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 – Willamette 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 Willamette AOI, which encompasses ten (10) square miles of the Willamette 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)	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 1

Atlantic acquired 10 passes of the AOI as a series of perpendicular and/or adjacent flight-lines executed in flight missions conducted between July 15, 2017 and July 15, 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.

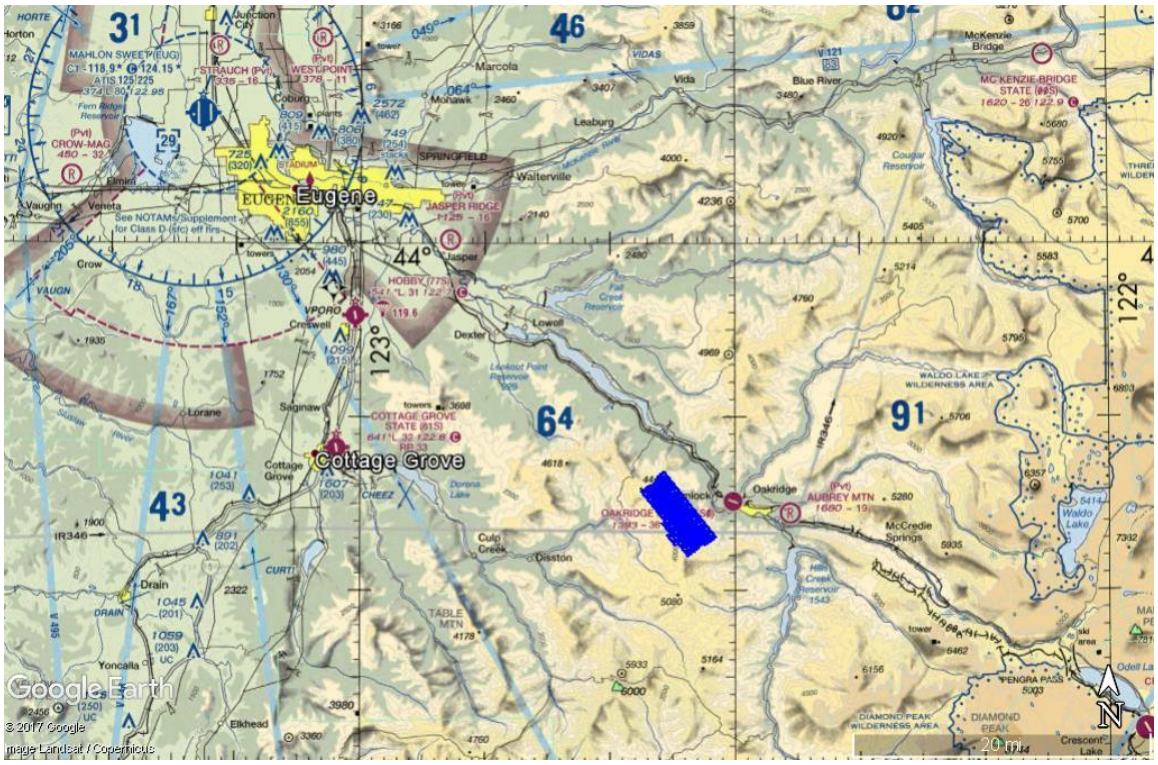


Figure 2: Orientation of Executed Flight-lines and LiDAR DPA

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 56 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	557652.7	4795134	1128.4
GCP02	556998.6	4798957	1003.412
GCP03	563188.4	4801048	1248.028
GCP04	568685.5	4802891	1740.491
GCP05	571132	4799865	1678.256
GCP06	573448.9	4798331	1529.29
GCP07	576422.2	4800239	1658.054
GCP08	570043.3	4781518	1619.533
GCP09	560785.2	4794096	1492.102
GCP10	562293.2	4796897	1366.436
GCP11	568483.5	4795864	1273.761
GCP12	568576.3	4794678	1284.966
GCP13	573295.2	4796554	1311.17
GCP14	569859.7	4792674	1349.207
GCP15	549017.2	4788739	808.193
GCP16	553383.4	4787261	1114.634
GCP17	555980.1	4791151	1174.818
GCP18	555898.6	4786453	1662.719

ID	Easting	Northing	Elevation
GCP19	560032.2	4786183	1263.63
GCP20	565467.7	4787749	1404.456
GCP21	566993.3	4789834	1381.438
GCP22	571844.1	4786973	1690.952
GCP23	575730.1	4786085	1991.77
GCP24	573164.5	4785873	1794.668
GCP25	570143.3	4784646	1571.553
GCP26	566235.8	4784514	1632.739
GCP27	560307.2	4784392	1325.097
GCP28	570112.2	4782418	1618.362
GCP29	567776.5	4779851	1582.122
GCP30	566283.4	4773068	1649.068
GCP31	564101.7	4774552	1774.468
GCP32	570462	4775290	1605.049
GCP33	573674.7	4771996	1791.328
GCP34	578317.2	4802078	1772.657
DL_GCP033	570462	4775290	1605.049
DL_GCP032	564101.7	4774552	1774.468
DL_GCP023	571844.1	4786973	1690.952
DL_GCP025	573164.5	4785873	1794.668
DL_GCP024	575730.1	4786085	1991.77
DL_GCP026	570143.3	4784646	1571.553
DL_GCP029	570112.2	4782418	1618.362
DL_GCP030	567776.5	4779851	1582.122
DL_GCP027	566235.8	4784514	1632.739
DL_GCP015	549017.2	4788739	808.193
DL_GCP016	553383.4	4787261	1114.634
DL_GCP019	555898.6	4786453	1662.719
DL_GCP028	560307.2	4784392	1325.097
DL_GCP031	566283.4	4773068	1649.068
W_GCP006	536223.3	4840922	1086.009
W_GCP005	533648.4	4841352	1130.137
W_GCP004	533462.7	4843558	992.815
W_GCP002	533234.8	4846644	979.698
W_GCP003	532462.2	4846487	1065.096
W_GCP001	531849.9	4845358	1172.505
W_GCPX01	531873.8	4845386	1171.457
W_GCPX02	532831.5	4841690	1084.708

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

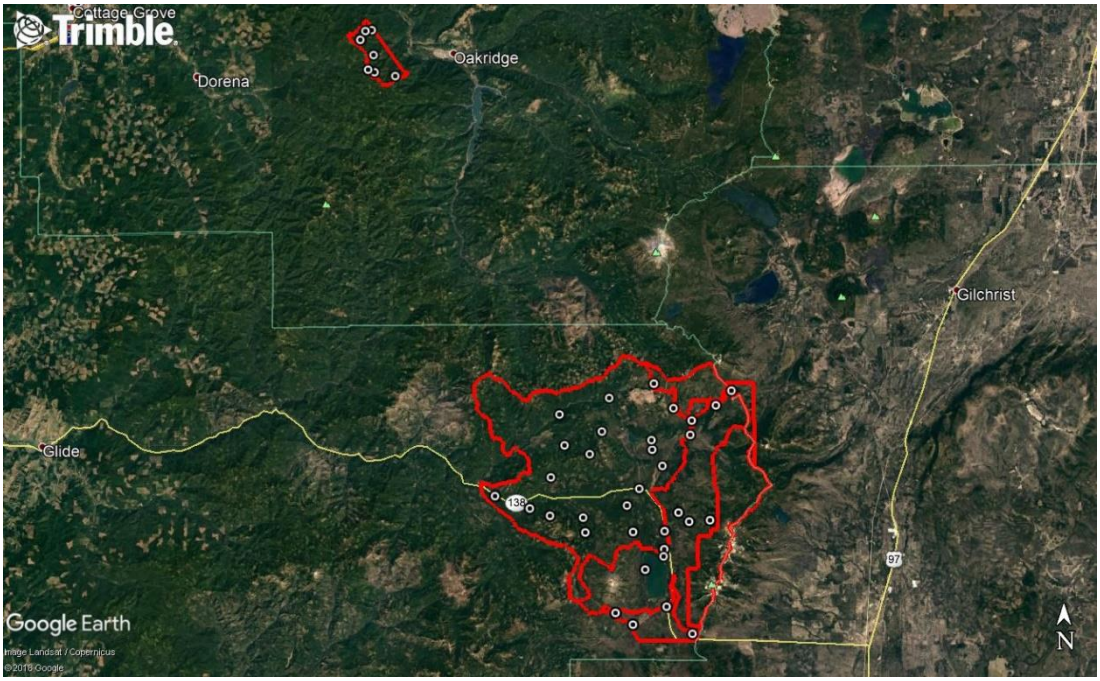


Figure 3: Non-Vegetated Vertical Accuracy (NVA) Point Distribution Data Production

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	619,182,016
Nominal Pulse Spacing (m)	0.3550
Nominal Pulse Density (pls/m²)	7.9349
Nominal Pulse Spacing (ft)	1.1647
Nominal Pulse Density (pls/ft²)	0.7372
Aggregate Total Points	619,182,016
Aggregate Nominal Pulse Spacing (m)	598,779,388
Aggregate Nominal Pulse Density (pls/m²)	0.2552
Aggregate Nominal Pulse Spacing (ft)	15.3525
Aggregate Nominal Pulse Density (pls/ft²)	0.8373

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	8	0.0713	0.1397	0.0978
NVA of DEM	8	0.0731	0.1432	0.0786

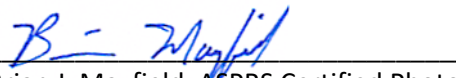
Table 9: NVA/VVA Accuracies

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
W_GCP001	390414.786	1080463.568	1172.505	1172.540	BARE EARTH	0.035
W_GCP002	391846.452	1081698.417	979.698	979.730	BARE EARTH	0.032
W_GCP003	391068.659	1081570.447	1065.096	1065.090	BARE EARTH	-0.006
W_GCP004	391959.477	1078603.645	992.815	992.700	BARE EARTH	-0.115
W_GCP005	392062.998	1076390.646	1130.137	1130.060	BARE EARTH	-0.077
W_GCP006	394619.929	1075864.990	1086.009	1086.060	BARE EARTH	0.051
W_GCPX01	390439.770	1080491.341	1171.457	1171.580	BARE EARTH	0.123
W_GCPX02	391259.274	1076758.515	1084.708	1084.670	BARE EARTH	-0.038

Table 10: Point Cloud Check Point Assessment

2. Digital Elevation Model (DEM) Check Point Assessment

Point ID	Easting	Northing	KnownZ	DEMZ	Description	DeltaZ
W_GCP001	390414.786	1080463.568	1172.505	1172.490	BARE EARTH	-0.015
W_GCP002	391846.452	1081698.417	979.698	979.736	BARE EARTH	0.038
W_GCP003	391068.659	1081570.447	1065.096	1065.080	BARE EARTH	-0.016
W_GCP004	391959.477	1078603.645	992.815	992.676	BARE EARTH	-0.139
W_GCP005	392062.998	1076390.646	1130.137	1130.062	BARE EARTH	-0.075
W_GCP006	394619.929	1075864.990	1086.009	1086.055	BARE EARTH	0.046
W_GCPX01	390439.770	1080491.341	1171.457	1171.553	BARE EARTH	0.096
W_GCPX02	391259.274	1076758.515	1084.708	1084.641	BARE EARTH	-0.067

Table 11: DEM Check Point Assessment