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
Umpqua National Forest – Tiller AOI

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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 Tiller AOI, which encompasses two-hundred sixty five (265) square miles of the Umpqua National Forest in Oregon.

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.

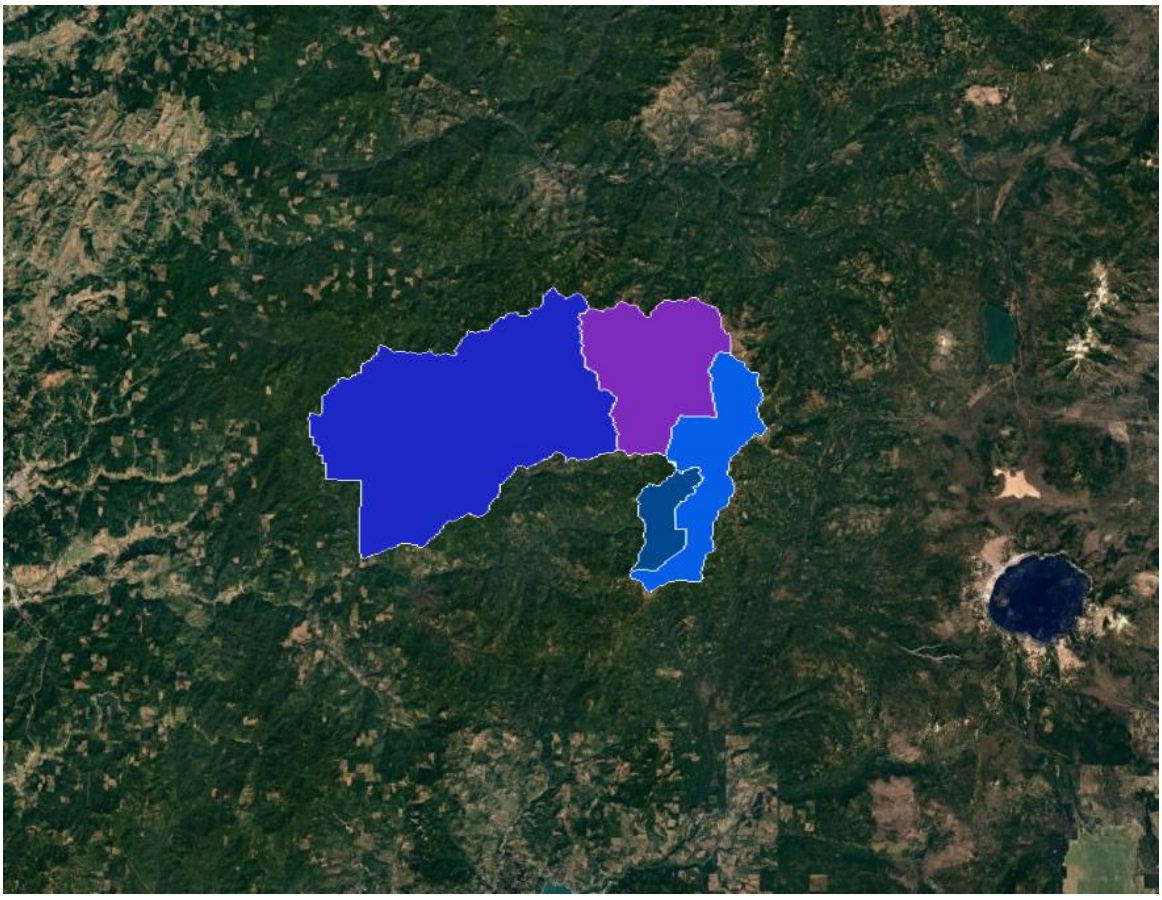


Figure 1: Aerial LiDAR Project Overview – Defined Project Area (DPA) and Associated Areas of Interest (AOIs)

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 July 10-14, 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 143 passes of the AOI as a series of perpendicular and/or adjacent flight-lines executed in 5 flight missions conducted between October 10, 2017 and October 14, 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.

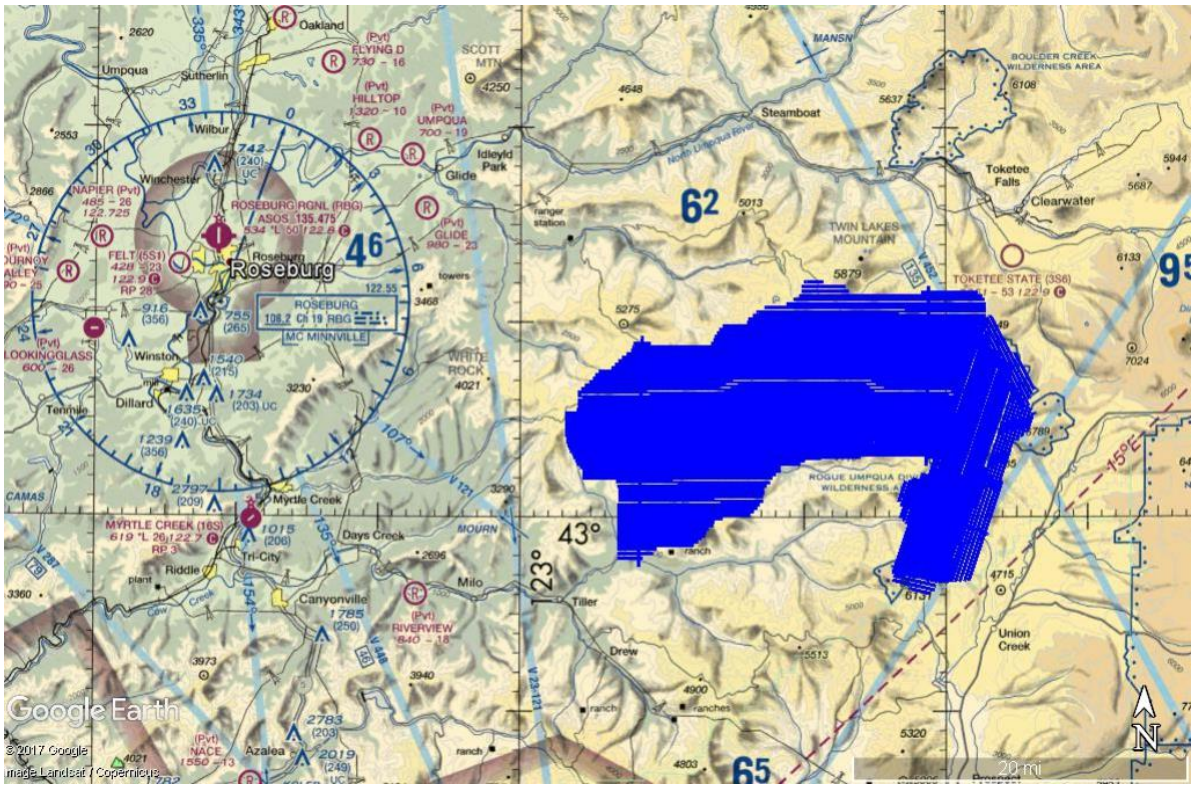


Figure 2: Orientation of Executed Flight-lines and LiDAR DPA

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.

Designation	Type	PID	Latitude (N)	Longitude (W)	Elevation
HAHD	CORS	HAHD	47 17 26.85798	121 47 17.05470	857.278
LINH	CORS	LINH	47 00 01.14685	120 32 18.55971	474.901

Table 5: GNSS Reference Stations

2. Ground Acquisition

a. Ground Control Survey

A total of 31 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
T_GCP001	22723.37	4789197	989.493
T_GCP002	25133.87	4788160	784.8
T_GCP003	28093.4	4789612	644.229
T_GCP004	29339.74	4792610	1030.384
T_GCP005	36461.11	4788872	1141.486
T_GCP006	38702.52	4793127	1291.379
T_GCP007	41770.87	4791146	1025.486
T_GCP008	43415.45	4793648	1168.786
T_GCP009	46745.34	4792092	792.756
T_GCP009_2	46806.75	4791914	797.423
T_GCP010	50793.25	4791923	906.642
T_GCP011	20969.44	4786145	976.323
T_GCP012	22641.45	4783118	1024.421
T_GCP013	25343.07	4783098	640.145
T_GCP014	29471.8	4785840	477.309
T_GCP015	27882.26	4785310	730.274
T_GCP016	42373.31	4786960	711.91
T_GCP017	49765.91	4788150	924.355

ID	Easting	Northing	Elevation
T_GCP018	48728.76	4786783	1026.405
T_GCP019	53541.79	4787118	1590.801
T_GCP020	52758.55	4786207	1462.926
T_GCP021	22963.76	4778951	636.655
T_GCP022	26637.12	4781296	412.292
T_GCP023	30760.42	4781824	478.468
T_GCP024	34835.27	4784344	598.055
T_GCP025	40250.87	4785501	548.483
T_GCP026	45620.54	4785767	956.698
T_GCP027	47837.23	4782362	1250.804
T_GCP028	51797.82	4778976	1402.241
T_GCP029	49611.86	4777173	977.298
T_GCP030	50088.2	4774645	1145.305

Table 6: Non-Vegetated Vertical Accuracy (NVA) Point Coordinates

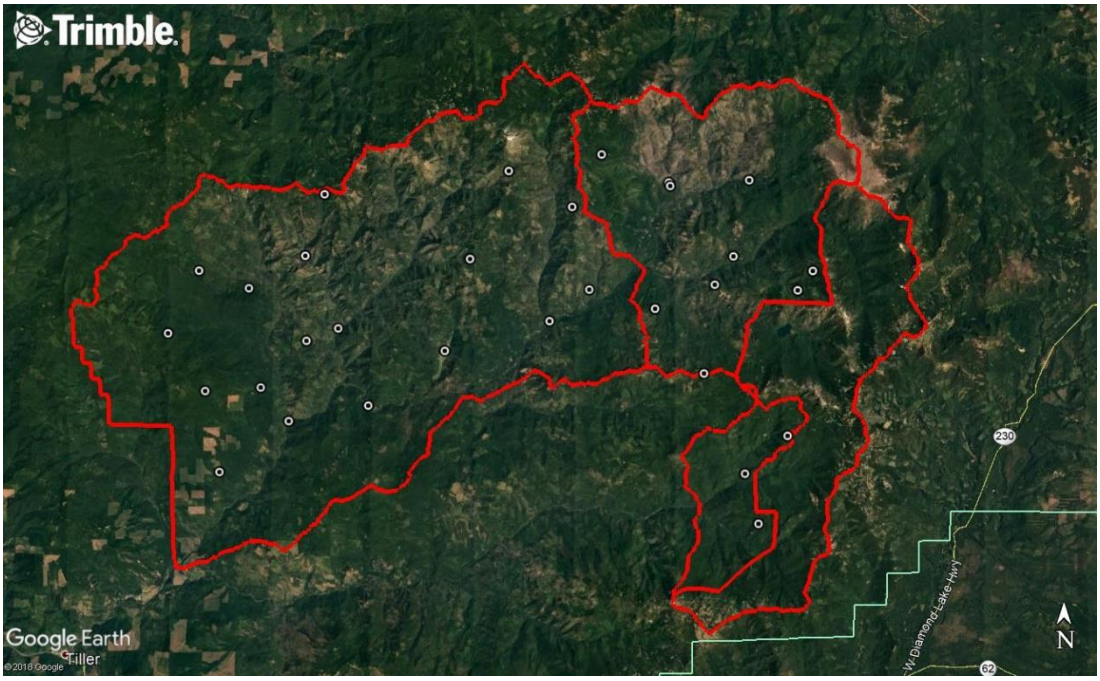


Figure 3: Non-Vegetated Vertical Accuracy (NVA) Point Distribution Data Production

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	14,228,330,503
Nominal Pulse Spacing (m)	0.3807
Nominal Pulse Density (pls/m²)	6.9011
Nominal Pulse Spacing (ft)	1.2489
Nominal Pulse Density (pls/ft²)	0.6411
Aggregate Total Points	13,760,510,711
Aggregate Nominal Pulse Spacing (m)	0.2381
Aggregate Nominal Pulse Density (pls/m²)	17.6462
Aggregate Nominal Pulse Spacing (ft)	0.7810
Aggregate Nominal Pulse Density (pls/ft²)	1.6394

Table 7: 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 8: 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 9: 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	31	0.0976	0.1913	0.1775
NVA of DEM	31	0.0844	0.1655	0.1367

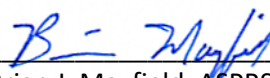
Table 10: NVA/VVA Accuracies

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

SECTION VI: CONTROL POINT ASSESSMENTS

1. Point Cloud Check Point Assessment

Point ID	Easting	Northing	KnownZ	LaserZ	Description	DeltaZ
T_GCP002	369299.381	1007414.509	784.800	784.820	BARE EARTH	0.020
T_GCP003	372200.063	1008964.206	644.229	644.150	BARE EARTH	-0.079
T_GCP004	373339.484	1011996.493	1030.384	1030.490	BARE EARTH	0.106
T_GCP005	380568.467	1008514.411	1141.486	1141.610	BARE EARTH	0.124
T_GCP006	382656.675	1012835.516	1291.379	1291.410	BARE EARTH	0.031
T_GCP007	385784.485	1010965.641	1025.486	1025.400	BARE EARTH	-0.086
T_GCP008	387338.000	1013517.545	1168.786	1168.810	BARE EARTH	0.024
T_GCP009	390712.138	1012080.925	792.756	792.850	BARE EARTH	0.094
T_GCP009_2	390779.524	1011905.634	797.423	797.560	BARE EARTH	0.137
T_GCP010	394754.536	1012052.655	906.642	906.740	BARE EARTH	0.098
T_GCP011	365216.789	1005263.082	976.323	976.270	BARE EARTH	-0.053
T_GCP012	366987.556	1002301.859	1024.421	1024.350	BARE EARTH	-0.071
T_GCP013	369681.710	1002374.971	640.145	640.250	BARE EARTH	0.105
T_GCP014	373704.011	1005250.365	477.309	477.370	BARE EARTH	0.061
T_GCP015	372137.386	1004667.846	730.274	730.410	BARE EARTH	0.136
T_GCP016	386529.541	1006811.581	711.910	711.860	BARE EARTH	-0.050
T_GCP017	393860.369	1008253.859	924.355	924.480	BARE EARTH	0.125
T_GCP018	392873.283	1006854.096	1026.405	1026.410	BARE EARTH	0.005
T_GCP019	397661.542	1007354.177	1590.801	1590.750	BARE EARTH	-0.051
T_GCP020	396911.863	1006419.422	1462.926	1462.910	BARE EARTH	-0.016
T_GCP021	367451.683	998158.143	636.655	636.600	BARE EARTH	-0.055
T_GCP022	371033.732	1000622.073	412.292	412.360	BARE EARTH	0.068
T_GCP023	375126.743	1001290.802	478.468	478.420	BARE EARTH	-0.048
T_GCP024	379103.155	1003943.230	598.055	598.080	BARE EARTH	0.025
T_GCP025	384463.380	1005283.532	548.483	548.390	BARE EARTH	-0.093
T_GCP026	389808.727	1005734.073	956.698	956.890	BARE EARTH	0.192
T_GCP027	392136.613	1002414.339	1250.804	1250.990	BARE EARTH	0.186
T_GCP028	396203.077	999173.552	1402.241	1402.410	BARE EARTH	0.169
T_GCP029	394085.064	997300.147	977.298	977.450	BARE EARTH	0.152
T_GCP030	394647.098	994794.931	1145.305	1145.340	BARE EARTH	0.035
TILL_S	382686.689	1003709.126	571.649	571.750	BARE EARTH	0.101

Table 11: Point Cloud Check Point Assessment

2. Digital Elevation Model (DEM) Check Point Assessment

Point ID	Easting	Northing	KnownZ	DEMZ	Description	DeltaZ
T_GCP002	369299.381	1007414.509	784.800	784.777	BARE EARTH	-0.023

Point ID	Easting	Northing	KnownZ	DEMZ	Description	DeltaZ
T_GCP003	372200.063	1008964.206	644.229	644.081	BARE EARTH	-0.148
T_GCP004	373339.484	1011996.493	1030.384	1030.425	BARE EARTH	0.041
T_GCP005	380568.467	1008514.411	1141.486	1141.592	BARE EARTH	0.106
T_GCP006	382656.675	1012835.516	1291.379	1291.379	BARE EARTH	0.000
T_GCP007	385784.485	1010965.641	1025.486	1025.392	BARE EARTH	-0.094
T_GCP008	387338.000	1013517.545	1168.786	1168.826	BARE EARTH	0.040
T_GCP009	390712.138	1012080.925	792.756	792.793	BARE EARTH	0.037
T_GCP009_2	390779.524	1011905.634	797.423	797.509	BARE EARTH	0.086
T_GCP010	394754.536	1012052.655	906.642	906.727	BARE EARTH	0.085
T_GCP011	365216.789	1005263.082	976.323	976.314	BARE EARTH	-0.009
T_GCP012	366987.556	1002301.859	1024.421	1024.331	BARE EARTH	-0.090
T_GCP013	369681.710	1002374.971	640.145	640.248	BARE EARTH	0.103
T_GCP014	373704.011	1005250.365	477.309	477.376	BARE EARTH	0.067
T_GCP015	372137.386	1004667.846	730.274	730.264	BARE EARTH	-0.010
T_GCP016	386529.541	1006811.581	711.910	711.838	BARE EARTH	-0.072
T_GCP017	393860.369	1008253.859	924.355	924.443	BARE EARTH	0.089
T_GCP018	392873.283	1006854.096	1026.405	1026.380	BARE EARTH	-0.025
T_GCP019	397661.542	1007354.177	1590.801	1590.733	BARE EARTH	-0.068
T_GCP020	396911.863	1006419.422	1462.926	1462.904	BARE EARTH	-0.022
T_GCP021	367451.683	998158.143	636.655	636.578	BARE EARTH	-0.077
T_GCP022	371033.732	1000622.073	412.292	412.289	BARE EARTH	-0.003
T_GCP023	375126.743	1001290.802	478.468	478.377	BARE EARTH	-0.091
T_GCP024	379103.155	1003943.230	598.055	598.019	BARE EARTH	-0.036
T_GCP025	384463.380	1005283.532	548.483	548.369	BARE EARTH	-0.114
T_GCP026	389808.727	1005734.073	956.698	956.847	BARE EARTH	0.149
T_GCP027	392136.613	1002414.339	1250.804	1250.992	BARE EARTH	0.188
T_GCP028	396203.077	999173.552	1402.241	1402.317	BARE EARTH	0.076
T_GCP029	394085.064	997300.147	977.298	977.422	BARE EARTH	0.124
T_GCP030	394647.098	994794.931	1145.305	1145.399	BARE EARTH	0.094
TILL_S	382686.689	1003709.126	571.649	571.618	BARE EARTH	-0.031

Table 121: DEM Check Point Assessment