Utah 2016 - Forge AOI
QL1 LiDAR Interim Project Report

Contract # AV2408

Submitted: February 15, 2017

Prepared by:

Quantum Spatial, Inc
523 Wellington Way, Suite 375
Lexington, KY 40503
859-277-8700

Contents

List of Figures

List of Tables

List of Appendices

1. Summary / Scope

1.1. Summary

This report contains a summary of the Utah 2016 - Forge AOI QL1 LiDAR acquisition task order, issued by State of Utah, Department of Technology Services, Division of Integrated Technology, Automated Geographic Reference Center (AGRC) under their contract signed on August 12, 2016. The task order yielded a project area covering approximately 7,536 square kilometers over western Utah and southern Idaho. 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	Minimum Side Overlap	RMSEz
9.8 pts / m^2	1,550 m	40°	63%	≤ 10 cm

1.3. Coverage

The total LiDAR project boundary covers approximately 7,536 square kilometers. This report focuses on the Forge QL1 area of interest, which covers approximately 531 km^2.

A buffer of 100 meters was created to meet task order specifications. LiDAR extents are shown in Figure 1.

1.4. Duration

LiDAR data was acquired from October 26, 2016 to November 3, 2016 in five total lifts. See “Section: 2.5. Time Period” for more details.

1.5. Issues

There were no issues to report for this project.

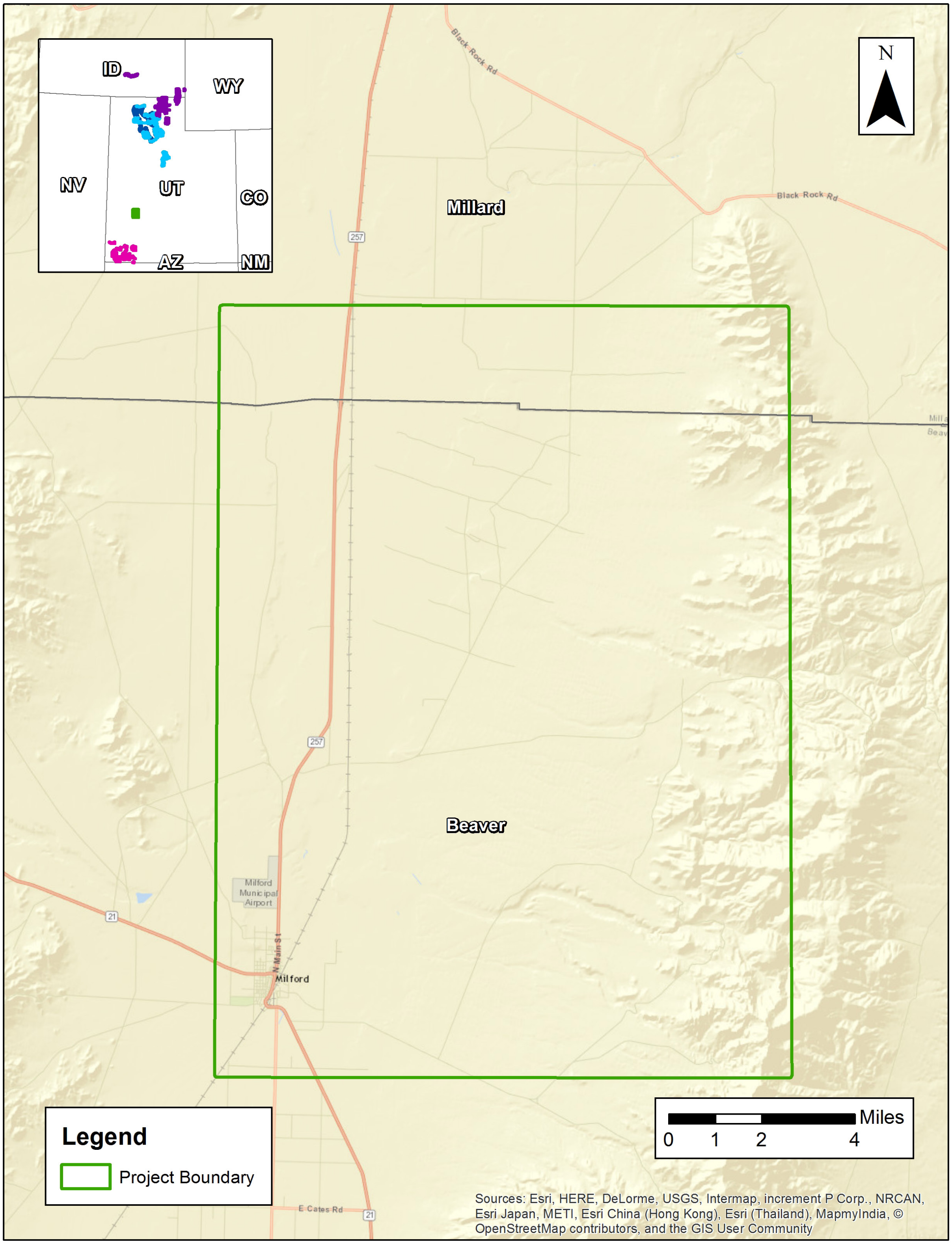
1.6. Deliverables

The following products were produced and delivered:

- Raw LiDAR point cloud data swaths in LAS 1.4 format
- Classified LiDAR point cloud data, tiled, in LAS 1.4 format
- 0.5-meter hydro-flattened bare-earth raster DEM, tiled, in ERDAS .IMG format Hydro-flattened breaklines in Esri shapefile format
- 0.5-meter first return raster DSM, tiled, in ERDAS .IMG format
- 0.5-meter intensity images, tiled, in GeoTIFF format
- Processing boundary in Esri shapefile format
- Tile index in Esri shapefile format
- Calibration and QC checkpoints in Esri shapefile format
- Accuracy assessment in .XLSX format
- Project-, deliverable-, and lift-level metadata in .XML format

All geospatial deliverables were produced in NAD83 UTM Zone 12, meters; NAVD88 (GEOID 12B), meters. All .LAS tiled deliverables have a tile size of 1,000 meters x 1,000 meters. All other tiled deliverables have a tile size of 2,000 meters x 2,000 meters. All tile names follow US National Grid naming convetions. Tile names are based on the southwest corner of the tile.

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 planning software. The entire target area was comprised of 73 planned flight lines measuring approximately 929.2 total flight line miles (Figure 2).

2.2. LiDAR Sensor

Quantum Spatial utilized a Leica ALS 80 LiDAR sensor (Figure 3), serial number 8227, during the project. The Leica ALS 80 system is capable of collecting data at a maximum frequency of 1,000 kHz. The system utilizes a Multi-Pulse in the Air option (MPIA). The sensor is also equipped with the ability to measure up to 6 returns per outgoing pulse from the laser. 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

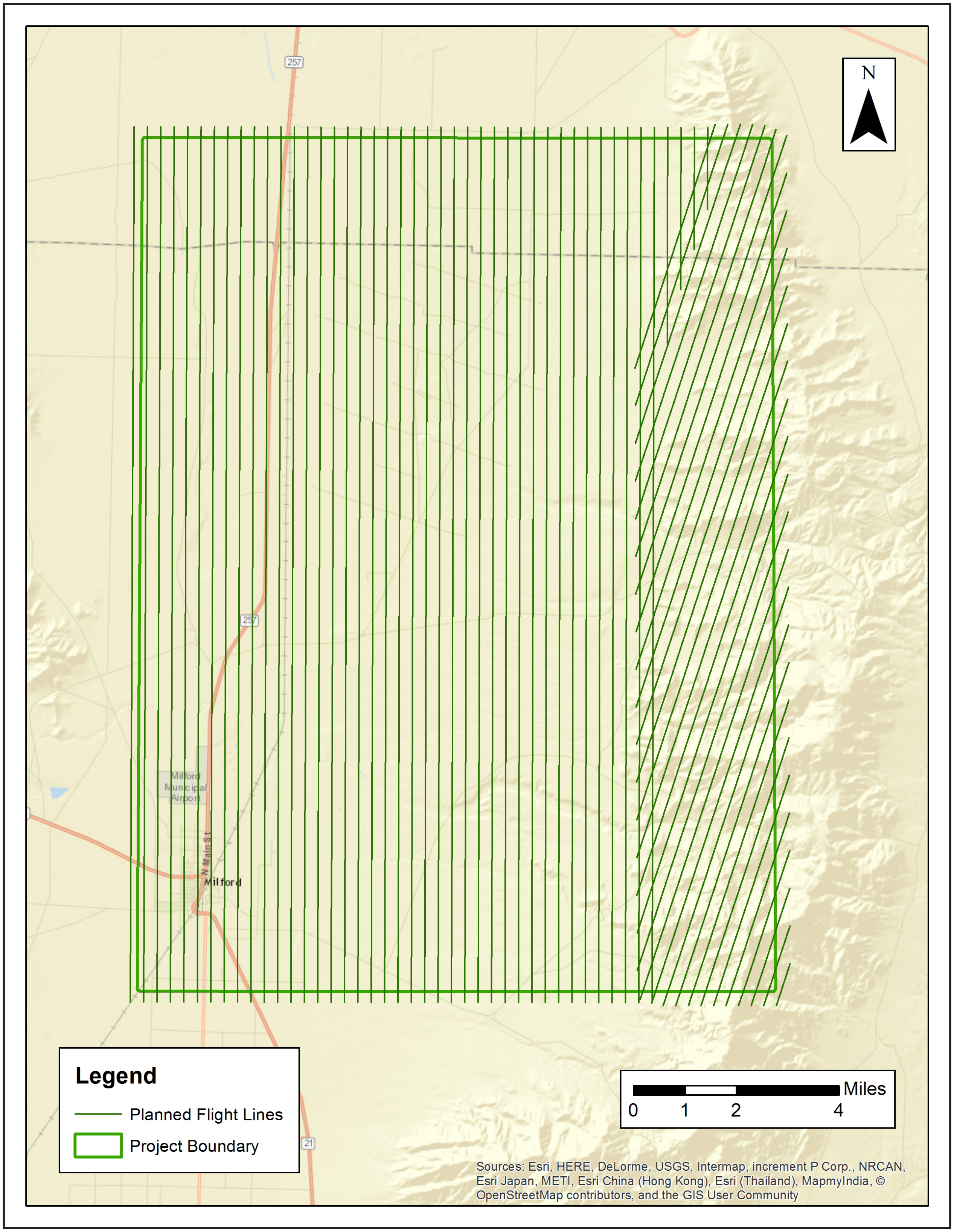


Table 2. Lidar System Specifications

Terrain and Aircraft Scanner	Flying Height	1,550 m
	Recommended Ground Speed	120 kts
Scanner	Field of View	40°
	Scan Rate Setting Used	50 Hz
Laser	Laser Pulse Rate Used	340 kHz
	Multi Pulse in Air Mode	Enabled
Coverage	Full Swath Width	1,128 m
	Line Spacing	1,374 m
Point Spacing and Density	Average Point Density	0.7 m
	Average Point Density	9.7 pts / m^2

Figure 3. Leica ALS 80 LiDAR Sensor

2.3. Aircraft

All flights for the project were accomplished through the use of a customized Cessna Caravan (single-turboprop) plane, tail number N208NR. 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. 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. The base station locations were verified using NGS OPUS service and subsequent surveys. Base station locations, data sheets, graphical depiction of base station locations or log sheets used during station occupation will be available in the final report.

2.5. Time Period

Project specific flights were conducted over several days. Five sorties, or aircraft lifts were completed. Accomplished sorties are listed below.

- October 26, 2016-A (N208NR, SN8227)
- October 27, 2016-A (N208NR, SN8227)
- October 28, 2016-A (N208NR, SN8227)
- November 1, 2016-A (N208NR, SN8227)
- November 3, 2016-A (N208NR, SN8227)

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 will be available in the full report.

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 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 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 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 point classification is performed as described below. 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-flattened 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 classified using standard LAS overlap bit. 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 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, Inc. 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 Breakline Creation

Class 2 (ground) lidar points 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 Stream and River Islands, using TerraModeler functionality. Elevation values were assigned to all inland streams and rivers using Quantum Spatial, Inc. 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 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 Creation

Class 2 (Ground) lidar points in conjunction with the hydro breaklines were used to create a 0.5 meter hydro-flattened 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. First Return Raster DEM Creation

First return lidar points were used to create a 0.5 meter first-return 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.

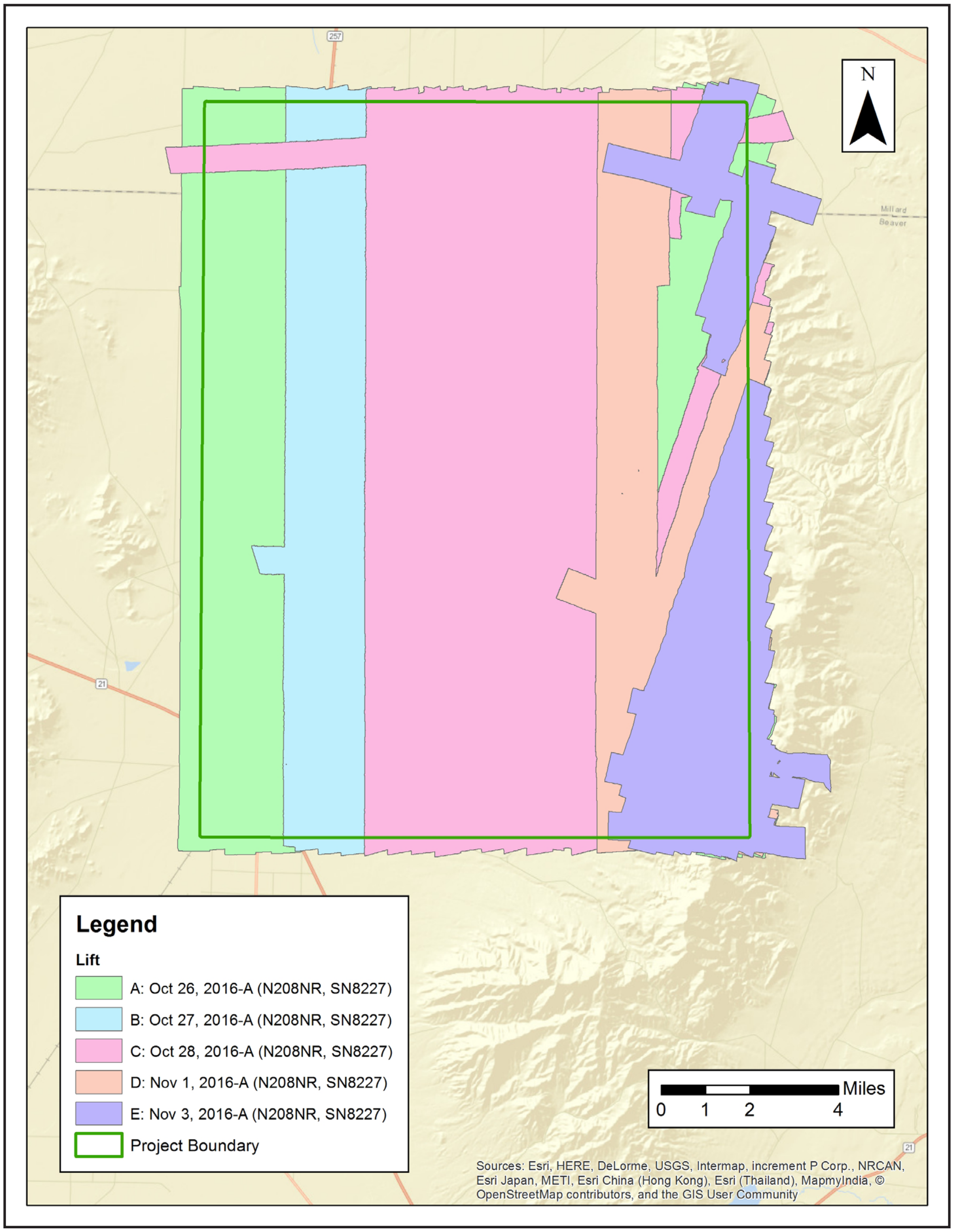
3.8. Intensity Image Creation

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

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



5. Ground Control and Check Point Collection

Quantum Spatial completed a field survey of 42 ground control (calibration) points along with 15 blind QA points in Vegetated and Non-Vegetated land cover classifications (total of 57 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 survey report will be inclued with the final report.

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 UTM Zone 12, meters; NAVD88 (GEOID 12B), meters.

5.1. Calibration Control Point Testing

Figure 6 shows the location of each bare earth calibration point for the project area. Table 3 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 0.020 meters in terms of the RMSEz. The resulting NVA stated as the 95% confidence level (RMSEz x 1.96) is 0.054 meters. This dataset meets the required NVA of 0.196 meters 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 4.

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 0.027 meters in terms of the RMSEz. The resulting accuracy stated as the 95% confidence level (RMSEz x 1.96) is 0.053 meters. This dataset meets the required NVA of 0.196 meters at the 95% confidence level (based on NSSDA). See Figure 8 and Table 5.

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 0.069 meters, which is stated in terms of the 95th percentile error. Therefore the data meets the required VVA of 0.294meters. This test was based on the 95th percentile error (based on ASPRS guidelines) across all land cover categories. See Figure 9 and Table 6.

Figure 6. Calibration Control Point Locations

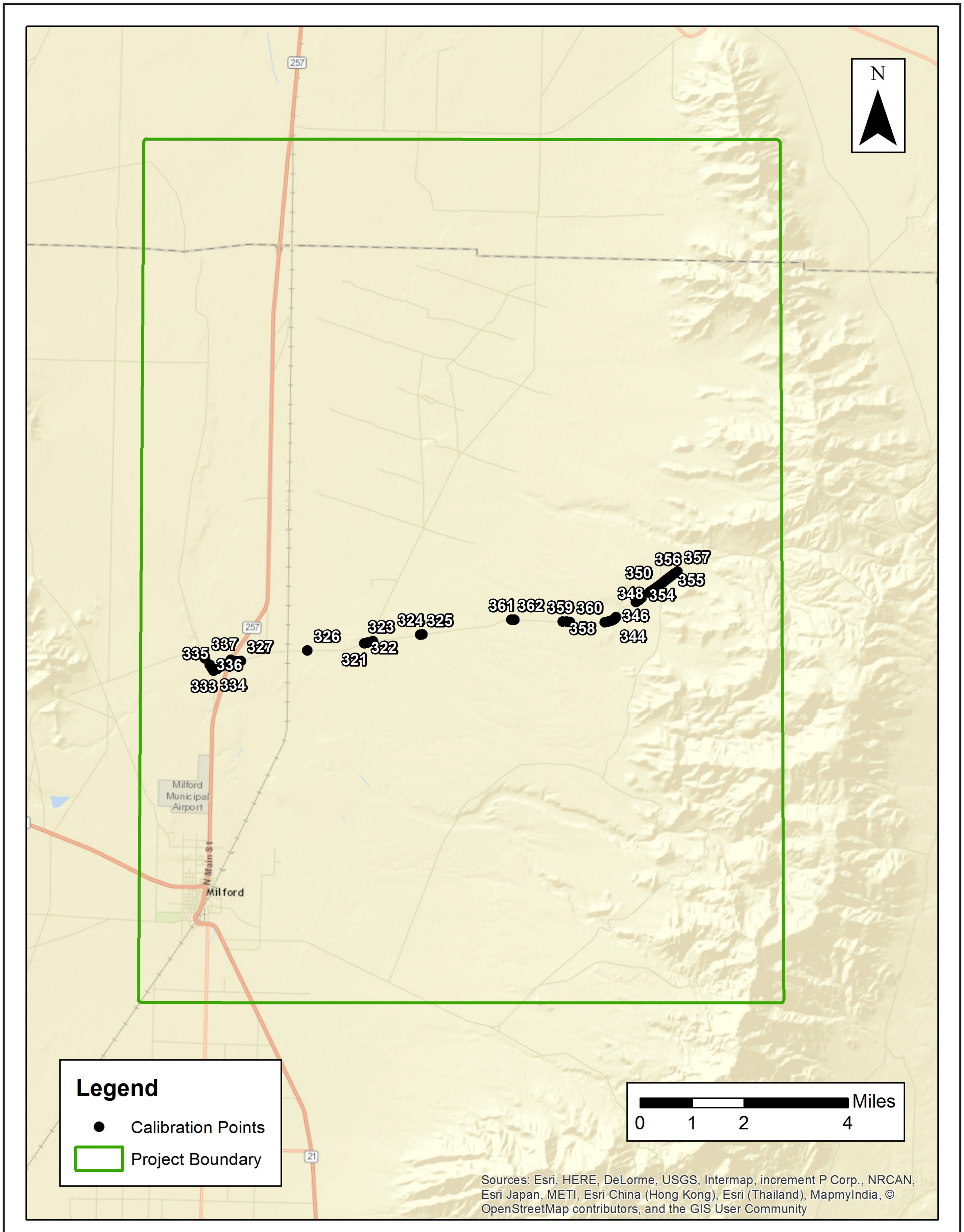


Table 3. Calibration Control Point Report

Units = Meters

Number	Easting	Northing	Known Z	Laser Z	Dz
321	329420.714	4259343.804	1556.05	1556.04	-0.01
322	329314.296	4259315.389	1555.34	1555.36	0.02
323	329576.623	4259381.524	1556.99	1557.01	0.02
324	331116.186	4259596.012	1586.69	1586.69	0.00
325	331038.413	4259584.886	1584.89	1584.88	-0.01
326	327550.460	4259098.376	1525.49	1525.51	0.02
327	325482.757	4258774.458	1515.71	1515.68	-0.03
328	325377.065	4258754.820	1514.12	1514.10	-0.02
329	325268.141	4258774.648	1515.24	1515.23	-0.01
330	325173.541	4258804.520	1513.63	1513.65	0.02
331	325122.160	4258707.942	1512.67	1512.67	0.00
332	324998.577	4258677.671	1509.67	1509.69	0.02
333	324748.029	4258518.010	1509.01	1509.01	0.00
334	324644.115	4258467.908	1510.49	1510.51	0.02
335	324582.755	4258557.891	1511.00	1511.04	0.04
336	324521.459	4258653.892	1511.80	1511.82	0.02
337	324377.598	4258856.623	1509.57	1509.61	0.04
338	337726.182	4260591.860	1796.97	1797.01	0.04
339	336761.611	4259967.730	1774.45	1774.46	0.01
340	337815.474	4260650.887	1801.41	1801.44	0.03
341	336870.851	4259996.027	1776.66	1776.66	0.00
342	337904.893	4260718.183	1807.03	1807.06	0.03
343	336979.315	4260028.876	1779.16	1779.14	-0.01
344	337027.816	4260053.964	1780.56	1780.56	0.00
345	337075.368	4260085.093	1782.33	1782.32	-0.01
346	337111.520	4260126.875	1782.00	1782.00	0.00
347	338131.898	4260886.069	1820.58	1820.62	0.04
348	338185.069	4260927.730	1824.51	1824.53	0.02
349	338279.538	4260995.769	1830.54	1830.56	0.02
350	338372.009	4261064.166	1836.49	1836.51	0.02
351	338464.020	4261132.764	1841.96	1841.98	0.02
352	338556.084	4261201.247	1847.84	1847.85	0.01

Number	Easting	Northing	Known Z	Laser Z	Dz
353	338648.834	4261270.704	1852.93	1852.94	0.01
354	338739.807	4261337.456	1858.81	1858.83	0.02
355	338831.440	4261406.732	1864.11	1864.13	0.02
356	338923.765	4261475.008	1870.78	1870.78	0.00
357	339012.184	4261540.404	1876.82	1876.83	0.01
358	335464.351	4259992.242	1714.26	1714.25	-0.01
359	335577.261	4259987.804	1718.78	1718.76	-0.02
360	335684.036	4259983.404	1723.53	1723.51	-0.02
361	333962.016	4260053.052	1658.34	1658.34	0.00
362	333861.802	4260048.295	1655.22	1655.19	-0.03
	Average Dz	0.010 m			
	Minimum Dz	-0.031 m			
	Maximum Dz	0.040 m			
	Root Mean Square	0.020 m			
	Std. Deviation	0.018 m			

Figure 7. QC Checkpoint Locations - Raw NVA

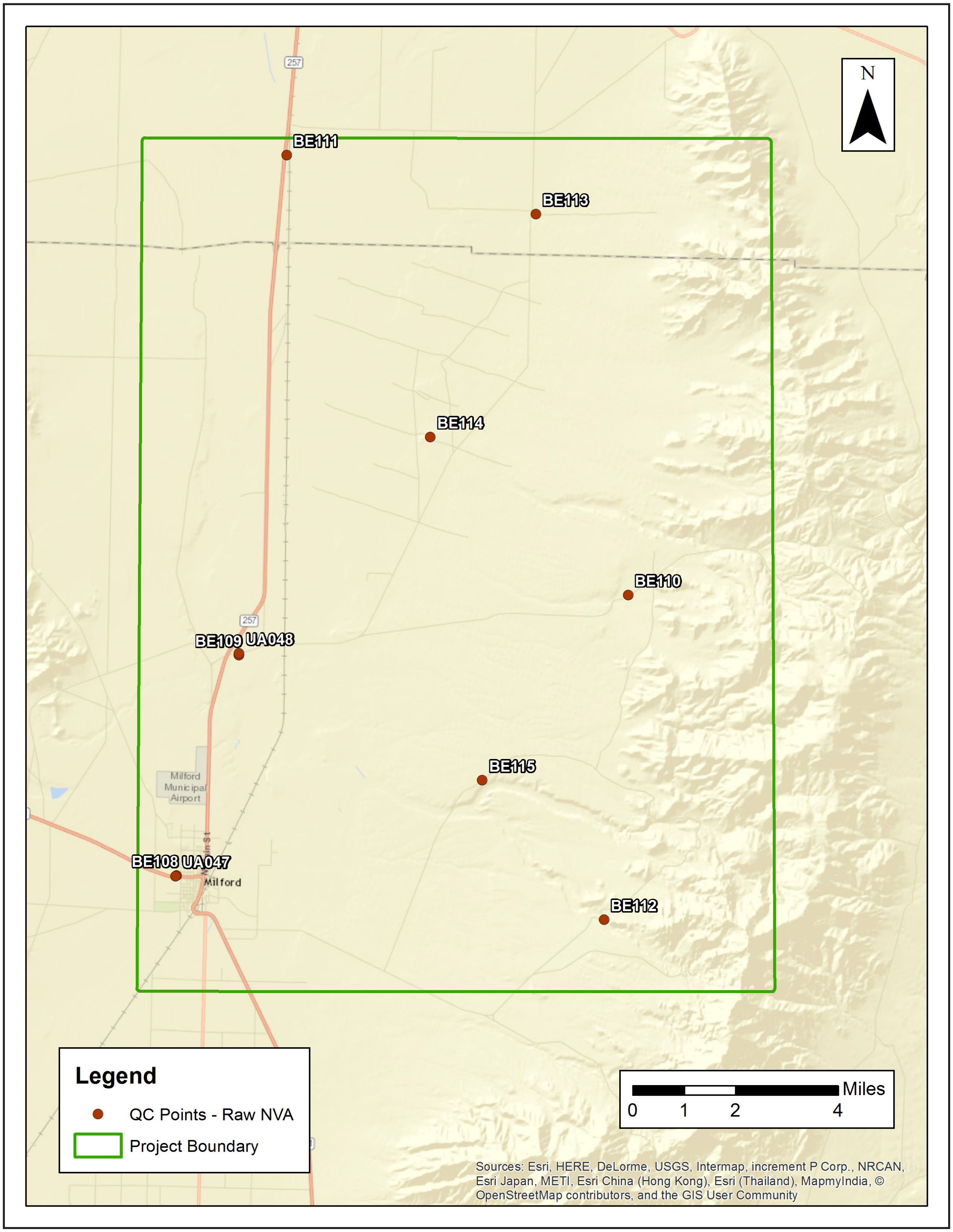


Table 4. QC Checkpoint Report - Raw NVA

Units = Meters

Number	Easting	Northing	Known Z	Laser Z	Dz
BE108	323560.633	4251824.193	1532.13	1532.08	-0.05
BE109	325512.173	4258729.380	1515.56	1515.52	-0.04
BE110	337708.068	4260605.842	1796.38	1796.41	0.03
BE111	327008.723	4274394.140	1487.07	1487.03	-0.04
BE112	336953.147	4250437.401	1935.57	1935.57	0.00
BE113	334816.511	4272543.092	1533.06	1533.08	0.02
BE114	331512.995	4265555.708	1552.04	1552.05	0.01
BE115	333136.631	4254810.037	1686.90	1686.89	-0.01
UA047	323528.162	4251798.487	1532.52	1532.49	-0.03
UA048	325508.808	4258779.259	1515.80	1515.79	-0.01

Average Dz	-0.010 m
Minimum Dz	-0.045 m
Maximum Dz	0.027 m
Root Mean Square	0.028 m
95% Confidence Level	0.054 m

Figure 8. QC Checkpoint Locations - NVA

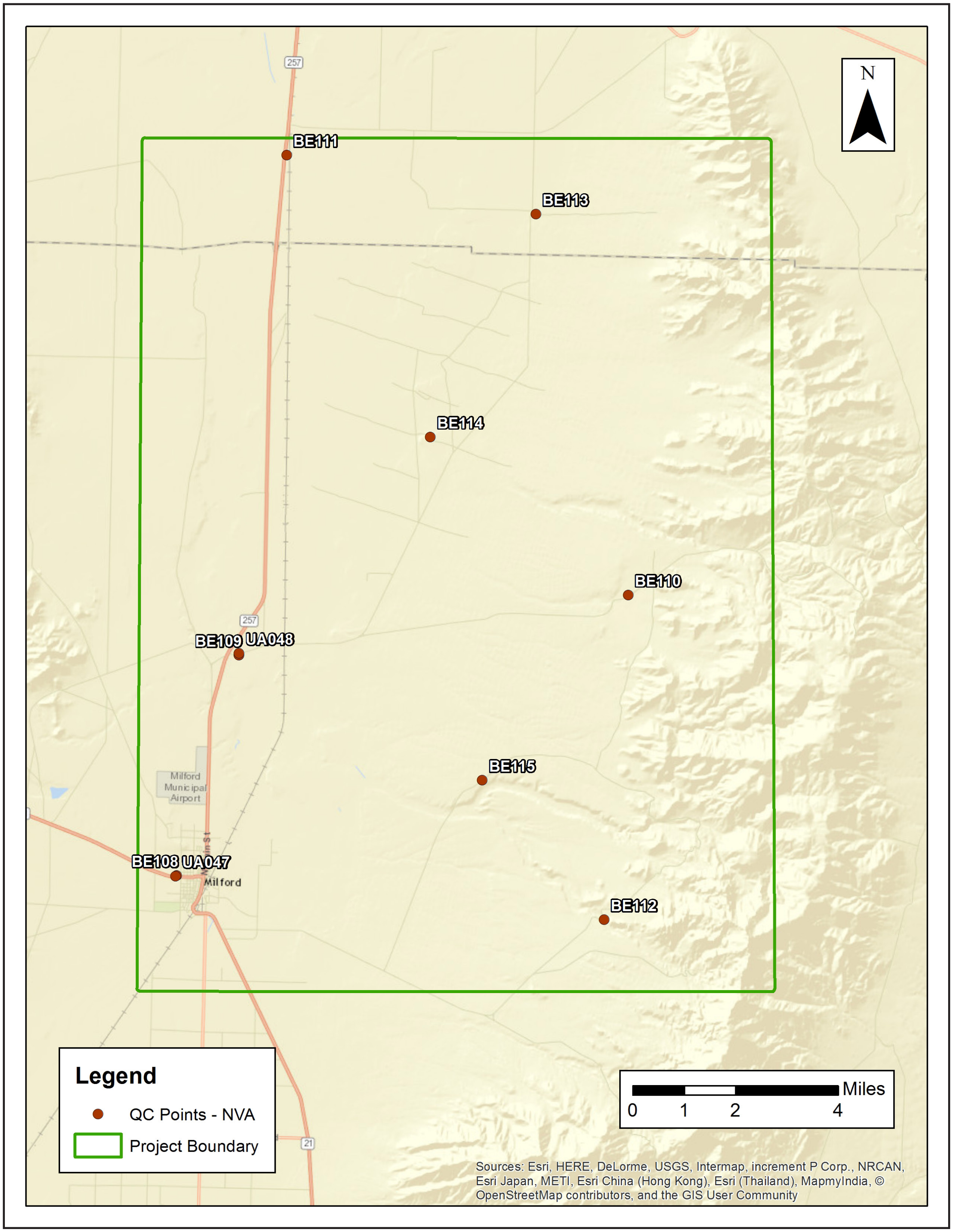


Table 5. QC Checkpoint Report - NVA

Units = Meters

Number	Easting	Northing	Known Z	Laser Z	Dz
BE108	323560.63	4251824.19	1532.13	1532.08	-0.05
BE109	325512.17	4258729.38	1515.56	1515.52	-0.04
BE110	337708.07	4260605.84	1796.38	1796.40	0.02
BE111	327008.72	4274394.14	1487.07	1487.03	-0.04
BE112	336953.15	4250437.40	1935.57	1935.56	-0.01
BE113	334816.51	4272543.09	1533.06	1533.07	0.01
BE114	331513.00	4265555.71	1552.04	1552.05	0.01
BE115	333136.63	4254810.04	1686.90	1686.89	-0.01
UA047	323528.16	4251798.49	1532.52	1532.49	-0.03
UA048	325508.81	4258779.26	1515.80	1515.78	-0.02

Average Dz	-0.020 m
Minimum Dz	-0.045 m
Maximum Dz	0.017 m
Root Mean Square	0.027 m
95% Confidence Level	0.053 m

Figure 9. QC Checkpoint Locations - VVA

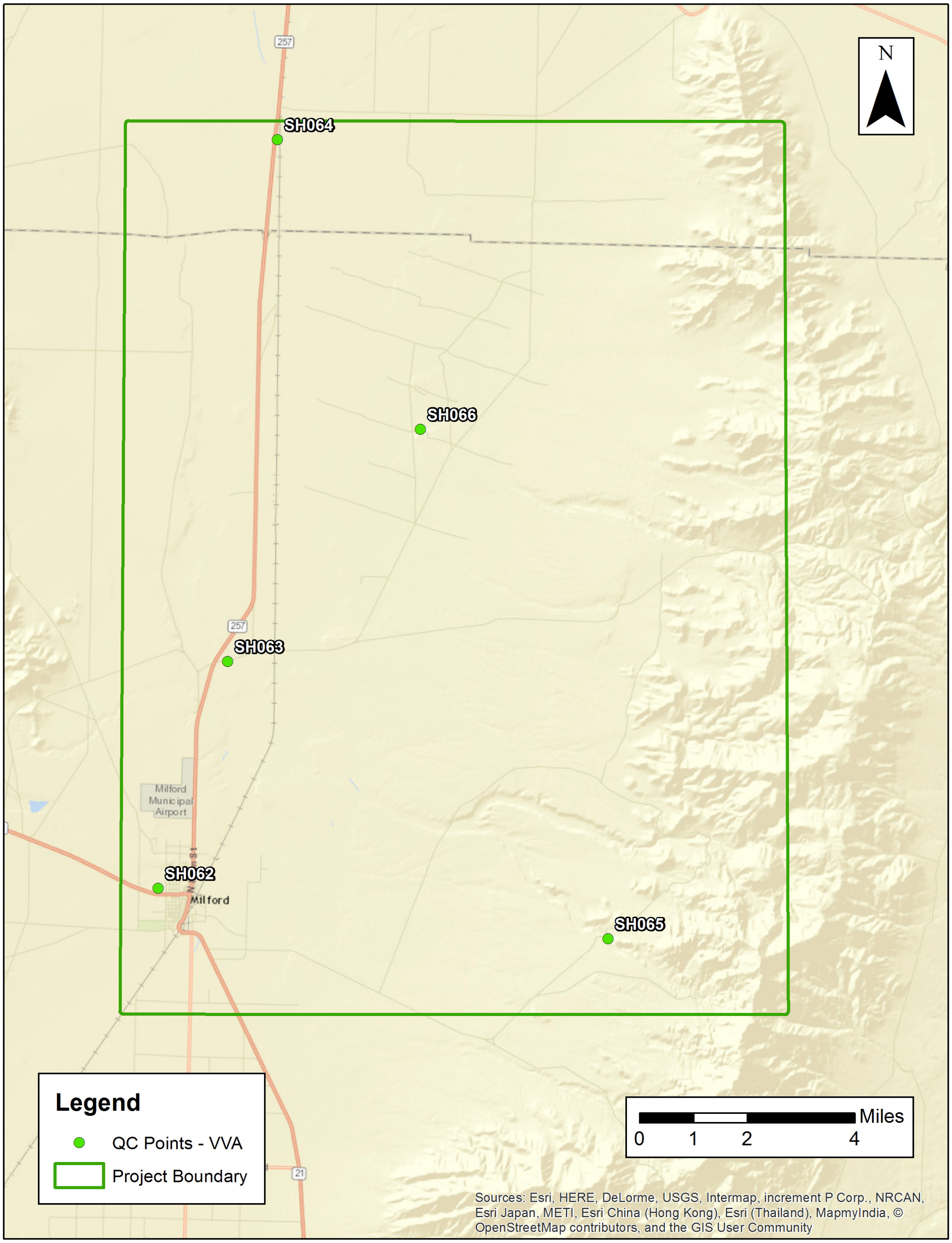


Table 6. QC Checkpoint Report - VVA

Units = Meters

Number	Easting	Northing	Known Z	Laser Z	Dz
SH062	323453.92	4251962.75	1537.13	1537.07	-0.06
SH063	325535.53	4258749.19	1515.71	1515.67	-0.04
SH064	327025.49	4274371.29	1487.54	1487.60	0.06
SH065	336912.58	4250452.32	1932.93	1933.02	0.09
SH066	331297.08	4265699.37	1532.10	1532.14	0.04

Average Dz	0.043 m
Minimum Dz	-0.055 m
Maximum Dz	0.086 m
Root Mean Square	0.060 m
95th Percentile	0.069 m