LiDAR PROJECT REPORT

Montana 2019 LiDAR – Treasure QL2 and QL1

Contract #: WO-AGI-190

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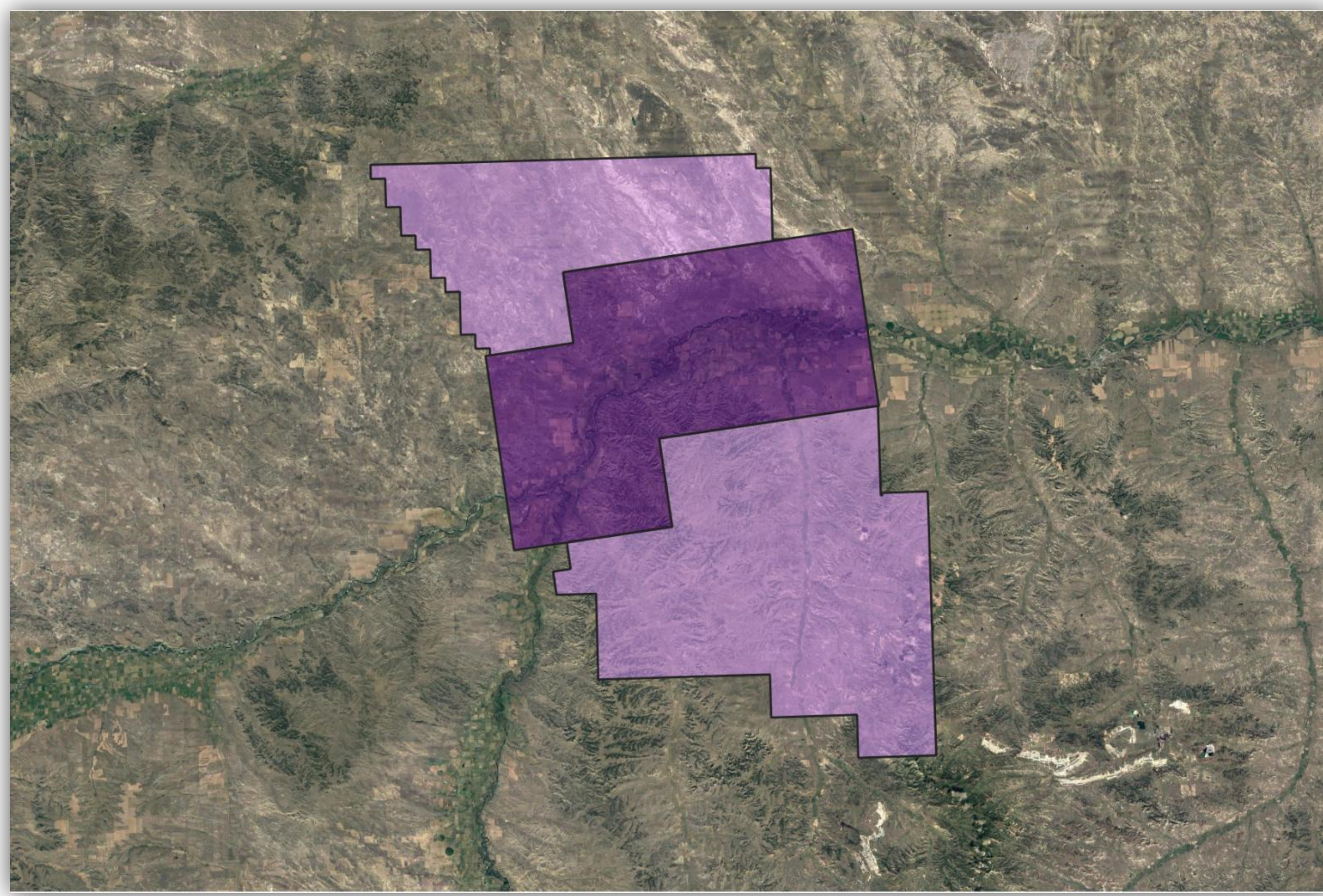

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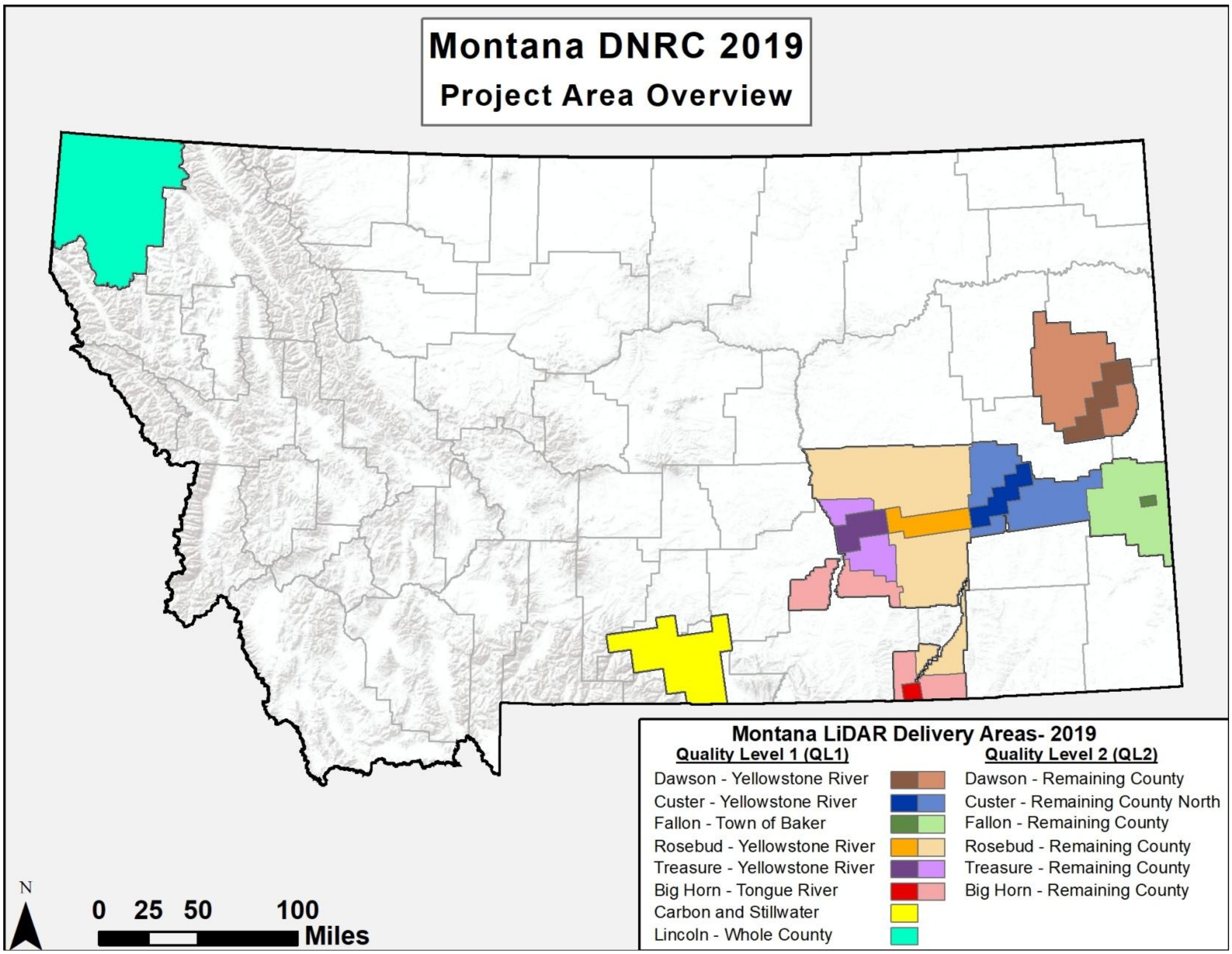
1. Introduction

1.1 Project Overview

Aero-Graphics, Inc., a full-service geospatial firm located in Salt Lake City, Utah, was contracted by the State of Montana 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 1.3 (2018). The assigned project areas cover portions of Montana totaling approximately 18,297 mi^2.

Exhibit 1: *Overview of the Montana DNRC LiDAR acquisition project by delivery areas.*

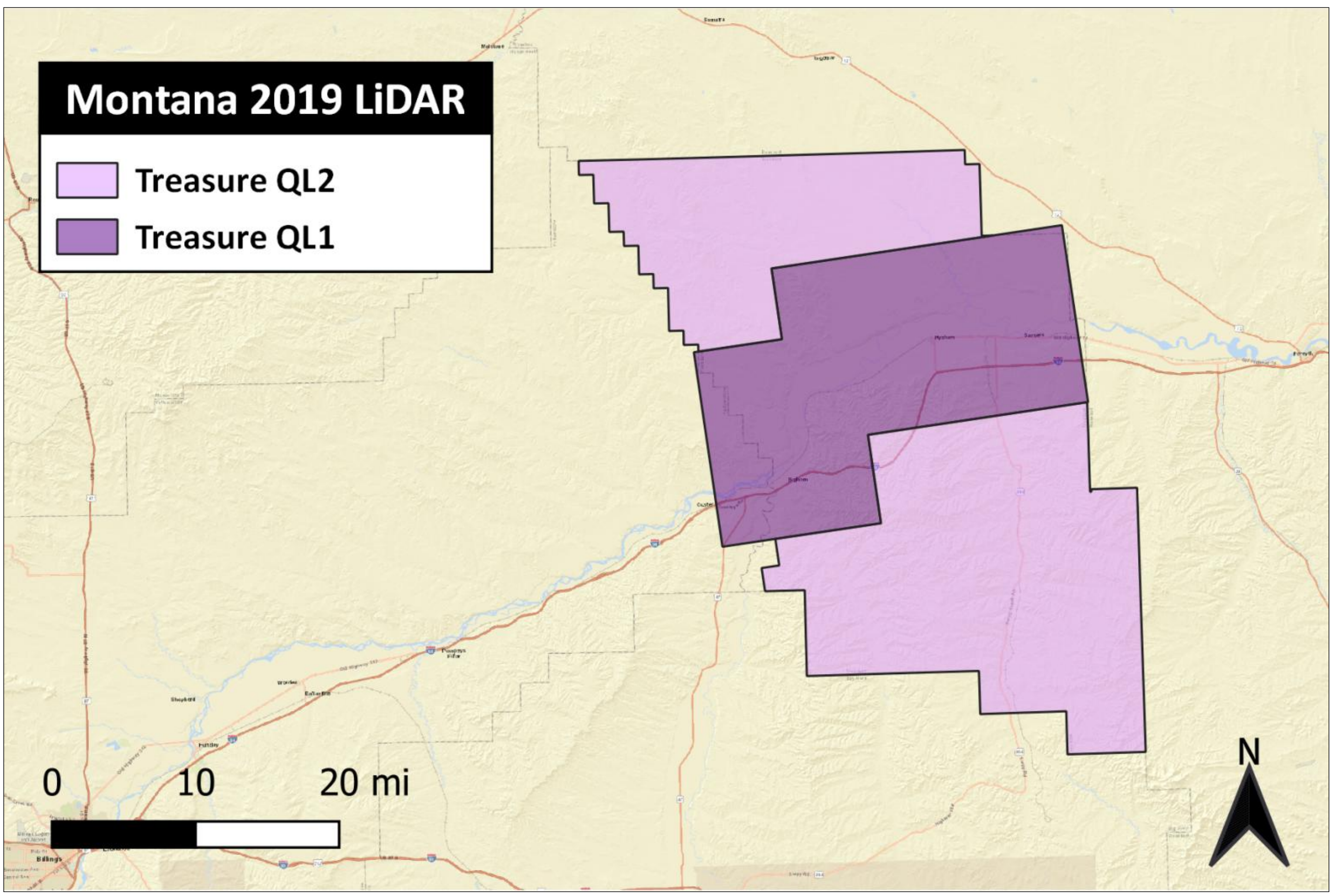


1.2 Project Area Description

Aero-Graphic's assigned area for Montana's 2019 LiDAR Acquisition Project was separated into eight (8) delivery areas roughly corresponding to county boundaries: Carbon/Stillwater Counties, Big Horn County, Custer County, Dawson County, Fallon County, Lincoln County, Rosebud County, and Treasure County. This report focuses on the Treasure area, which covers approximately 1,015 mi^2.

Treasure – QL2 and QL1 areas		
Sub-AOI Name	**Quality Level**	**Area (mi^2)**
Treasure	QL2	645 mi²
Treasure – Yellowstone River	QL1	370 mi²

Exhibit 2: *Overview of the Treasure QL2 and QL1 project areas.*



2. LiDAR Acquisition

2.1 Flight Planning

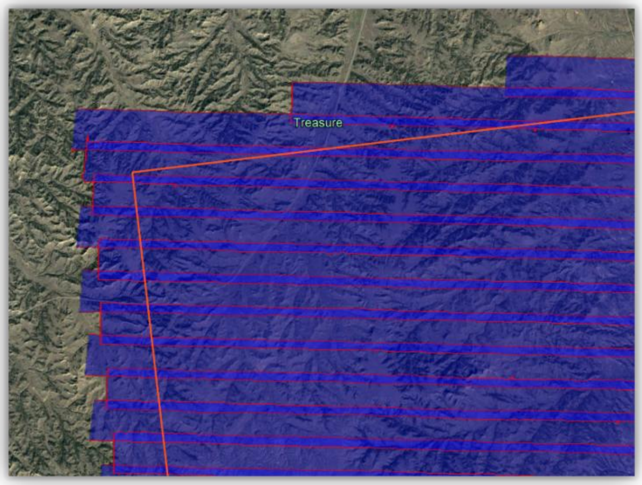
Specialized flight plans were developed by Keystone Aerial Surveys and Aero-Graphics to ensure complete coverage and that all contract specifications were met. Prior to mobilizing to the acquisition sites, all site conditions and potential weather hazards including wind, rain, snow, and blowing dust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

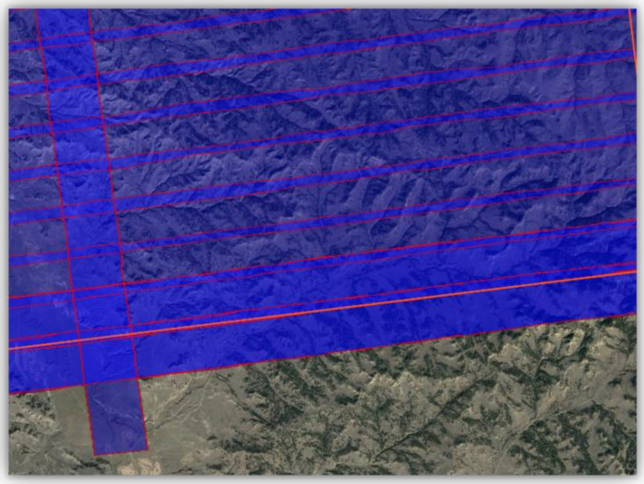
The table below contains the planned settings for the Treasure QL2 (flown by Keystone) and QL1 (flown by Aero-Graphics) project areas.

	Treasure QL2	Treasure QL1
Planned Specs	Optech Galaxy T1000	Optech Galaxy PRIME
Altitude (m)	1550	1550
Speed (kts)	170	120
PRF (kHz)	250	500
Scan Freq (Hz)	65	87
Scan Angle (°)	40	26
Swath Width (m)	1140	716
NPS (m)	0.67	0.35
Avg Point Density (ppm2)	2.20	8.91
Overlap (%)	20	20

Keystone and Aero-Graphics utilize 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 different sensors, mounts, and settings, thus ensuring the flight plan meets the needs of the project while being as efficient as possible. To compliment the flight planning process the Galaxy Prime is equipped with FMS Nav, which is the latest data collection and navigation software release from Optech. The use of FMS Nav 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. **Exhibit 3** shows the coverage of the acquired swaths in sections of both the QL2 and QL1 areas.

Exhibit 3: *Swath data for the project was recorded and viewed real-time by the sensor operator.*





2.2 LiDAR Sensors

Optech Galaxy PRIME & Optech Galaxy T1000

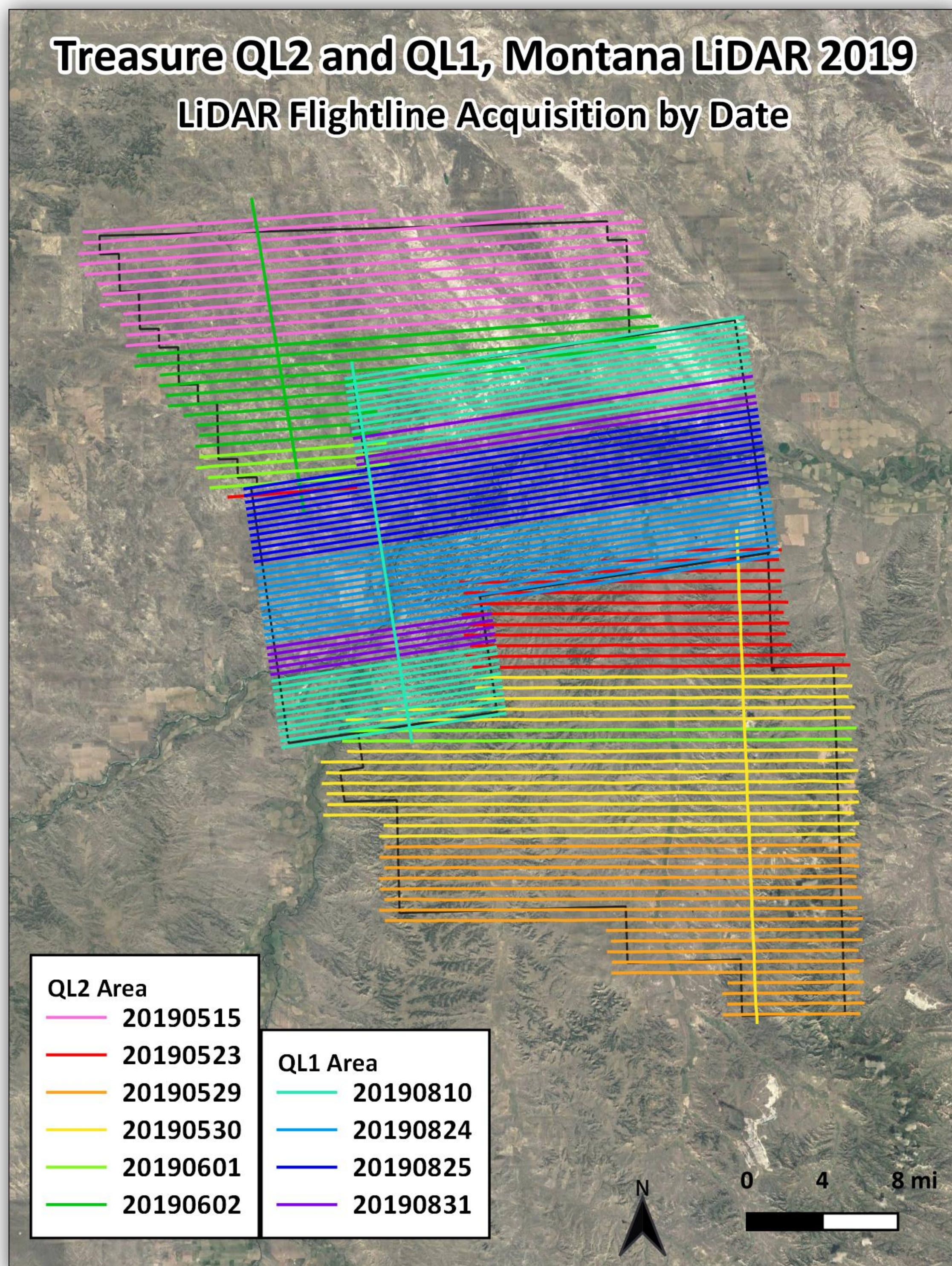
The Optech Galaxy PRIME is currently the most productive sensor available in the industry, followed closely by the T1000. These sensors feature SwathTRAK technology, which dynamically adjusts the scan FOV in real time during data acquisition. They also feature a 1MHz effective pulse rate, providing on-the-ground 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 Treasure QL2 project area occurred between May 15th and June 2nd, 2019, and QL1 acquisition occurred between August 10th and 31st, 2019. These flights took place when ground conditions were free of snow, ice, and standing water; rivers were at a stage of low flow; and lakes and reservoirs were close to the lowest levels of the year. A total of 11 lifts were required to complete LiDAR acquisition for the assigned Treasure QL2 and QL1 project areas.

Keystone and Aero-Graphics reflew areas as-needed throughout the acquisition period. 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 the flight.

Exhibit 4: *Flightlines organized by day of acquisition*



2.4 Flight Logs

Flight dates are listed in the tables below along with the AOI, sensor name, sensor number, and aircraft tail number for each lift.

Treasure Montana Flight Logs				
Flight Date	**AOI Covered**	**Sensor Name**	**Sensor Number**	**Aircraft Tail Number**
5/15/2019	QL2	Optech Galaxy T1000	354	N5038J
5/23/2019	QL2	Optech Galaxy T1000	354	N5038J
5/29/2019	QL2	Optech Galaxy T1000	354	N5038J
	QL2	Optech Galaxy T1000	354	N5038J
5/30/2019*	QL2	Optech Galaxy T1000	354	N5038J
6/1/2019*	QL2	Optech Galaxy T1000	354	N5038J
6/2/2019*	QL2	Optech Galaxy T1000	354	N5038J
8/10/2019*	QL1	Optech Galaxy Prime	5060410	N7269T
8/24/2019	QL1	Optech Galaxy Prime	5060410	N7269T
8/25/2019	QL1	Optech Galaxy Prime	5060410	N7269T
8/31/2019*	QL1	Optech Galaxy Prime	5060410	N7269T

**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), Montana State Plane, intl. ft.

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 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 20). 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.

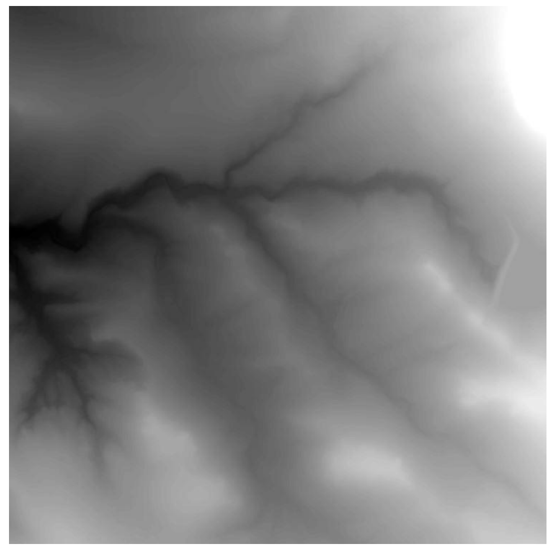
All data was manually reviewed and any remaining artifacts removed using functionality provided by TerraScan. LP360 was used as a final check of the bare earth dataset. LP360 was then used to create the deliverable industry-standard LAS files. Aero-Graphics, Inc. proprietary software was used to perform 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 3 ft 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.



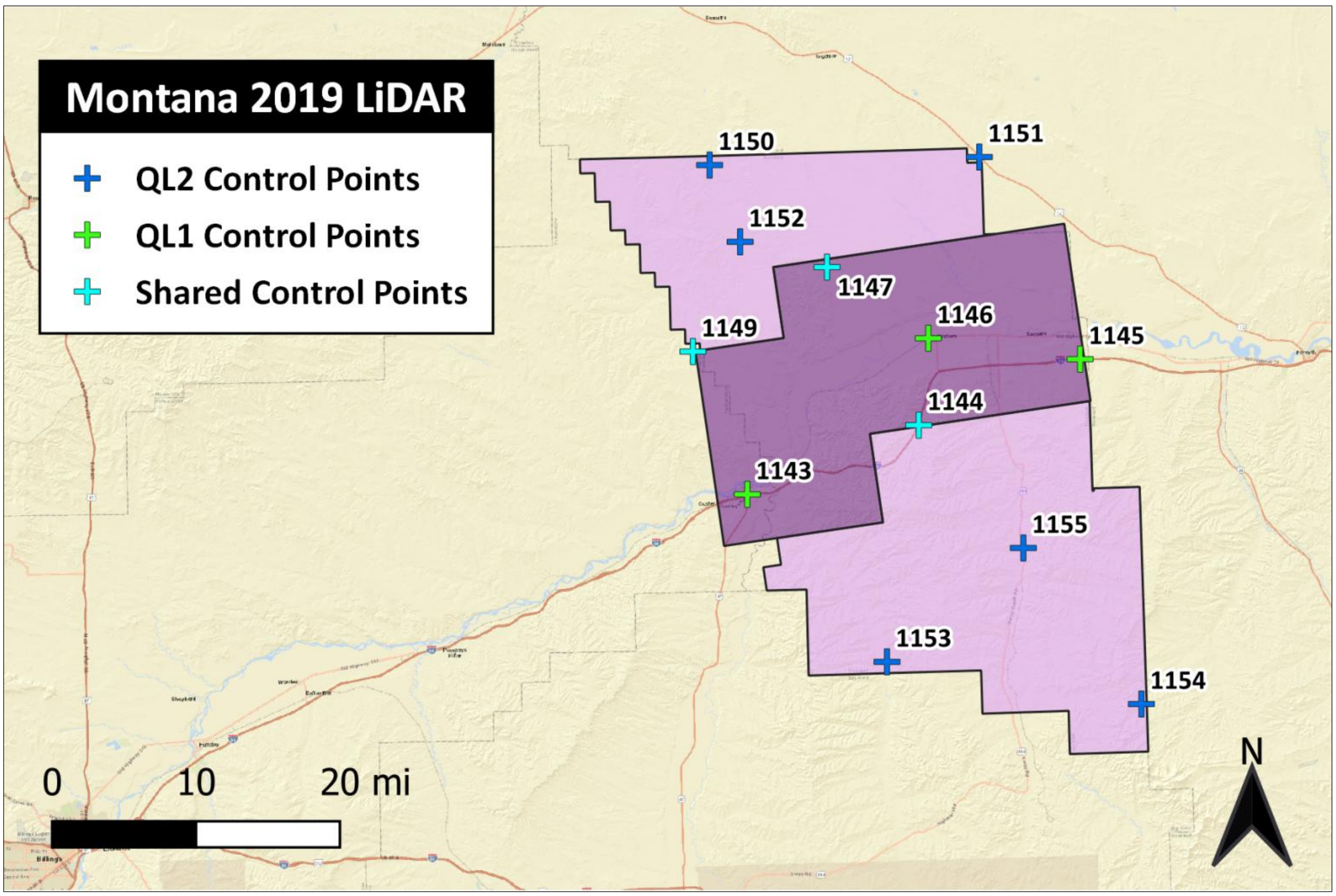
Breaklines were collected at bridges but not culverts. The distinction between bridges and culverts was based on the following guidelines: Bridges are structures carrying a road, path, railroad, canal, aircraft taxiway, or any other transit between two locations of higher elevation over an area of lower 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.

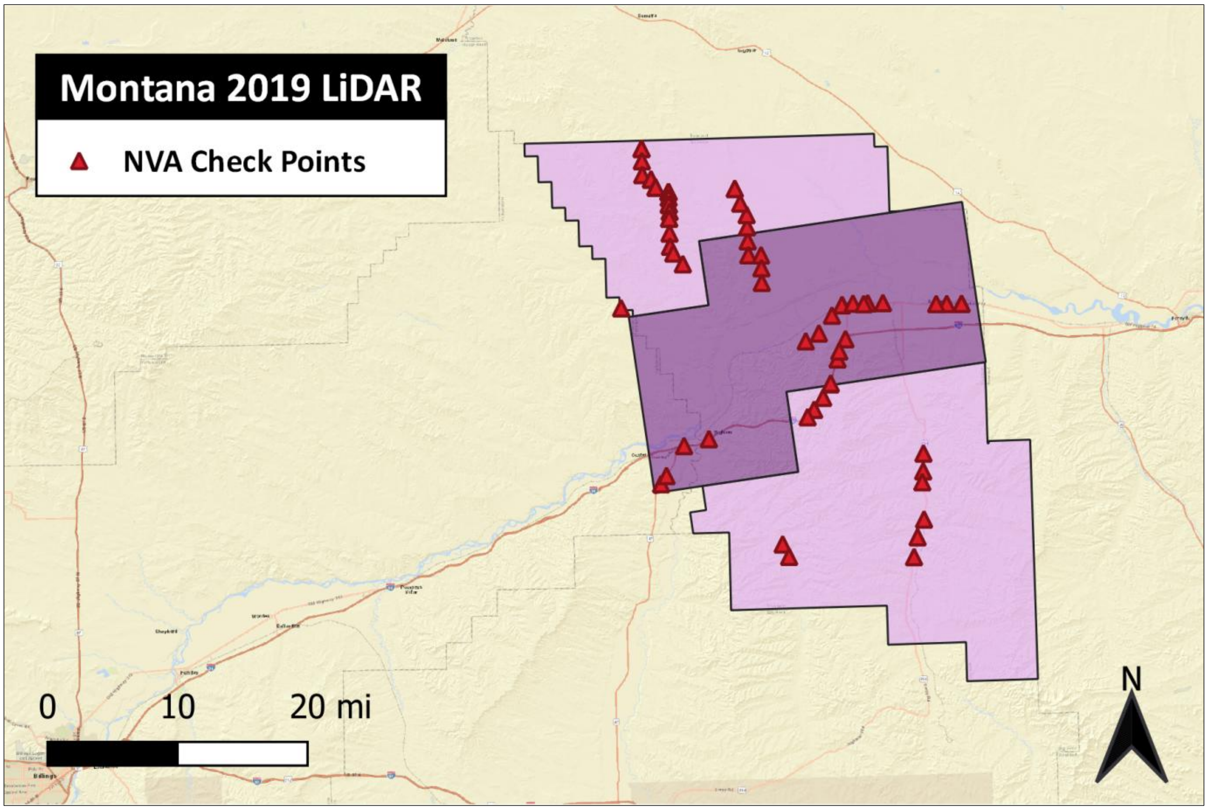
j. **First Return Raster DSM Creation.** First return LiDAR points were used to create 3 ft first-return raster DEMs. Using LP360 along with automated scripting routines within ArcMap, a GeoTIFF file was created for each tile. Each surface is reviewed using ESRI ArcMap and ArcScene to check for any surface anomalies or incorrect elevations found within the surface.

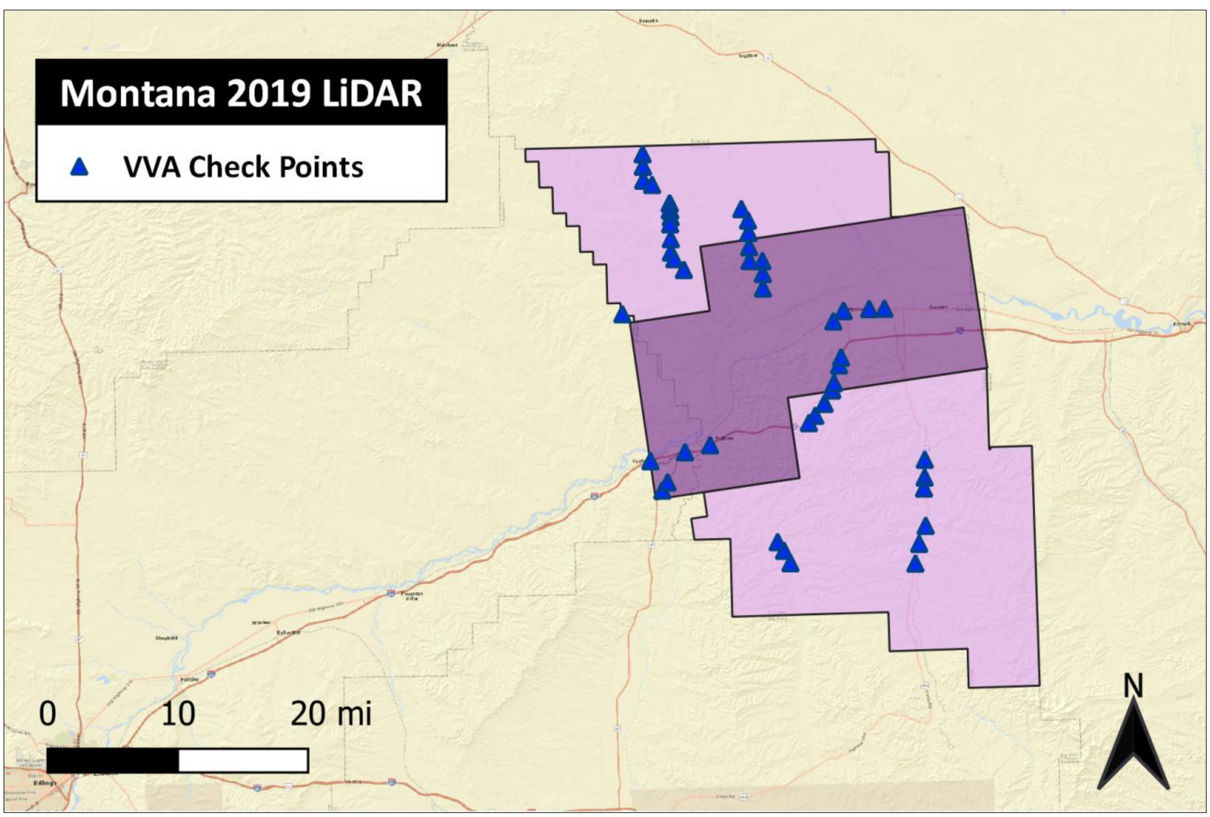
k. **Intensity Image Creation.** TerraScan software was used to create the deliverable Intensity Images. All overlap classes were ignored during this process as it helps to ensure a more aesthetically pleasing image. ESRI ArcMap software was then used to verify full project coverage. GeoTIFF files were provided as the deliverable for this dataset requirement.

4. Ground Control and Check Point Survey

Aero-Graphics' professional land surveyor identified, targeted, and surveyed 15 ground control points for use in data calibration as well as 124 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.




Montana 2019 LiDAR
NVA Check Points
0
10
20 mi
N


Montana 2019 LiDAR
VVA Check Points
0
10
20 mi
N

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.

Treasure QL2 project area

- Between-swath relative accuracy **average** of 0.029 intl. feet

Treasure QL1 project area

- Between-swath relative accuracy **average** of 0.039 intl. feet

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 on page 10.

Accuracy$_z$: Treasure QL2 Project Area	
Average Error = -0.005 ft	RMSE = 0.053 ft
Minimum Error = -0.061 ft	σ = 0.056 ft
Maximum Error = 0.097 ft	Average Magnitude = 0.047 ft
Survey Sample Size: n = 9	

Accuracy$_z$: Treasure QL1 Project Area	
Average Error = 0.004 ft	RMSE = 0.072 ft
Minimum Error = -0.080 ft	σ = 0.079 ft
Maximum Error = 0.101 ft	Average Magnitude = 0.064 ft
Survey Sample Size: n = 6	

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 68 check points (41 in QL2 area and 27 in QL1). 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 0.139 intl. ft for the QL2 area and 0.166 intl. ft for the QL1 area in terms of the RMSEz. The resulting NVA stated as the 95% confidence level (RMSEz x 1.96) is 0.272 intl. ft for the QL2 area and 0.325 intl. ft for the QL1 area. Therefore this dataset meets the required NVA of 0.643 intl. ft at the 95% confidence level as defined by the National Standards for Spatial Data Accuracy (NSSDA).

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 68 check points. The VVA was tested with 56 check points (36 in the QL2 area and 20 in QL1).

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 0.162 intl. ft for the QL2 area, and 0.144 intl. ft for the QL1 area in terms of the RMSEz. The resulting accuracy stated as the 95% confidence level (RMSEz x 1.96) is 0.318 intl. ft for the QL2 area and 0.282 intl. ft for the QL1 area. Therefore this dataset meets the required NVA of 0.643 intl. ft at the 95% confidence level.

The tested Vegetated Vertical Accuracy (VVA) for this dataset captured from the DEM using bi-linear interpolation for all vegetation classes was found to be 0.412 intl. ft for the QL2 area and 0.847 intl. ft for the QL1 area at the 95th percentile error. Therefore this dataset meets the required VVA of less than or equal to 0.984 intl. ft (0.30 m) based on the 95th percentile error.

5.5 Data Accuracy Summary

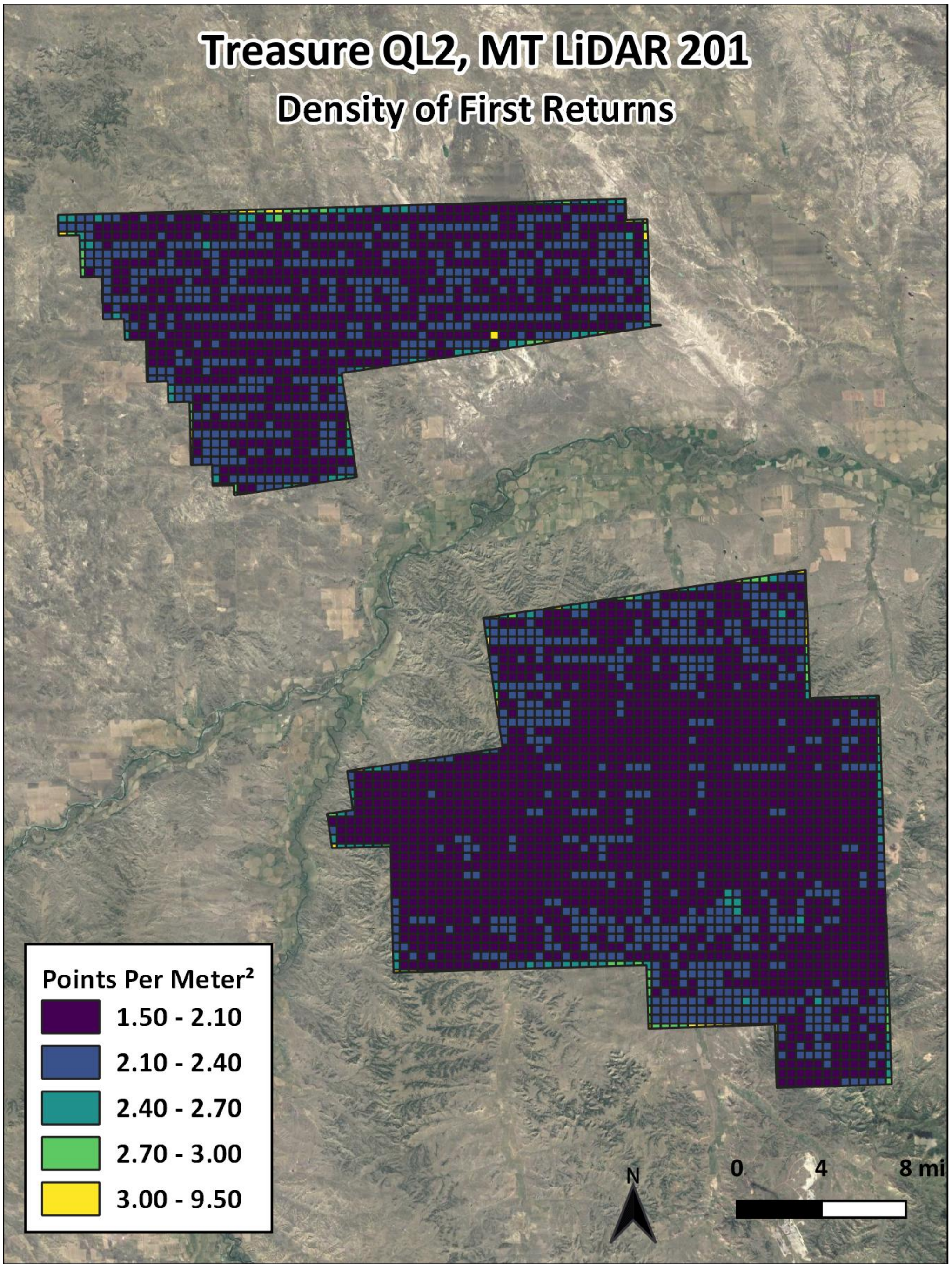
Accuracy has been tested to meet 19.6 cm or better Non-Vegetated Vertical Accuracy at 95% confidence level using RMSEz x 1.96 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation (NDEP)/ASPRS Guidelines.

Area	Raw Point Cloud NVA (RMSEz, intl. ft)	DEM NVA (RMSEz, intl. ft)	DEM VVA (95th percentile, intl. ft)	Points Tested NVA	Points Tested VVA
Treasure QL2	0.139	0.162	0.412	41	36
Treasure QL1	0.166	0.144	0.847	27	20

5.6 Data Density

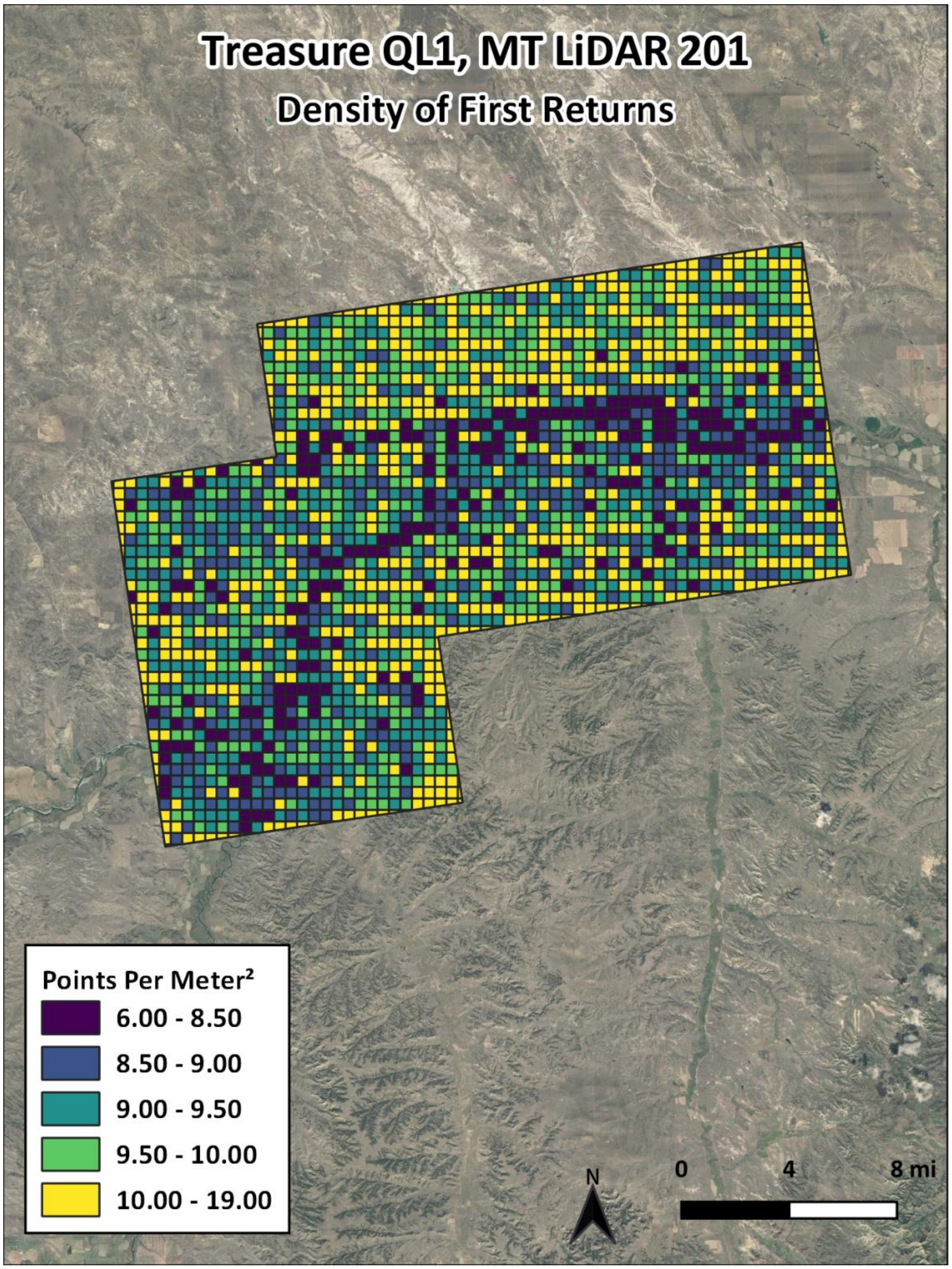
In order to fulfill USGS LBS 1.3 QL2 density requirements the density of the point cloud must be greater than or equal to 2 points per meter². Average density per tile for the Treasure QL2 project area was calculated based on first returns only. **Exhibit 5** illustrates that the acquisition met or exceeded the required density except in areas where lakes impeded the collection of data or tiles contained a proportionally significant area outside of the project boundaries. The QL2 project achieved an average per tile density of 2.2 points per meter² for first returns.

Exhibit 5: *QL2 Laser Point Density of First Return by Tile, points/m²*



In order to fulfill USGS LBS 1.3 QL1 density requirements the density of the point cloud must be greater than or equal to 8 points per meter². Average density per tile for the Treasure QL1 project area was calculated based on first returns only. **Exhibit 6** illustrates that the acquisition met or exceeded the required density except in areas where lakes impeded the collection of data or tiles contained a proportionally significant area outside of the project boundaries. The QL1 project achieved an average per tile density of 9.7 points per meter² for first returns.

Exhibit 6: *QL1 Laser Point Density of First Return by Tile, points/m²*



6. Project Coordinate System

Projection:		Montana State Plane
Datum	**Vertical:**	NAVD88 (GEOID12B)
	Horizontal:	NAD83
Horizontal Units:		International Foot
Vertical Units		US Survey Foot

7. Project Deliverables

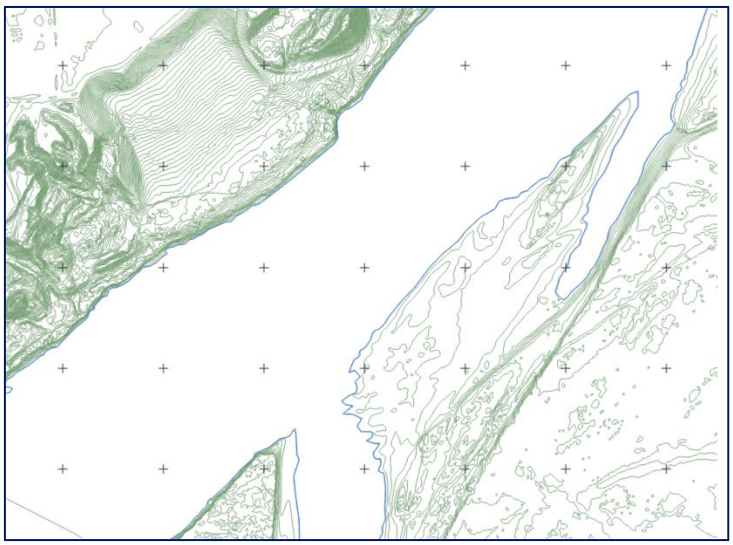
All required project deliverables and file formats are listed in the table below.

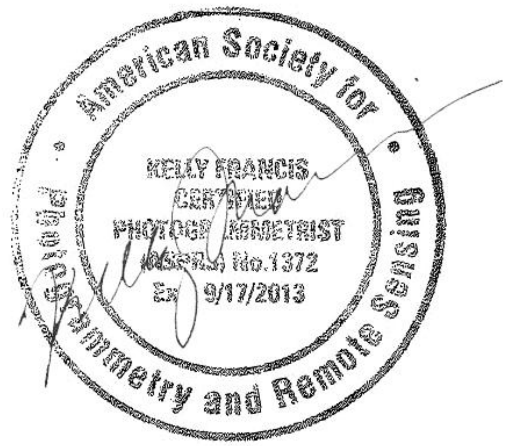
Delivery Item	Format
Calibrated LiDAR point cloud data	LAS 1.4 (.las)
Classified LiDAR point cloud data tiles	LAS 1.4 (.las)
Bare-earth raster DEM tiles with a cell size of 3’	GeoTIFF (.tif)
First-return raster DSM tiles with a cell size of 3’	GeoTIFF (.tif)
Intensity image tiles with a cell size of 3’	GeoTIFF (.tif)
DTM	ESRI GDB and ASCII
1’ contours	ESRI GDB
AOI, Processing Boundary (BPA), and Tile Index	ESRI Shapefile (.shp)
Breaklines used for hydro-flattening	ESRI GDB
Bathymetric survey data, cross-section point listing, field notes, and survey report	XLSX
Control Points and QC Checkpoints	ESRI Shapefile (.shp)
MT Licensed Surveyor Certification and Survey Report	PDF
Deliverable Metadata	XML (.xml)

8. CERTIFICATIONS

PHOTOGRAMMETRIST'S CERTIFICATION:

I, Kelly Francis, certify that I am an active American Society of Photogrammetry and Remote Sensing (ASPRS) Certified Photogrammetrist (recertified as #R1372), current Exp Date: 9/17/23; that all production work occurred under my supervision; and that I reviewed and approved all final products.





Appendix A

Control Point Coordinates

Treasure QL2 and QL1			
Survey Point	Montana State Plane, NAD83		
	Northing Intl. Ft	Easting Intl. Ft	Elev US Ft*(Geoid 12B)
1143	2473386.657	695697.296	2878.870
1145	2595463.889	745311.037	2777.557
1146	2539811.862	752972.287	2652.122
1144	2536295.546	721085.397	2975.974
1153	2524638.863	634261.003	3037.583
1154	2617957.770	618799.456	3501.033
1155	2574649.531	676035.017	2951.581
1147	2502632.911	779085.109	2998.745
1149	2453438.873	748097.309	3183.549
1150	2459562.447	816545.371	3126.521
1151	2558509.777	819509.823	2876.120
1152	2470770.308	788380.309	3077.669