26 March 2018

Patrick Emmett
USGS, MS 666
1400 Independence Road
Rolla, MO 65401

Dear Patrick,

This letter accompanies the QL1 portion of USGS Payette, Idaho 3DEP LiDAR project and provides a list of all deliverable items included with this delivery, presents initial processing methods, and summarizes QL1 density results and non-vegetated and vegetated vertical accuracy results within the entire project area.

The USGS 3DEP Payette LiDAR acquisition occurred between September 9th, 2017 and October 14th, 2017. This dataset is projected in UTM Zone 11 North, the horizontal datum is NAD83 (2011), and the vertical datum is NAVD88, Geoid12B. Horizontal and vertical units are in meters.

Processing of the QL2 portion of the Payette, Idaho 3DEP LiDAR project is scheduled to be completed in May 2018; upon completion, a full comprehensive report detailing all acquisition procedures, processing information, and accuracy assessments for the entire project area will be provided.

Please feel free to reach out to myself or the team at Quantum Spatial if you have any questions or concerns regarding this LiDAR data delivery.

Sincerely,

Joel Burroughs, Project Manager

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Project Summary

In August 2017, Quantum Spatial (QSI) was contracted by the United States Geological Survey (USGS) to collect Light Detection and Ranging (LiDAR) data for the Payette, Idaho 3DEP LiDAR project area (Contract No. G16PC00016, Task Order No. G17PD01150). The Payette, Idaho 3DEP LiDAR project area encompasses approximately 283,194 acres within the Payette National Forest and Idaho Department of Lands of QL1 LiDAR data, and approximately 802,618 acres of Washington County, Idaho of QL2 LiDAR data. Data were collected to support the USGS 3DEP mission in assessing the topographic and geophysical properties of the study area.

Table 1: Products Delivered to USGS

Payette, Idaho QL1 Products	
Points	LAS v 1.4 • All Classified Returns
Vectors	Index Shapefiles (*.shp) • LiDAR QL1 Project Boundary • QL1 LAS Index- 1/100th USGS quadrangles (0.75 minute x 0.75 minute) tiles • QL1 DEM Tile Index- 1/4th USGS quadrangles (3.75 minute by 3.75 minute) tiles • QL1 DEM Mosaic Index- USGS 7.5-minute quadrangle tiles • QL1 Water's Edge, Bridge, and Hydroenforcement Breaklines Index Shapefiles (*.gdb) • QL1 Flightline shapefile Ground Survey Shapefiles (*.shp) • Ground Check Points • Supplemental Ground Control Points • Ground Control Monuments
Rasters	0.5 meter ESRI Grid files delineated in both 1/4th USGS quadrangles and full 7.5-minute quadrangle mosaics • QL1 Highest Hit Digital Surface Model (DSM) 0.5 meter GeoTIFF (*.tif) files delineated in both 1/4th USGS quadrangles and full 7.5-minute quadrangle mosaics • QL1 Intensity Images • QL1 Hydroflattened Bare Earth Digital Elevation Model (DEM) • QL1 Hydroenforced Bare Earth Digital Elevation Model (DEM)

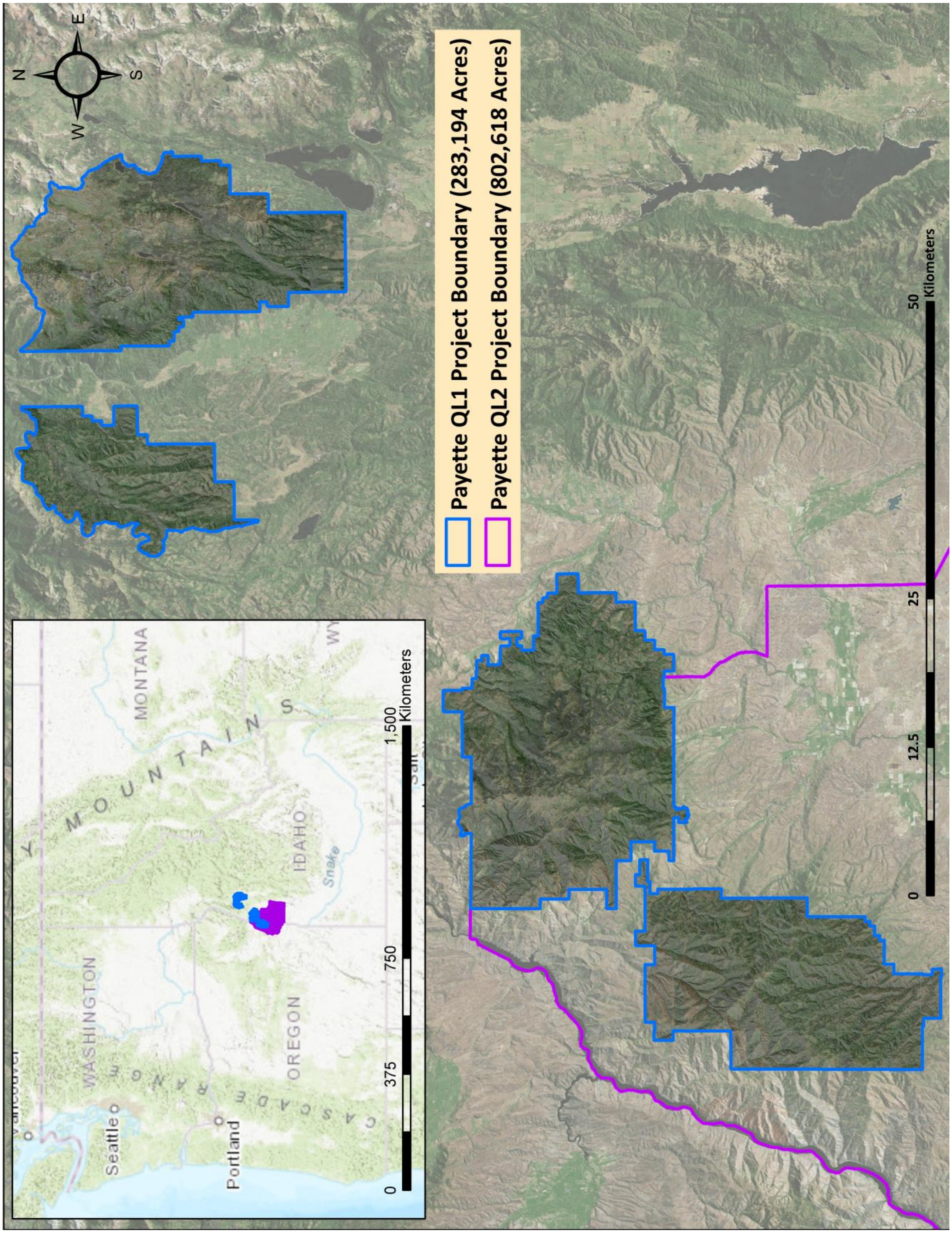

Figure 1: Location map of the Payette, Idaho 3DEP QL1 Site

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 (Table 2). Processing methodologies were tailored for the landscape. Brief descriptions of these tasks are shown in Table 3.

Table 2: ASPRS LAS classification standards applied to the Payette dataset

Classification Number	Classification Name	Classification Description
1	Default/Unclassified	Laser returns that are not included in the ground class, composed of vegetation and anthropogenic features below vegetation thresholds
1O	Default/Unclassified - Overlap	Laser returns that are deemed not necessary to form a complete single, non-overlapped, gap free coverage with respect to adjacent swaths
2	Ground	Laser returns that are determined to be ground using automated and manual cleaning algorithms
3	Low Vegetation	Laser returns that are determined to be vegetation between 0 and 1.8288 meters above the triangulated ground surface, developed using automated processes
4	Medium Vegetation	Laser returns that are determined to be vegetation between 1.8289 and 4.8768 meters above the triangulated ground surface, developed using automated processes
5	High Vegetation	Laser returns that are determined to be vegetation between 4.8768 meters and above the triangulated ground surface, developed using automated processes
7	Noise	Laser returns that are often associated with birds, scattering from reflective surfaces, or artificial points below the ground surface
9	Water	Laser returns that are determined to be water using automated and manual cleaning algorithms
10	Ignored Ground	Ground points proximate to water's edge breaklines; ignored for correct model creation
17	Bridge	Permanent bridge decks

Table 3: LiDAR Processing Workflow

LiDAR Processing Step	Software Used
Resolve kinematic corrections for aircraft position data using kinematic aircraft GPS and static ground 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 v.8.6
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. 1.4) format. Convert data to orthometric elevations by applying a geoid correction.	Waypoint Inertial Explorer v.8.6 Leica Cloudpro v. 1.2.2
Import raw laser points into manageable blocks (less than 500 MB) to perform manual relative accuracy calibration and filter erroneous points. Classify ground points for individual flight lines.	TerraScan v.17
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.17
Classify resulting data to ground and other client designated ASPRS classifications (Table 2). Assess statistical absolute accuracy via direct comparisons of ground classified points to ground control survey data.	Las Monkey 2.3.0 (QSI proprietary) TerraScan v.17 TerraModeler v.17
Generate bare earth models as triangulated surfaces. Generate highest hit models as a surface expression of all classified points. Export all surface models as ESRI Grids or GeoTIFFs at 0.5 meter pixel resolution.	TerraScan v.17 TerraModeler v.17 ArcMap v. 10.3.1
Correct intensity values for variability and export intensity images as GeoTIFFs at a 0.5 meter pixel resolution.	Las Monkey 2.3.0 (QSI proprietary) LAS Product Creator 1.5 (QSI proprietary) ArcMap v. 10.3.1

LiDAR Density

The acquisition parameters were designed to acquire an average first-return density of 8 points/m^2 for the QL1 portion of the Payette, Idaho 3DEP dataset. 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 density of ground-classified LiDAR returns was 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 penetrate the canopy, resulting in lower ground density.

The average first-return density of LiDAR data for the Payette QL1 project area was 18.00 points/m^2 while the average ground classified density was 2.93 points/m2 (Table 4). The statistical and spatial distributions of first return densities and classified ground return densities per 100 m x 100 m cell are portrayed in Figure 2.

Table 4: Average LiDAR point densities

Classification	Point Density
First-Return	18.00 points/m^2
Ground Classified	2.93 points/m^2

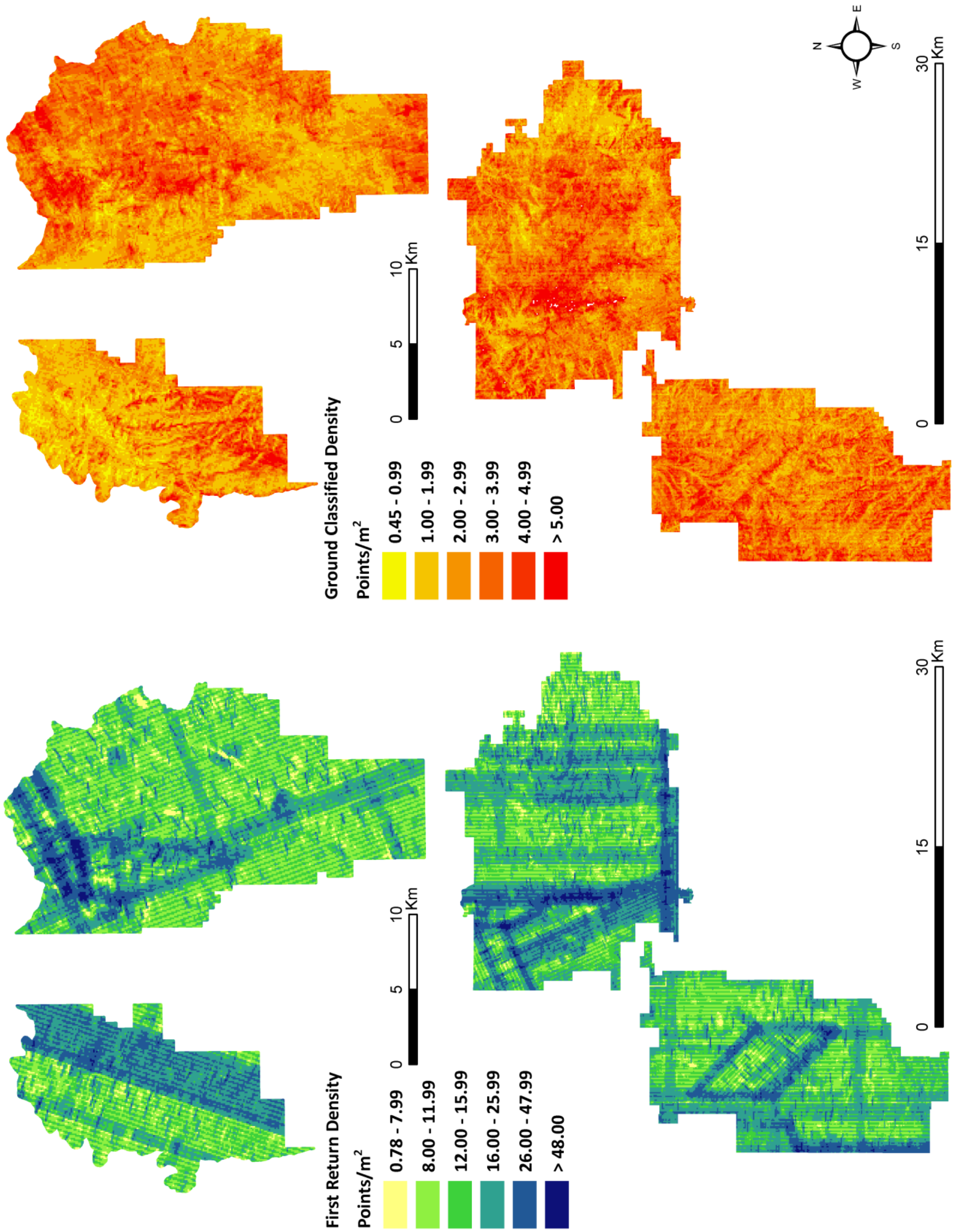

Figure 2: First return and ground-classified point density map for the Payette site (100 m x 100 m cells)

LiDAR Accuracy Assessments

The accuracy of the LiDAR data collection can be described in terms of vertical accuracy (the consistency of the data with external data sources) and relative accuracy (the consistency of the dataset with itself).

LiDAR Absolute Vertical Accuracy

Absolute accuracy was assessed using Non-Vegetated Vertical Accuracy (NVA) reporting designed to meet guidelines presented in the FGDC National Standard for Spatial Data Accuracy[1]. NVA compares known ground quality assurance point data collected on open, bare earth surfaces with level slope (<20°) to the unclassified point cloud, as well as the triangulated surface generated by the LiDAR points (Table 5). NVA 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).

The mean and standard deviation (sigma σ) of divergence of the ground surface model from quality assurance point coordinates are also considered during accuracy assessment. These statistics assume the error for x, y and z is normally distributed, and therefore the skew and kurtosis of distributions are also considered when evaluating error statistics. For the Payette survey, 96 quality assurance points were collected within the project area resulting in a non-vegetated vertical accuracy of 0.073 meters as compared to the bare earth DEM, and 0.085 meters as compared to the unclassified point cloud, with 95% confidence (Figure 3, Figure 4).

QSI also assessed absolute accuracy using 4,430 ground control points within the project area. Although these 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 Table 5 and Figure 5.

Table 5: Absolute accuracy results

Payette QL1 Absolute Accuracy			
	Quality Assurance Points (NVA), as compared to Bare Earth DEM	Quality Assurance Points (NVA), as compared unclassified LAS	Ground Control Points
Sample	96 points	96 points	4,430 points
95% Confidence (1.96*RMSE)	0.073 m	0.085 m	0.064 m
Average	0.004 m	0.024 m	0.004 m
Median	0.004 m	0.025 m	0.005 m
RMSE	0.037 m	0.043 m	0.033 m
Standard Deviation (1σ)	0.037 m	0.036 m	0.032 m

[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.

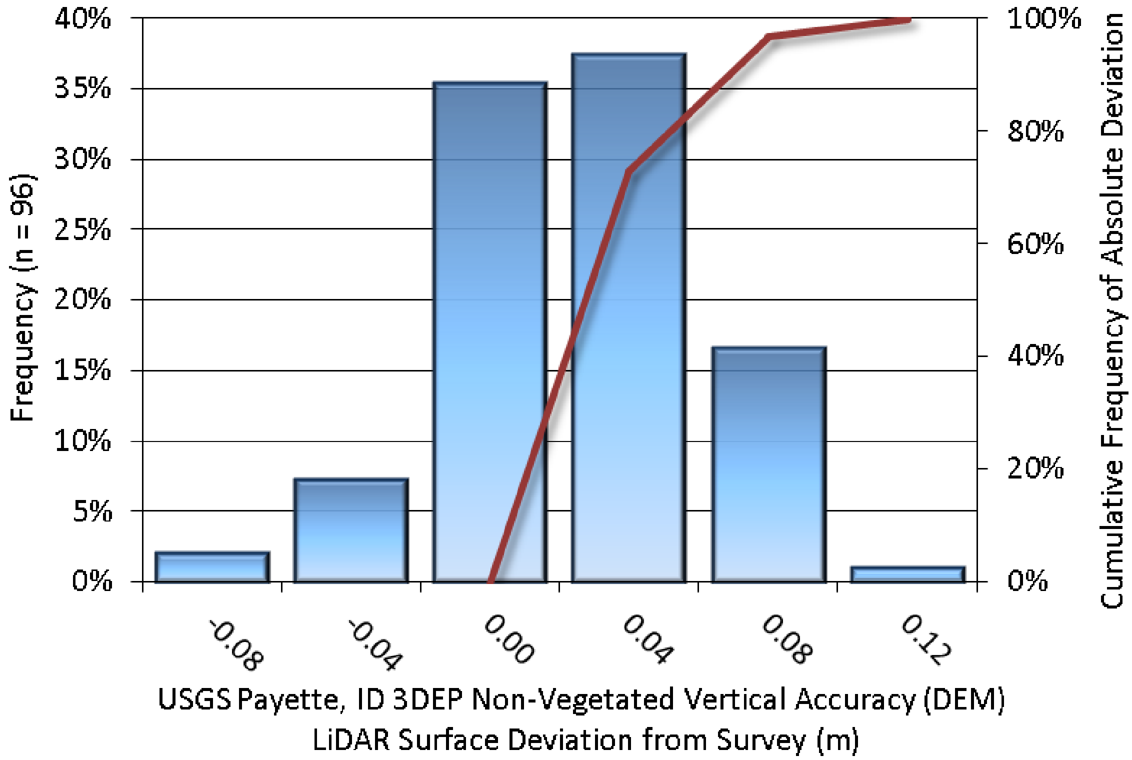

Figure 3: Frequency histogram for LiDAR surface deviation from non-vegetated quality assurance point values

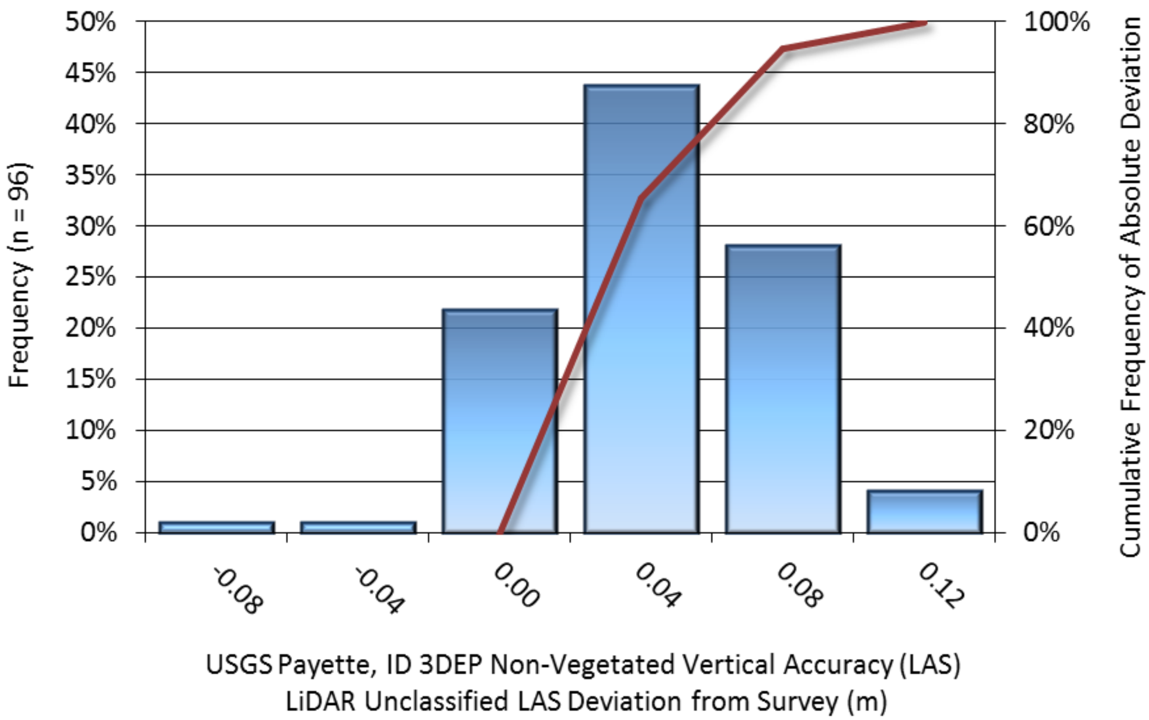

Figure 4: Frequency histogram for LiDAR unclassified point deviation from non-vegetated quality assurance point values

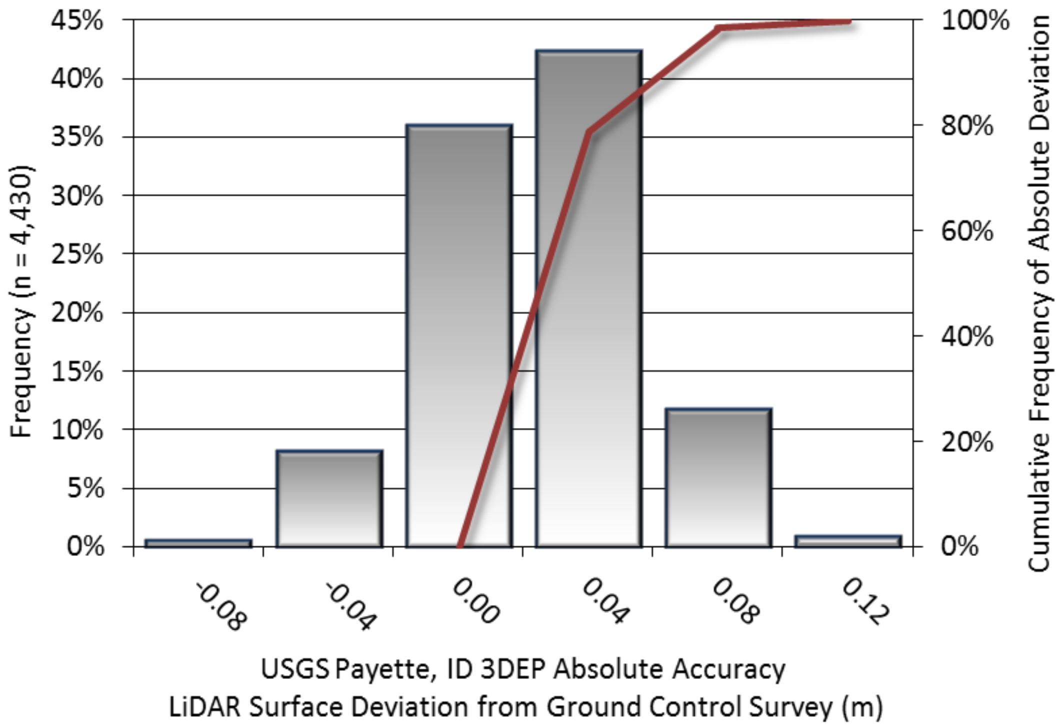

Figure 5: Frequency histogram for LiDAR surface deviation from ground control point values

LiDAR Vegetated Vertical Accuracy

QSI also assessed vertical accuracy using Vegetated Vertical Accuracy (VVA) reporting. VVA compares known ground quality assurance point data collected over vegetated surfaces using land class descriptions to the triangulated ground surface generated by the ground classified LiDAR points. For the Payette survey, 58 vegetated quality assurance points were collected within the project area resulting in a vegetated vertical accuracy of 0.188 meters, evaluated at the 95th percentile (Table 6, Figure 6).

Table 6: Absolute accuracy results

Payette QL1 Vegetated Vertical Accuracy (VVA)	
Sample	58 points
95th Percentile	0.188 m
Average	0.052 m
Median	0.041 m
RMSE	0.108 m
Standard Deviation (1σ)	0.096 m

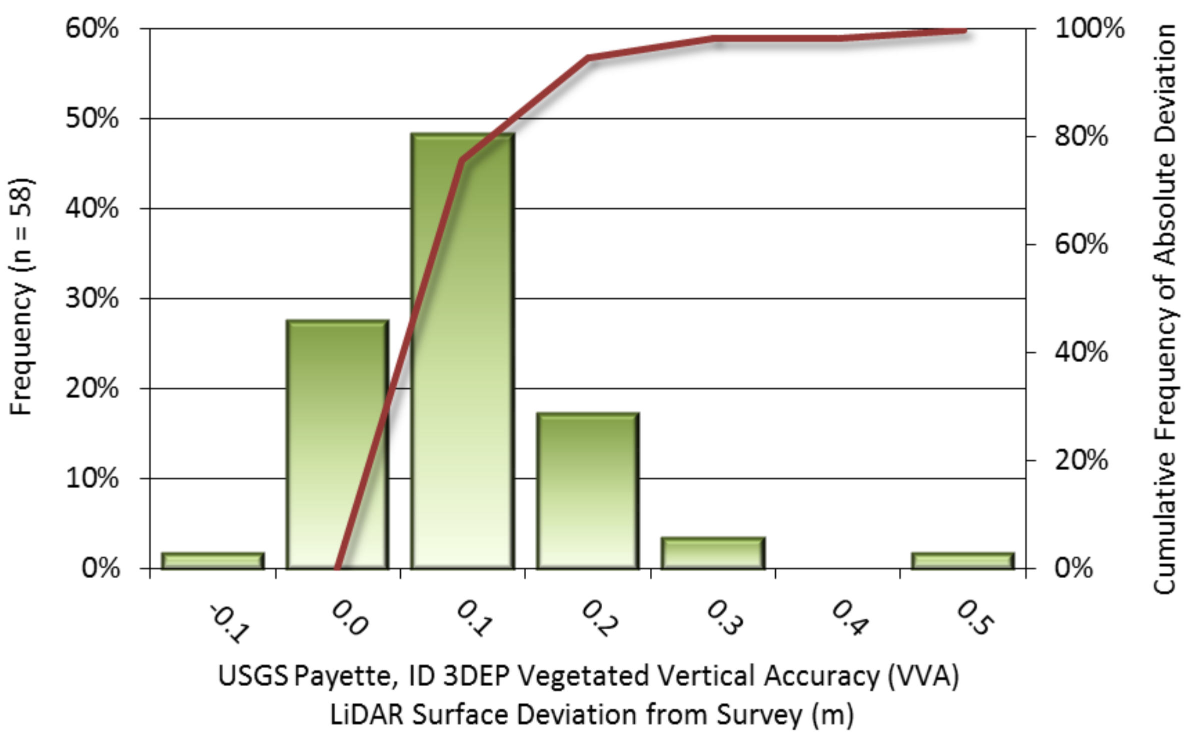

Figure 6: Frequency histogram for LiDAR surface deviation from vegetated quality assurance point values (VVA)

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 Payette QL1 LiDAR project was 0.043 meters (Table 7, Figure 7).

Table 7: Relative accuracy results

Relative Accuracy	
Sample	625 surfaces
Average	0.043 m
Median	0.043 m
RMSE	0.046 m
Standard Deviation (1σ)	0.010 m
1.96σ	0.019 m

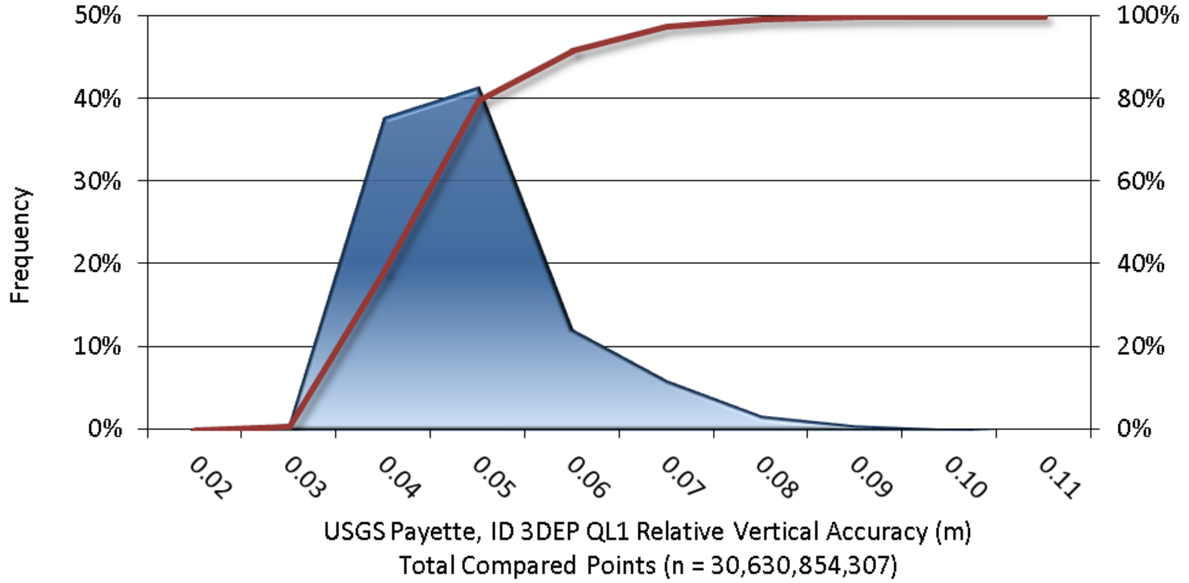

Figure 7: Frequency plot for relative vertical accuracy between flight lines