1 September 2017

Amanda Lowe
USGS NGTOC
1400 Independence Rd. MS547
Rolla, MO 65401

Dear Amanda,

This letter accompanies the Northern portion of the Western Washington 3DEP LiDAR project, and provides a list of all deliverable items, presents initial processing methods, and summarizes non-vegetated and vegetated vertical accuracies.

Quantum Spatial conducted LiDAR acquisition over the Northern portion of the Western Washington project between March 17th, 2016 and May 28th, 2017. This data is projected in Washington State Plane South, the horizontal datum is NAD83 (CORS96, labeled HARN), and the vertical datum is NAVD88, Geoid 03. Horizontal and vertical units are in US Survey Feet.

Processing of the Southern portion of the Western Washington 3DEP LiDAR project is scheduled to be completed in September 2017; upon completion, a full comprehensive project report which details all acquisition procedures, processing methods, and accuracy assessments 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.

Best,

Tucker Selko, Project Manager
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Project Summary

In March 2016, Quantum Spatial (QSI) was contracted by the United States Geological Survey (USGS) in collaboration with the Washington Department of Natural Resources (WADNR), to collect Light Detection and Ranging (LiDAR) data for the Western Washington 3DEP QL1 LiDAR Project area (Contract No. G16PC00016, Task Order No. G16PD00383). The Western Washington 3DEP LiDAR project area covers approximately 3.5 million acres within portions of thirteen counties in the state of Washington; Whatcom, Skagit, Snohomish, Thurston, Lewis, Clark, Cowlitz, Wahkiakum, Skamania, and Grays Harbor. Data were collected to aid USGS and WADNR in assessing the topographic and geophysical properties of the study area.

Table 1: Products Delivered to USGS

Western Washington North Products	
Points	LAS v 1.4 • All Classified Returns • Raw Unclassified Flightline Swaths
Vectors	Index Shapefiles (*.shp) • Site Boundary • LAS Tile Index (1/100th USGS Quadrangles) • DEM Tile Index (1/4 USGS Quadrangles) • Breaklines • Flightline Trajectories • Snow Classification Polygon Ground Survey Shapefiles (*.shp) • Non-Vegetated Ground Check Points • Vegetated Ground Check Points • Ground Control Points • Ground Control Monuments & CORS Stations
Rasters	3 Foot ESRI Grids • Hydroflattened Bare Earth Digital Elevation Model (DEM) • Highest Hit Digital Surface Model (DSM) 1.5 Foot GeoTiffs • Intensity Images

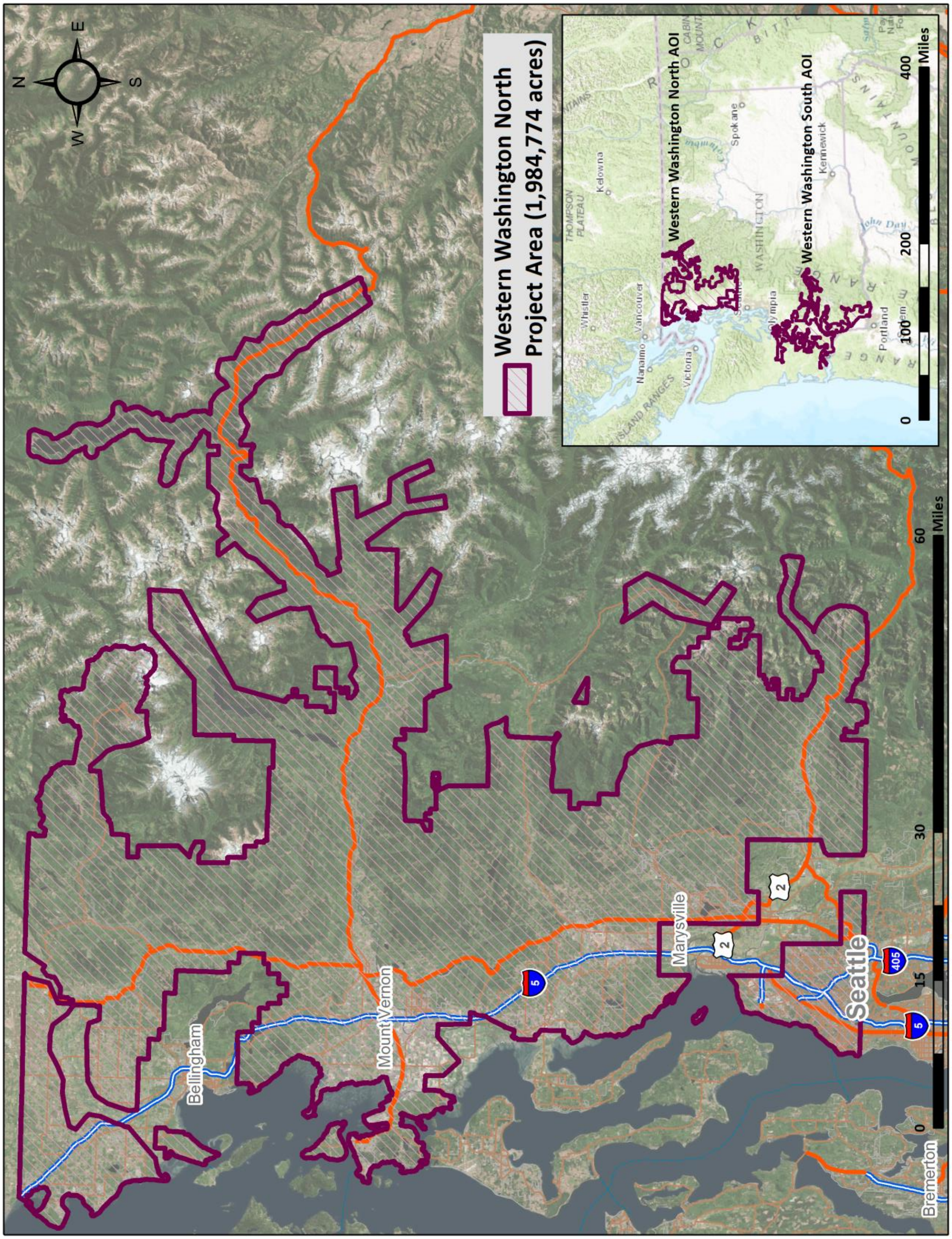

Figure 1: Location map of the Western Washington North project area

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 Western Washington 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
2	Ground	Laser returns that are determined to be ground using automated and manual cleaning algorithms
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
21	Temporal Snow	Areas which were observed to have possible snow coverage, identified during LiDAR acquisition

Temporal Snow Classification

While collecting the Western Washington North LiDAR dataset, QSI acquisition teams made note of areas within the project site that appeared to have, or may have had, snow on the ground, which would affect the laser's ability to penetrate to the ground surface. These areas were identified by manually drawing temporal snow polygons during acquisition. Later, during LiDAR processing, specific care was taken to edit the initial snow polygons to better identify and reclassify areas that may contain snow, which could cause temporal differences in the ground surface of the LiDAR point cloud. These areas should be considered to be ground classified, with the potential use limitation taken into account for any analysis purposes.

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 & v.8.7 PosPAC MMS v.7.SP3 & v.8.0
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 & v. 1.2.4 SDCImport v.2.0.1 RiProcess v.1.8.1 RiWorld v.5.0.2
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 2.2.7 (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 at a 3.0 foot pixel resolution.	TerraScan v.17 TerraModeler v.17 ArcMap v. 10.2.2
Correct intensity values for variability and export intensity images as GeoTIFFs at a 1.5 foot pixel resolution.	Las Monkey 2.2.7 (QSI proprietary) LAS Product Creator 1.5 (QSI proprietary) ArcMap v. 10.3.1

LiDAR Non-vegetated Vertical Accuracy

Absolute vertical 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] (NSSDA). NVA compares known ground quality assurance point data collected on open, bare earth surfaces with level slope (<20°) to the triangulated surface generated by the LiDAR points. 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), as shown in Table 4.

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 Western Washington survey, 182 quality assurance points tested 0.267 feet (0.081 meters) vertical accuracy at 95 percent confidence level as compared to the bare earth DEM (Figure 2). As compared to the unclassified point cloud, 182 quality assurance points tested 0.263 feet (0.080 meters) vertical accuracy at 95 percent confidence level (Figure 3).

QSI also assessed absolute accuracy using 14,675 supplemental ground control points. 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 4 and Figure 4.

Table 4: Absolute accuracy results

Absolute Accuracy			
	Quality Assurance Points (NVA), as compared to Bare Earth DEM	Quality Assurance Points (NVA), as compared to unclassified LAS	Supplemental Ground Control Points
Sample	182 points	182 points	14,675 points
NVA (1.96*RMSE)	0.267 ft 0.081 m	0.263 ft 0.080 m	0.204 ft 0.062 m
Average	-0.011 ft -0.003 m	0.047 ft 0.014 m	-0.029 ft -0.009 m
Median	-0.026 ft -0.008 m	0.036 ft 0.011 m	-0.030 ft -0.009 m
RMSE	0.136 ft 0.042 m	0.134 ft 0.041 m	0.104 ft 0.032 m
Standard Deviation (1σ)	0.136 ft 0.042 m	0.126 ft 0.038 m	0.100 ft 0.030 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.

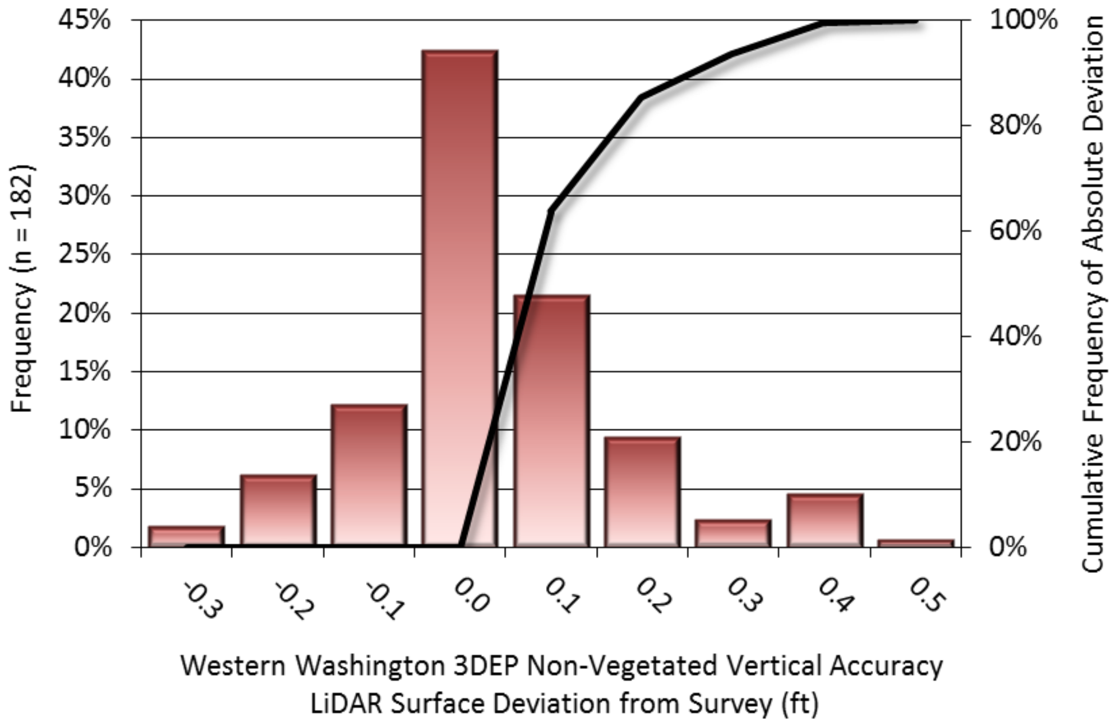

Figure 2: Frequency histogram for LiDAR DEM surface deviation from non-vegetated quality assurance point values

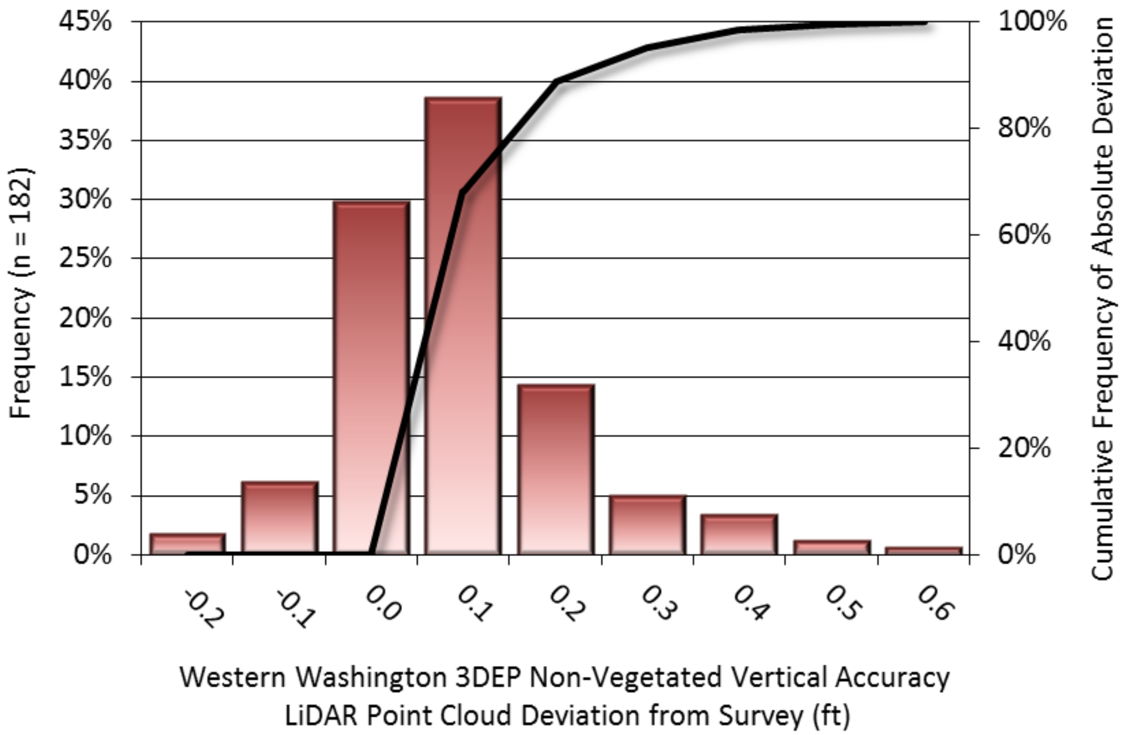

Figure 3: Frequency histogram for LiDAR unclassified point deviation from non-vegetated quality assurance point values

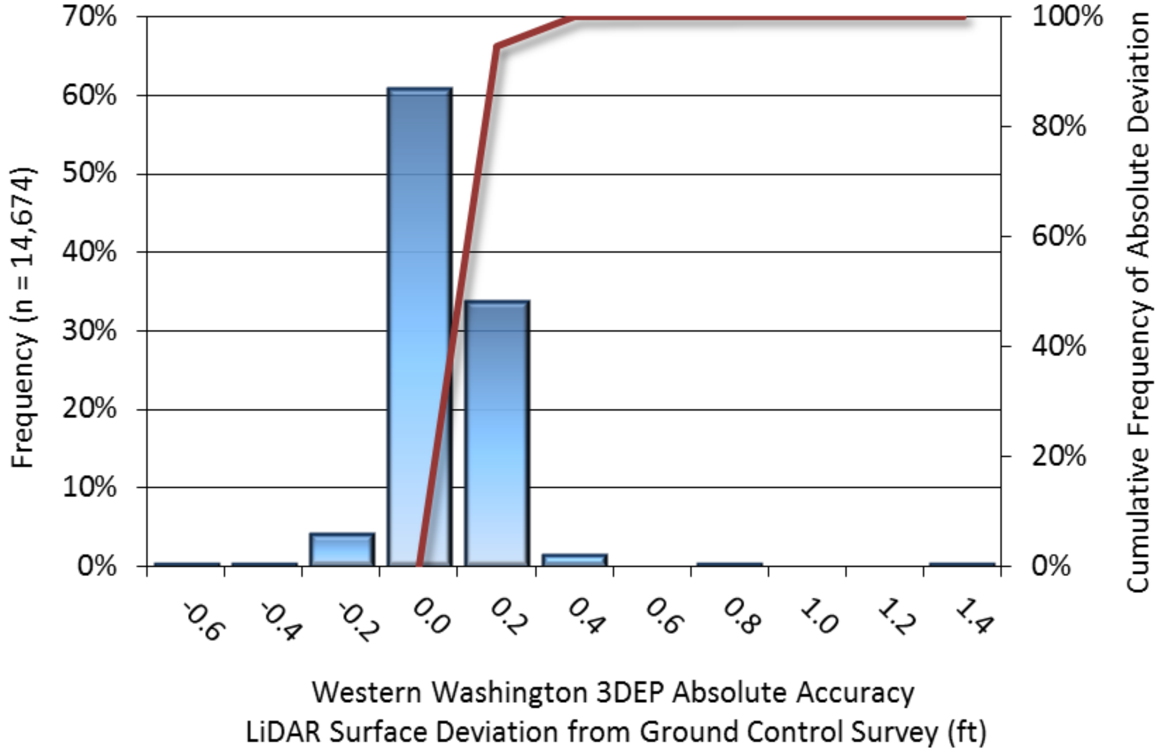

Figure 4: Frequency histogram for LiDAR surface deviation from ground control point values

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 Western Washington survey, 115 vegetated quality assurance points tested 0.680 feet (0.207 meters) vertical accuracy at the 95th percentile (Table 5, Figure 5).

Table 5: Vegetated Vertical Accuracy for the Western Washington Project

Vegetated Vertical Accuracy (VVA)	
Sample	115 points
Average Dz	0.215 ft 0.066 m
Median	0.199 ft 0.061 m
RMSE	0.369 ft 0.112 m
Standard Deviation (1σ)	0.301 ft 0.092 m
95th Percentile	0.680 ft 0.207 m

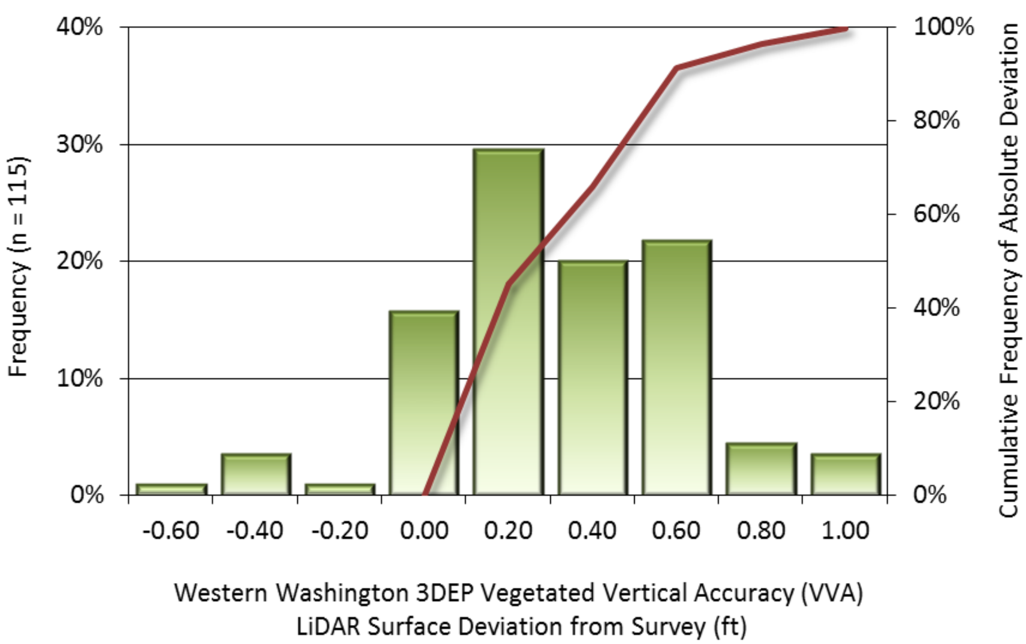

Figure 5: Frequency histogram for LiDAR surface deviation from all land cover class point values (VVA)