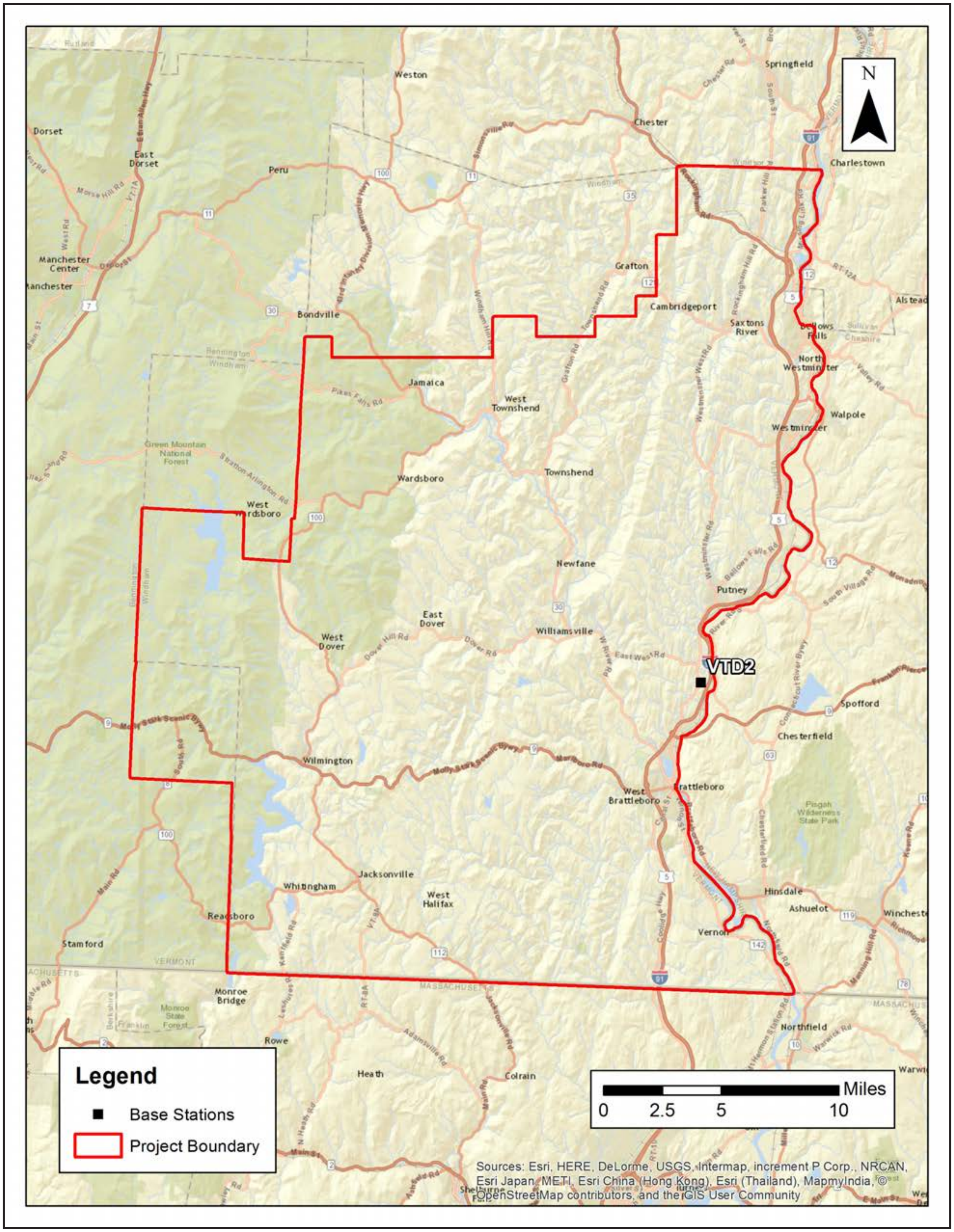
Base Station	Latitude	Longitude	Ellipsoid Height (m)
VTD2	42° 55’ 6.10798”	72° 32’ 6.4414”	98.04

2.5. Time Period

Project specific flights were conducted over two days. Four total sorties, or aircraft lifts were completed. These are listed below.

- Nov, 9, 2015-A
- Nov, 9, 2015-B
- Nov, 15, 2015-A
- Nov, 15, 2015-B

Figure 4. Base Station Locations



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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 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 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 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 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 Cloud Pro 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 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 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 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 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. Hydro-Flattened / Hydro-Enforced 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 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 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 0.7-meters 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 shapefile format using Esri conversion tools.

3.6. Hydro-Flattened Raster DEM Creation

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 .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 Creation

Class 2 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 Esri Grid 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.

3.8. Intensity Image Creation

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. 0.7-meter TIF/TWF files were then provided as the deliverable for this dataset requirement.

3.9. Contour Creation

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 continuous 1-foot contour dataset in Esri file geodatabase format.

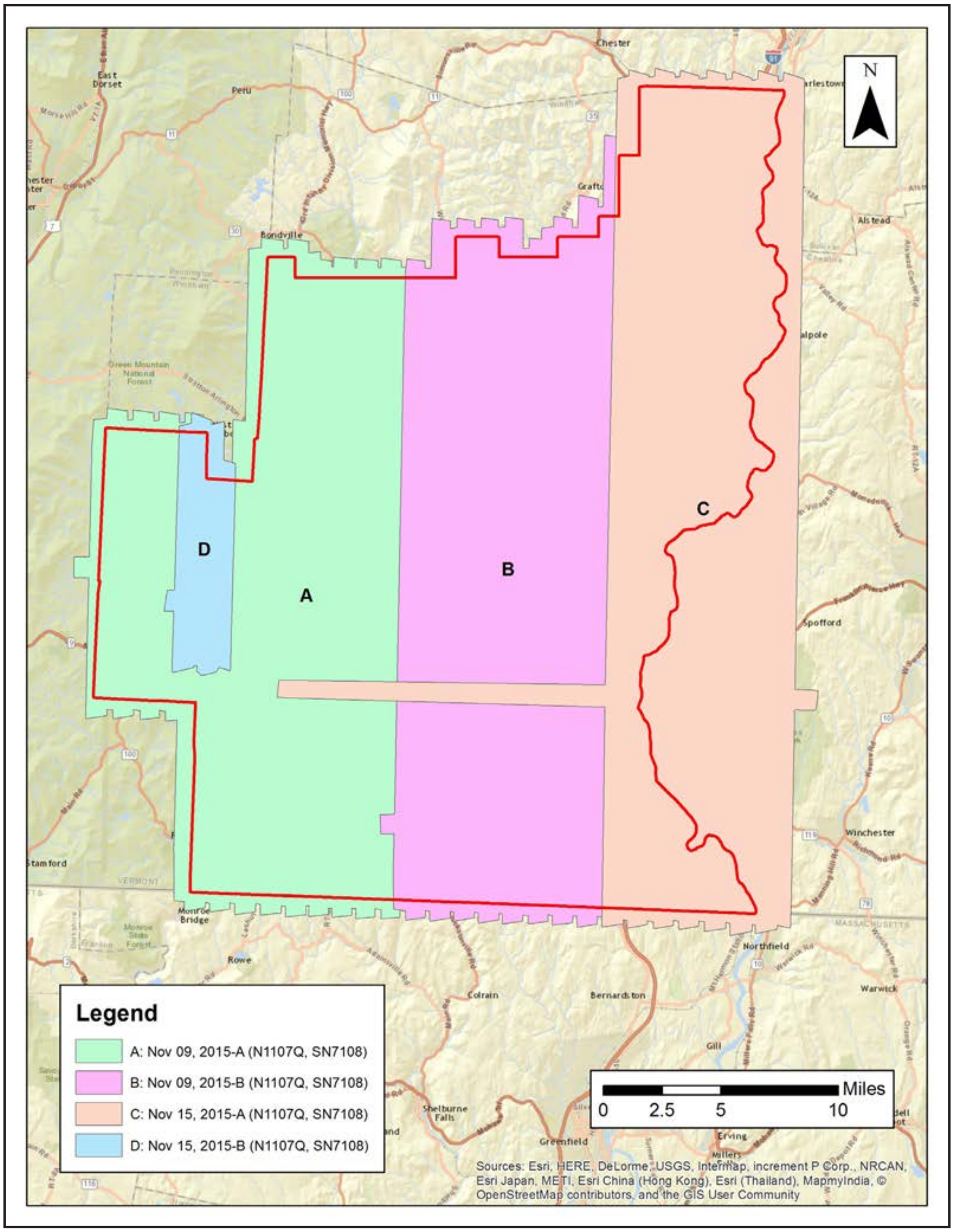
3.10. Hydro-Enforced Raster DEM Mosaic Creation

After final surface acceptance, a mosaic of the 0.7-meter bare-earth raster DEM files was created using automated scripting routines within ArcMap, in ERDAS .IMG format. The surface was reviewed for completeness to ensure all tiles were included in the mosaic.

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 5.

Figure 5. Flightline Swath LAS File Coverage



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5. Ground Control and Check Point Collection

Quantum Spatial completed a field survey of 30 ground control (calibration) points along with 70 blind QA points in Vegetated and Non-Vegetated land cover classifications (total of 100 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). In this document, horizontal coordinates for ground control and QA points for all LiDAR classes are reported in NAD83 (NSRS 2007) State Plane Vermont, meters; NAVD88 (Geoid 12B), meters.

5.1. Calibration Control Point Testing

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.

5.2. Point Cloud Testing

Raw Nonvegetated Vertical Accuracy (Raw NVA): The tested Raw NVA for the dataset was found to be 0.054 cm in terms of the RMSEz. The resulting NVA stated as the 95% confidence level (RMSEz x 1.96) is 0.106 cm. This dataset meets the required NVA 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 7 and Table 5.

5.3. 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 0.053 cm in terms of the RMSEz. The resulting accuracy stated as the 95% confidence level (RMSEz x 1.96) is 0.103 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 0.252 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 6. Calibration Control Point Locations

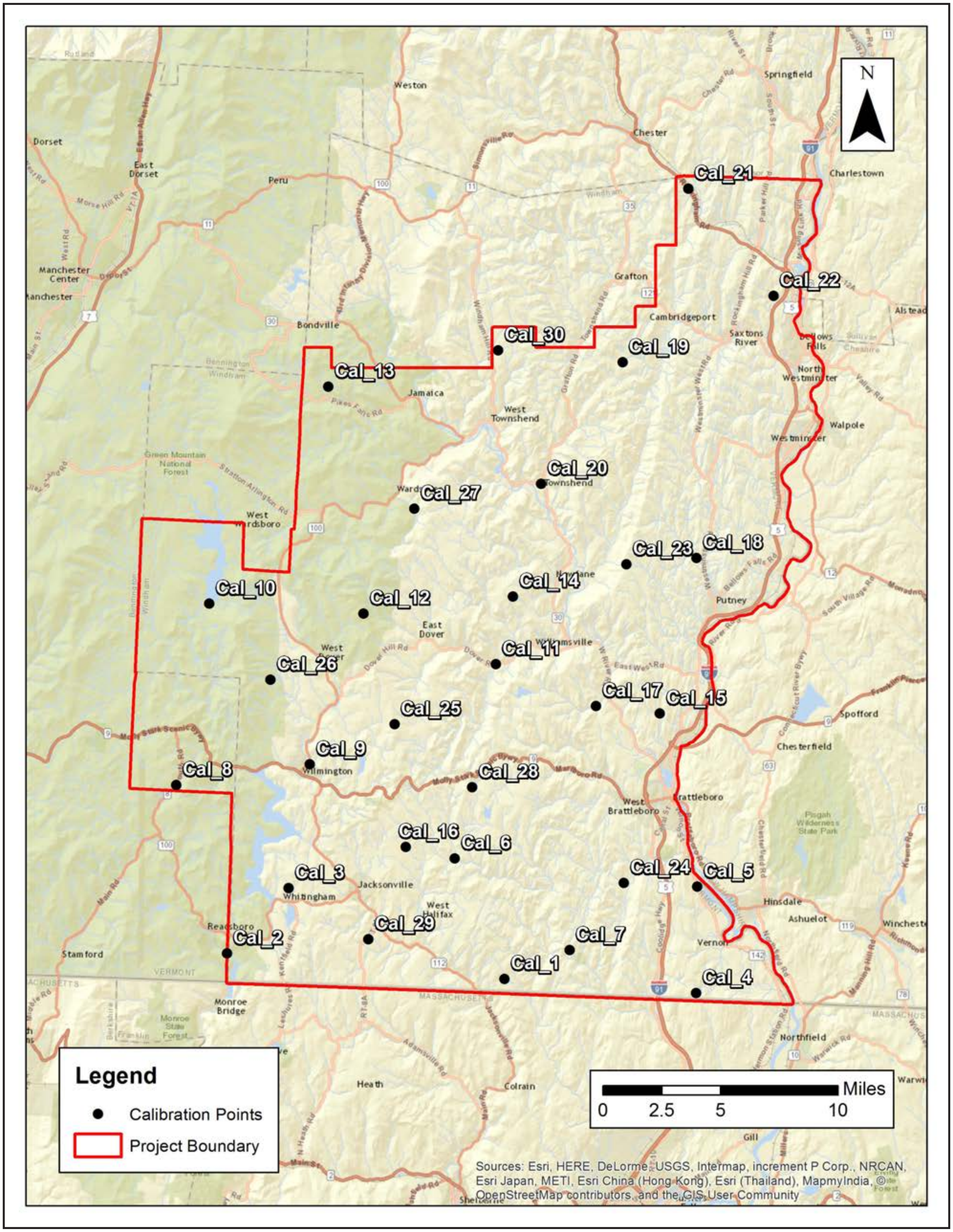

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Table 4. Calibration Point Report

Units = meters

Number	Easting	Northing	Known Z	Laser Z	Dz
Cal_1	483723.972	26849.312	333.98	333.91	-0.07
Cal_2	464720.488	28604.090	341.64	341.68	0.04
Cal_3	468939.495	33079.051	516.37	516.36	-0.01
Cal_4	496866.460	25907.319	264.09	264.12	0.03
Cal_5	496931.930	33191.515	94.68	94.63	-0.05
Cal_6	480336.821	35120.412	406.55	406.53	-0.02
Cal_7	488188.069	28834.741	377.42	377.44	0.02
Cal_8	461241.781	40156.168	755.14	755.17	0.03
Cal_9	470397.141	41566.407	475.93	475.92	-0.01
Cal_10	463512.975	52542.242	654.15	654.20	0.06
Cal_11	483140.626	48427.615	203.36	203.30	-0.06
Cal_12	474077.325	51862.344	758.55	758.48	-0.07
Cal_13	471669.162	67397.351	532.66	532.59	-0.07
Cal_14	484323.072	53031.442	462.14	462.14	0.00
Cal_15	494370.241	45056.412	181.40	181.37	-0.03
Cal_16	476984.975	35902.474	498.37	498.40	0.03
Cal_17	490000.188	45566.569	231.23	231.19	-0.04
Cal_18	496880.356	55670.610	152.77	152.75	-0.02
Cal_19	491822.225	69073.117	357.60	357.58	-0.02
Cal_20	486239.923	60738.389	173.73	173.75	0.02
Cal_21	496317.531	80973.166	166.66	166.63	-0.03
Cal_22	502158.856	73610.097	192.33	192.29	-0.04
Cal_23	492088.026	55228.157	446.48	446.42	-0.06
Cal_24	491903.921	33442.260	141.14	141.14	0.00
Cal_25	476198.390	44301.457	625.81	625.76	-0.05
Cal_26	467700.634	47356.934	624.12	624.18	0.06
Cal_27	477567.972	59040.365	348.50	348.48	-0.02
Cal_28	481529.400	39992.349	527.60	527.41	-0.19
Cal_29	474409.189	29573.680	477.63	477.67	0.04
Cal_30	483301.999	69875.608	461.31	461.29	-0.02

Number	Easting	Northing	Known Z	Laser Z	Dz
Average Dz		-0.02 m			
Minimum Dz		-0.194 m			
Maximum Dz		0.060 m			
Root Mean Square		0.053 m			
Std. Deviation		0.051 m			

Figure 7. QC Checkpoint Locations - Raw NVA

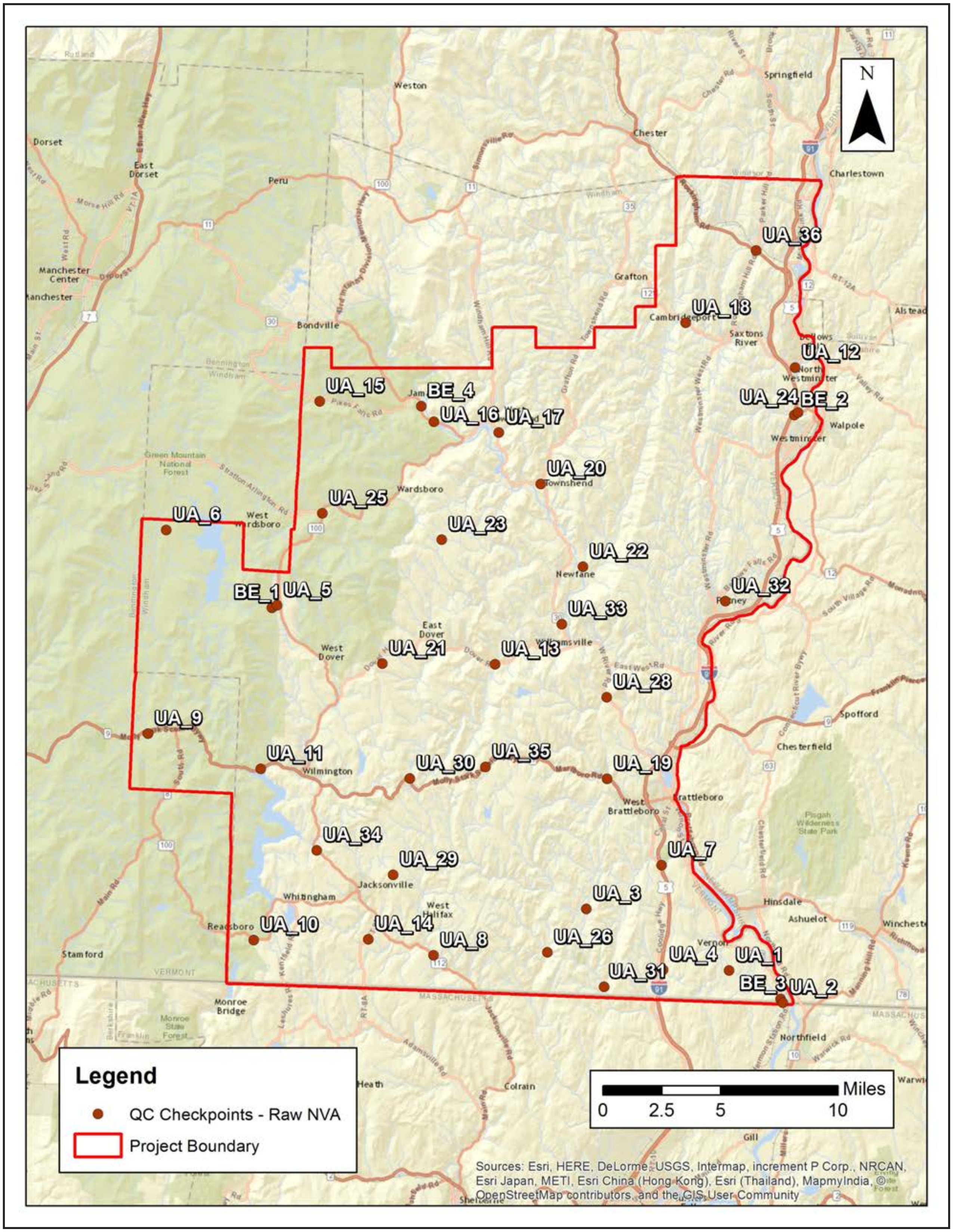

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Table 5. QC Checkpoints Report - Raw NVA

Units = meters

Number	Easting	Northing	Known Z	Laser Z	Dz
BE_1	467804.391	52254.467	601.89	601.94	0.05
BE_2	503604.014	65467.990	118.98	118.92	-0.06
BE_3	502656.887	25489.099	81.68	81.71	0.03
BE_4	478033.231	66076.898	200.37	200.36	-0.01
UA_1	499115.394	27439.418	116.94	116.9	-0.04
UA_2	502799.312	25234.625	92.55	92.6	0.05
UA_3	489354.602	31658.455	235.77	235.77	0.00
UA_4	494602.231	27499.851	161.67	161.61	-0.06
UA_5	468162.233	52441.804	621.83	621.89	0.06
UA_6	460573.832	57591.195	675.95	676.03	0.08
UA_7	494486.377	34654.698	125.62	125.63	0.01
UA_8	478866.365	28495.090	286.92	286.93	0.01
UA_9	459310.970	43668.877	685.82	685.86	0.04
UA_10	466549.447	29536.215	482.21	482.25	0.04
UA_11	467037.464	41259.477	457.73	457.88	0.15
UA_12	503650.493	68712.095	119.55	119.47	-0.08
UA_13	483103.853	48422.481	200.05	200.03	-0.02
UA_14	474415.344	29590.576	476.64	476.63	-0.01
UA_15	471082.068	66406.529	454.83	454.77	-0.06
UA_16	478910.719	65006.824	182.13	182.10	-0.03
UA_17	483344.495	64262.801	173.23	173.23	0.00
UA_18	496160.848	71787.323	189.40	189.41	0.01
UA_19	490755.453	40563.750	151.08	151.04	-0.04
UA_20	486229.002	60735.239	173.76	173.73	-0.03
UA_21	475378.287	48483.182	591.13	591.08	-0.04
UA_22	489115.308	55080.643	123.38	123.38	0.00
UA_23	479429.654	56928.523	495.48	495.35	-0.13
UA_24	503845.785	65651.256	112.97	112.95	-0.02
UA_25	471252.530	58737.525	446.14	446.09	-0.05
UA_26	486674.128	28679.816	200.14	200.14	0.00
UA_27	480190.860	35111.379	417.62	417.55	-0.07
UA_28	490748.361	46168.009	89.43	89.37	-0.05

Number	Easting	Northing	Known Z	Laser Z	Dz
UA_29	476109.412	33993.834	531.34	531.31	-0.03
UA_30	477240.037	40611.550	566.07	566.01	-0.06
UA_31	490564.125	26322.706	207.00	207.05	0.05
UA_32	498871.838	52728.264	116.82	116.78	-0.04
UA_33	487661.785	51136.178	157.02	156.96	-0.06
UA_34	470866.903	35678.166	481.02	480.95	-0.07
UA_35	482428.072	41397.574	473.23	473.14	-0.09
UA_36	500971.753	76750.305	133.68	133.64	-0.04
Average Dz		-0.01 m			
Minimum Dz		-0.131 m			
Maximum Dz		0.148 m			
Root Mean Square		0.054 m			
95% Confidence		0.106 m			

Figure 8. QC Checkpoint Locations - NVA

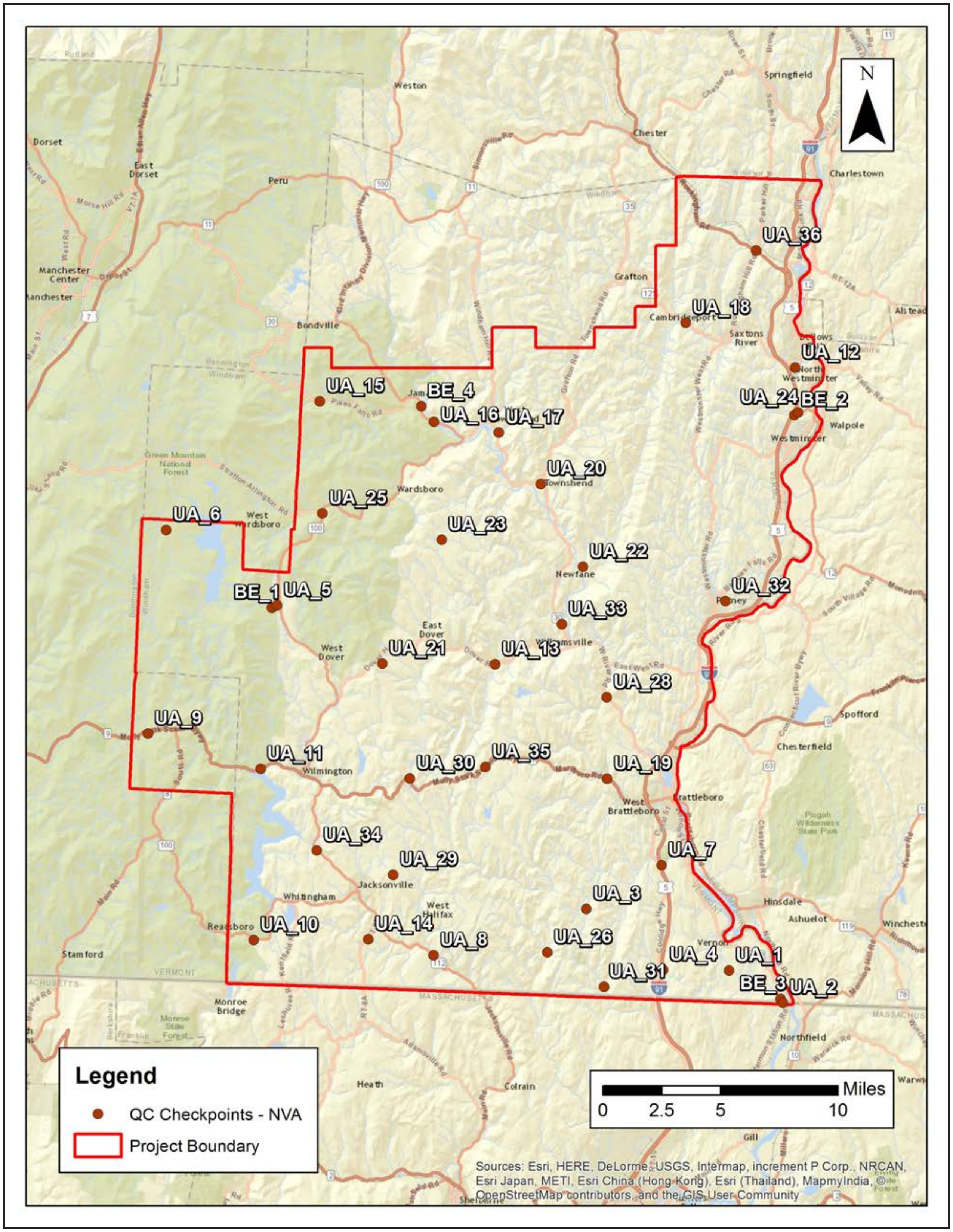

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Table 6. QC Checkpoint Report - NVA

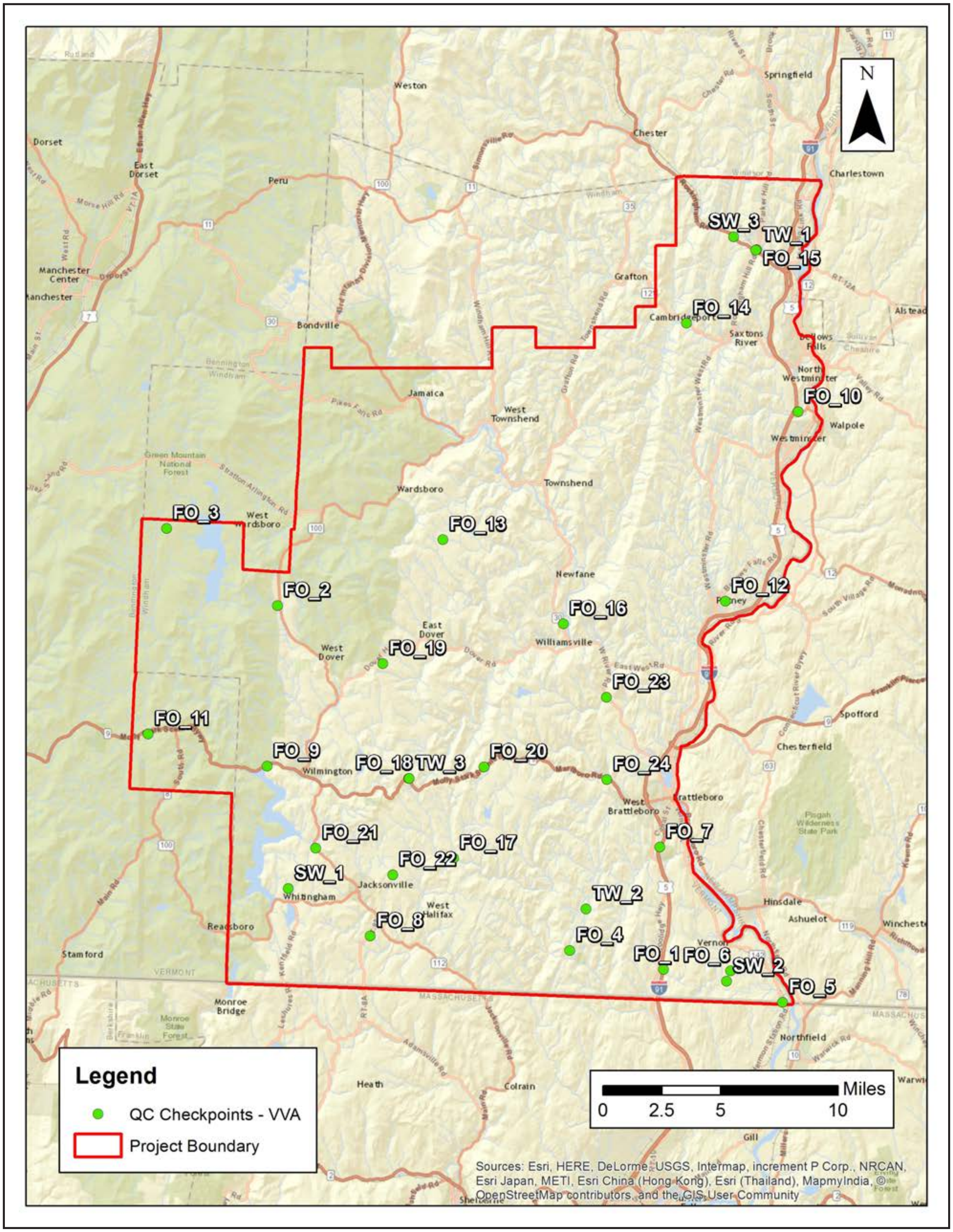
Units = meters

Number	Easting	Northing	Known Z	Laser Z	Dz
BE_1	467804.39	52254.47	601.89	601.946472	0.06
BE_2	503604.01	65467.99	118.98	118.939156	-0.04
BE_3	502656.89	25489.10	81.68	81.677406	0.00
BE_4	478033.23	66076.90	200.37	200.355759	-0.01
UA_1	499115.39	27439.42	116.94	116.921326	-0.02
UA_2	502799.31	25234.63	92.55	92.558037	0.01
UA_3	489354.60	31658.46	235.77	235.763306	-0.01
UA_4	494602.23	27499.85	161.67	161.608139	-0.06
UA_5	468162.23	52441.80	621.83	621.884521	0.06
UA_6	460573.83	57591.20	675.95	676.022705	0.07
UA_7	494486.38	34654.70	125.62	125.641487	0.02
UA_8	478866.37	28495.09	286.92	286.936401	0.02
UA_9	459310.97	43668.88	685.82	685.853271	0.03
UA_10	466549.45	29536.22	482.21	482.250793	0.04
UA_11	467037.46	41259.48	457.73	457.876038	0.14
UA_12	503650.49	68712.10	119.55	119.484711	-0.06
UA_13	483103.85	48422.48	200.05	200.022293	-0.03
UA_14	474415.34	29590.58	476.64	476.632477	0.00
UA_15	471082.07	66406.53	454.83	454.764191	-0.06
UA_16	478910.72	65006.82	182.13	182.03653	-0.09
UA_17	483344.50	64262.80	173.23	173.22821	0.00
UA_18	496160.85	71787.32	189.40	189.41449	0.01
UA_19	490755.45	40563.75	151.08	151.041168	-0.04
UA_20	486229.00	60735.24	173.76	173.757492	0.00
UA_21	475378.29	48483.18	591.13	591.082458	-0.04
UA_22	489115.31	55080.64	123.38	123.380402	0.00
UA_23	479429.65	56928.52	495.48	495.351715	-0.13
UA_24	503845.79	65651.26	112.97	112.927719	-0.04
UA_25	471252.53	58737.53	446.14	446.102692	-0.03
UA_26	486674.13	28679.82	200.14	200.134796	-0.01
UA_27	480190.86	35111.38	417.62	417.565582	-0.05
UA_28	490748.36	46168.01	89.43	89.372643	-0.05

Number	Easting	Northing	Known Z	Laser Z	Dz
UA_29	476109.41	33993.83	531.34	531.309509	-0.03
UA_30	477240.04	40611.55	566.07	566.014526	-0.05
UA_31	490564.13	26322.71	207.00	207.050354	0.05
UA_32	498871.84	52728.26	116.82	116.785645	-0.03
UA_33	487661.79	51136.18	157.02	156.961349	-0.06
UA_34	470866.90	35678.17	481.02	480.947205	-0.07
UA_35	482428.07	41397.57	473.23	473.141663	-0.09
UA_36	500971.75	76750.31	133.68	133.66423	-0.02

Average Dz	-0.02 m
Minimum Dz	-0.129 m
Maximum Dz	0.144 m
Root Mean Square	0.053 m
95% Confidence	0.103 m

Figure 9. QC Checkpoint Locations - VVA



Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Table 7. QC Checkpoint Report - VVA

Units = meters

Number	Easting	Northing	Known Z	Laser Z	Dz
FO_1	494630.20	27516.40	164.08	164.057587	-0.02
FO_2	468173.28	52403.18	619.91	620.123352	0.21
FO_3	460578.67	57706.98	673.19	673.321045	0.13
FO_4	488202.66	28806.10	377.53	377.569733	0.04
FO_5	502768.78	25271.55	96.97	97.068245	0.10
FO_6	499214.75	27423.68	112.42	112.480614	0.06
FO_7	494360.23	35911.26	167.10	167.125732	0.03
FO_8	474540.67	29805.13	456.75	456.913483	0.16
FO_9	467466.16	41434.57	460.52	460.742523	0.23
FO_10	503841.56	65686.12	111.28	111.169113	-0.11
FO_11	459320.75	43646.04	685.01	685.135376	0.12
FO_12	498857.45	52721.67	116.36	116.397476	0.04
FO_13	479511.09	56933.71	493.41	493.509186	0.10
FO_14	496199.36	71777.33	192.59	192.696121	0.11
FO_15	501007.42	76789.74	131.54	131.598236	0.06
FO_16	487761.41	51165.05	154.63	154.702179	0.08
FO_17	480246.16	35128.19	413.49	413.444336	-0.04
FO_18	477180.10	40590.68	565.47	565.501038	0.03
FO_19	475391.80	48467.34	589.56	589.562317	0.01
FO_20	482321.46	41389.80	478.76	478.516205	-0.24
FO_21	470801.98	35836.94	476.91	476.921082	0.01
FO_22	476080.91	33997.82	534.88	534.978577	0.09
FO_23	490725.54	46168.15	89.53	89.635147	0.11
FO_24	490742.79	40518.97	154.59	154.649887	0.06
SW_1	468919.18	33069.46	514.53	514.705261	0.17
SW_2	498936.01	26710.78	114.97	113.605507	-1.37
SW_3	499422.22	77688.78	154.37	154.626923	0.26
TW_1	500962.89	76769.64	132.17	132.160156	0.00
TW_2	489317.62	31648.45	238.88	239.102417	0.23
TW_3	477194.88	40604.37	565.36	565.411377	0.05

Number	Easting	Northing	Known Z	Laser Z	Dz
Average Dz		0.02 m			
Minimum Dz		-1.368 m			
Maximum Dz		0.258 m			
Root Mean Square		0.278 m			
95th Percentile		0.252 m			