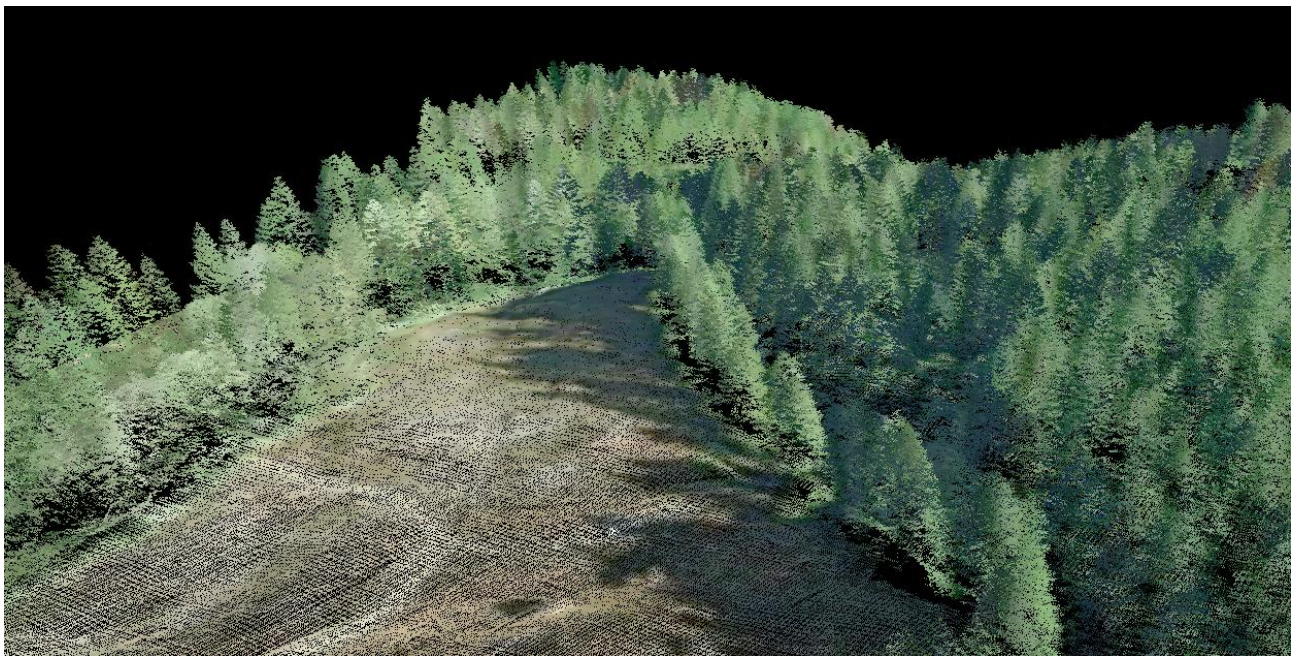
GeoTerra



Lidar Mapping Project Report

For Submittal to USGS #G22AC00258

Project Name: Oregon Western Wildfires A22

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Work Unit: 300425

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Presented to:
Oregon Department of Forestry
For Contribution to USGS 3DEP
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1. Project Overview

Figure 1. Three separate areas of Interest for the Western Wildfires Unit 2 A22 Lidar Project.

1.1 Description

GeoTerra, Inc. was selected by Oregon Department of Forestry (ODF) under contract #ODF-1109A-20 to acquire and process new Lidar during the summer of 2020 for four project areas in northwestern Oregon identified as Clatsop-Nehalem-Trask (1,070 mi²), Burnt Woods (65 mi²), Butte Creek (49 mi²), and Gates (77 mi²). All areas are in densely forested, mountainous terrain. Project planning and execution was focused on meeting the challenges of site conditions while providing data at a minimum density of at least 8 points/m² and with an emphasis on maximizing tree canopy returns as suitable for forest management purposes. Figure 1 above shows the location of three of the project areas that are the subject of this report.

In the 2022 calendar year, GeoTerra was again contracted by ODF to re-process the 2020 Lidar data to meet Quality Level 1 (QL1) specifications for submission to the United States Geological Survey (USGS) Three-Dimensional Elevation Program (3DEP). As a result of the Beachie Creek and Lionshead fires which burned in late summer of 2020, all the Butte Creek area of interest (AOI) and about 57% of the Gates AOI were excluded from re-processing. See Figure 2, below. Note that QL1 Lidar was subsequently flown in summer of 2022 over the entire burn area as part of the Western Wildfires Unit 1 A22 project.

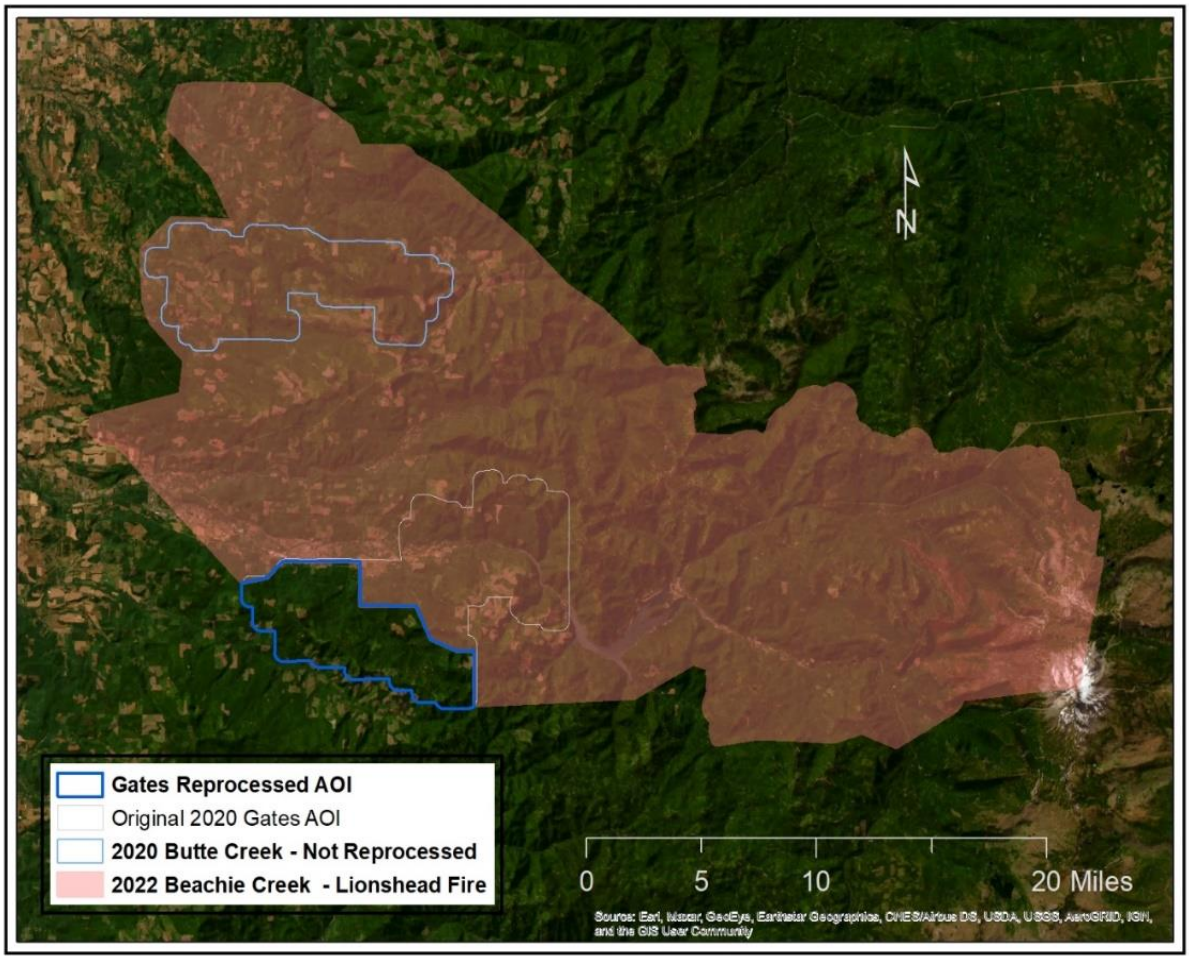

Figure 2. Wildfire burned Butte Creek and part of Gates areas shortly after the 2020 summer Lidar flights. Burn areas were excluded from reprocessing.

The following is a report explaining all procedures used to produce 1,174 mi² of QL1 Lidar data as submitted to USGS 3DEP as part of the Western Wildfires A22 project, including flight specifications, processing procedures, QC results, and deliverables.

1.2 Purpose

This project was part of an agreement to support a project to expand 3DEP Coverage in Oregon while aiding post-wildfire recovery work by state and federal agencies.

1.3 Specifications

All data delivered for this project was produced to meet the USGS Lidar Base Specifications v2022 Rev. A

1.4 Spatial Reference

All data for this project were produced using the following spatial data reference system:

- Horizontal Datum: NAD83(2011)(Epoch 2010.0)
- Horizontal Projection: Oregon Statewide Lambert
- Horizontal Units: International Feet
- Horizontal EPSG Code: 6557
- Vertical Datum: NAVD88
- Geoid Model: 12b
- Vertical Units: International Feet
- Vertical Datum EPSG Code: 8228

1.5 Task Order Deliverables

Table 1, below, provides details of items that were processed and delivered for this project, with an indication of format and compliance with contractual specifications. The final tiling scheme of LAS and raster-formatted data was based on the provided ODF 3000'x3000' tiling scheme.

Table 1. Project delivery items and formats

Deliverable	Format	Compliance notes
Classified Point Cloud	LAS 1.4 PDRF 7	Each point includes GPS week and GPS second OR Posix time, easting, northing, elevation, intensity, return number, return classification, scan angle, point source ID.
Bare Earth Surface Model	GeoTIFF, 32-bit floating point	1-foot resolution hydro-flattened ground model
Max Surface Height Model	GeoTIFF, 32-bit floating point	1-foot resolution from binning interpolation type and maximum value for determining cell value. Non-flagged returns only.
Survey Report	PDF	Describes control and checkpoint locations acquired for this project and methodology used.
Survey Data Points	GeoPackage	Includes control and QC checkpoints used for this project
Lidar Technical Report	PDF	This report: provides methodology used for planning, processing, assessment and delivery of final data.
FGDC Metadata	XML	Per USGS 3DEP Lidar Specifications 2022 rev. A

Swath Separation Images	GeoTIFF	4-foot resolution; color-coded as required
Intraswath results	Geodatabase	Polygons used to test intraswath precision, with min-max of slope-corrected range and RMSDz.
Interswath results	Geodatabase	Polygons used to test interswath accuracy, with min-max of slope-corrected range and RMSDz.
Breaklines	Geodatabase	Use for hydro-flattened flattening and defining sharp breaks around bridge abutments.
Swath Outlines	Geodatabase	Polygon of each flight swath
Project Index	Geodatabase	Polygons of final project delivery areas.
Tile scheme	Geodatabase	3000' x 3000' tiles

1.6 Lidar Data Classification

Classified Lidar point cloud data were provided in las v1.4 format using the following classification scheme shown in Table 2:

Table 2. Lidar classification scheme applied to all point returns.

Lidar Classification Scheme	
Class 1	Processed, but not classified
Class W1	Processed, but not classified with a withheld flag
Class 2	Ground (bare earth)
Class W2	Ground (bare earth) with a withheld flag
Class W7	Low Noise – with a withheld flag
Class 9	Water
Class W9	Water with a withheld flag
Class 17	Bridge Deck
Class W18	High Noise – with a withheld flag
Class 20	Ignored ground near breaklines
Class W20	Ignored ground near breaklines with withheld flag

2. Acquisition

2.1 Flight Planning

Lidar acquisition was planned using Teledyne Optech Flight Management Suite (FMS) to calculate optimum parameters to meet project requirements and accommodate extreme variations in mountainous terrain. FMS utilized an existing DEM surface to calculate the best flight parameters and swath layout to meet the desired point density. The project required a minimum aggregate density of 8 points per square meter and was designed to be achieved through overlapping adjacent swaths by greater than 55%. Adjacent lines were to be flown in opposing directions. The Galaxy's *PulseTRAK* and *SwathTRAK*

technologies were employed during flight to allow the sensor to maintain regular point distribution and constant-width swaths despite changes in terrain.

GeoTerra utilized an Optech Galaxy Prime sensor mounted in a Cessna 210 aircraft to acquire new lidar data for all areas. During flight, the on-board receiver logged airborne GNSS data at 1 Hz interval and IMU data at 200 Hz interval. Acquisition parameters including pulse rate, flight altitude, orientation relative to terrain, scan angle, and ground speed were optimized to meet the ODF contract specifications and objectives. Acquisition conditions at the time of each mission were free of clouds, fog, snow, and flooding. The flight acquisition specifications for this project are shown in Table 3, below.

Table 3. Lidar Acquisition Specifications.

LiDAR Settings & Specifications	
Aircraft Used	Cessna 210
Sensor	Optech Galaxy Prime
Intensity	12-bit, scaled to 16-bit
Wavelength	1064 nm
Beam Divergence	0.25 mrad
Maximum Sensor Returns Per Pulse	8
Target Pulse Rate	450 kHz
Scan Frequency	65 Hz
Target Aircraft Speed	119 kts
Maximum Scan Angle	20°
Maximum Survey Altitude (AGL)	5700 ft (1737 m)
Swath-to-Swath Overlap	> 55%
Average Swath Width (Flat Ground)	4147 ft (1264 m)
Maximum Beam Diameter on ground	43.4 cm
Aggregate Resolution (Density)	≥ 8 pulses/m^2
Aggregate Nominal Point Spacing	≤ 0.35 m
Planned Accuracy	$RMSE_Z$ ≤ 10 cm

2.2 Acquisition Timeline

Dates of acquisition for each area are shown in Table 3, below. The largest AOI known as Trask-Nehalem-Trask acquisition occurred in three logical blocks during the leaf-on period from May 7 – September 3, 2020, as shown in Table 4. Figure 3 shows flight dates by color for the large AOI. The two remaining blocks known as Burnt Woods and Gates were flown in single missions on May 7th and May 24th, 2020, respectively.

Table 4. Lidar acquisition dates by AOI

Area Name	Dates of Acquisition
Clatsop-Nehalem-Trask	May 7, 8,10, 27, 28; June 18, 25; July 30 and Sept 3, 2020
Burnt Woods	May 7, 2020
Gates	May 24, 2020

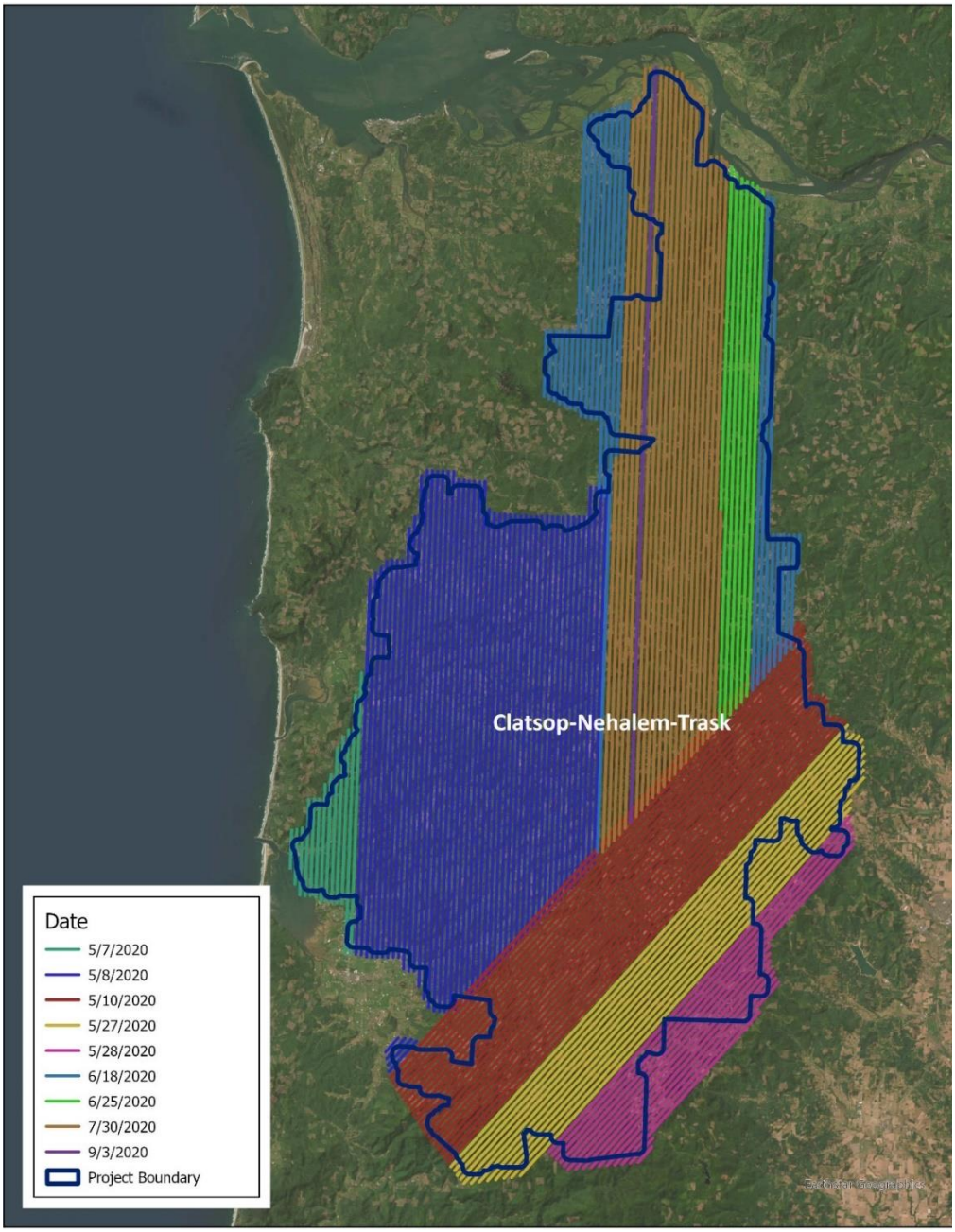

Figure 3. Flight dates for Clatsop-Nehalem-Trask AOI.

2.3 Post-Flight Evaluation

Upon completion of each mission, GeoTerra immediately reviewed the raw data to identify any potential issues affecting accuracy and the need for re-flights. Laser points were evaluated to ensure complete coverage of the project area. Positional Dilution of Precision (PDOP) during flight was assessed to ensure it remained below 3.0 to provide the best geometry of satellites for post processing.

3. Processing

3.1 SBET Processing

Kinematic corrections for aircraft position data were performed using the Precise Point Position (PPP) method. PPP utilizes an autonomous positioning method whereby data from the aircraft receiver is processed using dual frequency data and precise orbit and clock files. Processed GNSS data were then combined with IMU data using a loosely coupled technique where Novatel Inertial Explorer v8.9 also computes lever arm offsets between the IMU and the L1 phase center of the aircraft antenna. The final combined GNSS/IMU solution was output as a Smoothed Best Estimate Trajectory (SBET). Laser point positions were calculated by associating the SBET position to each laser point's return time, scan angle and intensity. Point positions were converted to orthometric elevations by applying a Geoid 12b correction. Methods used for airborne processing are included in a separate Survey Report.

3.2 Laser Post-Processing and Calibration

Data was processed into LAS format by flight line and used to perform the relative calibration and check for erroneous data. An initial auto-classification was performed and resulting ground points were used to perform an automatic line-to-line calibration to adjust for pitch, roll and heading, GPS/IMU drift, and mirror flex. Calibrations were applied to all returns and data was adjusted to surveyed ground control to achieve final adjusted positions. Table 5, below, provides a detailed list of equipment, software and processes used to produce the final calibrated data.

Table 5. Planning and Post-Processing Overview

Process	Software	Description
Flight Planning	Teledyne Optech FMS	Data acquisition was planned in consideration to terrain, environmental factors, and project objectives.
Flight Execution	Optech Galaxy Prime	Sensor equipped with POS AV™ AP50 (OEM); 220-channel dual frequency GNSS receiver; Type 08 AIMU; Up to and 8 range measurements and intensities for each pulse; Internal solid-state drive SSD.
ABGPS Data Post Processing	Novatel Inertial Explorer Version 8.9	The data collected during the flight is post-processed into Smoothed Best Estimate of Trajectory (SBET) binary file of the IMU trajectory which is combined processed data from both GNSS satellite data and IMU data and is used to geo-reference the laser point cloud.
Raw Lidar Post Processing to LAS Format	Optech LMS (Lidar Management Suite)	Data was processed from range format to LAS format and preliminary adjustment was made using tie plane methodology.
Lidar Strip Relative Adjustment	TerraMatch	Additional relative adjustment was performed using tie line methodology to further improve fit especially in areas where tie planes were not found.
Autoclassification	TerraScan	Rigorous selection as well as custom created algorithms built within TerraScan were used to automatically classify the data.
Lidar Strip Absolute Adjustment	LP360	Data was compared to non-vegetated control points set in appropriate terrain for absolute adjustment.

3.2 Boresight Calibration

Prior to acquisition, a Boresight Calibration was performed to determine exact angles between the IMU and lidar reference frame. A local site was chosen with slopes in different directions to provide viable observations for calculation of angle offsets. The determined offset values were then transferred to sensor instruction files to use for downstream processing.

3.3 Relative Adjustment

Relative and absolute adjustment of all strips was accomplished using Optech *LMS* and TerraSolid *TerraMatch* software packages. *LMS* was used to extract planar surfaces from the point cloud for determining spatial accuracy between overlapping flight lines.

TerraMatch was used to select appropriate tie planes for calibration using variables such as: size, shape, and slope of the plane; the number of laser points within the plane; orientation of the plane with respect to flight direction; and location of the plane within a flight line. Each criteria influences the amount and geometry of adjustments used to re-calculate laser point locations (x,y,z) for best relative fit of all strips. Planes from overlapping flight lines were then compared and measured for spatial accuracy and used to co-locate all lines within an acceptable tolerance.

3.4 Absolute Adjustment

After relative fit was established, surveyed control points acquired for the project were utilized to perform the absolute adjustment of Lidar points to ground coordinates. (Note: a separate Survey Report for the project is included with this delivery). The point cloud was classified and used to compare Lidar ground values to control values. A mean vertical offset from was calculated from all control within a project AOI and used to apply a final adjustment of the point cloud to absolute position. See Table 6 shows results of ground control compared to final adjusted points.

Table 6. Number of surveyed control points used for absolute adjustment.

	Clatsop-Nehalem-Trask	Burnt Woods	Gates
Number of Control Used for 2020 Project AOIs	**28**	**11**	**13**
Number of Control Used within 3DEP Delivery AOIs	**26**	**6**	**4**
Vertical RMSEz within 3DEP AOIs	**0.066 m**		

3.5 Relative Accuracy: Interswath Consistency

Swath to swath fit or interswath consistency is required to meet an RMSDz of less than ≤ 8cm. Consistency was assessed at multiple locations within overlapping data swaths in non-vegetated areas of less than 10-degrees slope using only single returns. Test areas were located across the full width of overlap, as much as possible given dense forest cover and steep terrain. The project-wide results are shown in Table 7. To visually evaluate the swath-to-swath fit for each AOI, signed difference (Dz) rasters were created using LP360 software at a cell size of 4ft using all unflagged last returns. Polygon assessment locations and Swath separation images for each AOI are shown in Figures 4 through 7.

Table 7. InterSwath results for each assessment polygon.

FID	dZ_MAX (m)	dZ_MIN (m)	RMSD (m)
0	0.046	0.000	0.016
1	0.079	0.000	0.040
2	0.060	0.000	0.022
3	0.035	0.001	0.014
4	0.066	0.000	0.027
5	0.083	0.000	0.021
6	0.094	0.000	0.036
7	0.092	0.000	0.048
8	0.066	0.000	0.025
9	0.040	0.000	0.019
10	0.070	0.017	0.041
11	0.031	0.000	0.014
12	0.059	0.001	0.030
13	0.039	0.000	0.016
14	0.038	0.000	0.016
15	0.068	0.000	0.029
16	0.060	0.000	0.020
17	0.092	0.001	0.043
18	0.063	0.001	0.031

FID	dZ_MAX (m)	dZ_MIN (m)	RMSD (m)
19	0.034	0.000	0.013
20	0.165	0.000	0.026
21	0.074	0.002	0.036
22	0.081	0.000	0.026
23	0.052	0.000	0.022
24	0.038	0.000	0.015
25	0.050	0.000	0.020
26	0.091	0.000	0.018
27	0.074	0.000	0.023
28	0.053	0.000	0.015
29	0.050	0.000	0.014
30	0.064	0.000	0.018
31	0.067	0.000	0.027
32	0.102	0.000	0.041
33	0.067	0.000	0.024
34	0.064	0.000	0.024
35	0.047	0.000	0.018
36	0.074	0.000	0.025
37	0.060	0.000	0.021

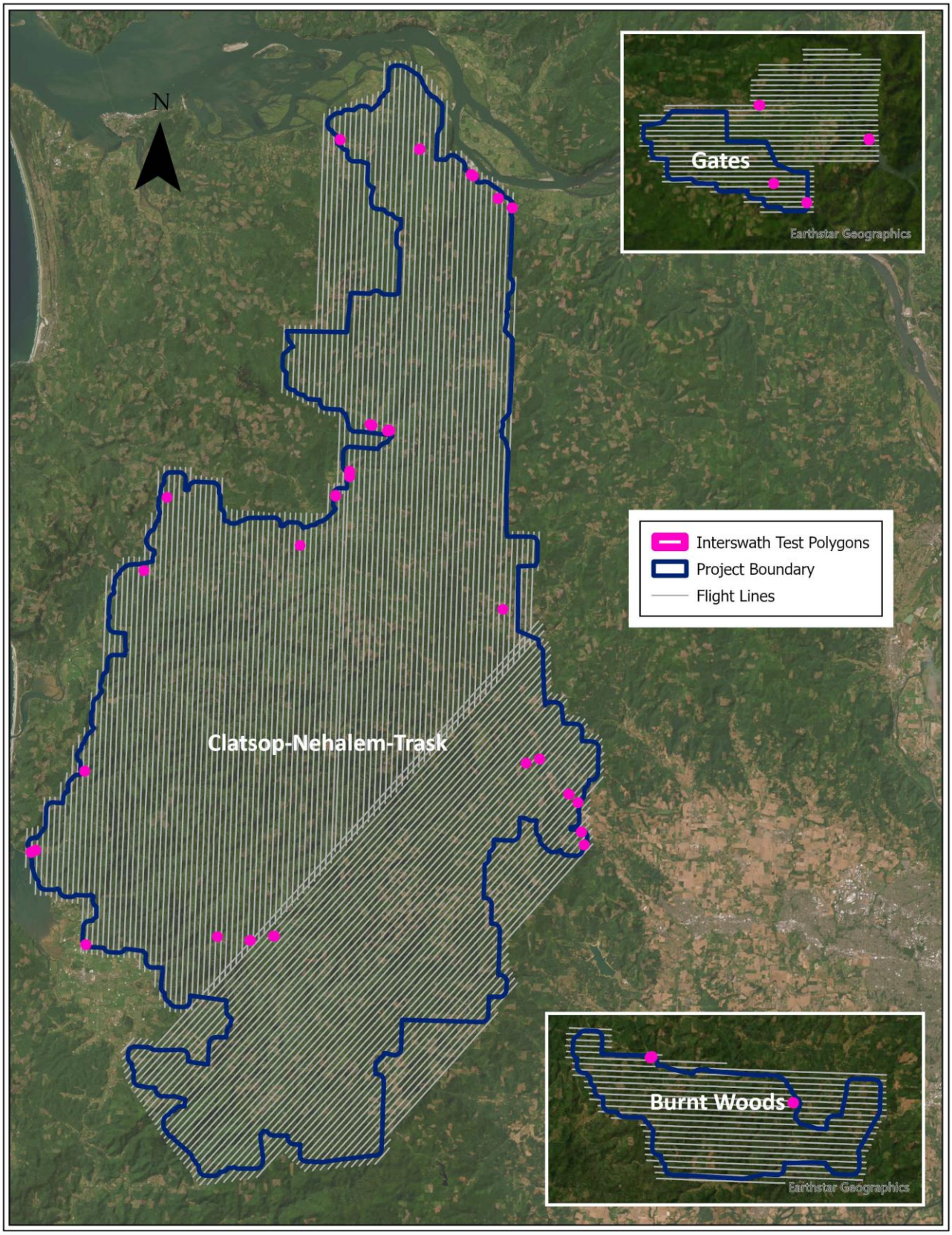

Figure 4. Location of polygons used to assess InterSwath accuracy.

Figure 5. Swath separation raster created to assess calibration of the Clatsop-Nehalem-Trask AOI.

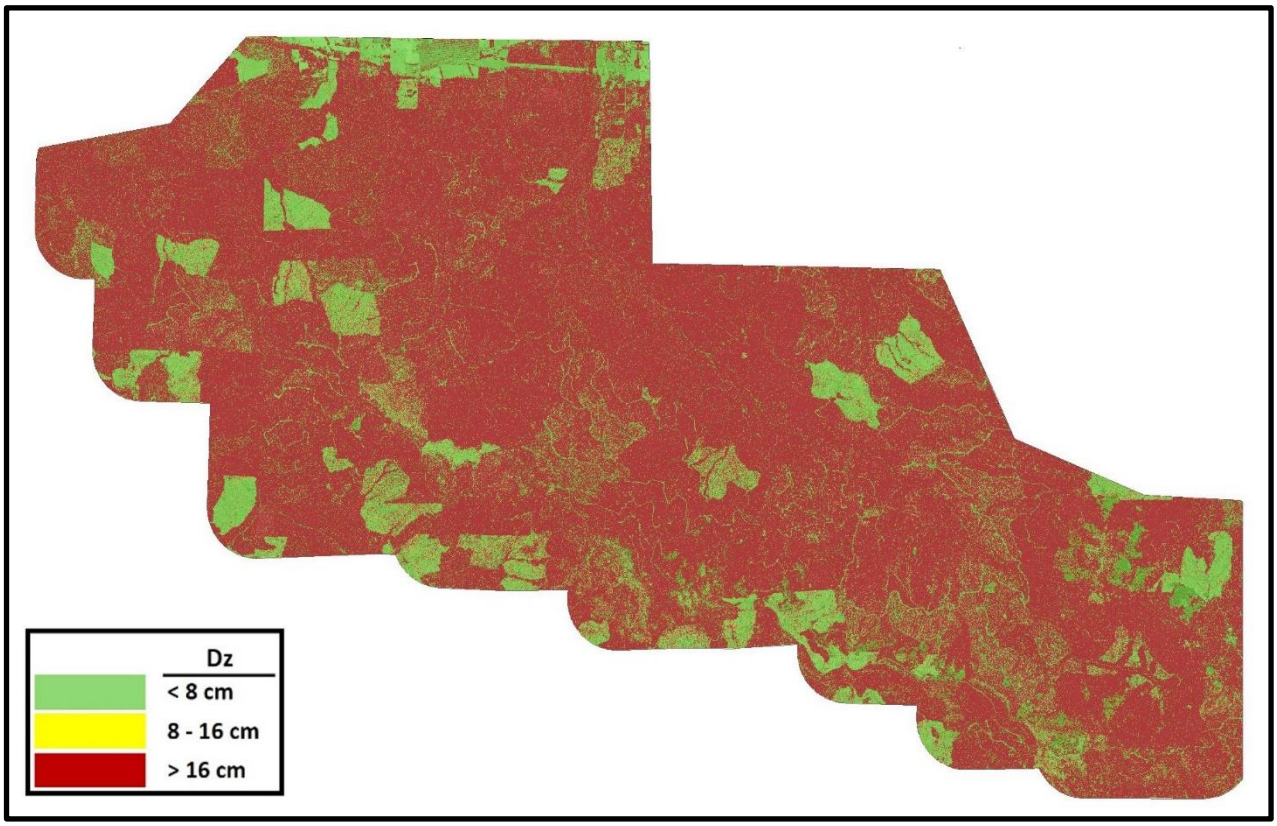

Figure 6. Swath separation raster created to assess calibration of the Gates AOI.

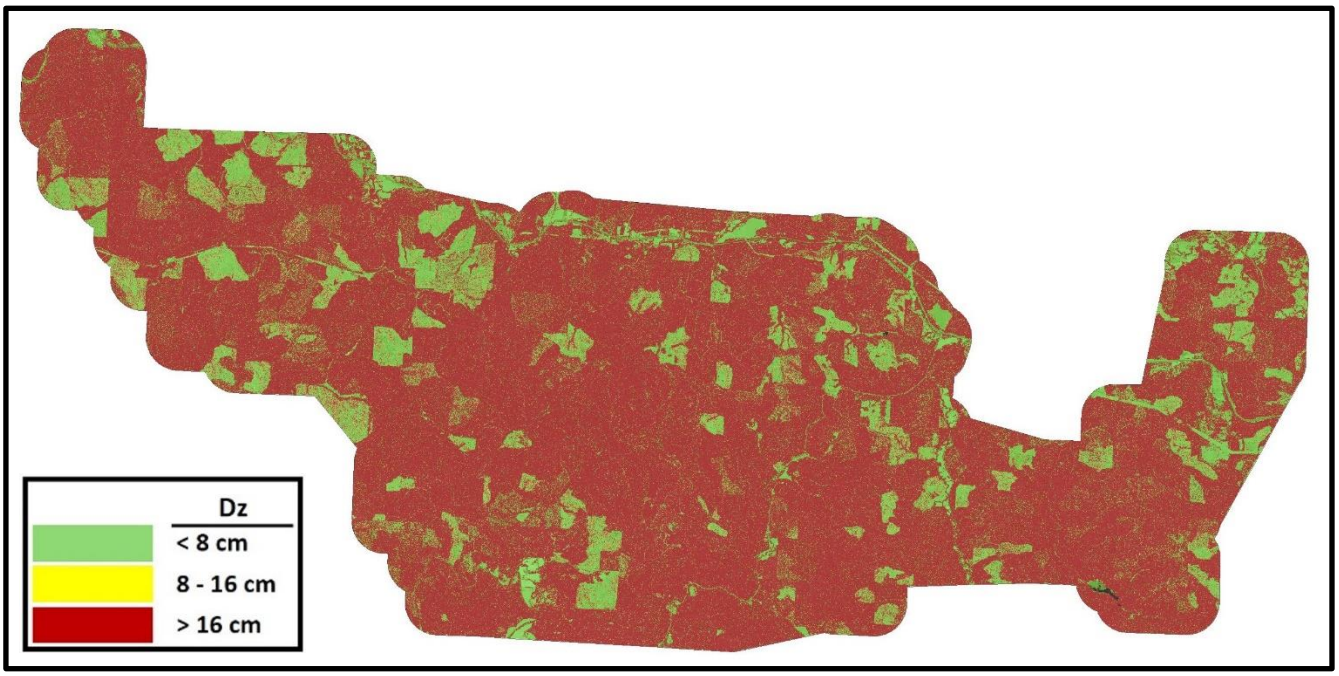

Figure 7. Swath separation raster created to assess calibration of the Burnt Woods AOI.

3.6 Intraswath Precision

Precision within swaths was evaluated on flat (less than 10° slope) hard surfaces such as roads, parking lots and rooftops. All pulses with single returns were used for evaluation. Each lift was assessed with a minimum of one sample area encompassing approximately 100-pixels at a pixel resolution of 4ft. A slope correction was applied to the range within each cell as dictated by the equation provided in the Lidar Base Specifications. Results were required to meet ≤ 6cm RMSDz. Intraswath consistency results were submitted as polygons of each area tested and include the calculated minimum and maximum range and RMSDz for each polygon. The project-wide results are shown below in Table 8; polygons locations for the large block are shown in Figure 8.

Table 8. IntraSwath results for each assessment polygon.

FID	dZ_MAX (m)	dZ_MIN (m)	RMSD (m)
0	0.054	-0.030	0.023
1	0.070	-0.053	0.026
2	0.100	-0.096	0.031
3	0.077	-0.226	0.055
4	0.068	-0.076	0.034
5	0.083	-0.067	0.035
6	0.078	-0.053	0.030
7	0.044	-0.054	0.015
8	0.082	-0.043	0.037
9	0.046	-0.050	0.024
10	0.052	-0.023	0.026
11	0.089	-0.051	0.044
12	0.093	-0.056	0.031
13	0.075	-0.032	0.025
14	0.063	-0.055	0.031
15	0.075	-0.089	0.040
16	0.058	-0.083	0.026
17	0.047	-0.110	0.035
18	0.077	-0.028	0.027
19	0.066	-0.090	0.028
20	0.099	-0.057	0.032
21	0.072	-0.096	0.035
22	0.063	-0.104	0.021
23	0.063	-0.082	0.029
24	0.060	-0.100	0.027
25	0.072	-0.043	0.021
26	0.041	-0.040	0.013
27	0.061	-0.085	0.028
28	0.072	-0.092	0.027
29	0.058	-0.073	0.023
30	0.074	-0.034	0.025
31	0.085	-0.098	0.034
32	0.064	-0.148	0.058
33	0.056	-0.077	0.025
34	0.109	-0.040	0.029
35	0.065	-0.069	0.027
36	0.065	-0.074	0.024
37	0.038	-0.068	0.018
38	0.068	-0.074	0.022
39	0.083	-0.065	0.025

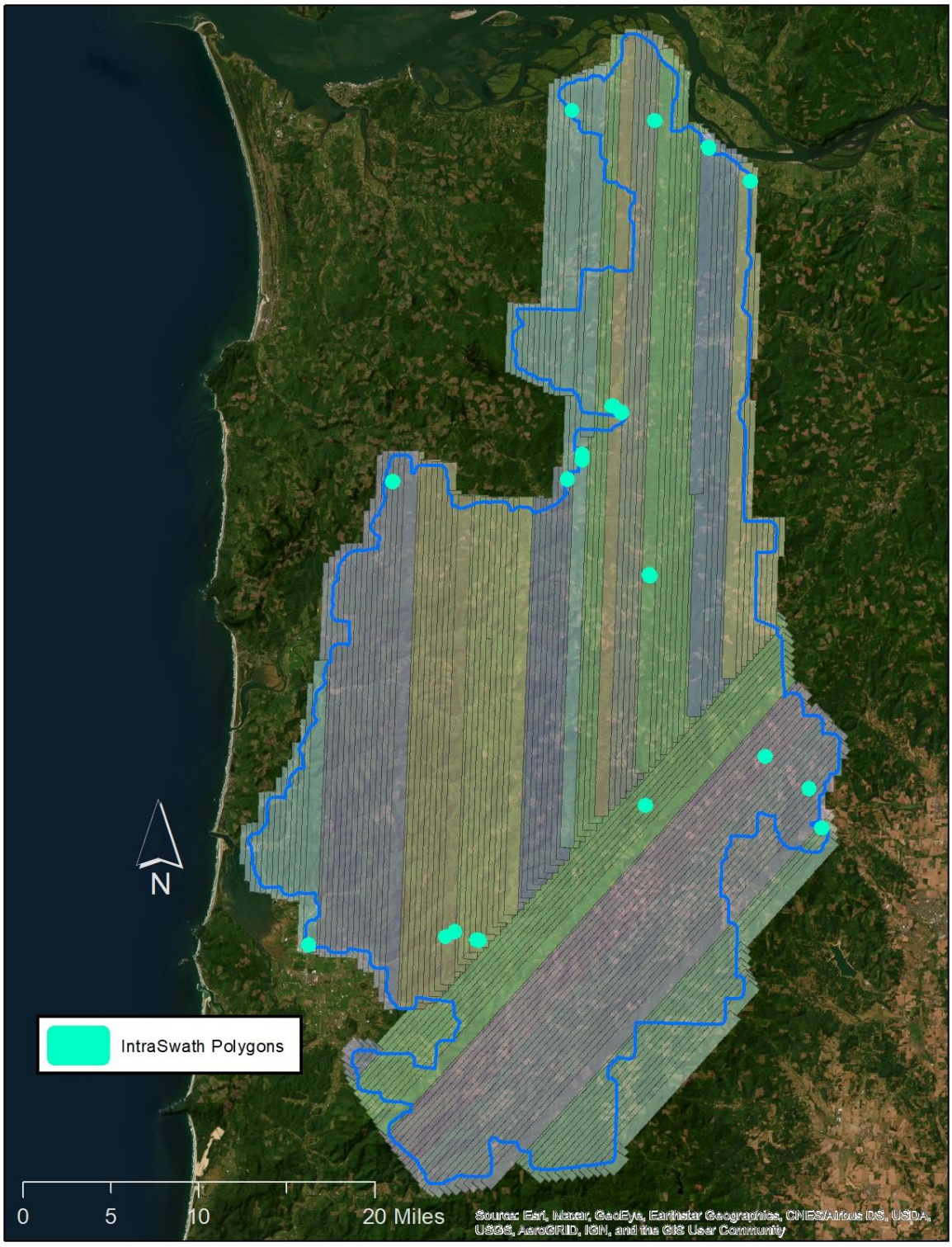

Figure 8. Location of IntraSwath polygons used for assessment of swath precision for the Clatsop–Trask-Nehalem AOI

3.7 Point Density

Point density is based upon acquisition at a > 50% swath overlap with each swath acquired at ≥ 4 points/m² to meet a final aggregate density of ≥ 8 points/m². Density was calculated using *LP360* within nominally created 100'x100' tiles. First return and ground-classified lidar density for each AOI is shown in Table 9, below. Note that the project was located within mountainous, dense coniferous forests resulting in limited ground returns.

Table 9. Lidar density results for first return and ground-only points, by area.

Block	**Clatsop-Nehalem-Trask**	**Burnt Woods**	**Gates**
First Returns (pts/m²)	13.9	14.0	13.6
Ground Returns (pts/m²)	2.0	1.8	1.3

3.6 Lidar Point Classification

Once the point cloud adjustment was achieved with desired relative and absolute accuracy, all data in LAS format were brought into classification software. Rigorous selection algorithms in *TerraScan* were used to automatically classify returns and ensure accurate ground classification based on software parameters as defined by the Lidar analyst. Data from the extreme edge of each swath, where most error occurs, was omitted during initial ground classification to increase quality. Ground identification was initiated at low-resolution seed points and increased in resolution and density with each passing review. A tailored approach was formulated for this project based on consideration of terrain and vegetation characteristics. Points determined to be geometrically incorrect were attributed with a withheld bit flag and delivered with the final point cloud data; examples include points identified as high noise, low noise, and points at the extreme edge of a swath within areas of triple swath overlap,

A manual review of auto-classified point data was performed to refine the ground-classified surface points where the automated process had limited success, thus improving the final bare earth surface. Manual review was assisted by evaluation of maximum surface rasters for high noise and bare earth surface rasters to find low noise and other misclassifications. Finally, hydro-breaklines were manually created. All points within the bounds of identified hydro breaklines were classified as water points. In addition, bridge breaklines were manually collected and used to classify all points on the top of each bridge deck. Bridge points were removed from the final bare earth surface. Additional breaklines at the top and bottom of each bridge were collected to sharply define these features in the final DEM. Points within 2 feet of breaklines were classified as ignored ground to avoid conflict. Software used for Lidar classification and review included TerraScan, LP360, and ArcGIS.

3.7 Hydrologic Flattening

Hydrologic breaklines were manually collected using ground-classified data on all bodies of water greater than 2 acres and on rivers and streams greater than 100-feet in width. A downstream constraint was applied to rivers and streams to ensure an equal elevation was maintained on both banks and

provide an improved appearance to the final ground model. Ground points within 2-feet of hydro breaklines were reclassified as Class 20 (Ignored Ground).

3.8 Bare Earth or Digital Elevation Model (DEM)

Classified ground point data were combined with all breaklines to create a digital elevation model (DEM) at a 1-foot resolution. The resulting model was cut into 3000'x3000' tiles and delivered in a 32-bit floating GeoTIFF format. A final QC was performed on the resulting Bare Earth raster data to verify no anomalies remained after previous review processes and edits.

3.9 Maximum Surface Height Surface Model (DSM)

An additional maximum height surface model or digital surface model (DSM) was created using all unflagged data (excluding all flagged noise points). The resulting data was used to create a 1-foot resolution raster data set which was cut into 3000'x3000' tiles and delivered in a 32-bit floating GeoTIFF format.

3.10 Swath Separation Rasters

Swath-to-swath separation (Dz) was reviewed by creating GeoTIFF rasters of all AOIs at a 4-foot resolution using LP360 software. Last returns of all unflagged points were used as input for each raster cell to calculate the maximum difference within each cell of unflagged last returns between each flight line. Resulting data was exported in GeoTIFF format and color-coded as required by USGS 3DEP Lidar Base Specifications. Resulting data was used for internal review and provided to USGS for initial data assessment.

3.11 Metadata

FGDC-compliant metadata was produced in XML format to include a complete description of the project, purpose, vendor information, acquisition planning, results and dates, processing steps, and quality control results. One XML-formatted metadata was submitted for each of the following products:

- Classified Lidar Point Cloud
- Bare Earth (DEM) Raster
- Max Surface Height (DSM) Raster
- Breaklines

4. Accuracy Assessment

4.1 Horizontal Accuracy

This data set was produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 0.57 ft (17.4 cm) RMSEx / RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 1.4 ft (42.6 cm) at a 95% confidence level.

4.2 Cloud Point Testing

Vertical accuracy of the point cloud data was tested for Non-Vegetated Vertical Accuracy (NVA) and Vegetated Vertical Accuracy (VVA) using independent QC checkpoints collected by a licensed surveyor. Points were distributed throughout the project as best possible given the constraints of heavily forested and mountainous terrain and property access. All points were located on ground with less than 10° slope. NVA points were located on hard flat surface free of any vegetation and VVA points were selected in multiple vegetation types such as grass, brush, and forested conditions. A separate survey report provides methodology, data sheets and photos of field-collected QC points.

Assessment of the ground data was performed creating a Triangulated Irregular Network (TIN) from the final calibrated and classified point data and comparing it to the surveyed checkpoint. Results and number NVA and VVA for the assessment are shown in Table 10. A graphic showing distribution of all checkpoints and control are shown in Figure 9.

Table 10. Results of NVA and VVA Checkpoint Assessment

TYPE	Data Tested	RMSEz	95% CL	Points Used
NVA	Point Cloud	0.050 m	0.098 m	75
	DEM	0.029 m	0.057 m	
VVA	Point Cloud	NA	0.219 m	66
	DEM	NA	0.211 m	

4.3 Digital Elevation Model Testing

Similar accuracy testing was performed on the Bare Earth surface. A hydro-flattened DEM raster model was created at a 1-foot resolution and used as a comparison of the same set of NVA and VVA checkpoints. The difference in accuracy results between the two data types were the same. Results are shown in Table 10, above. A graphic showing distribution of all checkpoints and control are shown in Figure 9, below.

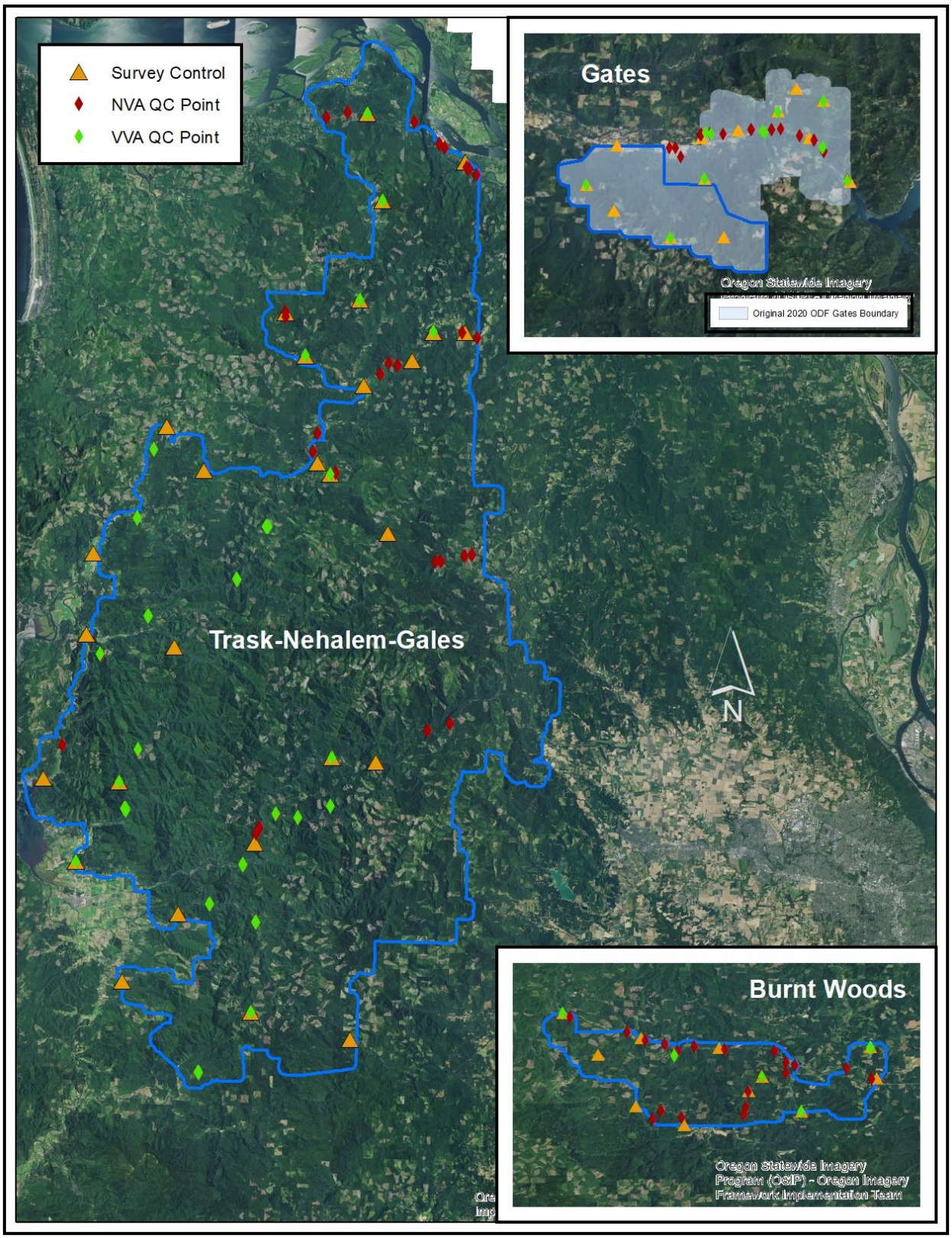

Figure 9. Location of all survey control and QC checkpoints used for adjustment and evaluation of the final data.