Project Report

USDA-FS Region-6, Gifford Pinchot et al National Forests
2017 Leaf-On Airborne LiDAR Data Acquisition
Sol. No. AG-05G2-S-17-0019
Atlantic Project No. 17042
Okanogan-Wenatchee National Forest – Swauk Pine AOI

TABLE OF CONTENTS

SECTION I: PROJECT OVERVIEW & PURPOSE

1. Aerial LiDAR Project

a. Project Overview

The United States Forest Service, Region 6, (USFS) required leaf-on airborne LiDAR surveys to be collected over of national forestry in Oregon and Washington State. The following areas were requested to be covered: Gifford Pinchot National Forest (GIP) in Vancouver, Washington; Okanogan-Wenatchee National Forest (OKA) in Wenatchee, Washington; Malheur National Forest (MAL) in John Day, Oregon; Deschutes National Forest (DES) in Bend, Oregon, Willamette National Forest (WIL) in Eugene, Oregon, Umpqua National Forest (UMP) in Douglas, Lane, and Jackson Counties, Oregon. The following report applies to the Swauk Pine AOI, which encompasses eleven (11) square miles of the Okanogan-Wenatchee National Forest in Washington State.

Aerial LiDAR data for this task order was planned, acquired, processed and produced at an aggregate nominal pulse spacing (ANPS) of 0.35 meters and aggregate nominal pulse density of 8 pulses per square meter.

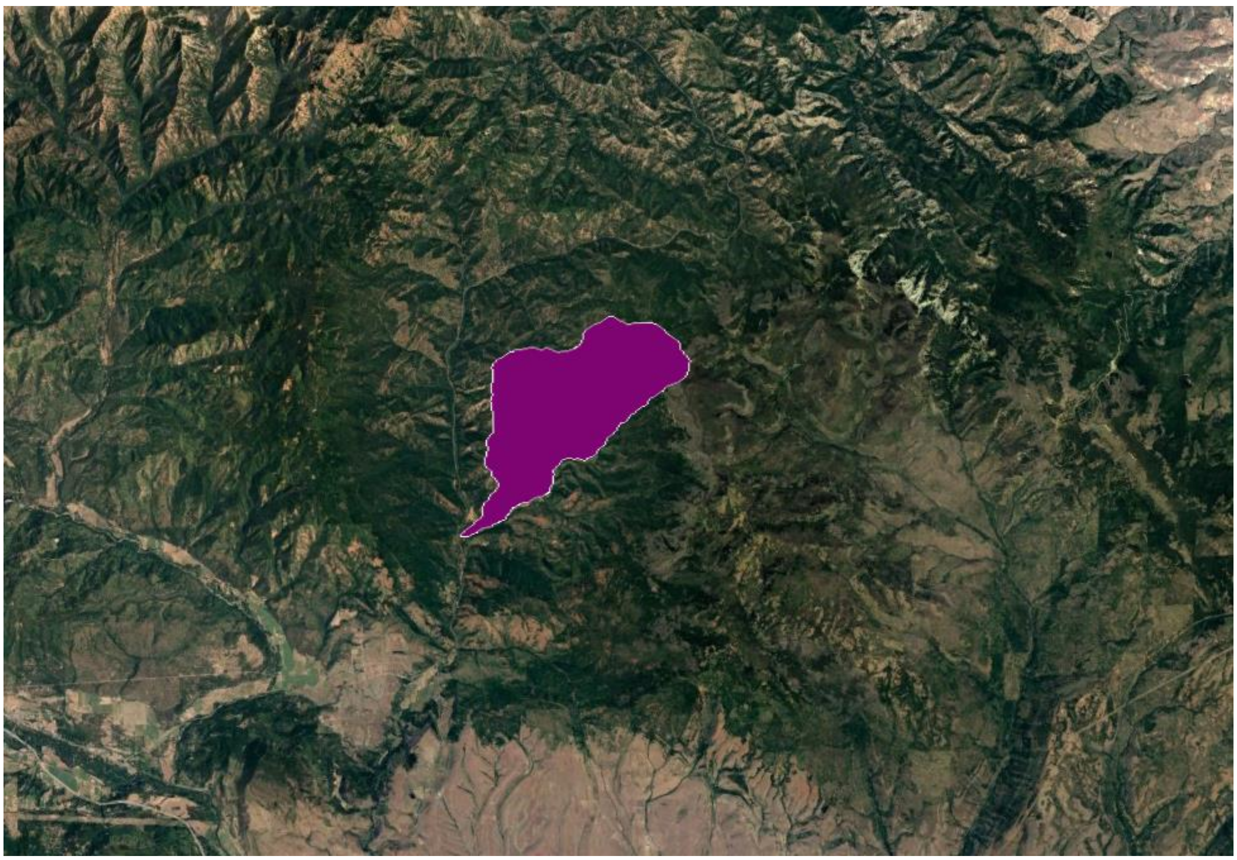

Figure 1: Aerial LiDAR Project Overview – Defined Project Area (DPA) and Associated Areas of Interest (AOIs)

b. Project Purpose

The primary goals of this project are to provide high accuracy Light Detection and Ranging (LiDAR) data to enhance project planning and implementation; identify areas for the implementation of forest restoration treatments designed to restore forest structure in young-growth stands; and to provide engineering and resource specialists more information for on-the-ground project planning. In addition, these data will be used by researchers and scientists to characterize vegetation type and structure as it currently exists on the landscape and to provide a detailed, accurate, and precise benchmark for future change detection work. The data products specified herein may also be used for vegetation mapping, road identification and mapping, hydrologic feature delineation, and landcover characterization applications including a canopy height model, understory vegetation prediction, and other stand metrics.

c. Client Contact Information

Client Contact Information	
Name of Contact	Mark Riley
Organization	Forest Service R6 Data Resources Management
Position	Remote Sensing Program Lead
Telephone	503.808.2989
E-Mail Address	markriley@fs.fed.us
Mailing Address	1220 SW 3rd Ave
City	Portland
State or Province	Oregon
Postal Code	97204

Table 1: Aerial LiDAR Client Contact Information

d. Contract Deliverables

Item	Specification/Format
Report	PDF
Metadata	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)
Aircraft Trajectories	ArcGIS shapefile
All-Return Point Cloud	LAS 1.2 in LAZ format
Bare Earth Elevation Model (Digital Terrain Model, DTM)	ERDAS .img format
Intensity Image	ERDAS .img
Supporting Shapefiles	ArcGIS shapefile
GPS Report	PDF
Quality Analysis/Quality Control	PDF

Table 2: Aerial LiDAR Contract Deliverables

SECTION II: FIELD OPERATIONS

1. Aerial Acquisition

a. Aircraft & Sensor Information

Atlantic operated a Leica ALS70-HP LiDAR system on a Cessna (N732JE) during October 16, 2017 for the project area. The specifications of this LiDAR system are presented in the following table:

Parameter	Specification
Model	ALS70-HP
Manufacturer	Leica
Platform	Fixed-Wing
Scan Pattern	Sine, Triangle, Raster
Maximum Scan Rate (Hz)	Sine: 200 Triangle: 158 Raster: 120
Field of View (°)	0 – 75 (Full Angle, User Adjustable)
Maximum Pulse Rate (kHz)	500
Maximum Flying Height (m AGL)	3500
Number of Returns	Unlimited
Number of Intensity Measurements	3 (First, Second, Third)
Roll Stabilization (Automatic Adaptive, °)	75 - Active FOV
Storage Media	Removable 500 GB SSD
Storage Capacity (Hours @ Max Pulse Rate)	6
Size (cm)	Scanner: 37 W x 68 L x 26 H Control Electronics: 45 W x 47 D x 36 H
Weight (kg)	Scanner: 43 Control Electronics: 45
Operation Temperature (°C)	0 – 40
Flight Management	FCMS
Power Consumption	927 @ 22.0 – 30.3 VDC

Table 3: System Specifications – ALS70-HP

b. Sensor Acquisition Information

The following table illustrates project specific system parameters for LiDAR acquisition on this project:

Parameter	Specification
System	Leica ALS70-HP
Nominal Pulse Spacing (m)	0.35
Nominal Pulse Density (pls/m²)	4.5
Nominal Flight Height (AGL meters)	2400
Nominal Flight Speed (kts)	120
Pass Heading (°)	Varies
Sensor Scan Angle (°)	24
Scan Frequency (Hz)	43.9
Pulse Rate of Scanner (kHz)	260,000

Parameter	Specification
Line Spacing (m)	400
Pulse Duration of Scanner (ns)	4
Central Wavelength of Sensor Laser (nm)	1064
Sensor Operated with Multiple Pulses	1
Beam Divergence (mrad)	0.15
Nominal Swath Width (m)	935
Nominal Swath Overlap (%)	55
Scan Pattern	Triangle

Table 4: Aerial LiDAR Sensor Acquisition Parameters

c. Flight Plan Execution

Atlantic acquired 19 passes of the AOI as a series of perpendicular and/or adjacent flight-lines executed in 1 flight missions conducted between October 16, 2017 and October 16, 2017. Onboard differential Global Navigation Satellite System (GNSS) unit(s) recorded sample aircraft positions at 2 hertz (Hz) or more frequency. LiDAR data was only acquired when a minimum of six (6) satellites were in view.

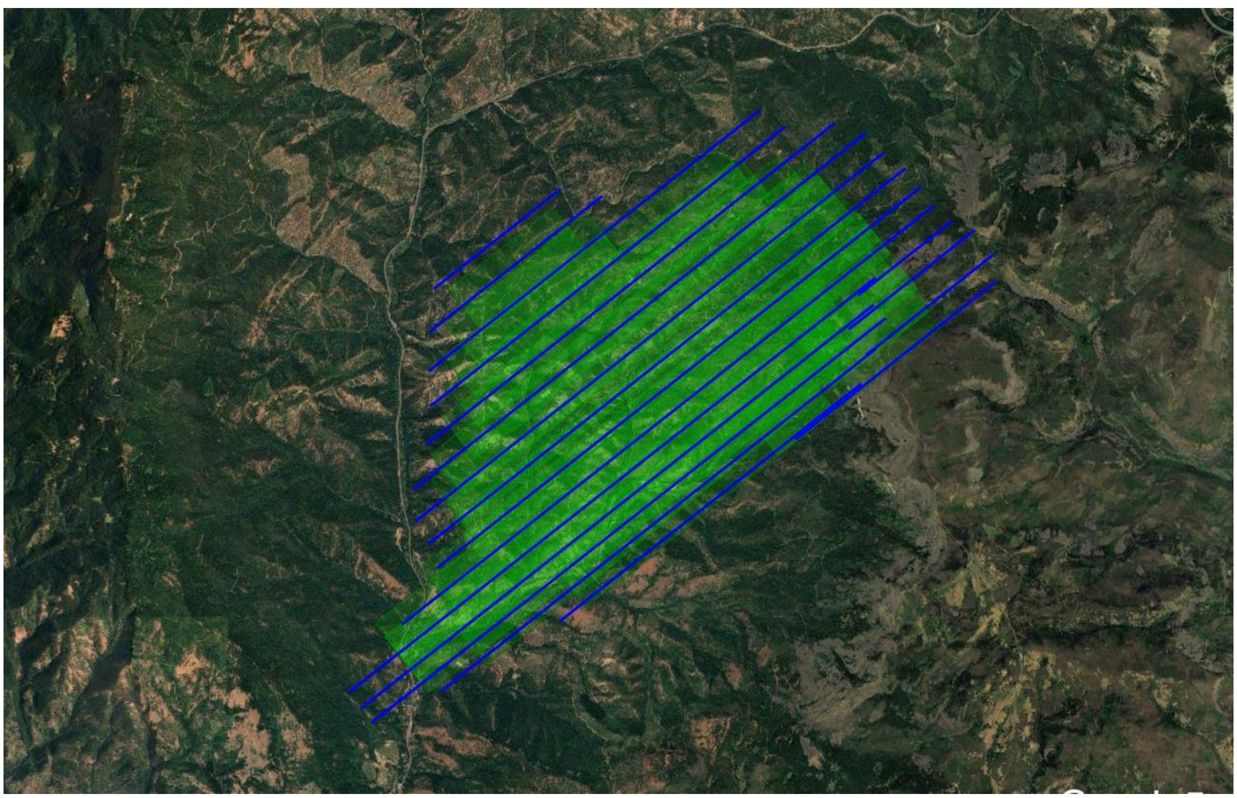

Figure 2: Orientation of Executed Flight-lines and LiDAR DPA

d. GNSS Reference Stations

2 Continuously Operating Reference Stations (CORS) were used to control the LiDAR acquisition for the defined project area. The coordinates provided in the table below are in the specified coordinate reference system for the project, as detailed in Section III-1-b.

2. Ground Acquisition

a. Ground Control Survey

A total of 29 Non-vegetated Vertical Accuracy (NVA) points were collected in support of this project.

Point cloud data accuracy was tested against a Triangulated Irregular Network (TIN) constructed from LiDAR points in clear and open areas. A clear and open area can be characterized with respect to topographic and ground cover variation such that a minimum of five (5) times the Nominal Pulse Spacing (NPS) exists with less than 1/3 of the RMSEZ deviation from a low-slope plane. Slopes that exceed ten (10) percent were avoided.

Each land cover type representing ten (10) percent or more of the total project area were tested and reported with a VVA. In land cover categories other than dense urban areas, the tested points did not have obstructions forty-five (45) degrees above the horizon to ensure a satisfactory TIN surface. The VVA value is provided as a target. It is understood that in areas of dense vegetation, swamps, or extremely difficult terrain, this value may be exceeded.

The NVA value is a requirement that must be met, regardless of any allowed "busts" in the VVA(s) for individual land cover types within the project. Checkpoints for each assessment (NVA & VVA) are required to be well-distributed throughout the land cover type, for the entire project area.

The following tables and figures outline the coordinate values and distribution of LCP, NVA and VVA points collected in support of this project:

ID	Easting	Northing	Elevation
SWAUKPINE_01	677809.2	5240750	1059.905
SWAUKPINE_02	675975	5238685	1040.117
SWAUKPINE_03	675305.3	5235213	780.614
SWAUKPINE_04	676204.8	5237887	880.747
SWAUKPINE_05	676170.6	5239073	934.534
SWAUKPINE_06	678513.7	5241160	1118.533
SWAUKPINE_07	679142.2	5241440	1198.683
SWAUKPINE_08	681219.4	5241764	1484.57
SWAUKPINE_09	680050.4	5240670	1380.28
SWAUKPINE_10	677788.7	5239260	985.23
SWAUKPINE_11	677941.9	5238177	931.109
SWAUKPINE_12	678894.9	5238855	1118.662
SWAUKPINE_13	678325.3	5238412	1095.955
SWAUKPINE_14	677196.9	5236269	838.319
SWAUKPINE_15	679170.9	5239792	1170.169
SWAUKPINE_16	679050.4	5240159	1231.561
SWAUKPINE_17	679923.8	5241332	1322.245

ID	Easting	Northing	Elevation
SWAUKPINE_18	680671.9	5241220	1439.079
GCP07	663771	5218450	716.377
GCP09	662761.1	5219260	735.245
GCP31	642830.2	5220813	1499.525
GCP32	645138	5218488	1497.722
GCP33	647175.5	5216788	1480.347
GCP34	644206	5219932	1225.635
GCP35	657032.1	5213386	1368.699
GCP36	657019.9	5216640	1405.652
GCP38	649089.8	5222061	1409.13
GCP39	654945.9	5220500	1055.543
GCP40	652385.7	5217753	1063.27

Table 9: Non-Vegetated Vertical Accuracy (NVA) Point Coordinates

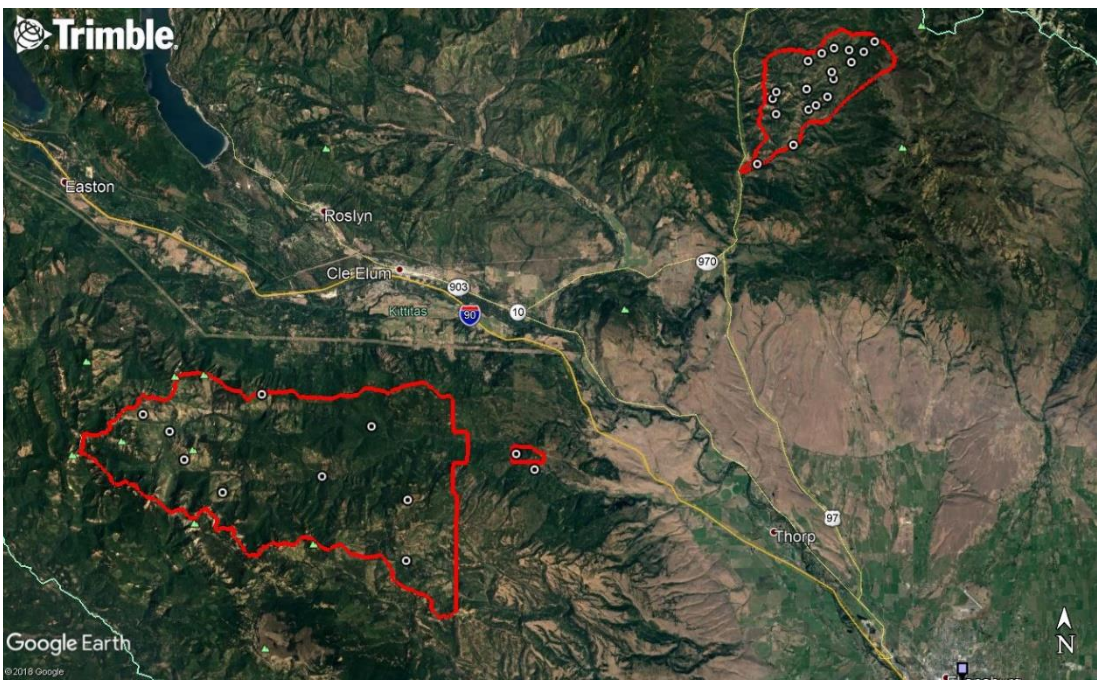

Figure 3: Non-Vegetated Vertical Accuracy (NVA) Point Distribution

SECTION III: DATA PRODUCTION

1. Calibration/Classification

a. LiDAR Point Cloud Generation

Atlantic used Leica software products to download the IPAS ABGNSS/IMU data and raw laser scan files from the airborne system. Waypoint Inertial Explorer is used to extract the raw IPAS ABGNSS/IMU data, which is further processed in combination with controlled base stations to provide the final Smoothed Best Estimate Trajectory (SBET) for each mission. The SBETs are combined with the raw laser scan files to export the LiDAR ASCII Standard (*.las) formatted swath point clouds.

b. Coordinate Reference System

Projection: NAD 1983 Oregon Washington Albers
Horizontal Datum: NAD83
Vertical Datum: NAVD88
Spheroid: GRS1980
Horizontal Units: Meter
Vertical Units: Meter

c. LiDAR Point Cloud Statistics

Category	Value
Total Points	1,526,663,101
Nominal Pulse Spacing (m)	0.4016
Nominal Pulse Density (pls/m²)	6.2009
Nominal Pulse Spacing (ft)	1.3175
Nominal Pulse Density (pls/ft²)	0.5761
Aggregate Total Points	613,564,872
Aggregate Nominal Pulse Spacing (m)	0.2688
Aggregate Nominal Pulse Density (pls/m²)	13.8402
Aggregate Nominal Pulse Spacing (ft)	0.8819
Aggregate Nominal Pulse Density (pls/ft²)	1.2858

Table 5: LiDAR Point Cloud Statistics

d. Smooth Surface Repeatability (Interswath)

Departures from planarity of first returns within single swaths in non-vegetated areas were assessed at multiple locations with hard surface areas (parking lots or large rooftops) inside the project area. Each area was evaluated using signed difference rasters (maximum elevation – minimum elevation) at a cell size equal to 2 x ANPS, rounded to the next integer. The following figure depicts a sample of the assessment.

e. LiDAR Calibration

Using a combination of GeoCue, TerraScan and TerraMatch; overlapping swath point clouds are corrected for any orientation or linear deviations to obtain the best fit swath-to-swath calibration. Relative calibration was evaluated using advanced plane-matching analysis and parameter corrections derived. This process was repeated interactively until residual errors between overlapping swaths, across all project missions, was reduced to ≤2cm. A final analysis of the calibrated lidar is preformed using a TerraMatch tie line report for an overall statistical model of the project area. Individual control point assessments for this project can be found in Section VI of this report.

Upon completion of the data calibration, a complete set of elevation difference intensity rasters (dZ Orthos) are produced. A user-defined color ramp is applied depicting the offsets between overlapping swaths based on project specifications. The dZ orthos provide an opportunity to review the data calibration in a qualitative manner. Atlantic assigns green to all offset values that fall below the required RMSDz requirement of the project. A yellow color is assigned for offsets that fall between the RMSDz value and 1.5x of that value. Finally, red values are assigned to all values that fall beyond 1.5x of the RMSDz requirements of the project.

f. LiDAR Classification

Multiple automated filtering routines are applied to the calibrated LiDAR point cloud identifying and extracting bare-earth and above ground features. GeoCue, TerraScan, and TerraModeler software was used for the initial batch processing, visual inspection and any manual editing of the LiDAR point clouds.

Code	Description
1	Processed, Unclassified
2	Ground
7	Low Point (Noise)
18	High Point (Noise)

Table 6: LiDAR Point Classification Codes and Descriptions

g. LiDAR Intensity Imagery

LiDAR intensity imagery was created from the final calibrated and classified lidar point cloud. Intensity images were produced from all classified points and posted to a 1.0-meter cell size. Intensity images were cut to match the tile index and its corresponding tile names and delivered in .tif format.

h. Bare Earth Elevation Model – Digital Terrain Model (DTM)

Bare earth Digital Elevation Models (DTMs) were derived using the bare earth (ground) LiDAR points. All DEMs were created with a grid spacing of 1.0-meter. DTMs for this project were cut to match the tile index and its corresponding tile names and delivered in img format.

SECTION IV: ACCURACY ASSESSMENT

1. Vertical Accuracy Assessment

a. Requirements

Per the table below, the Vertical Accuracy Assessment utilized the required parameters for Vertical Data Accuracy Class IV.

Vertical Data Accuracy Class	RMSEz in Non-Vegetated Terrain (cm)	Non-Vegetated Vertical Accuracy (NVA) at 95% Confidence Level (cm)	Vegetated Vertical Accuracy (VVA) at 95th Percentile (cm)
I	1.0	2.0	2.9
II	2.5	4.9	7.4
III	5.0	9.8	14.7
IV	10.0	19.6	29.4
V	12.5	24.5	36.8

Vertical Data Accuracy Class	RMSEz in Non-Vegetated Terrain (cm)	Non-Vegetated Vertical Accuracy (NVA) at 95% Confidence Level (cm)	Vegetated Vertical Accuracy (VVA) at 95th Percentile (cm)
VI	20.0	39.2	58.8
VII	33.3	65.3	98.0
VIII	66.7	130.7	196.0
IX	100.0	196.0	294.0
X	333.3	653.3	980.0

Table 7: Vertical Accuracy Standards, Source: ASPRS Positional Accuracy Standards for Digital Geospatial Data v1.0 (2014)

*The terms NVA and VVA are from the American Society for Photogrammetry and Remote Sensing (ASPRS) Positional Accuracy Standards for Digital Geospatial Data v1.0 (2014). The term NVA refers to assessments in clear, open areas (which typically produce only single LiDAR returns); the term VVA refers to assessments in vegetated areas (typically characterized by multiple return LiDAR).

b. Results

An overall statistical assessment of the check points can be found in the following two tables (values provided in meters):

Broad Land Cover Type	# of Points	RMSEz	95% Confidence Level	95th Percentile
NVA of Point Cloud	18	0.0587	0.1150	0.1073
NVA of DEM	18	0.0583	0.1142	0.0415

Table 8: NVA/VVA Accuracies

SECTION V: CERTIFICATION STATEMENT

This accuracy assessment confirms that the data may be used for the intended applications stated in Section I of this document. This dataset may also be used as a topographic input for other applications, but the user should be aware that this LiDAR dataset was designed with a specific purpose and was not intended to meet specifications and/or requirements of users outside of the United States Geological Survey.

It should also be noted that LiDAR points do not represent a continuous surface model. LiDAR points are discrete measurements of the surface and any values derived within a triangle of three LiDAR points are interpolated. As such, the user should not use the resultant LiDAR dataset for vertical placement of a planimetric feature such as a headwall, building footprint or any other planimetric feature unless there is an associated LiDAR point that can be reasonably located on this structure.

Consideration should be given by the end user of this dataset to the fact that this LiDAR dataset was developed differently and separately than previous LiDAR datasets that may be available for this geographic location. It is likely that the data in this project was created using different geodetic control, a different Geoid, newer LiDAR technology and more up-to-date processing techniques. As such, any direct comparative analysis performed between this dataset and previous datasets could result in misleading or inaccurate results. Users are encouraged to proceed with caution while performing this type of comparative analysis and to completely understand the variables that make each of these datasets unique and not corollary.

It is encouraged that the user refers to the full FGDC Metadata and project reports for a complete understanding on the content of this dataset.

I, hereby, certify to the extent of my knowledge that the statements and statistics represented in this document are true and factual.

____
Brian J. Mayfield, ASPRS Certified Photogrammetrist #R1276

American Society for Photogrammetry and Remote Sensing
BRIAN MAYFIELD
CERTIFIED
PHOTOGRAMMETRIST
(ASPRS) NO. R1276
Exp. 11/2/2020

SECTION VI: CONTROL POINT ASSESSMENTS

1. Point Cloud Check Point Assessment

Point ID	Easting	Northing	KnownZ	LaserZ	Description	DeltaZ
SWAUKPINE_01	551003.609	1470520.786	1059.905	1060.010	BARE EARTH	0.105
SWAUKPINE_02	549092.679	1468526.180	1040.117	1040.000	BARE EARTH	-0.117
SWAUKPINE_03	548291.183	1465080.631	780.614	780.590	BARE EARTH	-0.024
SWAUKPINE_04	549291.791	1467719.826	880.747	880.780	BARE EARTH	0.033
SWAUKPINE_05	549302.831	1468906.297	934.534	934.550	BARE EARTH	0.016
SWAUKPINE_06	551722.925	1470903.880	1118.533	1118.520	BARE EARTH	-0.013
SWAUKPINE_07	552361.343	1471159.742	1198.683	1198.610	BARE EARTH	-0.073
SWAUKPINE_08	554448.450	1471403.950	1484.570	1484.550	BARE EARTH	-0.020
SWAUKPINE_09	553238.987	1470354.447	1380.280	1380.350	BARE EARTH	0.070
SWAUKPINE_10	550926.184	1469031.442	985.230	985.350	BARE EARTH	0.120
SWAUKPINE_11	551037.799	1467943.426	931.109	931.110	BARE EARTH	0.001
SWAUKPINE_12	552015.608	1468584.430	1118.662	1118.600	BARE EARTH	-0.062
SWAUKPINE_13	551429.751	1468163.245	1095.955	1095.950	BARE EARTH	-0.005
SWAUKPINE_14	550220.852	1466063.956	838.319	838.280	BARE EARTH	-0.039
SWAUKPINE_15	552327.050	1469510.814	1170.169	1170.230	BARE EARTH	0.061
SWAUKPINE_16	552220.687	1469882.501	1231.561	1231.530	BARE EARTH	-0.031
SWAUKPINE_17	553137.917	1471022.009	1322.245	1322.240	BARE EARTH	-0.005
SWAUKPINE_18	553880.812	1470880.733	1439.079	1439.070	BARE EARTH	-0.009

Table 9: Point Cloud Check Point Assessment

2. Digital Elevation Model (DEM) Check Point Assessment

Point ID	Easting	Northing	KnownZ	DEMZ	Description	DeltaZ
SWAUKPINE_01	551003.609	1470520.786	1059.905	1059.844	BARE EARTH	-0.061
SWAUKPINE_02	549092.679	1468526.180	1040.117	1040.007	BARE EARTH	-0.110
SWAUKPINE_03	548291.183	1465080.631	780.614	780.544	BARE EARTH	-0.070
SWAUKPINE_04	549291.791	1467719.826	880.747	880.702	BARE EARTH	-0.045
SWAUKPINE_05	549302.831	1468906.297	934.534	934.557	BARE EARTH	0.023
SWAUKPINE_06	551722.925	1470903.880	1118.533	1118.476	BARE EARTH	-0.057
SWAUKPINE_07	552361.343	1471159.742	1198.683	1198.614	BARE EARTH	-0.069
SWAUKPINE_08	554448.450	1471403.950	1484.570	1484.556	BARE EARTH	-0.014
SWAUKPINE_09	553238.987	1470354.447	1380.280	1380.285	BARE EARTH	0.005
SWAUKPINE_10	550926.184	1469031.442	985.230	985.355	BARE EARTH	0.125
SWAUKPINE_11	551037.799	1467943.426	931.109	931.136	BARE EARTH	0.027
SWAUKPINE_12	552015.608	1468584.430	1118.662	1118.605	BARE EARTH	-0.057
SWAUKPINE_13	551429.751	1468163.245	1095.955	1095.922	BARE EARTH	-0.033
SWAUKPINE_14	550220.852	1466063.956	838.319	838.264	BARE EARTH	-0.055

Point ID	Easting	Northing	KnownZ	DEMZ	Description	DeltaZ
SWAUKPINE_15	552327.050	1469510.814	1170.169	1170.159	BARE EARTH	-0.010
SWAUKPINE_16	552220.687	1469882.501	1231.561	1231.507	BARE EARTH	-0.054
SWAUKPINE_17	553137.917	1471022.009	1322.245	1322.194	BARE EARTH	-0.051
SWAUKPINE_18	553880.812	1470880.733	1439.079	1439.066	BARE EARTH	-0.013

Table 10: DEM Check Point Assessment