Utah 2016 - Washington County AOI QL2 LiDAR Project Report

Contract # AV2408

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1. Summary / Scope

1.1. Summary

This report contains a summary of the Utah 2016 - Washington County 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 7,536 square miles over western Utah and southern Idaho. The intent of this document is only to provide specific validation information for the data acquisition/collection work completed as specified in the task order.

1.2. Scope

Aerial topographic LiDAR was acquired using state of the art technology along with the necessary surveyed ground control points (GCPs) and airborne GPS and inertial navigation systems. The aerial data collection was designed with the following specifications listed in Table 1 below.

Table 1. Originally Planned LiDAR Specifications

Average Point Density	Flight Altitude (AGL)	Field of View	Minimum Side Overlap	RMSEz
2 pts / m^2	2,100 m	40°	30%	≤ 10 cm

1.3. Coverage

The total LiDAR project boundary covers approximately 7,536 square kilometers. This report focuses on the QL2 Washington County area of interest, which covers approximately 1,271 square kilometers. This AOI includes partial coverage of Washington County in southern Utah.

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

1.4. Duration

LiDAR data was acquired from January 8, 2017 to March 10, 2017 in nine total lifts. See "Section: 2.5. Time Period" for more details.

1.5. Issues

There were no issues to report with this project.

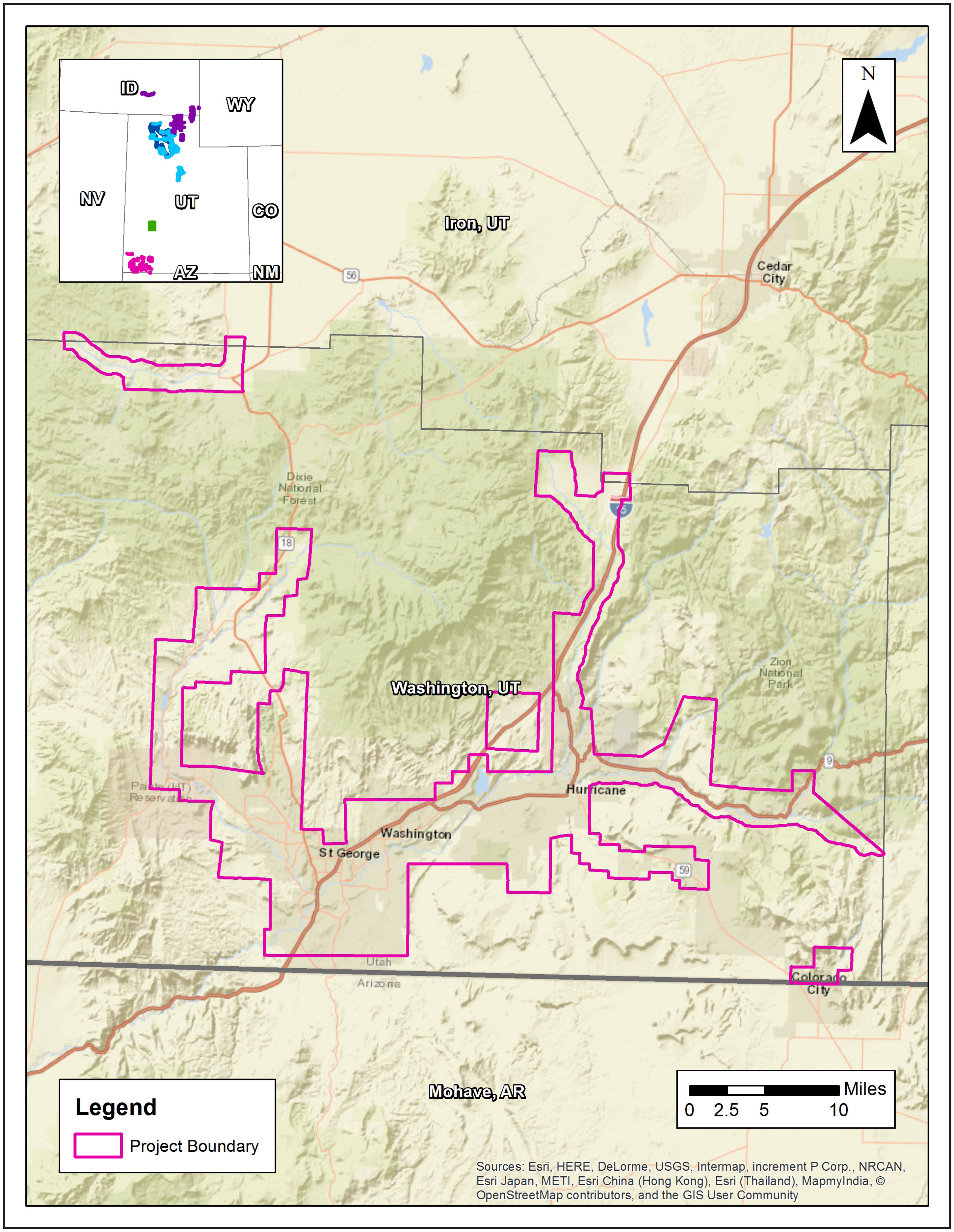
1.6. Deliverables

The following products were produced and delivered:

- Raw 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
- 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 (2011) 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



2. Planning / Equipment

2.1. Flight Planning

Flight planning was based on the unique project requirements and characteristics of the project site. The basis of planning included: required accuracies, type of development, amount / type of vegetation within project area, required data posting, and potential altitude restrictions for flights in project vicinity.

Detailed project flight planning calculations were performed for the project using Leica MissionPro planning software. The entire target area was comprised of 200 planned flight lines measuring approximately 1,751 total flight line miles (Figure 2).

2.2. LiDAR Sensor

Quantum Spatial utilized two Leica ALS 80 LiDAR sensors (Figure 3), serial numbers 8239 and 8121, during the project.

The Leica ALS 80 system is capable of collecting data at a maximum frequency of 1,000 kHz. The system utilizes a Multi-Pulse in the Air option (MPIA). The sensor is also equipped with the ability to measure up to 6 returns per outgoing pulse from the laser. The intensity of the returns is also captured during aerial acquisition.

A brief summary of the aerial acquisition parameters for the project are shown in the LiDAR System Specifications in Table 2.

Figure 2. Planned Flight Lines

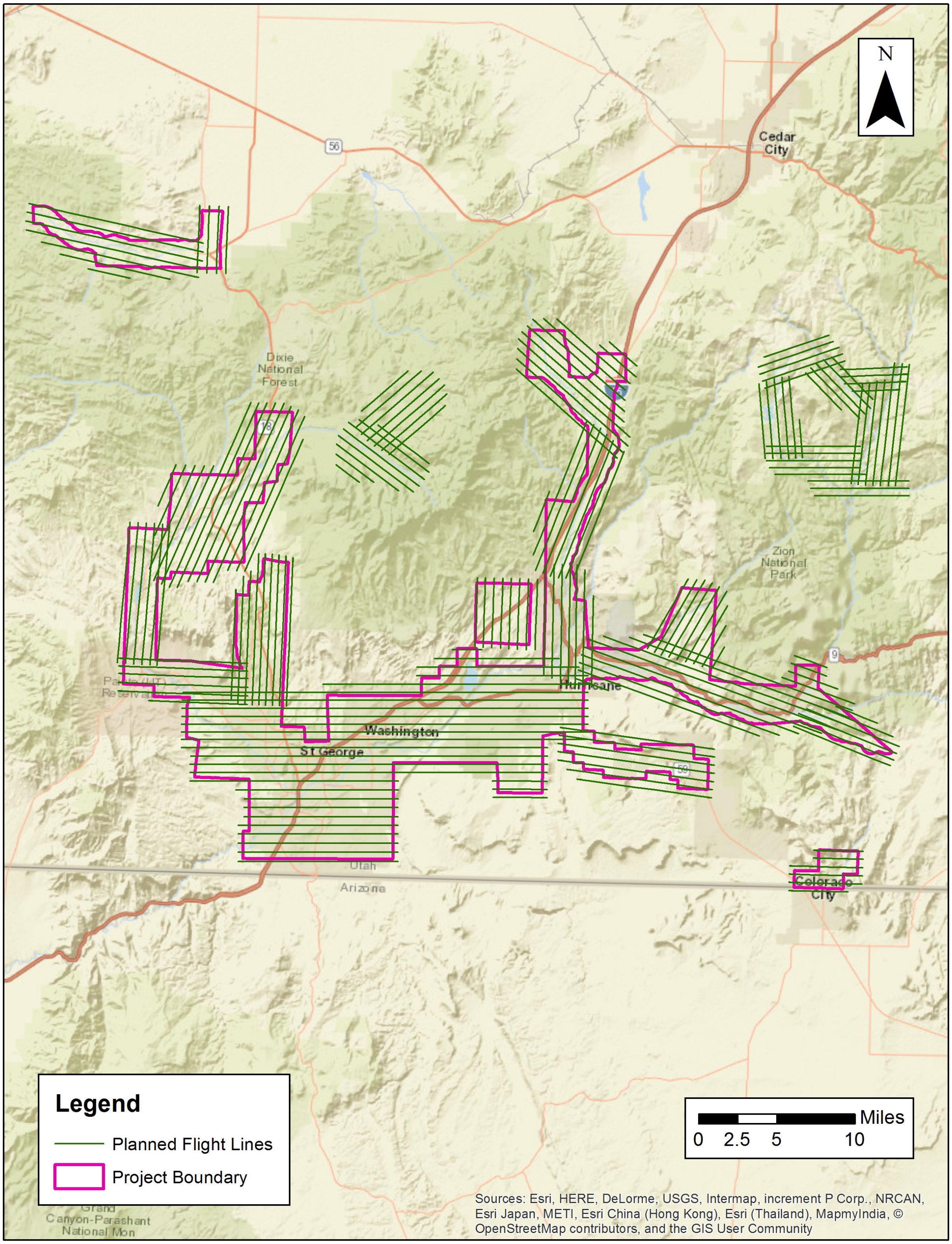


Table 2. Lidar System Specifications

		8121	8239
Terrain and Aircraft Scanner	Flying Height	2,100 m	2,100 m
	Recommended Ground Speed	110 kts	110 kts
Scanner	Field of View	38°	38°
	Scan Rate Setting Used	48.5 Hz	48.1 Hz
Laser	Laser Pulse Rate Used	263 kHz	253 kHz
	Multi Pulse in Air Mode	Enabled	Enabled
Coverage	Full Swath Width	1,446 m	1,446 m
Point Spacing and Density	Average Point Spacing	0.7 m	0.7 m
	Average Point Density	2 pts / m^2	2 pts / m^2

Figure 3. Leica ALS 80 LiDAR Sensor

2.3. Aircraft

All flights for the project were accomplished through the use of customized planes, two Cessna Caravan (single-turboprop) aircraft, Tail Numbers: N604MD and N704MD. These aircraft provided an ideal, stable aerial base for LiDAR and orthoimagery acquisition. These aerial platforms 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 systems. Some of Quantum Spatial's operating aircraft can be seen in Figure 4 below.

Figure 4. Some of Quantum Spatial's Planes

2.4. Base Station Information

GPS base stations were utilized during all phases of flight. The base station locations were verified using NGS OPUS service and subsequent surveys. Base station locations, data sheets, graphical depiction of base station locations or log sheets used during station occupation will be available in the final report

2.5. Time Period

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

- Jan 8, 2017-A (N604MD, SN8239)
- Jan 10, 2017-A (N604MD, SN8239)
- Jan 10, 2017-B (N604MD, SN8239)
- Jan 13, 2017-A (N604MD, SN8239)
- Jan 16, 2017-A (N208NR, SN8239)
- Jan 17, 2017-A (N208NR, SN8239)
- Mar 9, 2017-A (N704MD, SN8121)
- Mar 9, 2017-B (N704MD, SN8121)
- Mar 10, 2017-A (N704MD, SN8121)

3. Processing Summary

3.1. Flight Logs

Flight logs were completed by LIDAR sensor technicians for each mission during acquisition. These logs depict a variety of information, including:

- Job / Project #
- Flight Date / Lift Number
- FOV (Field of View)
- Scan Rate (HZ)
- Pulse Rate Frequency (Hz)
- Ground Speed
- Altitude
- Base Station
- PDOP avoidance times
- Flight Line #
- Flight Line Start and Stop Times
- Flight Line Altitude (AMSL)
- Heading
- Speed
- Returns
- Crab

Notes: (Visibility, winds, ride, weather, temperature, dew point, pressure, etc). Project specific flight logs for each sortie are available in Appendix A.

3.2. LiDAR Processing

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

During the sensor trajectory processing (combining GPS & IMU datasets) certain statistical graphs and tables are generated within the Inertial Explorer processing environment which are commonly used as indicators of processing stability and accuracy. This data for analysis include: Max horizontal / vertical GPS variance, separation plot, altitude plot, PDOP plot, base station baseline length, processing mode, number of satellite vehicles, and mission trajectory. All relevant graphs produced in the Inertial Explorer processing environment for each sortie during the project mobilization will be available in the full report.

The generated point cloud is the mathematical three dimensional composite of all returns from all laser pulses as determined from the aerial mission. Laser point data are imported into TerraScan and a manual calibration is performed to assess the system offsets for pitch, roll, heading and scale. At this point this data is ready for analysis, classification, and filtering to generate a bare earth surface model in which the above-ground features are removed from the data set. Point clouds were created using the Leica CloudPro software. GeoCue distributive processing software was used in the creation of some files needed in downstream processing, as well as in the tiling of the dataset into more manageable file sizes. TerraScan and TerraModeler software packages were then used for the automated data classification, manual cleanup, and bare earth generation. Project specific macros were developed to classify the ground and remove side overlap between parallel flight lines.

All data was manually reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler. Global Mapper was used as a final check of the bare earth dataset. GeoCue was used to create the deliverable industry-standard LAS files for both the All Point Cloud Data and the Bare Earth. In-house software was then used to perform final statistical analysis of the classes in the LAS files.

3.3. LAS Classification Scheme

The classification classes are determined by the USGS Version 1.2 specifications and are an industry standard for the classification of LIDAR point clouds. All data starts the process as Class 1 (Unclassified), and then through automated classification routines, the classifications are determined using TerraScan macro processing.

The classes used in the dataset are as follows and have the following descriptions:

- Class 1 – Processed, but Unclassified – These points would be the catch all for points that do not fit any of the other deliverable classes. This would cover features such as vegetation, cars, etc.
- Class 2 – Bare-Earth Ground – This is the bare earth surface
- Class 7 – Low Noise – Low points, manually identified below the surface that could be noise points in point cloud.
- Class 9 – In-land Water – Points found inside of inland lake/ponds
- Class 10 – Ignored Ground – Points found to be close to breakline features. Points are moved to this class from the Class 2 dataset. This class is ignored during the DEM creation process in order to provide smooth transition between the ground surface and hydro flattened surface.
- Class 17 – Bridge Decks – Points falling on bridge decks.
- Class 18 – High Noise – High points, manually identified above the surface that could be noise points in point cloud.

3.4. Classified LAS Processing

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

All ground (ASPRS Class 2) lidar data inside of the Lake Pond and Double Line Drain hydroflattened 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 LiDAR 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 DSM Processing

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

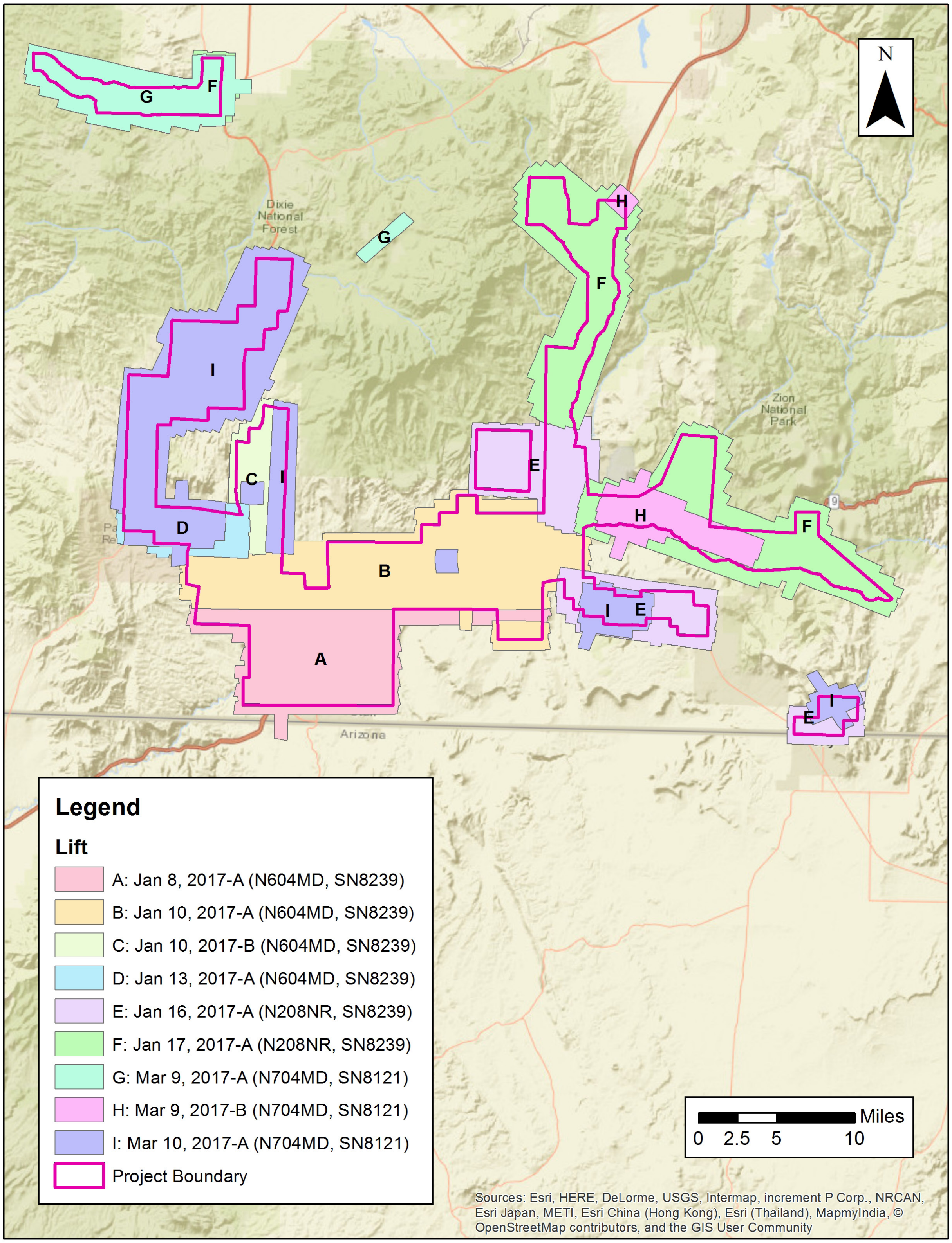
3.8. Intensity Image Processing

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 5.

Figure 5. Flightline Swath LAS File Coverage



5. Ground Control and Check Point Collection

Quantum Spatial completed a field survey of 117 ground control (calibration) points along with 38 blind QA points in Vegetated and Non-Vegetated land cover classifications (total of 155 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 (2011) UTM Zone 12, meters; NAVD88 (GEOID12B), meters.

5.1. Calibration Control Point Testing

Figure 6 shows the location of each bare earth calibration point for the project area. Table 3 depicts the Control Report for the LiDAR bare earth calibration points, as computed in TerraScan as a quality assurance check. Note that these results of the surface calibration are not an independent assessment of the accuracy of these project deliverables, but the statistical results do provide additional feedback as to the overall quality of the elevation surface.

5.2. Point Cloud Testing

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 28 checkpoints located in bare earth and urban (non-vegetated) areas. 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. See survey report for additional survey methodologies.

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 7 and Table 4.

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 28 checkpoints located in bare earth and urban (non-vegetated) areas. See Figure 8 and Table 5.

2. Vegetated Vertical Accuracy (VVA): VVA shall be reported for "forested", "brushlands/low trees" and "tall weeds/crops" 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 10 checkpoints located in forested, tall weeds/crops and brushlands/low trees (vegetated) areas. The checkpoints were distributed throughout the project area and were surveyed using GPS techniques. See Figure 9 and Table 6.

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.

Figure 6. Calibration Control Point Locations

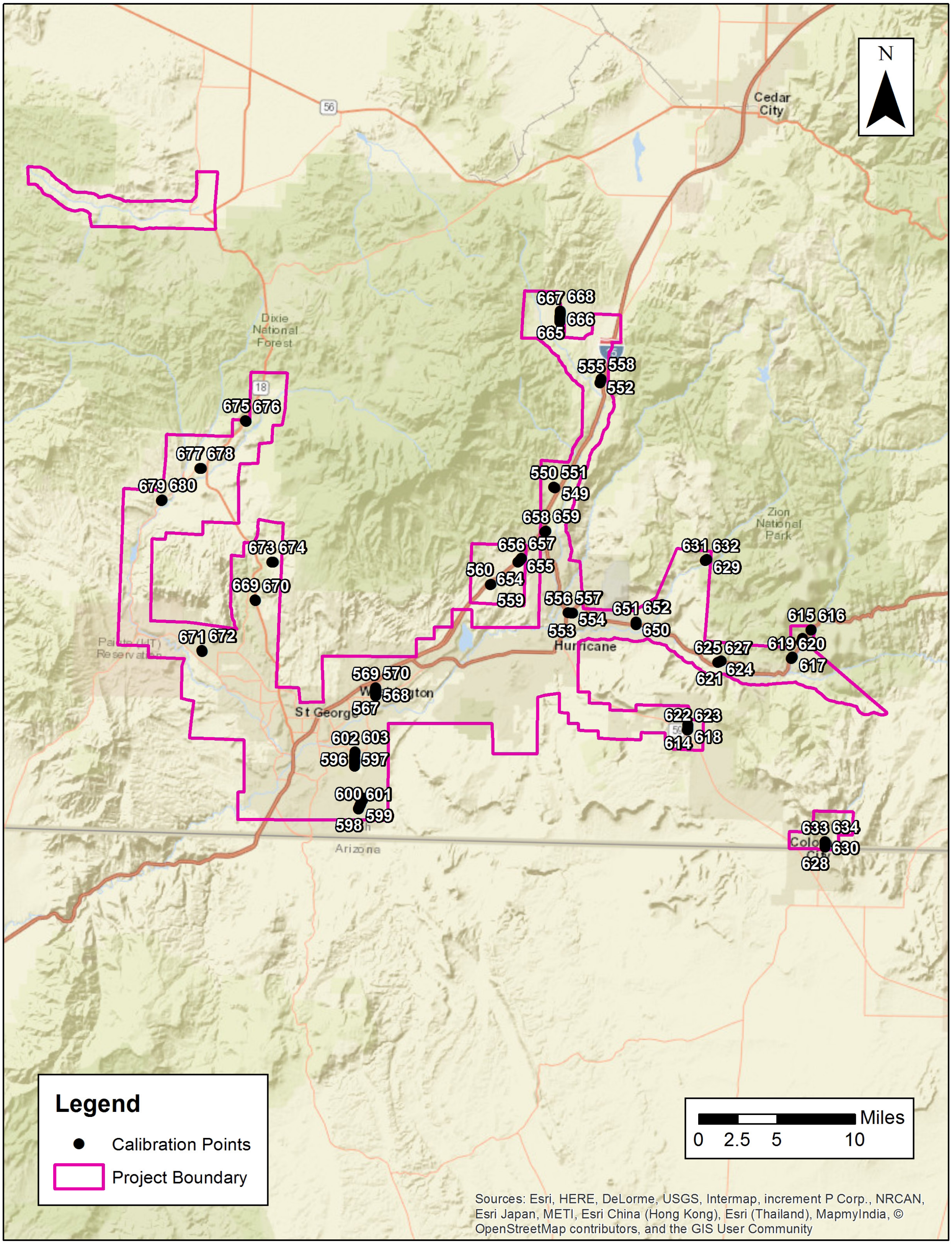


Table 3. Calibration Control Point Report

Units = Meters

Number	Easting	Northing	Known Z	Laser Z	Dz
549	297168.380	4133808.670	1292.09	1292.04	-0.05
550	297110.820	4133831.470	1295.39	1295.34	-0.05
551	297046.400	4133856.430	1298.48	1298.43	-0.05
552	301832.340	4144580.520	1467.05	1467.04	-0.01
553	298847.250	4120913.030	997.06	997.02	-0.04
554	298905.860	4120915.010	999.12	999.11	0.00
555	301902.490	4144785.610	1472.90	1472.88	-0.01
556	299023.880	4120913.730	1002.85	1002.83	-0.02
557	298556.890	4120945.320	990.47	990.45	-0.02
558	301946.900	4144991.770	1477.03	1476.99	-0.04
559	290548.340	4123808.770	1054.72	1054.74	0.02
560	290627.730	4123860.200	1057.34	1057.35	0.01
561	278730.520	4112370.460	868.98	868.98	0.00
562	278731.370	4112455.680	870.72	870.73	0.01
563	278732.440	4112552.960	872.44	872.44	0.01
564	278740.700	4112643.740	873.91	873.92	0.01
565	278734.920	4112745.040	876.27	876.28	0.01
566	278734.770	4112842.710	878.18	878.20	0.02
567	278735.620	4112943.370	879.67	879.67	0.00
568	278725.660	4113037.180	880.08	880.04	-0.04
569	278728.220	4113138.040	881.21	881.22	0.01
570	278730.060	4113222.990	883.40	883.39	-0.01
571	277472.060	4101875.680	868.53	868.57	0.04
572	276569.670	4105156.730	810.96	810.99	0.03
573	277439.720	4101805.380	867.95	867.97	0.02
574	277423.210	4101769.530	867.68	867.71	0.03
575	277407.140	4101734.230	867.46	867.47	0.01
576	277391.190	4101699.020	867.23	867.25	0.02
577	277375.000	4101663.583	867.02	867.03	0.01
578	277359.869	4101630.449	866.82	866.84	0.02
579	276572.804	4105427.699	806.77	806.81	0.04
580	277327.915	4101560.631	866.49	866.51	0.02

Number	Easting	Northing	Known Z	Laser Z	Dz
581	276574.327	4105508.757	806.62	806.65	0.03
582	276574.917	4105551.432	806.62	806.65	0.03
583	276575.960	4105597.329	806.58	806.58	0.00
584	276577.288	4105644.178	806.64	806.68	0.04
585	276578.838	4105698.923	806.66	806.68	0.02
586	277229.139	4101343.166	863.97	863.98	0.01
587	277211.740	4101305.031	863.51	863.53	0.02
588	276580.958	4105841.661	807.17	807.17	0.00
589	277177.403	4101230.157	862.87	862.89	0.02
590	277155.311	4101191.115	862.39	862.42	0.03
591	277137.093	4101141.821	862.12	862.15	0.03
592	277118.633	4101101.574	861.86	861.87	0.01
593	277099.786	4101059.903	861.58	861.60	0.02
594	276587.332	4106122.932	807.55	807.57	0.02
595	276588.742	4106168.679	807.56	807.58	0.03
596	276589.519	4106216.462	807.47	807.48	0.01
597	276590.141	4106262.795	807.21	807.20	-0.01
598	277015.573	4100875.137	860.33	860.34	0.01
599	276999.937	4100840.833	860.36	860.38	0.02
600	276979.749	4100796.555	860.58	860.60	0.02
601	276957.719	4100747.389	860.82	860.86	0.04
602	276594.838	4106536.131	805.53	805.55	0.02
603	276596.779	4106637.736	805.18	805.18	0.00
604	322547.215	4117956.452	1200.70	1200.71	0.01
605	308239.190	4121767.615	1104.80	1104.77	-0.03
606	308231.152	4121728.365	1103.73	1103.69	-0.04
607	308222.160	4121689.124	1102.48	1102.43	-0.04
608	308212.164	4121655.136	1101.64	1101.59	-0.05
609	308198.035	4121614.170	1100.80	1100.78	-0.02
610	308180.880	4121576.786	1100.57	1100.54	-0.03
611	308161.186	4121546.413	1100.45	1100.43	-0.02
612	310855.585	4109431.154	1463.90	1463.88	-0.02
613	322665.640	4118301.809	1211.36	1211.36	0.00
614	310863.68	4109354.70	1459.37	1459.36	-0.01
615	323562.65	4119179.21	1206.52	1206.46	-0.06

Number	Easting	Northing	Known Z	Laser Z	Dz
616	323541.74	4119147.97	1205.44	1205.40	-0.03
617	321620.43	4116369.51	1162.84	1162.84	0.00
618	310866.43	4109156.41	1451.06	1451.03	-0.03
619	321542.99	4116260.53	1164.61	1164.60	-0.01
620	321499.61	4116212.09	1165.58	1165.58	0.00
621	314306.04	4115969.95	1117.73	1117.74	0.02
622	310860.38	4108910.84	1446.05	1446.02	-0.03
623	310845.84	4108850.15	1445.80	1445.76	-0.04
624	314129.73	4115899.09	1115.14	1115.15	0.01
625	314071.26	4115867.80	1114.35	1114.35	0.00
626	325000.13	4096804.96	1531.54	1531.52	-0.02
627	313954.14	4115805.06	1113.51	1113.53	0.02
628	324998.71	4096935.20	1533.80	1533.78	-0.02
629	312808.63	4126410.25	1340.96	1340.93	-0.03
630	324995.96	4097088.14	1537.31	1537.32	0.01
631	312714.33	4126348.55	1336.32	1336.31	-0.01
632	312668.22	4126314.41	1332.56	1332.52	-0.04
633	324995.02	4097285.66	1542.06	1542.04	-0.02
634	324992.82	4097391.47	1544.21	1544.21	0.00
650	305524.49	4119717.59	1083.15	1083.17	0.02
651	305527.80	4119853.01	1091.08	1091.06	-0.02
652	305531.56	4119989.29	1098.68	1098.67	-0.01
653	293393.27	4126131.24	1127.32	1127.31	-0.01
654	293489.18	4126230.60	1125.04	1125.03	-0.01
655	293574.53	4126326.88	1123.69	1123.68	-0.01
656	293661.49	4126431.80	1123.44	1123.45	0.02
657	293745.50	4126538.70	1123.31	1123.27	-0.04
658	296144.69	4129285.77	1162.03	1162.00	-0.03
659	296274.60	4129338.90	1157.91	1157.89	-0.02
660	297708.58	4150862.61	1621.56	1621.51	-0.05
661	297711.98	4151004.64	1625.20	1625.16	-0.03
662	297714.95	4151137.78	1629.38	1629.34	-0.04
663	297718.06	4151276.47	1634.54	1634.50	-0.04
664	297721.20	4151417.27	1640.07	1640.02	-0.05
665	297724.18	4151560.49	1645.23	1645.20	-0.03

Number	Easting	Northing	Known Z	Laser Z	Dz
666	297727.67	4151703.69	1650.47	1650.44	-0.03
667	297730.67	4151844.52	1656.49	1656.48	-0.01
668	297733.84	4151985.12	1662.94	1662.94	0.00
669	266349.66	4122275.44	1215.05	1215.02	-0.03
670	266357.06	4122186.58	1214.16	1214.13	-0.03
671	260872.32	4116925.54	935.41	935.40	-0.01
672	260866.98	4117056.71	936.49	936.43	-0.06
673	268191.10	4126149.40	1386.86	1386.81	-0.05
674	268066.89	4126126.49	1387.22	1387.17	-0.05
675	265323.28	4140720.96	1543.78	1543.72	-0.06
676	265421.65	4140644.35	1539.86	1539.80	-0.06
677	260796.32	4135777.99	1358.27	1358.20	-0.07
678	260663.61	4135782.49	1357.11	1357.03	-0.08
679	256680.63	4132451.08	1189.70	1189.65	-0.05
680	256778.38	4132530.08	1191.24	1191.18	-0.06

Average Dz	-0.010 m
Minimum Dz	-0.078 m
Maximum Dz	0.045 m
Root Mean Square	0.030 m
Std. Deviation	0.029 m

Figure 7. QC Checkpoint Locations - Raw

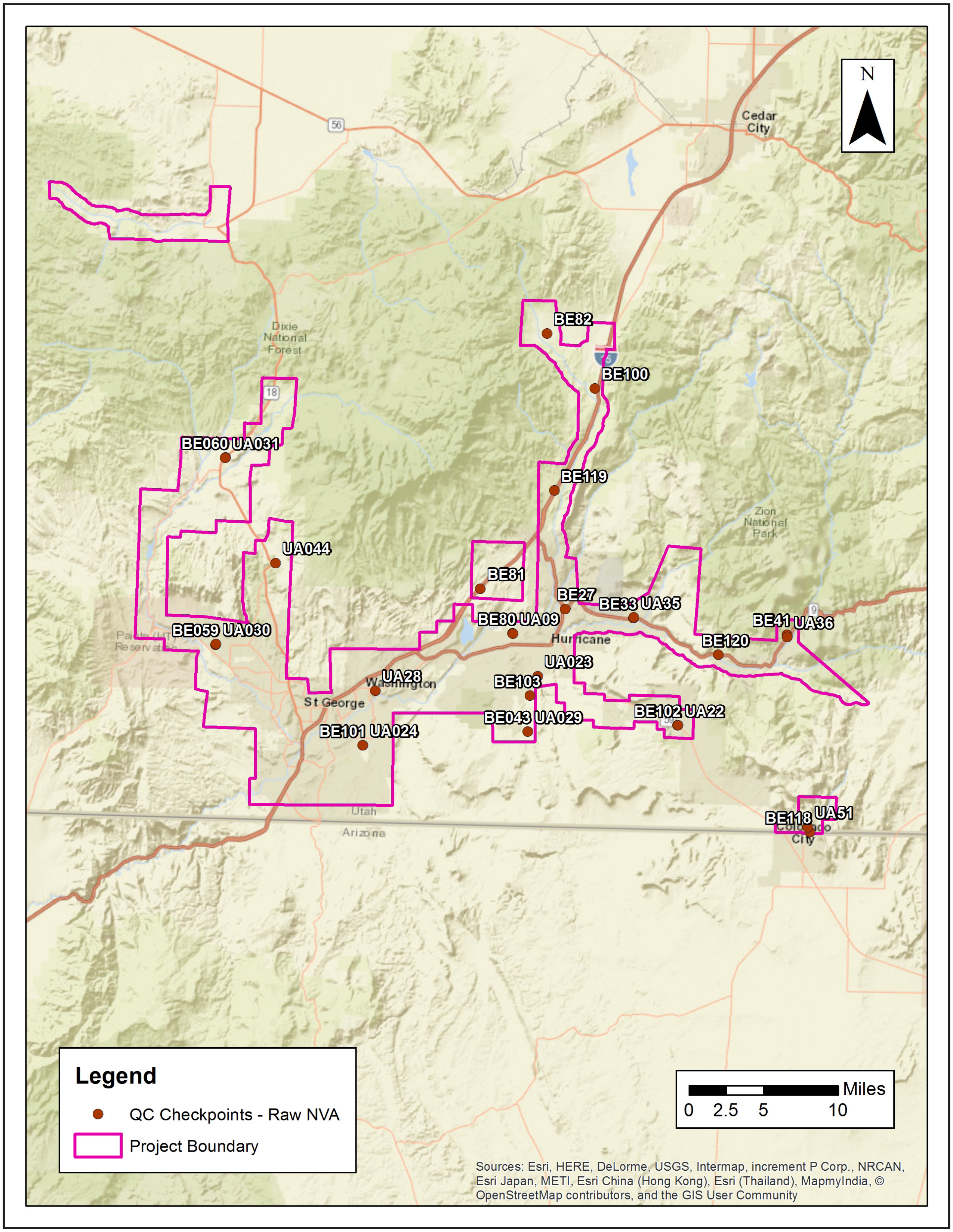


Table 4. QC Checkpoint Report - Raw NVA

Units = Meters

Number	Easting	Northing	Known Z	Laser Z	Dz
BE27	298629.390	4120757.170	989.02	988.97	-0.05
BE33	305993.490	4119773.300	1085.22	1085.22	0.01
BE41	322550.820	4117996.760	1200.83	1200.82	-0.01
BE043	294589.470	4107528.840	1038.76	1038.79	0.03
BE059	260895.050	4116922.320	934.81	934.76	-0.05
BE060	261956.350	4137096.700	1419.89	1419.82	-0.07
BE80	292952.730	4118131.010	978.17	978.16	-0.01
BE81	289477.350	4122946.690	1018.20	1018.20	0.00
BE82	296656.321	4150483.427	1615.54	1615.46	-0.08
BE100	301823.659	4144556.252	1466.55	1466.50	-0.05
BE101	276774.626	4106053.193	808.34	808.37	0.03
BE102	310752.558	4108210.015	1449.42	1449.40	-0.02
BE103	294805.628	4111414.059	1007.11	1007.12	0.00
BE118	325016.829	4096687.324	1530.04	1530.01	-0.03
BE119	297447.420	4133536.768	1260.87	1260.81	-0.06
BE120	315136.423	4115805.903	1120.40	1120.39	-0.01
UA09	292960.715	4118114.396	979.24	979.20	-0.04
UA22	310796.133	4108207.575	1448.84	1448.81	-0.03
UA023	295647.313	4113501.585	1017.41	1017.39	-0.02
UA024	276793.402	4106064.604	808.87	808.89	0.02
UA28	278118.180	4111959.963	861.15	861.20	0.05
UA029	294594.344	4107527.394	1039.13	1039.13	0.00
UA030	260922.741	4116972.396	935.27	935.23	-0.04
UA031	261941.389	4137054.245	1418.21	1418.14	-0.06
UA35	306031.414	4119849.606	1084.04	1084.03	-0.01
UA36	322592.553	4117729.370	1192.18	1192.16	-0.02
UA044	267386.215	4125709.553	1376.18	1376.12	-0.06
UA51	324810.713	4097232.207	1542.60	1542.57	-0.03
	Average Dz	-0.020 m			
	Minimum Dz	-0.077 m			
	Maximum Dz	0.049 m			
	Root Mean Square	0.038 m			
	95% Confidence Level	0.074 m			

Figure 8. QC Checkpoint Locations - NVA

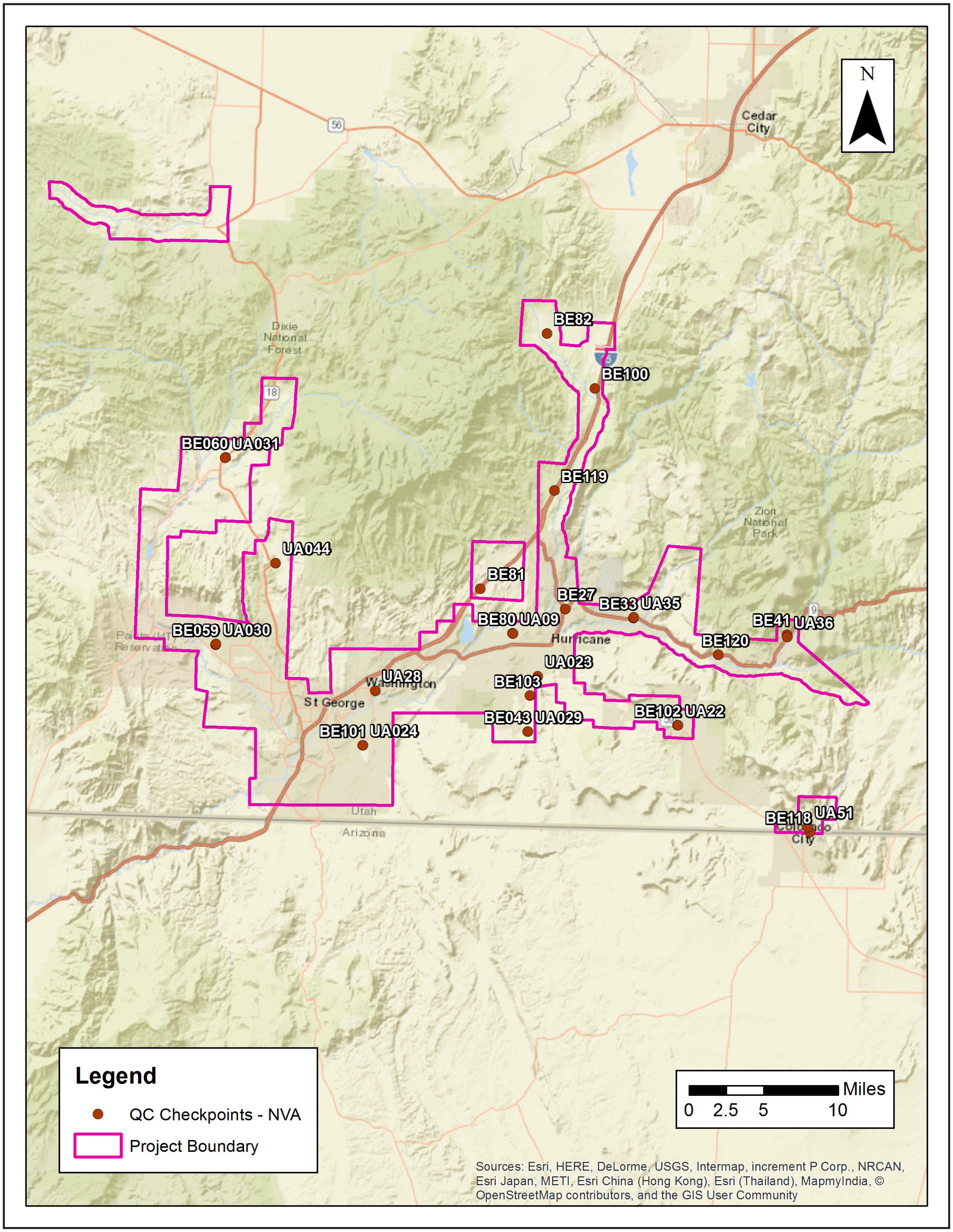


Table 5. QC Checkpoint Report - NVA

Units = Meters

Number	Easting	Northing	Known Z	Laser Z	Dz
BE27	298629.39	4120757.17	989.02	988.97	-0.05
BE33	305993.49	4119773.30	1085.22	1085.23	0.01
BE41	322550.82	4117996.76	1200.83	1200.84	0.01
BE043	294589.47	4107528.84	1038.76	1038.79	0.03
BE059	260895.05	4116922.32	934.81	934.76	-0.05
BE060	261956.35	4137096.70	1419.89	1419.82	-0.07
BE80	292952.73	4118131.01	978.17	978.16	-0.01
BE81	289477.35	4122946.69	1018.20	1018.20	0.01
BE82	296656.32	4150483.43	1615.54	1615.47	-0.06
BE100	301823.66	4144556.25	1466.55	1466.50	-0.06
BE101	276774.63	4106053.19	808.34	808.37	0.03
BE102	310752.56	4108210.02	1449.42	1449.41	-0.01
BE103	294805.63	4111414.06	1007.11	1007.10	-0.01
BE118	325016.83	4096687.32	1530.04	1530.00	-0.03
BE119	297447.42	4133536.77	1260.87	1260.80	-0.07
BE120	315136.42	4115805.90	1120.40	1120.37	-0.03
UA09	292960.72	4118114.40	979.24	979.23	0.00
UA22	310796.13	4108207.58	1448.84	1448.81	-0.02
UA023	295647.31	4113501.59	1017.41	1017.40	-0.01
UA024	276793.40	4106064.60	808.87	808.89	0.02
UA28	278118.18	4111959.96	861.15	861.20	0.05
UA029	294594.34	4107527.39	1039.13	1039.13	0.00
UA030	260922.74	4116972.40	935.27	935.23	-0.04
UA031	261941.39	4137054.25	1418.21	1418.14	-0.06
UA35	306031.41	4119849.61	1084.04	1084.03	-0.01
UA36	322592.55	4117729.37	1192.18	1192.16	-0.02
UA044	267386.22	4125709.55	1376.18	1376.13	-0.05
UA51	324810.71	4097232.21	1542.60	1542.57	-0.03

Average Dz	-0.020 m
Minimum Dz	-0.069 m
Maximum Dz	0.045 m
Root Mean Square	0.037 m
95% Confidence Level	0.073 m

Figure 9. QC Checkpoint Locations - VVA

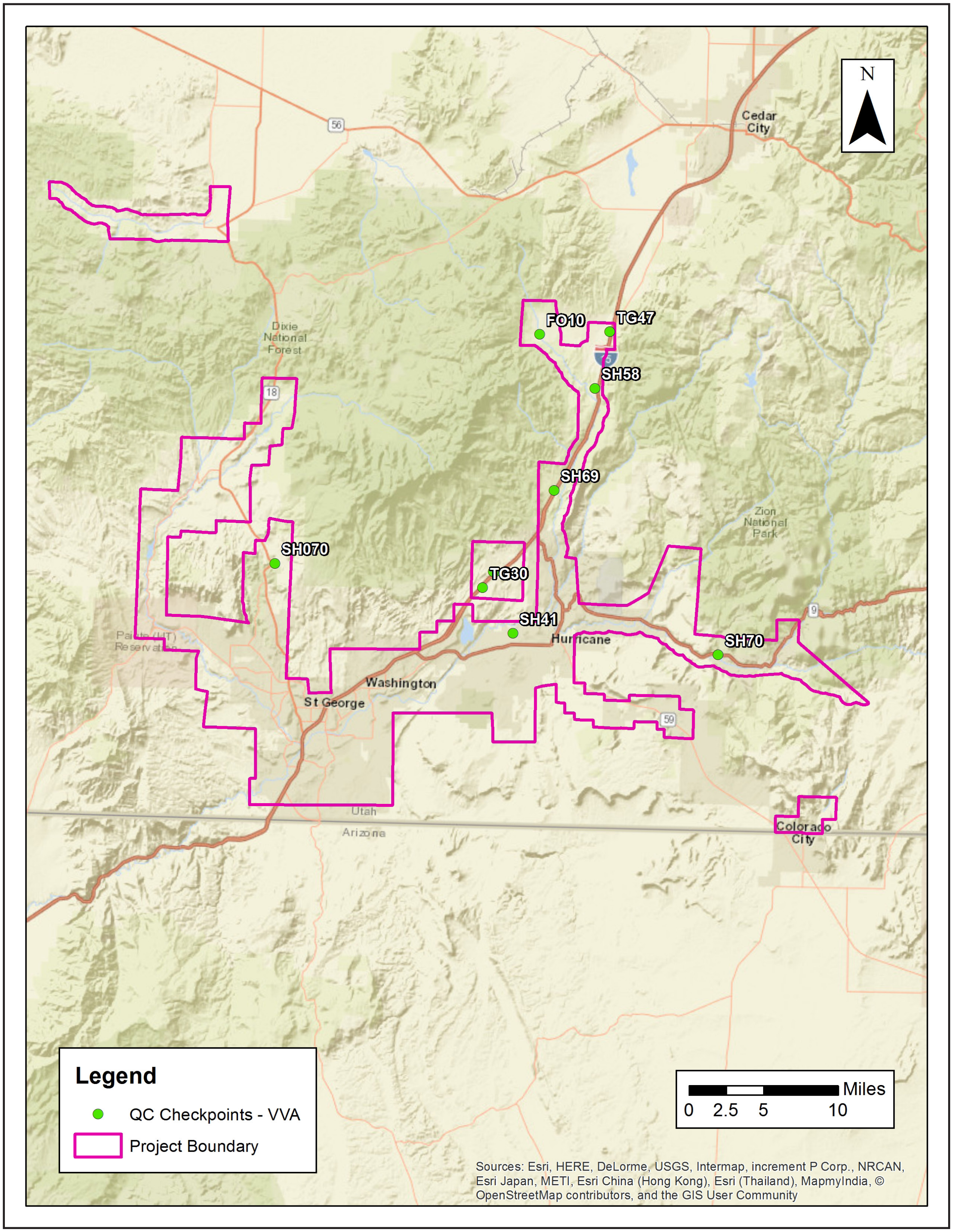


Table 6. QC Checkpoint Report - VVA

Units = Meters

Number	Easting	Northing	Known Z	Laser Z	Dz
FO09	291052.73	4124773.34	1103.29	1103.38	0.09
FO10	295850.59	4150379.39	1614.49	1614.47	-0.02
SH41	292964.79	4118125.70	978.58	978.57	-0.01
SH42	290850.61	4124771.57	1107.00	1107.08	0.09
SH58	301809.24	4144567.70	1466.61	1466.65	0.04
SH69	297407.89	4133555.06	1264.60	1264.64	0.04
SH070	267292.71	4125668.87	1373.08	1373.07	-0.01
SH70	315126.37	4115807.23	1119.90	1119.97	0.07
TG30	289708.95	4123060.59	1025.98	1026.13	0.15
TG47	303417.75	4150673.11	1571.30	1571.31	0.01

Average Dz	0.040 m
Minimum Dz	-0.020 m
Maximum Dz	0.152 m
Root Mean Square	0.055 m
95th Percentile	0.068 m