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Dear Walter,

This letter accompanies the Lima AOI of the Beaverhead County LiDAR data delivery and summarizes the airborne acquisition, provides a list of all deliverable items, and presents initial processing methods and results. A full report detailing survey information, final accuracy assessment, and detailed processing information will be provided upon project completion.

Quantum Spatial conducted the Lima, Beaverhead County LiDAR survey for the Montana Department of Natural Resources and Conservation on April 11, 2017. This data is projected in Montana State Plane, the horizontal datum is NAD83 (2011) - FIPS 2500, and the vertical datum is NAVD88, Geoid 12A. Horizontal units are International Feet. Vertical units are in US Survey Feet.

Table 1: Products Delivered to the Montana Department of Natural Resources and Conservation

Lima, Beaverhead County Delivered Products	
Points	LAS v 1.2 • All Classified Returns (1 – Default, 2 – Ground, 6 – Buildings, 7 Noise) • Raw Point Cloud All Returns, Calibrated and Adjusted to Ground by Swath
Vectors	Shapefiles (*.shp) • Site Boundary • Tile Index • 3D Building Footprints • 1ft Contours • Total Area Flown • Ground Control (Ground Check Points, Ground Control Points, Landcover Check Points) ESRI Geodatabase • 1ft Contours
Rasters	ESRI Grids • 3 ft Bare Earth DEM ASCII • 3ft Bare Earth DEM ESRI Geodatabase • 3 ft Bare Earth DEM

Acquisition

The LiDAR survey was accomplished using a Leica ALS80 system mounted in a Cessna Caravan 208B. Table 2 summarizes the settings used to yield an average pulse density of ≥8 pulses/m^2 over the Lima, Beaverhead County project area. The Leica ALS80 laser system can record unlimited range measurements (returns) per pulse. It is not uncommon for some types of surfaces (e.g., dense vegetation or water) to return fewer pulses to the LiDAR sensor than the laser originally emitted. The discrepancy between first return and overall delivered density will vary depending on terrain, land cover, and the prevalence of water bodies. All discernible laser returns were processed for the output dataset.

Table 2: LiDAR specifications and survey settings

LiDAR Survey Settings & Specifications	
Acquisition Dates	April 11th, 2017
Aircraft Used	Cessna Caravan 208B
Sensor	Leica
Laser	ALS80
Maximum Returns	Unlimited
Resolution/Density	Average 8 pulses/m^2
Nominal Pulse Spacing	0.35 m
Survey Altitude (AGL)	1600 m
Survey Speed	110 knots
Field of View	40°
Scan Rate	50 Hz
Target Pulse Rate	330.8 kHz
Pulse Length	2.5 ns
Laser Pulse Footprint Diameter	0.35 m
Central Wavelength	1064 nm
Pulse Mode	Multiple Pulses in Air (2PiA)
Beam Divergence	22 mrads
Swath Width	1165 m
Swath Overlap	63%
GPS Baselines	≤13 nm
GPS PDOP	≤3.0
GPS Satellite Constellation	≥6
Intensity	16-bit
Accuracy	$RMSE_Z \leq 10$ cm

All areas were surveyed with an opposing flight line side-lap of ≥60% (≥100% overlap) in order to reduce laser shadowing and increase surface laser painting. To accurately solve for laser point position (geographic coordinates x, y and z), the positional coordinates of the airborne sensor and the attitude of the aircraft were recorded continuously throughout the LiDAR data collection mission. Position of the aircraft was measured twice per second (2 Hz) by an onboard differential GPS unit, and aircraft attitude was measured 200 times per second (200 Hz) as pitch, roll and yaw (heading) from an onboard inertial measurement unit (IMU). To allow for post-processing correction and calibration, aircraft and sensor position and attitude data are indexed by GPS time.

LiDAR Processing

Upon completion of data acquisition, QSI processing staff initiated a suite of automated and manual techniques to process the data into the requested deliverables. Processing tasks included GPS control computations, smoothed best estimate trajectory (SBET) calculations, kinematic corrections, calculation of laser point position, sensor and data calibration for optimal relative and absolute accuracy, and LiDAR point classification. Processing methodologies were tailored for the landscape. Brief descriptions of these tasks are shown in Table 3.

Table 3: LiDAR processing workflow

LiDAR Processing Step	Software Used
Resolve kinematic corrections for aircraft position data using kinematic aircraft GPS and CORS GPS data. Develop a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with sensor head position and attitude recorded throughout the survey.	Waypoint Inertial Explorer
Calculate laser point position by associating SBET position to each laser point return time, scan angle, intensity, etc. Create raw laser point cloud data for the entire survey in *.las (ASPRS v. 1.2) format. Convert data to orthometric elevations by applying a geoid correction.	Waypoint Inertial Explorer Leica Cloudpro v. 1.2.2
Import raw laser points into manageable blocks to perform manual relative accuracy calibration and filter erroneous points. Classify ground points for individual flight lines.	Terramatch v.16
Using ground classified points per each flight line, test the relative accuracy. Perform automated line-to-line calibrations for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift. Calculate calibrations on ground classified points from paired flight lines and apply results to all points in a flight line. Use every flight line for relative accuracy calibration.	TerraMatch v.16
Classify resulting data to ground and other client designated ASPRS classifications.	TerraScan v.16 TerraModeler v.16
Generate bare earth models as triangulated surfaces. Export all elevation models as ESRI GRIDs, ESRI Geodatabase, and ASCII format at a 3 foot pixel resolution.	TerraScan v.16 TerraModeler v.16 ArcMap v. 10.2.2

LiDAR Point Density

The acquisition parameters were designed to acquire an average first-return density of 8 points/m^2. First return density describes the density of pulses emitted from the laser that return at least one echo to the system. Multiple returns from a single pulse were not considered in first return density analysis. Some types of surfaces (e.g., breaks in terrain, water and steep slopes) may have returned fewer pulses than originally emitted by the laser.

First returns typically reflect off the highest feature on the landscape within the footprint of the pulse. In forested or urban areas the highest feature could be a tree, building or power line, while in areas of unobstructed ground, the first return will be the only echo and represents the bare earth surface. The average first return point density value of LIDAR data for the Lima, Beaverhead County site was 0.97 points/ft^2 (10.41 points/m^2) (Table 4).

The density of ground classified LiDAR returns were also analyzed for this project. Terrain character, land cover, and ground surface reflectivity all influenced the density of ground surface returns. In vegetated areas, fewer pulses may have penetrated the canopy, resulting in lower ground density. The average ground classified point density value of LIDAR data for the Lima, Beaverhead County site was 0.51 points/ft^2 (5.44 points/m^2) (Table 4).

Table 4: Average LiDAR point densities

Classification	Point Density
First-Return	0.97 points/ft^2 10.41 points/m^2
Ground Classified	0.51 points/ft^2 5.44 points/m^2

LiDAR Absolute Vertical Accuracy

Absolute accuracy is assessed using Non-Vegetated Vertical Accuracy (NVA) reporting designed to meet guidelines presented in the FGDC National Standard for Spatial Data Accuracy[1]. Due to the ongoing acquisition schedule for the Beaverhead and Mineral Counties LiDAR project, QSI was unable to evaluate NVA for this Lima AOI delivery. Full summary statistics will be provided upon completion of the entire project area.

For the Lima AOI, QSI assessed absolute vertical accuracy using 128 ground control points. Absolute accuracy compares known ground control point data collected on open, bare earth surfaces with level slope (<20°) to the triangulated surface generated by the LiDAR points. Absolute vertical accuracy is a measure of the accuracy of LiDAR point data in open areas where the LiDAR system has a high probability of measuring the ground surface and is evaluated at the 95% confidence interval (1.96 * RMSE), as shown in Table 5.

[1] Federal Geographic Data Committee, ASPRS POSITIONAL ACCURACY STANDARDS FOR DIGITAL GEOSPATIAL DATA EDITION 1, Version 1.0, NOVEMBER 2014. http://www.asprs.org/PAD-Division/ASPRS-POSITIONAL-ACCURACY-STANDARDS-FOR-DIGITAL-GEOSPATIAL-DATA.html.

Although these ground control points were used in the calibration and post-processing of the LiDAR point cloud, they still provide a good indication of the overall accuracy of the LiDAR dataset, and therefore have been provided in Figure 1.

Table 5: Ground Control Absolute Accuracy

Absolute Accuracy	
	Ground Control Points
Sample	128 points
1.96*RMSE	0.077 ft 0.024 m
Average	-0.014 ft -0.004 m
Median	-0.015 ft -0.005 m
RMSE	0.040 ft 0.012 m
Standard Deviation (1σ)	0.037 ft 0.011 m

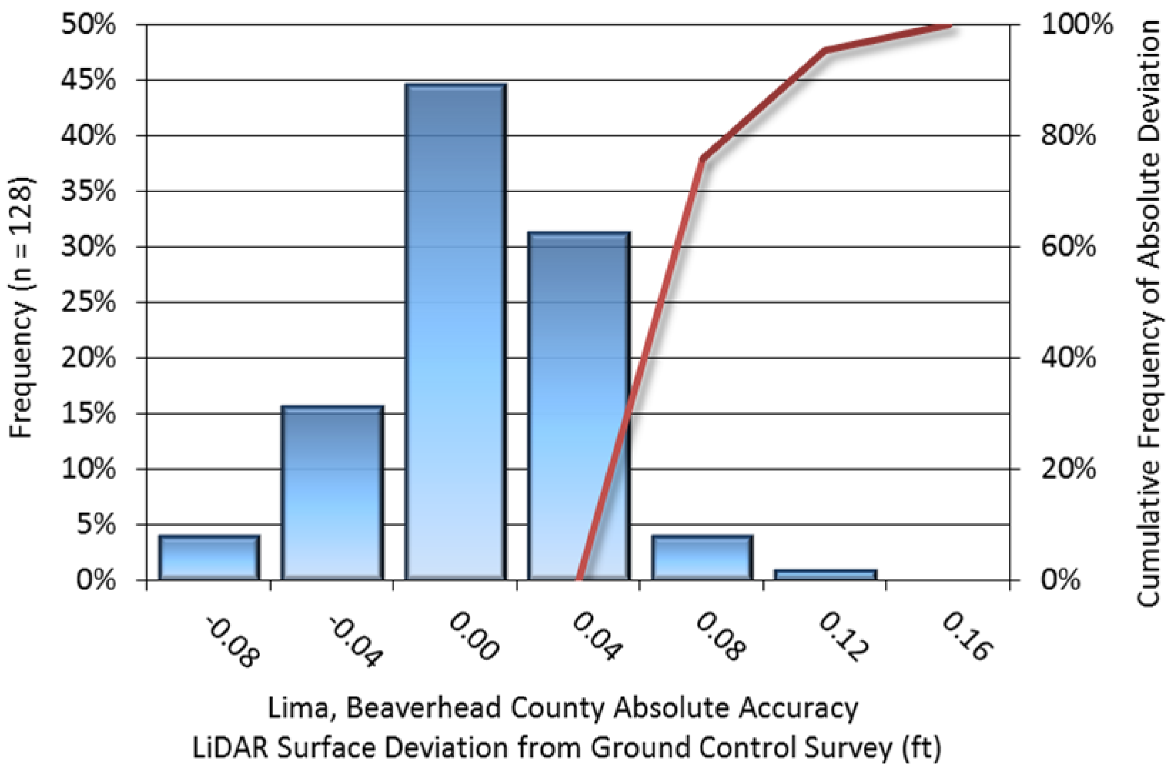

Figure 1: Frequency histogram for LiDAR surface deviation from ground control point values

LiDAR Relative Vertical Accuracy

Relative vertical accuracy refers to the internal consistency of the data set as a whole: the ability to place an object in the same location given multiple flight lines, GPS conditions, and aircraft attitudes. When the LiDAR system is well calibrated, the swath-to-swath vertical divergence is low (<0.10 meters). The relative vertical accuracy was computed by comparing the ground surface model of each individual flight line with its neighbors in overlapping regions. The average (mean) line to line relative vertical accuracy for the Lima, Beaverhead County LiDAR project was 0.081 feet (0.025 meters) (Table 6, Figure 2).

Table 6: Relative accuracy results

Relative Accuracy	
Sample	7 surfaces
Average	0.081 ft 0.025 m
Median	0.078 ft 0.024 m
RMSE	0.079 ft 0.024 m
Standard Deviation (1σ)	0.017 ft 0.005 m
1.96σ	0.032 ft 0.010 m

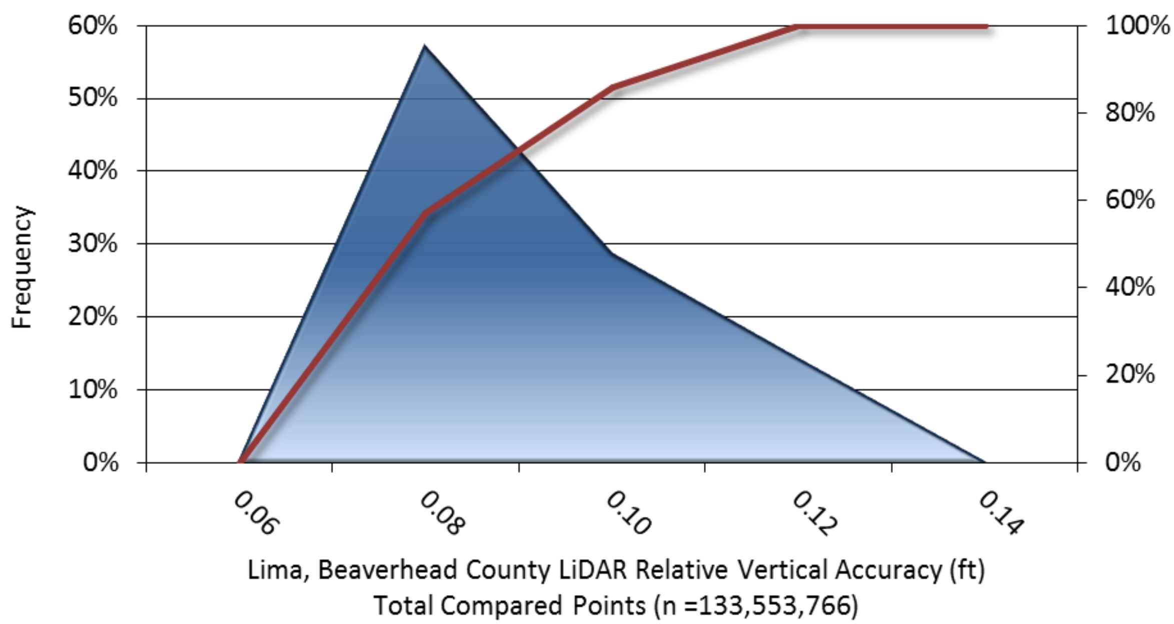

Figure 2: Frequency plot for relative vertical accuracy between flight lines