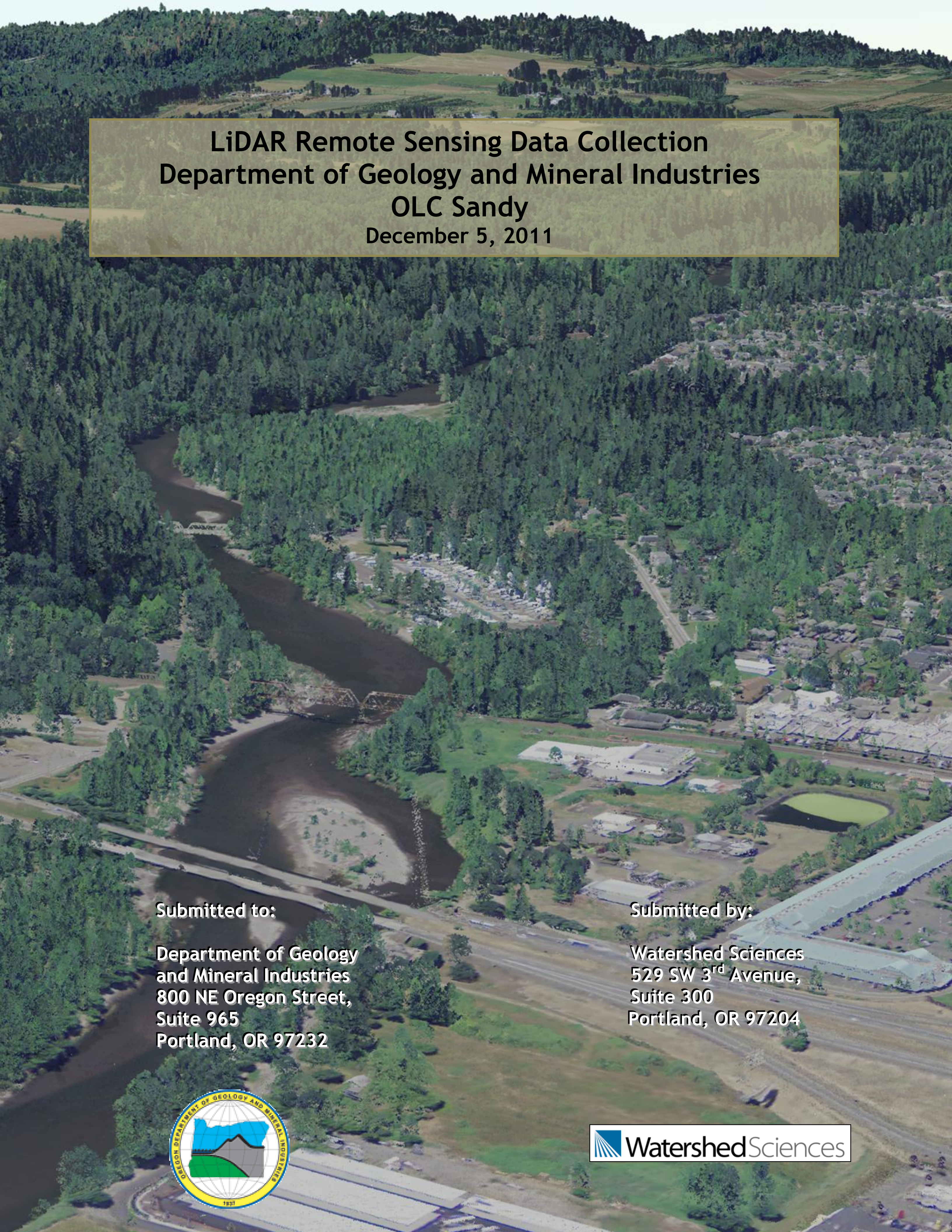

LiDAR Remote Sensing Data Collection
Department of Geology and Mineral Industries
OLC Sandy

December 5, 2011

Submitted to:

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and Mineral Industries
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Watershed Sciences

LiDAR Remote Sensing Data Collection:
OLC Sandy Study Area

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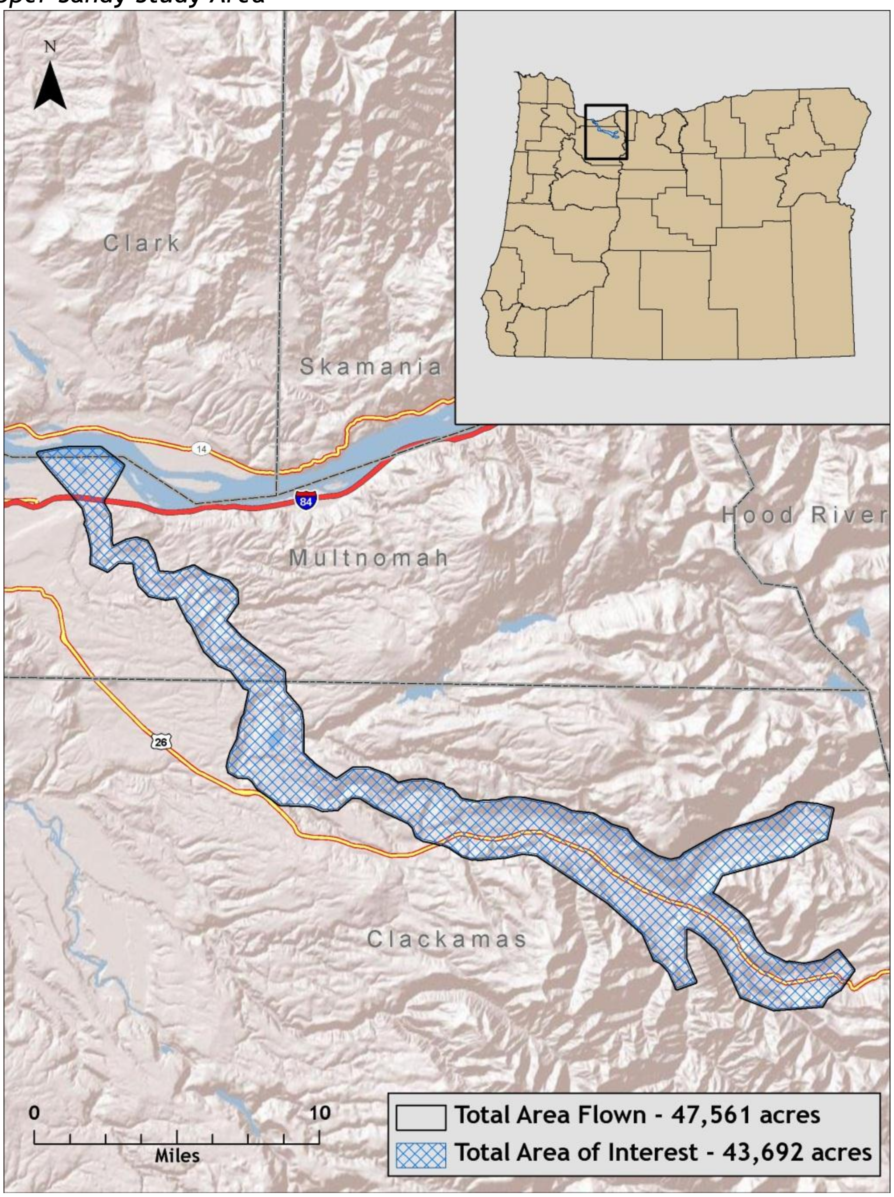
1. Overview

1.1 Study Area

Watershed Sciences, Inc. has collected Light Detection and Ranging (LiDAR) data of the Upper Sandy River study area for the Oregon Department of Geology and Mineral Industries (DOGAMI). The area of interest (AOI) totals 68 square miles (43,692 acres) and the total area flown (TAF) covers 74 square miles (47,561 acres). The TAF acreage is greater than the original AOI acreage due to buffering and flight planning optimization (**Figure 1.1** below). This report reflects all data and cumulative statistics for the overall LiDAR survey. DOGAMI data are delivered in OGIC (HARN): Projection: Oregon Statewide Lambert Conformal Conic; horizontal and vertical datum: NAD83 (HARN)/NAVD88 (Geoid03); units: International Feet.

Figure 1.1. *Upper Sandy Study Area*

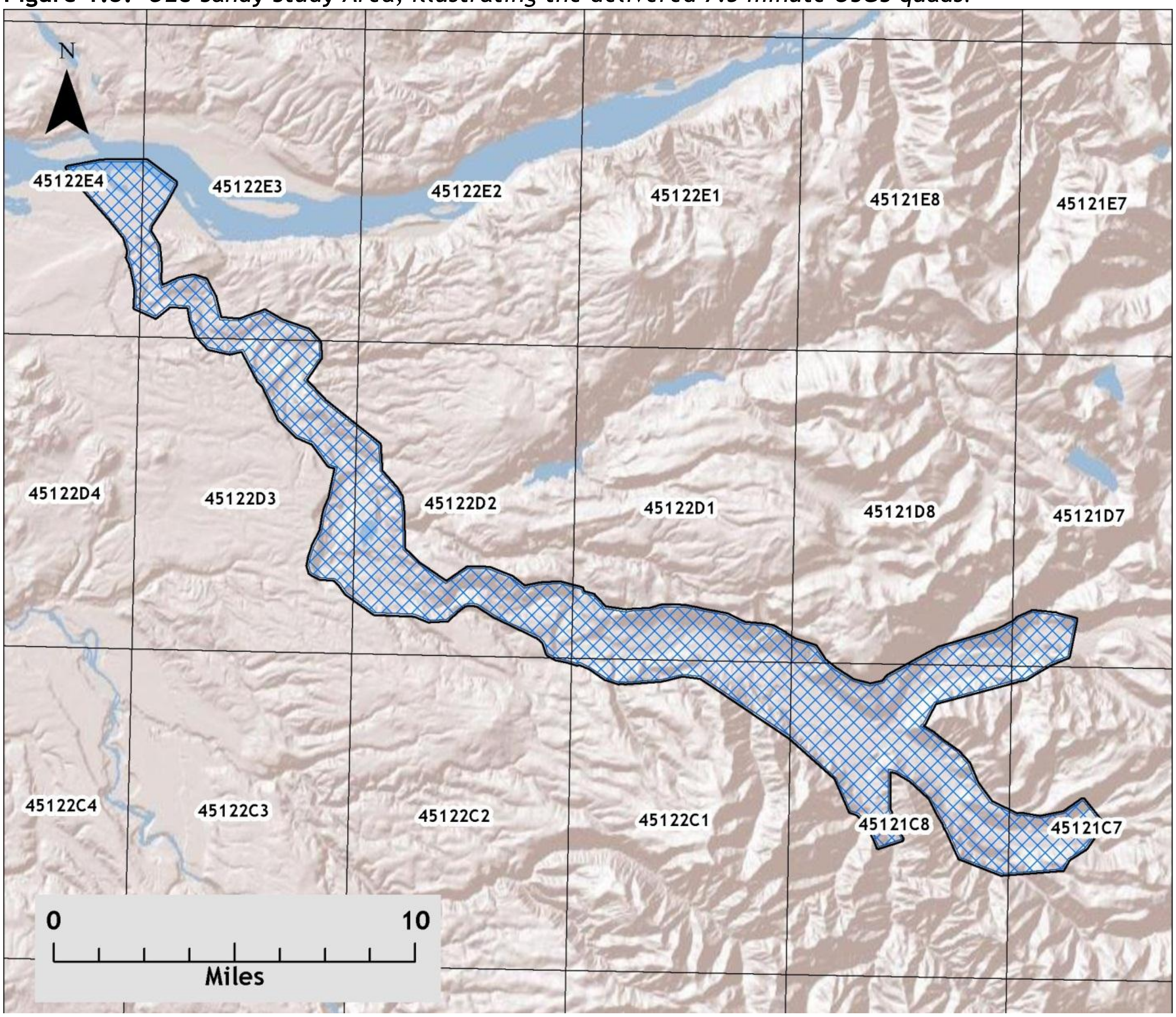


1.2 Area Delivered to Date

Total delivered acreage detailed below.

OLC Sandy Study Area				
	Delivery Date	**Acquisition Dates**	**AOI Acres**	**TAF Acres**
Delivery Area	November 18, 2011	August 30, 2011 – September 3, 2011	**43,692**	**47,561**

Figure 1.3. *OLC Sandy Study Area, illustrating the delivered 7.5 minute USGS quads.*



2. Acquisition

2.1 Airborne Survey Overview – Instrumentation and Methods

The LiDAR survey utilized a Leica ALS60 sensor mounted in Cessna Caravan 208B. The Leica system was set to acquire ≥105,000 laser pulses per second (i.e. 105 kHz pulse rate) and flown at 900 meters above ground level (AGL), capturing a scan angle of ±14^o from nadir[1]. These settings are developed to yield points with an average native density of ≥8 points per square meter over terrestrial surfaces. The native pulse density is the number of pulses emitted by the LiDAR system. Some types of surfaces (i.e. dense vegetation or water) may return fewer pulses than the laser originally emitted. Therefore, the delivered density can be less than the native density and lightly variable according to distributions of terrain, land cover and water bodies.

The Cessna Caravan is a powerful, stable platform, which is ideal for the often remote and mountainous terrain found in the Pacific Northwest. The Leica ALS60 sensor head installed in the Caravan is shown on the right.

Table 2.1 *LiDAR Survey Specifications*

Sensor	Leica ALS60
Survey Altitude (AGL)	900 m
Pulse Rate	>105KHz
Pulse Mode	Single
Mirror Scan Rate	61.1 Hz
Field of View	30^o (±14^o from nadir)
Roll Compensated	Up to 15^o
Overlap	100% (60% Side-lap)

The study area was surveyed with opposing flight line side-lap of ≥60% (≥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, it is vital to have an accurate description of aircraft position and attitude. Aircraft position is described as x, y and z and measured twice per second (2 Hz) by an onboard differential GPS unit. Aircraft attitude is measured 200 times per second (200 Hz) as pitch, roll and yaw (heading) from an onboard inertial measurement unit (IMU). **Figure 2.1** shows the flight lines completed for processing.

[1] Nadir refers to the perpendicular vector to the ground directly below the aircraft. Nadir is commonly used to measure the angle from the vector and is referred to a "degrees from nadir".

Figure 2.1. *Actual flightlines for the OLC Sandy study Area.*

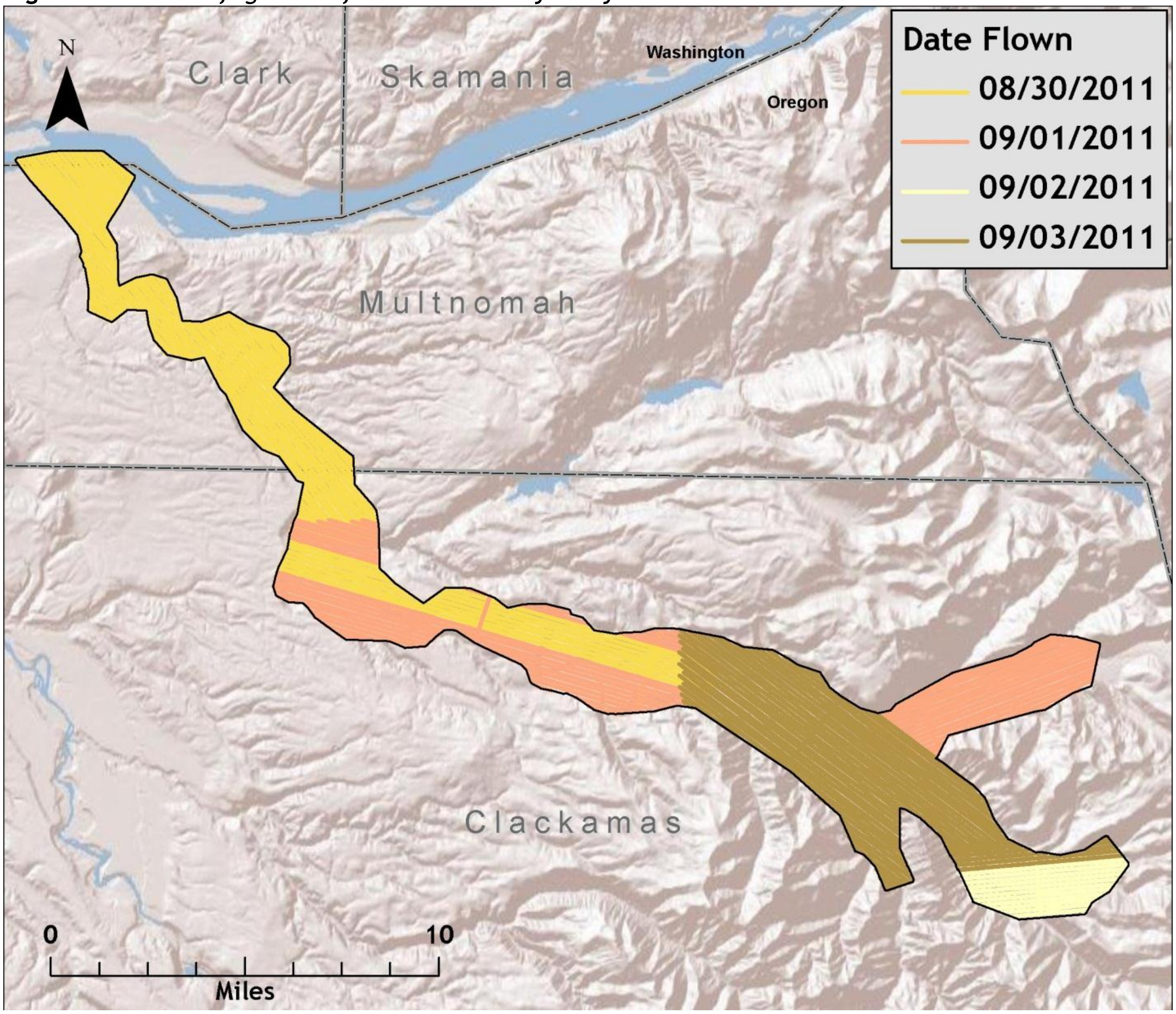


Table 2.2 *Acquisition Resource Utilization for OLC Sandy survey.*

Days on Project	Weather % Flyable	Utilized (hrs/day)	Productivity (acres/day)	Flight Time
5	58%	3.5	13,610	17 hours

2.2 Ground Survey – Instrumentation and Methods

During the LiDAR survey, static (1 Hz recording frequency) ground surveys were conducted over either known or set monuments. Monument coordinates are provided in **Table 2.2** and shown in **Figure 2.2** for the 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[2]) to quantify daily variance. Multiple sessions are processed over the same monument to confirm antenna height measurements and reported position accuracy. Control monuments are located within 13 nautical miles of the survey area(s). Indexed by time, these GPS data records are used to correct the continuous onboard measurements of aircraft position recorded throughout the mission.

2.2.1 Instrumentation

For this study area all Global Navigation Satellite System (GNSS[3]) survey work utilizes a Trimble GNSS receiver model R7 with a Zephyr Geodetic Model 2 antenna with ground plane for static control points. The Trimble GNSS R8 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 5 seconds then calculating the pseudo range position from at least three epochs with the relative error under 1.5 cm horizontal and 2 cm vertical. All GPS measurements are made with dual frequency L1-L2 receivers with carrier-phase correction.

2.2.2 Monumentation

Whenever possible, existing and established survey benchmarks shall serve as control points during LiDAR acquisition including those previously set by Watershed Sciences. In addition to NGS, the county surveyor's offices and the 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 monumentation, Watershed Sciences produces our own monuments. These monuments are spaced at a minimum of one

[2] Online Positioning User Service (OPUS) is run by the National Geodetic Survey to process corrected monument positions.
[3] GNSS: Global Navigation Satellite System consisting of the U.S. GPS constellation and Soviet GLONASS constellation

mile and every effort is made to keep these monuments within the public right of way or on public lands. If monuments are required on private property, consent from the owner is required. All monumentation is done with 5/8” x 30” rebar topped with a 2" diameter aluminum cap stamped “Watershed Sciences, Inc.".

2.2.3 Methodology

Each aircraft is assigned a ground crew member with two R7 receivers and an R8 receiver. The ground crew vehicles are equipped with standard field survey supplies and equipment including safety materials. All control points are observed for a minimum of two survey sessions lasting no fewer than 2 hours. At the beginning of every session the tripod and antenna are reset, resulting in two independent instrument heights and data files. Data are collected at a rate of 1Hz using a 10 degree mask on the antenna.

The ground crew uploads the GPS data to the Dropbox website 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 3 CORS stations resulting in a fully adjusted position. CORPSCON[4] 6.0.1 software is used to convert the geodetic positions from the OPUS reports. After multiple days of data have been collected at each monument, accuracy and error ellipses are calculated. This information leads to a rating of the monument based on FGDC-STD-007.2-1998[5] Part 2 table 2.1 at the 95% confidence level.

All RTK measurements were made during periods with a Position Dilution of Precision (PDOP) of ≤ 3.0 and in view of at least six satellites by the stationary reference and roving receiver. RTK positions are 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 are not taken on highly reflective surfaces such as center line stripes or lane markings on roads. 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 that have 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

[4] U.S. Army Corps of Engineers , Engineer Research and Development Center Topographic Engineering Center software

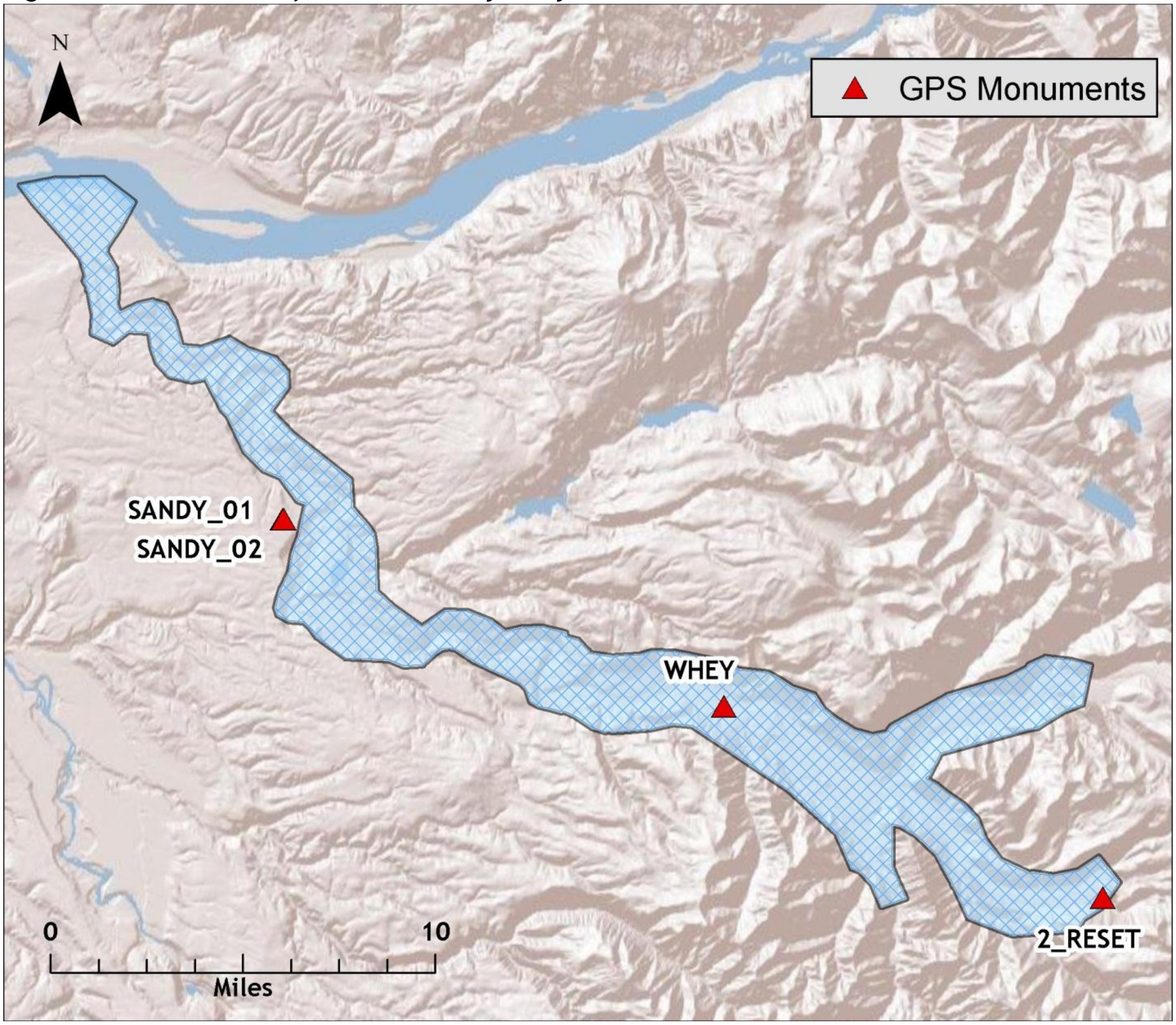
[5] Federal Geographic Data Committee Draft Geospatial Positioning Accuracy Standards

radio-relayed kinematic corrected positions from the base unit. This RTK survey allowed precise location measurement (σ ≤ 1.5 cm). **Figure 2.3** shows subsets of these RTK locations.

Table 2.2. *Base Station Surveyed Coordinates, (NAD83/NAVD88, OPUS corrected) used for kinematic post-processing of the aircraft GPS data for the OLC Sandy Study Area.*

	Datum NAD83 (HARN)		**GRS80**
Base Stations ID	**Latitude (North)**	**Longitude (West)**	**Ellipsoid Height (m)**
SANDY_01	45 26 36.0565	122 16 23.525	214.116
SANDY_02	45 26 36.0582	122 16 21.443	215.189
2_RESET	45 18 23.7527	121 49 50.181	807.686
WHEY	45 22 34.2072	122 02 05.442	302.077

Figure 2.2. *Base stations for the OLC Sandy Study Area.*



For data delivered to date, 193 RTK (Real-time kinematic) points were collected in the study area. **Figures 2.3** shows detailed views of selected RTK locations for all areas.

Figure 2.3 *Selected RTK point images are NAIP orthophotos.*

3. Hydro-Flattening Methodology

All bare-earth hydro-flattened digital elevation models (DEMs) have been hydro-flattened according to the U.S. Geological Survey's National Geospatial Program's "LiDAR Guidelines and Base Specification" Version 13 (USGS NGP). For all water bodies perceived to be “flat,” LiDAR points were sampled to arrive at an elevation threshold defining the water surface at a uniform elevation where the water edge meets the surrounding terrain. Three dimensional breaklines were then created to encompass all areas considered to be water and were assigned the water surface elevation value determined previously. All “flat” water bodies greater than 2 acres were considered for hydro-flattening. All “islands” greater than 100 m^2 were retained in the DEMs.

Centerlines were digitized for all water surfaces not perceived as “flat.” Thousands of points were sampled along the stream and channel centerlines to generate three-dimensional z values. A smoothing algorithm was then applied to ensure the centerlines consistently run downstream. LiDAR points were classified as water using the z threshold values of the appropriate centerlines. A breakline polygon was created around the water points with all discontinuities (e.g., bridges, overhanging vegetation, etc.) removed. Z values were applied to the breakline polygon based on the elevation values of the closest associated centerline vertex. Again, “islands” were retained in the bare-earth DEMs if greater than 100 m^2.

The bare-earth DEMs were created by triangulating all “ground” classified points and inserting 3-D breaklines utilizing TerraSolid’s TerraScan and TerraModeler software. Any ground points within 1 m of the breaklines were reclassified to “ignored-ground” (ASPRS code: 10) before triangulation. The highest-hit DEMs were generated from “ground” and “default” classified points. In instances where “water” classified points had the highest elevation value, the water surface elevation from the bare-earth raster was used.

Figure 3.1. *Hillshade comparison of (A) Non-hydro-flattened raster and (B) Hydro-flattened raster*

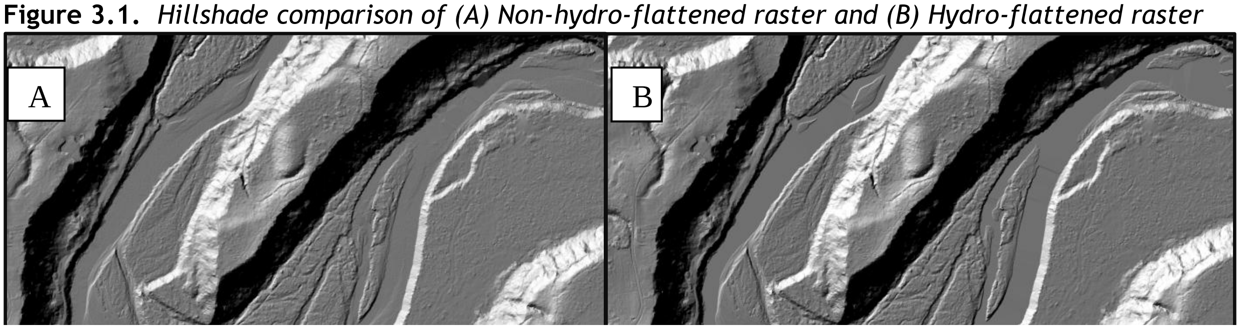
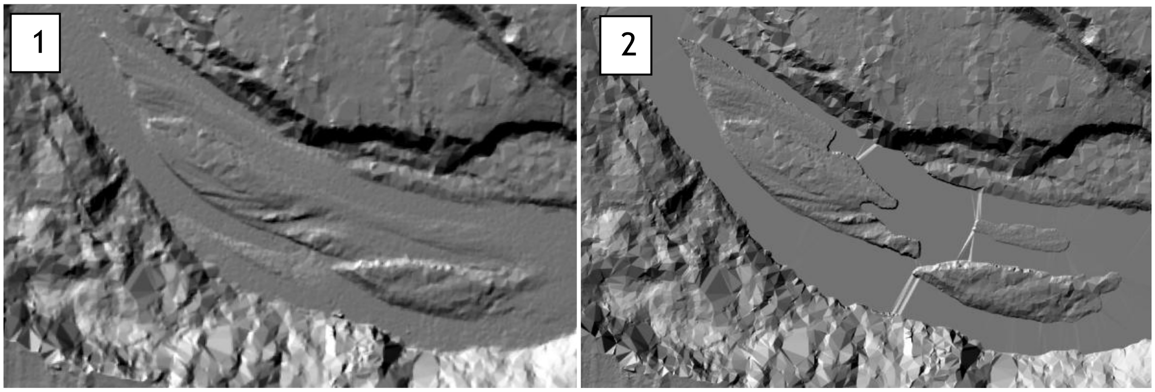
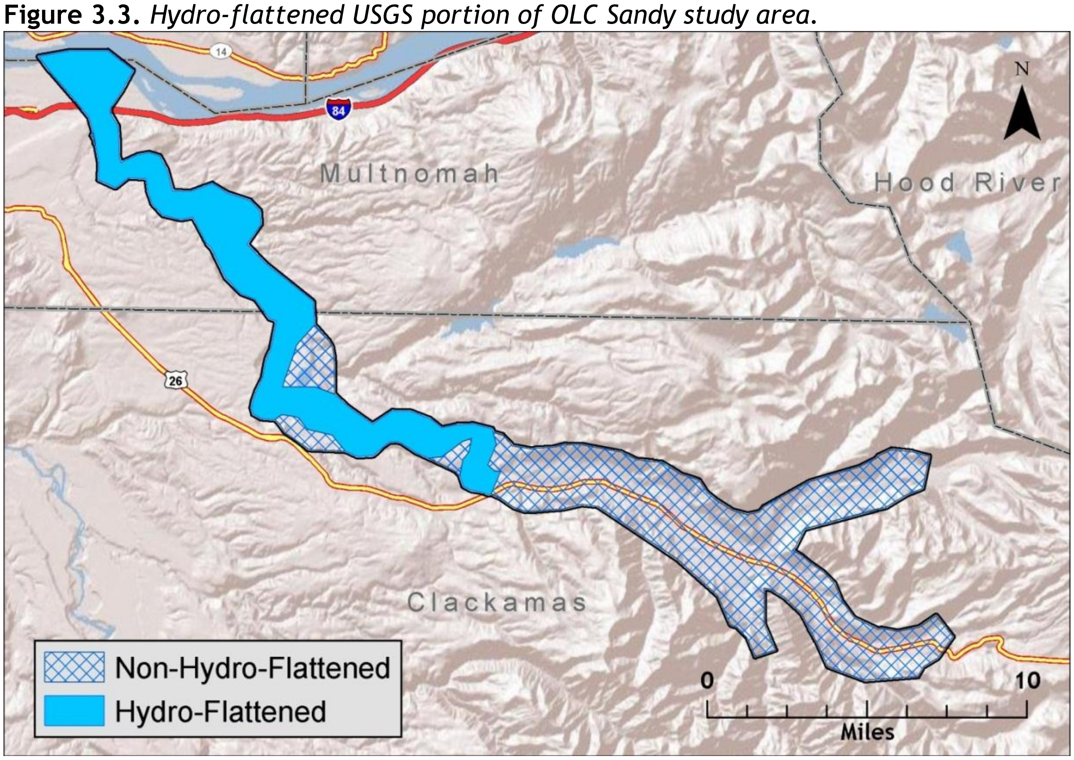


Figure 3.2. *Hydro-flattening artifacts that appear in the data*



Hydro-Flattening of the Sandy River was conducted in adherence to the USGS LiDAR Guidelines and Base Specifications Version 13 (USGS Spec). There were several processing challenges due to the complex nature of this fluvial system. In particular, high gradient streams with plentiful sediment flows tend to have cross current waterfalls not occurring perpendicular to the stream bank (Image 1). On page 8, guideline 3, section 2, bullet point 2, the USGS Spec states that river breaklines should be "level bank-to-bank (perpendicular to the apparent flow centerline)" and that "the water surface edge (is) at or below the immediately surrounding terrain". WSI adhered to these guidelines (Image 2), recognizing that the methodology would introduce artifacts markedly different from the true topography of the stream corridor (Image 1).

Figure 3.3. *Hydro-flattened USGS portion of OLC Sandy study area.*



4. Accuracy

4.1 Relative Accuracy

Relative Accuracy Calibration Results

Relative accuracy refers to the internal consistency of the data set and is measured as the divergence between points from different flightlines within an overlapping area. Divergence is most apparent when flightlines 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.

Relative accuracy statistics are based on the comparison of 152 flightlines and over 300 million points. Relative accuracy is reported for the portion of the study area shown in **Figure 4.1** below.

- Project Average = 0.12ft (0.03m)
- Median Relative Accuracy = 0.11 ft (0.03 m)
- 1σ Relative Accuracy = 0.13 ft (0.04m)
- 2σ Relative Accuracy = 0.21 ft (0.06 m)

Figure 4.1. *Relative Accuracy Covered Area.*

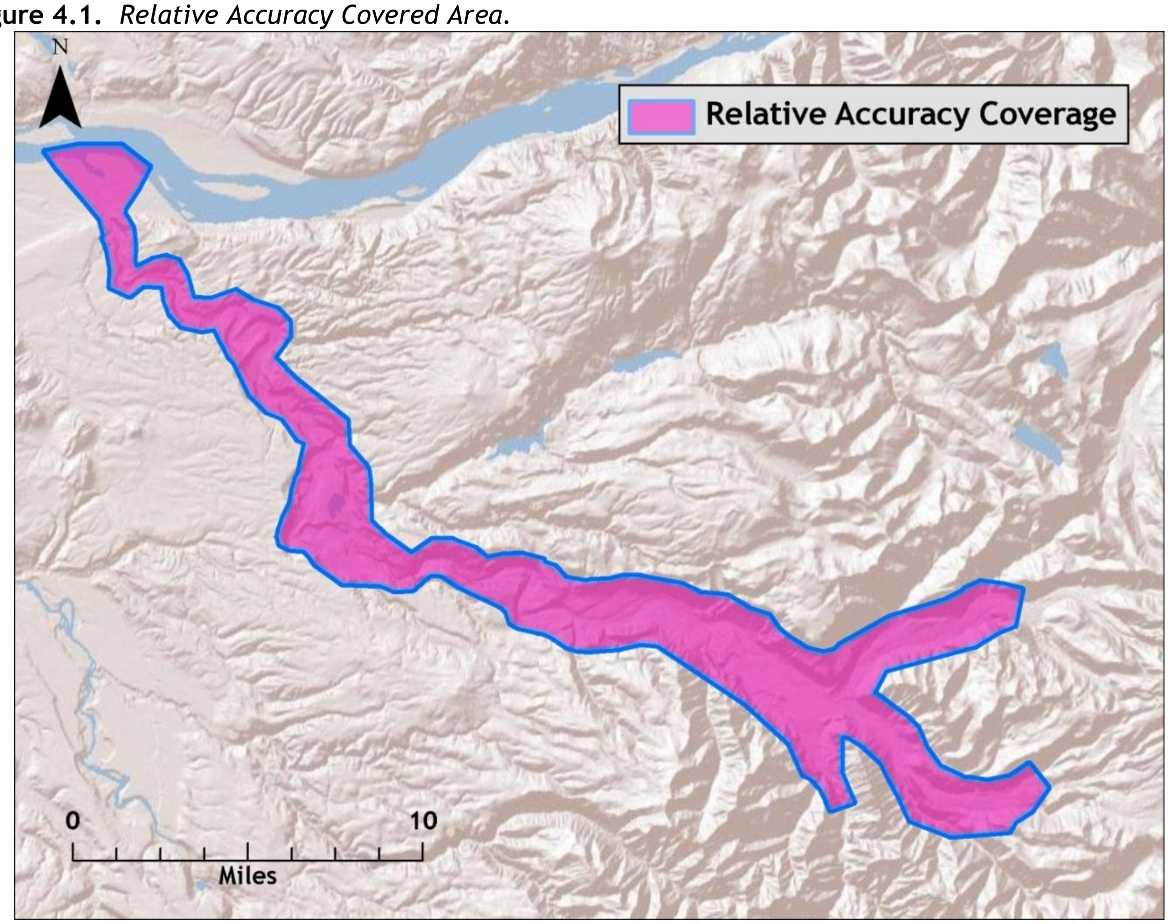


Figure 4.2. *Statistical relative accuracies, non slope-adjusted.*

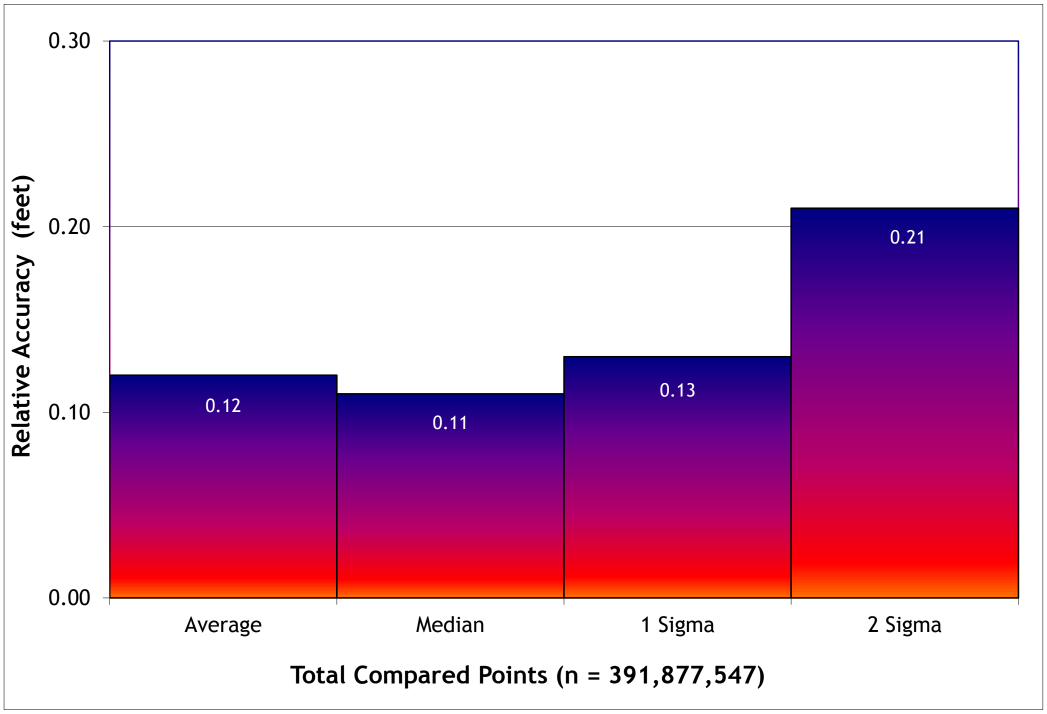
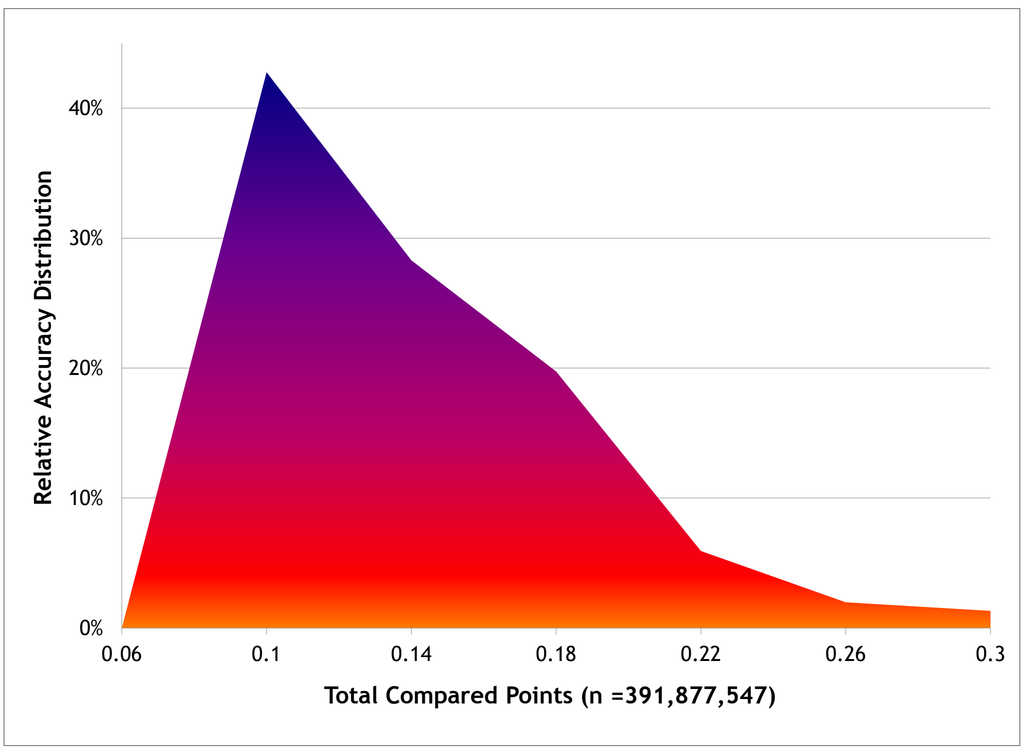


Figure 4.3. *Percentage distribution of relative accuracies, non slope-adjusted.*



4.2 Absolute Accuracy

Absolute accuracy compares known RTK ground survey points to the closest laser point. For the OLC Sandy Study Area, 193 RTK points were collected for data in the study area. Absolute accuracy is reported for the portion of the study area shown in **Figure 4.4** and reported in **Table 4.1** below. Histogram and absolute deviation statistics are reported in **Figures 3.5 and 3.6**.

Table 4.1. *Absolute Accuracy – Deviation between laser points and RTK survey points.*

Sample Size (n): 193	
Root Mean Square Error (RMSE): 0.13 ft (0.04m)	
Standard Deviations	**Deviations**
1 sigma (σ): 0.12ft (0.04 m)	**Minimum Δz:** -0.30 ft (-0.09m)
2 sigma (σ): 0.26 ft (0.08 m)	**Maximum Δz:** 0.37 ft (0.11 m)
	Average Δz: 0.01 ft (0.00 m)

Figure 4.4. *Absolute Accuracy Covered Area.*

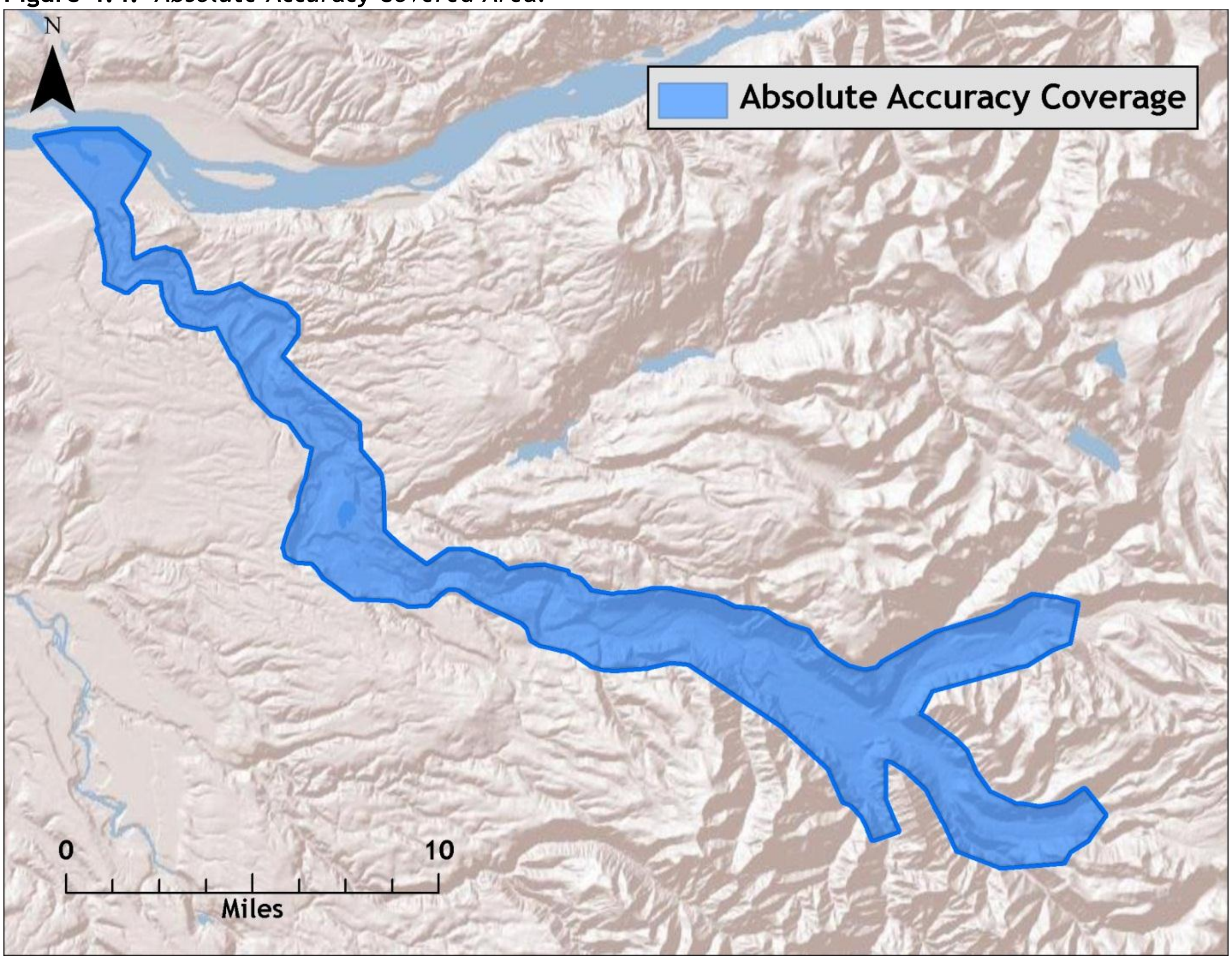


Figure 4.5. *OLC Sandy Study Area histogram statistics*

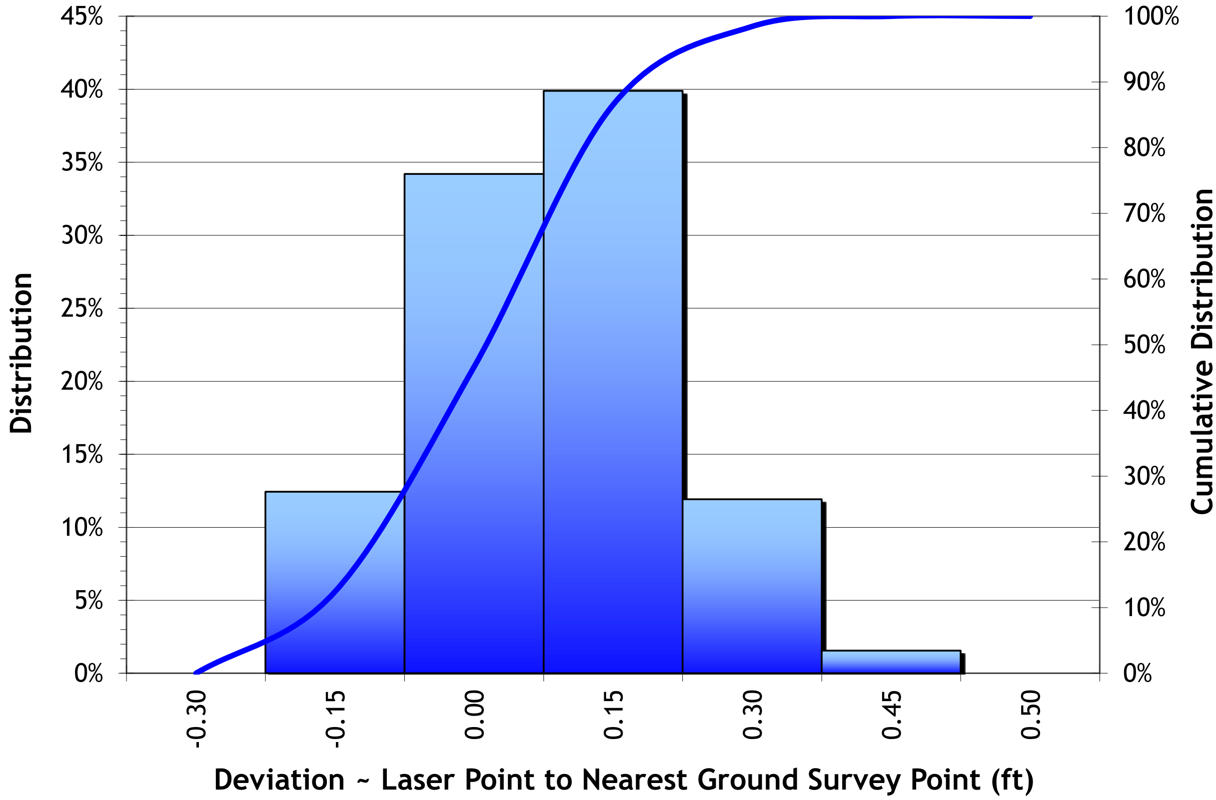
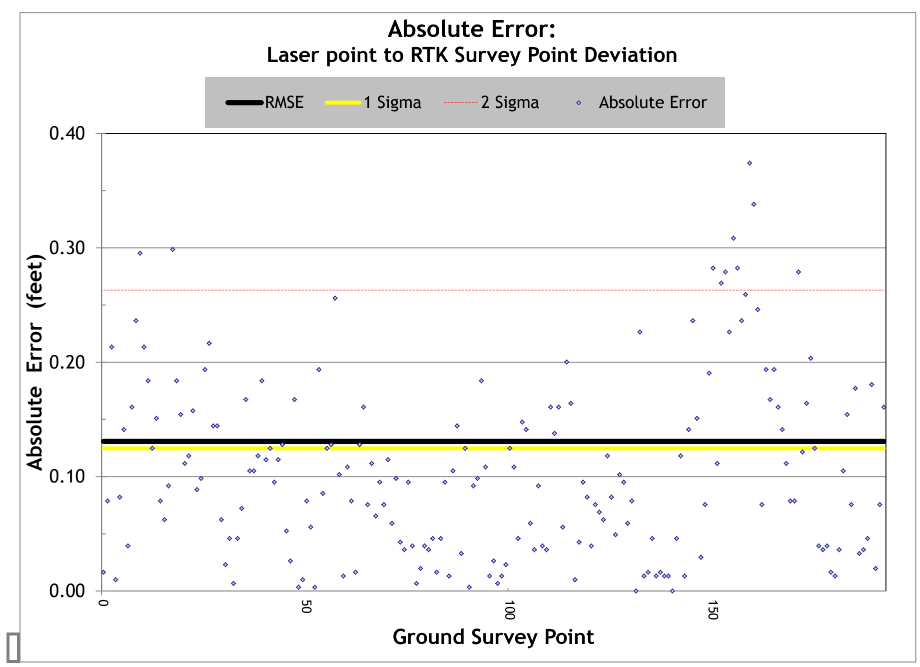


Figure 4.6. *OLC Sandy Study Area point absolute deviation statistics.*



5. Data Density/Resolution

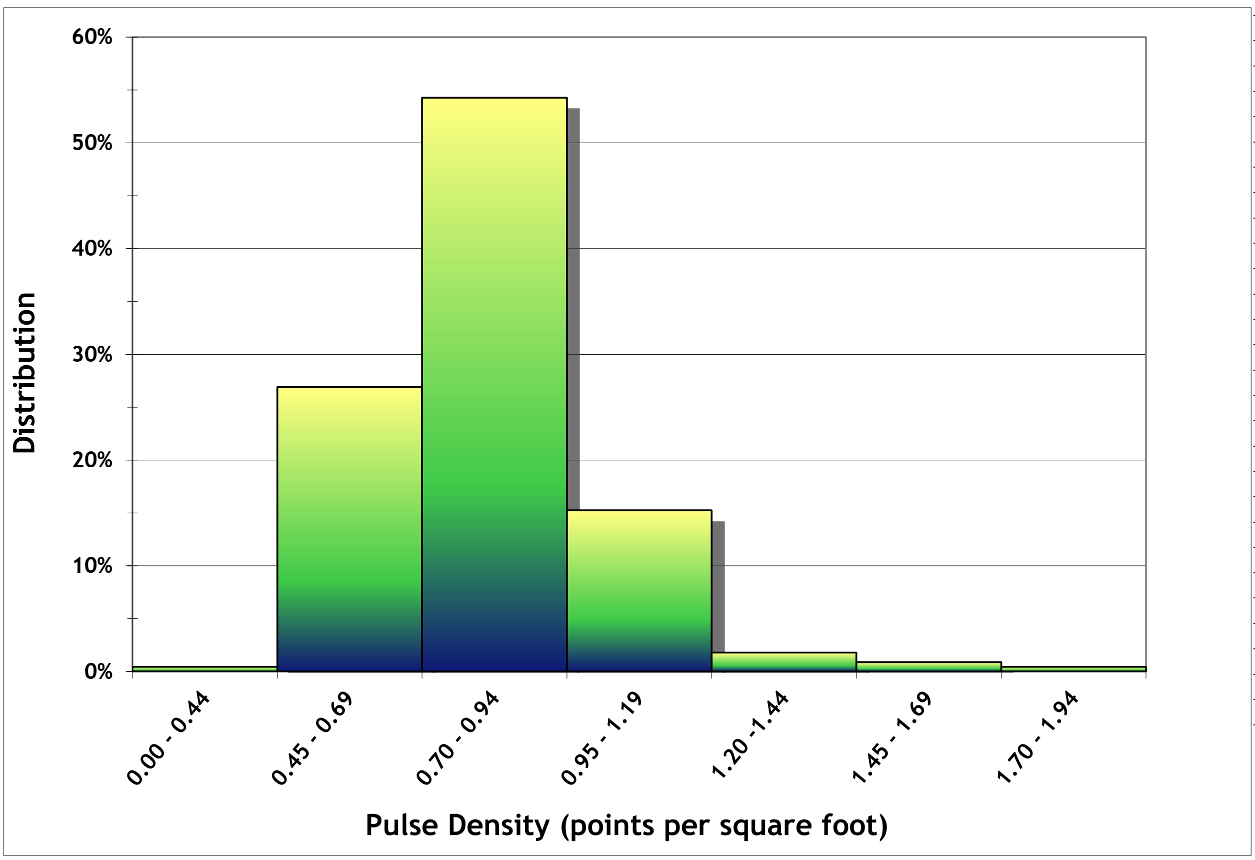
5.1 Density Statistics

Some types of surfaces (i.e. dense vegetation or water) may return fewer pulses than the laser originally emitted. Therefore, the delivered density can be less than the native density and vary according to terrain, land cover and water bodies. Density histograms and maps (**Figures 5.1 – 5.4)** have been calculated based on first return laser point density and ground-classified laser point density.

Table 5.1. *Average density statistics for the OLC Sandy Study Area.*

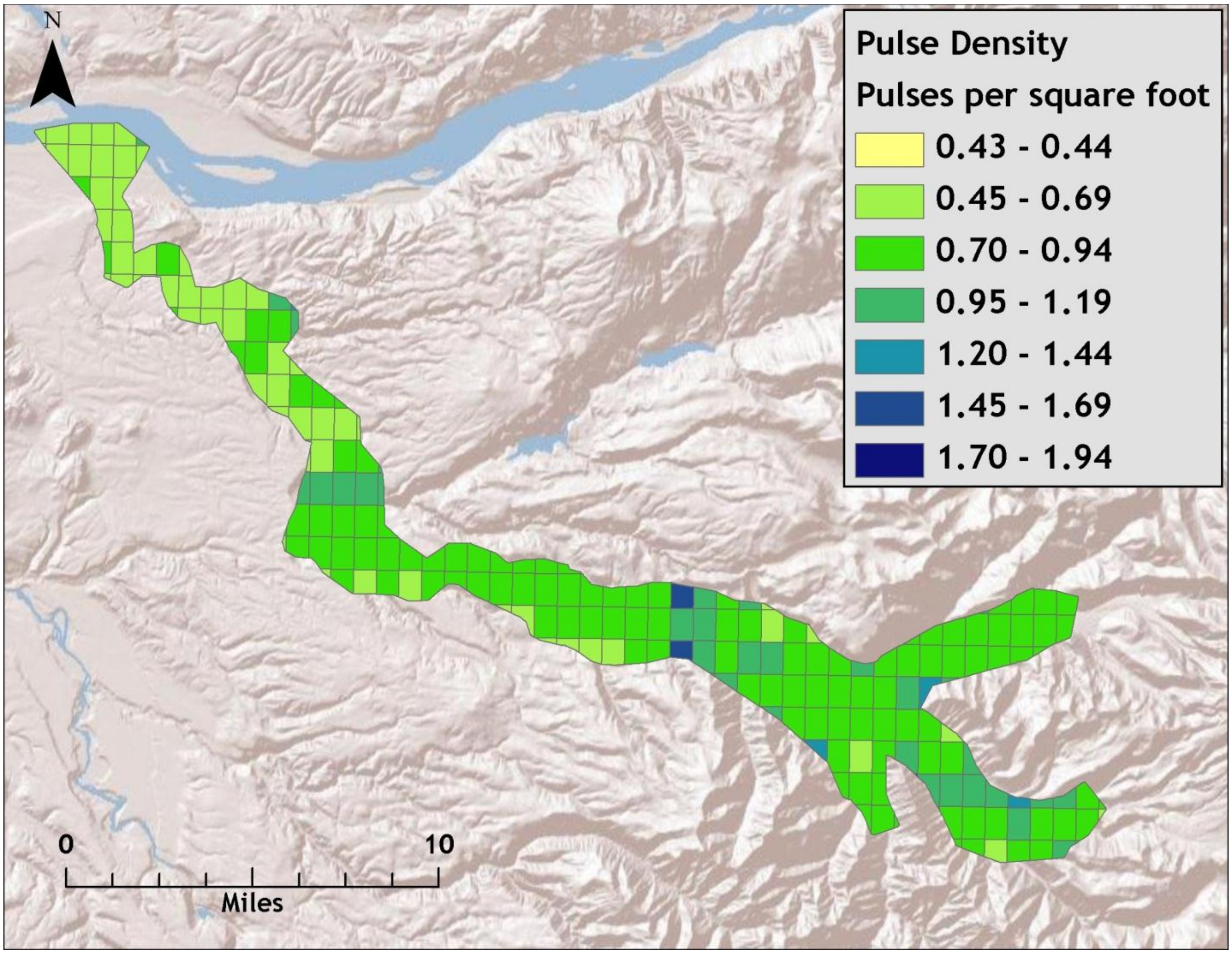
Average Pulse Density (per square ft)	Average Pulse Density (per square m)	Average Ground Density (per square ft)	Average Ground Density (per square m)
0.82	8.80	0.05	0.52

Figure 5.1. *Histogram of first return laser point density.*



Pts ft²	Pts m²
0.00	0.00
0.05	0.54
0.10	1.08
0.15	1.61
0.20	2.15
0.25	2.69
0.30	3.23
0.35	3.77
0.40	4.31
0.45	4.84
0.50	5.38
0.55	5.92
0.60	6.46
0.65	7.00
0.70	7.53
0.75	8.07
0.80	8.61
0.85	9.15
0.90	9.69
0.95	10.23
1.00	10.76
1.05	11.30
1.10	11.84
1.15	12.38
1.20	12.92
1.25	13.45
1.30	13.99
1.35	14.53
1.40	15.07
1.45	15.61
1.50	16.15

Figure 5.2. *First return laser point densities per 0.75' USGS Quad.*



Pts ft^2	Pts m^2
0.00	0.00
0.05	0.54
0.10	1.08
0.15	1.61
0.20	2.15
0.25	2.69
0.30	3.23
0.35	3.77
0.40	4.31
0.45	4.84
0.50	5.38
0.55	5.92
0.60	6.46
0.65	7.00
0.70	7.53
0.75	8.07
0.80	8.61
0.85	9.15
0.90	9.69
0.95	10.23
1.00	10.76
1.05	11.30
1.10	11.84
1.15	12.38
1.20	12.92
1.25	13.45
1.30	13.99
1.35	14.53
1.40	15.07
1.45	15.61
1.50	16.15

Figure 5.3. *Histogram of ground-classified laser point density.*

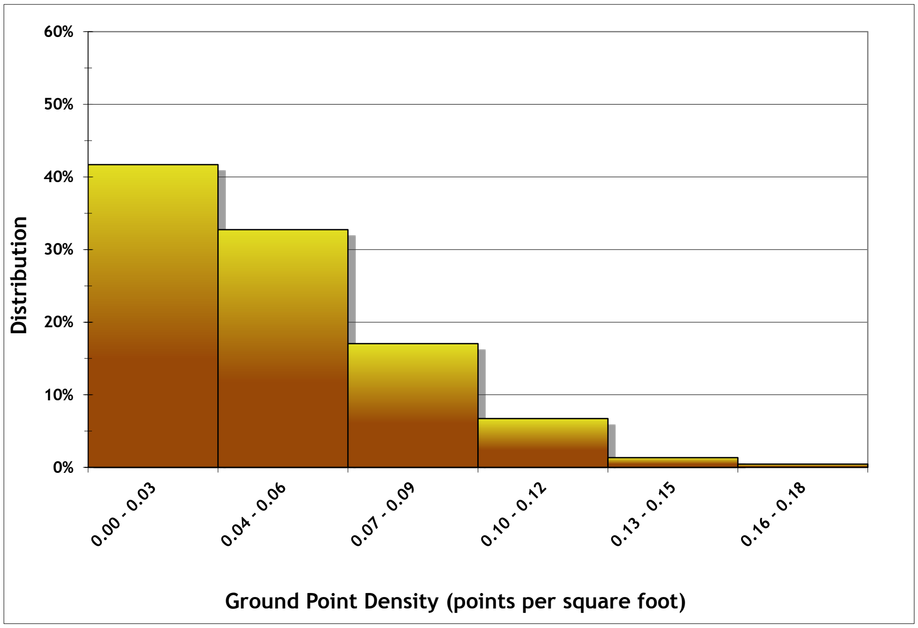
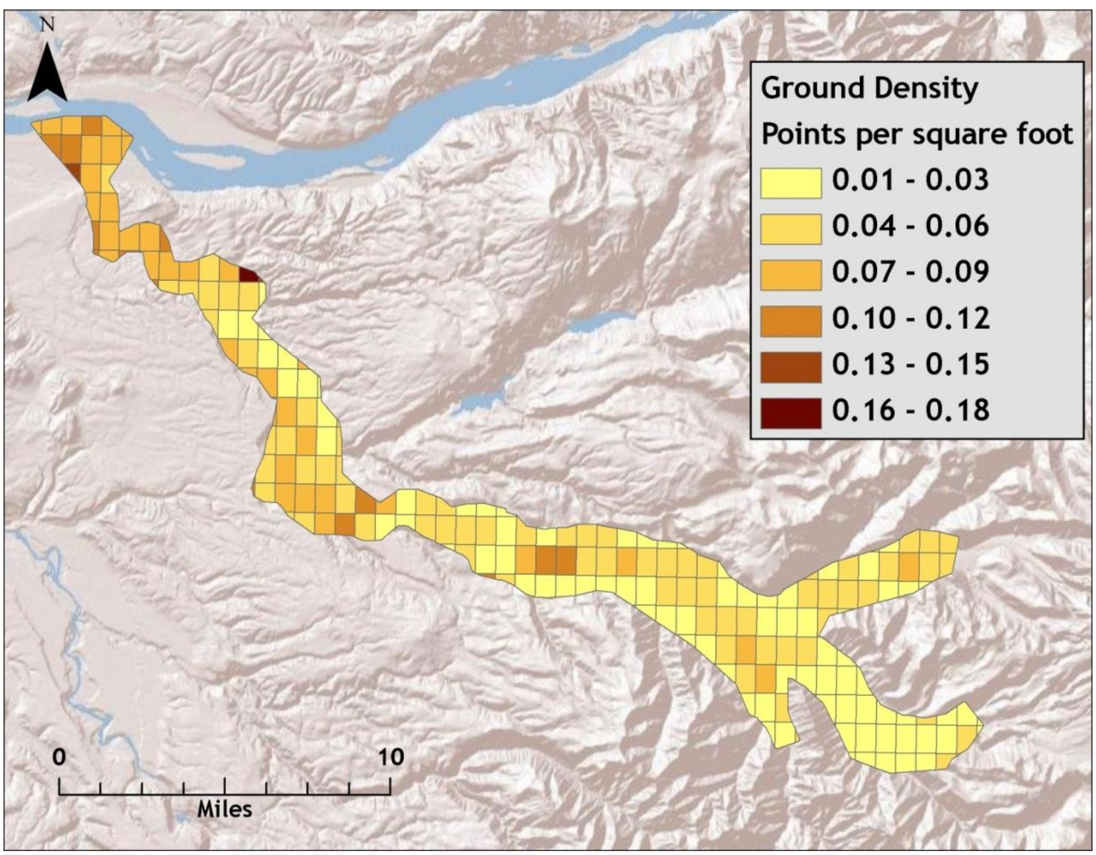


Figure 5.4. *Ground-classified laser point density per 0.75' USGS Quad for data delivered to date.*



Pts ft²	Pts m²
0.00	0.00
0.05	0.54
0.10	1.08
0.15	1.61
0.20	2.15
0.25	2.69
0.30	3.23
0.35	3.77
0.40	4.31
0.45	4.84
0.50	5.38
0.55	5.92
0.60	6.46
0.65	7.00
0.70	7.53
0.75	8.07
0.80	8.61
0.85	9.15
0.90	9.69
0.95	10.23
1.00	10.76
1.05	11.30
1.10	11.84
1.15	12.38
1.20	12.92
1.25	13.45
1.30	13.99
1.35	14.53
1.40	15.07
1.45	15.61
1.50	16.15

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6 Certifications

Watershed Sciences provided LiDAR services for the Sandy River study area as described in this report.

I, Mathew Boyd, have reviewed the attached report for completeness and hereby state that it is a complete and accurate report of this project.

Mathew Boyd
Principal
Watershed Sciences, Inc.

I, Christopher W. Yotter-Brown, being first dully sworn, say that as described in the Ground Survey subsection of the Acquisition section of this report was completed by me or under my direct supervision and was completed using commonly accepted standard practices. Accuracy statistics shown in the Accuracy Section have been reviewed by me to meet National Standard for Spatial Data Accuracy.

Christopher W. Yotter-Brown, PLS Oregon & Washington
Watershed Sciences, Inc
Portland, OR 97204

REGISTERED
PROFESSIONAL
LAND SURVEYOR

11/18/2011

OREGON
JULY 13, 2004
Christopher W. Yotter - Brown
60438 LS

RENEWAL DATE: 6/30/2012

6. Selected Imagery

Figure 6.1. *Interstate 5 crossing the Sandy River, two miles south of the confluence with the Columbia River. View to the South. RGB color extraction from 2009 NAIP orthoimagery.*

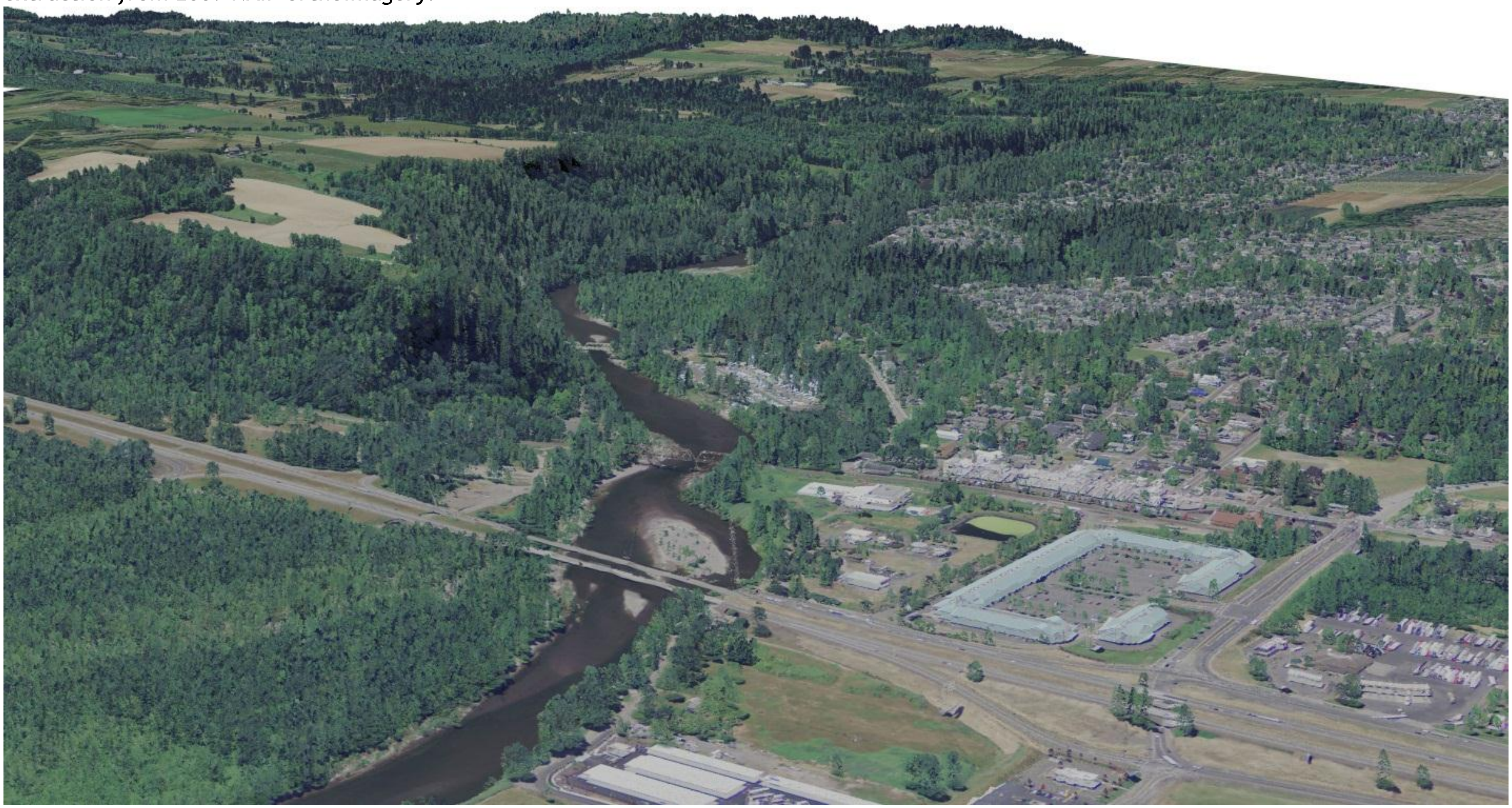

Figure 6.2 *Sandy River meander seven miles east of Gresham. View to the North. RGB color extraction from 2009 NAIP orthoimagery.*