AIRBORNE TOPOGRAPHIC LIDAR REPORT

CACHE OK QL2 LIDAR

Contract No. G10PC00026
Requisition No. 40183059
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1. SUMMARY / SCOPE

1.1. SUMMARY

This report contains a summary of the Cache, OK QL2 LiDAR acquisition task order, issued by USGS National Geospatial Technical Operations Center (NGTOC), under their Geospatial Product and Services Contract (GPSC) on November 19, 2014. The combined task orders yielded one study area covering 28 miles north and 33 miles south of Lawton, OK in the Cache Watershed. The intent of this document is to only provide specific validation information for the LiDAR data acquisition/collection work completed for the USGS NGTOC project.

1.2. SCOPE

The scope of the Cache, OK QL2 LiDAR task order included the acquisition of aerial topographic LiDAR using state of the art technology, along with necessary surveyed ground control points (GCPs) and airborne GPS and inertial navigation systems, for the Cache watershed. The aerial data collection was designed with the following specifications listed in Table 1 below.

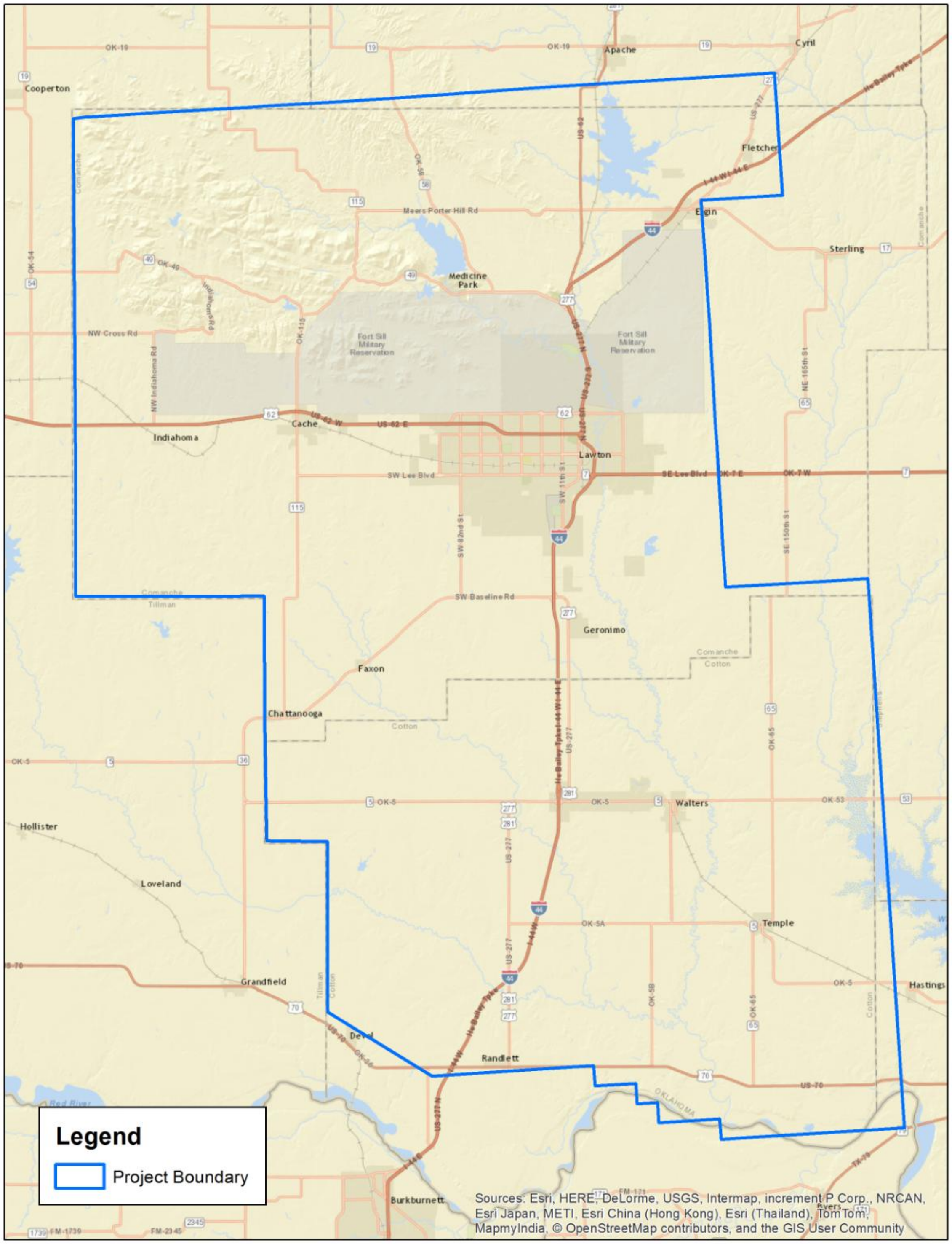
Table 1. Originally Planned LiDAR Specifications

Sensor ID	Average Point Density	Flight Altitude (AGL)	Field of View	Minimum Side Overlap	RMSEz
7161	2.45 pts / m^2	1,400 m	40.0 degrees	13.31%	9.25 cm or better
7170	4.91 pts / m^2	1,400 m	40.0 degrees	13.31%	9.25 cm or better
7178	2.46 pts / m^2	1,400 m	40.0 degrees	14.14%	9.25 cm or better

1.3. LOCATION / COVERAGE

The Cache, OK Q2 LiDAR project boundary consists of an area in Oklahoma. The project area totals approximately 1501 square miles as shown in Figure 1 on the following page.

Figure 1. Cache, OK Q2 LiDAR Project Boundary



1.4. Duration

The first mission was flown on December 8, 2014 and it took 15 total lifts to complete coverage of the area. See section 2.4 for more details.

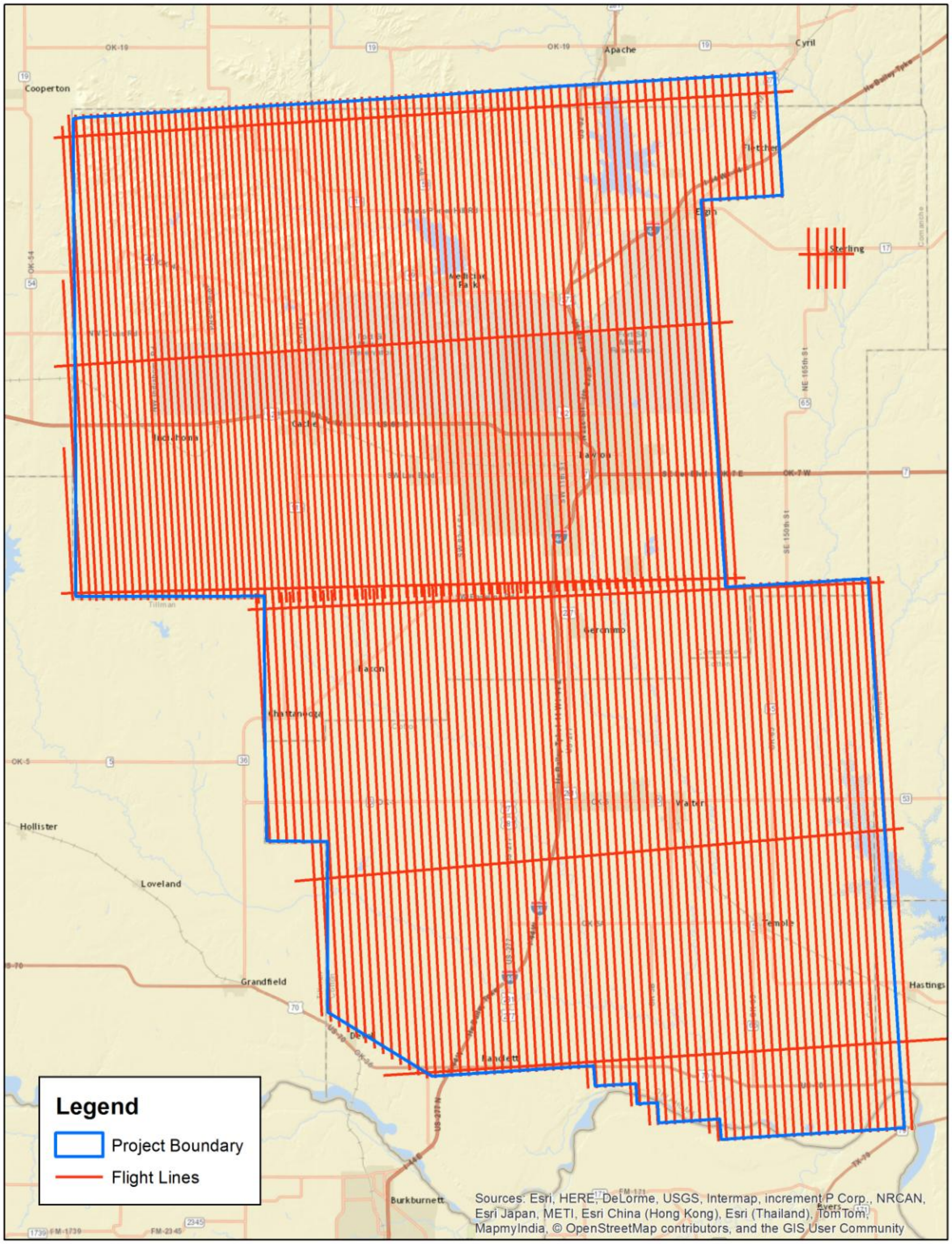
1.5. Issues

No issues encountered.

2. Planning / Equipment

The entire target area was comprised of 184 planned flight lines and approximately 6,921,007 flight line kilometers. Please refer to Figure 2 on the following pages.

Figure 2. Originally Planned Flight Lines



Detailed project flight planning calculations were performed for the Cache, OK QL2 project using the Leica Mission Pro planning software. Flight planning was based on the unique project requirements and characteristics of the project site. The basis of planning included: required accuracies, type of development, amount / type of vegetation within project area, required data posting, and potential altitude restrictions for flights in project vicinity. Please note that certain values in the table below are listed as "Variable" due to the various flight plans used, as described in Section 1.5 of this document. A brief summary of the aerial acquisition parameters for the project are shown in the LiDAR System Specification Table 2 below:

Table 2. LiDAR System Specifications for the Leica Sensors

		Leica 7160	Leica 7170	Leica 7178
Terrain and Aircraft	**Flying Height AGL:**	1400 m	1400 m	1056 – 1402 m
	Recommended Ground Speed (GS):	150 kts	150 kts	150 kts
Scanner	**Field of View (FOV):**	40º	40º	40º
	Scan Rate Setting used (SR):	53.4 Hz	53.4 Hz	34.6 Hz
Laser	**Laser Pulse Rate used:**	386,000 Hz	187,200 Hz	193,400 Hz
	Multi Pulse in Air Mode:	Enabled	Disabled	Disabled
Coverage	**Full Swath Width:**	1019.12 m	1019.12 m	1020.52 m
	Line Spacing:	245.42 m	245.42 m	659.95 m
Point Spacing and Density	**Maximum Point Spacing Across Track:**	0.62 m	1.23 m	1.12 m
	Maximum Point Spacing Along Track:	0.72 m	0.72 m	1.12 m
	Average Point Density:	4.91 pts / m^2	2.45 pts / m^2	2.46 pts / m^2

2.1. Equipment: Aircraft

All flights for the Cache, OK QL2 project were accomplished through the use of a customized Piper Navajo (twin piston) (Tail Number: N262AS, N22GE, and N73TN).This aircraft provided an ideal, stable aerial base for LiDAR acquisition. This aerial platform has relatively fast cruise speeds which are beneficial for project mobilization / demobilization while maintaining relatively slow stall speeds which proved ideal for collection of high-density, consistent data posting using a state-of-the-art Leica LiDAR system.

2.2. LiDAR Sensor

Quantum Spatial utilized three Leica LiDAR sensors during the project (see Figure 3), serial numbers 7161, 7170 and 7178. This 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.

Figure 3. Leica ALS70 LiDAR System

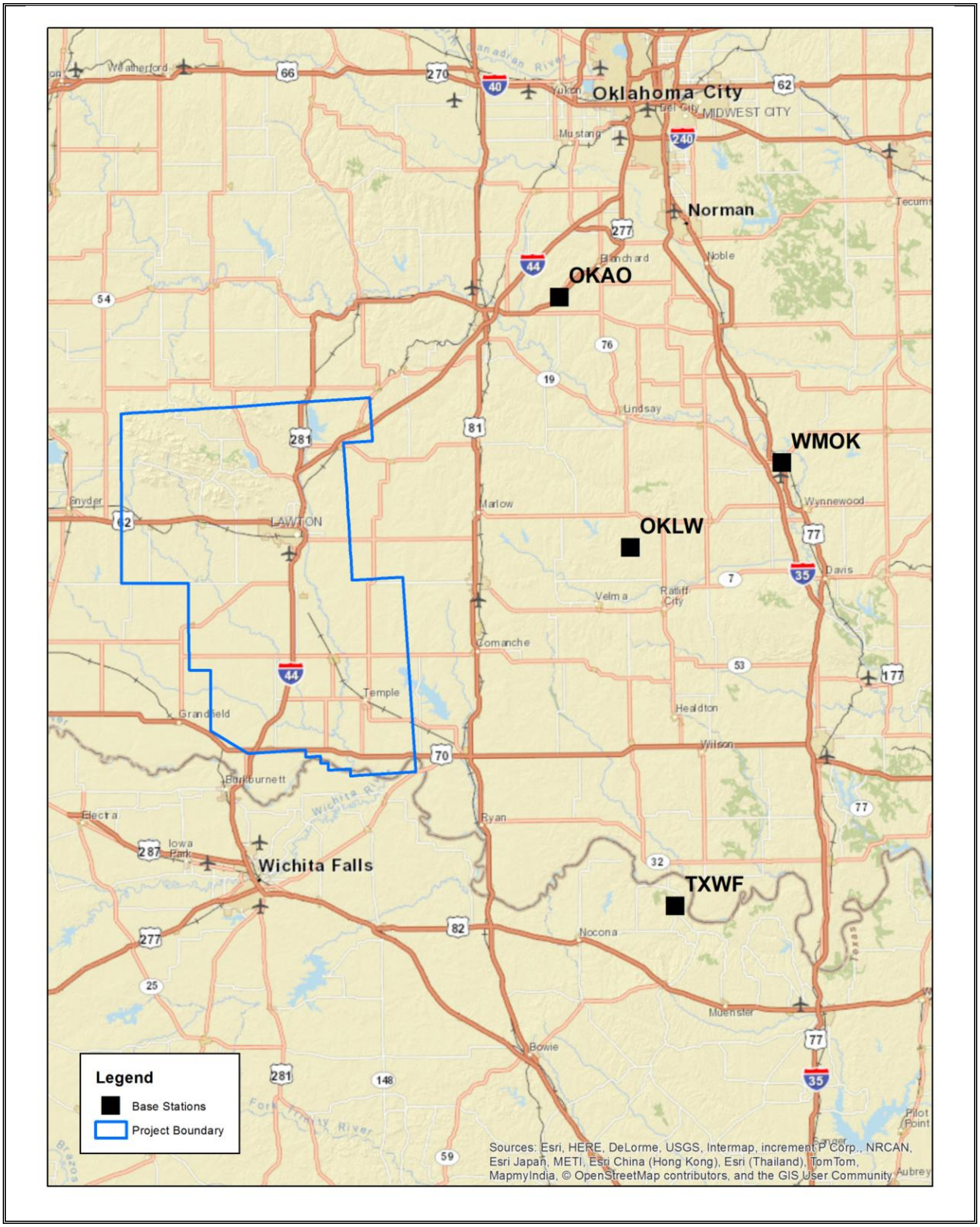
2.3. BASE STATION INFORMATION

GPS base stations were utilized during all phases of flight (see Table 3 below). The base station locations were verified using NGS OPUS service and subsequent surveys. Base Station locations can be seen in Figure 4.

Table 3. Base Station Locations

Base Station	Latitude	Longitude	Ellipsoid Height (m)
OKAO	35° 4' 35.04551"	98° 14' 45.20011"	340.446
OKLW	34° 34' 21.98746"	98° 24' 35.68905"	314.702
TXWF	33° 51' 14.10929"	98° 30' 19.96229"	281.316
WMOK	34° 44' 16.39683"	98° 46' 49.85402"	486.516

Figure 4. Base Station Locations



2.4. Time Period

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

- 20141208A_7178
- 20141209A_7178
- 20141210A_7178
- 20141214A_7178
- 20141215A_7170
- 20141215A_7178
- 20141215B_7178
- 20141216A_7178
- 20141216B_7178
- 20150115A_7161
- 20150116A_7161
- 20150116A_7170
- 20150116B_7161
- 20150116C_7161
- 20150117A_7161

3. Processing Summary

Applanix + POSPac Mobile Mapping Suite software was used for post-processing of airborne GPS and inertial data (IMU), which is critical to the positioning and orientation of the LiDAR sensor during all flights. POSPac combines aircraft raw trajectory data with stationary GPS base station data yielding a “Smoothed Best Estimate Trajectory (SBET) necessary for additional post processing software to develop the resulting geo-referenced point cloud from the LiDAR missions.

During the sensor trajectory processing (combining GPS & IMU datasets) certain statistical graphs and tables are generated within the Applanix POSPac processing environment which are commonly used as indicators of processing stability and accuracy. This data for analysis include: Max horizontal / vertical GPS variance, separation plot, altitude plot, PDOP plot, base station baseline length, processing mode, number of satellite vehicles, and mission trajectory. All relevant graphs produced in the POSPac processing environment for each sortie during the Quantum Spatial 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 ALS Post Processor 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 will manually be reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler. Global Mapper will be 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 will then be used to perform final statistical analysis of the classes in the LAS files.

Metadata was generated for the project on a deliverable level.

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. LAS Classification Scheme

The classification classes are determined by the USGS Version 1.0 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 – Noise – Low or high points, manually identified above or below the surface that could be noise points in point cloud.
- Class 9 – Inland 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 – Overlap Default (Unclassified) – Points found in the overlap between flight lines. These points are created through automated processing methods and not cleaned up during processing.
- Class 18 – Overlap Bare-earth ground – Points found in the overlap between flight lines. These points are created through automated processing, matching the specifications determined during the automated process, that are close to the Class 2 dataset (when analyzed using height from ground analysis)

- Class 25 – Overlap Water – Points found in the overlap between flight lines that are located inside hydro features. These points are created through automated processing methods and not cleaned up during processing.

3.3. Classified LAS Processing

The bare earth surface is then manually reviewed to ensure correct classification on the Class 2 (Ground) points. After the bare-earth surface is finalized; it is then used to generate all hydro-breaklines through heads-up digitization.

All ground (ASPRS Class 2) LiDAR data inside of the Lake Pond and Double Line Drain hydro flattening breaklines were then classified to water (ASPRS Class 9) using TerraScan macro functionality. A buffer of 1 meter was also used around each hydro flattened feature to classify these ground (ASPRS Class 2) points to Ignored ground (ASPRS Class 10). All Lake Pond Island and Double Line Drain Island features were checked to ensure that the ground (ASPRS Class 2) points were reclassified to the correct classification after the automated classification was completed.

All 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 to Class 17 (Overlap Default) and Class 18 (Overlap Ground). 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 is used as a final check of the bare earth dataset. GeoCue was then used to create the deliverable industry-standard LAS files for all point cloud data. Quantum Spatial 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.

3.4. Hydro Flattening Breakline Process

Class 2 LiDAR was used to create a bare earth surface model. The surface model was then used to heads-up digitize 2D breaklines of Inland Streams and Rivers with a 30 meter nominal width and Inland Ponds and Lakes of 2 acres or greater surface area.

Elevation values were assigned to all Inland Ponds and Lakes, Inland Pond and Lake Islands, Inland Streams and Rivers and Inland Stream and River Islands using TerraModeler functionality.

Elevation values were assigned to all Inland streams and rivers using Quantum Spatial proprietary software.

All ground (ASPRS Class 2) LiDAR data inside of the collected inland breaklines were then classified to water (ASPRS Class 9) using TerraScan macro functionality. A buffer of 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 Shapefile format using ESRI conversion tools.

3.5. HYDRO FLATTENING RASTER DEM PROCESS

Class 2 LiDAR in conjunction with the hydro breaklines were used to create a 1 meter Raster DEM. Using automated scripting routines within ArcMap, an ERDAS Imagine IMG file was created for each tile. Each surface is reviewed using Global Mapper to check for any surface anomalies or incorrect elevations found within the surface.

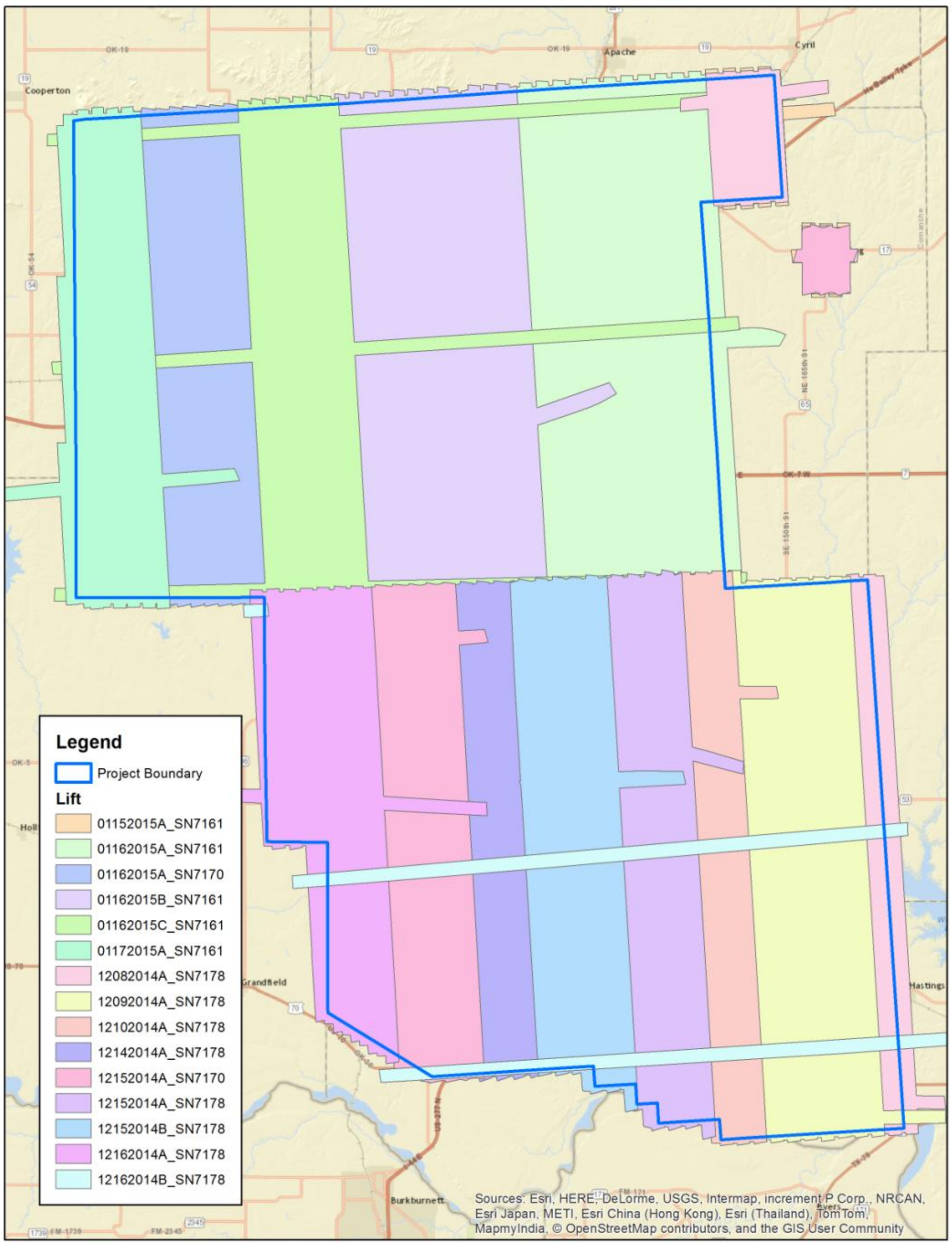
4. DELIVERABLES

- Calibrated, unclassified point cloud swath LAS in version 1.2 format
- Classified point cloud tiled LAS in version 1.2 format
- Hydro flattened raster DEM in ERDAS .IMG format
- Hydro flattened breaklines in shape file format
- Ground control points in shape file format
- Tile index in shape file format
- Project and deliverable level metadata in XML format
- Accuracy Assessment in XLS format
- FOCUS Report
- Delivery Lot Report
- Project Report

5. Project Coverage Verification

The Cache, OK QL2 project area 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



6. Ground Control and Check Point Collection

Quantum Spatial completed a field survey of 31 ground control (calibration) points along with 100 blind QA points in 3 different land cover classifications (total of 131 points) as an independent test of the accuracy of this project. The land cover classifications were selected from the dominant classifications for this project area. These included:

- Bare Earth and Low Grass
- Forested, fully covered by trees
- High Grass, Weeds, and Crops

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.

Figure 5 shows the location of each bare earth calibration point for the project area. Table 4 depicts the Control Report for the LiDAR bare earth calibration points shown in Figure 6, 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.

The project was delivered using the following horizontal projection(s): NAD83, UTM Zone 14, meters; NAVD88 (Geoid 12A), meters. In this document, horizontal coordinates for ground control and QA points for all LiDAR classes are reported in UTM Zone 14, meters.

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 1.0 (2012). The locations for all tested blind QA points are shown in Figure 7. The summary below provides the results of this testing:

Point Cloud Testing

- Raw Fundamental Vertical Accuracy (Raw FVA): The tested Raw FVA for the dataset was found to be 0.068 meters in terms of the RMSEz. The resulting FVA stated as the 95% confidence level (RMSEz x 1.96) is 0.133 meters. This dataset ***meets*** the required FVA of 18.13 cm at the 95% confidence level (according to the National Standard for Spatial Database Accuracy (NSSDA)), based on TINs derived from the final calibrated and controlled LiDAR swath data. This is summarized in Table 5.

Digital Elevation Model (DEM) Testing

- Fundamental Vertical Accuracy (FVA): The tested FVA for the dataset captured from the DEM using bi-linear interpolation to derive the DEM elevations was found to be 0.066 m in terms of the RMSEz. The resulting accuracy stated as the 95% confidence level (RMSEz x 1.96) is 0.129 m. This dataset ***meets*** the required FVA of 18.13 cm at the 95% confidence level (based on NSSDA). This is summarized in Table 6.

- Supplemental Vertical Accuracy (SVA): The tested SVA accuracies for the dataset for each of the land cover classes other than open ground are summarized below. These results are stated in terms of the 95th percentile error (based on ASPRS guidelines) for each of the land cover classes other than open ground.

  The following land cover classes were tested and the resulting 95th percentile error values are listed below:

  - Forested, Fully Covered by Trees: 0.152 m (Table 7)
  - High Grass, Weeds, and Crops: 0.203 m (Table 8)

- Consolidated Vertical Accuracy (CVA): The tested CVA for the dataset captured from the DEM using bi-linear interpolation for all classes (including the bare earth class) was found to be 0.177 m, which is stated in terms of the 95th percentile error. Therefore the data ***meets*** the required CVA of 36.3 cm. This test was based on the 95th percentile error (based on ASPRS guidelines) across <u>all</u> land cover categories

  This is also summarized in Table 9.

Figure 6. LiDAR Ground Control (Calibration) Points Used in Calibration

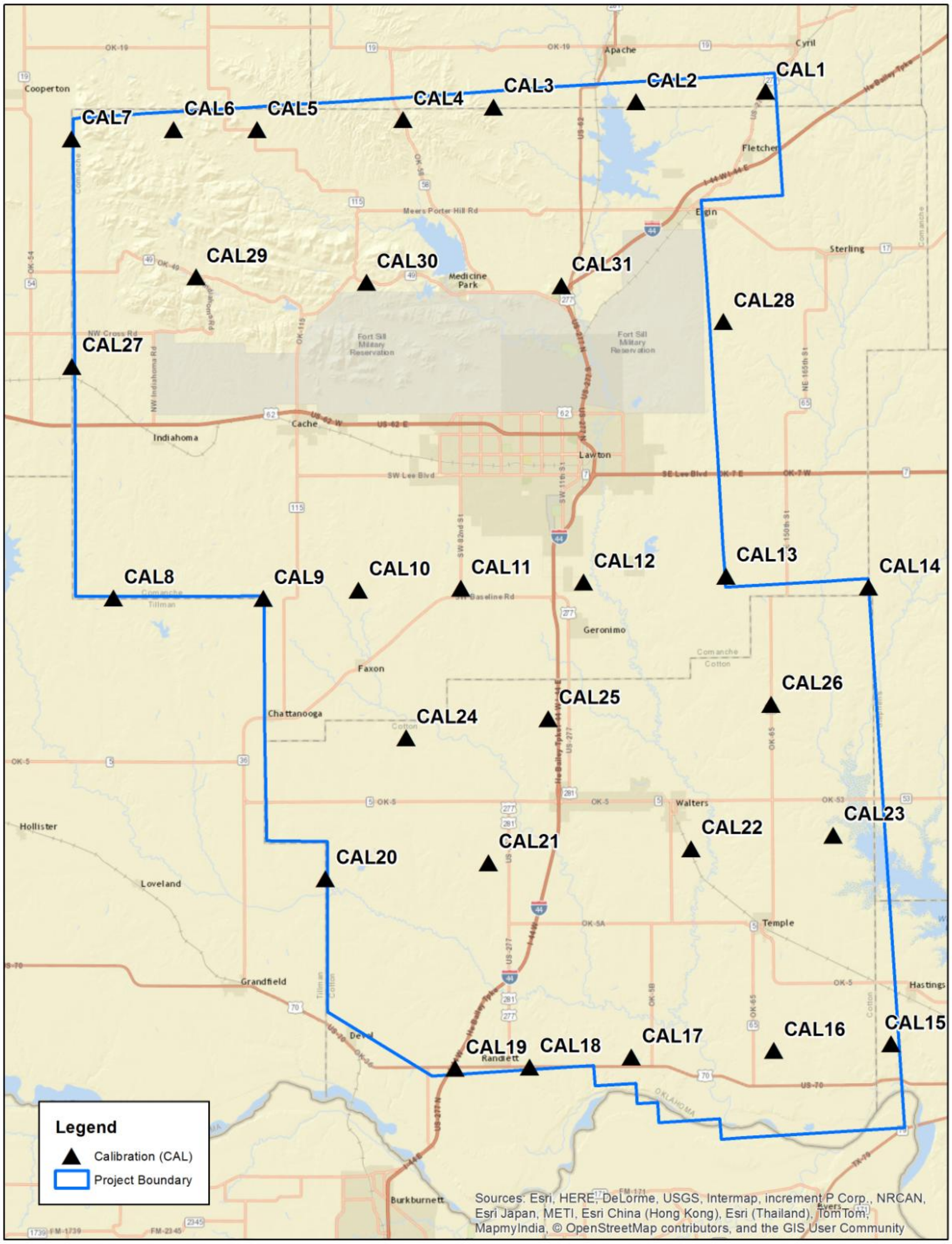


Figure 7. All Final LiDAR QA Point Locations

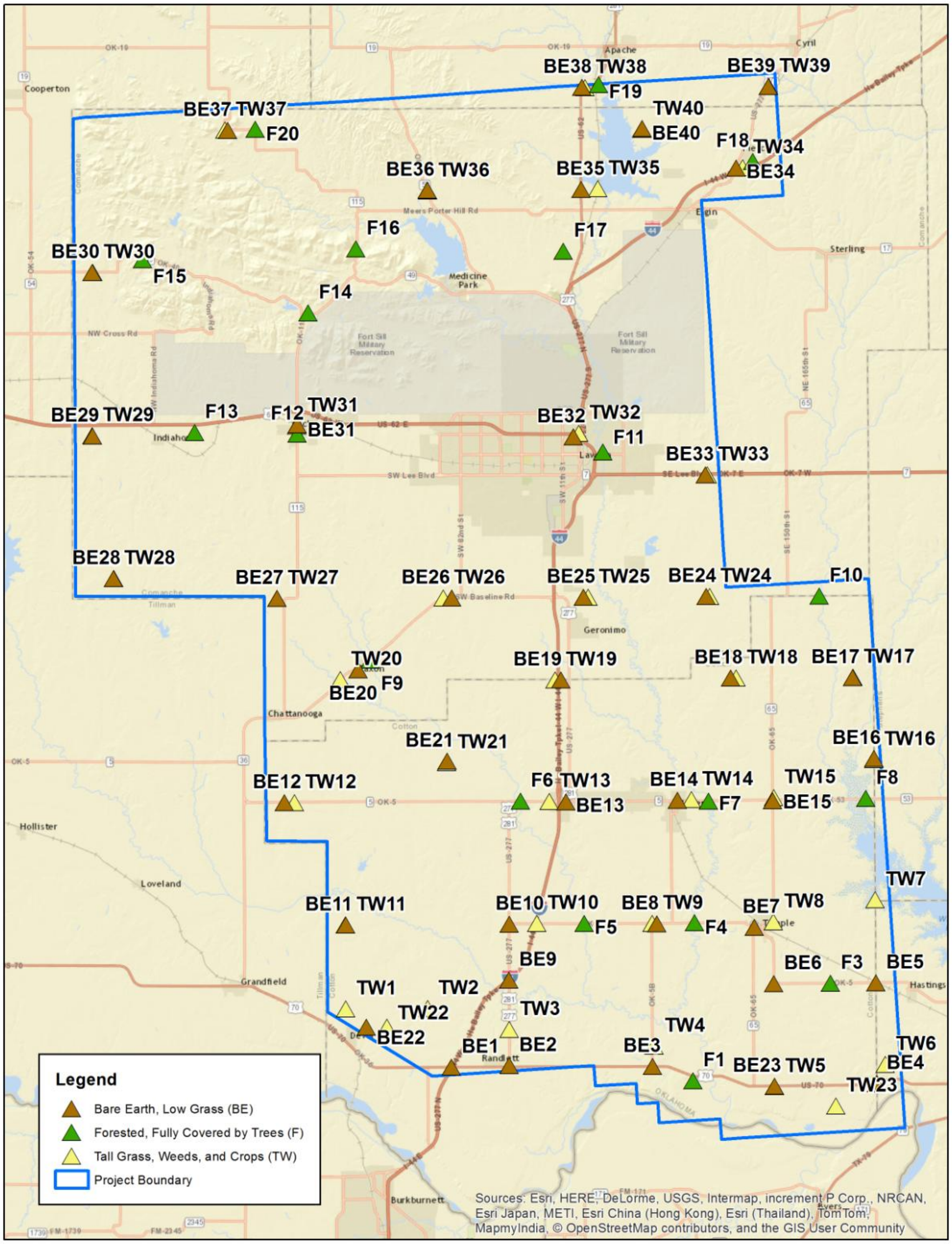


Figure 8. Bare Earth and Low Grass QA Point Locations

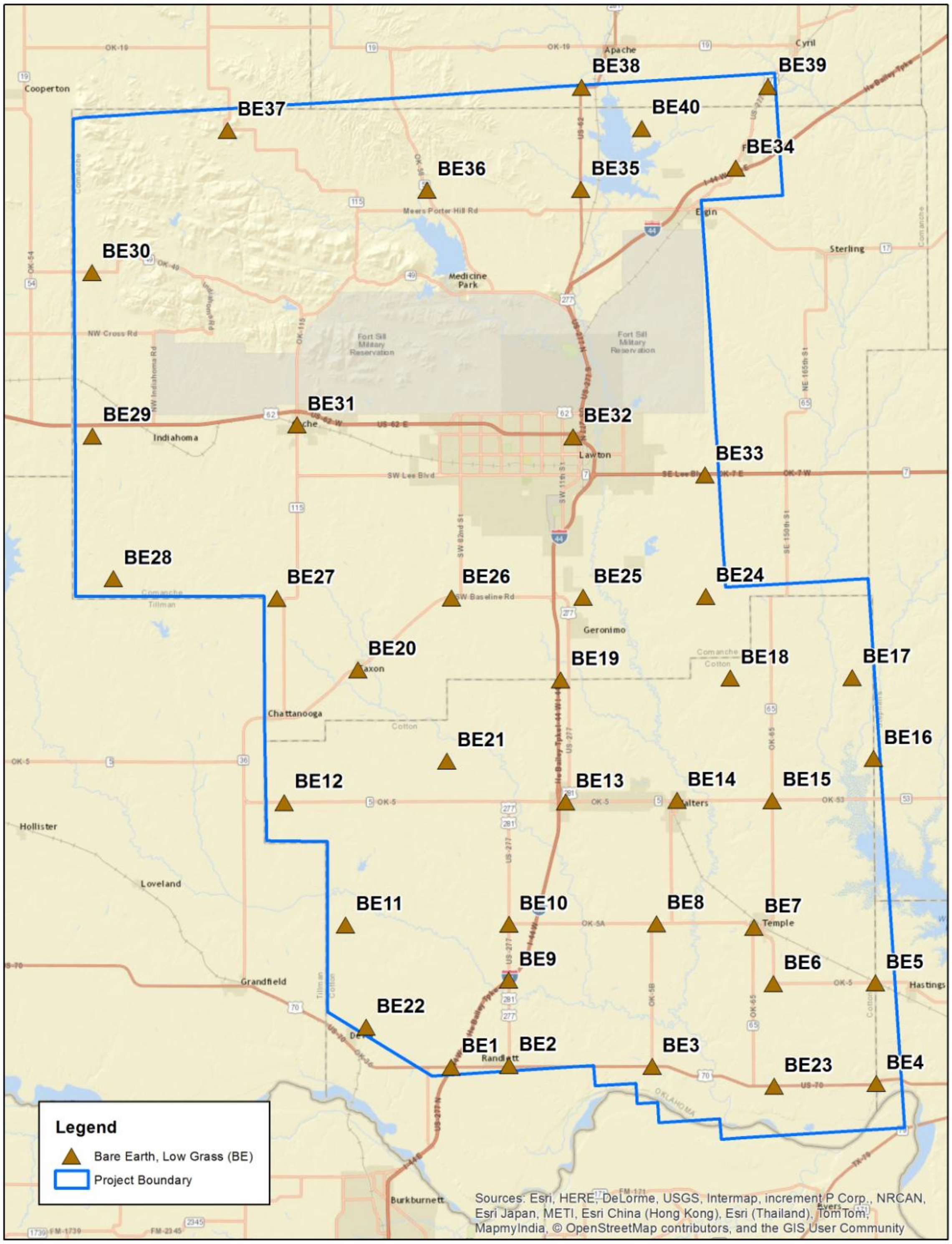


Figure 9. Forested, fully covered by trees QA Point Locations

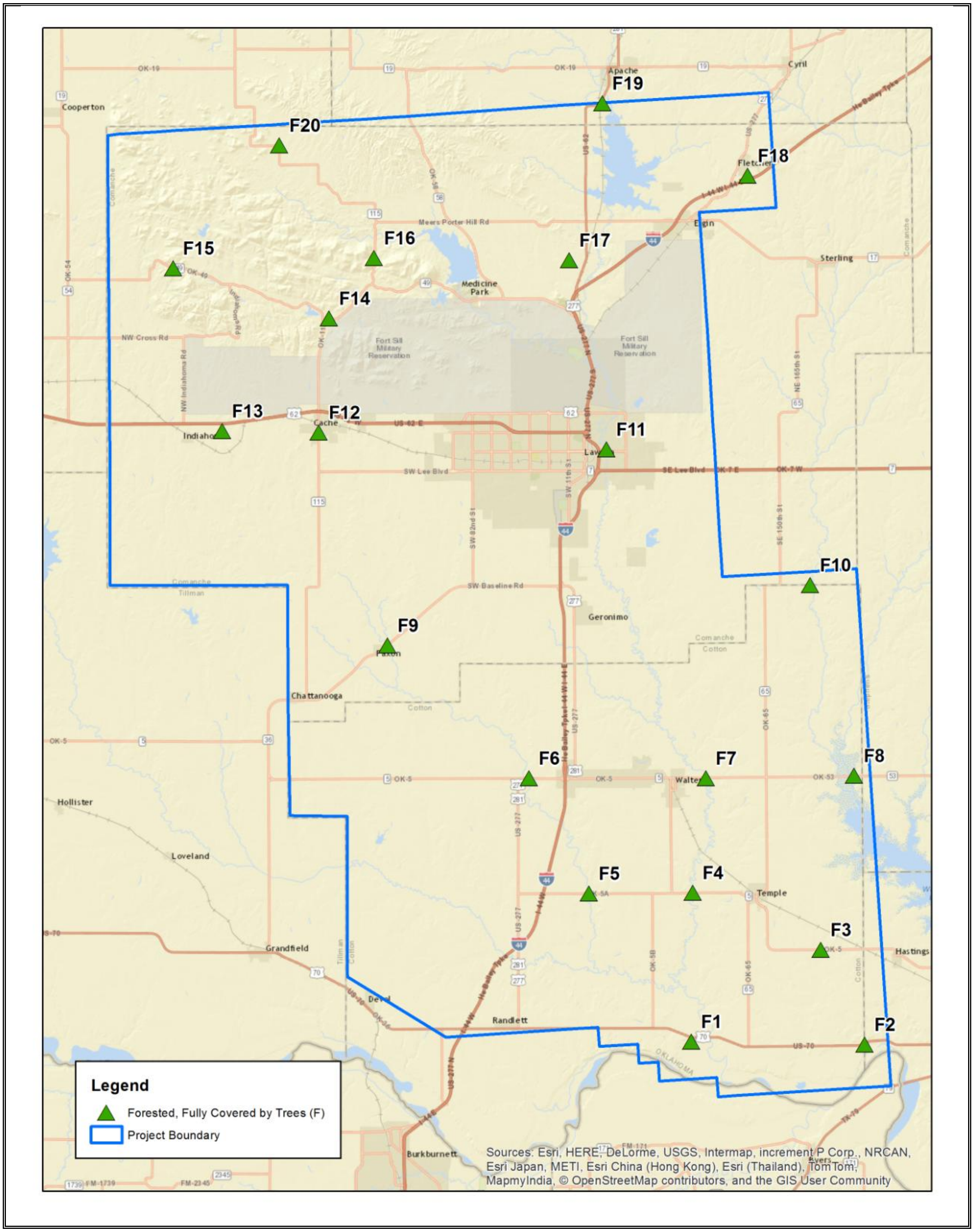


Figure 10. High Grass, Weeds, and Crops QA Point Locations

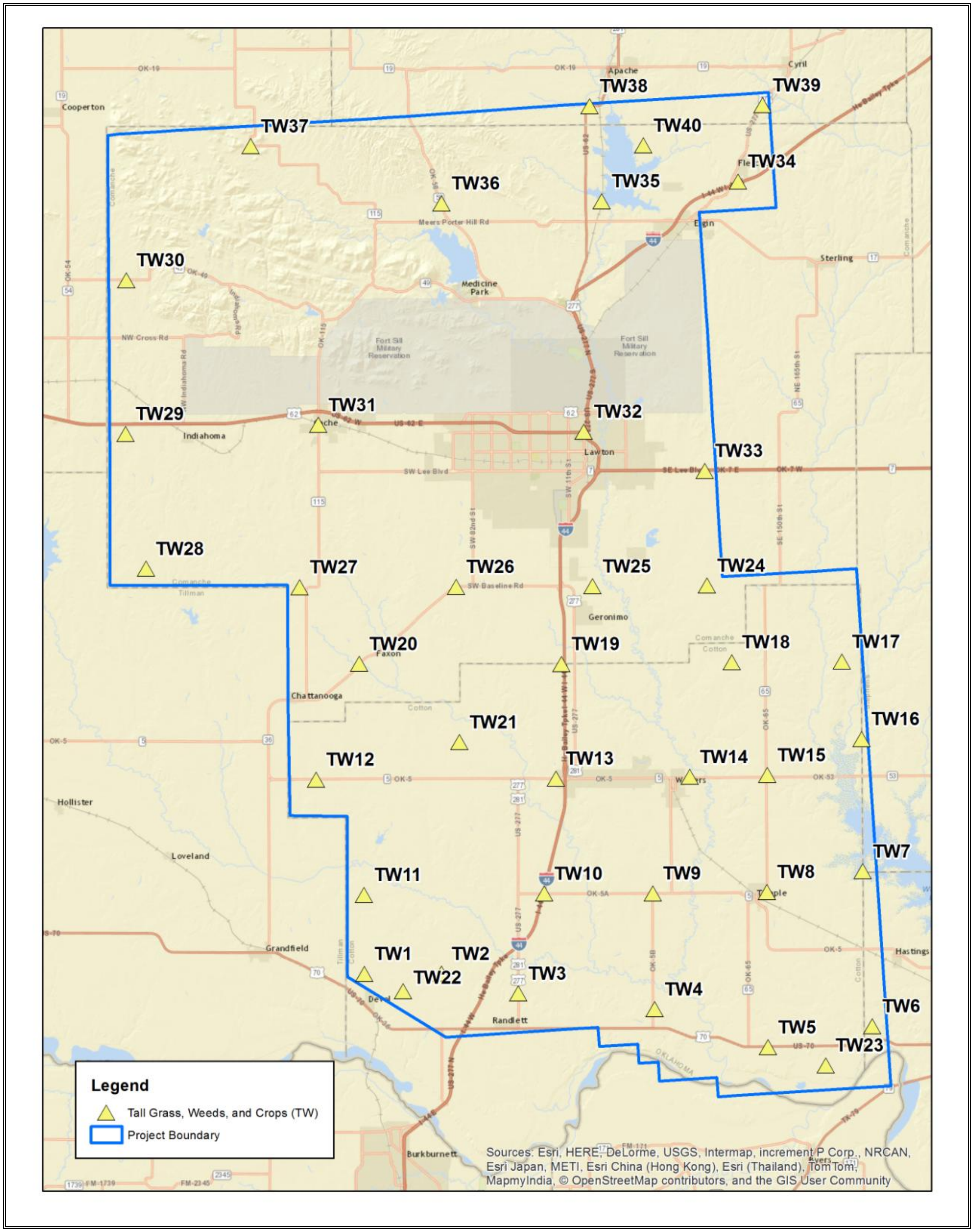


Table 4. LiDAR Ground Control Point Report (Units = Meters)

Number	Easting	Northing	Known Z	Laser Z	Dz
CAL1	570625.129	3858482.211	410.521	410.52	-0.001
CAL2	560412.356	3857629.068	400.516	400.52	0.004
CAL3	549162.796	3857216.436	449.059	449.07	0.011
CAL4	542035.469	3856220.62	493.647	493.68	0.033
CAL5	530514.936	3855427.013	518.401	518.42	0.019
CAL6	523961.385	3855436.693	541.829	541.84	0.011
CAL7	515895.454	3854707.747	492.121	492.15	0.029
CAL8	519205.87	3818514.733	381.969	382.04	0.071
CAL9	531026.771	3818479.837	362.175	362.22	0.045
CAL10	538523.599	3819140.965	338.335	338.36	0.025
CAL11	546585.178	3819287.163	343.876	343.84	-0.036
CAL12	556257.57	3819778.152	316.272	316.3	0.028
CAL13	567487.32	3820249.158	332.949	332.98	0.031
CAL14	578744.052	3819373.306	337.75	337.68	-0.07
CAL15	580510.784	3783381.783	289.012	288.96	-0.052
CAL16	571269.961	3782863.154	286.47	286.47	0
CAL17	560042.972	3782340.404	294.92	294.92	0
CAL18	552014.354	3781562.398	312.982	312.85	-0.132
CAL19	546151.221	3781454.961	320.738	320.68	-0.058
CAL20	535928.794	3796399.65	315.065	315.15	0.085
CAL21	548761.7	3797656.668	319.764	319.76	-0.004
CAL22	564749.039	3798759.08	301.741	301.77	0.029
CAL23	575963.746	3799837.003	314.89	314.85	-0.04
CAL24	542277.426	3807493.381	334.281	334.3	0.019
CAL25	553493.102	3809009.443	325.296	325.24	-0.056
CAL26	571059.803	3810142.021	331.283	331.26	-0.023
CAL27	515917.955	3836776.236	431.661	431.63	-0.031
CAL28	567291.299	3840316.342	352.784	352.84	0.056
CAL29	525717.39	3843827.181	515.343	515.39	0.047
CAL30	539159.365	3843404.677	488.826	488.78	-0.046
CAL31	554516.952	3843136.905	360.231	360.24	0.009

Average dz	**0.000 m**
Minimum dz	**-0.132 m**
Maximum dz	**0.085 m**
Root Mean Square	**0.045 m**
Std Deviation	**0.046 m**

Table 5. Raw FVA - Bare Earth and Low Grass QA – Unclassified Points (Units = Meters)

Number	Easting	Northing	Known Z	LiDAR Z	Dz
BE1	545830.14	3781563.27	319.65	319.71	0.07
BE2	550379.20	3781675.97	312.72	312.74	0.02
BE3	561674.71	3781599.50	302.50	302.54	0.04
BE4	579336.47	3780262.67	273.01	273.04	0.03
BE5	579283.47	3788181.92	311.69	311.69	0.00
BE6	571245.24	3788128.36	293.31	293.32	0.01
BE7	569711.59	3792576.80	305.98	306.00	0.02
BE8	562035.87	3792855.17	301.98	302.02	0.04
BE9	550356.57	3788400.79	298.67	298.72	0.06
BE10	550390.27	3792813.43	314.28	314.39	0.11
BE11	537508.42	3792756.38	316.68	316.76	0.08
BE12	532681.12	3802401.03	322.94	323.04	0.10
BE13	554846.75	3802449.69	316.44	316.48	0.04
BE14	563642.83	3802572.45	299.06	299.11	0.05
BE15	571149.38	3802561.07	325.11	325.12	0.01
BE16	579137.04	3805879.63	312.04	312.11	0.07
BE17	577459.15	3812264.29	321.81	321.80	-0.01
BE18	567849.93	3812219.72	333.15	333.20	0.05
BE19	554469.10	3812080.22	325.99	326.07	0.09
BE20	538479.85	3812871.86	338.13	338.27	0.14
BE21	545490.47	3805676.85	320.37	320.35	-0.02
BE22	539143.89	3784702.94	324.49	324.58	0.10
BE23	571290.88	3780039.00	287.14	287.19	0.06
BE24	565898.47	3818649.73	337.29	337.32	0.03
BE25	556249.69	3818583.81	327.30	327.36	0.06
BE26	545866.23	3818531.18	353.04	353.03	-0.01
BE27	532074.96	3818495.94	356.54	356.65	0.11
BE28	519210.06	3820046.45	382.64	382.75	0.11
BE29	517556.12	3831296.05	403.52	403.62	0.10
BE30	517509.23	3844178.47	484.38	484.46	0.08
BE31	533688.21	3832163.97	385.53	385.65	0.12
BE32	555455.40	3831236.87	343.85	343.93	0.08
BE33	565843.94	3828238.47	369.45	369.50	0.05
BE34	568261.56	3852413.31	418.92	418.99	0.07
BE35	556052.71	3850712.70	388.11	388.18	0.07
BE36	543945.69	3850666.03	437.53	437.57	0.04
BE37	528192.44	3855390.42	523.31	523.36	0.05
BE38	556118.90	3858773.99	388.88	388.92	0.044
BE39	570818.38	3858850.38	411.60	411.68	0.080
BE40	560846.19	3855530.57	381.94	381.99	0.055

Average dz	**0.06 m**
Minimum dz	**-0.017 m**
Maximum dz	**0.142 m**
Root Mean Square	**0.068 m**
95% Confidence	**0.133 m**

Table 6. FVA - Bare Earth and Low Grass QA – Derived DEMs Classified (Units = Meters)

Number	Easting	Northing	Known Z	LiDAR Z	Dz
BE1	545830.135	3781563.268	319.645	319.715	0.070
BE2	550379.201	3781675.971	312.721	312.735	0.014
BE3	561674.710	3781599.500	302.503	302.538	0.035
BE4	579336.466	3780262.668	273.008	273.043	0.035
BE5	579283.465	3788181.915	311.686	311.688	0.002
BE6	571245.243	3788128.357	293.311	293.334	0.023
BE7	569711.588	3792576.797	305.976	306.011	0.035
BE8	562035.870	3792855.172	301.983	302.015	0.032
BE9	550356.574	3788400.786	298.665	298.714	0.049
BE10	550390.274	3792813.432	314.281	314.369	0.088
BE11	537508.415	3792756.376	316.684	316.749	0.065
BE12	532681.120	3802401.027	322.944	323.036	0.092
BE13	554846.753	3802449.693	316.438	316.492	0.054
BE14	563642.834	3802572.454	299.061	299.110	0.049
BE15	571149.381	3802561.070	325.107	325.121	0.014
BE16	579137.044	3805879.627	312.042	312.101	0.059
BE17	577459.146	3812264.285	321.808	321.802	-0.006
BE18	567849.928	3812219.717	333.152	333.209	0.057
BE19	554469.101	3812080.218	325.985	326.064	0.079
BE20	538479.852	3812871.858	338.128	338.256	0.128
BE21	545490.472	3805676.851	320.367	320.359	-0.008
BE22	539143.887	3784702.936	324.485	324.585	0.100
BE23	571290.884	3780039.000	287.135	287.185	0.050
BE24	565898.467	3818649.727	337.286	337.329	0.043
BE25	556249.688	3818583.805	327.303	327.383	0.080
BE26	545866.233	3818531.175	353.039	353.036	-0.003
BE27	532074.961	3818495.935	356.541	356.635	0.094
BE28	519210.061	3820046.447	382.641	382.747	0.106
BE29	517556.119	3831296.054	403.519	403.623	0.104
BE30	517509.225	3844178.471	484.379	484.462	0.083
BE31	533688.208	3832163.971	385.530	385.643	0.113
BE32	555455.402	3831236.873	343.850	343.942	0.092
BE33	565843.941	3828238.466	369.452	369.504	0.052
BE34	568261.562	3852413.314	418.917	418.986	0.069
BE35	556052.706	3850712.701	388.113	388.171	0.058
BE36	543945.685	3850666.030	437.526	437.560	0.034
BE37	528192.438	3855390.417	523.314	523.358	0.044
BE38	556118.901	3858773.991	388.876	388.921	0.045
BE39	570818.384	3858850.382	411.600	411.673	0.073
BE40	560846.190	3855530.565	381.935	382.006	0.071

Average dz	**0.06 m**
Minimum dz	**-0.008 m**
Maximum dz	**0.128 m**
Root Mean Square	**0.066 m**
95% Confidence	**0.129 m**

Table 7. SVA Forested, Fully Covered by Trees QA – Derived DEMs (Units = Meters)

Number	Easting	Northing	Known Z	LiDAR Z	Dz
F1	564874.833	3780468.288	272.171	272.290	0.119
F2	579370.468	3780245.178	269.043	269.147	0.104
F3	575700.427	3788173.343	283.245	283.247	0.002
F4	564978.081	3792935.937	283.861	283.990	0.129
F5	556299.016	3792867.101	290.581	290.606	0.025
F6	551275.913	3802512.317	303.359	303.358	-0.001
F7	566097.229	3802515.874	294.569	294.682	0.113
F8	578484.639	3802724.205	293.004	293.052	0.048
F9	539447.690	3813618.386	327.925	328.055	-0.130
F10	574807.288	3818692.290	310.418	310.446	0.028
F11	557777.892	3830025.278	326.788	326.951	0.163
F12	533693.265	3831454.677	379.732	379.786	0.054
F13	525601.620	3831567.473	391.380	391.469	0.089
F14	534551.370	3840988.348	450.802	450.907	0.105
F15	521499.955	3845199.002	545.632	545.701	0.068
F16	538315.364	3846045.534	482.814	482.792	-0.022
F17	554661.869	3845869.979	362.800	362.898	0.098
F18	569594.289	3852936.089	410.269	410.356	0.087
F19	557440.106	3858997.739	377.659	377.780	0.121
F20	530390.333	3855467.375	518.745	518.897	0.152

Average dz	**0.07 m**
Minimum dz	**-0.130 m**
Maximum dz	**0.163**
Root Mean Square	**0.096 m**
95th Percentile	**0.152 m**

Table 8. SVA High Grass/Weeds/Crops QA – Derived DEMs (Units = Meters)

Number	Easting	Northing	Known Z	LiDAR Z	Dz
TW1	537515.151	3786144.995	334.967	335.134	0.167
TW2	543966.919	3786161.781	306.184	306.325	0.141
TW3	550380.613	3784511.932	312.320	312.379	0.059
TW4	561800.121	3783197.910	281.870	281.943	0.073
TW5	571284.538	3780017.061	286.935	287.111	0.176
TW6	580017.810	3781773.309	303.813	303.849	0.036
TW7	579226.091	3794730.502	292.788	292.913	0.125
TW8	571196.810	3793000.435	307.525	307.560	0.035
TW9	561644.968	3792880.711	297.706	297.766	0.060
TW10	552577.669	3792876.351	306.522	306.591	0.069
TW11	537483.093	3792758.974	317.131	317.184	0.053
TW12	533470.845	3802408.493	335.607	335.710	0.103
TW13	553534.977	3802488.560	320.205	320.277	0.072
TW14	564740.029	3802639.136	301.984	302.122	0.138
TW15	571250.214	3802780.749	324.251	324.334	0.083
TW16	579119.724	3805792.791	311.118	311.297	0.179
TW17	577470.614	3812267.165	322.444	322.505	0.061
TW18	568259.149	3812227.619	338.060	338.134	0.074
TW19	553998.862	3812082.014	327.728	327.831	0.103
TW20	537074.045	3812089.139	336.954	337.208	0.254
TW21	545477.458	3805533.703	318.344	318.473	0.129
TW22	540753.230	3784699.227	324.892	324.984	0.092
TW23	576120.123	3778498.096	267.303	267.366	0.063
TW24	566192.356	3818641.483	336.317	336.364	0.047
TW25	556619.936	3818572.566	323.804	323.934	0.130
TW26	545182.297	3818538.470	350.040	350.088	0.048
TW27	532092.426	3818508.325	356.190	356.332	0.142
TW28	519223.128	3820049.394	382.525	382.725	0.200
TW29	517529.621	3831319.450	404.036	404.151	0.115
TW30	517579.184	3844184.534	484.510	484.629	0.119
TW31	533646.868	3832075.199	384.311	384.438	0.127
TW32	555875.818	3831506.034	346.108	346.152	0.044
TW33	565993.430	3828238.537	373.093	373.184	0.091
TW34	568775.530	3852443.787	408.261	408.438	0.177
TW35	557374.405	3850786.622	378.633	378.821	0.188
TW36	543964.412	3850605.597	435.634	435.719	0.085
TW37	527994.494	3855402.491	519.442	519.561	0.119
TW38	556361.719	3858743.327	389.792	389.904	0.112
TW39	570844.436	3858827.447	410.728	410.983	0.255
TW40	560850.383	3855460.526	381.146	381.285	0.139

Average dz	**0.11 m**
Minimum dz	**0.035 m**
Maximum dz	**0.255 m**
Root Mean Square	**0.125 m**
95th Percentile	**0.203 m**

Table 9. CVA for the 3 Classified Land Cover Classes (Units = Meters)

Number	Easting	Northing	Known Z	LiDAR Z	Dz
BE1	545830.135	3781563.268	319.645	319.715	0.070
BE2	550379.201	3781675.971	312.721	312.735	0.014
BE3	561674.710	3781599.500	302.503	302.538	0.035
BE4	579336.466	3780262.668	273.008	273.043	0.035
BE5	579283.465	3788181.915	311.686	311.688	0.002
BE6	571245.243	3788128.357	293.311	293.334	0.023
BE7	569711.588	3792576.797	305.976	306.011	0.035
BE8	562035.870	3792855.172	301.983	302.015	0.032
BE9	550356.574	3788400.786	298.665	298.714	0.049
BE10	550390.274	3792813.432	314.281	314.369	0.088
BE11	537508.415	3792756.376	316.684	316.749	0.065
BE12	532681.120	3802401.027	322.944	323.036	0.092
BE13	554846.753	3802449.693	316.438	316.492	0.054
BE14	563642.834	3802572.454	299.061	299.110	0.049
BE15	571149.381	3802561.070	325.107	325.121	0.014
BE16	579137.044	3805879.627	312.042	312.101	0.059
BE17	577459.146	3812264.285	321.808	321.802	-0.006
BE18	567849.928	3812219.717	333.152	333.209	0.057
BE19	554469.101	3812080.218	325.985	326.064	0.079
BE20	538479.852	3812871.858	338.128	338.256	0.128
BE21	545490.472	3805676.851	320.367	320.359	-0.008
BE22	539143.887	3784702.936	324.485	324.585	0.100
BE23	571290.884	3780039.000	287.135	287.185	0.050
BE24	565898.467	3818649.727	337.286	337.329	0.043
BE25	556249.688	3818583.805	327.303	327.383	0.080
BE26	545866.233	3818531.175	353.039	353.036	-0.003
BE27	532074.961	3818495.935	356.541	356.635	0.094
BE28	519210.061	3820046.447	382.641	382.747	0.106
BE29	517556.119	3831296.054	403.519	403.623	0.104
BE30	517509.225	3844178.471	484.379	484.462	0.083
BE31	533688.208	3832163.971	385.530	385.643	0.113
BE32	555455.402	3831236.873	343.850	343.942	0.092
BE33	565843.941	3828238.466	369.452	369.504	0.052
BE34	568261.562	3852413.314	418.917	418.986	0.069
BE35	556052.706	3850712.701	388.113	388.171	0.058
BE36	543945.685	3850666.030	437.526	437.560	0.034
BE37	528192.438	3855390.417	523.314	523.358	0.044
BE38	556118.901	3858773.991	388.876	388.921	0.045
BE39	570818.384	3858850.382	411.600	411.673	0.073
BE40	560846.190	3855530.565	381.935	382.006	0.071
F1	564874.833	3780468.288	272.171	272.290	0.119
F2	579370.468	3780245.178	269.043	269.147	0.104
F3	575700.427	3788173.343	283.245	283.247	0.002
F4	564978.081	3792935.937	283.861	283.990	0.129
F5	556299.016	3792867.101	290.581	290.606	0.025
F6	551275.913	3802512.317	303.359	303.358	-0.001
F7	566097.229	3802515.874	294.569	294.682	0.113
F8	578484.639	3802724.205	293.004	293.052	0.048

Number	Easting	Northing	Known Z	LiDAR Z	Dz
F9	539447.690	3813618.386	327.925	328.055	-0.130
F10	574807.288	3818692.290	310.418	310.446	0.028
F11	557777.892	3830025.278	326.788	326.951	0.163
F12	533693.265	3831454.677	379.732	379.786	0.054
F13	525601.620	3831567.473	391.380	391.469	0.089
F14	534551.370	3840988.348	450.802	450.907	0.105
F15	521499.955	3845199.002	545.632	545.701	0.068
F16	538315.364	3846045.534	482.814	482.792	-0.022
F17	554661.869	3845869.979	362.800	362.898	0.098
F18	569594.289	3852936.089	410.269	410.356	0.087
F19	557440.106	3858997.739	377.659	377.780	0.121
F20	530390.333	3855467.375	518.745	518.897	0.152
TW1	537515.151	3786144.995	334.967	335.134	0.167
TW2	543966.919	3786161.781	306.184	306.325	0.141
TW3	550380.613	3784511.932	312.320	312.379	0.059
TW4	561800.121	3783197.910	281.870	281.943	0.073
TW5	571284.538	3780017.061	286.935	287.111	0.176
TW6	580017.810	3781773.309	303.813	303.849	0.036
TW7	579226.091	3794730.502	292.788	292.913	0.125
TW8	571196.810	3793000.435	307.525	307.560	0.035
TW9	561644.968	3792880.711	297.706	297.766	0.060
TW10	552577.669	3792876.351	306.522	306.591	0.069
TW11	537483.093	3792758.974	317.131	317.184	0.053
TW12	533470.845	3802408.493	335.607	335.710	0.103
TW13	553534.977	3802488.560	320.205	320.277	0.072
TW14	564740.029	3802639.136	301.984	302.122	0.138
TW15	571250.214	3802780.749	324.251	324.334	0.083
TW16	579119.724	3805792.791	311.118	311.297	0.179
TW17	577470.614	3812267.165	322.444	322.505	0.061
TW18	568259.149	3812227.619	338.060	338.134	0.074
TW19	553998.862	3812082.014	327.728	327.831	0.103
TW20	537074.045	3812089.139	336.954	337.208	0.254
TW21	545477.458	3805533.703	318.344	318.473	0.129
TW22	540753.230	3784699.227	324.892	324.984	0.092
TW23	576120.123	3778498.096	267.303	267.366	0.063
TW24	566192.356	3818641.483	336.317	336.364	0.047
TW25	556619.936	3818572.566	323.804	323.934	0.130
TW26	545182.297	3818538.470	350.040	350.088	0.048
TW27	532092.426	3818508.325	356.190	356.332	0.142
TW28	519223.128	3820049.394	382.525	382.725	0.200
TW29	517529.621	3831319.450	404.036	404.151	0.115
TW30	517579.184	3844184.534	484.510	484.629	0.119
TW31	533646.868	3832075.199	384.311	384.438	0.127
TW32	555875.818	3831506.034	346.108	346.152	0.044
TW33	565993.430	3828238.537	373.093	373.184	0.091
TW34	568775.530	3852443.787	408.261	408.438	0.177
TW35	557374.405	3850786.622	378.633	378.821	0.188
TW36	543964.412	3850605.597	435.634	435.719	0.085
TW37	527994.494	3855402.491	519.442	519.561	0.119
TW38	556361.719	3858743.327	389.792	389.904	0.112
TW39	570844.436	3858827.447	410.728	410.983	0.255

Number	Easting	Northing	Known Z	LiDAR Z	Dz
TW40	560850.383	3855460.526	381.146	381.285	0.139

Average dz	**0.08 m**
Minimum dz	**-0.130 m**
Maximum dz	**0.255 m**
Root Mean Square	**0.099 m**
95th Percentile	**0.177 m**