LiDAR PROJECT REPORT

Montana 2019 LiDAR - Town of Baker QL1

Contract #: WO-AGI-190

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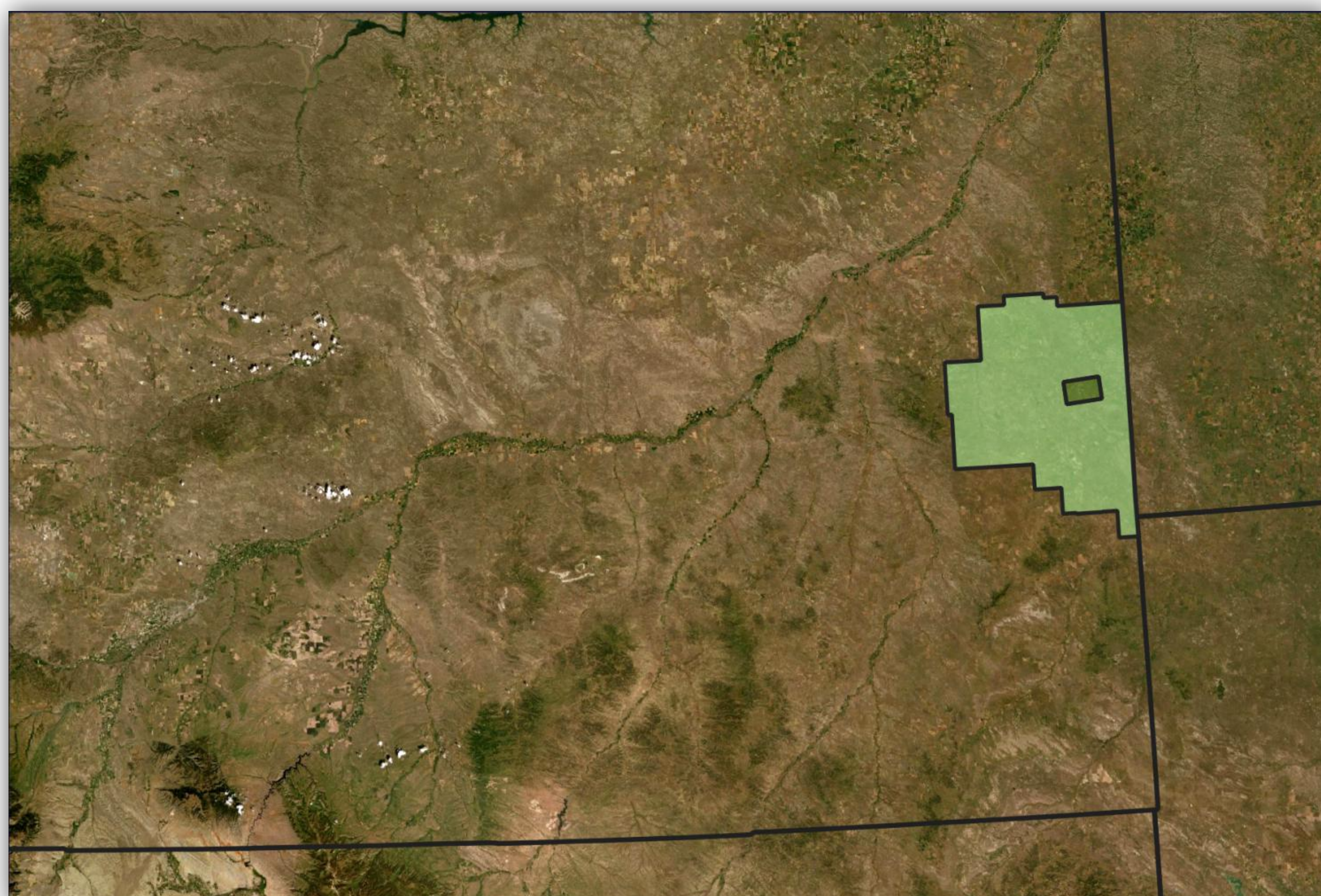

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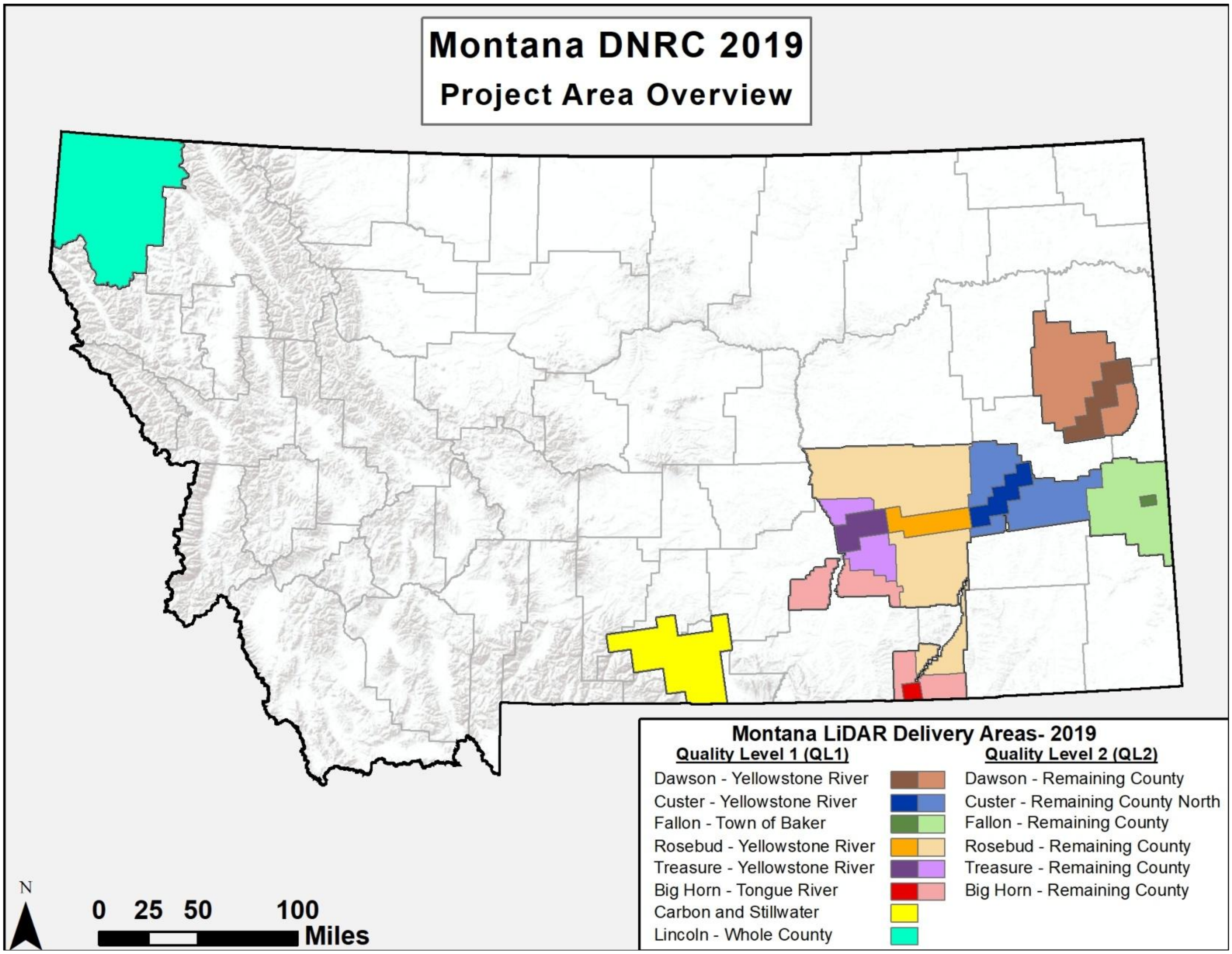
1. Introduction

1.1 Project Overview

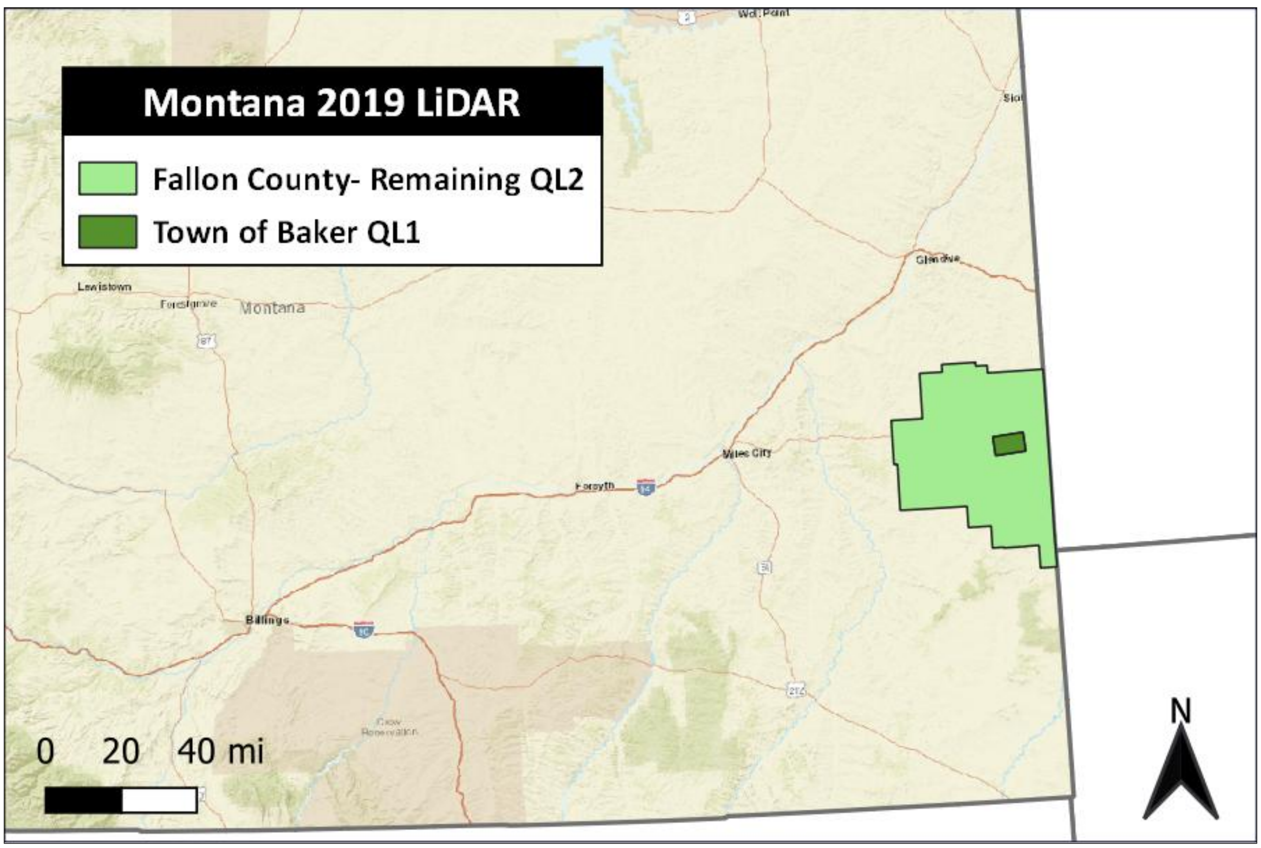
Aero-Graphics, Inc., a full-service geospatial firm located in Salt Lake City, Utah, was contracted by the State of Montana to acquire, process, and deliver aerial Lidar data and derivative products that adhere to U.S. Geological Survey (USGS) National Geospatial Program (NGP) Lidar Base Specification Version 1.3 (2018). The assigned project areas cover portions of Montana totaling approximately 18,297 mi^2.



1.2 Project Area Description

Montana's 2019 LiDAR Acquisition Project was separated into eight (8) delivery areas roughly corresponding to county boundaries: Big Horn County, Carbon/Stillwater County, Custer County, Dawson County, Fallon County, Lincoln County, Rosebud County, and Treasure County. This report focuses on the Town of Baker area, which covers 40 mi^2 (QL1) and is situated in larger delivery area of Fallon County.

Fallon County – QL1 and QL2 Areas		
Sub-AOI Name	**Quality Level**	**Area (mi^2)**
Town of Baker	QL1	40
Fallon County - Remaining	QL2	1,581



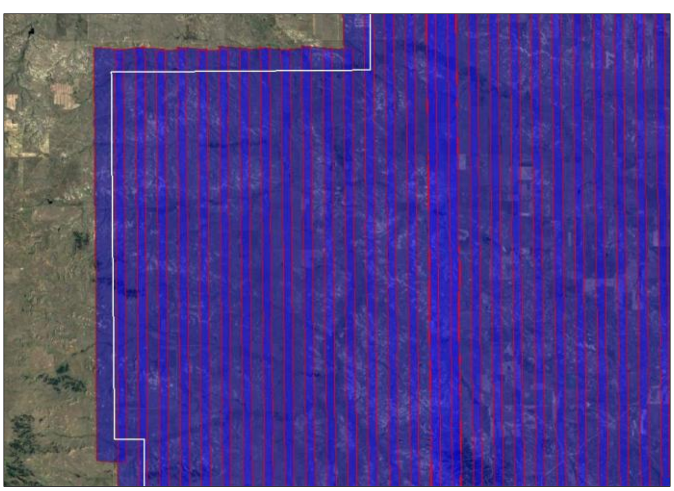
2. LiDAR Acquisition

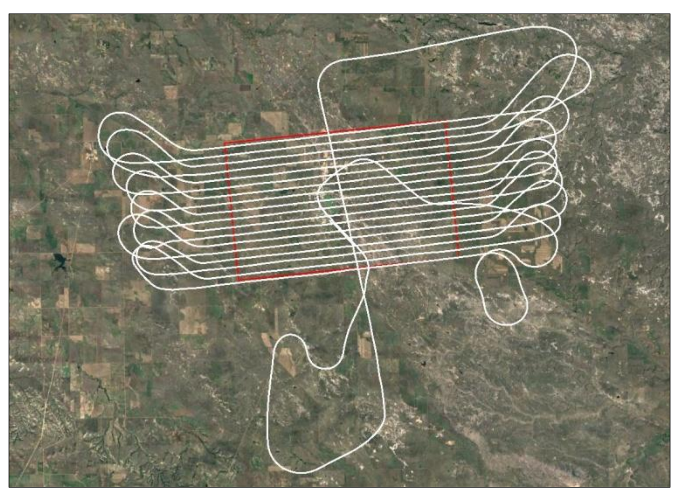
2.1 Flight Planning

A specialized flight plan for each area was developed by Aero-Graphics' Aerial Department Manager 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 Town of Baker QL1 project area. Additional flight information including area coverage and sensor settings can be found in the individual lift metadata files.

Planned Specs	Town of Baker QL1	Fallon County Remaining QL2
	Optech Galaxy PRIME	
Altitude (m)	1,250	--
Speed (kts)	150	--
PRF (kHz)	500	--
Scan Freq (Hz)	75	--
Scan Angle (°)	30	--
Swath Width (m)	670	--
NPS (m)	0.35	--
Point Density (ppm^2)	9.67	--
Overlap (%)	30	--





2.2 LiDAR Sensors

Optech Galaxy PRIME

The Optech Galaxy PRIME is currently the most productive sensor available in the industry. This sensor features SwathTRAK technology, which dynamically adjusts the scan FOV in real time during data acquisition. It also features 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 Flight Logs

Acquisition for the Town of Baker QL1 project area occurred on May 30th, 2019, 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 1 (QL1) lift was required to complete lidar acquisition for the assigned Town of Baker project area. Flight dates are listed in the tables below along with the AOI, sensor name, sensor number, and aircraft tail number for each lift.

Fallon County Montana Flight Logs				
Flight Date	AOI Covered	Sensor Name	Sensor Number	Aircraft Tail Number
20190530	Town of Baker QL1	Optech Galaxy PRIME	386	N7516Q

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.

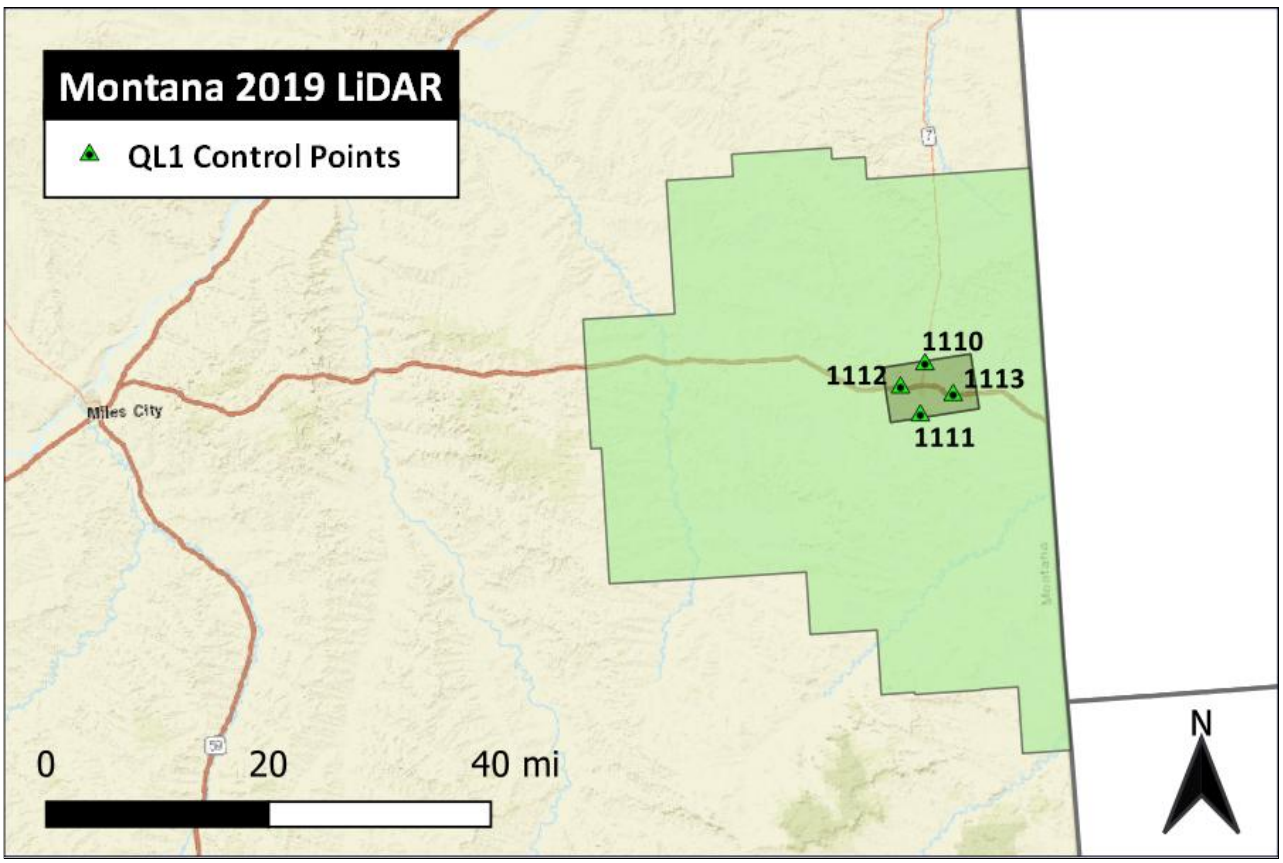
i. **Hydro-Flattened Raster DEM Creation.** Class 2 (Ground) LiDAR points in conjunction with the hydro breaklines were used to create 3 ft hydro-flattened raster DEMs. Using LP360 along with automated scripting routines within ArcMap, a GeoTIFF was created for each tile. Each surface is reviewed using ESRI ArcMap and ArcScene to check for any surface anomalies or incorrect elevations found within the surface.

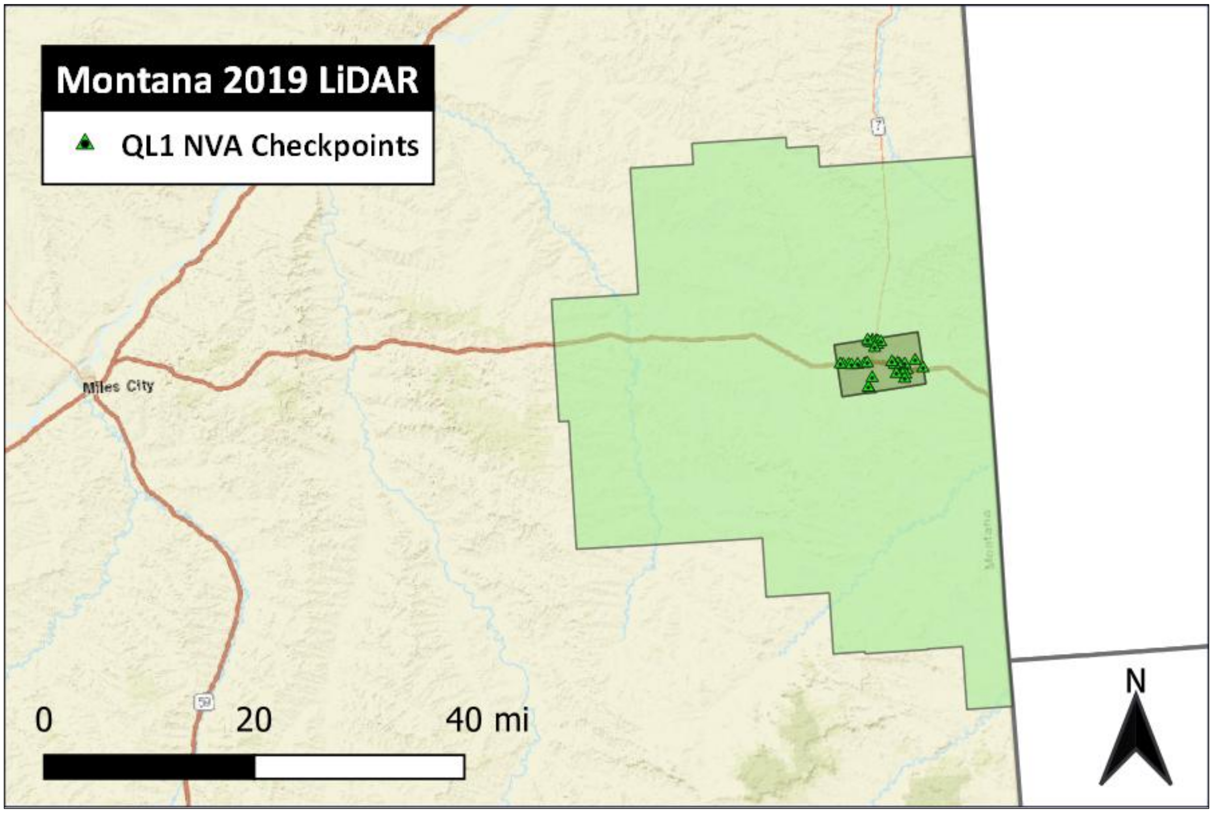
j. **First Return Raster DSM Creation.** First return LiDAR points were used to create 3 ft first-return raster DEMs. Using LP360 along with automated scripting routines within ArcMap, a GeoTIFF file was created for each tile. Each surface is reviewed using ESRI ArcMap and ArcScene to check for any surface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

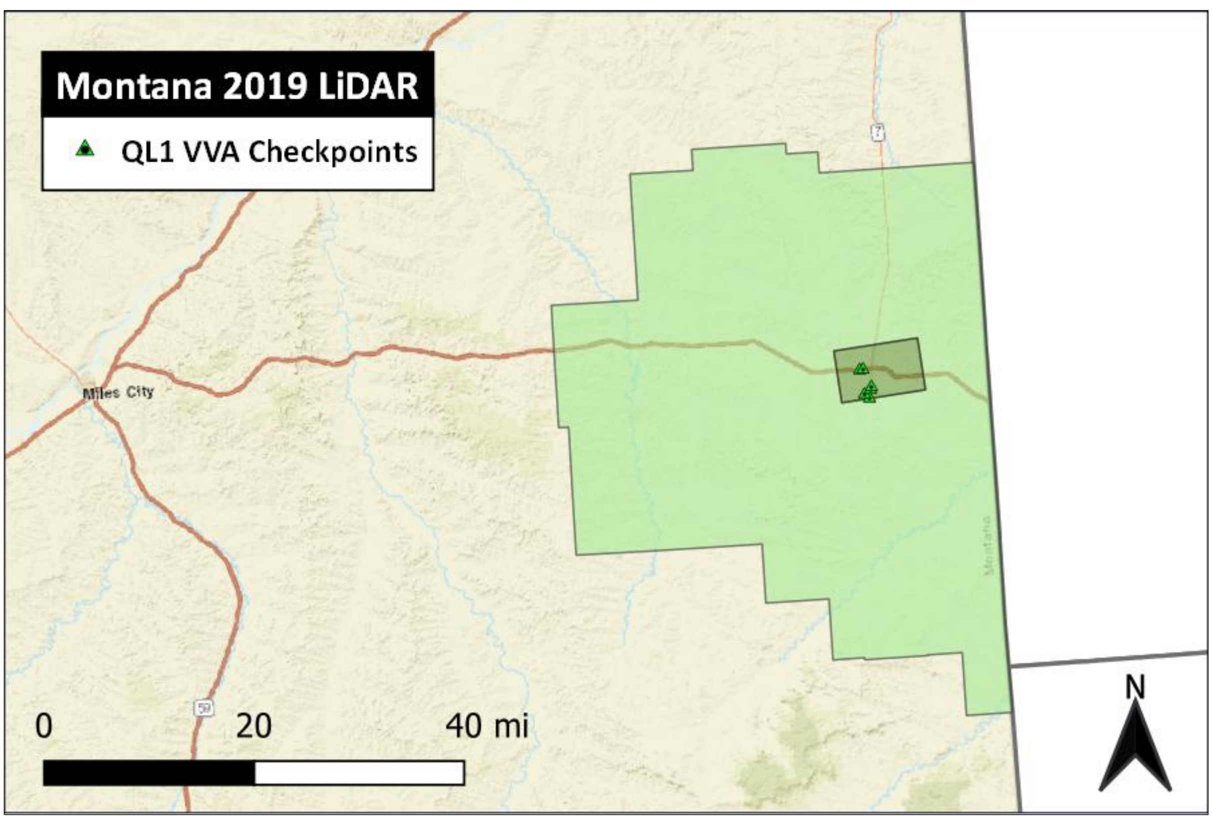
k. **Intensity Image Creation.** TerraScan software was used to create the deliverable Intensity Images. All overlap classes were ignored during this process as it helps to ensure a more aesthetically pleasing image. ESRI ArcMap software was then used to verify full project coverage. GeoTIFF files were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

4. Ground Control and Check Point Survey

Aero-Graphics' professional land surveyor identified, targeted, and surveyed 4 (QL1) ground control points for use in data calibration as well as 37 (QL1) 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
QL1 NVA Checkpoints
Miles City
0
20
40 mi
N


Montana 2019 LiDAR
QL1 VVA Checkpoints
Miles City
0
20
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5. Accuracy Testing and Results

5.1 Relative Calibration Accuracy Results

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

Fallon County – Town of Baker QL1 project area

- Between-swath relative accuracy **average** of 0.016 intl. feet

Fallon County – Remaining QL2 project area:

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

Within-swath relative accuracy is the amount of vertical separation, or "noise," among a set of points on open, paved ground that should have the same elevation. The within-swath relative accuracy average is less than **0.026 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 8.

Accuracy$_z$: Fallon County Project Area	
Average Error = 0.000 ft	RMSE = 0.105 ft
Minimum Error = -0.105 ft	σ = 0.077 ft
Maximum Error = 0.080 ft	2σ = 0.154 ft
Survey Sample Size: n = 4	

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 37 (QL1) 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 0.145 intl. ft (QL1) and -- intl. ft (QL2) in terms of the RMSEz. The resulting NVA stated as the 95% confidence level (RMSEz x 1.96) is 0.284 intl. ft (QL1) and -- intl. ft (QL2). 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 31 (QL1) and -- (QL2) check points. The VVA was tested with 6 (QL1) and -- (QL2) 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 0.179 intl. ft (QL1) and -- intl. ft (QL2) in terms of the RMSEz. The resulting accuracy stated as the 95% confidence level (RMSEz x 1.96) is 0.351 intl. ft (QL1) and -- intl. ft (QL2). 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 0.478 intl. ft (QL1) and -- intl. ft (QL2). Therefore this dataset meets the required VVA of 0.965 intl. ft 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
Fallon County - QL1 Town of Baker	0.284	0.351	0.478	31	6
Fallon County QL2	--	--	--	--	--

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’ and 2’ 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)

Appendix A

Control Point Coordinates

Survey Point	Montana State Plane, NAD83		
	Northing Intl. Ft	Easting Intl. Ft	Elev US Ft*(Geoid 12B)
1110	826488.080	3286828.396	3023.45
1111	802252.924	3284650.054	2994.10
1112	815466.359	3275248.554	2919.85
1113	811920.503	3300247.932	2986.40