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
Deschutes National Forest – Pole Creek/Whychus Creek AOIs

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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 Pole Creek and Whychus Creek AOIs, which encompasses fifty-two (52) square miles of the Deschutes 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.

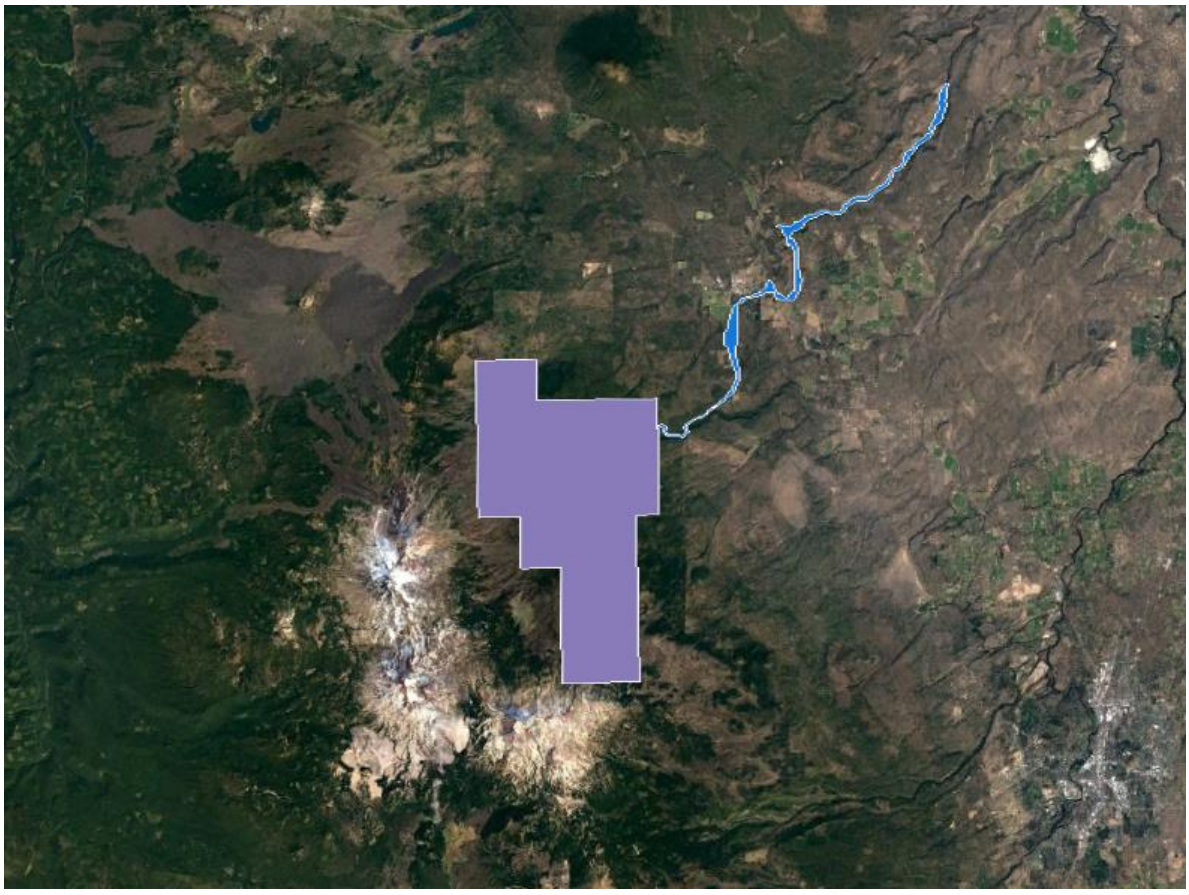


Figure 1: Aerial LiDAR Project Overview – Defined Project Area (DPA) and Associated Areas of Interest (AOIs)

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 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 40 passes of the AOI as a series of perpendicular and/or adjacent flight-lines executed in 1 flight missions conducted between July 16, 2017 and July 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.

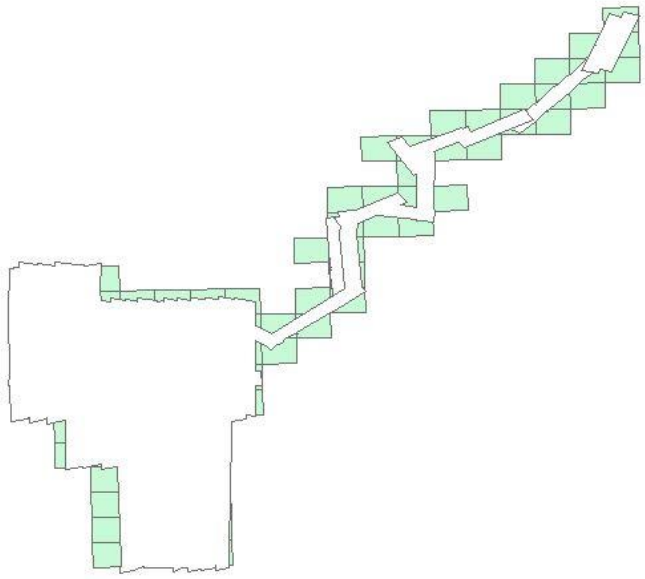


Figure 2: Orientation of Executed Flight-lines and LiDAR DPA

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.

Designation	Type	PID	Latitude (N)	Longitude (W)	Elevation
P421	CORS	P421	46 31 54.67444	122 25 45.24815	224.442
P431	CORS	P431	46 34 19.48164	121 59 18.45895	1426.470

Table 5: GNSS Reference Stations

2. Ground Acquisition

a. Ground Control Survey

A total of 27 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
PC05	606901.3	4889845	1637.295
PC15	608200.9	4893846	1459.264
PCX01	608197.9	4893845	1459.335
PC03	609767.9	4897407	1249.429
PCX02	609770.3	4897420	1249.665
PC11	607175.4	4897551	1394.645
PCX03	607170.5	4897548	1394.856
PC02	604188.3	4898230	1461.702
PCX04	604164.3	4898216	1462.194
PC01	604322	4901286	1327.744
PCX05	604341.7	4901294	1326.227
PC14	604429.4	4895110	1510.842
PCX06	604420.8	4895108	1510.987
PC08	603901.3	4893516	1614.595
PCX07	603905.4	4893517	1614.438
PCX08	603504.4	4894323	1622.129
PC10	603510.8	4894313	1622.18
PC12	611269.9	4897816	1213.42
PCX09	611274.7	4897807	1213.654
PC07	607870.1	4894541	1404.08

ID	Easting	Northing	Elevation
PCX10	607862.8	4894538	1403.908
PC06	608976.4	4890540	1573.171
PCX11	608992.1	4890542	1572.952
PC04	610051.5	4887387	1846.679
PCX12	610056.8	4887400	1846.423
PC17	610438	4884276	1993.061
PCX13	610436.7	4884269	1993.092

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

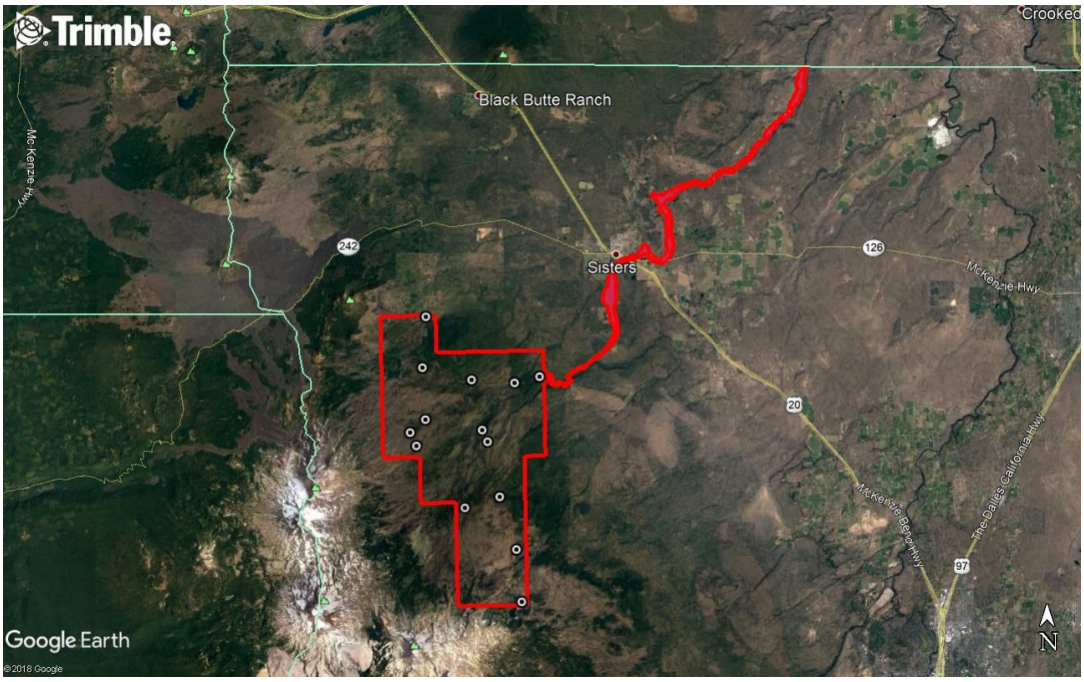


Figure 3: Non-Vegetated Vertical Accuracy (NVA) Point Distribution

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	2,360,170,746
Nominal Pulse Spacing (m)	0.3819
Nominal Pulse Density (pls/m²)	6.8574
Nominal Pulse Spacing (ft)	1.2529
Nominal Pulse Density (pls/ft²)	0.6371
Aggregate Total Points	2,249,001,465
Aggregate Nominal Pulse Spacing (m)	0.2719
Aggregate Nominal Pulse Density (pls/m²)	13.5226
Aggregate Nominal Pulse Spacing (ft)	0.8922
Aggregate Nominal Pulse Density (pls/ft²)	1.2563

Table 6: 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 7: 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 8: 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	27	0.0413	0.0809	0.0553
NVA of DEM	27	0.0444	0.0871	0.0143

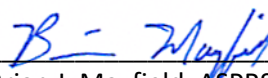
Table 9: NVA/VVA Accuracies

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
PC08	464184.328	1125963.646	1614.595	1614.590	BARE EARTH	(0.0050)
PC05	467045.365	1122180.850	1637.295	1637.290	BARE EARTH	(0.0050)
PC01	464891.808	1133720.653	1327.744	1327.750	BARE EARTH	0.0060
PCX09	471708.119	1129983.837	1213.654	1213.660	BARE EARTH	0.0060
PCX05	464911.799	1133727.685	1326.227	1326.220	BARE EARTH	(0.0070)
PCX07	464188.367	1125964.378	1614.438	1614.430	BARE EARTH	(0.0080)
PC04	470101.413	1119606.807	1846.679	1846.670	BARE EARTH	(0.0090)
PC11	467603.946	1129879.198	1394.645	1394.630	BARE EARTH	(0.0150)
PCX12	470107.205	1119619.189	1846.423	1846.440	BARE EARTH	0.0170
PC07	468186.620	1126842.872	1404.080	1404.100	BARE EARTH	0.0200
PCX08	463817.653	1126785.854	1622.129	1622.150	BARE EARTH	0.0210
PC14	464770.682	1127538.401	1510.842	1510.820	BARE EARTH	(0.0220)
PC02	464645.265	1130669.048	1461.702	1461.730	BARE EARTH	0.0280
PCX11	469159.653	1122801.355	1572.952	1572.980	BARE EARTH	0.0280
PC10	463823.721	1126775.325	1622.180	1622.210	BARE EARTH	0.0300
PC06	469143.928	1122799.647	1573.171	1573.140	BARE EARTH	(0.0310)
PCX01	468488.391	1126134.156	1459.335	1459.370	BARE EARTH	0.0350
PC03	470188.216	1129639.600	1249.429	1249.390	BARE EARTH	(0.0390)
PC15	468491.400	1126135.684	1459.264	1459.220	BARE EARTH	(0.0440)
PCX04	464620.816	1130655.850	1462.194	1462.240	BARE EARTH	0.0460
PCX03	467598.921	1129876.133	1394.856	1394.810	BARE EARTH	(0.0460)
PC17	470372.574	1116480.096	1993.061	1993.110	BARE EARTH	0.0490
PCX13	470371.113	1116473.261	1993.092	1993.150	BARE EARTH	0.0580
PC12	471703.653	1129992.967	1213.420	1213.490	BARE EARTH	0.0700
PCX10	468179.251	1126839.951	1403.908	1403.830	BARE EARTH	(0.0780)
PCX02	470191.165	1129652.366	1249.665	1249.580	BARE EARTH	(0.0850)
PCX06	464762.086	1127536.867	1510.987	1510.900	BARE EARTH	(0.0870)

Table 10: Point Cloud Check Point Assessment

2. Digital Elevation Model (DEM) Check Point Assessment

Point ID	Easting	Northing	KnownZ	DEMZ	Description	DeltaZ
PC01	464891.808	1133720.653	1327.744	1327.737	BARE EARTH	-0.007
PC02	464645.265	1130669.048	1461.702	1461.711	BARE EARTH	0.009
PC03	470188.216	1129639.600	1249.429	1249.397	BARE EARTH	-0.032
PC04	470101.413	1119606.807	1846.679	1846.645	BARE EARTH	-0.034
PC05	467045.365	1122180.850	1637.295	1637.239	BARE EARTH	-0.056

Point ID	Easting	Northing	KnownZ	DEMZ	Description	DeltaZ
PC06	469143.928	1122799.647	1573.171	1573.115	BARE EARTH	-0.056
PC07	468186.620	1126842.872	1404.080	1404.039	BARE EARTH	-0.041
PC08	464184.328	1125963.646	1614.595	1614.588	BARE EARTH	-0.007
PC10	463823.721	1126775.325	1622.180	1622.186	BARE EARTH	0.006
PC11	467603.946	1129879.198	1394.645	1394.597	BARE EARTH	-0.048
PC12	471703.653	1129992.967	1213.420	1213.462	BARE EARTH	0.042
PC14	464770.682	1127538.401	1510.842	1510.785	BARE EARTH	-0.057
PC15	468491.400	1126135.684	1459.264	1459.223	BARE EARTH	-0.041
PC17	470372.574	1116480.096	1993.061	1993.029	BARE EARTH	-0.033
PCX01	468488.391	1126134.156	1459.335	1459.298	BARE EARTH	-0.037
PCX02	470191.165	1129652.366	1249.665	1249.561	BARE EARTH	-0.105
PCX03	467598.921	1129876.133	1394.856	1394.782	BARE EARTH	-0.074
PCX04	464620.816	1130655.850	1462.194	1462.211	BARE EARTH	0.017
PCX05	464911.799	1133727.685	1326.227	1326.209	BARE EARTH	-0.018
PCX06	464762.086	1127536.867	1510.987	1510.909	BARE EARTH	-0.078
PCX07	464188.367	1125964.378	1614.438	1614.427	BARE EARTH	-0.011
PCX08	463817.653	1126785.854	1622.129	1622.136	BARE EARTH	0.007
PCX09	471708.119	1129983.837	1213.654	1213.613	BARE EARTH	-0.041
PCX10	468179.251	1126839.951	1403.908	1403.834	BARE EARTH	-0.074
PCX11	469159.653	1122801.355	1572.952	1572.939	BARE EARTH	-0.013
PCX12	470107.205	1119619.189	1846.423	1846.418	BARE EARTH	-0.005
PCX13	470371.113	1116473.261	1993.092	1993.065	BARE EARTH	-0.027

Table 11: DEM Check Point Assessment