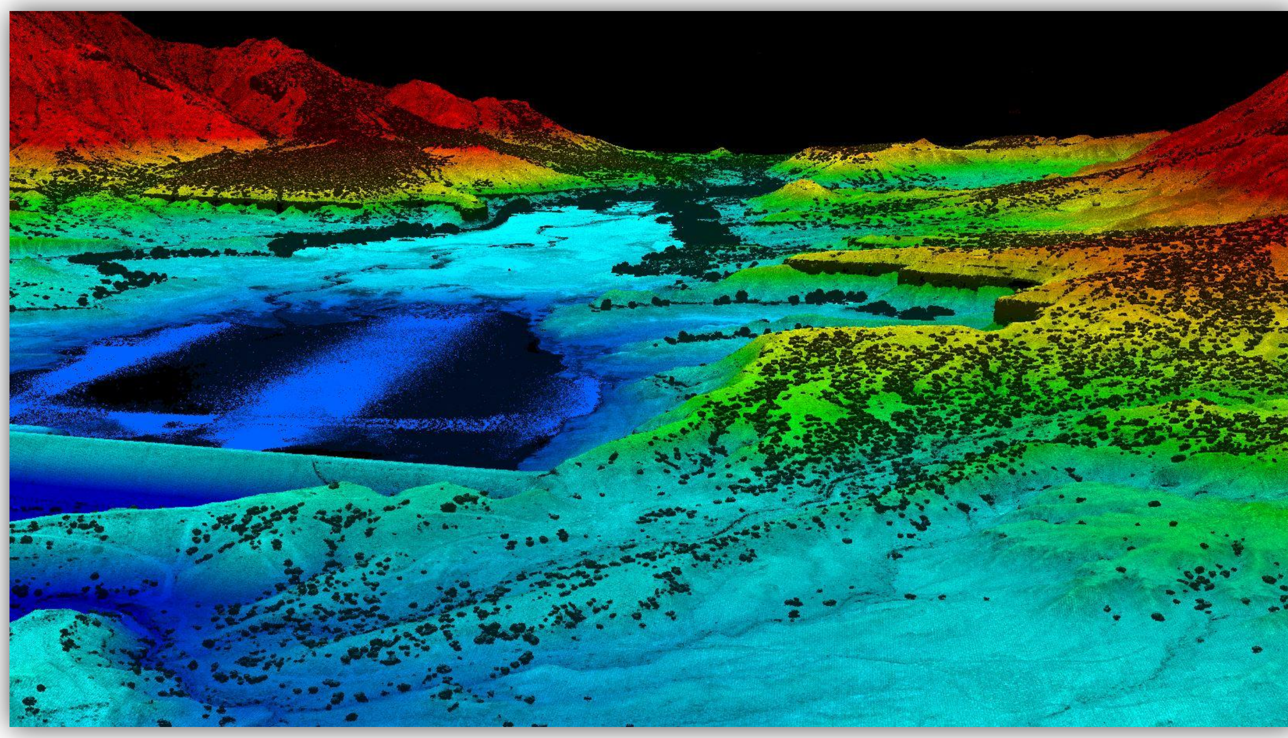
aero-graphics

FINAL PROJECT REPORT

MILLSITE RESERVOIR AERIAL SURVEY

EMERY COUNTY, UTAH

October 2017



Submitted to:

Rick Kelson
Utah AGRC
5130 State Office Building
Salt Lake City, UT 84114

Submitted by:

Aero-Graphics, Inc.
40 W. Oakland Avenue
Salt Lake City, UT 84115
www.aero-graphics.com

Final Project Report
Millsite Reservoir
Emery County, UT

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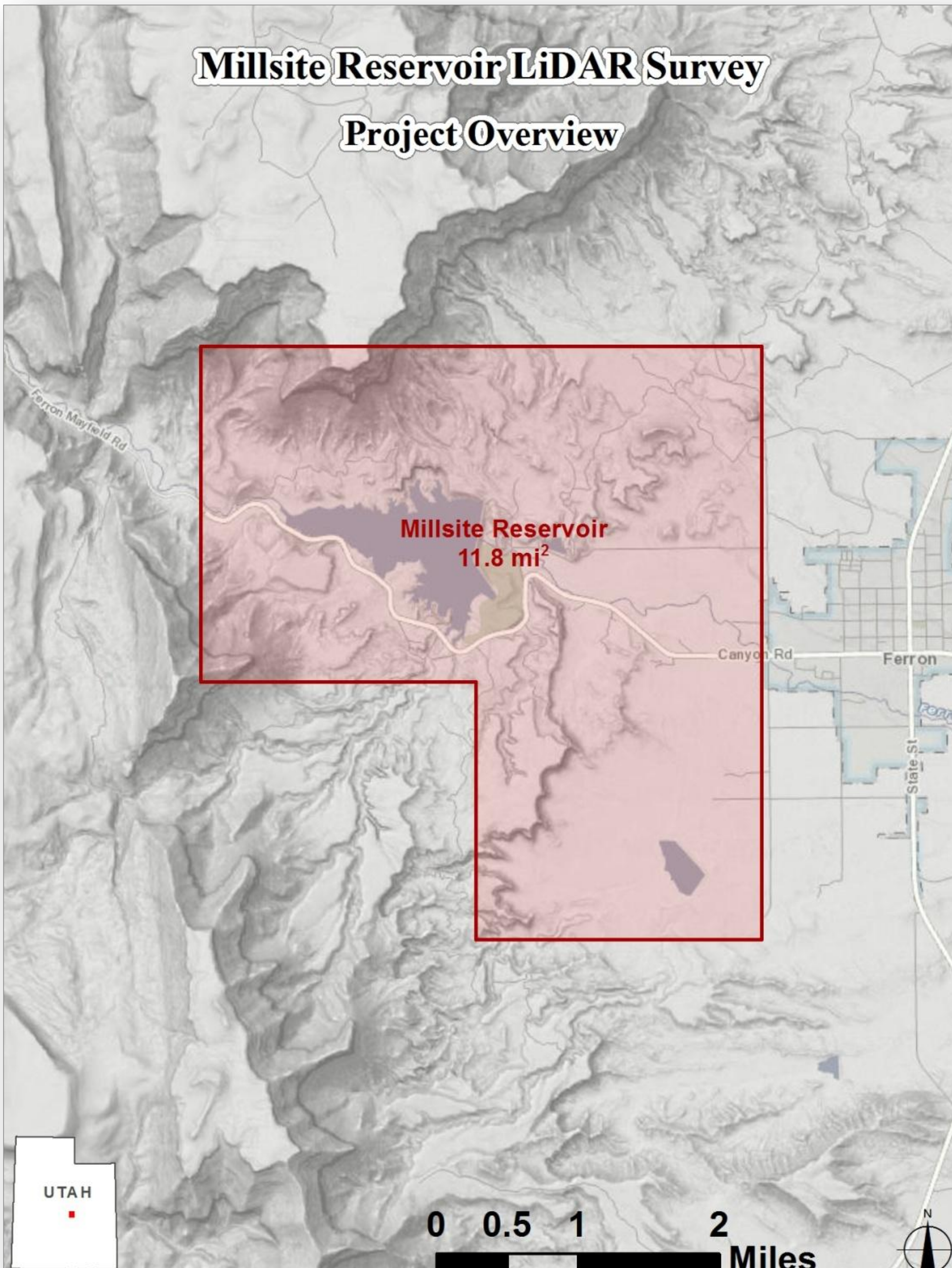
1. Overview

Aero-Graphics, Inc. was contracted by the State of Utah, Department of Technology Services, Division of Integrated Technology, Automated Geographic Reference Center (AGRC) and partners to acquire, process, and deliver aerial LiDAR data and derivative products that adhere to USGS Quality Level 1 LiDAR specifications. The project area covers approximately 11.8 square miles located in Emery County, Utah.

Exhibit 1: *Millsite Reservoir project boundary*



2. LiDAR Acquisition – Equipment and Methodology

LiDAR acquisition for the Millsite Reservoir project was performed on October 21 and 25, 2017, with an Optech ALTM Orion H300 LiDAR sensor. Aero-Graphics flew at an average altitude of 4,265 ft AGL (above ground level) and made appropriate adjustments to compensate for topographic relief. The PRF (pulse rate frequency) used for collection was 175 kHz, scan frequency 56.9 Hz, and scan angle +/- 13° from the nadir position (full scan angle 26°). LiDAR acquisition was performed with 50% overlap and yielded an average 11.5 points per square meter throughout the project areas.

Exhibit 2: *Summary of planned flight parameters*

Altitude (ft AGL)	Overlap (%)	Speed (kts)	PRF (kHz)	Scan Freq (Hz)	Scan Angle ° (full)
4,265	50	110	175	56.9	26

PPM^2 (mean)	Post spacing Cross Track (m)	Post Spacing Down Track (m)	Swath Width (m)	# Flightlines
4.05	0.35	0.35	600	46

Product Characterization Report

The Orion H300 can send/receive up to 300,000 pulses per second and is capable of receiving up to four range measurements, including 1st, 2nd, 3rd, and last returns for every pulse sent from the system. The Orion H300 features roll compensation that adjusts the mirror to maintain the full scan angle integrity in relation to nadir, even when less than perfect weather conditions push the sensor off nadir. It is also equipped with a GPS/IMU unit that continually records the XYZ position and roll, pitch and yaw attitude of the plane throughout the flight. This information allows us to correct laser return data positions that may have been thrown off by the plane's natural movement.

Exhibit 3: *The acquisition platform for the Millsite Reservoir project was a turbocharged Cessna 206. Our 206 has been customized for LiDAR and other airborne sensors with an upgraded power system and avionics. The stability of the Cessna 206 is ideal for LiDAR collection*

The ALTM Orion H300 LiDAR sensor is equipped with FMS Planner Flight Management System Software, which is the latest release from Optech. Aero-Graphics utilizes FMS Planner to both plan the flight and guide the airborne mission while in flight. This smooth transition from flight planning to aerial operations eliminates discrepancies between the flight plan and the actual airborne mission. The use of FMS Planner helps ensure an accurate and consistent acquisition mission with real-time quality assurance while still airborne. The system operator can monitor the point density and swath during the mission to confirm adequate coverage within the area of interest, as shown in **Exhibit 4.**

<u>Exhibit 4:</u> *Swath data for the Millsite Reservoir project was recorded and viewed real-time by the system operator.*

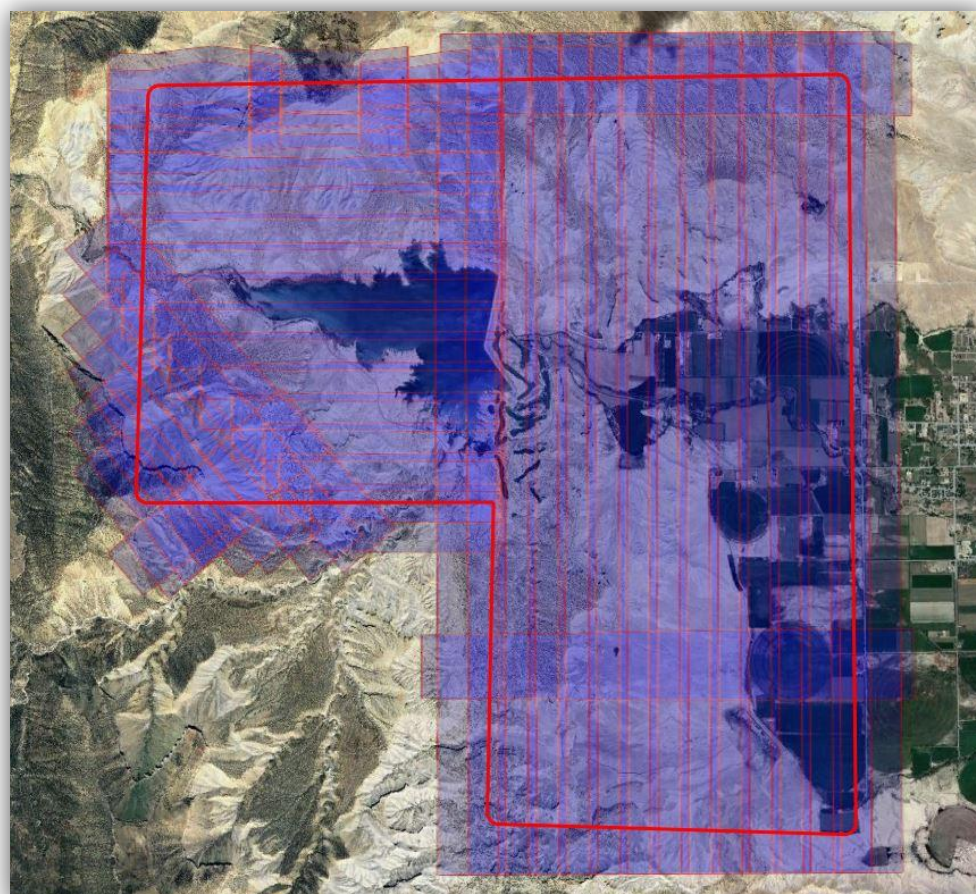
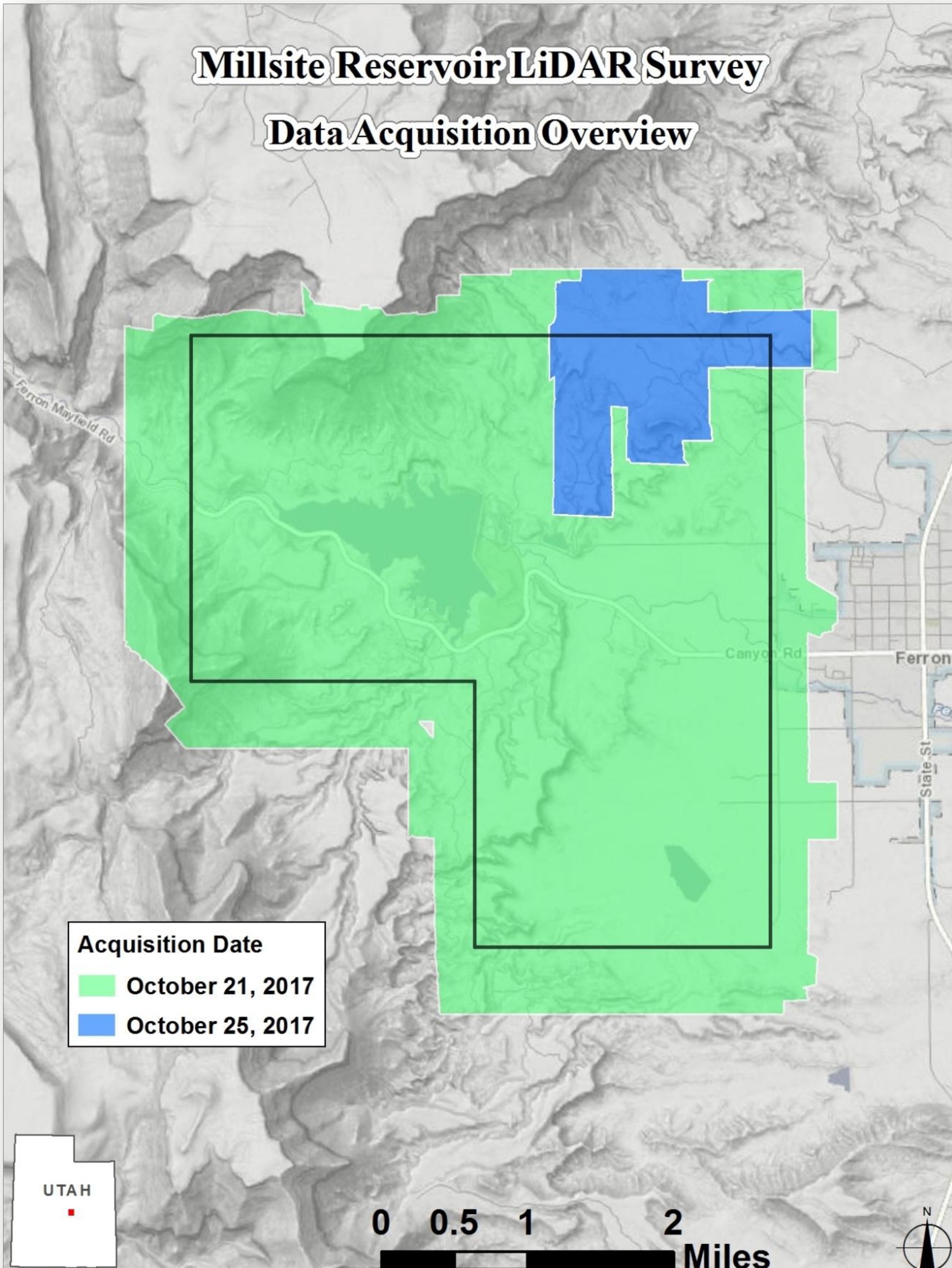


Exhibit 5: *Flight line swath coverage symbolized by date*



3. Ground Survey – Equipment and Methodology

Aero-Graphics surveyed 24 ground control points for use in data calibration as well as 71 QC check points in Vegetated and Non-Vegetated land cover classifications as an independent test of accuracy for 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 QC check points. Calibration control point, QC check point, and base station coordinates can be found in Appendix A. LiDAR positional accuracy results can be found in section 5.

Exhibit 6: *Calibration Control Point (Base)*

Exhibit 7: *Calibration Control Point (MR2)*

4. LiDAR Processing Workflow

a. **Absolute Sensor Calibration.** Our absolute sensor calibration adjusted for the difference in roll, pitch, heading, and scale between the raw laser point cloud from the sensor and surveyed control points on the ground.

b. **Kinematic Air Point Processing.** Differentially corrected the 1-second airborne GPS positions with ground base station; combined and refined the GPS positions with 1/200-second IMU (roll-pitch-yaw) data through development of a smoothed best estimate of trajectory (SBET).

c. **Raw LiDAR Point Processing (Calibration).** Combined SBET with raw LiDAR range data; solved real-world position for each laser point; produced point cloud data by flight strip in ASPRS v1.4 .LAS format; output in NAD83 (2011) UTM Zone 12, meters.

d. **Relative Calibration.** Performed relative calibration by correcting for roll, pitch, heading, and scale discrepancies between adjacent flightlines; tested resulting relative accuracy. Results presented in Section 5.

e. **Vertical Accuracy Assessment.** Performed comparative tests that showed Z-differences between surveyed points and the laser point surface. Results presented in Section 5.

f. **Tiling & Long/Short Filtering.** Cut data into project-specified tiles and filtered out grossly long and short returns.

g. **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.

   All data was manually reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler. LP360 was used as a final check of the bare earth dataset. LP360 was then used to create the deliverable industry-standard LAS files for both the All Point Cloud Data and the Bare Earth. Aero-Graphics, 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.

Exhibit 8: *USGS Version 1.2 minimum point cloud classification scheme used for this project*

CLASS #	CLASS NAME	DESCRIPTION
1	**Processed, but unclassified**	**Points that do not fit any other classes**
2	**Bare earth**	**Bare earth surface**
7	**Low noise**	**Low points identified below surface**
9	**Water**	**Points inside of lakes/ponds**
10	**Ignored ground (near a breakline)**	**Points near breakline features; ignored in DEM creation process**
17	**Bridge decks**	**Points on bridge decks**
18	**High noise**	**High points identified above surface**

h. **Hydro-Flattened Breakline Creation.** Class 2 (ground) LiDAR points were 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 LP360 functionality. Elevation values were assigned to all inland streams and rivers using Aero-Graphics, 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 shapefile 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 ArcMap tools and proprietary tools.

i. **Hydro-Flattened Raster DEM Creation.** Class 2 (Ground) LiDAR points in conjunction with the hydro breaklines were used to create a 0.5 meter hydro-flattened raster DEM. Using LP360 along with automated scripting routines within ArcMap, an ERDAS Imagine .IMG file was created for each tile. Each surface is reviewed using ESRI ArcMap and ArcScene to check for any surface anomalies or incorrect elevations found within the surface.

j. **First Return Raster DSM Creation.** First return LiDAR points were used to create a 0.5 meter first-return raster DEM. Using LP360 along with automated scripting routines within ArcMap, an ERDAS Imagine .IMG file was created for each tile. Each surface is reviewed using ESRI ArcMap and ArcScene to check for any surface anomalies or incorrect elevations found within the surface.

k. **Intensity Image Creation.** TerraScan 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 ESRI ArcMap software was then used to verify full project coverage. TIF/TFW files were then provided as the deliverable for this dataset requirement.

l. **Issues.** There were no issues to report for this project.

5. Accuracy Testing and Results

5.1 Relative Calibration Accuracy Results

Between-swath relative accuracy is defined as the elevation difference in overlapping areas between a given set of two adjacent flightlines. The statistics are based on the comparison of the flightlines and points listed below.

Millsite Reservoir project area: (52 flightlines, > 884 million points)

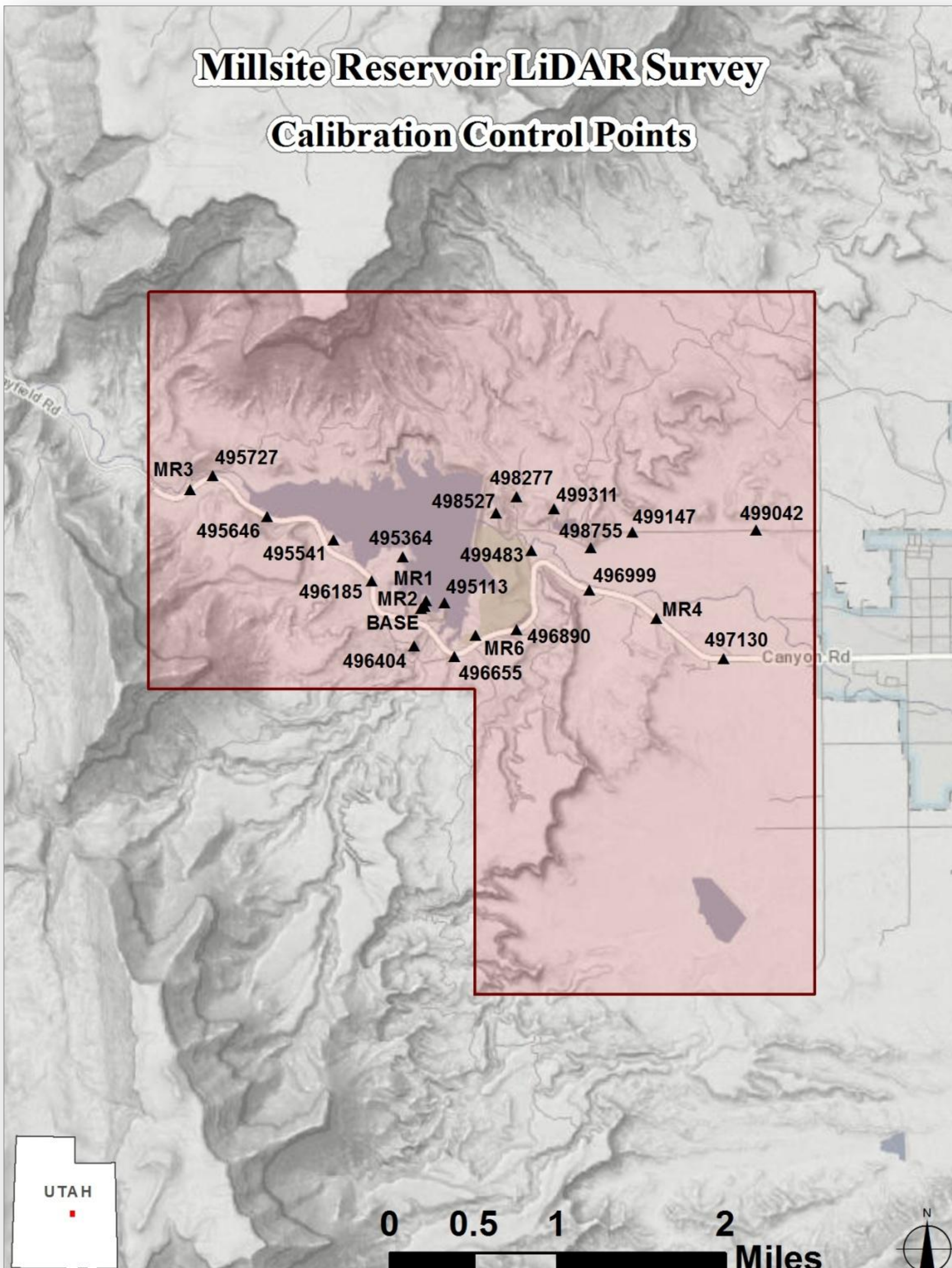
- Between-swath relative accuracy **average** of 0.035 meters

Within-swath relative accuracy is the amount of vertical separation, or “noise,” among a set of points on open, paved ground that should have the same elevation. The within-swath relative accuracy average is less than **0.008 meters.**

5.2 Calibration Control Point Testing

Calibration Control Point reports were generated as a quality assurance check. Note that the results are not an independent assessment of the accuracy of the project deliverables, but rather an additional indication of the overall accuracy of the dataset. The location of each control point is displayed below. Detailed results are included in Appendix B.

Exhibit 9: *Calibration Control Point locations for the Millsite Reservoir project*



5.3 Point Cloud Testing

The project specifications require that only Non-Vegetated Vertical Accuracy (NVA) be computed for raw LiDAR point cloud swath files. NVA is defined as the elevation difference between the LiDAR surface and ground surveyed static points collected in open terrain (bare soil, sand, rocks, and short grass) as well as urban terrain (asphalt and concrete surfaces). The NVA for this project was tested with 51 check points. These check points were not used in the calibration or post processing of the LiDAR point cloud data. Elevations from the unclassified LiDAR surface were measured for the xy location of each check point. Elevations interpolated from the LiDAR surface were then compared to the elevation values of the surveyed control points.

Raw Non-vegetated Vertical Accuracy (Raw NVA): The tested Raw NVA for this dataset was found to be 0.020 meters in terms of the RMSEz. The resulting NVA stated as the 95% confidence level (RMSEz x 1.96) is 0.040 meters. Therefore this dataset meets the required NVA of 0.196 meters at the 95% confidence level as defined by the National Standards for Spatial Data Accuracy (NSSDA). Individual point results are included in Appendix B.

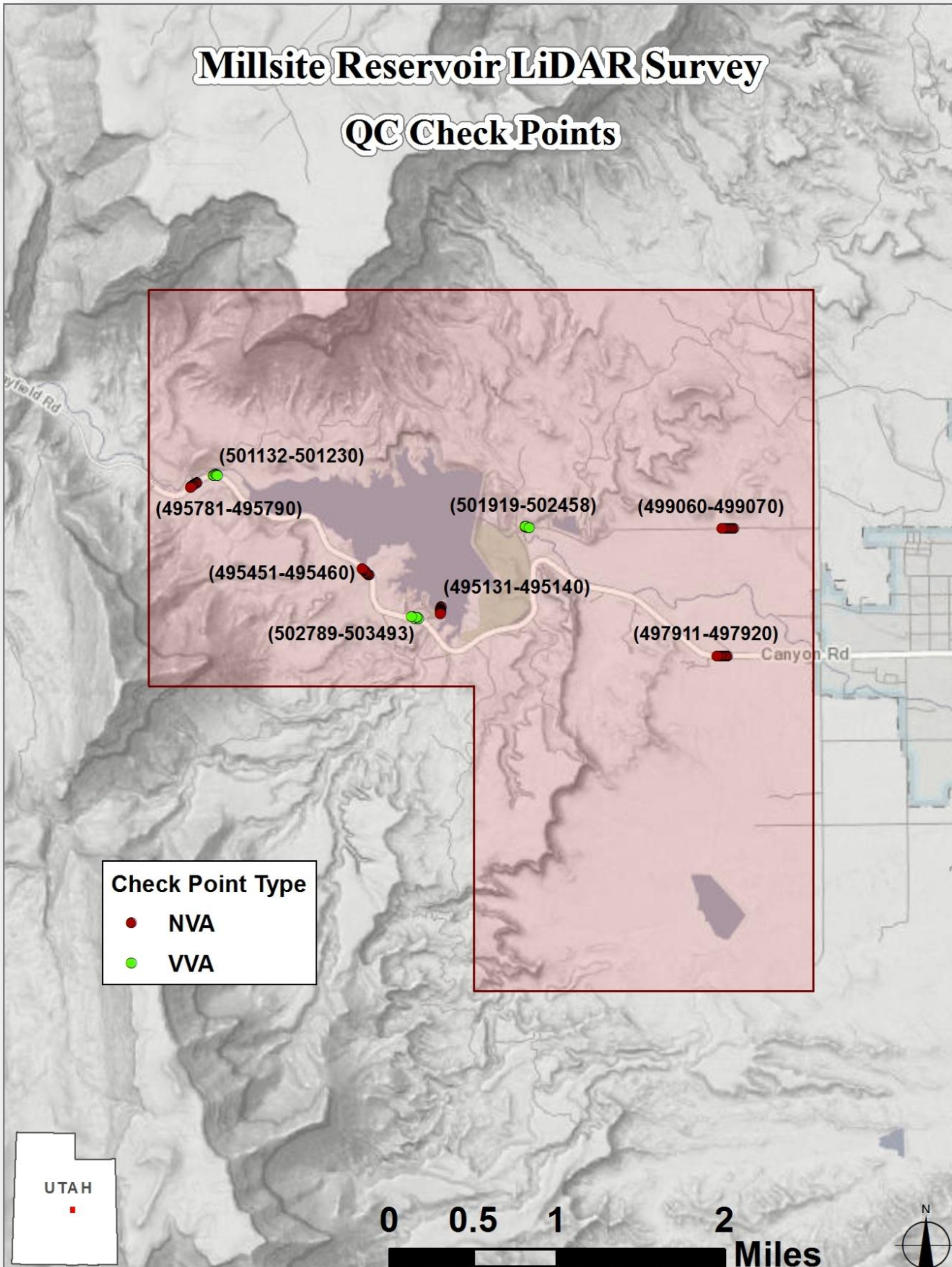
5.4 Digital Elevation Model (DEM) Testing

The project specifications require the accuracy of the derived DEM be calculated and reported in two ways: (1) Non-Vegetated Vertical Accuracy (NVA) calculated at a 95% confidence level in "bare earth" and "urban" land cover classes and (2) Vegetated Vertical Accuracy (VVA) in all vegetated land cover classes combined calculated based on the 95th percentile error. The NVA for this project was tested with 51 check points. The VVA was tested with 20 check points.

The tested Non-Vegetated Vertical Accuracy (NVA) for this dataset captured from the DEM using bi-linear interpolation to derive the DEM elevations was found to be 0.020 meters in terms of the RMSEz. The resulting accuracy stated as the 95% confidence level (RMSEz x 1.96) is 0.040 meters. Therefore this dataset meets the required NVA of 0.196 meters at the 95% confidence level. Individual point results are included in Appendix B.

The tested Vegetated Vertical Accuracy (VVA) for this dataset captured from the DEM using bi-linear interpolation for all classes was found to be 0.188 meters. Therefore this dataset meets the required VVA of 0.294 meters based on the 95th percentile error. Individual point results are included in Appendix B.

Exhibit 10: *QC Check Point locations for the Millsite Reservoir project*



5.5 Data Density

The requirement for this project was to achieve a LiDAR point density of **8** points per square meter. The acquisition mission achieved an actual average of **11.5** points per square meter. The following two exhibits show the density of **all collected points.**

<u>Exhibit 11:</u> Millsite Reservoir – All returns *Laser Point Density by Frequency, points/m^2. Demonstrates the percentage of project tiles with points in a given density range*

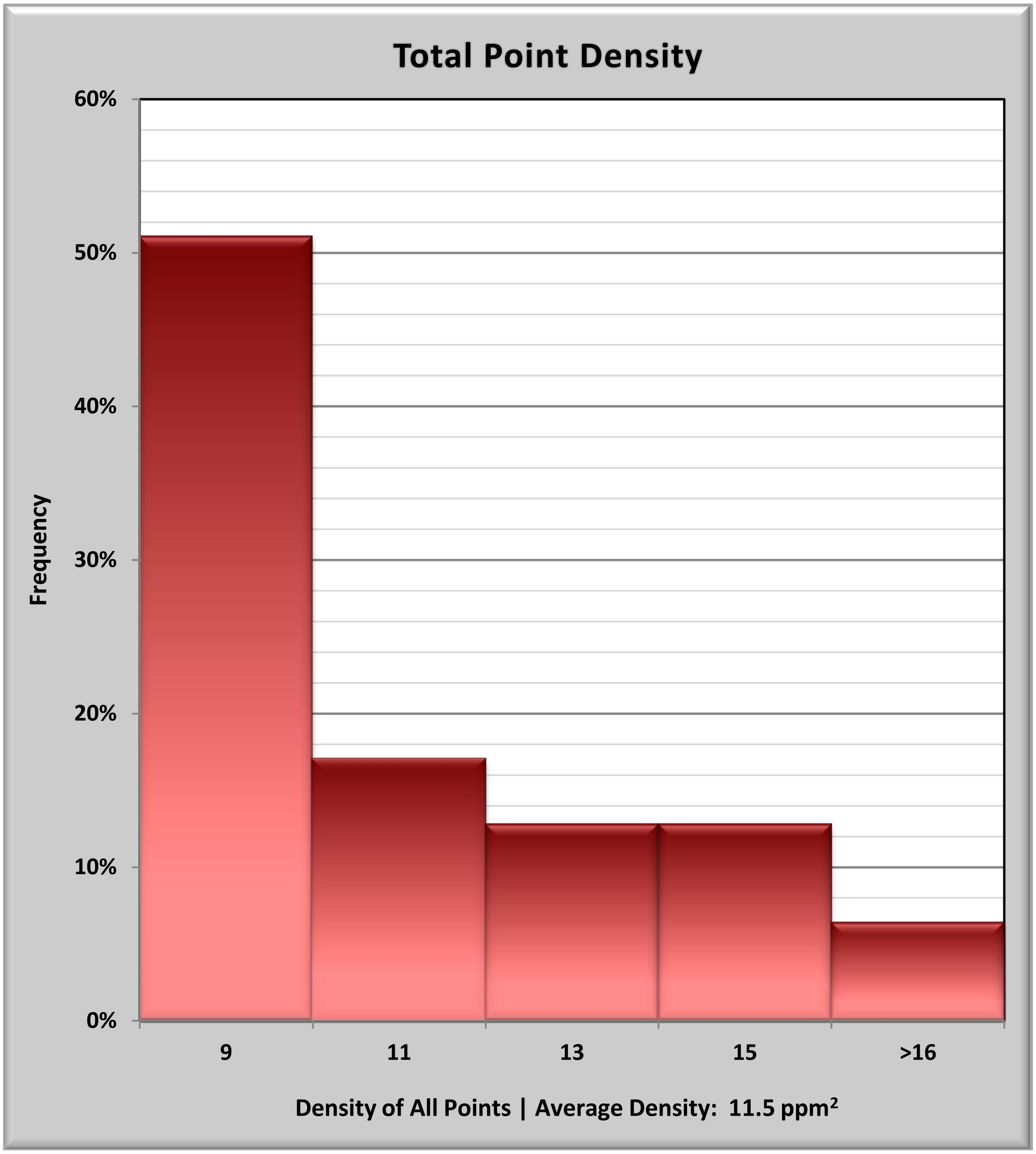
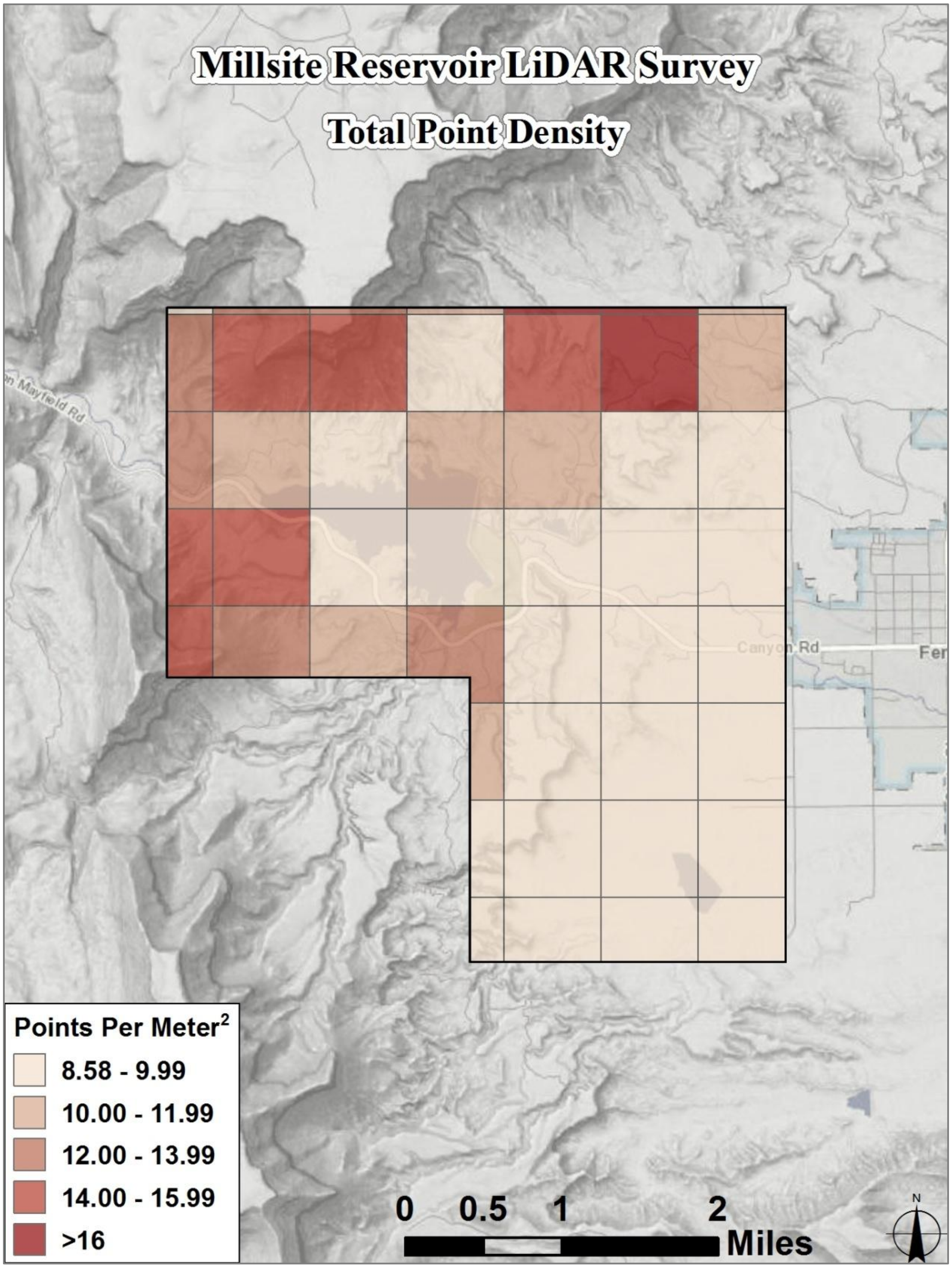


Exhibit 12: *Laser Point Density of All Returns by Tile, points/m²*



The following two exhibits show the density of **ground classified points**. Factors such as vegetation, water, and buildings will reduce the density of points classified to the ground. For the Millsite Reservoir project, an average of **9** ground classified points per square meter was achieved.

<u>Exhibit 13:</u> Millsite Reservoir - Ground Classified *Laser Point Density by Frequency, points/m^2. Demonstrates the percentage of project tiles with points in a given density range*

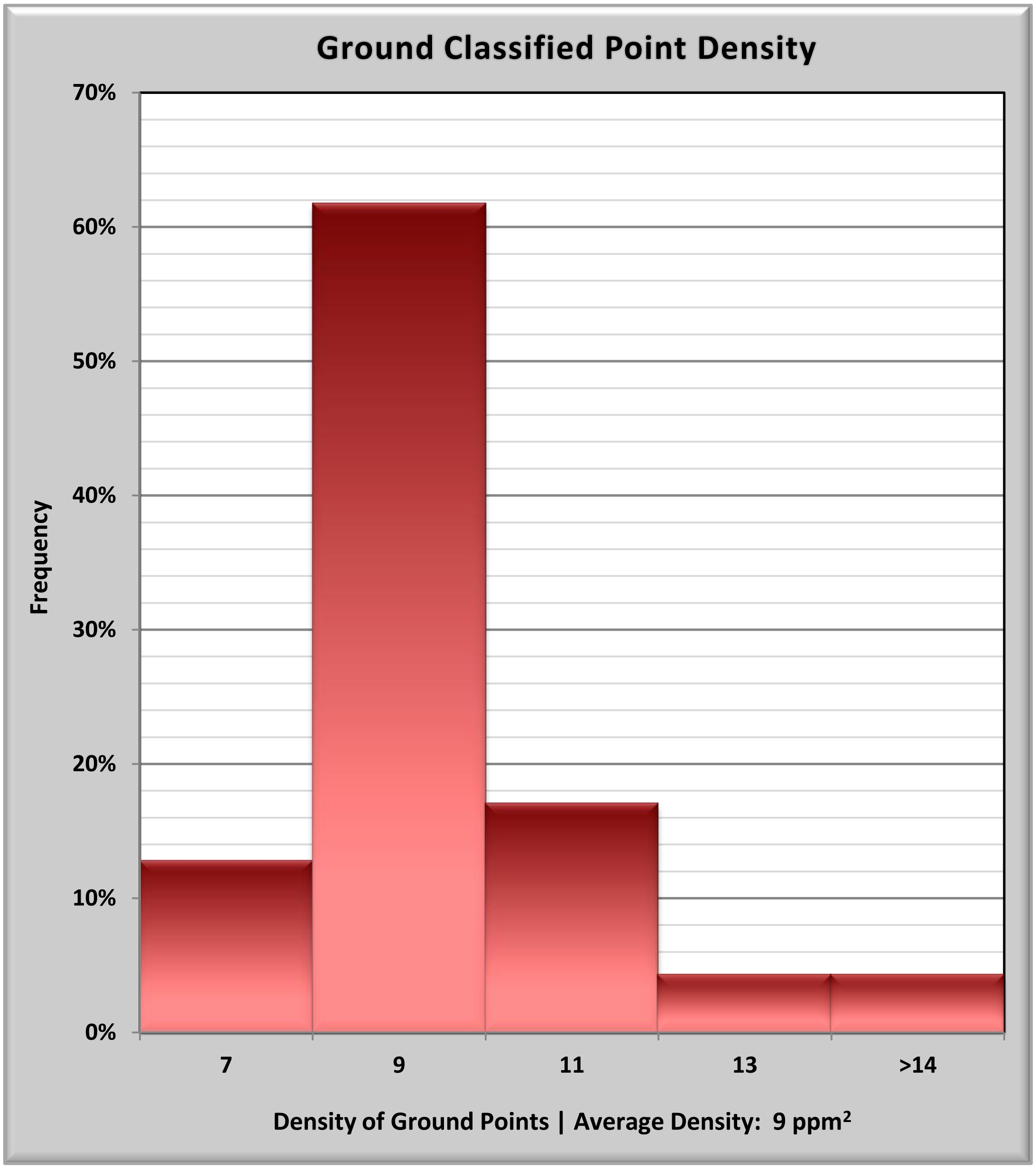
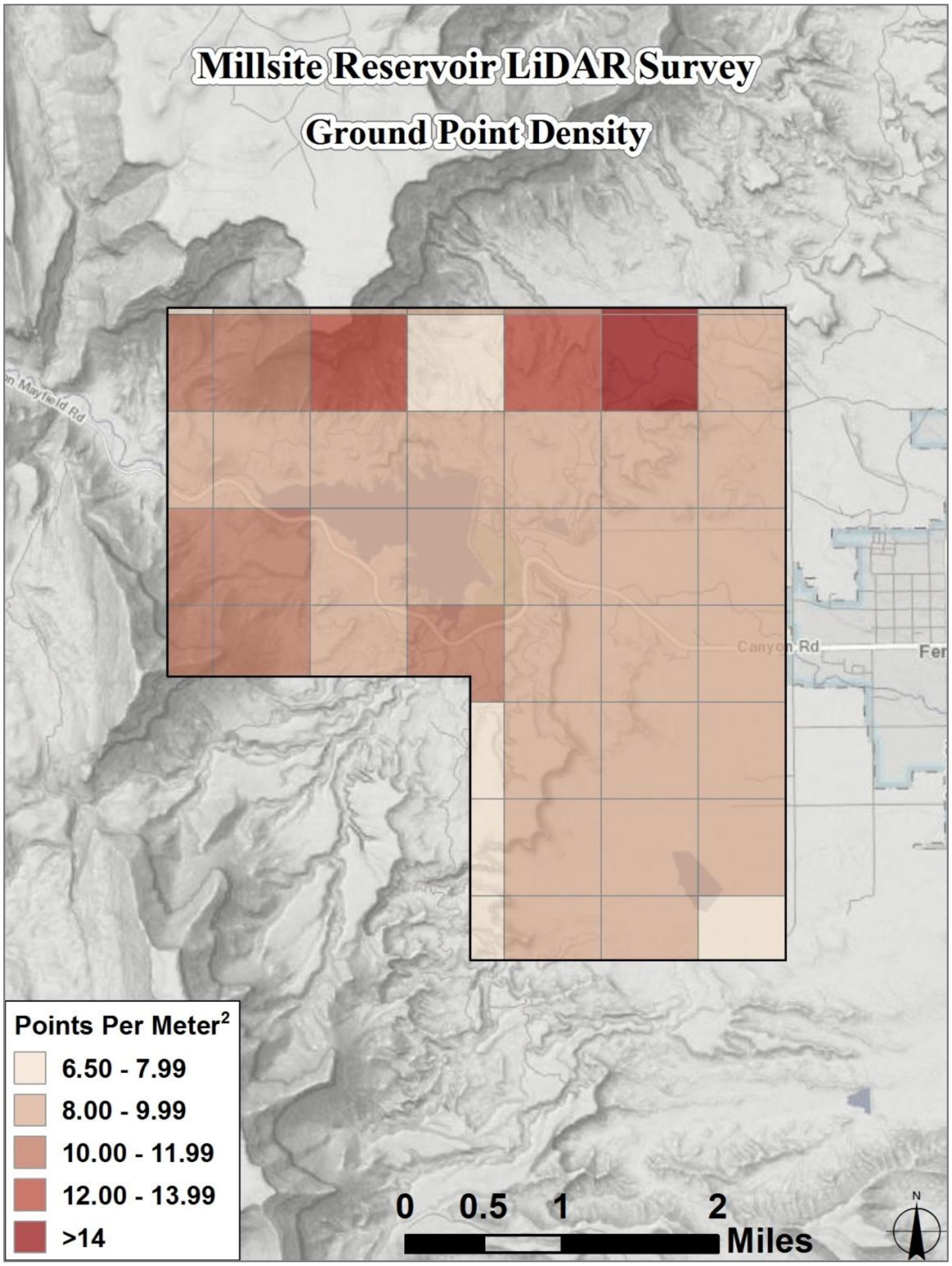


Exhibit 14: *Ground Classified Laser Point Density by Tile, points/m²*



5.6 Data Density Summary

Millsite Reservoir	Goal	Actual (mean)
Total Point Density:	8 points/m²	11.5 points/m²
Ground Classified Point Density:	-------	9 points/m²

6. Projection, Datums, and Mapping Units

Projection:		UTM Zone 12N
Datum	Vertical:	NAVD88 (GEOID12B)
	Horizontal:	NAD83 (2011)
Units:		Meters

7. Deliverables

LiDAR Point Data:	• Raw and classified LiDAR point cloud data in LAS v1.4 format
Raster Data:	• Bare-earth and first return DEMs with a cell size of 0.5 meters in ERDAS .IMG format • Intensity images at a 0.5 meter resolution in GeoTIFF format
Vector Data:	• Shapefiles containing processing boundary and tile index • Shapefiles containing all breaklines used for hydro-flattening • Separate shapefiles for control points and check points
Metadata:	• FGDC compliant metadata files in XML format
Report of Survey:	• Technical Project Report including methodology, accuracy, and results

*Tiling for the LiDAR deliverables is based on the U.S. National Grid System. Tile names are based on the SW corner of the tile. All .LAS tiles are 1,000 meters x 1,000 meters. All other deliverables are 2,000 meters x 2,000 meters.

Appendix A

Control Point Coordinates

Point	NAD83 (2011) UTM Zone 12		NAVD88 (GEOID12B)
	Easting	Northing	Elevation
BASE	483135.370	4327042.729	1898.437
MR1	483167.477	4327057.421	1896.779
MR2	483186.538	4327113.802	1896.454
MR3	480918.602	4328175.769	1910.467
MR4	485390.694	4326943.104	1844.503
MR6	483658.125	4326778.835	1905.712
495727	481138.045	4328310.967	1899.493
495541	482294.232	4327697.851	1893.589
495364	482962.466	4327536.467	1903.881
496404	483065.471	4326683.807	1934.293
495113	483362.803	4327093.505	1895.790
496655	483454.838	4326581.948	1908.878
498527	483854.888	4327954.781	1871.622
498277	484047.859	4328107.214	1873.567
499483	484191.081	4327593.036	1857.907
499311	484408.979	4327993.208	1866.434
499147	485164.280	4327771.522	1849.527
497130	486037.135	4326557.457	1833.628
499042	486344.994	4327789.900	1838.711
496999	484745.087	4327217.105	1844.686
496890	484053.142	4326834.962	1881.946
495646	481657.719	4327917.495	1898.603
496185	482661.213	4327302.149	1904.129
498755	484764.568	4327619.002	1858.751

NGS Reference Coordinates for Kinematic Survey Base Station (BASE)

CORS Station	NAD 83 (2011)		
	Latitude	Longitude	Height
P105	39° 23’ 15.14007”	-112° 30’ 14.66907”	1432.213
P012	38° 05’ 50.74025”	-109° 20’ 01.76305”	1789.330
PUC2	39° 35’ 38.10058”	-110° 45’ 41.52524”	1714.255

QC Check Point Coordinates

Point	Type	NAD83 (2011) UTM Zone 12		NAVD88 (GEOID12B)
		Easting	Northing	Elevation
495131	NVA	483329.957	4327030.016	1896.429
495132	NVA	483329.248	4327022.963	1896.524
495133	NVA	483328.700	4327015.764	1896.616
495134	NVA	483328.171	4327008.543	1896.681
495135	NVA	483327.666	4327001.350	1896.744
495136	NVA	483327.161	4326994.194	1896.816
495137	NVA	483326.785	4326987.030	1896.908
495138	NVA	483326.826	4326979.987	1897.001
495139	NVA	483327.401	4326973.200	1897.104
495140	NVA	483328.691	4326966.754	1897.217
495451	NVA	482642.766	4327334.282	1902.803
495452	NVA	482636.989	4327340.285	1902.469
495453	NVA	482630.340	4327346.684	1902.114
495454	NVA	482622.890	4327353.440	1901.742
495455	NVA	482614.821	4327360.646	1901.364
495456	NVA	482606.390	4327368.036	1901.011
495457	NVA	482597.790	4327375.340	1900.725
495458	NVA	482589.231	4327382.553	1900.526
495459	NVA	482580.814	4327389.662	1900.386
495460	NVA	482572.572	4327396.662	1900.306
495781	NVA	480987.747	4328226.612	1908.132
495782	NVA	480980.223	4328221.025	1908.481
495783	NVA	480972.716	4328215.294	1908.797
495784	NVA	480965.254	4328209.555	1909.206
495785	NVA	480957.959	4328203.956	1909.660
495786	NVA	480951.040	4328198.593	1910.000
495787	NVA	480944.301	4328193.427	1909.859
495788	NVA	480937.610	4328188.190	1909.603
495789	NVA	480930.994	4328182.993	1909.561
495790	NVA	480924.659	4328178.032	1909.907
497911	NVA	486082.015	4326561.791	1832.701
497912	NVA	486070.335	4326561.730	1832.910
497913	NVA	486058.680	4326561.716	1833.149
497914	NVA	486047.071	4326561.711	1833.402
497915	NVA	486035.488	4326561.739	1833.648
497916	NVA	486023.924	4326561.784	1833.923
497917	NVA	486012.388	4326561.843	1834.239
497918	NVA	486000.881	4326561.784	1834.565
497919	NVA	485989.382	4326561.621	1834.868
497920	NVA	485977.866	4326561.402	1835.167

Point	Type	Easting	Northing	Elevation
499060	NVA	486140.095	4327784.249	1841.079
499061	NVA	486129.091	4327784.194	1841.410
499062	NVA	486118.057	4327784.074	1841.618
499063	NVA	486106.835	4327783.830	1841.595
499064	NVA	486095.319	4327783.524	1841.423
499065	NVA	486083.629	4327783.282	1841.227
499066	NVA	486071.997	4327783.043	1841.082
499067	NVA	486060.518	4327782.836	1840.908
499068	NVA	486049.234	4327782.607	1840.766
499069	NVA	486038.132	4327782.306	1840.657
499070	NVA	486027.068	4327781.954	1840.496
501132	VVA	481147.359	4328289.787	1899.741
503160	VVA	483113.198	4326916.120	1907.380
502145	VVA	484139.858	4327800.566	1861.121
502458	VVA	484179.640	4327793.239	1860.828
503323	VVA	483104.938	4326931.106	1907.061
501166	VVA	481165.895	4328303.782	1899.530
501230	VVA	481186.045	4328293.673	1899.578
503493	VVA	483050.416	4326936.011	1910.030
501997	VVA	484160.915	4327793.206	1860.703
502108	VVA	484143.773	4327798.274	1861.088
503344	VVA	483098.069	4326931.703	1907.203
501207	VVA	481179.556	4328296.052	1899.378
501190	VVA	481172.740	4328298.886	1899.522
502807	VVA	483069.420	4326931.674	1908.545
502312	VVA	484144.572	4327807.210	1861.021
502178	VVA	484139.052	4327804.762	1861.127
502943	VVA	483083.264	4326919.395	1907.688
501144	VVA	481151.383	4328295.372	1899.780
502789	VVA	483063.346	4326938.518	1909.375
501919	VVA	484175.556	4327792.221	1860.793

Appendix B

Calibrated Control Point Report

Point	Easting	Northing	Known Z	Laser Z	Dz
BASE	483135.370	4327042.729	1898.437	1898.430	-0.007
MR1	483167.477	4327057.421	1896.779	1896.720	-0.059
MR2	483186.538	4327113.802	1896.454	1896.400	-0.054
MR3	480918.602	4328175.769	1910.467	1910.460	-0.007
MR4	485390.694	4326943.104	1844.503	1844.430	-0.073
MR6	483658.125	4326778.835	1905.712	1905.620	-0.092
495727	481138.045	4328310.967	1899.493	1899.500	0.007
495541	482294.232	4327697.851	1893.589	1893.580	-0.009
495364	482962.466	4327536.467	1903.881	1903.890	0.009
496404	483065.471	4326683.807	1934.293	1934.250	-0.043
495113	483362.803	4327093.505	1895.790	1895.790	0.000
496655	483454.838	4326581.948	1908.878	1908.920	0.042
498527	483854.888	4327954.781	1871.622	1871.650	0.028
498277	484047.859	4328107.214	1873.567	1873.570	0.003
499483	484191.081	4327593.036	1857.907	1857.930	0.023
499311	484408.979	4327993.208	1866.434	1866.500	0.066
499147	485164.280	4327771.522	1849.527	1849.510	-0.017
497130	486037.135	4326557.457	1833.628	1833.640	0.012
499042	486344.994	4327789.900	1838.711	1838.710	-0.001
496999	484745.087	4327217.105	1844.686	1844.720	0.034
496890	484053.142	4326834.962	1881.946	1881.990	0.044
495646	481657.719	4327917.495	1898.603	1898.620	0.017
496185	482661.213	4327302.149	1904.129	1904.150	0.021
498755	484764.568	4327619.002	1858.751	1858.760	0.009
	Average Dz	-0.002			
	Minimum Dz	-0.092			
	Maximum Dz	0.066			
	Root Mean Square	0.038			
	Std. Deviation	0.038			

Raw NVA Check Point Report

Point	Easting	Northing	Known Z	Laser Z	Dz
495131	483329.957	4327030.016	1896.429	1896.470	0.041
495132	483329.248	4327022.963	1896.524	1896.540	0.016
495133	483328.700	4327015.764	1896.616	1896.650	0.034
495134	483328.171	4327008.543	1896.681	1896.710	0.029
495135	483327.666	4327001.350	1896.744	1896.780	0.036
495136	483327.161	4326994.194	1896.816	1896.850	0.034
495137	483326.785	4326987.030	1896.908	1896.940	0.032
495138	483326.826	4326979.987	1897.001	1897.040	0.039
495139	483327.401	4326973.200	1897.104	1897.140	0.036
495140	483328.691	4326966.754	1897.217	1897.240	0.023
495451	482642.766	4327334.282	1902.803	1902.820	0.017
495452	482636.989	4327340.285	1902.469	1902.490	0.021
495453	482630.340	4327346.684	1902.114	1902.120	0.006
495454	482622.890	4327353.440	1901.742	1901.740	-0.002
495455	482614.821	4327360.646	1901.364	1901.380	0.016
495456	482606.390	4327368.036	1901.011	1901.030	0.019
495457	482597.790	4327375.340	1900.725	1900.740	0.015
495458	482589.231	4327382.553	1900.526	1900.540	0.014
495459	482580.814	4327389.662	1900.386	1900.420	0.034
495460	482572.572	4327396.662	1900.306	1900.330	0.024
495781	480987.747	4328226.612	1908.132	1908.140	0.008
495782	480980.223	4328221.025	1908.481	1908.480	-0.001
495783	480972.716	4328215.294	1908.797	1908.810	0.013
495784	480965.254	4328209.555	1909.206	1909.210	0.004
495785	480957.959	4328203.956	1909.660	1909.670	0.010
495786	480951.040	4328198.593	1910.000	1910.020	0.020
495787	480944.301	4328193.427	1909.859	1909.880	0.021
495788	480937.610	4328188.190	1909.603	1909.630	0.027
495789	480930.994	4328182.993	1909.561	1909.570	0.009
495790	480924.659	4328178.032	1909.907	1909.920	0.013
497911	486082.015	4326561.791	1832.701	1832.690	-0.011
497912	486070.335	4326561.730	1832.910	1832.900	-0.010
497913	486058.680	4326561.716	1833.149	1833.130	-0.019
497914	486047.071	4326561.711	1833.402	1833.380	-0.022
497915	486035.488	4326561.739	1833.648	1833.630	-0.018
497916	486023.924	4326561.784	1833.923	1833.900	-0.023
497917	486012.388	4326561.843	1834.239	1834.220	-0.019
497918	486000.881	4326561.784	1834.565	1834.540	-0.025
497919	485989.382	4326561.621	1834.868	1834.850	-0.018
497920	485977.866	4326561.402	1835.167	1835.150	-0.017
499060	486140.095	4327784.249	1841.079	1841.070	-0.009
499061	486129.091	4327784.194	1841.410	1841.410	0.000

499062	486118.057	4327784.074	1841.618	1841.620	0.002
499063	486106.835	4327783.830	1841.595	1841.600	0.005
499064	486095.319	4327783.524	1841.423	1841.430	0.007
499065	486083.629	4327783.282	1841.227	1841.210	-0.017
499066	486071.997	4327783.043	1841.082	1841.060	-0.022
499067	486060.518	4327782.836	1840.908	1840.920	0.012
499068	486049.234	4327782.607	1840.766	1840.790	0.024
499069	486038.132	4327782.306	1840.657	1840.660	0.003
499070	486027.068	4327781.954	1840.496	1840.510	0.014
	Average Dz	0.009			
	Minimum Dz	-0.025			
	Maximum Dz	0.041			
	Root Mean Square	0.021			
	Std. Deviation	0.019			
	95% Confidence Level	0.041			

DEM - NVA Check Point Report

Point	Easting	Northing	Known Z	Laser Z	Dz
495131	483329.957	4327030.016	1896.429	1896.460	0.031
495132	483329.248	4327022.963	1896.524	1896.550	0.026
495133	483328.700	4327015.764	1896.616	1896.650	0.034
495134	483328.171	4327008.543	1896.681	1896.720	0.039
495135	483327.666	4327001.350	1896.744	1896.780	0.036
495136	483327.161	4326994.194	1896.816	1896.840	0.024
495137	483326.785	4326987.030	1896.908	1896.940	0.032
495138	483326.826	4326979.987	1897.001	1897.040	0.039
495139	483327.401	4326973.200	1897.104	1897.140	0.036
495140	483328.691	4326966.754	1897.217	1897.240	0.023
495451	482642.766	4327334.282	1902.803	1902.820	0.017
495452	482636.989	4327340.285	1902.469	1902.490	0.021
495453	482630.340	4327346.684	1902.114	1902.120	0.006
495454	482622.890	4327353.440	1901.742	1901.750	0.008
495455	482614.821	4327360.646	1901.364	1901.380	0.016
495456	482606.390	4327368.036	1901.011	1901.020	0.009
495457	482597.790	4327375.340	1900.725	1900.740	0.015
495458	482589.231	4327382.553	1900.526	1900.540	0.014
495459	482580.814	4327389.662	1900.386	1900.410	0.024
495460	482572.572	4327396.662	1900.306	1900.320	0.014
495781	480987.747	4328226.612	1908.132	1908.140	0.008
495782	480980.223	4328221.025	1908.481	1908.490	0.009
495783	480972.716	4328215.294	1908.797	1908.810	0.013
495784	480965.254	4328209.555	1909.206	1909.210	0.004
495785	480957.959	4328203.956	1909.660	1909.670	0.010

495786	480951.040	4328198.593	1910.000	1910.010	0.010
495787	480944.301	4328193.427	1909.859	1909.870	0.011
495788	480937.610	4328188.190	1909.603	1909.630	0.027
495789	480930.994	4328182.993	1909.561	1909.580	0.019
495790	480924.659	4328178.032	1909.907	1909.930	0.023
497911	486082.015	4326561.791	1832.701	1832.690	-0.011
497912	486070.335	4326561.730	1832.910	1832.900	-0.010
497913	486058.680	4326561.716	1833.149	1833.130	-0.019
497914	486047.071	4326561.711	1833.402	1833.380	-0.022
497915	486035.488	4326561.739	1833.648	1833.630	-0.018
497916	486023.924	4326561.784	1833.923	1833.900	-0.023
497917	486012.388	4326561.843	1834.239	1834.220	-0.019
497918	486000.881	4326561.784	1834.565	1834.540	-0.025
497919	485989.382	4326561.621	1834.868	1834.840	-0.028
497920	485977.866	4326561.402	1835.167	1835.150	-0.017
499060	486140.095	4327784.249	1841.079	1841.080	0.001
499061	486129.091	4327784.194	1841.410	1841.410	0.000
499062	486118.057	4327784.074	1841.618	1841.600	-0.018
499063	486106.835	4327783.830	1841.595	1841.600	0.005
499064	486095.319	4327783.524	1841.423	1841.430	0.007
499065	486083.629	4327783.282	1841.227	1841.220	-0.007
499066	486071.997	4327783.043	1841.082	1841.060	-0.022
499067	486060.518	4327782.836	1840.908	1840.930	0.022
499068	486049.234	4327782.607	1840.766	1840.790	0.024
499069	486038.132	4327782.306	1840.657	1840.660	0.003
499070	486027.068	4327781.954	1840.496	1840.500	0.004

Average Dz	0.008
Minimum Dz	-0.028
Maximum Dz	0.039
Root Mean Square	0.020
Std. Deviation	0.019
95% Confidence Level	0.040

DEM - VVA Check Point Report

Point	Easting	Northing	Known Z	Laser Z	Dz
501132	481147.359	4328289.787	1899.741	1899.850	0.109
503160	483113.198	4326916.120	1907.380	1907.450	0.070
502145	484139.858	4327800.566	1861.121	1861.250	0.129
502458	484179.640	4327793.239	1860.828	1860.900	0.072
503323	483104.938	4326931.106	1907.061	1907.100	0.039
501166	481165.895	4328303.782	1899.530	1899.550	0.020
501230	481186.045	4328293.673	1899.578	1899.440	-0.138
503493	483050.416	4326936.011	1910.030	1910.000	-0.030
501997	484160.915	4327793.206	1860.703	1860.870	0.167
502108	484143.773	4327798.274	1861.088	1861.090	0.002
503344	483098.069	4326931.703	1907.203	1907.370	0.167
501207	481179.556	4328296.052	1899.378	1899.470	0.092
501190	481172.740	4328298.886	1899.522	1899.540	0.018
502807	483069.420	4326931.674	1908.545	1908.610	0.065
502312	484144.572	4327807.210	1861.021	1861.200	0.179
502178	484139.052	4327804.762	1861.127	1861.190	0.063
502943	483083.264	4326919.395	1907.688	1907.710	0.022
501144	481151.383	4328295.372	1899.780	1899.710	-0.070
502789	483063.346	4326938.518	1909.375	1909.740	0.365
501919	484175.556	4327792.221	1860.793	1860.830	0.037

Average Dz	0.069
Minimum Dz	-0.138
Maximum Dz	0.365
Root Mean Square	0.124
Std. Deviation	0.105
95th Percentile	0.188

Appendix C

Flight Logs

Date: 10/21/2017	Aircraft: N7269T		Sensor: 12 SEN 315
Project: Millsite Reservoir			**Job #:** 17182
	Flight 1		
Wheels Up:	0847		
Wheels Down:	1709		
Begin Tach:	7164.1		
End Tach:	7170.8		
Mobilization Tach:	2.7		
Online Tach:	4.0		
Pilot: Doxey		**Operator:** Wilets	
Notes: Windy/bumpy conditions late afternoon			

Date: 10/25/2017	Aircraft: N7269T		Sensor: 12 SEN 315
Project: Millsite Reservoir			**Job #:** 17182
	Flight 1		
Wheels Up:	1059		
Wheels Down:	1320		
Begin Tach:	7178.1		
End Tach:	7180.4		
Mobilization Tach:	2.0		
Online Tach:	0.3		
Pilot: McBeth		**Operator:** Wilets	
Notes: No issues to report			

Base Station Coordinates for Aerial Trajectory

Base Station	NAD 83 (2011)		
	Latitude	Longitude	Height
H61021p (Oct. 21)	39° 36’ 45.07708”	-110° 44’ 55.61369”	1771.365
CAST (Oct. 25)	39° 11’ 27.67920”	-110° 40’ 38.32680”	2245.041

NGS Reference Coordinates for Aerial Trajectory Base Station (H61021p)

CORS Station	NAD 83 (2011)		
	Latitude	Longitude	Height
MC06	39° 13’ 21.09183”	-108° 51’ 05.90441”	1393.278
ZLC1	40° 47’ 09.73905”	-111° 57’ 07.78593”	1287.693
PUC2	39° 35’ 38.10058”	-110° 45’ 41.52524”	1714.255

Appendix D

SOW

Scope of Work on Master Agreement # AV2406
Acquisition of Aerial Lidar Elevation Data
Millsite Reservoir

The State of Utah, Department of Technology Services, Division of Integrated Technology, Automated Geographic Reference Center (AGRC) and partners are contracting with Aero-Graphics, Inc. to acquire, process, and deliver aerial Lidar data and derivative products that meet the specifications described in this Scope of Work, and contracted under Master Agreement #AV2406.

This Scope of Work (SOW) identifies the specific acquisition requirements, production specifications and standards, deliverables, and schedule for Lidar data collection and deliverable data products that adhere to the U.S. Geological Survey (USGS) Quality Level 1 (QL1) Lidar specifications for the entire area defined in this agreement. The Lidar data will be acquired after October 20th, 2017 with leaf-off conditions and no snow on the ground. Pricing will be based on the cost submitted in the bid response to solicitation DTS20182658 for Millsite Reservoir project area by Aero-Graphics, Inc.

1. Lidar Data Products

The lidar data product must adhere to USGS National Geospatial Program (NGP) *Lidar Base Specification Version 1.2* (2014) available at http://pubs.usgs.gov/tm/11b4/. These lidar specifications are required minimum baseline specifications and project deliverables shall meet or exceed USGS QL1, as specified per project area. For any item which is not specifically addressed, the referenced *Lidar Base Specification Version 1.2* will be the required specification authority.

2. Project Areas, Performance Period, and Acquisition Modifications

The State of Utah 2017 Lidar Acquisition Project ("Project") covers portions of Utah shown in Millsite Reservoir - Figure 1.png, and are delineated in Millsite Reservoir - Attachment 1.zip (Millsite_Reservoir.shp).

2.1. Project Area

The Project acquisition areas total approximately 11.8 mi^2 in central Utah shown in Figure 1. Further explanation of the project areas is explained in Section 2.1.1. For the contracted acquisition areas, the delivered data products must cover at least the spatial extent (footprint) of the acquisition areas delineated in Attachment 1. Any acquisition footprints that extend beyond Attachment 1 are acceptable, and if data is acquired outside these footprints, at least the raw point cloud data shall be provided.

2.1.1. Millsite Reservoir and Millsite Reservoir

The Millsite Reservoir project area, located in Emery County, west of Ferron, UT is approximately 11.8 mi^2. Lidar acquisition in these areas require QL1 specifications.

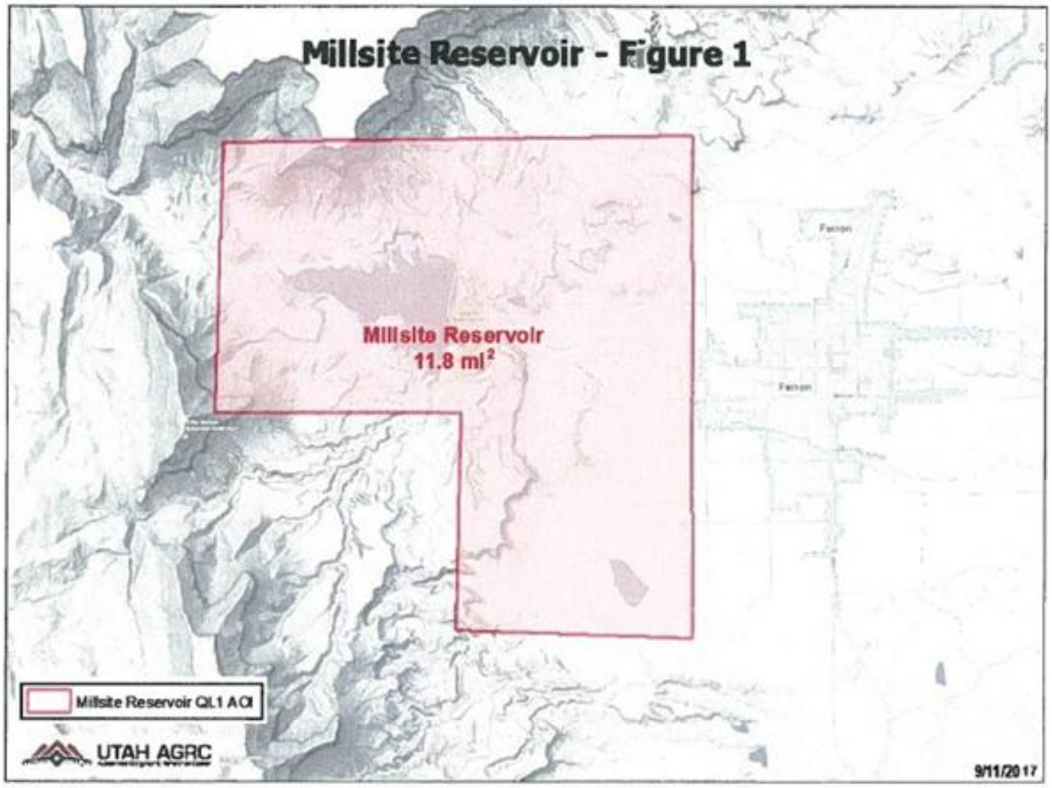


Figure 1: Acquisition Areas

2.2. Performance Period

For the areas described in Section 2.1. the acquisition shall be after October 20th, 2017, maximizing leaf-off conditions, low water levels, and no snow on the ground.

2.3. Acquisition Modifications

Any additions or modifications to the lidar project areas (including areas located outside of Utah), by either the State or the other cooperators, will adhere to the data deliverables, standards, specifications criteria, and inspection process described in this SOW. Any changes after initial contracts are negotiated will be made through the agreed upon contract amendment process.

3. Delivery and Quality Assessment and Acceptance Schedule

The Lidar data acquisition schedule will be agreed to by the State and Aero-Graphics, Inc. based on actual weather and on-the-ground conditions after the contract has been approved. This schedule may include a small initial pilot delivery, selected from within the project areas, to ensure that data meets the specifications and conditions of the contract.

A formal data product delivery schedule will be agreed to by AGRC and Aero-Graphics, Inc. after the contract has been approved and may be modified by changes in the acquisition schedule. Lidar acquisition should be timed to ensure the ground is free of snow, ice and standing water, rivers are free of ice and are at a stage of low flow, and lakes and reservoirs are close to the lowest levels of the year. Leaf-off vegetation conditions are preferred and lidar penetration to the ground must be adequate to produce a bare-earth surface DEM that meets or exceeds requirements for vertical accuracy.

The anticipated schedule of delivery and quality assurance is as follows:

- Flight of contracted area for data product.
  - Length of acquisition time to be determined by Aero-Graphics, Inc. in collaboration with AGRC.
- Process and deliver all data products to AGRC for initial inspection and review.
  - AGRC has 30 days to review and submit correction requests.
- Aero-Graphics, Inc. addresses initial review comments and redelivers areas to AGRC for final inspection.
  - Aero-Graphics, Inc. has 20 days to redeliver with corrections.
- AGRC final inspection and review.
  - AGRC has 20 days to review and submit correction requests.
- Aero-Graphics, Inc. addresses final review comments and delivers final and complete data products to AGRC.
  - Aero-Graphics, Inc. has 20 days to redeliver final data product.

If it is not possible to rework the data to correct error(s), a reflight of that area may be required.

3.1. Inspection Schedule

An inspection schedule for quality assurance of all products will be developed between Aero-Graphics, Inc. and AGRC. Aero-Graphics, Inc. shall document its internal quality assurance work as described in Section 6. A review committee designated by AGRC will quality check the lidar products. The USGS National Geospatial Technical Operations Center (NGTOC) will also be used to ensure that the delivered data products meet the requirements of the USGS NGP *Lidar Base Specification Version 1.2* (2014) and The National Map: 3D Elevation Program (3DEP) set forth in this SOW. Deliverables will not be accepted without acceptance by the USGS NGTOC. The inspection period for each initial data product delivery will be up to 30-calendar days; these inspection periods may be concurrent. Review of any redelivery of data with corrections will be completed within 20-calendar days of receipt. If collection conditions necessitate the need for a later acquisition, AGRC, and Aero-Graphics, Inc. can modify this date through a contract amendment. Deliveries will be made to AGRC.

4. Access to Lands and Airspace

Aero-Graphics, Inc. is responsible for applying for and obtaining all required permits, clearances, permissions, etc. for access, over-flight, or intrusion to restricted or otherwise limited ground access and/or airspace, which may be included within the requirement of this project. AGRC can assist with expediting these processes where possible.

5. Data Product Deliverables

See the USGS NGP *Lidar Base Specifications Version 1.2* (2014) (http://pubs.usgs.gov/tm/11b4/) "Data Processing and Handling" section and Section 15 "Cited Specifications and Standards" for requirements on the processing and handling of the lidar data.

5.1. Metadata

Descriptive information about the project to include textual reports, graphics, supporting shapefiles, and Federal Geographic Data Committee (FGDC) compliant metadata files are required. See National Spatial Data Infrastructure (NSDI) Content Standards for Digital Geospatial Metadata (FGDC, 1998) and Lidar Base Specifications Version 1.2 (USGS, 2014) "Metadata" section for metadata requirements for this project.

A current Product Characterization Report of the instrument used shall be included in the Project History Report/Folder (Section 6) as a deliverable.

5.2 Raw Point Cloud

Raw point cloud deliverables shall include or conform to the following procedures and specifications:

- No classifications are required; however, Overage (overlap) and Withheld Flags will be properly set.
- All collected points, fully calibrated, georeferenced, and adjusted to ground, organized and delivered in their original swaths, one file per swath, one swath per file.
- If production processing required segmentation of the swath files, the requirements listed in the section "Swath Size and Segmentation," shall be met.
- Fully compliant LAS Specification version 1.4, Point Data Record Format 6, 7, 8, 9, or 10.
- If collected, waveform data in external auxiliary files with the extension .wdp. See the LAS Specification version 1.4 (American Society for Photogrammetry and Remote Sensing, 2011) for additional information.
- Correct and properly formatted georeference information as Open Geospatial Consortium (OGC) well known text (WKT) in all LAS file headers.
- GPS times recorded as Adjusted GPS Time at a precision sufficient to allow unique timestamps for each pulse.
- Intensity values, normalized to 16-bit. See the LAS Specification version 1.4 (American Society for Photogrammetry and Remote Sensing, 2011) for additional information.
- A report of the assessed relative vertical accuracy of the point cloud (smooth surface repeatability and overlap consistency). Relative vertical accuracy requirements are listed in table 2. Raw swath point cloud data shall meet the

required accuracy levels before point cloud classification and derivative product generation.
- A report of the assessed absolute vertical accuracy (NVA only) of the unclassified lidar point data in accordance with the guidelines set forth in the Positional Accuracy Standards for Digital Geospatial Data (American Society for Photogrammetry and Remote Sensing, 2014). Absolute vertical accuracy requirements using the ASPRS methodology for the raw point cloud are listed in table 4. Raw swath point cloud data shall meet the required accuracy levels before point cloud classification and derivative product generation.

5.3 Classified Point Cloud

Classified point cloud deliverables shall include or conform to the following procedures and specifications:

- All project swaths, returns, and collected points, fully calibrated, adjusted to ground, and classified, by tiles. Project swaths exclude calibration swaths, cross-ties, and other swaths not used and not intended to be used, in product generation.
- Fully compliant LAS Specification version 1.4 Point Data Record Format 6, 7, 8, 9, or 10.
- If collected, waveform data in external auxiliary files with the extension .wdp. See the LAS Specification version 1.4 (American Society for Photogrammetry and Remote Sensing, 2011) for additional information.
- Correct and properly formatted georeferenced information as OGC WKT included in all LAS file headers.
- GPS times recorded as Adjusted GPS Time at a precision sufficient to allow unique timestamps for each pulse.
- Intensity values, normalized to 16-bit. See the LAS Specification version 1.4 (American Society for Photogrammetry and Remote Sensing, 2011) for additional information.
- Tiled delivery, without overlap, using the project tiling scheme.
- Classification, as defined below.

Code/Class	Description
1	Processed, but unclassified
2	Bare earth
7	Low noise
9	Water
10	Ignored ground (near a breakline)
17	Bridge decks
18	High noise

5.4 Bare-Earth Surface (Raster DTM), Hydro-Flattening, and Breaklines

Bare-earth deliverables include the following:

- Bare-earth DEM with hydro-flattening (see section 5.4.1 Hydro-Flattening).
- Cell size no greater than 0.5 meters and no less than the design Nominal Pulse Spacing (NPS) for QL1 collections.
- Delivery in an industry-standard, GIS-compatible, 32-bit floating point raster format (ESRI Grid preferred).
- Georeference information shall be included in each raster file.
- Tiled delivery, without overlap, using Project Tiling Scheme (section 7).
- DEM tiles will show no edge artifacts or mismatch. A quilted appearance in the overall project DEM surface, whether caused by differences in processing quality or character between tiles, swaths, lifts, or other non-natural divisions, will be cause for rejection of the entire deliverable.
- Void areas shall be coded using a unique 'NODATA' value. This value shall be identified in the appropriate location within the raster file header or external support files (for example, *.aux*).
- A report on the assessed absolute vertical accuracy (NVA and VVA) of the bare-earth surface in accordance with the guidelines set forth in the "Positional Accuracy Standards for Digital Geospatial Data" (American Society for Photogrammetry and Remote Sensing, 2014).
- The following thresholds represent the minimum vertical accuracy requirements using the NDEP/ASPRS methodology:
    - NVA ≤ 19.6 cm, 95% Confidence Level (≤10 cm $RMSE_z$)
    - VVA ≤ 29.4 cm, 95% Confidence Level (≤10 cm $RMSE_z$)
    - All Quality Assurance/Quality Control (QA/QC) analysis materials and results are to be delivered to the State.
- Depressions (sinks), natural or man-made, are not to be filled (as in hydro-conditioning and hydro-enforcement).
- Permanent islands 1 acre or larger shall be delineated within all water bodies.

5.4.1. Hydro-Flattening

- Hydro-flattening shall be applied to all water within the main channels of rivers and streams, along with all water bodies or impoundments, natural or man-made, that are larger than 2 acres in area (approximately equal to a round pond 350 feet in diameter), and to all streams that are nominally wider than 100 feet, and to all non-tidal boundary waters bordering the project area regardless of size are to be hydro-flattened within the delivered DEMs. Refer to *Lidar Base Specifications Version 1.2* (USGS, 2014) "Hydro-Flattening" section for further explanation.
- Hydro-flattened water bodies (lake and ponds) are leveled at a single elevation and streams and rivers are conditioned for continuous downhill flow.
- Hydro-flattened/Bare-earth surface must cover the entire water body and leave no holes in the center. This can be done with interpolation and does not require lidar collection over the entire water body.
- All hydro-flattened areas should have pleasing aesthetic appearance.
- The methodology used for hydro-flattening is at the discretion of Aero-Graphics, Inc. Refer to the "Digital Elevation Model Hydro-Flattening" section and "Appendix 2. Hydro-Flattening Reference" in the Lidar Base

Specifications Version 1.2 for detailed discussions concerning hydro-flattening.
- The bare-earth DEM data should keep intact all road culverts and similar features, regardless of size, defined as having earth between the road surface and the top of the structure.
- Bridges are required to be removed from the bare-earth DEM. Streams and rivers should be continuous at bridge locations.

5.4.2. Breaklines

All breaklines used for hydro-flattening are to be delivered in a shapefile and/or geodatabase format as PolylineZ or PolygonZ feature classes. See *Lidar Base Specifications Version 1.2* (USGS, 2014) “Breaklines” section for breakline requirements.

5.5 First Return Surface (Raster DSM)

First-return deliverables include the following:

- First return DEM (for example, highest hit).
- Cell size no greater than 0.5 meters and no less than the design Nominal Pulse Spacing (NPS) for QL1 collections.
- Delivery in an industry-standard, GIS-compatible, 32-bit floating point raster format (ESRI Grid preferred).
- Georeference information shall be included in each raster file.
- Tiled delivery, without overlap, using Project Tiling Scheme (Section 7).
- DEM tiles will show no edge artifacts or mismatch. A quilted appearance in the overall project DEM surface, whether caused by differences in processing quality or character between tiles, swaths, lifts, or other non-natural divisions, will be cause for rejection of the entire deliverable.

Void areas shall be coded using a unique ‘NODATA’ value. This value shall be identified in the appropriate location within the raster file header or external support files (for example, *.aux*).

5.6 Intensity Images

- 0.5 m resolution intensity images in 8-bit grayscale GeoTIFF format for QL1 collections.

6. Contractor’s Project History Report/Folder

Aero-Graphics, Inc. will compile and provide a project history report/folder upon conclusion of the lidar acquisition. This folder will be used by AGRC in the inspection process for the lidar. The report/folder, will contain, at a minimum, the following:

- Methods
    - A record of field work procedures.

- Data derivation and adjustments.
- Processing report detailing calibration, classification, and product generation procedures including methodology used for breakline collection and hydro-flattening.
- Any problems encountered and solutions used in resolving such problems.

- Correspondence and records
  - The Statement of Work (SOW) between AGRC and Aero-Graphics, Inc.
  - All production guidance received from AGRC to include all written guidance from telephone conferences, emails, or contractual modifications, or any other source.
  - Lidar acquisition methods; results; Aero-Graphics, Inc. accuracy assessments, including internal reproducibility and absolute accuracy; file formats; file-naming schemes; and tiling schemes.
- Flight information
  - Aircraft trajectory log
    - SBET files (smooth, best, estimated trajectory) detailing aircraft position (easting, northing, elevation), angle, rotation (heading, pitch, and roll), and GPS time, recorded at regular intervals of ≤ 1 second. May include additional attributes (ASCII text or shapefile and .dbf format).
  - Statistical report summarizing the results of the airborne GPS adjustment and the overall accuracy of the adjusted IMU data.
  - Collection report detailing mission planning and flight logs.
- Control
  - Survey Report detailing the collection of control and reference points used for calibration and QA/QC.
  - The documentation for the identity, published position, and measured position of all existing National Geodetic Survey (NGS) marks used for reference stations.
- Quality Assurance/Quality Control (QA/QC)
  - QA/QC Reports (detailing the analysis, accuracy assessment and validation of:
    - The point data (absolute, within swath, and between swath)
    - The bare-earth surface (absolute)
    - Other optional deliverables as appropriate
  - Quality control procedures and results.
  - All internal quality control checklists.
  - Internal quality control error calls and the corrective actions taken to correct the error(s).
  - All Aero-Graphics, Inc. QA validation reports/error reports and accuracy reports, generated from internal software QA programs demonstrating that the data meets requirements as stated in the SOW.

7. Tiling Scheme

A single non-overlapped tiling scheme for both data products will be established and agreed upon by AGRC and Aero-Graphics, Inc. before each collection. This scheme will be used for ALL tiled deliverables.

Tiling for the Lidar deliverables will be based on the U.S. National Grid and should be named according to the U.S. National Grid System based on the SW corner (ex. 12TVK060160). Tiles will be 2,000-meter x 2,000-meter tiles with the exception of tiles around the periphery of the project area that are better suited for 1,000-meter x 1,000-meter tiles. 1,000-meter x 1,000-meter tiles will be used for the .las point cloud files.

- Tile size is required to be an integer multiple of 0.5 meters for raster deliverables.
- Tiles are required to be sized using the same units as the coordinate system of the data.
- Tiles are required to be indexed in X and Y to an integer multiple of the tile's X-Y dimensions.
- All tiled deliverables will conform to the project tiling scheme, without added overlap.
- Tiled deliverables will edge-match seamlessly and without gaps.

7.1. Void Areas

The extent of lidar coverage over the project area shall be sufficient to ensure void areas do not exist within the project area. Void areas within delivered tiles and within the project area are not acceptable.

8. Delivery Medium and Format

Deliverables shall be delivered on USB3 compatible portable hard drives using an uncompressed and unencrypted NTFS file system. Delivery tiles shall be accompanied by an index shapefile, of the tiles delivered, suitable for loading into ArcMap.

All data and products associated with contract deliverables will meet or exceed relevant National Standard for Spatial Data Accuracy (NSSDA) standards. See *NSDI Geospatial Positioning Accuracy Standards, Part 3: National Standard for Spatial Data Accuracy* (FGDC, 1998).

At the completion of the project, after all deliverables have been accepted by AGRC, Aero-Graphics, Inc. will deliver hard drives containing all the finalized deliverables for the project, and become the property of the State of Utah.

9. Data Acquisition Requirements and Collection Conditions

Refer to *Lidar Base Specification Version 1.2* (2014) for the following specifications:

- Acquisition requirements
- Collection conditions

9.1. Additional Data Acquisition Requirements

- Instrument calibrated for every mission.
- Flight plans are parallel flight lines with a cross-tie at/and or near the end of each project flightlines.
- Flight plan considers requirements for point density, terrain, PDOP (positional dilution of position), and Geomagnetic *Kp* Index (see http://www-app3.gfz-potsdam.de/kp_index/description.html).

- The intensity values (signal strength) of each return pulse will be recorded in the LAS, in their files native radiometric resolution.
- In order to prevent clustering effects and ensure uniform densities throughout the data set, a regular 1 x 1 meter grid will be laid over the data. At least 90% of the cells in the grid shall contain the requisite number of points per square meter (ppsm).

10. Standards, Specifications, and Requirements

Refer to *Lidar Base Specification Version 1.2* (2014) for the following specifications:

- Quality Level 1 and Quality Level 2 Specifications
- Vertical Accuracy Requirements
- Positional Accuracy Validation
- Relative Accuracy Requirements
- Completeness of coverage

10.1. Projection and Mapping Units

- Projection (Coordinate System): Universal Transverse Mercator (UTM) Zone 12, NAD 83, Meters; NAVD88, Meters (NAD_1983_2011_UTM_Zone_12N).
- Mapping Units: Meters (UTM).
- Vertical Reference: Orthometric Heights, Meters.
- WKID: 6341 Authority: EPSG

10.2. Datums

All data collected must be tied to the datums listed below:

- Horizontal Datum:
  - North American Datum of 1983 / High Accuracy Resolution Network adjustment (NAD 83 [2011] / HARN) required.
- Vertical Datum:
  - North American Vertical Datum 1988 (NAVD88), using latest geoid model available from the NGS (for example, GEOID12B). All vertical units will be measured in meters.
- Geoid Model:
  - The most recent NGS approved geoid model is required to perform conversions from ellipsoidal heights to orthometric heights.

10.3. Usability

- Files shall have consistent internal formats.
- Aero-Graphics, Inc. shall propose all details of file names and file formats that are not specified here. Proposed names and formats must be approved by AGRC.
- Files may be gzip or zip compressed. Use of compression shall be lossless and uniform across a given data layer.
- GIS data (ESRI grids, shapefiles) shall have complete and correct associated projection, metadata, and sidecar files.
- All files must be readable and free of malicious code.

10.4. GPS Procedures

10.4.1. GPS Measurements

All GPS measurements shall be made with dual frequency Global Navigation Satellite System (GNSS) receivers with GLONASS. All GPS measurements shall be made during periods with PDOP ≤ 3.0 and with at least six satellites in common view of both a stationary reference receiver and the roving receiver.

10.4.2. Stationary Reference Receivers

Stationary reference receivers shall be located at existing NGS marks or at new marks. In the case of an existing mark, its location shall be verified by processing one GPS session of at least two hours duration and comparing the computed position with the position published by NGS. Each new mark shall be located by tying to one or more NGS Continuously Operating Reference Stations (CORS) by static GPS methods. If the distance to the nearest CORS is less than 80 km, use at least two independent GPS sessions, each at least two hours long. If the distance to the nearest CORS is greater than 80 km, use at least two sessions each at least four hours long.

10.4.3. GPS Reference Receivers

At least two GPS reference receivers shall be in operation during all lidar missions, sampling positions at ≥1 Hz. The roving GPS receiver in the aircraft shall sample positions at ≥ 2 Hz. Differential GPS baseline lengths shall be no longer than 30 km. Check Points, Ground Control Points (GCPs), or ground survey points used for both survey calibration and assessment of absolute vertical accuracy, shall be established using GPS and (or) other techniques that are expected to result in accuracies of 1.5 cm ($RMSE_z$) or better. Strongly clustered GCPs are useful, perhaps even desirable, for calibration. Vertical accuracy shall be assessed by calculating and averaging the distances between a subset of at least 30 GCPs that are not clustered and a surface interpolated from lidar first returns. At least 20% of flight line swaths should contain points in this subset and the maximum distance between these GCPs should be no less than one-half the maximum distance across the survey area.

10.4.4. Project History Report/Folder

Aero-Graphics, Inc. Project History Report/Folder (Section 6) shall document the identity, published position, and measured position of all existing NGS marks used for reference stations. The locations of new marks shall be described, along with their measured positions and the identity and published positions of CORS to which their locations were tied. The report shall describe the technique(s) used to establish GCPs and document the positions and residuals of all GCPs used to evaluate survey accuracy.

10.5. Ground Control

Two types of vertical accuracy GCP (or ground surveyed points) will be collected by Aero-Graphics, Inc. for this project: Control Points and Check Points. Refer to NSSDA guidelines, Lidar Base Specifications Version 1.2 (USGS, 2014) “Collection” section, and

ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data (ASPRS, 2004) "2.3 Selecting and Collecting Check Points" section for Check Point placement in land cover classes and guidelines on Check Points.

- The above two types of ground control will be clearly labeled and delivered as separate shapefiles to the State.

10.6. Supplemental Ground Control

Differentially corrected or real time GPS network (RTK) GPS ground control used to supplement the airborne GPS positional adjustment shall be stored on portable media, in a non-proprietary format mutually agreeable to AGRC and Aero-Graphics, Inc. Ground control is the responsibility of Aero-Graphics, Inc.

10.6.1. Utah Reference Network

AGRC maintains The Utah Reference Network (http://gis.utah.gov/#gps) of over 90 GPS VRS RTK stations and will facilitate use of this network upon request of Aero-Graphics, Inc.

11. Data Release, Data Use and Distribution Rights

11.1. Data Release

Aero-Graphics, Inc. will not release data produced in each project plan, to any other party or entity without approval by AGRC, prior to the processing, loading, incorporation, and AGRC's final acceptance of data products.

11.2. Data Use and Distribution Rights

After final acceptance has been made, all deliverable data and documentation will be free from restrictions regarding use and distribution (the State of Utah and partners require unrestricted rights to all delivered data and reports that are placed in the public domain). Data and documentation provided under this project plan shall be in the public domain and freely distributable by Federal, State, and local government agencies.

13. Project Communication

13.1. Production Status Reports

Aero-Graphics, Inc. shall provide weekly status reports for all work on projects to AGRC's Project Manager. Reports will include detailed information regarding the work accomplished for each production phase. An online website may be used to provide status information.

13.2. Acquisition Reports

Aero-Graphics, Inc. shall provide regular progress updates to AGRC's Project Manager throughout the data acquisition process.

- Update frequency shall be based upon the collection period, but no less than once a week.
- Reports shall include shapefiles representing the geographic extent of the acquired data.
- Updates shall commence at acquisition onset and shall continue until acquisition is complete.

13.3. Initial Project Meeting

An initial project meeting between AGRC and Aero-Graphics, Inc. will be scheduled after each project request. This meeting will ensure that both AGRC and Aero-Graphics, Inc. 1) understand the requirements necessary to produce the deliverables, 2) review source data, and 3) make any final adjustments to technical guidance.

13.4. Teleconference

Aero-Graphics, Inc. will teleconference regularly (weekly or as needed) with the State to discuss status, production, and technical issues during a project.

14. Delivery Date and Timely Completion

14.1. Delivery Date

AGRC and Aero-Graphics, Inc. will agree in writing to a delivery schedule for Lidar products. Deliver for all final Lidar products, including any redeliveries because of quality assurance rejection, is no later than May 31, 2018. Aero-Graphics, Inc. shall not exceed this date without agreement to a new date from AGRC. Any request for modifications of the final delivery date must be received 30 days prior to the expiration of the original date. Request will only be considered for reasons outside Aero-Graphics, Inc. control, such as unforeseen weather changes.

14.2. Timely Completion

The payment schedule shall include penalties for late delivery of products. The payment schedule will be based on 40% of the total project cost after completion of the lidar acquisition flights. After the completion of processing and corrections based on the quality assurance review by AGRC, and delivery of the final product(s) to AGRC, payment will be made as follows. If delivered on time as specified in the contract, another 30% of the total project cost will be paid. There will be a 30% holdback that will be paid after that final delivery of all data and required reports and metadata deliveries are confirmed by AGRC. If the final product(s) is not delivered on the schedule specified, there will be a 3% (of the total bid) penalty for each week the product delivery is delayed.

15. List of Cited Specifications and Standards

Specifications for the acquisition of Lidar and deliverables not explicitly outlined above must adhere to the required specifications in the following documents:

Proponent Agency/ Organization	Name	Published Date	Website
American Society for Photogrammetry and Remote Sensing (ASPRS)	LAS Specification Version 1.4	July 2011	http://www.asprs.org/a/society/committees/standards/LAS_1_4_r13.pdf
U.S. Geological Survey, National Geospatial Program (USGS NGP)	Lidar Base Specifications Version 1.2	2014	http://pubs.usgs.gov/tm/11b4/
Federal Geographic Data Committee (FGDC)	National Spatial Data Infrastructure (NSDI) Geospatial Positioning Accuracy Standards,	1998	http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3