# Utah 2016 - Cache Valley AOIs
# QL1 LiDAR Project Report

Contract # AV2408

Submitted: September 27, 2017

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# 1. Summary / Scope

## 1.1. Summary

This report contains a summary of the Utah 2016 - Minidoka 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**

| Sub-AOI | Average Point Density | Flight Altitude (AGL) | Field of View | Minimum Side Overlap | RMSEz |
|---|---|---|---|---|---|
| Bear Lake | 8 pts / $m^2$ | 1,000 m | 40° | 60% | ≤ 10 cm |
| Bear River | 8 pts / $m^2$ | 1,200 m | 40° | 60% | ≤ 10 cm |
| Cache Valley | 8 pts / $m^2$ | 1,200 m | 40° | 60% | ≤ 10 cm |
| Minidoka | 8 pts / $m^2$ | 1,000 m | 40° | 60% | ≤ 10 cm |
| Thomas Fork Unit | 8 pts / $m^2$ | 1,550 m | 40° | 60% | ≤ 10 cm |
| Weber Valley | 8 pts / $m^2$ | 1,200 m | 40° | 60% | ≤ 10 cm |

## 1.3. Coverage

**The total LiDAR project boundary covers approximately 7,536 square kilometers. This report focuses on the Cache Valley sub-AOIs, which covers approximately 2,009 km$^2$. Sub-AOIs are detailed below.**

| Sub-AOI | Area | Description |
|---|---|---|
| Bear Lake | 319 km$^2$ | partial coverage of Bear Lake County in southeastern Idaho and Rich County in northern Utah |
| Bear River | 286 km$^2$ | partial coverage of Box Eldar County in northern Utah |
| Cache Valley | **986 km$^2$** | partial coverage of Cache County in northern Utah |
| Minidoka | **182 km$^2$** | partial coverage of Blaine, Cassia, and Power Counties in southern Idaho |
| Thomas Fork Unit | **28 km$^2$** | partial coverage of Bear Lake County in southeastern Idaho and Lincoln County in western Wyoming |
| Weber Valley | **208 km$^2$** | Weber County in Northern Utah |

**A buffer of 100 meters was created to meet task order specifications. LiDAR extents are shown in Figure 1 through Figure 6.**

## 1.4. Duration

**LiDAR data was acquired from September 19, 2016 through March 18, 2017 in 40 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 conventions. Tile names are based on the southwest corner of the tile.

**Figure 1. Project Boundary - Bear Lake**

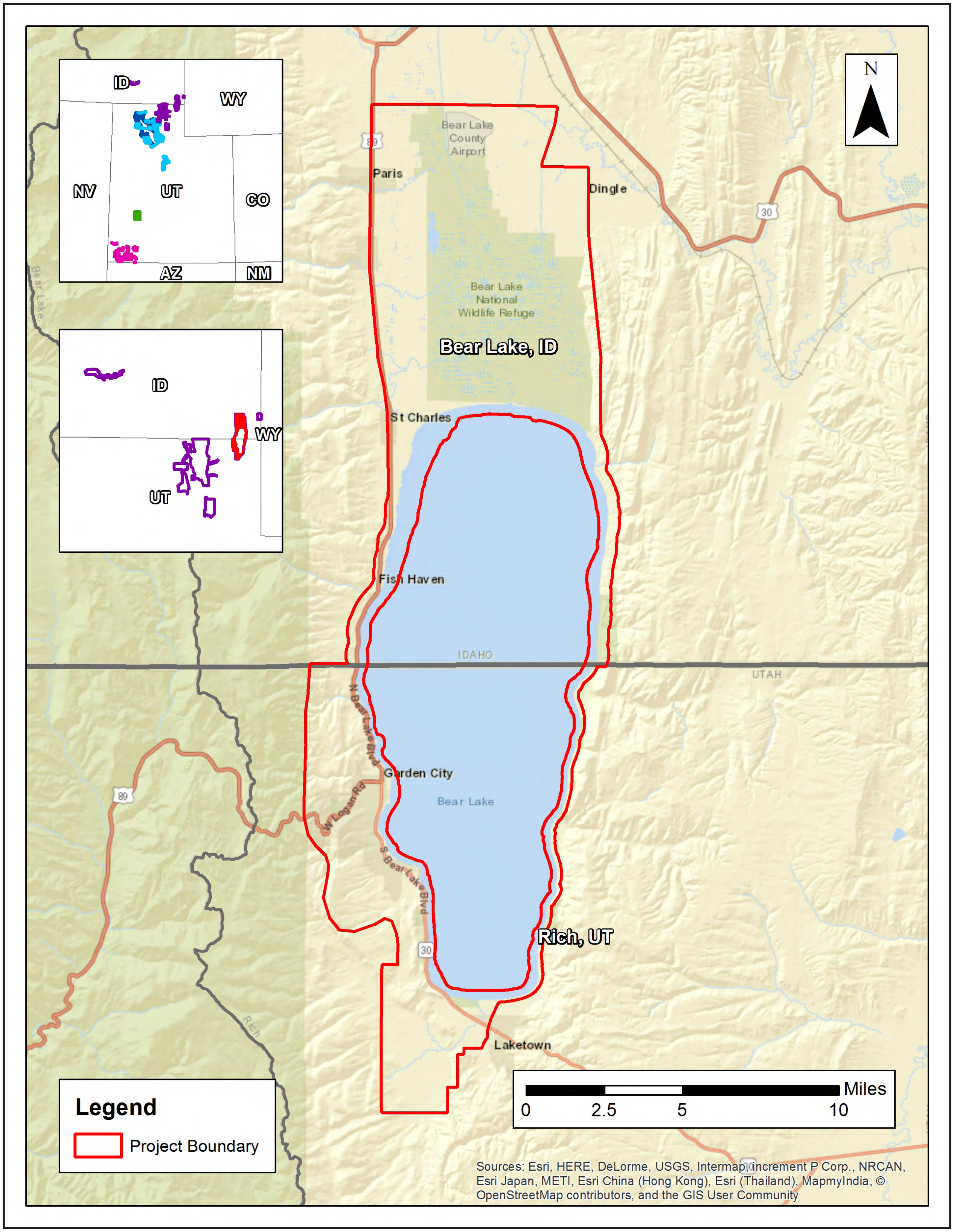


Figure 2. Project Boundary - Bear River

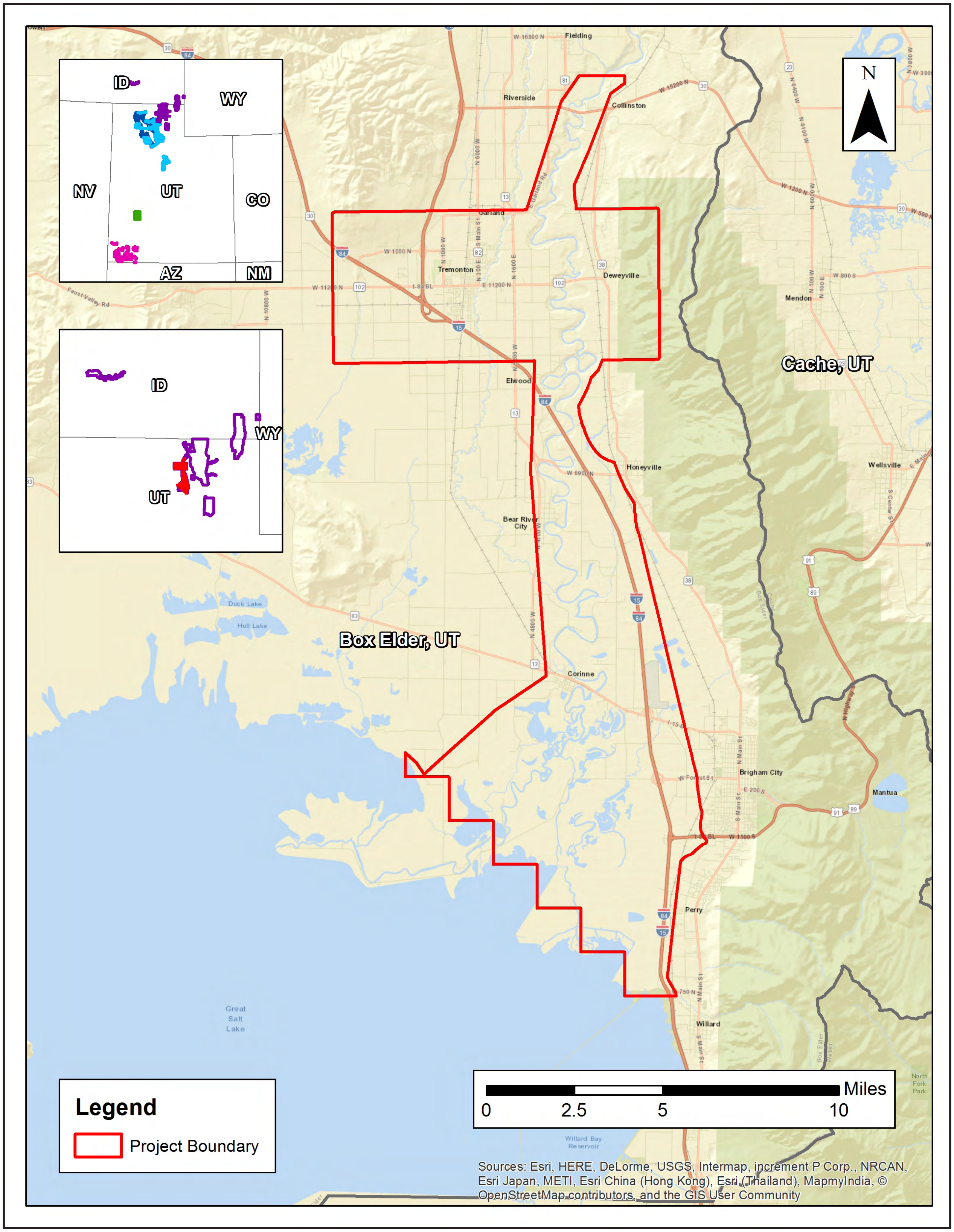


Figure 3. Project Boundary - Cache Valley

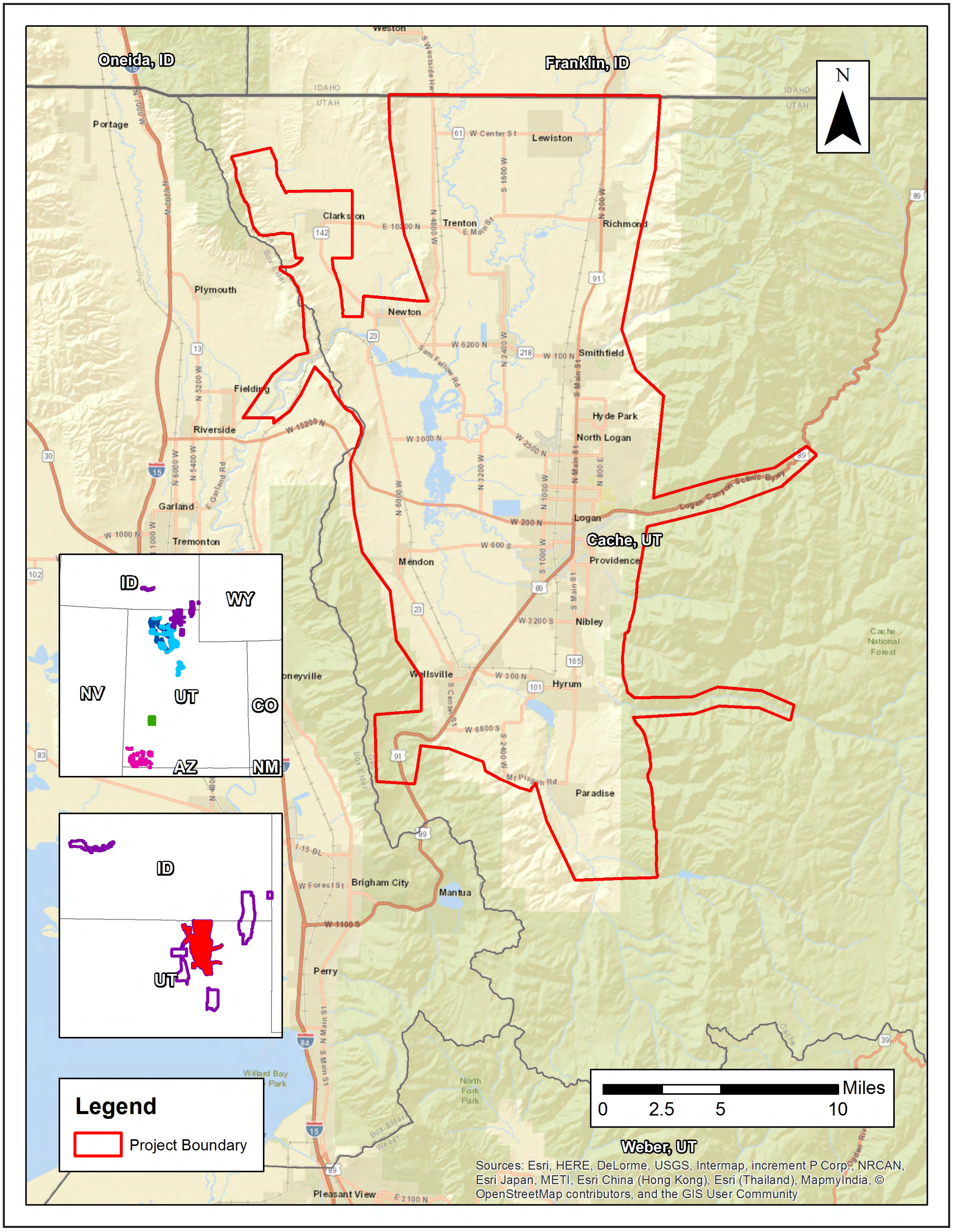


Figure 4. Project Boundary - Minidoka

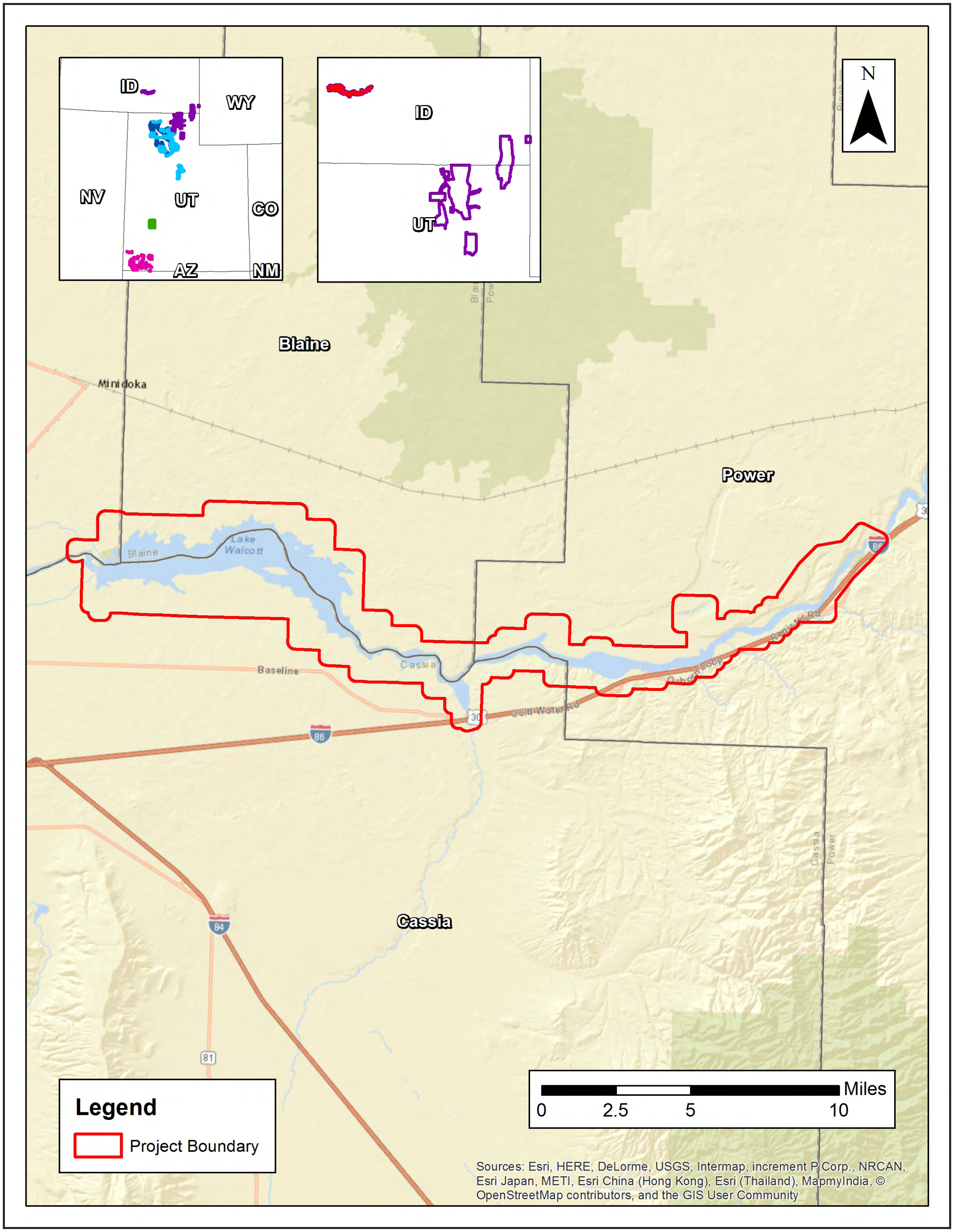


Figure 5. Project Boundary - Thomas Fork Unit

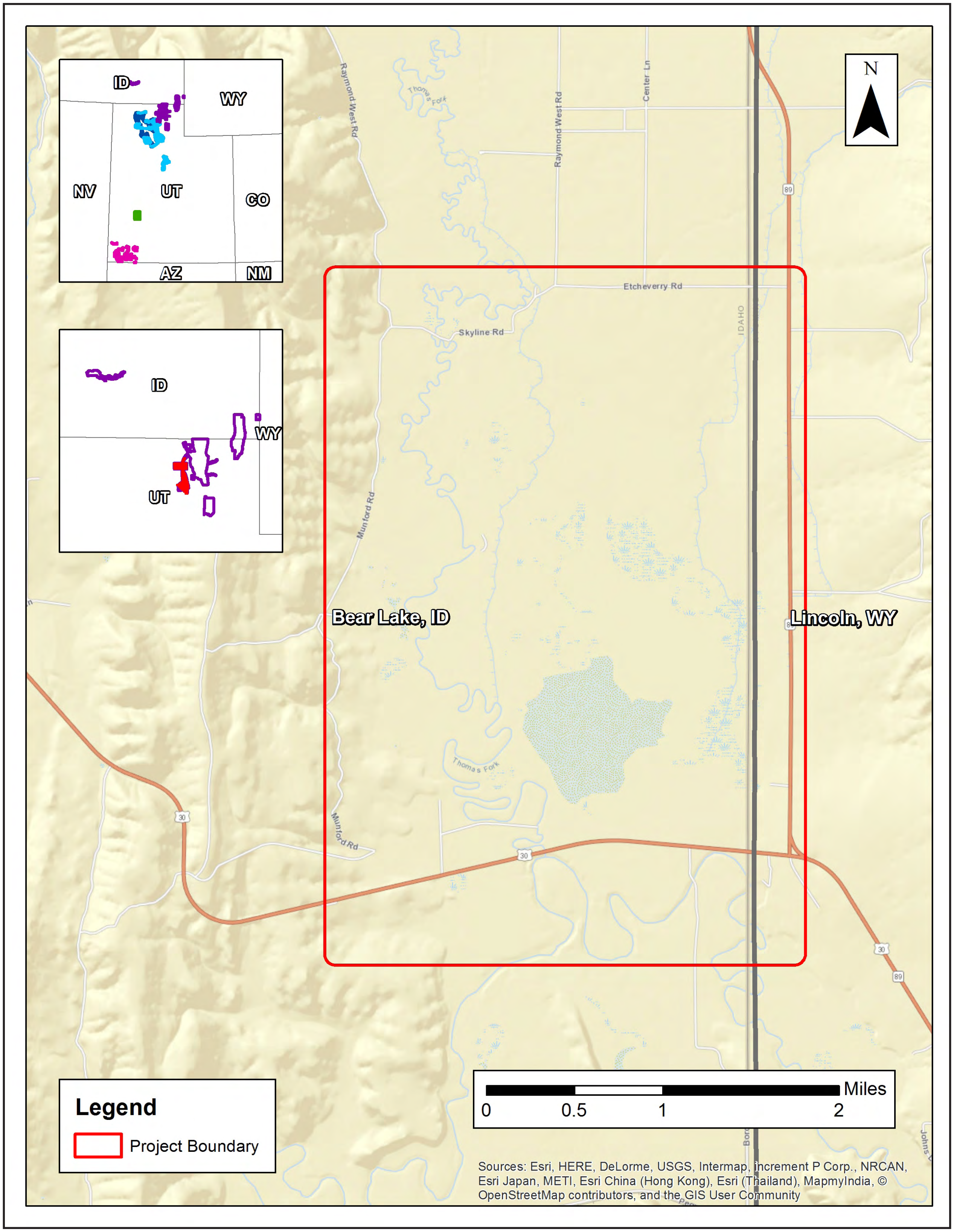
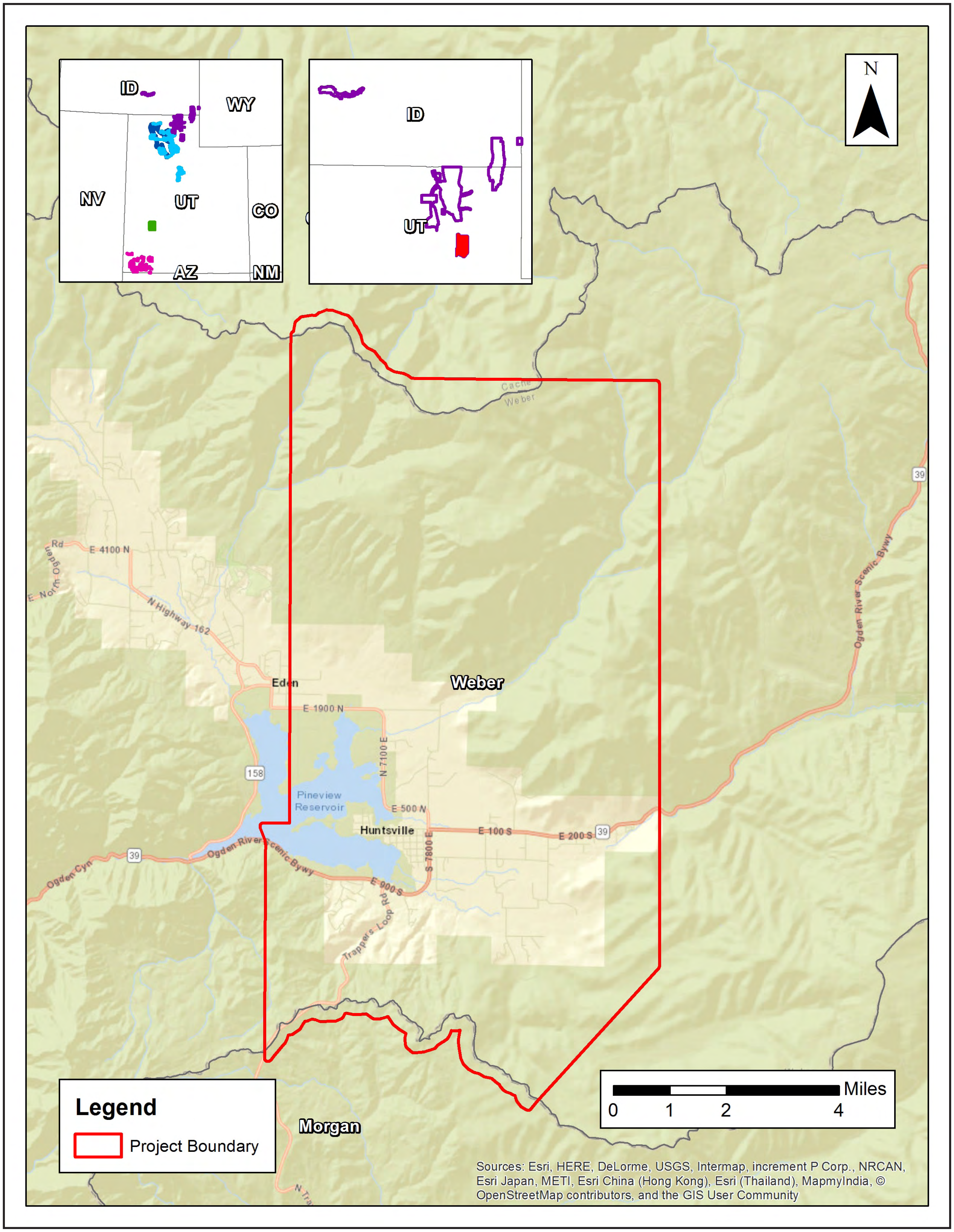


Figure 6. Project Boundary - Weber Valley



# 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 7 through Figure 13.

| Sub-AOI | Planned Lines | Total Length (miles) |
|---|---|---|
| Bear Lake | 148 | 1,692 |
| Bear River | 168 | 1,600 |
| Cache Valley | 139 | 2,001 |
| Minidoka | 59 | 732 |
| Thomas Fork Unit | 13 | 59 |
| Weber Valley | 274 | 1,247 |

## 2.2. LiDAR Sensor

Quantum Spatial utilized Leica ALS 70 and ALS 80 LiDAR sensors (Figure 14), 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.

Figure 7. Planned LiDAR Flight Lines - Bear Lake ALS70

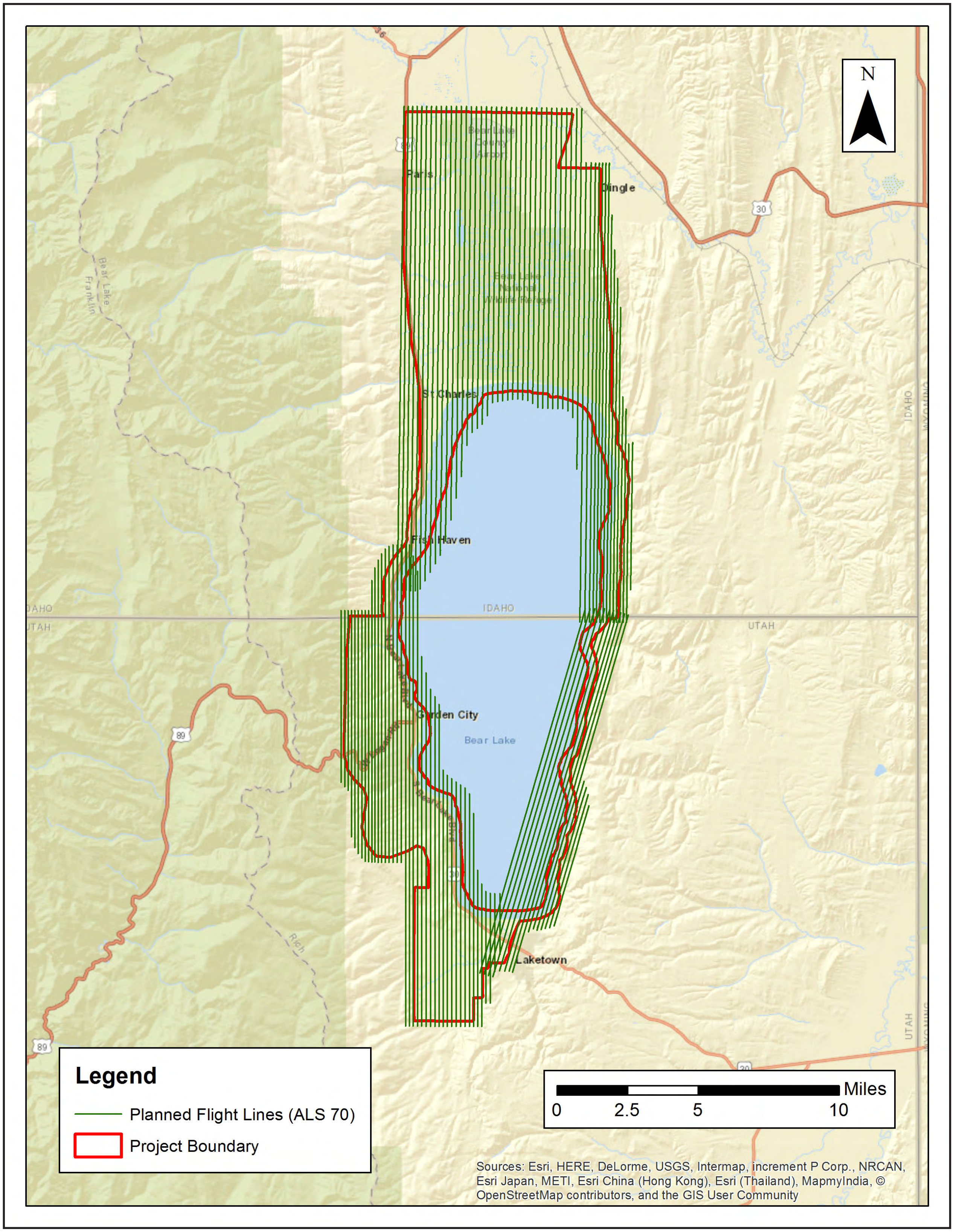


Figure 8. Planned LiDAR Flight Lines - Bear Lake ALS80

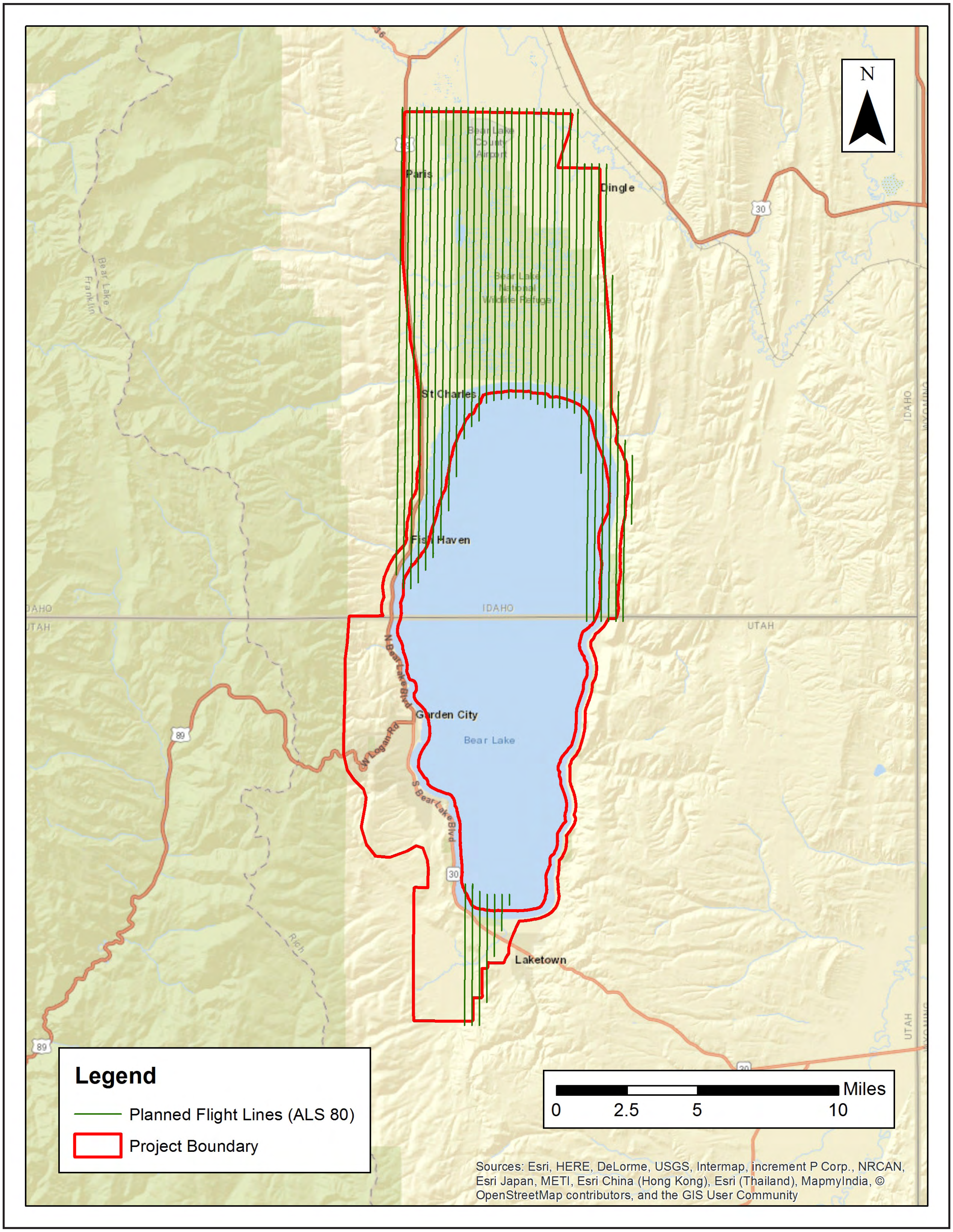


**Figure 9. Planned LiDAR Flight Lines - Bear River**

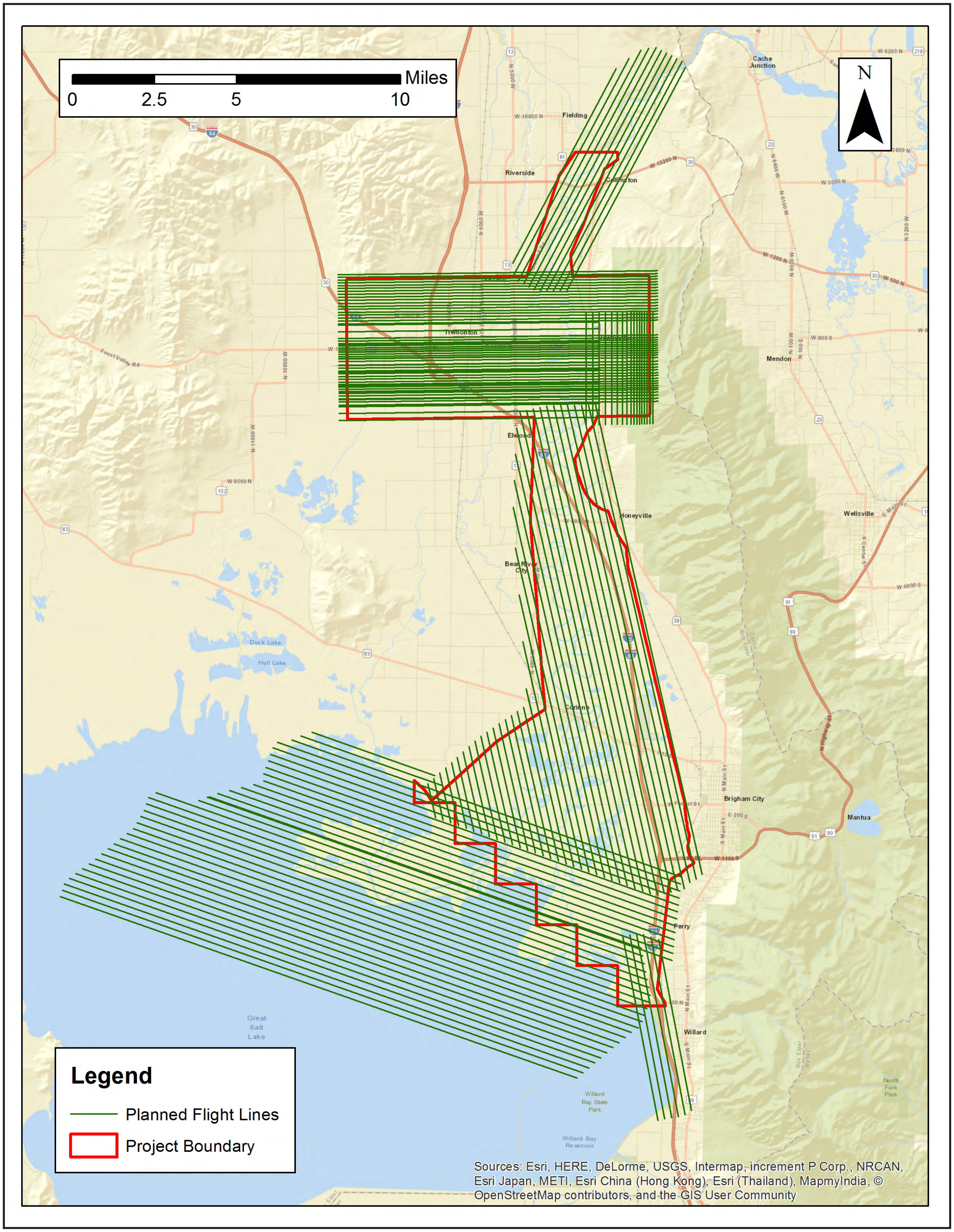


Figure 10. Planned LiDAR Flight Lines - Cache Valley

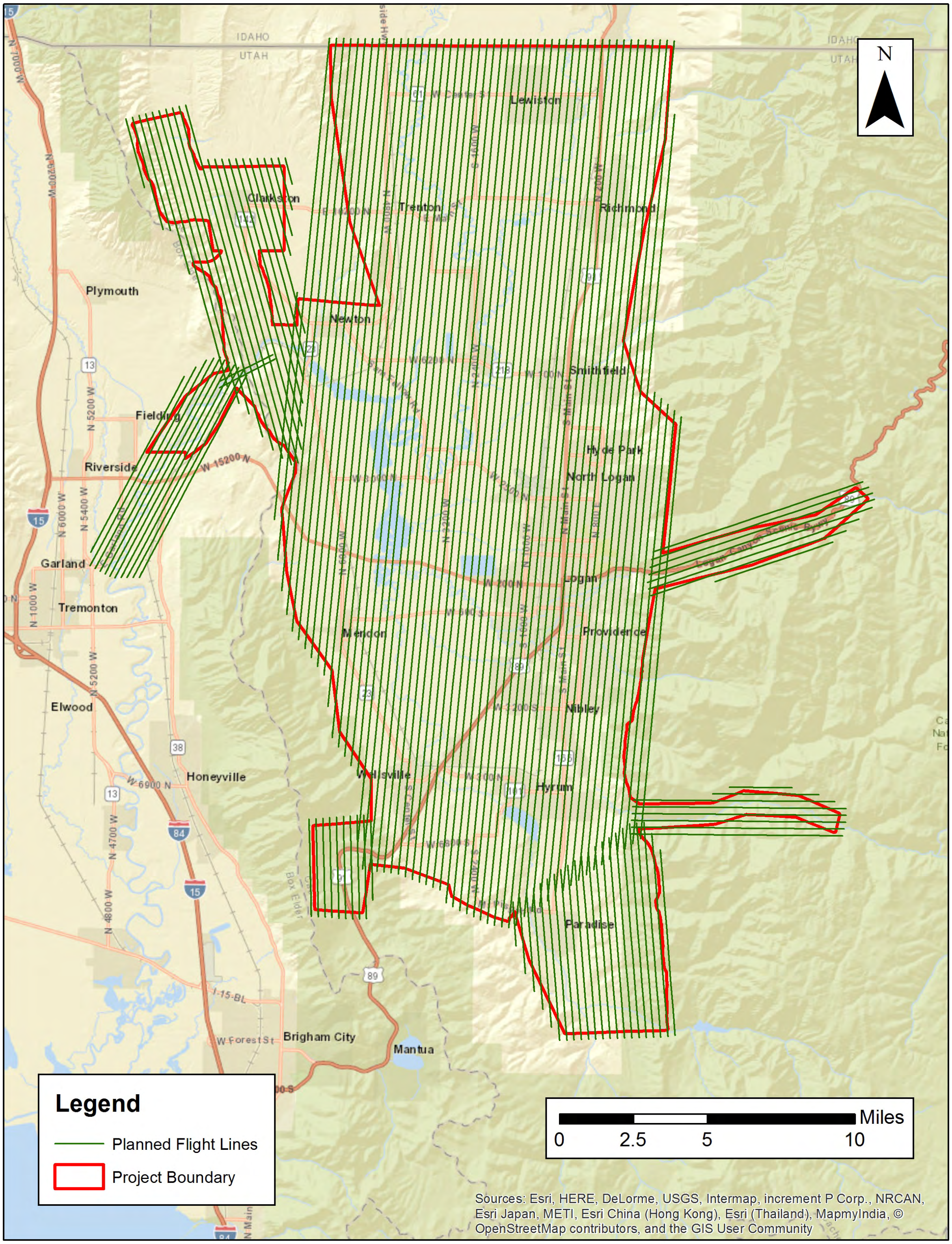


Figure 11. Planned LiDAR Flight Lines - Minidoka

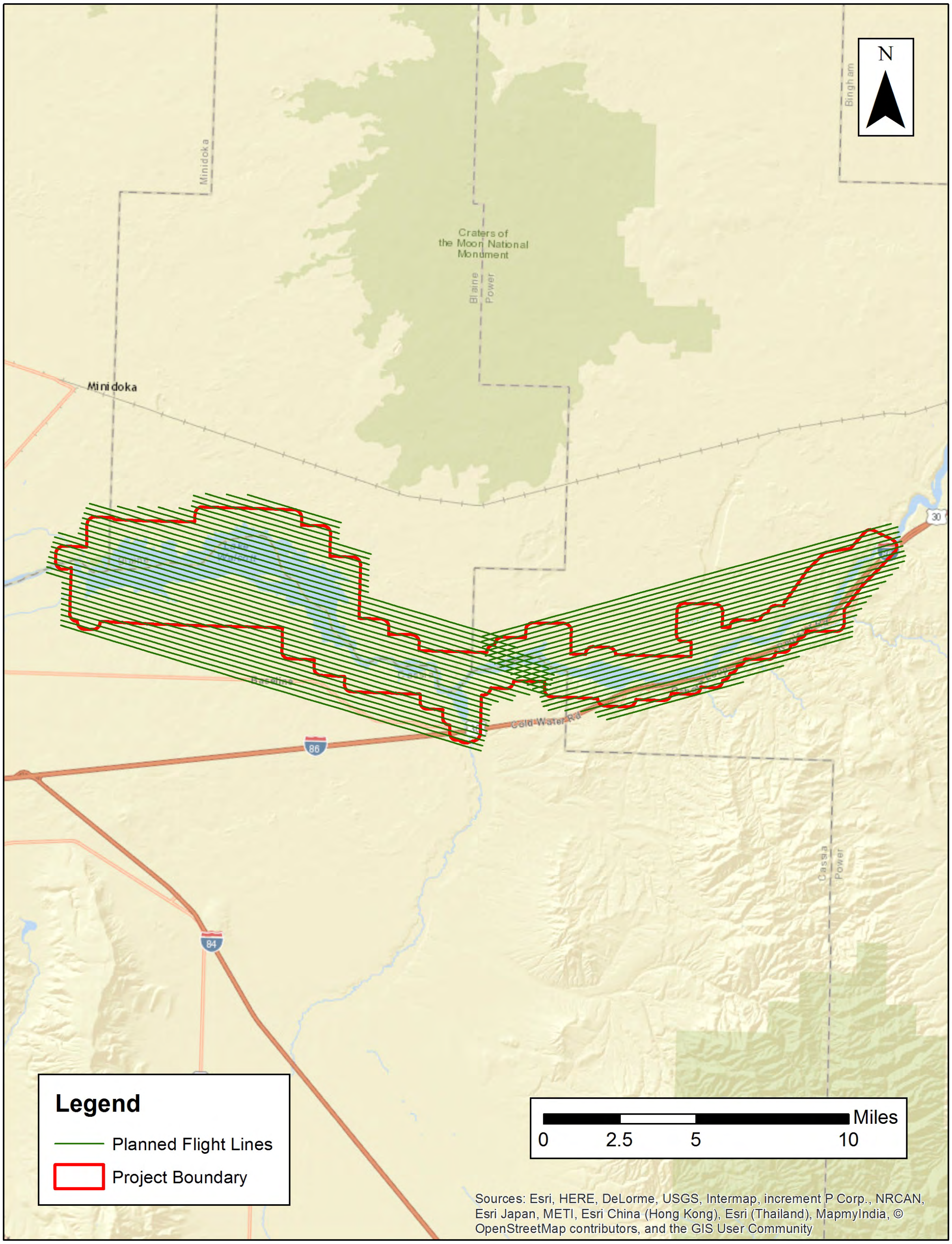


Figure 12. Planned LiDAR Flight Lines - Thomas Fork Unit

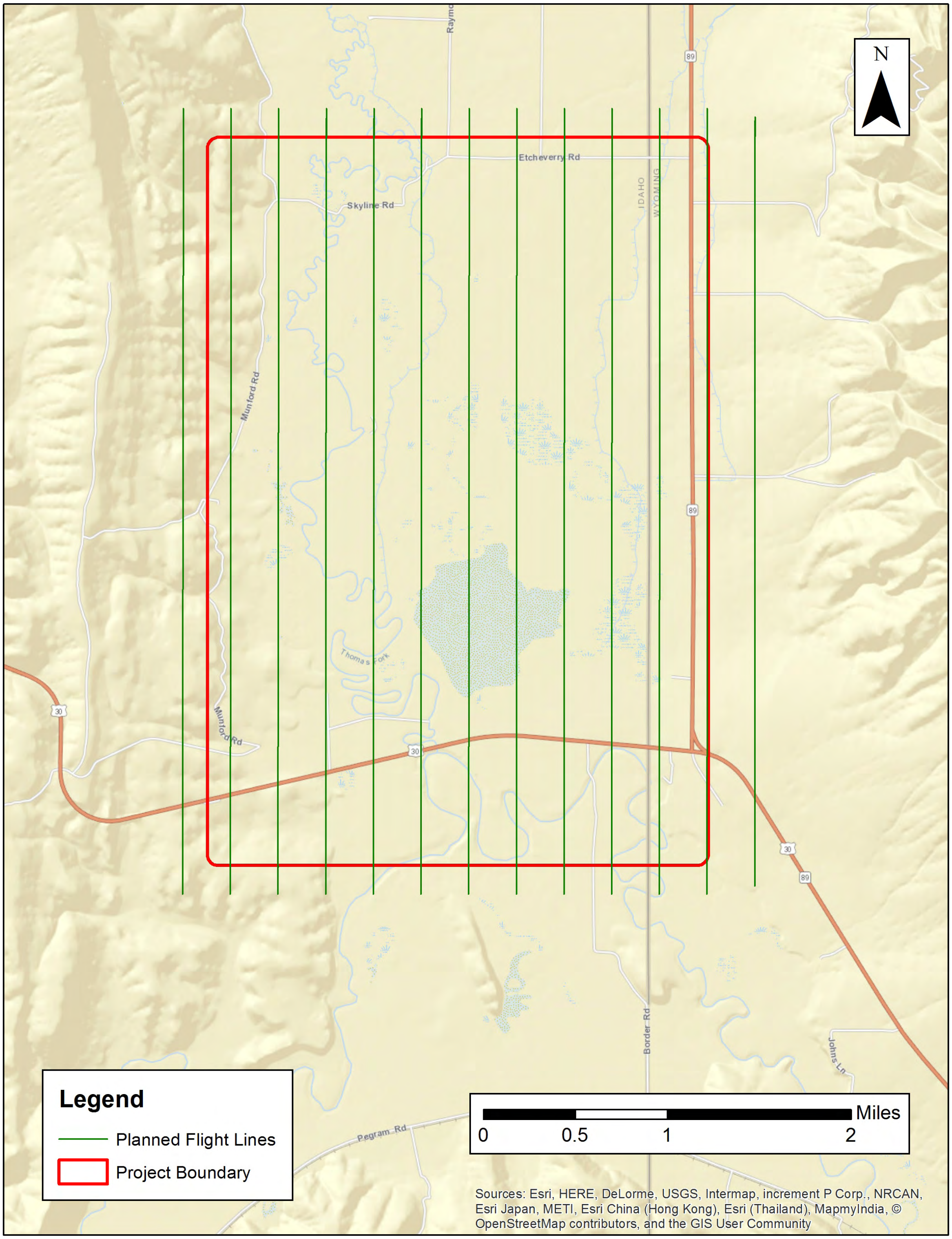


Figure 13. Planned LiDAR Flight Lines - Weber Valley

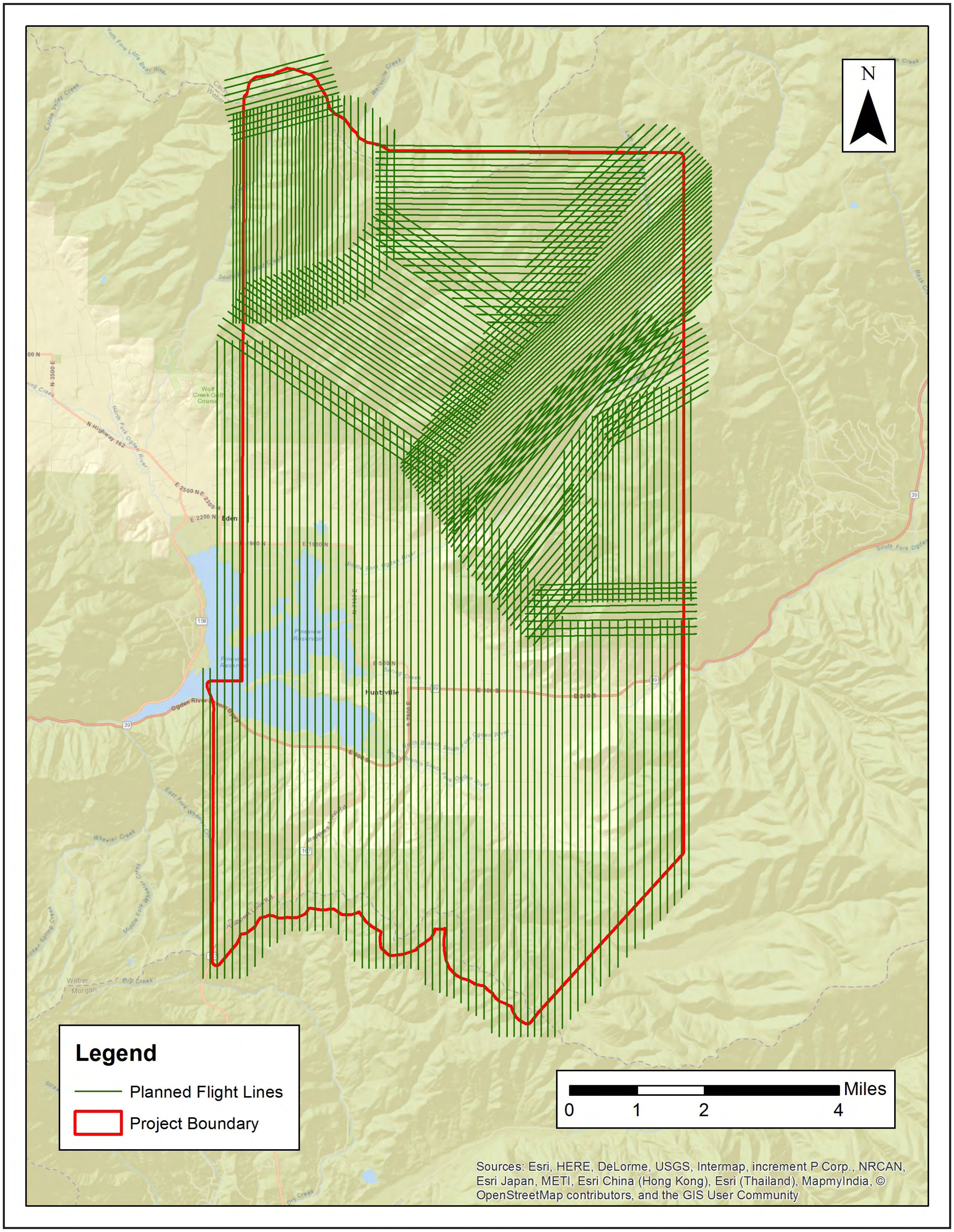


Table 2. Lidar System Specifications

| | | Bear Lake ALS 70 | Bear Lake ALS 80 | Bear River | Cache Valley ALS 70 |
|---|---|---|---|---|---|
| Terrain and Aircraft Scanner | Flying Height (m) | 1,000 | 1,550 | 1,200 | 1,200 |
| | Recommended Ground Speed (kts) | 145 | 145 | 105 | 105 |
| Scanner | Field of View (deg) | 40 | 30 | 40 | 40 |
| | Scan Rate Setting Used (Hz) | 53.4 | 58.4 | 53.4 | 53.4 |
| Laser | Laser Pulse Rate Used (kHz) | 267.8 | 351.8 | 215 | 215 |
| | Multi Pulse in Air Mode | Disabled | Enabled | Disabled | Disabled |
| Coverage | Full Swath Width (m) | 728 | 831 | 874 | 874 |
| Point Spacing and Density | Average Point Density (m) | 0.35 | 0.35 | 0.35 | 0.35 |
| | Average Point Density (pts / m²) | 8 | 8 | 8 | 8 |

| | | Cache Valley ALS 80 | Minidoka | Thomas Fork Unit | Weber Valley |
|---|---|---|---|---|---|
| Terrain and Aircraft Scanner | Flying Height | 1,150 | 1,000 | 1,550 | 1,000 |
| | Recommended Ground Speed | 120 | 145 | 145 | 145 |
| Scanner | Field of View | 40 | 40 | 30 | 40 |
| | Scan Rate Setting Used | 52 | 53.4 | 58.4 | 53.25 |
| Laser | Laser Pulse Rate Used | 340 | 267.8 | 351.8 | 267.8 |
| | Multi Pulse in Air Mode | Enabled | Disabled | Enabled | Disabled |
| Coverage | Full Swath Width | 1,128 | 728 | 831 | 728 |
| Point Spacing and Density | Average Point Density | 0.38 | 0.35 | 0.35 | 0.35 |
| | Average Point Density | 9.8 | 8 | 8 | 8 |

Figure 14. Leica ALS 70 and ALS 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 a state-of-the-art Leica LiDAR system. Some of Quantum Spatial's operating aircraft can be seen in Figure 15 below.

Figure 15. Some of Quantum Spatial's Planes

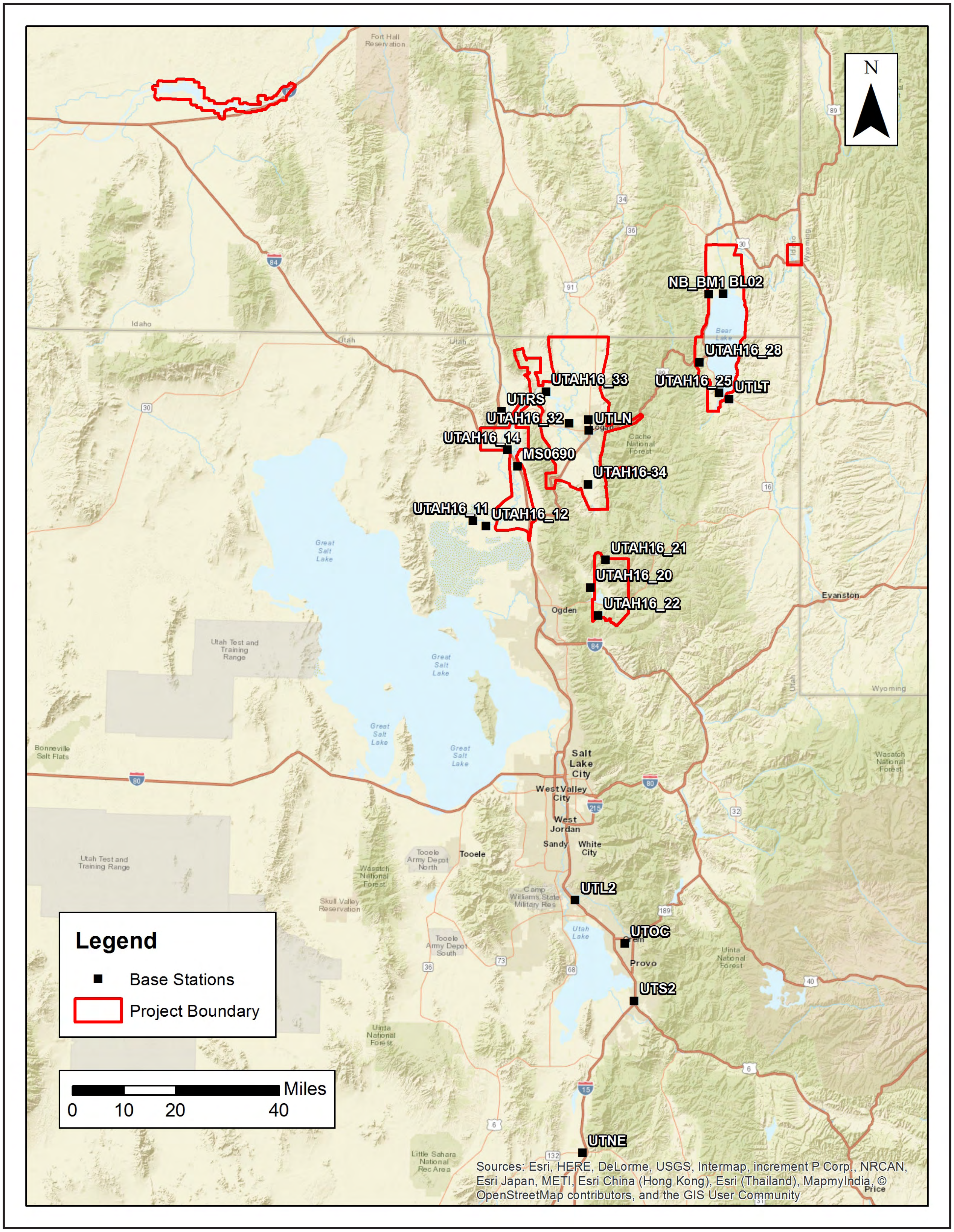
## 2.4. Base Station Information

**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 16 and Table 3 .**

**Table 3. Base Station Locations**

| Base Station | Longitude | Latitude | Ellipsoid Height (m) |
|---|---|---|---|
| BL02 | 111° 20′ 9.39715″ | 42° 7′ 21.10153″ | 1794.262 |
| MS0690 | 112° 6′ 8.47082″ | 41° 38′ 3.88146″ | 1285.809 |
| NB_BM1 | 111° 23′ 24.72041″ | 42° 7′ 17.8354″ | 1802.154 |
| NW, NW_43 | 111° 50′ 19.71218″ | 41° 46′ 4.72342″ | 1352.539 |
| 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_14 | 112° 8′ 27.76917″ | 41° 40′ 49.5621″ | 1299.063 |
| UTAH16_20 | 111° 49′ 34.4977″ | 41° 17′ 47.36502″ | 1482.531 |
| UTAH16_21 | 111° 46′ 13.92959″ | 41° 22′ 28.63604″ | 2624.242 |
| UTAH16_22 | 111° 47′ 47.26102″ | 41° 13′ 4.70826″ | 1776.802 |
| UTAH16_25 | 111° 20′ 58.60306″ | 41° 50′ 40.67043″ | 1798.059 |
| UTAH16_28 | 111° 25′ 27.41907″ | 41° 55′ 49.15997″ | 1951.358 |
| UTAH16_32 | 111° 54′ 41.40038″ | 41° 45′ 22.68323″ | 1333.034 |
| UTAH16_33 | 111° 59′ 55.60663″ | 41° 50′ 40.0788″ | 1333.993 |
| UTAH16-34 | 111° 50′ 15.73004″ | 41° 35′ 7.98321″ | 1459.27 |
| UTL2 | 111° 52′ 13.08922″ | 40° 25′ 9.49565″ | 1391.436 |
| UTLN | 111° 50′ 11.99495″ | 41° 44′ 13.04741″ | 1376.43 |
| UTLT | 111° 18′ 45.9088″ | 41° 49′ 39.72712″ | 1831.49 |
| UTNE | 111° 50′ 5.00862″ | 39° 42′ 37.9727″ | 1561.007 |
| UTOC | 111° 41′ 11.47676″ | 40° 17′ 54.89014″ | 1453.351 |
| UTRS | 112° 9′ 53.51884″ | 41° 47′ 15.86153″ | 1334.81 |
| UTS2 | 111° 39′ 5.50612″ | 40° 8′ 16.20885″ | 1371.47 |

Figure 16. Base Station Locations



## 2.5. Time Period

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

### Bear Lake

- Oct 22, 2016-A (N22GE, SN7161)
- Oct 22, 2016-B (N22GE, SN7161)
- Oct 23, 2016-A (N22GE, SN7161)
- Oct 23, 2016-B (N22GE, SN7161)
- Oct 27, 2016-A (N22GE, SN7161)
- Oct 27, 2016-B (N22GE, SN7161)
- Nov 19, 2016-A (N208NR, SN8146)

### Bear River

- Sep 19, 2016-A (N704MD, SN7161)
- Sep 19, 2016-B (N704MD, SN7161)
- Sep 20, 2016-A (N704MD, SN7161)
- Sep 21, 2016-A (N704MD, SN7161)
- Sep 24, 2016-A (N704MD, SN7161)
- Sep 25, 2016-A (N704MD, SN7161)

### Cache Valley

- Sep 20, 2016-A (N704MD, SN7161)
- Nov 20, 2016-A (N280NR, SN8146)
- Nov 23, 2016-A (N280NR, SN8146)
- Nov 23, 2016-B (N280NR, SN8146)
- Nov 24, 2016-A (N280NR, SN8146)
- Nov 25, 2016-A (N280NR, SN8146)
- Nov 26, 2016-A (N280NR, SN8146)
- Nov 26, 2016-B (N280NR, SN8146)
- Mar 17, 2017-A (N704MD, SN8121)
- Mar 18, 2017-A (N704MD, SN8121)

### Minidoka

- October 23, 2016-A (N22GE, SN7161)

### Thomas Fork Unit

- Nov 19, 2016-A (N208NR, SN8146)

# Weber Valley

- Oct 7, 2016-A (N22GE, SN7161)
- Oct 8, 2016-A (N22GE, SN7161)
- Oct 8, 2016-B (N22GE, SN7161)
- Oct 8, 2016-C (N22GE, SN7161)
- Oct 9, 2016-A (N22GE, SN7161)
- Oct 10, 2016-A (N22GE, SN7161)
- Oct 12, 2016-A (N22GE, SN7161)
- Oct 13, 2016-A (N22GE, SN7161)
- Oct 13, 2016-B (N22GE, SN7161)
- Oct 20, 2016-A (N22GE, SN7161)
- Oct 20, 2016-B (N22GE, SN7161)
- Oct 20, 2016-C (N22GE, SN7161)
- Oct 20, 2016-D (N22GE, SN7161)
- Oct 21, 2016-A (N22GE, SN7161)
- Oct 21, 2016-B (N22GE, SN7161)

# 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 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 Processing

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 Processing

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 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. 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 17 through Figure 22.

**Figure 17. Flightline Swath LAS File Coverage - Bear Lake**

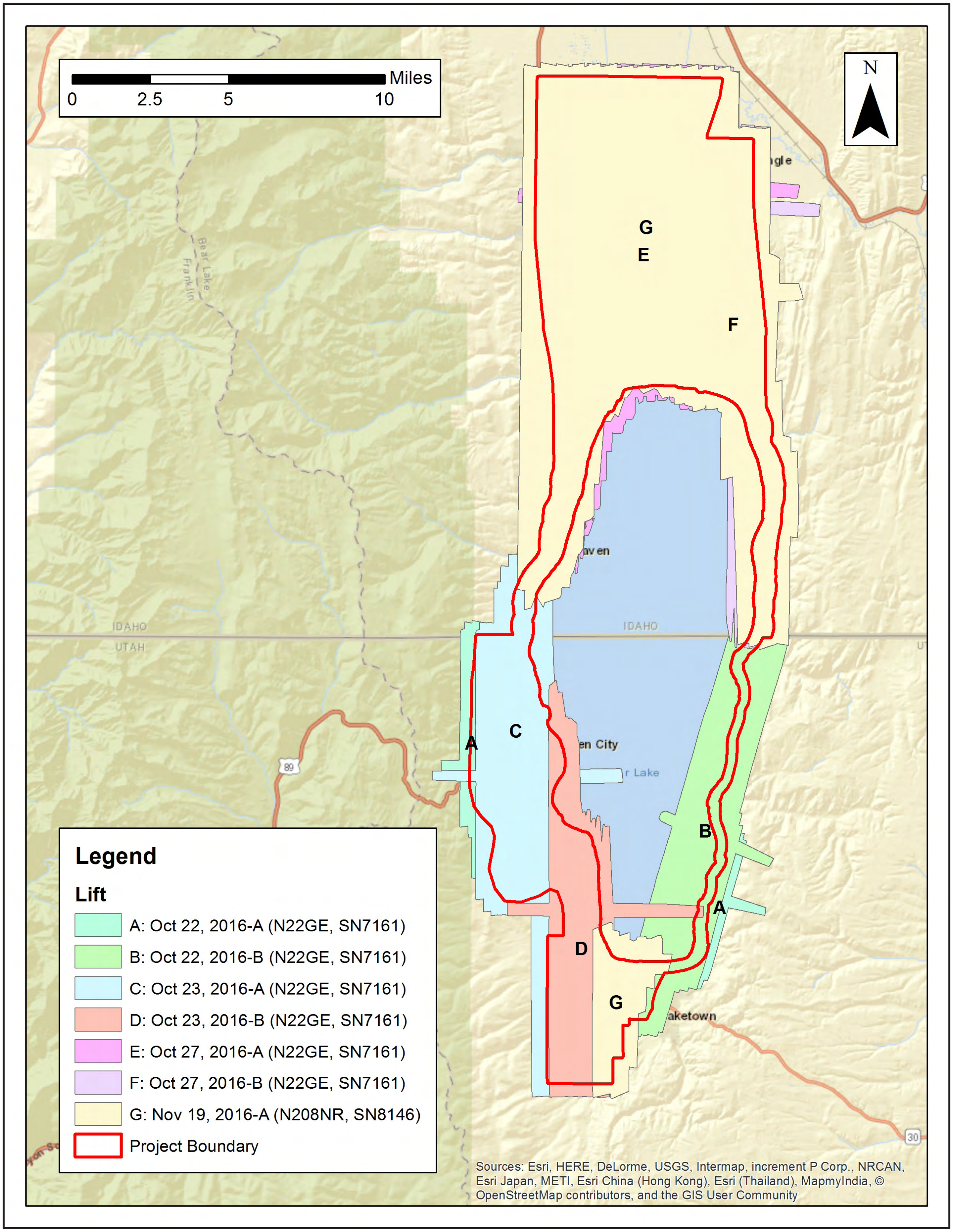


**Figure 18. Flightline Swath LAS File Coverage - Bear River**

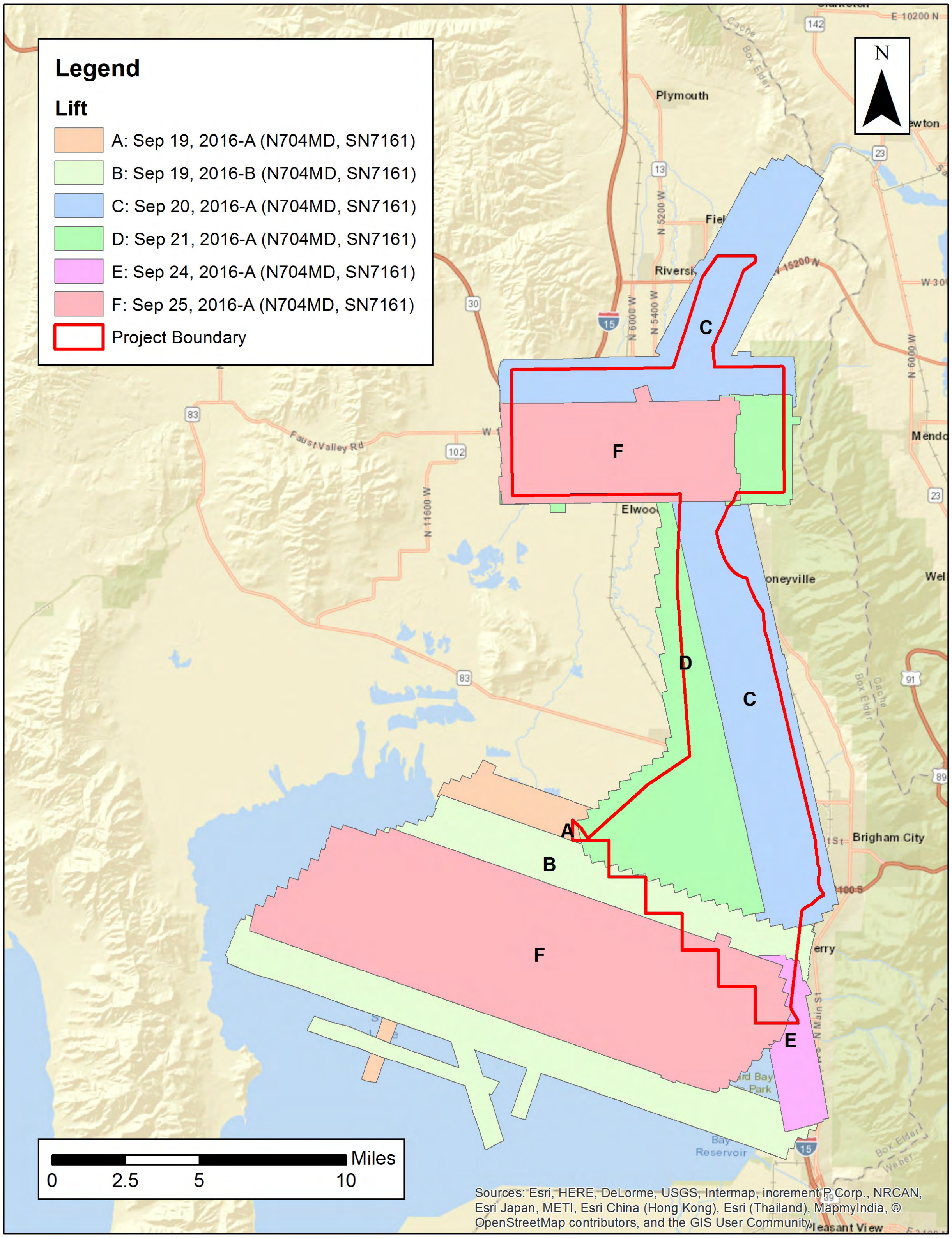


**Figure 19. Flightline Swath LAS File Coverage - Cache Valley**

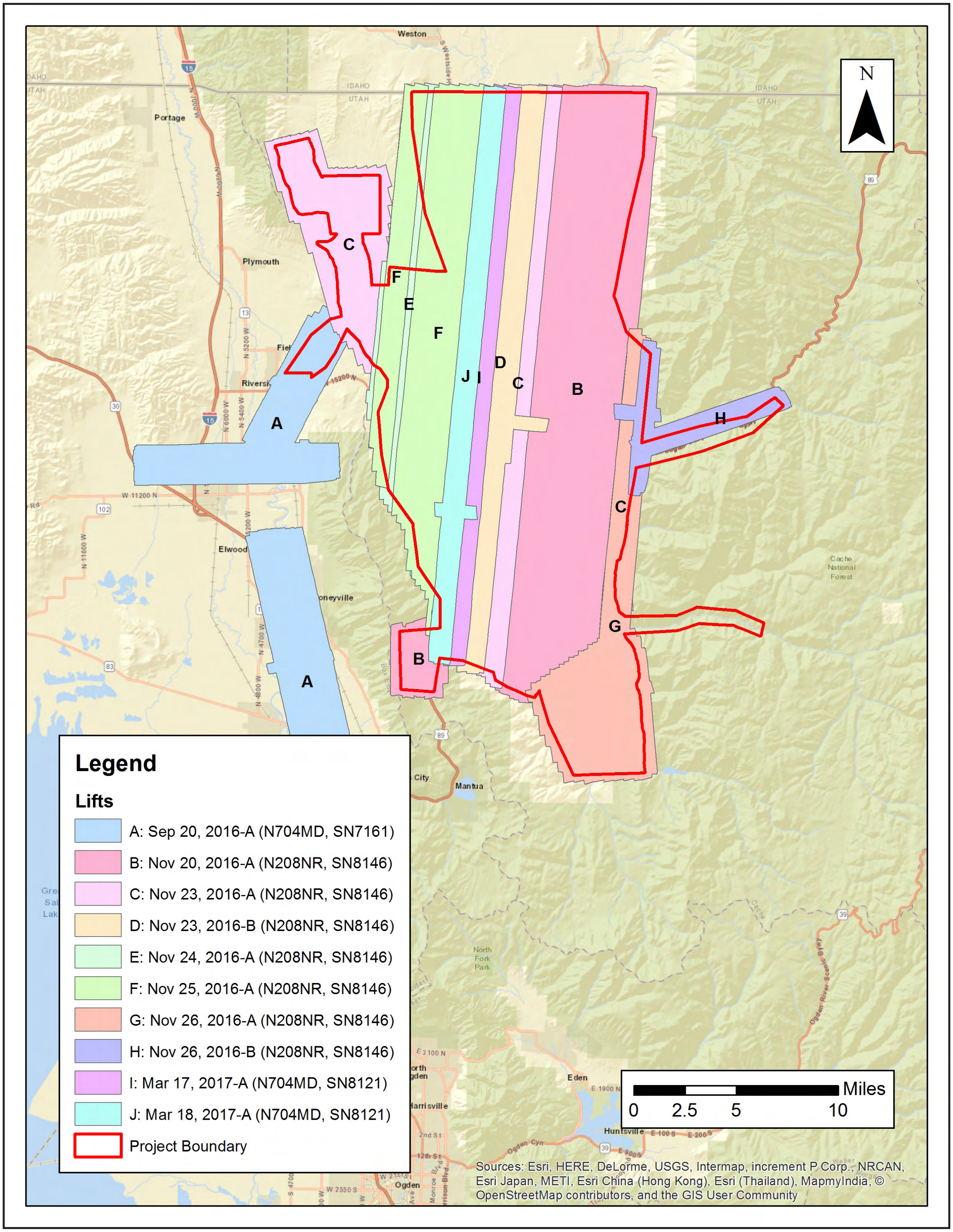


**Figure 20. Flightline Swath LAS File Coverage - Minidoka**

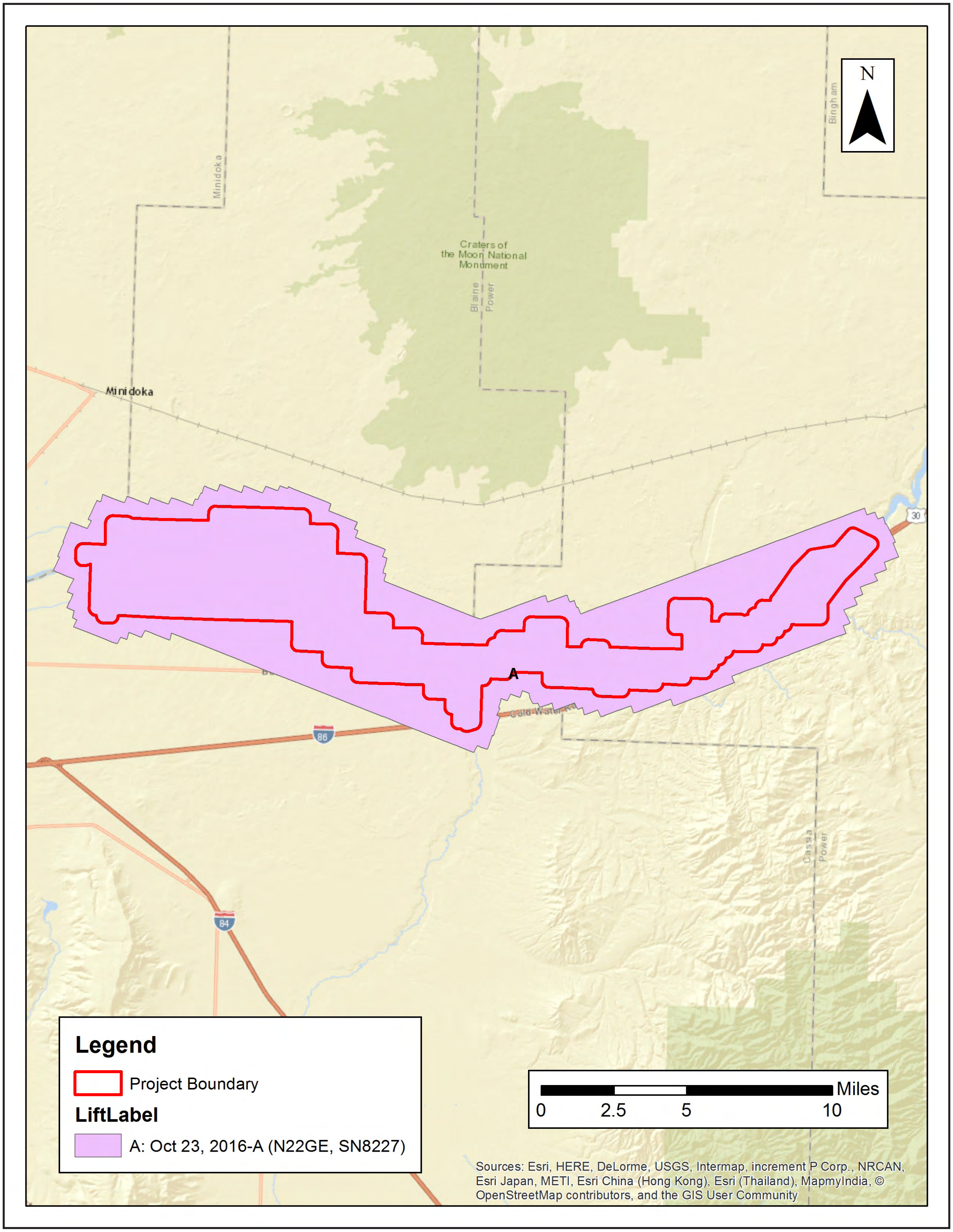


Figure 21. Flightline Swath LAS File Coverage - Thomas Fork Unit

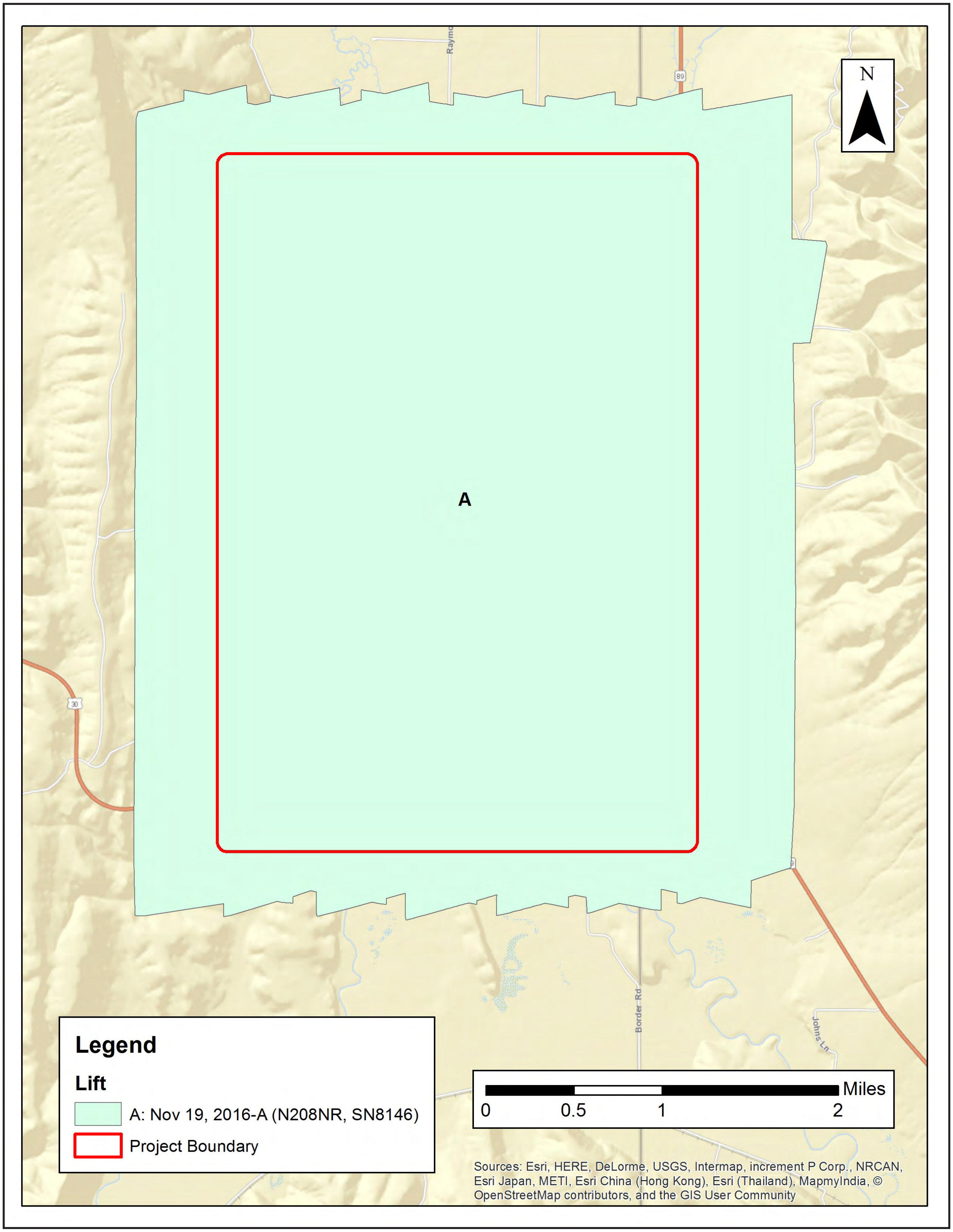
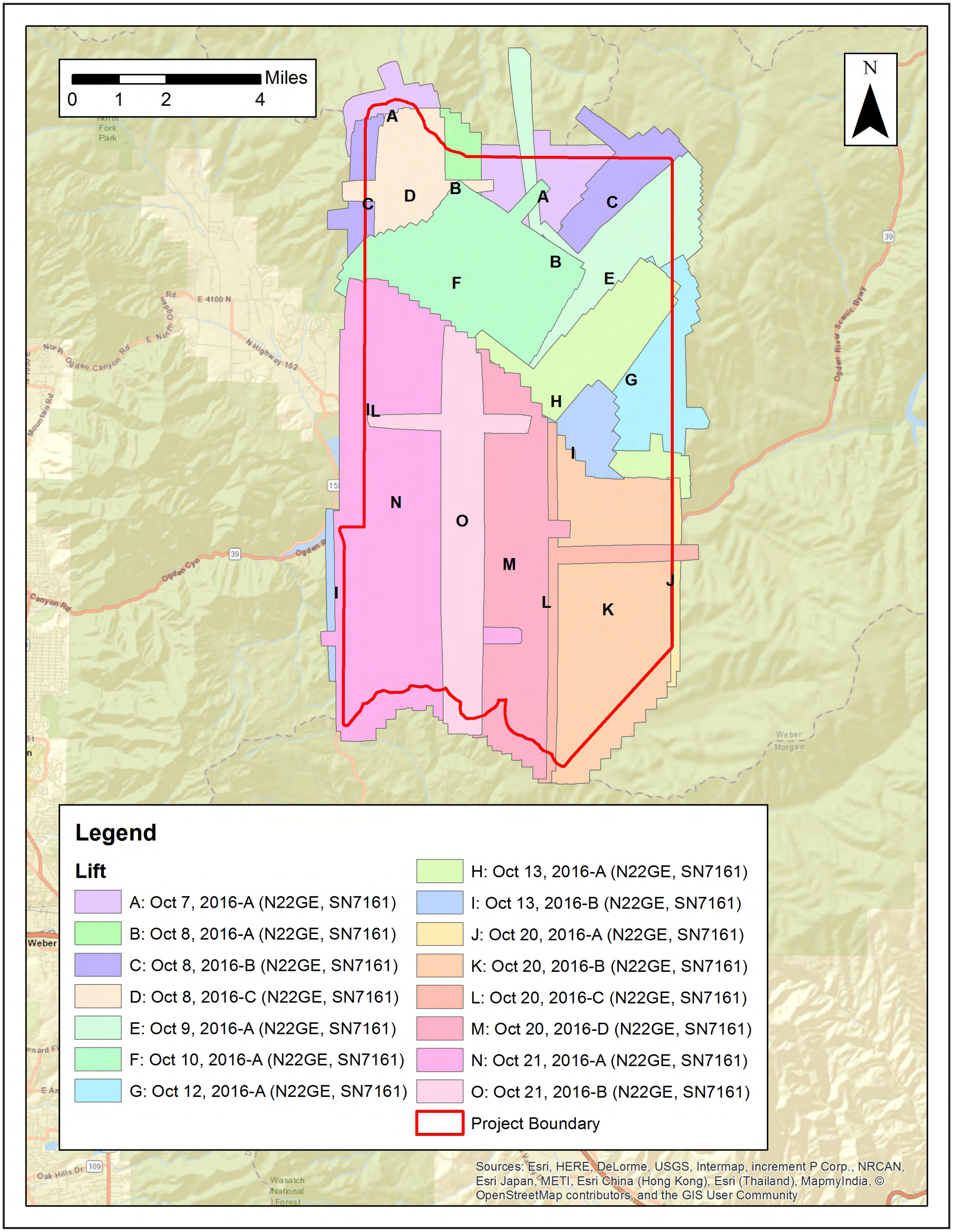


**Figure 22. Flightline Swath LAS File Coverage - Weber Valley**



# 5. Ground Control and Check Point Collection

Quantum Spatial completed a field survey of 284 ground control (calibration) points along with 123 blind QA points in Vegetated and Non-Vegetated land cover classifications (total of 409 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.

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 23 through Figure 28 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 62 of 63 checkpoints located in bare earth and urban (non-vegetated) areas; point BE95 was excluded as it fell beneath power lines. 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. See Figure 29 through Figure 34.

## 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 62 of 63 checkpoints located in bare earth and urban (non-vegetated) areas; point BE95 was excluded as it fell beneath power lines. See Figure 29 through Figure 34.

2. Vegetated Vertical Accuracy (VVA): VVA shall be reported for “forested”, “shrubs”, and “tall weeds” 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 forested and tall grass (vegetated) areas. The checkpoints were distributed throughout the project area and were surveyed using GPS techniques. See Figure 35 through Figure 40.

**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.**

| | Target | Measured | Point Count |
|---|---|---|---|
| Raw NVA | 0.196 m | 0.0611 m | 62 |
| NVA | 0.196 m | 0.0668 m | 62 |
| VVA | 0.294 m | 0.2357 m | 60 |

**Figure 23. Calibration Control Point Locations - Bear Lake**

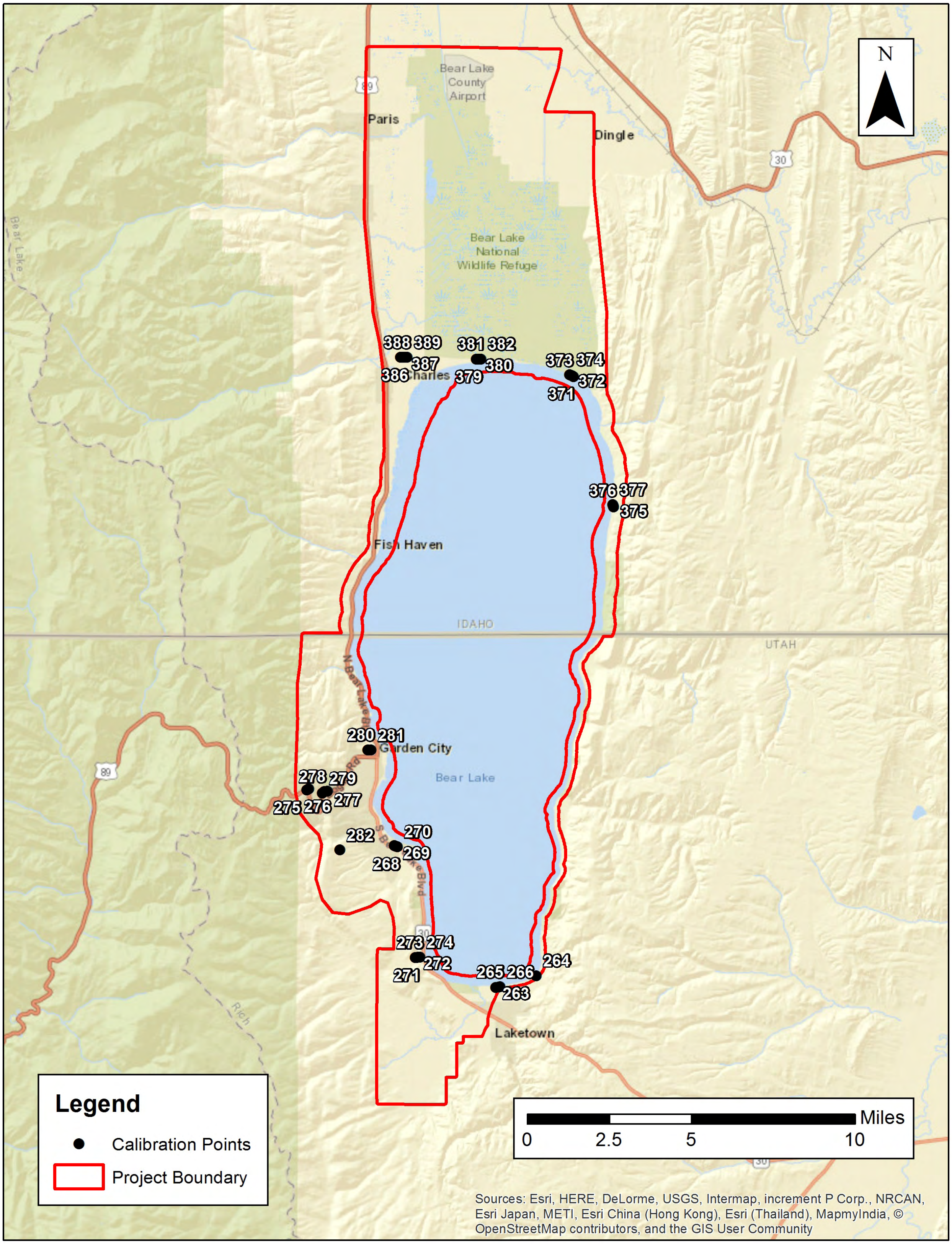


Figure 24. Calibration Control Point Locations - Bear River

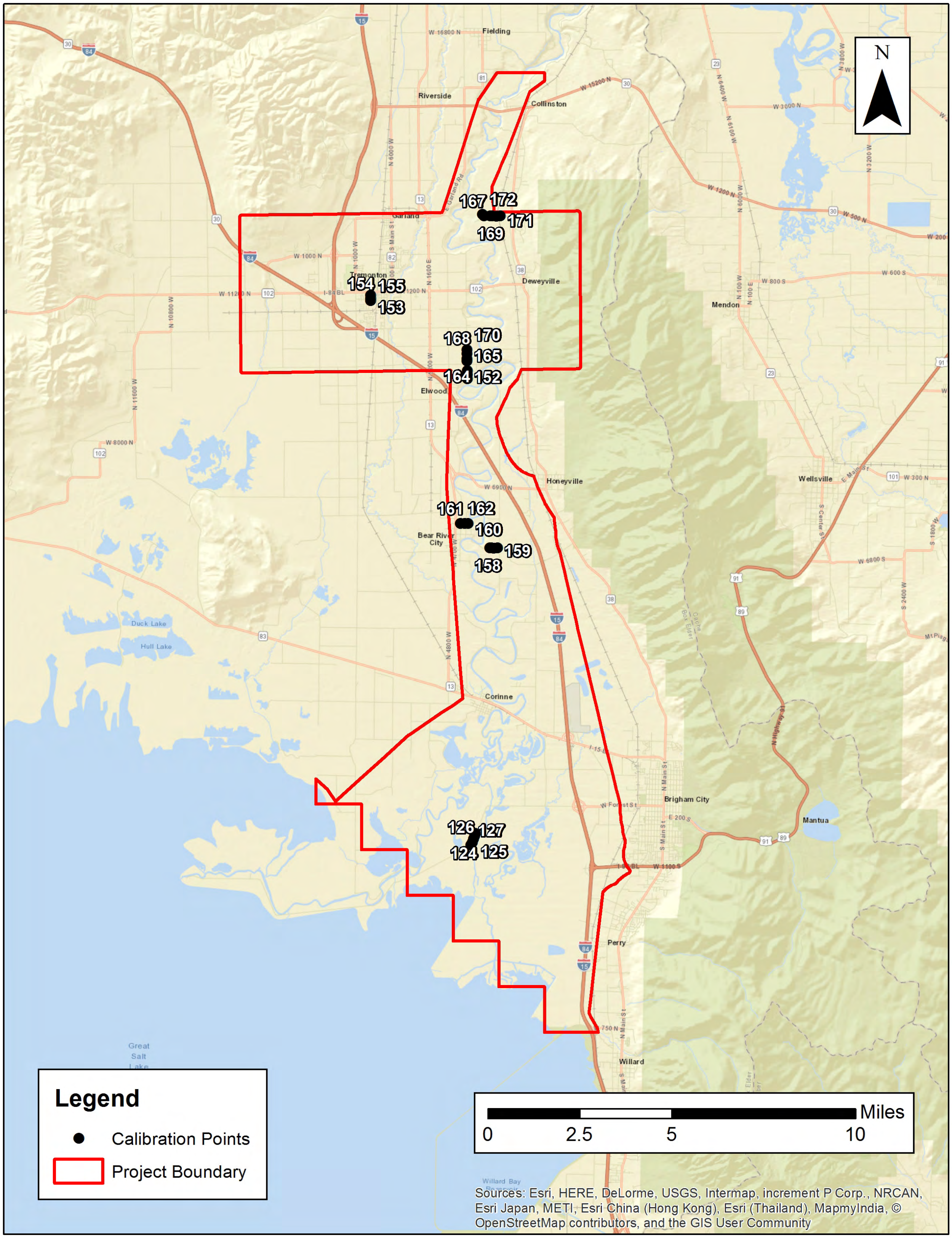


Figure 25. Calibration Control Point Locations - Cache Valley

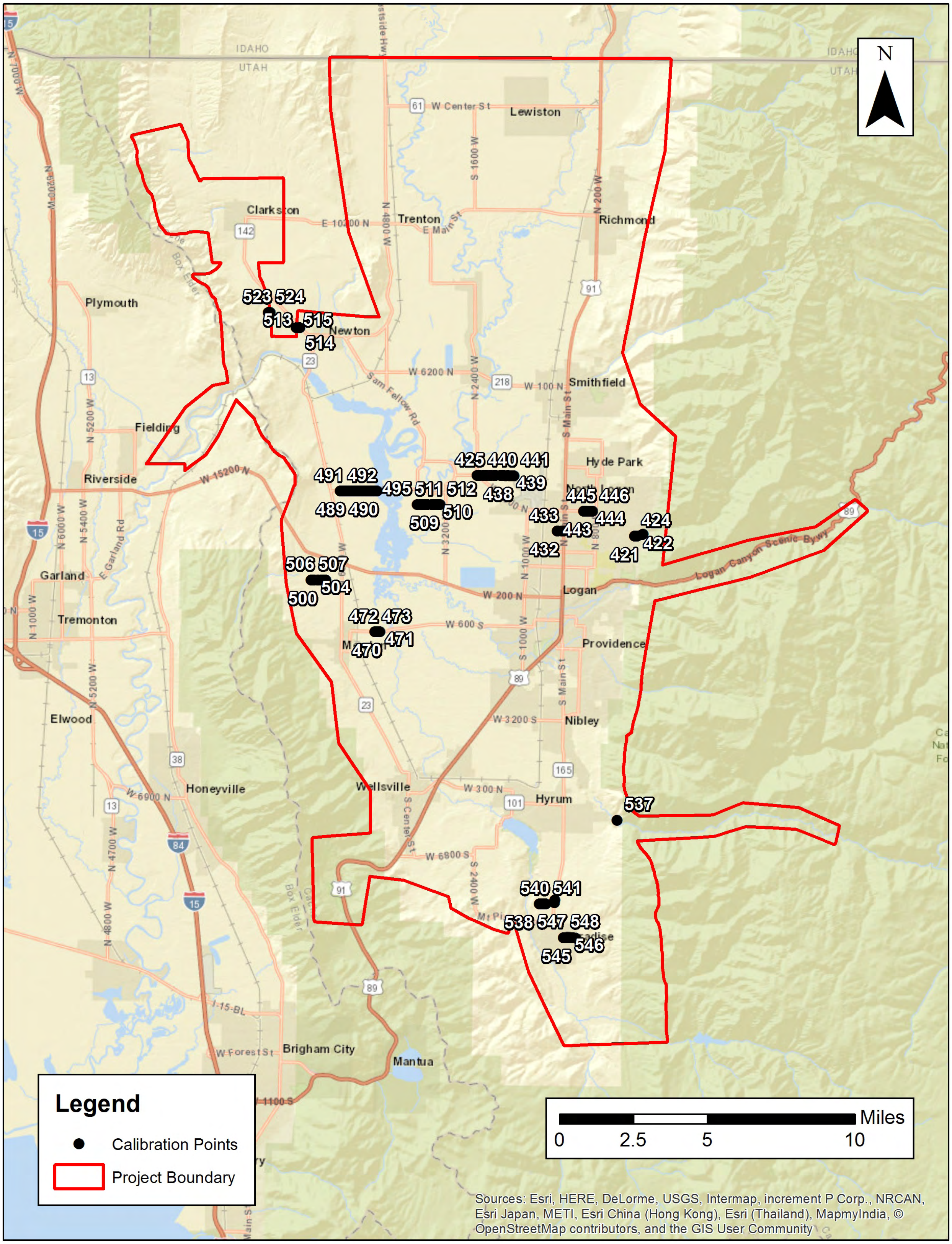


**Figure 26. Calibration Control Point Locations - Minidoka**

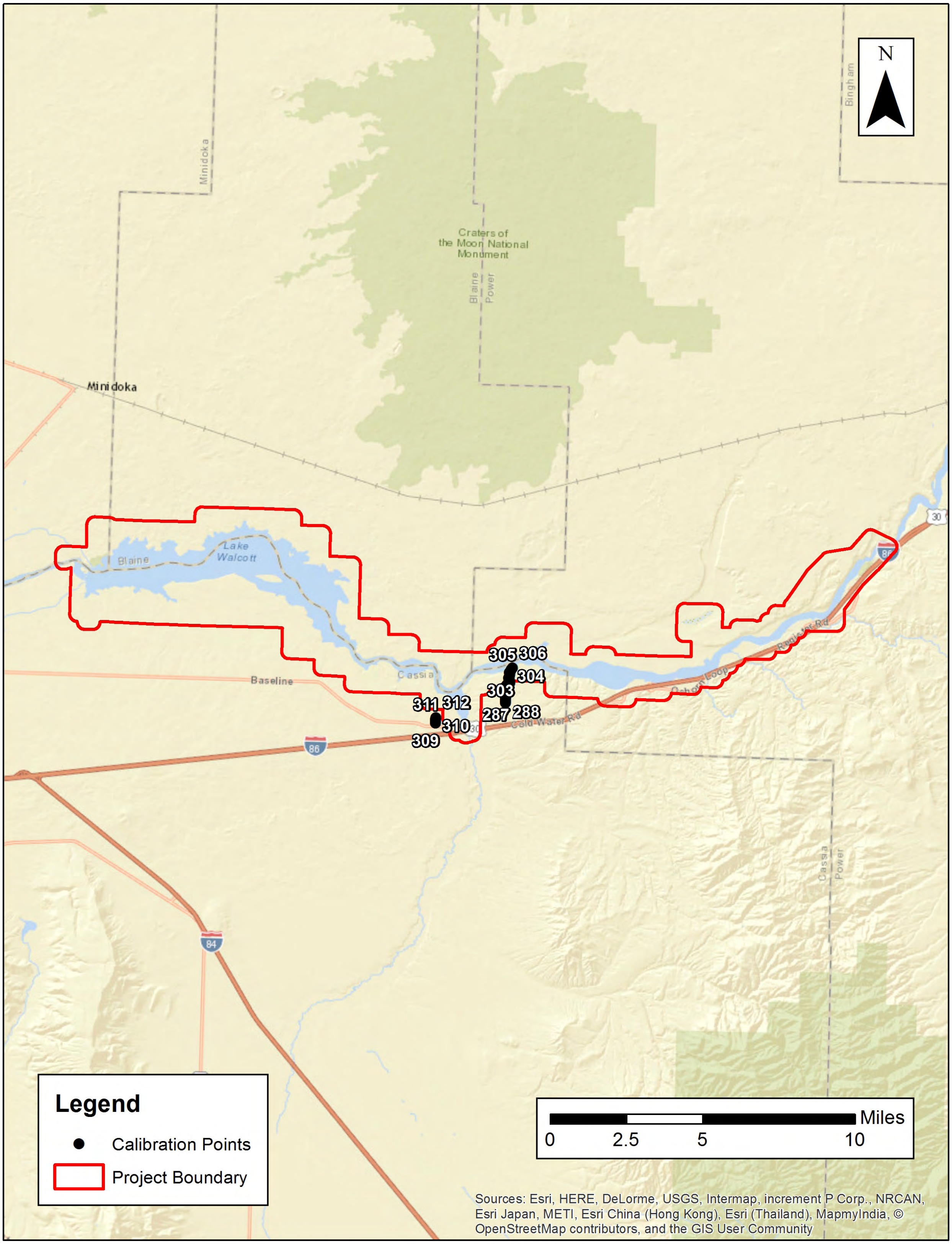


**Figure 27. Calibration Control Point Locations - Thomas Fork Unit**

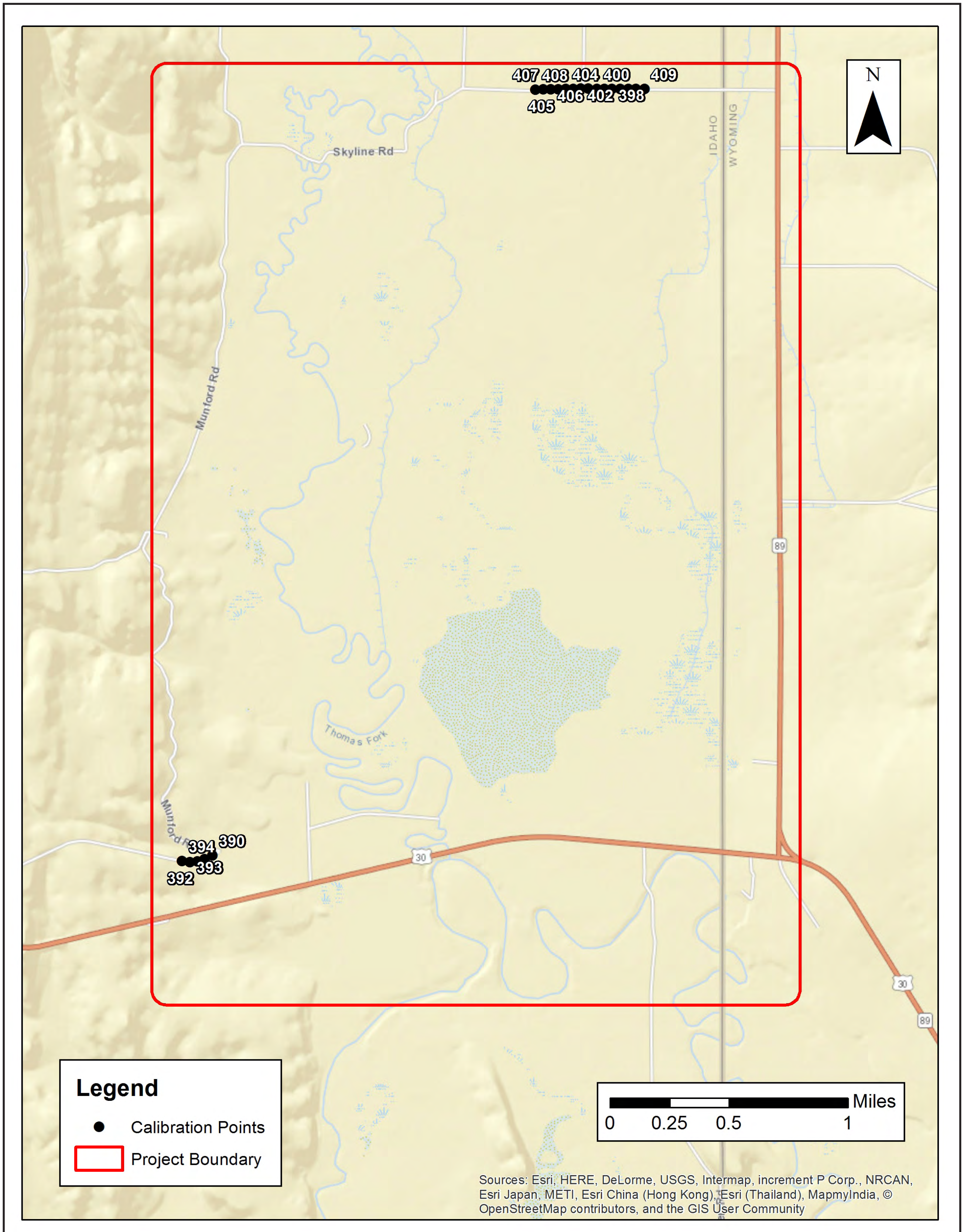


Figure 28. Calibration Control Point Locations - Weber Valley

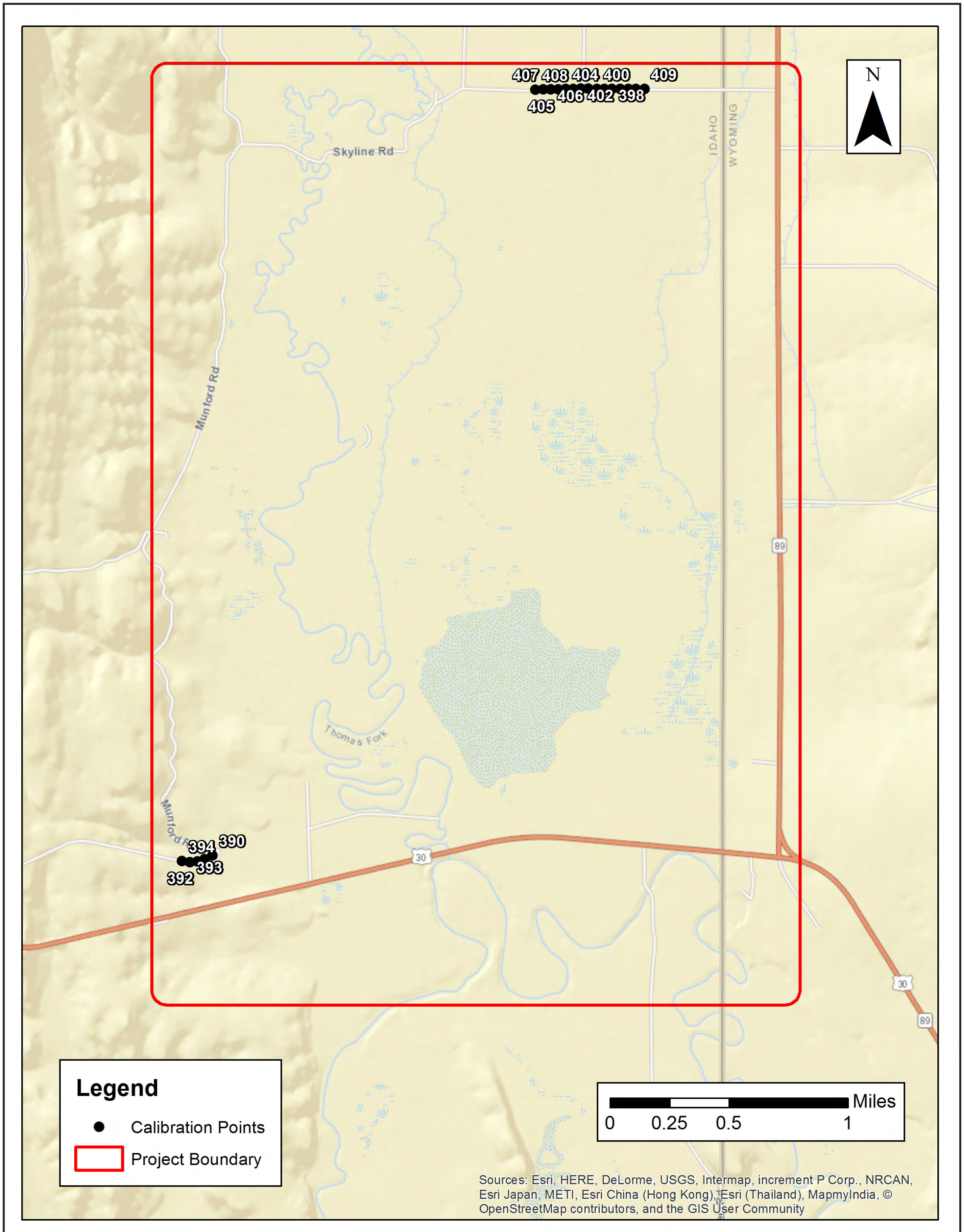


Figure 29. QC Checkpoint Locations - NVA - Bear Lake

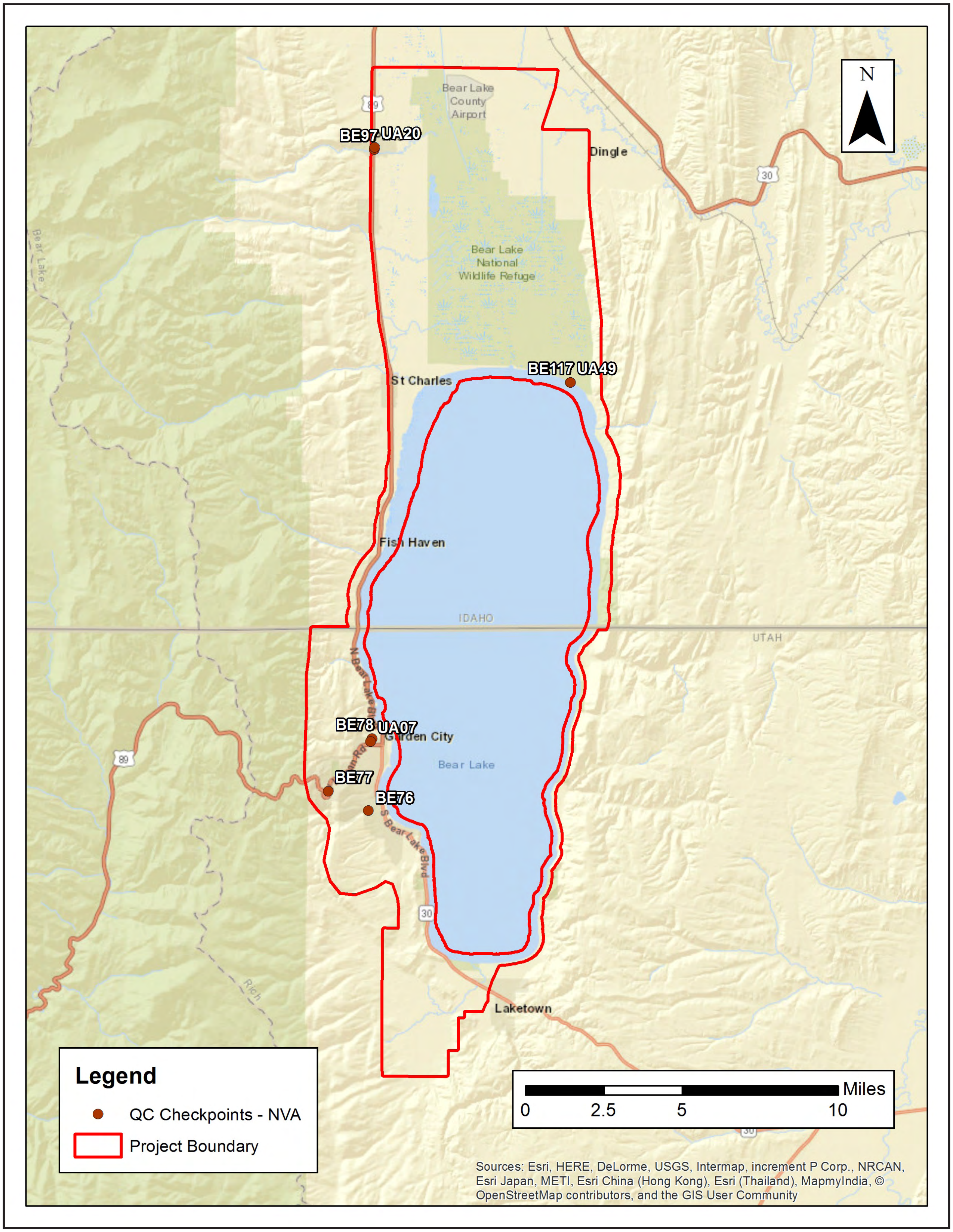


Figure 30. QC Checkpoint Locations - NVA - Bear River

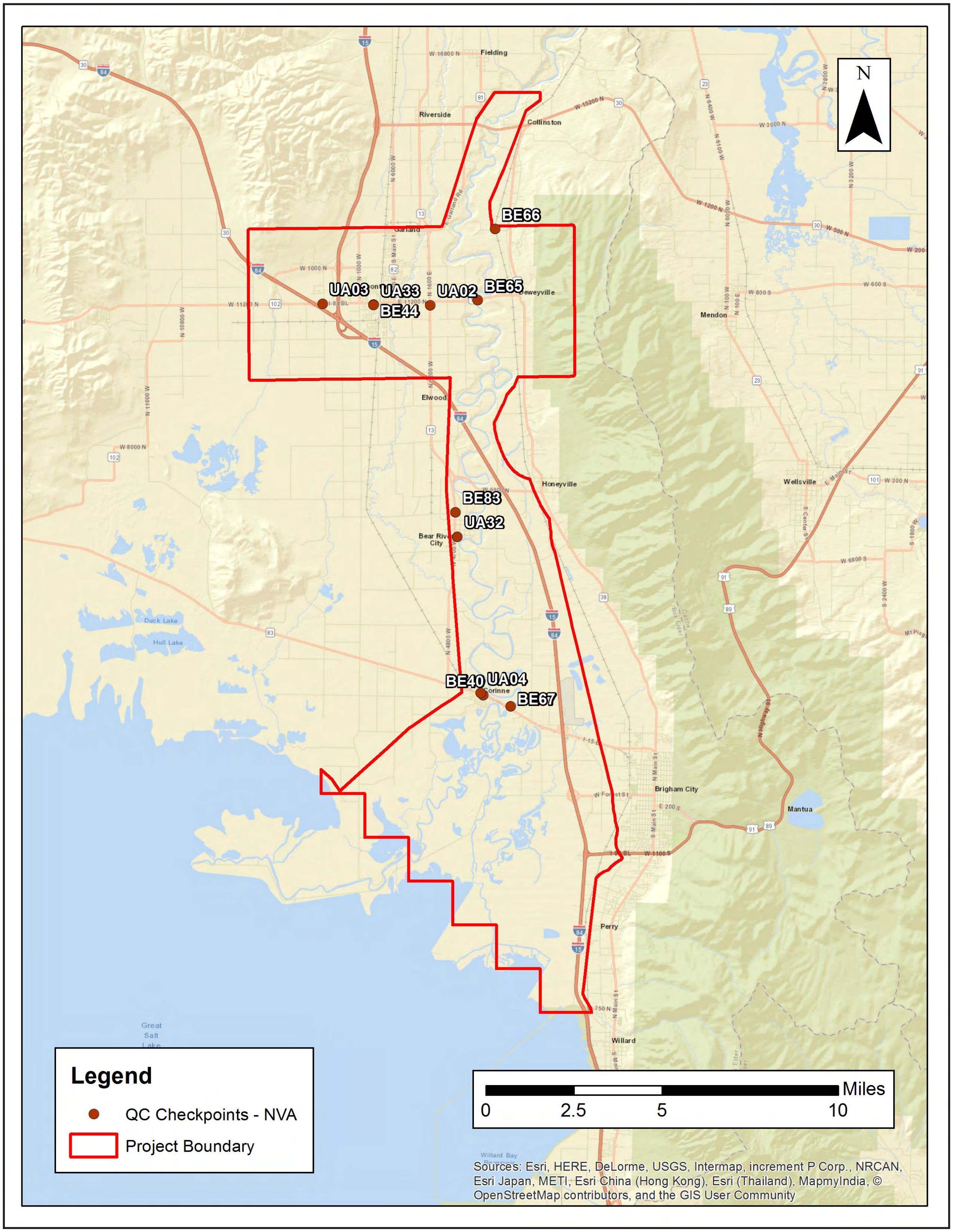


Figure 31. QC Checkpoint Locations - NVA - Cache Valley

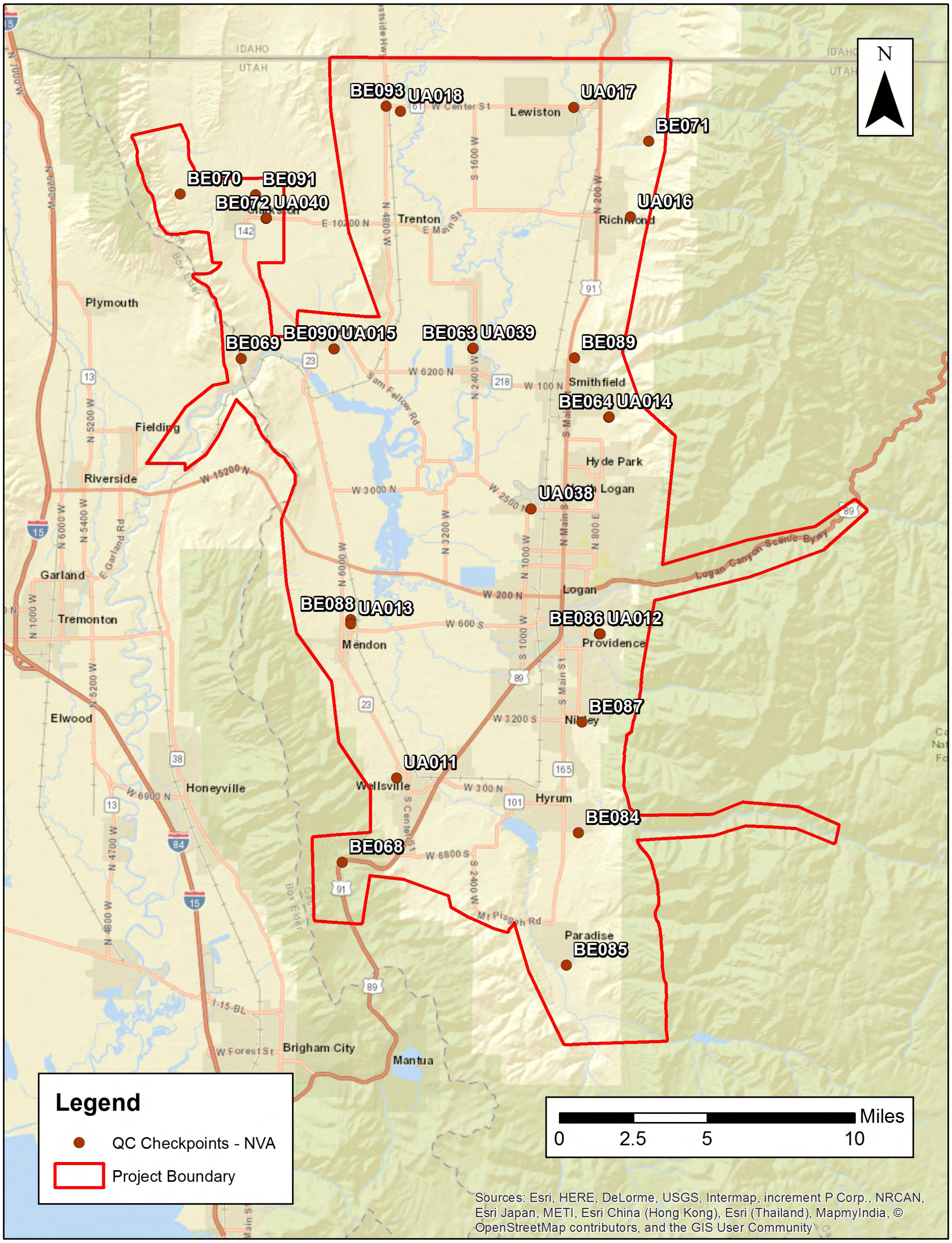


Figure 32. QC Checkpoint Locations - NVA - Minidoka

Figure 33. QC Checkpoint Locations - NVA - Thomas Fork Unit

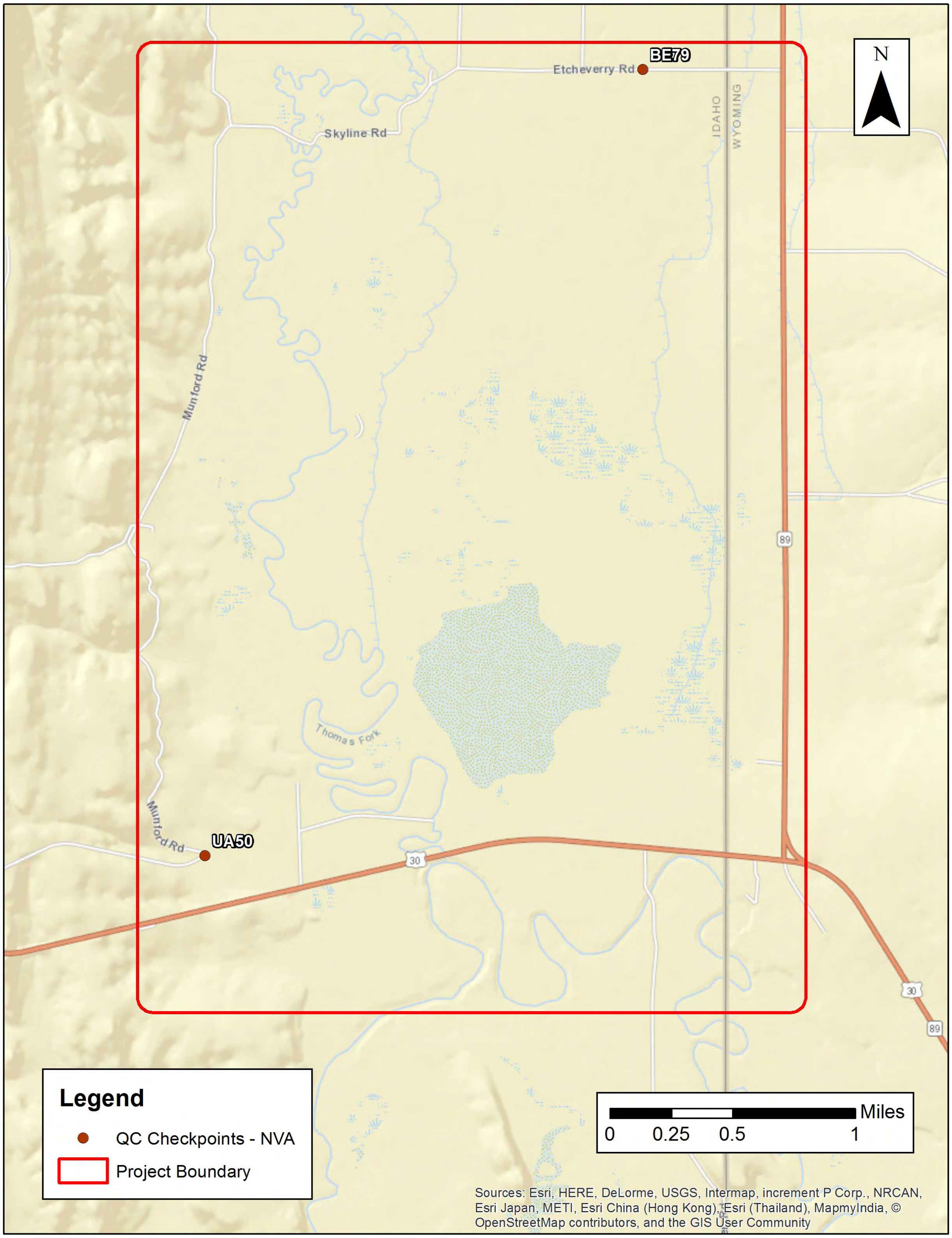


Figure 34. QC Checkpoint Locations - NVA - Weber Valley

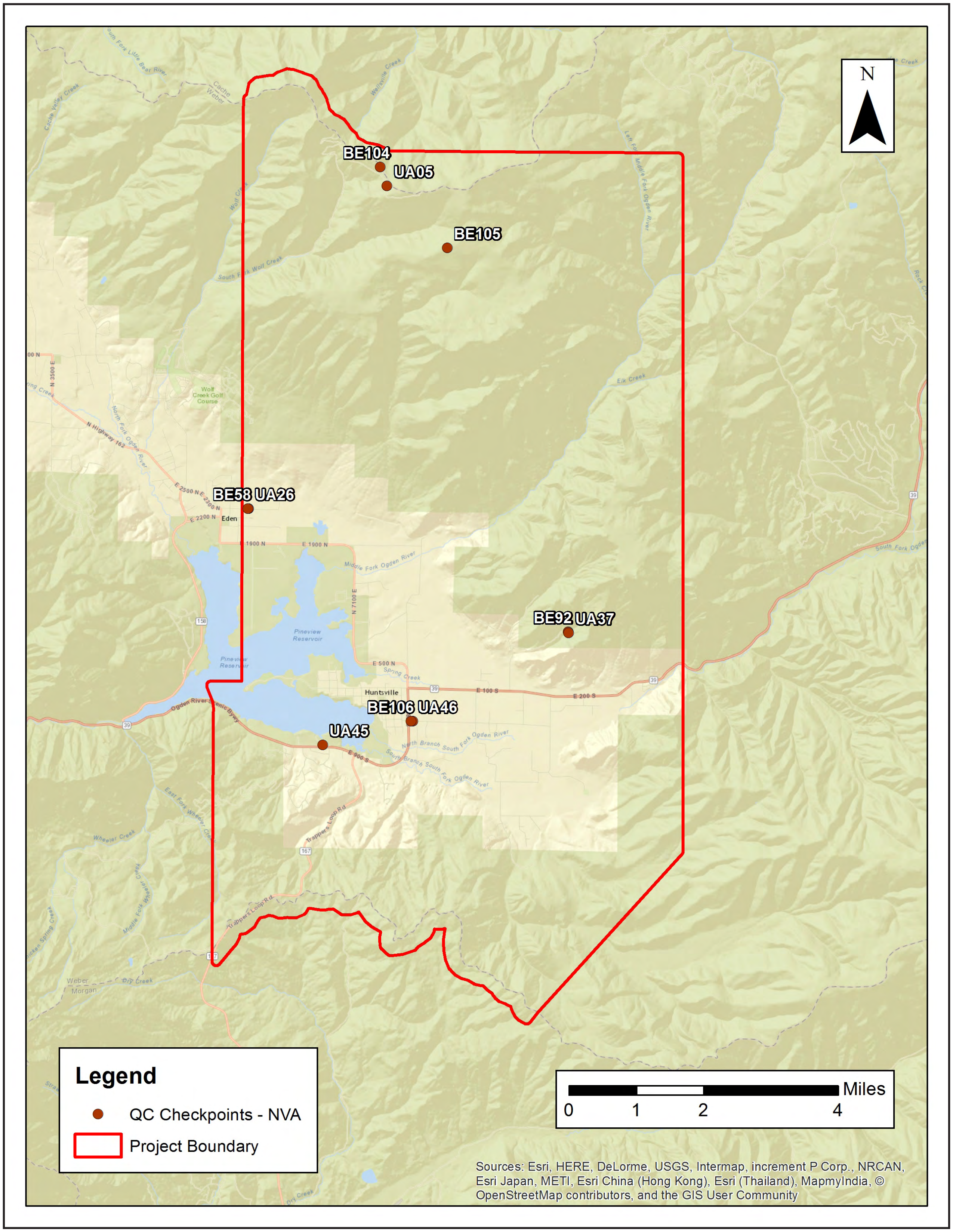


Figure 35. QC Checkpoint Locations - VVA - Bear Lake

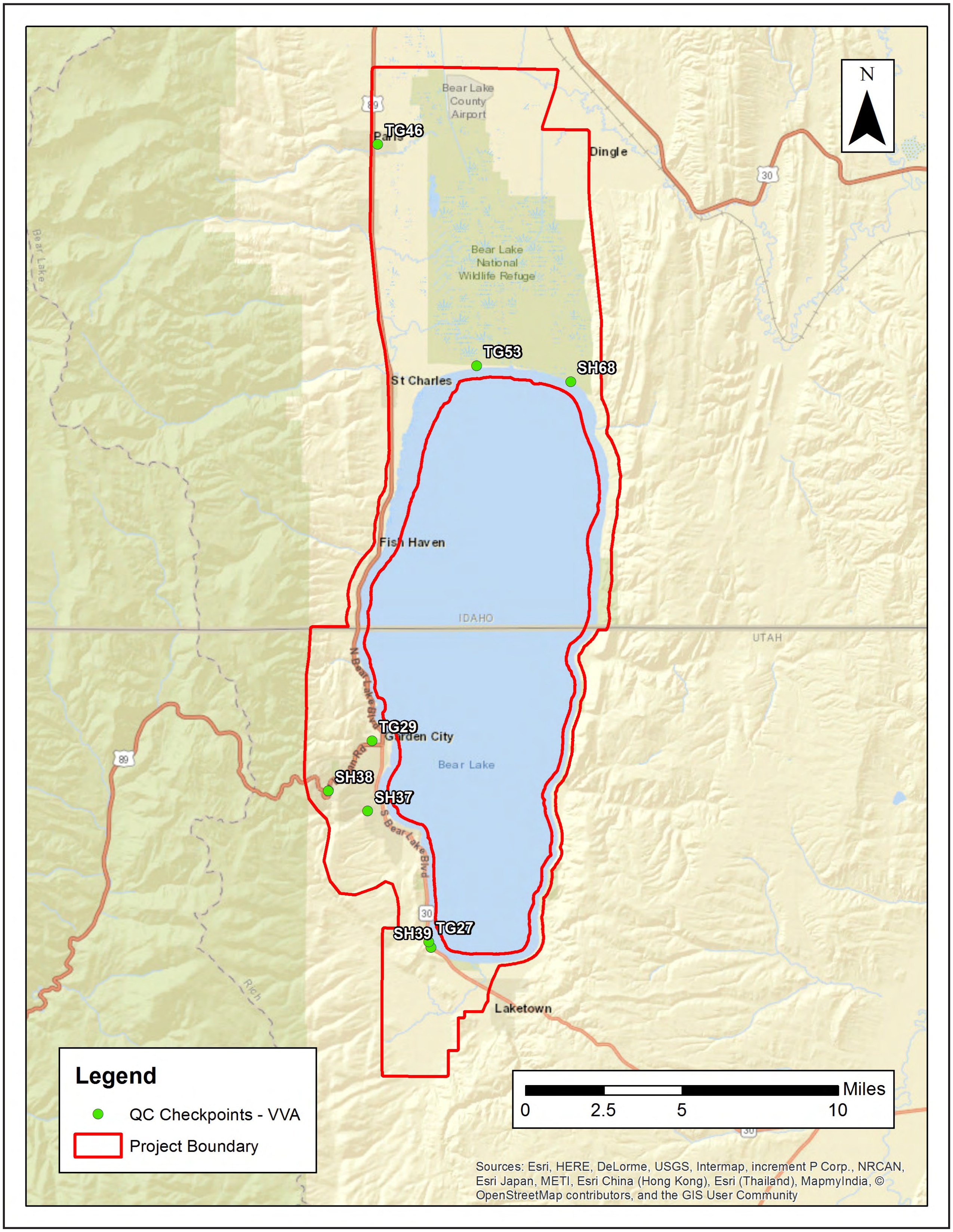


Figure 36. QC Checkpoint Locations - VVA - Bear River

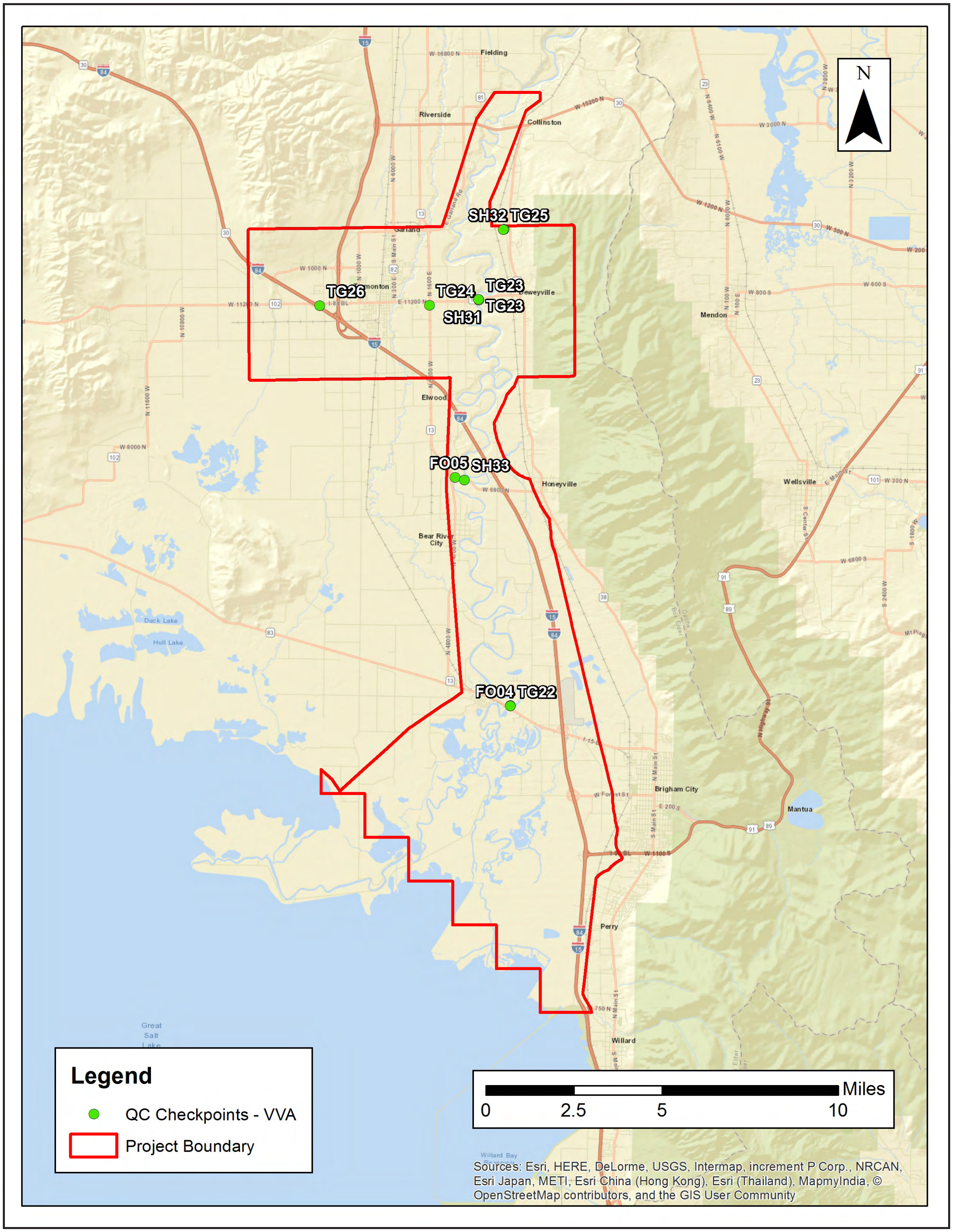


Figure 37. QC Checkpoint Locations - VVA - Cache Valley

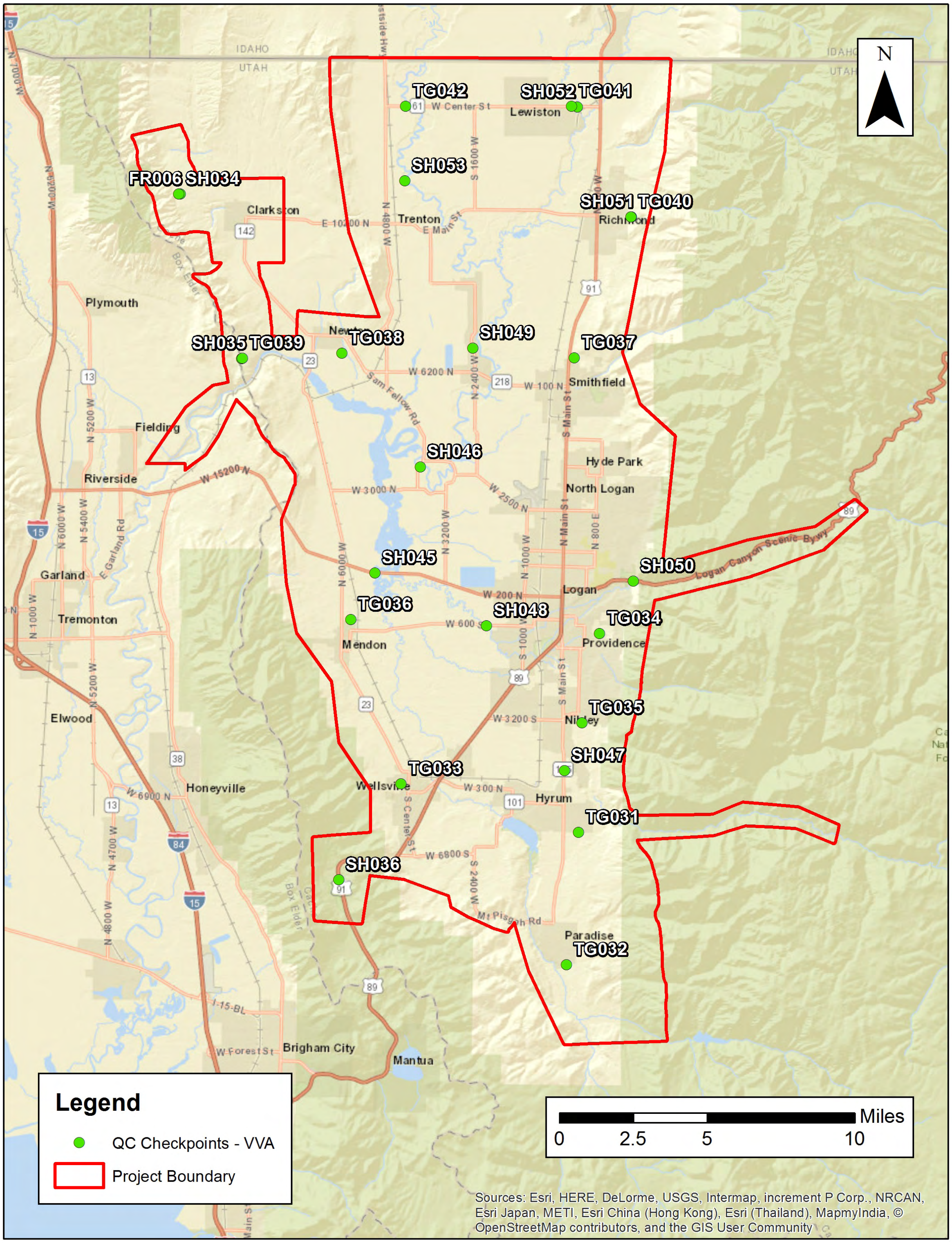


Figure 38. QC Checkpoint Locations - VVA - Minidoka

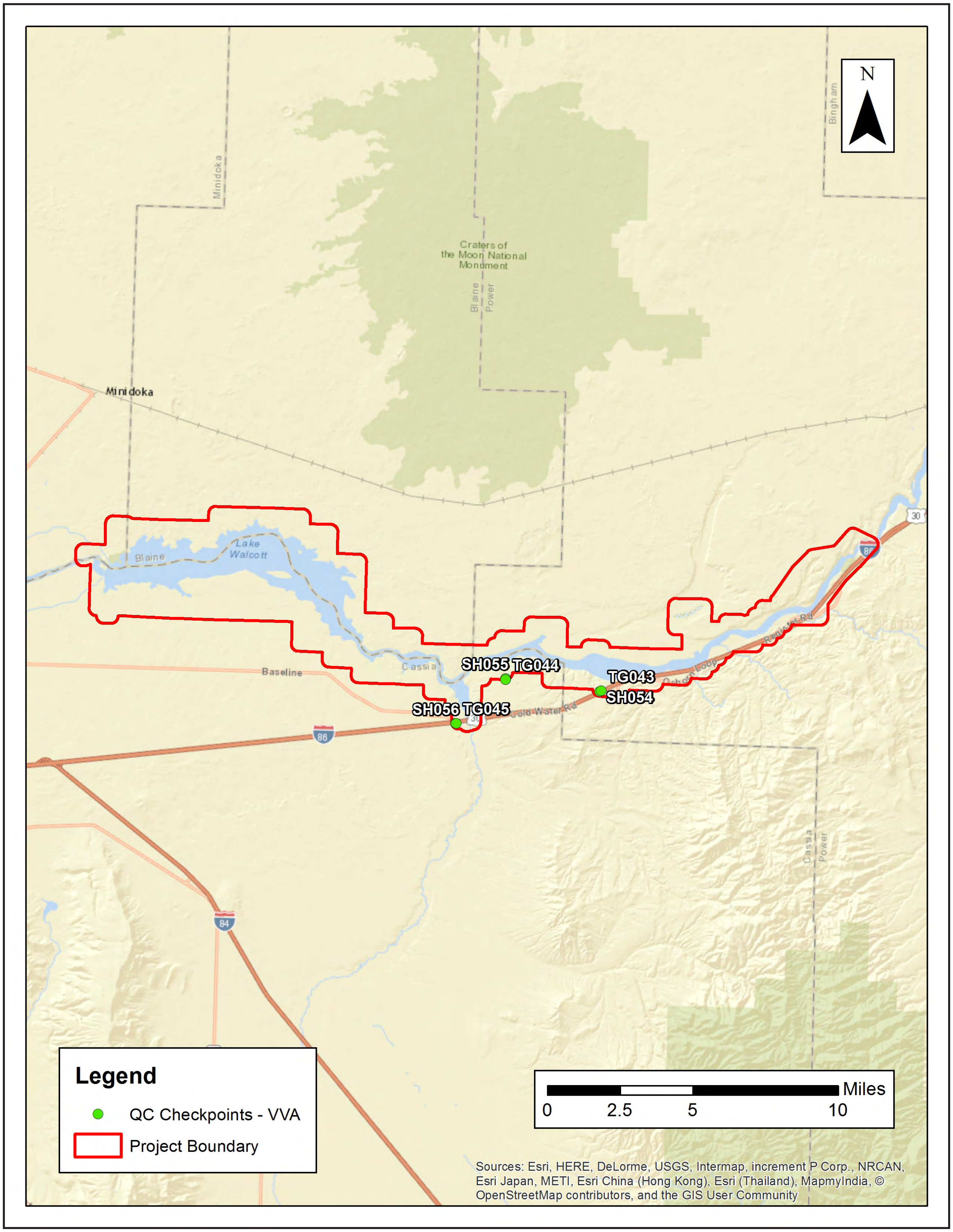


Figure 39. QC Checkpoint Locations - VVA - Thomas Fork Unit

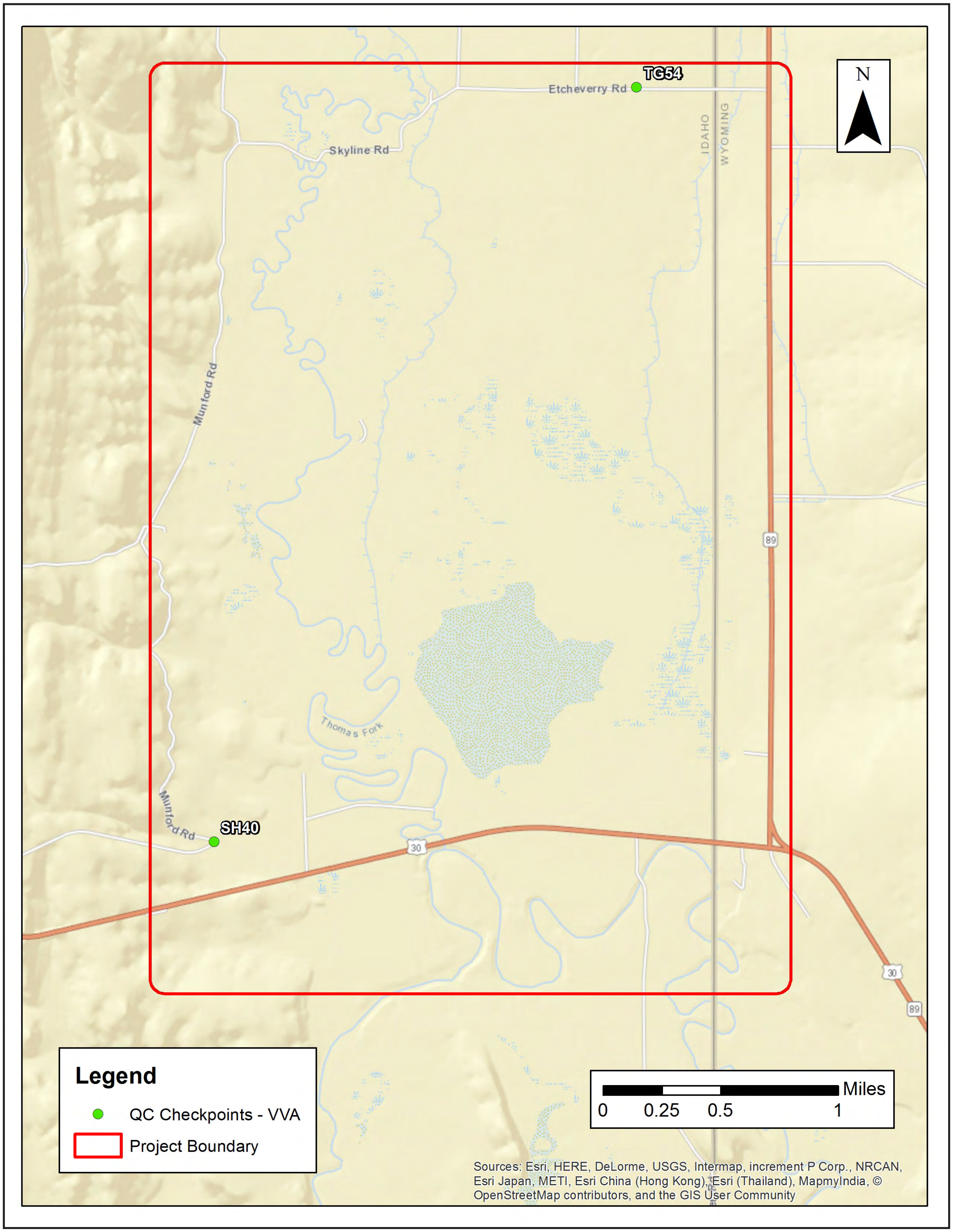


Figure 40. QC Checkpoint Locations - VVA - Weber Valley