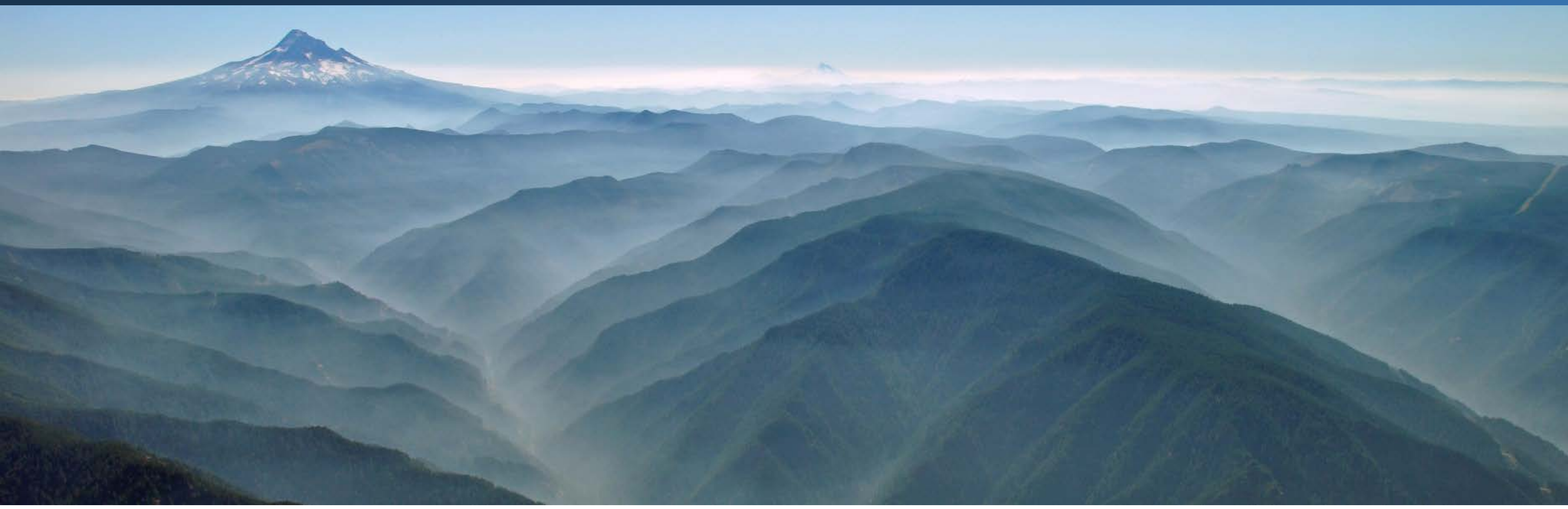
November 26, 2012



Technical Data Report

Western Wildland Environmental Threat Assessment Center

Colville Study Area

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WSI Applied Remote Sensing and Analysis

WWETAC

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Orthophoto image in the Colville study area, just east of Vulcan Mountain

WSI is pleased to report that WWETAC data collection, processing and reporting are complete for the Colville study area. Schedules, specifications, and resolution and accuracy statistics are presented within.

Completed fully on schedule as prescribed by WWETAC

Conducted without injuries or safety violations

Project Extent

Climate change, insect attack, and other diseases have far-reaching impacts on the health of forests, especially on the east side of the Cascades where water is most limiting. New remote sensing techniques provide new opportunities to map and analyze forest structure and plant vigor. This data can be used to better understand and predict where and why forest mortality occurs.
The study area includes over 250,000 acres of forest land in Colville National Forest that experienced a rare windstorm event in July 2012. The data provided can be used to assess windstorm impacts on forest structure to quantify the magnitude of disturbance and assist managers in implementing appropriate management options. Deliverables include LiDAR point data, digital orthophotos, thermal infrared images, rasters, and vectors of the study areas.

Projection:

Universal Transverse Mercator Coordinate System, NAD83 (2011), Zone 11N

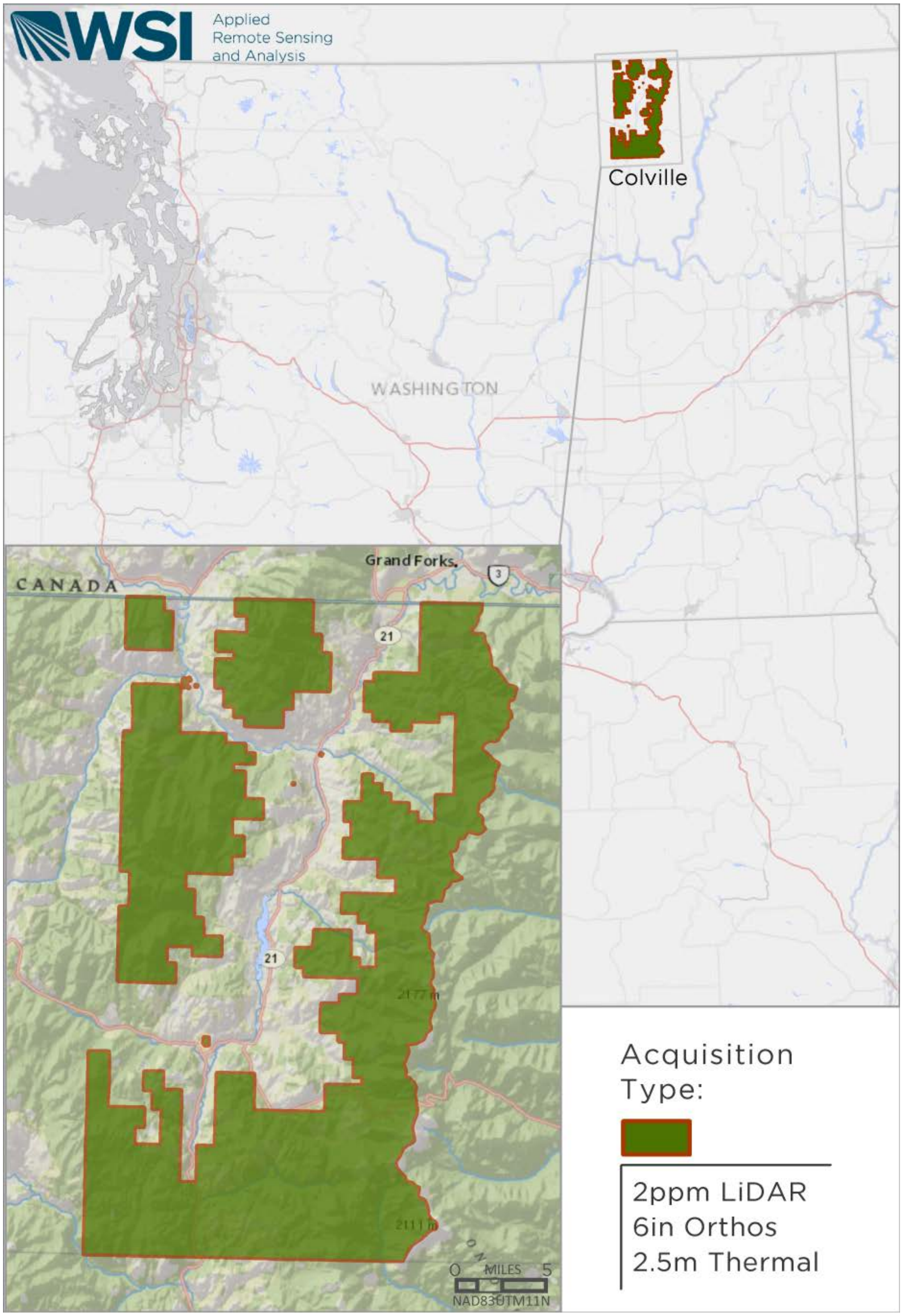
Datum:

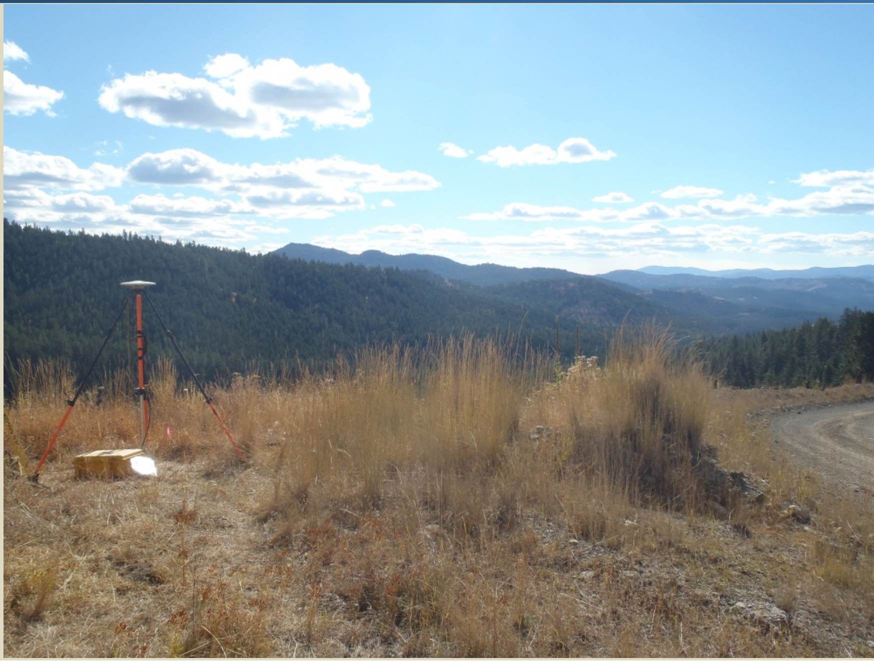
North American Vertical Datum 1988 (NAVD88), GEOID 12

Units:

Meters

AOI Acres	TAF Acres	LiDAR Acquisition Dates	Delivery Date
256,155	282,901	10/03/2012 – 10/09/2012	11/26/2012





A WSI base station set up in the survey area. A total of 11 monuments were used in this project.

Planning

WSI received a shapefile of the study area from WWETAC. This shape was reviewed using National Agriculture Imagery Program (NAIP) imagery and Google Earth. Flightlines were developed using ALTM-NAV Planner (v.3.0) software. Careful planning of the pulse rate, flight altitude and ground speed ensured that data quality and coverage conditions were met while optimizing flight paths for minimal flight times. Also precisely calculated were the pulse rate, flight altitude, and ground speed needed in order to achieve the recommended single-swath pulse density of greater than 2 pulses per square meter.

The mission planning conducted at WSI was designed to optimize flight efficiency while meeting or exceeding project accuracy and resolution specifications. In this process, known factors were prepared for, such as GPS constellation availability, photography and acquisition windows, and resource allocation. In addition, a variety of logistical barriers were anticipated, namely private property access, air space restrictions and acquisition personnel logistics. Finally, weather hazards and conditions affecting flight were continuously monitored due to their impact on the daily success of airborne and ground operations.

Careful planning ensured that data quality and coverage conditions were met while optimizing flight paths for minimal flight times.

Ground Survey

Monumentation

Using the High Accuracy Reference Network (HARN) and the Continuous Operation Reference System (CORS), WSI tied to a network of points with orthometric heights determined by differential leveling. Where available, First Order NGS (HARN) published monuments with NAVD88 were used. Existing and established survey benchmarks served as control points during LiDAR acquisition, including those of the National Geodetic Survey (NGS), the county surveyor's offices and the Washington Department of Transportation (WSDOT). In the absence of NGS benchmarks, county surveys, or WSDOT monumentation, WSI produces our own monuments. These monuments are spaced at a minimum of one mile apart 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.".

Ground data was collected for every mission, which included establishing and occupying survey control, collecting static positional data, collecting ground check points using GPS real-time kinematic (RTK) survey with a roving radio relayed unit and installing air targets and/or thermal blankets.

During each LiDAR mission, a minimum of two ground-based technicians was deployed, each outfitted with two Trimble Base Stations (R7) and one RTK Rover (R8).

WSI owns and operates multiple sets of Trimble GPS and Global Navigation Satellite System (GNSS[1]) dual-frequency L1-L2 receivers, which were used in both static and RTK surveys (listed in the table below).

Trimble R7 GNSS base station set up over ODOT monument DOT_31125.

Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R7	Zephyr Geodetic	TRM41249.00	Static
Trimble R7 GNSS	Zephyr GNSS Geodetic Model 2	TRM55971.00	Static
Trimble R8	Integrated Antenna R8 Model 2	TRM_R8_Model2	Static & RTK

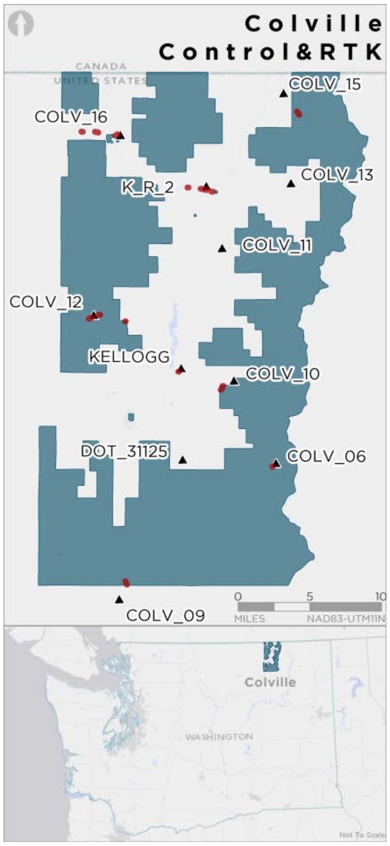
Monument Accuracy FGDC-STD-007.2-1998 Rating	
St Dev NE	0.050 m
St Dev z	0.050 m

[1] GNSS consists of the U.S. GPS constellation and Soviet GLONASS constellation.

Final Monument Positions

All static control points were observed for a minimum of one 2-hour session and one 4-hour session. At the beginning of every session the tripod and antenna were reset, resulting in two independent instrument heights and data files. Fixed height tripods were used when available. Data were collected at a recording frequency of 1Hz using a ten degree mask on the antenna.

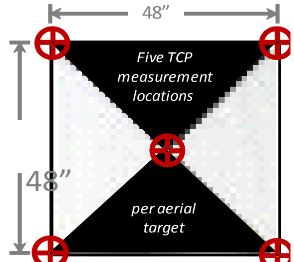
GPS data was uploaded to WSI servers daily for WSI PLS QA/QC and oversight. OPUS processing triangulated the monument position using three CORS stations resulting in a fully adjusted position. After multiple sessions of data collection at each monument, accuracy was calculated. Blue Marble Geographics Desktop v. 2.5.0 software was used to convert the geodetic positions from the OPUS reports. A total of 11 control monuments were surveyed for this project. Upon completion of the project, a total network adjustment was performed. The final monument positions are presented in the table below.



PID	UTM	Latitude	Longitude	Ellipsoid
COLV_6		48 36 05.00343	-118 30 53.39030	1518.598
COLV_9		48 27 47.65807	-118 45 10.19103	578.817
COLV_10		48 41 06.00809	-118 34 43.16929	1128.017
COLV_11		48 49 09.22445	-118 35 48.84083	617.547
COLV_12		48 45 04.41022	-118 47 34.57614	1137.182
COLV_13	11	48 53 06.11669	-118 29 29.35726	946.983
COLV_15		48 58 35.12355	-118 30 09.36791	603.976
COLV_16		48 56 00.93416	-118 45 09.96215	548.986
DOT_31125		48 36 17.58428	-118 39 24.68369	862.431
K_R_2		48 52 55.58179	-118 37 15.35126	530.36
KELLOGG		48 41 51.08773	-118 39 32.90069	740.342

RTK

A Trimble R7 base unit was set up over an appropriate monument to broadcast a kinematic correction to a roving R8 unit. This RTK survey allows for precise location measurement (σ ≤ 2.0 cm). 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. For RTK data, the collector began recording after remaining stationary for five seconds, then calculated the pseudorange position from at least three one-second epochs with the relative error less than 1.5 cm horizontal and 2 cm vertical. RTK positions were collected on bare earth locations such as paved, gravel or stable dirt roads, and other locations where the ground was clearly visible (and was likely to remain visible) from the sky during the data acquisition and RTK measurement periods. In order to facilitate comparisons with LiDAR data, RTK measurements were not taken on highly reflective surfaces such as center line stripes or lane markings on roads. For each control monument, at least 50 RTK points were taken within 5 nautical miles of the base. The planned locations for these control points were determined prior to field deployment, and the suitability of these locations was verified on site. Clusters of RTK were made up of no less than 25 points and were separated by no more than 20 miles. However, the distribution of RTK points depended on ground access constraints, and may not be equitably distributed throughout the study area.



Above: close up of a deployed air target.

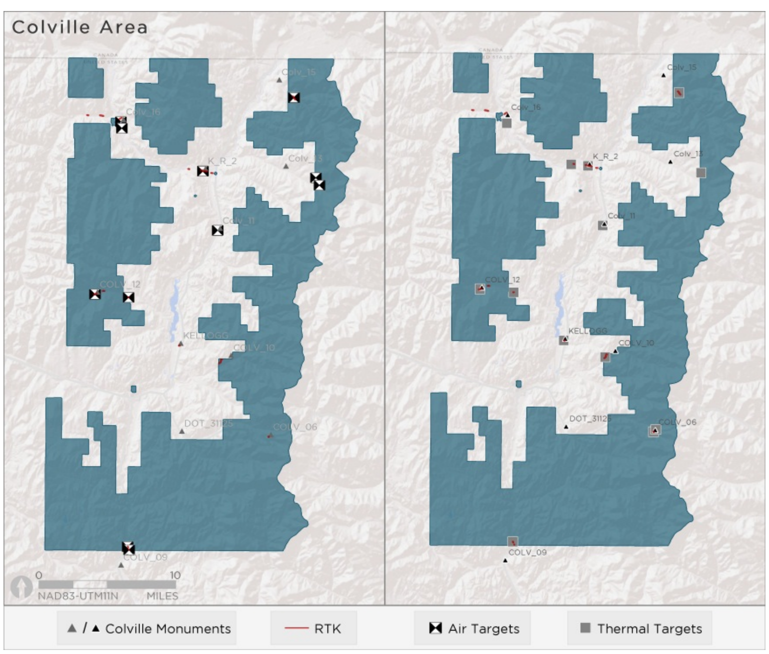
Below: air target and space blanket

Aerial Targets

Prior to photo acquisition, aerial photo targets were installed at each monument in our control network. Targets were distributed evenly throughout the study area, with at least two targets placed in proximity to the monument (within 0.5 mi) and at least two additional targets placed within 3.0 miles of the monument, depending on radio range.

Temporary Targets

WSI uses vinyl and canvas aerial targets measuring 48" x 48" for orthophotos and space blankets and catalytic portable heaters for thermal infrared. We have identified potential aerial target locations based on the allocation of 2 per base station, and at least ½-mi apart. RTK target check points (TCPs) were collected on each target, at a collection rate of five points per target, yielding 10 TCPs per base station. After the survey, the temporary targets were collected. A total of 21 temporary air targets and 14 thermal blankets were deployed.



Specifications for Ground Level Data Collection	Survey Control Monuments	Ground Check Points (GCPs)	Target Check Points (TCPs)
Accuracy	$RMSE_{XY} \leq$ 1.5 cm (0.6 in) $RMSE_{Z} \leq$ 2.0 cm (0.8 in)	$RMSE_{XYZ} \leq$ 1.5 cm (0.6 in) (Deviation from monument coordinates)	$RMSE_{XYZ} \leq$ 1.5 cm (0.6 in) (Deviation from monument coordinates)
Resolution	Spacing of at least one mile	≥50 per surveyed monument	≤ 2 TCPs per surveyed monument
	Minimum independent occupations of 4 hrs. & 2hrs	≥ 100 total per field day	5 points per TCP (10 TCPs per monument location)
Equipment	Trimble R7 R8 GNSS GLONASS	Trimble R7 R8 GNSS GLONASS	Trimble R7 R8 GNSS GLONASS

Airborne Survey

Airborne acquisition was conducted between 10:00am and 2:00pm each day. The table below is a summary of airborne acquisition for WWETAC.

Data collected	Equipment	Date Range	Aircraft	Elevation
LiDAR	Leica ALS50	10/03/2012 – 10/09/2012	Cessna Caravan	2,000m
Orthophotos	UltraCam Eagle	10/03/2012 – 10/08/2012		
Thermal Infrared	FLIR SC6000	10/03/2012 – 10/08/2012		

LiDAR Survey

The LiDAR survey utilized a Leica ALS50 sensor mounted in a Cessna Grand Caravan. The system was set to acquire ≥114,600 laser pulses per second and flown at 2,000 meters above ground level (AGL), capturing a scan angle of ±40° from nadir. These settings are developed to yield points with an average native density of ≥2 points per square meter over terrestrial surfaces. The native pulse density is the number of pulses emitted by the LiDAR system. The LiDAR system settings and flight parameters were designed to yield high-resolution data of >2 pulses per square meter. To solve for laser point position, an accurate description of aircraft position and attitude is vital. Aircraft position is described as x, y, and z and was measured twice per second (2 Hz) by an onboard differential GPS unit. Aircraft attitude is described as pitch, roll, and yaw (heading) and was measured 200 times per second (200 Hz) from an onboard inertial measurement unit (IMU).

The LiDAR sensor operators constantly monitored the data collection settings during acquisition of the data, including pulse rate, power setting, scan rate, gain, field of view, and pulse mode. For each flight, the crew performed airborne calibration maneuvers designed to improve the calibration results during the data processing stage. They were also in constant communication with the ground crew to ensure proper ground GPS coverage for data quality. The LiDAR coverage was completed with no data gaps or voids, barring non-reflective surfaces (e.g., open water, wet asphalt, etc.). All necessary measures were taken to acquire data under conditions (e.g., minimum cloud decks) and in a manner (i.e., adherence to flight plans) that prevented the possibility of data gaps. Moreover, terrain following to maintain consistent aircraft altitudes eliminated the potential for data gaps related to both acquisition and laser shadowing of targets. All WSI LIDAR systems are calibrated per the manufacturer and our own specifications, and tested by WSI for internal consistency for every mission using proprietary methods.

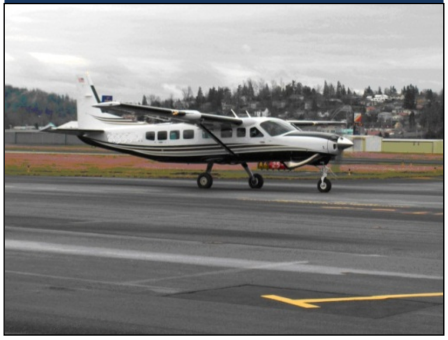
The acquisition occurred at maximum solar zenith angles given latitude and time of year, under clear conditions with no cloud cover and less than 10% cloud shadow. Weather conditions were constantly assessed in flight, as adverse conditions not only affect data quality, but can prove unsafe for flying.

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 discernible laser returns were processed for the output dataset.

WSI field crew monitoring data acquisition in-flight

LiDAR Survey Specifications	
Sensor	Leica ALS50
Aircraft	Cessna Grand Caravan 208B
Survey Altitude (AGL)	2,000m Above Ground Level (AGL)
Pulse Frequency	114600Hz
Pulse Mode	Multi
Mirror Scan Rate	40.7Hz
Field of View	40˚
GPS Baselines	≤13 nm
GPS PDOP	≤3.0
GPS Satellite Constellation	≥6
Resolution/Density	> 2 pulses/m^2

Leica sensor (above) mounted in the Cessna Caravan (below)



Photography

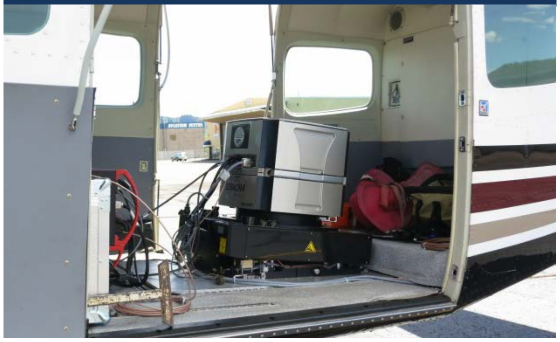
The photography surveys utilized an UltraCam Eagle 260 megapixel camera mounted in a Cessna 208B Caravan.

The UltraCam-Eagle is a large format digital aerial camera manufactured by the Microsoft Corporation. The system is gyro-stabilized and simultaneously collects panchromatic and multispectral (RGB, NIR) imagery. Panchromatic lenses collect high resolution imagery by illuminating 9 CCD (charged coupled device) arrays, writing 9 raw image files. RGB and NIR lenses collect lower resolution imagery, written as 4 individual raw image files. Level 2 images are created by stitching together raw image data from the 9 panchromatic CCDs, and ultimately combined with the multispectral image data to yield Level 3 pan-sharpened tiffs.

UltraCam Eagle Manufacturer Specifications	
Focal Length	80mm
Data format	RGBNIR
Pixel size	5.2 µm
Image size	20,010 x 13,080 pixels
Frame rate	>1.8 seconds
FOV	66 x 46 deg
GSD at 1000m	6.5 cm
Image Width at 800m	1,040 m
FOV	66 x 46 deg

Digital Orthophotography Survey Specifications	
Sensor	UltraCam Eagle
Aircraft	Cessna Grand Caravan 208B
Height	2,000m AGL
GPS Satellite Constellation	≥6
GPS PDOP	≤3.0
GPS Baselines	≤16 nm
Image	8-bit GeoTiff
Along Track Overlap	≥60%
Spectral Bands	Red, Green, Blue, NIR
Resolution	6 inch pixel size

Above: A Cessna Grand Caravan 208B was employed in the collection of all orthoimagery. Below: UltraCam Eagle installed in the aircraft.



UltraCam Eagle lens configuration as viewed from the Cessna Caravan.

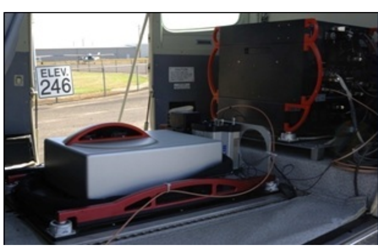
Thermal Infrared

The thermal infrared surveys utilized a FLIR SC6000-LWIR infrared camera mounted in a Cessna 208B Caravan. The SC6000 is a science-grade infrared camera manufactured by the FLIR Systems, Inc. The system has a 640x512 quantum well infrared photo detector (QWIP) array capable of collecting 14-bit digital frames directly from the sensor to an on-board computer. The SC6000 is a calibrated radiometer with a Noise Equivalent Temperature Difference (NETD) of 0.05°C, internal non-uniformity correction and drift compensation. Images were initially collected in a binary data format representing the measured, emitted radiance in the scene. The TIR sensor has a total horizontal field-of-view of 36°.

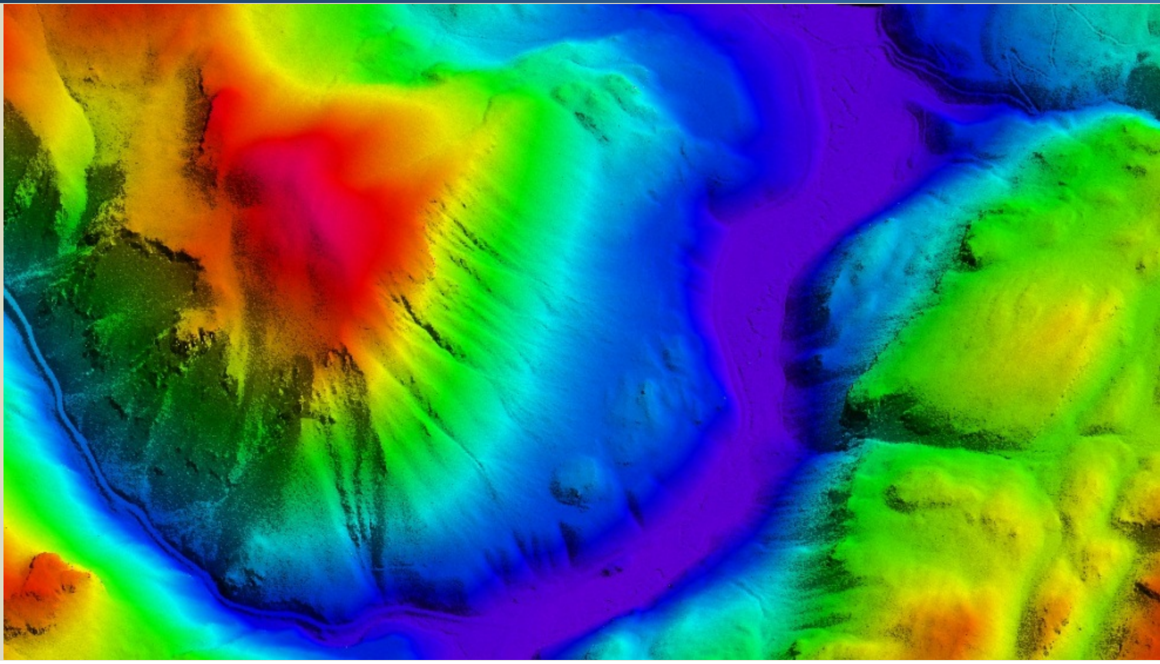
Thermal acquisition included calibration via space blankets, heaters (pending fire risk), and water thermistor if water present. Before and after each mission, the FLIR camera was flown over the nearest water thermistor in order to collect temperature data for thermal calibration and accuracy assessment.

FLIR SC6000-LWIR Manufacturer Specifications	
Spectral Range	8.0-9.2µm
Pixel Size	25µm
Image Size	640 (H) x 512 (V)
Shutter Speed	9µS
FOV	36 deg
NETD	<35mK

Thermal Infrared Survey Specifications	
Sensor	FLIR SC6000
Aircraft	Cessna Grand Caravan 208B
Height	900m AGL
GPS Satellite Constellation	≥6
GPS PDOP	≤3.0
GPS Baselines	≤16 nm
Image	8-bit GeoTiff
Along Track Overlap	≥60%
Spectral Bands	Thermal Infrared (8.0-9.2µm)
Resolution	2.5m pixel size



WSI's FLIR SC6000 integrated with a Leica ALS50-Phase II LiDAR System



Northern view of the Sanpoil River as it intersects with Scatter Creek and McMann Creek. LiDAR bare earth model colored by elevation.

This section describes the processing methodologies for all data acquired by WSI for the WWETAC project, including LiDAR, orthophotography, and thermal infrared. All of our methodologies and deliverables are compliant with Federal and industry specifications and guidelines (FEMA, USGS v.13, FGDC NSSDA, and ASPRS).

The overall goal of LiDAR point processing is to rapidly create highly accurate data.

LiDAR Data Processing

Calibration

Once the LiDAR data arrived in the laboratory, WSI employed a suite of automated and manual techniques for processing tasks. Processing tasks included: GPS, kinematic corrections, calculation of laser point position, relative accuracy testing and calibrations, classification of ground and non-ground points, and assessments of statistical absolute accuracy.

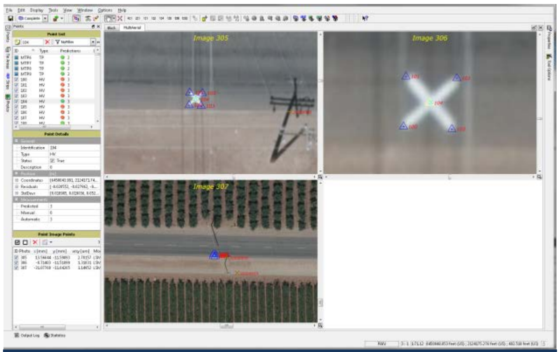
Orthophoto of Little Goosmus Creek Rd, 5 miles north of Curlew, WA.

The general workflow for calibration of the LiDAR data was as follows:

LiDAR Processing Step	Software Used
Resolve GPS kinematic corrections for aircraft position data using kinematic aircraft GPS (Collected at 2 Hz) and static ground GPS (1 Hz) data collected over geodetic controls.	POSGNSS v. 5.3, Trimble Business Center v. 2.81, PosPacMMS v 5.4
Develop a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with attitude data. Sensor heading, position, and attitude are calculated throughout the survey.	POSGNSS v. 5.3, PosPacMMS v5.4
Calculate laser point position by associating SBET information to each laser point return time, with offsets relative to scan angle, intensity, etc. included. This process creates the raw laser point cloud data for the entire survey in *.las (ASPRS v1.2) format, in which each point maintains the corresponding scan angle, return number (echo), intensity, and x, y, z information. These data are converted to orthometric elevation (NAVD88) by applying a Geoid 12 correction.	OPTECH LiDAR Mapping Suite (LMS) v. 2.1
Import raw laser points into subset bins (less than 500 MB, to accommodate file size constraints in processing software). Filter for noise and perform manual relative accuracy calibration. Ground points are then classified for individual flight lines to be used for relative accuracy testing and calibration.	TerraScan v.12, Custom Watershed Sciences software
Test relative accuracy using ground classified points per each flight line. Perform automated line-to-line calibrations for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift. Calibrations are performed on ground classified points from paired flight lines. Every flight line is used for relative accuracy calibration.	TerraMatch v.12, TerraScan v.12, Custom Watershed Sciences software
Assess Fundamental vertical accuracy via direct comparisons of ground classified points to ground RTK survey data.	TerraScan v.12

Orthophoto Processing

Digital orthophotos were collected using a 260 megapixel ultra large format digital aerial camera. Image radiometric values were calibrated to specific gain and exposure settings associated with each capture using Microsoft's UltraMap software suite. The calibrated images were saved in TIFF format for input to subsequent processes. Photo position and orientation were calculated by linking the time of image capture, the corresponding aircraft position and attitude, and the smoothed best estimate of trajectory (SBET) data in POSPAC. Within the Inpho software suite, automated aerial triangulation was performed to tie images together and adjust block to align with ground control. Adjusted images were then draped upon a ground model and orthorectified. Individual orthorectified tiffs were blended together to remove seams and corrected for any remaining radiometric differences between images using Inpho's OrthoVista. The processing workflow for orthophotos is as follows:



Inpho's Multi Photo measurement tool. Air target RTK is measured for use as orthophoto ground control.

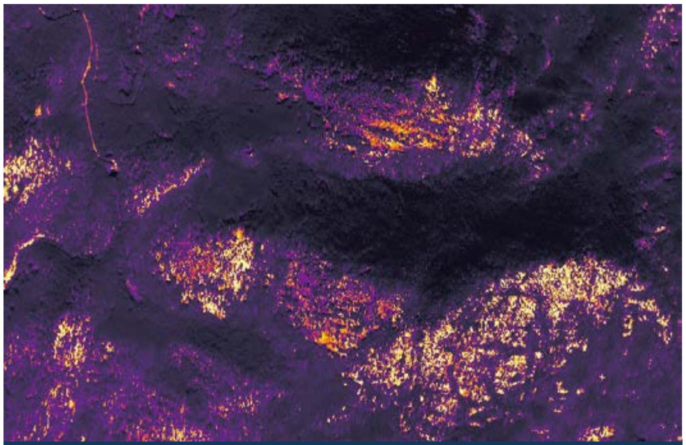
Orthophoto Processing Step	Software
Resolve GPS kinematic corrections for aircraft position data using kinematic aircraft GPS (Collected at 2 Hz) and static ground GPS (1 Hz) data collected over geodetic controls.	Pos Pac MMS v.5.4
Develop a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with attitude data. Sensor heading, position, and attitude will be calculated throughout the survey.	Pos Pac MMS v.5.4
Create an exterior orientation file (EO) for each photo image with omega, phi, and kappa	POS-EO and Pos Pac MMS v.5.
Convert Level 00 raw imagery into geometrically corrected Level 02 image files	UltraMap Raw Data Center v.2.3
Apply radiometric adjustments to Level 2 image files to create Level 3 Pan-sharpened tiffs	Ultra Map Radiometry v.2.3
Apply EO to photos, measure ground control points and perform aerial triangulation	Inpho Match-AT v.5.3
Import DEM, orthorectify and clip triangulated photos to specified area of interest	Inpho OrthoMaster v.5.3
Mosaic orthorectified imagery, blending seams between individual photos and correcting for radiometric differences between photos	Inpho OrthoVista v.4.5

Sample output of orthophoto processing steps.

East Kettle River Road, 2 miles south of Midway.

6 inch orthophotos acquired in the Colville study area.

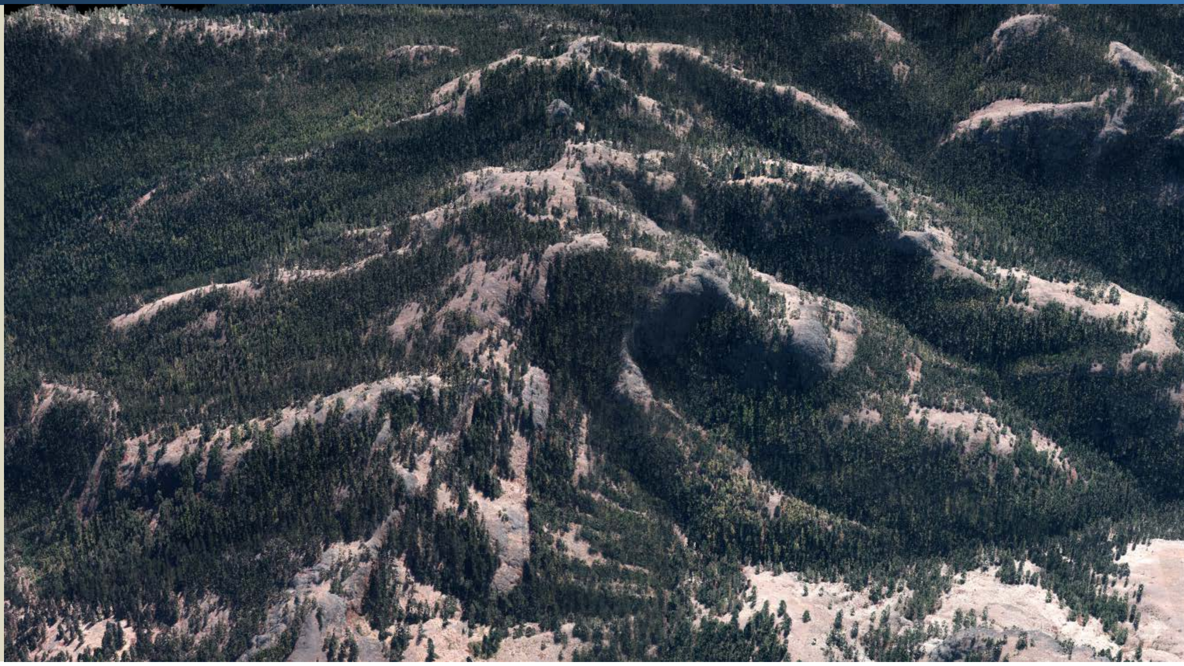
Thermal Infrared Processing



Thermal Infrared image of the Granite Mountain and Fire Mountain in the Colville study area.

Individual 8 bit tiffs were exported from the raw sequence files acquired by the FLIR thermal camera using FLIR's ExaminIR Max software. Frames were exported using a fixed radiance scale so radiance values were uniform across all exported frames. Frame position and orientation was calculated by linking the time of image capture, the corresponding aircraft position and attitude, and the post-processed trajectory solution (.sol) in Leica's IPAS CO+. Within the Inpho software suite, automated aerial triangulation was performed to tie frames together and adjust the block to align with ground control. Adjusted images were then draped upon a ground model and orthorectified. Individual orthorectified tiffs were blended together into final mosaics using Inpho's OrthoVista, with care to not apply any radiometric adjustments. In order to calibrate thermal rasters, radiance values were extracted from the mosaic tiffs at thermistor locations and compared to temperature values recorded by the thermistors. Temperature rasters (output in degrees Celsius) were generated from the radiance rasters (in watts per square meter).

Thermal Infrared Processing Step	Software
Process monument static GPS data with aircraft GPS data to resolve kinematic corrections.	IPAS-TC v 3.1
Calculate an exterior orientation (EO) for the perspective center (image center point position X,Y,Z) and orientation angles of the image (omega, phi, kappa) for each camera exposure event.	IPAS-CO+ v 2.1.06
Apply EO to photos, measure ground control points and perform aerial triangulation.	Inpho Match-AT v 5.3
Perform orthorectification resampling using the LiDAR derived bare-earth model for elevation values. Resample images at a ground sample distance of 1.0/2.5 meters.	Inpho OrthoMaster v 5.3
Generate seams and create mosaics from thermal images. No adjustments are made to color or contrast so that temperature information is preserved.	Inpho OrthoVista v.4.5
Generate radiance rasters (in watts per square meter) from 8 Bit mosaic tiffs and temperature rasters (in degrees Celsius) from radiance tiffs.	ArcGIS 10.0



RGB colored point cloud of a flank of Bamber Mountain in Colville National Forest. View to the South.

WSI strives to provide the most comprehensive and user friendly deliverable products possible. Deliverables can be categorized according to LiDAR, rasters, orthophotography, and thermal infrared.
This section describes all specifications and deliverable formats that are required by WWETAC. WSI is committed to meeting or exceeding all data specifications at all times. Deliverables are designed to provide WWETAC with accurate and useful information.

WWETAC Data Products

- **Calibrated LiDAR Point Data**
- **Rasters**
- **Calibrated Orthophoto Data**
- **Calibrated Thermal Infrared Data**
- **Vectors**
- **Technical Data Report**

Delivered Data

LiDAR Point Data

LiDAR point data (LAS 1.2*) with the following attributes: Number, XYZ, Intensity (8-bit), Return Number, Class, GPS Time, and RGB values from orthophotography (8-bit).

Rasters

Bare earth DTM and highest hit DTMs in ESRI Grid format as well as intensity images in .tiff format.

6 inch orthophoto of Kettle River, 1 mile south of Midway.

Digital Orthophotography

6 inch resolution data tiles

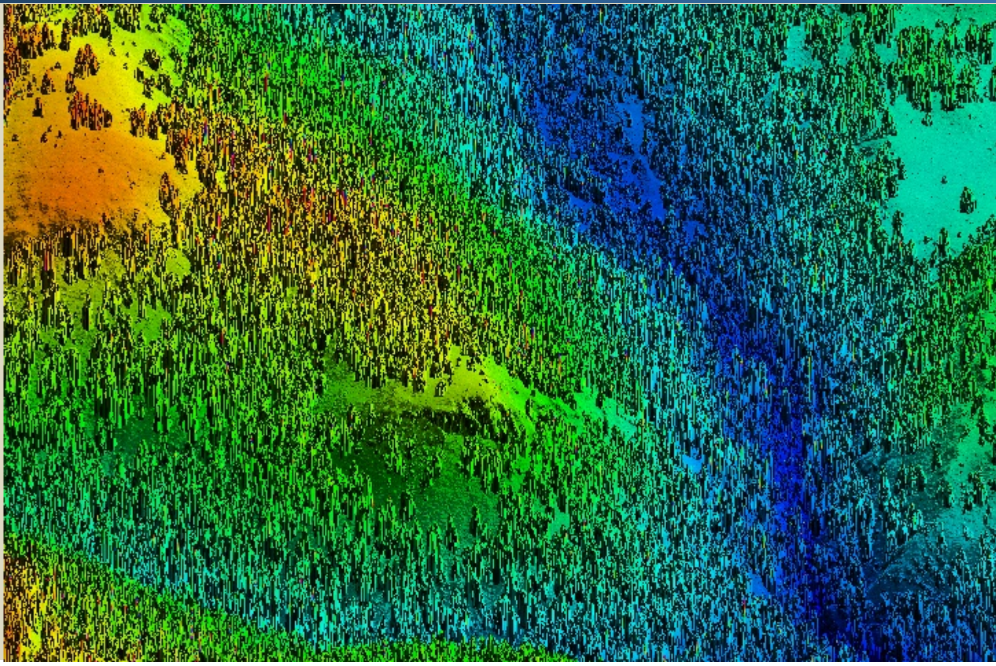
Thermal Infrared

2.5m resolution radiance (watts/m^2) and temperature (degrees Celsius) mosaics in .tiff format

Vectors

Area of Interest (AOI), Total Area Flown (TAF), tiling delineation for every deliverable product, certified monument locations, all RTK check points, and all aerial target check points in ESRI .shp format.

LiDAR point cloud of Harvest Creek, 5 miles south of Republic, colored by elevation. View to the north.



WSI is committed to meeting or exceeding all contract specifications in order to provide WWETAC with the highest quality LiDAR data, rasters, orthoimagery and thermal infrared. This section presents the accuracy statistics for each area surveyed. Additionally, the project's cumulative statistics are presented.

WSI met or exceeded accuracy and specifications for all areas surveyed.

LiDAR Accuracy Assessment

LiDAR Vertical Accuracy

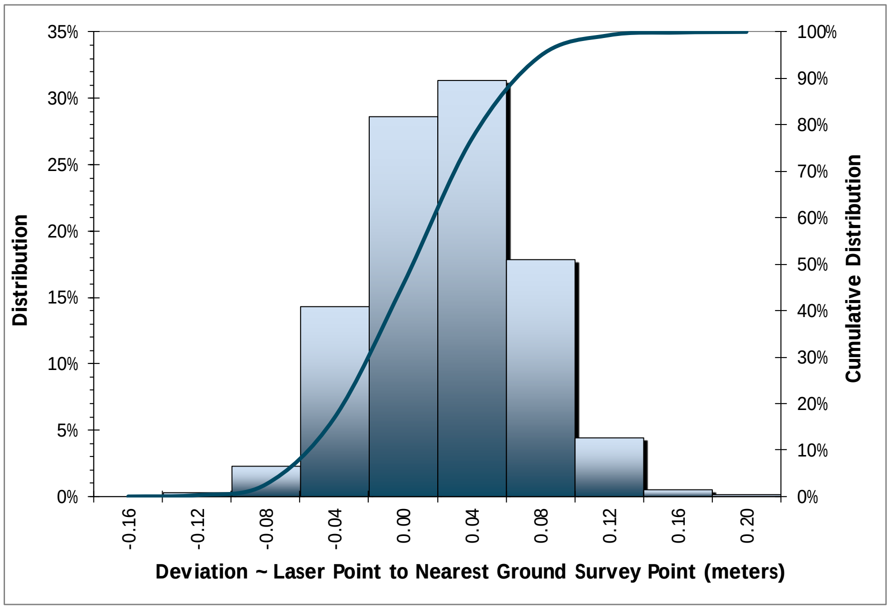
Vertical absolute accuracy was primarily assessed from ground check points on open, bare earth surfaces with level slope. For the WWETAC LiDAR survey, 698 RTK points were collected in total.

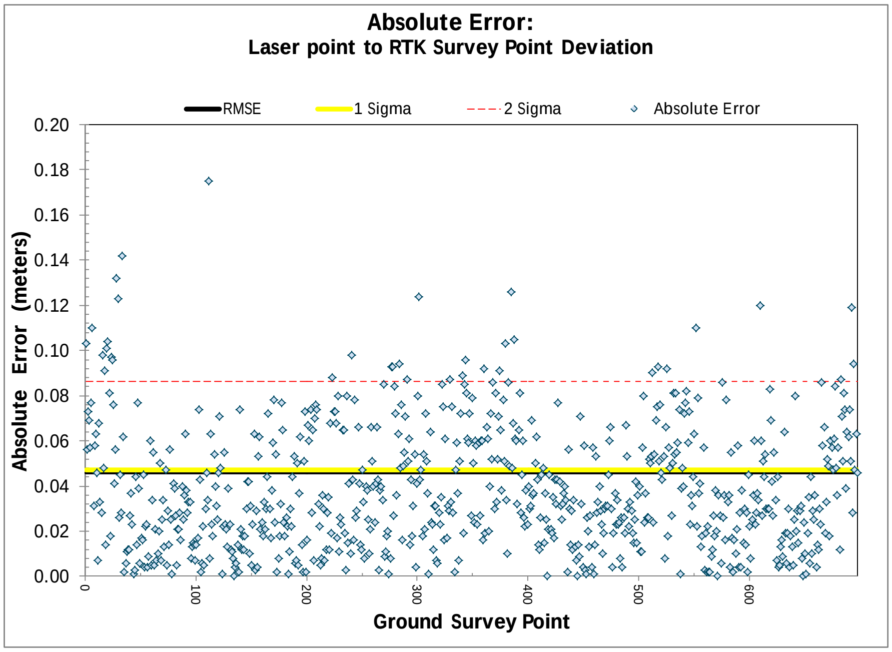
For this project, no independent survey data were collected, nor were reserved points collected for testing. As such, vertical accuracy statistics are reported as

"Compiled to Meet," in accordance with the ASPRS Guidelines for Vertical Accuracy Reporting for LiDAR Data V1.0 (ASPRS, 2004).

The values for vertical accuracy statistics are shown to the right.

Vertical Accuracy Sample Size = 698 RTK pts	WSI Spec (meters)	WSI Achieved (meters)
RMSE:	-	0.05
1 Sigma:	≤0.06	0.05
2 Sigma:	≤0.12	0.09
Minimum Δz:	-	-0.14
Maximum Δz:	-	0.18
Average Δz:	-	0.01



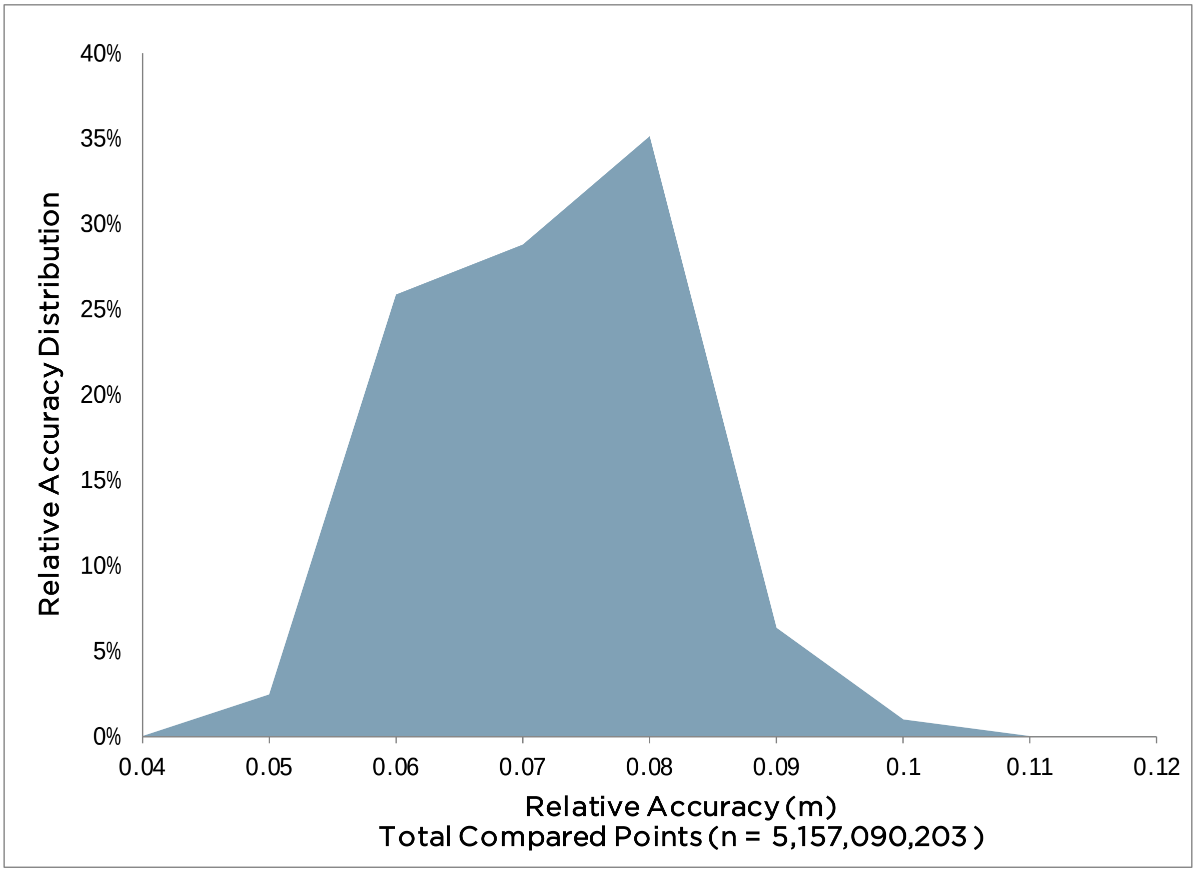


LiDAR Relative Accuracy

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 172 flightlines and over 5 billion points. Relative accuracy is reported for the entire study area.

Relative Accuracy Sample Size = 5,157,090,203 pts	WSI Achieved (m)
Average:	0.0671
Median:	0.0682
1 Sigma:	0.0719
2 Sigma:	0.0822
Minimum:	0.0471
Maximum:	0.1024



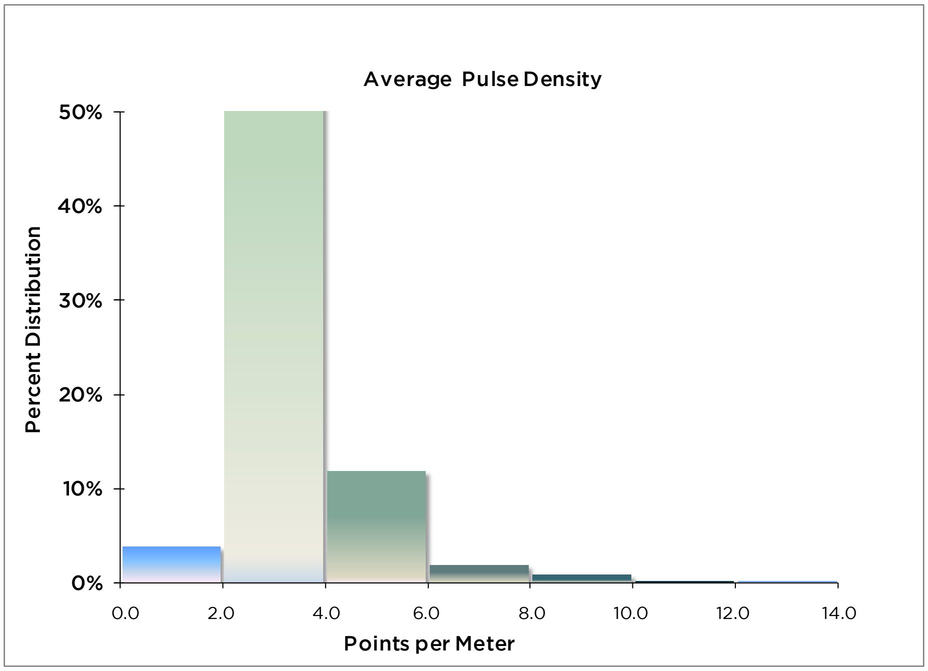
LiDAR Density

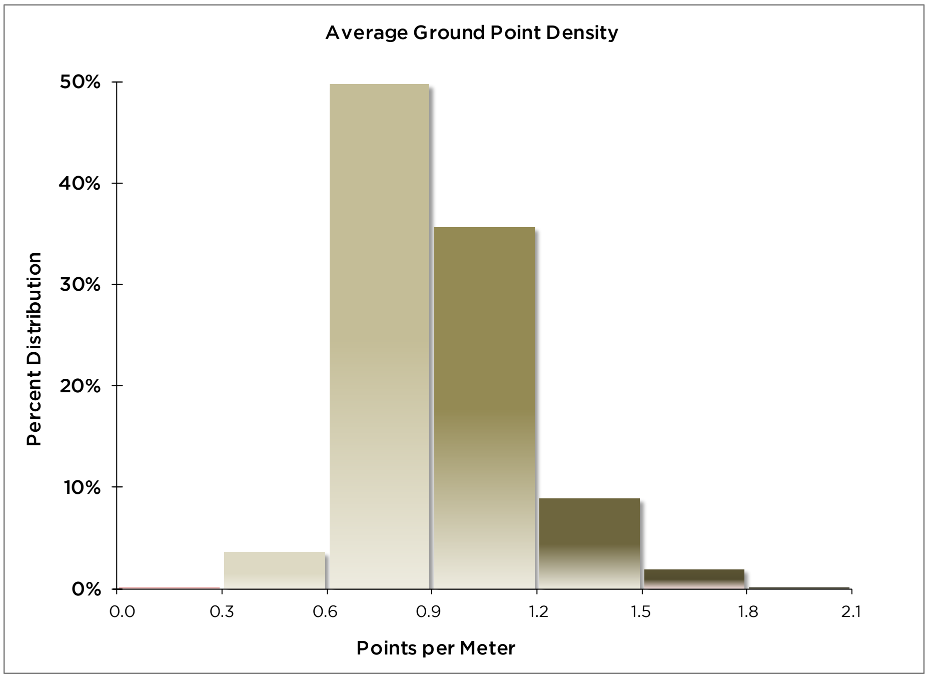
Project statistics are listed in the table to the right.

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 have been calculated based on first return laser point density and ground-classified laser point density.

Pulse Density		Ground Density	
(pulses/m^2)	(pulses/ft^2)	(pulses/m^2)	(pulses/ft^2)
3.13	**0.29**	**0.75**	**0.09**





Orthophoto Accuracy Assessment

To assess the spatial accuracy of the orthophotographs, they were compared against control points identified from the LiDAR intensity images. 20 control points, distributed evenly across the total acquired area, were collected/measured on surface features such as painted road lines and fixed high-contrast objects on the ground surface. The accuracy of the final mosaic was calculated in relation to the LiDAR-derived control points and is listed below. The orthophoto horizontal accuracy achieved by WSI for WWETAC was 0.31 meters or less at a 65% confidence interval, which meets the set standard of 0.61 meters.

Orthophoto Horizontal Accuracy Sample Size = 20 control points	WSI Achieved (m)
RMSE	0.2750
1 Sigma	0.3063
2 Sigma	0.4313

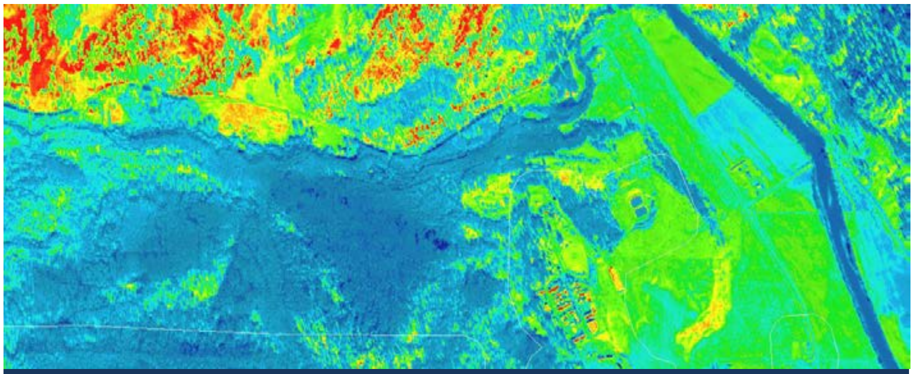
Example of co-registration of color images with LiDAR intensity images

Thermal Accuracy Assessment

The accuracy of the thermal data was assessed by comparing temperatures pulled from the thermal imagery to the kinematic temperatures recorded by the water thermistors. Before and after each acquisition mission, the FLIR sensor was flown over the nearest water thermistor in order to collect a temperature reading at the location of the thermistor. Radiance and temperature values were calculated from these flyover images and compared to the temperatures recorded by the water thermistors.

Thermal Horizontal Accuracy Sample Size = 16 control points	WSI Achieved (m)
RMSE	4.1182
1 Sigma	4.2700
2 Sigma	7.0477

Thermal Temperature Accuracy Sample Size = 12 check points	WSI Achieved (°C)
Average Difference	0.6771
1 Sigma	0.8453
2 Sigma	1.2643



RGB thermal image of the US Job Corps campus in Curlew, WA.

Best Practices/Standards

WSI has high standards and adheres to best practices in all efforts. In the field, rigorous quality control methods include deployment of base stations at pre-surveyed level I monuments and collecting RTK (real-time kinematic), and efficient planning to reduce flight times and mobilizations.

In the laboratory, quality checks are built in throughout processing steps, and automated methodology allows for rapid data processing. There is no off-shoring, which allows for in house, US citizen-based project control for all data collection and processing. WSI's innovation and adaptive culture rises to technical challenges and the needs of clients like WWETAC. Reporting and communication to our clients are prioritized through regular updates and meetings.

CERTIFICATION

WSI provided LiDAR services for the Toutle WWETAC Data 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.

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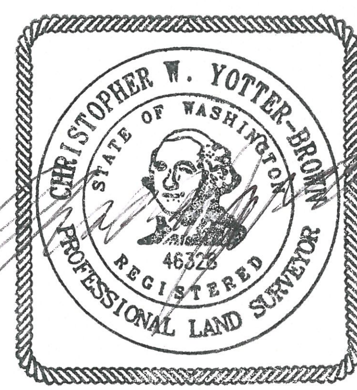
Mathew Boyd
Principal
WSI

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.

11/21/2012

Christopher W. Yotter-Brown, PLS Oregon & Washington
WSI
Portland, OR 97204



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