

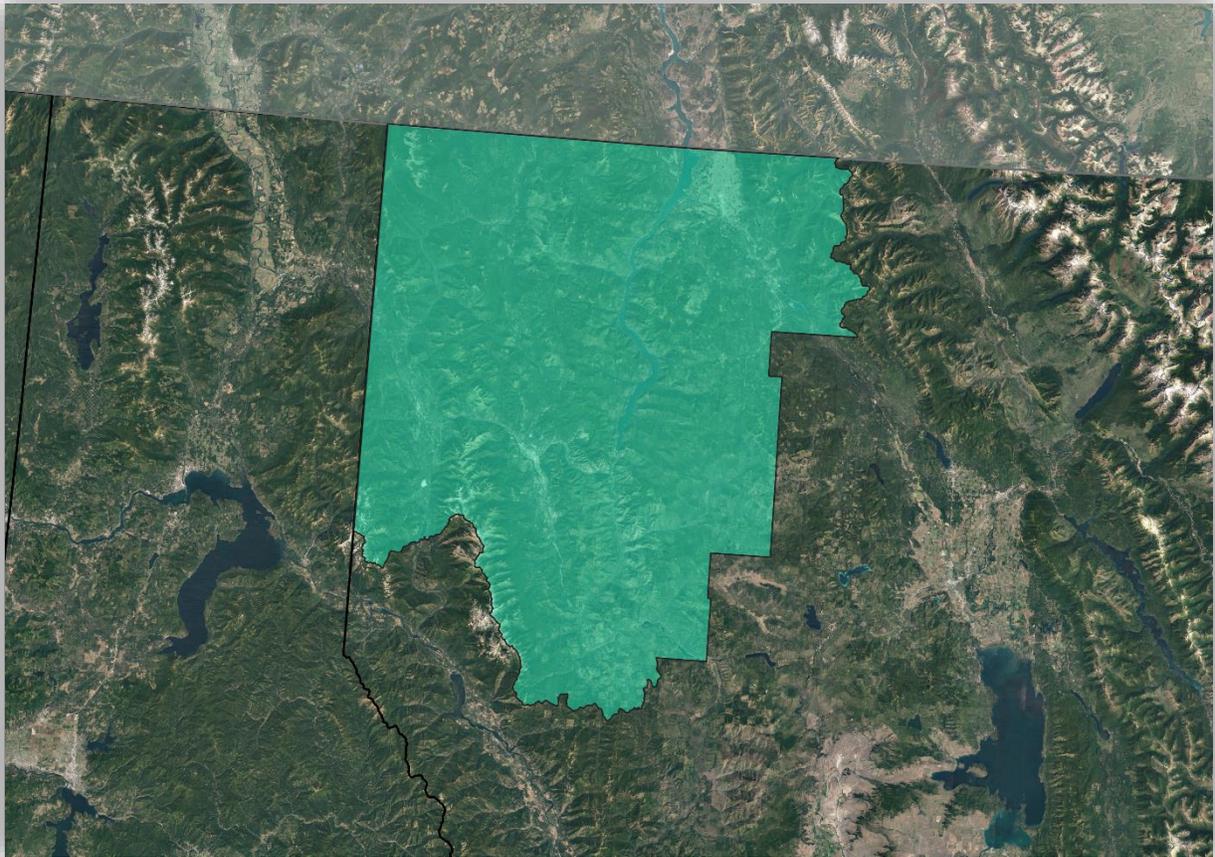


LiDAR PROJECT REPORT

Montana 2019 LiDAR – Lincoln QL1

Contract #: WO-AGI-190

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Submitted to:

Steve Story, PE, CFM
Chief, Water Operations Bureau
Dept. of Natural Resources & Conservation
1424 9th Avenue
Helena, MT 59620

Submitted by:

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

LiDAR Project Report

Montana 2019 LiDAR – Lincoln QL1

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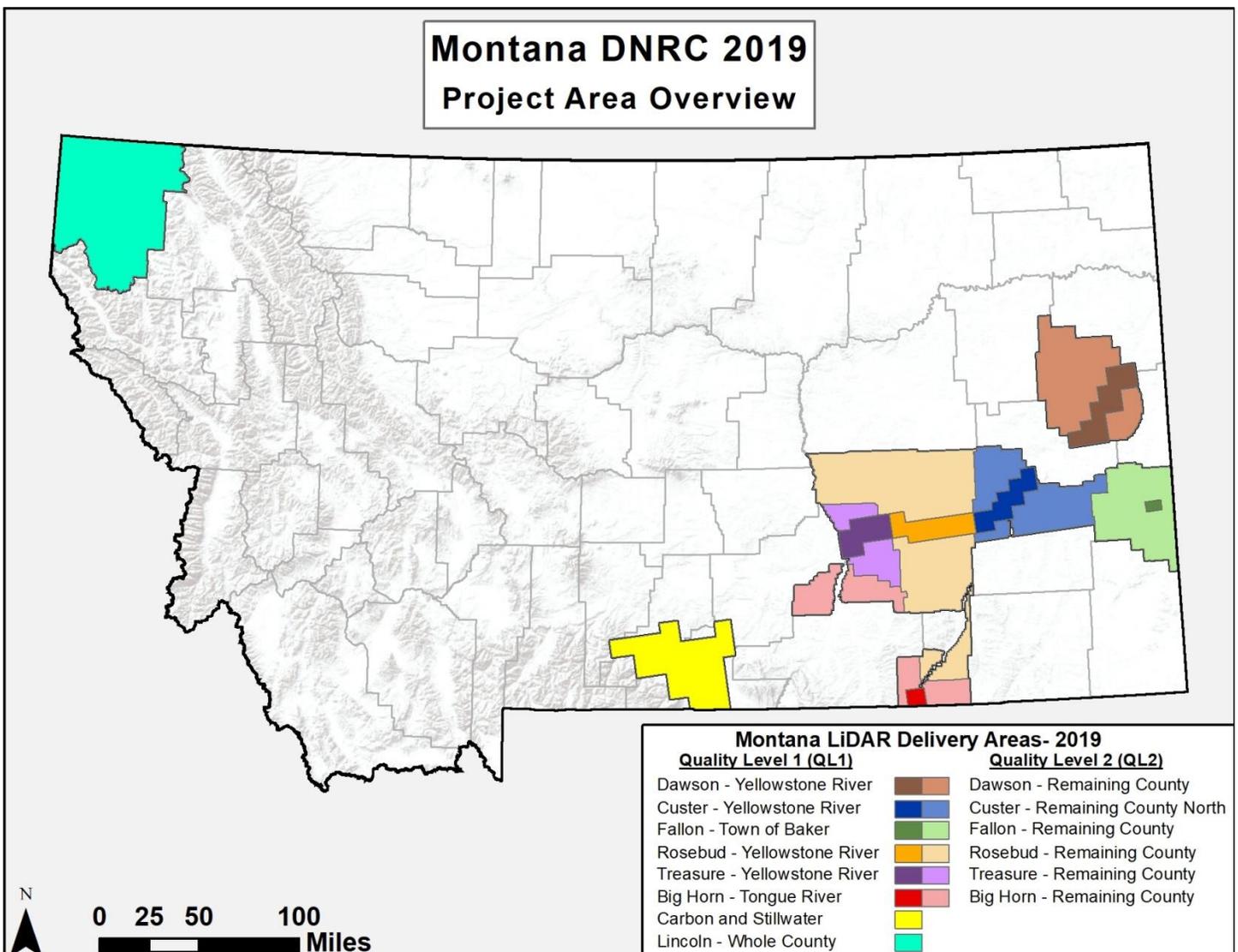
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1. INTRODUCTION

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 mi².

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

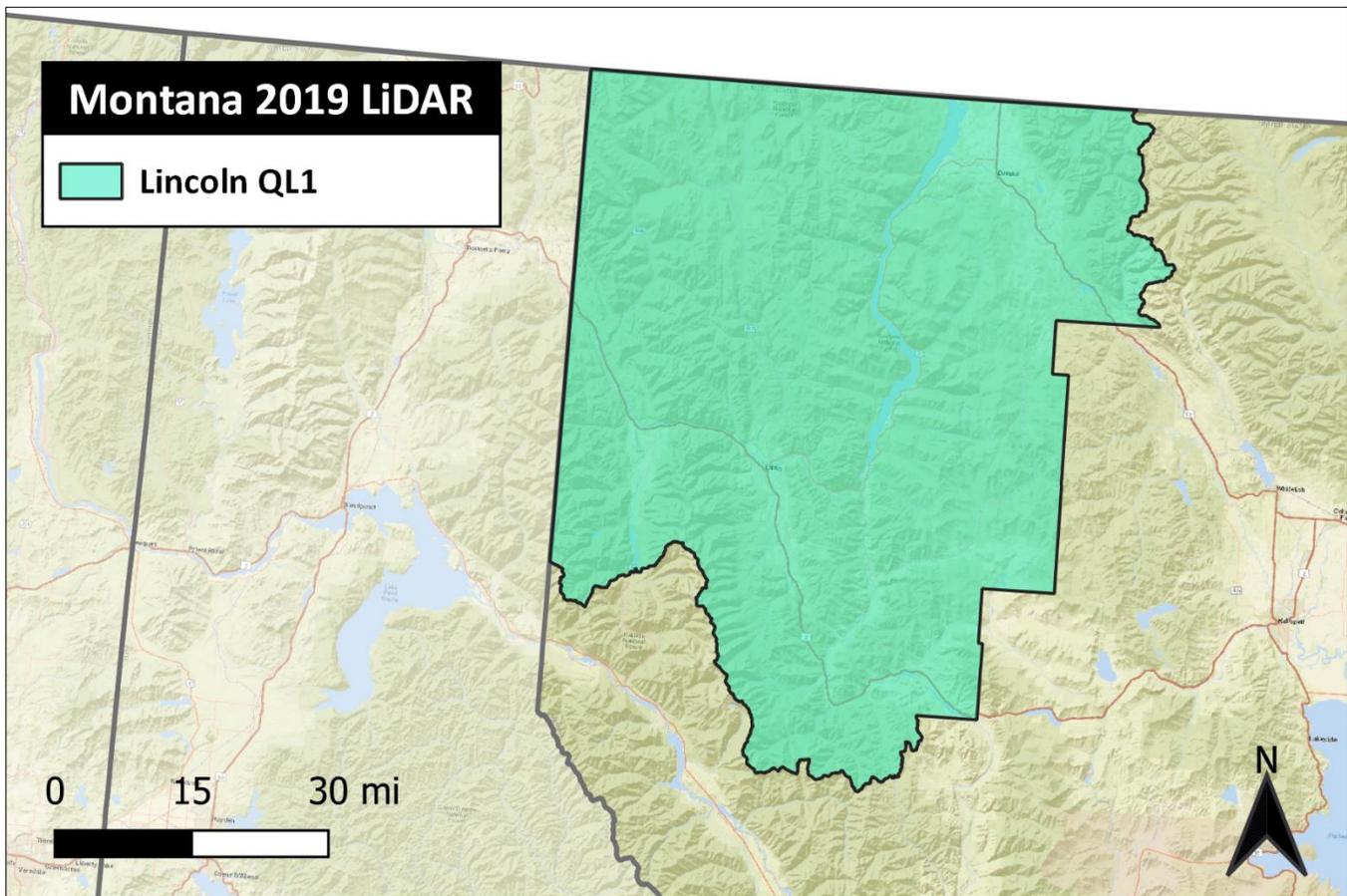


1.2 PROJECT AREA DESCRIPTION

Aero-Graphics' 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 Lincoln County area, which covers approximately 3,665 mi².

Lincoln – QL1 area		
Sub-AOI Name	Quality Level	Area (mi ²)
Lincoln	QL1	3,665

Exhibit 2: Overview of the Lincoln QL1 project area.



2. LIDAR ACQUISITION

2.1 FLIGHT PLANNING

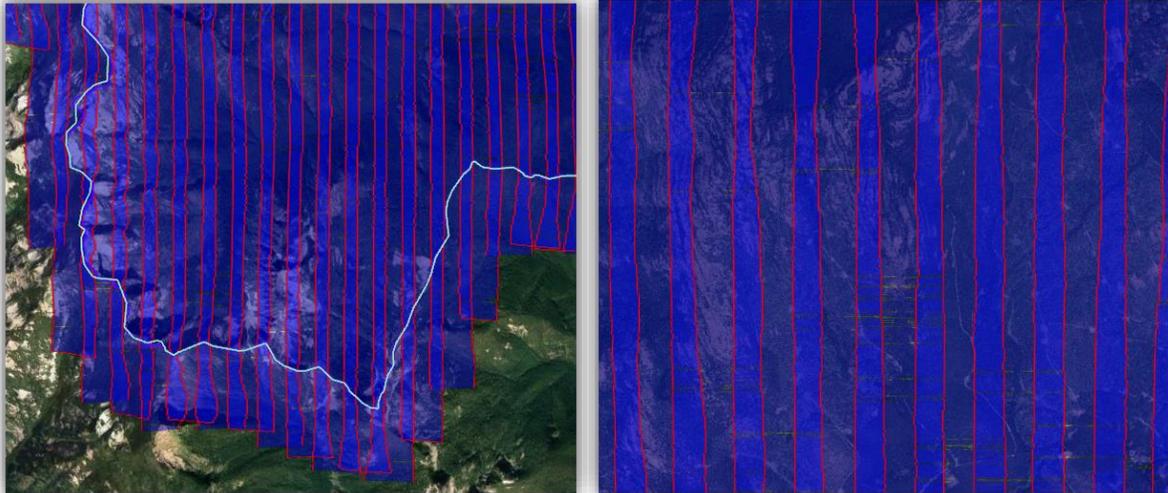
Specialized flight plans were developed by Aero-Graphics and Aerial Surveys International (ASI) and were checked by Aero-Graphics to ensure complete coverage and that all contract specifications were met. Prior to mobilizing to the acquisition sites, ASI and Aero-Graphics monitored all site conditions and potential weather hazards including wind, rain, snow, and blowing dust. In addition, ASI 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 Lincoln QL1 project area.

Planned Specs	Lincoln QL1		
	Optech Galaxy PRIME (AG)	Optech Galaxy PRIME (ASI)	Optech Galaxy T2000 (ASI)
Altitude (m)	1550	1400	1400
Speed (kts)	120	150	150
PRF (kHz)	500	500	500
Scan Freq (Hz)	87	80	80
Scan Angle (°)	26	26	26
Swath Width (m)	716	646	646
NPS (m)	0.35	0.35	0.35
Avg Point Density (ppm2)	8.91	8.1	8.1
Overlap (%)	30	30	30

ASI 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 complement 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 the Lincoln QL1 area.

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



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.

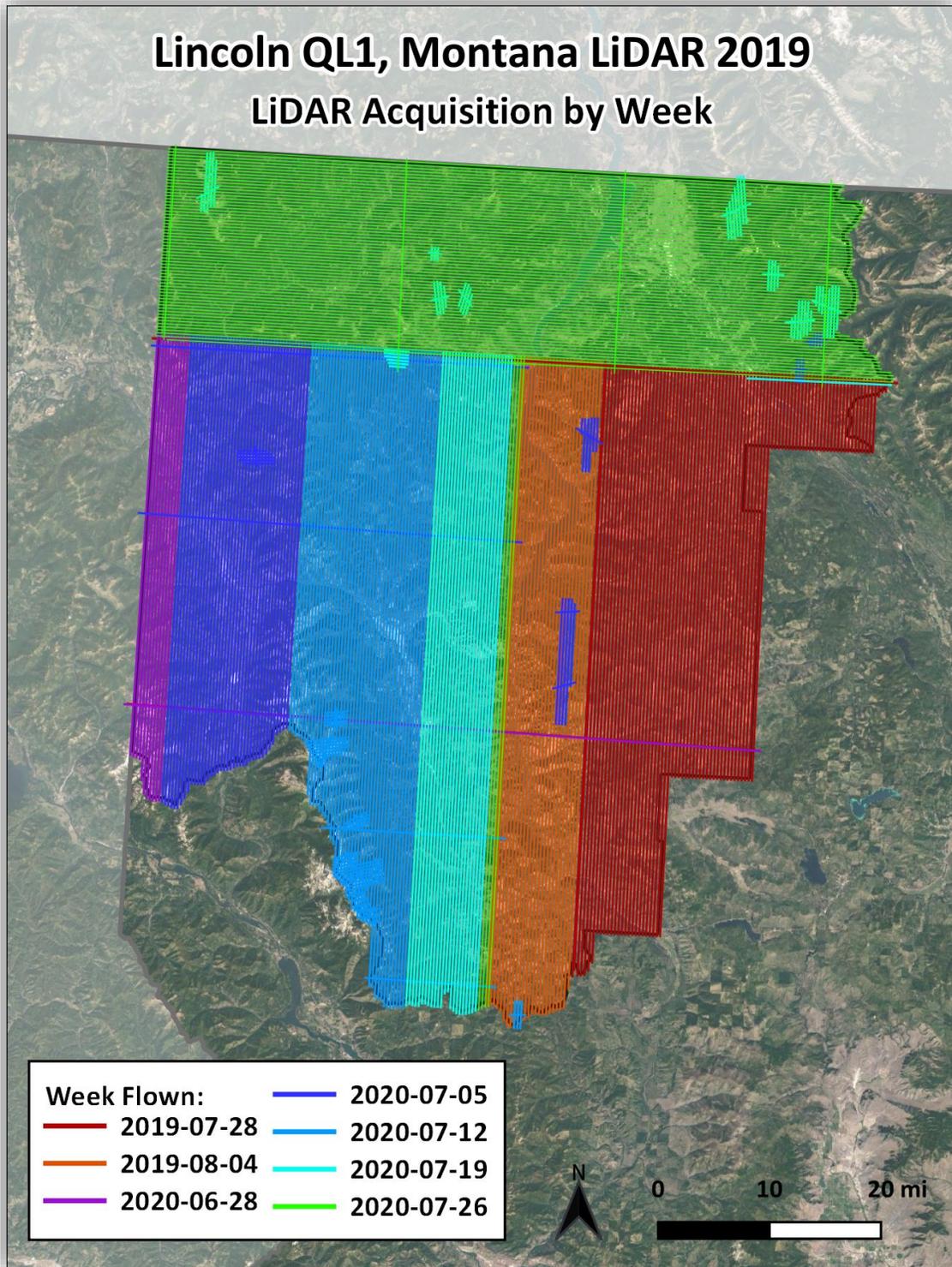


2.3 ACQUISITION SUMMARY

Acquisition for the Lincoln QL1 project area occurred between July 29th and August 6th, 2019 and again between July 4th and July 30th, 2020. The survey 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 41 lifts were required to complete LiDAR acquisition for the assigned Lincoln QL1 project area.

ASI and Aero-Graphics refllew 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 week 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.

Lincoln QL1 Montana Flight Logs			
Flight Date	Sensor Name	Sensor Number	Aircraft Tail Number
7/29/2019	Galaxy Prime	SN5060410	N7269T
	Galaxy Prime	SN5060410	N7269T
7/30/2019	Galaxy Prime	SN5060410	N7269T
7/31/2019*	Galaxy Prime	SN5060410	N7269T
	Galaxy Prime	SN5060410	N7269T
8/1/2019*	Galaxy Prime	SN5060410	N7269T
8/4/2019*	Galaxy Prime	SN5060410	N7269T
8/5/2019	Galaxy Prime	SN5060410	N7269T
8/6/2019	Galaxy Prime	SN5060410	N7269T
7/4/2020	Galaxy Prime	SN5060386	N7516Q
7/5/2020	Galaxy Prime	SN5060386	N7516Q
7/6/2020	Galaxy Prime	SN5060386	N7516Q
	Galaxy Prime	SN5060386	N7516Q
7/11/2020*	Galaxy Prime	SN5060386	N7516Q
	Galaxy Prime	SN5060386	N7516Q
7/13/2020*	Galaxy Prime	SN5060386	N7516Q
7/14/2020	Galaxy Prime	SN5060386	N7516Q
	Galaxy Prime	SN5060386	N7516Q
7/15/2020*	Galaxy Prime	SN5060386	N7516Q
7/16/2020	Galaxy Prime	SN5060386	N7516Q
	Galaxy Prime	SN5060386	N7516Q
7/17/2020	Galaxy Prime	SN5060386	N7516Q
7/19/2020	Galaxy Prime	SN5060386	N7516Q
7/20/2020	Galaxy Prime	SN5060386	N7516Q
7/21/2020	Galaxy Prime	SN5060386	N7516Q
7/22/2020*	Galaxy T2000	SN5060448	N989DE
7/23/2020*	Galaxy T2000	SN5060448	N989DE
7/24/2020*	Galaxy T2000	SN5060448	N989DE
7/25/2020*	Galaxy T2000	SN5060448	N989DE
7/26/2020*	Galaxy Prime	SN5060386	N7516Q
	Galaxy Prime	SN5060386	N7516Q
	Galaxy T2000	SN5060448	N989DE
	Galaxy T2000	SN5060448	N989DE

7/27/2020	Galaxy Prime	SN5060386	N7516Q
	Galaxy Prime	SN5060386	N7516Q
7/28/2020	Galaxy Prime	SN5060386	N7516Q
	Galaxy T2000	SN5060448	N989DE
7/29/2020*	Galaxy Prime	SN5060386	N7516Q
	Galaxy T2000	SN5060448	N989DE
7/30/2020	Galaxy Prime	SN5060386	N7516Q
	Galaxy T2000	SN5060448	N989DE

*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.

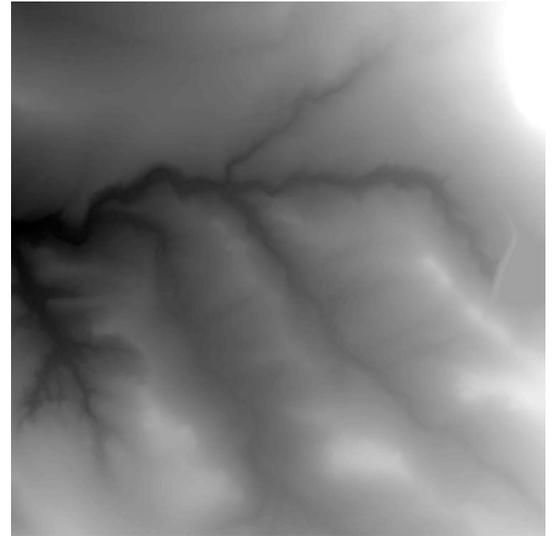
USGS Version 1.3 minimum point cloud classification scheme		
CLASS #	CLASS NAME	DESCRIPTION
1	Processed, but unclassified	Points that do not fit any other classes
2	Bare earth	Bare earth surface
7	Low noise	Low points identified below surface
9	Water	Points inside of lakes/ponds
17	Bridge decks	Points 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.

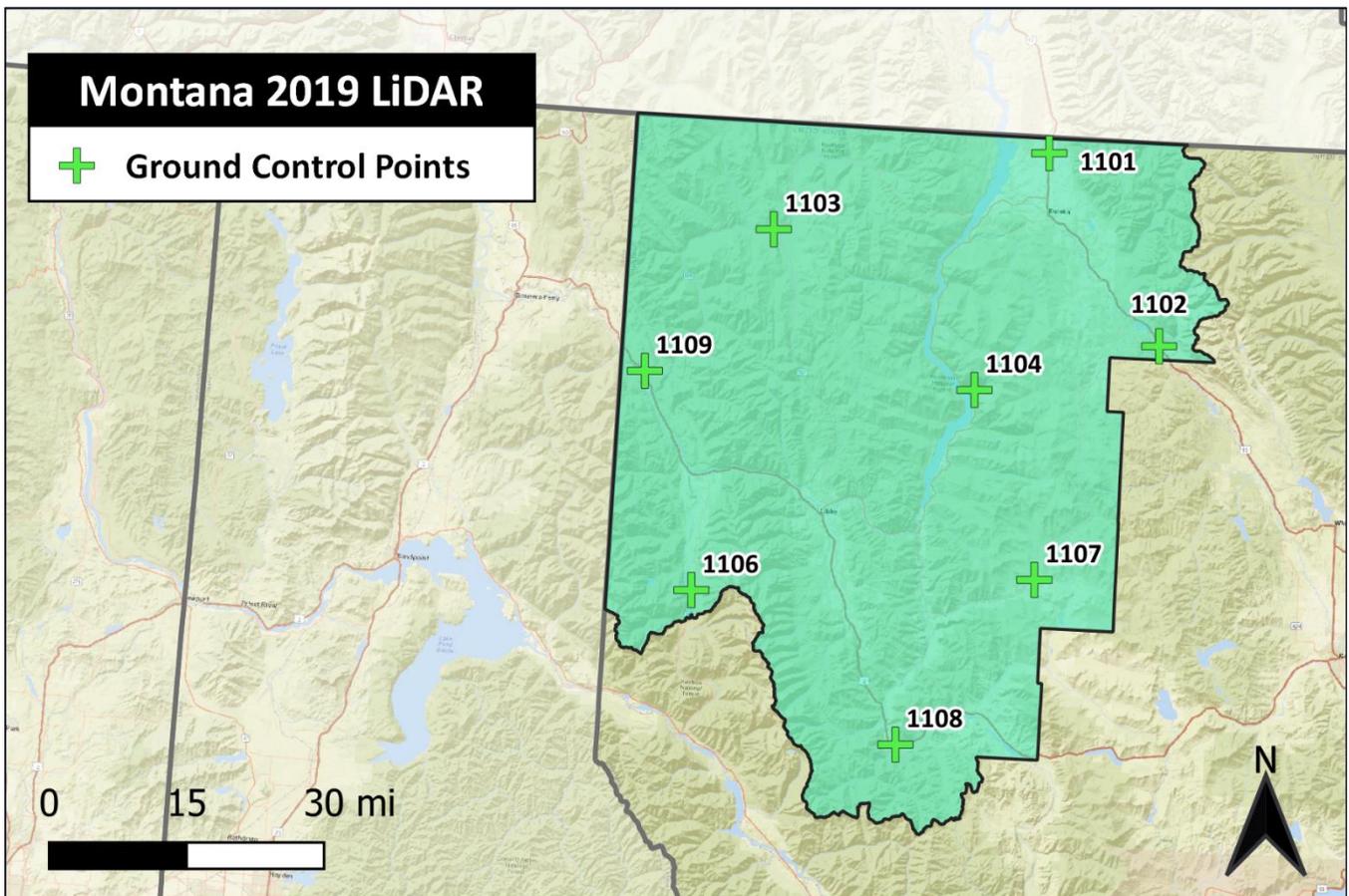
Breaklines were collected at bridges but not culverts. The distinction between bridges and culverts was based on the following guidelines: Bridges are structures carrying a road, path, railroad, canal, aircraft taxiway, or any other transit between two locations of higher elevation over an area of lower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

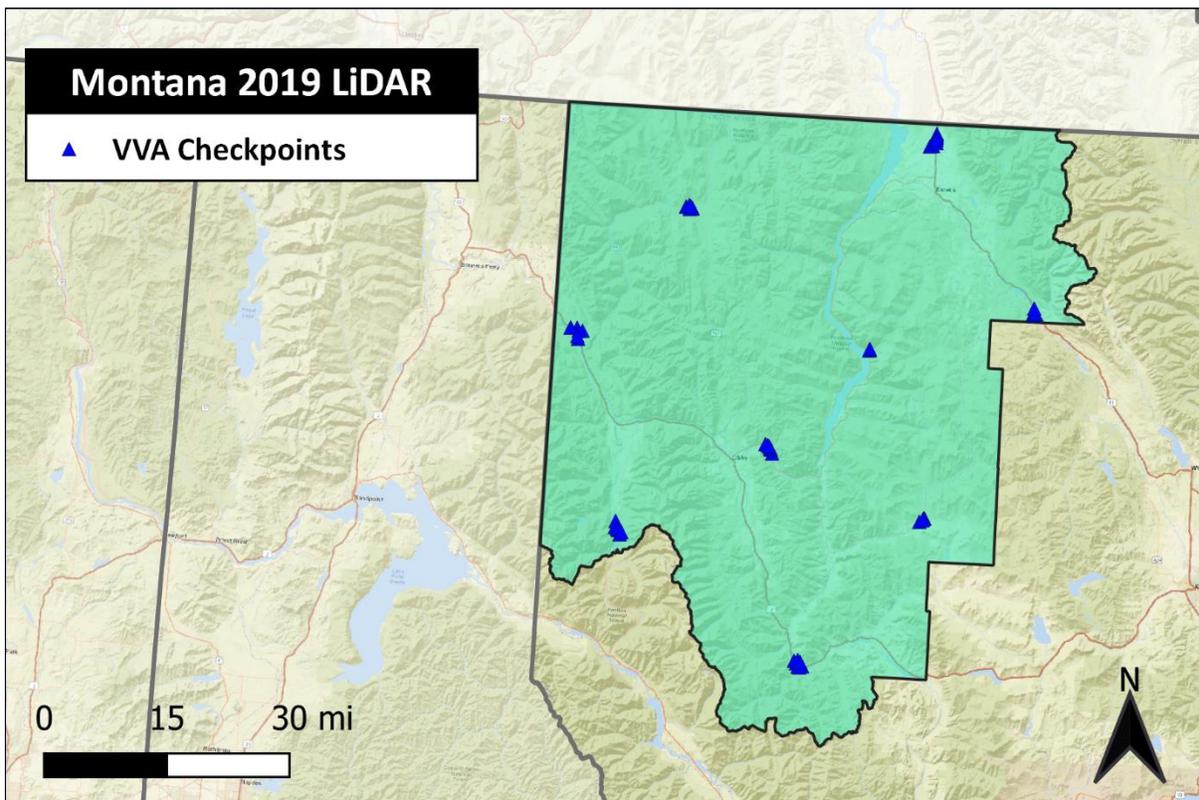
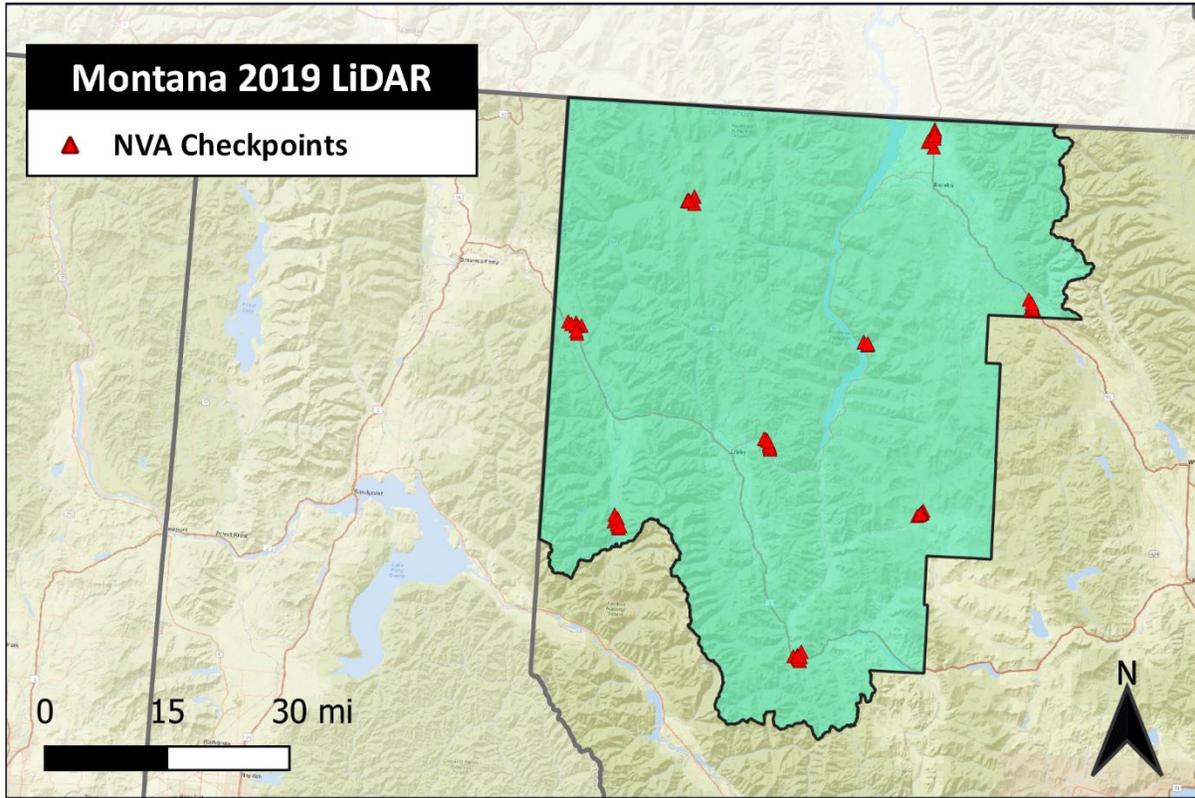


- j. **First Return Raster DSM Creation.** First return LiDAR points were used to create 3 ft first-return raster DEMs. Using LP360 along with automated scripting routines within ArcMap, a GeoTIFF file was created for each tile. Each surface is reviewed using ESRI ArcMap and ArcScene to check for any 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 8 ground control points for use in data calibration as well as 129 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.





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.

Lincoln QL1 project area

- Between-swath relative accuracy **average** of 0.063 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 11.

Accuracy _z : Lincoln QL1 Project Area	
Average Error = -0.050 ft	RMSE = 0.130 ft
Minimum Error = -0.234 ft	σ = 0.128 ft
Maximum Error = 0.179 ft	Average Magnitude = 0.104 ft
Survey Sample Size: n = 8	

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 72 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 0.183 intl. ft for the Lincoln QL1 area in terms of the RMSEz. The resulting NVA stated as the 95% confidence level (RMSEz x 1.96) is 0.358 intl. ft. 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 72 check points. The VVA was tested with 57 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 0.199 intl. ft for the Lincoln QL1 area in terms of the RMSEz. The resulting accuracy stated as the 95% confidence level (RMSEz x 1.96) is 0.390 intl. ft. 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 classes was found to be 0.616 intl. ft for the Lincoln QL1 area in terms of the RMSEz. The resulting accuracy stated as the 95% confidence level (RMSE x 1.96) is 0.625 intl. ft. 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

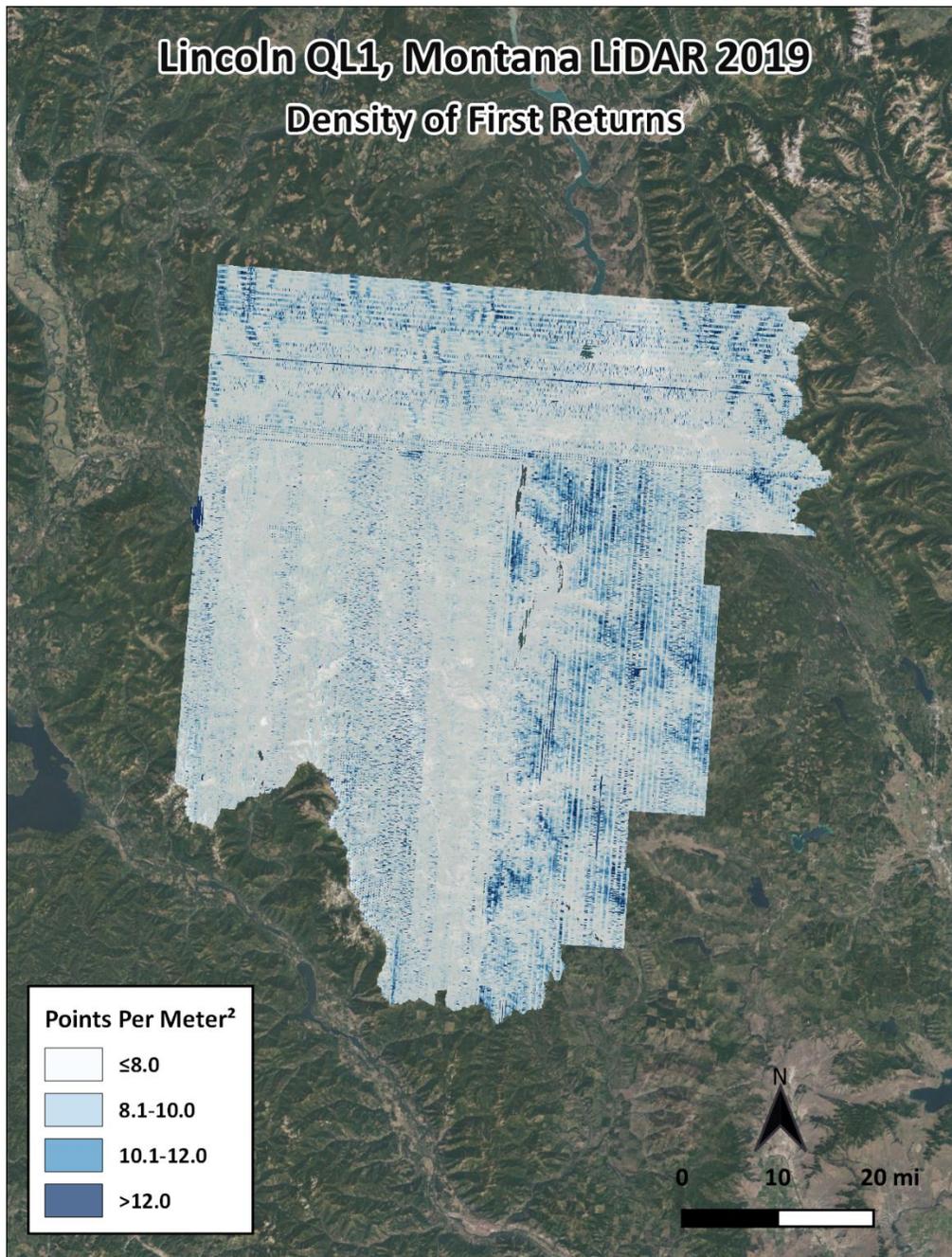
Accuracy has been tested to meet 19.6 cm or better Non-Vegetated Vertical Accuracy at 95% confidence level using RMSEz x 1.96 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation (NDEP)/ASPRS Guidelines.

Area	Raw Point Cloud NVA (intl. ft)	DEM NVA (intl. ft)	DEM VVA (intl. ft)	Points Tested NVA	Points Tested VVA
Lincoln QL1	0.183	0.390	0.616	72	57

5.6 DATA DENSITY

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 Lincoln 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 8.6 points per meter² for first returns.

Exhibit 5: 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

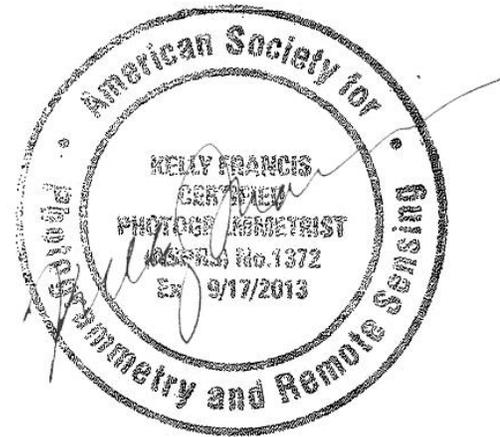
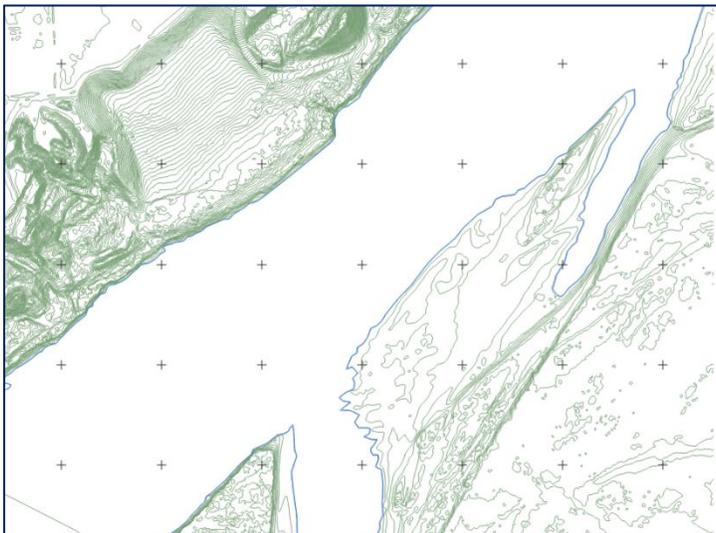
All required project deliverables and file formats are listed in the table below.

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

Lincoln QL1			
Survey Point	Montana State Plane, NAD83		
	Northing Intl. Ft	Easting Intl. Ft	Elev US Ft*(Geoid 12B)
1101	634570.807	1770510.958	2740.70
1102	695819.236	1658189.027	3290.17
1103	475240.424	1729441.365	2946.17
1104	589072.734	1634858.189	2607.52
1106	424157.850	1522509.324	2329.04
1107	621606.424	1524836.787	2964.52
1108	539913.004	1431427.958	3365.17
1109	399640.991	1649244.666	2301.89