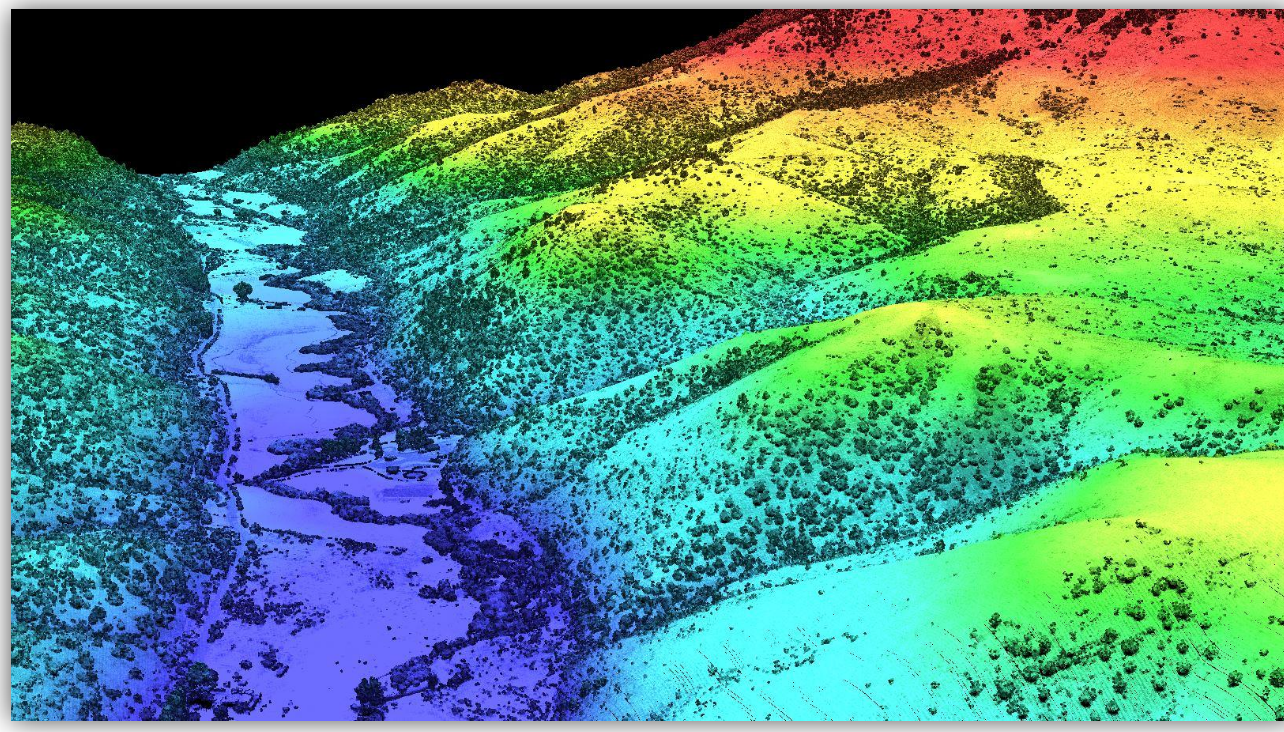
TECHNICAL PROJECT REPORT

VIRGINIA CITY AERIAL SURVEY

MADISON COUNTY, MONTANA

June 2017



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Technical Project Report
Virginia City Aerial Survey
Madison County, MT

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1. Overview

On June 3, 2017, Aero-Graphics acquired high resolution LiDAR data over approximately 33 square miles located in the vicinity of Virginia City, Montana. The project deliverables will support MBMG's Ground Water Investigation Program.

Exhibit 1: *Virginia City, MT project boundary*

2. Acquisition

2.1 LiDAR Acquisition – Equipment and Methodology

LiDAR acquisition for the Virginia City, MT project was performed with an Optech ALTM Orion H300 LiDAR sensor. Aero-Graphics flew at an average altitude of 5,900 ft AGL (above ground level) and made appropriate adjustments to compensate for topographic relief. LiDAR acquisition was performed with 30% overlap and yielded an average 4 points per square meter throughout the project area. The PRF (pulse rate frequency) used for collection was 125 kHz, scan frequency 41.8 Hz, and scan angle +/- 14° from the nadir position (full scan angle 28°).

Exhibit 2: *Summary of planned flight parameters*

Altitude (ft AGL)	Overlap (%)	Speed (kts)	PRF (kHz)	Scan Freq (Hz)	Scan Angle ° (full)
5,900	30	115	125	41.8	28

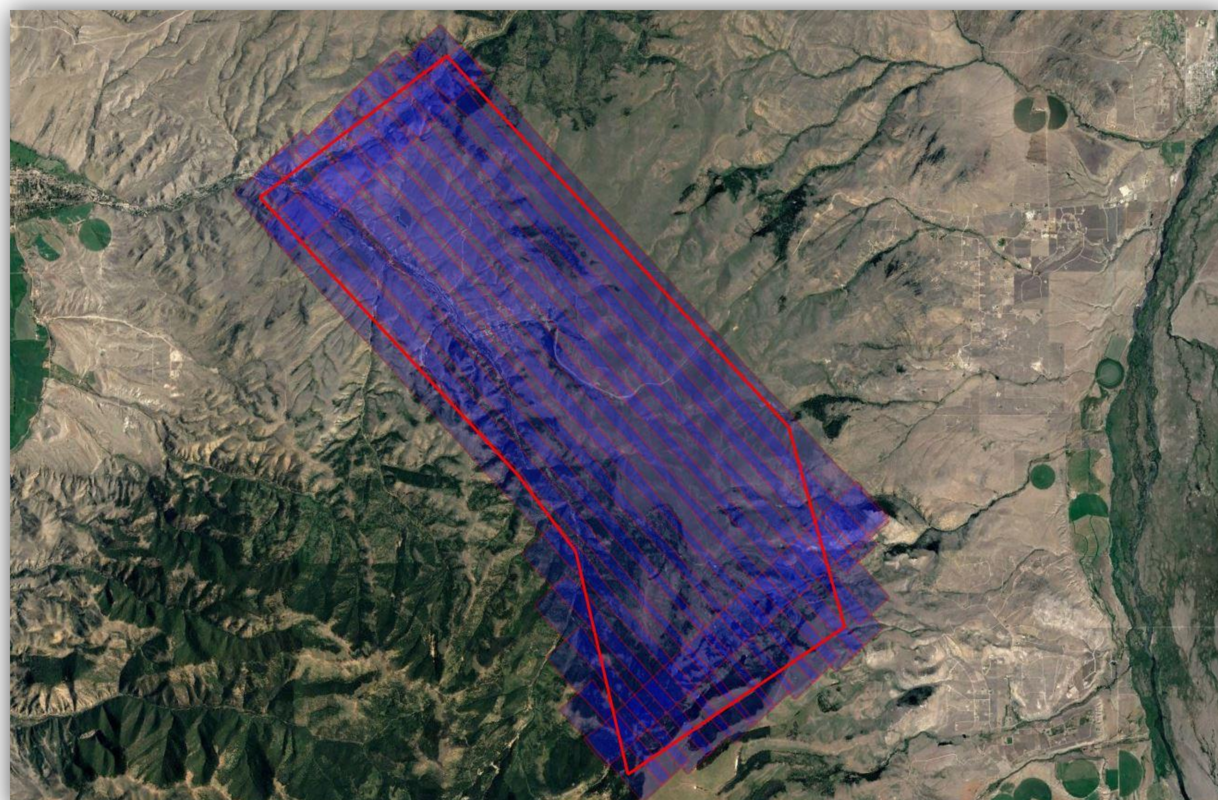
PPM^2 (mean)	Post spacing Cross Track (m)	Post Spacing Down Track (m)	Swath Width (m)	# Flightlines
2.35	0.70	0.70	897.58	16

The Orion H300 can send/receive up to 300,000 pulses per second and is capable of receiving up to four range measurements, including 1^{st}, 2^{nd}, 3^{rd}, and last returns for every pulse sent from the system. The Orion H300 features roll compensation that adjusts the mirror to maintain the full scan angle integrity in relation to nadir, even when less than perfect weather conditions push the sensor off nadir. It is also equipped with a GPS/IMU unit that continually records the XYZ position and roll, pitch and yaw attitude of the plane throughout the flight. This information allows us to correct laser return data positions that may have been thrown off by the plane's natural movement.

Exhibit 3: *The acquisition platform for the Virginia City, MT project was a turbocharged Cessna 206. Our 206 has been customized for LiDAR and other airborne sensors with an upgraded power system and avionics. The stability of the Cessna 206 is ideal for LiDAR collection*

The ALTM Orion H300 LiDAR sensor is equipped with FMS Planner Flight Management System Software, which is the latest release from Optech. Aero-Graphics utilizes FMS Planner to both plan the flight and guide the airborne mission while in flight. This smooth transition from flight planning to aerial operations eliminates discrepancies between the flight plan and the actual airborne mission. The use of FMS Planner 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, as shown in **Exhibit 4.**

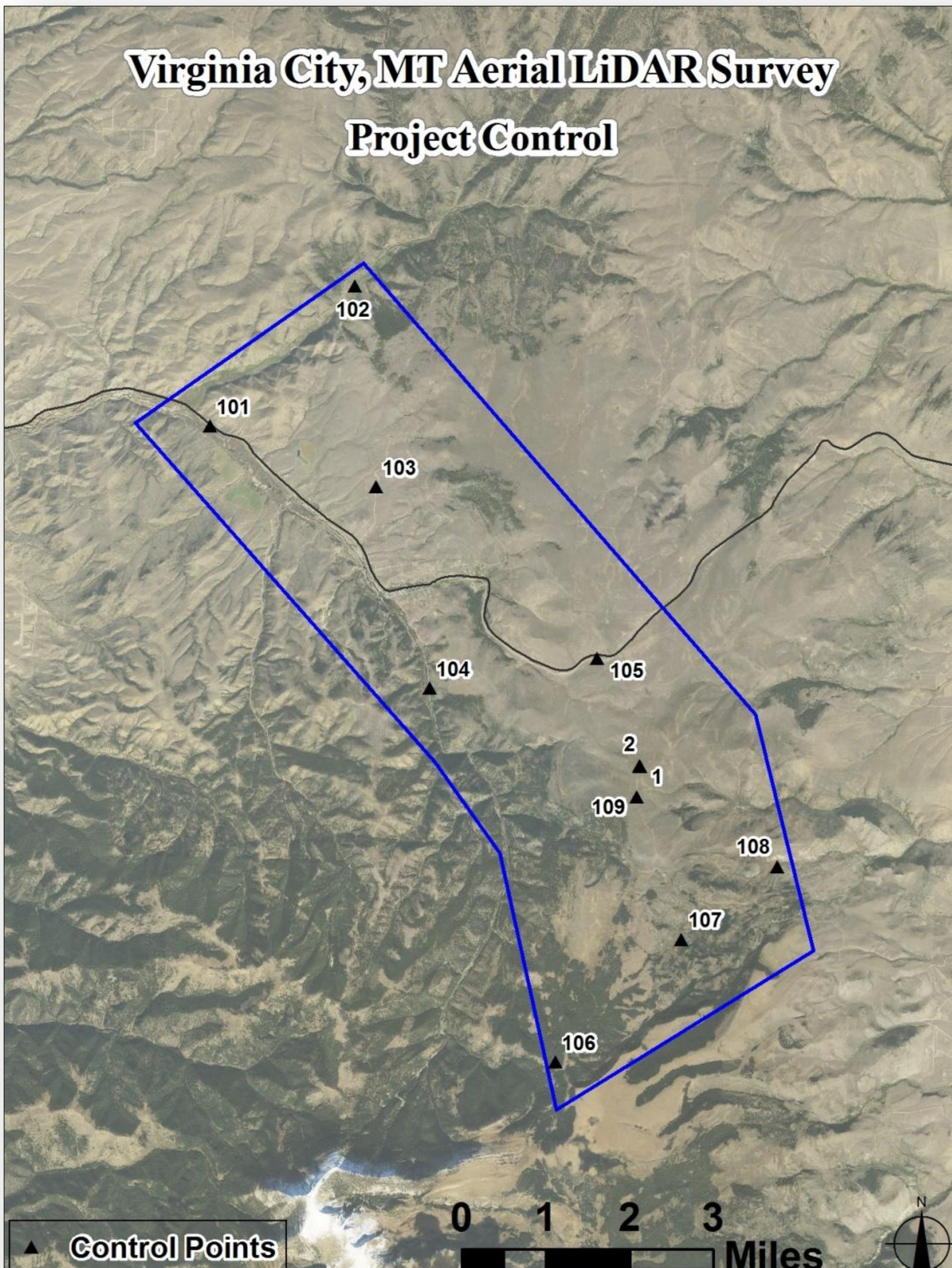
Exhibit 4: *Swath data for the Virginia City, MT project was recorded and viewed real-time by the operator.*



2.2 Ground Survey – Equipment and Methodology

Aero-Graphics used CORS base stations and statically-collected survey data at strategic points throughout the project area to ensure that the LiDAR data maintained its true geographic integrity. A single-base solution was used to differentially correct the aircraft's trajectory data. Control point and base station coordinates can be found in Appendix A. LiDAR positional accuracy can be found in section 4.2.

Exhibit 5: *Static ground control for the Virginia City, MT project*



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.** Differentially corrected the 1-second airborne GPS positions with ground base station; 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 NAD83 (2011) State Plane Montana Zone, International Ft.

d. **Relative Calibration.** Performed relative calibration by correcting for roll, pitch, heading, and scale discrepancies between adjacent flightlines; tested resulting relative accuracy. Results presented in Section 4.1.

e. **Vertical Accuracy Assessment.** Performed comparative tests that showed Z-differences between each static survey point and the laser point surface. Results presented in Section 4.2.

f. **Tiling & Long/Short Filtering.** Cut data into project-specified tiles and filtered out grossly long and short returns.

g. **Classification & QA/QC.** Ran classification algorithms on points in each tile; separated into the following classes: 1-Processed, but unclassified, 2-Bare Earth, 7-Low Noise, 9-Water, 10-Ignored Ground, 17-Bridge Decks, 18-High Noise; revisited areas not completely classified automatically and manually corrected them.

4. Results

4.1 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 statistics are based on the comparison of the flightlines and points listed below.

Virginia City, MT project area: (17 flightlines, > 264 million points)

- Between-swath relative accuracy **average** of 0.082 int. foot

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 foot.**

4.2 Vertical Accuracy

The following exhibits display the Non-vegetated Vertical Accuracy (NVA) and Vegetated Vertical Accuracy (VVA) results for the Virginia City, MT project. 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). VVA is defined as the elevation difference between the LiDAR surface and ground surveyed static points collected in all vegetated land cover categories combined, including tall weeds and crops, brush lands, and lightly- to fully-forested land cover categories.

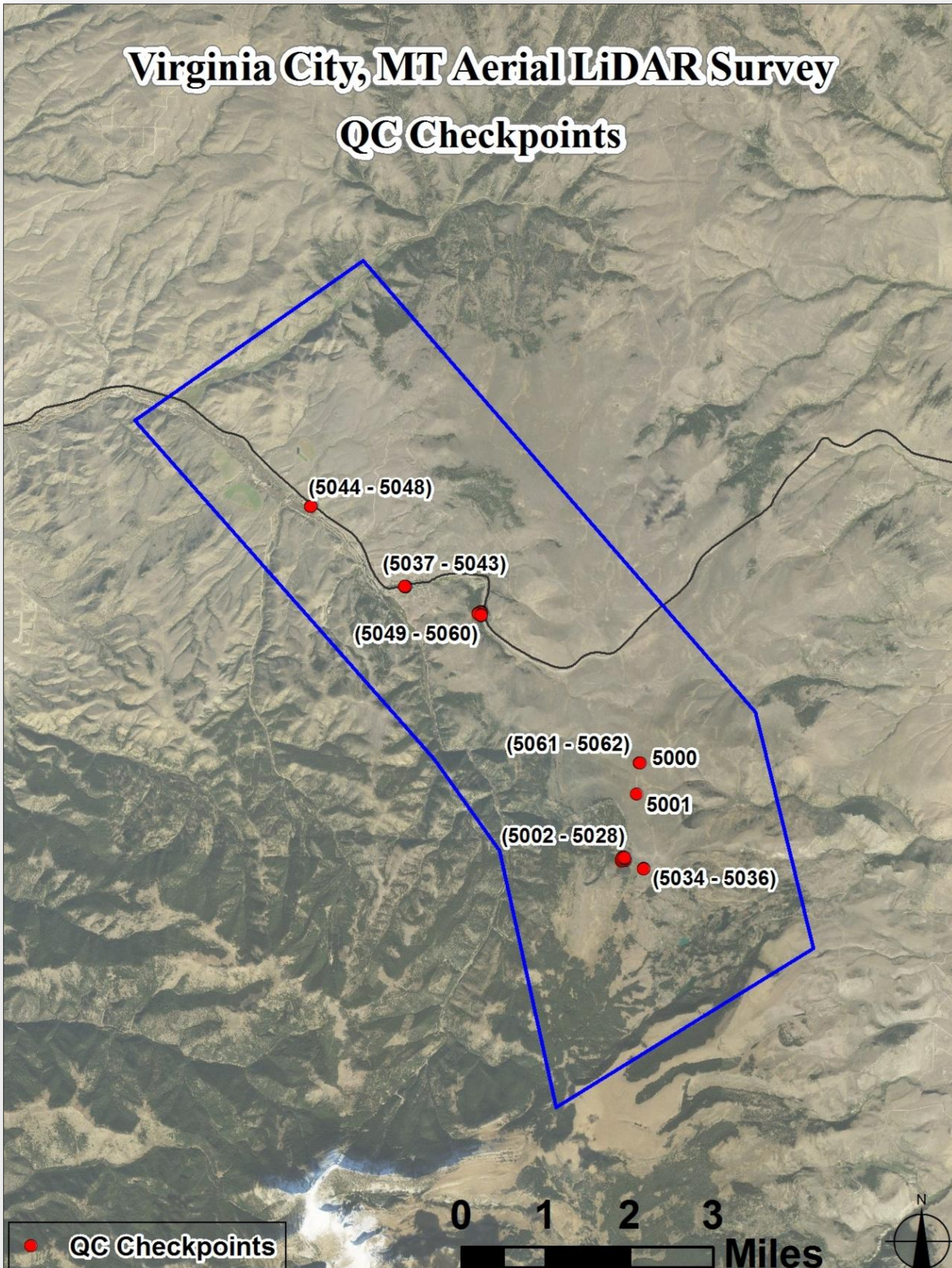
Exhibit 6: *Non-vegetated Vertical Accuracy (NVA) of the Virginia City, MT project*

Accuracy$_z$: Tested 0.290 feet Non-vegetated Vertical Accuracy (NVA) at 95 percent confidence level in all open and non-vegetated land cover categories combined using RMSEz x 1.96.	
Average Error = -0.028 int. ft	RMSE = 0.148 int. ft
Minimum Error = -0.293 int. ft	σ = 0.147 int. ft
Maximum Error = 0.294 int. ft	2σ = 0.294 int. ft
Survey Sample Size: n = 35	

Exhibit 7: *Vegetated Vertical Accuracy (VVA) of the Virginia City, MT project*

Accuracy$_z$: Tested 0.836 feet Vegetated Vertical Accuracy (VVA) at 95th percentile in all vegetated land cover categories combined using the absolute value 95th percentile error.	
Average Error = -0.098 int. ft	RMSE = 0.457 int. ft
Minimum Error = -0.996 int. ft	σ = 0.462 int. ft
Maximum Error = 0.561 int. ft	2σ = 0.924 int. ft
Survey Sample Size: n = 15	

***Exhibit 8**: LiDAR checkpoints used for the NVA and VVA assessments*



4.3 Data Density

The goal for this project was to achieve a LiDAR point density of **2** points per square meter. The acquisition mission achieved an actual average of **4** points per square meter. The following two exhibits show the density of **all collected points.**

Exhibit 9: ***Virginia City, MT – All returns*** *Laser Point Density by Frequency, points/m². Demonstrates the percentage of project tiles with points in a given density range*

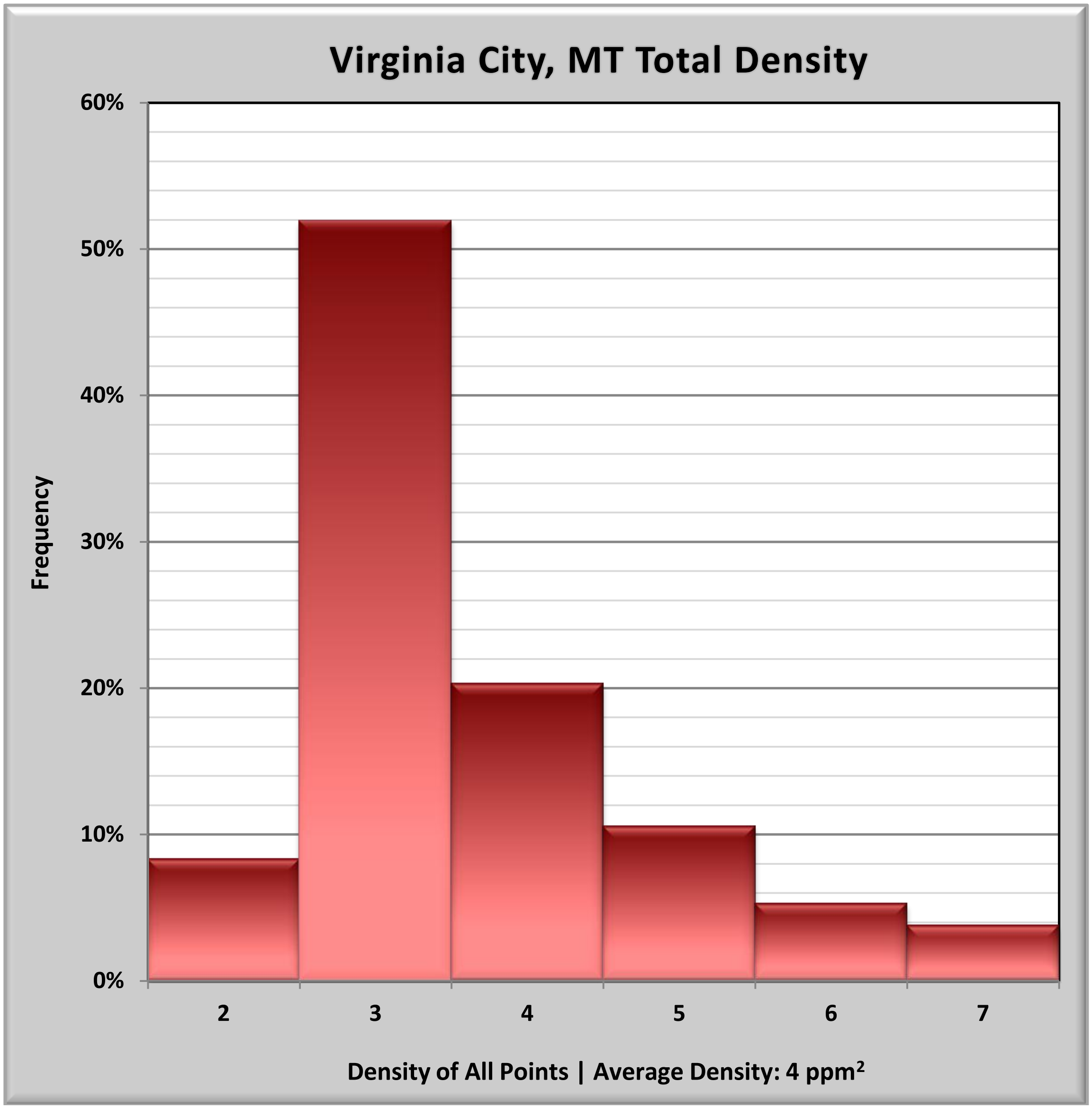
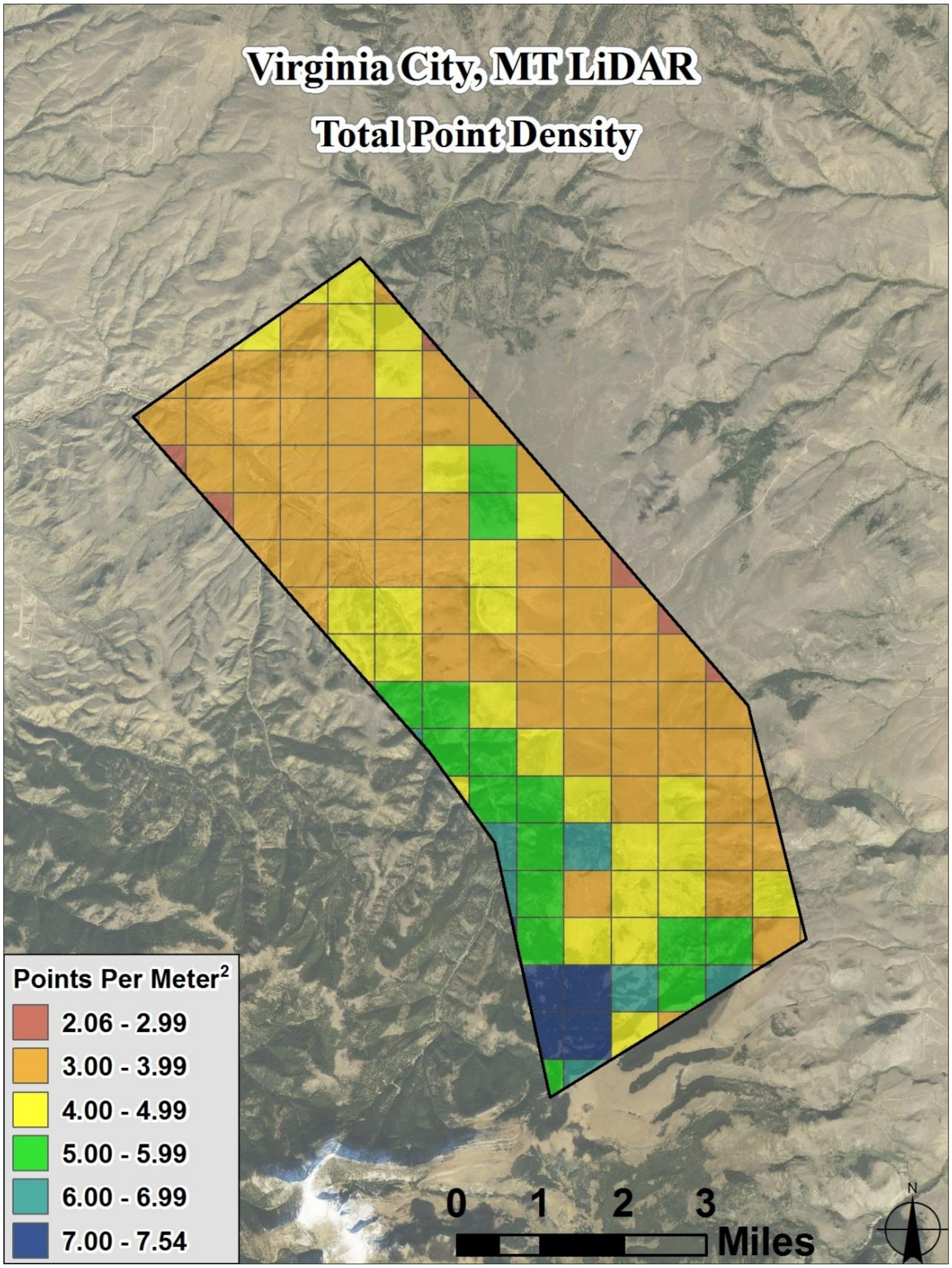


__Exhibit 10:__ Laser Point Density of All Returns by Tile, points/m^2



The following two exhibits show the density of **ground classified points**. Factors such as vegetation, water, and buildings will reduce the density of points classified to the ground. For the Virginia City, MT project, an average of **2** ground classified points per square meter was achieved.

***<u>Exhibit 11:</u>* Virginia City, MT - Ground Classified** *Laser Point Density by Frequency, points/m^2. Demonstrates the percentage of project tiles with points in a given density range*

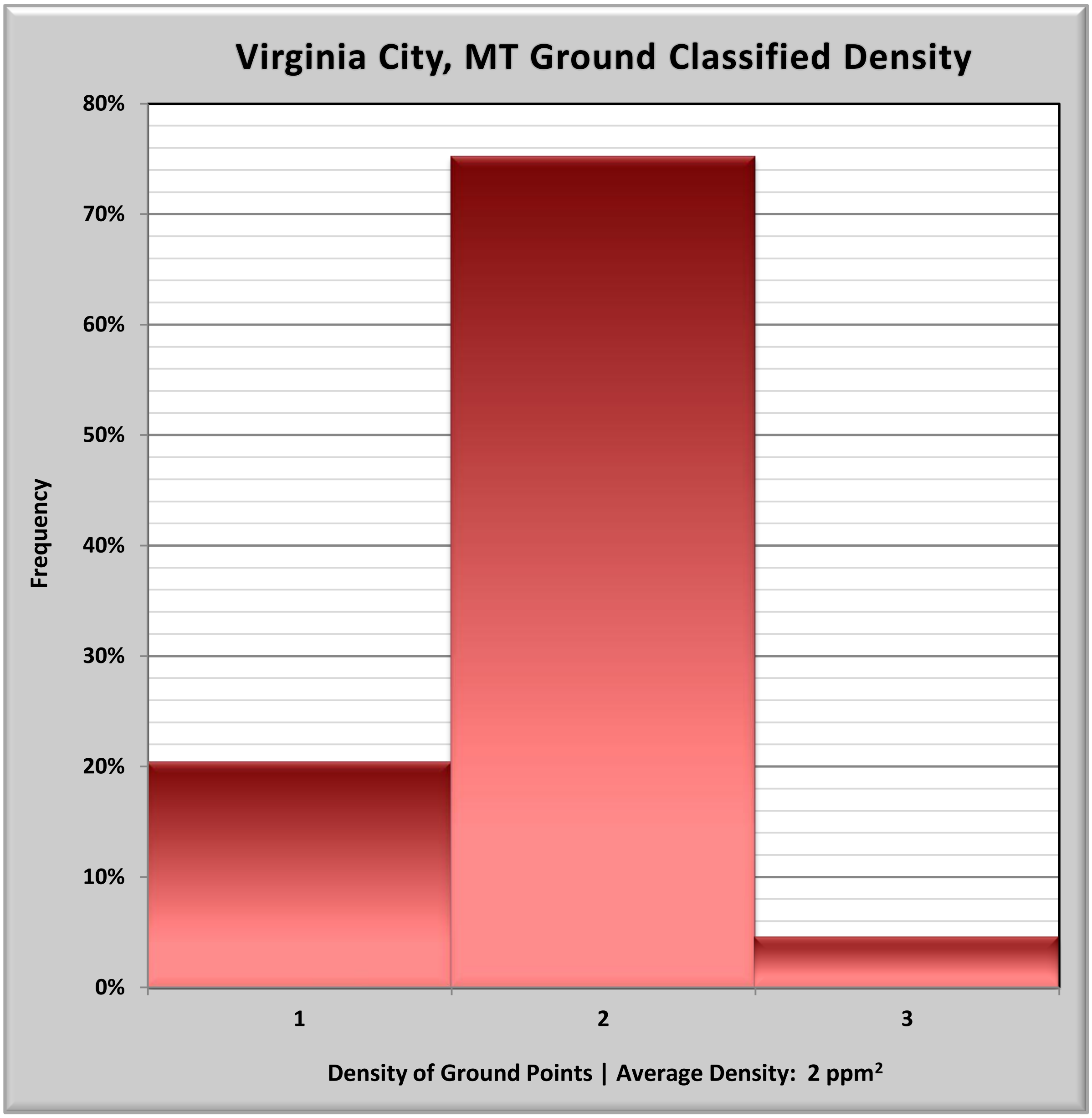
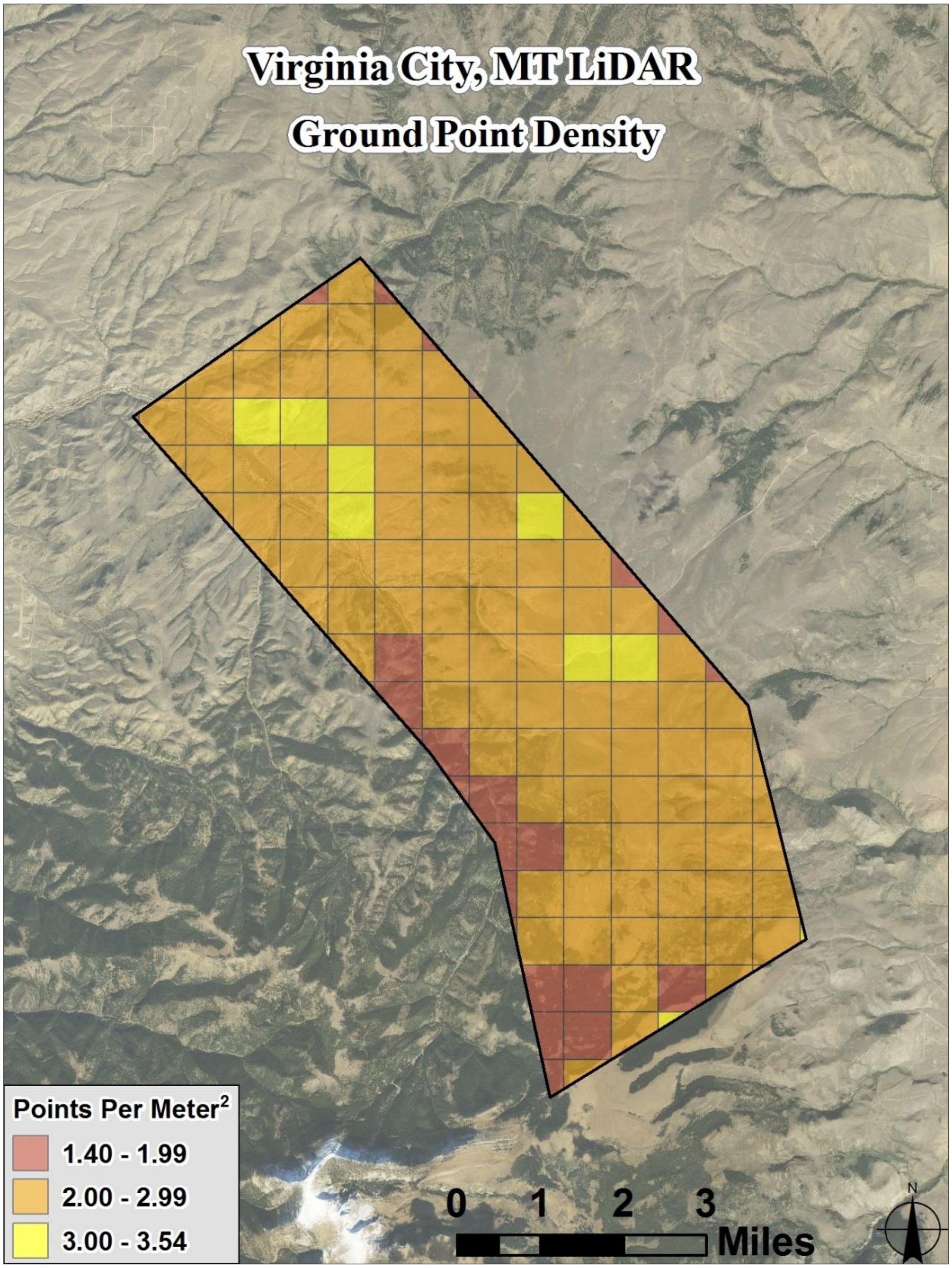


Exhibit 12: *Ground Classified Laser Point Density by Tile, points/m²*



4.4 Data Density Summary

Virginia City, MT	Goal	Actual (mean)
Total Point Density:	2 points/m^2	4 points/m^2
Ground Classified Point Density:	-------	2 points/m^2

4.5 Projection, Datum, and Units

Projection:		Montana State Plane
Datum	**Vertical:**	NAVD88, Geoid12B
	Horizontal:	NAD83 (2011)
Units:		International Feet

5. Deliverables

LiDAR Point Data:	• Classified LiDAR point data in .LAS v1.4 format
Raster Data:	• Hydro-Enforced, Bare-Earth DEMs at a 2' cell size in ESRI Grid format
Vector Data:	• Breaklines and hydro-enforcement of water and drainage features in ESRI .GDB format
Metadata:	• FGDC-compliant metadata in .XML format
Report of Survey:	• Technical Project Report including methodology, accuracy, and results

Appendix A – Surveyed Ground Control

Point#	Latitude	Longitude	Height	Description	Northing	Easting	Elevation	CSF	Convergence Angle
1	45d15'51.82743"	-111d53'07.97117"	7222.63	RPA Control point	379252.56	1354432.16	7255.27	0.999507182	-1d44'42"
2	45d15'51.94287"	-111d53'08.42120"	7219.67	RPA Control point	379265.22	1354400.35	7252.31	0.999507306	-1d44'42"
101	45d19'14.76577"	-111d59'35.67223"	5424.71	6X6WEED-FABRIC	400656.69	1327373.32	5458.53	0.999563917	-1d49'26"
102	45d20'44.37893"	-111d57'31.90477"	5624.92	14X14X2 TARGET	409447.57	1336495.92	5658.44	0.999541876	-1d47'55"
103	45d18'40.24570"	-111d57'08.05287"	5818.19	14X14X2 TARGET	396829.76	1337804.85	5851.64	0.999550021	-1d47'38"
104	45d16'36.40110"	-111d56'14.97690"	5941.94	14X14X2 TARGET	384175.98	1341205.28	5975.01	0.999561789	-1d46'59"
105	45d16'57.94054"	-111d53'48.77463"	6822.60	14X14X2 TARGET	386033.68	1351720.32	6855.45	0.999516709	-1d45'12"
106	45d12'46.59803"	-111d54'14.26441"	8201.30	14X14X2 TARGET	360648.16	1349117.80	8233.32	0.999487792	-1d45'31"
107	45d14'05.09541"	-111d52'26.96100"	7191.16	14X14X2 TARGET	368359.73	1357036.06	7223.46	0.999524295	-1d44'12"
108	45d14'51.83008"	-111d51'04.92737"	6379.95	6X6WEED-FABRIC	372913.37	1363045.21	6412.46	0.999556097	-1d43'12"
109	45d15'32.66235"	-111d53'10.17388"	7202.39	14X14X2 TARGET	377317.43	1354215.59	7234.98	0.999510931	-1d44'44"

Horizontal Coordinates are NAD83(2011) Montana State Plane Coordinates Zone 2500, International Feet
Elevations are NAVD 88 based on NGS's Online Position User Service (OPUS) using GEOID 12B

Base Station

Base Station	NAD83 (2011)		
	Latitude	Longitude	Ellipsoid Height (m)
1	45° 15' 51.82722	-111° 53' 07.97165	2201.476