March 17, 2016

USGS Mt. Baker LiDAR

Technical Data Report: Contract No. G10PC00026, Task Order No. G15PD00888

Randy MacCash
US Geological Survey, NGTOC
1400 Independence Road, MS 547
Rolla, MO 65401

QSI Corvallis
517 SW 2nd St., Suite 400
Corvallis, OR 97333
PH: 541-752-1204

Table of Contents

Cover Photo: A view looking east at the snowy and glaciated peak of Mt. Baker. The photograph was captured by QSI employee Amanda Reinholtz.

INTRODUCTION

This photo courtesy of QSI's airborne operator, Tyler Cousins, shows a view of Mount Baker and the nose of the Cessna Caravan 208B in flight.

In August 2015, Quantum Spatial (QSI) was contracted by the United States Geological Survey (USGS) to collect Quality Level 1 (8ppsm) Light Detection and Ranging (LiDAR) data in the fall of 2015 for the Mt. Baker site in Whatcom County, Washington. Mount Baker is the third highest peak in the state of Washington and is the second most thermally active mountain in the Cascade Range, surpassed only by Mt. Saint Helens. Data were collected to aid USGS in assessing the topographic and geophysical properties of the study area to support increased seismic monitoring and volcanic hazard assessment to neighboring communities and infrastructure.

This report accompanies the delivered LiDAR data and documents contract specifications, data acquisition procedures, processing methods, and analysis of the final dataset including LiDAR accuracy and density. Acquisition dates and acreage are shown in Table 1, a complete list of contracted deliverables provided to USGS is shown in Table 2, and the project extent is shown in Figure 1.

Table 1: Acquisition dates, acreage, and data types collected on the Mt. Baker site

Project Site	Contracted Acres	Buffered Acres	Acquisition Dates	Data Type
Mt. Baker	129,101	132,500	08/26/2015 – 09/27/2015	LiDAR

Deliverable Products

Table 2: Products delivered to USGS for the Mt. Baker site

Mt. Baker Products **Projection: UTM Zone 10 North** **Horizontal Datum: NAD83 (CORS96)*** **Vertical Datum: NAVD88 (GEOID03)** **Units: Meters**	
Points	LAS v 1.4 • All Returns • Raw Flightline Swaths
Rasters	1.0 Meter ERDAS Imagine Files (*.img) and GeoTIFFs • Hydroflattened Bare Earth Model • Normalized Intensity Images
Vectors	Shapefiles (*.shp) • Site Boundary • LiDAR Tile Index • DEM Tile Index • Water's Edge Breaklines • SBETS

**Data were created in NAD83 (CORS96), but for GIS purposes are defined as NAD83 (HARN) as per USGS specifications.*

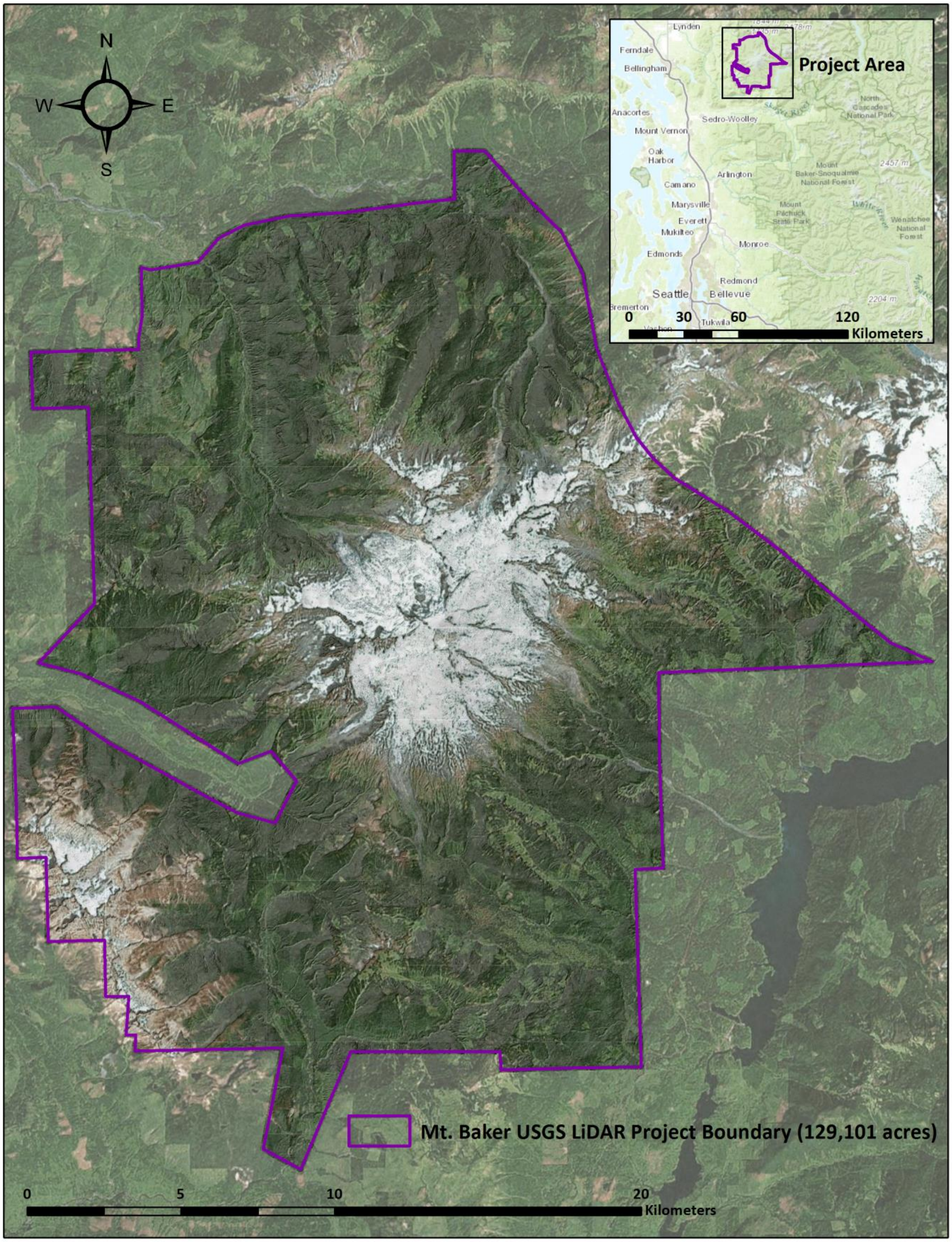


Figure 1: Location map of the Mt. Baker site in Washington

QSI's Cessna Caravan

Planning

In preparation for data collection, QSI reviewed the project area and developed a specialized flight plan to ensure complete coverage of the QL1 Mt. Baker LiDAR study area at the target point density of ≥8.0 points/m^2. Acquisition parameters including orientation relative to terrain, flight altitude, pulse rate, scan angle, and ground speed were adapted to optimize flight paths and flight times while meeting all contract specifications.

Factors such as satellite constellation availability and weather windows must be considered during the planning stage. Any weather hazards or conditions affecting the flights were continuously monitored due to their potential impact on the daily success of airborne and ground operations. In addition, logistical considerations including private property access and potential air space restrictions were reviewed.

Airborne Survey

LiDAR

The LiDAR survey was accomplished using a Leica ALS80 system mounted in a Cessna Caravan 208B. Table 3 summarizes the settings used to yield an average pulse density of ≥8 pulses/m^2 over the Mt. Baker 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 3: LiDAR specifications and survey settings

LiDAR Survey Settings & Specifications	
Acquisition Dates	08/26/15 – 08/27/15, 09/05/15, 09/09/15 – 09/13/15, 09/16/15, 09/22/15 – 09/24/15, 09/27/15
Aircraft Used	Cessna Caravan
Sensor	Leica ALS80
Survey Altitude (AGL)	1650 m
Target Pulse Rate	165 kHz
Pulse Mode	Single Pulse in Air (SPiA)
Laser Pulse Diameter	36 cm
Mirror Scan Rate	53.3 Hz
Field of View	22°
GPS Baselines	≤13 nm
GPS PDOP	≤3.0
GPS Satellite Constellation	≥6
Maximum Returns	Unlimited
Intensity	8-bit, scaled to 16-bit
Resolution/Density	Average 8 pulses/m^2
Accuracy	$RMSE_Z \leq 10$ cm

Leica ALS80 LiDAR sensor

All areas were surveyed with an opposing flight line side-lap of ≥50% (≥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.

Ground Control

QSI-Established Monument MT Baker 01

Ground control surveys, including monumentation and ground survey points (GSPs) were conducted to support the airborne acquisition. Ground control data were used to geospatially correct the aircraft positional coordinate data and to perform quality assurance checks on final LiDAR data.

Monumentation

The spatial configuration of ground survey monuments provided redundant control within 13 nautical miles of the mission areas for LiDAR flights. Monuments were also used for collection of ground survey points using real time kinematic (RTK), post processed kinematic (PPK), and fast-static (FS) survey techniques.

Monument locations were selected with consideration for satellite visibility, field crew safety, and optimal location for GSP coverage. QSI utilized four existing monuments and established six new monuments for the Mt. Baker LiDAR project (Table 4, Figure 2). New monumentation was set using 5/8” x 30” rebar topped with stamped 2 1/2" aluminum caps. QSI’s professional land surveyor, Christopher Glantz (WA PLS #48755) oversaw and certified the establishment of all monuments.

Table 4: Monuments utilized for the Mt. Baker acquisition. Coordinates are on the NAD83 (HARN) datum

Monument ID	Latitude	Longitude	Ellipsoid (meters)
MTBAKER_01	48° 51' 30.84683"	-121° 56' 38.00674"	1161.642
MTBAKER_02	48° 51' 47.11263"	-121° 56' 08.65222"	971.917
MTBAKER_03	48° 49' 07.80690"	-121° 55' 25.18792"	1251.565
MTBAKER_04	48° 48' 13.32476"	-121° 54' 07.90954"	1198.401
MTBAKER_05	48° 45' 21.49225"	-121° 41' 03.69988"	696.235
MTBAKER_06	48° 40' 50.09068"	-121° 46' 37.31589"	638.398
MTBAKER_07	48° 41' 03.96369"	-121° 48' 21.28088"	828.527
MTBAKER_08	48° 52' 02.82425"	-121° 45' 59.71083"	739.855
NF_NOOK_02_RESET	48° 54' 34.23945"	-121° 47' 54.74507"	554.099
DKBT	48° 39' 59.53345"	-121° 46' 35.56633"	1055.292

To correct the continuously recorded onboard measurements of the aircraft position, QSI concurrently conducted multiple static Global Navigation Satellite System (GNSS) ground surveys (1 Hz recording frequency) over each monument. During post-processing, the static GPS data were triangulated with nearby Continuously Operating Reference Stations (CORS) using the Online Positioning User Service

(OPUS[1]) for precise positioning. Multiple independent sessions over the same monument were processed to confirm antenna height measurements and to refine position accuracy.

Monuments were established according to the national standard for geodetic control networks, as specified in the Federal Geographic Data Committee (FGDC) Geospatial Positioning Accuracy Standards for geodetic networks.[2] This standard provides guidelines for classification of monument quality at the 95% confidence interval as a basis for comparing the quality of one control network to another. The monument rating for this project is shown in Table 5.

Table 5: Federal Geographic Data Committee monument rating for network accuracy

Direction	Rating
1.96 * St Dev $_{NE}$:	0.020 m
1.96 * St Dev $_{z}$:	0.050 m

For the Mt. Baker LiDAR project, the monument coordinates contributed no more than 5.4 cm of positional error to the geolocation of the final ground survey points and LiDAR, with 95% confidence.

Ground Survey Points (GSPs)

Ground survey points were collected using real time kinematic, post-processed kinematic (PPK), and fast-static (FS) survey techniques. A Trimble R7 and Trimble R10 base unit was positioned at a nearby monument to broadcast a kinematic correction to a roving Trimble R8 and Trimble R10 GNSS receiver. All GSP measurements were made during periods with a Position Dilution of Precision (PDOP) of ≤ 3.0 with at least six satellites in view of the stationary and roving receivers. When collecting RTK and PPK data, the rover records data while stationary for five seconds, then calculates the pseudorange position using at least three one-second epochs. FS surveys record observations for up to fifteen minutes on each GSP in order to support longer baselines for post-processing. Relative errors for any GSP position must be less than 1.5 cm horizontal and 2.0 cm vertical in order to be accepted. See Table 6 for Trimble unit specifications.

GSPs were collected in areas where good satellite visibility was achieved on paved roads and other hard surfaces such as gravel or packed dirt roads. GSP measurements were not taken on highly reflective surfaces such as center line stripes or lane markings on roads due to the increased noise seen in the laser returns over these surfaces. GSPs were collected within as many flightlines as possible; however the distribution of GSPs depended on ground access constraints and monument locations and may not be equitably distributed throughout the study area (Figure 2).

[1] OPUS is a free service provided by the National Geodetic Survey to process corrected monument positions. http://www.ngs.noaa.gov/OPUS.

[2] Federal Geographic Data Committee, Geospatial Positioning Accuracy Standards (FGDC-STD-007.2-1998). Part 2: Standards for Geodetic Networks, Table 2.1, page 2-3. http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part2/chapter2

Table 6: Trimble equipment identification

Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R7 GNSS	Zephyr GNSS Geodetic Model 2 RoHS	TRM57971.00	Static
Trimble R8	Integrated Antenna R8 Model 2	TRM_R8_GNSS	Rover
Trimble R10	Integrated Antenna R10	TRMR10	Static, Rover

Land Cover Class

In addition to ground survey points, land cover class check points were collected throughout the study area. Accuracies were calculated for non-vegetated and vegetated land cover types to assess confidence in the LiDAR derived ground models across land cover check points. Land cover types and descriptions are shown in Table 7.

Table 7: Land Cover Types and Descriptions

Land cover type	Land cover code	Example	Accuracy Type
Bare Earth	BARE		NVA
Urban	URBAN		NVA
Tall Weeds	TALL_WEEDS		VVA
Forested	LCFOR		VVA

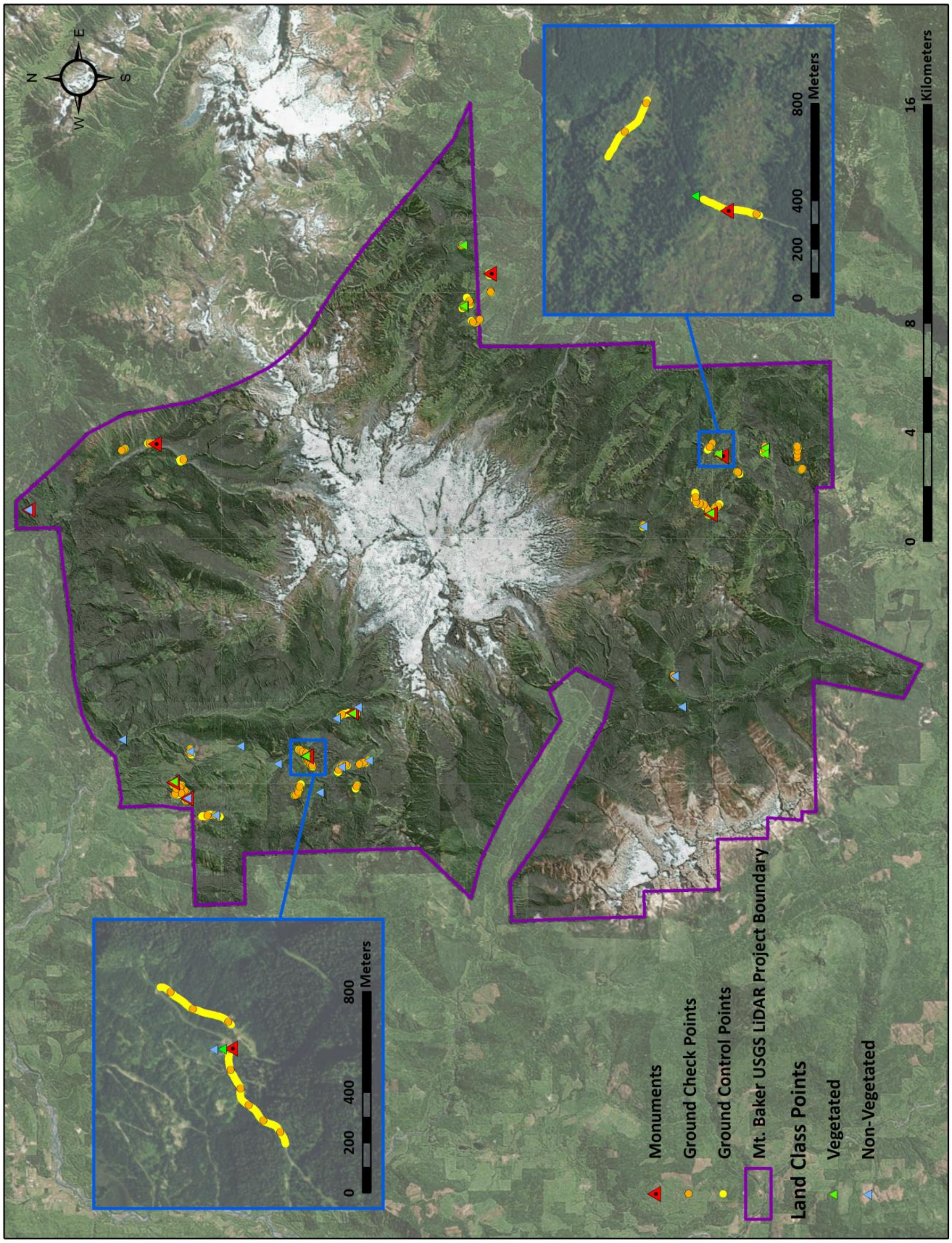
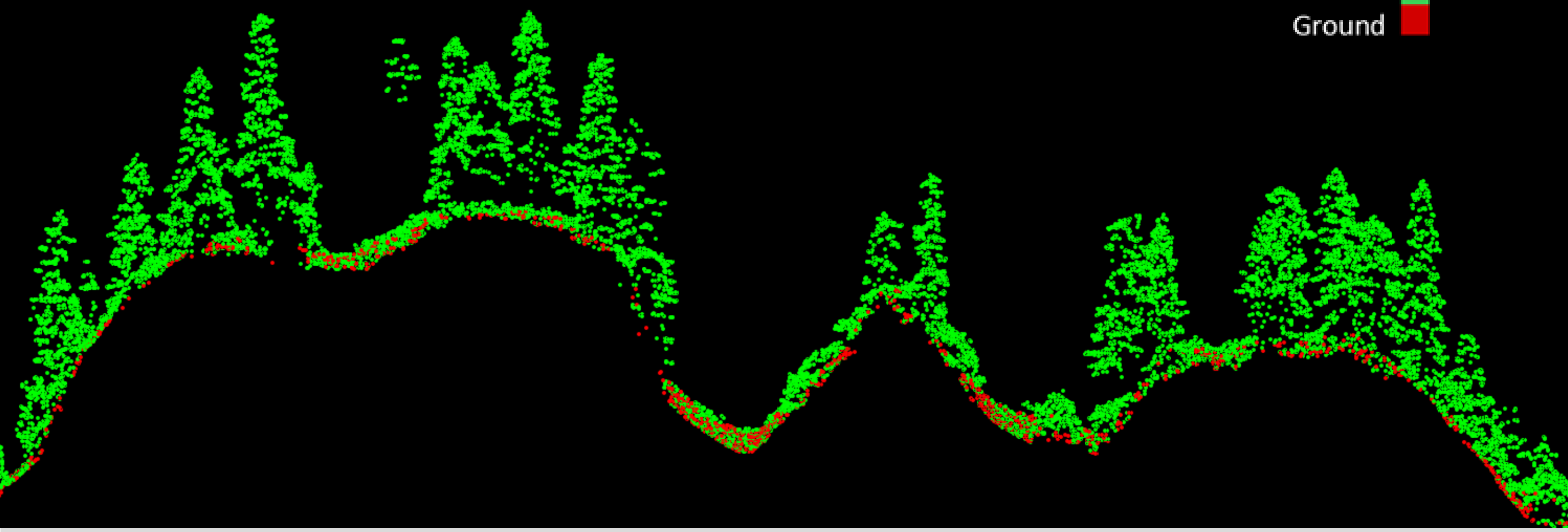


Figure 2: Ground survey location map



This 2 foot cross section shows a view of the Mt. Baker terrain colored by point classification.

LiDAR Data

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 8). Processing methodologies were tailored for the landscape. Brief descriptions of these tasks are shown in Table 9.

Table 8: ASPRS LAS classification standards applied to the Mt. Baker dataset

Classification Number	Classification Name	Classification Description
1	Default/Unclassified	Laser returns that are not included in the ground class, composed of vegetation and man-made structures
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

Classification Number	Classification Name	Classification Description
10	Ignored Ground	Ground points proximate to water's edge breaklines; ignored for correct model creation
17	Bridge Decks	Laser Returns that are determined to be bridges using manual classification.
18	High Noise	Laser Returns that are often associated with birds and scattering from reflective surfaces.
64	Temporal Difference	Laser returns that were determined to be snow, classified to a temporal difference class using manual classification.

Table 9: 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. 1.2) format. Convert data to orthometric elevations by applying a geoid 03 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.15
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.15
Classify resulting data to ground and other client designated ASPRS classifications (Table 8). Assess statistical absolute accuracy via direct comparisons of ground classified points to ground control survey data.	TerraScan v.15 TerraModeler v.15
Generate bare earth models as triangulated surfaces. Generate highest hit models as a surface expression of all classified points. Export all surface models in EDRAS Imagine (.img) format at a 1 meter pixel resolution.	TerraScan v.15 TerraModeler v.15 ArcMap v. 10.1
Correct intensity values for variability and export intensity images as GeoTIFFs at a 1 meter pixel resolution.	Las Monkey (QSI proprietary) v.2.1.1 DZOrtho Creator ArcMap v. 10.1

Feature Extraction

Hydro-flattening and Water's edge breaklines

Flattened bodies of water include lakes and other closed water bodies covering areas greater than 2 acres. The hydro-flattening process eliminates artifacts in the digital terrain model caused by both increased variability in ranges or dropouts in laser returns due to the low reflectivity of water.

Hydro-flattening of closed water bodies was performed through manual detection. Boundary polygons were manually digitized to define the water's edge. Once polygons were developed, the initial ground classified points falling within water polygons were reclassified as water points to omit them from the final ground model. Elevations were then obtained from the filtered LiDAR returns to create the final breaklines. All water bodies were assigned a consistent elevation for the entire polygon.

Water boundary breaklines were then incorporated into the hydro-flattened DEM by enforcing triangle edges (adjacent to the breakline) to the elevation values of the breakline. This implementation corrected interpolation along the hard edge. Water surfaces were obtained from a TIN of the 3-D water edge breaklines resulting in the final hydroflattened model (Figure 3).

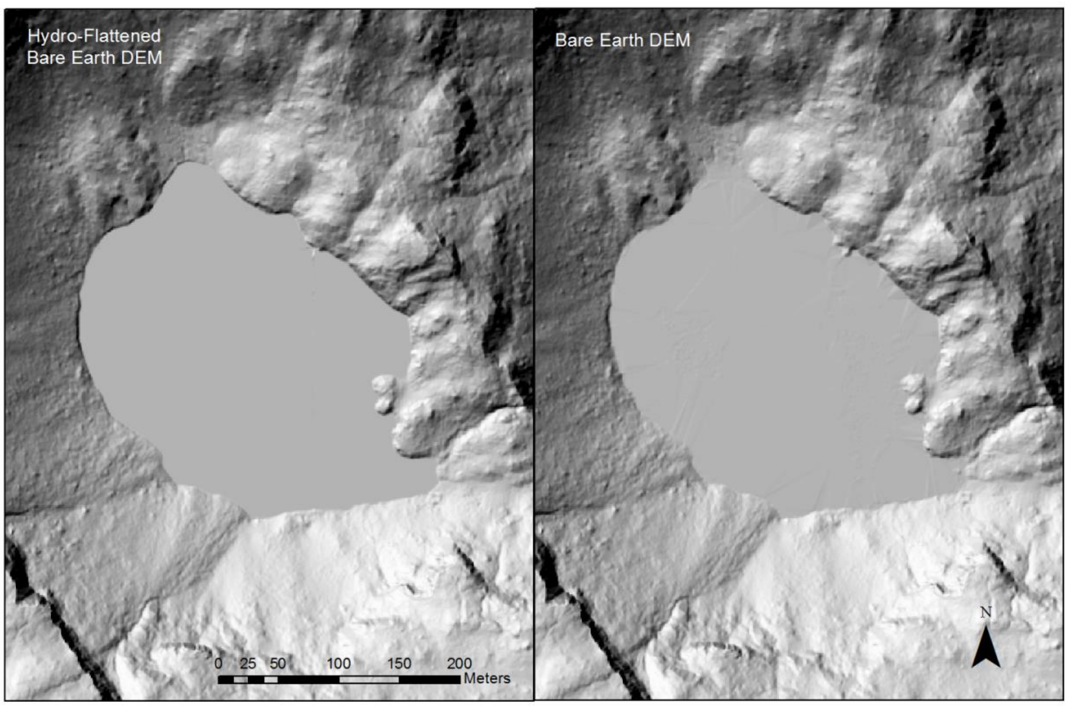
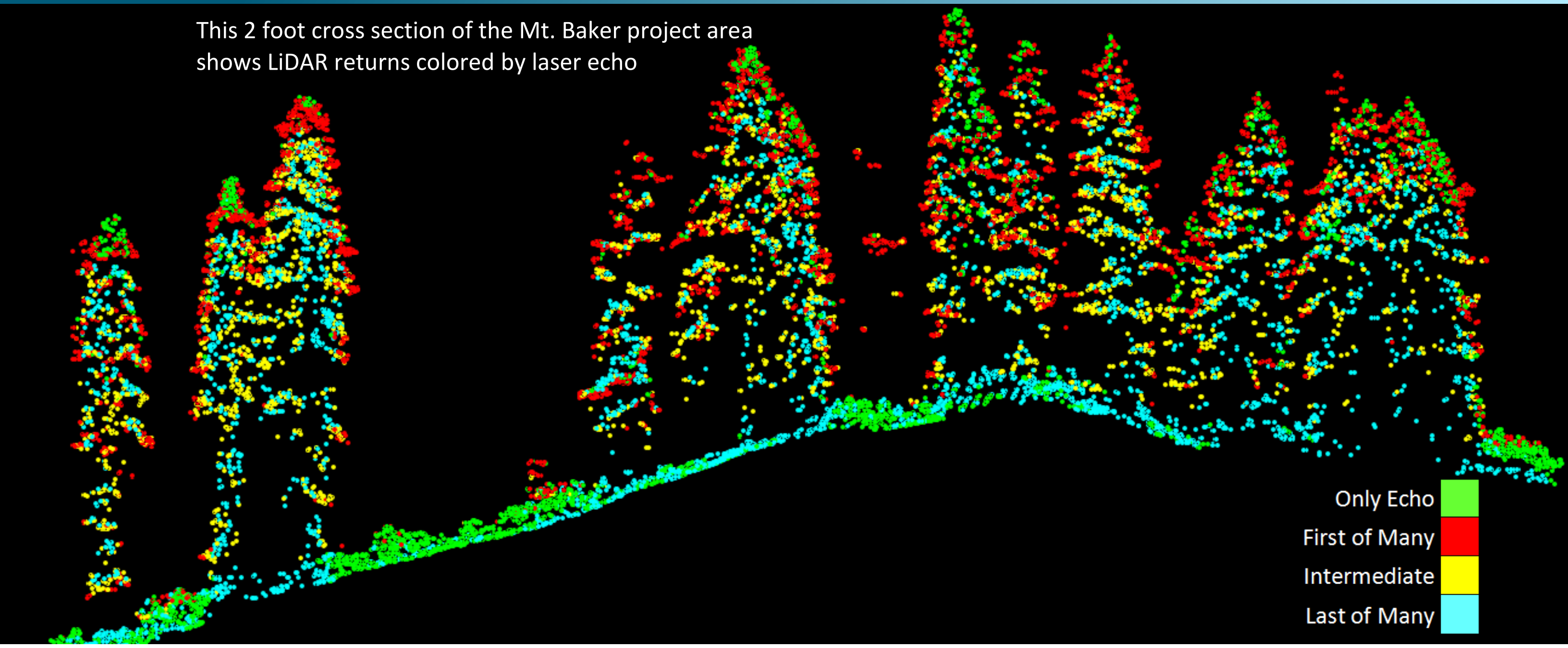


Figure 3: Example of hydro-flattening in the Mt. Baker LiDAR dataset



LiDAR 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 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 Mt. Baker project was 19.73 points/m^2 while the average ground classified density was 2.34 points/m^2 (Table 10). 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 4 through Figure 13.

Table 10: Average LiDAR point densities

Classification	Point Density
First-Return	19.73 points/m^2
Ground Classified	2.34 points/m^2

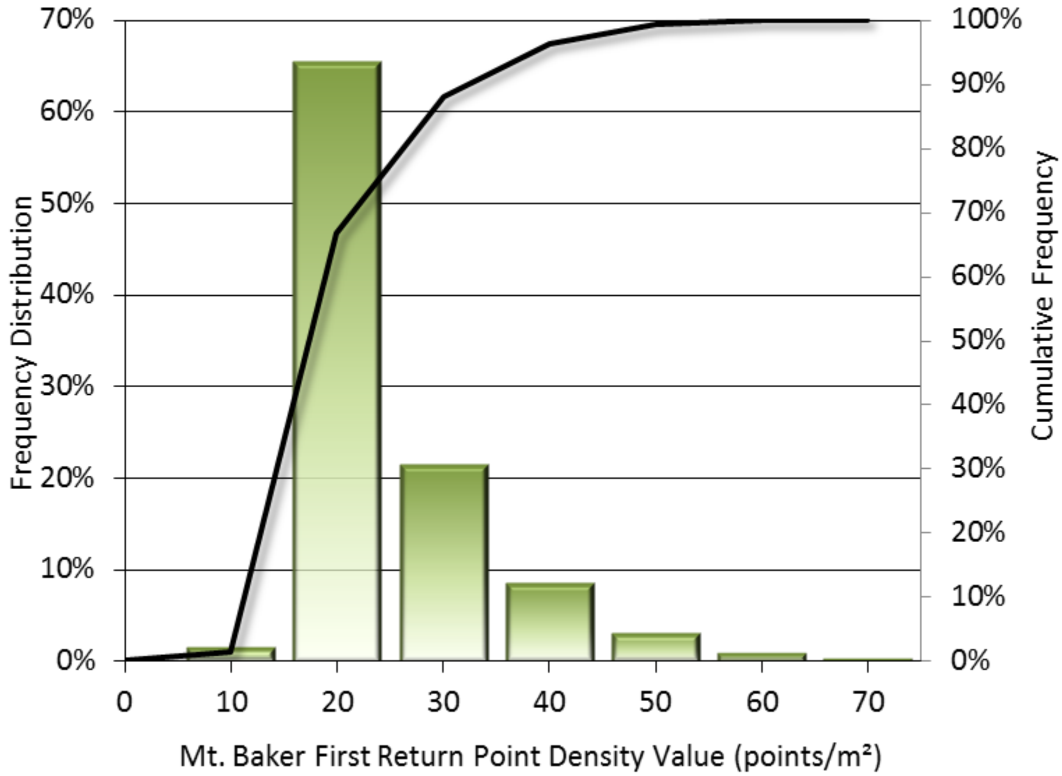


Figure 4: Frequency distribution of first return point density values per 100 x 100 m cell

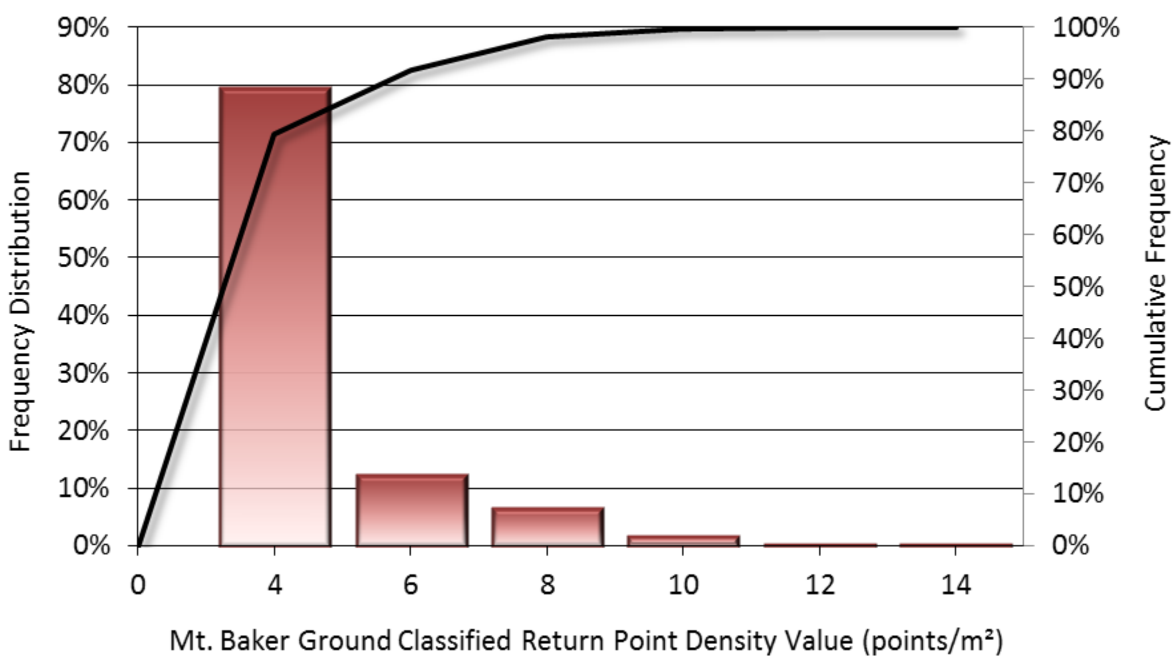


Figure 5: Frequency distribution of ground-classified return point density values per 100 x 100 m cell

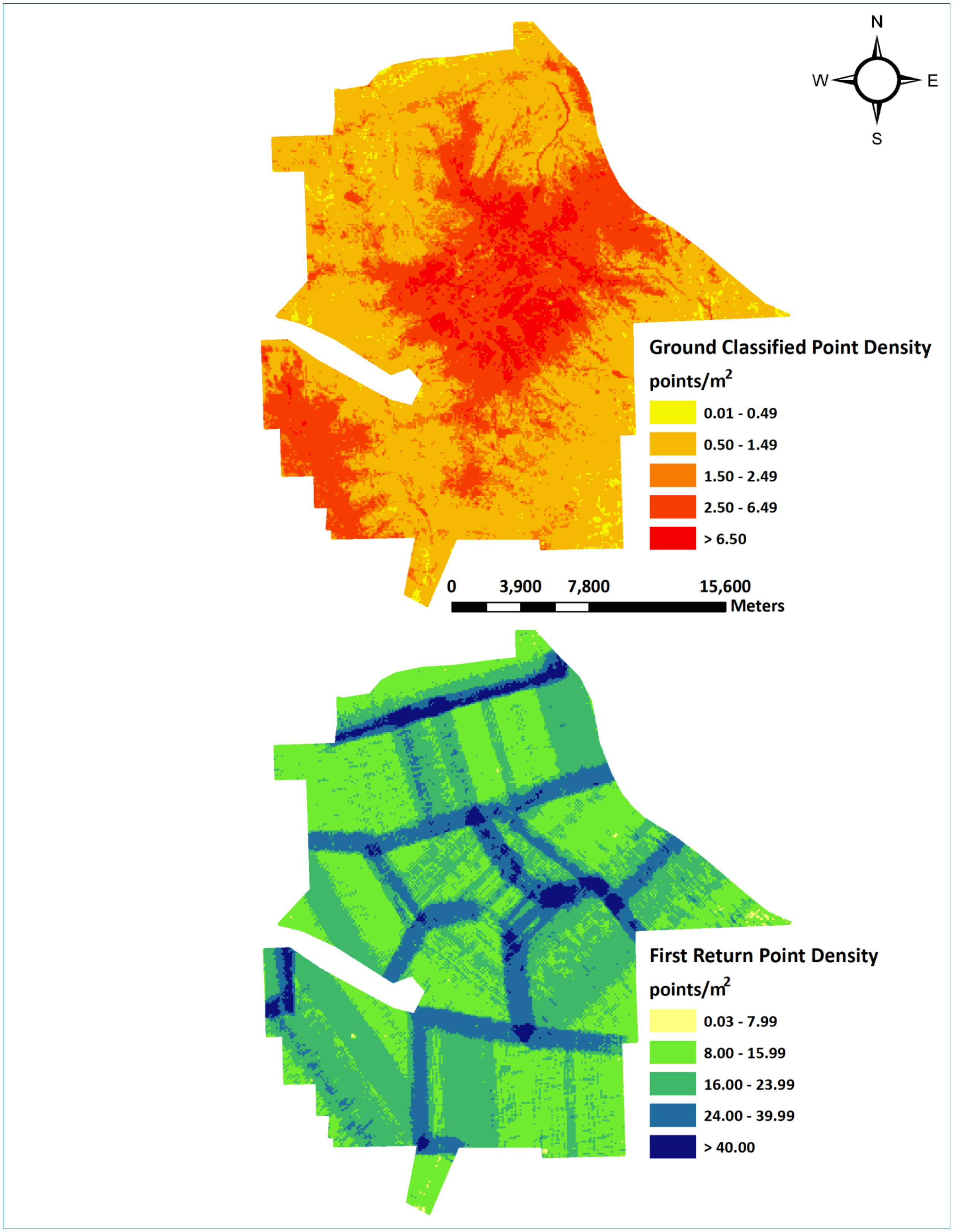


Figure 6: Ground Classified and First Return point density map for the Mt. Baker site (100 m x 100 m cells)

LiDAR Accuracy Assessments

The accuracy of the LiDAR data collection can be described in terms of absolute accuracy (the consistency of the data with external data sources) and relative accuracy (the consistency of the dataset with itself). See Appendix A for further information on sources of error and operational measures used to improve relative accuracy.

LiDAR Non-vegetated Vertical Accuracy

Non-vegetated Vertical Accuracy (NVA) was assessed according to guidelines presented in the USGS LiDAR Base Specifications Version 1.2, November 2014. NVA compares known ground check point data collected on open, bare earth surfaces with level slope (<20°) to the raw LiDAR point cloud and to the digital elevation model (DEM). 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 11. Specifications for this project require that the NVA be 19.6 cm or better AccuracyZ (1.96*RMSE) at a 95 percent confidence level.

The mean and standard deviation (sigma σ) of divergence of the ground surface model from ground check 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 Mt. Baker, 94 ground check points were withheld in total resulting in a non-vegetated vertical accuracy of 0.071 meters computed form the raw LiDAR point cloud and 0.081 meters computed from the DEM (Table 11, Figure 7).

Table 11: Non-vegetated Vertical Accuracy for the Mt. Baker Project

Non-Vegetated Vertical Accuracy		
	Raw LiDAR Point Cloud	**DEM**
Sample	94 points	94 points
NVA (1.96*RMSE)	0.071 m	0.081 m
Average	0.004 m	-0.015 m
Median	0.006 m	-0.014 m
RMSE	0.036 m	0.041 m
Standard Deviation (1σ)	0.036 m	0.039 m

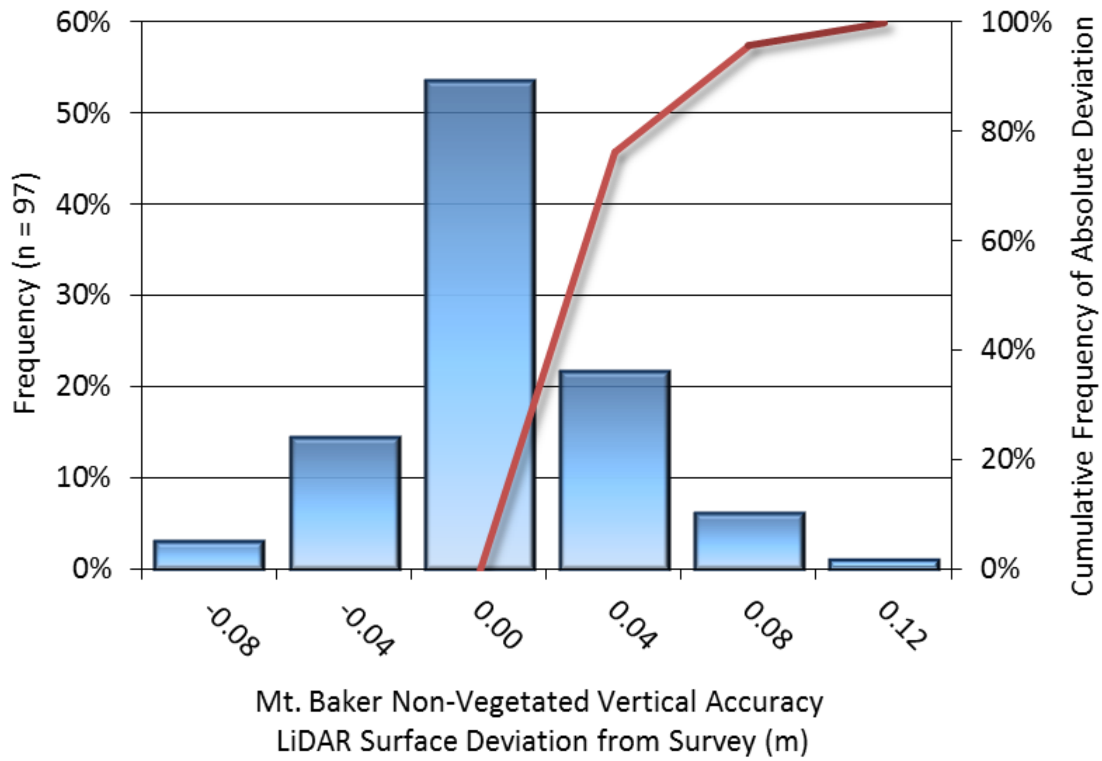


Figure 7: Frequency histogram for LiDAR surface deviation from ground check point values

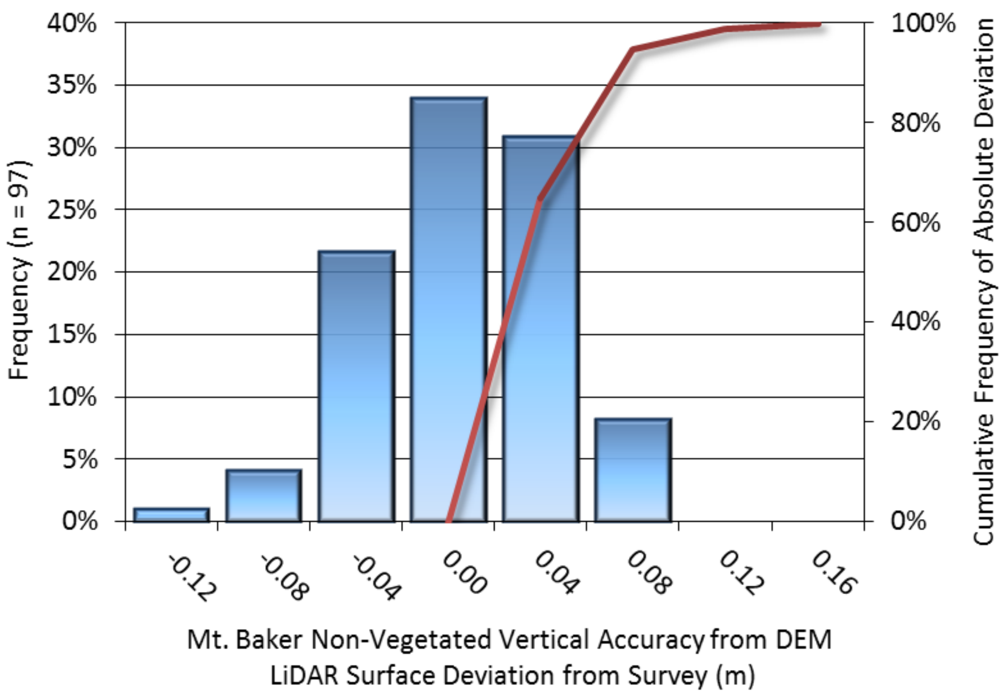


Figure 8: Frequency histogram for LiDAR surface deviation from ground check point values

LiDAR Vegetated Vertical Accuracies

QSI also assessed vertical accuracy using Vegetated Vertical Accuracy (VVA) reporting. VVA compares known ground check point data within all vegetated land cover class categories to the digital elevation model (DEM) created from the ground classified LiDAR points. VVA is evaluated at the 95th percentile, as shown in Table 12.

Table 12: Vegetated Vertical Accuracy for the Mt. Baker Project

Vegetated Vertical Accuracy	
Sample	10 points
95th Percentile	0.123 m
Average Dz	-0.009 m
Median	-0.007 m
RMSE	0.068 m
Standard Deviation (1σ)	0.071 m

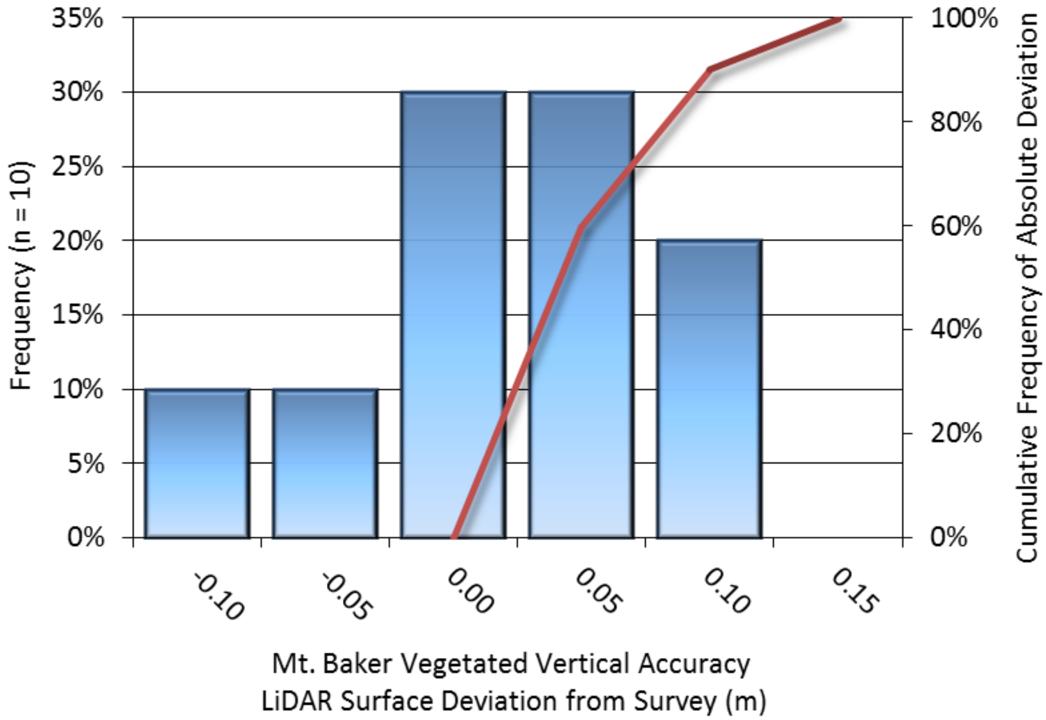


Figure 9: Frequency histogram for LiDAR surface deviation from all vegetated land cover class point values (VVA)

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 Mt. Baker LiDAR project was 0.059 meters (Table 13, Figure 10).

Table 13: Relative accuracy results

Relative Accuracy	
Sample	700 surfaces
Average	0.059 m
Median	0.059 m
RMSE	0.061 m
Standard Deviation (1σ)	0.013 m
1.96σ	0.025 m

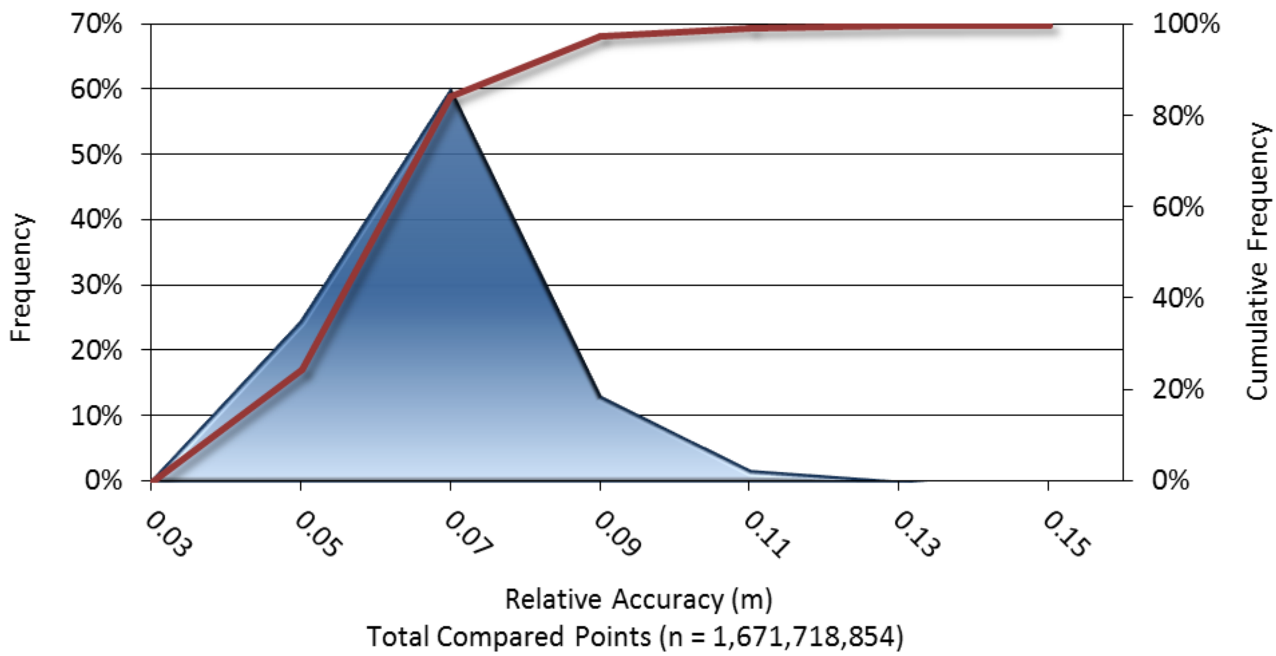


Figure 10: Frequency plot for relative vertical accuracy between flight lines

CERTIFICATIONS

Quantum Spatial provided LiDAR services for the Mt. Baker project as described in this report.

I, Christopher Glantz, PLS, being duly registered as a Professional Land Surveyor in and by the state of Washington, hereby certify that the methodologies, static GNSS occupations used during airborne flights, and ground survey point collection were performed using commonly accepted Standard Practices. Field work conducted for this report was conducted between August 25, 2015 and September 27, 2015.

Accuracy statistics shown in the Accuracy Section of this Report have been reviewed by me and found to meet the "National Standard for Spatial Data Accuracy".

3/11/2016

Christopher Glantz, PLS
Land Survey Manager
Quantum Spatial, Inc.

Figure 11: View looking west over Mt. Baker. The image was created from the LiDAR bare earth model.

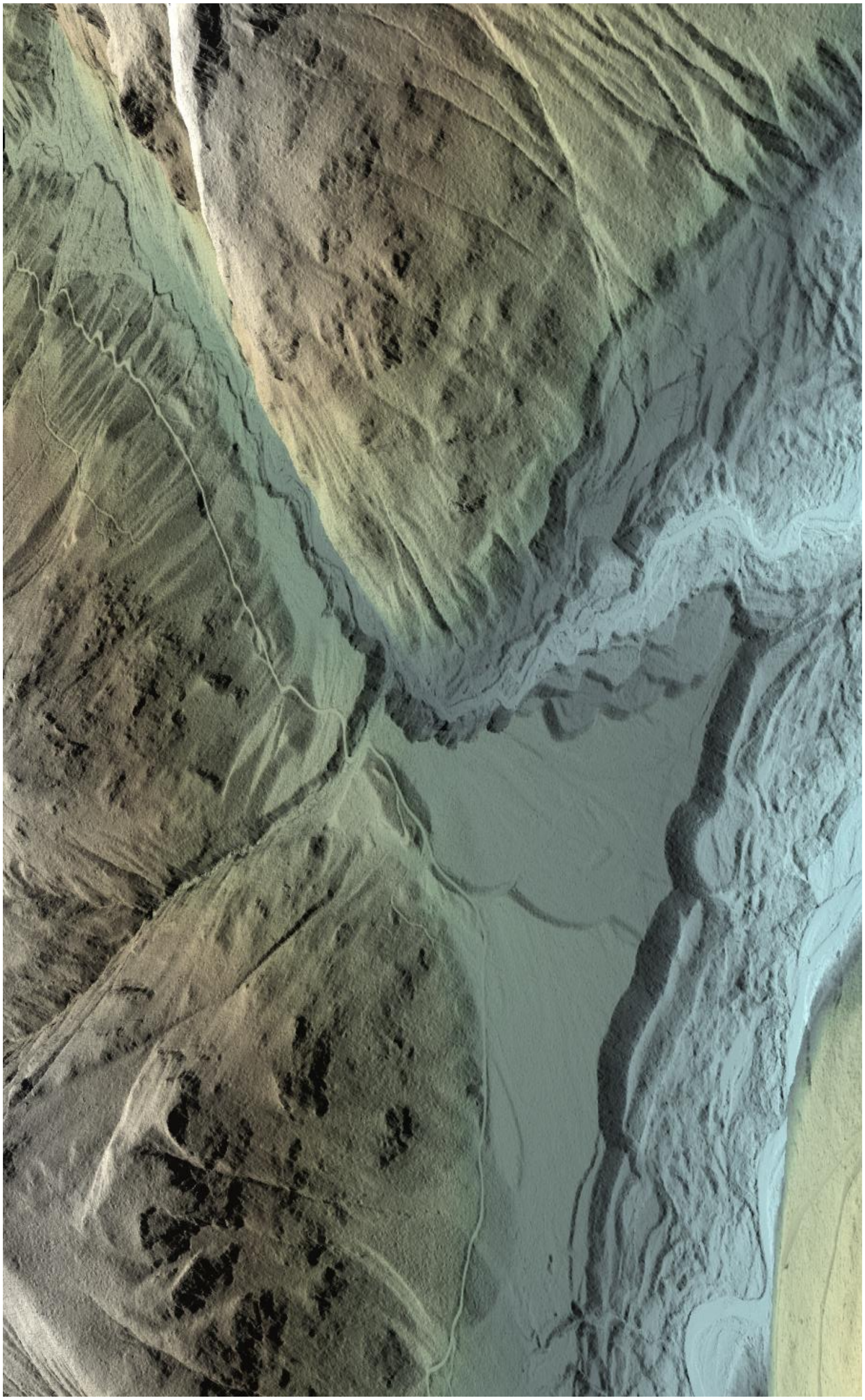


Figure 12: View looking north east up Wanlick Creek. The Pacific Northwest Trail passes through this site of the Mt. Baker area.

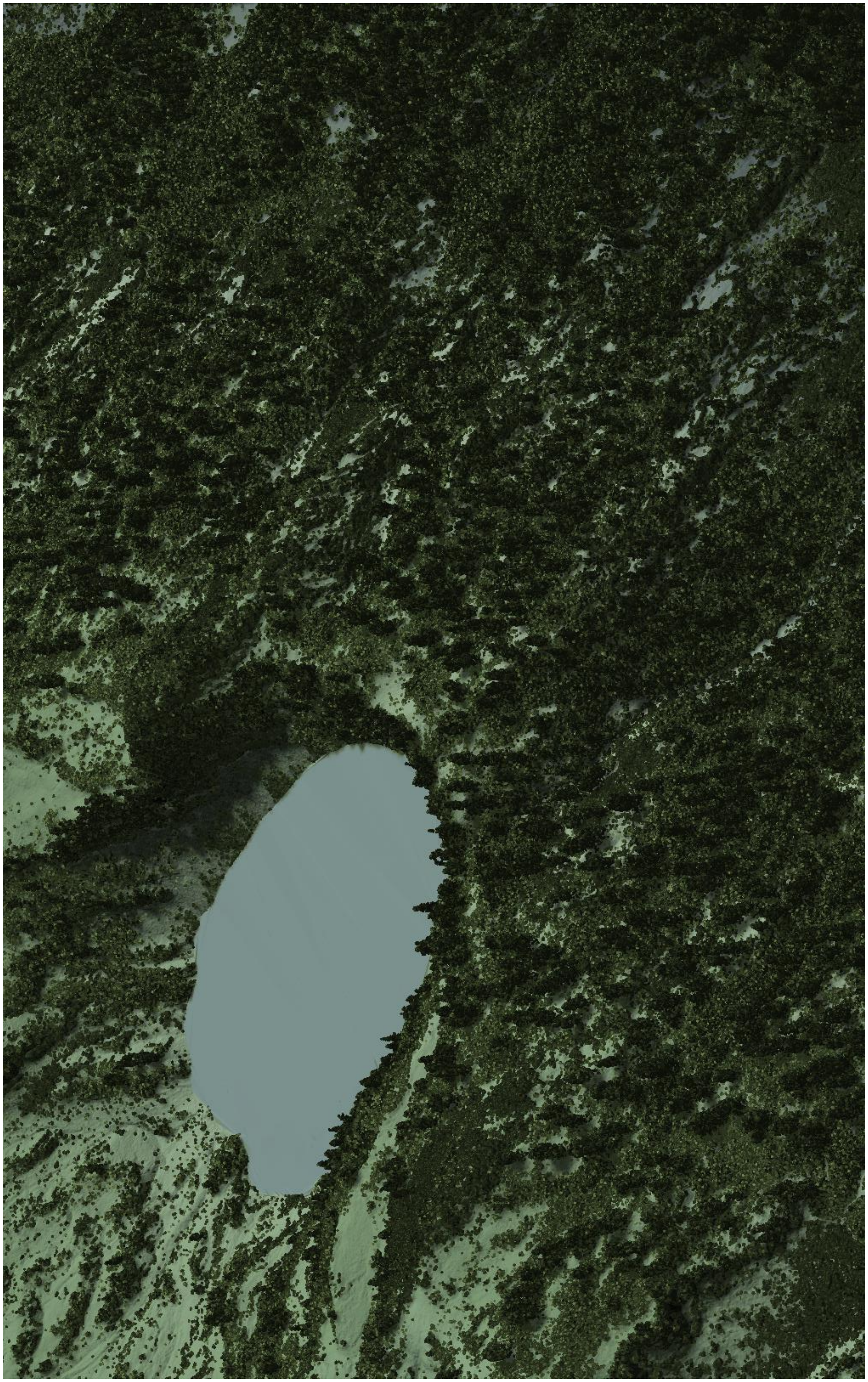


Figure 13: View of Wiseman Lake looking South. This image was created with the bare earth model with the LiDAR point cloud layered on top

1-sigma (σ) Absolute Deviation: Value for which the data are within one standard deviation (approximately 68th percentile) of a normally distributed data set.

1.96 * RMSE Absolute Deviation: Value for which the data are within two standard deviations (approximately 95th percentile) of a normally distributed data set, based on the FGDC standards for Fundamental Vertical Accuracy (FVA) reporting.

Accuracy: The statistical comparison between known (surveyed) points and laser points. Typically measured as the standard deviation (sigma σ) and root mean square error (RMSE).

> **Absolute Accuracy:** The vertical accuracy of LiDAR data is described as the mean and standard deviation (sigma σ) of divergence of LiDAR point coordinates from ground survey point coordinates. To provide a sense of the model predictive power of the dataset, the root mean square error (RMSE) for vertical accuracy is also provided. These statistics assume the error distributions for x, y and z are normally distributed, and thus we also consider the skew and kurtosis of distributions when evaluating error statistics.
>
> **Relative Accuracy:** Relative accuracy refers to the internal consistency of the data set; i.e., the ability to place a laser point in the same location over multiple flight lines, GPS conditions and aircraft attitudes. Affected by system attitude offsets, scale and GPS/IMU drift, internal consistency is measured as the divergence between points from different flight lines within an overlapping area. Divergence is most apparent when flight lines are opposing. When the LiDAR system is well calibrated, the line-to-line divergence is low (<10 cm).
>
> **Root Mean Square Error (RMSE):** A statistic used to approximate the difference between real-world points and the LiDAR points. It is calculated by squaring all the values, then taking the average of the squares and taking the square root of the average.

Data Density: A common measure of LiDAR resolution, measured as points per square meter.

Digital Elevation Model (DEM): File or database made from surveyed points, containing elevation points over a contiguous area. Digital terrain models (DTM) and digital surface models (DSM) are types of DEMs. DTMs consist solely of the bare earth surface (ground points), while DSMs include information about all surfaces, including vegetation and man-made structures.

Intensity Values: The peak power ratio of the laser return to the emitted laser, calculated as a function of surface reflectivity.

Nadir: A single point or locus of points on the surface of the earth directly below a sensor as it progresses along its flight line.

Overlap: The area shared between flight lines, typically measured in percent. 100% overlap is essential to ensure complete coverage and reduce laser shadows.

Pulse Rate (PR): The rate at which laser pulses are emitted from the sensor; typically measured in thousands of pulses per second (kHz).

Pulse Returns: For every laser pulse emitted, the number of wave forms (i.e., echos) reflected back to the sensor. Portions of the wave form that return first are the highest element in multi-tiered surfaces such as vegetation. Portions of the wave form that return last are the lowest element in multi-tiered surfaces.

Real-Time Kinematic (RTK) Survey: A type of surveying conducted with a GPS base station deployed over a known monument with a radio connection to a GPS rover. Both the base station and rover receive differential GPS data and the baseline correction is solved between the two. This type of ground survey is accurate to 1.5 cm or less.

Post-Processed Kinematic (PPK) Survey: GPS surveying is conducted with a GPS rover collecting concurrently with a GPS base station set up over a known monument. Differential corrections and precisions for the GNSS baselines are computed and applied after the fact during processing. This type of ground survey is accurate to 1.5 cm or less.

Scan Angle: The angle from nadir to the edge of the scan, measured in degrees. Laser point accuracy typically decreases as scan angles increase.

Native LiDAR Density: The number of pulses emitted by the LiDAR system, commonly expressed as pulses per square meter.

Relative Accuracy Calibration Methodology:

Manual System Calibration: Calibration procedures for each mission require solving geometric relationships that relate measured swath-to-swath deviations to misalignments of system attitude parameters. Corrected scale, pitch, roll and heading offsets were calculated and applied to resolve misalignments. The raw divergence between lines was computed after the manual calibration was completed and reported for each survey area.

Automated Attitude Calibration: All data were tested and calibrated using TerraMatch automated sampling routines. Ground points were classified for each individual flight line and used for line-to-line testing. System misalignment offsets (pitch, roll and heading) and scale were solved for each individual mission and applied to respective mission datasets. The data from each mission were then blended when imported together to form the entire area of interest.

Automated Z Calibration: Ground points per line were used to calculate the vertical divergence between lines caused by vertical GPS drift. Automated Z calibration was the final step employed for relative accuracy calibration.

LiDAR accuracy error sources and solutions:

Type of Error	Source	Post Processing Solution
GPS (Static/Kinematic)	Long Base Lines	None
	Poor Satellite Constellation	None
	Poor Antenna Visibility	Reduce Visibility Mask
Relative Accuracy	Poor System Calibration	Recalibrate IMU and sensor offsets/settings
	Inaccurate System	None
Laser Noise	Poor Laser Timing	None
	Poor Laser Reception	None
	Poor Laser Power	None
	Irregular Laser Shape	None

Operational measures taken to improve relative accuracy:

Low Flight Altitude: Terrain following was employed to maintain a constant above ground level (AGL). Laser horizontal errors are a function of flight altitude above ground (about 1/3000th AGL flight altitude).

Focus Laser Power at narrow beam footprint: A laser return must be received by the system above a power threshold to accurately record a measurement. The strength of the laser return (i.e., intensity) is a function of laser emission power, laser footprint, flight altitude and the reflectivity of the target. While surface reflectivity cannot be controlled, laser power can be increased and low flight altitudes can be maintained.

Reduced Scan Angle: Edge-of-scan data can become inaccurate. The scan angle was reduced to a maximum of ±11^{o} from nadir, creating a narrow swath width and greatly reducing laser shadows from trees and buildings.

Quality GPS: Flights took place during optimal GPS conditions (e.g., 6 or more satellites and PDOP [Position Dilution of Precision] less than 3.0). Before each flight, the PDOP was determined for the survey day. During all flight times, a dual frequency DGPS base station recording at 1 second epochs was utilized and a maximum baseline length between the aircraft and the control points was less than 13 nm at all times.

Ground Survey: Ground survey point accuracy (<1.5 cm RMSE) occurs during optimal PDOP ranges and targets a minimal baseline distance of 4 miles between GPS rover and base. Robust statistics are, in part, a function of sample size (n) and distribution. Ground survey points are distributed to the extent possible throughout multiple flight lines and across the survey area.

50% Side-Lap (100% Overlap): Overlapping areas are optimized for relative accuracy testing. Laser shadowing is minimized to help increase target acquisition from multiple scan angles. Ideally, with a 50% side-lap, the nadir portion of one flight line coincides with the swath edge portion of overlapping flight lines. A minimum of 50% side-lap with terrain-followed acquisition prevents data gaps.

Opposing Flight Lines: All overlapping flight lines have opposing directions. Pitch, roll and heading errors are amplified by a factor of two relative to the adjacent flight line(s), making misalignments easier to detect and resolve.

Point ID	BE_01
Project No.	26762
Project Name	USGS MT. BAKER
State	WASHINGTON
County	WHATCOM
Quad	BAKER PASS

	Aerial Target
	LiDAR Ground Control
X	LiDAR QC Point
	New Control
	Photo ID
	Published Control

Coordinate System
NAD83(2011)(Epoch 2010.00)
UTM – Zone 10N
NAVD88
GEOID12B
Meters

Northing	Easting	Elevation
5391054.016	590323.219	1068.359

Operator	ROBBIE ROBERTSON
Receiver Model	TRIMBLE R-10 ROVER
Receiver S/N	2936
Antenna Height	2.000 Meters

Date (MM-DD-YYYY)	09-03-2015
RMSE Hz	0.015
RMSE Z	0.019
GPS Method	STATIC/RTK

PHOTOS:

						Coordinate System
Point ID	BE_02			Aerial Target		NAD83(2011)(Epoch 2010.00)
Project No.	26762			LiDAR Ground Control		UTM – Zone 10N
Project Name	USGS MT. BAKER		X	LiDAR QC Point		NAVD88
State	WASHINGTON			New Control		GEOID12B
County	WHATCOM			Photo ID		Meters
Quad	SHUKSAN ARM			Published Control		

Northing	Easting	Elevation
5402111.434	595507.232	1100.420

Operator	ROBBIE ROBERTSON	Date (MM-DD-YYYY)	09-04-2015
Receiver Model	TRIMBLE R-10 ROVER	RMSE Hz	0.013
Receiver S/N	2936	RMSE Z	0.017
Antenna Height	2.000 Meters	GPS Method	STATIC/RTK

PHOTOS:

Point ID	BE_03		Aerial Target		Coordinate System
Project No.	26762		LiDAR Ground Control		NAD83(2011)(Epoch 2010.00)
Project Name	USGS MT. BAKER	X	LiDAR QC Point		UTM – Zone 10N
State	WASHINGTON		New Control		NAVD88
County	WHATCOM		Photo ID		GEOID12B
Quad	SHUKSAN ARM		Published Control		Meters

Northing	Easting	Elevation
5402171.389	597754.993	433.660

Operator	ROBBIE ROBERTSON	Date (MM-DD-YYYY)	09-04-2015
Receiver Model	TRIMBLE R-10 ROVER	RMSE Hz	0.033
Receiver S/N	2936	RMSE Z	0.038
Antenna Height	2.000 Meters	GPS Method	STATIC/RTK

PHOTOS:

Point ID	BE_04		Aerial Target		Coordinate System
Project No.	26762		LiDAR Ground Control		NAD83(2011)(Epoch 2010.00)
Project Name	USGS MT. BAKER	X	LiDAR QC Point		UTM – Zone 10N
State	WASHINGTON		New Control		NAVD88
County	WHATCOM		Photo ID		GEOID12B
Quad	GROAT MOUNTAIN		Published Control		Meters

Northing	Easting	Elevation
5406802.428	580388.713	1270.341

Operator	ROBBIE ROBERTSON	Date (MM-DD-YYYY)	09-05-2015
Receiver Model	TRIMBLE R-10 ROVER	RMSE Hz	0.012
Receiver S/N	2936	RMSE Z	0.017
Antenna Height	2.000 Meters	GPS Method	STATIC/RTK

PHOTOS:

Point ID	BE_05
Project No.	26762
Project Name	USGS MT. BAKER
State	WASHINGTON
County	WHATCOM
Quad	GROAT MOUNTAIN

	Aerial Target
	LiDAR Ground Control
X	LiDAR QC Point
	New Control
	Photo ID
	Published Control

Coordinate System
NAD83(2011)(Epoch 2010.00)
UTM – Zone 10N
NAVD88
GEOID12B
Meters

Northing	Easting	Elevation
5407945.830	579005.083	1281.553

Operator	ROBBIE ROBERTSON
Receiver Model	TRIMBLE R-10 ROVER
Receiver S/N	2936
Antenna Height	2.000 Meters

Date (MM-DD-YYYY)	09-05-2015
RMSE Hz	0.025
RMSE Z	0.032
GPS Method	STATIC/RTK

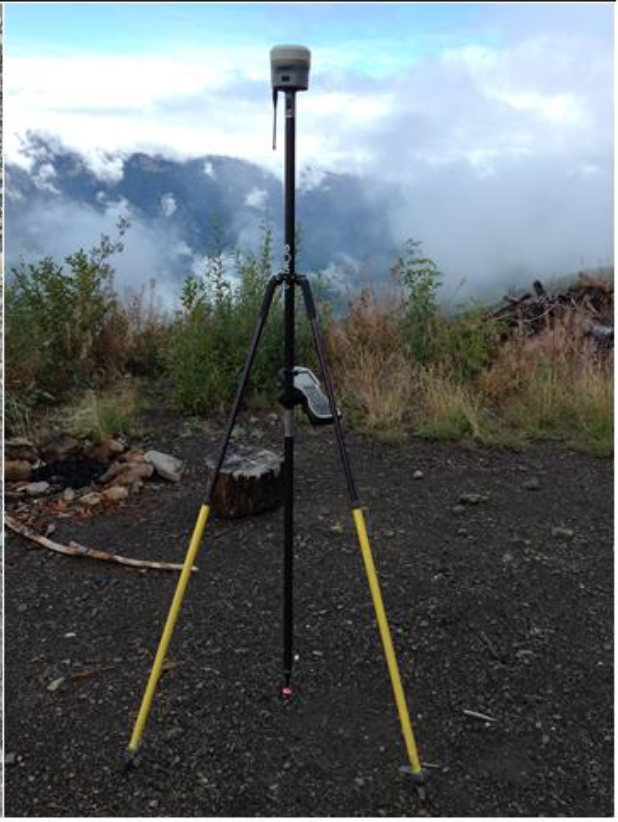
PHOTOS:

Point ID	BE_06		Aerial Target		Coordinate System
Project No.	26762		LiDAR Ground Control		NAD83(2011)(Epoch 2010.00)
Project Name	USGS MT. BAKER	X	LiDAR QC Point		UTM – Zone 10N
State	WASHINGTON		New Control		NAVD88
County	WHATCOM		Photo ID		GEOID12B
Quad	GROAT MOUNTAIN		Published Control		Meters

Northing	Easting	Elevation
5412269.778	577470.950	1180.585

Operator	ROBBIE ROBERTSON	Date (MM-DD-YYYY)	09-05-2015
Receiver Model	TRIMBLE R-10 ROVER	RMSE Hz	0.017
Receiver S/N	2936	RMSE Z	0.016
Antenna Height	2.000 Meters	GPS Method	STATIC/RTK

PHOTOS:



Point ID	BE_07		Aerial Target		Coordinate System
Project No.	26762		LiDAR Ground Control		NAD83(2011)(Epoch 2010.00)
Project Name	USGS MT. BAKER	X	LiDAR QC Point		UTM – Zone 10N
State	WASHINGTON		New Control		NAVD88
County	WHATCOM		Photo ID		GEOID12B
Quad	GROAT MOUNTAIN		Published Control		Meters

Northing	Easting	Elevation
5410309.370	579375.116	1165.549

Operator	ROBBIE ROBERTSON	Date (MM-DD-YYYY)	09-06-2015
Receiver Model	TRIMBLE R-10 ROVER	RMSE Hz	0.015
Receiver S/N	2936	RMSE Z	0.019
Antenna Height	2.000 Meters	GPS Method	STATIC/RTK

PHOTOS:

Point ID	BE_08
Project No.	26762
Project Name	USGS MT. BAKER
State	WASHINGTON
County	WHATCOM
Quad	GROAT MOUNTAIN

	Aerial Target
	LiDAR Ground Control
X	LiDAR QC Point
	New Control
	Photo ID
	Published Control

Coordinate System
NAD83(2011)(Epoch 2010.00)
UTM – Zone 10N
NAVD88
GEOID12B
Meters

Northing	Easting	Elevation
5412162.312	579174.611	881.257

Operator	ROBBIE ROBERTSON
Receiver Model	TRIMBLE R-10 ROVER
Receiver S/N	2936
Antenna Height	2.000 Meters

Date (MM-DD-YYYY)	09-06-2015
RMSE Hz	0.013
RMSE Z	0.015
GPS Method	STATIC/RTK

PHOTOS:

Point ID	BE_09
Project No.	26762
Project Name	USGS MT. BAKER
State	WASHINGTON
County	WHATCOM
Quad	BAKER PASS

	Aerial Target
	LiDAR Ground Control
X	LiDAR QC Point
	New Control
	Photo ID
	Published Control

Coordinate System
NAD83(2011)(Epoch 2010.00)
UTM – Zone 10N
NAVD88
GEOID12B
Meters

Northing	Easting	Elevation
5393067.690	587876.290	847.503

Operator	ROBBIE ROBERTSON
Receiver Model	TRIMBLE R-10 ROVER
Receiver S/N	2936
Antenna Height	2.000 Meters

Date (MM-DD-YYYY)	09-07-2015
RMSE Hz	0.018
RMSE Z	0.021
GPS Method	STATIC/RTK

PHOTOS:

Point ID	BE_10
Project No.	26762
Project Name	USGS MT. BAKER
State	WASHINGTON
County	WHATCOM
Quad	TWIN SISTERS MOUNTAIN

	Aerial Target
	LiDAR Ground Control
X	LiDAR QC Point
	New Control
	Photo ID
	Published Control

Coordinate System
NAD83(2011)(Epoch 2010.00)
UTM – Zone 10N
NAVD88
GEOID12B
Meters

Northing	Easting	Elevation
5394387.328	581945.874	776.973

Operator	ROBBIE ROBERTSON
Receiver Model	TRIMBLE R-10 ROVER
Receiver S/N	2936
Antenna Height	2.000 Meters

Date (MM-DD-YYYY)	09-08-2015
RMSE Hz	0.008
RMSE Z	0.014
GPS Method	STATIC/RTK

PHOTOS:

Point ID	BE_11		Aerial Target		Coordinate System
Project No.	26762		LiDAR Ground Control		NAD83(2011)(Epoch 2010.00)
Project Name	USGS MT. BAKER	X	LiDAR QC Point		UTM – Zone 10N
State	WASHINGTON		New Control		NAVD88
County	WHATCOM		Photo ID		GEOID12B
Quad	TWIN SISTERS MOUNTAIN		Published Control		Meters

Northing	Easting	Elevation
5394119.660	580812.431	916.658

Operator	ROBBIE ROBERTSON	Date (MM-DD-YYYY)	09-08-2015
Receiver Model	TRIMBLE R-10 ROVER	RMSE Hz	0.031
Receiver S/N	2936	RMSE Z	0.039
Antenna Height	2.000 Meters	GPS Method	STATIC/RTK

PHOTOS:

Point ID	BE_12			Aerial Target		Coordinate System
Project No.	26762			LiDAR Ground Control		NAD83(2011)(Epoch 2010.00)
Project Name	USGS MT. BAKER		X	LiDAR QC Point		UTM – Zone 10N
State	WASHINGTON			New Control		NAVD88
County	WHATCOM			Photo ID		GEOID12B
Quad	BAKER PASS			Published Control		Meters

Northing	Easting	Elevation
5395531.923	587432.952	1013.589

Operator	ROBBIE ROBERTSON	Date (MM-DD-YYYY)	09-08-2015
Receiver Model	TRIMBLE R-10 ROVER	RMSE Hz	0.026
Receiver S/N	2936	RMSE Z	0.037
Antenna Height	2.000 Meters	GPS Method	STATIC/RTK

PHOTOS:

Point ID	BE_13
Project No.	26762
Project Name	USGS MT. BAKER
State	WASHINGTON
County	WHATCOM
Quad	GROAT MOUNTAIN

	Aerial Target
	LiDAR Ground Control
X	LiDAR QC Point
	New Control
	Photo ID
	Published Control

Coordinate System
NAD83(2011)(Epoch 2010.00)
UTM – Zone 10N
NAVD88
GEOID12B
Meters

Northing	Easting	Elevation
5411236.736	576852.825	1049.602

Operator	ROBBIE ROBERTSON
Receiver Model	TRIMBLE R-10 ROVER
Receiver S/N	2936
Antenna Height	2.000 Meters

Date (MM-DD-YYYY)	09-10-2015
RMSE Hz	0.024
RMSE Z	0.030
GPS Method	STATIC/RTK

PHOTOS:

NO PHOTOS

Point ID	BE_14		Aerial Target		Coordinate System
Project No.	26762		LiDAR Ground Control		NAD83(2011)(Epoch 2010.00)
Project Name	USGS MT. BAKER	X	LiDAR QC Point		UTM – Zone 10N
State	WASHINGTON		New Control		NAVD88
County	WHATCOM		Photo ID		GEOID12B
Quad	GROAT MOUNTAIN		Published Control		Meters

Northing	Easting	Elevation
5407410.645	577680.494	1267.532

Operator	ROBBIE ROBERTSON	Date (MM-DD-YYYY)	09-11-2015
Receiver Model	TRIMBLE R-10 ROVER	RMSE Hz	0.014
Receiver S/N	2936	RMSE Z	0.018
Antenna Height	2.000 Meters	GPS Method	STATIC/RTK

PHOTOS:

Point ID	BE_15			Aerial Target		Coordinate System
Project No.	26762			LiDAR Ground Control		NAD83(2011)(Epoch 2010.00)
Project Name	USGS MT. BAKER		X	LiDAR QC Point		UTM – Zone 10N
State	WASHINGTON			New Control		NAVD88
County	WHATCOM			Photo ID		GEOID12B
Quad	GROAT MOUNTAIN			Published Control		Meters

Northing	Easting	Elevation
5406617.589	578611.948	1288.042

Operator	ROBBIE ROBERTSON	Date (MM-DD-YYYY)	09-11-2015
Receiver Model	TRIMBLE R-10 ROVER	RMSE Hz	0.018
Receiver S/N	2936	RMSE Z	0.021
Antenna Height	2.000 Meters	GPS Method	STATIC/RTK

PHOTOS:

Point ID	BE_16		Aerial Target		Coordinate System
Project No.	26762		LiDAR Ground Control		NAD83(2011)(Epoch 2010.00)
Project Name	USGS MT. BAKER	X	LiDAR QC Point		UTM – Zone 10N
State	WASHINGTON		New Control		NAVD88
County	WHATCOM		Photo ID		GEOID12B
Quad	GROAT MOUNTAIN		Published Control		Meters

Northing	Easting	Elevation
5405605.273	578857.252	1307.809

Operator	ROBBIE ROBERTSON	Date (MM-DD-YYYY)	09-13-2015
Receiver Model	TRIMBLE R-10 ROVER	RMSE Hz	0.017
Receiver S/N	2936	RMSE Z	0.028
Antenna Height	2.000 Meters	GPS Method	STATIC/RTK

PHOTOS:

Point ID	BE_17		Aerial Target		Coordinate System
Project No.	26762		LiDAR Ground Control		NAD83(2011)(Epoch 2010.00)
Project Name	USGS MT. BAKER	X	LiDAR QC Point		UTM – Zone 10N
State	WASHINGTON		New Control		NAVD88
County	WHATCOM		Photo ID		GEOID12B
Quad	GROAT MOUNTAIN		Published Control		Meters

Northing	Easting	Elevation
5405999.810	580803.740	1128.277

Operator	ROBBIE ROBERTSON	Date (MM-DD-YYYY)	09-13-2015
Receiver Model	TRIMBLE R-10 ROVER	RMSE Hz	0.026
Receiver S/N	2936	RMSE Z	0.034
Antenna Height	2.000 Meters	GPS Method	STATIC/RTK

PHOTOS:

NO PHOTOS

Point ID	BE_18
Project No.	26762
Project Name	USGS MT. BAKER
State	WASHINGTON
County	WHATCOM
Quad	GROAT MOUNTAIN

	Aerial Target
	LiDAR Ground Control
X	LiDAR QC Point
	New Control
	Photo ID
	Published Control

Coordinate System
NAD83(2011)(Epoch 2010.00)
UTM – Zone 10N
NAVD88
GEOID12B
Meters

Northing	Easting	Elevation
5408947.122	578722.279	1404.326

Operator	ROBBIE ROBERTSON
Receiver Model	TRIMBLE R-10 ROVER
Receiver S/N	2936
Antenna Height	2.000 Meters

Date (MM-DD-YYYY)	09-13-2015
RMSE Hz	0.015
RMSE Z	0.020
GPS Method	STATIC/RTK

PHOTOS:

NO PHOTOS

Point ID	FO_01		Aerial Target		Coordinate System
Project No.	26762		LiDAR Ground Control		NAD83(2011)(Epoch 2010.00)
Project Name	USGS MT. BAKER	X	LiDAR QC Point		UTM – Zone 10N
State	WASHINGTON		New Control		NAVD88
County	WHATCOM		Photo ID		GEOID12B
Quad	SHUSKAN ARM		Published Control		Meters

Northing	Easting	Elevation
5402128.528	595514.665	1102.714

Operator	ROBBIE ROBERTSON	Date (MM-DD-YYYY)	09-09-2015
Receiver Model	TRIMBLE S6	RMSE Hz	0.016
Receiver S/N		RMSE Z	0.024
Antenna Height	1.560 Meters	TPS Method	Double Set of Angles

PHOTOS:

Point ID	FO_02		Aerial Target		Coordinate System
Project No.	26762		LiDAR Ground Control		NAD83(2011)(Epoch 2010.00)
Project Name	USGS MT. BAKER	X	LiDAR QC Point		UTM – Zone 10N
State	WASHINGTON		New Control		NAVD88
County	WHATCOM		Photo ID		GEOID12B
Quad	GROAT MOUNTAIN		Published Control		Meters

Northing	Easting	Elevation
5412764.018	578070.617	993.044

Operator	ROBBIE ROBERTSON	Date (MM-DD-YYYY)	09-09-2015
Receiver Model	TRIMBLE S6	RMSE Hz	0.006
Receiver S/N		RMSE Z	0.006
Antenna Height	1.451 Meters	TPS Method	Double Set of Angles

PHOTOS:

Point ID	FO_03		Aerial Target		Coordinate System	
Project No.	26762		LiDAR Ground Control		NAD83(2011)(Epoch 2010.00)	
Project Name	USGS MT. BAKER	X	LiDAR QC Point		UTM – Zone 10N	
State	WASHINGTON		New Control		NAVD88	
County	WHATCOM		Photo ID		GEOID12B	
Quad	GROAT MOUNTAIN		Published Control		Meters	

Northing	Easting	Elevation
5407910.637	579007.199	1284.667

Operator	ROBBIE ROBERTSON	Date (MM-DD-YYYY)	09-11-2015
Receiver Model	TRIMBLE S6	RMSE Hz	0.006
Receiver S/N		RMSE Z	0.010
Antenna Height	1.425 Meters	TPS Method	Double set of Angles

PHOTOS:

Point ID	FO_04
Project No.	26762
Project Name	USGS MT. BAKER
State	WASHINGTON
County	WHATCOM
Quad	GROAT MOUNTAIN

	Aerial Target
	LiDAR Ground Control
X	LiDAR QC Point
	New Control
	Photo ID
	Published Control

Coordinate System
NAD83(2011)(Epoch 2010.00)
UTM – Zone 10N
NAVD88
GEOID12B
Meters

Northing	Easting	Elevation
5406217.586	580573.451	1227.407

Operator	ROBBIE ROBERTSON
Receiver Model	TRIMBLE S6
Receiver S/N	
Antenna Height	1.512 Meters

Date (MM-DD-YYYY)	09-13-2015
RMSE Hz	0.016
RMSE Z	0.020
TPS Method	Double set of Angles

PHOTOS:

Point ID	FO_05			Aerial Target		Coordinate System
Project No.	26762			LiDAR Ground Control		NAD83(2011)(Epoch 2010.00)
Project Name	USGS MT. BAKER		X	LiDAR QC Point		UTM – Zone 10N
State	WASHINGTON			New Control		NAVD88
County	WHATCOM			Photo ID		GEOID12B
Quad	BAKER PASS			Published Control		Meters

Northing	Easting	Elevation
5392800.734	590080.468	654.426

Operator	ROBBIE ROBERTSON	Date (MM-DD-YYYY)	09-07-2015
Receiver Model	TRIMBLE S6	RMSE Hz	0.011
Receiver S/N		RMSE Z	0.015
Antenna Height	1.450 Meters	GPS Method	Double set of Angles

PHOTOS:

Point ID	FO_06		Aerial Target		Coordinate System	
Project No.	26762		LiDAR Ground Control		NAD83(2011)(Epoch 2010.00)	
Project Name	USGS MT. BAKER	X	LiDAR QC Point		UTM – Zone 10N	
State	WASHINGTON		New Control		NAVD88	
County	WHATCOM		Photo ID		GEOID12B	
Quad	BAKER PASS		Published Control		Meters	

Northing	Easting	Elevation
5393077.298	587916.525	846.502

Operator	ROBBIE ROBERTSON	Date (MM-DD-YYYY)	09-07-2015
Receiver Model	TRIMBLE S6	RMSE Hz	0.010
Receiver S/N		RMSE Z	0.014
Antenna Height	1.509 Meters	TPS Method	Double set of Angles

PHOTOS:

Point ID	FO_07
Project No.	26762
Project Name	USGS MT. BAKER
State	WASHINGTON
County	WHATCOM
Quad	BAKER PASS

	Aerial Target
	LiDAR Ground Control
X	LiDAR QC Point
	New Control
	Photo ID
	Published Control

Coordinate System
NAD83(2011)(Epoch 2010.00)
UTM – Zone 10N
NAVD88
GEOID12B
Meters

Northing	Easting	Elevation
5402151.259	597737.204	433.649

Operator	ROBBIE ROBERTSON
Receiver Model	TRIMBLE S6
Receiver S/N	
Antenna Height	1.562 Meters

Date (MM-DD-YYYY)	09-15-2015
RMSE Hz	0.016
RMSE Z	0.037
TPS Method	Double Set of Angles

PHOTOS:

Point ID	FO_08		Aerial Target		Coordinate System
Project No.	26762		LiDAR Ground Control		NAD83(2011)(Epoch 2010.00)
Project Name	USGS MT. BAKER	X	LiDAR QC Point		UTM – Zone 10N
State	WASHINGTON		New Control		NAVD88
County	WHATCOM		Photo ID		GEOID12B
Quad	BAKER PASS		Published Control		Meters

Northing	Easting	Elevation
5391085.835	590090.139	1074.162

Operator	ROBBIE ROBERTSON	Date (MM-DD-YYYY)	09-07-2015
Receiver Model	TRIMBLE S6	RMSE Hz	0.007
Receiver S/N		RMSE Z	0.006
Antenna Height	1.518 Meters	TPS Method	Double set of Angles

PHOTOS:

Point ID	TW_01
Project No.	26762
Project Name	USGS MT. BAKER
State	WASHINGTON
County	WHATCOM
Quad	BAKER PASS

	Aerial Target
	LiDAR Ground Control
X	LiDAR QC Point
	New Control
	Photo ID
	Published Control

Coordinate System
NAD83(2011)(Epoch 2010.00)
UTM – Zone 10N
NAVD88
GEOID12B
Meters

Northing	Easting	Elevation
5391076.504	590297.352	1068.649

Operator	ROBBIE ROBERTSON
Receiver Model	TRIMBLE R-10 ROVER
Receiver S/N	2936
Antenna Height	2.000 Meters

Date (MM-DD-YYYY)	09-03-2015
RMSE Hz	0.017
RMSE Z	0.021
GPS Method	STATIC/RTK

PHOTOS:

Point ID	TW_02		Aerial Target		Coordinate System
Project No.	26762		LiDAR Ground Control		NAD83(2011)(Epoch 2010.00)
Project Name	USGS MT. BAKER	X	LiDAR QC Point		UTM – Zone 10N
State	WASHINGTON		New Control		NAVD88
County	WHATCOM		Photo ID		GEOID12B
Quad	SHUKSAN ARM		Published Control		Meters

Northing	Easting	Elevation
5402121.840	595465.530	1099.902

Operator	ROBBIE ROBERTSON	Date (MM-DD-YYYY)	09-04-2015
Receiver Model	TRIMBLE R-10 ROVER	RMSE Hz	0.015
Receiver S/N	2936	RMSE Z	0.017
Antenna Height	2.000 Meters	GPS Method	STATIC/RTK

PHOTOS:

Point ID	UA_01		Aerial Target		Coordinate System
Project No.	26762		LiDAR Ground Control		NAD83(2011)(Epoch 2010.00)
Project Name	USGS MT. BAKER	X	LiDAR QC Point		UTM – Zone 10N
State	WASHINGTON		New Control		NAVD88
County	WHATCOM		Photo ID		GEOID12B
Quad	BEARPAW MOUNTAIN		Published Control		Meters

Northing	Easting	Elevation
5418094.497	588042.659	572.731

Operator	DAN CASSELL	Date (MM-DD-YYYY)	09-18-2015
Receiver Model	TRIMBLE R-8 ROVER	RMSE Hz	0.013
Receiver S/N	1794	RMSE Z	0.017
Antenna Height	2.000 Meters	GPS Method	STATIC/RTK

PHOTOS:

Point ID	UA_02
Project No.	26762
Project Name	USGS MT. BAKER
State	WASHINGTON
County	WHATCOM
Quad	GLACIER

	Aerial Target
	LiDAR Ground Control
X	LiDAR QC Point
	New Control
	Photo ID
	Published Control

Coordinate System
NAD83(2011)(Epoch 2010.00)
UTM – Zone 10N
NAVD88
GEOID12B
Meters

Northing	Easting	Elevation
5414656.262	579611.674	353.100

Operator	DAN CASSELL
Receiver Model	TRIMBLE R-8 ROVER
Receiver S/N	1794
Antenna Height	2.000 Meters

Date (MM-DD-YYYY)	09-18-2015
RMSE Hz	0.012
RMSE Z	0.022
GPS Method	STATIC/RTK

PHOTOS: