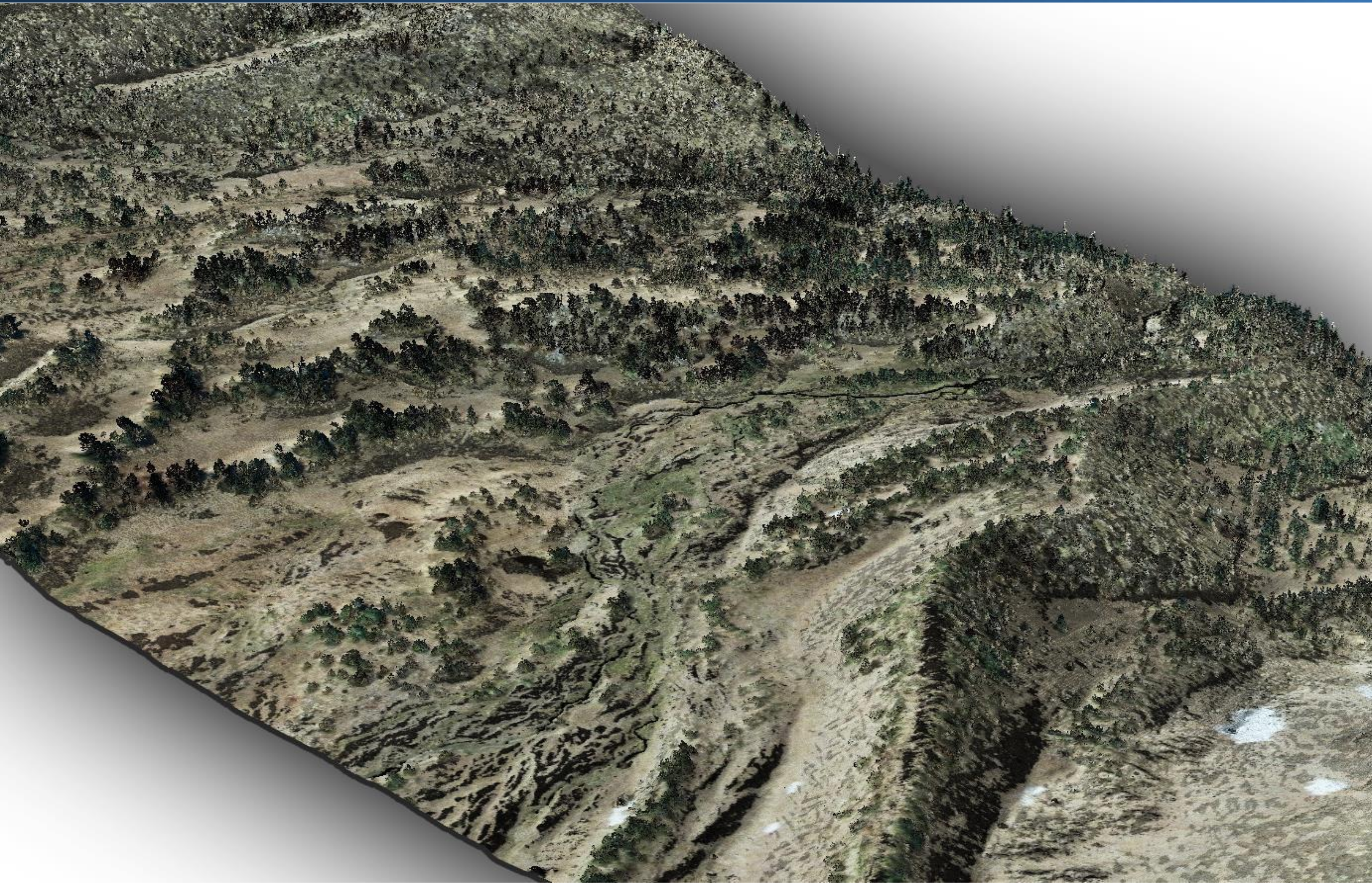
WSI Applied Remote Sensing and Analysis

November 15, 2013



Pole Creek LiDAR

Technical Data Report

WOOLPERT
DESIGN | GEOSPATIAL | INFRASTRUCTURE

John Gerhard
Woolpert, Inc.
116 Inverness Drive East, Suite 105
Englewood, CO
PH: 720-279-3762

WSI Corvallis Office
517 SW 2nd St., Suite 400
Corvallis, OR 97333
PH: 541-752-1204

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Cover Photo: Forest transition line in the Pole Creek study area. The bare-earth model and vegetative LiDAR point cloud are colored by intensity and NAIP imagery.

INTRODUCTION

View of the Pole Creek site in Oregon showing the high desert mixed shrub landscape in various successional stages of regrowth after exposure to wildfire.

In August 2013, WSI (Watershed Sciences, Inc.) was contracted by Woolpert, Inc. to collect Light Detection and Ranging (LiDAR) data in the fall of 2013 for the Pole Creek site in Oregon. Data were collected to aid Woolpert in assessing the topographic and geophysical properties of the study area to support planning and development for fire rehabilitation and restoration efforts.

This report accompanies the delivered LiDAR data and documents data acquisition procedures, processing methods, and results of all accuracy assessments. Project specifics are shown in Table 1, the project extent can be seen in Figure 1, and a complete list of contracted deliverables provided to Woolpert, Inc. can be found in Table 2.

Table 1: Acquisition dates, acreages, and data types collected on the Pole Creek site

Project Site	Contracted Acres	Buffered Acres	Acquisition Dates	Data Type
Pole Creek	55,543	57,084	October 8, 2013 October 10-11, 2013	LiDAR

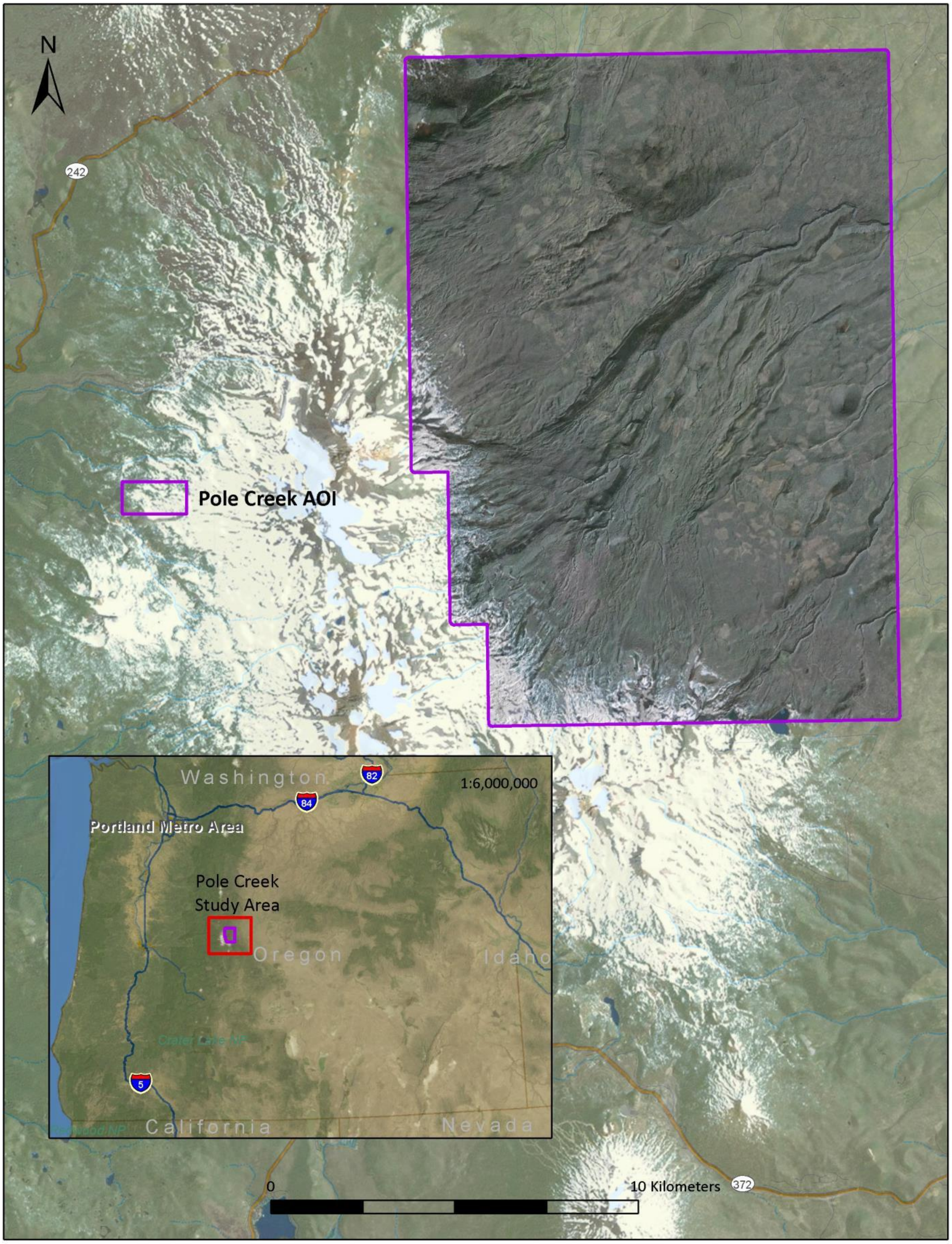


Figure 1: Location map of the Pole Creek site in Oregon

Table 2: Products delivered to USGS for the Pole Creek site

Pole Creek **Products** **Projection: UTM Zone 10 North** **Horizontal Datum: NAD83 (CORS96)** **Vertical Datum: NAVD88 (GEOID09)** **Units: Meters**	
LAS Files	LAS v 1.2 • All Returns • Swaths
Rasters	1.0 Meter ERDAS IMG files • Highest Hit Model • Hydroflattened Bare Earth Model
Vectors	Shapefiles (*.shp) • Site Boundary • LiDAR Index • RTK checkpoints • Hydrologic Breaklines

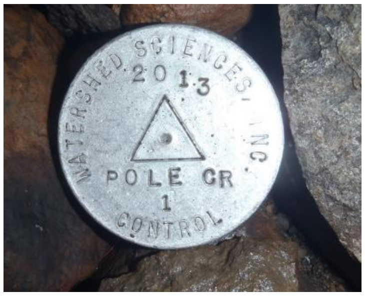
WSI Cessna Caravan

Planning

In preparation for data collection, WSI reviewed the project area using Google Earth, and flightlines were developed using a combination of specialized software. Careful planning by acquisition staff entailed adapting the pulse rate, flight altitude, scan angle, and ground speed to ensure complete coverage of the Pole Creek LiDAR study area at the target point density of ≥8 pulses per square meter (0.74 pulses/square foot). Efforts are taken to optimize flight paths by minimizing flight times while meeting all accuracy specifications.

Factors such as satellite constellation availability and weather windows must be considered during the planning stage. Any weather hazards or conditions affecting the flight were continuously monitored due to their potential impact on the daily success of airborne and ground operations. In addition, a variety of logistical considerations required review including land class RTK collection, potential air space restrictions, and availability of company resources (both staff and equipment).

Ground Survey



Ground survey data are used to geospatially correct the aircraft positional coordinate data and to perform quality assurance checks on final LiDAR data. Ground surveys, including monumentation and ground check points, are conducted to support the airborne acquisition process.

Monumentation

The spatial configuration of ground survey monuments provided redundant control within 13 nautical miles of the mission areas for LiDAR flights. Monuments were also used for collection of ground control points using RTK survey techniques (see **RTK** below).

Monument locations were selected with consideration for satellite visibility, field crew safety, and optimal location for RTK coverage. WSI established 2 new monuments for the Pole Creek project (Table 3, Figure 2). New monumentation was set using 5/8”x30” rebar topped with stamped 2" aluminum caps. WSI’s professional land surveyor, Chris Yotter-Brown (ORPLS#60438LS) oversaw and certified the establishment of all monuments.

Table 3: Monuments established for the Pole Creek acquisition. Coordinates are on the NAD83 (2011) datum, epoch 2010.00

Monument ID	Latitude	Longitude	Ellipsoid (meters)
POLE_CR_1	44° 11’ 09.59448”	-121° 38’ 26.67809”	1454.299
POLE_CR_2	44° 13’ 04.42301”	-121° 34’ 54.94019”	1165.270

To correct the continuous onboard measurements of the aircraft position recorded throughout the missions, WSI concurrently conducted multiple static Global Navigation Satellite System (GNSS) ground surveys (1 Hz recording frequency) over each monument. After the airborne survey, the static GPS data were post-processed using Trimble’s CenterPoint RTX Post-Processing[1] service. Multiple independent sessions over the same monument were processed to confirm antenna height measurements and to refine position accuracy.

Monuments were established according to the national standard for geodetic control networks, as specified in the Federal Geographic Data Committee (FGDC) Geospatial Positioning Accuracy Standards for geodetic networks.[2] This standard provides guidelines for classification of monument quality at the 95% confidence interval as a basis for comparing the quality of one control network to another. The monument rating for this project can be seen in Table 4.

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[1] CenterPoint RTK-PP is a free post-processing service provided by Trimble for precise point positioning of GNSS data worldwide. This was used in lieu of the NGS OPUS service between October 1st and October 16th, 2013 due to the United States federal government shutdown. (http://trimblertx.com/Home.aspx)

[2] Federal Geographic Data Committee, Geospatial Positioning Accuracy Standards (FGDC-STD-007.2-1998). Part 2: Standards for Geodetic Networks, Table 2.1, page 2-3. http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part2/chapter2

Table 4: Federal Geographic Data Committee monument rating

Direction	Rating
St Dev $_{NE}$:	0.005 m
St Dev $_{z}$:	0.010 m

For the Tulalip LiDAR project, the monument positions contributed no more than 5 mm of horizontal error and 1 cm vertical error to the final RTK and LiDAR positions, with 95% confidence.

RTK Surveys

For the real time kinematic (RTK) check point data collection, a Trimble R7 base unit was positioned at a nearby monument to broadcast a kinematic correction to a roving Trimble R8 GNSS receiver. All RTK measurements were made during periods with a Position Dilution of Precision (PDOP) of ≤ 3.0 with at least six satellites in view of the stationary and roving receivers. When collecting RTK data, the rover would record data while stationary for five seconds, then calculate the pseudorange position using at least three one-second epochs. Relative errors for the position must be less than 1.5 cm horizontal and 2.0 cm vertical in order to be accepted. See Table 5 for Trimble unit specifications.

RTK positions were collected on paved roads and other hard surface locations such as gravel or stable dirt roads that also had good satellite visibility. RTK measurements were not taken on highly reflective surfaces such as center line stripes or lane markings on roads due to the increased noise seen in the laser returns over these surfaces. The distribution of RTK points depended on ground access constraints and may not be equitably distributed throughout the study area. See Figure 2 for the distribution of RTK in this project.

Table 5: Trimble equipment identification

Receiver Model	Antenna	Example	OPUS Antenna ID	Use
Trimble R7 GNSS	Zephyr GNSS Geodetic Model 2		TRM57971.00	Static
Trimble R8	Integrated Antenna R8 Model 2		TRM_R8_GNSS	RTK

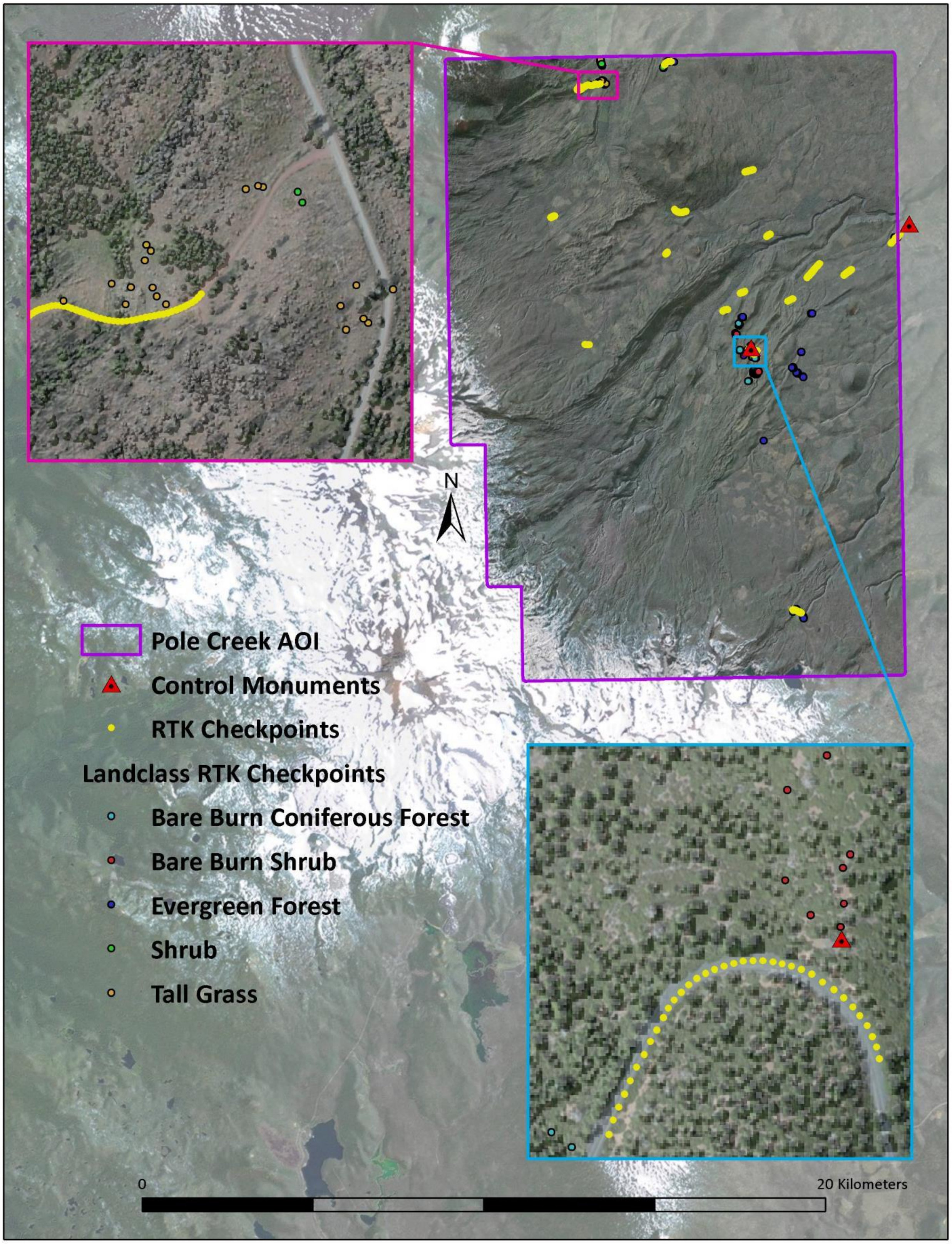


Figure 2: Basestation, RTK checkpoint, and Landclass RTK checkpoint location map

Land Cover

The land class names listed in table 6 are named using WSI's method. For reporting purposes, Woolpert did the following: Combined Bare burn shrub and bare burn coniferous forest into a single land class and named it Bare Earth/Open Terrain. For the same purpose, Woolpert renamed Shrub to Brush Lands and trees, renamed Evergreen forest to Forested and Fully Grown, and renamed Tall grass to Tall Weeds and Crops

Table 6: Land cover descriptions of check points taken for the Pole Creek AOI

Land cover type	Land cover code	Example	Description
Bare burn shrub	BARE_BURN_SHRUB		Areas dominated by shrubs that have been exposed to fire damage.
Bare burn coniferous forest	BARE_BURN_CONIF		Areas dominated by coniferous forest that have been exposed to fire damage.
Shrub	SHRUB		Areas dominated by shrubs; shrub canopy accounts for 25-100 percent of the cover.
Evergreen forest	EVER_FOR		Areas dominated by trees where 75 percent or more of the tree species maintain their leaves all year. Canopy is never without green foliage.
Tall grass	TALL_GRASS		Grass height is above knee.

Airborne Survey

LiDAR

The LiDAR survey was accomplished using a Leica ALS50 system mounted in a Cessna Caravan. Table 7 summarizes the settings used to yield an average pulse density of ≥8 pulses/m^2 over the Pole Creek terrain. It is not uncommon for some types of surfaces (e.g. dense vegetation or water) to return fewer pulses to the LiDAR sensor 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.

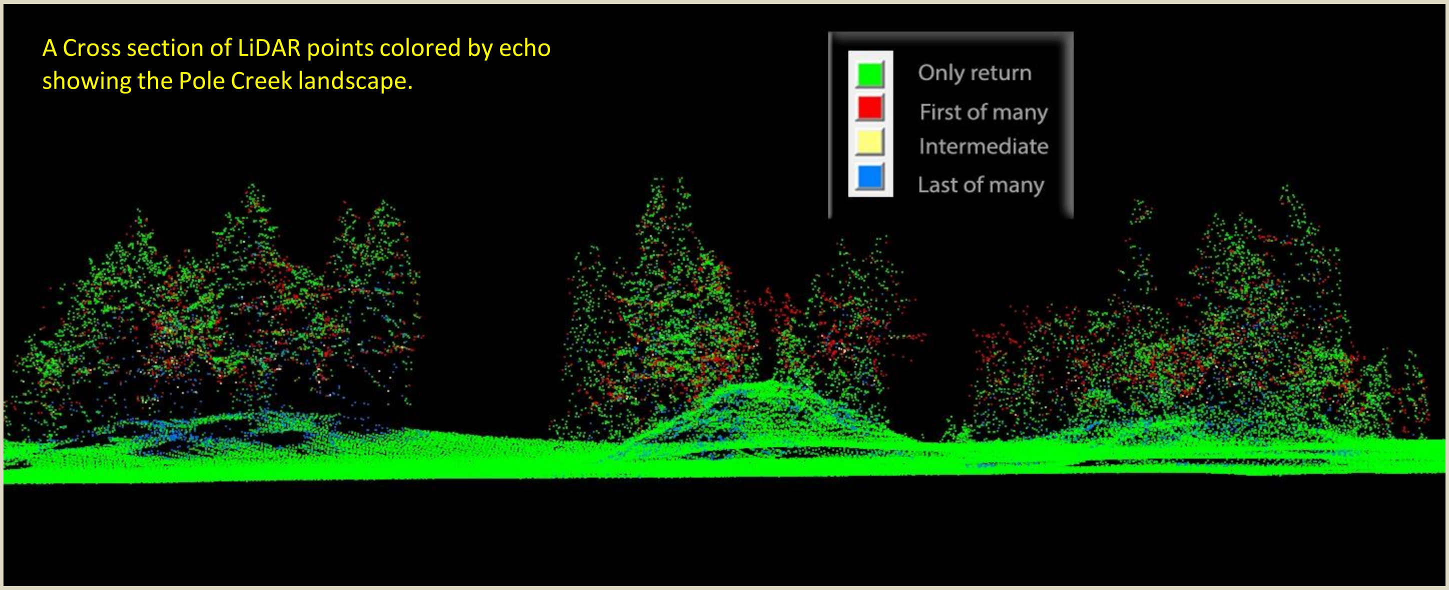
Table 7: LiDAR specifications and survey settings

LiDAR Survey Settings & Specifications	
Sensor	Leica ALS50
Survey Altitude (AGL)	900 m
Target Pulse Rate	95-106 kHz
Sensor Configuration	Single Pulse in Air (SPiA)
Laser Pulse Diameter	21 cm
Field of View	28^{o}
GPS Baselines	≤13 nm
GPS PDOP	≤3.0
GPS Satellite Constellation	≥6
Maximum Returns	4
Intensity	8-bit
Resolution/Density	Average 8 pulses/m^2
Accuracy	$RMSE_Z$ ≤ 15 cm

Leica ALS50 LiDAR sensor

To reduce laser shadowing and increase surface laser painting, all areas were surveyed with an opposing flight line side-lap of ≥50% (≥100% overlap). The Leica laser systems record up to four range measurements (returns) per pulse. All discernible 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. Position of the aircraft 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.



LiDAR Data

Upon the LiDAR data's arrival to the office, WSI processing staff initiates a suite of automated and manual techniques to process the data into the requested deliverables. Processing tasks include GPS control computations, smoothed best estimate trajectory (SBET) calculations, kinematic corrections, calculation of laser point position, calibration for optimal relative and absolute accuracy, and classification of ground and non-ground points (Table 8). Processing methodologies are tailored for the mountainous terrain and intended wildfire restoration application of the point data. A full description of these tasks can be found in Table 9.

Table 8: ASPRS LAS classification standards applied to the Pole Creek dataset

Classification Number	Classification Name	Classification Description
1	Default/ Unclassified	Laser returns that are not included in the ground class and not dismissed as Noise or Withheld points
2	Ground	Ground that is determined by a number of automated and manual cleaning algorithms to determine the best ground model the data can support
7	Noise	Laser returns that are often associated with birds or artificial points below the ground surface also known as "pits." Laser returns that have intensity values of 0 or 255.

Table 9: LiDAR processing workflow

LiDAR Processing Step	Software Used
Resolve kinematic corrections for aircraft position data using kinematic aircraft GPS and static ground GPS data.	Waypoint GPS v.8.3 Trimble Business Center v.3.03 Geographic Calculator 2013
Develop a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with attitude data. Sensor head position and attitude are calculated throughout the survey. The SBET data are used extensively for laser point processing.	IPAS TC v.3.1
Calculate laser point position by associating SBET position to each laser point return time, scan angle, intensity, etc. Create raw laser point cloud data for the entire survey in *.las (ASPRS v. 1.2) format. Data are converted to orthometric elevations (NAVD88) by applying a GEOID09 correction.	ALS Post Processing Software v.2.74
Import raw laser points into manageable blocks (less than 500 MB) to perform manual relative accuracy calibration and filter erroneous points. Ground points are then classified for individual flight lines (to be used for relative accuracy testing and calibration).	TerraScan v.13.008
Using ground classified points per each flight line, the relative accuracy is tested. Automated line-to-line calibrations are then performed for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift. Calibrations are calculated on ground classified points from paired flight lines and results are applied to all points in a flight line. Every flight line is used for relative accuracy calibration.	TerraMatch v.13.002
Classify resulting data to ground and other client designated ASPRS classifications (Table 8). Assess statistical absolute accuracy via direct comparisons of ground classified points to ground RTK survey data.	TerraScan v.13.008 TerraModeler v.13.002
Generate bare earth models as triangulated surfaces. Highest hit models were created as a surface expression of all classified points (excluding the noise and withheld classes). All surface models were exported as image files at a 1 meter pixel resolution.	TerraScan v.13.008 ArcMap v. 10.1 TerraModeler v.13.002

Feature Extraction

Water's edge breaklines

Lakes and other closed water bodies with surface area >2 acres were flattened to a consistent water level. The hydro-flattening process eliminates artifacts in the digital terrain model caused by both increased variability in ranges or dropouts in laser returns due to the low reflectivity of water.

Hydro-flattening of closed water bodies was performed through a combination of automated and manual detection and adjustment techniques designed to identify lake boundaries and water levels. Boundary polygons were developed using an algorithm which weights LiDAR-derived slopes, intensities, and return densities to detect the lake edge. The lake edges were then manually reviewed and edited as necessary. Specific care was taken to not hydro-flatten wetland and marsh habitat found throughout the study site.

Once polygons were developed, lake elevations were obtained from the filtered LiDAR returns. Lake-boundary polygons were then incorporated into the final terrain model and enforced as hard-breaklines. The initial ground classified points falling within lake polygons were reclassified as water points to omit them from the final ground model and replaced with the flat water surface of the lake boundary hydrolines (Figure 3).

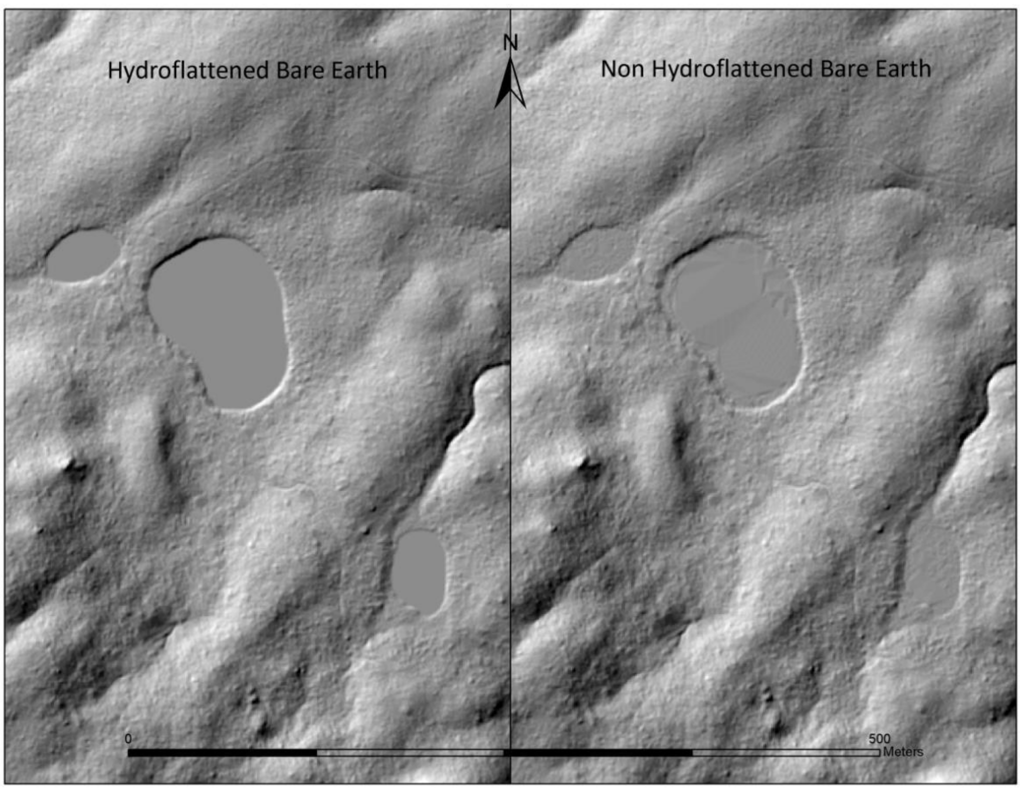
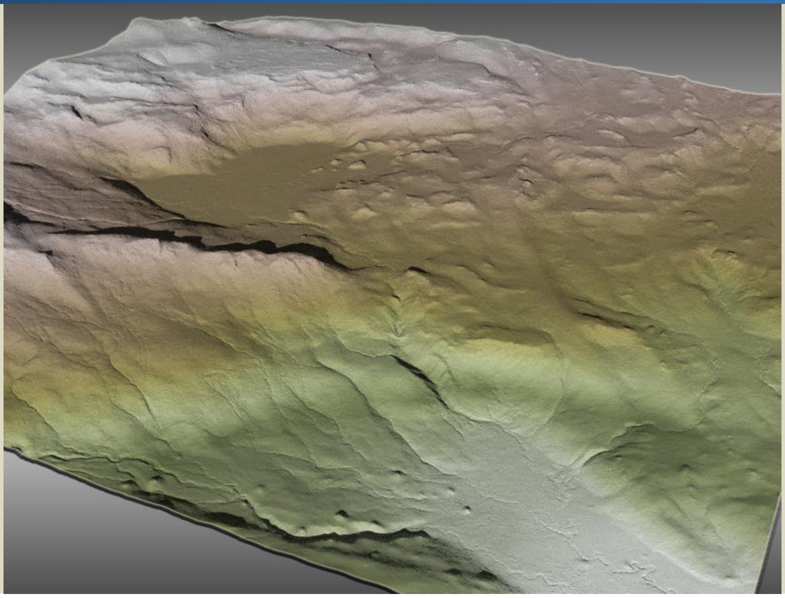


Figure 3: Example of hydro-flattening in the Pole Creek LiDAR dataset

Bare earth image colored by elevation, looking southwest over the Squaw Creek Tributaries in the Pole Creek site.



LiDAR Density

The sensor is set to acquire a native density of 8 points/m^2. Depending on the nature of the terrain, the first returned echo will be the highest hit surface. In vegetated areas, the first return surface will represent the top of the canopy, while in clearings or on paved roads, the first return surface will represent the ground. The ground density differs from the first return density due to the fact that in vegetated areas, fewer returns may penetrate the canopy. The ground classification is generally determined by first echo returns in non-vegetated areas combined with last echo returns in vegetated areas. The pulse density distribution will vary within the study area due to laser scan pattern and flight conditions. Additionally, some types of surfaces (i.e. breaks in terrain, water, steep slopes) may return fewer pulses to the sensor than originally emitted by the laser.

The average first-return density for the LiDAR data for the Pole Creek study area was 10.43 points/m^2 while the average ground classified density was 4.20 points/m^2 (Table 10). The statistical distribution of first returns (Figure 4) and classified ground points (Figure 5) are portrayed below. Also presented are the spatial distribution of average first return densities (Figure 6) and ground point densities (Figure 7) for each 100mx100m cell.

Table 10: Average LiDAR point densities

Classification	Point Density
First-Return	10.43 points/m^2
Ground Classified	4.20 points/m^2

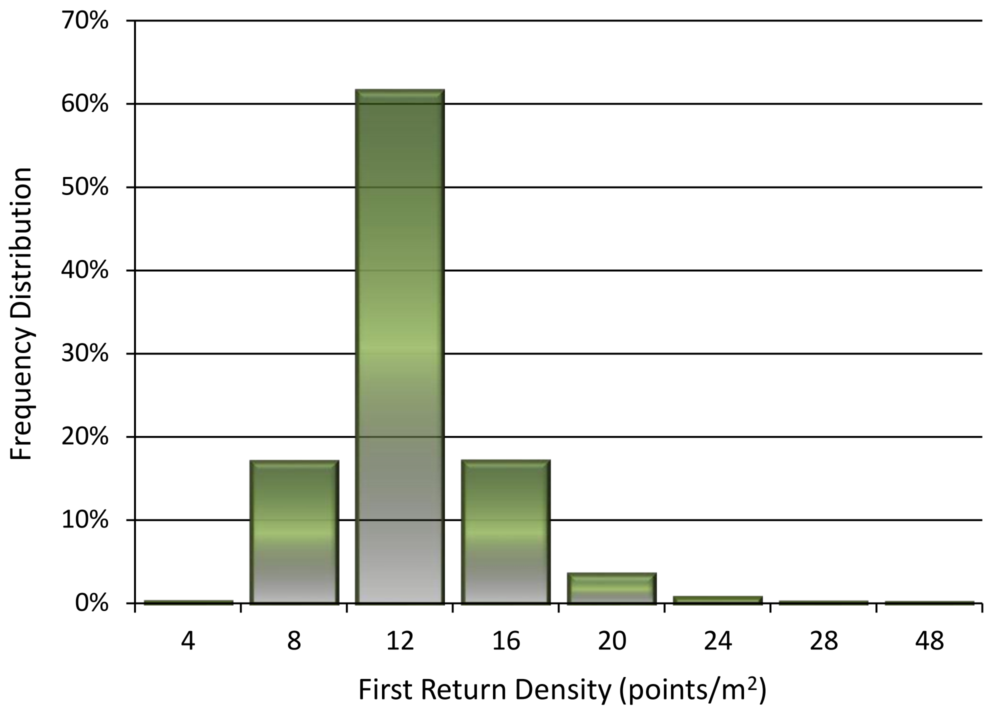


Figure 4: Frequency distribution of first return densities (native densities) of the gridded study area

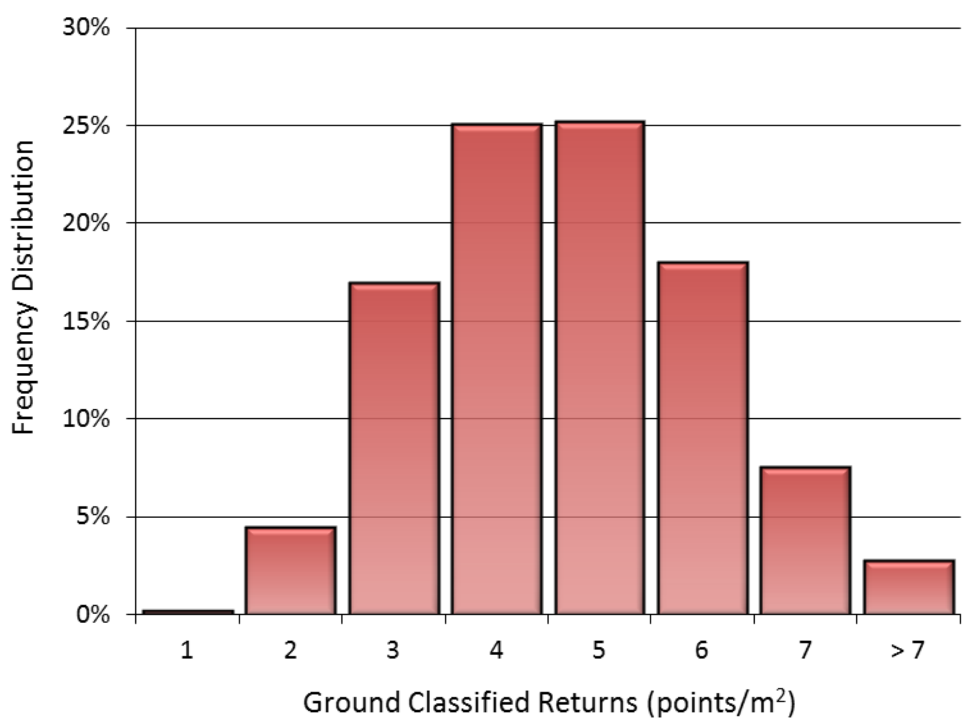


Figure 5: Frequency distribution of ground return densities of the gridded study area

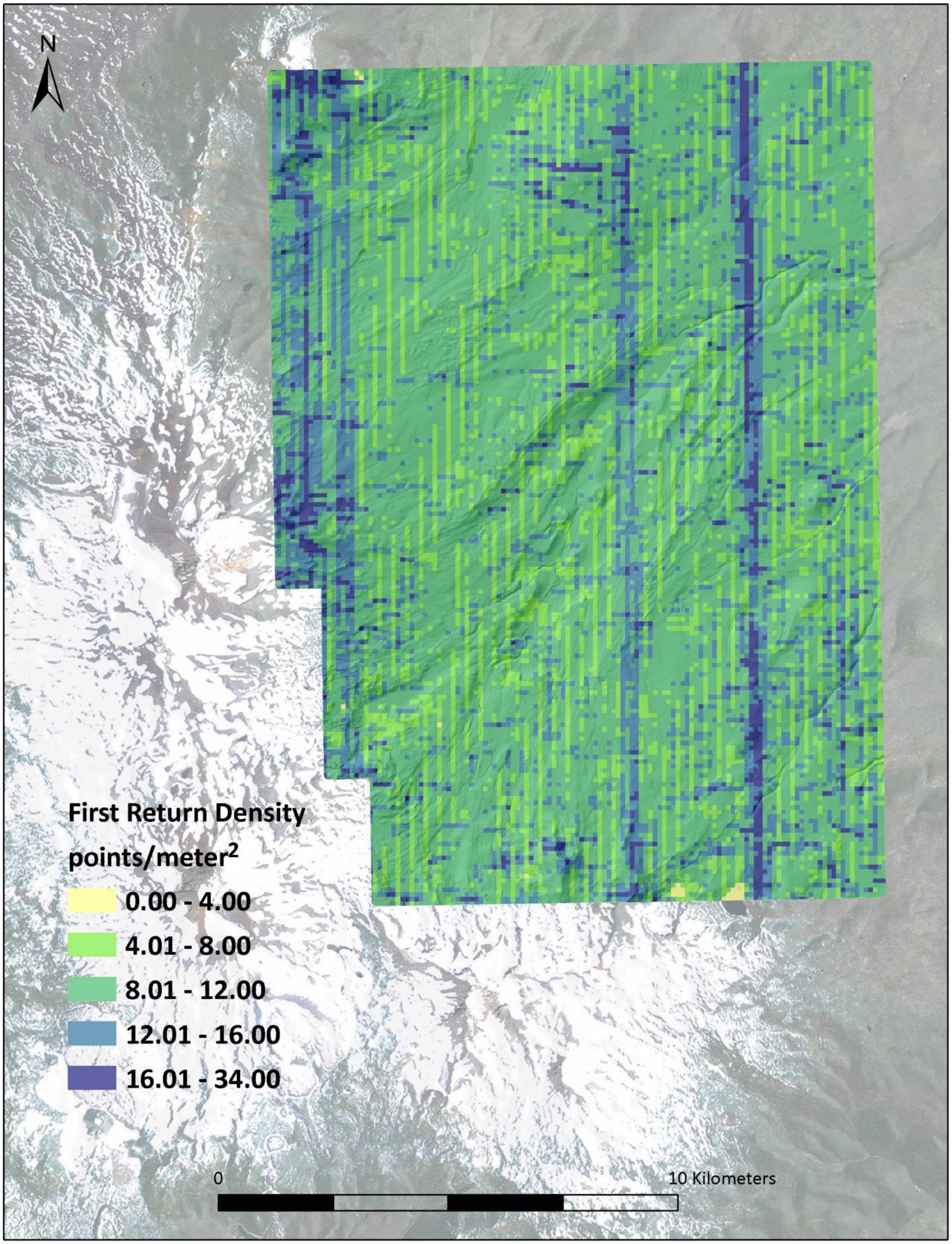


Figure 6: Native density map for the Pole Creek site (100mx100m cells)

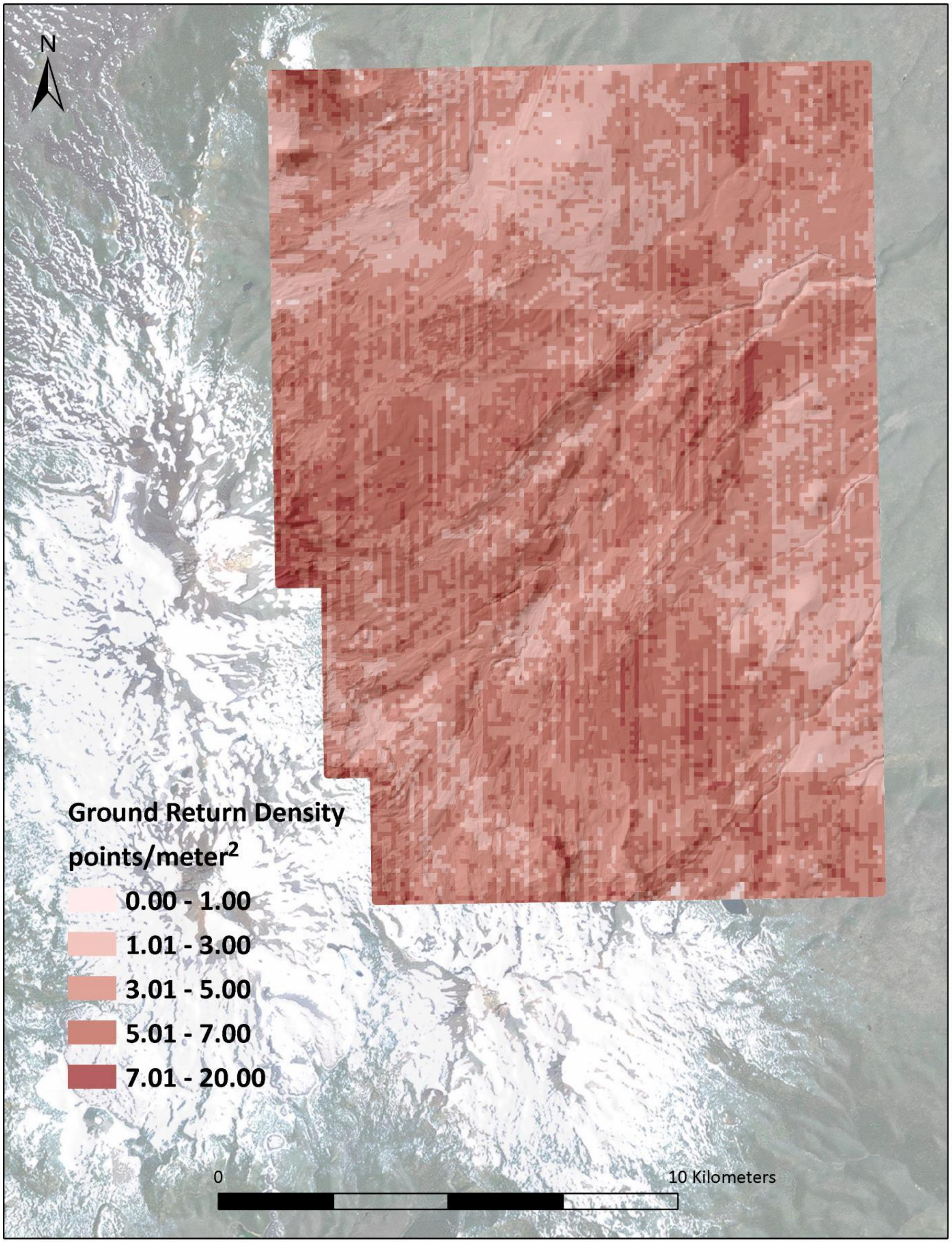


Figure 7: Ground density map for the Pole Creek site (100mx100m cells)

LiDAR Accuracy Assessments

LiDAR Absolute Accuracy

Vertical absolute accuracy was primarily assessed from RTK ground check point (GCP) data collected on open, bare earth surfaces with level slope (<20°). Fundamental Vertical Accuracy (FVA) reporting is designed to meet guidelines presented in the FGDC National Standard for Spatial Data Accuracy[3]. FVA compares known RTK ground survey check points to the triangulated ground surface generated by the LiDAR points. FVA is a measure of the accuracy of LiDAR point data in open areas where the LiDAR system has a "very high probability" of measuring the ground surface and is evaluated at the 95% confidence interval (RMSEz x 1.96).

Absolute accuracy is described as the mean and standard deviation (sigma σ) of divergence of the ground surface model from ground survey point coordinates. These statistics assume the error for x, y, and z is normally distributed, and therefore the skew and kurtosis of distributions are also considered when evaluating error statistics. For the Pole Creek survey, 906 RTK points were collected in total resulting in an average accuracy of -0.007 meters (Table 11, Figure 8).

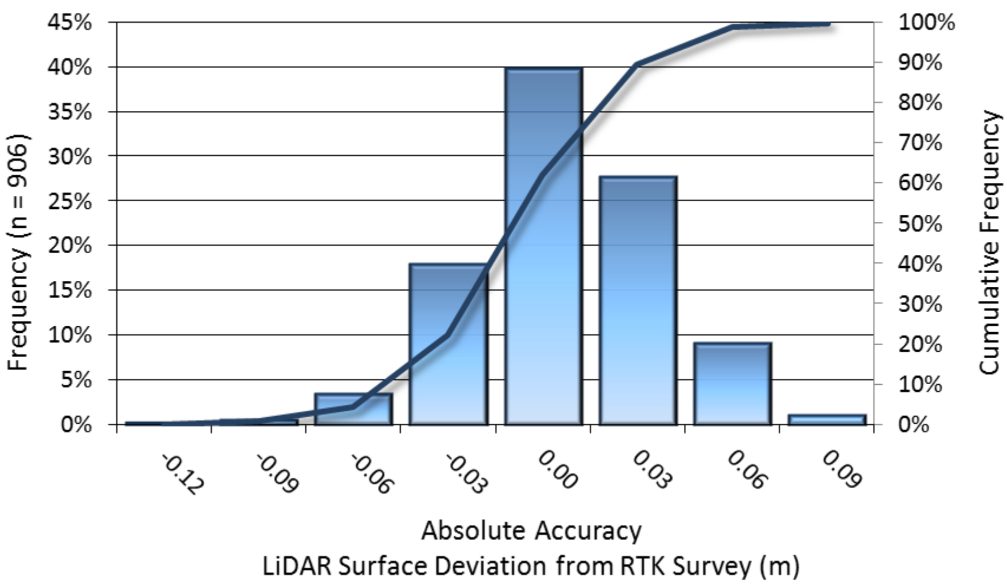


Figure 8: Frequency histogram for LiDAR surface deviation from RTK values

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[3] Federal Geographic Data Committee, Geospatial Positioning Accuracy Standards (FGDC-STD-007.3-1998). Part 3: National Standard for Spatial Data Accuracy. http://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3

Table 11: Overall Swath Vertical Accuracy Statistics, Pole Creek

Average Error	0.018	meters
Minimum Error	-0.071	meters
Maxium Error	+0.095	meters
Average Magnitude	0.029	meters
Root Mean Square	0.037	meters
Standard Deviation	0.032	meters

Table 12: Swath Analysis, UTM 10N, NAD83 CORS96, NAVD88 GEOID09, Pole Creek

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Dz (meters)
4	608546.662	4893360.764	1467.509	0.001
5	608540.025	4893365.743	1465.854	0.016
6	608525.238	4893348.859	1462.490	0.020
7	608525.242	4893327.723	1463.426	-0.006
8	608524.298	4893320.433	1463.457	-0.027
10	608299.393	4893360.889	1459.832	-0.032
11	608310.971	4893359.193	1457.179	-0.009
12	608316.658	4893368.788	1456.368	0.032
18	608282.941	4894072.515	1449.821	-0.011
19	608291.175	4894097.479	1449.167	0.063
20	608300.089	4894120.395	1446.385	-0.015
21	608279.972	4894143.536	1442.247	0.003
27	608669.764	4893168.923	1464.027	0.043
28	608682.472	4893162.255	1464.454	0.026
29	608689.972	4893161.075	1465.034	-0.004
30	608781.274	4893120.710	1475.699	0.011
31	608771.078	4893121.864	1476.478	0.012
32	608759.090	4893121.620	1477.452	-0.022
33	608730.195	4892728.015	1500.059	-0.019
34	608711.516	4892748.958	1497.697	0.043
35	608700.988	4892748.474	1497.572	-0.002
49	608575.851	4892457.757	1516.748	0.022
50	608549.141	4892446.267	1521.084	0.026
110	610393.060	4894437.299	1354.339	0.041
115	610012.794	4892703.902	1466.849	-0.059

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Dz (meters)
116	610004.296	4892706.171	1467.060	0.040
133	609880.089	4885720.617	1945.319	0.011
134	609871.466	4885711.684	1946.014	0.056
135	609868.340	4885703.613	1945.820	0.010
0	608636.079	4893433.879	1475.075	0.095
1	608637.214	4893441.632	1474.909	0.011
2	608636.854	4893453.482	1474.661	0.059
3	608639.300	4893458.083	1474.609	0.051
13	608189.087	4893843.837	1458.473	0.037
14	608177.705	4893856.898	1456.592	0.008
15	608186.551	4893812.791	1456.856	0.014
16	608221.188	4893798.650	1458.578	0.032
17	608223.925	4893827.199	1460.413	0.017
37	608732.614	4892680.813	1506.672	0.018
38	608743.145	4892675.168	1509.463	0.027
39	608762.367	4892669.224	1513.890	0.000
40	608773.159	4892651.333	1518.766	0.054
41	608795.915	4892653.794	1522.785	0.085
42	608806.020	4892690.588	1520.376	0.014
43	608825.789	4892719.235	1521.681	0.029
44	608833.820	4892729.473	1522.404	0.076
45	608840.415	4892743.953	1521.665	0.055
46	608847.393	4892743.416	1523.879	0.061
47	608858.893	4892740.461	1527.358	-0.008
48	608860.224	4892734.365	1528.382	-0.002
106	608626.127	4893437.917	1474.300	0.040
107	608617.746	4893449.421	1472.778	0.012
108	608618.385	4893479.501	1471.784	0.036
109	608631.516	4893490.985	1473.306	0.004
123	609868.446	4892861.248	1482.793	0.007
124	609874.039	4892866.425	1482.011	-0.071

Table 13: DEM Analysis, UTM 10N, NAD83 CORS96, NAVD88 GEOID09, Pole Creek

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Abs. Dz (meters)
1	608546.662	4893360.760	1467.509	0.029
2	608540.025	4893365.740	1465.854	0.106
3	608525.238	4893348.860	1462.490	0.060
4	608525.242	4893327.720	1463.426	0.064
5	608524.298	4893320.430	1463.457	0.033
6	608299.393	4893360.890	1459.832	0.082
7	608310.971	4893359.190	1457.179	0.101
8	608316.658	4893368.790	1456.368	0.012
9	608282.941	4894072.520	1449.821	0.071
10	608291.175	4894097.480	1449.167	0.053
11	608300.089	4894120.400	1446.385	0.045
12	608279.972	4894143.540	1442.247	0.057
13	608669.764	4893168.920	1464.027	0.083
14	608682.472	4893162.260	1464.454	0.026
15	608689.972	4893161.080	1465.034	0.074
16	608781.274	4893120.710	1475.699	0.021
17	608771.078	4893121.860	1476.478	0.008
18	608759.090	4893121.620	1477.452	0.022
19	608730.195	4892728.020	1500.059	0.049
20	608711.516	4892748.960	1497.697	0.053
21	608700.988	4892748.470	1497.572	0.028
22	608575.851	4892457.760	1516.748	0.022
23	608549.141	4892446.270	1521.084	0.036
24	610393.060	4894437.300	1354.339	0.031
25	610012.794	4892703.900	1466.849	0.029
26	610004.296	4892706.170	1467.060	0.060
27	609880.089	4885720.620	1945.319	0.059
28	609871.466	4885711.680	1946.014	0.036
29	609868.340	4885703.610	1945.820	0.020
30	608636.079	4893433.880	1475.075	0.075
31	608637.214	4893441.630	1474.909	0.041
32	608636.854	4893453.480	1474.661	0.009
33	608639.300	4893458.080	1474.609	0.201
34	608189.087	4893843.840	1458.473	0.107
35	608177.705	4893856.900	1456.592	0.018
36	608186.551	4893812.790	1456.856	0.024
37	608221.188	4893798.650	1458.578	0.002

38	608223.925	4893827.200	1460.413	0.047
39	608732.614	4892680.810	1506.672	0.018
40	608743.145	4892675.170	1509.463	0.013
41	608762.367	4892669.220	1513.890	0.030
42	608773.159	4892651.330	1518.766	0.134
43	608795.915	4892653.790	1522.785	0.035
44	608806.020	4892690.590	1520.376	0.074
45	608825.789	4892719.240	1521.681	0.001
46	608833.820	4892729.470	1522.404	0.004
47	608840.415	4892743.950	1521.665	0.145
48	608847.393	4892743.420	1523.879	0.091
49	608858.893	4892740.460	1527.358	0.098
50	608860.224	4892734.370	1528.382	0.038
51	608626.127	4893437.920	1474.300	0.050
52	608617.746	4893449.420	1472.778	0.038
53	608618.385	4893479.500	1471.784	0.056
54	608631.516	4893490.990	1473.306	0.044
55	609868.446	4892861.250	1482.793	0.037
56	609874.039	4892866.430	1482.011	0.081

Vertical Accuracy Conclusions

LAS Swath Fundamental Vertical Accuracy (FVA) tested 0.073 meters fundamental vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using (RMSEz) x 1.96000 Tested against the TIN using independent check points.

Bare-Earth DEM Fundamental Vertical Accuracy (FVA) tested 0.125 meters fundamental vertical accuracy at a 95 percent confidence level, derived according to NSSDA, in open terrain using (RMSEz) x 1.96000 Tested against the DEM using independent check points.

Supplemental Vertical Accuracy Conclusions

Table 14: QA/QC Analysis, Bare Earth and Open Terrain, UTM 10N, NAD83 CORS96, NAVD88 GEOID09, Pole Creek

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Dz (meters)
1	608546.662	4893360.760	1467.509	0.029
2	608540.025	4893365.740	1465.854	0.106
3	608525.238	4893348.860	1462.490	0.060
4	608525.242	4893327.720	1463.426	0.064
5	608524.298	4893320.430	1463.457	0.033
6	608299.393	4893360.890	1459.832	0.082
7	608310.971	4893359.190	1457.179	0.101

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Dz (meters)
8	608316.658	4893368.790	1456.368	0.012
9	608282.941	4894072.520	1449.821	0.071
10	608291.175	4894097.480	1449.167	0.053
11	608300.089	4894120.400	1446.385	0.045
12	608279.972	4894143.540	1442.247	0.057
13	608669.764	4893168.920	1464.027	0.083
14	608682.472	4893162.260	1464.454	0.026
15	608689.972	4893161.080	1465.034	0.074
16	608781.274	4893120.710	1475.699	0.021
17	608771.078	4893121.860	1476.478	0.008
18	608759.090	4893121.620	1477.452	0.022
19	608730.195	4892728.020	1500.059	0.049
20	608711.516	4892748.960	1497.697	0.053
21	608700.988	4892748.470	1497.572	0.028
22	608575.851	4892457.760	1516.748	0.022
23	608549.141	4892446.270	1521.084	0.036
24	610393.060	4894437.300	1354.339	0.031
25	610012.794	4892703.900	1466.849	0.029
26	610004.296	4892706.170	1467.060	0.060
27	609880.089	4885720.620	1945.319	0.059
28	609871.466	4885711.680	1946.014	0.036
29	609868.340	4885703.610	1945.820	0.020
30	608636.079	4893433.880	1475.075	0.075
31	608637.214	4893441.630	1474.909	0.041
32	608636.854	4893453.480	1474.661	0.009
33	608639.300	4893458.080	1474.609	0.201
34	608189.087	4893843.840	1458.473	0.107
35	608177.705	4893856.900	1456.592	0.018
36	608186.551	4893812.790	1456.856	0.024
37	608221.188	4893798.650	1458.578	0.002
38	608223.925	4893827.200	1460.413	0.047
39	608732.614	4892680.810	1506.672	0.018
40	608743.145	4892675.170	1509.463	0.013
41	608762.367	4892669.220	1513.890	0.030
42	608773.159	4892651.330	1518.766	0.134
43	608795.915	4892653.790	1522.785	0.035
44	608806.020	4892690.590	1520.376	0.074
45	608825.789	4892719.240	1521.681	0.001
46	608833.820	4892729.470	1522.404	0.004
47	608840.415	4892743.950	1521.665	0.145

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Dz (meters)
48	608847.393	4892743.420	1523.879	0.091
49	608858.893	4892740.460	1527.358	0.098
50	608860.224	4892734.370	1528.382	0.038
51	608626.127	4893437.920	1474.300	0.05
52	608617.746	4893449.420	1472.778	0.038
53	608618.385	4893479.500	1471.784	0.056
54	608631.516	4893490.990	1473.306	0.044
55	609868.446	4892861.250	1482.793	0.037
56	609874.039	4892866.430	1482.011	0.081

Accuracy Conclusions

Bare Earth/Open Terrain Land Cover Classification Supplemental Vertical Accuracy (SVA) tested 0.077 meters supplemental vertical accuracy at the 95th percentile in Bare Earth/Open Terrain. Tested against the DEM. Errors larger than 95th percentile include:

- Point 0, Easting 608636.079, Northing 4893433.879, Z-Error 0.095 meters
- Point 41, Easting 608795.915, Northing 4892653.794, Z-Error 0.085 meters

Table 15: QA/QC Analysis, Tall Weeds/Crops, UTM 10N, NAD83 CORS96, NAVD88 GEOID09, Pole Creek

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Dz (meters)
72	604372.960	4901135.395	1336.386	0.004
73	604368.640	4901139.422	1336.675	-0.005
74	604352.495	4901129.430	1338.167	0.033
75	604347.474	4901151.387	1338.829	0.011
76	604362.207	4901170.197	1337.005	0.075
77	604396.121	4901166.697	1334.156	0.014
78	604275.836	4901261.005	1331.987	0.063
79	604271.738	4901261.821	1332.367	0.003
80	604260.247	4901259.119	1333.299	0.001
81	604186.863	4901152.873	1343.592	0.068
82	604178.291	4901160.231	1342.842	0.028
83	604174.093	4901168.111	1342.337	-0.017
84	604167.271	4901193.310	1341.303	0.167
85	604172.806	4901202.298	1340.937	0.093
86	604168.601	4901207.564	1340.579	0.031
87	604154.180	4901168.323	1342.062	0.058
88	604136.517	4901171.849	1341.964	0.066

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Dz (meters)
89	604149.408	4901152.582	1342.453	0.097
90	604092.141	4901155.809	1345.825	0.075
91	604236.979	4901759.055	1307.929	0.041
92	604231.147	4901788.865	1311.809	0.051
93	604232.916	4901794.602	1311.839	-0.029
94	604235.076	4901802.843	1311.693	0.027
95	604222.323	4901835.992	1313.145	0.025
96	604222.956	4901878.536	1310.995	0.005
97	604229.565	4901884.766	1309.612	0.038
98	604233.050	4901870.794	1309.874	0.026
101	612851.476	4896579.271	1204.212	-0.022
102	612857.021	4896583.663	1204.027	0.013
103	612859.281	4896638.599	1203.260	-0.020
104	612844.031	4896667.567	1203.362	-0.032
105	612919.274	4896657.309	1201.55	0.020

Accuracy Conclusions

Tall Weeds/Crops Land Cover Classification Supplemental Vertical Accuracy (SVA) tested 0.122 meters supplemental vertical accuracy at the 95th percentile in Tall Weeds/Crops. Tested against the DEM. Tall Weeds/Crops Errors larger than 95th percentile include:

- Point 84, Easting 323984.844, Northing 3638881.316, Z-Error 0.167 meters

Table 16: QA/QC Analysis, Brush Lands and Trees, UTM 10N, NAD83 CORS96, NAVD88 GEOID09, Pole Creek

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Dz (meters)
22	608353.283	4894314.740	1435.080	0.150
23	608378.538	4894322.718	1435.117	0.203
24	608401.592	4894326.025	1435.012	0.178
53	606216.527	4901798.723	1352.422	0.068
54	606216.631	4901793.142	1353.719	0.051
55	606209.045	4901791.588	1353.752	0.128
56	606212.904	4901822.336	1347.639	0.121
57	606201.904	4901823.309	1346.700	0.250
58	606189.184	4901820.559	1346.286	0.224
59	606072.874	4901640.197	1359.155	-0.115
60	606071.924	4901632.282	1359.604	0.046
61	606060.864	4901644.864	1357.972	0.088
62	604308.290	4901256.639	1331.438	0.112

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Dz (meters)
63	604312.708	4901246.408	1333.205	0.045
64	603622.694	4900980.129	1387.685	0.025
65	603627.070	4900998.835	1389.055	0.045
66	603925.779	4901118.351	1357.883	0.037
67	603924.834	4901123.527	1358.431	0.079
68	604275.749	4901691.469	1309.120	0.000
69	604272.131	4901690.609	1309.727	0.163
70	604272.194	4901699.909	1308.904	0.026
71	604274.105	4901698.076	1308.799	0.041
99	604264.130	4901746.789	1305.420	0.050
100	604259.516	4901739.342	1306.340	-0.090

Accuracy Conclusions

Brush Lands and Trees Land Cover Classification Supplemental Vertical Accuracy (SVA) tested 0.244 meters supplemental vertical accuracy at the 95th percentile in Brush Lands and Trees. Tested against the DEM. Brush Lands and Trees Errors larger than 95th percentile include:

- Point 57, Easting 604167.271, Northing 4901193.310, Z-Error 0.250 meters

Table 17: QA/QC Analysis, Forested and Fully Grown, UTM 10N, NAD83 CORS96, NAVD88 GEOID09, Pole Creek

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Dz (meters)
9	608428.057	4893209.653	1462.840	-0.040
25	608390.849	4894341.066	1433.442	0.078
26	607880.830	4894532.075	1405.401	0.039
36	608700.970	4892684.788	1498.733	0.037
51	606392.601	4901797.120	1349.367	0.133
52	606385.670	4901796.323	1349.793	0.257
111	610424.187	4894445.210	1351.276	-0.026
112	610108.913	4893297.019	1426.309	-0.029
113	610110.965	4893299.998	1425.931	0.069
114	610113.570	4893310.151	1425.082	0.008
117	610000.275	4892677.529	1467.449	0.001
118	610018.377	4892676.110	1467.053	0.077
119	609958.962	4892706.541	1468.821	0.039
120	609856.787	4892838.900	1482.227	-0.017

Point ID	Easting (UTM meters)	Northing (UTM meters)	Elevation (meters)	Dz (meters)
121	609874.001	4892837.678	1480.188	-0.068
122	609884.372	4892837.399	1478.404	-0.004
125	609839.202	4892850.171	1483.765	0.045
126	610154.017	4892593.756	1466.683	0.007
127	610163.607	4892574.920	1467.051	0.059
128	609009.857	4890707.869	1565.39	-0.040
129	609958.347	4885778.064	1938.917	0.023
130	609963.591	4885765.800	1937.919	0.041
131	609959.150	4885760.406	1936.926	0.014
132	609966.178	4885741.677	1932.095	0.095
136	610163.531	4885568.481	1926.995	-0.015
137	610159.499	4885554.703	1927.618	-0.018
138	610177.150	4885549.690	1930.469	0.001
139	610179.421	4885538.767	1931.709	-0.029
140	610174.133	4885521.233	1932.321	0.029
141	610176.619	4885513.604	1932.929	0.011

Accuracy Conclusions

Forested and Fully Grown Land Cover Classification Supplemental Vertical Accuracy (SVA) tested 0.188 meters supplemental vertical accuracy at the 95th percentile in Forested and Fully Grown. Tested against the DEM. Forested and Fully Grown Errors larger than 95th percentile include:

- Point 52, Easting 606385.670, Northing 4901796.323 Z-Error 0.257 meters

CONSOLIDATED VERTICAL ACCURACY ASSESSMENT

Accuracy Conclusions

Consolidated Vertical Accuracy (CVA) Tested 0.161 meters consolidated vertical accuracy at the 95th percentile level, derived according to ASPRS Guidelines for Vertical Accuracy Reporting for LiDAR Data. Tested against the DEM. Based on the 95th percentile error in all land cover categories combined.

- Point 69, Easting 604272.131, Northing 3592297.418, Z-Error 0.163 meters
- Point 84, Easting 323984.844, Northing 3638881.316, Z-Error 0.167 meters
- Point 24, Easting 608401.592, Northing 4894326.025, Z-Error 0.178 meters
- Point 23, Easting 608378.538, Northing 4894322.718, Z-Error 0.203 meters
- Point 57, Easting 604167.271, Northing 4901193.310, Z-Error 0.250 meters
- Point 52, Easting 606385.670, Northing 4901796.323 Z-Error 0.257 meters

CERTIFICATIONS

Approved By:			
Title	Name	Signature	Date
LiDAR Specialist Certified Photogrammetrist #1281	Qian Xiao		February 5, 2014

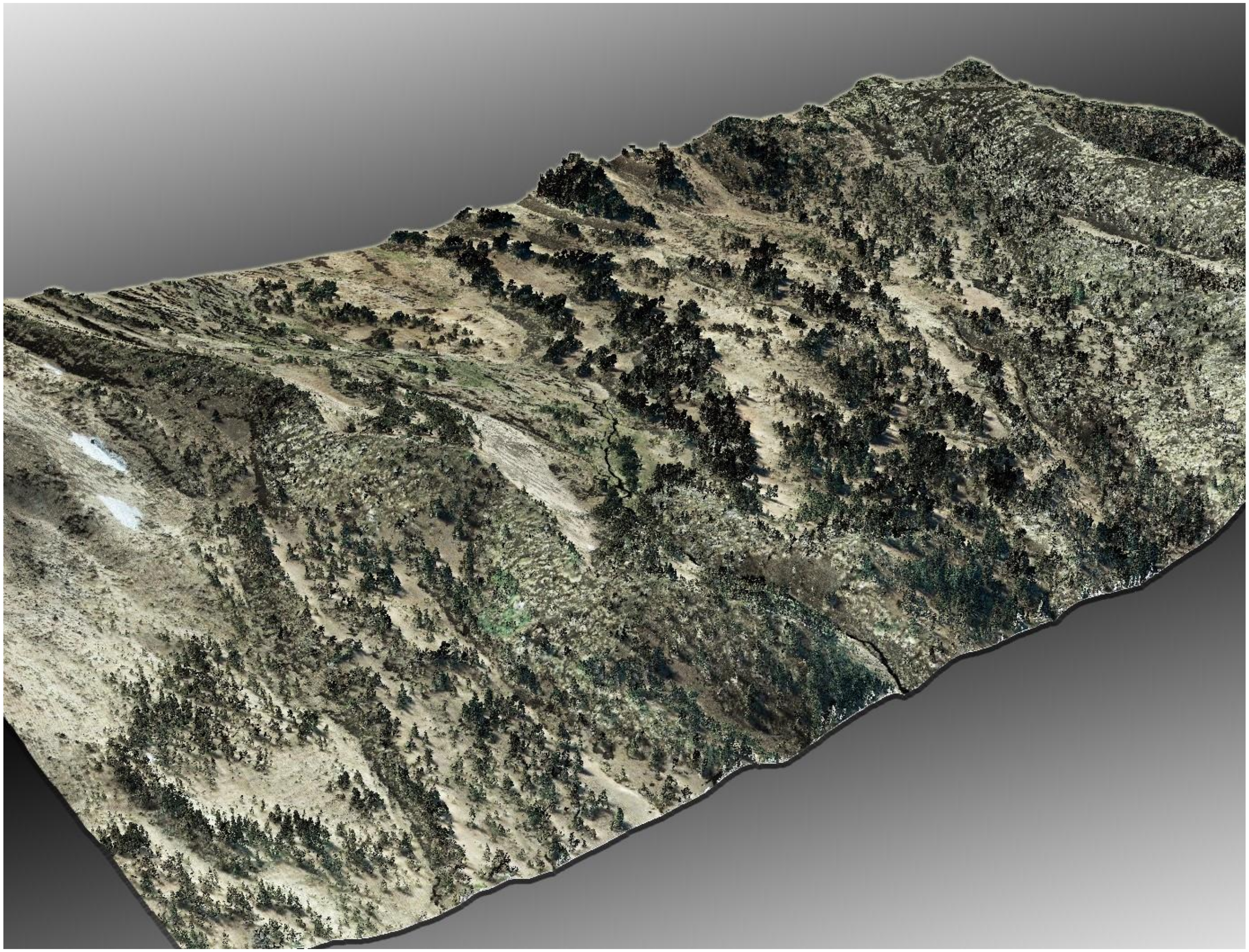

Figure 9: This image shows a forest transition line in the Pole Creek study area. The bare-earth model and vegetative LiDAR point cloud are colored by intensity and NAIP imagery.

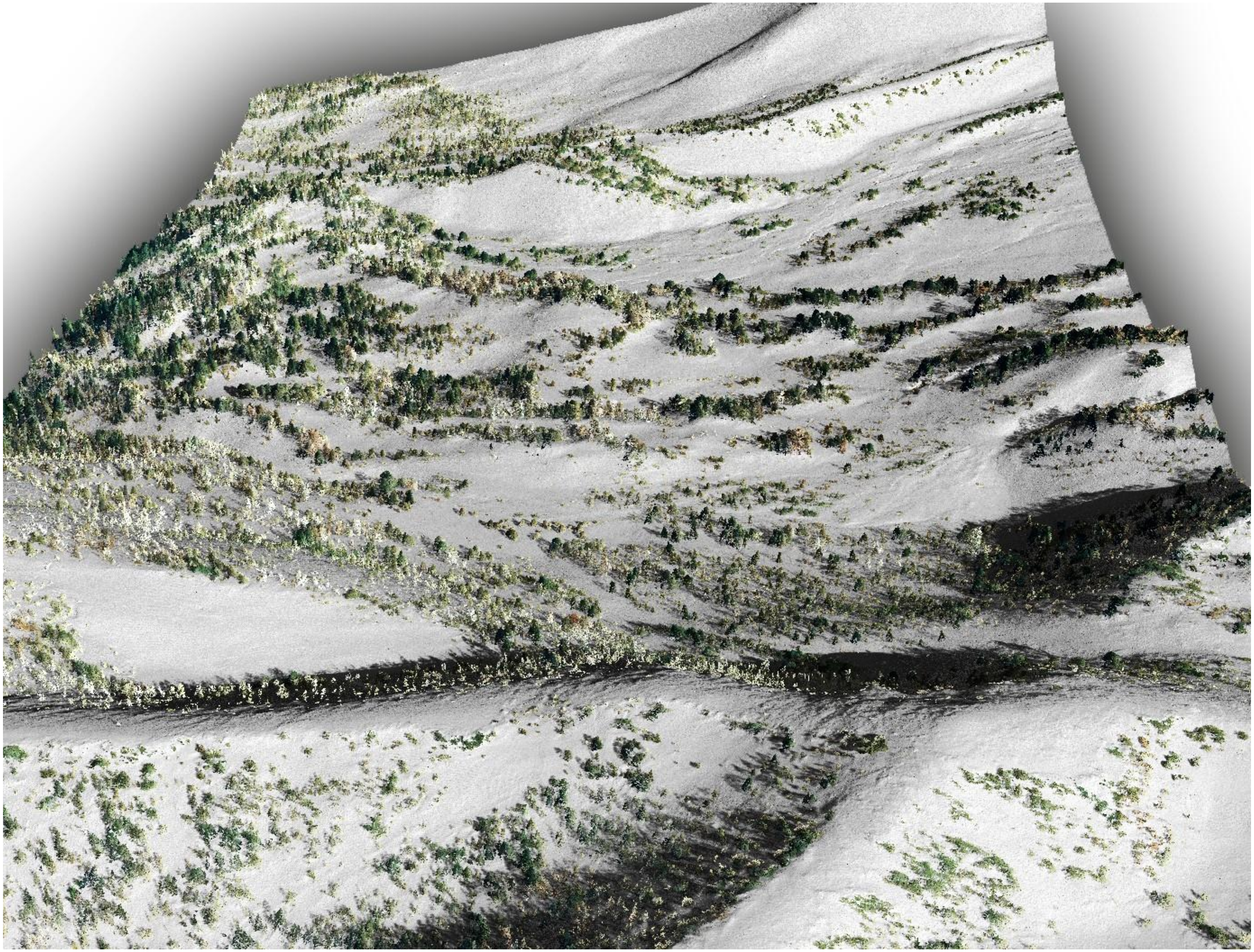

Figure 10: This image is a cross section of ridgelines in the Pole Creek study area. The shaded bare-earth model is overlayed with the vegetative LiDAR point cloud colored by NAIP imagery.