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February 9, 2012

Teresa Dean
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National Mapping Program
12201 Sunrise Valley Dr, **Mail Stop 511**
Reston, VA 20192

Subject: Final Technical Report

Reference: U.S. Geological Survey (USGS) Award No. G10AC00103

Title: 2010-2011 Lidar Update for Pierce County, Washington

Term: March 1, 2010 – September 30, 2011

Dear Ms. Dean:

Please find our final Technical report attached as stipulated in our contract for USGS ARRA Assistance Award No. G10AC00103. We are excited with the final product and believe that USGS will be pleased as well. We would like to thank USGS for their understanding and patience regarding the initial failure of contract negotiations, updated acquisition specifications and weather related delays in the acquisition and delivery of the data.

Please contact me at 253-798-6064 or rheasty@co.pierce.wa.us for any questions or to request additional information.

Sincerely,

Ross Heasty
Principal Investigator for Award G10AC00103
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Enclosure: USGS Award No. G10AC00103 Final Technical Report

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Abstract

Pierce County, Washington has used lidar data since 2004 as a mission critical component of the County's Geographic Information System (GIS). The data, collected from 2000 to 2004, has been used for a variety of purposes, including economic development, environmental planning, construction and transportation projects, and emergency management. However, this data was collected with older technology under outdated standards. Much of the original data was not accepted by the U.S. Geological Survey (USGS) for the National Elevation Dataset due to its poor quality. As such, this project acquired new airborne lidar data to provide a high quality dataset for use by regional partners and the general public. The coverage extent is part of the USGS lidar priority collection areas for the National Elevation Dataset. It will include all of Pierce County except Mount Rainier National Park and military bases. Resulting high quality LAS and DEM products will be part of the National Elevation Dataset and used by Pierce County, the Puyallup, Muckleshoot and Nisqually tribes, and over 25 agencies, cities and businesses that use Pierce County Geographic Information Systems (GIS). This report addresses the acquisition, processing and Quality Assurance/Quality Control processes used during the project to ensure complete and accurate data acquisition.

Project Summary

Project Area

Located in the west central portion of Washington State, Pierce County has a unique topographic profile that ranges from sea level at Puget Sound to 14,411 feet at the peak of Mt. Rainier. The county has over 225 miles of coastal shoreline and includes Anderson Island, McNeil Island, Fox Island, and portions of the Kitsap Peninsula. Four major rivers (Puyallup, Nisqually, White, and Carbon), several smaller tributaries, and over 361 lakes provide a wealth of recreational activities for residents and tourists.

The county's total land area is 1,794 square miles, with over 38% of it controlled by State and Federal governments. 22 cities and towns are within county boundaries. As of 2009, the total population was 813,600, making Pierce County the second most populous county in Washington State.

The lidar collection area (Figure 1) will cover 1,461 square miles and encompass all of Pierce County except Mt. Rainier National Park, Joint Base Lewis-McChord. These Federal lands have been excluded due to recent lidar collection in their respective areas. The collection area will include Puyallup tribal lands and portions of the Muckleshoot and Nisqually reservations.

Watershed Sciences project workflow

Acquisition Overview

Watershed Sciences, Inc. collected Light Detection and Ranging (LiDAR) data for Pierce County at various time periods (weather permitting) during the following time period: October, 2010 – September, 2011 (Table 1). The 21 deliveries for Pierce County totaled 932,850 acres (Figure 2).

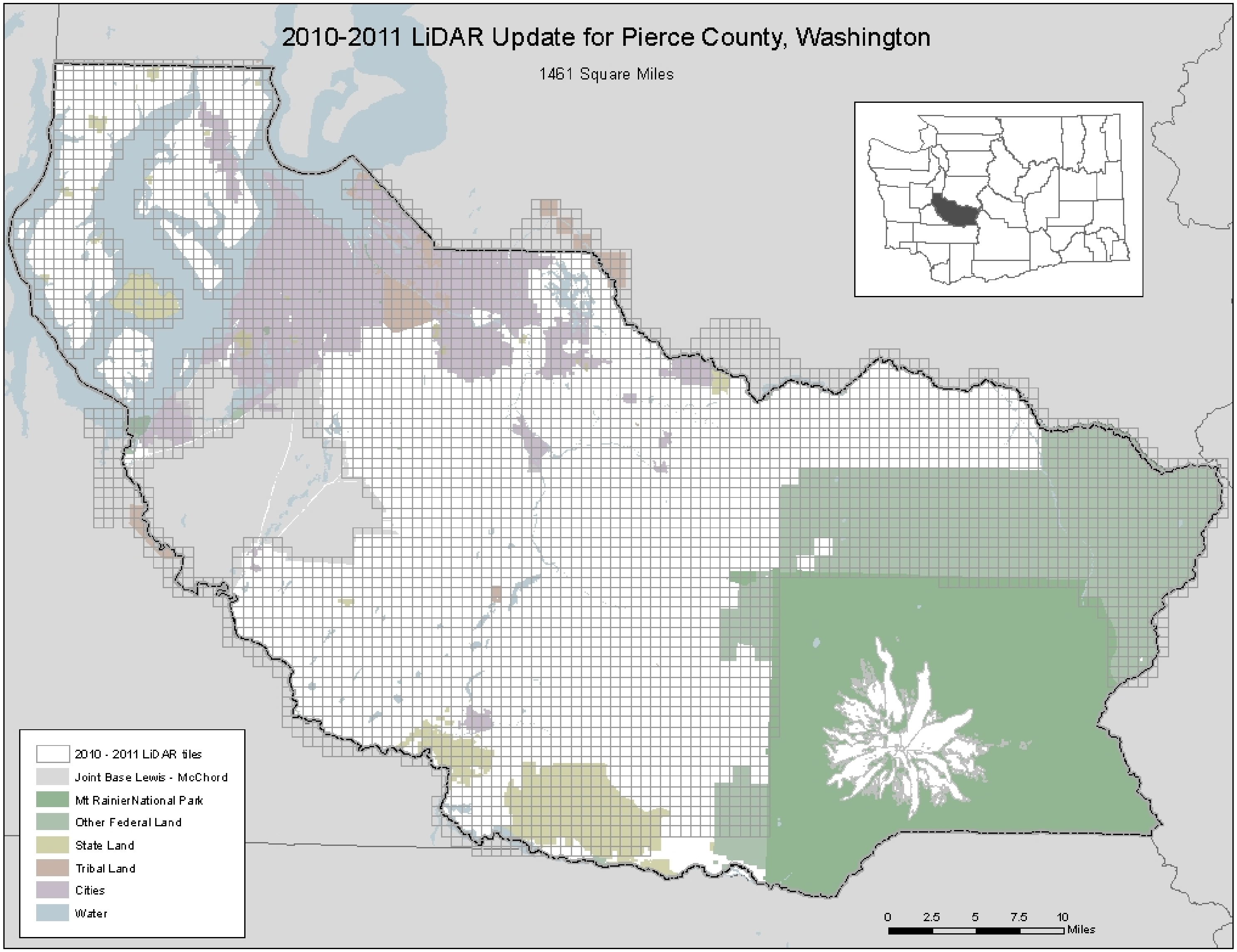


Figure 1: LiDAR acquisition delivery tiles for the 2010-2011 LiDAR update project for Pierce County.

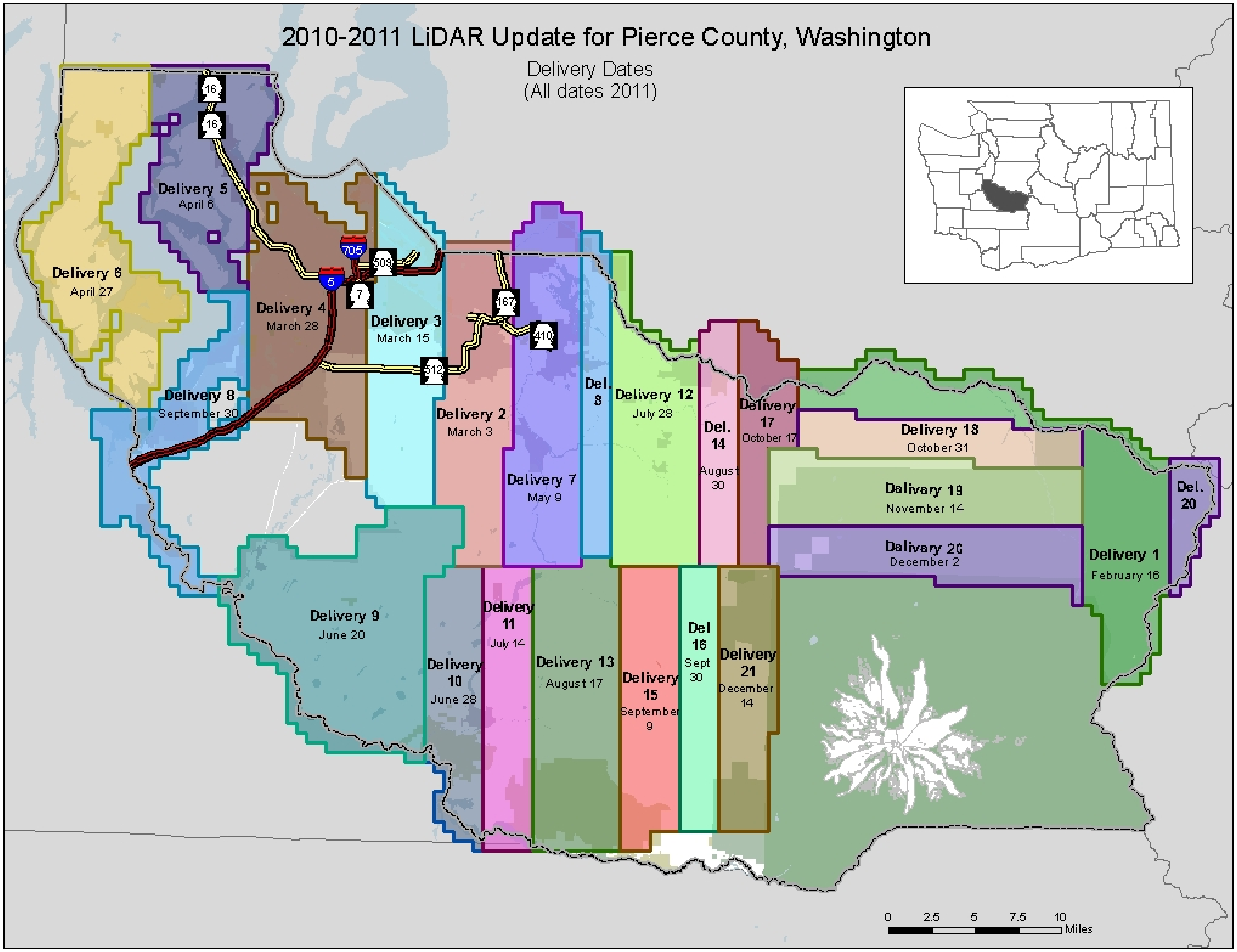


Figure 2: LiDAR deliveries for the 2010-2011 LiDAR update project for Pierce County.

Table 1: Acquisition schedule per delivery for the 2010-2011 LiDAR update project for Pierce County.

Delivery	Area	Flight Dates	Delivery Dates	Delivery	Area	Flight Dates	Delivery Dates
Delivery 1	66,942 acres	10/19/10 - 10/21/10 11/03/10 - 11/04/10	02/14/11	Delivery 15	34,711 acres	02/10/11,04/22/11, 04/29/11, 06/04/11 07/02/11, 07/04/11	09/07/11
Delivery 2	45,455 acres	12/03/10 - 12/06/10 12/08/10, 12/10/10	02/28/11	Delivery 16	22,314 acres	04/22/11, 04/23/11 06/05/11, 07/04/11 07/24/11	09/30/11
Delivery 3	47,107 acres	12/03/10 - 12/06/10 12/08/10, 12/10/10	03/07/11	Delivery 17	21,281 acres	11/03/10, 11/04/10 06/05/11, 07/23/11 07/28/11, 07/30/11 08/27/11, 09/03/11 09/04/11 - 09/06/11	10/15/11
Delivery 4	62,810 acres	12/08/10, 12/10/10 01/02/11, 01/04/11	03/25/11	Delivery 18	25,620 acres	10/19/10, 07/23/11 07/28/11, 07/30/11 09/04/11 - 09/06/11	10/28/11
Delivery 5	46,281 acres	01/02/11, 01/04/11 01/26/11, 01/30/11	04/05/11	Delivery 19	45,041 acres	10/19/10, 07/23/11 07/28/11, 07/30/11 09/04/11, 09/05/11	11/11/11
Delivery 6	60,537 acres	01/26/11, 01/27/11 01/30/11, 02/05/11	04/26/11	Delivery 20	46,694 acres	10/19/10,10/21/10 07/23/11, 07/28/11 09/03/11, 09/04/11 09/06/11	12/01/11
Delivery 7	54,545 acres	12/03/10, 12/04/10 02/09/11	05/05/11	Delivery 21	31,405 acres	04/23/11, 06/05/11 07/23/11, 07/24/11 07/28/11, 08/27/11 09/03/11, 09/06/11	12/13/11
Delivery 8	55,578 acres	01/03/11 02/08/11 - 02/10/11 02/20/11	05/31/11	**Total Delivered Area**	**932,850 acres**		
Delivery 9	82,851 acres	12/04/10 - 12/06/10 02/01/11, 02/02/11 02/07/11, 02/20/11	06/17/11				
Delivery 10	31,818 acres	12/04/10 - 12/05/10 02/01/11, 04/20/11	06/27/11				
Delivery 11	29,959 acres	12/03/10 - 12/04/10 02/09/11, 04/20/11 04/22/11 - 04/23/11	07/12/11				
Delivery 12	46,901 acres	02/10/11 04/22/11 - 04/23/11 04/29/11	07/28/11				
Delivery 13	54,545 acres	02/09/11 - 02/10/11 04/22/11 - 04/23/11 04/29/11, 06/03/11 06/04/11	08/15/11				
Delivery 14	20,455 acres	04/22/11 - 04/23/11 06/05/11	08/29/11				

Acquisition

Airborne Survey – Instrumentation and Methods

The LiDAR survey used two Leica ALS50 Phase II and an ALS 60 laser systems mounted in a Cessna Caravan 208B. The Leica systems were set to acquire ≥83,000 – 105,900 laser pulses per second (i.e., 83 – 105.9 kHz pulse rate) and flown at 900 - 1300 meters above ground level (AGL) depending on weather and terrain, capturing a scan angle of ±14o from nadir. These settings were developed to yield points with an average native pulse density of ≥8 pulses per square meter over terrestrial surfaces. It is not uncommon for some types of surfaces (e.g. dense vegetation or water) to return fewer pulses than the laser originally emitted. These discrepancies between 'native' and 'delivered' density will vary depending on terrain, land cover, and the prevalence of water bodies.

All areas were surveyed with an opposing flight line side-lap of ≥50% (≥100% overlap) to reduce laser shadowing and increase surface laser painting. The Leica laser systems allow up to four range measurements (returns) per pulse, and all discernable laser returns were processed for the output dataset.

To accurately solve for laser point position (geographic coordinates x, y, z), the positional coordinates of the airborne sensor and the attitude of the aircraft were recorded continuously throughout the LiDAR data collection mission. Aircraft position was 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). To allow for post-processing correction and calibration, aircraft/sensor position and attitude data are indexed by GPS time.

Ground Survey – Instrumentation and Methods

WSI staff surveyor, Chris Yotter-Brown (WA PLS 46328), certified all monuments and provided PLS oversight for the Pierce County data collection. The survey control plan was designed to provide redundant control within 13 nautical miles of the mission areas for LiDAR flights. The controls were set prior to the airborne missions. Monument coordinates are provided (Table 2) and shown (Figure 3). In addition, cover classes have been collected and a full statistical analysis was performed (Table 5).

Simultaneous with the airborne data collection mission, Watershed Sciences conducted multiple static (1 Hz recording frequency) ground surveys over the survey monuments. Indexed by time, these GPS data are used to correct the continuous onboard measurements of aircraft position recorded throughout the mission. After the airborne survey, the static GPS data are processed using triangulation with Continuously Operating Reference Stations (CORS) and checked using the Online Positioning User Service (OPUS[1]) to quantify daily variance. Multiple sessions are processed over the same monument to confirm antenna height measurements and reported position accuracy.

[1] Online Positioning User Service (OPUS) is run by the National Geodetic Survey to process corrected monument positions.

Table 2: Base Station control coordinates for Pierce County, Washington.

Base Station ID	Datum: NAD83 (CORS96)		GRS80
	Latitude	Longitude	Ellipsoid Z (meters)
PIERCE5_DT1	47°04'42.75983"N	121°32'12.57157"W	1479.911
PIERCE5_DT2	47°03'28.67722"N	121°31'33.99588"W	1614.859
PRC5_JM1*	47°03'37.90999"N	121°39'02.36162"W	1399.087
PRC5_JM2*	47°02'45.45128"N	121°39'03.28117"W	1323.192
CANYON_FALL	47°07'35.87273"N	122°13'31.45962"W	17.654
THUN_FIELD_RES	47°06'08.99191"N	122°17'23.21542"W	140.792
PRC_05	47°09'00.95667"N	122°20'09.48913"W	102.405
PRC_06	47°14'03.96855"N	122°29'48.51236"W	84.086
PRC_07	47°16'34.94795"N	122°34'26.89973"W	62.339
PRC_08	47°14'04.14993"N	122°29'48.91289"W	84.186
PRC_09	47°04'02.57741"N	122°42'53.17806"W	-15.941
PRC_10	47°05'39.36891"N	122°37'22.60117"W	57.472
PRC_11	47°09'20.13636"N	122°05'59.66019"W	182.229
PRC_12	47°10'12.88897"N	122°05'13.30278"W	182.531
PRC_13	47°09'48.75262"N	122°00'03.48110"W	207.153
PRC_13B*	47°09'49.20703"N	122°00'03.47643"W	207.094
FS2762*	47°05'39.36896"N	122°27'48.38614"W	80.642
TOWHEAD*	47°16'24.98888"N	122°39'04.73026"W	-17.754
PRC_JM1	46°56'15.11896"N	122°27'49.81342"W	128.644
PRC_JM2*	46°56'15.76860"N	122°30'28.44968"W	113.205
PRC_14	46°51'48.18146N	122°15'28.94994"W	237.698
PRC_15	46°51'52.87082"N	122°16'07.64355"W	268.068
PRC_16	47°05'41.55215"N	121°58'49.22075"W	508.384
PRC_16B*	47°05'41.41029"N	121°58'49.14234"W	508.409
PIERCE_17	46°58'02.68909"N	122°00'31.20599"W	871.040
PIERCE_18*	46°56'49.56910"N	122°12'26.79502"W	423.250
PRC_19*	46°57'39.02310"N	122°00'13.41752"W	900.955
PRC_20*	47°00'55.82779"N	121°38'44.38894"W	1416.250

*Basestations that have not been published by the PLS to date.

Instrumentation

For this project area, both Trimble GPS receiver model R7 with Zephyr Geodetic antenna with ground plane and Trimble GNSS receiver model R7 with Zephyr Geodetic Model 2 antenna where deployed for all static control. A Trimble model R8 GNSS unit was used for collecting check points using real time kinematic (RTK) survey techniques. For RTK data, the collector began 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.

Monumentation

Watershed Sciences incorporated control monuments that were located by Watershed Sciences field staff and certified by their staff surveyor, Chris Yotter-Brown (WA PLS 46328). Monuments selected were found to have good visibility and optimal location to support a LiDAR Acquisition flight (Table 2). Published PLS monuments can be found in Appendix B.

Methodology

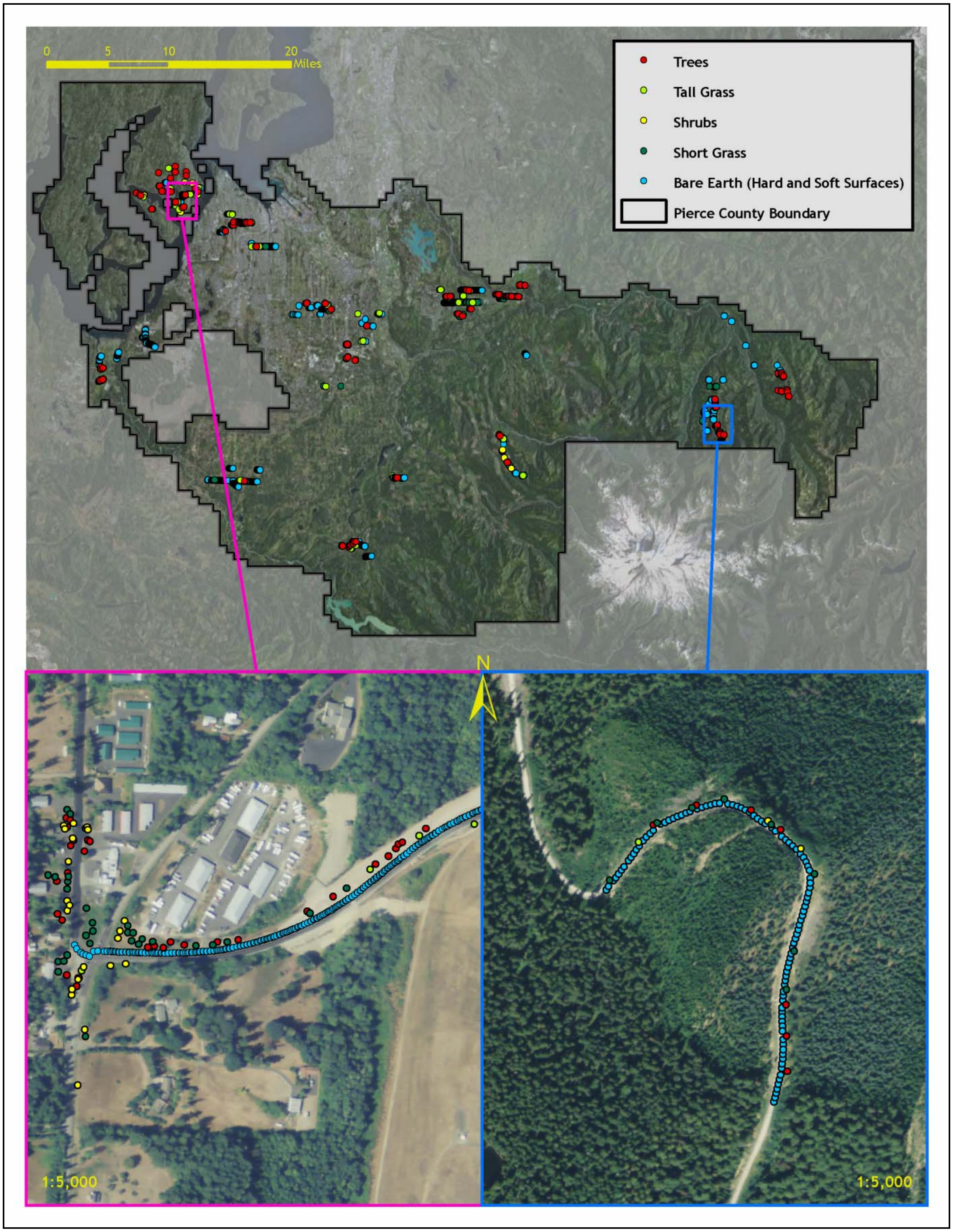
Each aircraft is assigned a ground crew member with two Trimble R7 receivers and an R8 receiver. The ground crew vehicles are equipped with standard field survey supplies and equipment including safety materials. All control monuments are observed for a minimum of one survey session lasting no fewer than 4 hours and another session 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 is collected at a rate of 1Hz using a 10 degree mask on the antenna.

The ground crew uploads the static GPS data collected during the flight on a daily basis to be returned to the office for Professional Land Surveyor (PLS) oversight, QA/QC review and processing. OPUS processing triangulates the monument position using 3 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[2] Part 2 table 2.1 at the 95% confidence level. When a statistically stable position is found, CORPSCON[3] 6.0.1 software is used to convert the UTM positions to geodetic positions.

RTK and aircraft mounted GPS measurements are made during periods with PDOP[4] less than or equal to 3.0 and with at least 6 satellites in view of both a stationary reference receiver and the roving receiver. Static GPS data collected in a continuous session average the high PDOP into the final solution in the method used by CORS stations. RTK positions are collected 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). 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.

[2] Federal Geographic Data Committee Draft Geospatial Positioning Accuracy Standards
[3] U.S. Army Corps of Engineers , Engineer Research and Development Center Topographic Engineering Center software
[4]PDOP: Point Dilution of Precision is a measure of satellite geometry, the smaller the number the better the geometry between the point and the satellites.

Figure 3: Landcover locations including RTK used for Pierce County data acquisition, processing, and accuracy checks.



LiDAR Data Processing

Applications and Work Flow Overview

1. Resolved kinematic corrections for aircraft position data using kinematic aircraft GPS and static ground GPS data.

   Software: Waypoint GPS v.8.10, Trimble Geomatics Office v.1.62

2. Developed a smoothed best estimate of trajectory (SBET) file that blends 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 v.1.35

3. Calculated laser point position by associating SBET position to each laser point return time, scan angle, intensity, etc. Created raw laser point cloud data for the entire survey in *.las (ASPRS v. 1.2) format. Data were converted to orthometric elevations (NAVD88) by applying a Geoid09 correction.

   Software: ALS Post Processing Software v.2.70, Corpscon 6.0.1

4. Imported raw laser points into manageable blocks (less than 500 MB) to perform manual relative accuracy calibration and filter 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 and v. 11.007

5. Using ground classified points per 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.10.006 and v. 11.005

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.

   Software: TerraScan v.10.009 and v. 11.007, TerraModeler v.10.004 and v. 11.002

7. Bare Earth models were created as a triangulated surface and exported as ERDAS Imagine grids at a 3–foot pixel resolution.

   Software: TerraScan v.10.009, ArcMap v. 9.3.1, TerraModeler v.10.004 and v. 11.002

Aircraft Kinematic GPS and IMU Data

LiDAR survey datasets were referenced to the 1 Hz static ground GPS data collected over pre-surveyed monuments with known coordinates. While surveying, the aircraft collected 2 Hz kinematic GPS data, and the onboard inertial measurement unit (IMU) collected 200 Hz aircraft attitude data. Waypoint GPS v.8.10 was used to process the kinematic corrections for the aircraft. The static and kinematic GPS data were then post-processed after the survey to obtain an accurate GPS solution and aircraft positions. IPAS v.1.35 was used to develop a trajectory file that includes corrected aircraft position and attitude information. The trajectory data for the entire flight survey session were incorporated into a final smoothed best estimated trajectory (SBET) file that contains accurate and continuous aircraft positions and attitudes.

Laser Point Processing

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, z) coordinate along with unique intensity values (0-255). The data were output into large LAS v. 1.2 files with each point maintaining the corresponding scan angle, return number (echo), intensity, and x, y, z (easting, northing, and elevation) information.

These initial laser point files were too large for subsequent processing. To facilitate laser point processing, bins (polygons) were created to divide the dataset into manageable sizes (< 500 MB). Flightlines and LiDAR data were then reviewed to ensure complete coverage of the survey area and positional accuracy of the laser points.

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

LiDAR points were then filtered for noise, pits (artificial low points), and birds (true birds as well as erroneously high points) by screening for absolute elevation limits, isolated points and height above ground. Each bin was then manually inspected for remaining pits and birds and spurious points were removed. In a bin containing approximately 7.5-9.0 million points, an average of 50-100 points are typically found to be artificially low or high. Common sources of non-terrestrial returns are clouds, birds, vapor, haze, decks, brush piles, etc.

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 scale). Automated sensor attitude and scale corrections yielded 3-5 cm improvements in the relative accuracy. Once system misalignments were corrected, vertical GPS drift was then resolved and removed per flight line, yielding a slight improvement (<1 cm) in relative accuracy.

The TerraScan software suite is designed specifically for classifying near-ground points (Soininen, 2004). The processing sequence began by 'removing' all points that were 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 to improve ground detail. This manual editing of ground often occurs in areas with known ground modeling deficiencies, such as: bedrock outcrops, cliffs, deeply incised stream banks, and dense vegetation. In some cases, automated ground point classification erroneously included known vegetation (i.e., understory, low/dense shrubs, etc.). These points were manually reclassified as default. Ground surface rasters were then developed from triangulated irregular networks (TINs) of ground points.

LiDAR Accuracy Assessment

Laser Noise and Relative Accuracy

Laser point absolute accuracy is largely a function of laser noise and relative accuracy. To minimize these contributions to absolute error, a number of noise filtering and calibration procedures were performed prior to evaluating absolute accuracy.

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 survey was approximately 0.02 meters.

Relative Accuracy

Relative accuracy refers to the internal consistency of the data set - 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). See Appendix A for further information on sources of error and operational measures that can be taken to improve relative accuracy.

Relative Accuracy Calibration Methodology

1. 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.
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 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.
3. 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.

Absolute Accuracy

To minimize the contributions of laser noise and relative accuracy to absolute error, a number of noise filtering and calibration procedures were performed prior to evaluating absolute accuracy. The LiDAR quality assurance process uses the data from the real-time kinematic (RTK) ground survey conducted in Pierce County. For the area delivered area in Pierce County thus far, a total of 11,148 RTK GPS measurements were collected by Watershed Sciences, Inc. on hard surfaces distributed among multiple flight swaths.

The vertical accuracy of the LiDAR data is described as the mean and standard deviation (sigma ~σ) of divergence of LiDAR point coordinates from RTK 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, thus we also consider the skew and kurtosis of distributions when evaluating error statistics.

Statements of statistical accuracy apply to fixed terrestrial surfaces only and may not be applied to areas of dense vegetation or steep terrain (See Appendix A).

Study Area Results

Summary statistics for point resolution and accuracy (relative and absolute) of the LiDAR data collected in Pierce County are presented below in terms of central tendency, variation around the mean, and the spatial distribution of the data (for point resolution by tile). Overall statistics have been updated with each delivery.

Data Summary

Table 3: LiDAR Resolution and Accuracy – Specifications and Achieved Values 2010-2011 LiDAR update project for Pierce County.

	Targeted	Achieved
Resolution:	≥ 8 points/m^2	0.837 points/ft^2 (9.01 points/m^2)
Vertical Accuracy (1 σ):	<15 cm	0.103 ft (3.15 cm)

Data Density/Resolution

The average first-return density of delivered dataset is 0.837 points per square foot (9.01 points/m^2) (Table 3). The initial dataset, acquired to be ≥8 points per square meter, was filtered as described previously to remove spurious or inaccurate points. Additionally, some types of surfaces (i.e., dense vegetation, breaks in terrain, water, steep slopes) may return fewer pulses (delivered density) than the laser originally emitted (native density).

Ground classifications were derived from automated ground surface modeling and manual, supervised classifications where it was determined that the automated model had failed. Ground return densities will be lower in areas of dense vegetation, water, or buildings. Figures 4-7 show the distribution of average native and ground point densities for each tile.

Cumulative LiDAR data resolution for Pierce County:

- Average Point (First Return) Density = 0.837 points/ft^2 (9.01 points/m^2)
- Average Ground Point Density = 0.165 points/ft^2 (1.77 points/m^2)

Figure 4: Cumulative density distribution for first return laser points for the 2010-2011 LiDAR update project for Pierce County.

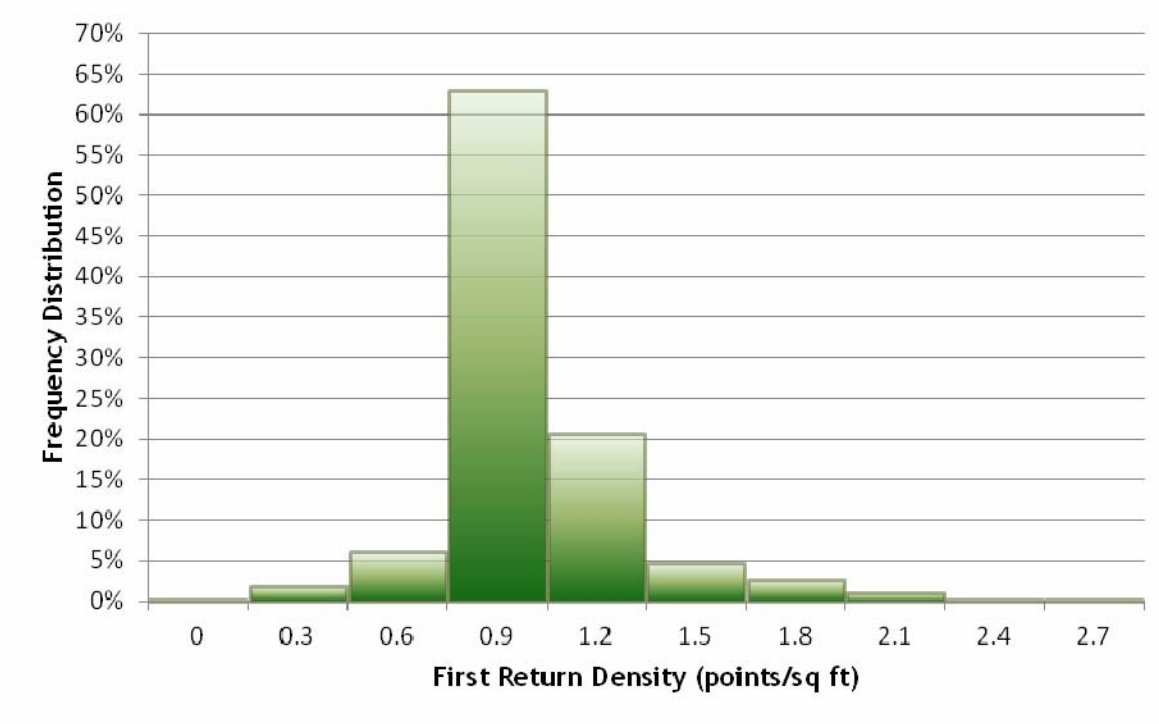


Figure 5: Cumulative density distribution for ground classified laser points for the 2010-2011 LiDAR update project for Pierce County.

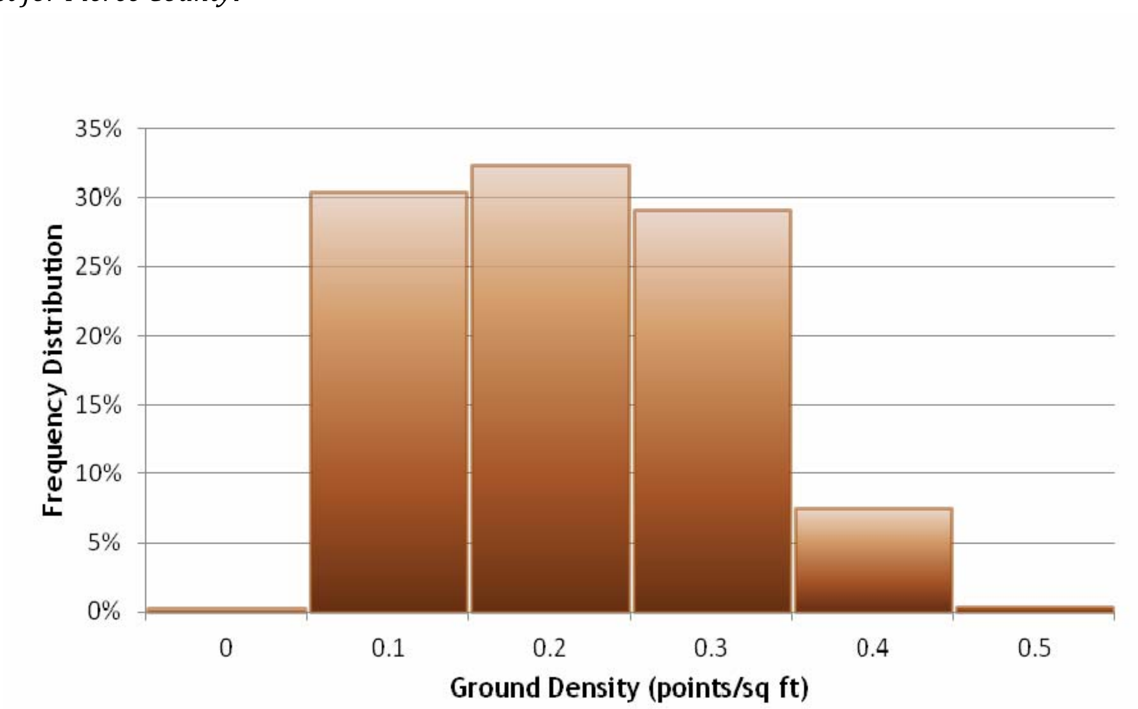


Figure 6: Density distribution map for first return points by tile for the 2010-2011 LiDAR update project for Pierce County.

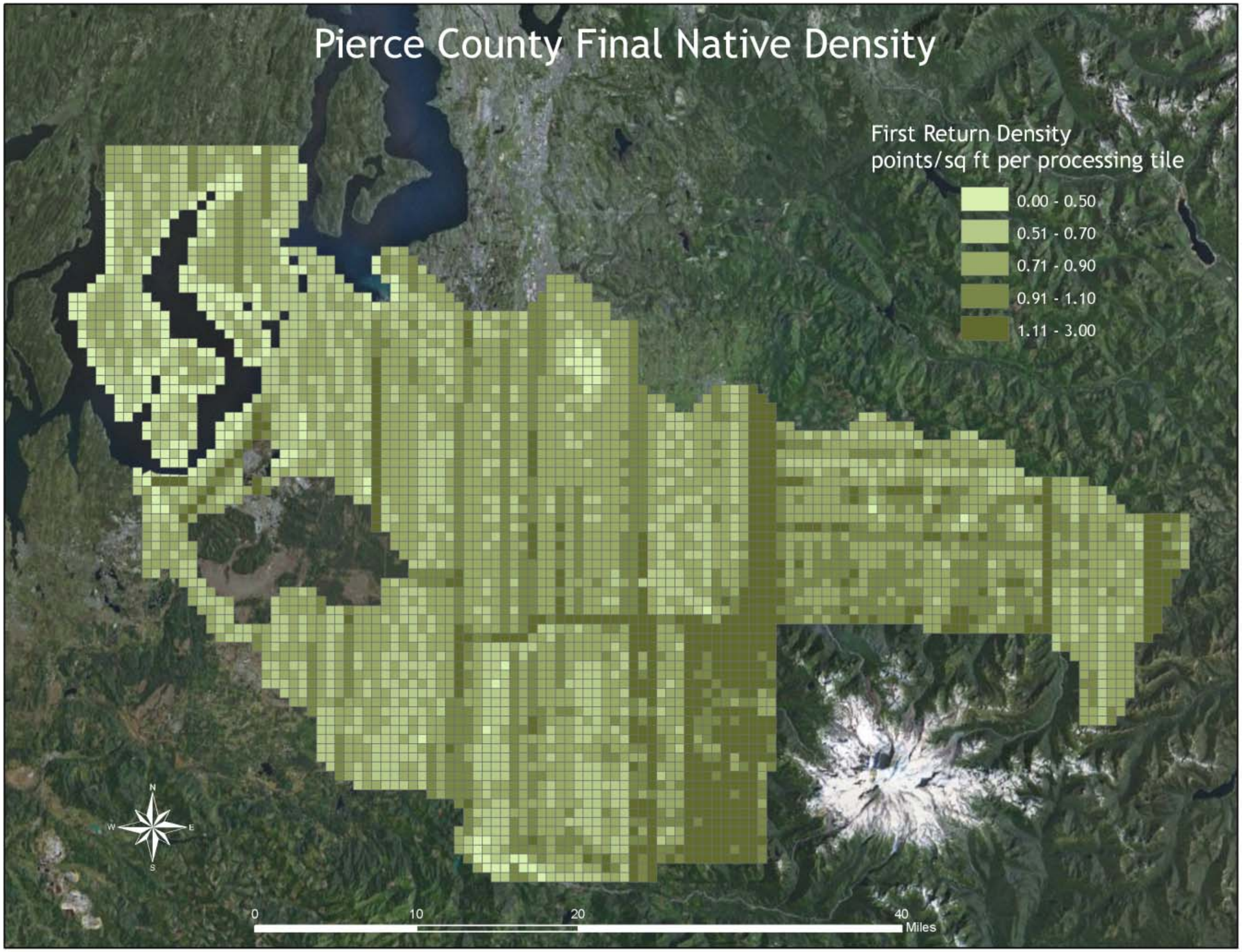
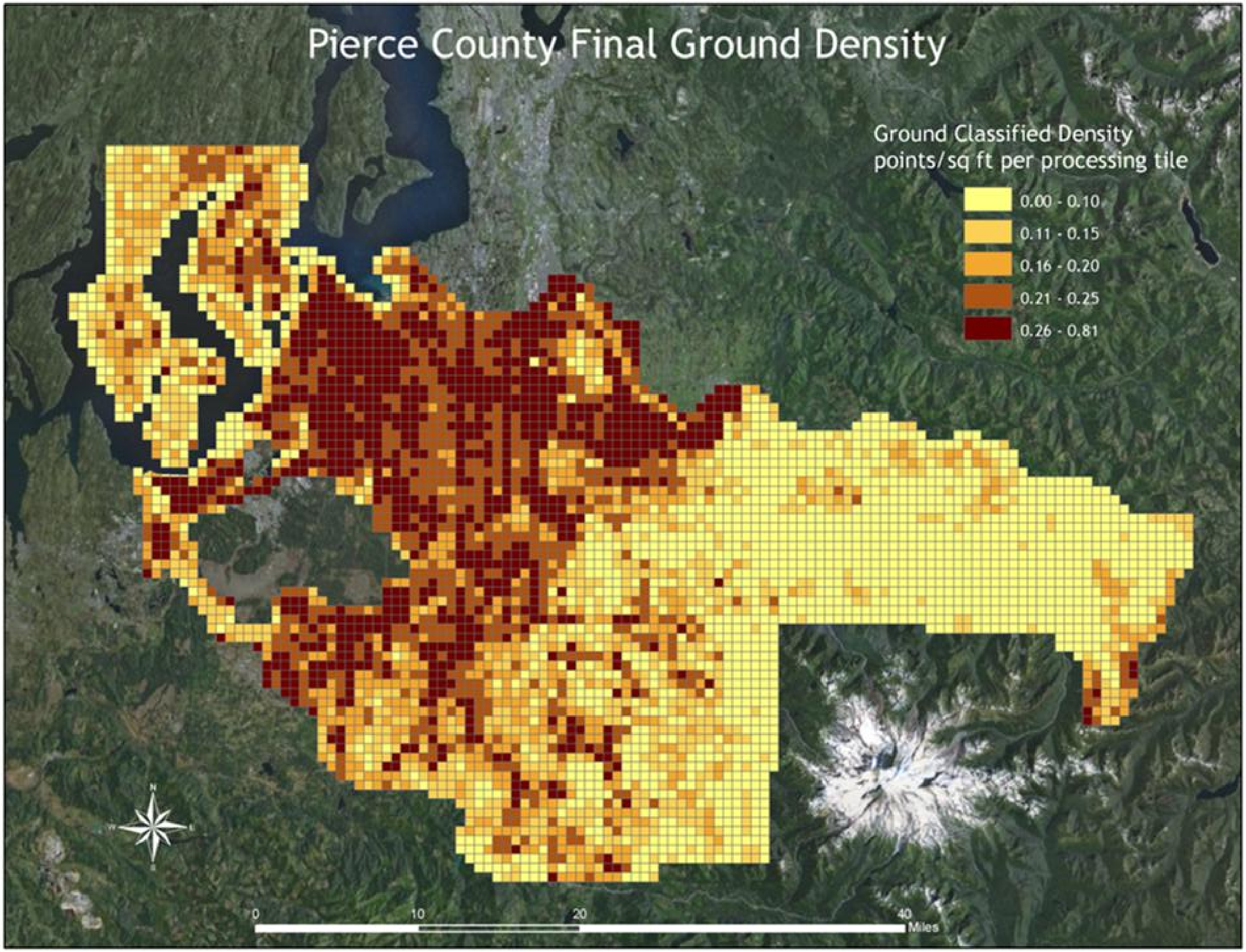


Figure 7: Density distribution map for ground classified points by tile for the 2010-2011 LiDAR update project for Pierce County.

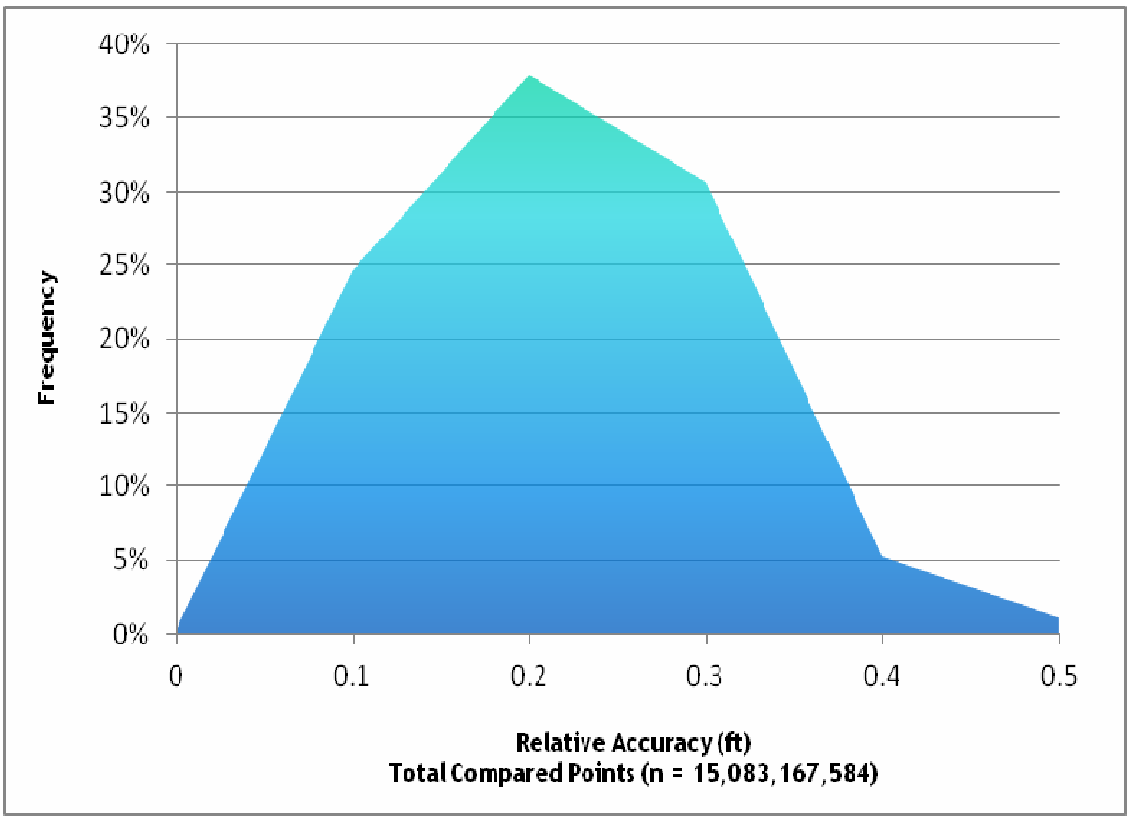


Relative Accuracy Calibration Results

Relative accuracy statistics for the Pierce County dataset measure the full survey calibration including areas outside the delivered boundary.

- Project Average = 0.174 ft (0.047m)
- Median Relative Accuracy = 0.169 ft (0.052m)
- 1σ Relative Accuracy = 0.081 ft (0.025m)
- 1.96σ Relative Accuracy = 0.159 ft (0.048m)

Figure 8: Distribution of relative accuracies per flight line, non slope adjusted for the 2010-2011 LiDAR update project for Pierce County.



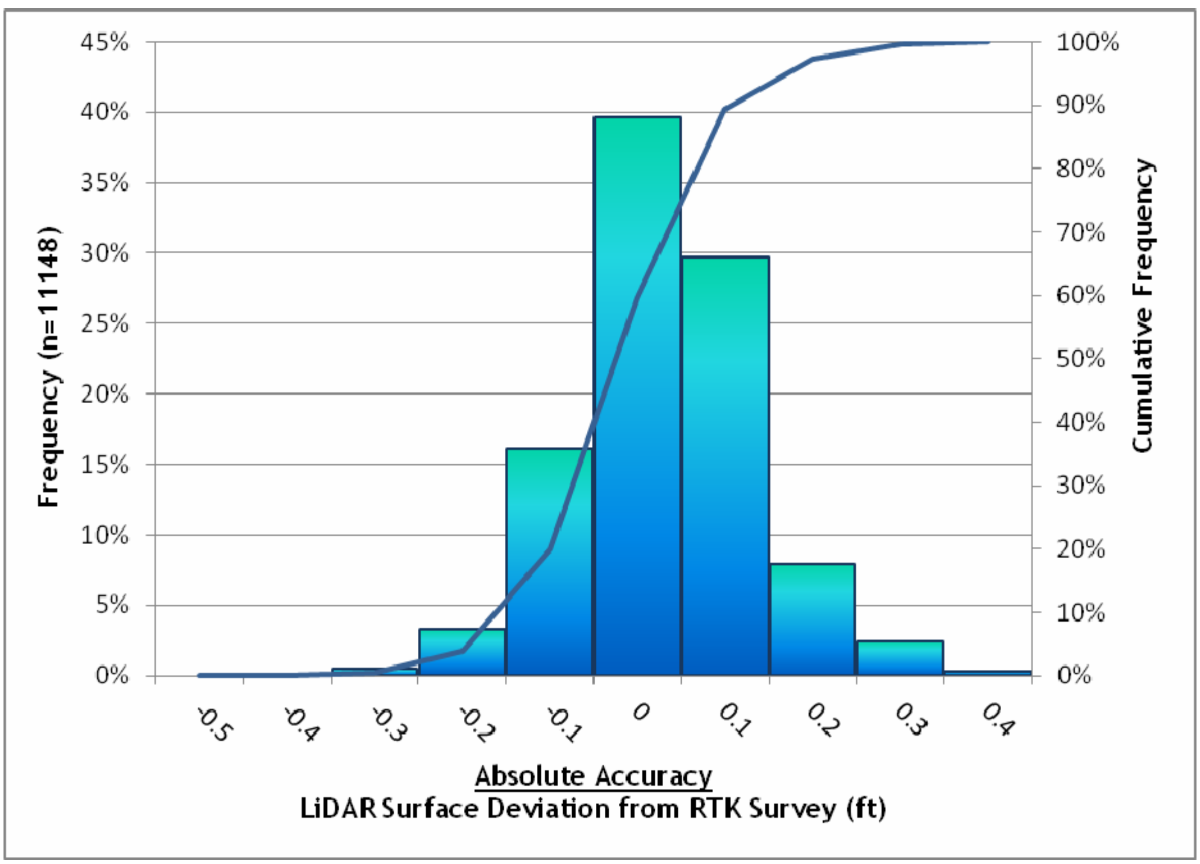
Absolute Accuracy

Absolute accuracies for Pierce County delivered data:

Table 4: Absolute Accuracy – Cumulative deviation between laser points and RTK hard surface survey points for the 2010-2011 LiDAR update project for Pierce County.

Absolute Accuracy Assessment	
RTK Survey Sample Size (n): 11,148	
Root Mean Square Error (RMSE) = 0.105 ft (0.157m)	Minimum Δz = -0.486 ft (-0.148m)
Standard Deviations 1 sigma (σ): 0.103 ft (0.032m) 1.96 sigma (σ): 0.202 ft (0.062m)	Maximum Δz = 0.384 ft (0.117m) Average Δz = -0.020 ft (-0.006m)

Figure 9: Absolute Accuracy – Histogram Statistics the 2010-2011 LiDAR update project for Pierce County.



Land Cover Accuracy

Accuracies for different land cover classes collected for the Pierce County dataset:

Table 5: Land Cover Accuracy – Deviation between laser points and cover class point locations for the 2010-2011 LiDAR update project for Pierce County.

Landcover Type	Count	Average (ft)	RMSE (ft)	1 Sigma ft(m)	1.96 Sigma ft(m)
Bare Earth (Hard and Soft Surfaces)	11166	-0.020 ft (-0.006m)	0.105 ft (0.034m)	0.103 ft (0.031m)	0.202 ft (0.062m)
Trees	281	0.077 ft (0.023m)	0.275 ft (0.089m)	0.264 ft (0.081m)	0.518 ft (0.158m)
Tall Grass	162	0.184 ft (0.056m)	0.336 ft (0.109m)	0.283 ft (0.086m)	0.554 ft (0.169m)
Shrubs	307	0.138 ft (0.042m)	0.440 ft (0.143m)	0.418 ft (0.127m)	0.819 ft (0.250m)
Short Grass	397	0.031 ft (0.009m)	0.160 ft (0.052m)	0.157 ft (0.048m)	0.308 ft (0.094m)

Model Development

Hydro Flattened and Breakline Enforced Terrain Models

David C. Smith and Associates (DSA), Portland, OR created breaklines for Pierce County using LiDAR-grammetry techniques. Table 6 describes the type and definition of each breakline collected. The breaklines were used to supplement the LiDAR data in creation of a hydro-flattened ground model. A breakline was created around lakes and ponds with areas larger than ~2 acres. Rivers with widths greater than ~10ft were represented as a double line feature and flatten from side-to-side. A single line feature was used to represent streams less than ~10ft to ensure downstream flow. Road crossings (i.e. culverts) were retained in the ground model, but bridges were removed.

- Water boundaries were enforced using hard breaklines and water surfaces were flattened based on the elevation from the breaklines. The breakline boundaries were also used to reassign any ground classified points within the water delineated areas to a water class.
- Hard breaklines (lake edges, islands, etc.) were incorporated into the TIN by enforcing triangle edges (adjacent to the breakline) to the elevation values derived from the LiDAR-grammetric breakline. This implementation corrected interpolation along the hard edge.
- LiDAR data points within three feet of a breakline were ignored from the ground classification, giving precedence to breakline Z values.

Table 6: Breaklines collected for the 2010-2011 LiDAR update project for Pierce County.

Feature	Implementation	Description
Water Lake	Hard Breakline	Lake Bodies
Water Stream	Hard Breakline	Streams smaller than ~10 feet were digitized as single stream centerlines.
Water Island	Hard Breakline	Islands
Water River	Hard Breakline	Rivers wider than 10 ft were digitized as double line features outlining the edge of bank.
Breakline	Hard Breakline	Breakline to supplement LiDAR data

Projection

	Projection:	Washington State Plane South (FIPS 4602)
Datum	**Vertical:**	NAVD88 Geoid09
	Horizontal:	NAD83 (1991 HARN)
	Units:	U.S. Survey Feet

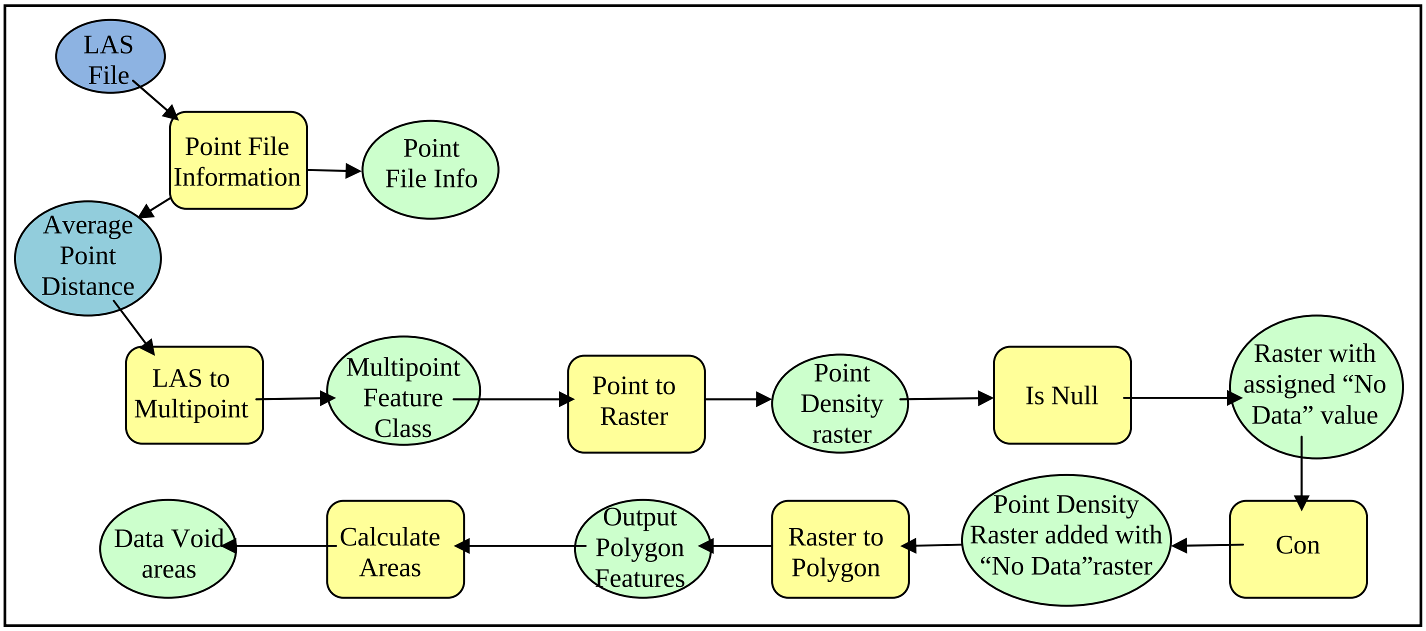
Pierce County Quality Assurance/Quality Control Procedures Project Workflow

Pierce County performed various QC procedures on all data received from Watershed Sciences to ensure a complete and accurate product. This portion of the document details the steps taken during the quality assurance/quality control portion of the project.

Assessing LiDAR Coverage

Pierce County received 21 separate deliveries of LiDAR and associated data throughout 2011 (Figure 2) from Watershed Sciences and performed a rigorous set of quality assurance/quality control (QA/QC) procedures. After verifying a complete delivery, including verification of Raster DEM files, breaklines, intensity images and reports, Pierce County performed the procedures outlined to assess LiDAR coverage and first return density(Figure 10).

Figure 10: Model used to Assess LiDAR coverage and calculate first return void areas to ensure contract compliance for the 2010-2011 LiDAR update project for Pierce County.



A batch script was created based on this model to help minimize the time it would take to run this process on each LAS tile and allow it to run over night. Although there were many useful data sets created from the model there were a couple of datasets that were used to check every tile in the dataset. The rasters created from the Con tool, which added the Point Density raster with the raster with an assigned value to “No Data”, were used to help identify areas of void clustering (Figure 11) to help determine complete LAS point coverage. The Feature Class results from the Calculate Areas tool were used to determine void size and shape (Figure 12).

Figure 11: Raster created from adding the Point Density raster and the Is Null Raster together using the Con tool displaying void clustering, in red, for a LAS tile for the 2010-2011 LiDAR update project for Pierce County.

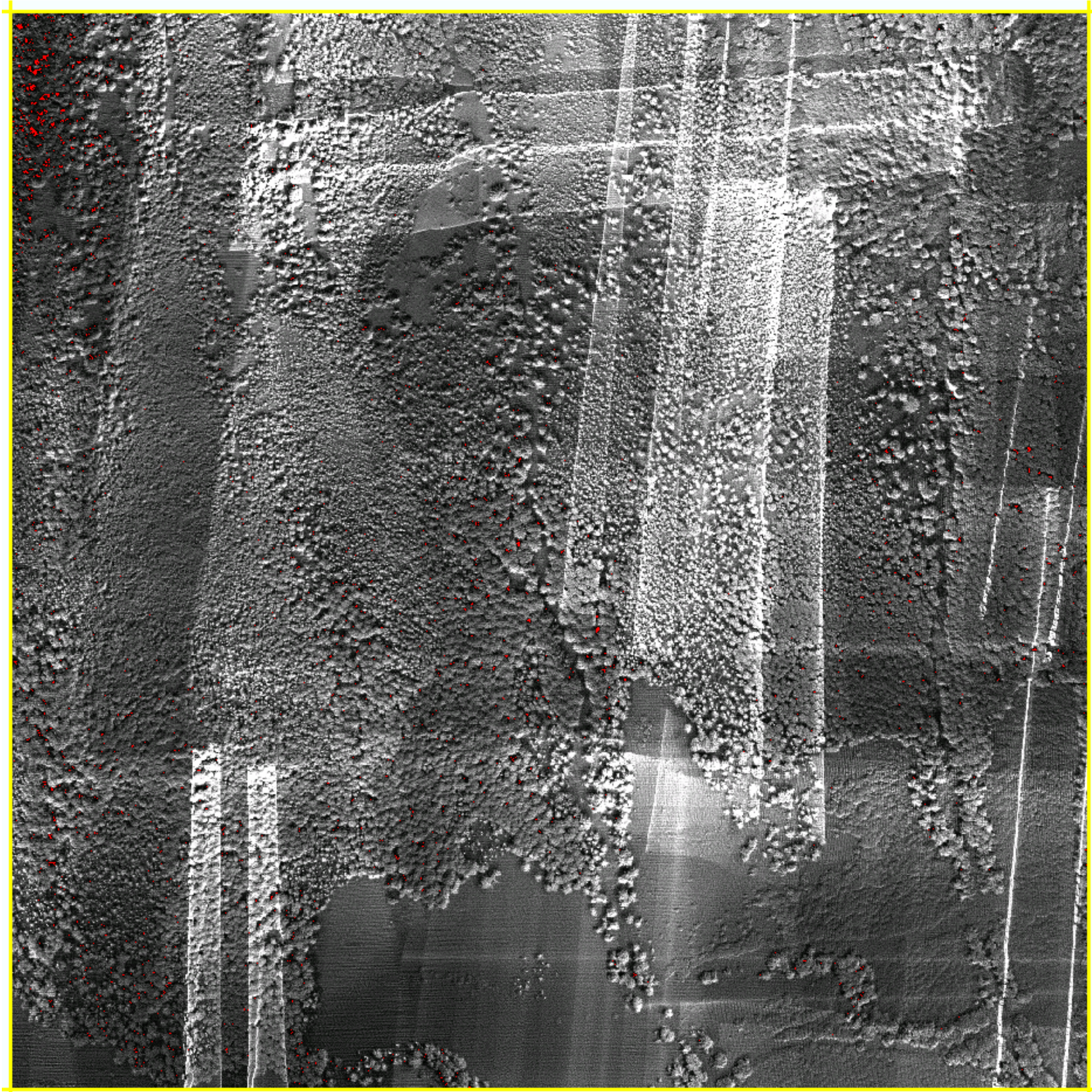
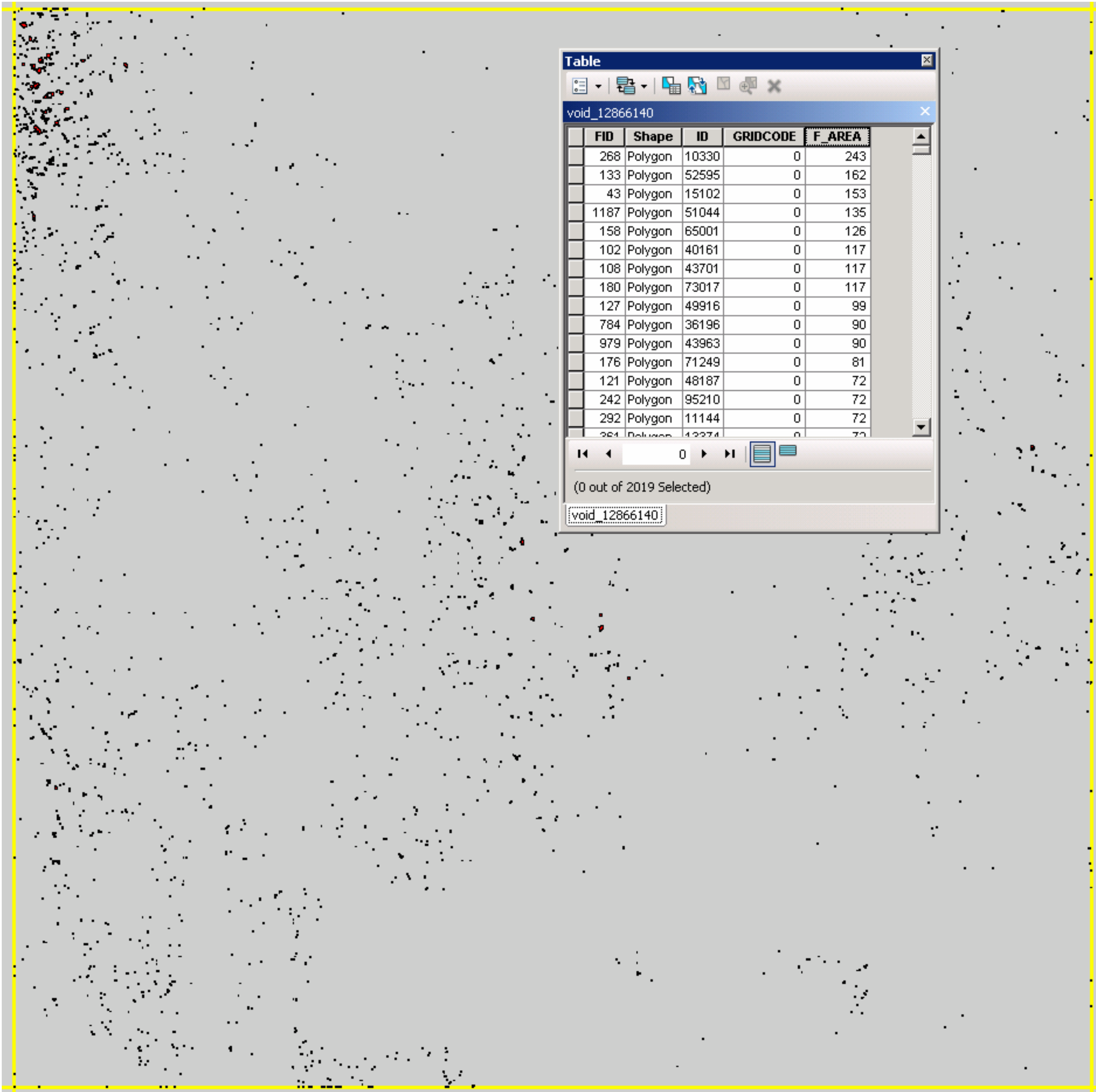


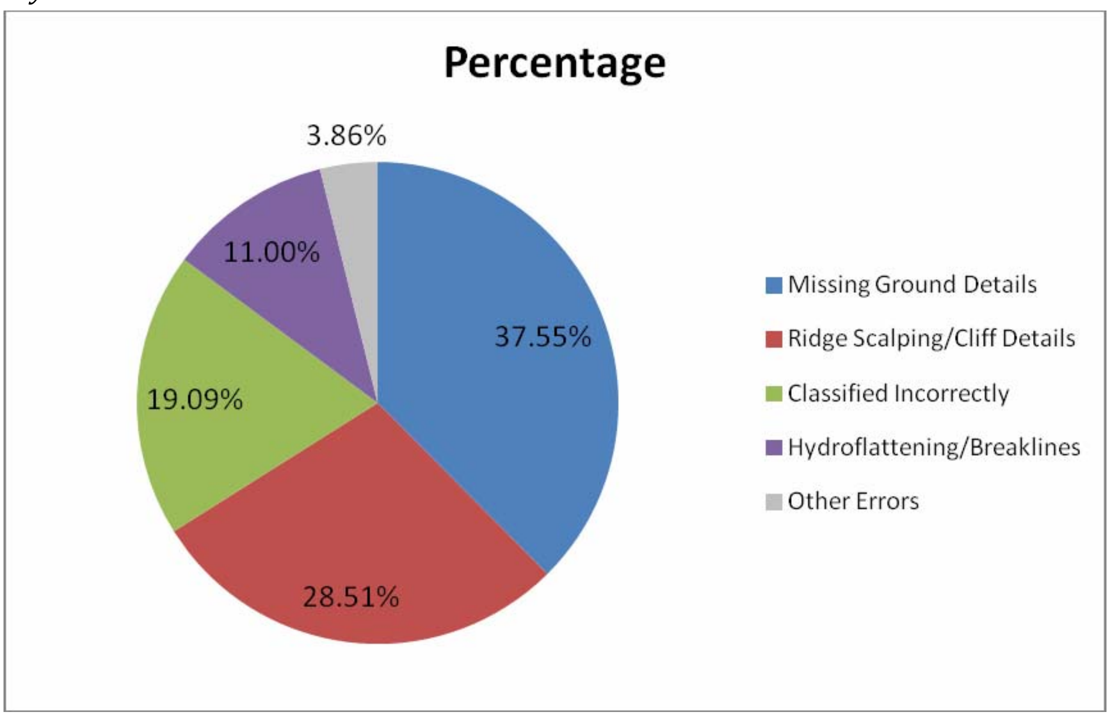
Figure 12: Data Void Feature Class showing First Return data voids (red color outlined in black) per LAS tile and their area for the 2010-2011 LiDAR update project for Pierce County.



Pierce County, after determining first return void contract compliance, used the LP360 extension in AcrGIS 10 to review the delivered classified LAS files. Every LAS tile was viewed at a 1:800 scale with delivered vector files such as lake, island and river breaklines as well as other ancillary data, such as orthophotos and County streams and lake layers, to determine classification accuracy, alignment and completeness of data received. The elevation of the bare-earth hydroflattened raster files were checked for accuracy compared to the LAS files and vector files. Pierce County also verified that hydro-flattening processes, as opposed to hydro-enforcement, were completed for the project area using visual QC methods as well as automated checks.

Error files were created and areas of concern were circled. The error files were sent to Watershed Sciences, Inc. for their review and to complete the requested fixes. Watershed Sciences redelivered the corrected tiles which would be reviewed by Pierce County. This process was continued until the errors were corrected. Once all the errors were corrected the tile and/or delivery would be accepted. Some common errors included ridge scalping, incorrect attributes for vectors, lake areas not hydroflattened in rasters and slash piles classified as ground (Figure 13).

Figure 13: Error types and percentage of occurrence for the 2010-2011 LiDAR update project for Pierce County.



Results

Watershed Sciences, Inc delivered and Pierce County accepted 1461 square miles of LiDAR data that meets or exceeds the Base LiDAR Specification for USGS ARRA projects. There are many economic benefits that will result in the completion of this LiDAR acquisition project for Pierce County and USGS:

- Emergency Management – Lidar will be used to update hazard mitigation plans for both natural and manmade disasters. 2D and 3D models will be used to assess hazards and develop evacuation plans and first responder emergency routes. These plans will greatly reduce the loss of life and property.
- Floodplain Mapping – Lidar will be used to update the Pierce County Flood Hazard Management Plan to address public safety issues, reduce property losses, protect fish and wildlife habitat, and increase cost efficiencies. County floodplain information is also provided to the Federal Emergency Management Agency for updating Flood Insurance Rate Maps.
- Natural Resource Management – Forestry agencies and timber industries will use lidar to calculate biomass, timber volumes, and tree-stand heights to promote more cost-efficient forest management practices while still protecting the County's natural resources.
- Urban Planning & Economic Development – Cities, community planning partners, and economic development departments will develop and use 3D models from bare-earth and reflective-surface lidar data for urban planning, construction projects, growth management analysis, and permit regulation.
- Transportation and Utility Planning – Lidar will supplement orthophotography and ground surveys to support several transportation and utility improvement projects throughout the county.
- Base Mapping – Along with providing digital elevation models and the elevation point cloud for inclusion in the National Elevation Dataset, Pierce County will produce 2-foot elevation contours and update land use/land cover classifications and planimetric features using the lidar data. These datasets will be included in their GIS enterprise systems, which are used by both internal and external agencies to perform their business activities more cost-efficiently.

Certifications

Watershed Sciences provided LiDAR services for the Pierce County study area as described in this report.

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

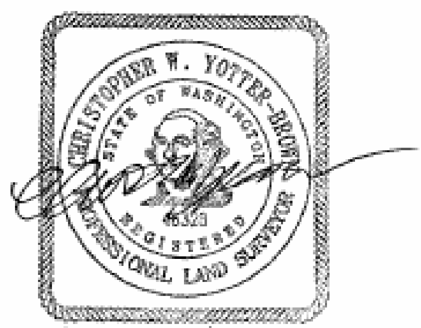
____

Russ Faux
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.

12/13/2011

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



Renews: 12/21/2012

Citations

Soininen, A. 2004. TerraScan User's Guide. TerraSolid.

Appendix A

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:

1. Low Flight Altitude: Terrain following is employed to maintain a constant above ground level (AGL). Laser horizontal errors are a function of flight altitude above ground (i.e., ~ 1/3000th AGL flight altitude).
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 can be maintained.
3. Reduced Scan Angle: Edge-of-scan data can become inaccurate. The scan angle was reduced to a maximum of ±15° from nadir, creating a narrow swath width and greatly reducing laser shadows from trees and buildings.
4. 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 19 km (11.5 miles) at all times.
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. Ground survey RTK points are distributed to the extent possible throughout multiple flight lines and across the survey area.
6. 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 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.

Appendix B

PLS Survey attachments:

SURVEY DATASHEET (Version 1.0)

PID: BBCK63
Designation: PIERCE5_DT1
Stamping: PIERCE5_DT1
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: Drive approximately 23.7 miles SE of Enumclaw on Hwy 410 to NF 72 on the east side of the Hwy. Turn left onto NF 72, stay to the right at the Y in the road off the Hwy. Continue 1.4 miles then turn left to stay on NF 72. Continue 2.5 miles then turn sharply right to stay on NF 72. Drive .9 miles stay to the right, continue .4 miles stay to the left. Continue another 2.1 miles turn sharply right onto NF 7250. Drive .2 miles and monument is on the right side of the road to the north.
Observed: 2010-10-20T16:29:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME:	EPOCH:	SOURCE:	UNITS:	SET PROFILE	DETAILS
NAD_83(CORS96)	2002.0000	NAVD88 (Computed using GEOID09)	m		

LAT:	47° 4' 42.75983"	± 0.010 m
LON:	-121° 32' 12.57157"	± 0.007 m
ELL HT:	1479.911	± 0.018 m
X:	-2276457.939	± 0.012 m
Y:	-3709487.961	± 0.015 m
Z:	4648799.277	± 0.007 m
ORTHO HT:	1499.627	± 0.034 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5214931.215m	194502.094m
EASTING:	611074.707m	421264.916m
CONVERGENCE:	1.07157412°	-0.75314563°
POINT SCALE:	0.99975163	0.99995168
COMBINED FACTOR:	0.99951977	0.99971977

CONTRIBUTED BY

WSIOPUS
Watershed Sciences

Horizon View

The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID: BBCK64
Designation: PIERCE5_DT2
Stamping: PIERCE5_DT2
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: Drive approximately 23.7 miles SE of Enumclaw on Hwy 410 to NF 72 on the east side of the Hwy. Stay on 72 for 7.3 miles and turn sharply right onto NF 7250. Drive .2 miles and stay to the left at the Y in the road past PIERCE5_DT1 and continue for .8 miles on NF 7250 stay to the right at the Y in the road. Drive 1.1 miles then take a sharp left and continue .1 mile uphill to the second clearing where the road dead-ends with a fire pit. Monument is on the north side of the clearing.
Observed: 2010-10-21T15:42:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME: NAD_83(CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

LAT:	47° 3' 28.67722"	± 0.003 m
LON:	-121° 31' 33.99588"	± 0.006 m
ELL HT:	1614.859	± 0.027 m
X:	-2276688.269	± 0.009 m
Y:	-3711420.124	± 0.019 m
Z:	4647339.450	± 0.018 m
ORTHO HT:	1634.448	± 0.049 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5212659.698m	192204.004m
EASTING:	611931.224m	422048.828m
CONVERGENCE:	1.07906283°	-0.74536195°
POINT SCALE:	0.99975398	0.99994865
COMBINED FACTOR:	0.99950098	0.99969560

CONTRIBUTED BY

WSIOPUS
Watershed Sciences

Horizon View

The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID: BBCK73
Designation: CANYON_FALLS
Stamping: CANYON_FALLS
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: From the intersection of 128th St E and MC Cutcheon Rd E, turn right (heading south) and drive 0.9 miles to mark on your right side (E). The monument is located 4.8 meters @ 280 degrees from the approximate center-line of the road. For added reference the monument is 1.5 meters @ 75 degrees from the witness post (marker)
Observed: 2010-12-05T15:27:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME:	EPOCH:	SOURCE: NAVD88 (Computed using GEOID09)	UNITS:	SET PROFILE	DETAILS
NAD_83(CORS96)	2002.0000		m		

LAT:	47° 7' 35.87273"	± 0.004 m
LON:	-122° 13' 31.45962"	± 0.013 m
ELL HT:	17.654	± 0.020 m
X:	-2318253.665	± 0.011 m
Y:	-3677706.861	± 0.018 m
Z:	4651367.423	± 0.012 m
ORTHO HT:	39.823	± 0.038 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5219527.390m	200762.096m
EASTING:	558749.586m	369098.708m
CONVERGENCE:	0.56768492°	-1.25332724°
POINT SCALE:	0.99964242	0.99995927
COMBINED FACTOR:	0.99963965	0.99995651

CONTRIBUTED BY

wsiopus
Watershed Sciences

Horizon View

The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID: AH8377
Designation: THUN FIELD RESET
Stamping: THUN FIELD RESET
Stability: May hold commonly subject to ground movement
Setting: Set in top of concrete monument
Mark Condition: G
Description:
Observed: 2010-12-04T15:29:00Z — See Also 1994
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME: NAD_83(CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

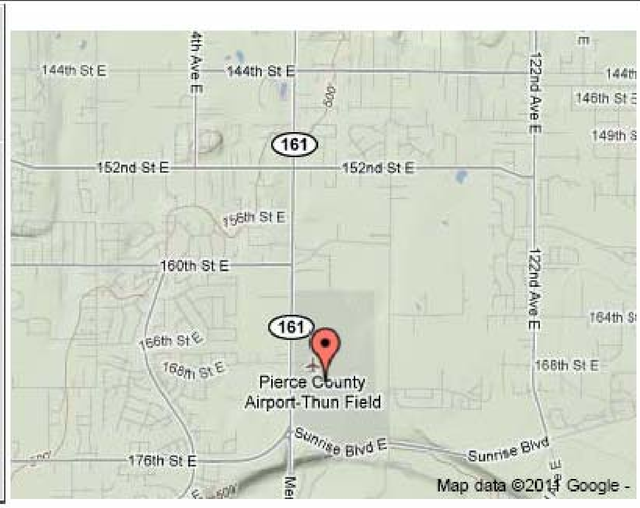
LAT:	47° 6' 8.99191"	± 0.014 m
LON:	-122° 17' 23.21542"	± 0.020 m
ELL HT:	140.792	± 0.014 m
X:	-2323479.367	± 0.020 m
Y:	-3676832.518	± 0.017 m
Z:	4649631.749	± 0.006 m
ORTHO HT:	162.990	± 0.029 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5216799.107m	198188.729m
EASTING:	553891.282m	364154.600m
CONVERGENCE:	0.52029865°	-1.30009014°
POINT SCALE:	0.99963569	0.99995537
COMBINED FACTOR:	0.99961363	0.99993331

CONTRIBUTED BY

wsiopus
Watershed Sciences

Horizon View



The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID:	BBCK75
Designation:	PRC_05
Stamping:	PRC_05
Stability:	Monument will probably hold position well
Setting:	Object driven into ground
Description:	Traveling on 112th St E turn left at stop light onto Woodland Ave E. Follow Woodland Ave E for apprx 0.3 miles. Monument will be on the left hand side of the road at a pullout for a recreational area. Monument is located 1 meter SE of the Northern Corner of fence and 5 paces (roughly 4-5 meters) East of the Eastern edge of the road.
Observed:	2010-12-06T15:48:00Z
Source:	OPUS - page5 1106.16

Close-up View

REF_FRAME: NAD_83(CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

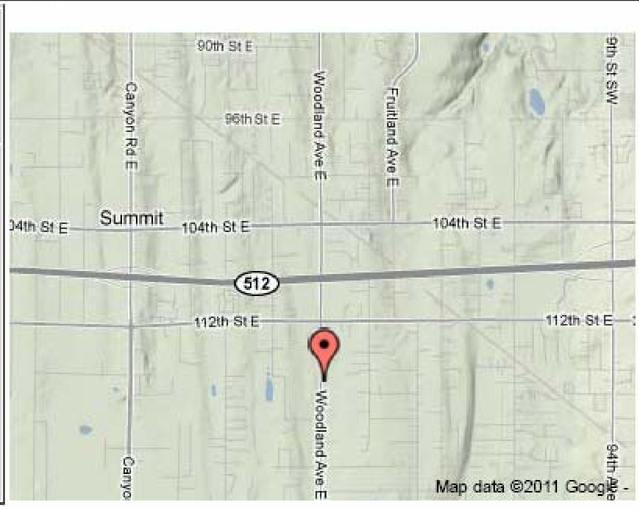
LAT:	47° 9' 0.95667"	± 0.010 m
LON:	-122° 20' 9.48913"	± 0.005 m
ELL HT:	102.405	± 0.005 m
X:	-2324346.877	± 0.006 m
Y:	-3671647.868	± 0.009 m
Z:	4653216.880	± 0.005 m
ORTHO HT:	124.816	± 0.019 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5222076.691m	203578.171m
EASTING:	550341.529m	360773.191m
CONVERGENCE:	0.48683759°	-1.33364029°
POINT SCALE:	0.99963115	0.99996326
COMBINED FACTOR:	0.99961510	0.99994721

CONTRIBUTED BY

wsiopus
Watershed Sciences

Horizon View



The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID: BBCK74
Designation: PRC_06
Stamping: PRC_06
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: From intersection of Union Ave and Center St, follow Center street west for 0.9 miles. Take ramp right (N), after the timed light for traffic control, immediately turn right to the roads shoulder. Drive on the grass "road" for 0.2 miles, driving towards the dark brown/black fence (of the park & ride parking lot). Monument is marked by a stake and orange flagging. It is 2 feet from the fringe of the fence.
Observed: 2010-12-11T14:54:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME: NAD_83(CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

LAT:	47° 14' 3.96855"	± 0.022 m
LON:	-122° 29' 48.51236"	± 0.022 m
ELL HT:	84.086	± 0.006 m
X:	-2330949.675	± 0.020 m
Y:	-3659307.807	± 0.019 m
Z:	4659562.363	± 0.014 m
ORTHO HT:	106.691	± 0.020 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5231339.422m	213228.797m
EASTING:	538087.695m	348815.609m
CONVERGENCE:	0.36941611°	-1.45047363°
POINT SCALE:	0.99961783	0.99997887
COMBINED FACTOR:	0.99960465	0.99996570

CONTRIBUTED BY

wsiopus
Watershed Sciences

Horizon View

The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID:	BBCK77
Designation:	PRC_07
Stamping:	PRC_07
Stability:	Monument will probably hold position well
Setting:	Object driven into ground
Description:	Drive to the end of 24th St SW where you will turn left (follow the signs for Tacoma Narrows Airport). Follow this side road for 0.2 miles to the end of the road and turn right onto Stone Dr NW. Drive 0.4 miles along Stone Dr. NW until a gravel road pullout appears on your right. Take the gravel road until you reach the end (0.1 miles) of it. Monument is 5 meters up a small hill to the South.
Observed:	2010-12-11T15:44:00Z
Source:	OPUS - page5 1106.16

Close-up View

REF_FRAME: NAD_83(CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

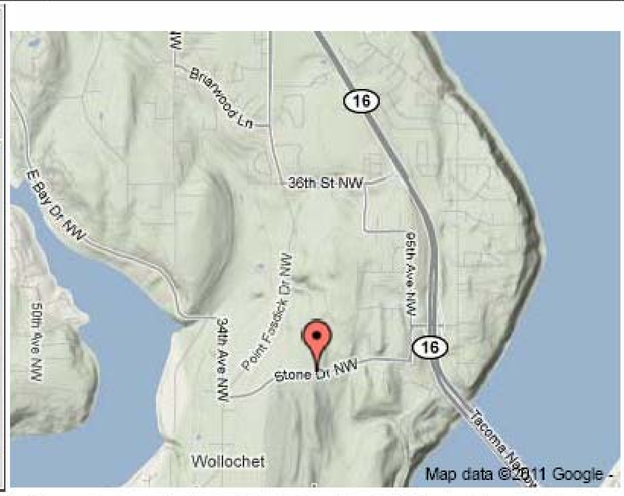
LAT:	47° 16' 34.94795"	± 0.008	m
LON:	-122° 34' 26.89973"	± 0.014	m
ELL HT:	62.339	± 0.001	m
X:	-2334034.885	± 0.012	m
Y:	-3653260.515	± 0.008	m
Z:	4662711.063	± 0.006	m
ORTHO HT:	85.000	± 0.017	m

	UTM 10	SPC 4602(WA S)
NORTHING:	5235965.279m	218040.767m
EASTING:	532208.989m	343084.651m
CONVERGENCE:	0.31285517°	-1.50664569°
POINT SCALE:	0.99961275	0.99998747
COMBINED FACTOR:	0.99960298	0.99997769

CONTRIBUTED BY

wsiopus
Watershed Sciences

Horizon View



The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID: BBCK82
Designation: PRC_08
Stamping: PRC_08
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: From Center St (west) take WA-16E ramp on your left (east), continue on WA-16E. After the timed light for traffic control immediately turn to the roads shoulder. There you will head east on the grass service road for approximately 0.2 miles towards a dark brown/black fence (located near a park and ride parking lot). The monument is located 37 feet NxNW of the Western end of the fence.
Observed: 2011-01-02T16:00:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME:	EPOCH:	SOURCE:	UNITS:	SET PROFILE	DETAILS
NAD_83(CORS96)	2002.0000	NAVD88 (Computed using GEOID09)	m		

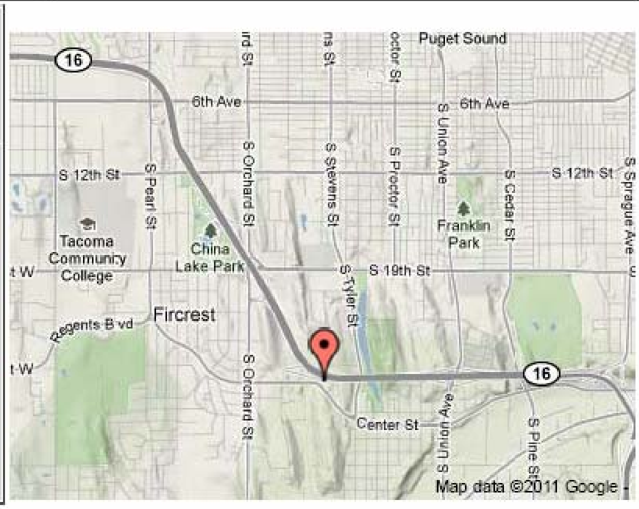
LAT:	47° 14' 4.14993"	± 0.005 m
LON:	-122° 29' 48.91289"	± 0.018 m
ELL HT:	84.186	± 0.010 m
X:	-2330954.608	± 0.013 m
Y:	-3659299.870	± 0.013 m
Z:	4659566.240	± 0.009 m
ORTHO HT:	106.791	± 0.024 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5231344.966m	213234.609m
EASTING:	538079.237m	348807.329m
CONVERGENCE:	0.36933472°	-1.45055445°
POINT SCALE:	0.99961782	0.99997888
COMBINED FACTOR:	0.99960463	0.99996569

CONTRIBUTED BY

wsiopus
Watershed Sciences

Horizon View



The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID: BBCK83
Designation: PRC_09
Stamping: PRC_09
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: Traveling on I-5 South take exit 114 toward Nisqually. Turn left at Nisqually Cut Off Rd and continue for apprx. 0.2 miles. Monument is located on the right side apprx. 18 feet from the white line on the edge of the road.
Observed: 2011-02-06T16:26:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME:	EPOCH:	SOURCE: NAVD88 (Computed using	UNITS:	SET	DETAILS
NAD_83(CORS96)	2002.0000	GEOID09)	m	PROFILE	

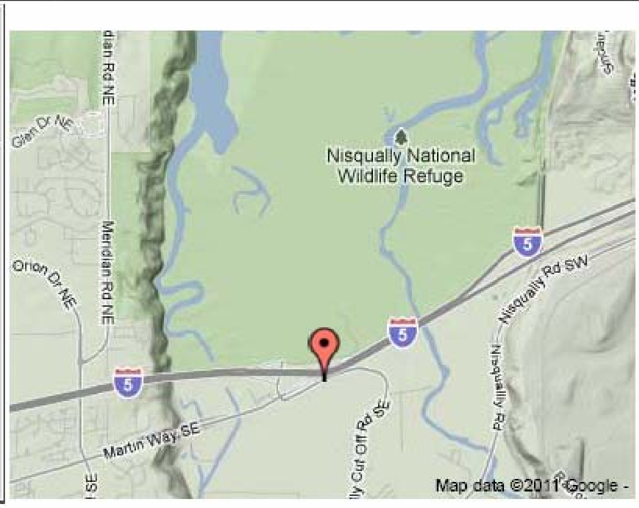
LAT:	47° 4' 2.57741"	± 0.013 m
LON:	-122° 42' 53.17806"	± 0.017 m
ELL HT:	-15.941	± 0.018 m
X:	-2352175.508	± 0.023 m
Y:	-3661812.932	± 0.013 m
Z:	4646858.762	± 0.011 m
ORTHO HT:	6.228	± 0.035 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5212691.608m	195105.434m
EASTING:	521657.363m	331795.733m
CONVERGENCE:	0.20883222°	-1.60880081°
POINT SCALE:	0.99960576	0.99995002
COMBINED FACTOR:	0.99960826	0.99995252

CONTRIBUTED BY

wsiopus
Watershed Sciences

Horizon View



The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID:	BBCK84
Designation:	PRC_10
Stamping:	PRC_10
Stability:	Monument will probably hold position well
Setting:	Object driven into ground
Description:	From I-5 Southbound take exit 119 towards Steilacoom/Dupont Rd. Turn right on Steilcoom road and follow for 0.1 miles and turn into gravel parking lot. Monument is on the south end of the undeveloped lot closest to the freeway slightly into the vegetation.
Observed:	2011-02-06T16:00:00Z
Source:	OPUS - page5 1106.16

Close-up View

REF_FRAME: NAD_83(CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

LAT:	47° 5' 39.36891"	± 0.009 m
LON:	-122° 37' 22.60117"	± 0.012 m
ELL HT:	57.472	± 0.013 m
X:	-2345150.651	± 0.016 m
Y:	-3663776.528	± 0.004 m
Z:	4648947.965	± 0.013 m
ORTHO HT:	79.842	± 0.028 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5215708.952m	197901.487m
EASTING:	528615.368m	338848.385m
CONVERGENCE:	0.27618532°	-1.54209813°
POINT SCALE:	0.99961006	0.99995408
COMBINED FACTOR:	0.99960106	0.99994508

CONTRIBUTED BY

wsiopus
Watershed Sciences


Horizon View

The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID:	BBCL04
Designation:	PRC_11
Stamping:	PRC_11
Stability:	Monument will probably hold position well
Setting:	Object driven into ground
Description:	The monument is located on the South side of 112th St E. Apprx. 170 ft West of 248th Ave and 360 ft East of 246th Ave Ct E. The monument lies 4 feet South of the edge of the pavement (112th St) within the gravel shoulder, very close to where grass and gravel meet.
Observed:	2011-02-10T15:35:00Z
Source:	OPUS - page5 1106.16

Close-up View

REF_FRAME: NAD_83(CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

LAT:	47° 9' 20.13636"	± 0.014 m
LON:	-122° 5' 59.66019"	± 0.015 m
ELL HT:	182.229	± 0.009 m
X:	-2308997.761	± 0.020 m
Y:	-3680871.296	± 0.010 m
Z:	4653678.203	± 0.007 m
ORTHO HT:	204.316	± 0.023 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5222847.850m	203780.432m
EASTING:	568231.078m	378683.947m
CONVERGENCE:	0.65997729°	-1.16216469°
POINT SCALE:	0.99965722	0.99996419
COMBINED FACTOR:	0.99962866	0.99993563

CONTRIBUTED BY

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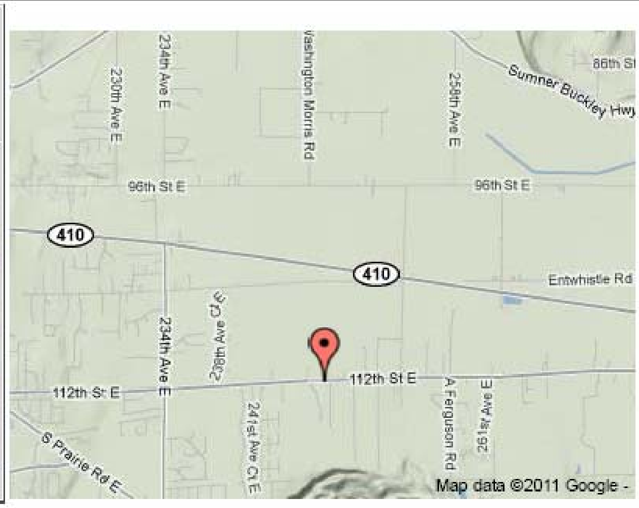
Horizon View



The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID: BBCK85
Designation: PRC_12
Stamping: PRC_12
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: From 254th Ave turn right (E) on 96th St and continue 0.2 miles. Site is on N shoulder of road ~0.04 miles E of two red sheds that are located in the corners of two adjacent pastures. Monument is 15ft 6in N of the centerline of 96th St, 6ft 10in SE of a wooden fence post on which there is a ~8 inch square wooden sign board that no longer contains a sign, 4ft S of a fence made of wire mesh with barbed wire strands, and 98ft WNW of a power pole numbered "567380" and "160566".
Observed: 2011-04-12T14:55:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME:	EPOCH:	SOURCE:	UNITS:	SET PROFILE	DETAILS
NAD_83(CORS96)	2002.0000	NAVD88 (Computed using GEOID09)	m		

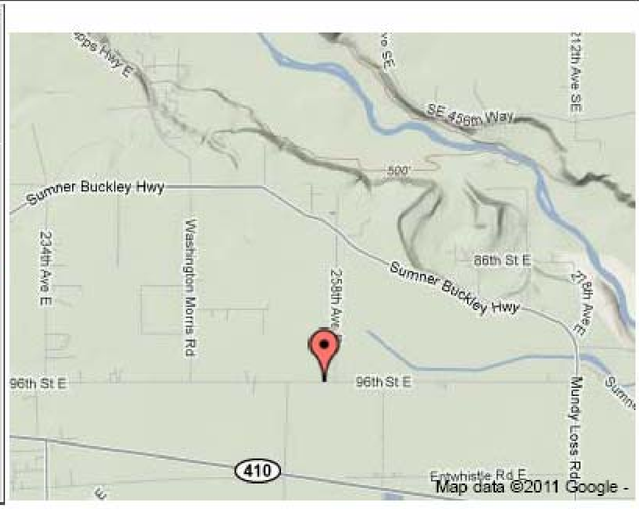
LAT:	47° 10' 12.88897"	± 0.010	m
LON:	-122° 5' 13.30278"	± 0.031	m
ELL HT:	182.531	± 0.013	m
X:	-2307535.952	± 0.028	m
Y:	-3680378.178	± 0.017	m
Z:	4654786.100	± 0.003	m
ORTHO HT:	204.657	± 0.028	m

	UTM 10	SPC 4602(WA S)
NORTHING:	5224487.596m	205389.409m
EASTING:	569188.180m	379693.018m
CONVERGENCE:	0.66957864°	-1.15281085°
POINT SCALE:	0.99965883	0.99996677
COMBINED FACTOR:	0.99963023	0.99993816

CONTRIBUTED BY

wsiopus
Watershed Sciences

Horizon View



The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID:	BBCK86
Designation:	PRC_13
Stamping:	PRC_13
Stability:	Monument will probably hold position well
Setting:	Object driven into ground
Description:	After entering the town of Buckley, WA travel east on Main St and continue 1.4 miles (follow road as it jogs sharply left and immediately sharply right, at which point it becomes Collins Rd) to site on S shoulder of road. Monument is 21ft 4in S of center-line of Collins Rd, 8ft 3in N of a tall wire strand fence, and 157ft E of a yellow fire hydrant.
Observed:	2011-04-08T16:24:00Z
Source:	OPUS - page5 1106.16

Close-up View

REF_FRAME:	EPOCH:	SOURCE:	UNITS:	SET PROFILE	DETAILS
NAD_83(CORS96)	2002.0000	NAVD88 (Computed using GEOID09)	m		

LAT:	47° 9' 48.75262"	± 0.010 m
LON:	-122° 0' 3.48110"	± 0.020 m
ELL HT:	207.153	± 0.011 m
X:	-2302303.756	± 0.020 m
Y:	-3684317.833	± 0.005 m
Z:	4654297.389	± 0.011 m
ORTHO HT:	228.962	± 0.025 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5223822.347m	204516.491m
EASTING:	575719.709m	386202.047m
CONVERGENCE:	0.73262295°	-1.09029608°
POINT SCALE:	0.99967046	0.99996558
COMBINED FACTOR:	0.99963800	0.99993311

CONTRIBUTED BY

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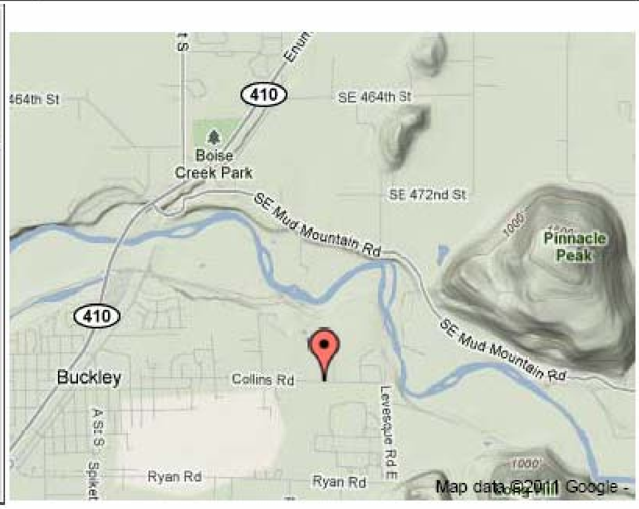
Horizon View



The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID: BBCL03
Designation: PRC_JM1
Stamping: PRC_JM1
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: From Gig Harbor, WA. Take WA-16 E toward Tacoma. Then merge to I-5 southbound and follow for 4.7 miles. Take exit 127 for WA-512 E toward Puyallup and continue for 2.0 miles. Take WA-7 toward Spanaway and continue for 5.1 miles. Slight right onto WA-507 for 12.5 miles. Turn left at WA-702 South and continue 4.3 miles. Monument is on right of the road at the intersection with an unmarked roadway.
Observed: 2011-02-05T16:26:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME: NAD_83(CORS96)	EPOCH: 2002.0000	SOURCE: NAVD88 (Computed using GEOID09)	UNITS: m	SET PROFILE	DETAILS

LAT:	46° 56' 15.11896"	± 0.008 m
LON:	-122° 27' 49.81342"	± 0.013 m
ELL HT:	128.644	± 0.008 m
X:	-2341835.690	± 0.008 m
Y:	-3681070.720	± 0.012 m
Z:	4637119.895	± 0.009 m
ORTHO HT:	150.646	± 0.022 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5198361.929m	180170.454m
EASTING:	540809.541m	350489.812m
CONVERGENCE:	0.39173123°	-1.42652296°
POINT SCALE:	0.99962047	0.99993350
COMBINED FACTOR:	0.99960031	0.99991333

CONTRIBUTED BY

WSIOPUS
Watershed Sciences

Horizon View

The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID: BBCK87
Designation: PRC_14
Stamping: PRC_14
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: Heading West on Center St W from Eatonville take a left (SW) on Larson St W, which will then make a sharp 90 degree turn to your right and become Orchard Ave (S). Drive apprx. 75 meters, there will be a pull out to your left (E). The monument resides in this area and is approximately 5 feet away from the edge of the road. Noticeable markings near the monument are a long pile of rocks as well as concrete dividers that run perpendicular to the road.
Observed: 2011-04-19T16:39:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME:	EPOCH:	SOURCE:	UNITS:	SET PROFILE	DETAILS
NAD_83(CORS96)	2002.0000	NAVD88 (Computed using GEOID09)	m		

LAT:	46° 51' 48.18146"	± 0.008 m
LON:	-122° 15' 28.94994"	± 0.003 m
ELL HT:	237.698	± 0.012 m
X:	-2331851.234	± 0.007 m
Y:	-3694611.391	± 0.006 m
Z:	4631567.118	± 0.010 m
ORTHO HT:	258.996	± 0.026 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5190249.825m	171560.335m
EASTING:	556551.330m	365970.916m
CONVERGENCE:	0.54144018°	-1.27703404°
POINT SCALE:	0.99963931	0.99992638
COMBINED FACTOR:	0.99960206	0.99988912

CONTRIBUTED BY

wsiopus
Watershed Sciences

Horizon View

The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID: BBCM31
Designation: PRC_15
Stamping: PIERCE 15
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: From Eatonville HWY take a right (E) on Larson St W for 0.21 miles where it will then make a sharp right turn and become Orchard Ave S. Travel approximately 250 feet and pull off to the left shoulder(E). The monument is located 80 feet East of the edge of the road's pavement. It is apprx. 15 feet away from where the pullout (with a ground cover of 5-8 inch grass) meets a shrub fence line.
Observed: 2011-04-19T16:28:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME:	EPOCH:	SOURCE:	UNITS:	SET	
NAD_83(CORS96)	2002.0000	NAVD88 (Computed using GEOID09)	m	PROFILE	DETAILS

LAT:	46° 51' 52.87082"	± 0.006	m
LON:	-122° 16' 7.64355"	± 0.015	m
ELL HT:	268.068	± 0.009	m
X:	-2332498.939	± 0.013	m
Y:	-3694102.093	± 0.008	m
Z:	4631688.293	± 0.007	m
ORTHO HT:	289.405	± 0.023	m

	UTM 10	SPC 4602(WA S)
NORTHING:	5190386.889m	171723.415m
EASTING:	555730.766m	365154.879m
CONVERGENCE:	0.53360769°	-1.28484151°
POINT SCALE:	0.99963817	0.99992649
COMBINED FACTOR:	0.99959617	0.99988447

CONTRIBUTED BY

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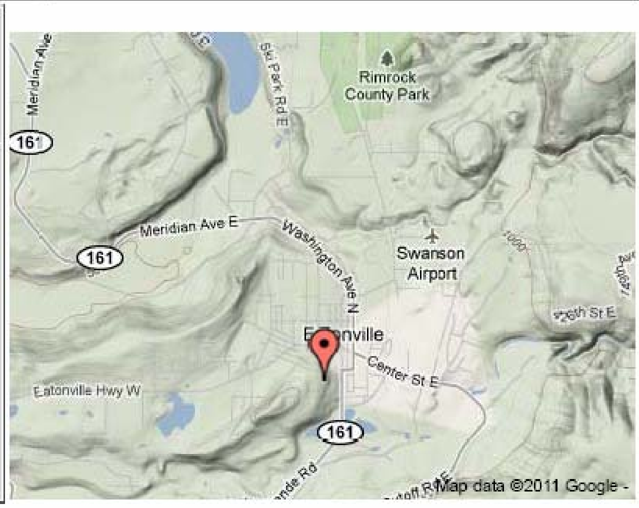
Watershed Sciences

Horizon View



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SURVEY DATASHEET (Version 1.0)

PID: BBCK88
Designation: PRC_16
Stamping: PRC_16
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: The monument is located within a clear cut next to the gravel road you drive in on. Its apprx. location is 30 meters past the beginning of the clear cut. And is 7 feet from the left side (S) of the edge of the gravel road.
Observed: 2011-04-28T16:39:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME:	EPOCH:	SOURCE:	UNITS:	SET PROFILE	DETAILS
NAD_83(CORS96)	2002.0000	NAVD88 (Computed using GEOID09)	m		

LAT:	47° 5' 41.55215"	± 0.012 m
LON:	-121° 58' 49.22075"	± 0.013 m
ELL HT:	508.384	± 0.016 m
X:	-2304049.047	± 0.015 m
Y:	-3690066.278	± 0.005 m
Z:	4649324.150	± 0.018 m
ORTHO HT:	529.646	± 0.032 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5216211.768m	196854.667m
EASTING:	577382.683m	387622.537m
CONVERGENCE:	0.74692016°	-1.07531208°
POINT SCALE:	0.99967359	0.99995418
COMBINED FACTOR:	0.99959394	0.99987450

CONTRIBUTED BY

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Watershed Sciences

Horizon View

The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.

SURVEY DATASHEET (Version 1.0)

PID: BBCM30
Designation: PRC_17
Stamping: PIERCE 17
Stability: Monument will probably hold position well
Setting: Object driven into ground
Description: MONUMENT IS LOCATED OFF WA 165 APPROX. 5 MI. E. OF MT. RAINIER NAT'L PARK. MONUMENT IS LOCATED APPROX. 6 MI. E. FROM FORK OF WA 165 AND CARBON CRK. RD. ON WA 165. MONUMENT IS LOCATED ON N. SIDE OF WA 165 APPROX 150 YDS. FROM RD. ON A SMALL HILLTOP.
Observed: 2011-07-06T18:16:00Z
Source: OPUS - page5 1106.16

Close-up View

REF_FRAME:	EPOCH:	SOURCE:	UNITS:	SET PROFILE	DETAILS
NAD_83(CORS96)	2002.0000	NAVD88 (Computed using GEOID09)	m		

LAT:	46° 58' 2.68909"	± 0.023 m
LON:	-122° 0' 31.20599"	± 0.015 m
ELL HT:	871.040	± 0.012 m
X:	-2311500.757	± 0.018 m
Y:	-3697929.438	± 0.020 m
Z:	4639930.099	± 0.012 m
ORTHO HT:	891.736	± 0.027 m

	UTM 10	SPC 4602(WA S)
NORTHING:	5202019.814m	182728.654m
EASTING:	575412.118m	385201.231m
CONVERGENCE:	0.72466344°	-1.09589032°
POINT SCALE:	0.99966990	0.99993684
COMBINED FACTOR:	0.99953342	0.99980033

CONTRIBUTED BY

wsiopus
Watershed Sciences

Horizon View

The numerical values for this position solution have satisfied the quality control criteria of the National Geodetic Survey. The contributor has verified that the information submitted is accurate and complete.