TECHNICAL PROJECT REPORT

EKALAKA AERIAL SURVEY

CARTER COUNTY, MONTANA

May 2017

Submitted to:

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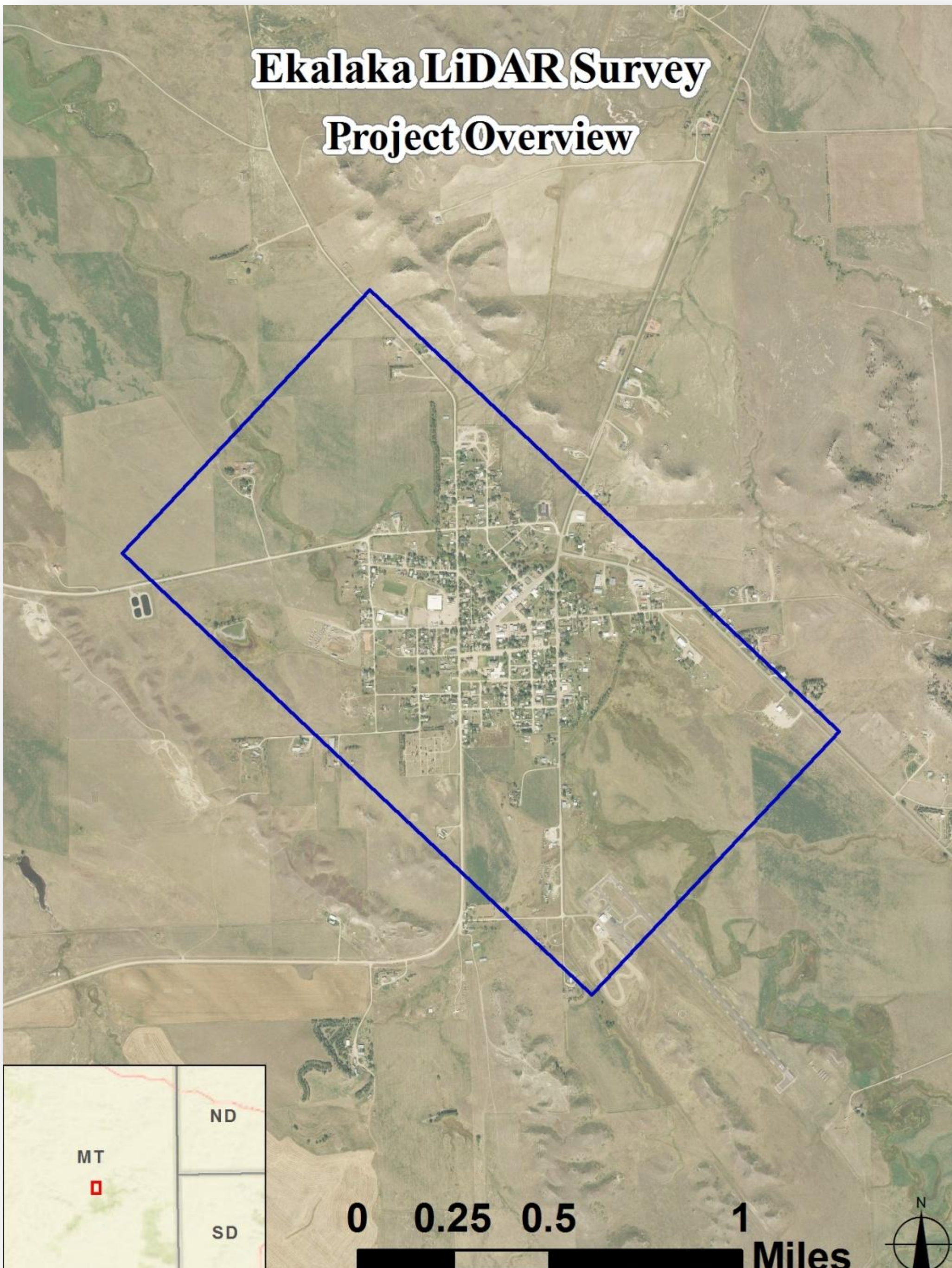
1. Overview

On May 5, 2017, Aero-Graphics acquired high resolution LiDAR data and digital 3-band stereo imagery over the Town of Ekalaka in southeastern Montana. The project area covers approximately 1.5 square miles. The project deliverables will support planning and analysis efforts for floodplain mapping activities.

Exhibit 1: *Ekalaka project boundary*



2. Acquisition

2.1 LiDAR and Imagery Acquisition – Equipment and Methodology

LiDAR and imagery acquisition for the Ekalaka project was performed simultaneously with an Optech ALTM Orion H300 LiDAR sensor and an Optech CS-10000 aerial camera system. The LiDAR sensor and the aerial camera were paired in a customized mount to minimize error and increase accuracy between datasets. Aero-Graphics flew at an average altitude of 4,101 ft AGL (above ground level) and made appropriate adjustments to compensate for topographic relief. The imagery was acquired at a 0.3' (9.3cm) ground sampling distance with 50% overlap, collecting 92 images over 8 flightlines. LiDAR acquisition was performed with 50% overlap and yielded an average 9 points per square meter throughout the project area. The PRF (pulse rate frequency) used for collection was 175 kHz, scan frequency 54.1 Hz, and scan angle +/- 14.5° from the nadir position (full scan angle 29°).

Exhibit 2: *Summary of planned flight parameters*

Altitude (ft AGL)	Overlap (%)	Speed (kts)	PRF (kHz)	Scan Freq (Hz)	Scan Angle ° (full)
4,101	50	105	175	54.1	29

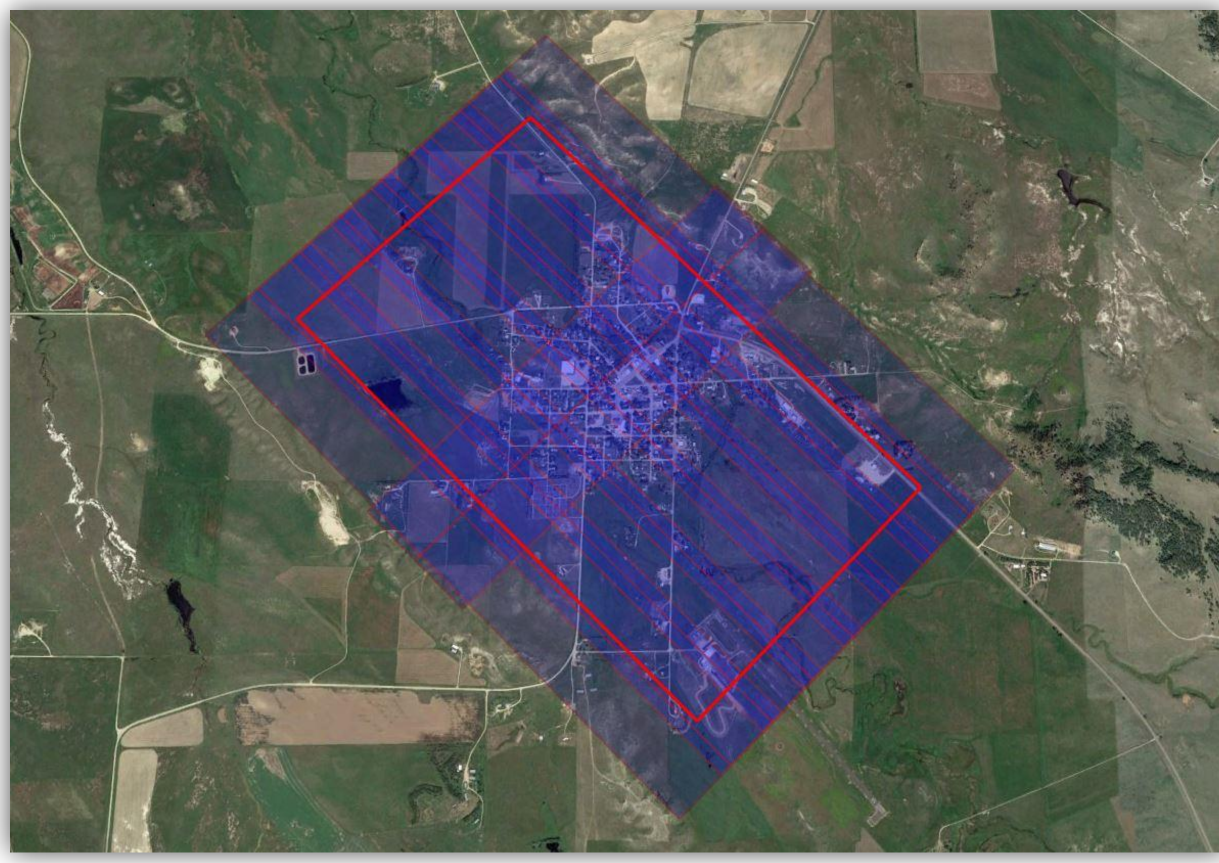
PPM^2 (mean)	Post spacing Cross Track (m)	Post Spacing Down Track (m)	Swath Width (m)	# Flightlines	# Images
5.01	0.49	0.49	646.54	8	92

The Orion H300 can send/receive up to 300,000 pulses per second and is capable of receiving up to four range measurements, including 1st, 2nd, 3rd, 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 Ekalaka 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.**

<u>Exhibit 4:</u> *Swath data for the Ekalaka project was recorded and viewed real-time by the operator.*



2.2 Ground Survey – Equipment and Methodology

Morrison-Maierle, Inc. performed the control survey using GNSS static and RTK methods of survey on May 4th and 5th, 2017. Three Trimble R8 Model-3 GNSS receivers were used with SECO fixed height tripods and rods. GNSS raw and vector data were downloaded, processed, and adjusted using Trimble Business Center, version 3.90. Raw GNSS data for RTK base stations were also uploaded and processed using the NGS On-Line Positioning User Service (OPUS).

NGS control station EKALAKA EAST BASE (Point ID 1001) was recovered in good condition and used as the primary GNSS RTK base station. The NGS published NAD83(2011) geographic coordinates were constrained horizontally. The mean orthometric height of two OPUS solutions for EKALAKA EAST BASE was constrained vertically. A second GNSS RTK base station (105) was established with redundant GNSS RTK ties from EKALAKA EAST BASE. Two OPUS solutions for 105 were also computed as a check on the GNSS RTK tie to 105. Check observations were also performed on NGS Second Order Class 0 vertical control stations E 206 and Q 209. Deltas between the NGS published elevations of E 206 and Q 209, and the OPUS-derived coordinates and elevation of 105, are provided in the following table:

Exhibit 5: *Control Coordinate Comparisons*

Point ID	Easting (Int. Foot)	Northing (Int. Foot)	Elevation (Int. Foot)
1002 (E 206)	NA	NA	-0.184
1003 (Q 209)	NA	NA	0.089
105 (MMI OPUS)	0.111	-0.061	-0.027

All new control points were established using redundant GNSS RTK ties from EKALAKA EAST BASE, and 105. A minimally constrained network adjustment was performed to test the internal consistency of the network vectors. The results were satisfactory, and provided the final adjusted positions of the new control points.

Exhibit 6: *Adjusted Control Coordinates*

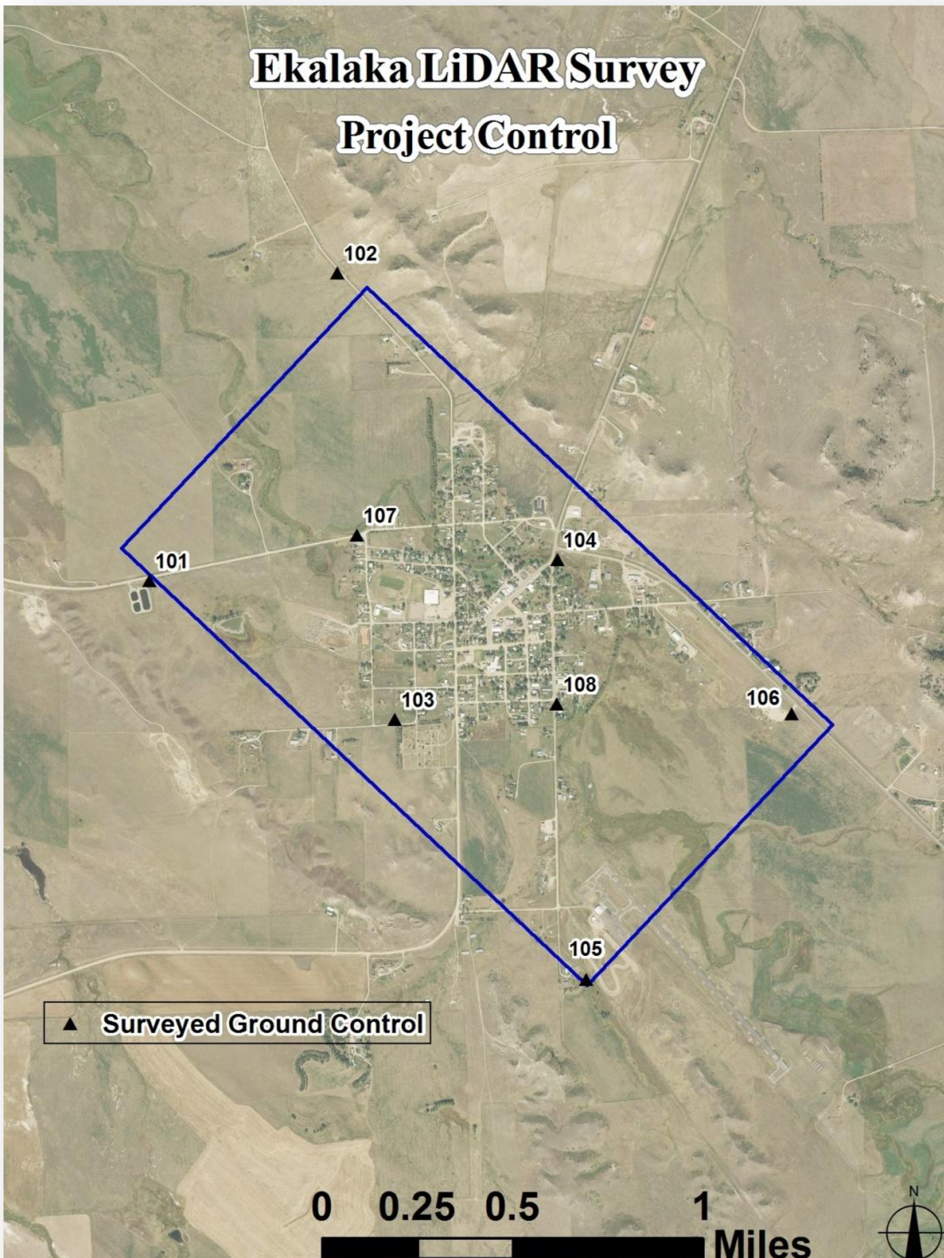
Point ID	Easting (Int. Foot)	Northing (Int. Foot)	Elevation (Int. Foot)
101	1750579.198	16673426.564	3412.25
102	1753188.453	16677695.017	3469.35
103	1753987.913	16671493.841	3438.36
104	1756237.561	16673713.376	3420.30
105	1756636.460	16667893.840	3478.60
106	1759485.576	16671572.736	3472.40
107	1753462.847	16674053.180	3408.36
108	1756233.002	16671713.488	3436.99
1001	1742280.808	16673932.480	3473.98
1002	1745471.698	16673918.661	3406.07
1003	1763765.244	16693654.549	3319.05

Control points 101, 103, 104, 105, 107, were monumented with #5 rebar and 2-inch Morrison-Maierle aluminum caps. Control points 102, 106, and 108 were monumented with a hub and tack.

Exhibit 7: *Base Station Coordinates*

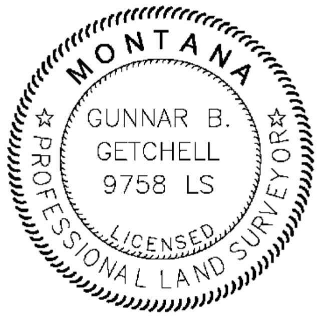
Base Station	Latitude	Longitude	Ellipsoid Height
Base	45° 52' 42.99298"	-104° 32' 36.35236"	1040.711

Exhibit 8: *Static ground control for the Ekalaka project*



Surveyor's Certification

I, Gunnar B. Getchell, a Professional Land Surveyor licensed to practice land surveying in the state of Montana, hereby certify that the ground control survey to support LiDAR mapping for the Ekalaka floodplain study was performed under my supervision in May, 2017, using commonly accepted standards of practice to support LiDAR mapping for engineering applications.



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 in project coordinate system.

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, 3-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.

Ekalaka project area: (8 flightlines, > 83 million points)

- Between-swath relative accuracy **average** of 0.037 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 Ekalaka 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. GNSS RTK methods were used for the ground surveyed static points.

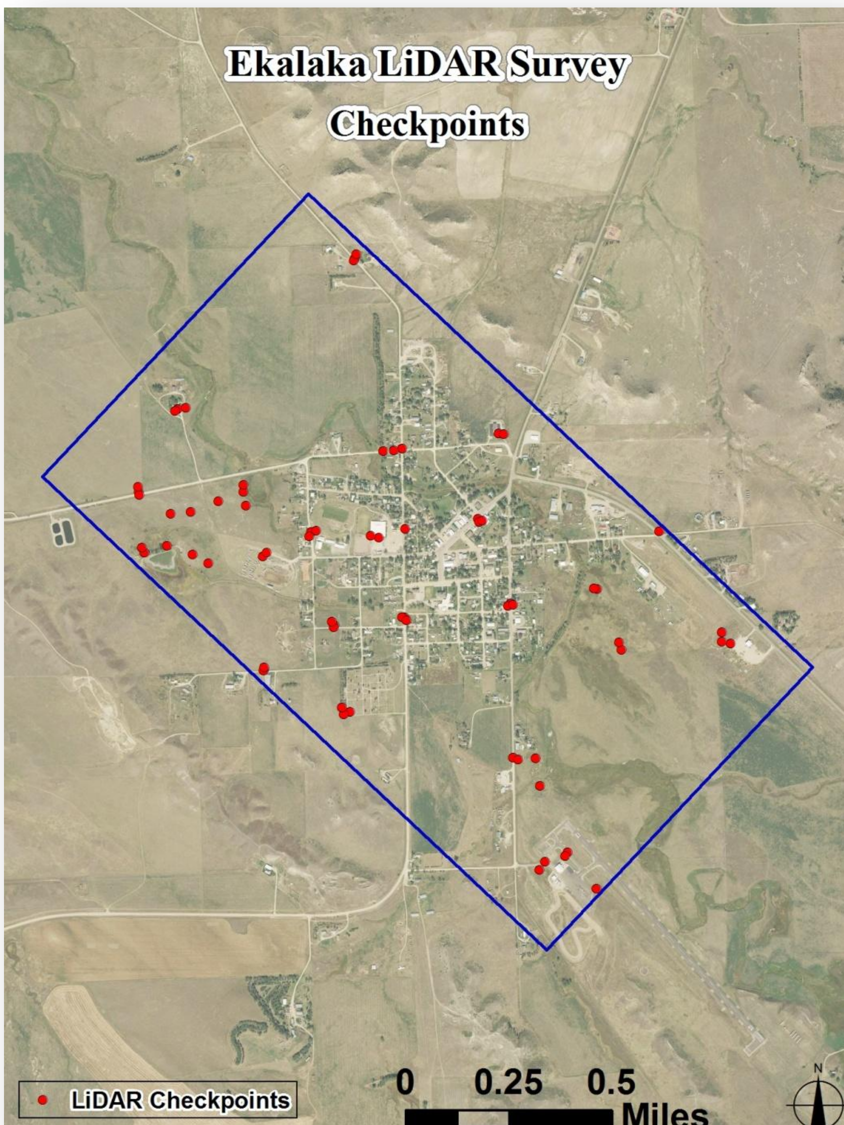
Exhibit 9: *Non-vegetated Vertical Accuracy (NVA) of the Ekalaka project*

Accuracy$_z$: Tested 0.145 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 = -0.022 int. ft	RMSE = 0.074 int. ft
Minimum Error = -0.110 int. ft	σ = 0.073 int. ft
Maximum Error = 0.160 int. ft	2σ = 0.146 int. ft
Survey Sample Size: n = 20	

Exhibit 10: *Vegetated Vertical Accuracy (VVA) of the Ekalaka project*

Accuracy$_z$: Tested 0.272 feet Vegetated Vertical Accuracy (VVA) at 95th percentile in all vegetated land cover categories combined using the absolute value 95th percentile error.	
Average Error = 0.030 int. ft	RMSE = 0.128 int. ft
Minimum Error = -0.180 int. ft	σ = 0.126 int. ft
Maximum Error = 0.430 int. ft	2σ = 0.252 int. ft
Survey Sample Size: n = 48	

Exhibit 11: *LiDAR checkpoints used for the NVA and VVA assessments*



4.3 Orthophoto Accuracy

Horizontal accuracy of the orthophoto is dependent upon the quality of the aerotriangulation solution and the resulting ortho surface creation. Each bundle-adjusted AT solution is checked visually with the stereoimagery to ensure the surveyed control point falls directly on the center of the target and within a specified vertical tolerance (one-quarter the equivalent contour interval). If these tolerances are met, horizontal accuracy is always acceptable. In addition, Aero-Graphics utilized the project's survey grade control throughout the block to verify the integrity of the ortho's positional accuracy. Control and check points yielded a 0.5' RMSE XY.

4.4 Data Density

The goal for this project was to achieve a LiDAR point density of **8** points per square meter. The acquisition mission achieved an actual average of **9** points per square meter. The following two exhibits show the density of **all collected points.**

***<u>Exhibit 12:</u>* Ekalaka – All returns** *Laser Point Density by Frequency, points/m^2. Demonstrates the percentage of project tiles with points in a given density range*

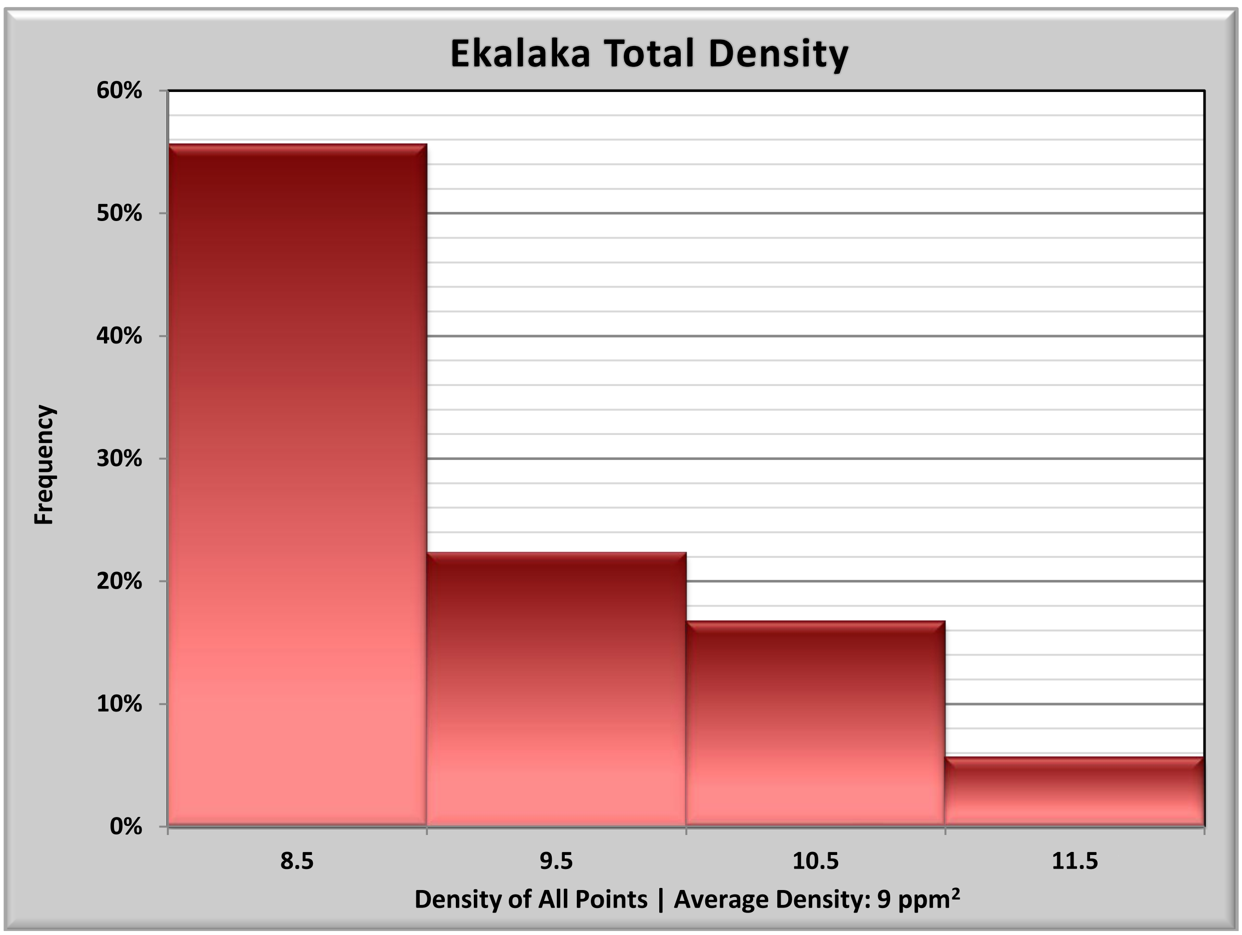
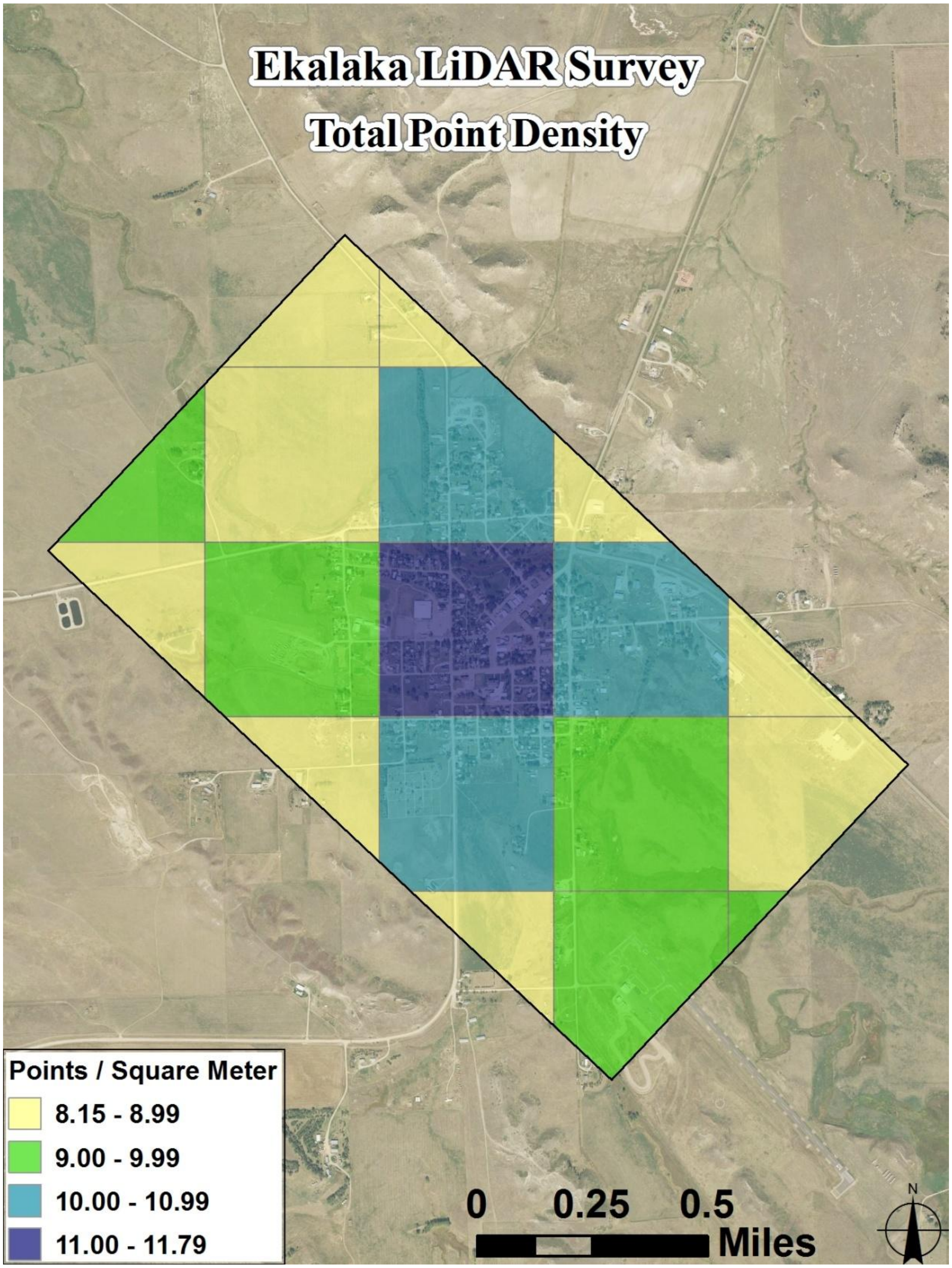


Exhibit 13: *Laser Point Density of All Returns by Tile, points/m^2*



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 Ekalaka project, an average of **6** ground classified points per square meter was achieved.

<u>Exhibit 14:</u>* *Ekalaka - Ground Classified *Laser Point Density by Frequency, points/m^2. Demonstrates the percentage of project tiles with points in a given density range*

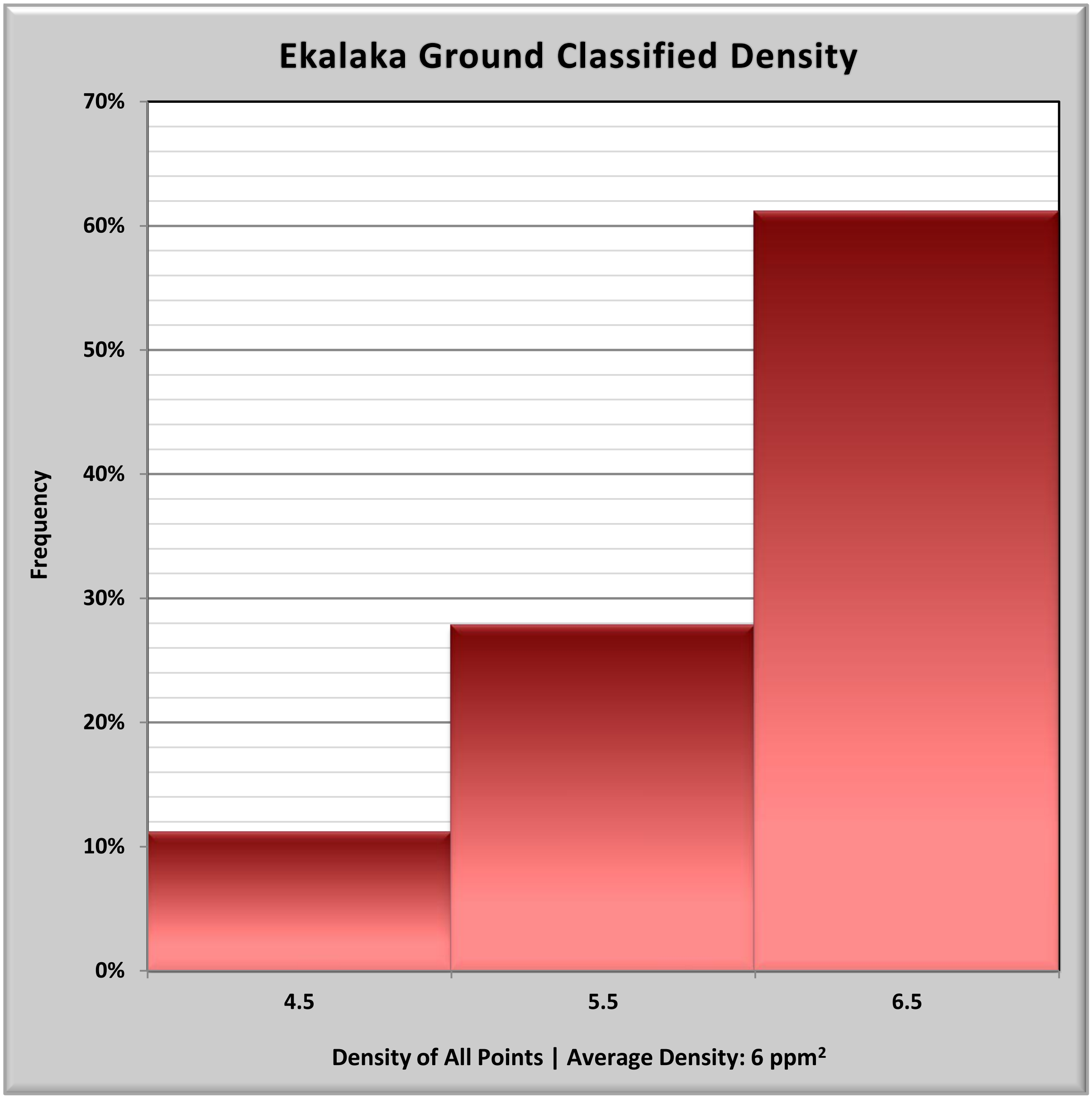
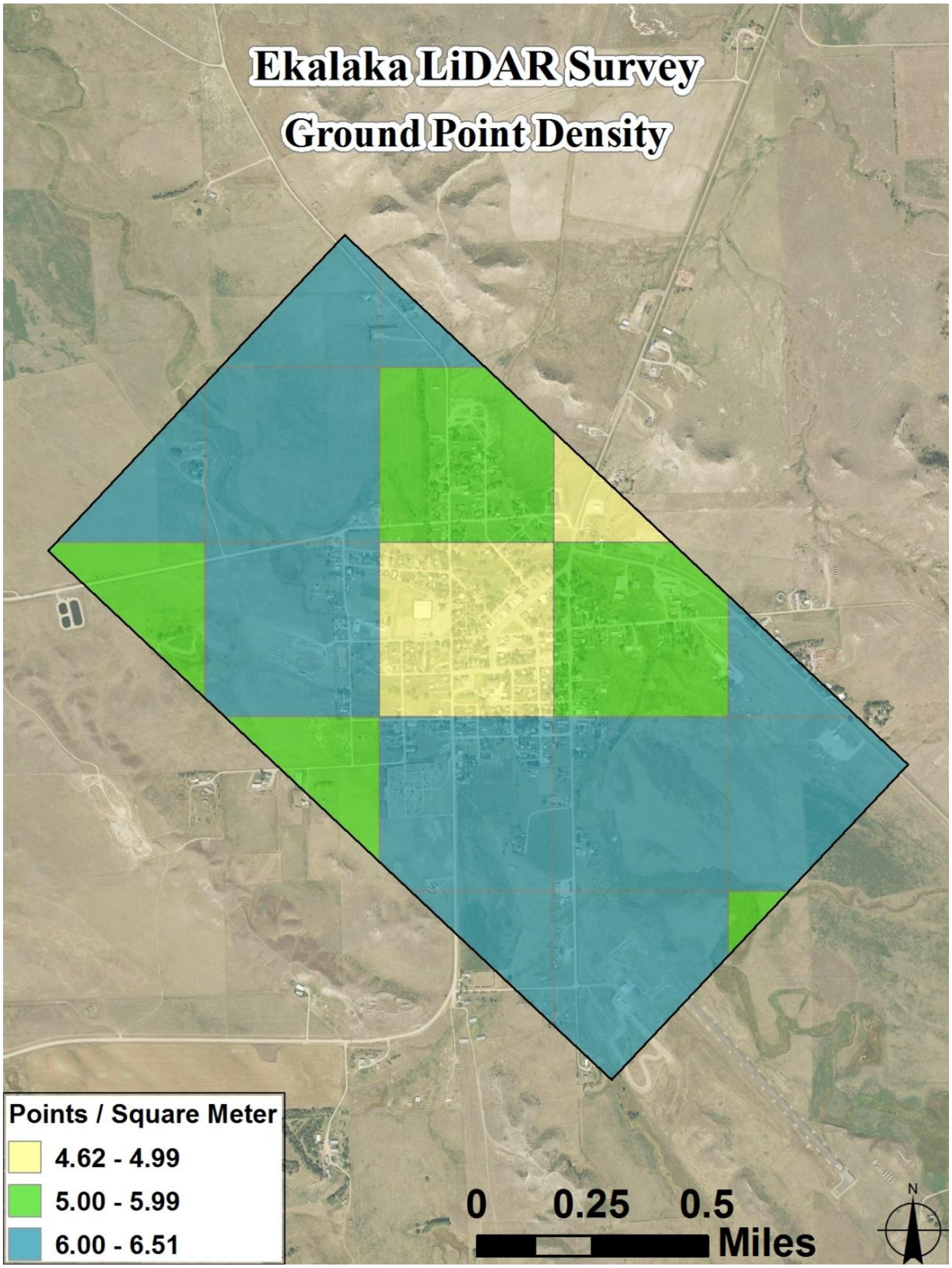


Exhibit 15: *Ground Classified Laser Point Density by Tile, points/m²*



4.5 Data Density Summary

Ekalaka LiDAR	Goal	Actual (mean)
Total Point Density:	8 points/m^2	9 points/m^2
Ground Classified Point Density:	-------	6 points/m^2

4.6 Projection, Datum, and Units

Projection:		NAD83
Datum	**Vertical:**	NAD88, Geoid 12A
	Horizontal:	UTM Zone 13
Units:		International Feet

5. Deliverables

LiDAR Point Data:	• Classified LiDAR point data in .LAS v1.4 format
Raster Data:	• 3-band orthorectified imagery in TIF and SID formats at a 0.25' pixel resolution • Hydro-flattened DEM surface data at a 1' cell size in ESRI Grid format • Intensity imagery of LAST return in TIF format at a 1' pixel resolution
Vector Data:	• Water features and breakline shapefiles in ESRI GDB format
Metadata:	• FGDC compliant metadata
Report of Survey:	• Technical Project Report including methodology, accuracy, and results

6. Highlighted Images

Exhibit 16: *LiDAR point cloud colored by orthophoto RGB values*

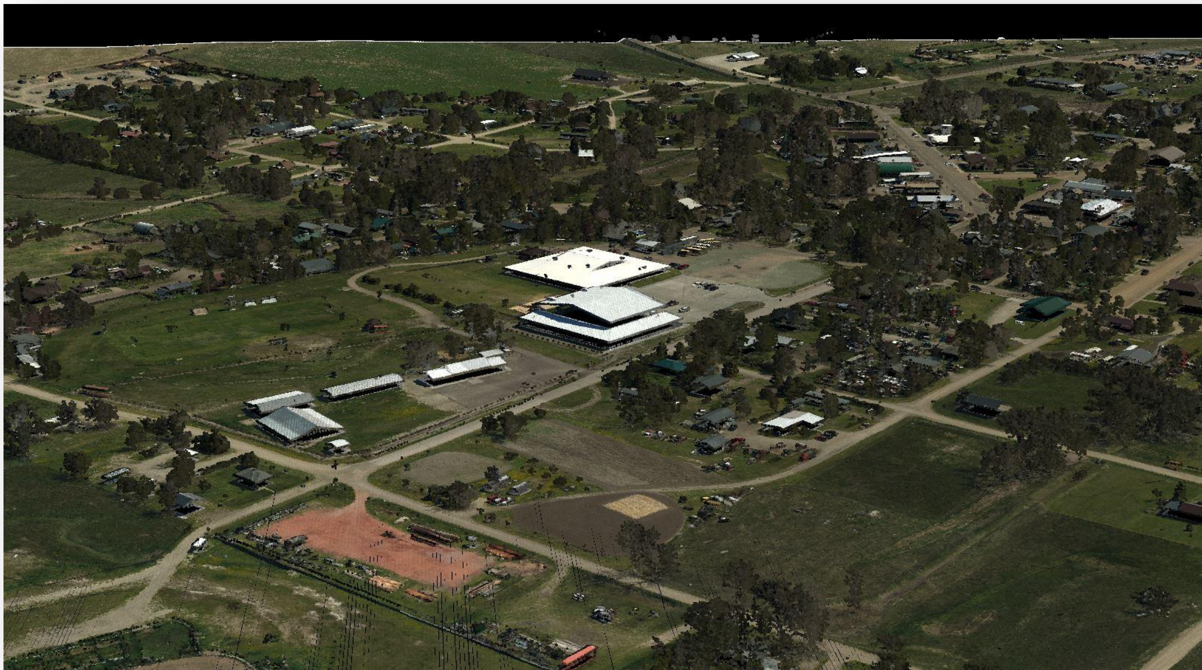


Exhibit 17: *LiDAR point cloud colored by elevation and intensity values*