Utah 2016 - Great Salt Lake AOIs LiDAR Project Report

Contract # AV2408

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1. Summary / Scope

1.1. Summary

This report contains a summary of the Utah 2016 - Great Salt Lake AOI 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

Sub-AOI	QL	Average Point Density	Flight Altitude (AGL)	Field of View	Minimum Side Overlap	RMSEz
GSL QL1	QL1	8 pts / m²	1,200 - 1,550 m	40°	60%	≤ 10 cm
GSL QL1	QL2	2 pts / m²	1,400 - 1,900 m	40°	60%	≤ 10 cm
Utah Lake	QL1	8 pts / m²	1,000 m	40°	60%	≤ 10 cm

1.3. Coverage

The total LiDAR project boundary covers approximately 7,536 square kilometers. This report focuses on the Great Salt Lake sub-AOIs, which cover approximately 3,862 total km². Sub-AOIs are detailed below.

A buffer of 100 meters was created to meet task order specifications. LiDAR extents are shown in Figure 1 and Figure 3.

Sub-AOI	Area	Description
Great Salt Lake QL1	1,537 **km²**	Box Elder, Davis, Salt Lake, Tooele, and Weber Counties in northern Utah
Great Salt Lake QL2	2,147 km²	
Utah Lake	178 km²	Coverage around Utah Lake in Utah County, in central Utah

1.4. Duration

LiDAR data was acquired on September 3, 2016 through November 30, 2016 in 48 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
- Hydro-flattened breaklines in Esri shapefile format
- 0.5-meter hydro-flattened bare-earth raster DEM, tiled, in ERDAS .IMG format - QL1
- 1-meter hydro-flattened bare-earth raster DEM, tiled, in ERDAS .IMG format - QL2
- 0.5-meter first return raster DSM, tiled, in ERDAS .IMG format - QL1
- 1-meter first return raster DSM, tiled, in ERDAS .IMG format - QL2
- 0.5-meter intensity images, tiled, in GeoTIFF format - QL1
- 1-meter intensity images, tiled, in GeoTIFF format - QL2
- 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 (GEOID12B), 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 conventions. Tile names are based on the southwest corner of the tile.

Figure 1. Project Boundary - GSL QL1

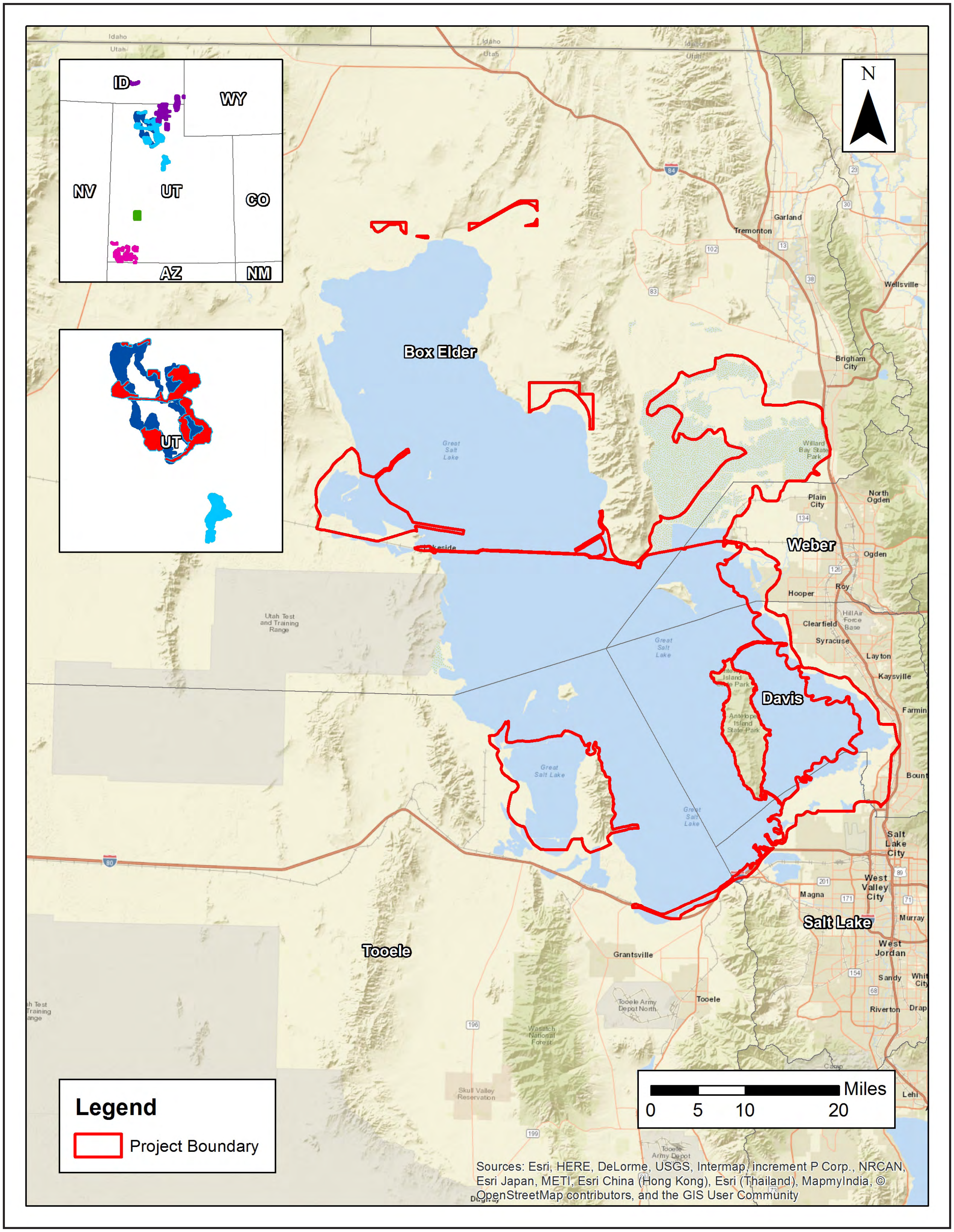


Figure 2. Project Boundary - GSL QL2

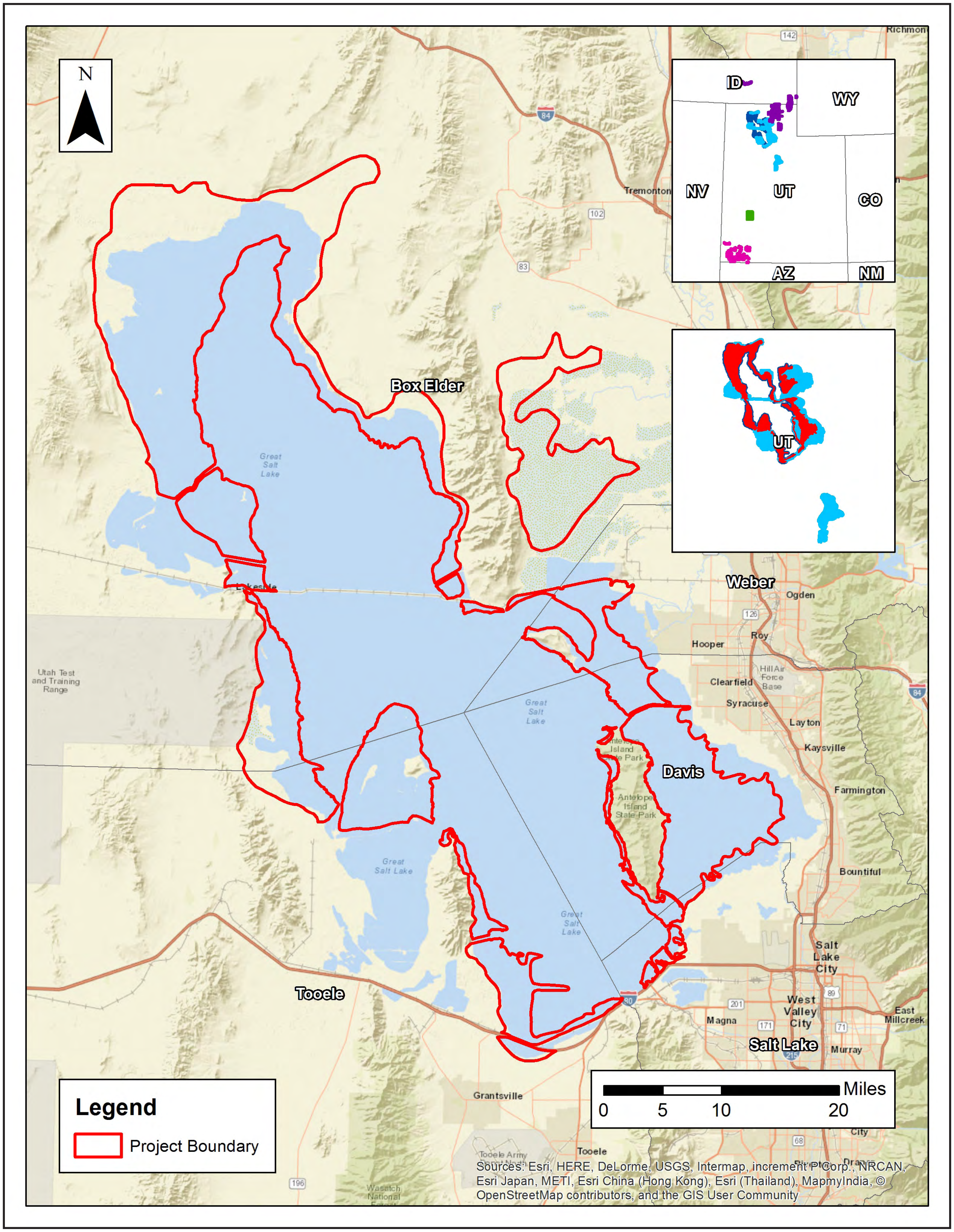
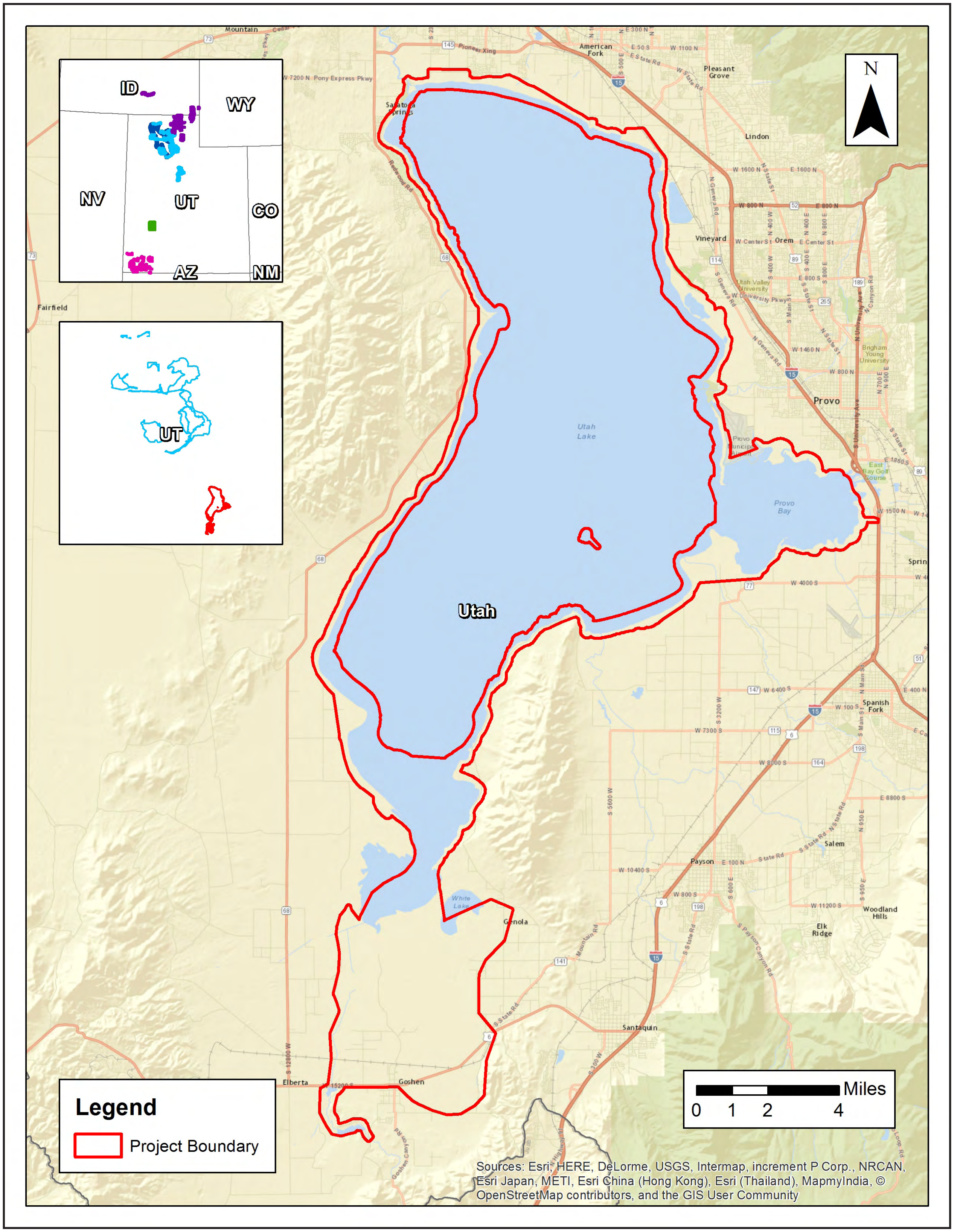


Figure 3. Project Boundary - Utah Lake



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. Total line counts and flight line lengths are listed below. See Figure 4 through Figure 6.

Sub-AOI	Planned Lines	Total Length (miles)
GSL QL1	443	5,168
GSL QL2	216	3,103
Utah Lake	119	782

2.2. LiDAR Sensor

Quantum Spatial utilized several Leica ALS 70 and ALS 80 LiDAR sensors (Figure 7), serial numbers 7161, 8121, 8146, and 8227, 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 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 through Table 4.

Figure 4. Planned LiDAR Flight Lines - GSL QL1

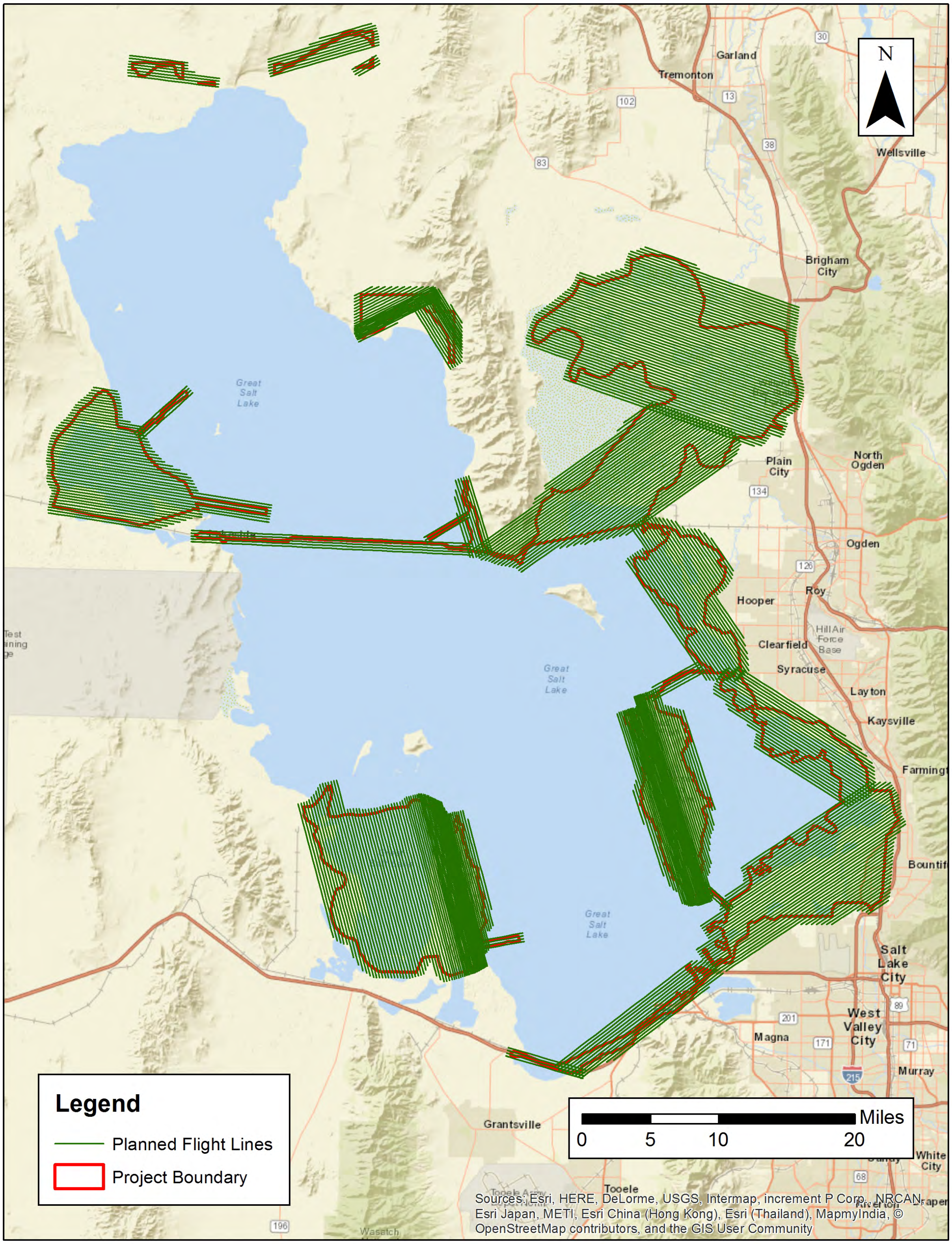


Figure 5. Planned LiDAR Flight Lines - GSL QL2

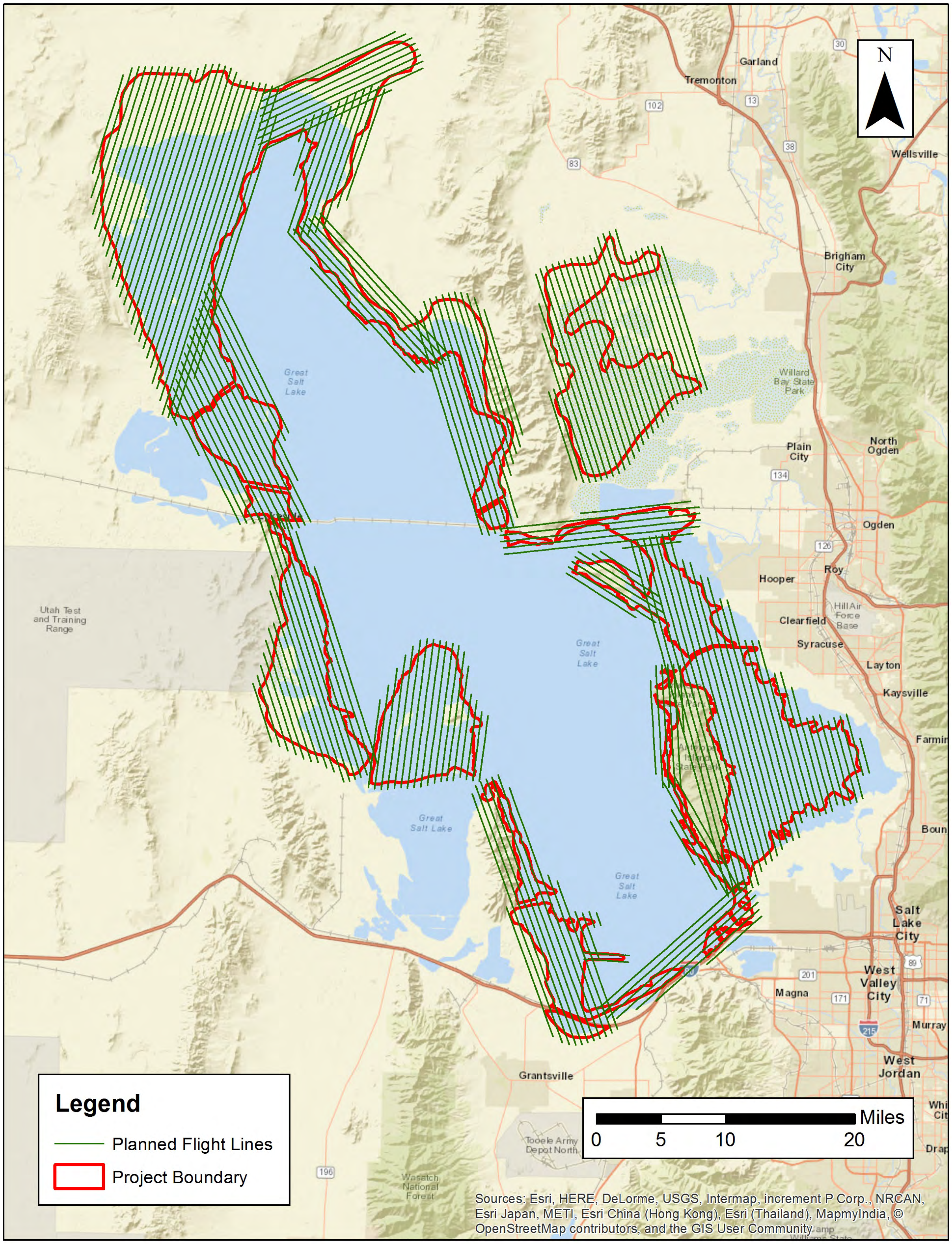


Figure 6. Planned LiDAR Flight Lines - Utah Lake

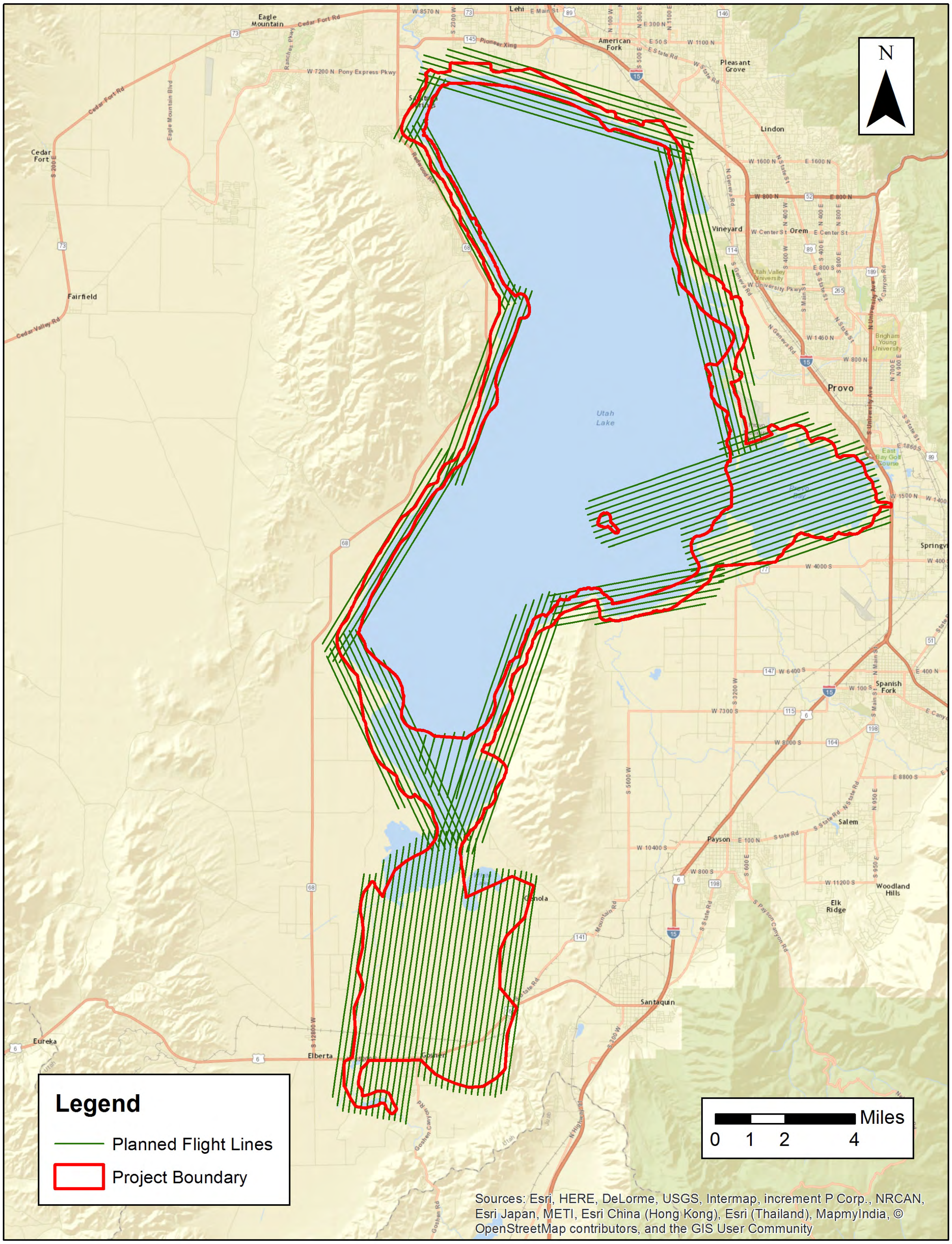


Table 2. Lidar System Specifications - GSL QL1

		ALS 70	ALS 80
Terrain and Aircraft Scanner	Flying Height	1,200 m	1,550 m
	Recommended Ground Speed	145 kts	145 kts
Scanner	Field of View	40°	40°
	Scan Rate Setting Used	53.4 Hz	50 Hz
Laser	Laser Pulse Rate Used	215 kHz	330 kHz
	Multi Pulse in Air Mode	Disabled	Enabled
Coverage	Full Swath Width	874 m	1,128 m
Point Spacing and Density	Average Point Density	0.35 m	0.35 m
	Average Point Density	8 pts / m^2	9.5 pts / m^2

Table 3. Lidar System Specifications - GSL QL2

		ALS 70 7161 (N704MD)	ALS 70 7161 (N22GE)	ALS 80 8146	ALS 80 8121
Terrain and Aircraft Scanner	Flying Height	1,600 m	1,400 m	1,900 m	1,800 m
	Recommended Ground Speed	105 kts	145 kts	150 kts	150 kts
Scanner	Field of View	40°	40°	40°	40°
	Scan Rate Setting Used	41 Hz	53.4 Hz	52 Hz	52 Hz
Laser	Laser Pulse Rate Used	160 kHz	193.6 kHz	288.2 kHz	288.2 kHz
	Multi Pulse in Air Mode	Disabled	Disabled	Enabled	Enabled
Coverage	Full Swath Width	1,164 m	1019 m	1,383 m	1,316 m
Point Spacing and Density	Average Point Density	0.7 m	0.7 m	0.7 m	0.7 m
	Average Point Density	2 pts / m^2	2 pts / m^2	2 pts / m^2	2 pts / m^2

Table 4. Lidar System Specifications - Utah Lake

		ALS 70	ALS 80
Terrain and Aircraft Scanner	Flying Height	1,000 m	1,550 m
	Recommended Ground Speed	145 kts	120 kts
Scanner	Field of View	40°	40°
	Scan Rate Setting Used	53.4 Hz	52 Hz
Laser	Laser Pulse Rate Used	247.8 kHz	340 kHz
	Multi Pulse in Air Mode	Disabled	Enabled
Coverage	Full Swath Width	728 m	1,128 m
Point Spacing and Density	Average Point Density	0.35 m	0.35 m
	Average Point Density	8 pts / m^2	9.5 pts / m^2

Figure 7. Leica ALS 70 and 80 LiDAR Sensors

2.3. Aircraft

All flights for the project were accomplished through the use of the customized planes listed below.

- Cessna Caravan (single-turboprop), Tail Numbers N704MD, N208NR
- Piper Navajo (twin-piston), Tail Number N22GE

These aircraft provided an ideal, stable aerial base for LiDAR acquisition. These aerial platforms have 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 Leica LiDAR systems. Some of Quantum Spatial's operating aircraft can be seen in Figure 8 below.

Figure 8. Some of Quantum Spatial's Planes

2.4. Base Station Information

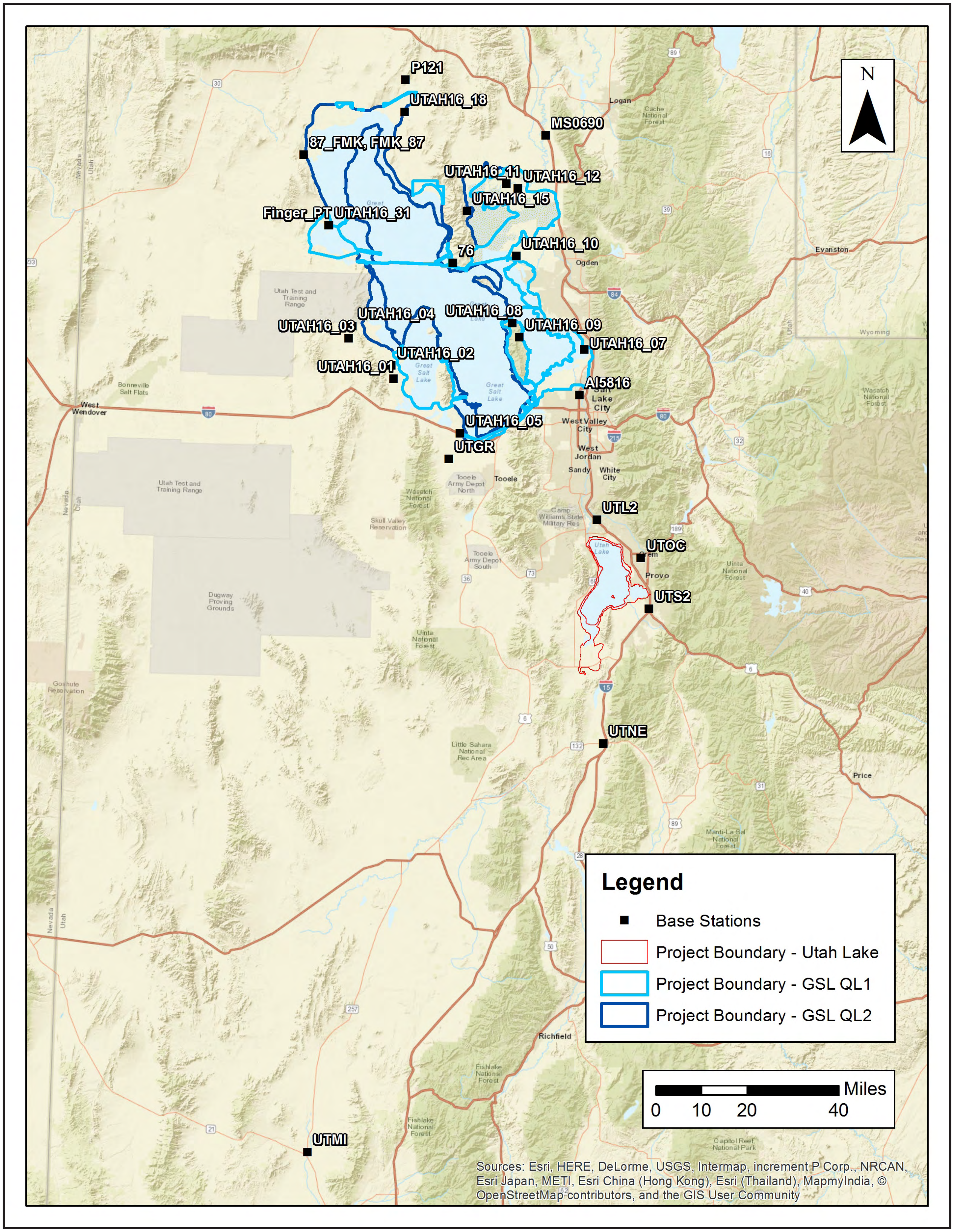
GPS base stations were utilized during all phases of flight. The base station locations were verified using NGS OPUS service and subsequent surveys. Base station locations, data sheets, graphical depiction of base station locations or log sheets used during station occupation can be found in Appendix A. See Figure 9 and Table 5.

Table 5. Base Station Locations

Base Station	Longitude	Latitude	Ellipsoid Height (m)
76	112° 29′ 5.40581″	41° 13’ 30.28256”	1270.554
87_FMK, FMK_87	113° 7′ 10.95886″	41° 33′ 31.74167″	1278.703
AI5816	111° 56′ 54.21205″	40° 48′ 46.7034″	1274.976
Finger_PT	113° 0′ 31.99185″	41° 20′ 16.39424″	1269.972
MS0690	112° 6′ 8.47082″	41° 38′ 3.88146″	1285.809
P121	112° 41′ 53.79553″	41° 48′ 12.1794″	1453.116
UTAH16, UTAH16_06	112° 13′ 16.54181″	40° 43′ 17.59509″	1286.613
UTAH16_01	112° 43′ 25.6121″	40° 51′ 20.49869″	1271.297
UTAH16_02	112° 43′ 59.98011″	40° 53′ 50.8026″	1267.906
UTAH16_03	112° 54′ 50.87139″	40° 58′ 51.26495″	1306.892
UTAH16_04	112° 53′ 59.62739″	41° 1′ 10.60837″	1410.162
UTAH16_05	112° 26′ 34.06501″	40° 41′ 11.85346″	1267.552
UTAH16_07	111° 55′ 47.23107″	40° 57′ 27.00288″	1273.978
UTAH16_08	112° 13′ 55.55965″	41° 2′ 17.37223″	1338.735
UTAH16_09	112° 12′ 7.73734″	40° 59′ 39.21278″	1361.339
UTAH16_10	112° 13′ 7.06672″	41° 15′ 4.88969″	1269.98
UTAH16_11	112° 15′ 53.7638″	41° 28′ 47.27155″	1267.28
UTAH16_12	112° 12′ 59.28876″	41° 27′ 55.05608″	1267.698
UTAH16_15	112° 25′ 44.98407″	41° 23′ 27.45072″	1349.584

Base Station	Longitude	Latitude	Ellipsoid Height (m)
UTAH16_18	112° 41′ 57.05219″	41° 42′ 3.90037″	1289.38
UTAH16_31	113° 0′ 28.80842″	41° 20′ 15.95115″	1270.535
UTGR	112° 29′ 11.80159″	40° 36′ 17.44208″	1319.914
UTL2	111° 52′ 13.08922″	40° 25′ 9.49565″	1391.436
UTMI	113° 0′ 37.18806″	38° 24′ 6.80981″	1506.239
UTNE	111° 50′ 8.00862″	39° 42′ 37.9727″	1561.007
UTOC	111° 41′ 11.47676″	40° 17′ 54.89014″	1453.351
UTS2	111° 39′ 5.50612″	40° 8′ 16.20885″	1371.47

Figure 9. Base Station Locations



2.5. Time Period

Project specific flights were conducted over several months. Forty-eight sorties, or aircraft lift was completed. Accomplished sorties are listed below.

GSL QL 1

- Sep 3, 2016-B2 (N704MD SN7161)
- Sep 4, 2016-A (N704MD, SN7161)
- Sep 5, 2016-A (N704MD, SN7161)
- Sep 6, 2016-A (N704MD, SN7161)
- Sep 7, 2016-A (N704MD, SN7161)
- Sep 8, 2016-A (N704MD, SN7161)
- Sep 10, 2016-A (N704MD, SN7161)
- Sep 11, 2016-A (N704MD, SN7161)
- Sep 12, 2016-A (N704MD, SN7161)
- Sep 13, 2016-A (N704MD, SN7161)
- Sep 13, 2016-C (N704MD, SN7161)
- Sep 14, 2016-A (N704MD, SN7161)
- Sep 17, 2016-A (N704MD, SN7161)
- Sep 18, 2016-A (N704MD, SN7161)
- Sep 19, 2016-A (N704MD, SN7161)
- Sep 19, 2016-B (N704MD, SN7161)
- Sep 24, 2016-A (N704MD, SN7161)
- Sep 25, 2016-A (N704MD, SN7161)
- Sep 26, 2016-A (N704MD, SN7161)
- Sep 27, 2016-A (N704MD, SN7161)
- Sep 28, 2016-A (N704MD, SN7161)
- Nov 4, 2016-A (N208NR, SN8227)

GSL QL 2

- Sep 3, 2016-A (N704MD, SN7161)
- Sep 3, 2016-B1 (N704MD, SN7161)
- Sep 6, 2016-A (N704MD, SN7161)
- Sep 7, 2016-A (N704MD, SN7161)
- Sep 9, 2016-A (N704MD, SN7161)
- Sep 14, 2016-A (N704MD, SN7161)
- Sep 16, 2016-A (N704MD, SN7161)
- Sep 16, 2016-B (N704MD, SN7161)
- Sep 17, 2016-A (N704MD, SN7161)
- Sep 18, 2016-A (N704MD, SN7161)
- Sep 26, 2016-A (N704MD, SN7161)
- Sep 27, 2016-A (N704MD, SN7161)
- Sep 28, 2016-A (N704MD, SN7161)
- Oct 4, 2016-A2 (N22GE, SN7161
- Oct 4, 2016-B (N22GE, SN7161)
- Oct 5, 2016-A (N22GE, SN7161)
- Nov 4, 2016-A (N208NR, SN8227)
- Nov 6, 2016-A (N704MD, SN8121)
- Nov 6, 2016-B (N704MD, SN8121)
- Nov 30, 2016-A (N280NR, SN8146)

Utah Lake

- Oct 26, 2016-A (N22GE, SN7161)
- Oct 26, 2016-B (N22GE, SN7161)
- Oct 29, 2016-A (N22GE, SN7161)
- Nov 2, 2016-A (N208NR, SN8227)
- Nov 3, 2016-A (N208NR, SN8227)
- Nov 18, 2016-A (N208NR, SN8146)

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 and B.

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 Processing

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 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).

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 (Ground) lidar points in conjunction with the hydro breaklines were used to create hydro-flattened raster DEMs with a 0.5-meter cell size for the QL1 AOIs and a 1-meter cell size for the QL2 AOI. 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 DSM Processing

First return lidar points were used to create a first-return raster DSMs with a 0.5-meter cell size for the QL1 AOIs and a 1-meter cell size for the QL2 AOI. 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 Processing

GeoCue software was used to create the deliverable Intensity Images with a 0.5-meter cell size for the QL1 AOIs and a 1-meter cell size for the QL2 AOI. 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 10 through Figure 12.

Figure 10. Flightline Swath LAS File Coverage - GSL QL1

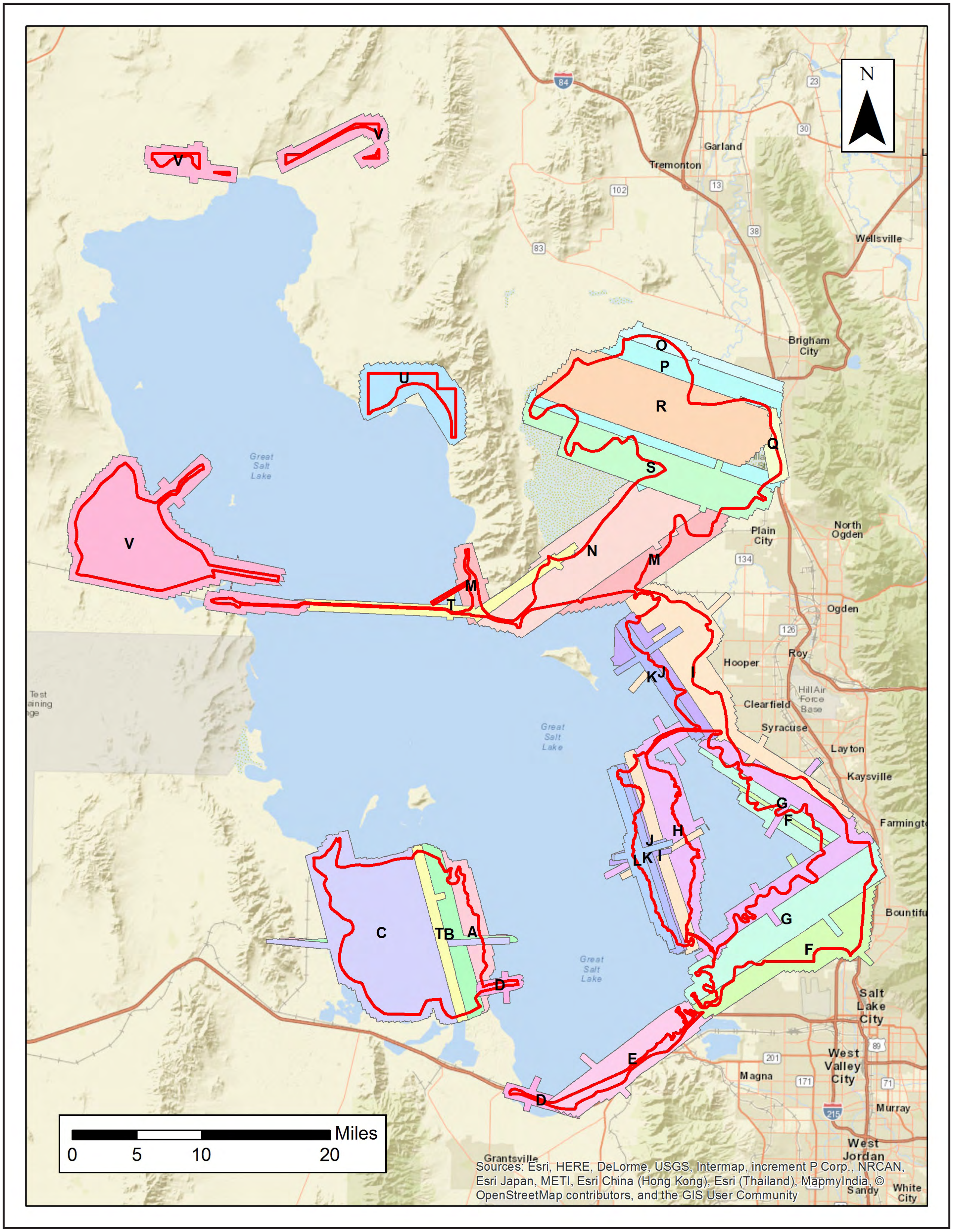
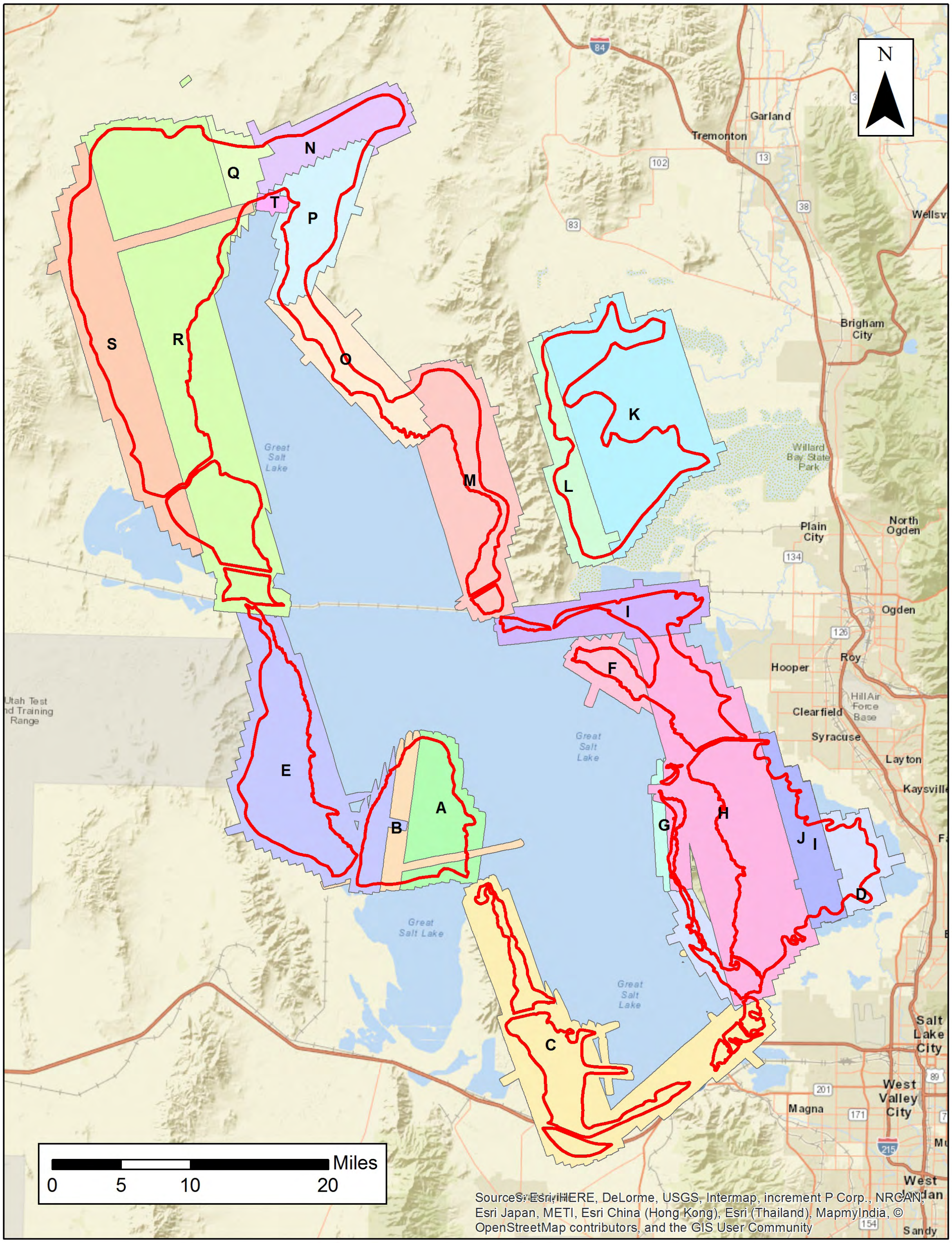


Figure 11. Flightline Swath LAS File Coverage - GSL QL2



GSL QL1

Legend

Lift

A: Sep 3, 2016-B2 (N704MD SN7161)
B: Sep 4, 2016-A (N704MD, SN7161)
C: Sep 5, 2016-A (N704MD, SN7161)
D: Sep 6, 2016-A (N704MD, SN7161)
E: Sep 7, 2016-A (N704MD, SN7161)
F: Sep 8, 2016-A (N704MD, SN7161)
G: Sep 10, 2016-A (N704MD, SN7161)
H: Sep 11, 2016-A (N704MD, SN7161)
I: Sep 12, 2016-A (N704MD, SN7161)
J: Sep 13, 2016-A (N704MD, SN7161)
K: Sep 13, 2016-C (N704MD, SN7161)
L: Sep 14, 2016-A (N704MD, SN7161)
M: Sep 17, 2016-A (N704MD, SN7161)
N: Sep 18, 2016-A (N704MD, SN7161)
O: Sep 19, 2016-A (N704MD, SN7161)
P: Sep 19, 2016-B (N704MD, SN7161)
Q: Sep 24, 2016-A (N704MD, SN7161)
R: Sep 25, 2016-A (N704MD, SN7161)
S: Sep 26, 2016-A (N704MD, SN7161)
T: Sep 27, 2016-A (N704MD, SN7161)
U: Sep 28, 2016-A (N704MD, SN7161)
V: Nov 4, 2016-A (N208NR, SN8227)
Project Boundary

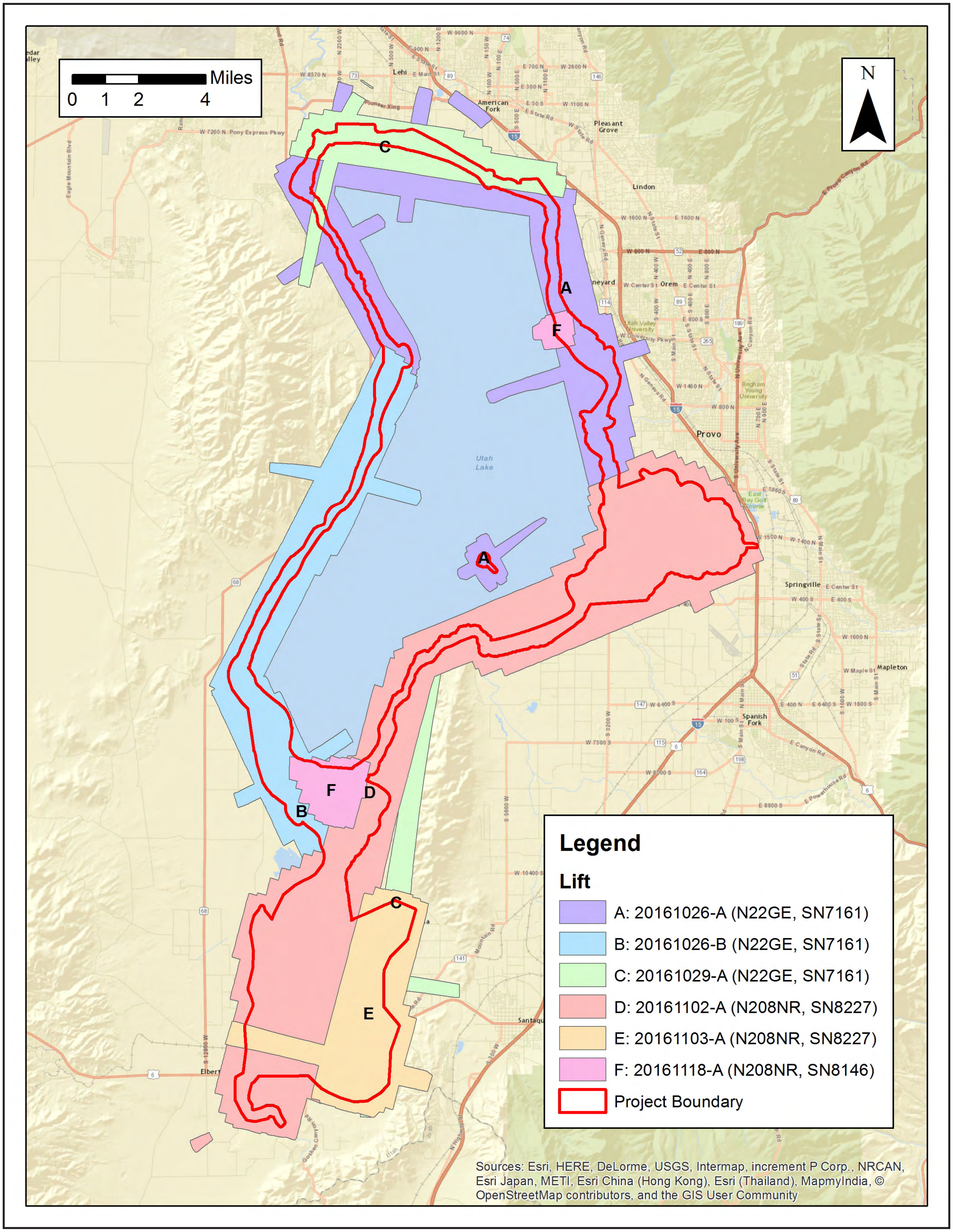
GSL QL

Legend

Lift

A: Sep 3, 2016-A (N704MD, SN7161)
B: Sep 3, 2016-B1 (N704MD, SN7161)
C: Sep 6, 2016-A (N704MD, SN7161)
D: Sep 7, 2016-A (N704MD, SN7161)
E: Sep 9, 2016-A (N704MD, SN7161)
F: Sep 14, 2016-A (N704MD, SN7161)
G: Sep 16, 2016-A (N704MD, SN7161)
H: Sep 16, 2016-B (N704MD, SN7161)
I: Sep 17, 2016-A (N704MD, SN7161)
J: Sep 18, 2016-A (N704MD, SN7161)
K: Sep 26, 2016-A (N704MD, SN7161)
L: Sep 27, 2016-A (N704MD, SN7161)
M: Sep 28, 2016-A (N704MD, SN7161)
N: Oct 4, 2016-A2 (N22GE, SN7161
O: Oct 4, 2016-B (N22GE, SN7161)
P: Oct 5, 2016-A (N22GE, SN7161)
Q: Nov 4, 2016-A (N208NR, SN8227)
R: Nov 6, 2016-A (N704MD, SN8121)
S: Nov 6, 2016-B (N704MD, SN8121)
T: Nov 30, 2016-A (N280NR, SN8146)
Project Boundary

Figure 12. Flightline Swath LAS File Coverage - Utah Lake



5. Ground Control and Check Point Collection

Quantum Spatial completed a field survey of 245 ground control (calibration) points along with 127 blind QA points in Vegetated and Non-Vegetated land cover classifications (total of 372 points) as an independent test of the accuracy of this project. Accuracies were calculated for the entire Great Salt Lake AOIs (GSL QL1, GSL QL2, and Utah Lake) as a whole.

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.

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 13 and Figure 14 show the location of each bare earth calibration point for the project area. 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

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 66 of 67 checkpoints located in bare earth and urban (non-vegetated) areas; point BE23 was excluded as it fell under a feature. 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.

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.

5.3. 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 66 checkpoints located in bare earth and urban (non-vegetated) areas; point BE23 was excluded as it fell under a feature. See Figure 15 and Figure 16.

2. Vegetated Vertical Accuracy (VVA): VVA shall be reported for “forest”, “shrubs”, and “tall grass” 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 60 checkpoints located in forest, shrubs, and tall grass (vegetated) areas. The checkpoints were distributed throughout the project area and were surveyed using GPS techniques. See Figure 17 and Figure 18.

See survey report for additional survey methodologies. 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.

For more information, see the FOCUS on Accuracy report.

Figure 13. Calibration Control Point Locations - GSL QL1 & QL2

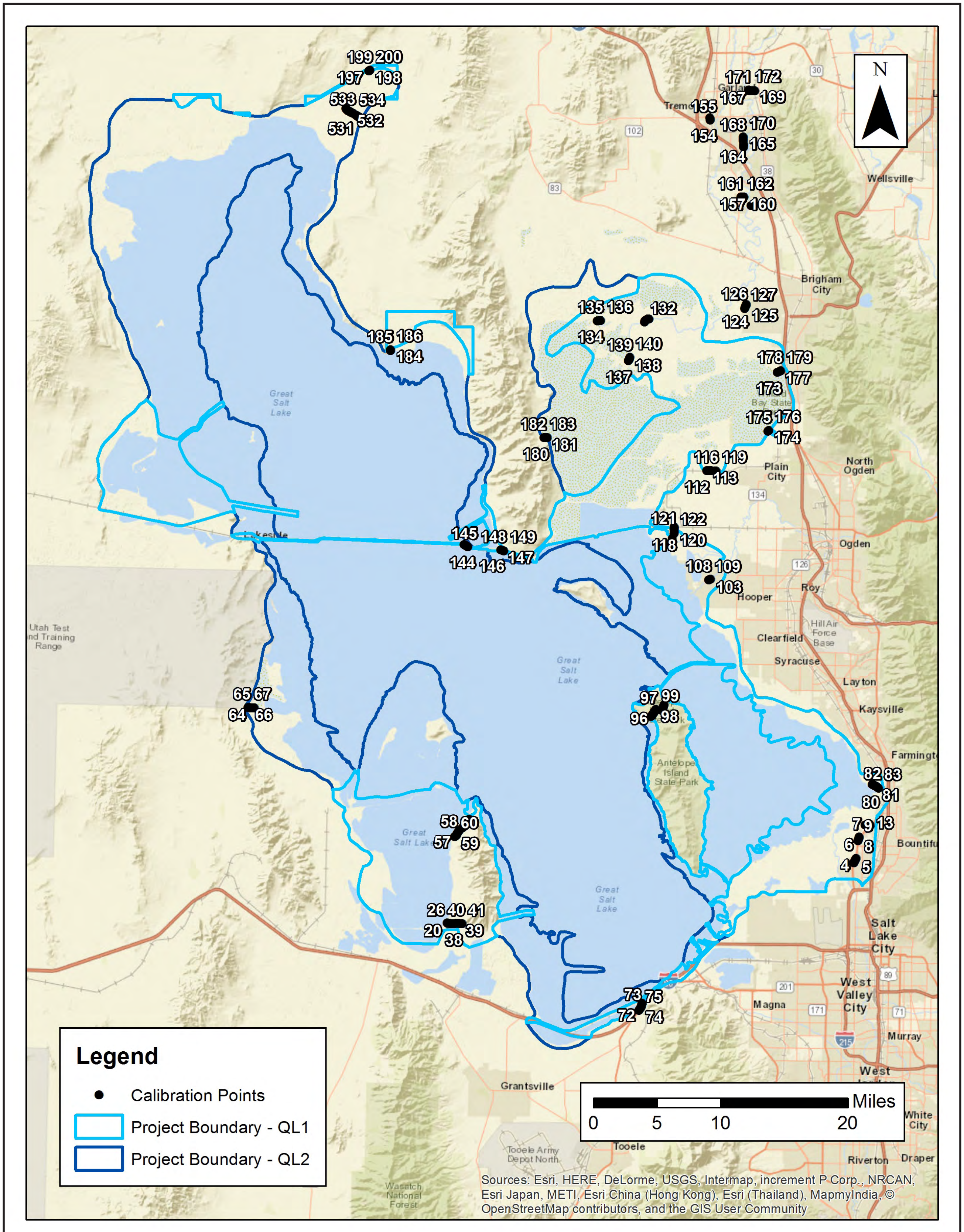


Figure 14. Calibration Control Point Locations - Utah Lake

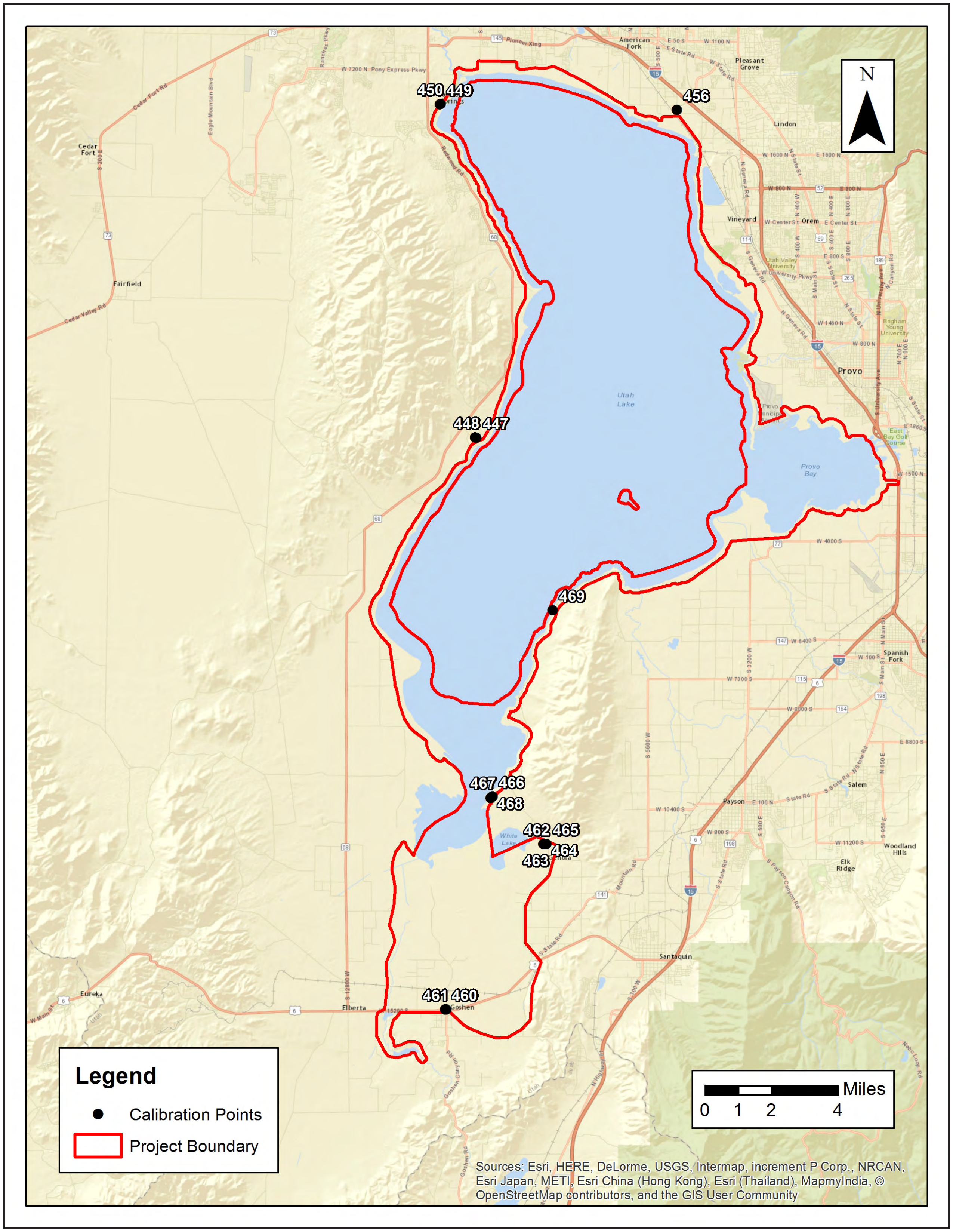


Figure 15. QC Checkpoint Locations - NVA - GSL QL1 & QL2

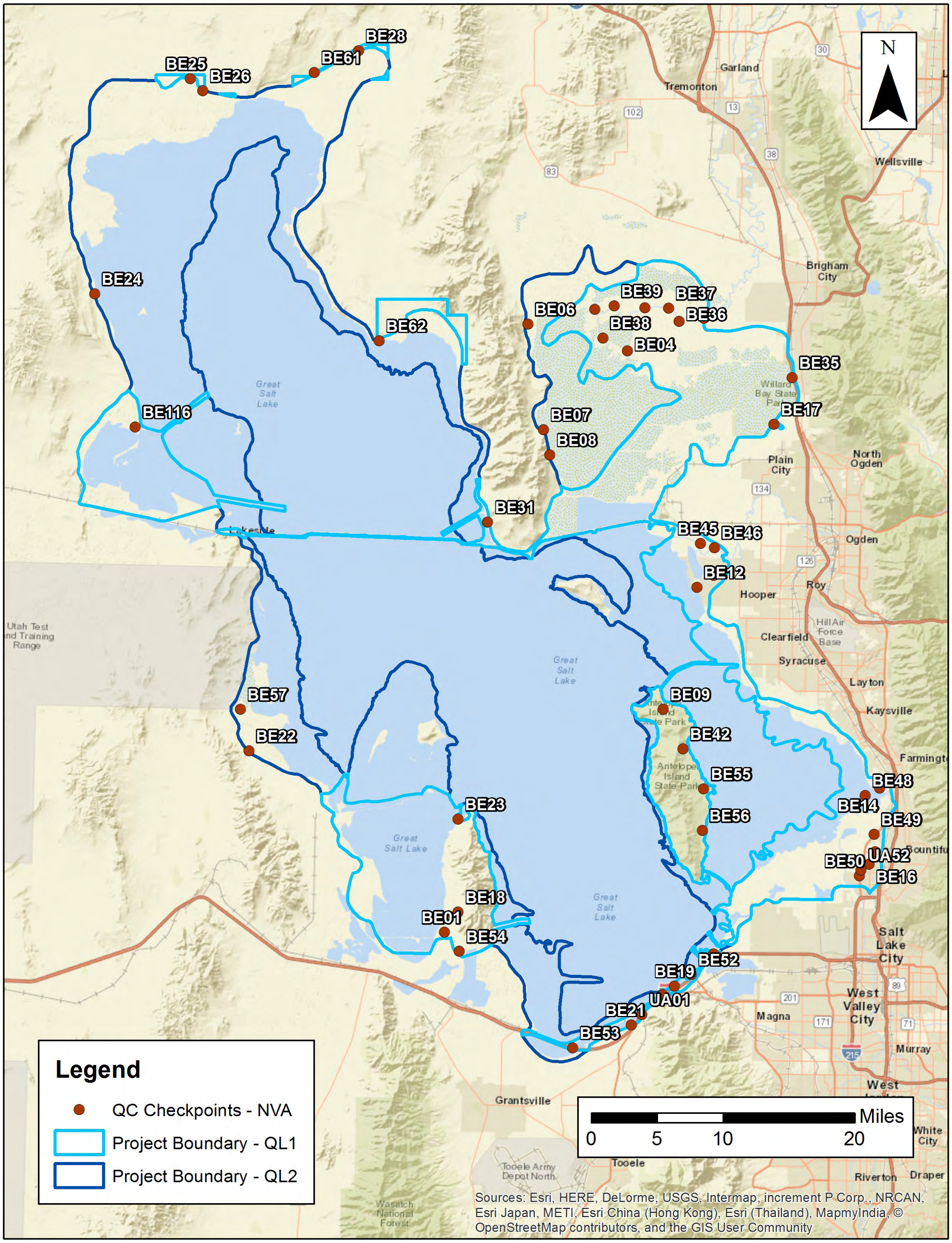


Figure 16. QC Checkpoint Locations - NVA - Utah Lake

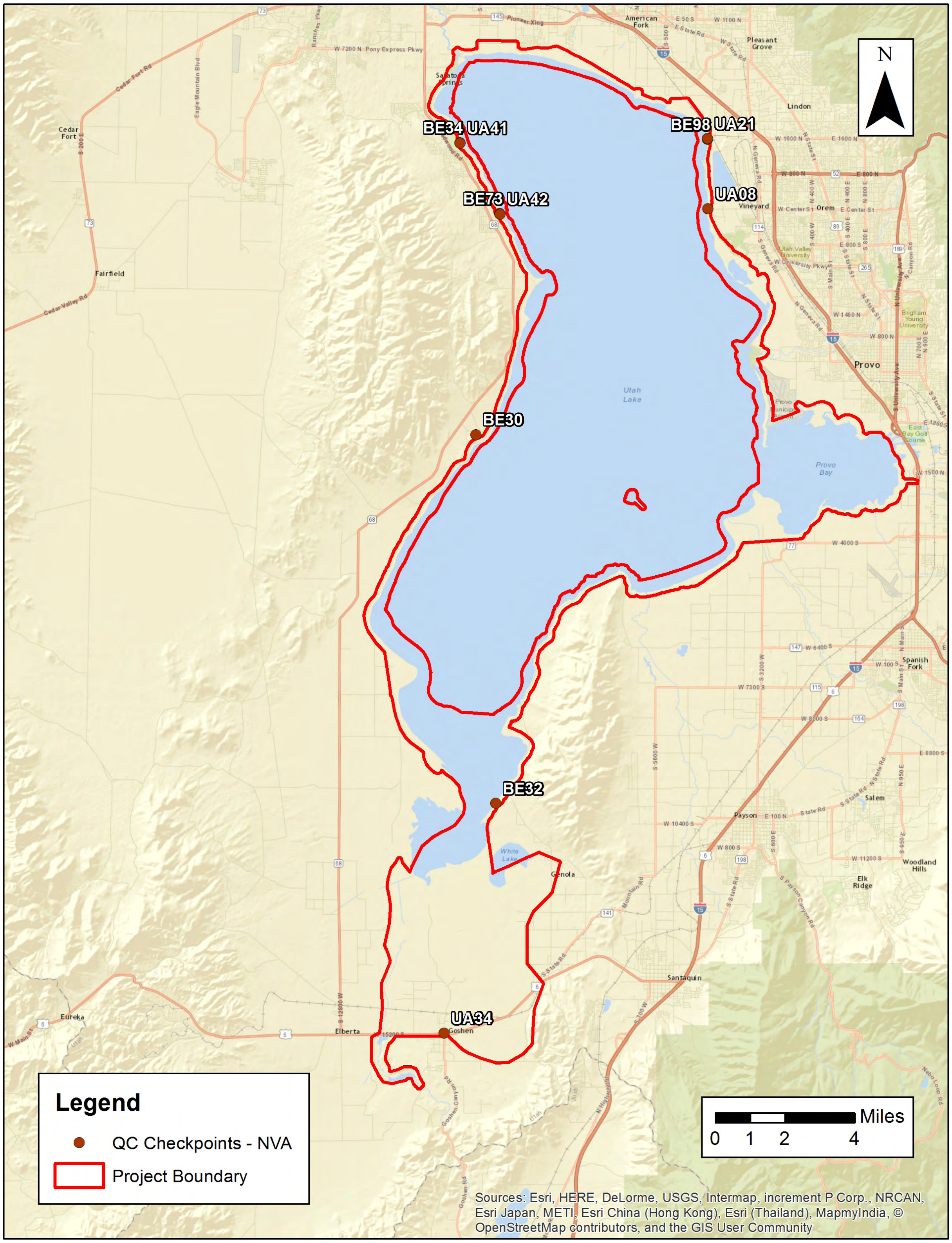


Figure 17. QC Checkpoint Locations - VVA - GSL QL1 & QL2

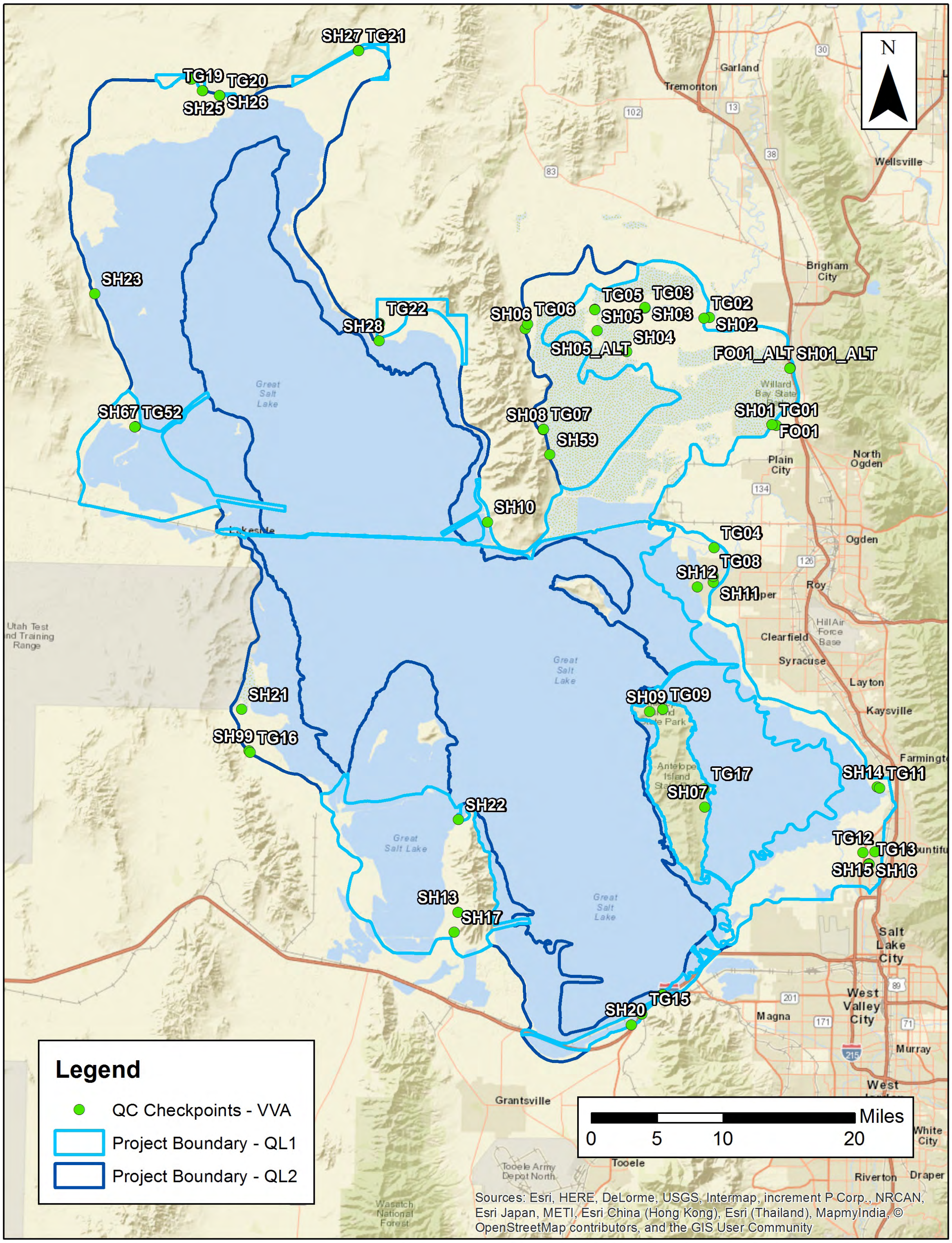


Figure 18. QC Checkpoint Locations - VVA - Utah Lake