AIRBORNE LIDAR PROJECT REPORT

SANDY RIVER ARRA LIDAR TASK ORDER

UNITED STATES GEOLOGICAL SURVEY (USGS)

CONTRACT NUMBER: G10PC00057
TASK ORDER NUMBER: G10PD00843

WOOLPERT PROJECT #70395

DECEMBER 2010

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Task order Number: G10PD00843

For:
For: United States Geological Survey (USGS)
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Summary of Contents

Figures

Tables

SECTION 1: OVERVIEW

Task Order Name: Sandy River ARRA LiDAR

Woolpert Project #70395

This report contains a comprehensive outline of the airborne LiDAR data acquisition for the Sandy River ARRA LiDAR Task Order; Contract Number G10PC00057; Task Order Number G10PD00843, for the United States Geological Survey (USGS). The task order consisted of LiDAR data acquisition, processing, hydrologic flattening of water bodies and production of derivative products for approximately 25.3 square miles of river corridor along the Sandy River in Oregon. The LiDAR data was collected at a nominal pulse spacing (NPS) of 0.35 meters (8 Pulses Per Square Meter {ppsm}).

The Sandy River task order data were delivered in the Oregon Lambert projection, with projection units in international feet. The horizontal datum is NAD 83 (CORS 96, EPIC 2002) and the vertical datum is NAVD 88 Geoid 03.

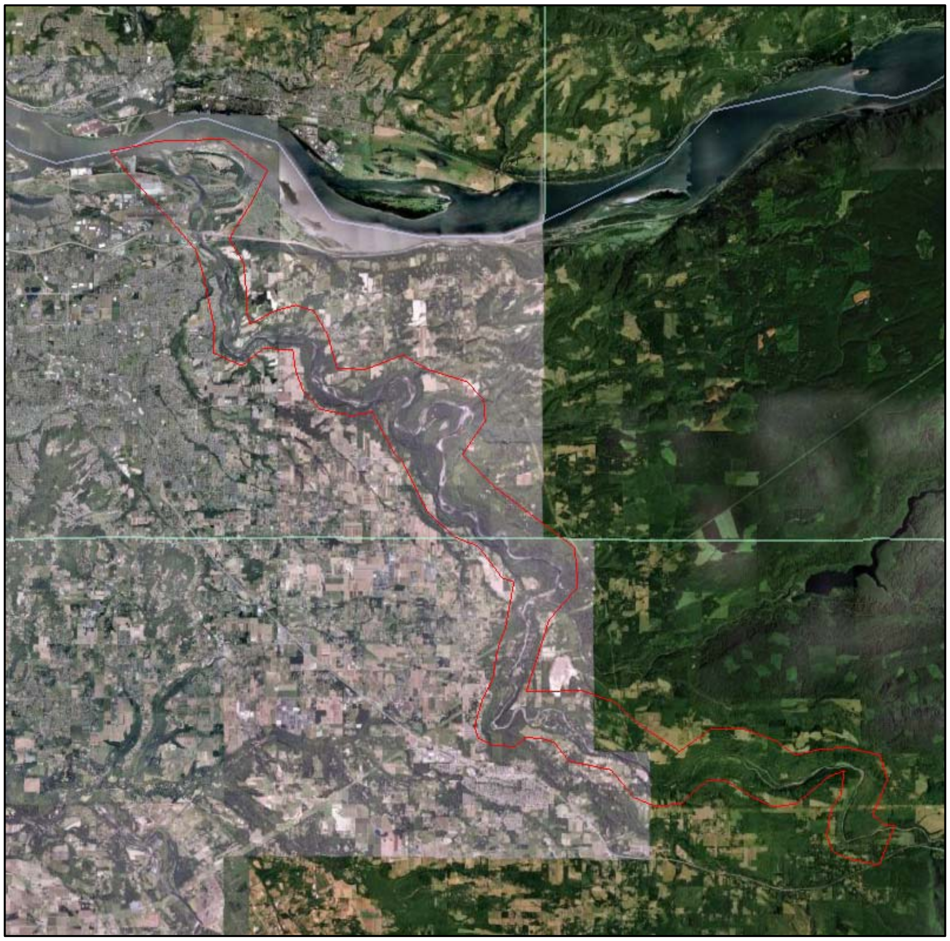


Figure 1.1: Sandy River ARRA LiDAR Task Order Area of Interest

Woolpert's teammate, Watershed Sciences, Inc., collected the LiDAR data with a Leica ALS50 Phase II sensor. The sensor was mounted in a Cessna Caravan 208B. The LiDAR system was set to acquire ≥83,000 laser pulses per second (i.e., 83 kHz pulse rate) and flown at 900 meters above ground level (AGL), capturing a scan angle of ±14° from nadir. These settings were developed to yield points with an average native pulse density of ≥8 pulses per square meter over terrestrial surfaces. Some types of surfaces (i.e., dense vegetation) may return fewer pulses than the laser originally emitted. Therefore, the delivered density can be less than the native density and vary according to distributions of terrain, land cover, and water bodies.

The ALS50 Phase II sensor collects up to four returns per pulse, as well as intensity data, for the first three returns. If a fourth return was captured, the system does not record an associated intensity value.

The LiDAR data for the Sandy River AOI was acquired at the following specifications:

Flying Height	900 Meters AGL
Scan Angle	28 degrees (±14 from Nadir)
Side Lap (Average)	50%
Scan Frequency	54 Hz
Laser Pulse Rate	105,000 Hz

The area of interest was surveyed with opposing flight line side-lap of ≥50% (≥100% overlap) to reduce laser shadowing and increase surface laser painting. The system allows up to four range measurements per pulse, and all discernable laser returns were processed for the output dataset. To solve for laser point position, an accurate description of aircraft position and attitude is vital. Aircraft position is described as x, y, and z and measured twice per second (2 Hz) by an onboard differential GPS unit. Aircraft attitude was measured 200 times per second (200 Hz) as pitch, roll, and yaw (heading) from an onboard inertial measurement unit (IMU).

LiDAR data was collected for the Sandy River study area on September 30 and October 5, 2010. The flight lines are illustrated in **Figure 1.2**.

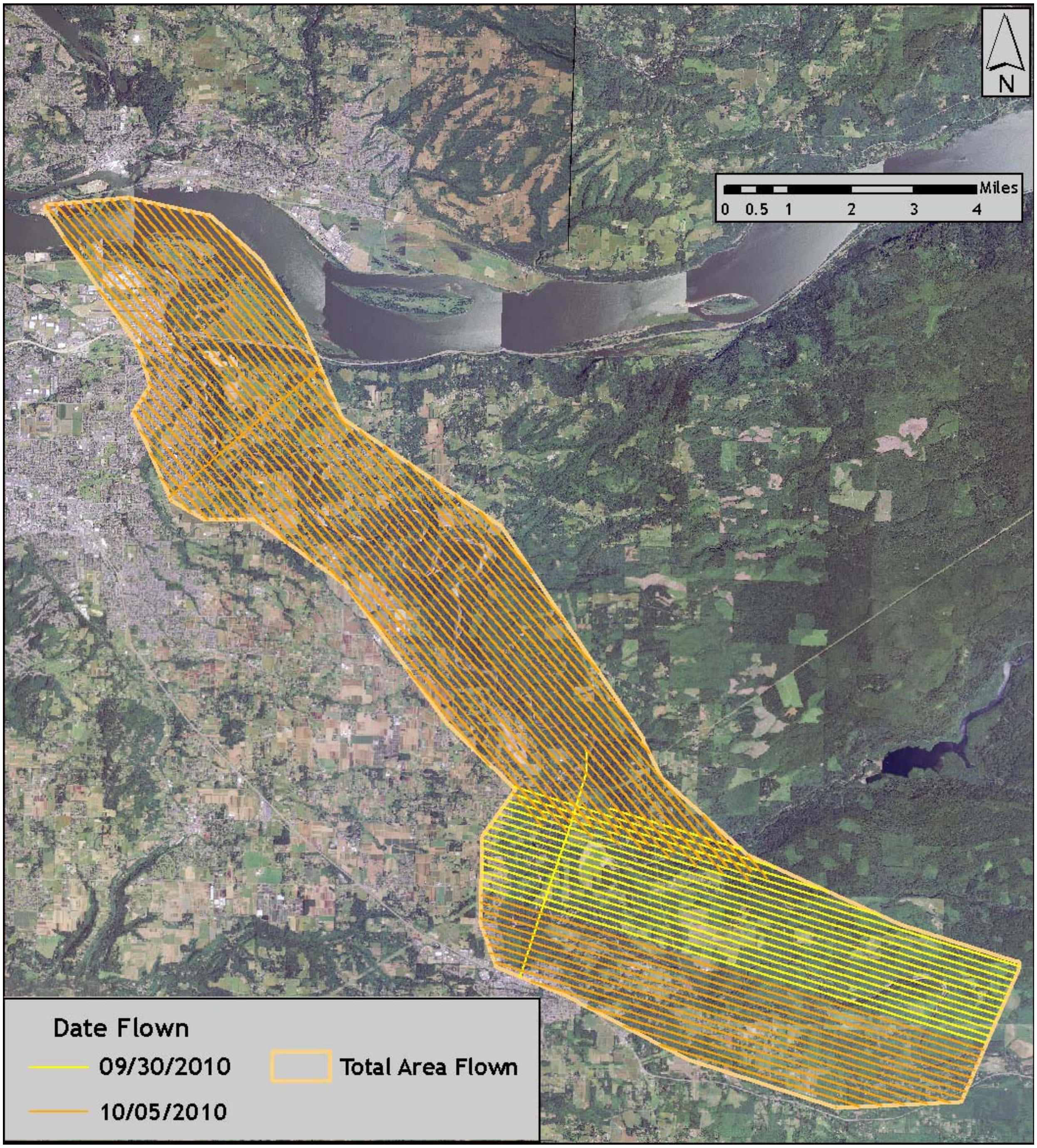


Figure 1.2: Sandy River ARRA LiDAR Task Order Area of Interest displayed over 2009 NAIP imagery

The requested area of interest (AOI) for the task order totals approximately 34,074 acres. The AOI was buffered to ensure appropriate LiDAR data coverage, resulting in a total area flown (TAF) of 35,940 acres.

SECTION 2: GROUND SURVEY - INSTRUMENTATION AND METHODS

During the LiDAR survey, static (1 Hz recording frequency) ground surveys were conducted over either known or previously set monuments. Monument coordinates are provided in **Table 2.1** and illustrated in **Figure 2.1** for the task order AOI. After the airborne survey, the static GPS data are processed using triangulation with continuous operation stations (CORS) and checked using the Online Positioning User Service (OPUS) to quantify daily variance. The Online Positioning User Service (OPUS) is run by the National Geodetic Survey to process corrected monument positions. Multiple sessions are processed over the same monument to confirm antenna height measurements and reported position accuracy. Indexed by time, these GPS data records are used to correct the continuous onboard measurements of aircraft position recorded throughout the mission.

Table 2.1: Base Station Surveyed Coordinates, (NAD83/NAVD88, OPUS Corrected) Used for Kinematic Post-Processing of the Aircraft GPS Data for the Sandy River Task Order.

	Datum NAD83(CORS96)		
Base Station ID	Latitude (North)	Longitude (West)	Ellipsoid Height (L1 Phase center)
CBSD1	45 26 36.07230	110 16 21.40137	215.217
GKSD1	45 26 36.06930	110 16 23.26705	214.312

Instrumentation

For this task order, all Global Navigation Satellite System (GNSS) survey work utilized a Trimble GNSS receiver model R7 with a Zephyr Geodetic Model 2 antenna with ground plane for static control points. The GNSS, Global Navigation Satellite System, consists of the U.S. GPS constellation and Soviet GLONASS constellation. The Trimble GPS R8 GNSS unit is used primarily for Real Time Kinematic (RTK) work but can also be used as a static receiver. For RTK data, the collector begins recording after remaining stationary for five seconds then calculating the pseudo range position from at least three epochs with the relative error under 1.5 cm horizontal and 2.0 cm vertical. All GPS measurements are made with dual frequency L1-L2 receivers with carrier-phase correction.

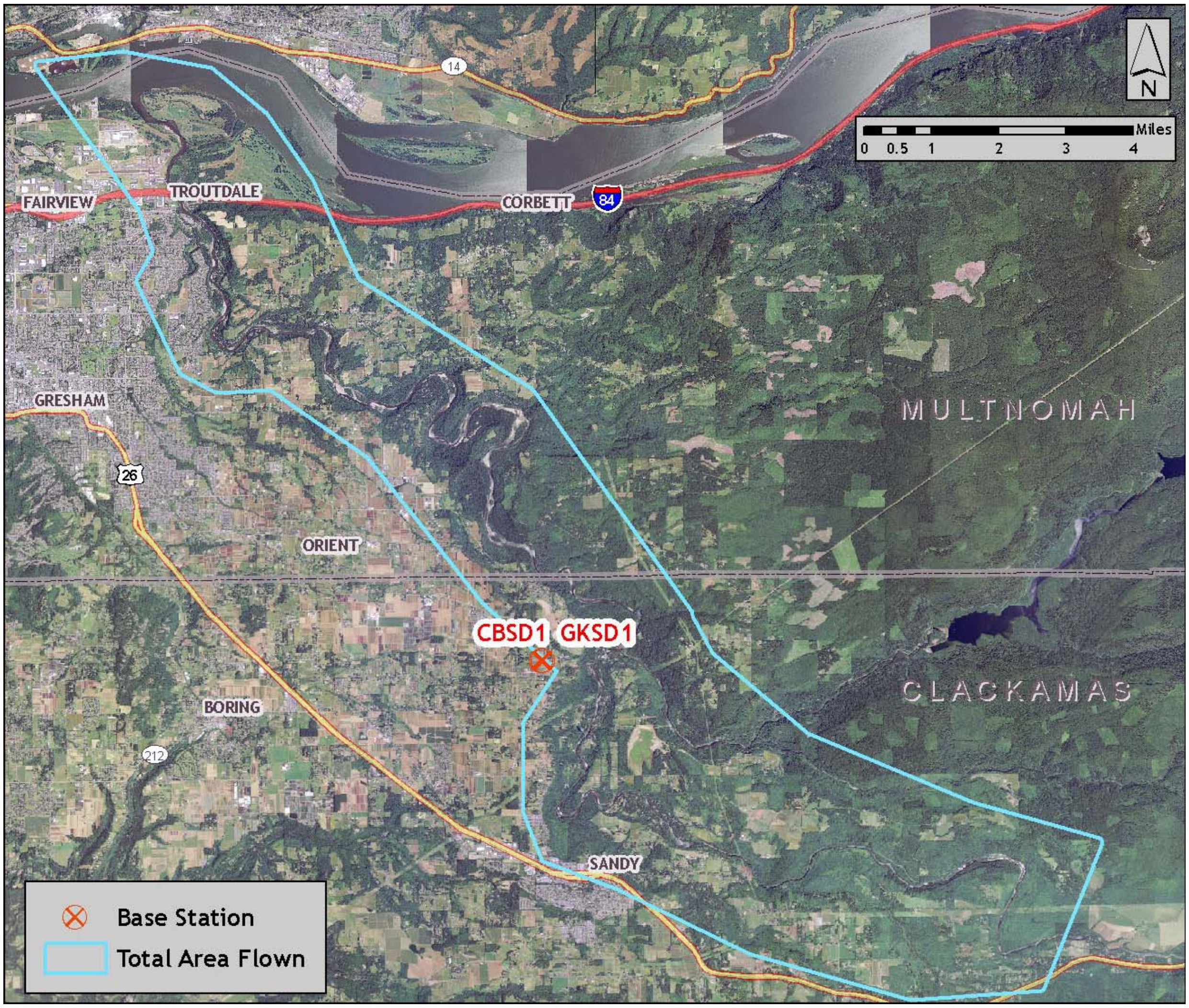


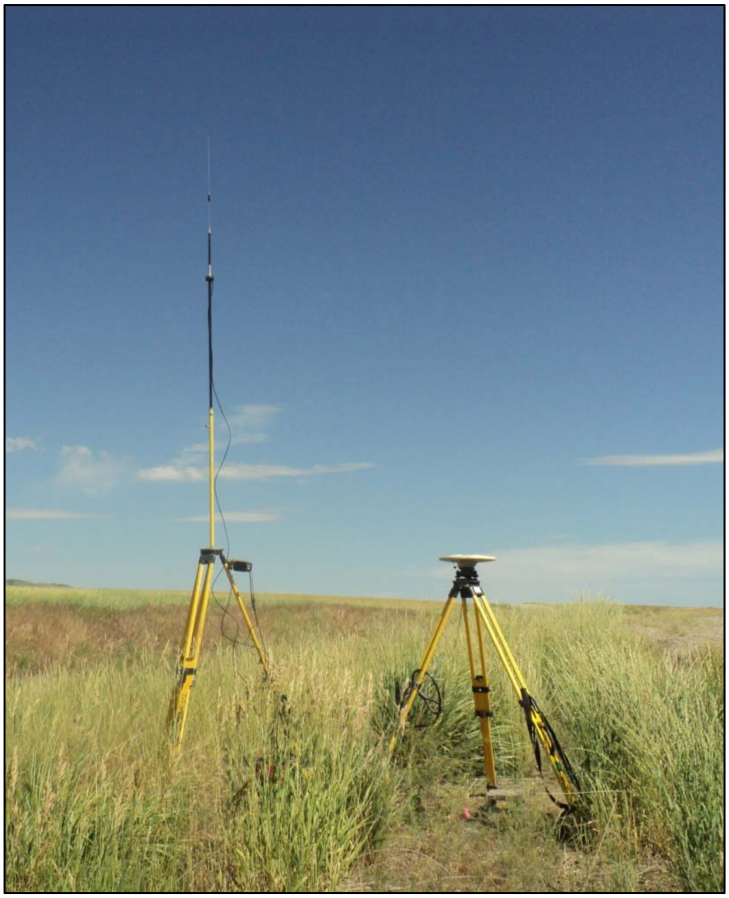
Figure 2.1: GPS base station locations covering the Sandy River task order AOI, displayed over 2009 NAIP imagery.

Monumentation

Whenever possible, existing and established survey benchmarks served as control points during LiDAR acquisition, including those previously set by Watershed Sciences, Inc. In addition to NGS, the county surveyor's offices and Oregon Department of Transportation (ODOT) often establish their own benchmarks. NGS benchmarks are preferred for control points. In the absence of NGS benchmarks, county surveys, or ODOT monuments, Watershed Sciences, Inc. produces monuments. These monuments are spaced at a minimum of one mile apart and every effort is made to keep the monuments within the public right of way or on public lands. If monuments were required on private property, consent from the owner was required. All monumentation is created with 5/8" x 30" rebar topped with an aluminum cap with "Watershed Sciences Inc." and monument identification stamped permanently into the metal.

Methodology

The aircraft was assigned a ground survey crew member with two R7 receivers and an R8 receiver. The ground crew vehicle was equipped with standard field survey supplies and equipment including safety materials. All data points are observed for a minimum of two survey sessions lasting no fewer than six hours. At the beginning of every session the tripod and antenna are reset, resulting in two independent instrument heights and data files. Data is collected at a rate of 1Hz using a ten degree mask on the antenna.



The ground crew uploaded the GPS data to the FTP site on a daily basis to be returned to the office for professional land surveyor (PLS) oversight, quality assurance/quality control (QA/QC) review and processing. OPUS processing triangulates the monument position using three CORS stations resulting in a fully adjusted position. After multiple days of data have been collected at each monument, accuracy and error ellipses are calculated from the OPUS reports. This information leads to a rating of the monument based on FGDC-STD-007.2-1998 Part 2 table 2.1 at the 95% confidence level. When a statistical stable position is found, CORPSCON 6.0.1 software was used to convert the UTM positions to geodetic positions. This geodetic position is used for processing the LiDAR data.

All GPS measurements were made during periods with PDOP less than or equal to 3.0 and with at least six satellites in view of both a stationary reference receiver and the roving receiver. RTK positions were collected on 20% of the flight lines and on bare earth locations such as paved, gravel or stable dirt roads, and other locations where the ground is clearly visible (and is likely to remain visible) from the sky during the data acquisition and RTK measurement period(s).

In order to facilitate comparisons with LiDAR measurements, RTK measurements were not taken on highly reflective surfaces such as center line stripes or lane markings on roads. The RTK points were taken no closer than one meter to any nearby terrain breaks such as road edges or drop offs. In addition, it is desirable to include locations that can be readily identified and occupied during subsequent field visits in support of other quality control procedures described later. Examples of identifiable locations would include manhole and other flat utility structures having clearly indicated center points or other measurement locations. In the absence of utility structures, a PK nail can be driven into asphalt or concrete and marked with paint.

Multiple differential GPS units were used in the ground based real-time kinematic (RTK) portion of the survey. To collect accurate ground surveyed points, a GPS base unit was set up over monuments to broadcast a kinematic correction to a roving GPS unit. The ground crew used a roving unit to receive radio-relayed kinematic corrected positions from the base unit. This RTK survey allows precise location measurement (σ ≤ 1.5 cm). **Figures 2.2 and 2.3** illustrate these hard-surface, calibration RTK locations, as well as additional ground control points measured throughout the task order AOI.

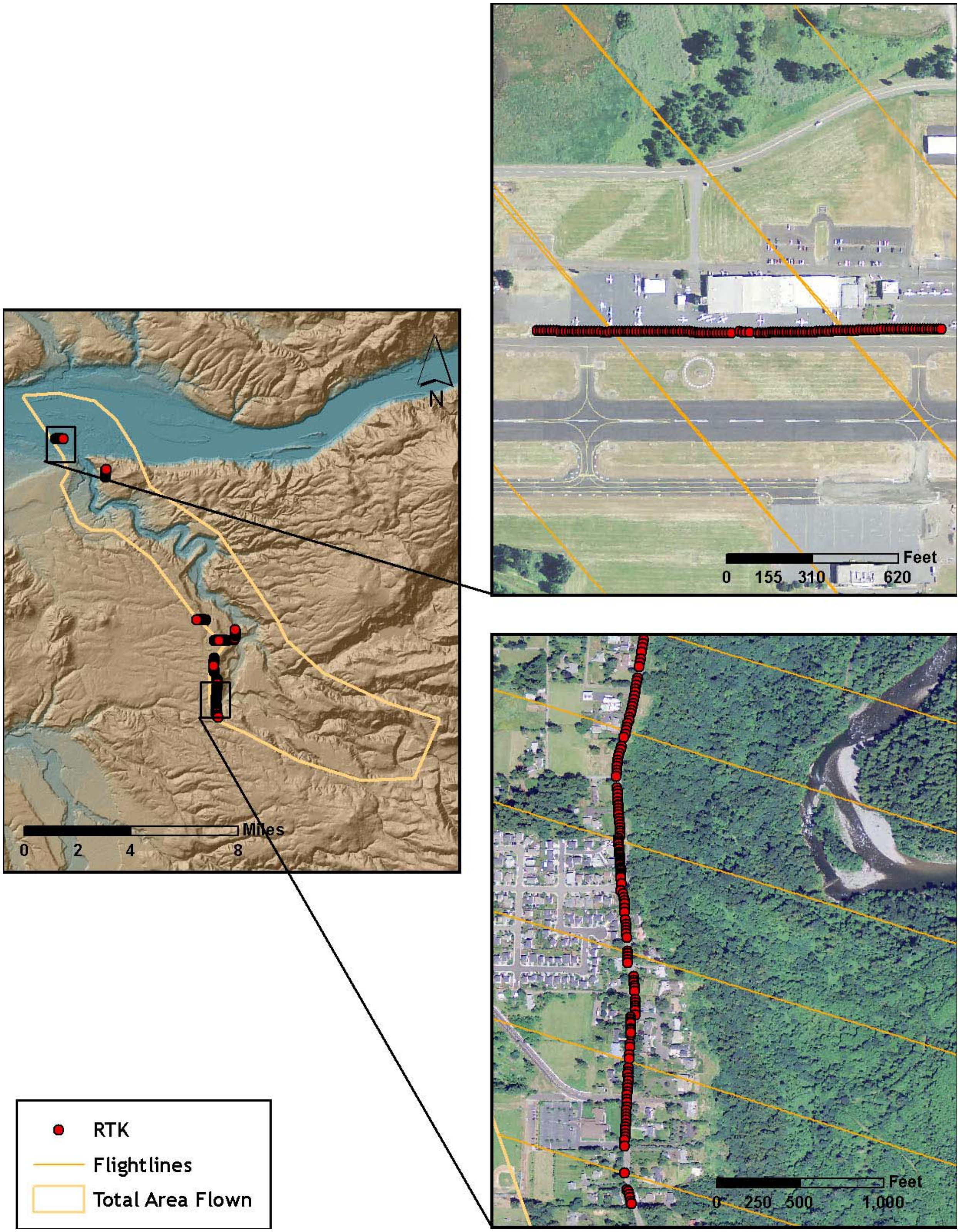


Figure 2.2: Sample selection of ground control RTK points in the Sandy River AOI displayed over 2009 NAIP imagery and a 30 meter DEM. These points were not used in the calibration of the LiDAR data.

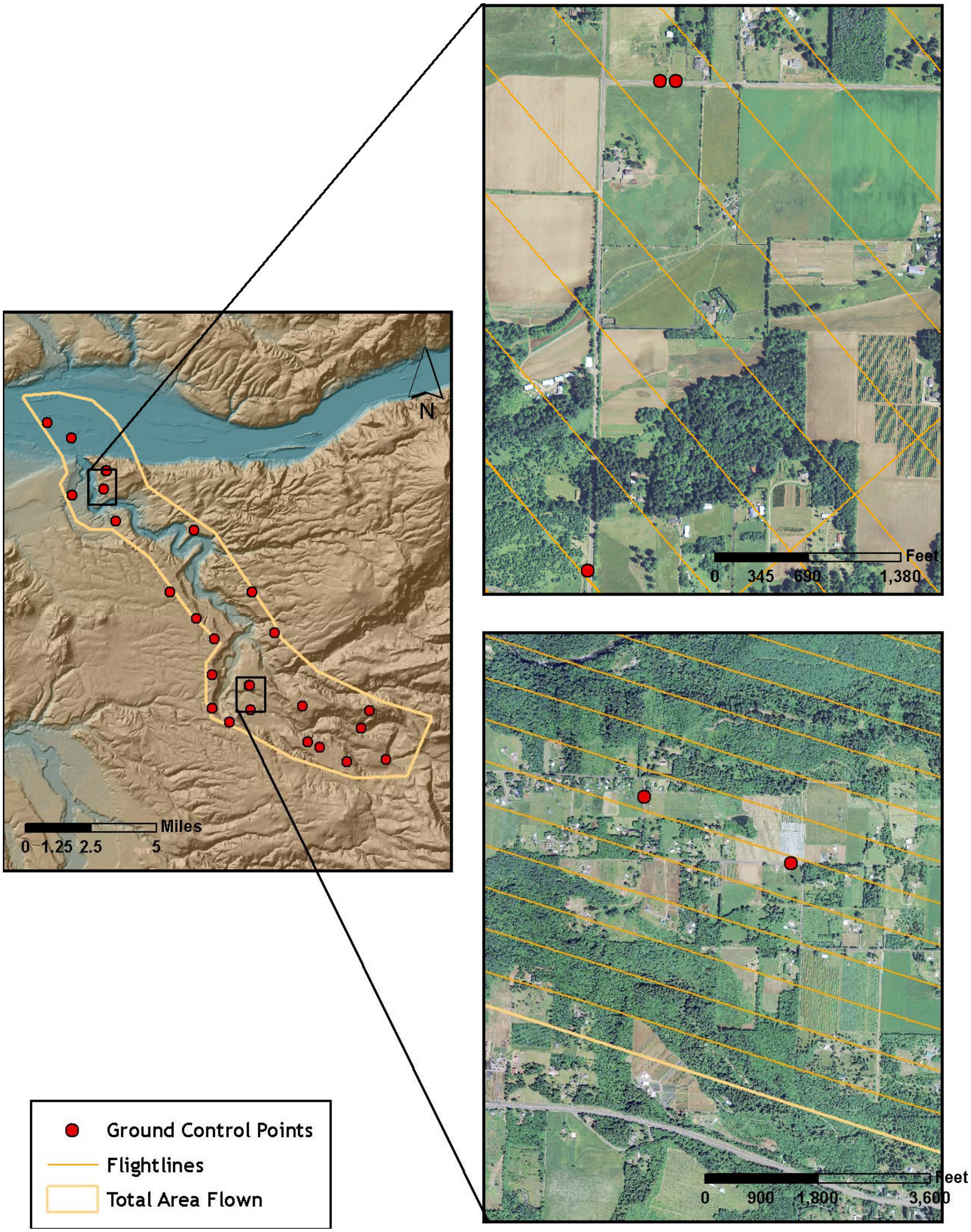


Figure 2.3: Sample selection of ground control RTK points in the Sandy River AOI displayed over 2009 NAIP Imagery and a 30 meter DEM. These points were not used in the calibration of the LiDAR data.

SECTION 3: LIDAR SYSTEM SPECIFICATIONS

The LiDAR data was acquired using a Leica ALS50 Phase II LiDAR sensor system, on board a Cessna 208B. The ALS50 Phase II LiDAR system, developed by Leica Geosystems of Heerbrugg, Switzerland, includes the simultaneous first, intermediate and last pulse data capture module, the extended altitude range module, and the target signal intensity capture module. The system software is operated on an OC50 Operation Controller aboard the aircraft.

The ALS50 Phase II LiDAR system has the following specifications.

Table 3.1: ALS50 Phase II LiDAR System Specifications

Specification	
Operating Altitude	200 - 6,000 meters
Scan Angle	0 to 75° (variable)
Swath Width	0 to 1.5 X altitude (variable)
Scan Frequency	0 – 90 Hz (variable based on scan angle)
Maximum Pulse Rate	150 kHz
Range Resolution	Better than 1 cm
Elevation Accuracy	8 – 24 cm single shot (one standard deviation)
Horizontal Accuracy	7 – 64 cm (one standard deviation)
Number of Returns per Pulse	4 (first, second, third, last)
Number of Intensities	3 (first, second, third)
Intensity Digitization	8 bit intensity + 8 bit AGC (Automatic Gain Control) level
MPiA (Multiple Pulses in Air)	8 bits @ 1nsec interval @ 50kHz
Laser Beam Divergence	0.22 mrad @ $1/e^2$ (~0.15 mrad @ 1/e)
Laser Classification	Class IV laser product (FDA CFR 21)
Eye Safe Range	400m single shot depending on laser repetition rate
Roll Stabilization	Automatic adaptive, range = 75 degrees minus current FOV
Power Requirements	28 VDC @ 25A
Operating Temperature	0-40°C
Humidity	0-95% non-condensing
Supported GNSS Receivers	Ashtech Z12, Trimble 7400, Novatel Millenium

SECTION 4: LIDAR DATA PROCESSING

Applications and Workflow Overview

1. Resolved kinematic corrections for aircraft position data using kinematic aircraft GPS and static ground GPS data.
   Software: Waypoint GraphNav v.8.20, Trimble Geomatics Office v.1.63
2. Developed a smoothed best estimate of trajectory (SBET) file blending post-processed aircraft position with attitude data. Sensor head position and attitude were calculated throughout the survey. The SBET data were used extensively for laser point processing.
   Software: IPAS Pro v.1.35
3. Calculated laser point position by associating the SBET position to each laser point return time, scan angle, intensity, etc. Created raw laser point cloud data for the entire survey in LAS v1.2 format.
   Software: ALS Post Processing Software v.2.70
4. Imported raw laser points into manageable blocks (less than 500 MB) to perform manual relative accuracy calibration and filtered for pits/birds. Ground points were then classified for individual flight lines (to be used for relative accuracy testing and calibration).
   Software: TerraScan v.10.009
5. Using ground classified points for each flight line, the relative accuracy was tested. Automated line-to-line calibrations were then performed for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift. Calibrations were performed on ground classified points from paired flight lines. Every flight line was used for relative accuracy calibration.
   Software: TerraMatch v.10.004
6. Position and attitude data were imported. Resulting data were classified as ground and non-ground points. Statistical absolute accuracy was assessed via direct comparisons of ground classified points to ground RTK survey data. Data were then converted to orthometric elevations (NAVD88) by applying a Geoid03 correction. Ground models were created as a triangulated surface and exported as ArcInfo ASCII grids.
   Software: TerraScan v.10.009, TerraModeler v.10.006

7. All flat water bodies larger than two acres and all streams wider than 100 feet were hydrologically flattened using a combination of breaklines and interpolated elevation data. Ground points within 5 feet of a breakline were ignored when triangulating the bare earth surface and reclassified as "ignored ground" (class 10).
   Software: TerraScan v.10.009, TerraModeler v.10.006, ArcView 9.3.1

Aircraft Kinematic GPS and IMU Data

The LiDAR survey datasets were referenced to 1 Hz static ground GPS data collected over a pre-surveyed monument with known coordinates. During LiDAR data acquisition, the aircraft collected 2 Hz kinematic GPS data and the inertial measurement unit (IMU) collected 200 Hz attitude data. Waypoint GraphNav v.8.20 was used to process the kinematic corrections for the aircraft. The static and kinematic GPS data were then post-processed after the acquisition to obtain an accurate GPS solution and aircraft positions. IPAS Pro v.1.35 was used to develop a trajectory file including corrected aircraft position and attitude information. The trajectory data for the entire flight acquisition mission were incorporated into a final smoothed best estimated trajectory (SBET) file containing accurate and continuous aircraft positions and attitudes.

Laser Point Processing

The laser point coordinates were computed using the IPAS and ALS Post Processor software suites based on independent data from the LiDAR system (pulse time, scan angle), and aircraft trajectory data (SBET). Laser point returns (first through fourth) were assigned an associated (x, y, and z) coordinate along with unique intensity values (0-255). The data were output into large LAS v. 1.2 files; each point maintaining the corresponding scan angle, return number (echo), intensity, and x, y, and z (easting, northing, and elevation) information.

The flight lines and LiDAR data were then reviewed to ensure complete coverage of the task order AOI and positional accuracy of the laser points.

Once the laser point data were imported into TerraScan, a manual calibration was performed to assess the system offsets for pitch, roll, heading and mirror scale. Using a geometric relationship developed by Watershed Sciences, each of these offsets was resolved and corrected if necessary.

The LiDAR points were then filtered for noise, pits and birds by screening for absolute elevation limits, isolated points and height above ground. Next, the data were manually inspected for pits and birds, and spurious points were removed. For a .las file containing approximately 7.5-9.0 million points, an average of 50-100 points were typically found to be artificially low or high. These spurious non-terrestrial laser points must be removed from the dataset. Common sources of non-terrestrial returns are clouds, birds, vapor, and haze.

Internal calibration was refined using TerraMatch. Points from overlapping lines were tested for internal consistency and final adjustments were made for system misalignments (i.e., pitch, roll, heading offsets and mirror scale). Automated sensor attitude and scale corrections yielded 3-5 cm improvements in the relative accuracy. Once the system misalignments were corrected, vertical GPS drift was resolved and removed per flight line, yielding a slight improvement (<1 cm) in relative accuracy. In summary, the data must complete a robust calibration designed to reduce inconsistencies from multiple sources (i.e., sensor attitude offsets, mirror scale, GPS drift).

- The TerraScan software suite was designed specifically for classifying near-ground points (Soininen, 2004). The processing sequence begins by ‘removing’ all points that are not ‘near’ the earth based on geometric constraints used to evaluate multi-return points. The resulting bare earth (ground) model was visually inspected and additional ground point modeling was performed in site-specific areas (over a 50-meter radius) to improve ground detail. This was only done in areas with known ground modeling deficiencies, such as: bedrock outcrops, cliffs, deeply incised stream banks, and dense vegetation. In some cases, ground point classification included known vegetation (i.e., understory, low/dense shrubs, etc.) and these points were manually reclassified as ignored ground. The ground surface rasters were developed from triangulated irregular networks (TINs) of ground points.

- The LiDAR LAS files were classified into the Default (Class 1), Ground (Class 2), Noise (Class 7), Water (Class 9) and Ignored Ground (Class 10) classifications.

SECTION 5: LIDAR DATA ACCURACY AND RESOLUTION

Laser Point Accuracy

Laser point absolute accuracy is largely a function of internal consistency (measured as relative accuracy) and laser noise:

- **Laser Noise**: For any given target, laser noise is the breadth of the data cloud per laser return (i.e., last, first, etc.). Lower intensity surfaces (roads, rooftops, still/calm water) experience higher laser noise. The laser noise range for this mission is approximately 0.02 meters.
- **Relative Accuracy**: Internal consistency refers to the ability to place a laser point in the same location over multiple flight lines, GPS conditions, and aircraft attitudes.
- **Absolute Accuracy**: RTK GPS measurements taken in the study areas compared to LiDAR point data.

Statements of statistical accuracy apply to fixed terrestrial surfaces only, not to free-flowing or standing water surfaces, moving automobiles, et cetera.

Table 5.1: LiDAR accuracy is a combination of several sources of error. These sources of error are cumulative. Some error sources that are biased and act in a patterned displacement can be resolved in post processing

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

Relative Accuracy

Relative accuracy refers to the internal consistency of the data set and 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). Internal consistency is affected by system attitude offsets (pitch, roll and heading), mirror flex (scale), and GPS/IMU drift.

Operational Measures Taken to Improve Relative Accuracy

1. **Low Flight Altitude:** Terrain following was targeted at a flight altitude of 900 meters above ground level (AGL). Laser horizontal errors are a function of flight altitude above ground; lower flight altitudes decrease laser noise on all surfaces.

2. **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 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 maintained.

3. **Reduced Scan Angle:** Edge-of-scan data can become inaccurate. The scan angle was reduced to a maximum of $\pm 14^{o}$ from nadir, creating a narrow swath width and greatly reducing laser shadows from trees and buildings.

4. **Quality GPS:** The data acquisition occurred during optimal GPS conditions (e.g., 6 or more satellites and PDOP {Position Dilution of Precision} less than 3.0). 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 point was less than 24 km (13 nautical miles).

5. **Ground Survey:** Ground survey point accuracy (i.e., <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.

6. **50% Side-Lap (100% Overlap):** Overlapping areas were optimized for relative accuracy testing. Laser shadowing was minimized to help increase target acquisition from multiple scan angles. Ideally, with a 50% side-lap, the most nadir portion of one flight line coincides with the edge (least nadir) portion of overlapping flight lines. A minimum of 50% side-lap with terrain-followed acquisition prevents data gaps.

7. **Opposing Flight Lines:** All overlapping flight lines are opposing. 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.

Relative Accuracy Calibration Methodology

1. **Manual System Calibration:** The calibration procedures for each mission require solving geometric relationships relating 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 and reported for the study area.

2. **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 mirror scale was solved for each individual mission. Attitude misalignment offsets (and mirror scale) occurs for each individual mission. The data from each mission were then blended when imported together to form the entire area of interest.

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

Relative Accuracy Calibration Results

The relative accuracy statistics are based on the comparison of 86 flight lines and over 780 million points. The figures below show the distribution and the statistical analysis.

- Project Average = 0.13 feet
- Median Relative Accuracy = 0.13 feet
- 1σ Relative Accuracy = 0.13 feet
- 2σ Relative Accuracy = 0.16 feet

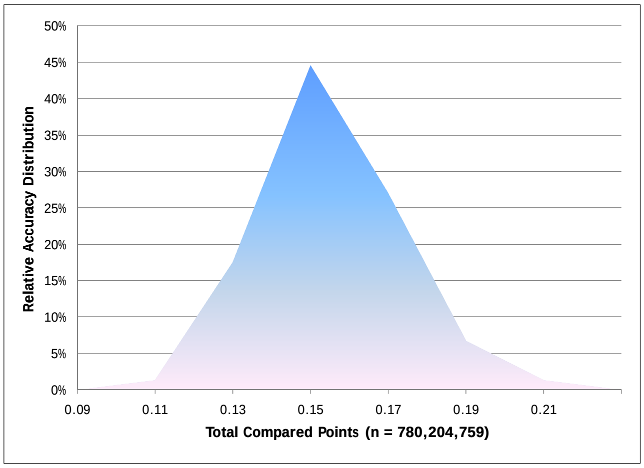


Figure 5.1: Distribution of relative accuracies, non slope-adjusted

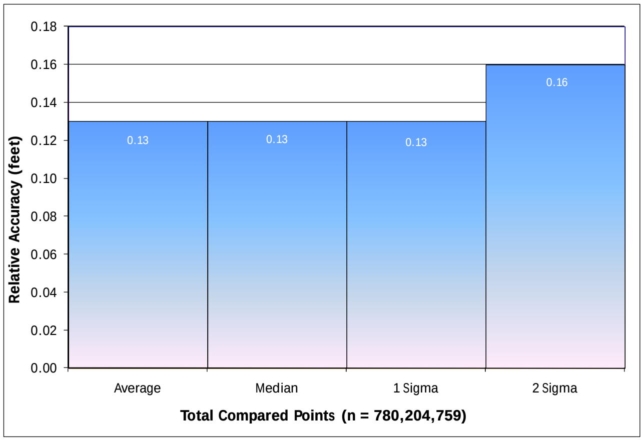


Figure 5.2: Statistical relative accuracies, non slope-adjusted

Absolute Accuracy

Absolute accuracy compares known Real Time Kinematic (RTK) ground survey points to the closest laser point. For the Sandy River task order AOI, Watershed Sciences collected 1,038 RTK points. 1,010 were hard surface points used for data calibration; the statistics derived from these points is presented in the figures below. The remaining 28 points were used as a supplemental ground control point dataset, well-distributed throughout the study area. Absolute accuracy is reported in the figures below.

Table 5.2: Absolute accuracy—deviation between laser points and RTK hard surface survey points

Sample Size (n): 1010	
Root Mean Square Error (RMSE): 0.17 feet	
Standard Deviations	**Deviations**
1 sigma (σ): 0.16 ft	Minimum Δz: -0.53 ft
2 sigma (σ): 0.36 ft	Maximum Δz: 0.49 ft
	Average Δz: 0.14 ft

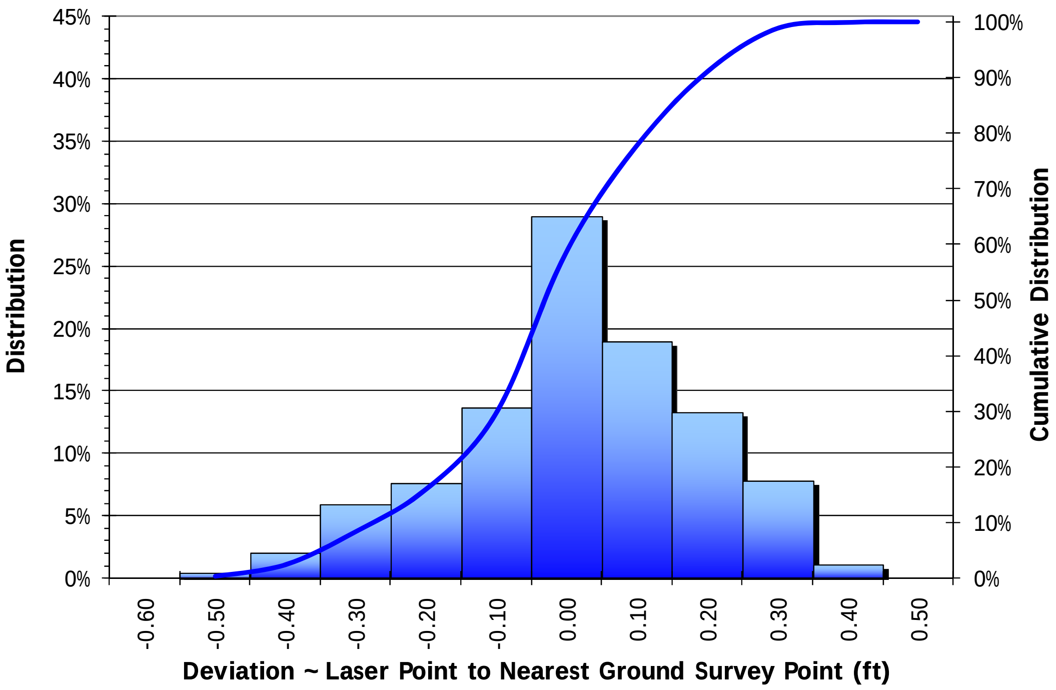


Figure 5.3: Histogram statistics, calculated from 1010 hard surface calibration points

Figure 5.4: Absolute deviation—statistics calculated from 1010 hard surface calibration points

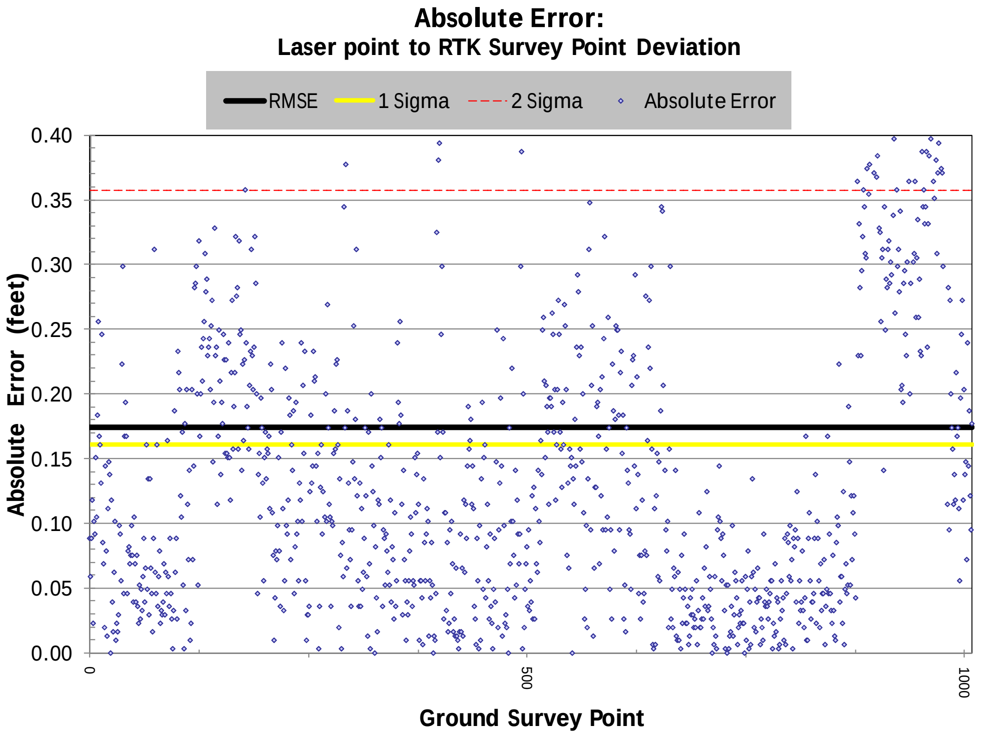


Figure 5.4: Absolute deviation statistics, calculated from 1010 hard surface calibration points

Data Density/Resolution

Some types of surfaces (i.e., dense vegetation or water) may return fewer pulses than originally emitted by the laser. The delivered density may therefore be less than the native density and vary according to distributions of terrain, land cover, and vegetation. The density histograms and maps (**Figures 5.5 - 5.8**) have been calculated based on first return laser point density and ground-classified laser point density.

Table 5.3: Average Densities for the Sandy River AOI.

Average Pulse Density (per square m)	Average Ground Density (per square m)
8.42	.83

First Return Data Density

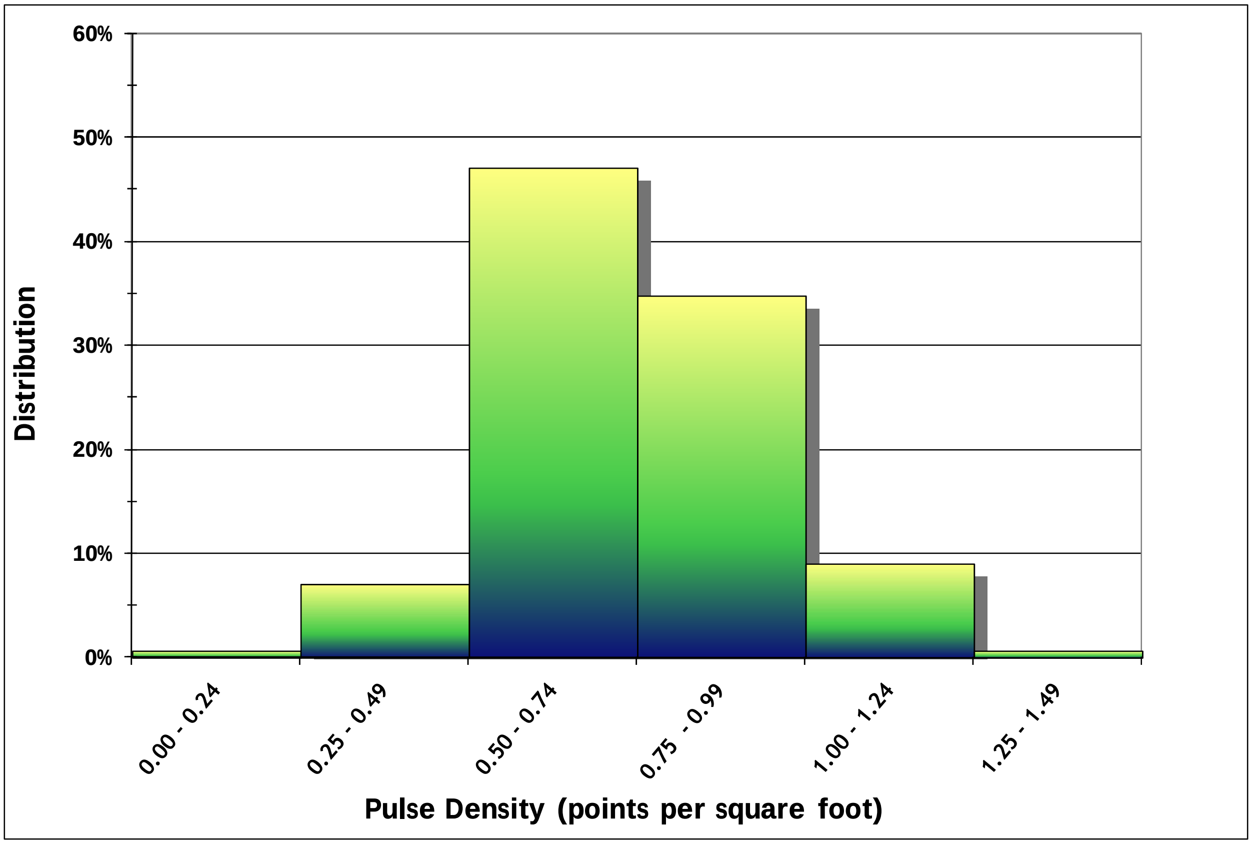


Figure 5.5: Histogram of first return laser point density for the Sandy River Task Order AOI

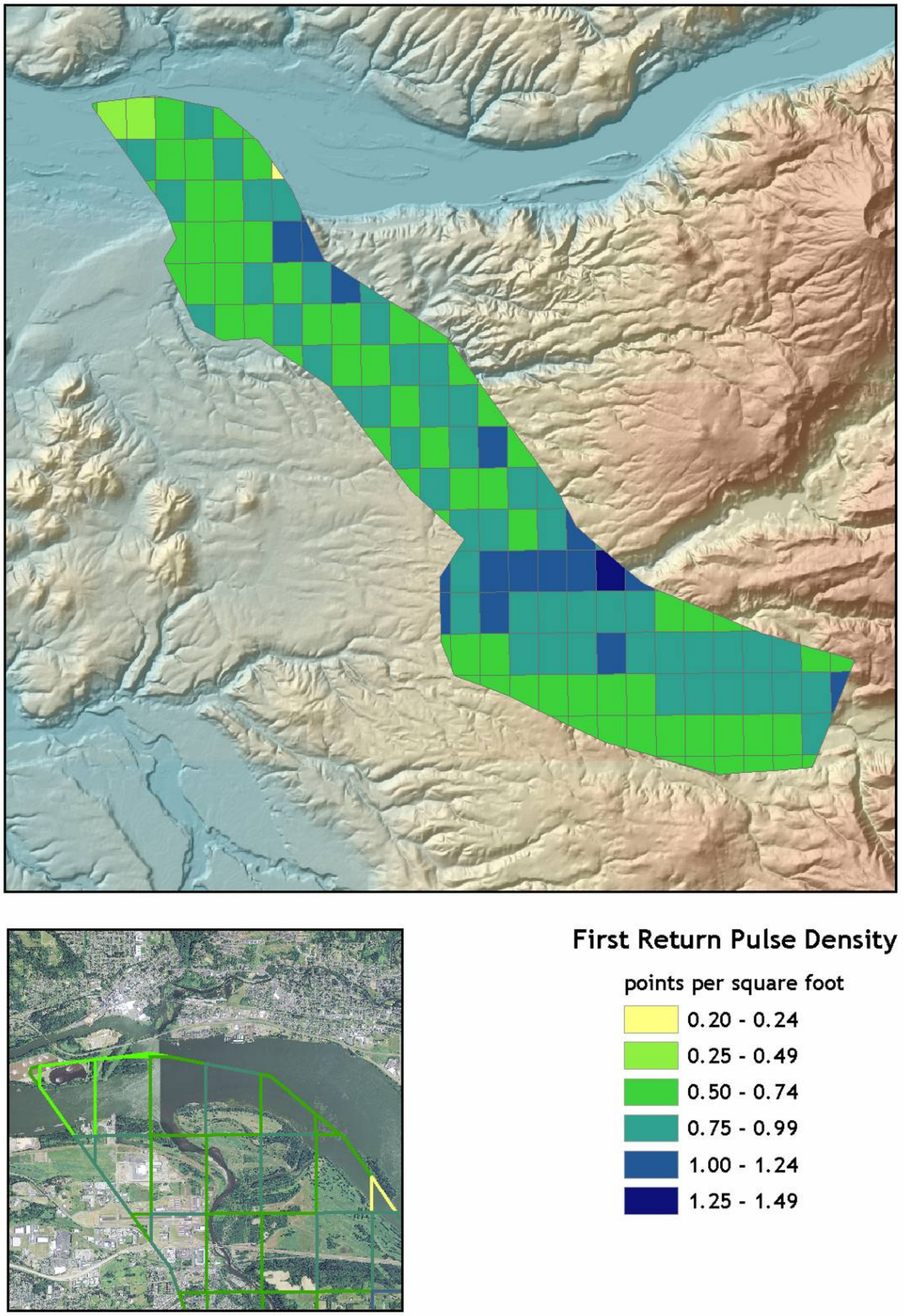


Figure 5.6: First return laser point data density for the Sandy River Task Order AOI displayed over a 30 meter DEM

Ground-Classified Data Density

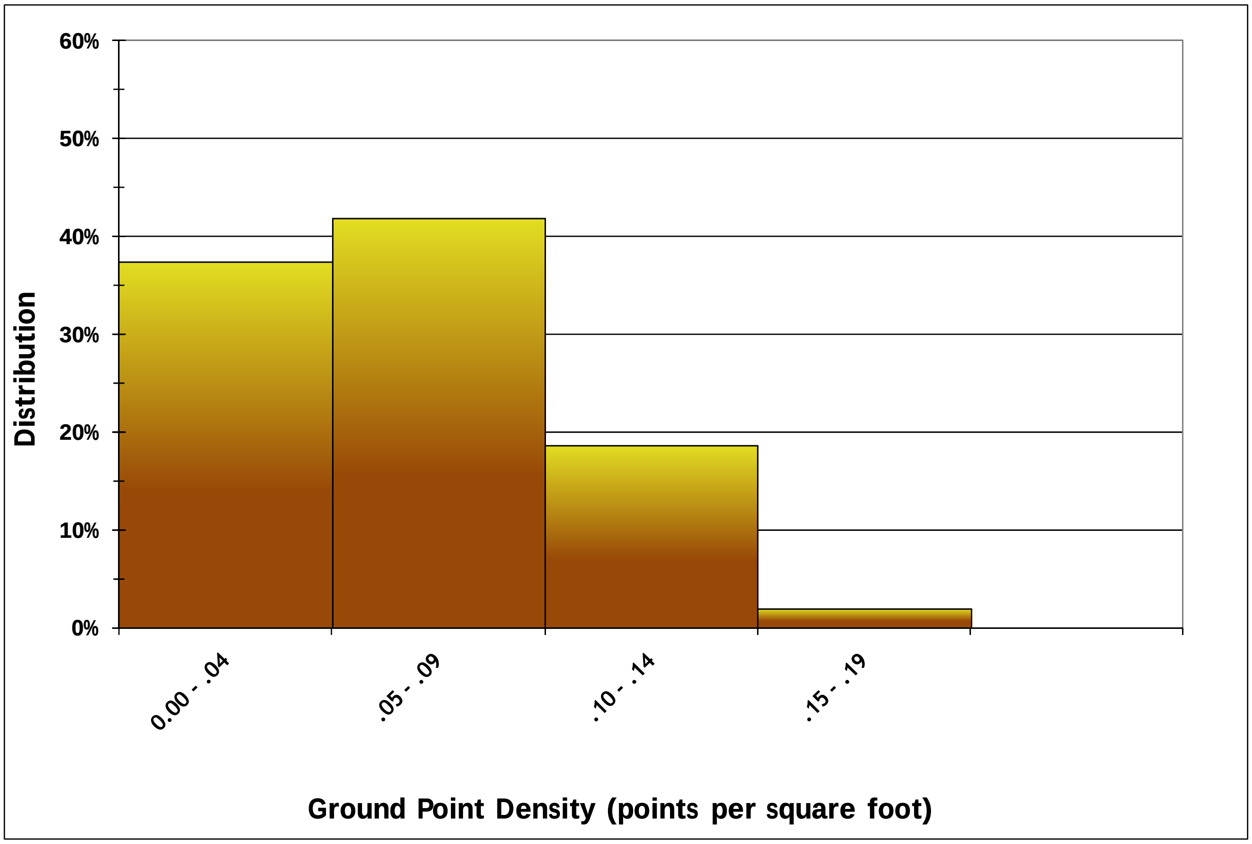
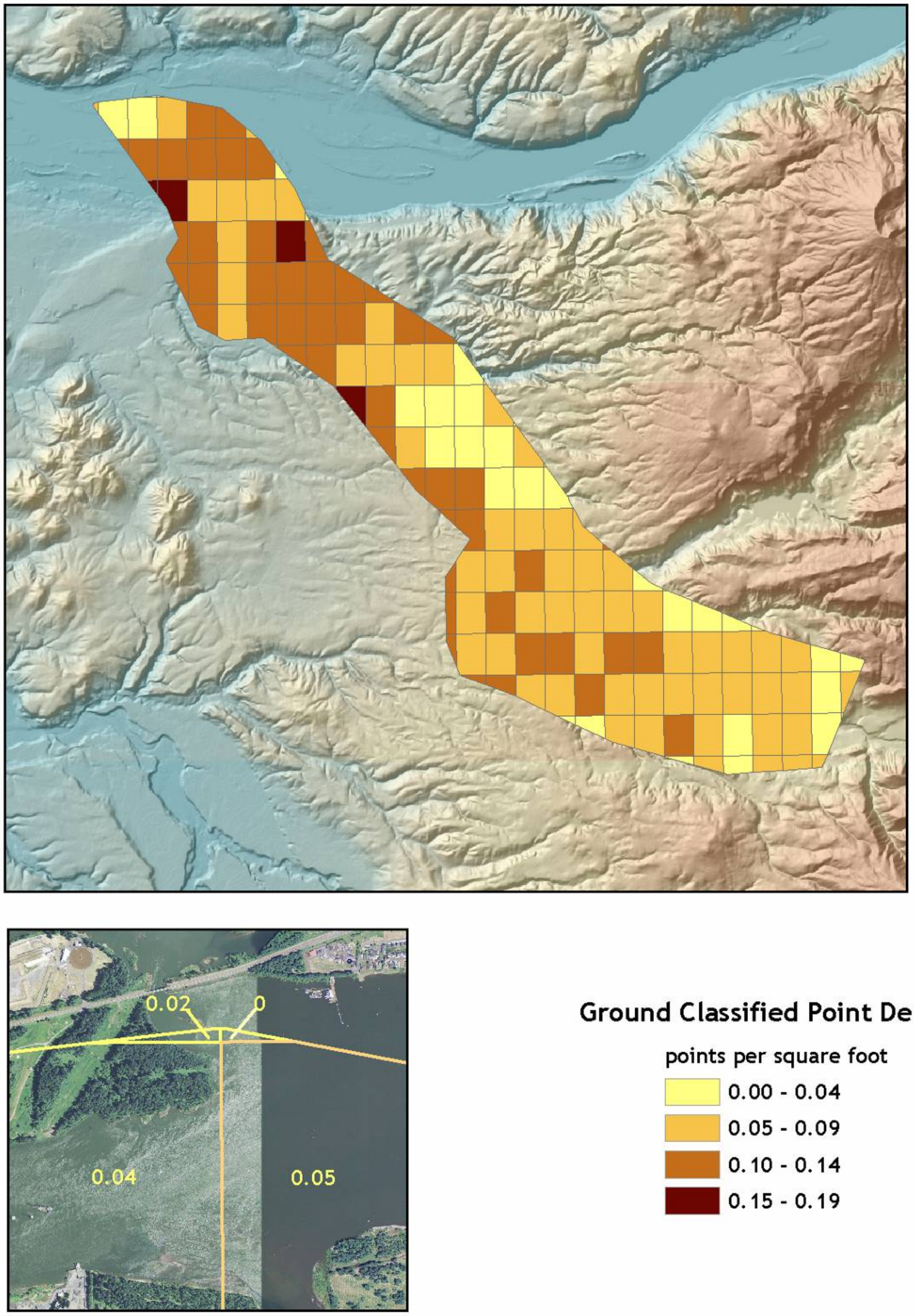


Figure 5.7: Histogram of ground-classified laser point density for the Sandy River



Low ground density bins over water.

Figure 5.8: Ground-classified laser point data density for the Sandy River Task Order AOI displayed over a 30 meter DEM

SECTION 6: HYDRO FLATTENING PROCESSING AND QUALITY CONTROL

Hydro Flattening of LiDAR Data

This task required the compilation of breaklines defining water bodies and streams. The breaklines were used to perform the hydrologic flattening of water bodies, and gradient hydrologic flattening of double line streams. Lakes, reservoirs and ponds, at a nominal minimum size of two (2) acres or greater, were compiled as closed polygons. The closed water bodies were collected at a constant elevation. Rivers and streams, at a nominal minimum width of 100-feet, were compiled in the direction of flow with both sides of the stream maintaining an equal gradient elevation. The hydrologic flattening of the LiDAR data was performed for inclusion in the National Elevation Dataset (NED).

LiDAR Data Review and Processing

Woolpert utilized the following steps to hydrologically flatten the water bodies and for gradient hydrologic flattening of the double line streams within the existing LiDAR data.

1. Woolpert used the newly acquired (2010) LiDAR bare-earth data and the 2009 NAIP color (RGB) imagery. The hydro features were manually drawn in a 2D environment using the NAIP imagery as a resource.
2. Woolpert utilized an integrated software approach to combine the LiDAR data and 2D breaklines. This process “drapes” the 2D breaklines onto the 3D LiDAR surface model. A monotonicity process is performed on the data to ensure the streams are consistently flowing in a gradient manner. A procedure within the processing validates the elevation of the stream edges. The closed water bodies are draped onto the 3D LiDAR surface and assigned a constant elevation.
3. The lakes, reservoirs and ponds, at a nominal minimum size of two (2) acres or greater, were compiled as closed polygons. The image to the right, illustrates a good example of approximate two (2) acre lakes identified and defined with hydrologic breaklines in a dataset. During the collection of linework, the technical staff used a program that displayed the polygon measurement area as a reference to identify lakes larger than two (2) acres. If the lake was larger than the cursor in width and/or length, the lake was defined with a breakline to be hydrologically flattened.
4. The breaklines defining rivers and streams, at a nominal minimum width of 100-feet, were draped with both sides of the stream maintaining an equal gradient elevation.
5. All DEM points were reclassified from inside the hydrologic feature polygons.
6. All DEM points were reclassified from within a five (5) foot buffer along the hydrologic feature breaklines.
7. The LiDAR mass points and hydrologic feature breaklines were used to generate a new digital elevation model.
8. The new hydrologically flattened DEM was delivered in ArcGRID format.

The Sandy River task order data were delivered in the Oregon Lambert projection, with projection units in international feet. The horizontal datum is NAD 83 (CORS 96, EPIC 2002) and the vertical datum is NAVD 88 Geoid 03.

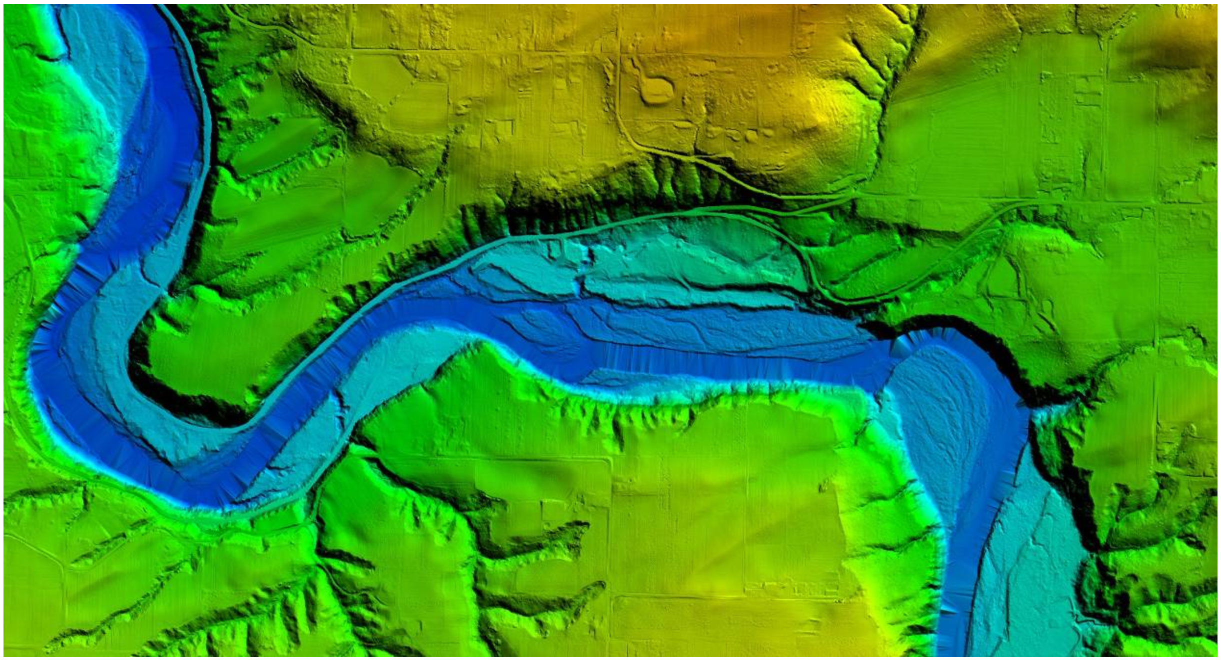


Figure 6.1 reflects a DEM generated from an original LiDAR bare earth point data prior to the hydrologic flattening process. Note the "tinning" across the water.

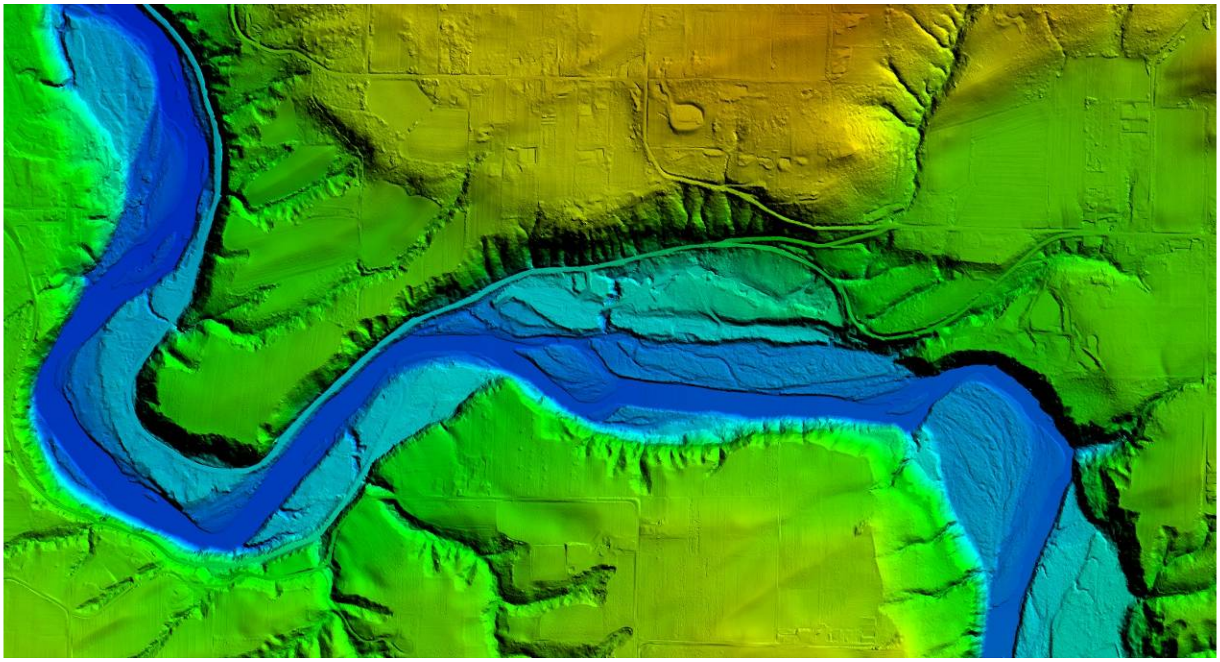


Figure 6.2: reflects a DEM generated from LiDAR with breaklines compiled to define the hydrologic features. This figure illustrates the results of adding the breaklines to hydrologically flatten the DEM data. Note the smooth appearance of the water in the DEM.

The hydrologically flattened DEM data was provided to USGS in ArcGRID format at a 3-foot posting.

Terrascan was used to add the hydrologic breakline vertices and export lattice models.

The hydrologic breaklines compiled as part of the flattening process were provided to the USGS as a shapefile. The breaklines defining the water bodies greater than two (2) acres were provided as a Polygon Z file. The breaklines compiled for the gradient flattening of all rivers and streams at a nominal minimum width of 100-feet were provided as a Polyline Z file.

Woolpert tested and refined our process during production. Woolpert found that this process would yield virtually error-free results in a very efficient manner.

Data QA/QC

Initial QA/QC for this task order was performed in Global Mapper, by reviewing the grids and hydrologic breakline features.

Edits and corrections were addressed individually by tile. If a water body breakline needed to be lowered or adjusted to improve the flattening of the ArcGRID DEM, the area was cross referenced to the tile number, fixed, regenerated by individual tile and reviewed in GlobalMapper.

Final Deliverables

- All Return point dView Upstream Over the Former Site of Marmont Damata with discrete returns in LAS v1.2 format delineated in 1/100th USGS 7.5 minute quadrangle (0.75 minute by 0.75 minute) tiles.
- Ground classified point data in LAS v1.2 format delineated in 1/100th USGS 7.5 minute quadrangle (0.75 minute by 0.75 minute) tiles.
- Raw unclassified flight line strips, no greater than 2GB in file size, in LAS v1.2 format.
- Total Area Flown in shapefile format delineated in 1/4th USGS 7.5 minute quadrangle (3.75 minute by 3.75 minute) tiles.
- Area of Interest in shapefile format delineated in 1/4th USGS 7.5 minute quadrangle (3.75 minute by 3.75 minute) tiles.
- Shape file of LiDAR flight plan.
- Shape file of SBET containing aircraft position, attitude, and GPS time.
- Shape file of RTK calibration points.
- Shape file of supplemental ground control points.
- Breaklines compiled as part of the hydrologic flattening process as ESRI Polyline Z or PolygonZ shape files.
- Highest hit hydrologically flattened DEM in 3 foot ESRI grid format delineated in 1/4th USGS 7.5 minute quadrangle (3.75 minute by 3.75 minute) tiles.
- Bare earth hydrologically flattened DEM in 3 foot ESRI grid format delineated in 1/4th USGS 7.5 minute quadrangle (3.75 minute by 3.75 minute) tiles.
- Intensity images in 1 foot GeoTiff format delineated in 1/4th USGS 7.5 minute quadrangle (3.75 minute by 3.75 minute) tiles.
- FGDC compliant metadata by file in XML format.
- The project data was delivered on an external USB 2.0 hard drive.

Selected Sample Imagery

Figure 6.3: View upstream over the former site of Marmot Dam on the Sandy River. Imagery created with RGB values extracted from 2009 NAIP orthophotos onto a three-dimensional LiDAR point cloud.

Figure 6.4: View upstream on the Sandy River over Revenue Bridge. Imagery created with RGB values extracted from 2009 NAIP orthophotos onto a three-dimensional point cloud.

Figure 6.5: View upstream at Bull Run Powerhouse. Imagery created with RGB values extracted from 2009 NAIP Orthophotos onto a three-dimensional LiDAR point cloud.