OLC Upper John Day 3DEP

May 14, 2021

Data collected for:
Oregon Department of Geology and Mineral Industries

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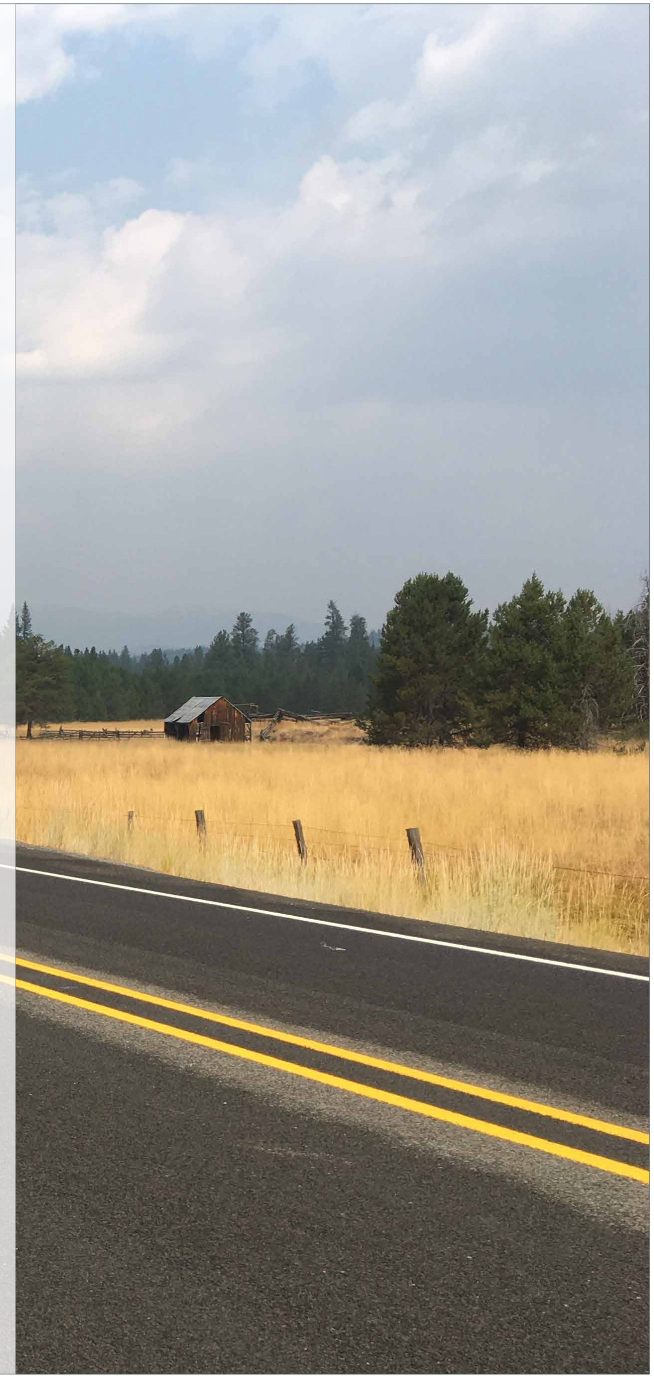
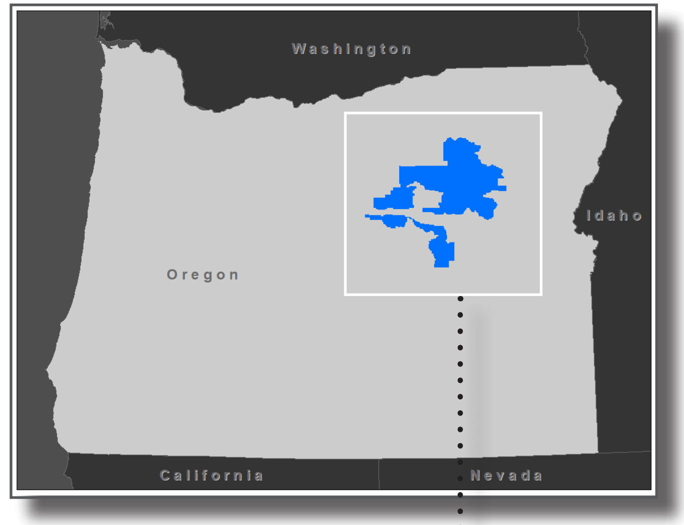


Project Overview

NV5 Geospatial has completed the acquisition and processing of Light Detection and Ranging (Lidar) data describing the OLC Upper John Day 3DEP Study Area. The Upper John Day study area, shown in Figure 1 encompasses 2,054,958.7 acres of Quality Level 1 (QL1) data within Baker, Grant, Umatilla, Union, and Wheeler County, Oregon. The collection of high resolution geographic data is part of an ongoing pursuit to amass a library of information accessible to government agencies as well as the general public. For the Upper John Day project, all final deliverables are projected in Oregon Lambert, endorsed by the Oregon Geographic Information Council (OGIC),[1] using the NAD83 (2011) horizontal datum and the NAVD88 (Geoid 12B) vertical datum, with units in International feet..



Lidar data acquisition for the OLC Upper John Day 3DEP project was completed between July 28 and August 21, 2020. Settings for Lidar data capture produced an average resolution of at least eight pulses per square meter. Final products are listed on pages three and four.

This report details project information for the delivered QL1 data. Documented herein are contract specifications, data acquisition procedures, processing methods, and analysis of the OLC Upper John Day 3DEP dataset, including Lidar accuracy and density. Acquisition dates and acreage are shown in Table 1, a complete list of contracted deliverables provided to OLC and USGS is shown in Tables 2 and 3, and the project extent is shown in Figure 1.

Table 1: OLC Upper John Day 3DEP delivery details

OLC Upper John Day 3DEP	
Acquisition Dates	July 28 - August 21, 2020
Study Area	2,054,958.7 acres
Projection	OGIC Lambert
Datum: horizontal & vertical	NAD83 (2011) NAVD88 (Geoid 12B)
Units	International Feet

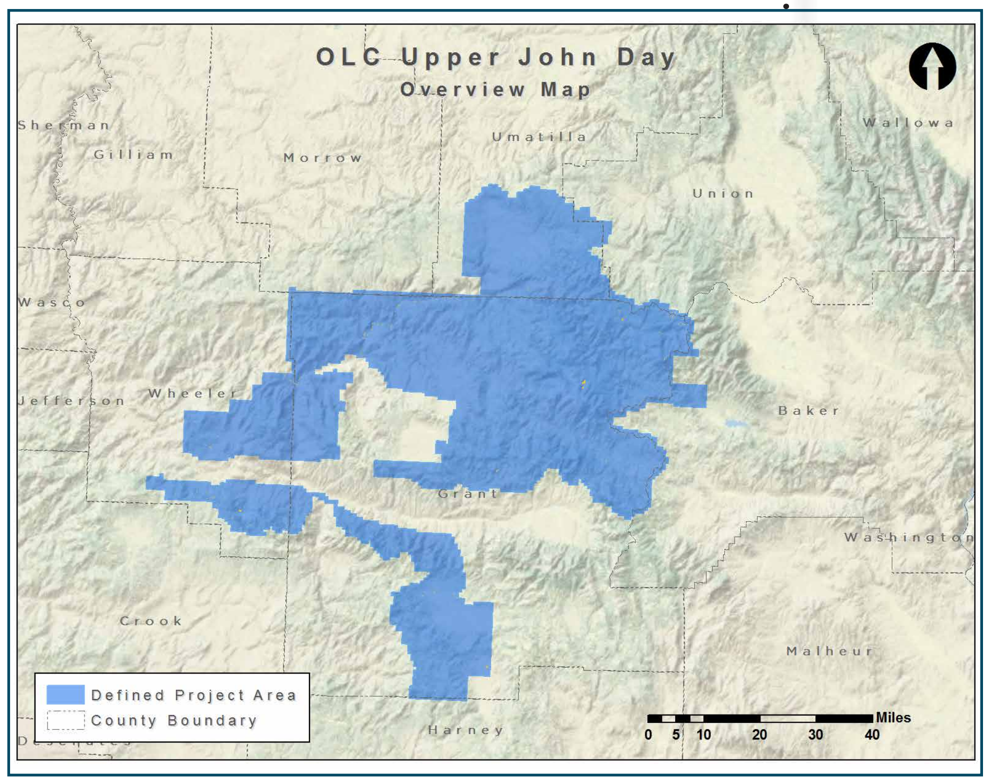


Figure 1: OLC Upper John Day 3DEP study area location

1 http://www.oregon.gov/DAS/EISPD/GEO/pages/coordination/projections/projections.aspx

Deliverable OLC Products

Table 2: Products delivered to OLC for the Upper John Day study area.

OLC Upper John Day 3DEP Projection: OGIC Lambert Horizontal Datum: NAD83 (2011) Vertical Datum: NAVD88 (GEOID12B) Units: International Feet	
Points	LAS v 1.4 tiled by 3,000 foot DPA tiles • Classified Points: default (1), bare earth (2), low noise (7), water (9), bridge decks (17), high noise (18), ignored ground (20) • Intensities
Rasters	3 foot resolution GeoTIFFs tiled by 3,000 foot DPA tiles • Bare earth model • Highest hit model 1.5 foot GeoTiffs tiled by 3,000 foot DPA tiles • Intensity images
Vectors	Shapefiles (*.shp) • Defined project area (DPA) • 3,000 ft DPA tile index • Flightlines • Ground control points (GCPs) used for LiDAR calibration • Vegetated ground survey points (GSPs) • Non-Vegetated GSPs • Project survey monuments
Metadata	• FGDC compliant metadata for all data products

Deliverable 3DEP Products

Table 3: Products delivered to USGS for the Upper John Day study area.

OLC Upper John Day 3DEP Projection: OGIC Lambert Horizontal Datum: NAD83 (2011) Vertical Datum: NAVD88 (GEOID12B) Units: International Feet	
Points	LAS v 1.4 tiled by 3,000 foot processing tiles • Default (1), ground (2), low noise (7), water (9), bridge decks (17), high noise (18), Ignored ground near a breakline (20) classified points. LAS v 1.4 Swath files • Unclassified points
Rasters	3 foot resolution ESRI GRID tiled to match 3,000 ft LAS processing tiles • Hydroflattened bare earth model
Vectors	Shapefiles (*.shp) • Project area (PA) • 3,000 ft LAS tiling scheme, clipped to the DPA • Hydro breaklines in file geodatabase • Check points used for testing Non-Vegetated Vertical Accuracy • Check points used for testing Vegetated Vertical Accuracy • Ground control points used for LiDAR calibration • Project survey monuments
Metadata	• FGDC compliant metadata for all data products

Planning

In preparation for data collection, NV5 reviewed the project area and developed a specialized flight plan to ensure complete coverage of the OLC Upper John Day 3DEP study area at the target point density of ≥8.0 points/m^2 to achieve QL1 specifications. Acquisition parameters including orientation relative to terrain, flight altitude, pulse rate, scan angle, and ground speed were adapted to optimize flight paths and flight times while meeting all contract specifications.

Factors such as satellite constellation availability and weather windows must be considered during the planning stage. Any weather hazards or conditions affecting the flights were continuously monitored due to their potential impact on the daily success of airborne and ground operations. In addition, logistical considerations including private property access and potential air space restrictions were reviewed.

Aerial Acquisition

Lidar Survey

The Lidar survey utilized a Riegl VQ 1560ii sensor mounted in a Cessna 208B Caravan. For system settings, please see Table 4. These settings are developed to yield points with an average native density of greater than eight pulses per square meter over terrestrial surfaces.

The native pulse density is the number of pulses emitted by the Lidar system. Some types of surfaces such as dense vegetation or water may return fewer pulses than the laser originally emitted. Therefore, the delivered density can be less than the native density and lightly vary according to distributions of terrain, land cover, and water bodies. The study area was surveyed with opposing flight line side-lap of 55 percent to reduce laser shadowing and increase surface laser painting. The system allows an unlimited number of measurements per pulse, but typically does not record more than five returns per pulse.

To solve for laser point position, it is vital to have an accurate description of aircraft position and attitude. Aircraft position is described as x, y, and z and measured twice per second (two hertz) by an onboard differential GPS unit. Aircraft attitude is measured 200 times per second (200 hertz) as pitch, roll, and yaw (heading) from an onboard inertial measurement unit (IMU).

Figure 2: Cessna 208B Caravan used for data acquisition

Table 4: OLC Upper John Day 3DEP acquisition specifications

OLC Upper John Day 3DEP	
Quality Level	QL1
Acquisition Dates	July 28 - August 21, 2020
Aircraft Used	Cessna 208B Caravan
Sensor	Riegl VQ 1560ii
Maximum Returns	14
Resolution/Density	Average 8 pulses/m^2
Aggregate Nominal Pulse Spacing	0.35
Survey Altitude (AGL)	1,950 m
Survey Speed	145 kts
Field of View	58.5°
Mirror Scan Rate	234 Hz
Target Pulse Rate	1,000 kHz
Pulse Length	3 ns
Central Wavelength	1064 nm
Pulse Mode	Multi (MPiA)
Beam Divergence	0.18 mrad
Planned Swath Width	2,044 m
Swath Overlap	55% sidelap
Intensity	16-bit
Accuracy	NVA (95% Confidence Level) ≤ 19.6 cm VVA (95th Percentile) ≤ 30 cm Relative < 8cm between swaths

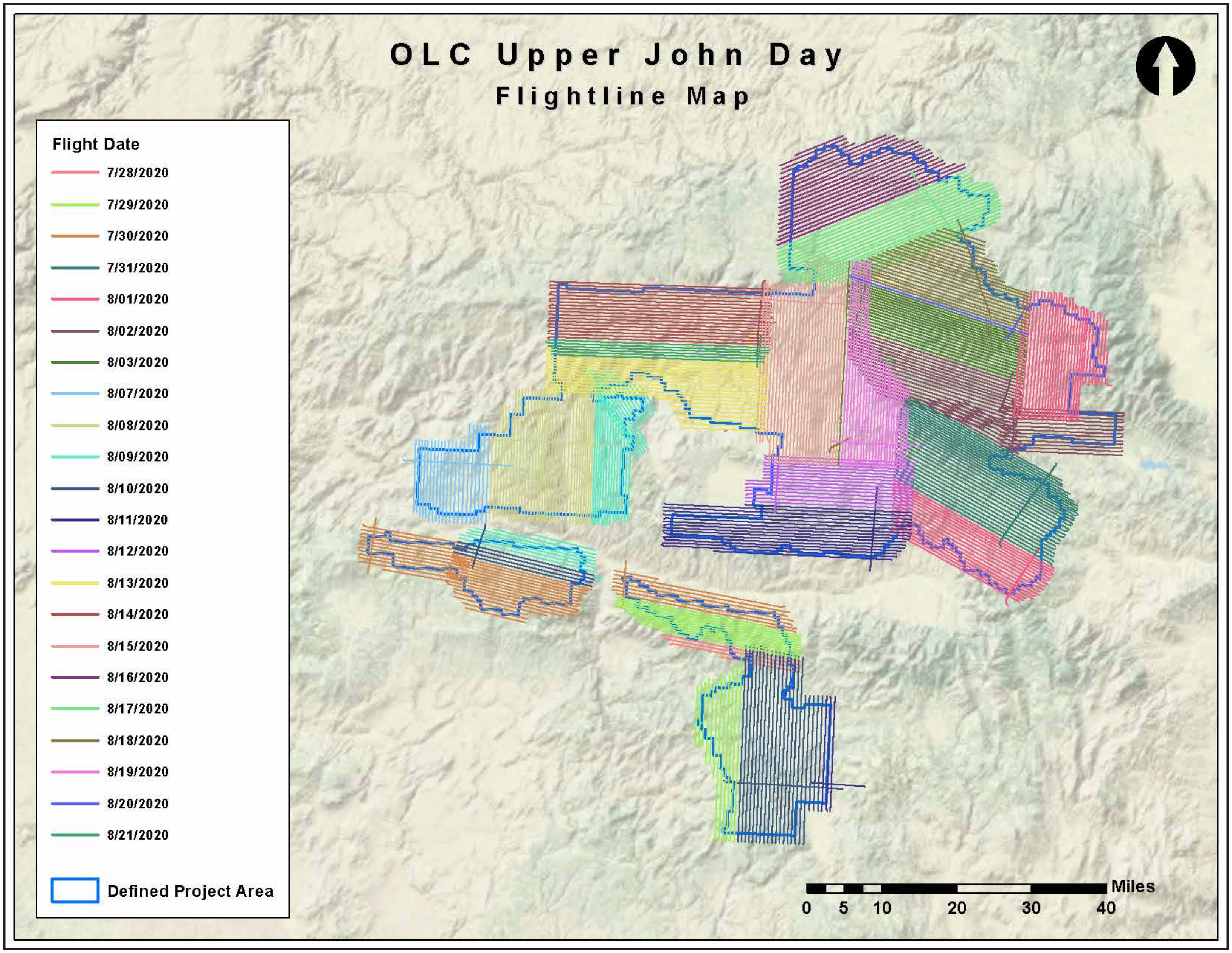


Figure 3: OLC Upper John Day acquisition flightlines

Geospatial Corrections of Aircraft Positional Data

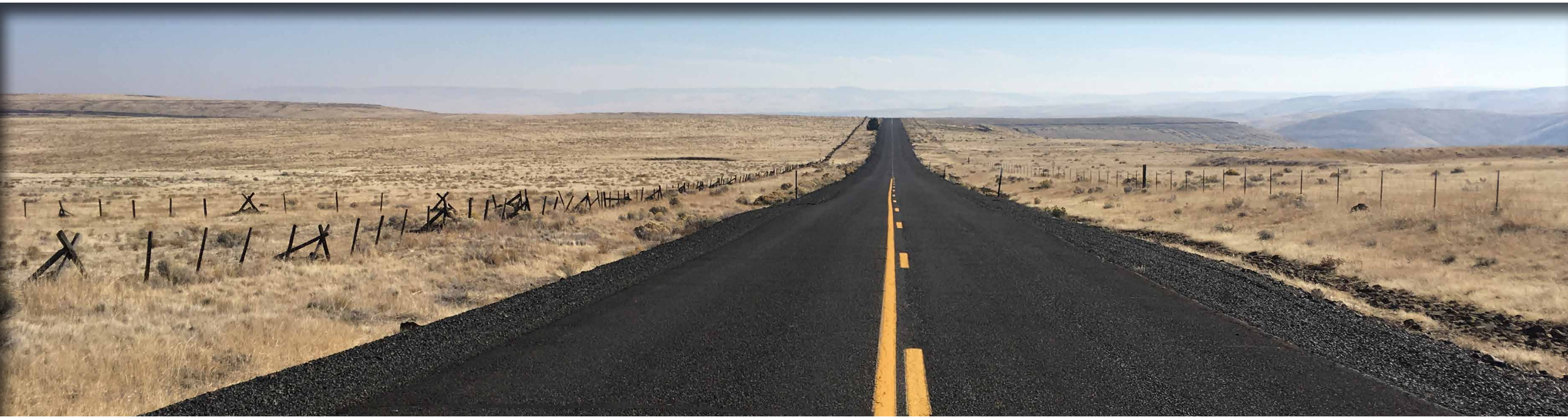
PP-RTX

To improve precision and accuracy of the aircraft trajectory, the latest generation of Global Navigation Satellite System (GNSS) satellites and recent advances in GNSS post-processing technology have made possible trajectory processing methods that do not require conventional base support: specifically, Trimble® CenterPoint™ Post-Processed Real-Time Extended (PP-RTX).

PP-RTX using Applanix POSPac MMS software leverages near real-time atmospheric models from Trimble's extensive worldwide network of continuously operating base stations to produce highly accurate trajectories.

When utilized properly and sufficiently controlled by a ground survey during post-processing, PP-RTX has the following advantages over conventional collection methods:

- Agility: The airborne acquisition is untethered by access constraints of the ground survey team at the time of acquisition, particularly in remote areas that lack permanent base stations.
- Flexibility: The airborne acquisition team can instantly shift collection priorities based on weather and client needs without waiting for a ground survey team to relocate.
- Accuracy: If properly controlled with a ground survey and datum adjustment during post-processing, PP-RTX produces results at least as accurate as conventional methods utilizing base stations.



Ground Survey

Ground control surveys were conducted to support data acquisition, including monumentation, ground control points (GCPs), and reserved check points. Bare earth GCPs were collected to correct the final dataset to match the true ground surface and correct any bias from the satellite-based aircraft positional data, sensor installation, or sensor ranging. Reserved check points however, were withheld from the calibration process and compared to the final ground surface (within vegetated and non-vegetated land cover) providing an independent assessment of the Non-Vegetated and Vegetated Vertical Accuracy of the lidar point data.

Base Stations

A continuously operating reference station from the Oregon Real-Time GNSS Network (ORGN) network was utilized to support collection of all ground survey points. A table of the stations used during ground survey are included in Table 6.

Ground Survey Points

Ground survey points (GSPs) were collected using real time kinematic (RTK), fast-static (FS), and total station (TS) survey techniques. For RTK surveys, a roving receiver receives corrections from a nearby base station or Real-Time Network (RTN) via radio or cellular network, enabling rapid collection of points with relative errors less than 1.5 cm horizontal and 2.0 cm vertical. FS surveys compute these corrections during post-processing to achieve comparable accuracy. RTK surveys record data while stationary for at least five seconds, calculating the position using at least three one-second epochs. FS surveys record observations for up to fifteen minutes on each GSP in order to support longer baselines. All GSP 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. See Table 7 for ground survey equipment specifications.

In order to facilitate comparisons with high quality Lidar data, GSP measurements were not taken on highly reflective surfaces such as center line stripes or lane markings on roads. GSPs were taken no closer than one meter to any nearby terrain breaks such as road edges or drop offs. GSPs were collected within as many flight lines as possible; however, the distribution depended on ground access constraints and may not be equitably distributed throughout the study area.

Land Cover Class

In addition to ground survey points, land cover class check points were collected throughout the study area to evaluate vertical accuracy. Vertical accuracy statistics were calculated for all land cover types to assess confidence in the Lidar derived ground models across land cover classes (Table 5). Forested check points are collected using total stations in order to measure positions under dense canopy. Total station backsight and setup points are established using GNSS survey techniques.

Table 5: Land cover types and descriptions

Land Cover Type	Land Cover Code	Description	Accuracy Assessment Type
Tall Grass	TG	Tall grass, tall weeds, and tall crops.	VVA
Brush Lands and Short Trees	SH	Brush lands and short trees.	VVA
Forested Areas	FR	Forested areas covered by trees, including hard-woods, conifers, and mixed forests.	VVA
Urban Areas	UA	Urban areas such as dense buildings and paved roads.	NVA
Bare Earth	BE	Clear or open bare earth, low grass.	NVA

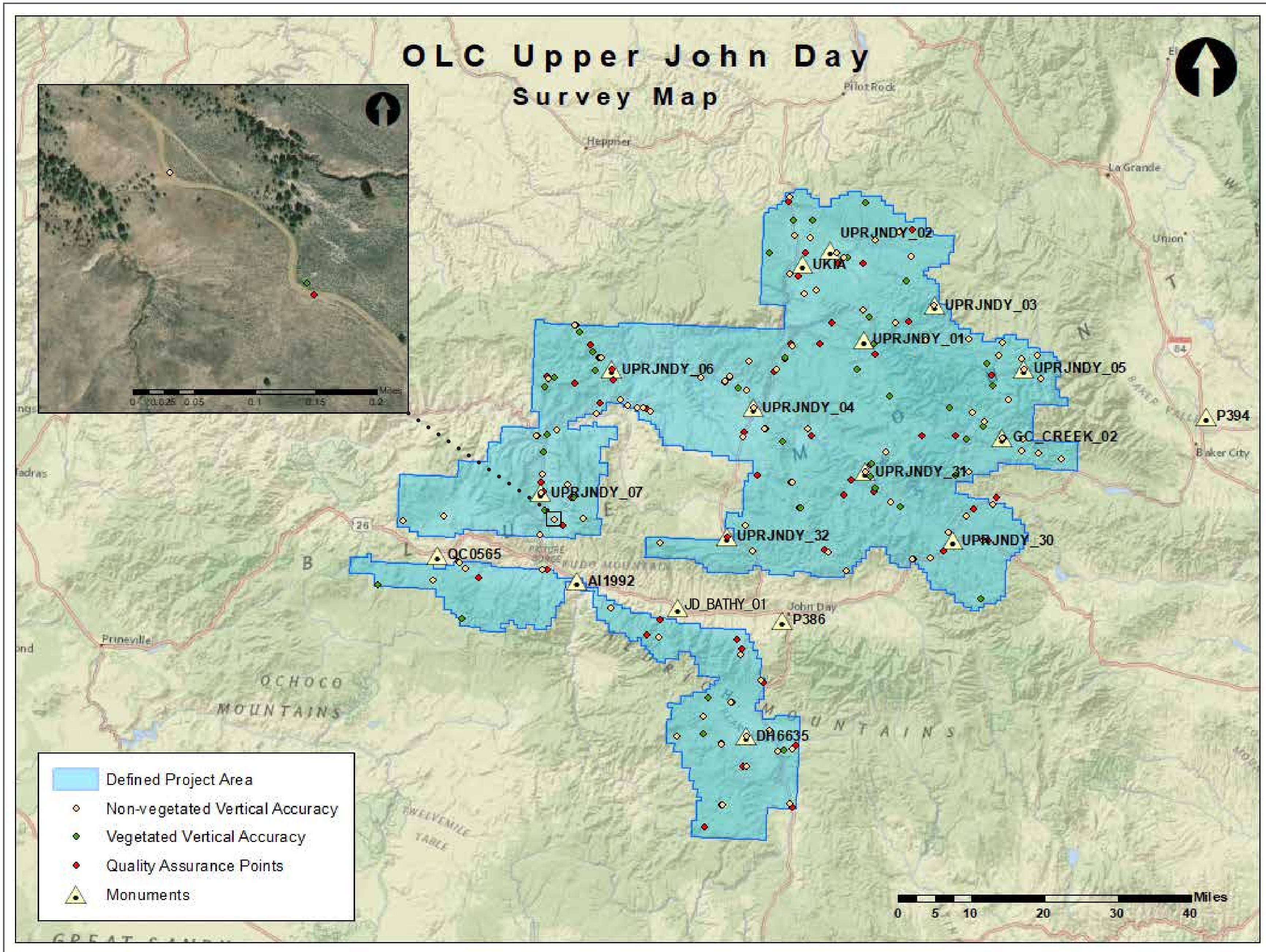


Figure 4: OLC Upper John Day study area ground survey map

Table 6: OLC Upper John Day 3DEP ORGN and OPUS monument stations. Coordinates are on the NAD83 (2011) datum, epoch 2010.00. NAVD88 orthometric referenced to Geoid12B

PID	Latitude	Longitude	Ellipsoid Height (m)	Orthometric Height (m)	Source
AI1992	44° 28' 19.99340"	-119° 32' 18.60954"	713.891	732.904	OPUS
DH6635	44° 09' 51.36842"	-119° 03' 29.55621"	1437.720	1455.977	OPUS
GC_CREEK_02	44° 47' 10.59105"	-118° 22' 01.24966"	1430.596	1447.557	OPUS
JD_BATHY_01	44° 25' 24.68297"	-119° 15' 34.62820"	804.058	822.588	OPUS
P386	44° 24' 10.16342"	-118° 58' 04.08532"	1103.980	1122.167	ORGN
P394	44° 50' 05.55486"	-117° 47' 58.64029"	1011.194	1028.268	ORGN
QC0565	44° 30' 56.55827"	-119° 55' 48.16105"	1184.974	1204.189	OPUS
UKIA	45° 07' 58.05613"	-118° 56' 11.63734"	1009.481	1027.912	ORGN
UPRJNDY_01	44° 58' 50.88982"	-118° 45' 37.52229"	941.140	958.859	OPUS
UPRJNDY_02	45° 09' 47.29219"	-118° 51' 36.00638"	1110.086	1128.405	OPUS
UPRJNDY_03	45° 03' 16.20160"	-118° 33' 49.65473"	2053.166	2070.461	OPUS
UPRJNDY_04	44° 50' 11.68513"	-119° 03' 53.98508"	1204.297	1222.690	OPUS
UPRJNDY_05	44° 55' 38.31799"	-118° 18' 43.38231"	2006.101	2022.746	OPUS
UPRJNDY_06	44° 54' 26.82558"	-119° 27' 41.26246"	938.432	957.715	OPUS
UPRJNDY_07	44° 38' 59.47380"	-119° 38' 52.82293"	603.142	622.413	OPUS
UPRJNDY_30	44° 34' 26.00012"	-118° 30' 03.90280"	1275.277	1292.739	OPUS
UPRJNDY_31	44° 42' 40.93102"	-118° 44' 51.49001"	1488.664	1506.176	OPUS
UPRJNDY_32	44° 34' 18.31697"	-119° 07' 37.95820"	1416.911	1434.966	OPUS

Table 7: Ground survey instrumentation

Instrumentation			
Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R8 GNSS	Integrated Antenna R8 Model 2 & 3	TRMR8_GNSS	Rover
Trimble R10 GNSS	Integrated Antenna R10 Model 2	TRMR10-2	Rover
Trimble M3 Total Station	n/a	n/a	VVA
Nikon NPL-322+ 5" P Total Station	n/a	n/a	VVA

Processing

This section describes the processing methodologies for all data acquired by NV5 for the OLC Upper John Day 3DEP project.

Lidar Processing

Once the Lidar data arrived in the laboratory, NV5 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. Points that were determined to be geometrically invalid, or invalid surface returns, were removed from the data set. The general workflow for calibration of the Lidar data was as follows:

Table 8: Lidar processing steps

Lidar Processing Step	Software Used
Resolve GPS kinematic corrections for aircraft position data using kinematic aircraft GNSS (collected at 2 Hz) and IMU (collected at 200 Hz) with Trimble CenterPoint PP-RTX methodologies.	POSGNSS Trimble CenterPoint PosPac MMS
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 POSPac MMS
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 v. 1.4) 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 12B correction.	RiProcess
Import raw laser points into subset bins. Filter for noise and perform manual relative accuracy calibration.	LASTools TerraScan Custom NV5 software
Classify ground points and 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 TerraScan Custom NV5 software
Assess Non-Vegetated Vertical Accuracy and Vegetated Vertical Accuracy via direct comparisons of ground classified points to reserved non-vegetated and vegetated checkpoint survey data.	TerraScan
Assign headers (e.g., projection information, variable length record, project name) to *.las files.	Las Monkey

LAS Classification Scheme

The classification classes are determined by the USGS Lidar Base Specification, version 1.3 specifications and are an industry standard for the classification of Lidar point clouds. The classes used in the dataset are as follows and have the following descriptions:

Table 9: Lidar processing steps

Classification Number	Clasification Name	Classification Description
1	Processed, but unclassified	This class covers features such as vegetation, cars, utility poles, or any other point that does not fit into other deliverable class.
2	Bare earth ground	Points used to crate bare earth surfaces.
7	Low noise	Erroneous points not meant for use below the identified ground surface.
9	Water	Point returned off water surfaces.
17	Bridge decks	Points falling on bridge decks.
18	High noise	Erroneous points above ground surface not attributed to real features.
20	Ignored grounds	Ignored grounds near breakline features.

Hydro-flattening and Water's Edge Breaklines

Water bodies within the OLC Upper John Day 3DEP project area were flattened to a consistent water level. Bodies of water that were flattened include lakes and other closed water bodies with a surface area greater than 2 acres, all streams and rivers that are nominally wider than 30 meters, all non-tidal waters bordering the project, and select smaller bodies of water as feasible. 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 water boundaries and water levels. Boundary polygons were developed using an algorithm which weights Lidar-derived slopes, intensities, and return densities to detect the water's edge. The water 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 the initial ground classified points falling within water polygons were reclassified as water points to omit them from the final ground model. Elevations were then obtained from the filtered Lidar returns to create the final breaklines. Lakes were assigned a consistent elevation for an entire polygon while rivers were assigned consistent elevations on opposing banks and smoothed to ensure downstream flow through the entire river channel.

Water boundary breaklines were then incorporated into the hydro-flattened DEM by enforcing triangle edges (adjacent to the breakline) to the elevation values of the breakline. This implementation corrected interpolation along the hard edge. Water surfaces were obtained from a TIN of the 3-D water edge breaklines resulting in the final hydroflattened model.

Results & Discussion

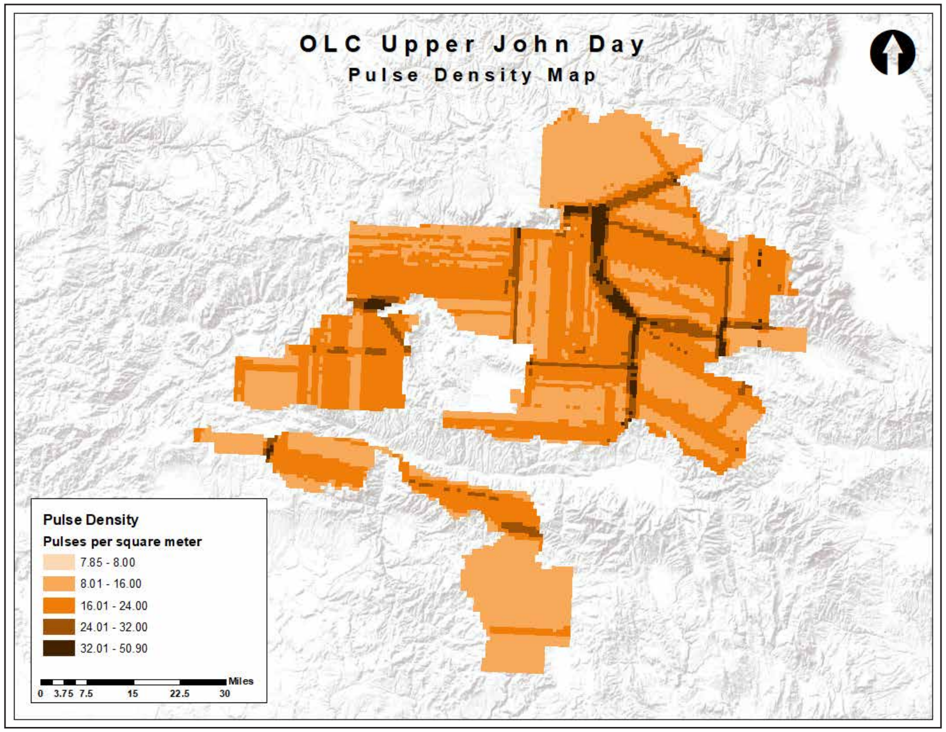
Lidar Density

The acquisition parameters were designed to acquire an average first-return density of 8 points/m². First return density describes the density of pulses emitted from the laser that return at least one echo to the system. Multiple returns from a single pulse were not considered in first return density analysis. Some types of surfaces (e.g., breaks in terrain, water and steep slopes) may have returned fewer pulses than originally emitted by the laser. First returns typically reflect off the highest feature on the landscape within the footprint of the pulse. In forested or urban areas the highest feature could be a tree, building or power line, while in areas of unobstructed ground, the first return will be the only echo and represents the bare earth surface.

The density of ground-classified Lidar returns was also analyzed for this project. Terrain character, land cover, and ground surface reflectivity all influenced the density of ground surface returns. In vegetated areas, fewer pulses may penetrate the canopy, resulting in lower ground density. The average first-return density of Lidar data for the 2020 OLC Upper John Day 3DEP project was **17.55 points/m²** (Table 10) while the average ground classified density was **3.52 points/ m²** (Table 11). The statistical and spatial distributions of first return densities and classified ground return densities per 3,000 ft x 3,000 ft cell are portrayed in Figures 5 and 6.

Table 10: Average pulse density

Average Pulse Density	pulses per square meter	pulses per square foot
	17.55	1.63



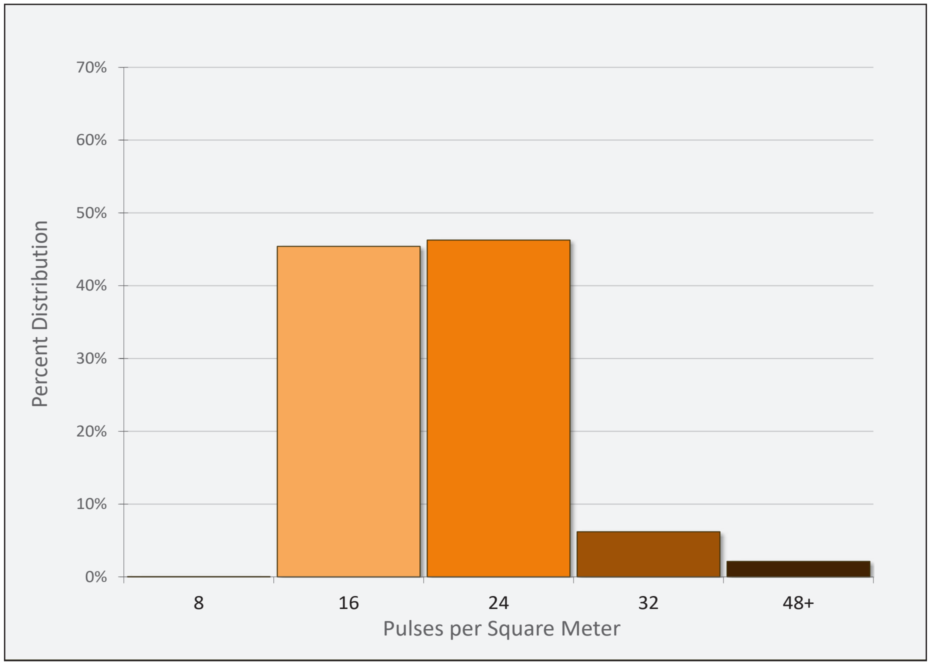
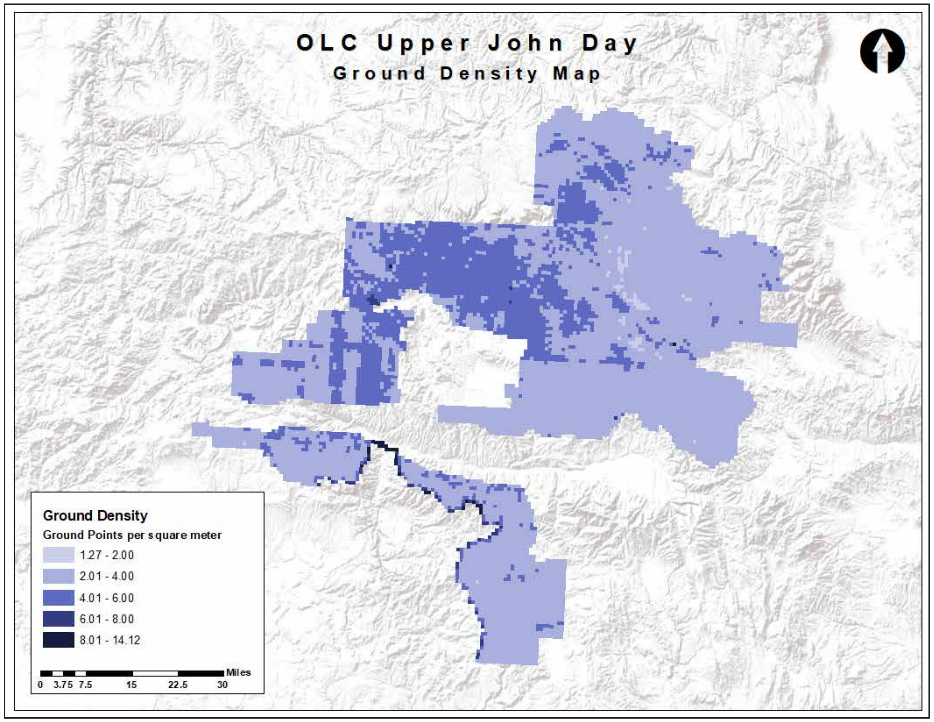


Figure 5: Average pulse density per 3,000 ft x 3,000 ft tile (color scheme aligns with density chart).

Table 11: Average ground density

Average Ground Density	points per square meter	points per square foot
	3.52	0.33



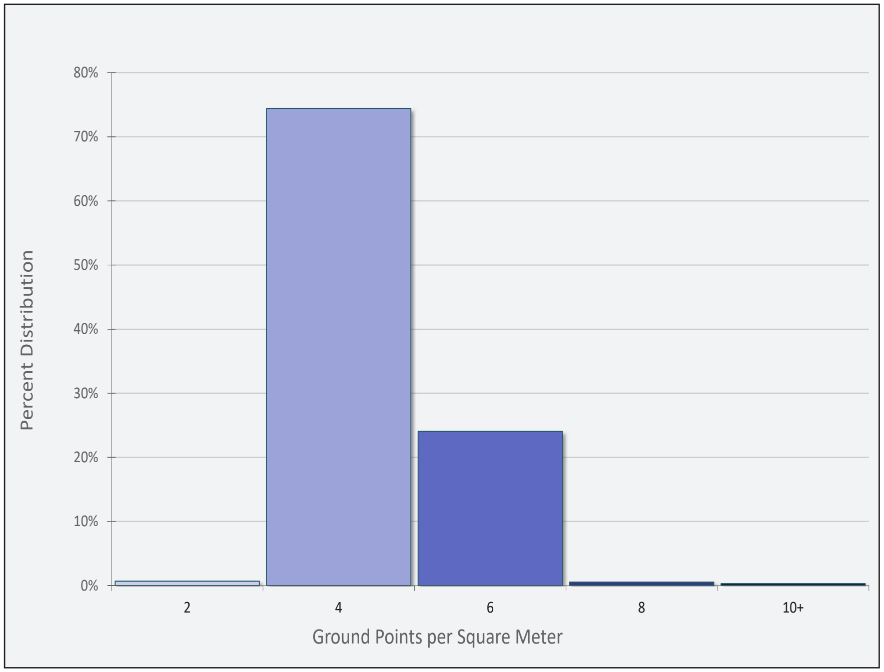


Figure 6: Average ground density per 3,000 ft x 3,000 ft tile (color scheme aligns with density chart).

Lidar Accuracy Assessments

Relative Accuracy

Relative vertical 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 centimeters). Internal consistency is affected by system attitude offsets (pitch, roll, and heading), mirror flex (scale), and GPS/IMU drift.

Relative accuracy statistics, reported in Table 12 are based on the comparison of 538 full and partial flightlines and over approximately 233 billion sample points within the OLC Upper John Day 3DEP study area.

Table 12: Relative accuracy

Relative Accuracy Calibration Results		
Project Average	0.038 m	0.125 ft
Median Relative Accuracy	0.037 m	0.121 ft
1σ Relative Accuracy	0.042 m	0.136 ft
2σ Relative Accuracy	0.050 m	0.165 ft
Flightlines	n = 538	
Sample points	233,002,969,418	

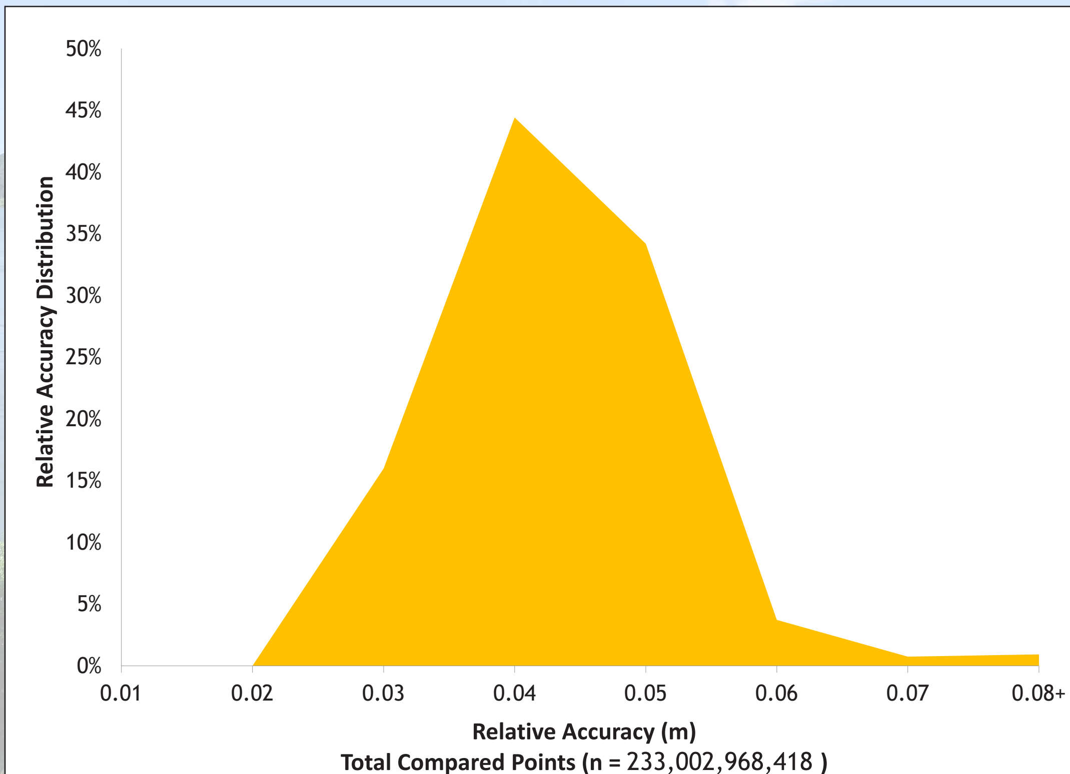


Figure 7: Relative accuracy based on 538 flightlines.

Vegetated and Non-Vegetated Vertical Accuracy

Vertical Accuracy reporting is designed to meet guidelines presented in the National Standard for Spatial Data Accuracy (NSSDA) (FGDC, 1998) and the ASPRS Positional Accuracy Standards for Digital Geospatial Data V1.0 (ASPRS, 2014). The statistical model compares known ground survey points (GSPs) to the ground model, triangulated from the neighboring laser points. Vertical accuracy statistical analysis uses ground survey points in open areas where the Lidar system has a “very high probability” that the sensor will measure the ground surface.

For the 2019 OLC Upper John Day 3DEP study area, a total of 90 ground control points were collected and used for calibration of the Lidar data. An additional 95 reserved ground survey points were collected for independent verification. The reserved ground survey points were used to determine the Non-Vegetated Vertical Accuracy (NVA) of the LAS and of the Bare Earth DEM, evaluated at the 95% confidence interval; see Table 13 for results.

NV5 collected 80 additional ground survey points in areas of vegetated land cover. These vegetated ground survey points were tested against the LAS and the bare earth DEM to determine the Vegetated Vertical Accuracy (VVA) evaluated at the 95th percentile; results are included in Table 14 on the following page.

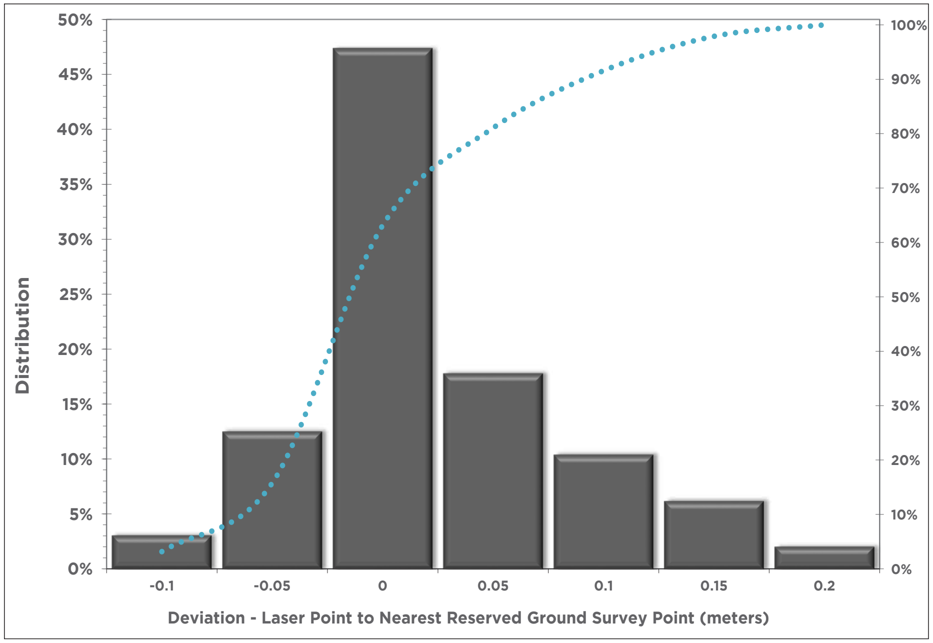


Figure 8: Non-Vegetated Vertical Accuracy distribution; points tested against the unclassified TIN.

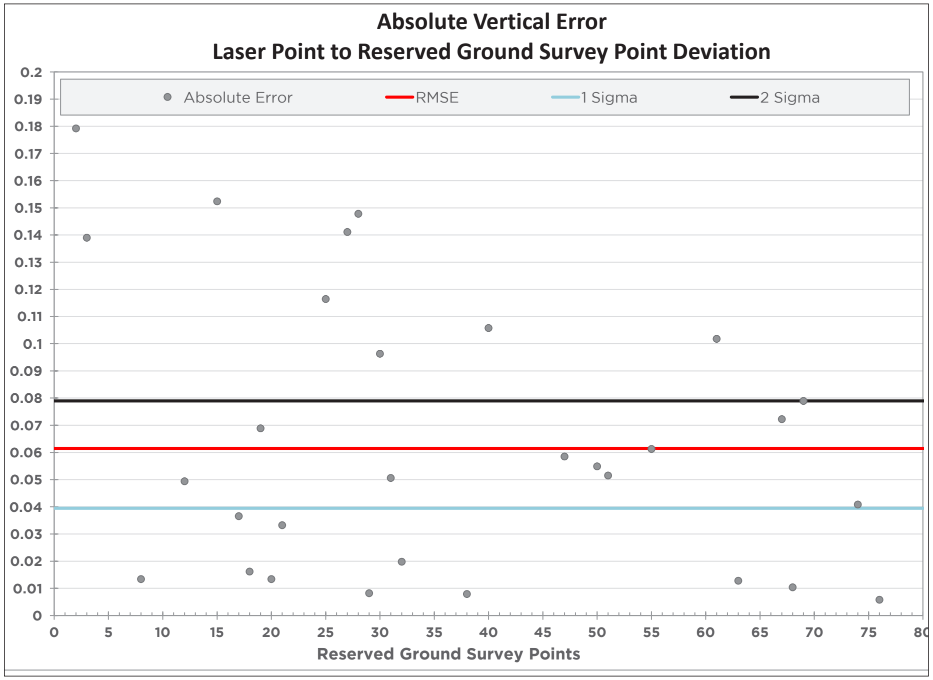


Figure 9: Reserved ground survey point absolute error; points tested against the unclassified TIN.

LAS Swath NVA:
Required NVA of the Lidar swath data is 19.6 centimeters according to specification. Upper John Day NVA at a 95 percent confidence level (derived according to NSSDA, in open terrain using 0.062 m (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA)) is **0.121 m, or 12.1 cm**; assessed and reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines.

Bare Earth DEM NVA:
Required NVA of the bare earth DEM is 19.6 centimeters according to specification. Upper John Day NVA at a 95 percent confidence level (derived according to NSSDA, in open terrain using 0.051 m (RMSEz) x 1.96000 as defined by the National Standards for Spatial Data Accuracy (NSSDA)) is **0.099 m, or 9.9 cm**; assessed and reported at the 95% confidence level in accordance with the National Digital Elevation Program (NDEP)/ASPRS Guidelines.

LAS Swath VVA:
The required VVA of the Lidar swath data at the 95th percentile according to specification is 29.4 centimeters. The VVA tested **0.176 m, or 17.6 cm,** at the 95th percentile using National Digital Elevation Program (NDEP)/ASPRS Guidelines against the DEM using 80 VVA points.

Bare Earth DEM VVA:
The required VVA of the bare earth DEM at the 95th percentile according to specification is 29.4 centimeters. The VVA tested **0.215 m, or 21.5 cm,** at the 95th percentile using National Digital Elevation Program (NDEP)/ASPRS Guidelines against the DEM using 80 VVA points.

Table 13: Non-Vegetated Vertical Accuracy results

Non-vegetated Vertical Accuracy	Tested against Classified TIN		Tested against BE DEM	
Sample Size (n)	95 Reserved Ground Survey Points		95 Reserved Ground Survey Points	
Vertical Accuracy at 95% confidence level (RMSE*1.96)	**0.121 m**	0.396 ft	**0.099 m**	0.325 ft
Root Mean Square Error	0.062 m	0.202 ft	0.051 m	0.166 ft
Standard Deviation	0.039 m	0.129 ft	0.036 m	0.118 ft
Minimum Deviation	-0.123 m	-0.405 ft	-0.154 m	-0.504 ft
Maximum Deviation	0.179 m	0.588 ft	0.087 m	0.285 ft

Table 14: Vegetated Vertical Accuracy results

Vegetated Vertical Accuracy	Tested against Classified TIN		Tested against BE DEM	
Sample Size (n)	80 Reserved Ground Survey Points		80 Reserved Ground Survey Points	
Vertical Accuracy at 95th percentile	**0.176 m**	0.264 ft	**0.215 m**	0.565 ft
Root Mean Square Error	0.116 m	0.306 ft	0.104 m	0.273 ft
Standard Deviation	0.106 m	0.279 ft	0.080 m	0.210 ft
Minimum Deviation	-0.299 m	-0.785 ft	-0.570 m	-1.498 ft
Maximum Deviation	0.490 m	1.288 ft	0.125 m	0.328 ft

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Certifications

NV5 Geospatial provided LiDAR services for the 2020 OLC 3DEP Upper John Day project as described in this report.

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

John T. English Jun 8, 2021

John English, PMP
Project Manager
NV5 Geospatial

I, Evon P. Silvia, being duly registered as a Professional Land Surveyor in and by the state of Oregon, hereby certify that the methodologies, static GNSS occupations used during airborne flights, and ground survey point collection were performed using commonly accepted Standard Practices. Field work conducted for this report was conducted between July 28 and September 6, 2020 for the new acquisition.

Accuracy statistics shown in the Accuracy Section of this Report have been reviewed by me and found to meet the "National Standard for Spatial Data Accuracy".

Evon P. Silvia Jun 8, 2021

Evon P. Silvia, PLS
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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.

1.**96 * RMSE Absolute Deviation:** Value for which the data are within two standard deviations (approximately 95th percentile) of a normally distributed data set, based on the FGDC standards for Fundamental Vertical Accuracy (FVA) reporting.

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).

Absolute Accuracy: The vertical accuracy of Lidar data is described as the mean and standard deviation (sigma σ) of divergence of Lidar point coordinates from 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, and thus the skew and kurtosis of distributions are also considered when evaluating error statistics.

Relative Accuracy: Relative accuracy refers to the internal consistency of the data set (i.e., 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).

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.

Data Density: A common measure of Lidar resolution, measured as points per square meter.

Digital Elevation Model (DEM): File or database made from surveyed points, containing elevation points over a contiguous area. Digital terrain models (DTM) and digital surface models (DSM) are types of DEMs. DTMs consist solely of the bare earth surface (ground points), while DSMs include information about all surfaces, including vegetation and man-made structures.

Intensity Values: The peak power ratio of the laser return to the emitted laser, calculated as a function of surface reflectivity.

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.

Overlap: The area shared between flight lines, typically measured in percent. 100% overlap is essential to ensure complete coverage and reduce laser shadows.

Pulse Rate (PR): The rate at which laser pulses are emitted from the sensor; typically measured in thousands of pulses per second (kHz).

Pulse Returns: For every laser pulse emitted, the number of wave forms (i.e., echos) reflected back to the sensor. Portions of the wave form that return first 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.

Real-Time Kinematic (RTK) Survey: A type of surveying 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.

Post-Processed Kinematic (PPK) Survey: GPS surveying is conducted with a GPS rover collecting concurrently with a GPS base station set up over a known monument. Differential corrections and precisions for the GNSS baselines are computed and applied after the fact during processing. This type of ground survey is accurate to 1.5 cm or less.

Scan Angle: The angle from nadir to the edge of the scan, measured in degrees. Laser point accuracy typically decreases as scan angles increase.

Native Lidar Density: The number of pulses emitted by the Lidar system, commonly expressed as pulses per square meter.

Appendix A - Accuracy Controls

Relative Accuracy Calibration Methodology:

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.

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 data sets. The data from each mission were then blended when imported together to form the entire area of interest.

Automated Z Calibration: Ground points per line were used to calculate the vertical divergence between lines caused by vertical GPS drift. Automated Z calibration was the final step employed for relative accuracy calibration.

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:

Low Flight Altitude: Terrain following was employed to maintain a constant above ground level (AGL). Laser horizontal errors are a function of flight altitude above ground (about 1/3000th AGL flight altitude).

Focus Laser Power at narrow beam footprint: A laser return must be received by the system above a power threshold to accurately record a measurement. The strength of the laser return (i.e., intensity) 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.

Reduced Scan Angle: Edge-of-scan data can become inaccurate. The scan angle was reduced to a maximum of 312o from nadir, creating a narrow swath width and greatly reducing laser shadows from trees and buildings.

Quality GPS: Flights took place during optimal GPS conditions (e.g., 6 or more satellites and PDOP [Position Dilution of Precision] less than 3.0). Before each flight, the PDOP was determined for the survey day. During all flight times, a dual frequency DGPS base station recording at 1 second epochs was utilized and a maximum baseline length between the aircraft and the control points was less than 13 nm at all times.

Ground Survey: Ground survey point accuracy (<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 points are distributed to the extent possible throughout multiple flight lines and across the survey area.

50% Side-Lap (100% Overlap): Overlapping areas are optimized for relative accuracy testing. Laser shadowing is minimized to help increase target acquisition from multiple scan angles. Ideally, with a 50% side-lap, the nadir portion of one flight line coincides with the swath edge portion of overlapping flight lines. A minimum of 50% side-lap with terrain-followed acquisition prevents data gaps.

Opposing Flight Lines: All overlapping flight lines have opposing directions. 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.