aero-graphics

LiDAR PROJECT REPORT

Utah 2020 LiDAR – QL1 UTM11 & UTM12

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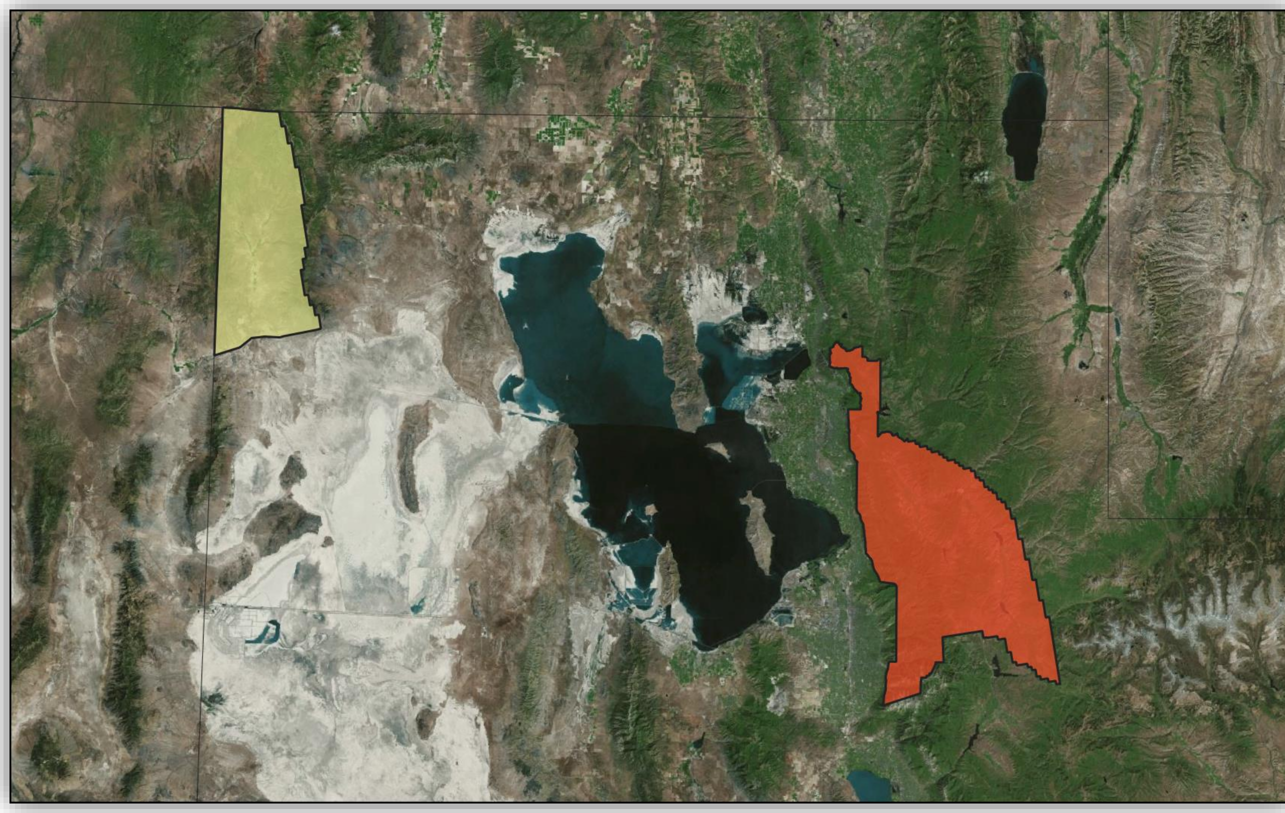

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LiDAR Project Report
Utah 2020 LiDAR – QL1 UTM11 & UTM12

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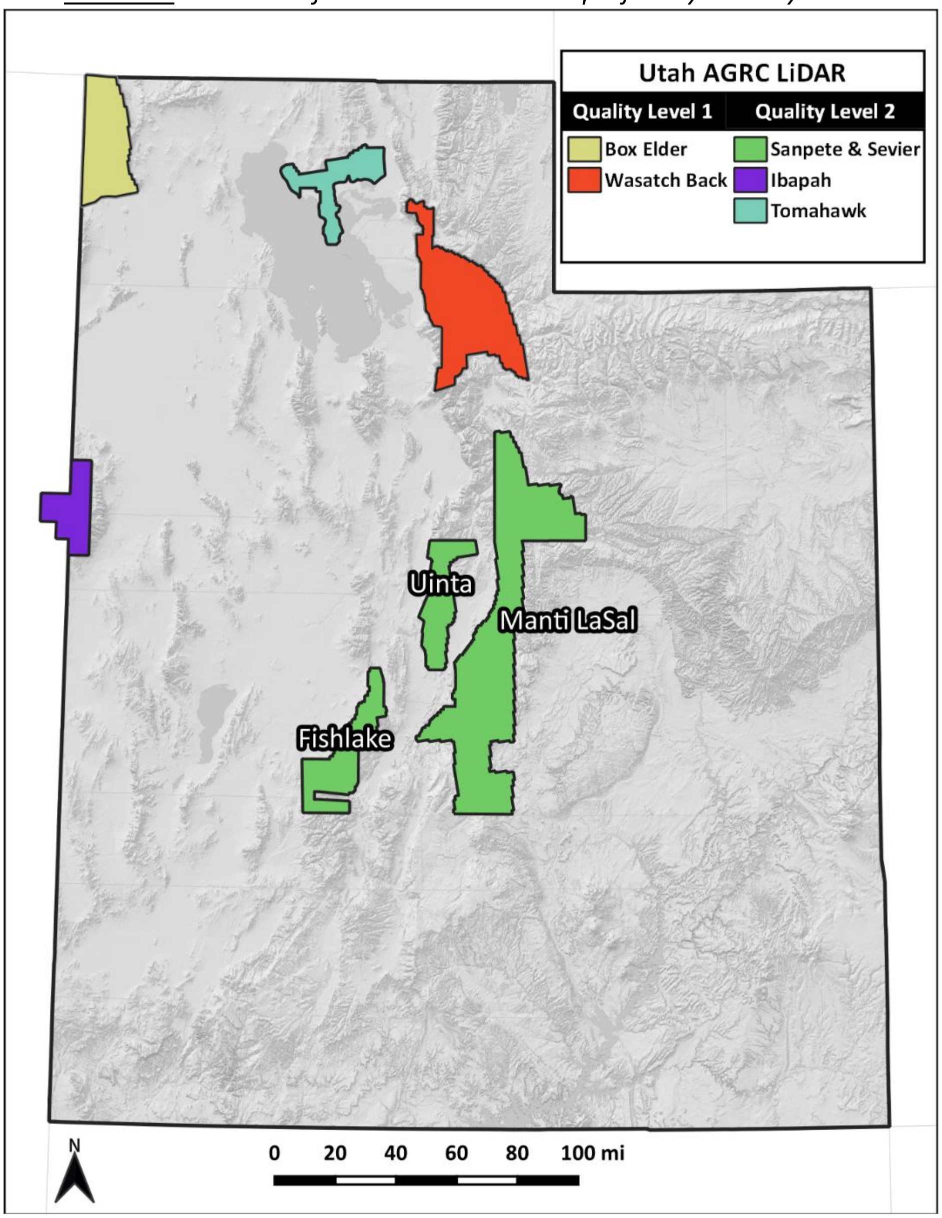
1. Introduction

1.1 Project Overview

Aero-Graphics, Inc., a full-service geospatial firm located in Salt Lake City, Utah, 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 U.S. Geological Survey (USGS) National Geospatial Program (NGP) Lidar Base Specification Version 2.1 (2019). The assigned project areas cover portions of Utah totaling approximately 5,182 mi^2.

Exhibit 1: Overview of the Utah 2020 LiDAR project by delivery areas.

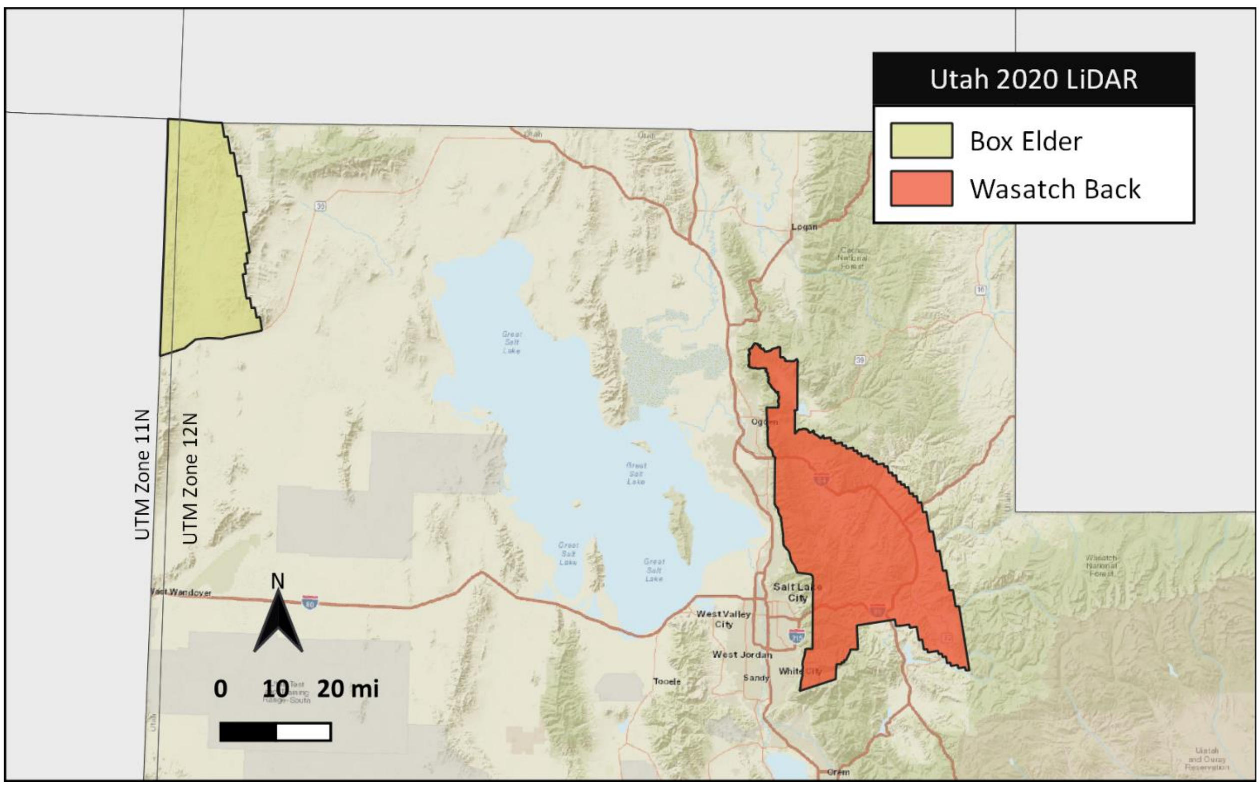


1.2 Project Area Description

As described in the Scope of Work (SOW), the Utah 2020 LiDAR project was separated into two (2) delivery areas: QL1 (Box Elder and Wasatch Back), and QL2 (Tomahawk, Ibapah, and Sanpete and Sevier). This report focuses on the QL1 AOIs, which cover 1,641.10 mi^2 of the total project area.

QL1 Project Areas	
AOI Name	**Area (mi^2)**
Box Elder QL1	584.40
Wasatch Back QL1	1,056.70

Exhibit 2: *Overview of the Box Elder and Wasatch Back QL1 project areas.*



2. LiDAR Acquisition

2.1 Flight Planning

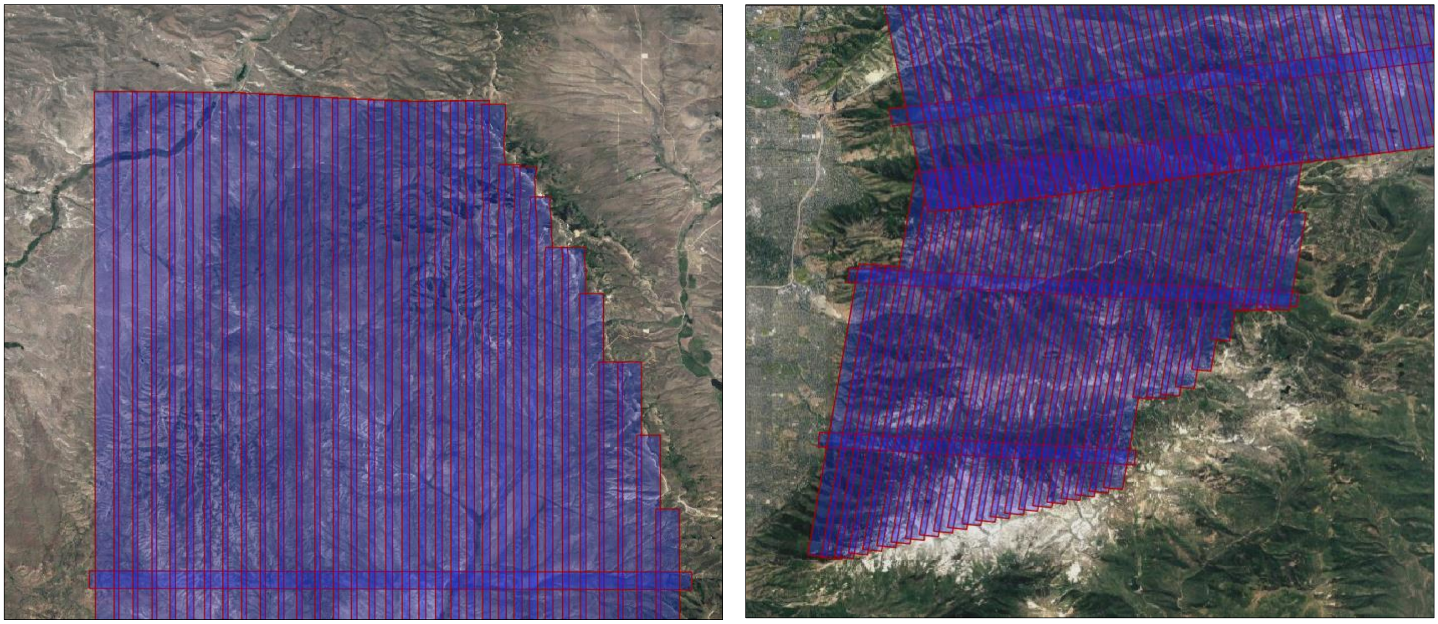
Specialized flight plans were developed by Aero-Graphics' Aerial Department to ensure complete coverage and that all contract specifications were met. Prior to mobilizing to the acquisition sites, Aero-Graphics' staff monitored all site conditions and potential weather hazards including wind, rain, snow, and blowing dust. In addition, Aero-Graphics ensured that all airspace clearances were secured by the proper officials before acquisition occurred.

The table below contains the planned settings for the Box Elder and Wasatch Back QL1 AOIs.

Planned Specs	Box Elder QL1	Wasatch Back QL1	Wasatch Back QL1
	Optech Galaxy Prime	Optech Galaxy Prime	Optech Galaxy T2000
Altitude (m)	1600	1600	1739
Speed (kts)	120	120	120
PRF (kHz)	650	550	700
Scan Freq (Hz)	85	88.5	88.7
Scan Angle (°)	36	30	33.5
Swath Width (m)	1040	857	1047
NPS (m)	0.31	0.31	0.30
Average Point Density (ppm^2)	8.17	8.19	8.58
Overlap (%)	20	30	20

AGI utilizes Optech's Airborne Mission Manager (AMM) software to plan flight lines and sensor settings. AMM is the most advanced and versatile flight planning software available and allows the aerial department to simulate the effects of the different sensors, mounts, and settings, thus ensuring the flight plan meets the needs of the project while being as efficient as possible. To complement the flight planning process, the Galaxy Prime and T2000 are equipped with FMS NAV software, which ensures accurate and consistent acquisition with its real-time quality assurance. The system operator monitored the point density and swath during the mission to confirm there was adequate coverage of each AOI. Exhibit 3 shows the coverage of the acquired swaths in portions of each AOI.

Exhibit 3: *Swath data for the project was recorded and viewed real-time by the sensor operator. Left: the northern section of the Box Elder AOI. Right: The southwestern section of the Wasatch Back AOI.*



2.2 LiDAR Sensors

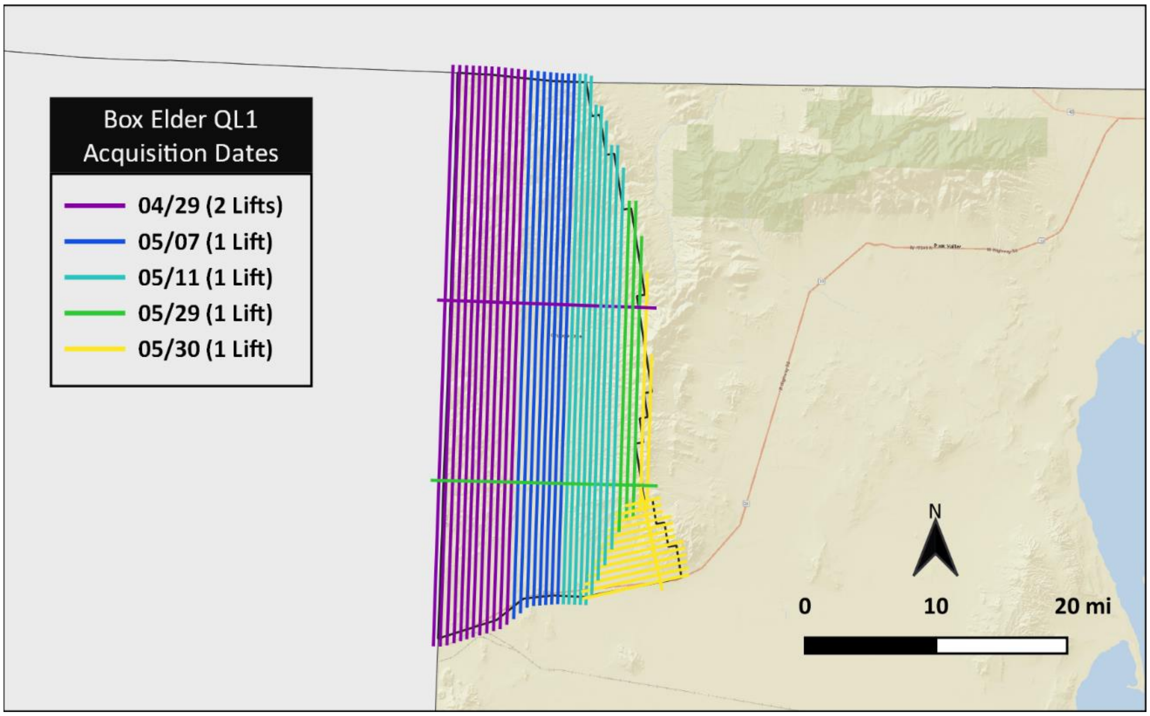
Optech Galaxy PRIME and T2000

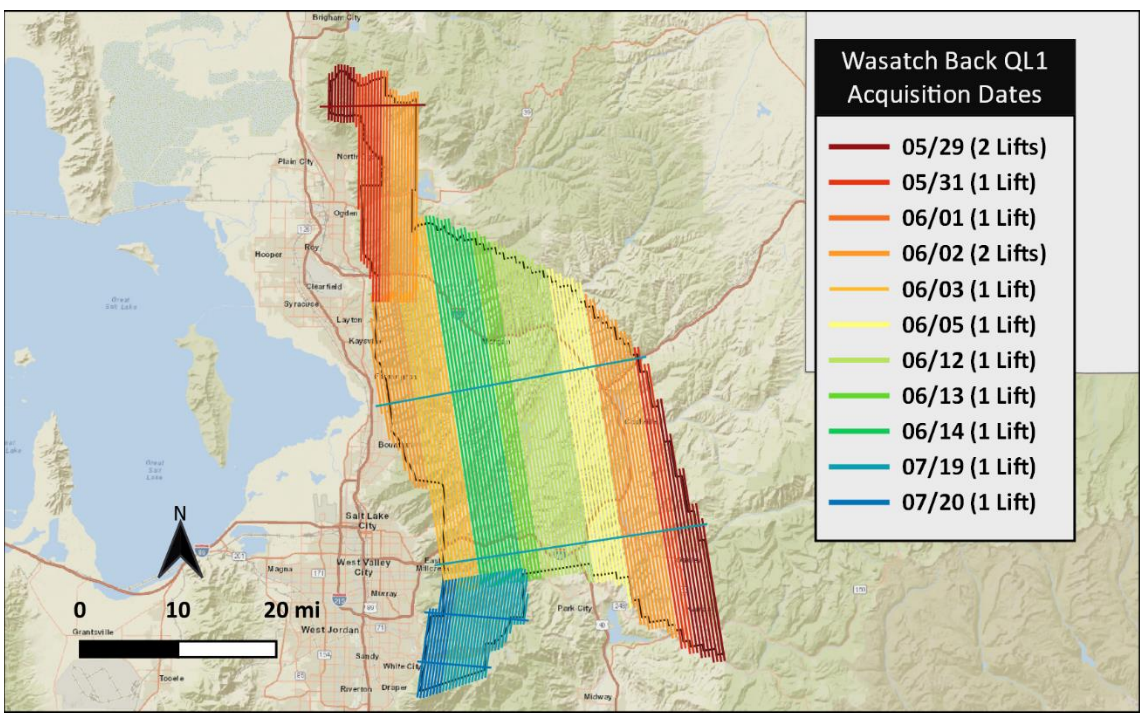
The Optech Galaxy PRIME and T2000 are currently two of the most productive sensors available in the industry. These sensors feature SwathTRAK technology, which dynamically adjusts the scan FOV in real time during data acquisition. The Prime and T2000 also feature a 1MHz and 2MHz effective pulse rate, respectively, providing on-the-ground point density and efficiency formerly reserved for dual-beam sensors. Up to 8 returns per pulse are possible for increased vertical resolution of complex targets without the need for full waveform recording and processing. Industry-leading data precision and accuracy (<5cm $RMSE_z$) results in the highest-quality datasets possible.

2.3 Acquisition Summary

Acquisition for the Box Elder QL1 and the Wasatch Back QL1 AOIs occurred between April 29 and July 20, 2020, and a reflight was performed on July 23, 2020. These flights took place when ground conditions were free of snow, ice, and standing water. A total of 22 lifts were required to complete lidar acquisition for the assigned Box Elder QL1 and Wasatch Back AOIs.

Exhibit 4: *Flightlines organized by day of acquisition*





2.4 Flight Logs

Flight dates are listed in the table on the following page along with the lift ID, the AOI covered, take-off and landing times (in Mountain Time), the weather and ground conditions, the sensor name and number, the aircraft's tail number, and any in-flight disturbances and instrument anomalies. Optech serviced and updated the Galaxy Prime and Galaxy T2000 in December 2019 and June 2020, respectively. Reflights are sometimes necessary in order to fill gaps in the LiDAR coverage due to clouds, extreme terrain, sensor malfunctions, or other issues that can't be resolved during flight.

QL1 Flight Logs												
Flight Date	Lift ID	AOI Covered	Take-off Time (MT)	Landing Time (MT)	Weather Conditions	Ground Conditions	Sensor Name	Sensor Number	Aircraft Make & Model	Aircraft Tail Number	In-flight Disturbances	Instrumental Anomalies
4/29/2020	BE_0429_1	Box Elder	09:20	12:50	Few clouds	Light snow	Optech Galaxy Prime	5060430	Cessna 206	N7269T	None reported	None reported
	BE_0429_2	Box Elder	14:00	15:35	Few clouds	Light snow	Optech Galaxy Prime	5060430	Cessna 206	N7269T	None reported	None reported
5/5/2020	BE_0505_1	Box Elder	09:45	12:20	Clear	Light snow	Optech Galaxy Prime	5060430	Cessna 206	N65474	None reported	None reported
5/7/2020*	BE_0507_1	Box Elder	11:30	15:35	Clear	Light snow	Optech Galaxy Prime	5060430	Cessna 206	N65474	None reported	None reported
5/11/2020	BE_0511_1	Box Elder	09:50	14:25	Clear	Light snow	Optech Galaxy Prime	5060430	Cessna 206	N65474	None reported	None reported
5/29/2020*	BE_0529_1	Box Elder	09:55	-	Stormy	Clear	Optech Galaxy Prime	5060410	Cessna 206	N7269T	Some turbulence	None reported
	WB_0529_1	Wasatch Back	-	15:00	Windy	Clear	Optech Galaxy Prime	5060410	Cessna 206	N7269T	Some turbulence	None reported
	WB_0529_2	Wasatch Back	10:20	13:05	Some rain at end	Clear	Optech Galaxy Prime	5060430	Cessna 206	N27DV	Some turbulence	Swath control error
5/30/2020*	BE_0530_1	Box Elder	09:00	12:00	Clear	Clear	Optech Galaxy Prime	5060410	Cessna 206	N7269T	None reported	None reported
5/31/2020	WB_0531_1	Wasatch Back	08:25	10:55	Windy	Clear	Optech Galaxy Prime	5060410	Cessna 206	N7269T	Some turbulence	None reported
	WB_0531_2	Wasatch Back	08:55	10:55	Some rain at end	Clear	Optech Galaxy Prime	5060430	Cessna 206	N27DV	Some turbulence	None reported
6/1/2020	WB_0601_1	Wasatch Back	09:05	11:40	Windy	Clear	Optech Galaxy Prime	5060410	Cessna 206	N7269T	Some turbulence	None reported
6/2/2020*	WB_0602_1	Wasatch Back	06:10	11:20	Clear	Clear	Optech Galaxy Prime	5060410	Cessna 206	N7269T	None reported	None reported
	WB_0602_2	Wasatch Back	06:15	09:45	Some wind	Clear	Optech Galaxy Prime	5060430	Cessna 206	N27DV	Some turbulence	None reported
6/3/2020	WB_0603_1	Wasatch Back	06:15	10:40	Windy	Clear	Optech Galaxy Prime	5060430	Cessna 206	N7269T	Some turbulence	None reported
6/5/2020	WB_0605_1	Wasatch Back	08:10	11:55	Windy	Clear	Optech Galaxy Prime	5060430	Cessna 206	N27DV	Some turbulence	None reported
6/12/2020*	WB_0612_1	Wasatch Back	12:40	18:20	Clear	Clear	Optech Galaxy Prime	5060410	Cessna 206	N7269T	None reported	None reported
6/13/2020	WB_0613_1	Wasatch Back	06:50	09:50	Clear	Clear	Optech Galaxy Prime	5060410	Cessna 206	N7269T	None reported	None reported
6/14/2020	WB_0614_1	Wasatch Back	08:05	13:00	Few clouds	Clear	Optech Galaxy Prime	5060410	Cessna 206	N7269T	None reported	None reported
7/19/2020*	WB_0719_1	Wasatch Back	14:30	18:00	Clear	Clear	Optech Galaxy T2000	5060452	Cessna 206	N65474	None reported	None reported
7/20/2020	WB_0720_1	Wasatch Back	14:00	17:00	Clear	Clear	Optech Galaxy T2000	5060452	Cessna 206	N65474	None reported	None reported
7/23/2020*	WB_0723_1	Wasatch Back	12:15	13:25	Clear	Clear	Optech Galaxy Prime	5060410	Cessna 206	N7269T	None reported	None reported

**Flight included reflights*

3. 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.** Used Applanix' industry-leading POSPac MMS GNSS Inertial software (PP-RTX) to post-process the 1-second airborne GPS positions; 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 and UTM Zone 11, meters.

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

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

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 bridge decks were classified to Class 17. All overlap data was processed using TerraScan macro functionality to set the overlap bit flag on overlapping flight line data.

   All data was manually reviewed and any remaining artifacts were removed using functionality provided by TerraScan. LP360 was used as a final check of the bare earth dataset. LP360 was then used to create the deliverable industry-standard LAS files. 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.

USGS Version 1.3 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

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 20).

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 horizontal placement, 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 0.5 meter (QL1) hydro-flattened raster DEMs. Using LP360 along with automated scripting routines within ArcMap, a GeoTIFF 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.

Breaklines were collected at bridges but not culverts. The distinction between bridges and culverts was based on the following guidelines: Bridges are structures carrying a road, path, railroad, canal, aircraft taxiway, or any other transit between two locations of higher elevation over an area of lower elevation. A bridge may traverse a river, ravine, road, railroad, or other obstacle. “Bridge” also includes but is not limited to aqueduct, drawbridge, flyover, footbridge, overpass, span, trestle, and viaduct. In mapping, the term “bridge” is distinguished from a roadway over a culvert in that a bridge is an elevated deck that is not underlain with earth or soil. Culverts are a tunnel carrying a stream or open drainage under a road or railroad or through another type of obstruction to natural drainage. Typically constructed of formed concrete or corrugated metal and surrounded on all sides, top, and bottom by earth or soil.

j. **First Return Raster DSM Creation.** First return LiDAR points were used to create 0.5 meter (QL1) first-return raster DEMs. Using LP360 along with automated scripting routines within ArcMap, a GeoTIFF 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 as it helps to ensure a more aesthetically pleasing image. ESRI ArcMap software was then used to verify full project coverage. GeoTIFF files were provided as the deliverable for this dataset requirement.

4. Ground Control and Check Point Survey

Aero-Graphics' professional land surveyor identified, targeted, and surveyed 11 ground control points for use in data calibration as well as 95 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 and QC check point coordinates are included in the deliverable ESRI shapefiles.

Exhibit 5: *Locations and names for each ground control point throughout the project area*

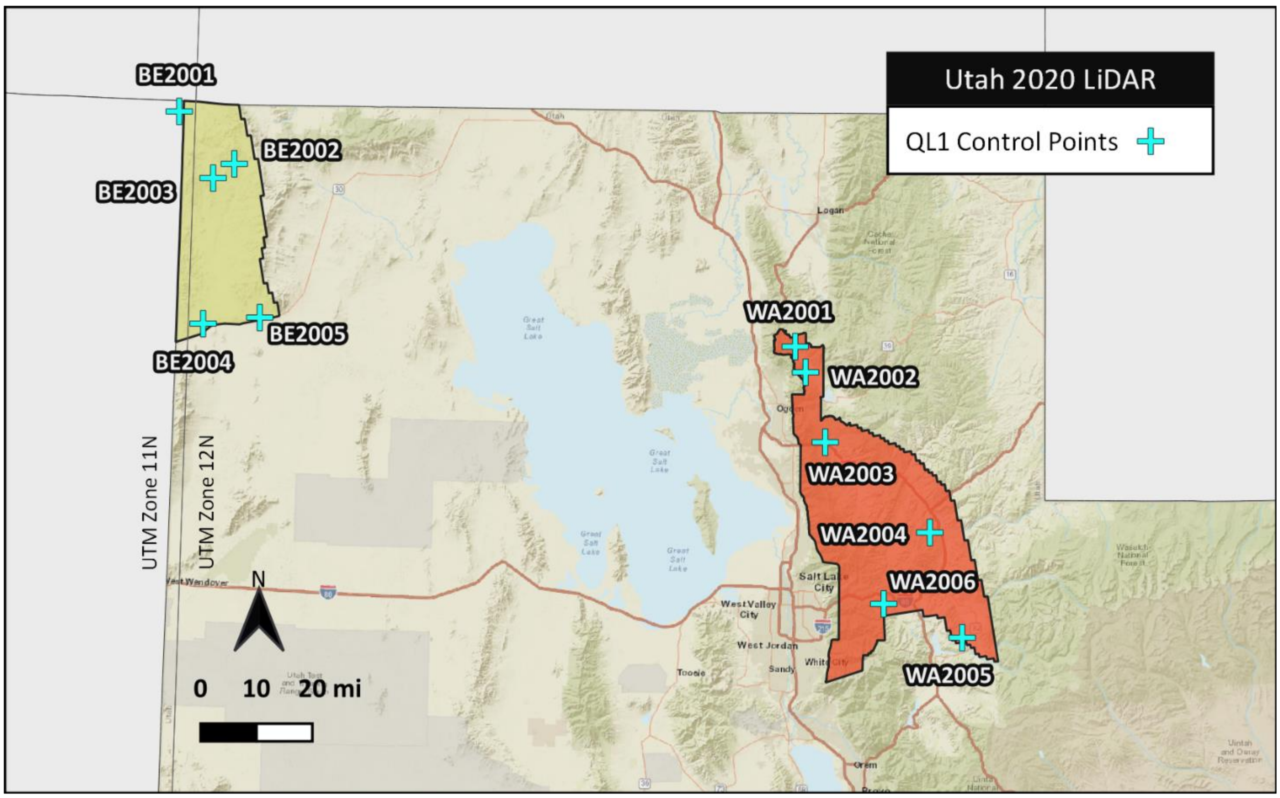


Exhibit 6: *Locations of NVA checkpoints throughout the project area*

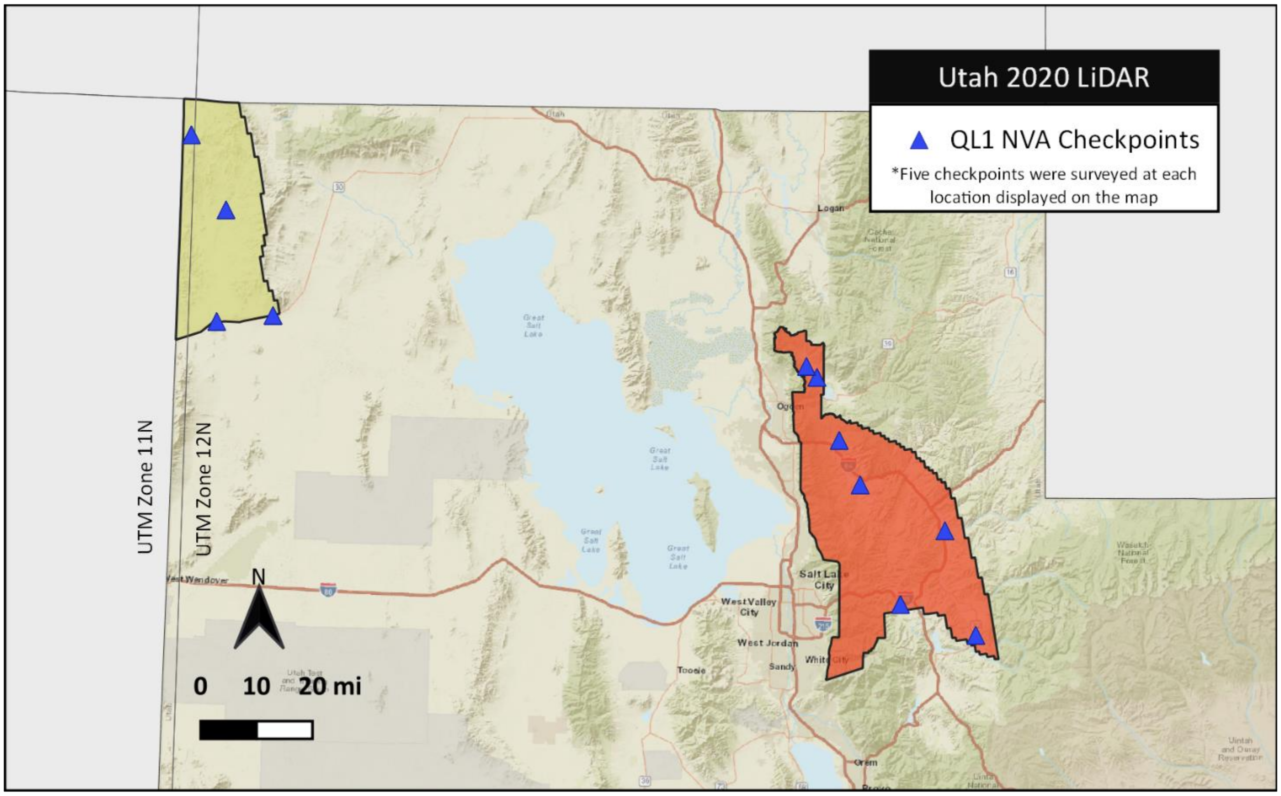
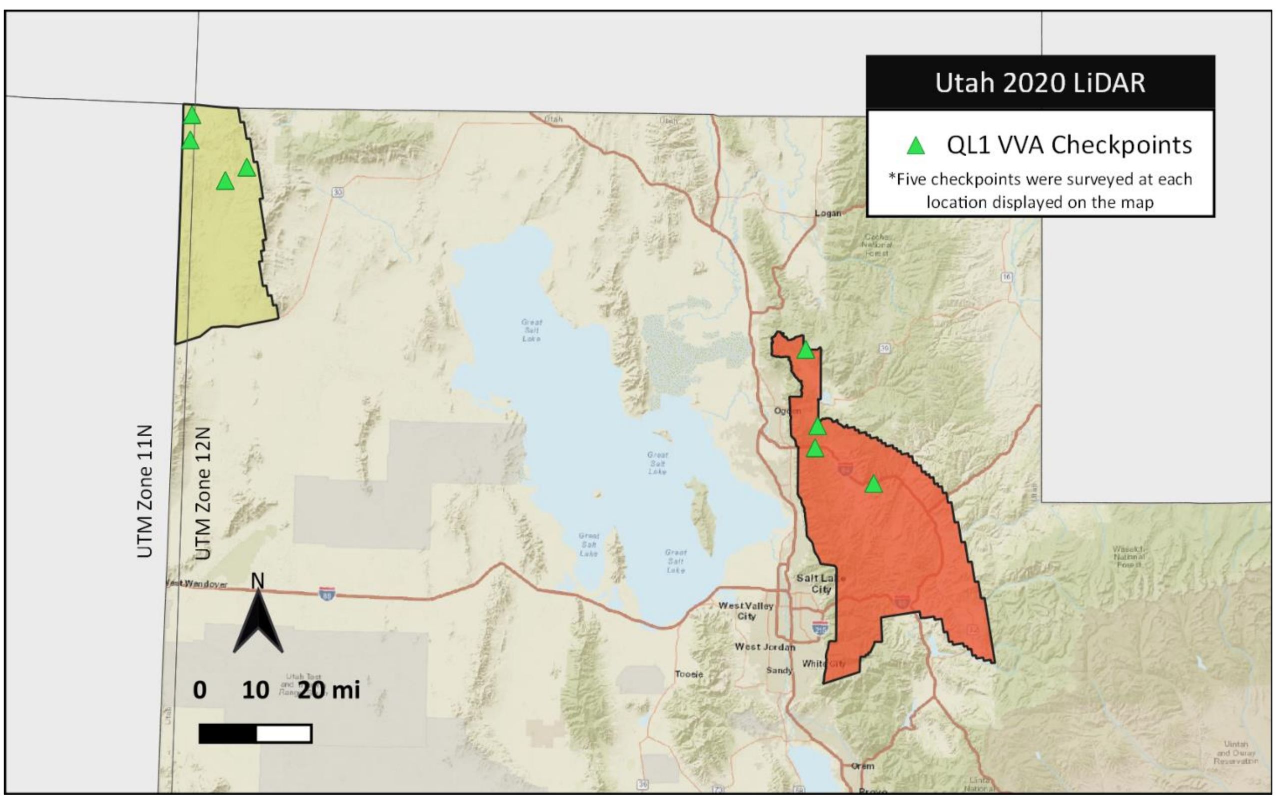


Exhibit 7: *Locations of VVA checkpoints throughout the project area*



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. During the calibration process coincident tie-lines are created in the overlapping regions of each swath. The elevation difference between these tie lines was used to measure the between-swath relative accuracy of the dataset. During calibration, this process is carried out to verify consistency from swath to swath but as a quality assurance measure it can point toward the internal consistency of the overall dataset. The results are based on the comparison of the flightlines and points for each area. The results below include any reflights that were completed over each area, increasing the number of flightlines from what was originally planned.

QL1 project areas: (278 flightlines, > 46 billion points)

- Between-swath relative accuracy **average** of 0.040 meters

5.2 Calibration Control Point Testing

Calibration Control Point reports were generated as a quality assurance check by testing 0.109 meters at 95 percent confidence level in all open and non-vegetated land cover categories combined using RMSEz x 1.96. 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 on page 11.

Only one control point was located within the Box Elder QL1 UTMz11N area; it yielded a difference of +0.007 meters. The results for UTMz12N are shown below.

Calibration Control Accuracy$_Z$: UTMz12N (Box Elder QL1 & Wasatch Back QL1)	
Average Error = -0.000 m	RMSE = 0.039 m
Minimum Error = -0.045 m	σ = 0.043 m
Maximum Error = +0.074 m	Average Magnitude = 0.031 m
Survey Sample Size: n = 6	

5.3 Absolute Horizontal Accuracy

The data set collected at 1,600m AGL was produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 24.8 cm RMSEx / RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 43.0 cm at a 95% confidence level. The data set collected at 1,739m AGL was produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 26.6 cm RMSEx / RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 46.0 cm at a 95% confidence level.

5.4 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 55 check points (5 in UTMz11 and 55 in UTMz12). 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 0.046 meters in UTMz11 and 0.040 meters in UTMz12, in terms of the RMSEz. The resulting NVA stated as the 95% confidence level (RMSEz x 1.96) is 0.091 meters in UTMz11 and 0.078 meters in UTMz12. 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).

5.5 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 55 check points (5 in UTMz11 and 55 in UTMz12). The VVA was tested with 40 check points (10 in UTMz11 and 40 in UTMz12).

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 0.044 meters in UTMz11 and 0.042 meters in UTMz12 in terms of the RMSEz. The resulting accuracy stated as the 95% confidence level (RMSEz x 1.96) is 0.087 meters in UTMz11 and 0.082 meters in UTMz12. Therefore, this dataset meets the required NVA of 0.196 meters 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 0.174 meters in UTMz11 and 0.190 meters in UTMz12. Therefore this dataset meets the required VVA of 0.294 meters based on the 95th percentile error.

5.6 Data Accuracy Summary

Accuracy has been tested to meet 19.6 cm or better Non-Vegetated Vertical Accuracy at 95% confidence level using RMSEz x 1.96 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation (NDEP)/ASPRS Guidelines.

Area	Raw Point Cloud NVA (m)	DEM NVA (m)	DEM VVA (m)	Points Tested NVA	Points Tested VVA
UTMz11	0.091	0.087	0.174	5	10
UTMz12	0.078	0.082	0.190	55	40

5.7 Data Density

In order to fulfill USGS LBS 1.3 QL2 density requirements, the density of the point cloud must be greater than or equal to 8 points per meter^2. Average density per tile for the Box Elder and Wasatch Back QL1 project areas was calculated based on first returns of tiles greater than 2,500 m^2 only. Exhibits 8-10 illustrates that the acquisition met or exceeded the required density except in areas where bodies of water impeded the collection of data or tiles contained a proportionally significant area outside of the project boundaries. The QL1 project achieved and average per tile density of 8.1 points per meter^2 for first returns in UTMz11 and 8.5 points per meter^2 for first returns in UTMz12.

Exhibit 8: *Laser point density of first returns by tile, point/m^2 (Box Elder UTMz11)*

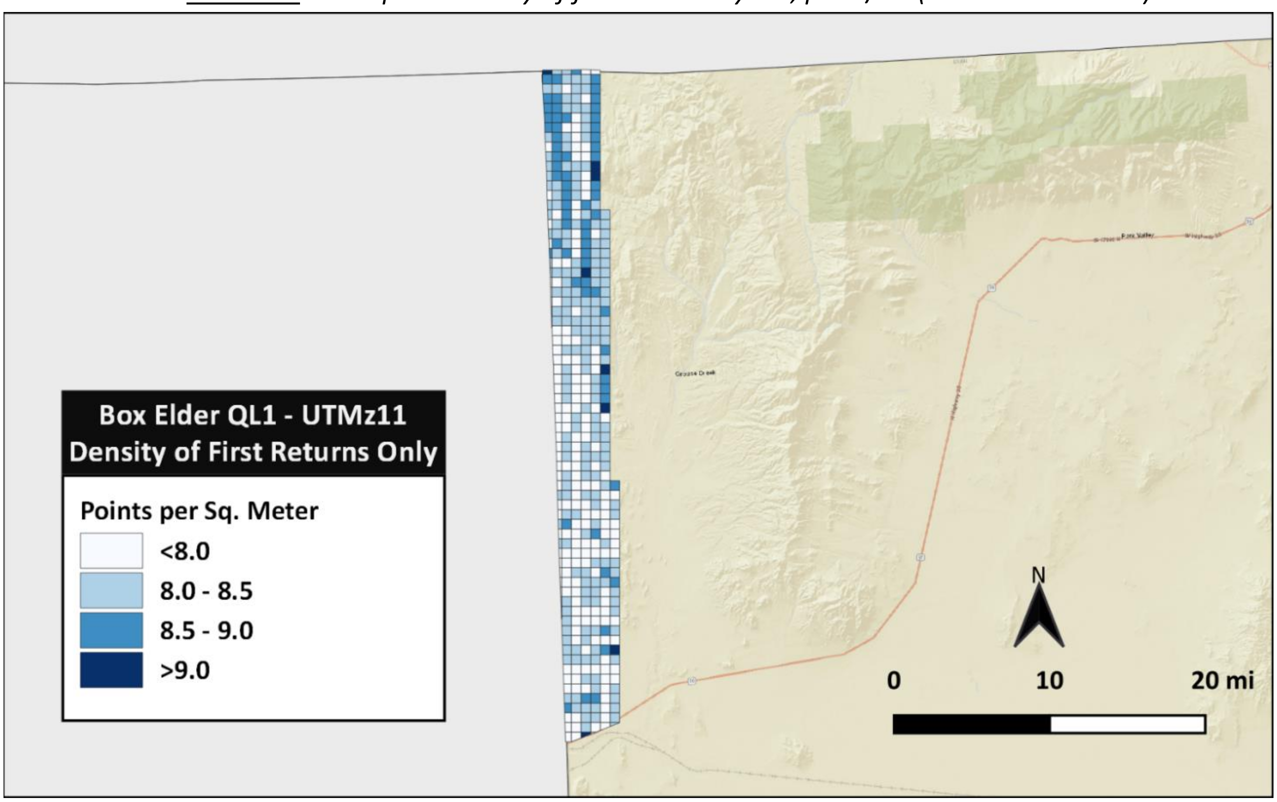


Exhibit 9: *Laser point density of first returns by tile, point/m² (Box Elder UTMz12)*

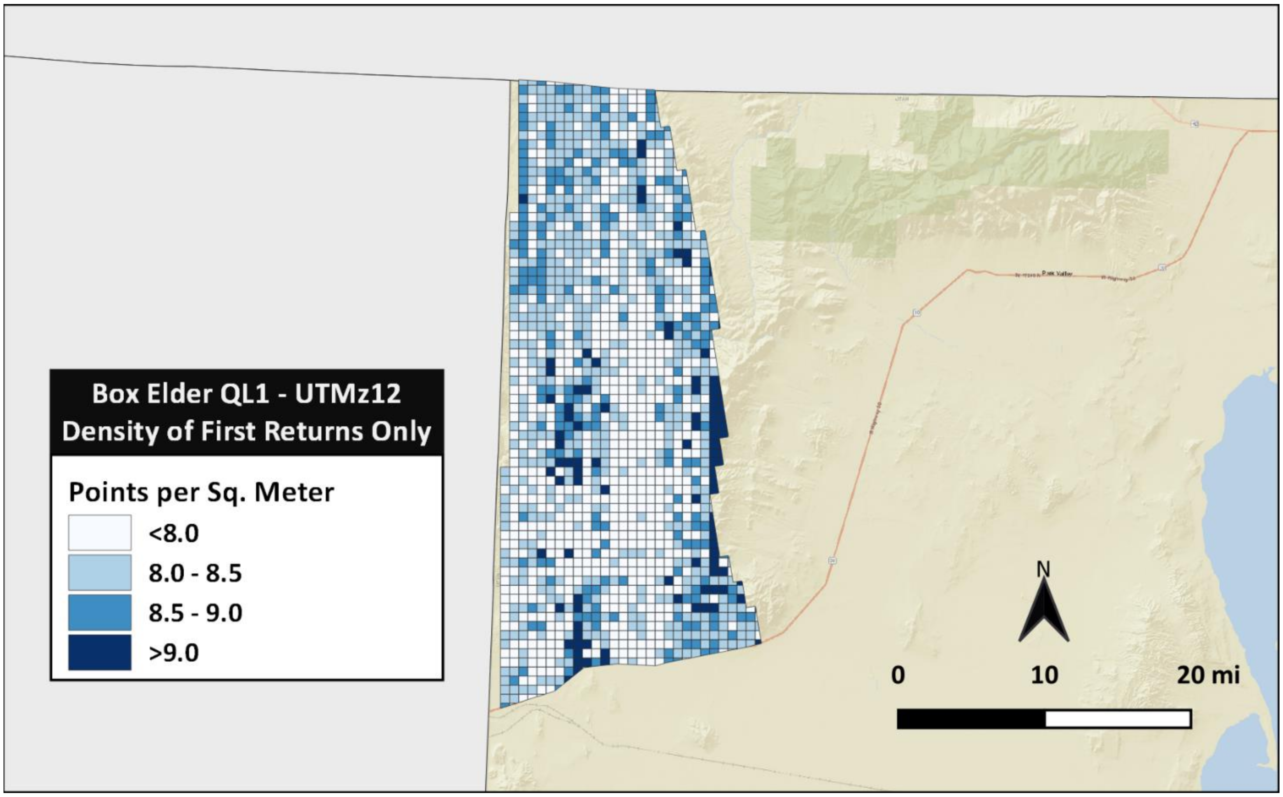
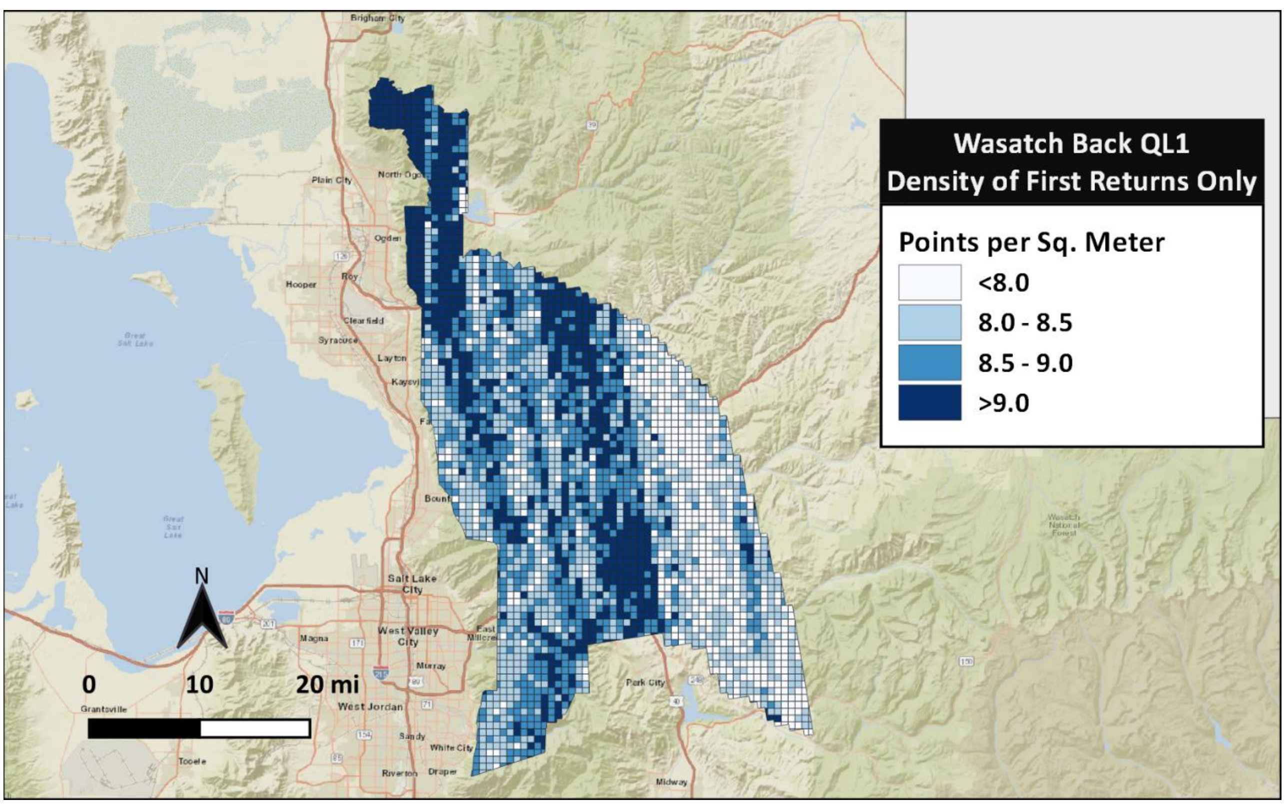


Exhibit 10: *Laser point density of first returns by tile, point/m² (Wasatch Back)*



6. Project Coordinate Systems

Projection:		UTM Zone 12 & UTM Zone 11
Datum	Vertical:	NAVD88 (Geoid12B)
	Horizontal:	NAD83 (2011) / HARN
Units:		Meters
EPSG:		6341 & 6340

7. Project Deliverables

All required project deliverables and file formats are listed in the table below.

LiDAR Data:	• Raw and classified point clouds in LAS v1.4 format
Raster Data:	• Bare-earth and first return DEMs with a cell size of 0.5 meter in .GeoTIFF format • Intensity images at a 0.5 meter resolution in GeoTIFF format
Vector Data:	• Breaklines in SHP format
Report of Survey:	• Reports and metadata as described in SOW

*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 and Raster tiles are 1,000 meters x 1,000 meters.

Appendix A

Control Point Coordinates

UTMz11N (Box Elder UTMz11)			
Survey Point	NAD83 (2011) / HARN		
	Northing	Easting	Elev (m) - Geoid 12B
BE2001	250523.273	4650530.898	1525.783

UTMz12N (Box Elder UTMz12 & Wasatch Back)			
Survey Point	NAD83 (2011) / HARN		
	Northing	Easting	Elev (m) - Geoid 12B
BE2001	250523.273	4650530.898	1525.783
BE2002	266389.305	4635441.893	1818.424
BE2003	260286.632	4631323.703	1744.130
BE2004	257412.482	4589454.670	1433.906
BE2005	273712.93	4591189.541	1381.806
BE2005	273712.93	4591189.541	1381.806
WA2001	427942.492	4582836.628	1977.225
WA2002	430927.076	4575456.540	1609.694
WA2003	436605.670	4555307.666	1577.145
WA2004	466733.613	4529340.203	1720.506
WA2005	476045.890	4499064.829	1973.121
WA2006	453432.847	4508772.431	1951.331
WA2007	433001.027	4496830.954	1489.933

APPENDIX B

While every effort has been made to meet the requirements of the latest LBS2.1 Rev. A specification, it should be noted that the Rev. A spec was released well after the inception of this project. Most notably, the following parts of the Rev. A spec have not been met:

- The data supplied is in Geoid12B (as per the task order)
- Photographs have not been captures from all four cardinal points (North, South, East, and West)
- We have NOT supplied Swath Separation Images