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
Willamette National Forest – Diamond Lake 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 Diamond Lake AOI, which encompasses three hundred twenty three (323) 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 15, 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)	8
Nominal Flight Height (AGL meters)	1300-3200
Nominal Flight Speed (kts)	110
Pass Heading (°)	Varies
Sensor Scan Angle (°)	22
Scan Frequency (Hz)	40.5
Pulse Rate of Scanner (kHz)	239.800

Parameter	Specification
Line Spacing (m)	335
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)	933
Nominal Swath Overlap (%)	50
Scan Pattern	Triangle

Table 4: Aerial LiDAR Sensor Acquisition Parameters

c. Flight Plan Execution 1

Atlantic acquired 247 passes of the AOI as a series of perpendicular and/or adjacent flight-lines executed in 6 flight missions conducted between July 7, 2017 and July 14, 2018. 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.

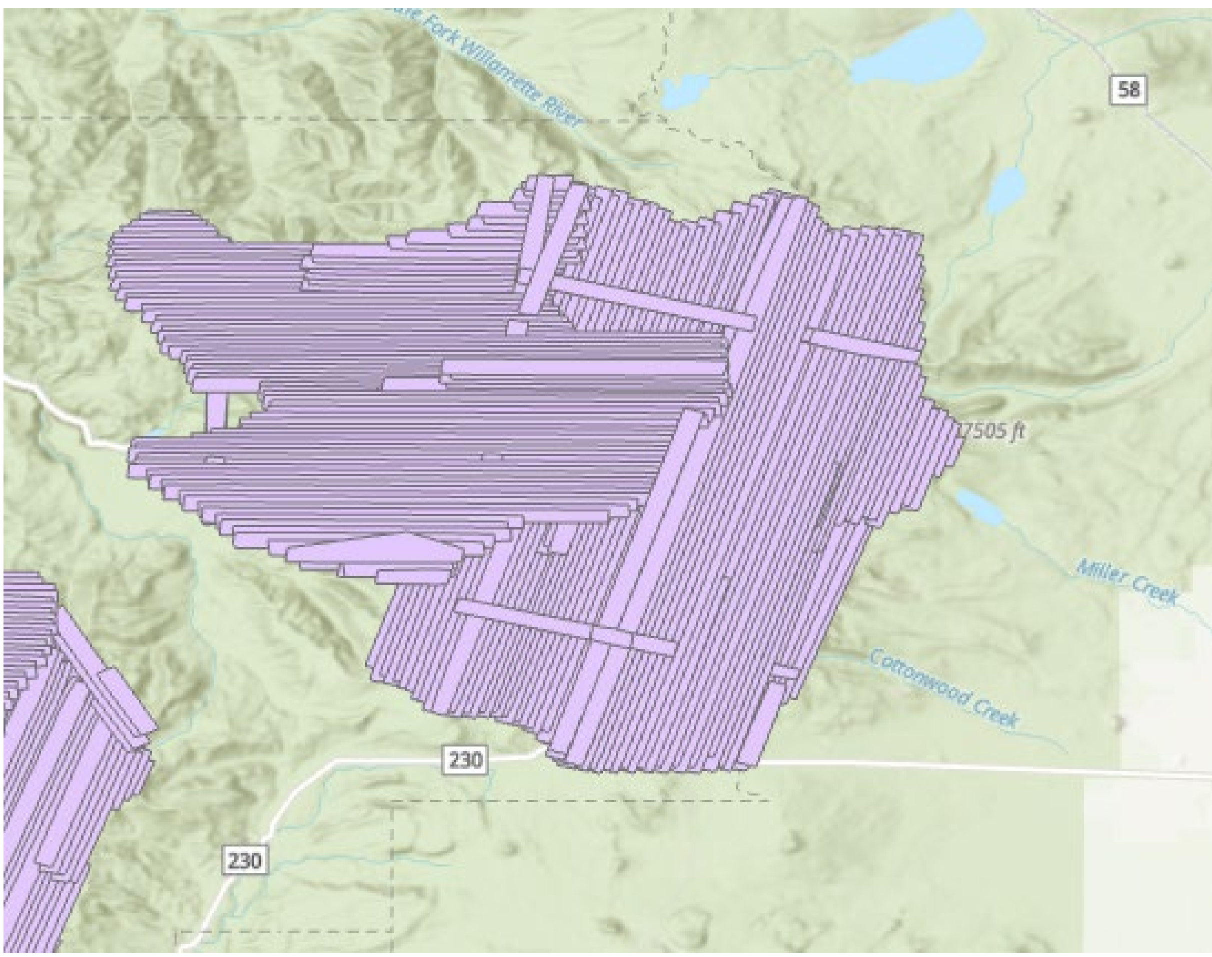


Figure 2: Orientation of Executed Flight-lines and LiDAR

d. GNSS Reference Stations

Four (4) 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
P737	CORS	P737	42°43' 37.70927"	122°36'34.69417"	1245.764
P371	CORS	P371	43°21' 47.78317"	123°03'28.44361"	1198.066
P382	CORS	P382	43°10' 37.40186"	121°46' 10.47216	1453.228
SWNB	CORS	SWNB	43°40' 21.85257"	121°21'19.60699"	1550.354

2. Ground Acquisition

a. Ground Control Survey

A total of 34 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
GCP01	414337.669	1029281.181	1128.400
GCP02	413825.401	1033128.330	1003.412
GCP03	420089.039	1034990.646	1248.028
GCP04	425650.915	1036629.588	1740.491
GCP05	427984.293	1033514.305	1678.256
GCP06	430243.232	1031895.190	1529.290
GCP07	433285.158	1033692.948	1658.054
GCP08	426219.069	1015210.609	1619.533
GCP09	417430.112	1028127.943	1492.102

ID	Easting	Northing	Elevation
GCP10	419040.896	1030873.303	1366.436
GCP11	425189.528	1029611.223	1273.761
GCP12	425238.555	1028422.126	1284.966
GCP13	430024.050	1030123.357	1311.170
GCP14	426447.236	1026370.975	1349.207
GCP15	405469.907	1023206.605	808.193
GCP16	409779.222	1021567.251	1114.634
GCP17	412518.638	1025360.856	1174.818
GCP18	412263.394	1020666.952	1662.719
GCP19	416385.058	1020244.267	1263.630
GCP20	421875.677	1021608.625	1404.456
GCP21	423477.497	1023637.401	1381.438
GCP22	428220.267	1020598.100	1690.952
GCP23	432071.538	1019566.136	1991.770
GCP24	429499.382	1019448.862	1794.668
GCP25	426434.455	1018333.867	1571.553
GCP26	422523.957	1018345.668	1632.739
GCP27	416593.658	1018442.579	1325.097
GCP28	426321.088	1016107.510	1618.362
GCP29	423891.771	1013627.259	1582.122
GCP30	422149.078	1006901.078	1649.068
GCP31	420023.031	1008464.803	1774.468
GCP32	426407.881	1008968.581	1605.049
GCP33	429497.744	1005556.448	1791.328
GCP34	435246.928	1035462.058	1772.657

Table 5: Non-Vegetated Vertical Accuracy (NVA) Point Coordinates

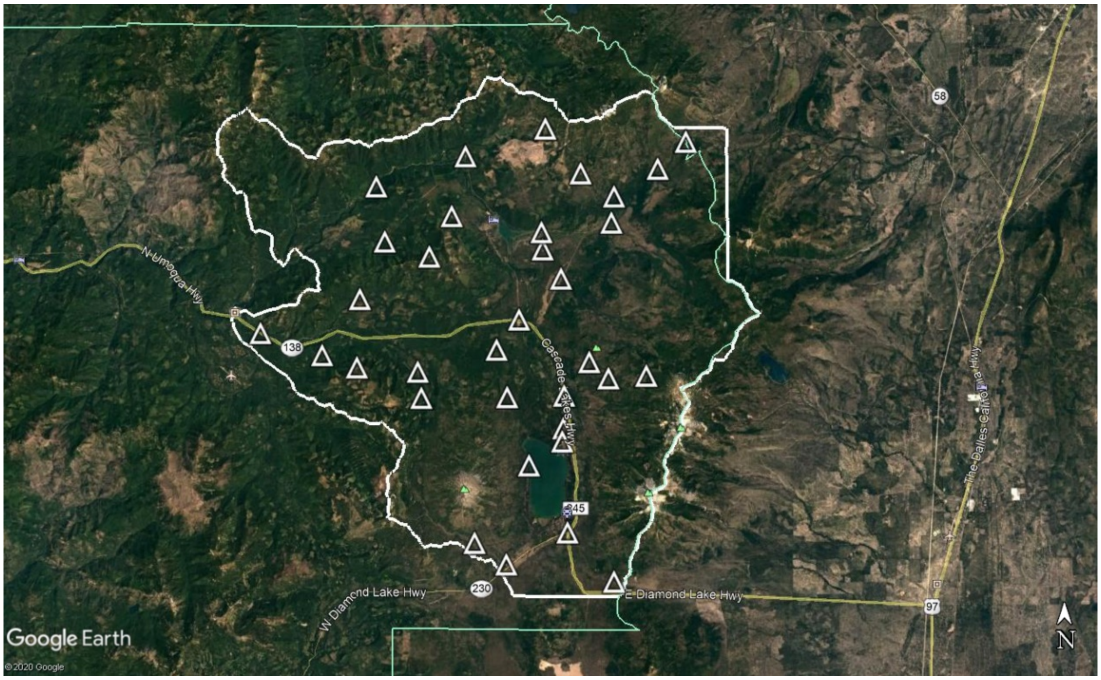


Figure 3: Non-Vegetated Vertical Accuracy (NVA) Point Distribution Data Production

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	10,921,684,401
Nominal Pulse Spacing (m)	0.4568
Nominal Pulse Density (pls/m²)	4.7933
Aggregate Total Points	10,921,684,401
Aggregate Nominal Pulse Spacing (m)	0.2953
Aggregate Nominal Pulse Density (pls/m²)	11.4679

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.

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
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	32	0.0999	0.1957	0.0619
NVA of DEM	32	0.0956	0.1875	0.2010

Table 9: NVA/VVA Accuracies

PointID	Easting	Northing	KnownZ	LaserZ	Description	DeltaZ
GCP04	425650.9150	1036629.5880	1740.4910	removed	*	GCP04
GCP15	405469.9070	1023206.6050	808.1930	removed	*	GCP15

Table10: Outlier Check Points

SECTION V: CERTIFICATION STATEMENT

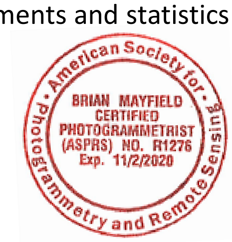
This accuracy assessment confirms that the data may be used for the intended applications stated in Section I of this document. This dataset may also be used as a topographic input for other applications, but the user should be aware that this LiDAR dataset was designed with a specific purpose and was 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.



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Brian J. Mayfield, ASPRS Certified Photogrammetrist #R1276

SECTION VI: CONTROL POINT ASSESSMENTS

1. Point Cloud Check Point Assessment

Point ID	Given (X)	Given (Y)	Given (Z)	Laser (Z)	Delta (Z)
GCP01	414337.6690	1029281.1810	1128.4000	1128.3200	-0.0800
GCP02	413825.4010	1033128.3300	1003.4120	1003.4200	0.0080
GCP03	420089.0390	1034990.6460	1248.0280	1247.8100	-0.2180
GCP05	427984.2930	1033514.3050	1678.2560	1678.3600	0.1040
GCP06	430243.2320	1031895.1900	1529.2900	1529.3200	0.0300
GCP07	433285.1580	1033692.9480	1658.0540	1658.0500	-0.0040
GCP08	426219.0690	1015210.6090	1619.5330	1619.5800	0.0470
GCP09	417430.1120	1028127.9430	1492.1020	1492.0000	-0.1020
GCP10	419040.8960	1030873.3030	1366.4360	1366.4700	0.0340
GCP11	425189.5280	1029611.2230	1273.7610	1273.7200	-0.0410
GCP12	425238.5550	1028422.1260	1284.9660	1284.8600	-0.1060
GCP13	430024.0500	1030123.3570	1311.1700	1311.1700	0.0000
GCP14	426447.2360	1026370.9750	1349.2070	1349.2000	-0.0070
GCP16	409779.2220	1021567.2510	1114.6340	1114.6200	-0.0140
GCP17	412518.6380	1025360.8560	1174.8180	1174.7600	-0.0580
GCP18	412263.3940	1020666.9520	1662.7190	1662.6300	-0.0890
GCP19	416385.0580	1020244.2670	1263.6300	1263.6700	0.0400
GCP20	421875.6770	1021608.6250	1404.4560	1404.5300	0.0740
GCP21	423477.4970	1023637.4010	1381.4380	1381.4400	0.0020
GCP22	428220.2670	1020598.1000	1690.9520	1690.9200	-0.0320
GCP23	432071.5380	1019566.1360	1991.7700	1991.5700	-0.2000
GCP24	429499.3820	1019448.8620	1794.6680	1794.3600	-0.3080
GCP25	426434.4550	1018333.8670	1571.5530	1571.5500	-0.0030
GCP26	422523.9570	1018345.6680	1632.7390	1632.7100	-0.0290
GCP27	416593.6580	1018442.5790	1325.0970	1325.0100	-0.0870
GCP28	426321.0880	1016107.5100	1618.3620	1618.3200	-0.0420
GCP29	423891.7710	1013627.2590	1582.1220	1582.0700	-0.0520
GCP30	422149.0780	1006901.0780	1649.0680	1649.0100	-0.0580
GCP31	420023.0310	1008464.8030	1774.4680	1774.5200	0.0520
GCP32	426407.8810	1008968.5810	1605.0490	1604.8900	-0.1590
GCP33	429497.7440	1005556.4480	1791.3280	1791.3400	0.0120
GCP34	435246.9280	1035462.0580	1772.6570	1772.4900	-0.1670

Table 11: Point Cloud Check Point Assessment

2. Digital Elevation Model (DEM) Check Point Assessment

Point ID	Given (X)	Given (Y)	Given (Z)	DEM (Z)	DEM (DZ)
GCP01	414337.6690	1029281.1810	1128.4000	1128.3290	0.0710
GCP02	413825.4010	1033128.3300	1003.4120	1003.4000	0.0120
GCP03	420089.0390	1034990.6460	1248.0280	1247.8160	0.2120
GCP05	427984.2930	1033514.3050	1678.2560	1678.3300	-0.0740
GCP06	430243.2320	1031895.1900	1529.2900	1529.3050	-0.0150
GCP07	433285.1580	1033692.9480	1658.0540	1658.0450	0.0090
GCP08	426219.0690	1015210.6090	1619.5330	1619.5890	-0.0560
GCP09	417430.1120	1028127.9430	1492.1020	1491.9960	0.1060
GCP10	419040.8960	1030873.3030	1366.4360	1366.4570	-0.0210
GCP11	425189.5280	1029611.2230	1273.7610	1273.7160	0.0450
GCP12	425238.5550	1028422.1260	1284.9660	1284.8640	0.1020
GCP13	430024.0500	1030123.3570	1311.1700	1311.1360	0.0340
GCP14	426447.2360	1026370.9750	1349.2070	1349.2170	-0.0100
GCP16	409779.2220	1021567.2510	1114.6340	1114.6060	0.0280
GCP17	412518.6380	1025360.8560	1174.8180	1174.7760	0.0420
GCP18	412263.3940	1020666.9520	1662.7190	1662.6370	0.0820
GCP19	416385.0580	1020244.2670	1263.6300	1263.6620	-0.0320
GCP20	421875.6770	1021608.6250	1404.4560	1404.5510	-0.0950
GCP21	423477.4970	1023637.4010	1381.4380	1381.4330	0.0050
GCP22	428220.2670	1020598.1000	1690.9520	1690.9140	0.0380
GCP23	432071.5380	1019566.1360	1991.7700	1991.5780	0.1920
GCP24	429499.3820	1019448.8620	1794.6680	1794.3780	0.2900
GCP25	426434.4550	1018333.8670	1571.5530	1571.5680	-0.0150
GCP26	422523.9570	1018345.6680	1632.7390	1632.6980	0.0410
GCP27	416593.6580	1018442.5790	1325.0970	1325.0230	0.0740
GCP28	426321.0880	1016107.5100	1618.3620	1618.3230	0.0390
GCP29	423891.7710	1013627.2590	1582.1220	1582.0750	0.0470
GCP30	422149.0780	1006901.0780	1649.0680	1648.9950	0.0730
GCP31	420023.0310	1008464.8030	1774.4680	1774.5170	-0.0490
GCP32	426407.8810	1008968.5810	1605.0490	1604.9170	0.1320
GCP33	429497.7440	1005556.4480	1791.3280	1791.3220	0.0060
GCP34	435246.9280	1035462.0580	1772.6570	1772.4830	0.1740

Table 12: DEM Check Point Assessment