LiDAR MAPPING REPORT

UTAH 3DEP – UINTAH TRIBAL AERIAL SURVEY

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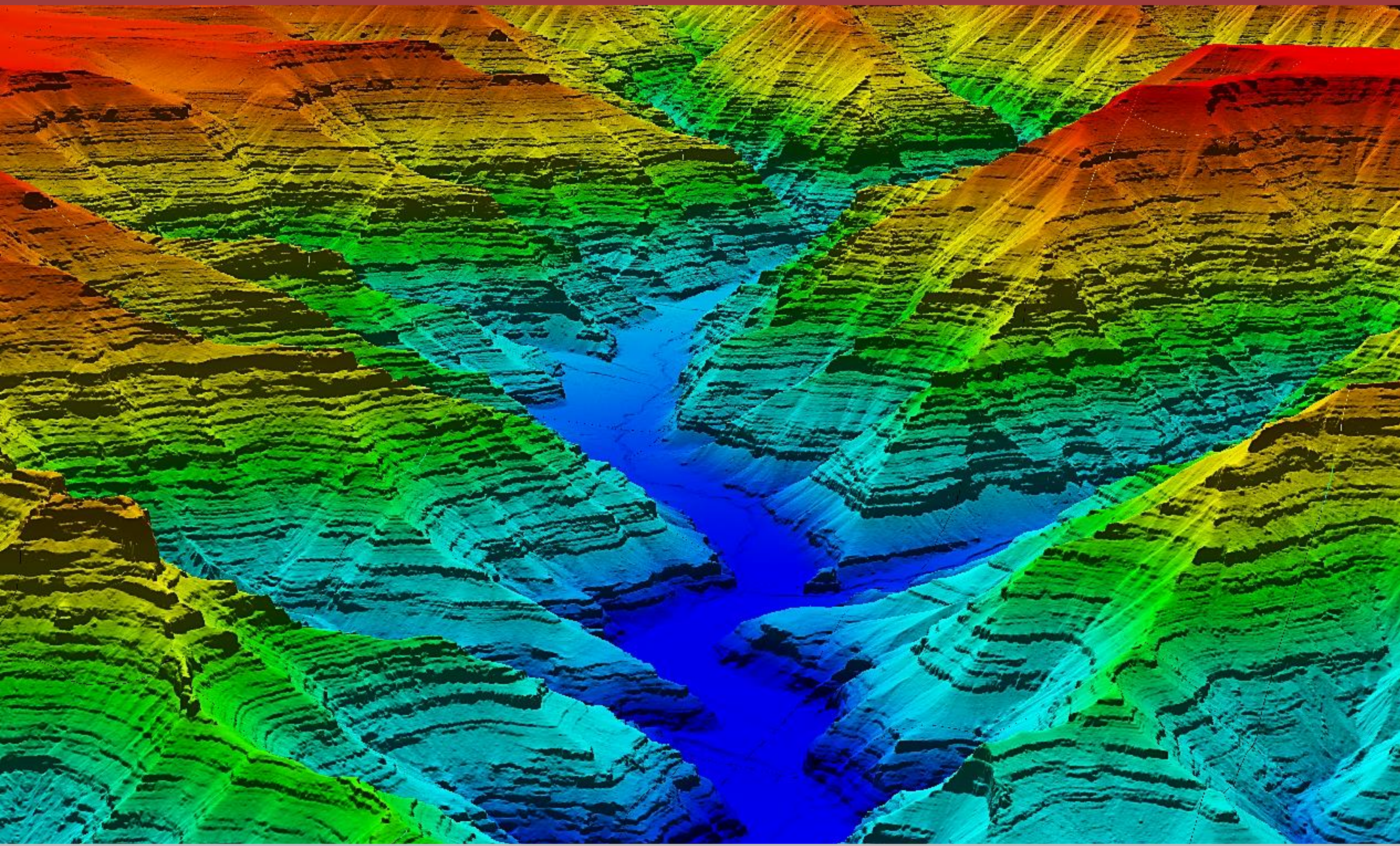

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LiDAR Mapping Report
Utah 3DEP - Uintah Tribal Aerial Survey

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1. Overview

1.1 Project Area

Aero-Graphics, Inc., a full-service geospatial firm located in Salt Lake City, Utah, was contracted by the U.S. Geological Survey (USGS) and partners to acquire, process, and deliver aerial lidar data and derivative products that adhere to U.S. Geological Survey (USGS) National Geospatial Program (NGP) Lidar Base Specification 2022, Revision A, QL2 standards. The assigned project area covers approximately 2,231 mi2 in Uintah County, Utah. Lidar data was delivered as processed Classified LAZ 1.4 files, formatted to 6,014 individual 1000 m x 1000 m tiles, as tiled Intensity Imagery and DSMs, and as tiled bare earth DEMs; all tiled to the same 1000 m x 1000 m schema.

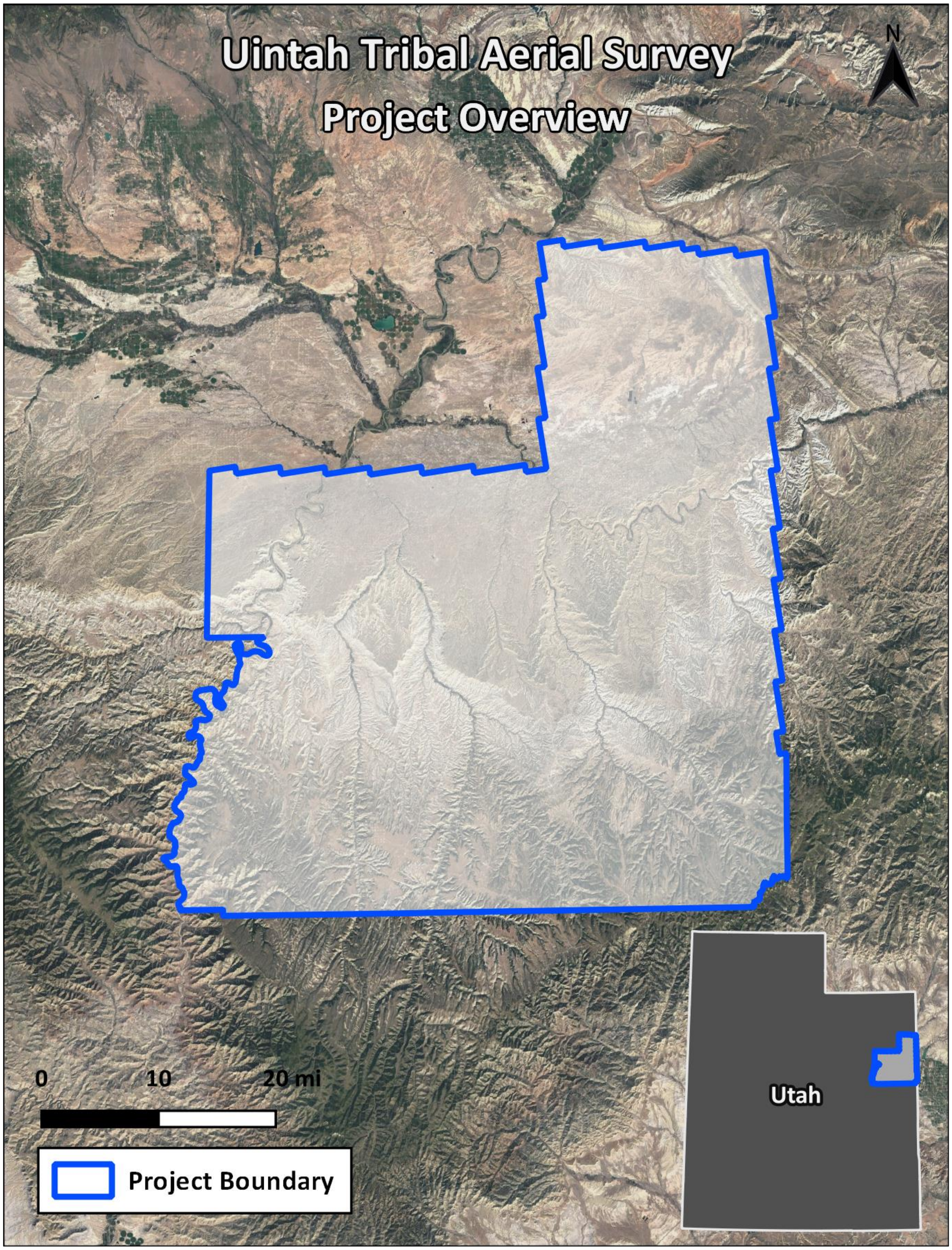
1.2 Project Deliverables

LiDAR Data	▪ Classified point cloud data in LAZ v1.4 format
Raster Data	▪ Bare-earth DEM, Digital Surface Model (DSM), and intensity imagery with a cell size of 1.0 meter in GeoTIFF format ▪ Swath separation images and maximum surface height rasters in GeoTIFF format
Vector Data	▪ Breaklines in SHP format, Flight index in SHP format ▪ Surveyed GCPs and checkpoints in .gpkg format
Report of Survey	▪ Reports and metadata as described in TO

1.3 Projection, Datum, Units

Projection		UTM Zone 12N
EPSG		6341
Datum	**Vertical**	NAVD88 (Geoid18)
	Horizontal	NAD83 (2011)
Units		Meters

Exhibit 1: **Utah 3DEP - Uintah Tribal project boundary**



2. Acquisition

2.1 Flight Planning

Aero-Graphics Aerial Department created a unique flight plan for this project using Optech's Airborne Mission Manager (AMM) flight planning software. AMM simulates flight plans based on the project area's terrain, as well as the sensor's model, mount, and settings. These features helped ensure that all contract specifications are met in the most efficient way possible. Prior to mobilizing to the acquisition sites, Aero-Graphics' staff monitored all site conditions and potential weather hazards including wind, rain, snow, and blowing dust. Additionally, Aero-Graphics ensured all airspace clearances were secured by the proper officials before acquisition occurred. A summary of the flight parameters and sensor settings for the Utah 3DEP - Uintah Tribal Aerial Survey are outlined in **Exhibit 2**.

<u>Exhibit 2:</u> Summary of planned flight parameters and sensor settings

Planned Specifications		
Aircraft		Cessna 310
Altitude (ft above ground level)		8,500
Speed (kts)		135
LiDAR Sensor		Optech Galaxy T2000
PRF (kHz)		700
Scan frequency (Hz)		73
Laser power		High
Scan Angle	Full	45°
	From nadir	± 22.5°
Planned Average Point Density (p/m²)		4.03
Post Spacing at Nadir	Cross Track (m)	0.52
	Down Track (m)	0.48
Swath Width (m)		2,117
Sidelap (%)		20
No. of Flightlines		94

2.2 Data Acquisition

Aero-Graphics acquired LiDAR data throughout June and July, 2022 with a turbocharged Cessna 310 (**Exhibit 3**). The stability of this platform is ideal for efficient data collection at high and low altitudes and at a variety of airspeeds. Additionally, our Cessna 310 has been customized to house a variety of airborne sensors, and the power system and avionics have been upgraded specifically to meet aerial survey needs.

<u>Exhibit 3</u>: A Cessna 310 was the acquisition platform for this project

The Optech Galaxy T2000 was selected for this project on account of its high accuracy and efficiency (**Exhibit 4**). This sensor uses SwathTrak technology, which dynamically adjusts the scan field of view in real time to maintain a constant swath width over a variety of terrains. It also features up to 8 returns per pulse, which increases the vertical resolution of complex terrains. The sensor is complemented with the use of FMS Nav, which allowed the system operator to monitor the point density and swath attributes of this project in real time, ensuring quality data and full coverage, as shown in **Exhibit 5**. More information about point density can be found in Section 4.4.

<u>Exhibit 4:</u> The Optech Galaxy T2000 was used for data acquisition

<u>Exhibit 5:</u> **Swath data for the Utah 3DEP - Uintah Tribal project was recorded and viewed in real-time by the sensor operator.**

2.3 Acquisition Summary

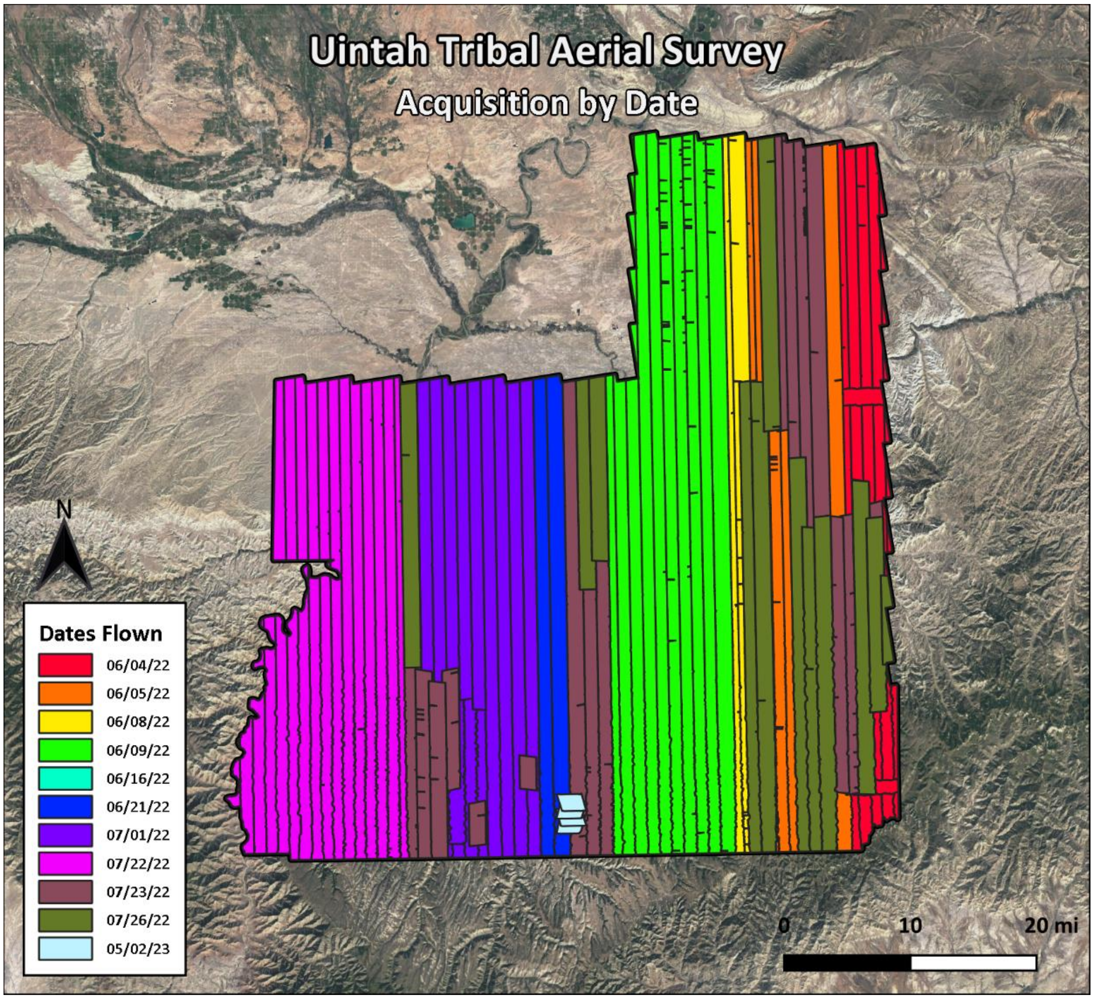


Exhibit 6: **The lines flown by date for the Utah 3DEP - Uintah Tribal project**

2.4 Ground Control and Check Point Survey

Aero-Graphics' professional land surveyor identified, targeted, and surveyed 25 ground control points (**Exhibit 7**) for use in data calibration as well as 68 QC check points (**Exhibit 8**) in vegetated and non-vegetated land cover classification 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 control points and QC check points. Ground control coordinates can be found in Appendix A. A summary of LiDAR calibration control vertical accuracy can be found in Section 4.2 with a more detailed report in Appendix B.

Exhibit 7: **Static ground control for the Utah 3DEP - Uintah Tribal project**

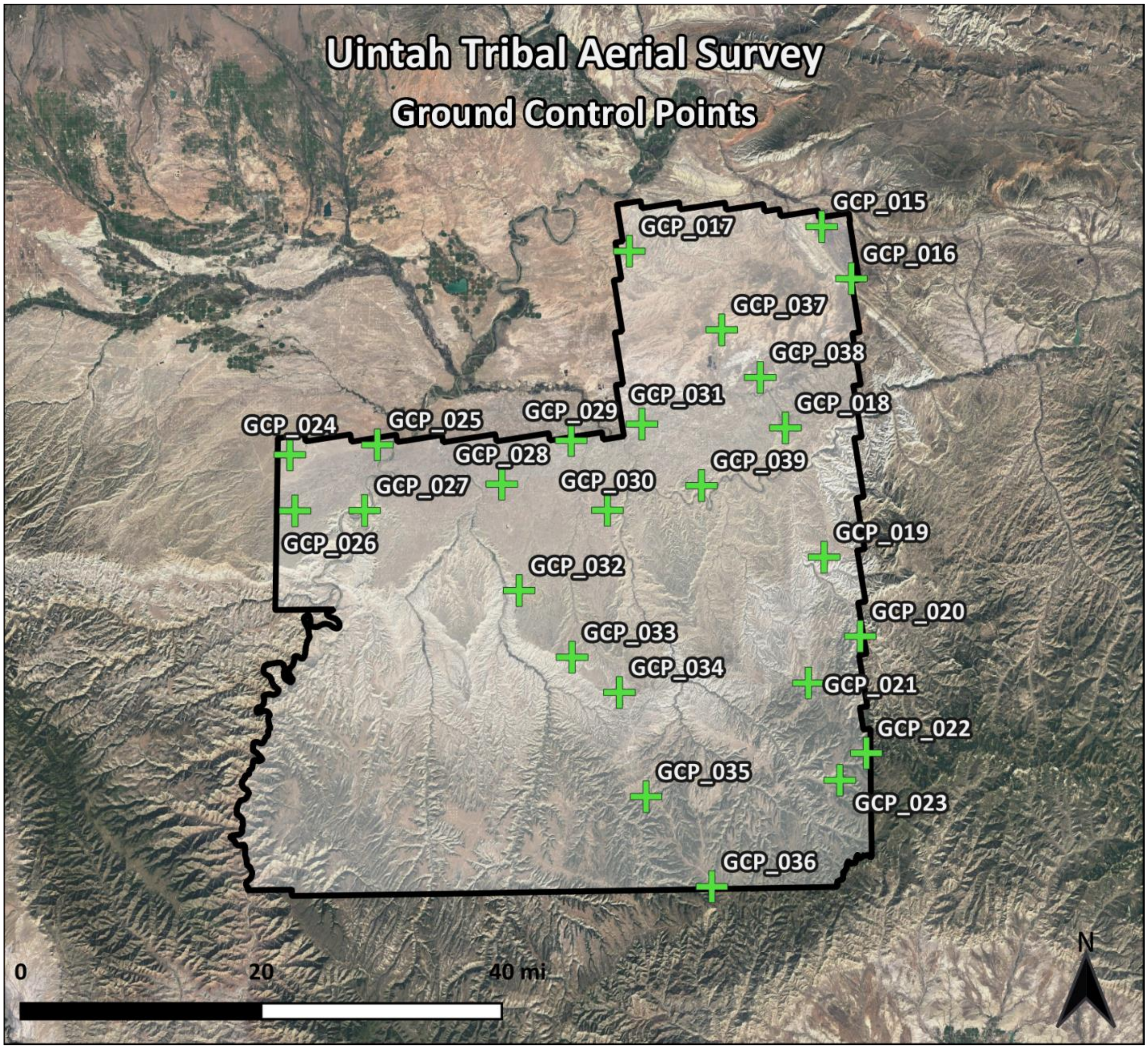
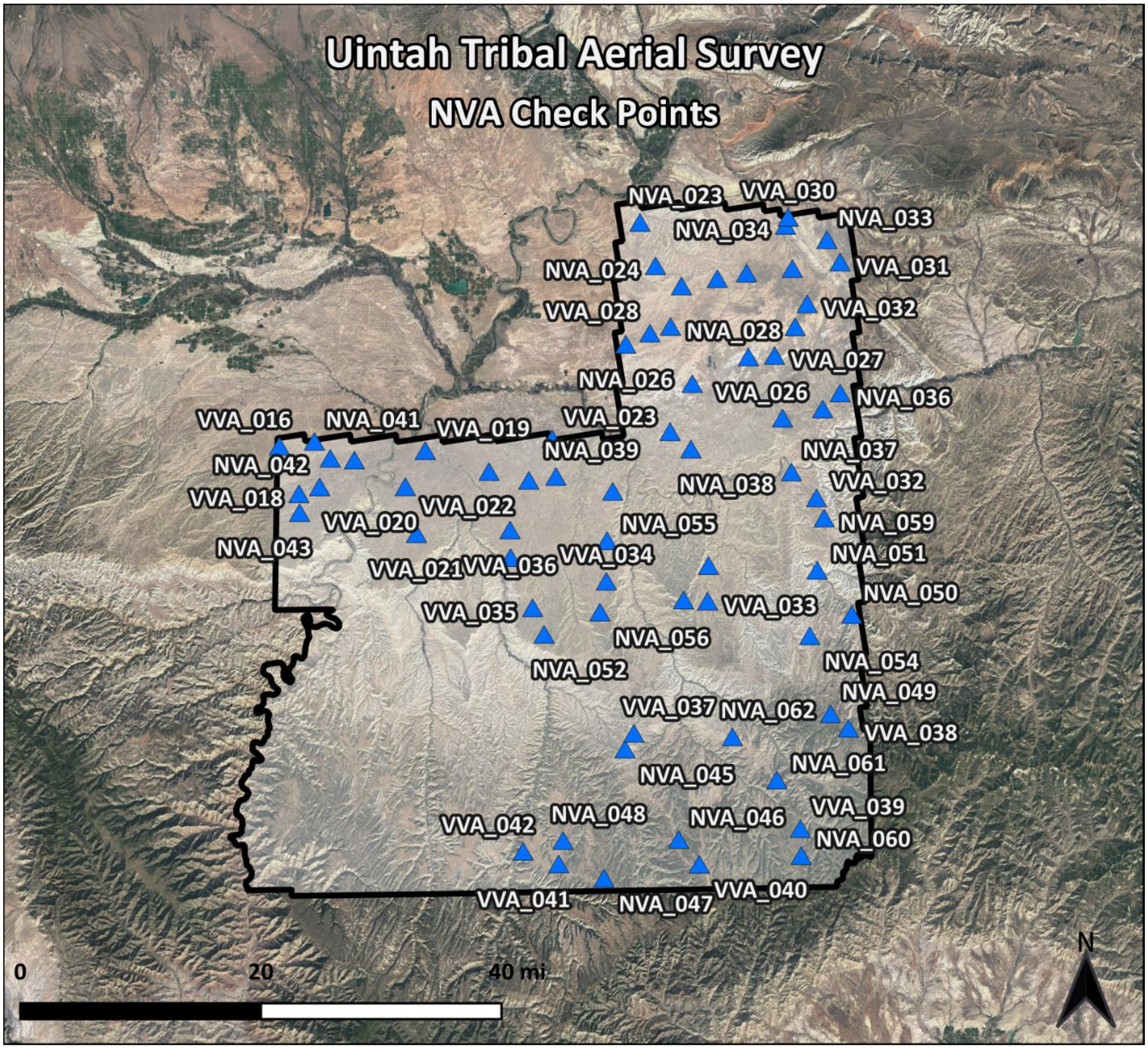


Exhibit 8: **Check Points for the Utah 3DEP - Uintah Tribal project**



3. LiDAR Processing Workflow

1. **Absolute Sensor Calibration**. Following sensor installation, lever arm values were surveyed. A boresight mission was flown over our fully controlled local range, and when adjusted to the surveyed ground control for roll, pitch, heading, and scale errors, boresight angles were developed for application to the POS processing in subsequent steps.
2. **Kinematic Air Point Processing.** The airborne GPS positions (collected at 1-second intervals) were post-processed using Applanix's POSPac MMS GNSS Inertial software (PP-RTX). A smoothed best estimate of trajectory (SBET) was developed by combining the corrected GPS positions with 1/200-second inertial measurement unit (IMU) data, which tracked the plane's roll, pitch, and yaw throughout the flight.
3. **Raw LiDAR Point Processing (Calibration).** The SBET and LiDAR range data were combined to solve for the real-world positions of each laser point. Point cloud data was produced by flight strip in ASPRS v1.4 LAS format. Flight strips were output in the project's coordinate system.
4. **Relative Calibration.** Performed relative calibration by correcting for roll, pitch, heading, and scale discrepancies between adjacent flightlines; tested resulting relative accuracy. Aero-Graphics generated swath separation images (SSI) using COTS software. These images were created from the last return of all points excluding points classified as noise and/or flagged as withheld. SSIs are made by using the Point Insertion surface method and the cell size was set to 2x the deliverable DEM cell size. The SSIs are symbolized by the following ranges:

   i. +/- 0-8 cm: **Green**
   ii. +/- 8-16 cm: **Yellow**
   iii. +/- 16 cm: **Red**

   The output GeoTIFF rasters were tiled to the project tile grid, clipped to the master DPA, and formatted (including defining the CRS which matches the project CRS) using GDAL software. These results are presented in Section 4.1.

   b. A **Dz Ortho Raster** was generated as part of this process (**Exhibit 9**). This raster identifies clusters of large residuals and differences in measured elevations between overlapping flightlines. These errors are usually caused by topographic relief or environmental factors and require manual adjustments to correct. In most cases, multiple iterations of the Dz ortho raster are created to aid in fine tuning relative calibration parameters.

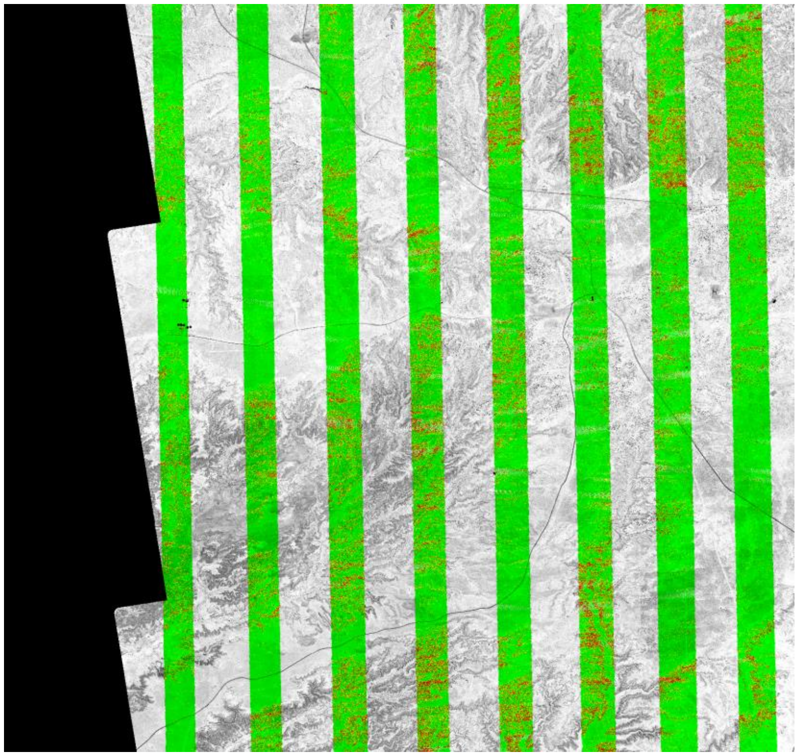


Exhibit 9: **A Dz ortho raster sample generated for the Utah 3DEP - Uintah Tribal project**

5. **Vertical Accuracy Assessment** Height differences between each static survey point and the laser point surface were identified through comparative tests. Results are presented in Section 4.2.

6. **Tiling & Long/Short Filtering** Extremely long and short returns were also filtered out as outliers and classified to a temporary class to be reclassified to low or high noise after completion of ground point classification.

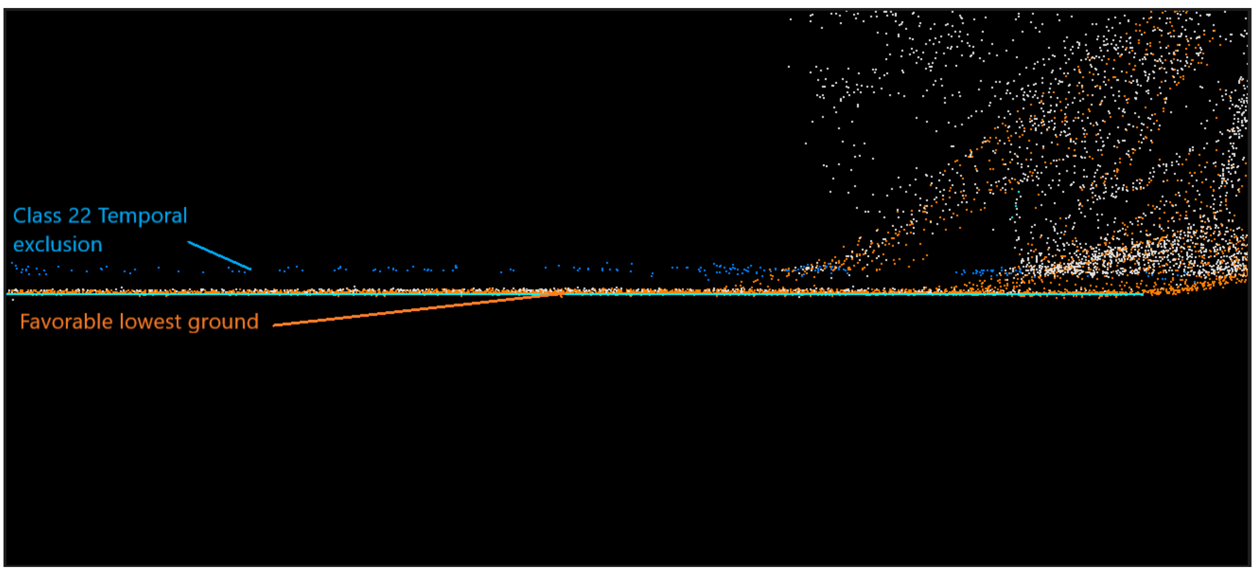
7. **Classified LAS Processing.** The point classification was performed with the ASPRS classes described in **Exhibit 10**. The bare-earth surface is classified using a combination of TerraScan macro functionality as well as proprietary software. The bare-earth surface is then manually reviewed and corrected to ensure correct classification on the Class 2 (Ground) points. All data is then reviewed and any remaining artifacts removed using functionality provided by TerraScan. LP360 is then used as a final check of the bare-earth dataset. LP360 and TerraScan software was used to perform statistical analysis of the classes in the LAS files, on a per tile level to verify classification metrics and full LAS header information.

   Class code 22 Temporal exclusion is typically used for non-favored data in intertidal zones. AGI used this class code to represent non-favored river high elevation flow. Due to fluctuations in river elevation from mission to mission during the flight season for this project AGI used Temporal exclusion class coding to exclude non-favorable high water for the more favorable lowest ground "water" elevation.

Exhibit 10: The ASPRS classes used in lidar point classification

USGS Version 1.4 minimum point cloud classification scheme		
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
17	Bridge decks	Points on bridge decks
18	High noise	High points identified above surface
20	Ignored ground	Points near breakline features; ignored in DEM creation process
22	Temporal exclusion	Used for non-favored data in intertidal zones

Exhibit 11: Sample of the points included within the Temporal Exclusion class



8. **Hydro-Flattened Breakline Collection**. Full point cloud intensity imagery, DEMs, and bare earth terrains were used to manually digitize 3D breaklines. Breakline features were collected of inland streams and rivers with a 30-meter nominal width, and inland ponds and lakes of 2 acres or greater surface area. Elevation values were assigned to all inland ponds and lakes, inland pond and lake islands, and inland stream and river islands, using ESRI and LP360 functionality.

9. **Hydro-Flattened Raster DEM Creation.** A hydro-flattened raster digital elevation model (DEM) was created using the ground classified LiDAR points. A raster was generated in LP360 from the lidar data with breaklines enforced and clipped to the project tile grid. Each surface was reviewed to check for any surface anomalies or incorrect elevations found within the surface.

    a. Hydro-Flattened DEMs were not created for one tile due to the fact that the tile only contained water and no ground. The tile number is 12SWJ8372.

    b. A total of 6,013 tiles were created during the processing of the LAS data to the deliverable DEMs. 1 LAS file contained only points classified as Water so could not be processed into DEMs. A shapefile named "No_DEM_Tiles.shp" is included in the delivery with just this tile.

10. **Maximum Surface Height Rasters Creation**. MSHRs are delivered as tiled GeoTIFFs (32-bit, floating point), with the tile size and naming convention matching the project tile grid. All points, excluding points flagged as withheld, are used to produce MSHRs. The rasters are produced with a binning method in which the highest elevation of all lidar points intersecting each pixel is applied as the pixel elevation in the resulting raster. Final MSHRs are formatted using GDAL software, spatially defined to match the project CRS, and the cell size equals 2x the deliverable DEM cell size.

4. Accuracy Testing and Results

4.1 Relative Calibration Accuracy Results

Inter-swath relative accuracy is defined as the elevation difference in the overlapping area of parallel swaths. The inter-swath accuracy was tested in 341 areas across the project in a total of 882 square kilometers.

Utah 3DEP - Uintah Tribal project area: (98 flightlines, > 42 billion points)

- Inter-swath relative accuracy **average** of 0.028 m

Intra-swath Precision is a measure of the expected precision of the laser ranging measurement. The metric is derived by calculating the variation in elevation values across a smooth flat surface and was calculated using a kernal size of 2 meters around each control and NVA checkpoint. The intra-swath precision average was found to be 0.017 m

4.2 Calibration Control Vertical Accuracy

Vertical absolute accuracy reports were generated as a quality assurance check. The location of each control point is displayed in the Surveyed Ground Control map in **Exhibit 7**. Detailed results for each point are included in **Appendix B**.

Exhibit 12: Calibration control vertical accuracy results summary

Calibration Control Accuracy$_z$: Utah 3DEP - Uintah Tribal Project Area	
Average Error = +0.001 m	Average Magnitude = 0.020 m
Minimum Error = -0.101 m	RMSE = 0.031 m
Maximum Error = +0.067 m	σ = 0.032 m
Survey Sample Size: n = 25	

4.3 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 40 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.

The bare-earth LiDAR dataset was designed to meet or exceed ASPRS Positional Accuracy Standards at the 10 cm vertical accuracy class. Absolute accuracy for non-vegetated areas (NVA) must be accurate within 10.0 cm (0.32 ft) RMSEz and 19.6 cm (0.64 ft) at the 95% confidence level. The tested NVA for this dataset was found to be accurate within 4 cm (0.13 ft) in terms of the RMSEz. The resulting NVA stated at the 95% confidence level (RMSEz x 1.96) is 7.9 cm (0.26 ft). Therefore, this dataset meets the required NVA of 10 cm (0.32 ft) at the 95% confidence level as defined by the National Standards for Spatial Data Accuracy (NSSDA).

4.4 Digital Elevation Model 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 40 check points. The VVA was tested with 27 check points.

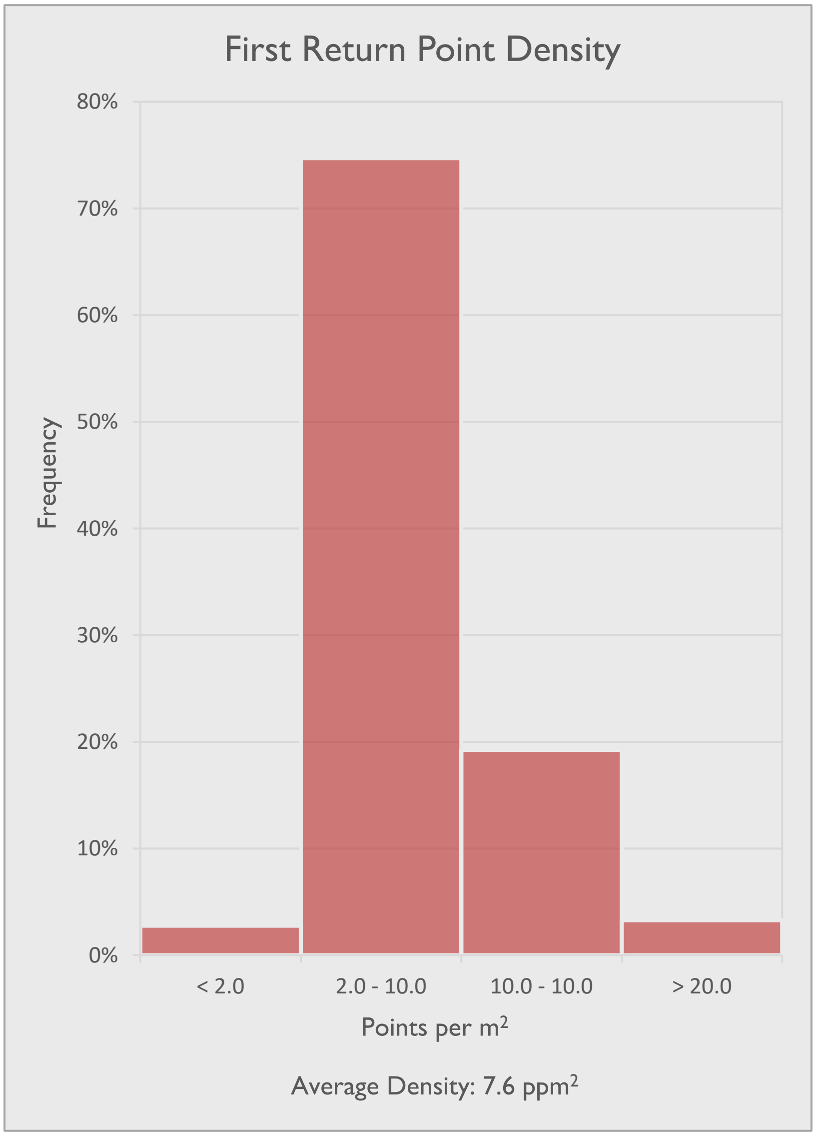
The tested Non-Vegetated Vertical Accuracy (NVA) for this dataset captured from the DEM using bi-linear interpolation to derive the DEM elevations was found to be 4 cm in terms of the RMSEz. The resulting accuracy stated as the 95% confidence level (RMSEz x 1.96) is 7.8 cm. Therefore, this dataset meets the required NVA of 19.6 cm at the 95% confidence level.

The tested Vegetated Vertical Accuracy (VVA) for this dataset captured from the DEM using bi-linear interpolation for all classes was found to be 5.3 cm. Therefore, this dataset meets the required VVA of 10.3 cm based on the 95th percentile error.

4.5 Data Density

The goal for this project was to achieve a minimum LiDAR point density of **2.0** points per square meter. First return density is the best representation of the quality of the acquisition because the density of first returns is independent of vegetation and other random factors that could increase the overall point density. The acquisition mission achieved an actual average of **7.6** points per square meter for first returns. Please note that loss of point density over water is to be expected.

Exhibit 13: First returns laser point density by frequency, points/m2 . This figure displays the percentage of points in a given density range



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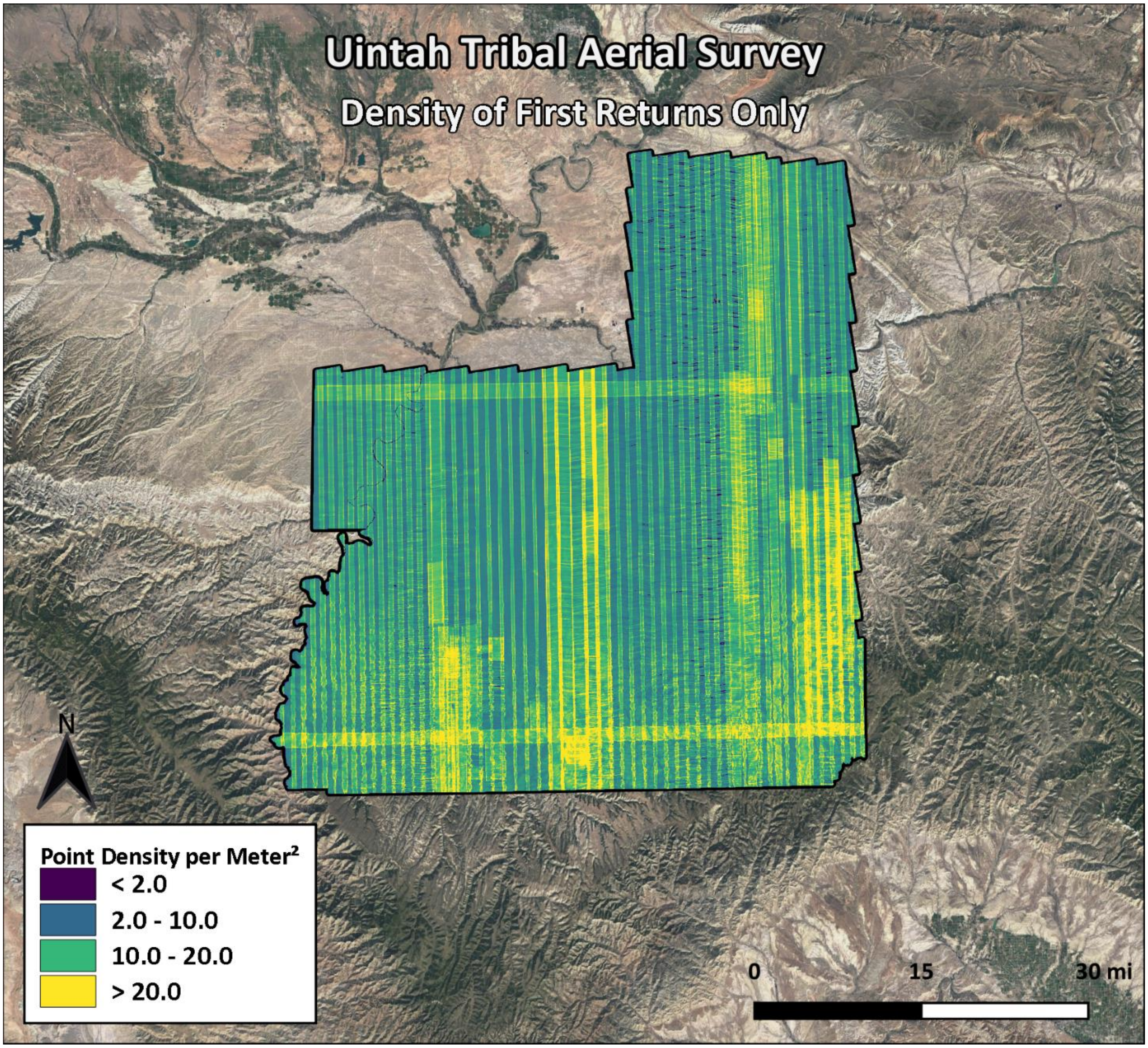

Exhibit 14: Density of first returns only in points per meter² for the Utah 3DEP - Uintah Tribal project.

Appendix A – Check Points

Survey Point	Utah 3DEP - Uintah Tribal Aerial Survey		
	Easting	Northing	Elevation (m)
NVA-023	636635.014	4458137.271	1541.781
NVA-024	638703.244	4452354.960	1660.082
NVA-025	642205.096	4449660.725	1717.898
NVA-026	634717.360	4441855.807	1543.248
NVA-027	655717.817	4431997.150	1658.156
NVA-028	640723.101	4444224.429	1657.437
NVA-029	651118.417	4440160.349	1578.489
NVA-030	643576.015	4436913.014	1521.276
NVA-031	650870.577	4451364.137	1754.861
NVA-032	657021.683	4451996.077	1787.834
NVA-033	661640.285	4455833.989	1734.909
NVA-034	656113.678	4457776.428	1638.410
NVA-035	657390.309	4444203.530	1680.738
NVA-036	663409.523	4435337.438	1778.315
NVA-037	656884.384	4424774.345	1613.341
NVA-038	643529.546	4427811.945	1616.991
NVA-039	625396.476	4424195.635	1558.080
NVA-040	616564.521	4424752.379	1546.807
NVA-041	593085.128	4428879.808	1567.263
NVA-042	593751.598	4422775.857	1557.162
NVA-043	591111.634	4419368.001	1650.872
NVA-044	619323.378	4413344.430	1734.608
NVA-045	634625.957	4387765.442	2086.176
NVA-046	641820.779	4375688.334	2351.722
NVA-047	631826.602	4370536.160	2295.959
NVA-048	626292.463	4375505.611	2215.924
NVA-049	662118.999	4392490.147	2323.089
NVA-050	664981.636	4405739.514	1760.236
NVA-051	660261.746	4411663.387	1688.662
NVA-052	623830.653	4403101.629	1917.980
NVA-053	598448.686	4426397.890	1538.717
NVA-054	659358.589	4402990.438	2044.115
NVA-055	632231.921	4415622.035	1738.079
NVA-056	631393.820	4406019.569	1929.984
NVA-057	642474.172	4407697.967	1888.558
NVA-058	645804.150	4412294.881	1688.516
NVA-059	661268.560	4418650.874	1793.725
NVA-060	658222.161	4374398.568	2394.247

NVA-061	654946.197	4383633.770	2224.317
NVA-062	649263.139	4389351.807	2041.066
VVA-016	588400.363	4428242.765	1615.283
VVA-017	595235.453	4426605.532	1542.242
VVA-018	590965.401	4421871.769	1631.061
VVA-019	608015.161	4427723.541	1473.132
VVA-020	605189.561	4422868.406	1577.782
VVA-021	606780.524	4416422.654	1666.539
VVA-022	621614.488	4423753.211	1553.182
VVA-023	624815.799	4429231.727	1514.461
VVA-024	632969.022	4422305.613	1623.084
VVA-025	640799.476	4430248.054	1577.683
VVA-026	661028.289	4433152.481	1779.276
VVA-027	654640.400	4440333.427	1641.064
VVA-028	637979.735	4443343.780	1614.090
VVA-029	646978.551	4450619.025	1726.447
VVA-030	656408.041	4458935.670	1628.694
VVA-031	663601.647	4452639.583	1800.203
VVA-032	658985.998	4447238.794	1720.918
VVA-033	645668.682	4407352.616	1781.291
VVA-034	632132.210	4410230.471	1847.805
VVA-035	622326.318	4406472.389	1829.419
VVA-036	619237.127	4417028.302	1643.585
VVA-037	635852.737	4389833.956	2037.496
VVA-038	664483.206	4390632.959	2374.373
VVA-039	658079.196	4377294.473	2315.401
VVA-040	644545.263	4372415.905	2445.501
VVA-041	625708.838	4372448.973	2262.066
VVA-042	621278.055	4374172.233	2225.448

APPENDIX B – CALIBRATION CONTROL ACCURACY REPORT

Utah 3DEP - Uintah Tribal Aerial Survey			
Survey Point	**Known Z (m)**	**Laser Z (m)**	**Dz (m)**
GCP-015	1676.033	1676.040	0.007
GCP-016	1838.660	1838.680	0.020
GCP-017	1596.605	1596.620	0.015
GCP-018	1675.824	1675.850	0.026
GCP-019	1846.291	1846.290	-0.001
GCP-020	1787.616	1787.620	0.004
GCP-021	2202.683	2202.680	-0.003
GCP-022	2461.667	2461.620	-0.047

GCP-023	2137.405	2137.400	-0.005
GCP-024	1612.670	1612.650	-0.020
GCP-026	1679.831	1679.730	-0.101
GCP-027	1413.279	1413.280	0.001
GCP-028	1561.173	1561.240	0.067
GCP-029	1526.557	1526.570	0.013
GCP-030	1654.030	1654.040	0.010
GCP-031	1522.756	1522.790	0.034
GCP-032	1809.918	1809.920	0.002
GCP-033	1920.094	1920.110	0.016
GCP-034	1961.537	1961.550	0.013
GCP-035	2186.096	2186.060	-0.036
GCP-036	2487.233	2487.230	-0.003
GCP-037	1579.345	1579.340	-0.005
GCP-039	1708.661	1708.680	0.019

Average Dz (m)	+0.001
Minimum Dz (m)	-0.101
Maximum Dz (m)	+0.067
Average Magnitude (m)	0.020
RMSE (m)	0.031
Std. Deviation (m)	0.032