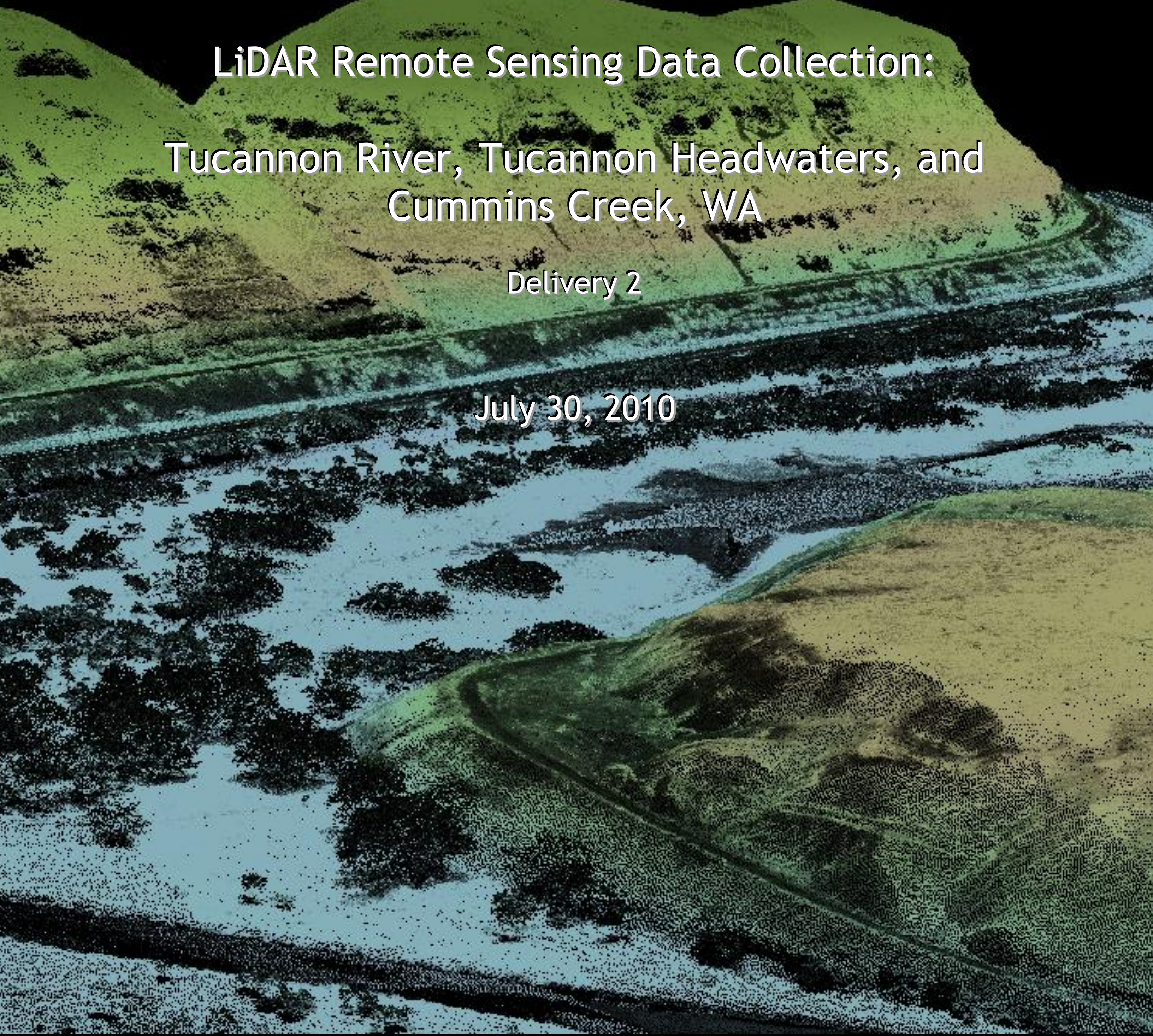
Watershed Sciences

LiDAR Remote Sensing Data Collection:

Tucannon River, Tucannon Headwaters, and Cummins Creek, WA

Delivery 2

July 30, 2010



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1. Overview

Watershed Sciences, Inc. (WS) collected Light Detection and Ranging (LiDAR) data and true-color orthophotographs of the Tucannon River floodplain and LiDAR data for the Cummins Creek and Tucannon Headwaters study areas. Data collection occurred from March 31, 2010 to April 16, 2010 and was extended to June 19, 2010 to June 24, 2010 due to remnant snow on the ground during initial acquisition in the headwater areas. The total area of LiDAR data delivered for the entire Tucannon project is 23,890 acres, including a 100 m buffer. True color orthophotographs were acquired for 18,580 acres of the Tucannon project area (**Figure 1**). The Tucannon River project area was acquired as part of the Tucannon/Touchet Rivers collaborative project area, enabling data integration and more robust accuracy methodologies.

***Figure 1**. Tucannon River floodplain study area*

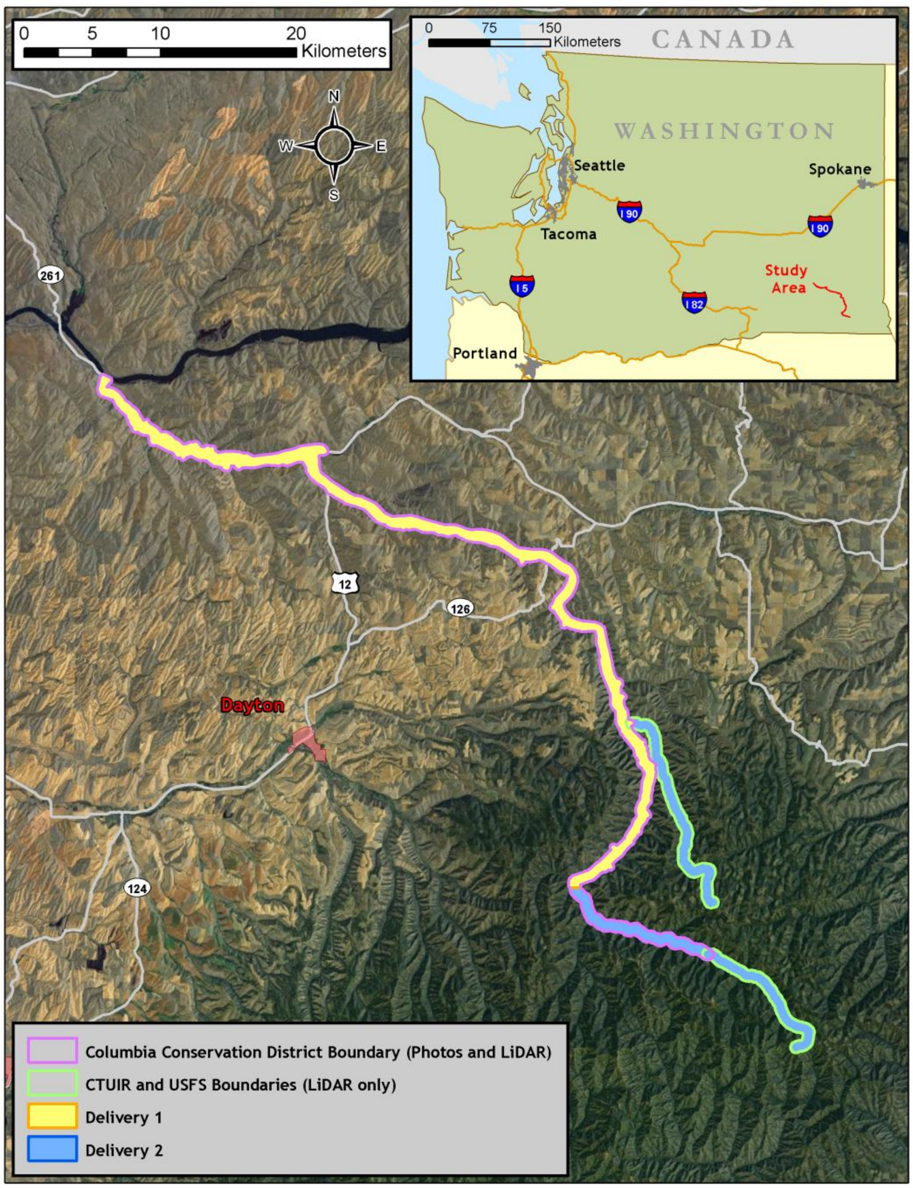


Table 1*. Delivery schedule for the Tucannon River project area.*

Delivery	Area	Partner	Date	Data
Delivery 1 & 2	18,580 acres	CCD	07/02/2010 07/30/2010	Photos and LiDAR
Delivery 2	1,810 acres	CTUIR	07/30/2010	LiDAR only
Delivery 2	3,500 acres	USFS	07/30/2010	LiDAR only

2. Acquisition

2.1 Airborne Survey – Instrumentation and Methods

The LiDAR survey used a Leica ALS50 Phase II laser system. For the Tucannon River project area the sensor scan angle was ±14° from nadir[1] with a pulse rate designed to yield an average native density (number of pulses emitted by the laser system) of ≥ 8 points 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 survey areas were aquired with an opposing flight line side-lap of ≥50% (=100% overlap) to reduce laser shadowing and increase surface laser painting. The Leica ALS50 Phase II system allows up to four range measurements (returns) per pulse, and all discernable laser returns were processed for the output dataset.

The aerial imagery was collected using a Leica RCD-105 39 megapixel digital camera. For the Tucannon River study area, images were collected in 3 spectral bands (red, green, blue) with 60% along track overlap and 40% sidelap between frames. The acquisition flight parameters were designed to yield native pixel resolution of 10-31cm.

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

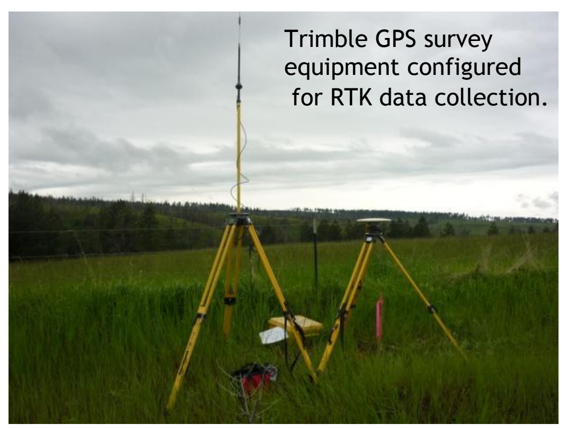
The Cessna Caravan is a stable platform, ideal for flying slow and low for high density projects. The Leica ALS50 Phase II sensor head installed in the Caravan is shown on the left.

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.

2.2 Ground Survey – Instrumentation and Methods

The following ground survey data were collected to enable the geo-spatial correction of the aircraft positional coordinate data collected throughout the flight, and to allow for quality assurance checks on final LiDAR data products.

2.2.1 Survey Control



Trimble GPS survey equipment configured for RTK data collection.

Simultaneous with the airborne data collection mission, we conducted multiple static (1 Hz recording frequency) ground surveys over monuments with known coordinates (**Table 2, Figure 2**). Indexed by time, these GPS data are used to correct the continuous onboard measurements of aircraft position recorded throughout the mission. Multiple sessions were processed over the same monument to confirm antenna height measurements and reported position accuracy.

Whiteshield Inc., Pasco, WA (WA Professional Licensed Surveyor, Michael LeJeune (PLS #19580)) provided the professional oversight and control certification for the project. Redundant control monuments for the Tucannon River Project were set within 13 nautical miles of the mission area. The survey control report is included as **Appendix B**.

Table 2. *Base Station Survey Control coordinates for the Tucannon River project area*

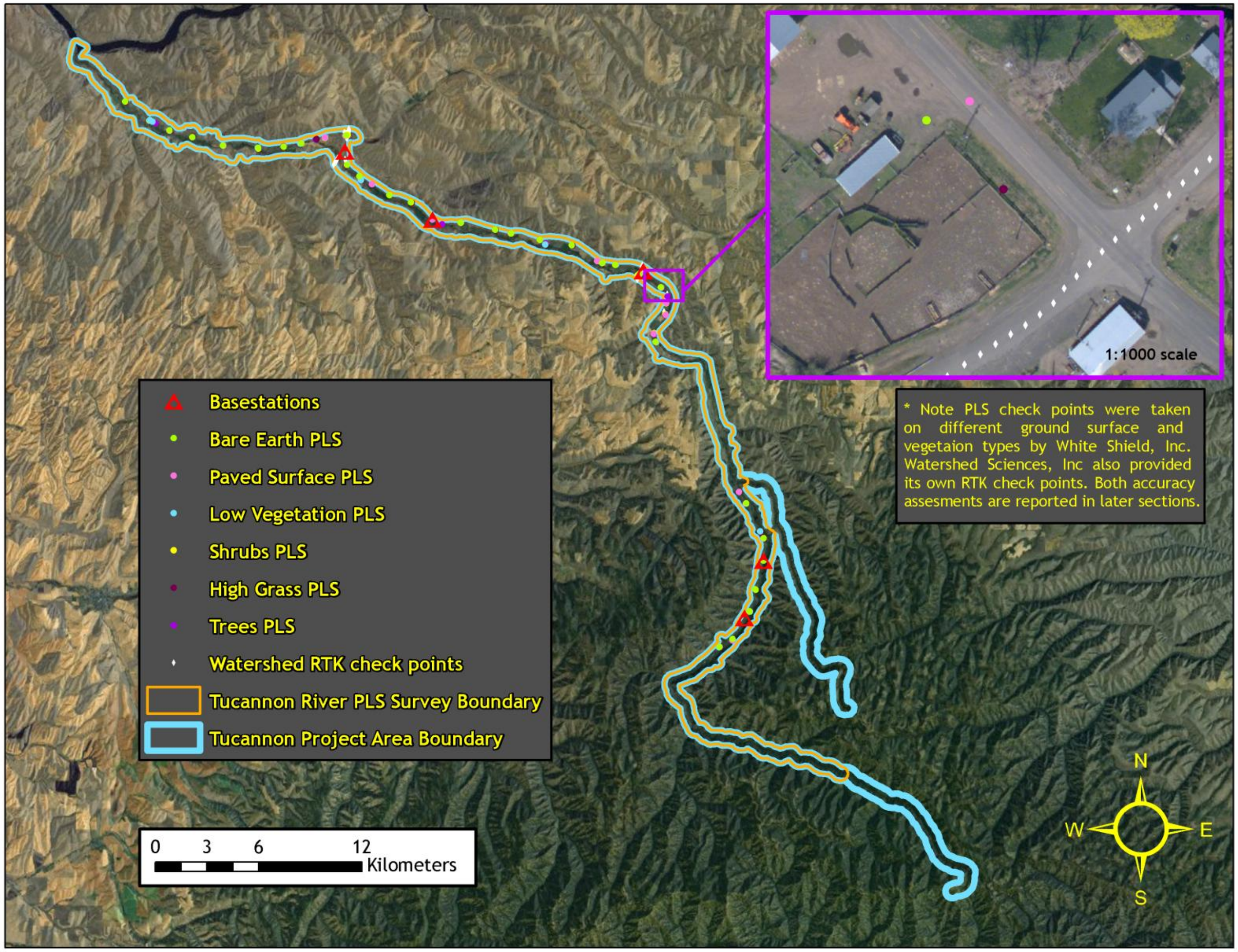
Base Station ID	Datum: NAD83 (CORS96)		GRS80
	Latitude	Longitude	Ellipsoid Z (meters)
TUC-01	46° 30' 10.94797"	117° 58' 24.57466"	270.858
TUC-02	46° 28' 04.69818"	117° 54' 23.95945"	319.688
TUC-03	46° 26' 32.32455"	117° 44' 49.01967"	439.108
TUC-04	46° 17' 29.72309"	117° 39' 16.14917"	691.382
*TUC-05	46° 15' 42.37533"	117° 40' 06.39514"	776.309

** Basestation TUC-05 was established as a redundant check, but is not included in the PLS report (Appendix B).*

2.2.2 RTK Survey

To enable assessment of LiDAR data accuracy, ground truth points were collected using GPS based real-time kinematic (RTK) surveying. For an RTK survey, the ground crew uses a roving unit to receive radio-relayed corrected positional coordinates for all ground points from a GPS base station set up over a survey control monument. Instrumentation includes multiple Trimble DGPS units (R8). RTK surveying allows for precise location measurements with an error (σ) of ≤ 1.5 cm. **Figure 2** below portrays a distribution of Base station and RTK point locations used for the survey areas. LiDAR data was collected beyond the delivered survey boundary; these areas were included in the RTK survey.

Figure 2. PLS, RTK, and base station locations used for the Tucannon River project area



3. Data Processing

3.1 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.

   Software: ALS Post Processing Software v.2.7
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
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
6. Position and attitude data were imported. Resulting data were classified as ground and non-ground points. Statistical absolute accuracy was assessed via direct comparisons of ground classified points to ground RTK survey data. Data were then converted to orthometric elevations (NAVD88) by applying a Geoid03 correction. Ground models were created as a triangulated surface and exported as ArcInfo ASCII grids at a 1 –meter pixel resolution.

   Software: TerraScan v.10.009, ArcMap v. 9.3.1, TerraModeler v.10.004
7. Converted raw images to tif format, calibrating raw image pixels for gain and exposure settings of each image.

   Software: Leica Calibration Post Processing v.1.0.4
8. Calculated photo position and orientation by associating the SBET position (Step 3) to each image capture time.

   Software: IPASCO v.1.3
9. Orthorectified calibrated tiffs utilizing photo orientation information (Step 8) and the LiDAR-derived ground surface (Step 6).

   Software: Leica Photogrammetry Suite v.9.2
10. To correct light imbalances between overlapping images, radiometric global tilting adjustments were applied to the rectified images.

    Software: OrthoVista v.4.4.
11. The color corrected images were then mosaicked together for the survey area and subset into tiles to make the file size more manageable.

    Software: OrthoVista v.4.4.
12. Mosaicked tiles were inspected for misalignments introduced by automatic seam generation. Misalignments were corrected by manual adjustments to seams.

    Software: Adobe Photoshop 7.0, OrthoVista v.4.4.

3.2 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. Leica IPAS Suite 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. Waypoint 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.

3.3 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; each point maintains 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 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 grounds 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 non-grounds. Ground surface rasters were developed from triangulated irregular networks (TINs) of ground points.

3.4 Orthophotograph Processing

Image radiometric values were calibrated to specific gain and exposure settings associated with each capture using Leica's Calibration Post Processing software. The calibrated images were saved in tiff format to be used as inputs for the rectification process. Photo position and orientation was then calculated by assigning aircraft position and attitude information to each image by associating the time of image capture with trajectory file (SBET) in IPASCO. Photos were then orthorectified to the LiDAR derived ground surface using LPS. This typically results in <2 pixel relative accuracy between images. Relative accuracy can vary slightly with terrain but offsets greater than 2 pixels tend to manifest at the image edges which are typically removed in the mosaic process.

The rectified images were mosaicked together in a three step process using Orthovista. Firstly color correction was applied to each image using global tilting adjustments designed to homogenize overlapping regions. Secondly, discrepancies between images were minimized by an automated seam generation process. The most nadir portion of each image was selected and seams were drawn around landscape features. The high resolution orthophotos were delineated into a manageable size (~2250 x 2250 m) appropriate to the pixel resolution and requested spatial reference.

4. LiDAR Accuracy Assessment

Our LiDAR quality assurance process uses the data from the real-time kinematic (RTK) ground survey conducted in the survey area. In this project, a total of **938** RTK GPS measurements were collected on hard surfaces distributed among multiple flight swaths. To assess absolute accuracy, we compared the location coordinates of these known RTK ground survey points to those calculated for the closest laser points.

4.1 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, we first performed a number of noise filtering and calibration procedures 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 utilized to calculate the vertical divergence between lines caused by vertical GPS drift. Automated Z calibration was the final step employed for relative accuracy calibration.

4.2 Absolute Accuracy

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. To calibrate laser accuracy for the LiDAR dataset, 938 RTK ground survey points were collected on fixed, hard-packed road surfaces within the survey area.

5. Photo Accuracy Assessment

To assess spatial accuracy of the orthophotographs they are compared against check points identified from the LiDAR intensity images. The check points were collected and measured on surface features such as painted road-lines and corners of sidewalks. The accuracy of the final mosaic, expressed as root mean square error (RMSE), was calculated in relation to the LiDAR-derived check points. **Figure 3** displays the co-registration between orthorectified photographs and LiDAR intensity images.

Figure 3. *Example of co-registration of color images with LiDAR intensity images*

6. Study Area Results

Summary statistics for point resolution and accuracy (relative and absolute) of the LiDAR data collected in the Tucannon River study area are presented below in terms of central tendency, variation around the mean, and the spatial distribution of the data (for point resolution by tile).

6.1 Data Summary

Table 3. *Resolution and Accuracy - Specifications and Achieved Values*

	Targeted	Achieved
Resolution:	≥ 8 points/m^2	9.74 points/m^2
Vertical Accuracy (1 σ):	<15 cm	3.70 cm

6.2 Data Density/Resolution

Certain types of surfaces (e.g. water, dense vegetation, breaks in terrain, 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-classified return densities will be lower in areas of dense vegetation, water, or buildings. **Figures 6 and 7** display the distribution of average first return and ground classified point densities by processing tile

Data Resolution for the Tucannon River project area:

- Average Point (First Return) Density = 9.74 points/m^2
- Average Ground Point Density = 2.86 points/m^2

***Figure 4**. Density distribution for first return laser points*

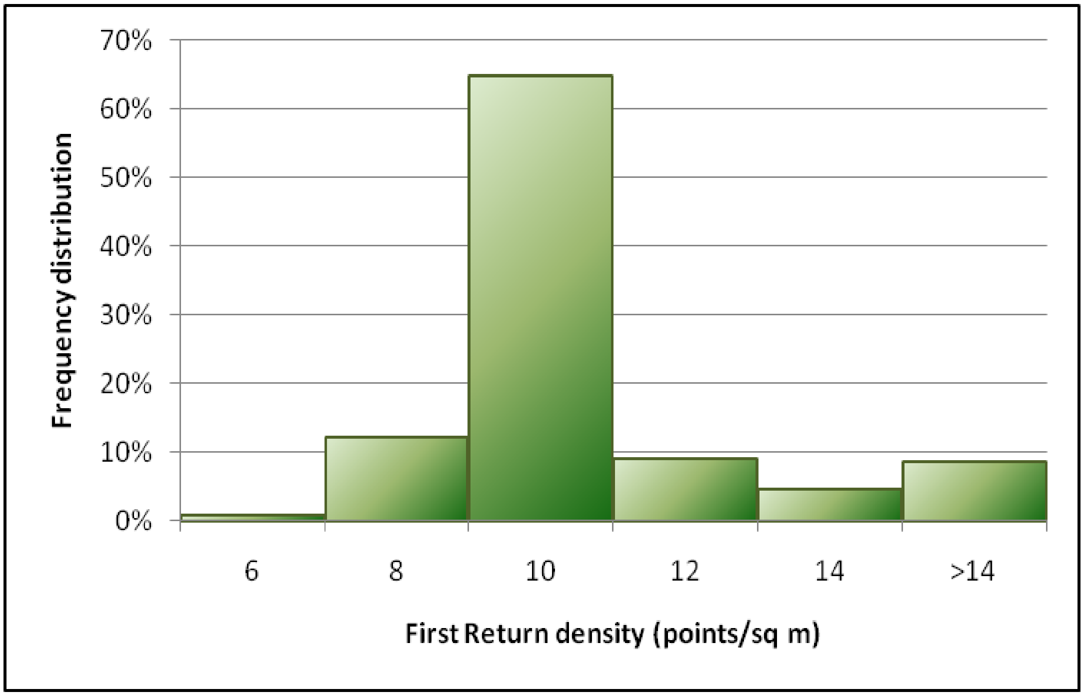


***Figure 5**. Density distribution for ground classified laser points*

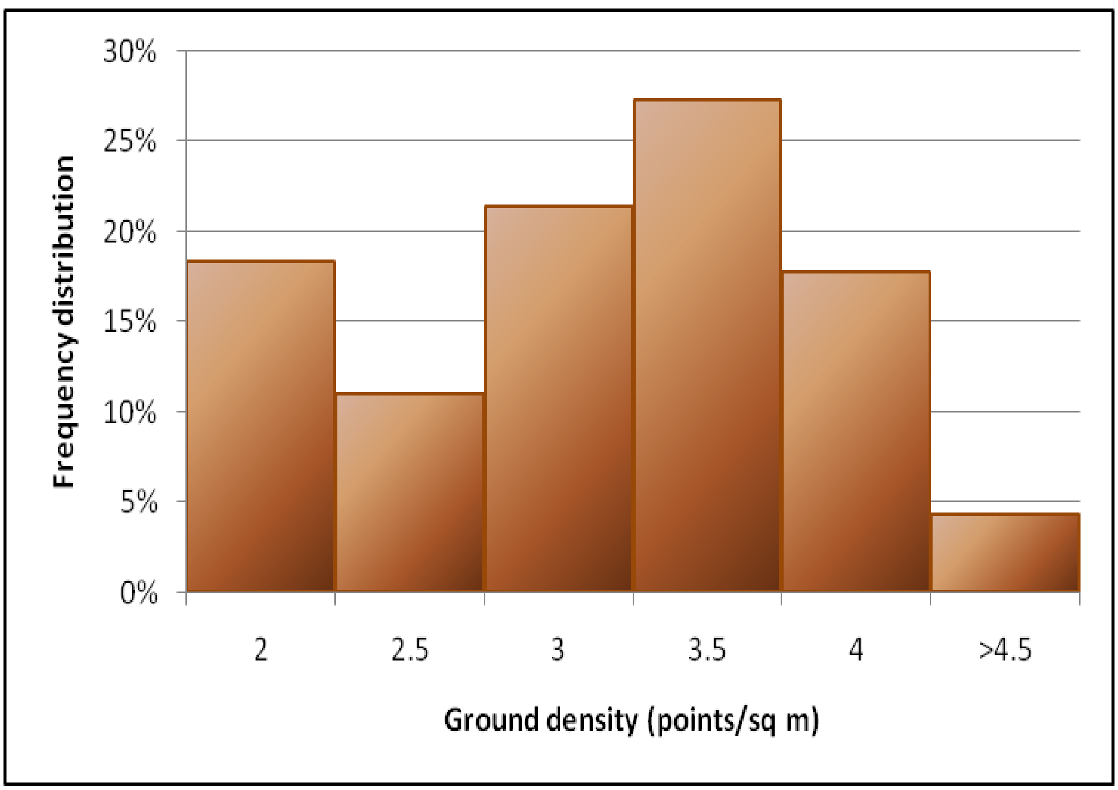


***Figure 6**. First Return laser point data density per processing tile*

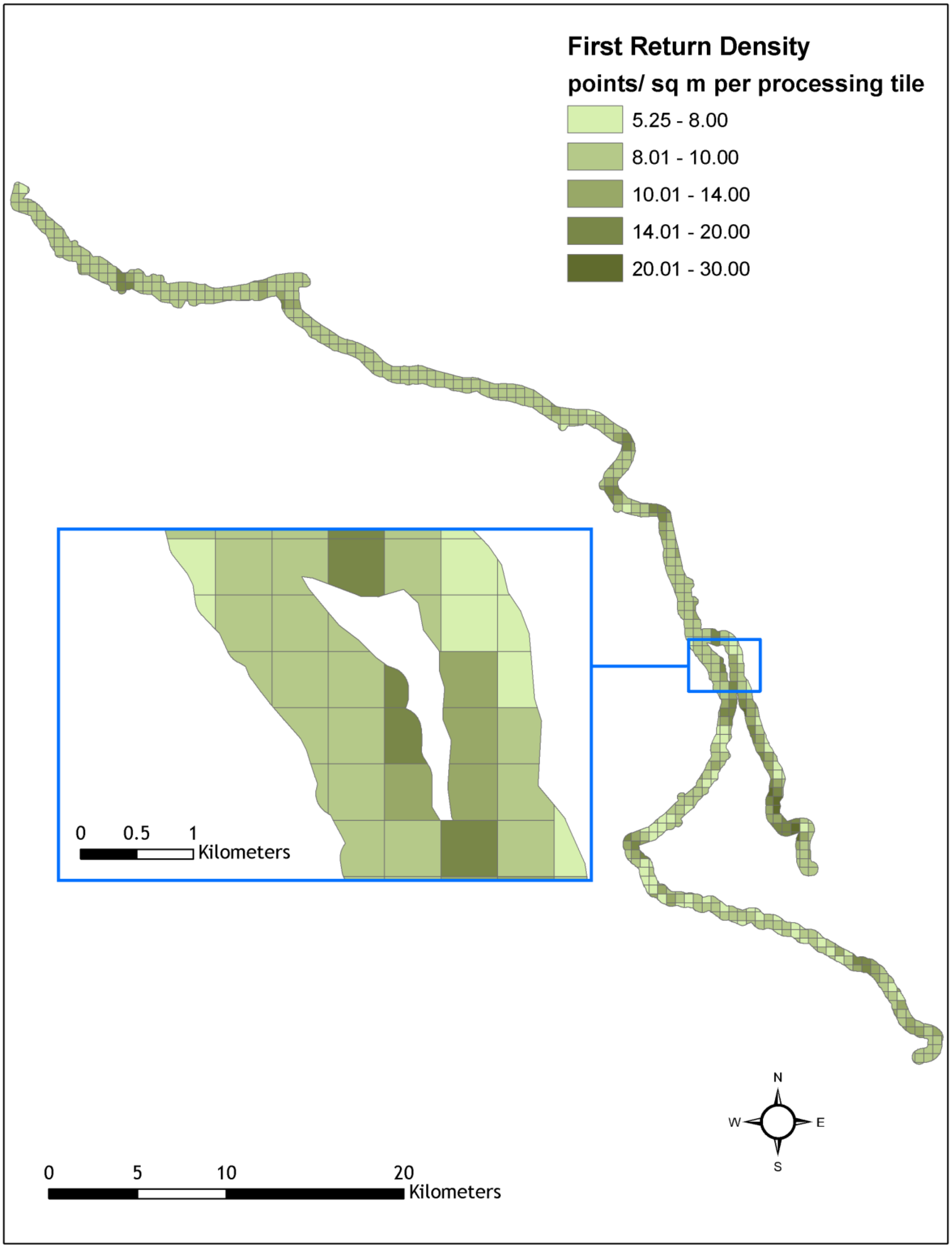
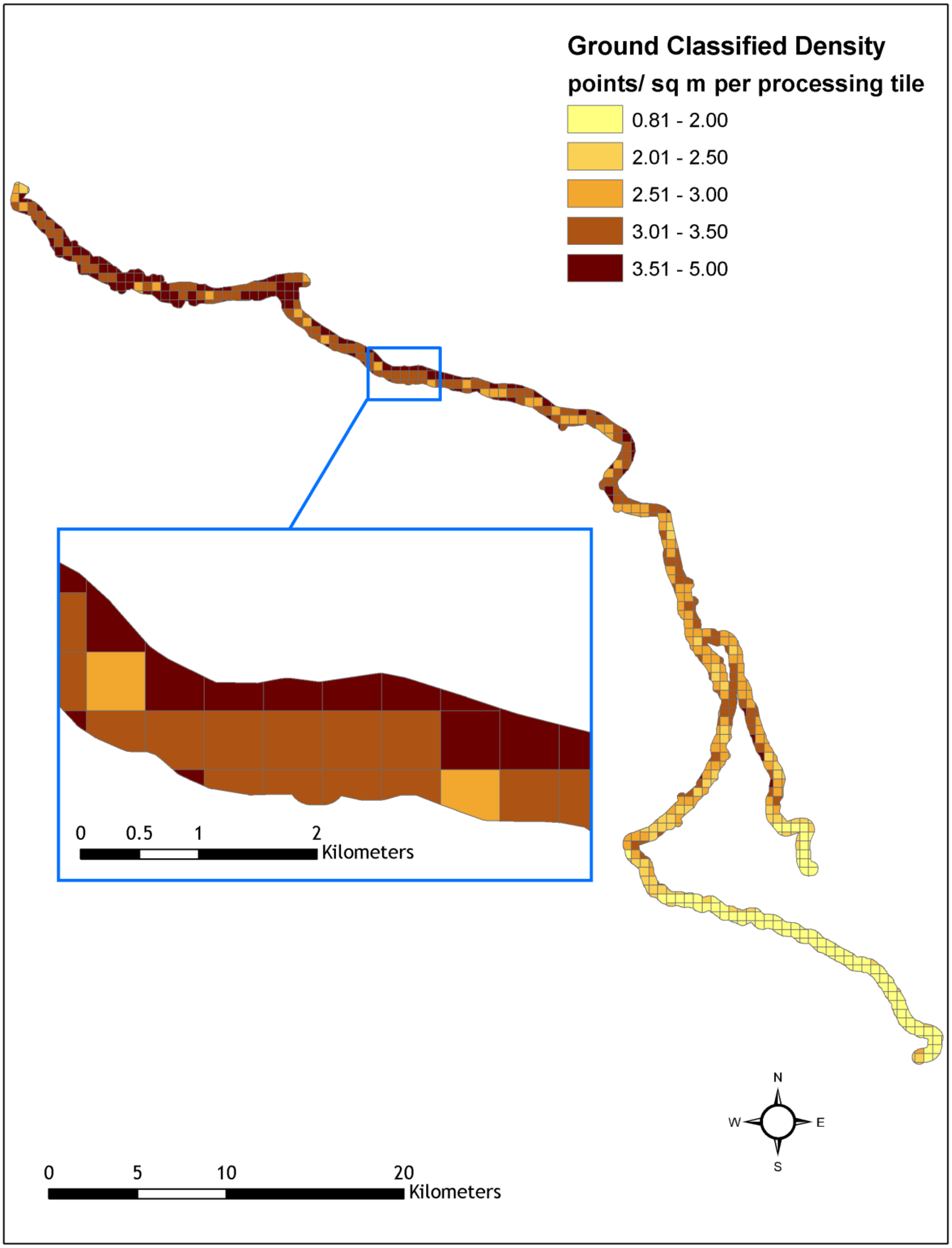


Figure 7. *Ground classified laser point data density per processing tile*

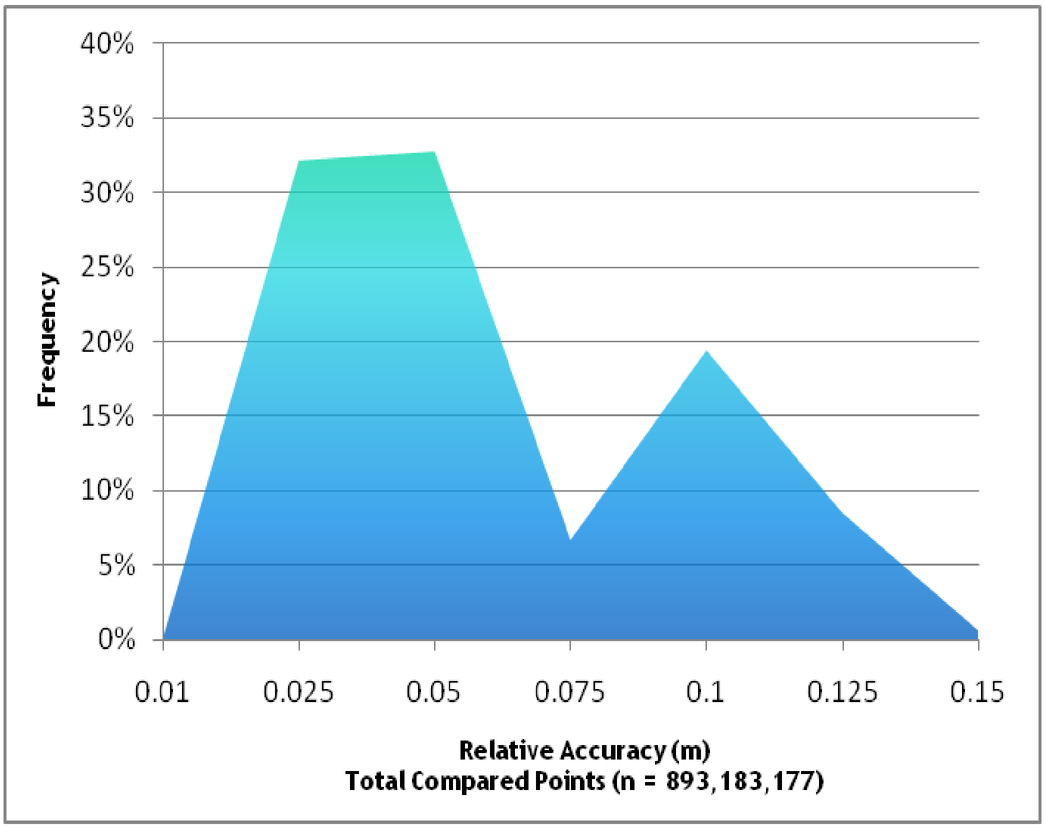


6.3 Relative Accuracy Calibration Results

Relative accuracies for the Tucannon River study area measure the full survey calibration including areas outside the delivered boundary:

- Project Average = 0.048 m
- Median Relative Accuracy = 0.033 m
- 1σ Relative Accuracy = 0.032m
- 2σ Relative Accuracy = 0.064 m

Figure 8. *Distribution of relative accuracies per flight line, non slope-adjusted*



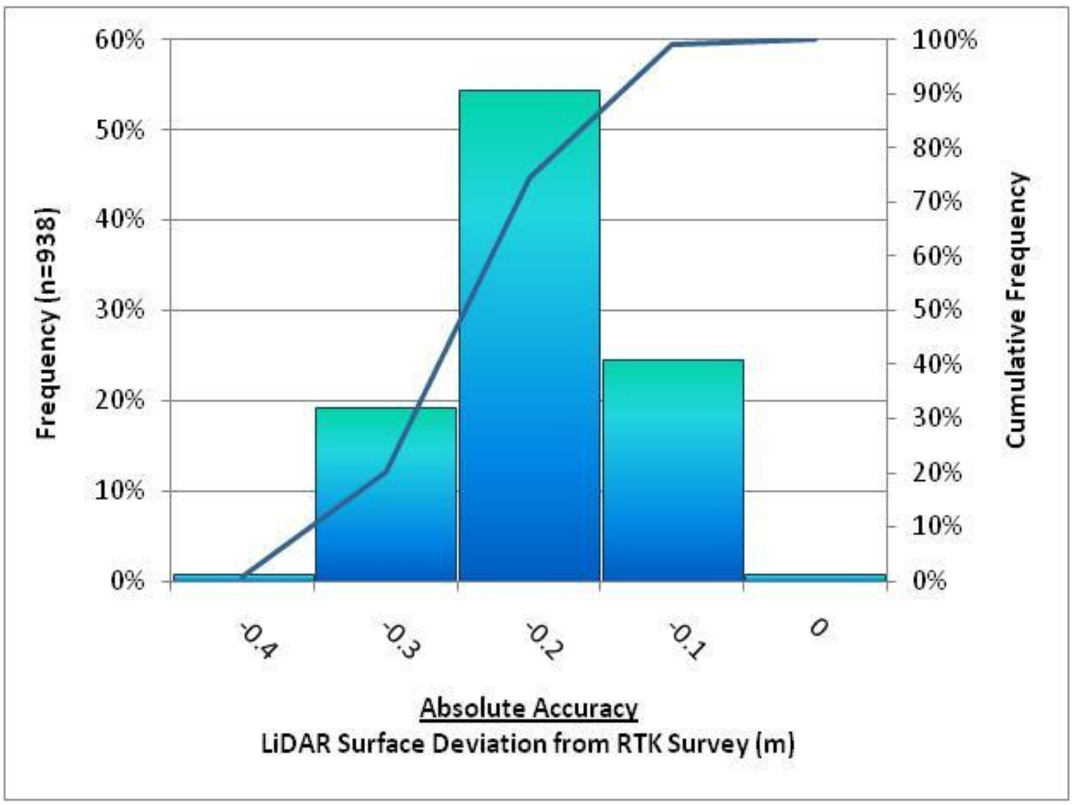
6.4 Absolute Accuracy

Absolute accuracies for the Tucannon River project area

Table 4. *Absolute Accuracy – Deviation between laser points and RTK hard surface survey points*

RTK Survey Sample Size (n): 938	
Root Mean Square Error (RMSE) = 0.040 m	Minimum Δz = -0.178 m
Standard Deviations:	Maximum Δz = 0.079 m
1 sigma (σ) = 0.032 m 2 sigma (σ) = 0.064 m	Average Δz = -0.022 m

Figure 9. *Absolute Accuracy - Histogram Statistics, based on 938 hard surface points*



6.5 Accuracy per Land Cover

In addition to the hard surface RTK data collection, points were also collected independently on six different land cover types within in the Tucannon River data collection area by Whiteshield Inc. (WA Professional Licensed Surveyor, Micheal LeJeune (PLS #19580)). Individual accuracies were calculated for each land-cover type to assess confidence in the LiDAR derived ground models across land-cover classes. Accuracy statistics for each land cover class are reported in **Table 5**.

The land cover classes for Tucannon River study area include:

Bare Earth: Open, barely vegetated surfaces.
High Grasses: Generally incorporates weeds and crops.
Low Vegetation: Generally incorporates grass and low lying herbaceous vegetation (blackberries and sage).
Paved: Hard man made surfaces (e.g. sidewalks and paved roads).
Shrubs: Shrubs and low trees (e.g. willows, and small trees).
Trees: Vegetation exceeding shrub heights.

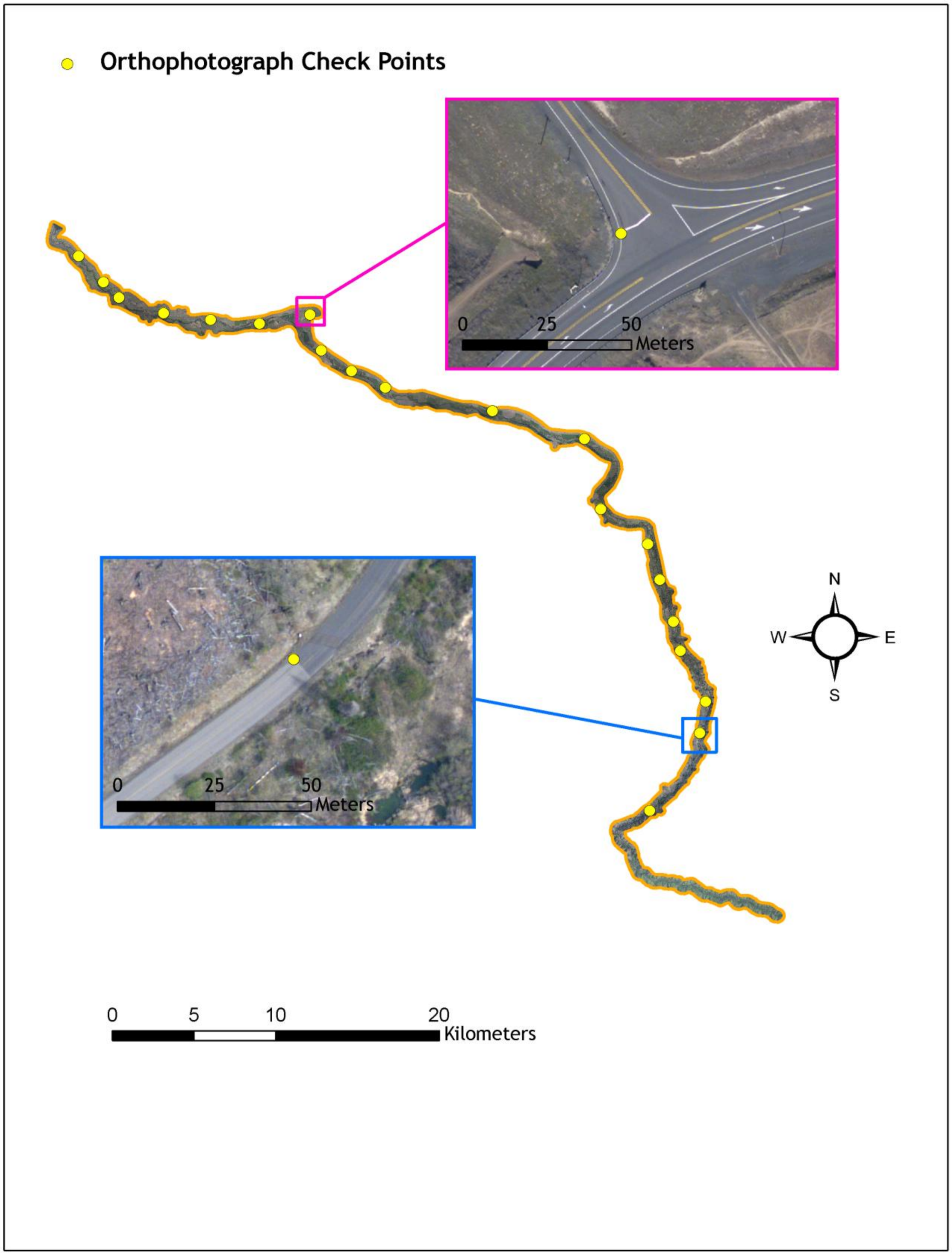
Table 5. *Summary of absolute accuracy statistics for each land cover type at Tucannon River*

Land cover	Sample size (n)	Mean Dz : meters	1 sigma (σ): meters	2 sigma (σ): meters	RMSE: meters
Bare Earth	29	0.003	0.570	0.112	0.056
High Grasses	26	0.069	0.098	0.193	0.119
Low Vegetation	23	0.094	0.081	0.158	0.123
Paved	35	-0.049	0.049	0.095	0.069
Shrubs	17	0.111	0.095	0.186	0.144
Trees	21	0.007	0.010	0.196	0.098

This analysis shows that the vertical accuracy of the interpolated ground surface meets or exceeds vertical accuracy specifications.

6.6 Orthophotograph Accuracy

***Figure 10**. Orthophotograph check point location map for Tucannon River study area*

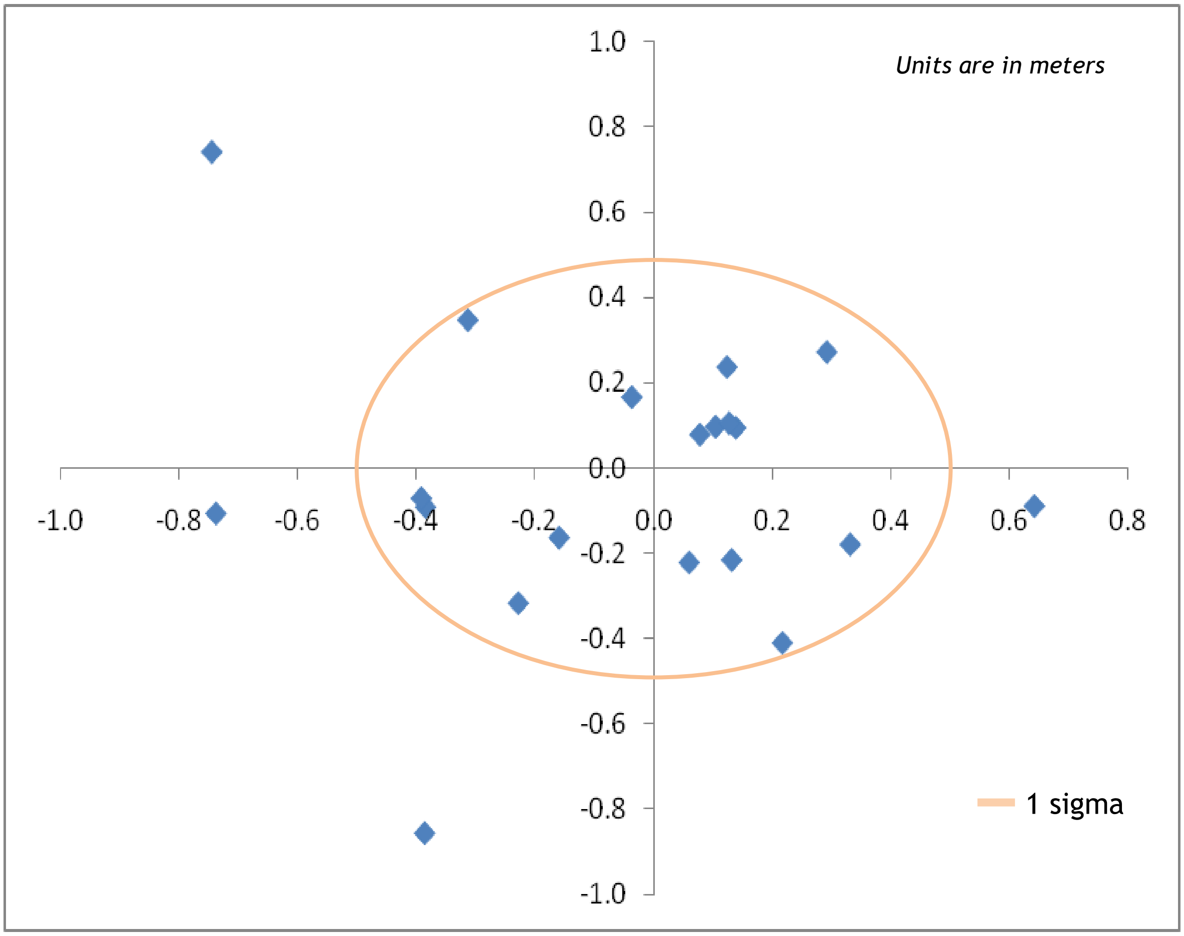


Aerial imagery accuracies for the Tucannon River study area are found in **Figure 10, Figure 11** and **Table 6.**

Table 6. *Deviation between aerial photos and intensity images based on 20 accuracy check points*

	Mean	Standard Deviation (1 Sigma)	Root Mean Square Error (RMSE)
Tucannon River Photos	0.06 m	0.48 m	0.82 m

Figure 11. *Checkpoint residuals derived from comparing aerial photos to intensity images*



7. Projection/Datum and Units

Projection:		UTM Zone 11
Datum	Vertical:	NAVD88 Geoid03
	Horizontal:	NAD 83
Units:		Meters

8. Deliverables

Point Data:	• All laser returns (LAS v. 1.2 format) • Model keypoints (LAS v. 1.2 format)
Vector Data:	• Survey boundary (shapefile format) • SBET Trajectories (shape file format) • LiDAR tile delineation (shapefile format) • Ortho Photo tile delineation (shapefile format) • DEM tile delineation (shapefile format)

Raster Data:	• Elevation models (1 meter resolution):
	    • Bare Earth Model (ESRI GRID format)
	    • Highest Hit Model (ESRI GRID format)
	• Intensity images (GeoTIFF format; 0.5 meter resolution)
	• Ortho photo tiles (GeoTIFF format 15 cm resolution)

Data Report:	• Full report containing introduction, methodology, and accuracy

9. Selected Images

***Figure 12**. Orthophotograph referenced to highest hit model. Looking southwest at the confluence of the Snake River and Tucannon River with Highway 261 on the right.*

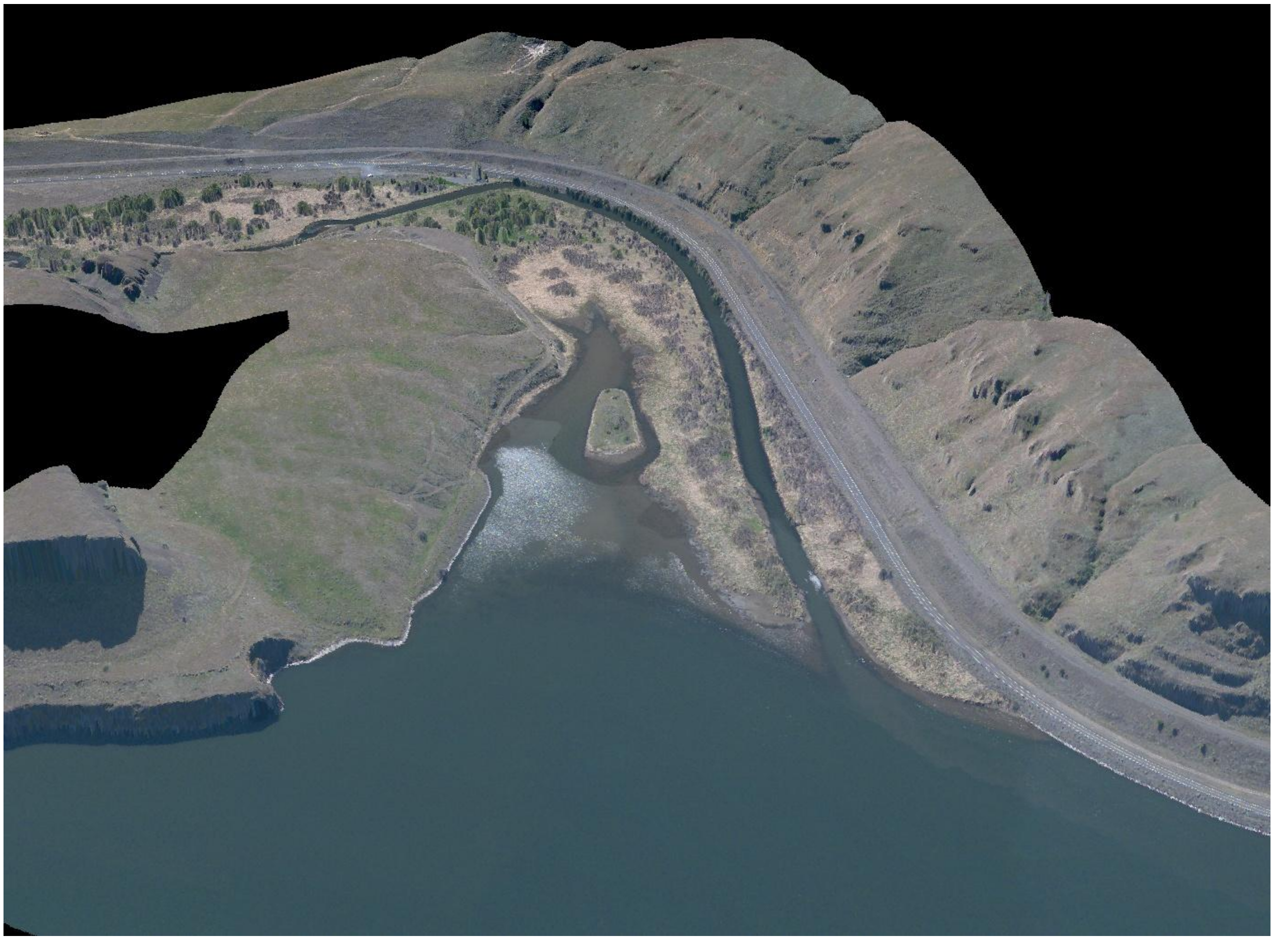


Figure 13. *Orthophotograph referenced to highest hit model. Looking northeast at the Tucannon River meeting the town of Starbuck.*

Figure 14. *3D Point cloud image derived from LiDAR returns colored by height. Looking west at the confluence of Pataha Creek and the Tucannon River with Highway 261 on the right.*

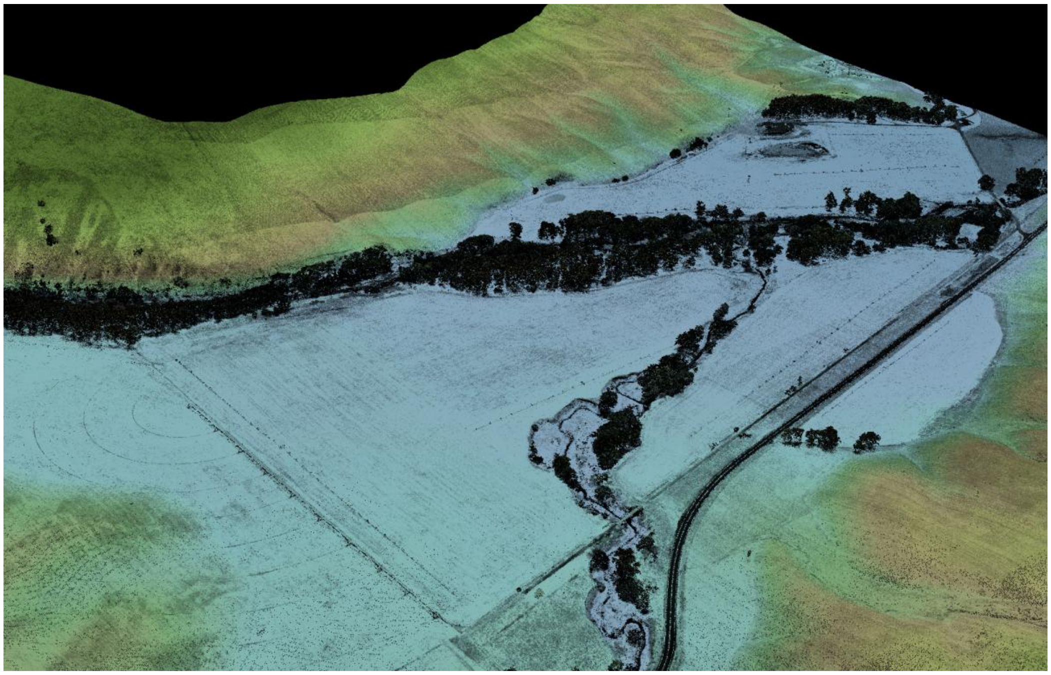
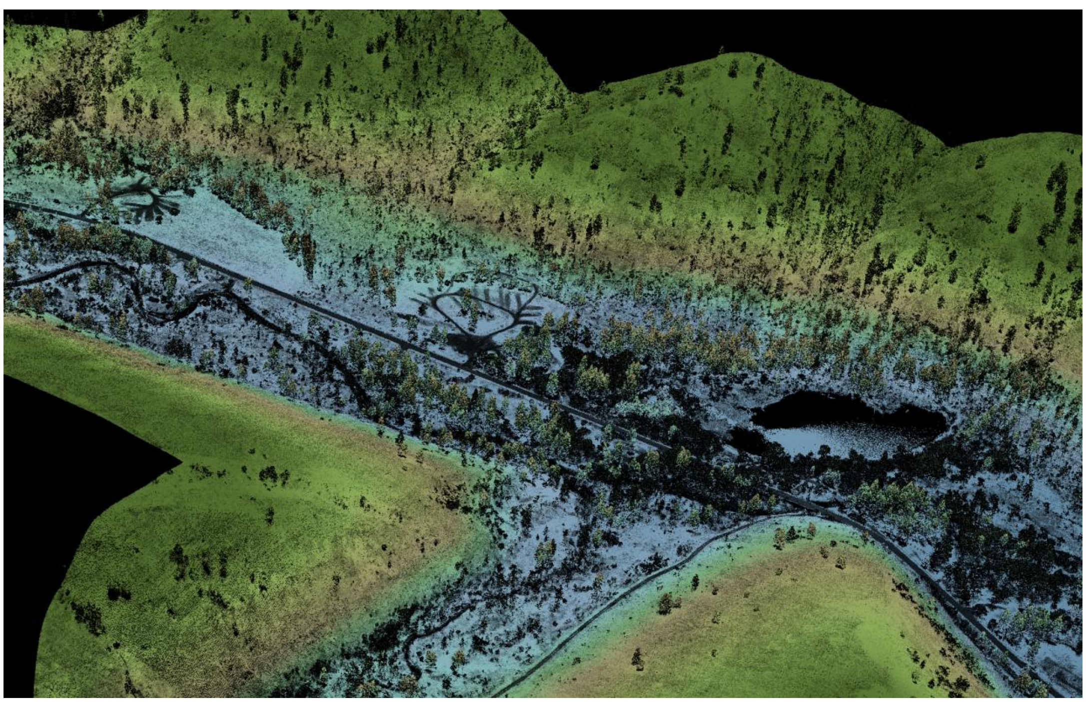


Figure 15. *3D Point cloud image derived from LiDAR returns colored by height. Looking east at the confluence of summing Creek and the Tucannon River. Spring Lake can be viewed on the east side of the Tucannon River.*



10. Glossary

1-sigma (σ) Absolute Deviation: Value for which the data are within one standard deviation (approximately 68th percentile) of a normally distributed data set.
2-sigma (σ) Absolute Deviation: Value for which the data are within two standard deviations (approximately 95th percentile) of a normally distributed data set.
Root Mean Square Error (RMSE): A statistic used to approximate the difference between real-world points and the LiDAR points. It is calculated by squaring all the values, then taking the average of the squares and taking the square root of the average.
Pulse Rate (PR): The rate at which laser pulses are emitted from the sensor; typically measured as thousands of pulses per second (kHz).
Pulse Returns: For every laser pulse emitted, the Leica ALS 50 Phase II system can record *up to four* wave forms reflected back to the sensor. Portions of the wave form that return earliest are the highest element in multi-tiered surfaces such as vegetation. Portions of the wave form that return last are the lowest element in multi-tiered surfaces.
Accuracy: The statistical comparison between known (surveyed) points and laser points. Typically measured as the standard deviation (sigma, σ) and root mean square error (RMSE).
Intensity Values: The peak power ratio of the laser return to the emitted laser. It is a function of surface reflectivity.
Data Density: A common measure of LiDAR resolution, measured as points per square meter.
Spot Spacing: Also a measure of LiDAR resolution, measured as the average distance between laser points.
Nadir: A single point or locus of points on the surface of the earth directly below a sensor as it progresses along its flight line.
Scan Angle: The angle from nadir to the edge of the scan, measured in degrees. Laser point accuracy typically decreases as scan angles increase.
Overlap: The area shared between flight lines, typically measured in percents; 100% overlap is essential to ensure complete coverage and reduce laser shadows.
DTM / DEM: These often-interchanged terms refer to models made from laser points. The digital elevation model (DEM) refers to all surfaces, including bare ground and vegetation, while the digital terrain model (DTM) refers only to those points classified as ground.
Real-Time Kinematic (RTK) Survey: GPS surveying is conducted with a GPS base station deployed over a known monument with a radio connection to a GPS rover. Both the base station and rover receive differential GPS data and the baseline correction is solved between the two. This type of ground survey is accurate to 1.5 cm or less.

11. 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:
<u>Low Flight Altitude</u>: 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., ~ $1/3000^{th}$ AGL flight altitude).
<u>Focus Laser Power at narrow beam footprint</u>: 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.
<u>Reduced Scan Angle</u>: Edge-of-scan data can become inaccurate. The scan angle was reduced to a maximum of $\pm 14^{o}$ from nadir, creating a narrow swath width and greatly reducing laser shadows from trees and buildings.
<u>Quality GPS</u>: 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.
<u>Ground Survey</u>: 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.
<u>50% Side-Lap (100% Overlap)</u>: 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.
<u>Opposing Flight Lines</u>: 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 – Ground Survey Control Certification

Survey Report – Control Verification

Watershed Sciences, Inc.
517 SW 2nd Street, Suite 400
Corvallis, OR 97333
for
City of Dayton, Columbia Conservation District, Columbia County,
Washington Department of Fish & Wildlife, and the Snake River Salmon Recovery Board.

Overview

Watershed Sciences was contracted to acquire LiDAR datasets in two general project areas (Touchet and Tucannon River). Each area being about a 40 mile river corridor segment. The project areas are located in Garfield, Columbia and Walla-Walla County, Washington. City of Dayton was the lead in administrating the prime contract. Other involved stakeholders include; Columbia Conservation District, Columbia County, Washington Department of Fish & Wildlife, and the Snake River Salmon Recovery Board. Partial funding was provided by Bonneville Power Administration. A third project area was added in conjunction with another Watershed Sciences Inc. flight (Eckler Mountain).

Scope of survey services, Watershed Sciences, Inc. with White Shield, Inc.:

1. Provide WA Professional License Surveyor (WA PLS) oversight and certification for ground control to support LiDAR data acquisition.
2. White Shield will also provide independent collection of ground check points for quality control/quality assurance checks of the LiDAR derived ground model.
3. White Shield will certify the positional coordinates of all ground control monuments selected by Watershed Sciences. Number of monuments will total 8 sites – 2 in the Touchet River acquisition area, 4 in the Tucannon River project area, and 2 in the Eckler Mountain project area.
4. Watershed Sciences will set the monuments prior the LiDAR acquisition and provide White Shield with the OPUS solution coordinate locations of all bases. All base locations will be monumented with rebar and metal caps by Watershed Sciences prior to surveying by White Shield.
5. Watershed Sciences will occupy all monuments with survey grade GPS for a minimum of one 8-hr session and one 4-hr session prior to and during the LiDAR missions.
6. White Shield, Inc. will collect spatially distributed ground check points in prominent land cover types for the areas of interest (AOIs). These check points will be used for independent quality assurance checks of the LiDAR derived ground classification.

Coordinate System

Horizontal Coordinates: UTM, Zone 11 North, NAD 1983(2007)
Vertical Datum: NAVD 1988
Units: Meters
Geoid 2009 (Conus) model for orthometric height modeling.

Final Adjusted Coordinates

ID	Northing Latitude	Easting Longitude	Ortho el. Ellip. Ht.	Description
186	5119561.925 46°13'26.31252"N	412283.001 118°08'14.72206"W	451.700 431.538	L-430 BRASS DISK
187	5130182.091 46°19'15.71245"N	424704.117 117°58'41.09938"W	492.096 472.303	PATIT BRASS CAP
188	5148174.122 46°29'08.59587"N	456311.374 117°34'09.18751"W	713.003 693.959	C-334 BRASS DISK
189	5151607.716 46°30'45.68924"N	415158.065 118°06'21.43507"W	208.878 188.247	X-341 BRASS DISK
191	5127161.649 46°17'42.29211"N	436742.590 117°49'16.73863"W	1038.958 1020.017	EM-02 ALUM CAP
192	5130258.919 46°19'20.30464"N	430160.348 117°54'26.02183"W	753.448 733.967	EM-01 ALUM CAP
193	5126654.077 46°17'29.72309"N	449588.562 117°39'16.14917"W	709.727 691.382	TUC-04 ALUM CAP
194	5143464.374 46°26'32.32455"N	442624.615 117°44'49.01967"W	458.500 439.108	TUC-03 ALUM CAP
195	5146443.808 46°28'04.69818"N	430389.924 117°54'23.95945"W	339.707 319.688	TUC-02 ALUM CAP
196	5150401.608 46°30'10.94797"N	425306.395 117°58'24.57466"W	291.202 270.858	TUC-01 ALUM CAP
197	5124885.617 46°16'26.67261"N	431354.801 117°53'27.34602"W	599.009 579.810	TOUCHET_EG3 ALUM CAP
198	5126683.908 46°17'20.95080"N	421185.239 118°01'23.51628"W	461.789 441.903	TOUCHET_EG2 ALUM CAP
199	5127037.064 46°17'35.10858"N	427974.795 117°56'06.43670"W	546.502 526.997	TOUCHET_EG1 ALUM CAP
POME	5147568.247 46°28'47.78568"N	451511.312 117°37'54.09094"W	570.676 551.488	POMEROY WSRN-CORS ARP

Existing Control Stations

Published NGS control stations that were occupied include:

1. L-430, PID SA0136, (WSI-186), Horizontal order=A, Vertical order= First Order Class One. This is a Height Modernization Survey Station. NGS adjusted elevation was held in adjustment. General description: 3.35 miles south along U.S. Highway 12 from the junction of State Highway 124 at Waitsburg, at the junction of an east-west roads, in the top and 1.1 feet east of the west end of the south concrete curb of a concrete bridge under the road east, 30' feet east of the center line of the highway, 20 feet south of the center line of the road east. The station is a 3 inch brass disk set flush in concrete wall of a bridge.

2. Patit, PID RZ1886, (WSI-187), Horizontal order= B-order. This is a Cooperative Base Network Control Station.
    - General description: The station is at the southeast corner of the courthouse lawn in Dayton. The station is at the northeast angle of the intersection of Third Street and Main Street. The mark is set in the top of a round concrete monument that is flush with the ground surface.

3. C-334, PIDRZ1151, (WSI-188), Horizontal order=A, Vertical order= Second Order Class O. This is a Federal Base Network Control Station. NGS adjusted elevation was held in adjustment.
    - General description: The station is located about 3.0 mi northeast of Pomeroy on the north side of a county gravel road at the entrance to an old metal hangar building which is now used to house farm tractors and equipment, ownership -- Washington State Department of Transportation. To reach the station from the Garfield County Courthouse in Pomeroy, go east on Highway 12 for 1.70 mi to Maryview road on the left. Turn left and go north on Maryview road for 1.1 mi to the intersection of a graveled county road. Turn right and go east on the county road for 0.25 mi to a gravel entrance road leading northeast into a storage area for farm equipment and the station. The station mark is a Coast and Geodetic Survey bench mark disk set in the top of a 30 cm diameter round concrete post projecting 12 cm above ground level.

4. X-341, PID SA0047, (WSI-189), Horizontal order=A, Vertical order= Second Order Class 0. This is a Height Modernization Survey Station. NGS adjusted elevation was held in adjustment.
    - General description: 1.1 mi east from Starbuck. 0.4 mile east along the Union Pacific Railroad from the station at Starbuck, thence 0.7 mile east along the Delaney-Starbuck road, 96' feet northwest of the center of the T junction of a gravel road leading south, 30 feet north of the center line of the road, 1.0 feet south of a fence, 1.7 feet northeast of a witness post, about 1 foot lower than the road, and set in the top of a concrete post projecting 0.5 foot above the ground.

5. POME, a Washington State Reference Station (WSRN) located in Pomeroy was used as a virtual base station, Broadcast position was enabled as a check only, results are noted Complete NGS control data sheets are attached. Retrieval data April 16, 2010

GPS Sessions

Watershed Sciences Inc. provided their static occupations in Trimble DAT format and log spreadsheet. The sessions were included in the final networks adjustment as redundant baselines. Session times varied ±4-8 hours. Observations by White Shield Inc. were generally ±1-hour sessions or longer. Each station was occupied a minimum of 2 sessions by White Shield. Station L-430 was office entered with the published coordinates. Baselines were processed as they flowed out from L-430 working to the northeast. All antenna heights measured in feet and meters and checked in the field. On check-in to the project Trimble Geomatics office Software, height inputs were double checked by entering the heights in feet and allowing the software to convert to meters.

Adjustment notes

All possible baselines were processed. Then trivial baselines were disabled leaving a network shown in figure

1. For L-430 and X-341 the adjusted level line elevations were used in the adjustment versus the height modernization GPS observed values, ±0.06m difference. A loop closure report was run using a minimum of 3-leg closure; of the 150+ loops, the computed worst closure was horizontal 25mm, vertical 45mm. Loop Closure Summary Report is attached.

A free/minimal constrained adjustment was made with the residual noted at the other NGS Control stations. Maximum residual were northing 0.019m, easting 0.013m, ortho 0.042m. No outliers were noted. A full adjustment report is attached.

The fixed/fully constrained adjustment was computed holding horizontal and vertical at L-430, X-341, and C- 334. Patit was held for horizontal. No outliers were noted. A full adjustment report is attached.

Residual noted at the broadcast position of POME, northing 0.014m, easting 0.007m, ortho 0.029m. Two sessions were observed directly connecting POME to C-334.

Watershed Sciences, Inc had submitted their static session data to NGS for a full OPUS solution and had provided a spreadsheet of the multiple results/means. Average residuals are in the 0.01-0.02m area with the maximum being 0.042m.

Equipment

Static GPS occupations by Watershed Sciences included Trimble R7 (zephyr antenna) and R8 receivers (dual frequency, geodetic grade). White Shield, Inc. GPS equipment included 3 Trimble 4800, 1-5700, 1-5800 receivers (dual frequency, geodetic grade). Quality Checks were collected using RTK methods with the Trimble 4800 receivers.

Software

GPS static observations and RTK observations were reduced with Trimble Geomatics Office 1.63.

Personnel

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Respectfully submitted

Michael P. LeJeune, PLS WA 19580
Survey Project Manager

May 02, 2010

5/2/10