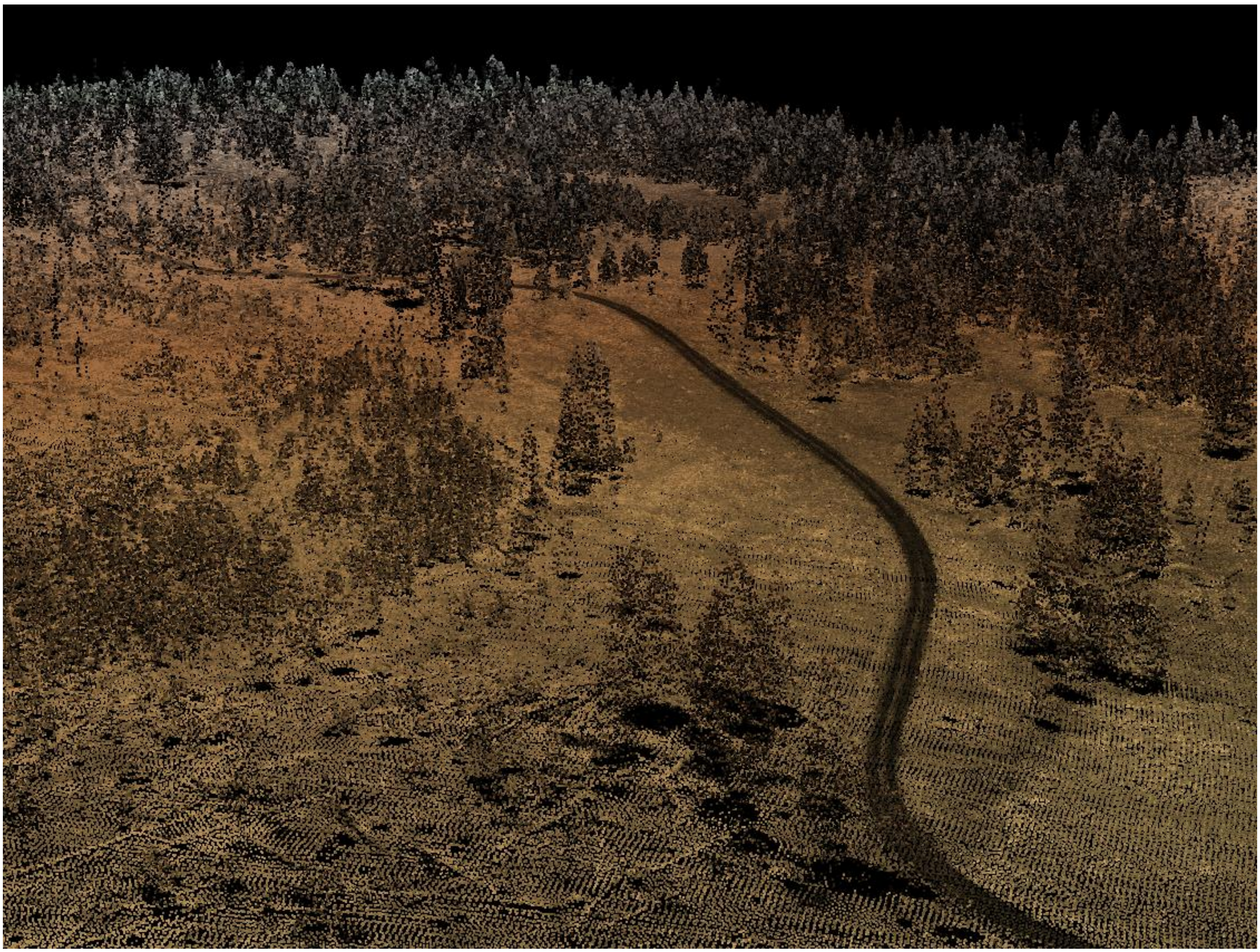
LiDAR DATA COLLECTION

LC WEST
MALHEUR NATIONAL FOREST, OREGON
July 27 – August 19, 2010



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LiDAR Data Collection
LC West, Oregon

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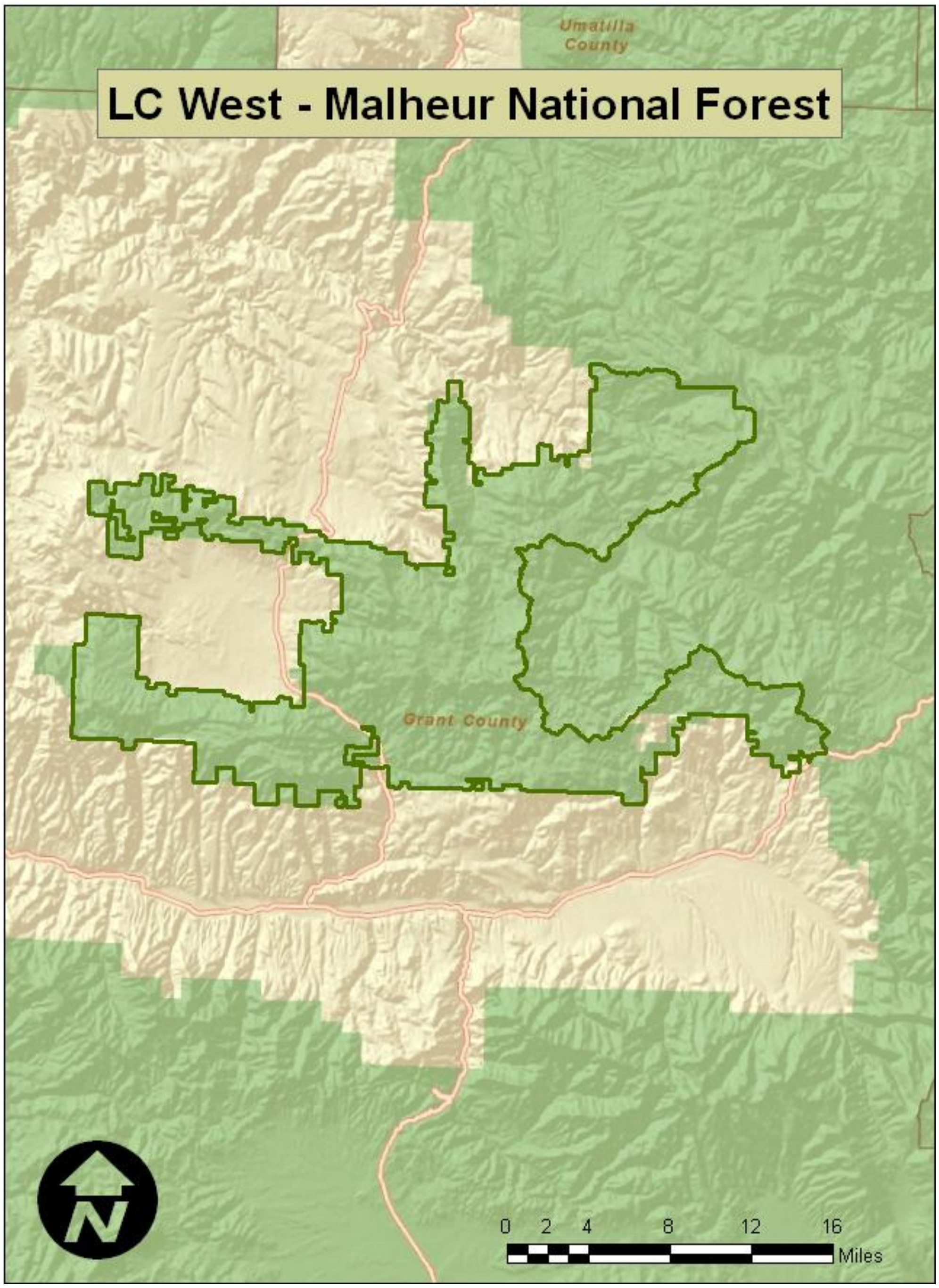
1. Overview

Between July 27 and August 19, 2010, Aero-Graphics acquired LiDAR data over a portion of the Mahleur National Forest called LC West. The acquisition covers roughly 323 square miles (206,724 acres).

Exhibit 1: *LC West project boundary (in green)*



2. Acquisition

2.1 Airborne Acquisition – Equipment and Methodology

LiDAR acquisition of LC West was performed with an Optech ALTM Orion sensor. Aero-Graphics flew at an average altitude of 3280 ft AGL (above ground level) and made appropriate adjustments to compensate for topographic relief. The PRF (pulse rate frequency) used for collection was 100 kHz, scan frequency of 70 Hz, and scan angle of +/- 11° from the nadir position (full scan angle 22°). The ALTM Orion 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. Acquisition was performed with a 50% side lap and yielded >12.5 points per square meter throughout the project boundary. The Optech ALTM Orion is capable of receiving up to four range measurements, including 1st, 2nd, 3rd, and last returns for every pulse sent from the system.

Exhibit 2: *Summary of flight parameters*

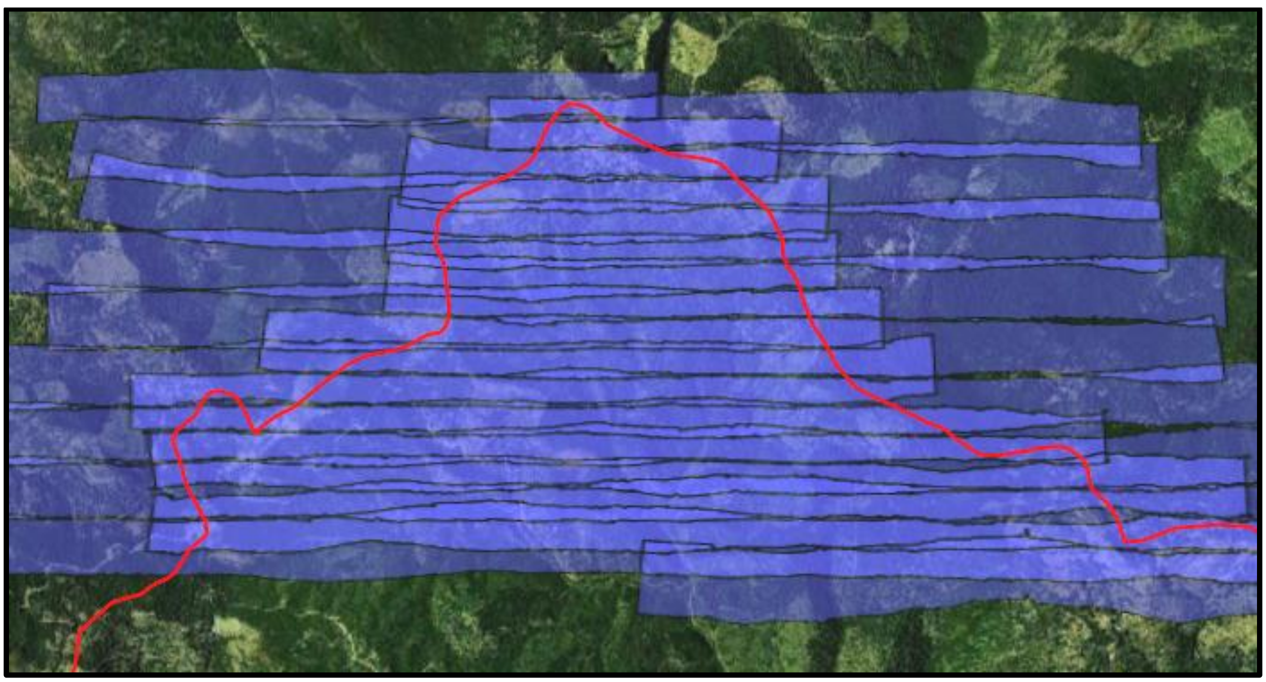
Altitude (ft AGL)	Overlap (%)	Speed (kts)	PRF (kHz)	Scan Freq (Hz)	Scan Angle ° (full)	PPM^2 (nominal)
3280	50	110	100	70	22	9.1

The ALTM Orion 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 LC West area was a turbo charged 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 LiDAR sensor is equipped with ALTM-Nav Flight Management System Software. ALTM-Nav is not only used to guide the airborne mission in flight, but our office flight planning is performed using a combination of Nav and traditional flight planning practices. The smooth transition from flight planning to aerial operations eliminates discrepancies between the flight plan and what is actually acquired. The use of ALTM-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, as shown in **Exhibit 4.**

Exhibit 4: *Real time swath data for LC West was recorded and viewed real-time by the operator.*



2.2 Ground Survey – Equipment and Methodology

Aero-Graphics used the following survey data to differentially correct the aircraft's trajectory data and to ensure that the LiDAR data maintained its true geographic integrity.

2.2.1 Base Stations

Using our own static base stations at strategic points in the project area, with data collected during the time of the LiDAR mission, we used Multi-Base processing in Applanix's POS GNSS software to accurately correct the aircraft's real-time GPS trajectory.

Exhibit 5: *Ground bases and their geographic positions (#116 pictured)*

Base Station	Datum: WGS84		WGS84
	Latitude	Longitude	Ellipsoid Height (m)
112	44° 35' 49.22318"	-119° 07' 55.42067"	1427.375
116	44° 41' 34.58673"	-118° 47' 33.09639"	1039.209

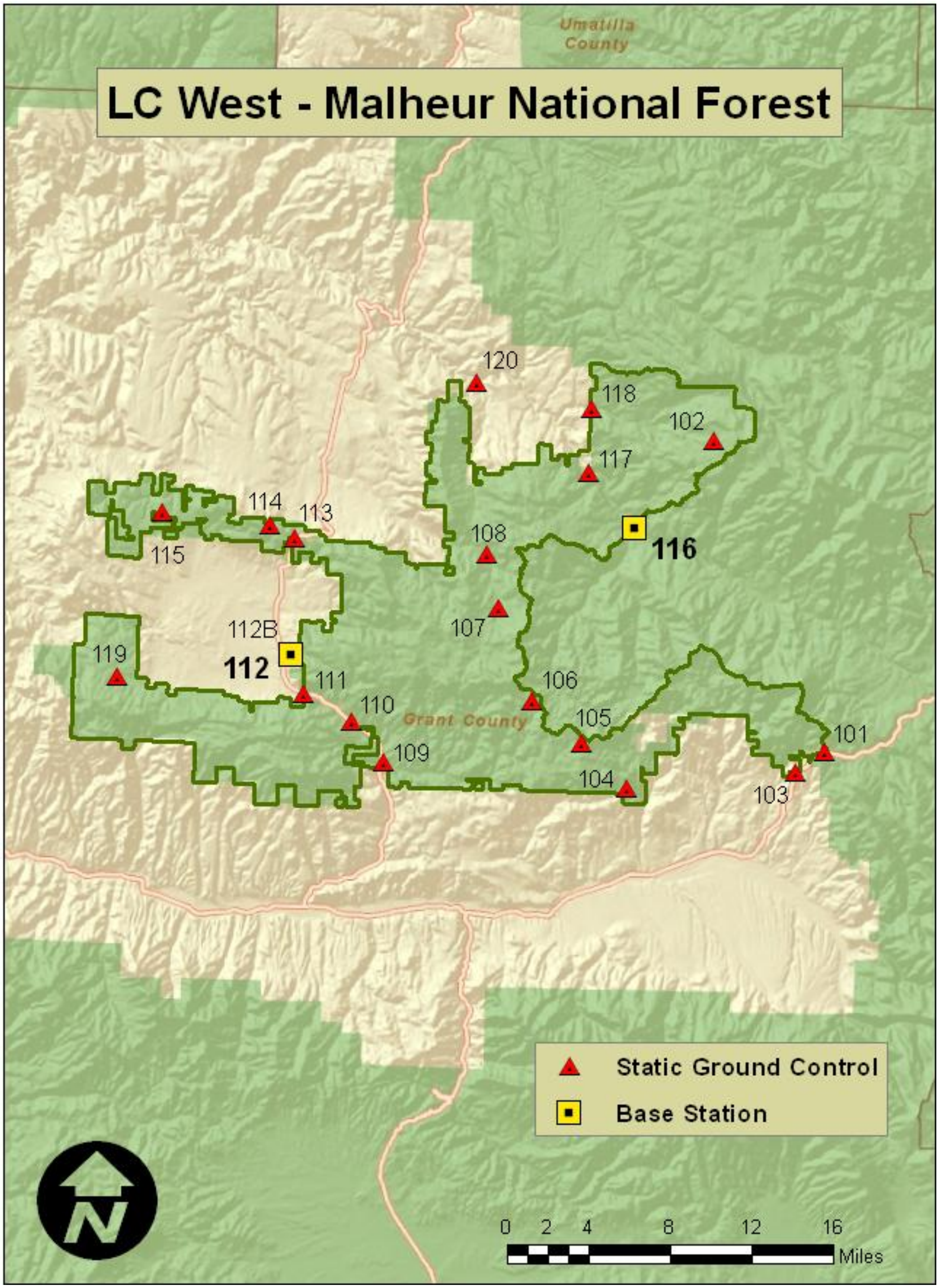
2.2.2 Ground Survey Control

Aero-Graphics collected the following static measurements, which allowed us to ensure project-specified accuracy on the final LiDAR and surface deliverables. This final accuracy is presented in section 4.2.

Exhibit 6: *Static ground survey measurements (#109 & #118 pictured)*

Survey Point	Datum: WGS84		WGS84
	Latitude	Longitude	Ellipsoid Height (m)
101	44° 32’ 10.50998”	-118° 35’ 57.86882”	1582.925
102	44° 45’ 23.11077”	-118° 42’ 57.03079”	1888.829
103	44° 31’ 15.13124”	-118° 37’ 37.87388”	1429.174
104	44° 30’ 28.12114”	-118° 47’ 46.44403”	1413.356
105	44° 32’ 20.64869”	-118° 50’ 26.72720”	1591.409
106	44° 34’ 04.49330”	-118° 53’ 30.74885”	1596.583
107	44° 38’ 02.78410”	-118° 55’ 39.90817”	1494.185
108	44° 40’ 18.58388”	-118° 56’ 22.52248”	1353.463
109	44° 31’ 17.17779”	-119° 02’ 18.15659”	1059.013
110	44° 33’ 01.16570”	-119° 04’ 13.59181”	1197.251
111	44° 34’ 10.05619”	-119° 07’ 07.75776”	1393.074
112B	44° 35’ 47.90119”	-119° 08’ 06.93225”	1416.862
113	44° 40’ 47.66487”	-119° 07’ 54.95503”	1537.248
114	44° 41’ 19.90564”	-119° 09’ 27.26509”	1616.958
115	44° 41’ 43.67090”	-119° 15’ 53.24584”	1492.167
117	44° 43’ 53.62710”	-118° 50’ 27.31768”	1003.928
118	44° 46’ 39.53588”	-118° 50’ 20.37597”	1074.212
119	44° 34’ 41.59962”	-119° 18’ 21.80098”	1452.183
120	44° 47’ 39.55090”	-118° 57’ 13.63137”	912.066

Exhibit 7: *AGI static ground control and base locations for LC West*



3. LiDAR Processing Workflow and Software

a. **Absolute Sensor Calibration.** The absolute sensor calibration is defined as the difference in roll, pitch, heading, and scale between the raw laser point cloud from the sensor and surveyed control points on the ground over two separate sites. **Software:** Dashmap 4.1801; ACalib 1.3.5.7.

b. **Kinematic Air Point Processing.** Differentially corrected the 1-second airborne GPS positions with ground base stations; 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). **Software:** Applanix POSPac 5.3.3664.28463.

c. **Raw LiDAR Point Processing.** Combined SBET with raw LiDAR range data; solved real-world position for each laser point; produced point cloud data by flight strip in ASPRS v1.1 .LAS format; output in WGS84 UTM Ellipsoid Heights. **Software:** LiDAR Mapping Suite 1.0.

d. **Relative Calibration.** Tested relative accuracy; performed relative calibration by correcting for roll, pitch, heading, and scale discrepancies between adjacent flightlines. Results presented in Section 4.1. **Software:** LiDAR Mapping Suite 1.0.

e. **Tiling & Long/Short Filtering.** Cut data into project-specified tiles and filtered out grossly long and short returns. **Software:** TerraScan 10.011.

f. **Classification.** Ran classification algorithms on points in each tile; separated into ground, unclassified, high outliers and low outliers; revisited areas not completely classified automatically and manually corrected them. **Software:** TerraScan 10.011.

g. **Absolute 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. **Software:** TerraScan 10.001.

h. **Datum Transformation.** Transformed all .LAS tiles from WGS84 UTM 11N Ellipsoid Heights into NAD83 UTM 11N, adjusted for orthometric heights on NAVD88 (Geoid03). Integrity of the .LAS file format was maintained throughout the process. **Software:** Blue Marble Desktop 2.1.

i. **DEM Creation.** Generated 2-meter first-return DEMs and 1-meter ground surface DEMs in ESRI Raster Grid format, tiled according to project specifications. **Software:** TerraScan 10.011.

j. **Intensity Image Creation.** Generated 1-meter pixel intensity images in GeoTIFF format, tiled according to project specifications. **Software:** TerraScan 10.011.

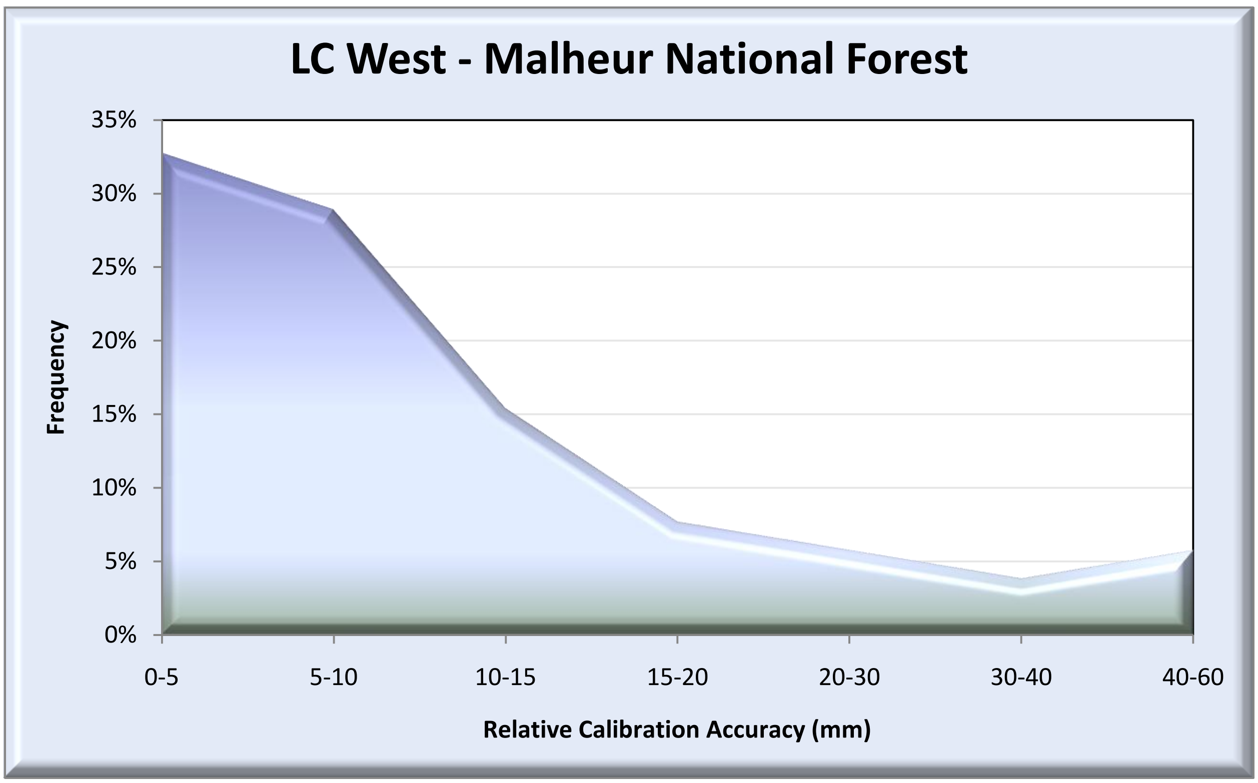
4. Results

4.1 Relative Calibration Accuracy Results

Relative accuracy statistics for LC West are based on the comparison of 52 flightlines and over 110 million points.

- Relative accuracy **average** of 12.1 mm
- Relative accuracy **median** of 8.7 mm

Exhibit 8: *Inter-flightline relative calibration accuracies, post-calibration. Demonstrates the percentage of compared points within a given accuracy range.*



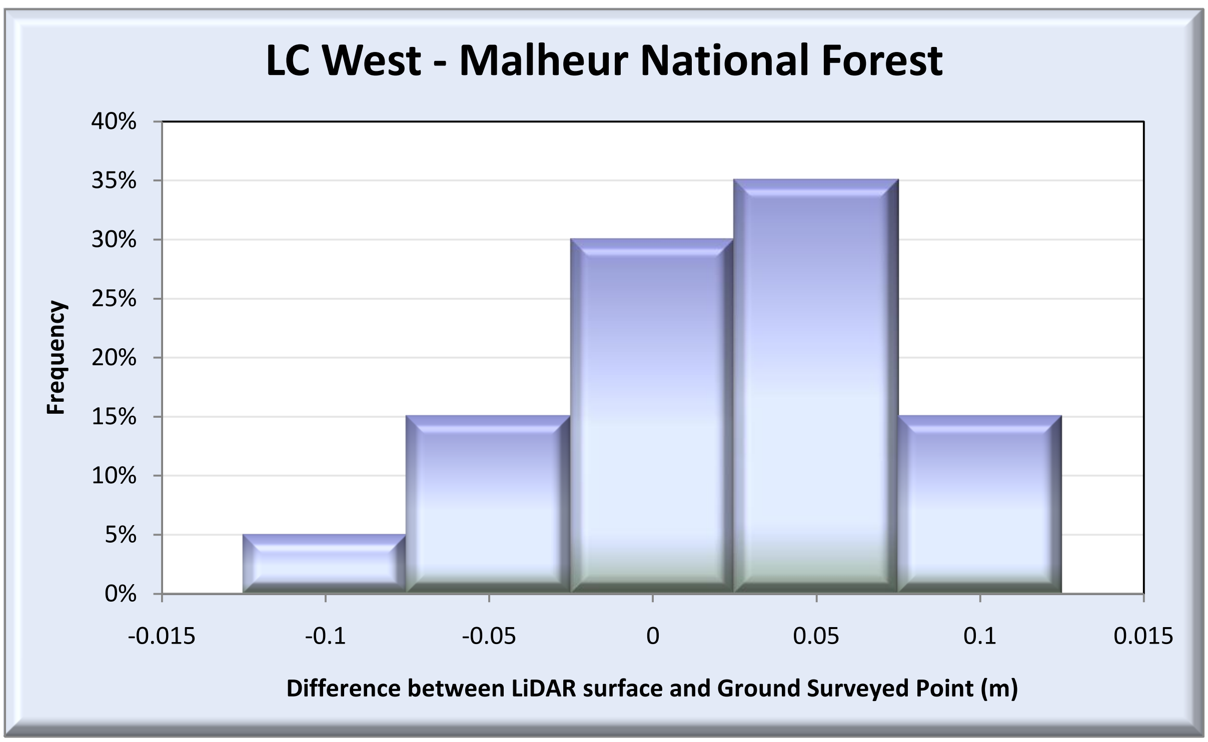
4.2 Absolute Accuracy

Absolute accuracy is defined as the elevation difference between ground surveyed static points and the elevation of the LiDAR surface at that same horizontal location. The statistics of the results are presented here.

Exhibit 9: *Absolute accuracy of the LC West project*

Average Error = 0.017 m	**RMSE = 0.054 m**
Minimum Error = -0.118 m	**σ = 0.052 m**
Maximum Error = 0.110 m	**2 σ = 0.104 m**
Survey Sample Size: n = 20	

Exhibit 10: *Distribution of the errors between LiDAR surface and Ground Surveyed points. Demonstrates the percentage of compared points within a given accuracy range.*



4.3 Data Density

The goal for this project was to achieve a LiDAR point density of greater than nine points per square meter. The acquisition mission achieved an actual average of 12.7 points per square meter.

***<u>Exhibit 11:</u>* LC West – All returns** *Laser Point Density by Frequency, points/m². Demonstrates the percentage of compared points within a given density range*

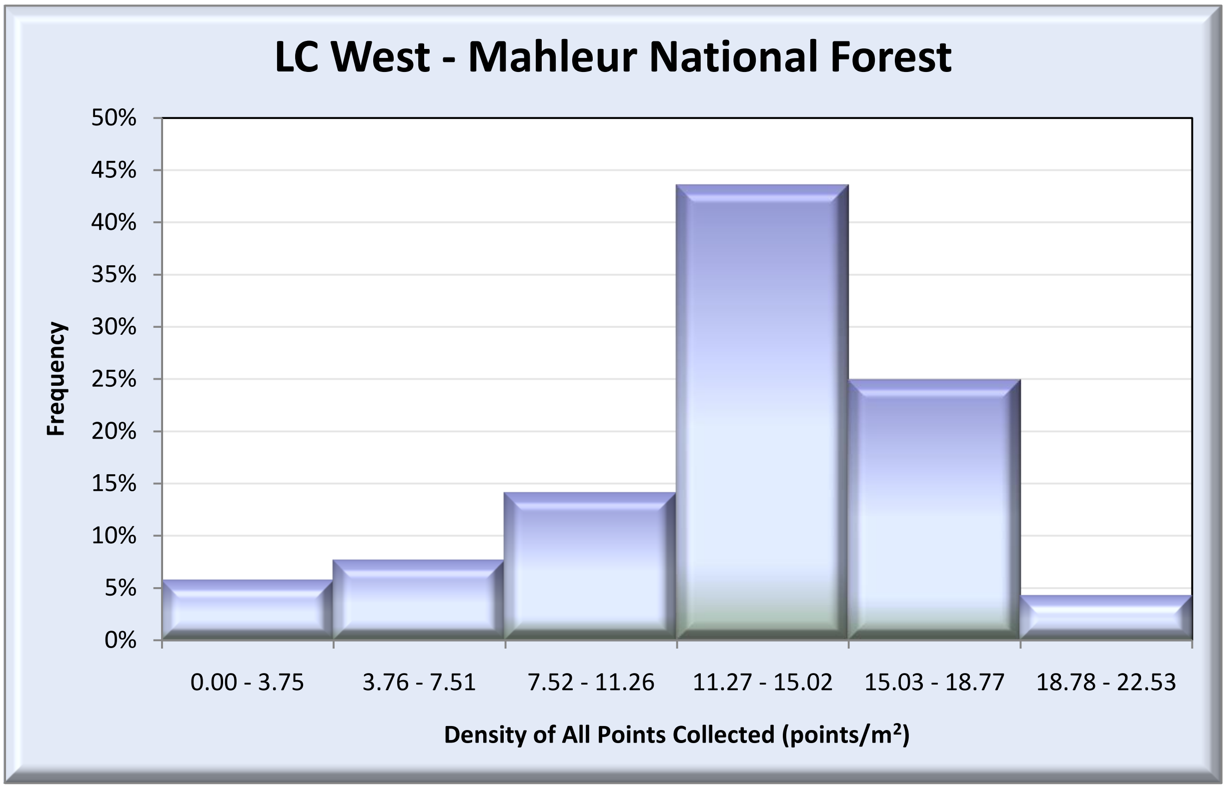
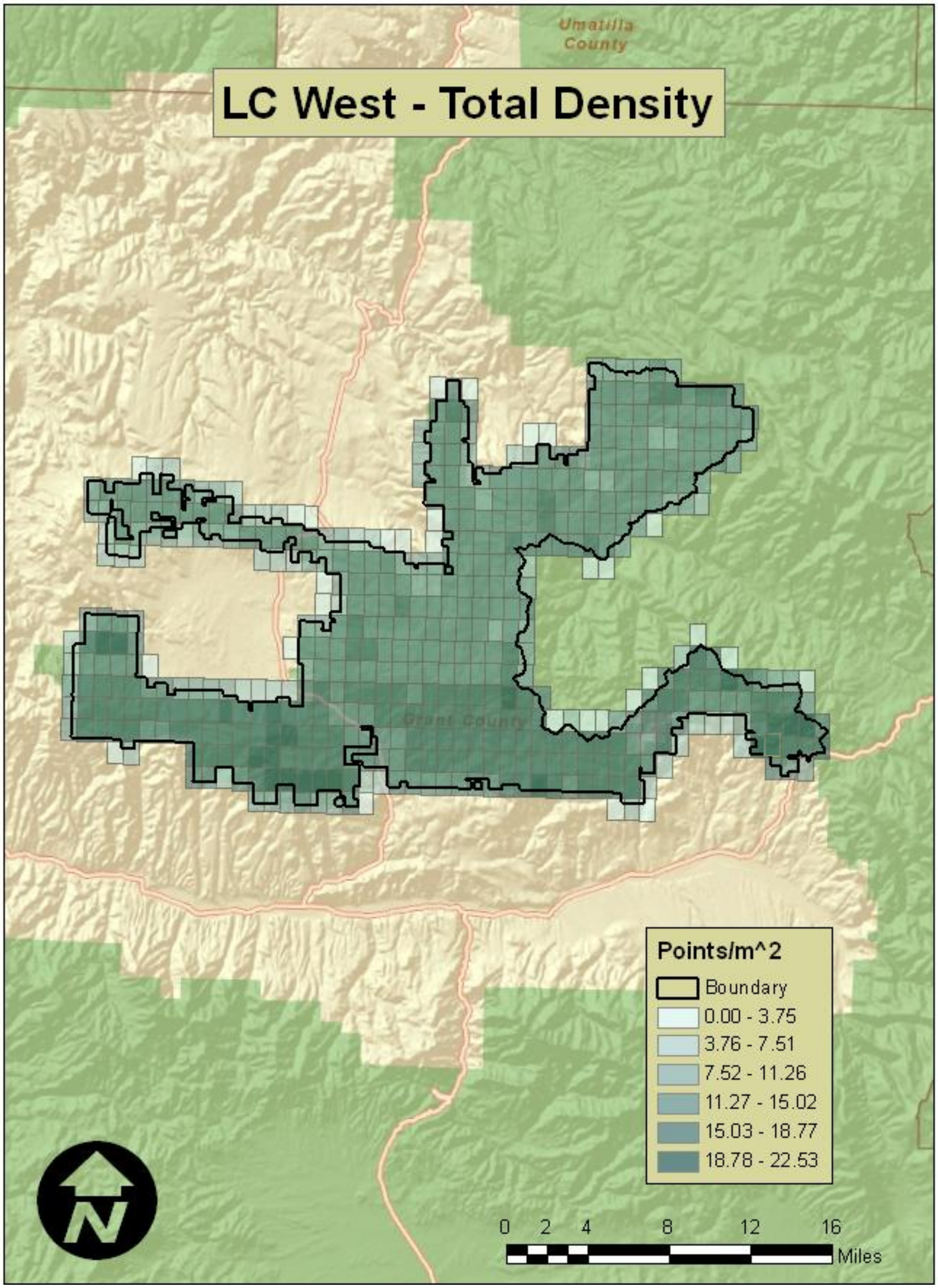


Exhibit 12: *Total Laser Point Density by Tile, points/m²*



The following two exhibits show the density of **ground classified points**. Factors such as vegetation, water, and buildings will affect how points are classified. For the LC West project area, an average of 2.8 ground classified points per square meter was achieved.

***__Exhibit 13:__ LC West - Ground Classified** Laser Point Density by Frequency, points/m^2. Demonstrates the percentage of compared points within a given density range*

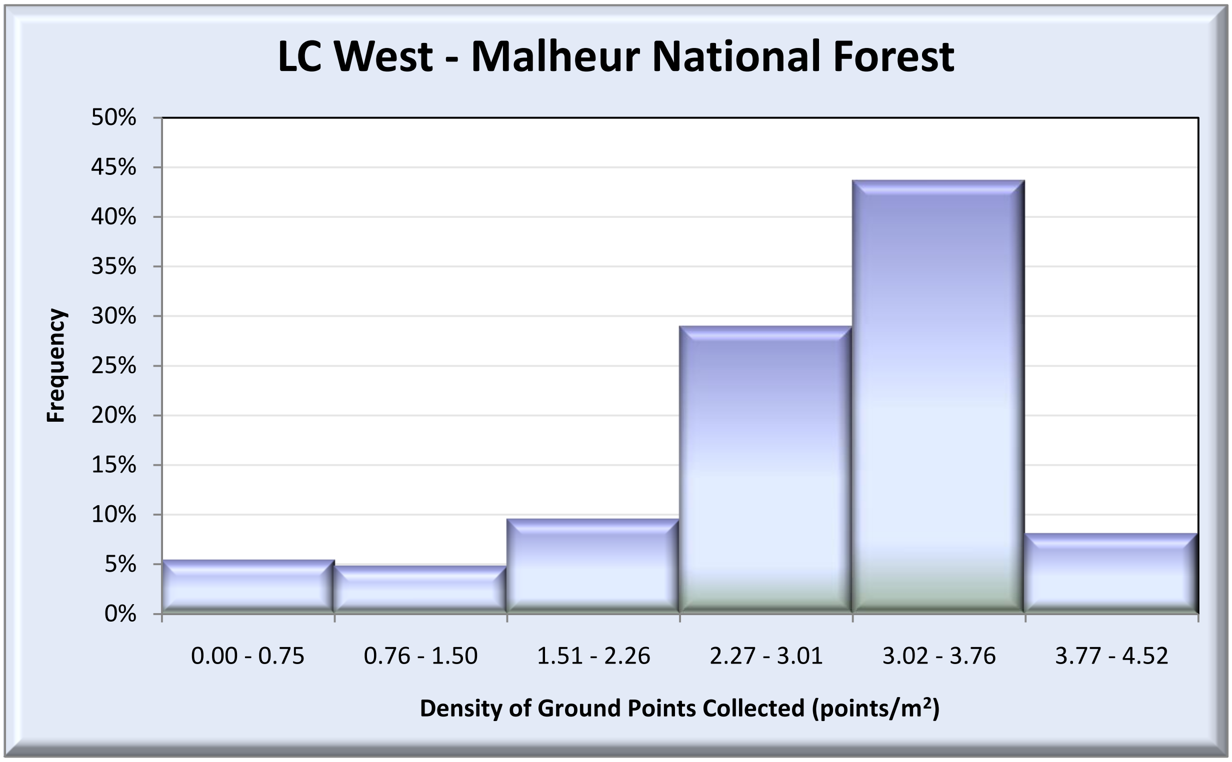
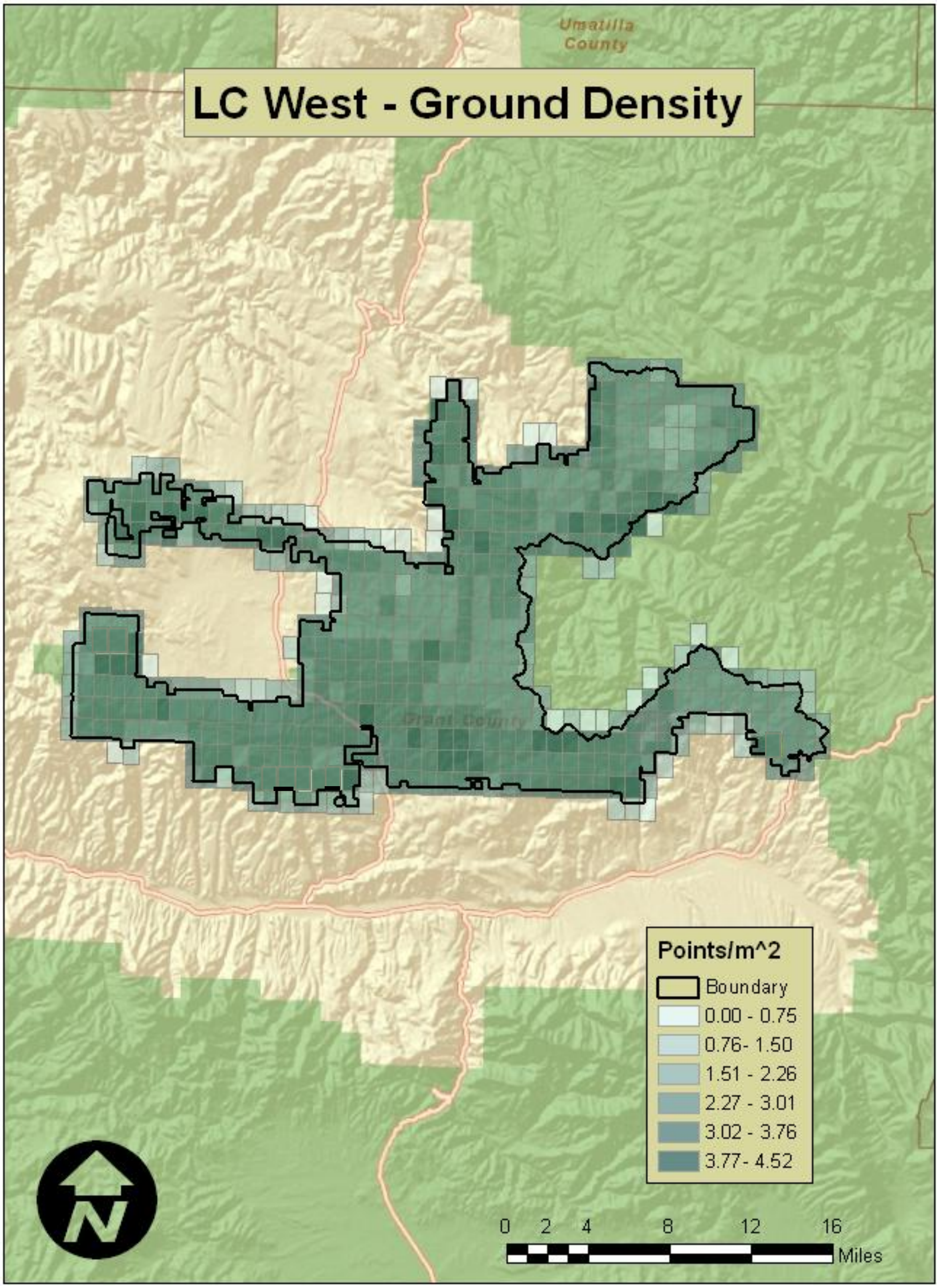


Exhibit 14: *Ground Classified Laser Point Density by Tile, points/m²*



4.4 Data Density Summary

LC West Project Area	Goal	Actual (mean)
Total Point Density:	**>9 points/m^2**	**12.7 points/m^2**
Ground Classified Point Density:	**-------**	**2.8 points/m^2**

4.5 Projection, Datum, and Units

	Projection:	UTM Zone 11N
	Ellipsoid:	WGS84
Datum	**Vertical:**	NAVD88 Geoid 03
	Horizontal:	NAD83
	Units:	Meters

5. Deliverables

Point Data:	• All laser returns (classified into ground and non-ground features) in LAS 1.1 format • Ground laser returns in LAS 1.1 format
Vector Data:	• Aircraft trajectories in ASCII format
Raster Data:	• Ground surface DEMs in ESRI Raster Grid format at a 1m cell size • First-return surface DEMs in ESRI Raster Grid format at a 2m cell size • Intensity Imagery in GeoTIFF format at a 1m pixel size
Report of Survey:	• Post-Deliverable Report including methodology, accuracy, and results

6. Selected Images

Exhibit 15: *Intensity image derived from LiDAR over Mud Lake*

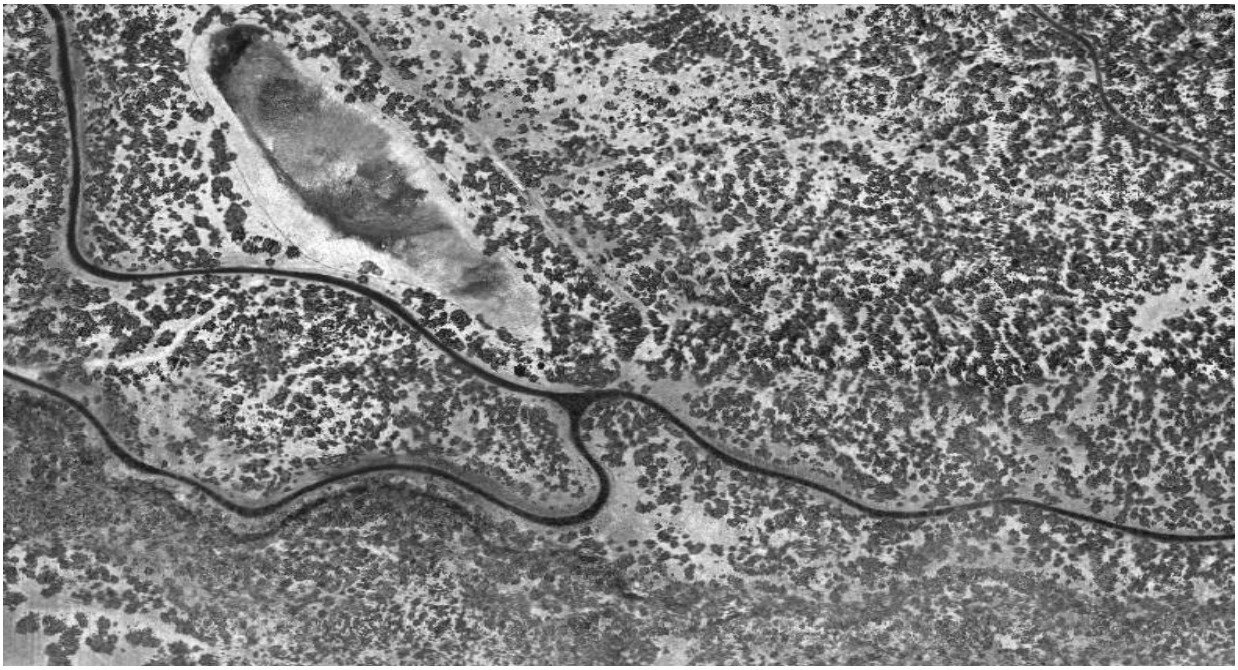


Exhibit 16: *Shaded relief image of LiDAR-derived bare-earth surface – Indian Rock*