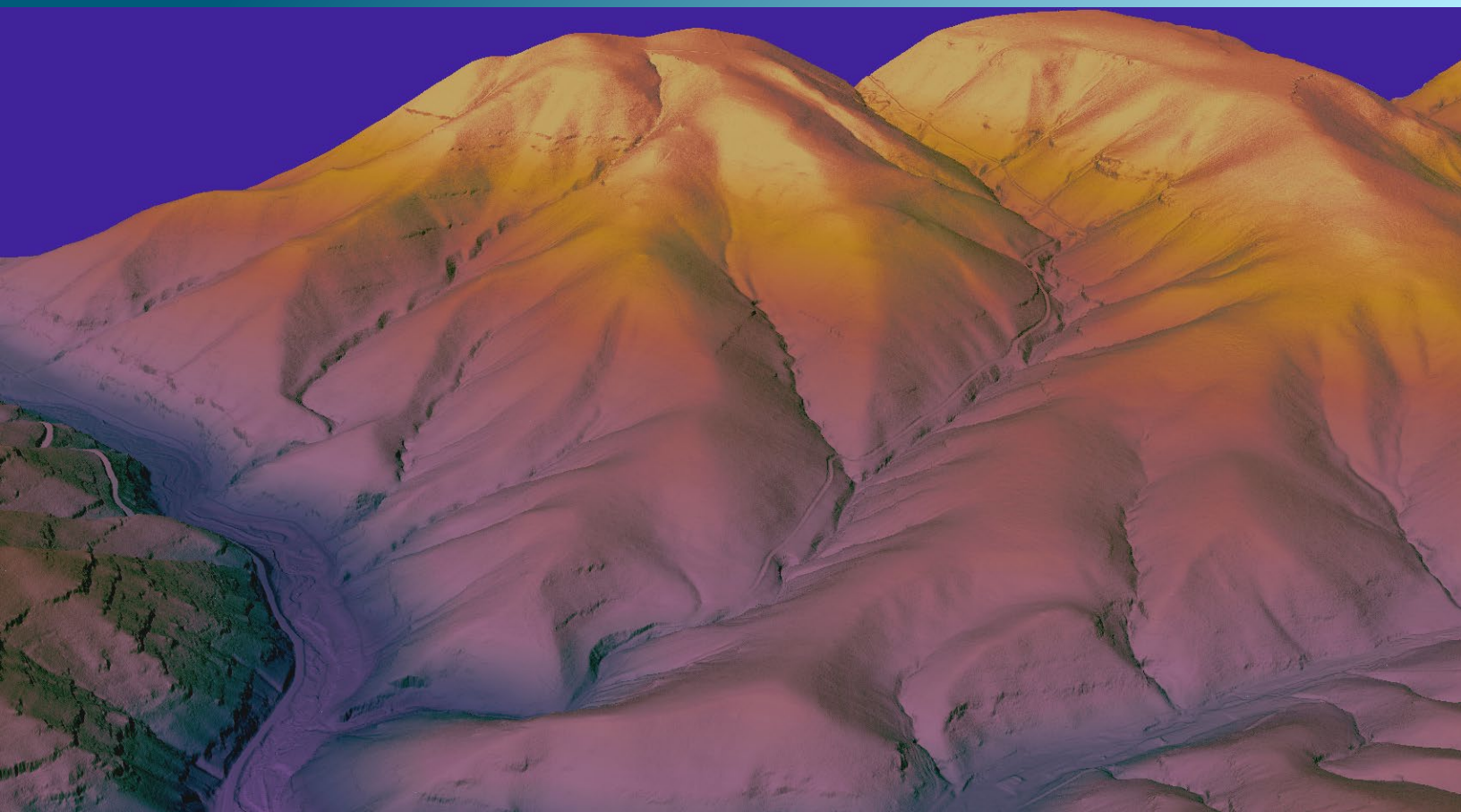


September 20, 2023



Asotin County, Washington and Lewiston, Idaho

2023 Lidar Technical Data Report

Prepared For:



Washington Dept. of Natural Resources
Abby Gleason
Washington Geological Survey
1111 Washington St. DE, Rm 148
Olympia, WA 98501-7007

Prepared By:

NV5 GEOSPATIAL

NV5 Geospatial Corvallis
1100 NE Circle Blvd, Ste. 126
Corvallis, OR 97330
PH: 541-752-1204

TABLE OF CONTENTS

INTRODUCTION	1
Deliverable Products	2
ACQUISITION	4
Planning.....	4
Airborne Lidar Survey	4
Lidar	4
Ground Survey.....	7
Base Stations.....	7
Ground Survey Points (GSPs).....	8
Land Cover Class	10
PROCESSING	12
NIR Lidar Data.....	12
Feature Extraction.....	15
Hydroflattening and Water’s Edge Breaklines.....	15
RESULTS & DISCUSSION.....	16
Lidar Density.....	16
Lidar Accuracy Assessments.....	21
Lidar Non-Vegetated Vertical Accuracy.....	21
Lidar Vegetated Vertical Accuracies	24
Lidar Relative Vertical Accuracy	26
Lidar Horizontal Accuracy	27
CERTIFICATIONS	28
GLOSSARY	29
APPENDIX A - ACCURACY CONTROLS	30

Cover Photo: A view looking south in the Blue Mountains in the Asotin Lewiston area of interest. The image was created from the lidar bare earth model colored by elevation.

LIST OF FIGURES

Figure 1: Location map of the Asotin Lewiston site in Washington	3
Figure 2: Flightlines map	6
Figure 3: Ground survey location map.....	11
Figure 4: Example of hydroflattening in the Asotin Lewiston Lidar dataset.....	15
Figure 5: Frequency distribution of first return point density values per 100 x 100 m cell	17
Figure 6: Frequency distribution of ground-classified return point density values per 100 x 100 m cell ..	18
Figure 7: First return and ground-classified point density map for the Asotin Lewiston site (100 m 100 m cells)	19
Figure 8: Ground point density map for the Asotin Lewiston site (100 m x 100 Am cells)	20
Figure 9: Frequency histogram for lidar classified LAS deviation from ground check point values (NVA).	22
Figure 10: Frequency histogram for the lidar bare earth DEM surface deviation from ground check point values (NVA).....	23
Figure 11: Frequency histogram for the lidar surface deviation from ground control point values	23
Figure 12: Frequency histogram for the lidar surface deviation from all land cover class point values (VVA)	25
Figure 13: Frequency histogram for the lidar bare earth DEM deviation from vegetated check point values (VVA)	25
Figure 14: Frequency plot for relative vertical accuracy between flight lines.....	26

LIST OF TABLES

Table 1: Acquisition dates, acreage, and data types collected on the Asotin Lewiston site	1
Table 2: Deliverable product projection information	2
Table 3: Products delivered to WADNR for the Asotin Lewiston site	2
Table 4: Lidar specifications and aerial survey settings	5
Table 5: Base station positions for the Asotin Lewiston acquisition. Coordinates are on the NAD83(HARN) datum	7
Table 6: Federal Geographic Data Committee monument rating for network accuracy	8
Table 7: NV5 Geospatial ground survey equipment identification	9
Table 8: Land Cover Types and Descriptions	10
Table 9: ASPRS LAS classification standards applied to the Asotin Lewiston dataset	13
Table 10: lidar processing workflow	14
Table 11: Average lidar point densities	17
Table 12: Absolute accuracy results	22
Table 13: Vegetated vertical accuracy results	24
Table 14: Relative accuracy results	26
Table 15: Horizontal Accuracy	27

INTRODUCTION

This photo taken by NV5 Geospatial acquisition staff shows a view of the Blue Mountains from the Asotin-Lewiston site in Washington.



In February 2023, NV5 Geospatial (NV5) was contracted by Washington Department of Natural Resources (WADNR) to collect Light Detection and Ranging (lidar) data in the summer of 2023 for the Asotin County, Washington and Lewiston, Idaho. Data were collected to aid WADNR in assessing the topographic and geophysical properties of the study area.

This report accompanies the delivered lidar data, and documents contract specifications, data acquisition procedures, processing methods, and analysis of the final dataset including lidar accuracy and density. Acquisition dates and acreage are shown in Table 1, deliverable projection information is shown in Table 2, a complete list of contracted deliverables provided to WADNR is shown in Table 3, and the project extent is shown in Figure 2.

Table 1: Acquisition dates, acreage, and data types collected on the Asotin County, Washington and Lewiston, Idaho site

Project Site	Contracted Acres	Buffered Acres	Aerial Acquisition Dates	Data Type
Asotin County, Washington and Lewiston, Idaho	760,308	768,469	3/18/2023 – 6/26/2023	NIR - Lidar

Deliverable Products

Table 2: Deliverable product projection information

Projections	Horizontal Datum	Vertical Datum	Units
Washington State Plane South	NAD83 (HARN)	NAV88 (GEOID 12b)	US Survey Feet

*The data were created in NAD83 (CORS96), but for GIS purposes are defined as NAD83 (HARN) as per PSLC specifications.

Table 3: Products delivered to WADNR for the Asotin County, Washington and Lewiston, Idaho site

Product Type	File Type	Product Details
Points	LAS v.1.4 (*.las)	All Classified Returns
Rasters	1.5 feet GeoTiffs (*.tif)	- Hydroflattened Bare Earth Model (DEM) - Highest Hit Digital Surface Model (DSM) - Highest Hit Digital Elevation Model (DEM) - Intensity Images
	1640.5 feet GeoTiff (*.tif)	Flightline Overlap Raster
Vectors	Shapefiles (*.shp)	- Buffered Area of Interest - Lidar Tile Index - Smooth Best Estimate Trajectory (SBETs) - Aerial Acquisition Shapes (Flightlines and Swath Polygons) - Ground Survey Data - Breaklines
Metadata	Extensible Markup Language (*.xml)	Metadata
Reports	Adobe Acrobat (*.pdf)	- Lidar Technical Data Report - Certificate of Completeness (FEMA) - Project Narrative (FEMA) - Acquisition Reports
Reports	Text Document (*.txt)	Readme (FEMA)

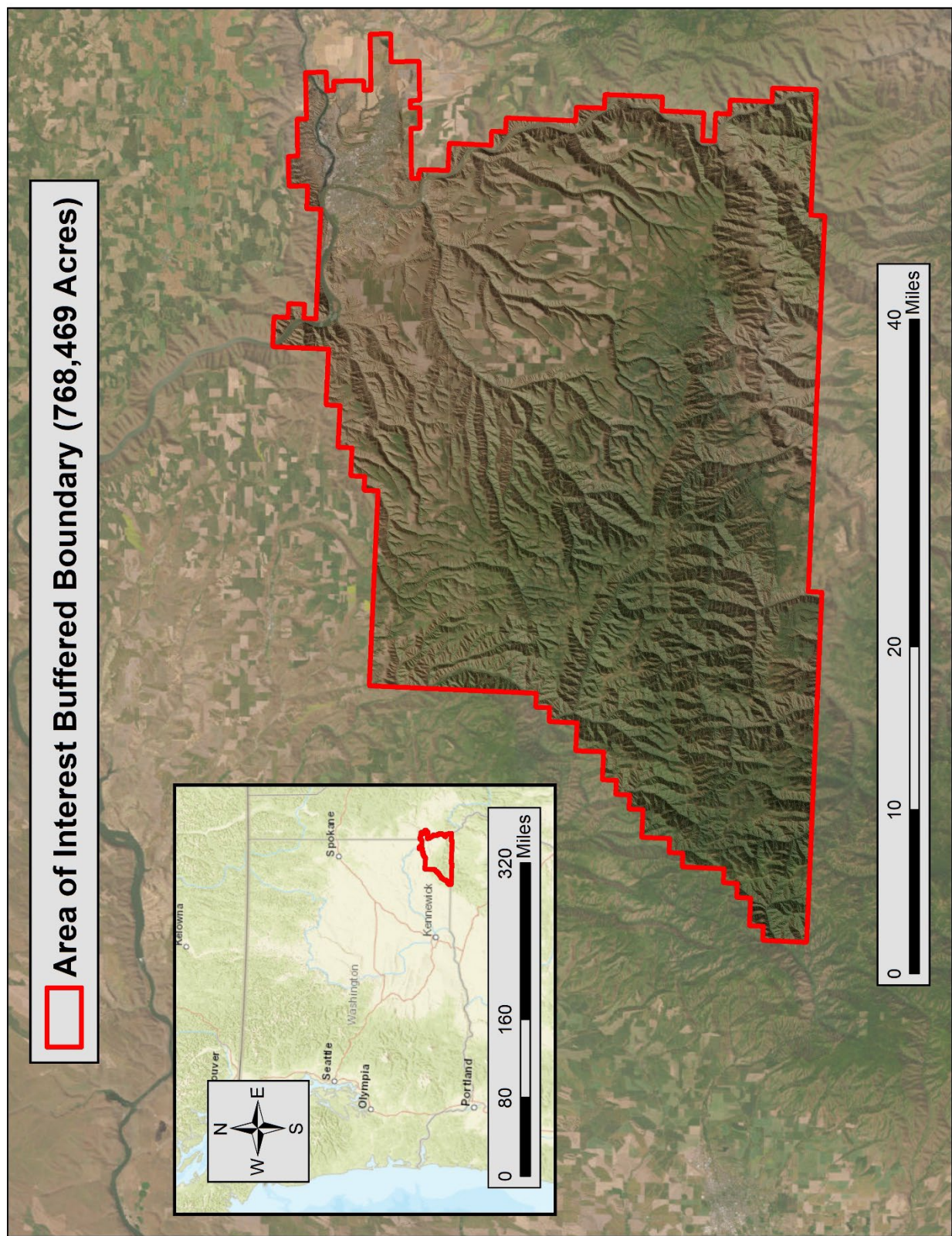


Figure 1: Location map of the Asotin County, Washington and Lewiston, Idaho

ACQUISITION

NV5 Geospatial's Cessna Caravan



Planning

In preparation for data collection, NV5 Geospatial reviewed the project area and developed a specialized flight plan to ensure complete coverage of the Asotin County, Washington and Lewiston, Idaho lidar study area at the target point density of ≥ 8.0 points/m² (0.74 points/ft²). 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. shows these optimized flight paths and dates.

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, logistical considerations including private property access and potential air space restrictions were reviewed.

Airborne Lidar Survey

Lidar

The lidar survey was accomplished using a Riegl VQ-1560ii-S system mounted in a Cessna Caravan. Table 4 summarizes the settings used to yield an average pulse density of ≥ 8 pulses/m² (≥ 0.74 pulses/ft²) over the Asotin County, Washington and Lewiston, Idaho project area. The Riegl VQ-1560ii-S laser system can record unlimited range measurements (returns) per pulse, however a maximum of 15 returns can be stored due to LAS v1.4 file limitations. The typical number of returns digitized from a single pulse range

from 1 to 10 for the Asotin County, Washington and Lewiston, Idaho project area. 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. The discrepancy between first return and overall delivered density will vary depending on terrain, land cover, and the prevalence of water bodies. All discernible laser returns were processed for the output dataset. shows the flightlines acquired using these lidar specifications.

Table 4: Lidar specifications and aerial survey settings

Parameter	NIR Laser
Acquisition Dates	3/18/2023 – 6/26/2023
Aircraft Used	Cessna Caravan
Sensor	Riegl
Laser Channel	VQ-1560ii-S
Maximum Returns	15
Resolution/Density	Average 8 pulses/m ²
Nominal Pulse Spacing	0.35 m
Survey Altitude (AGL)	2500 m
Survey speed	145 knots
Field of View	58.5°
Mirror Scan Rate	Uniform Point Spacing
Target Pulse Rate	767 kHz
Pulse Length	3 ns
Laser Pulse Footprint Diameter	57.5 cm
Central Wavelength	1064 nm
Pulse Mode	Multiple Times Around (MTA)
Beam Divergence	0.23 mrad
Swath Width	2800 m
Swath Overlap	55%
Intensity	16-bit
Vertical Accuracy	RMSE _z ≤ 10 cm
Horizontal Accuracy	RMSE _z ≤ 30 cm

Riegl VQ-1560ii-S



All areas were surveyed with an opposing flight line side-lap of ≥55% (≥100% overlap) in order to reduce laser shadowing and increase surface laser painting. To accurately solve for laser point position (geographic coordinates x, y and z), the positional coordinates of the airborne sensor and the orientation of the aircraft to the horizon (attitude) 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, and 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 and sensor position and attitude data are indexed by GPS time.

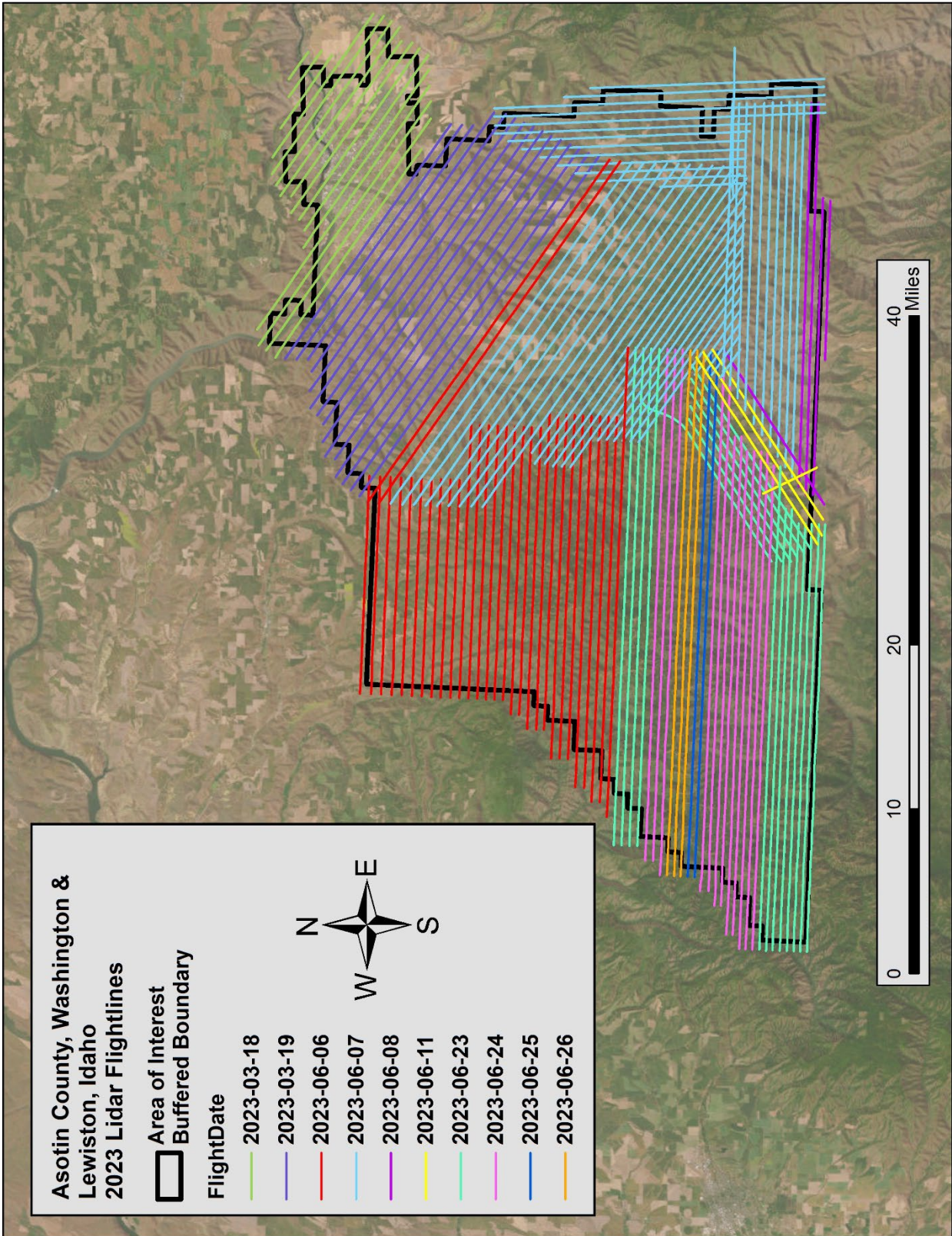


Figure 3: Flightlines map

Ground Survey

Ground control surveys, including monumentation and ground survey points (GSPs) were conducted to support the airborne acquisition. Ground control data were used to geospatially correct the aircraft positional coordinate data and to perform quality assurance checks on final lidar.

Base Stations

Base stations were utilized for collection of ground survey points using real time kinematic (RTK), fast static (FS), and total station (TS) survey techniques.

Base station locations were selected with consideration for satellite visibility, field crew safety, and optimal location for GSP coverage. NV5 Geospatial utilized three permanent real-time network (RTN) base stations from the Washington State Reference Network (WSRN) for the Asotin County, Washington and Lewiston, Idaho Lidar project and one existing mag hub nail. NV5 Geospatial also established five new monuments using 6" mag hub nails with orange survey washers (Table 5, Figure 5). NV5's professional land surveyor Steven Hyde (WAPLS#22028821, L-10235) oversaw and certified the ground survey.



NV5 Geospatial-Established Monument

Table 5: Base station positions for the Asotin County, Washington and Lewiston, Idaho acquisition. Coordinates are on the NAD83(HARN) datum

Monument ID	Owner	Latitude	Longitude	Ellipsoid (meters)
ANAT	WSRN	46° 07' 58.29432"	-117° 08' 07.48187"	1087.798
LWST	WSRN	46° 22' 23.42432"	-117° 00' 08.24804"	427.611
POME	WSRN	46° 28' 47.78541"	-117° 37' 54.09041"	551.503
ASOTIN_01	NV5	46° 16' 27.08811"	-117° 16' 33.74362"	831.168
ASOTIN_02	NV5	46° 18' 31.84260"	-117° 28' 49.64476"	1238.377
ASOTIN_03	NV5	46° 12' 55.25107"	-117° 29' 23.20137"	1585.681
ASOTIN_04	NV5	46° 06' 52.15499"	-117° 01' 21.95184"	1018.595
ASOTIN_05	NV5	46° 01' 14.58395"	-117° 32' 40.42355"	1190.68
ASOTIN_06	NV5	46° 04' 47.30737"	-117° 53' 05.80650"	1644.73

NV5 Geospatial utilized static Global Navigation Satellite System (GNSS) data collected at 1 Hz recording frequency for each base station. During post-processing, the static GNSS data were triangulated with nearby Continuously Operating Reference Stations (CORS) using the Online Positioning User Service (OPUS¹) for precise positioning. 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 is shown in Table 6.

Table 6: Federal Geographic Data Committee monument rating for network accuracy

Direction	Rating
1.96 * St Dev _{NE} :	0.020 m
1.96 * St Dev _z :	0.050 m

For the Asotin County, Washington and Lewiston, Idaho Lidar project, the monument coordinates contributed no more than 5.6 cm of positional error to the geolocation of the final ground survey points and lidar, with 95% confidence.

Ground Survey Points (GSPs)

Ground survey points 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, while 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 Trimble unit specifications.

Forested checkpoints 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.

¹ OPUS is a free service provided by the National Geodetic Survey to process corrected monument positions.
<http://www.ngs.noaa.gov/OPUS>.

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: [FGDC Standards Website](#)

GSPs were collected in areas where good satellite visibility was achieved on paved roads and other hard surfaces such as gravel or packed dirt roads. GSP 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. GSPs were collected within as many flightlines as possible; however, the distribution of GSPs depended on ground access constraints and monument locations and may not be equably distributed throughout the study area (Figure 5).

Table 7: NV5 Geospatial ground survey equipment identification

Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R8 Model 4	Integrated Antenna	TRMR8_GNSS4	Rover
Trimble R10 Model 2	Integrated Antenna	TRMR10-2	Static
Trimble R12	Integrated Antenna	TRMR12	Rover
Nikon NPL-322+ 5" P Total Station	N/A	n/a	VVA

Land Cover Class

In addition to ground survey points, land cover class checkpoints 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 8, see Lidar Accuracy Assessments, page 21).

Table 8: Land Cover Types and Descriptions

Land cover type	Land cover code	Example	Description	Accuracy Assessment Type
Shrub	SH		Low growth shrub	VVA
Tall Grass	TG		Herbaceous grasslands in advanced stages of growth	VVA
Forest	FR		Forested areas	VVA
Bare Earth	BARE, BE		Areas of bare earth surface	NVA
Urban	UA		Areas dominated by urban development, including parks	NVA

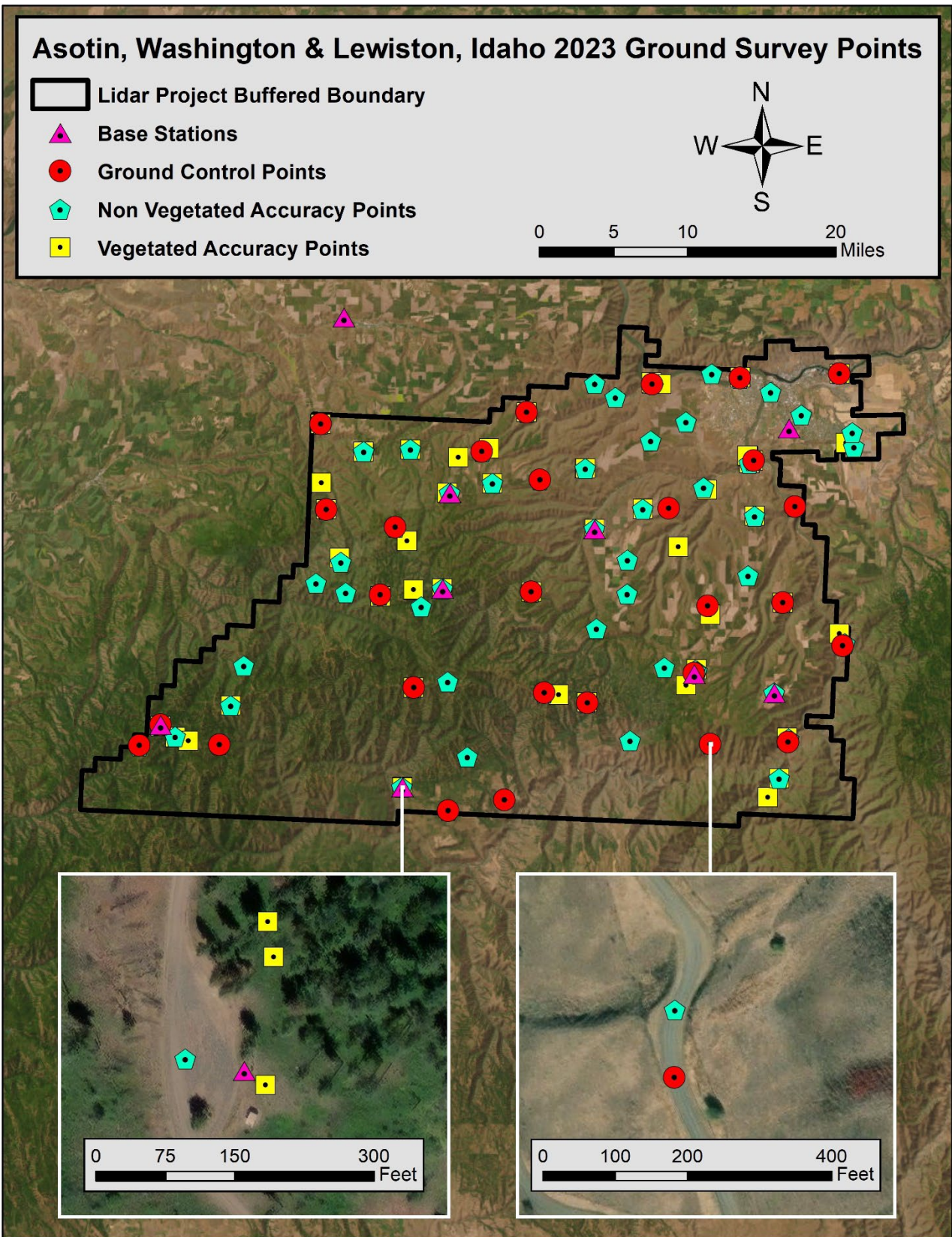
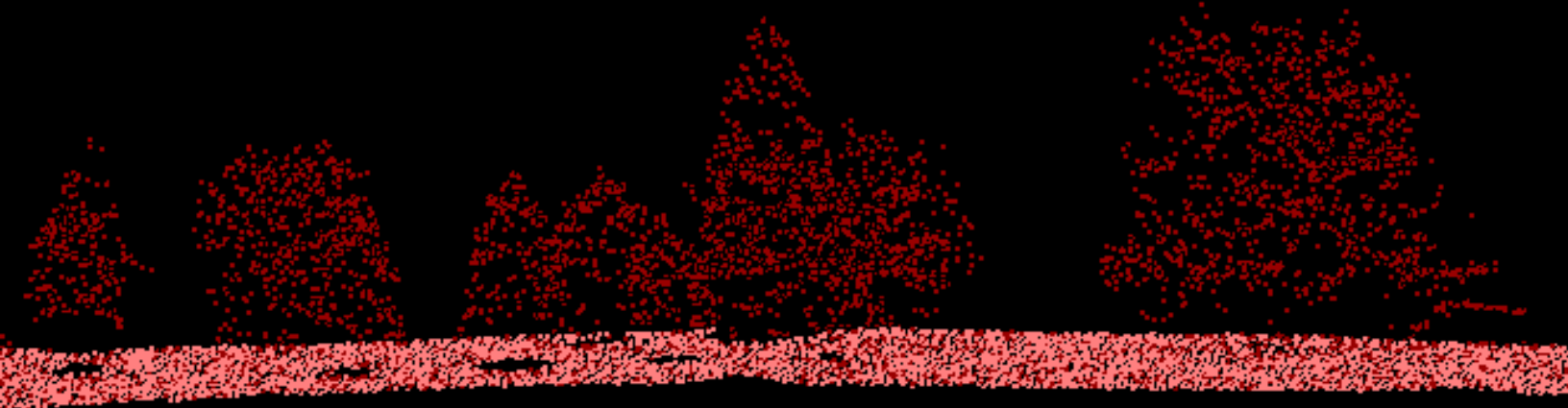


Figure 5: Ground survey location map

PROCESSING

This 6 foot lidar cross section shows a view of the Asotin-Lewiston landscape, colored by point classification.

Ground
Default



NIR Lidar Data

Upon completion of data acquisition, NV5 Geospatial processing staff initiated a suite of automated and manual techniques to process the data into the requested deliverables. Processing tasks included GPS control computations, smoothed best estimate trajectory (SBET) calculations, kinematic corrections, calculation of laser point position, sensor and data calibration for optimal relative and absolute accuracy, and lidar point classification (Table 9). Processing methodologies were tailored for the landscape. Brief descriptions of these tasks are shown in Table 10.

Table 9: ASPRS LAS classification standards applied to the Asotin County, Washington and Lewiston, Idaho dataset

Classification Number	Classification Name	Classification Description
1	Default/Unclassified	Laser returns that are not included in the ground class, composed of vegetation and anthropogenic features
1W	Edge Clip/Withheld	Laser returns at the outer edges of flightlines that are geometrically unreliable
2	Ground	Laser returns that are determined to be ground using automated and manual cleaning algorithms
7W	Noise/Withheld	Laser returns that are often artificial points below the ground surface
9	Water	Laser returns that are determined to be water using automated and manual cleaning algorithms
17	Bridge	Bridge decks
18W	High Noise/Withheld	Laser returns that are often associated with birds or scattering from reflective surfaces
20	Ignored Ground	Ground points proximate to water's edge breaklines, ignored for correct model creation
22	Temporal Exclusion	Data excluded due to temporal variation with adjacent lift

Table 10: lidar processing workflow

Lidar Processing Step	Software Used
Resolve kinematic corrections for aircraft position data using kinematic aircraft GPS and static ground GPS data. Develop a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with sensor head position and attitude recorded throughout the survey.	POSPac MMS v.8.9
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. 1.4) format. Convert data to orthometric elevations by applying a geoid correction.	RiUnite v.1.0.3
Import raw laser points into manageable blocks to perform manual relative accuracy calibration and filter erroneous points. Classify ground points for individual flight lines.	TerraScan v.19.005
Using ground classified points per each flight line, test the relative accuracy. Perform automated line-to-line calibrations for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift. Calculate calibrations on ground classified points from paired flight lines and apply results to all points in a flight line. Use every flight line for relative accuracy calibration.	StripAlign v.2.21
Classify resulting data to ground and other client designated ASPRS classifications (Table 9). Assess statistical absolute accuracy via direct comparisons of ground classified points to ground control survey data.	TerraScan v.19.005 TerraModeler v.19.003
Generate bare earth models as triangulated surfaces. Generate highest hit models as a surface expression of all classified points. Export all surface as Cloud Optimized GeoTIFFs at a 1.5 foot pixel resolution.	LAS Product Creator 4.0 (NV5 Geospatial proprietary)
Export intensity images as Cloud Optimized GeoTIFFs at a 1.5 foot pixel resolution.	Las Monkey 2.6.8 (NV5 Geospatial proprietary) LAS Product Creator 4.0 (NV5 Geospatial proprietary)
Export flightline overlap images as Cloud Optimized GeoTIFFs at a 1640.5 foot pixel resolution. Mosaic to a single deliverable image.	Las Tools - Las Overlap v221128 LAS Product Creator 4.0 (NV5 Geospatial proprietary)

Feature Extraction

Hydroflattening and Water's Edge Breaklines

The Asotin County, Washington and Lewiston, Idaho River and other water bodies within the 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 hydroflattening 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.

Hydroflattening 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.

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 hydroflattened 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 (Figure 6).

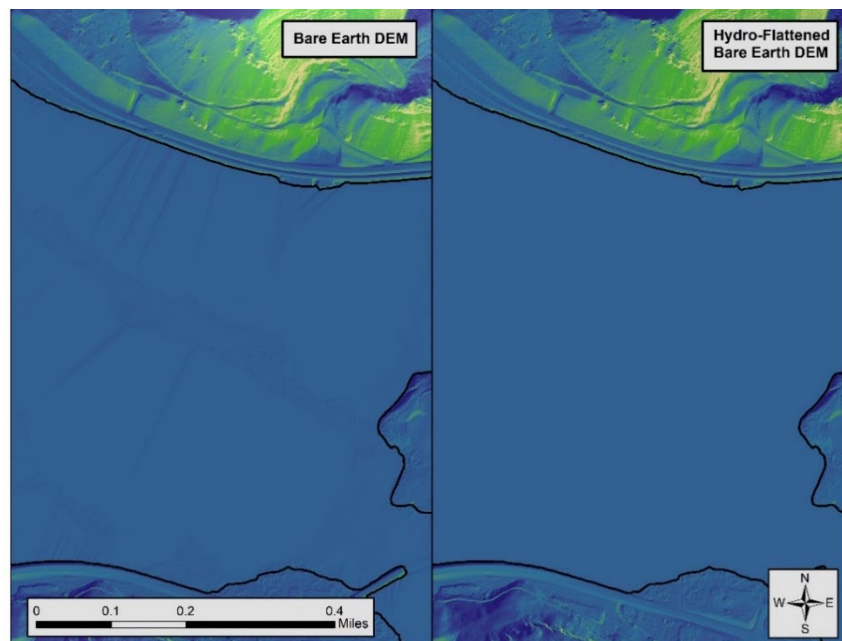
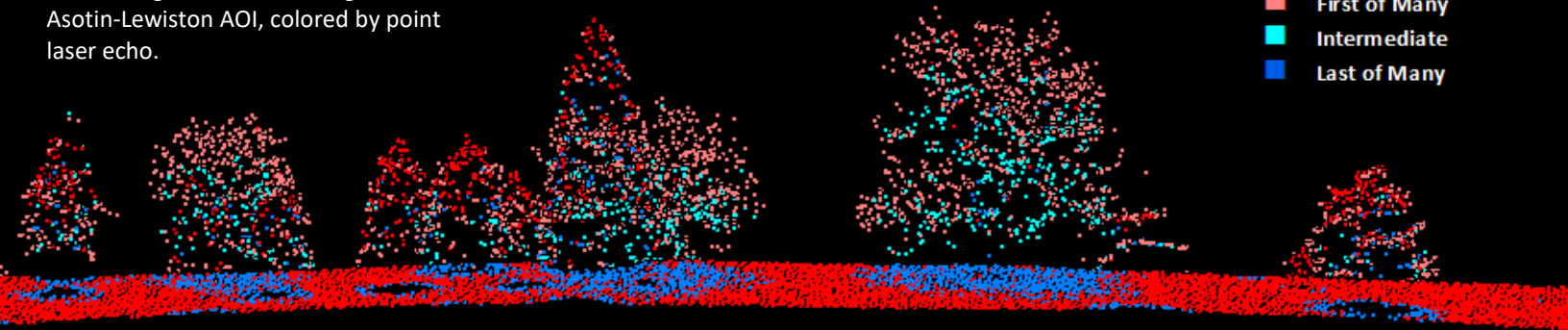


Figure 6: Example of hydroflattening in the Asotin County, Washington and Lewiston, Idaho Lidar dataset

RESULTS & DISCUSSION

This 6 foot Lidar cross section shows a view of vegetation and bare ground in the Asotin-Lewiston AOI, colored by point laser echo.

■ Only Echo
■ First of Many
■ Intermediate
■ Last of Many



Lidar Density

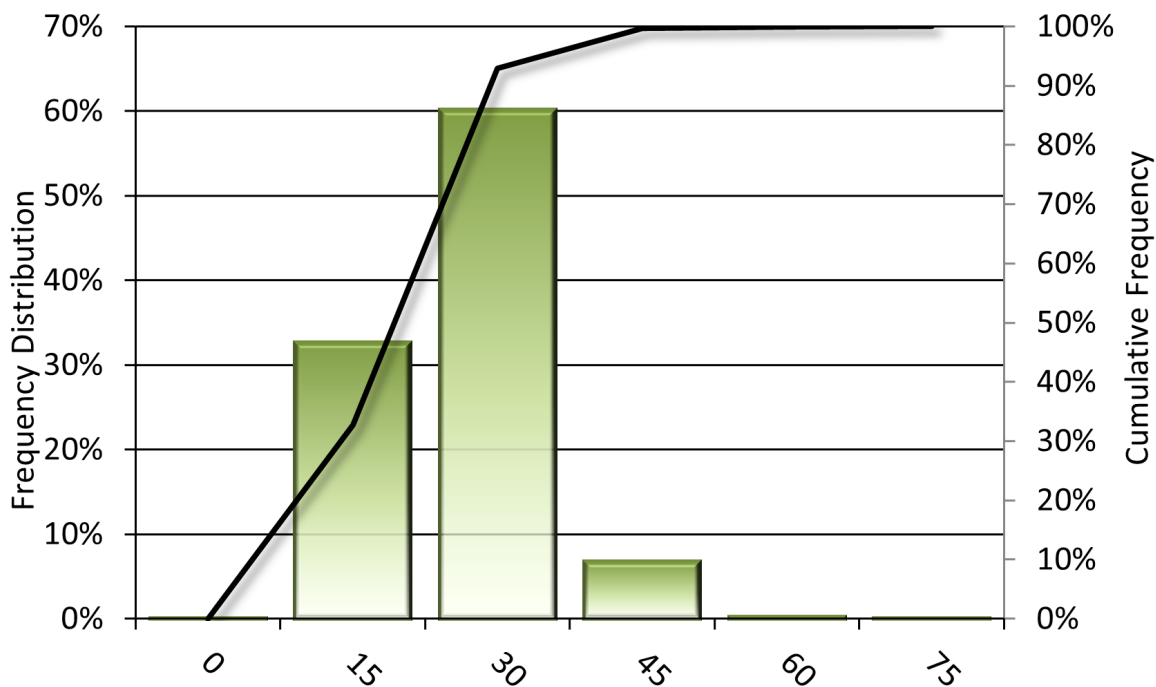
The acquisition parameters were designed to acquire an average first-return density of 8 points/m² (0.74 points/ft²). First return density describes the density of pulses emitted from the laser that return at least one echo to the system. Multiple returns from a single pulse were not considered in first 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 Asotin County, Washington and Lewiston, Idaho project was 1.69 points/ft² (18.20 points/m²) while the average ground classified density was 0.61 points/ft² (6.54 points/m²) (Table 11). The statistical and spatial distributions of first return densities and classified ground return densities per 100 m x 100 m cell are portrayed in Figure 7 through Figure 12.

Table 11: Average lidar point densities

Classification	Point Density
First-Return	1.69 points/ft ² 18.20 points/m ²
Ground Classified	0.61 points/ft ² 6.54 points/m ²



Asotin County, Washington & Lewiston, Idaho 2023 Lidar
First Return Point Density Value (points/m²)

Figure 7: Frequency distribution of first return point density values per 100 x 100 m cell

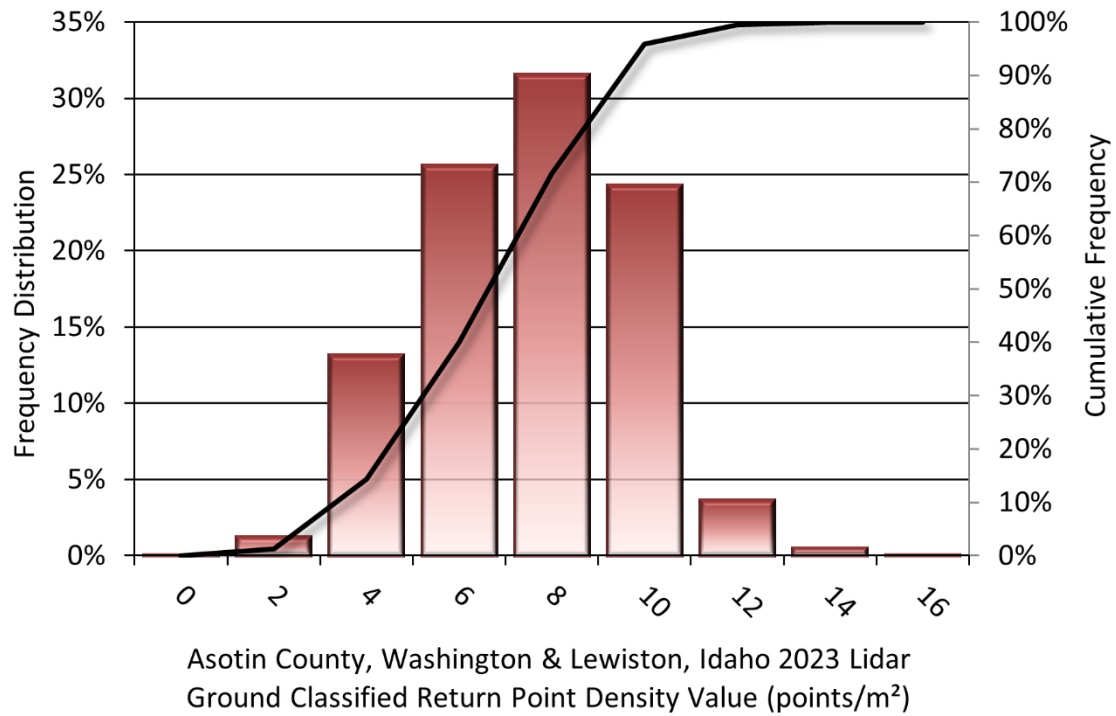


Figure 8: Frequency distribution of ground-classified return point density values per 100 x 100 m cell

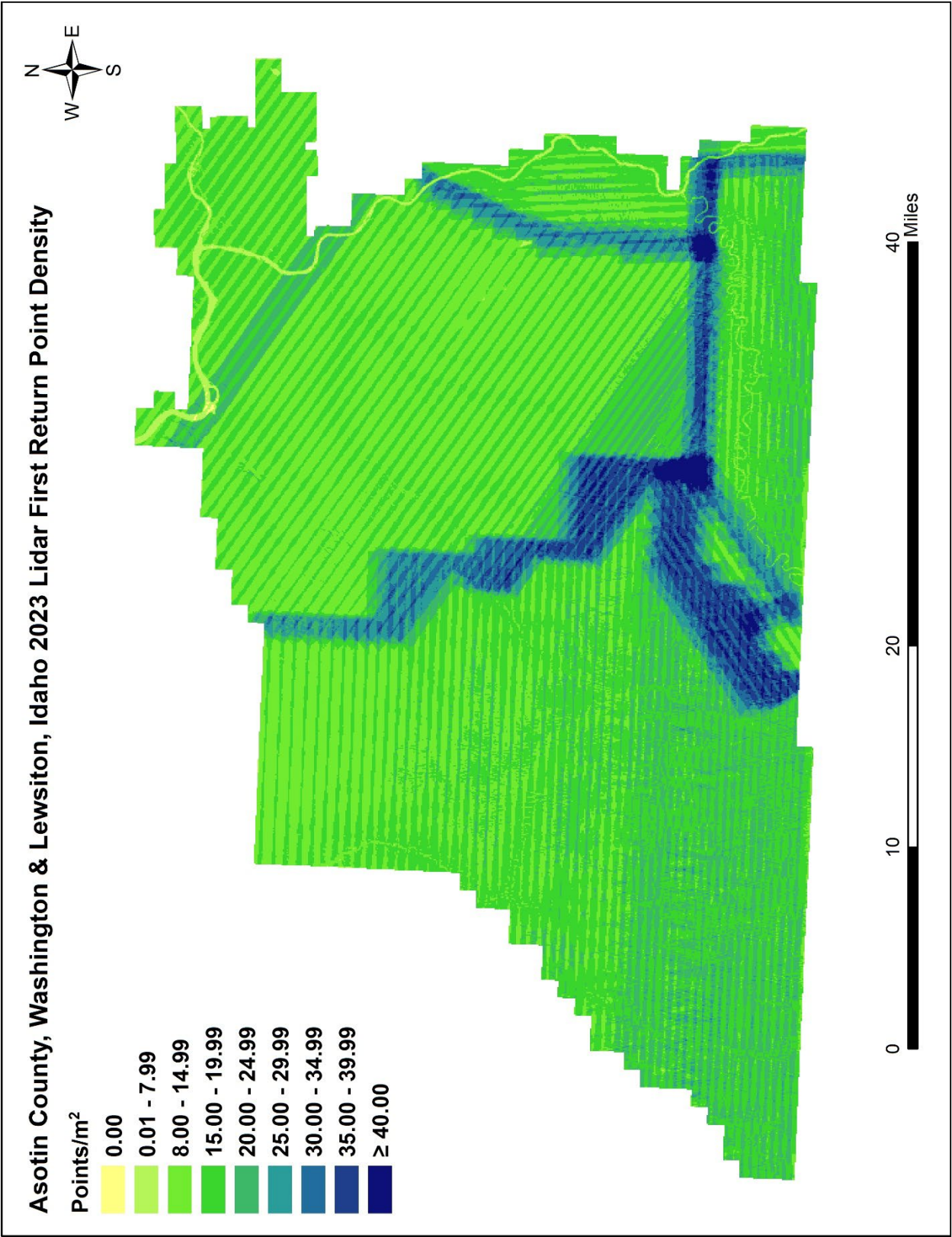


Figure 9: First return and ground-classified point density map for the Asotin County, Washington and Lewiston, Idaho site (100 m 100 m cells)

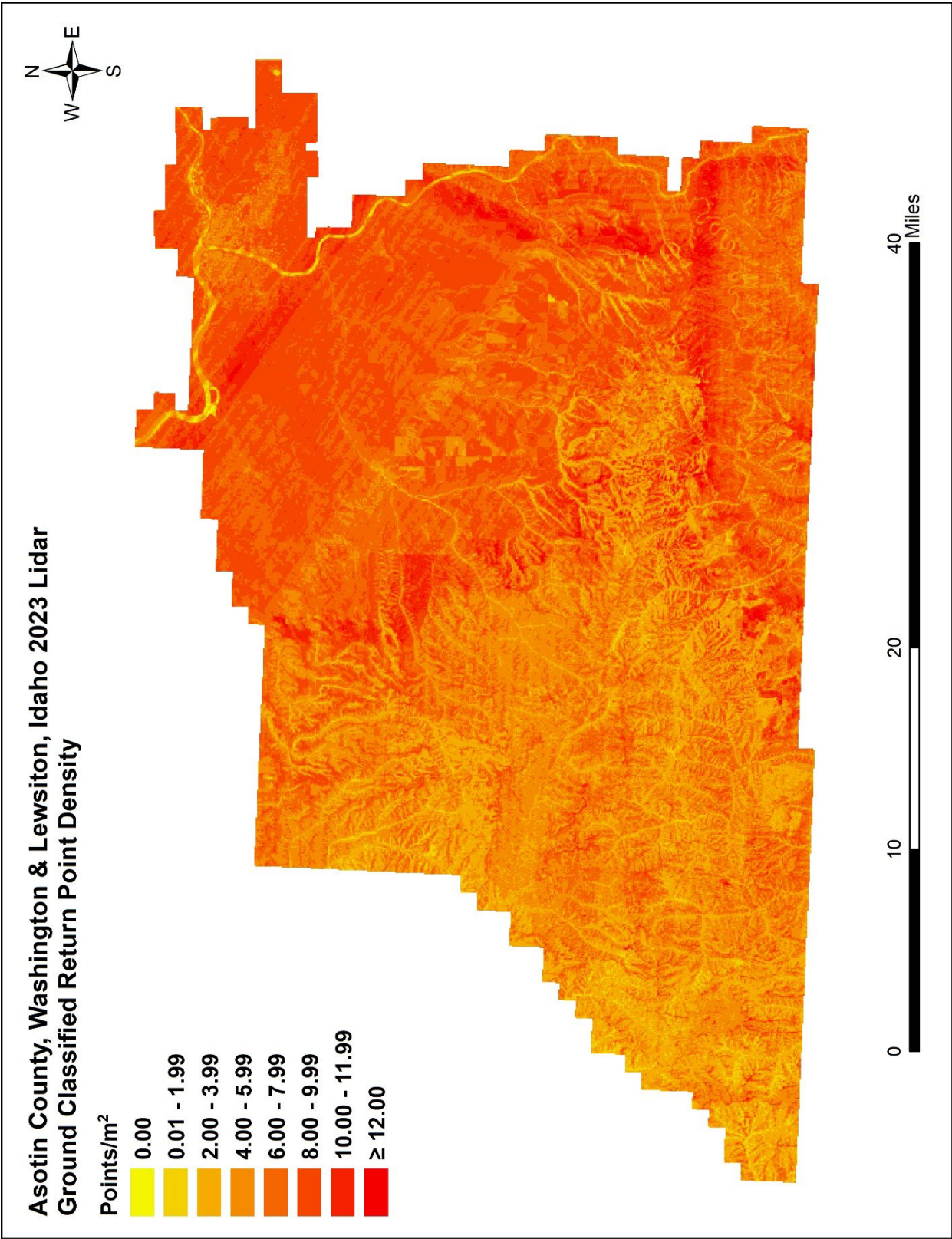


Figure 11: Ground point density map for the Asotin County, Washington and Lewiston, Idaho site (100 m x 100 m cells)

Lidar Accuracy Assessments

The accuracy of the lidar data collection can be described in terms of absolute accuracy (the consistency of the data with external data sources) and relative accuracy (the consistency of the dataset with itself). See Appendix A for further information on sources of error and operational measures used to improve relative accuracy.

Lidar Non-Vegetated Vertical Accuracy

Absolute accuracy was assessed using Non-Vegetated Vertical Accuracy (NVA) reporting designed to meet guidelines presented in the FGDC National Standard for Spatial Data Accuracy³. NVA compares known ground check point data that were withheld from the calibration and post-processing of the lidar point cloud to the triangulated surface generated by the classified lidar point cloud as well as the derived gridded bare earth DEM. NVA is a measure of the accuracy of lidar point data in open areas where the lidar system has a high probability of measuring the ground surface and is evaluated at the 95% confidence interval ($1.96 * RMSE$), as shown in Table 12.

The mean and standard deviation (σ) of divergence of the ground surface model from quality assurance point coordinates are also considered during accuracy assessment. 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 Asotin County, Washington and Lewiston, Idaho survey, 65 ground checkpoints were withheld from the calibration and post processing of the lidar point cloud, with resulting non-vegetated vertical accuracy of 0.181 feet (0.055 meters) as compared to classified LAS, and 0.216 feet (0.066 meters) as compared to the bare earth DEM, with 95% confidence (Figure 13, Figure 14).

NV5 Geospatial also assessed absolute accuracy using 28 ground control points. Although these points were used in the calibration and post-processing of the lidar point cloud, they still provide a good indication of the overall accuracy of the lidar dataset, and therefore have been provided in Table 12 and Figure 15.

³ Federal Geographic Data Committee, ASPRS POSITIONAL ACCURACY STANDARDS FOR DIGITAL GEOSPATIAL DATA EDITION 1, Version 1.0, NOVEMBER 2014.
https://www.asprs.org/a/society/committees/standards/Positional_Accuracy_Standards.pdf.

Table 12: Absolute accuracy results

Parameter	NVA, as compared to classified LAS	NVA, as compared to bare earth DEM	Ground Control Points
Sample	65 points	65 points	28 points
95% Confidence (1.96*RMSE)	0.181 ft 0.055 m	0.216 ft 0.066 m	0.179 ft 0.055 m
Average	0.007 ft 0.002 m	0.002 ft 0.001 m	-0.008 ft -0.002 m
Median	0.003 ft 0.001 m	0.007 ft 0.002 m	-0.011 ft -0.004 m
RMSE	0.092 ft 0.028 m	0.110 ft 0.034 m	0.091 ft 0.028 m
Standard Deviation (1σ)	0.093 ft 0.028 m	0.111 ft 0.034 m	0.093 ft 0.028 m

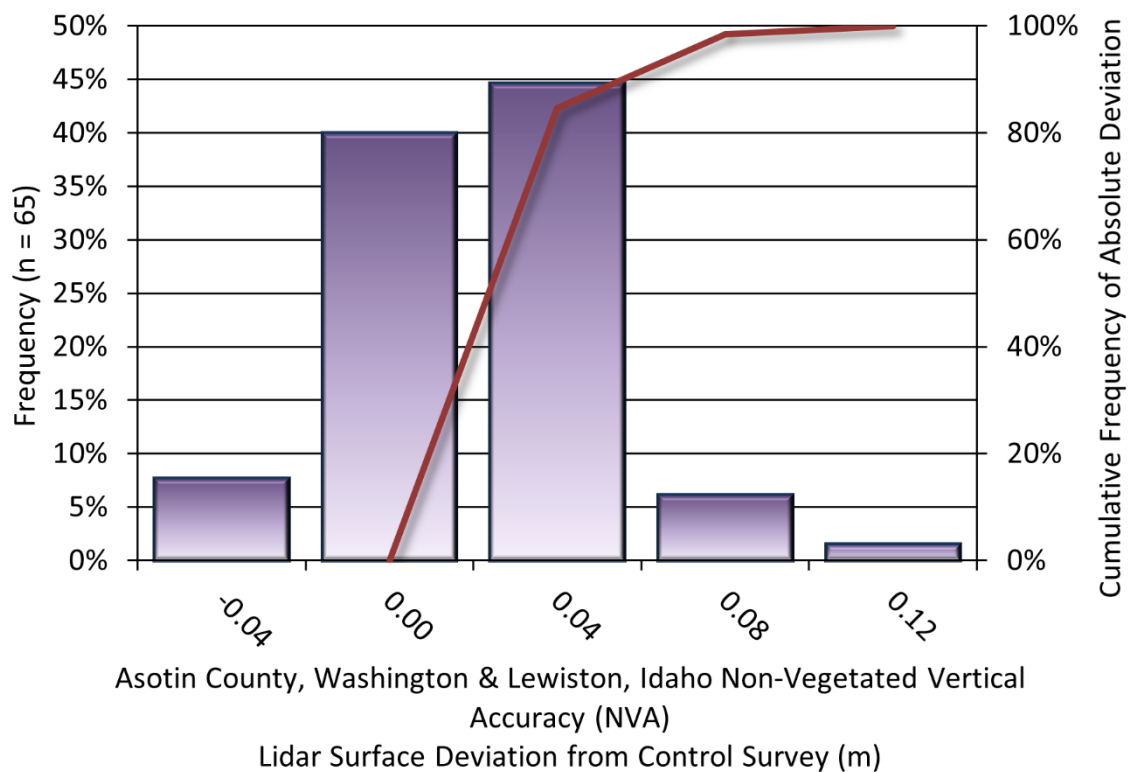


Figure 13: Frequency histogram for lidar classified LAS deviation from ground check point values (NVA)

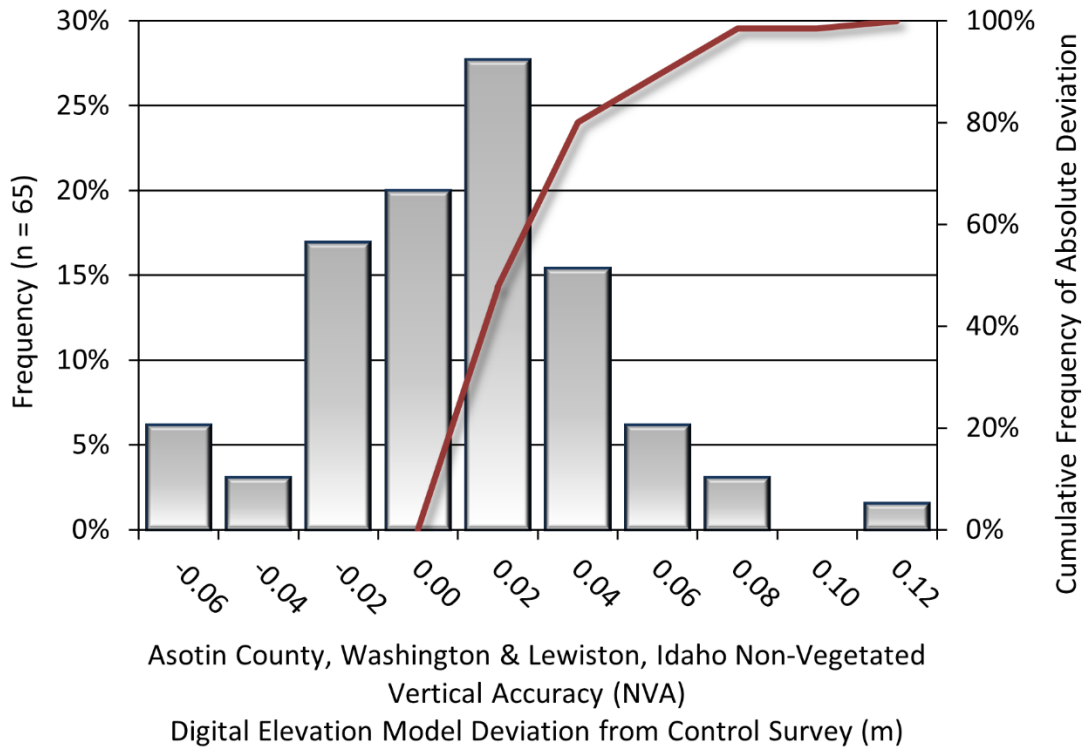


Figure 14: Frequency histogram for the lidar bare earth DEM surface deviation from ground check point values (NVA)

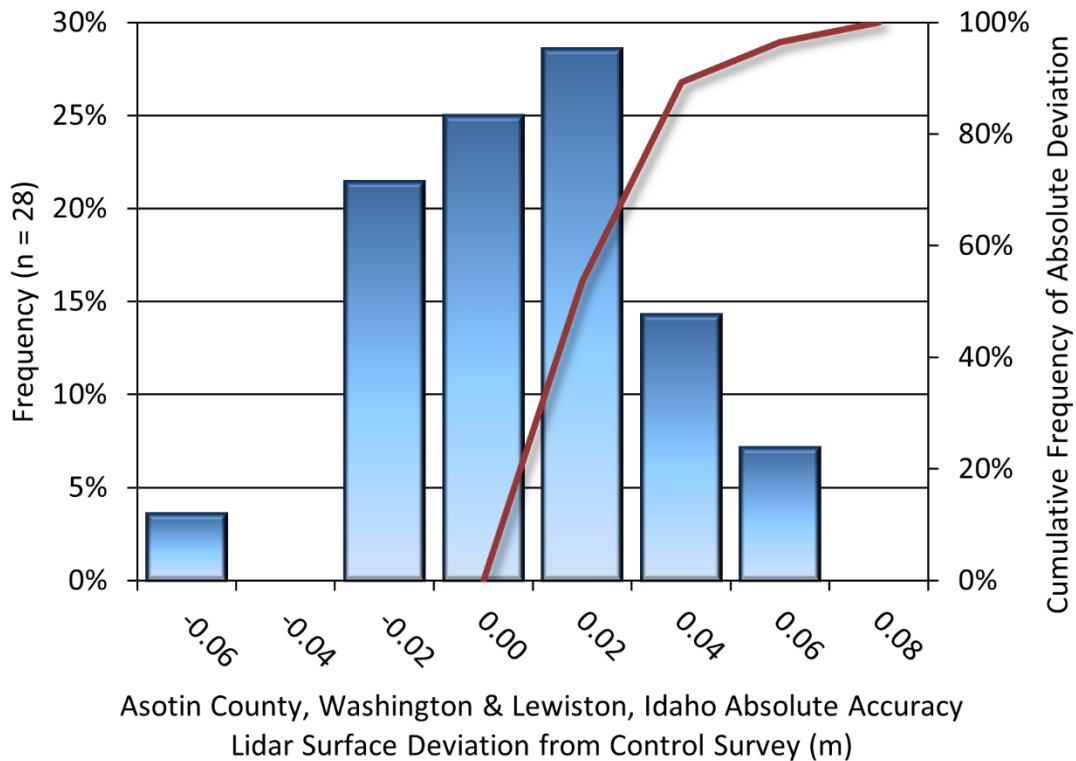


Figure 15: Frequency histogram for the lidar surface deviation from ground control point values

Lidar Vegetated Vertical Accuracies

NV5 Geospatial also assessed vertical accuracy using Vegetated Vertical Accuracy (VVA) reporting. VVA compares known ground check point data collected over vegetated surfaces using land class descriptions to the triangulated ground surface generated by the ground classified lidar points. For the Asotin County, Washington and Lewiston, Idaho survey, 53 vegetated checkpoints were collected, with resulting vegetated vertical accuracy of 0.923 feet (0.281 meters) as compared to the classified LAS, and 0.901 feet (0.275 meters) as compared to the bare earth DEM evaluated at the 95th percentile (Table 13, Figure 16, and Figure 17).

Table 13: Vegetated vertical accuracy results

Parameter	VVA, as compared to classified LAS	VVA, as compared to bare earth DEM
Sample	53 points	53 points
95 th Percentile	0.923 ft	0.901 ft
	0.281 m	0.275 m
Average	0.334 ft	0.339 ft
	0.102 m	0.103 m
Median	0.253 ft	0.207 ft
	0.077 m	0.063 m
RMSE	0.485 ft	0.508 ft
	0.148 m	0.155 m
Standard Deviation (1 σ)	0.355 ft	0.382 ft
	0.108 m	0.117 m

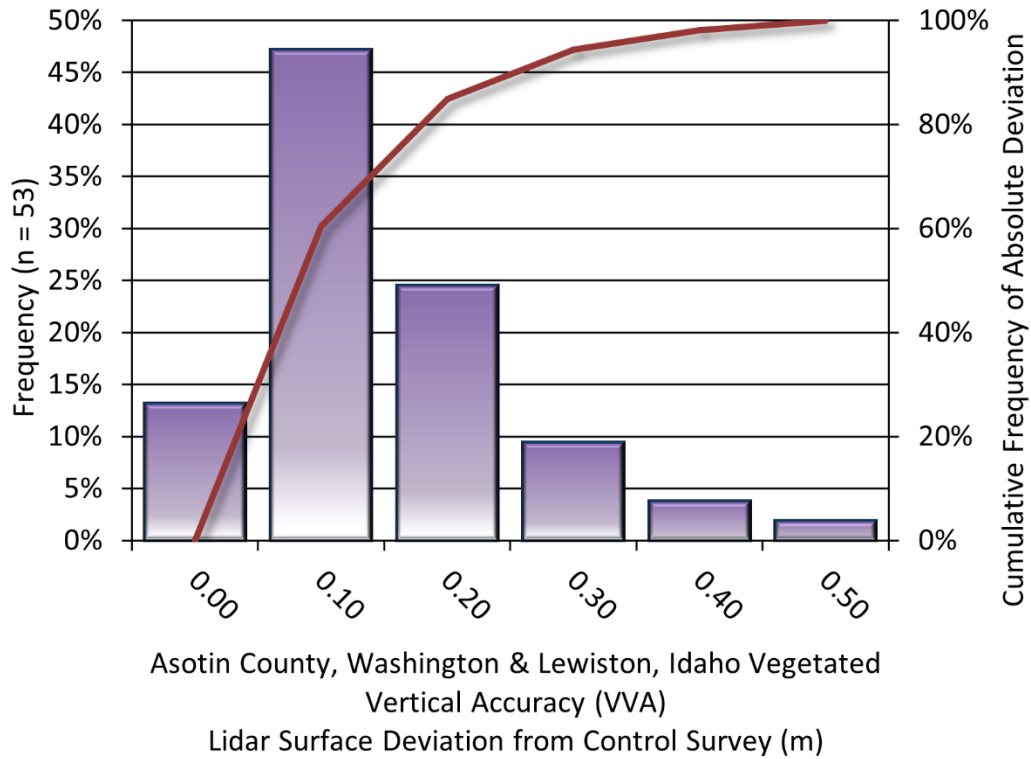


Figure 16: Frequency histogram for the lidar surface deviation from all land cover class point values (VVA)

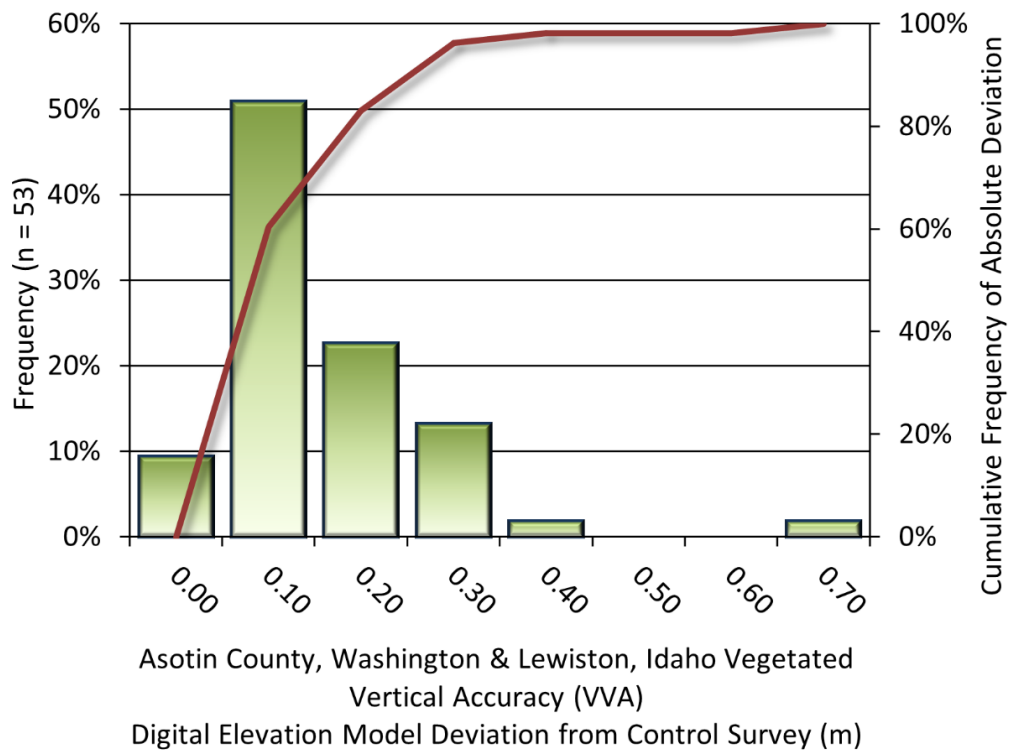


Figure 17: Frequency histogram for the lidar bare earth DEM deviation from vegetated check point values (VVA)

Lidar Relative Vertical Accuracy

Relative vertical accuracy refers to the internal consistency of the data set as a whole: the ability to place an object in the same location given multiple flight lines, GPS conditions, and aircraft attitudes. When the lidar system is well calibrated, the swath-to-swath vertical divergence is low (<0.10 meters). The relative vertical accuracy was computed by comparing the ground surface model of each individual flight line with its neighbors in overlapping regions. The average (mean) line to line relative vertical accuracy for the Asotin County, Washington and Lewiston, Idaho Lidar project was 0.104 feet (0.032 meters) (Table 14, Figure 18).

Table 14: Relative accuracy results

Parameter	Relative Accuracy
Sample	156 surfaces
Average	0.104 ft 0.032 m
Median	0.099 ft 0.030 m
RMSE	0.109 ft 0.033 m
Standard Deviation (1 σ)	0.034 ft 0.010 m
1.96 σ	0.066 ft 0.020 m

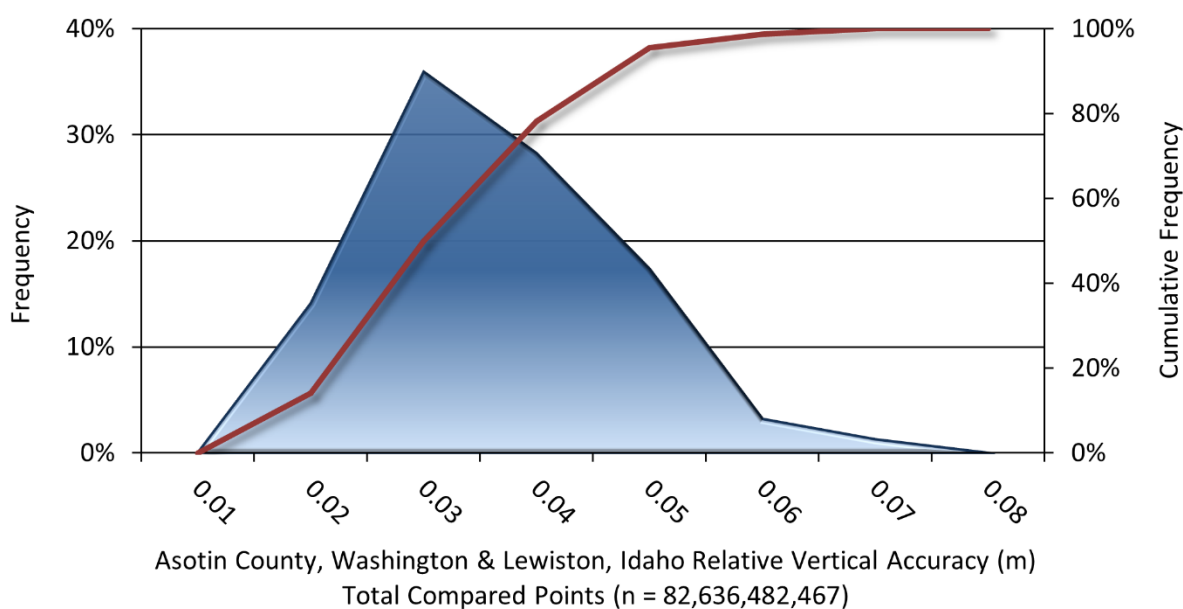


Figure 18: Frequency plot for relative vertical accuracy between flight lines

Lidar Horizontal Accuracy

Lidar horizontal accuracy is a function of Global Navigation Satellite System (GNSS) derived positional error, flying altitude, and INS derived attitude error. The obtained $RMSE_r$ value is multiplied by a conversion factor of 1.7308 to yield the horizontal component of the National Standards for Spatial Data Accuracy (NSSDA) reporting standard where a theoretical point will fall within the obtained radius 95 percent of the time. Based on a flying altitude of 2500 meters, an IMU error of 0.003 decimal degrees, and a GNSS positional error of 0.023 meters, this project was produced to meet 1.336 feet (0.407 m) horizontal accuracy at the 95% confidence level (Table 15).

Table 15: Horizontal Accuracy

Parameter	Horizontal Accuracy
$RMSE_r$	0.772 ft
	0.235 m
ACC_r	1.336 ft
	0.407 m

CERTIFICATIONS

NV5 Geospatial provided lidar services for the Asotin County, Washington and Lewiston, Idaho project as described in this report.

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

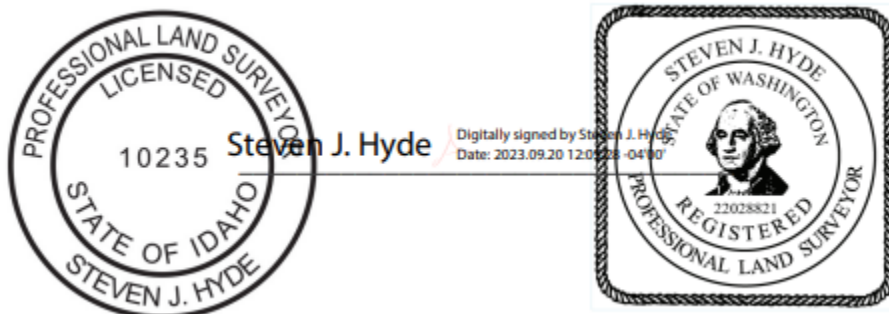

Brian Von Seggern (Sep 20, 2023 11:29 PDT)

Sep 20, 2023

Brian Von Seggern
Project Manager
NV5 Geospatial

I, Steven J. Hyde, PLS, being duly registered as a Professional Land Surveyor in and by the states of Washington and Idaho, 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 March 18 and June 26, 2023.

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".



Steven J. Hyde, PLS
NV5 Geospatial
Corvallis, OR 97330

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 Non-vegetated Vertical Accuracy (NVA) 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 we also consider the skew and kurtosis of distributions 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., echoes) 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 datasets. 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:

Source	Type	Post Processing Solution
Long Base Lines	GPS	None
Poor Satellite Constellation	GPS	None
Poor Antenna Visibility	GPS	Reduce Visibility Mask
Poor System Calibration	System	Recalibrate IMU and sensor offsets/settings
Inaccurate System	System	None
Poor Laser Timing	Laser Noise	None
Poor Laser Reception	Laser Noise	None
Poor Laser Power	Laser Noise	None
Irregular Laser Shape	Laser Noise	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 $\pm 29^\circ$ 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.

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.