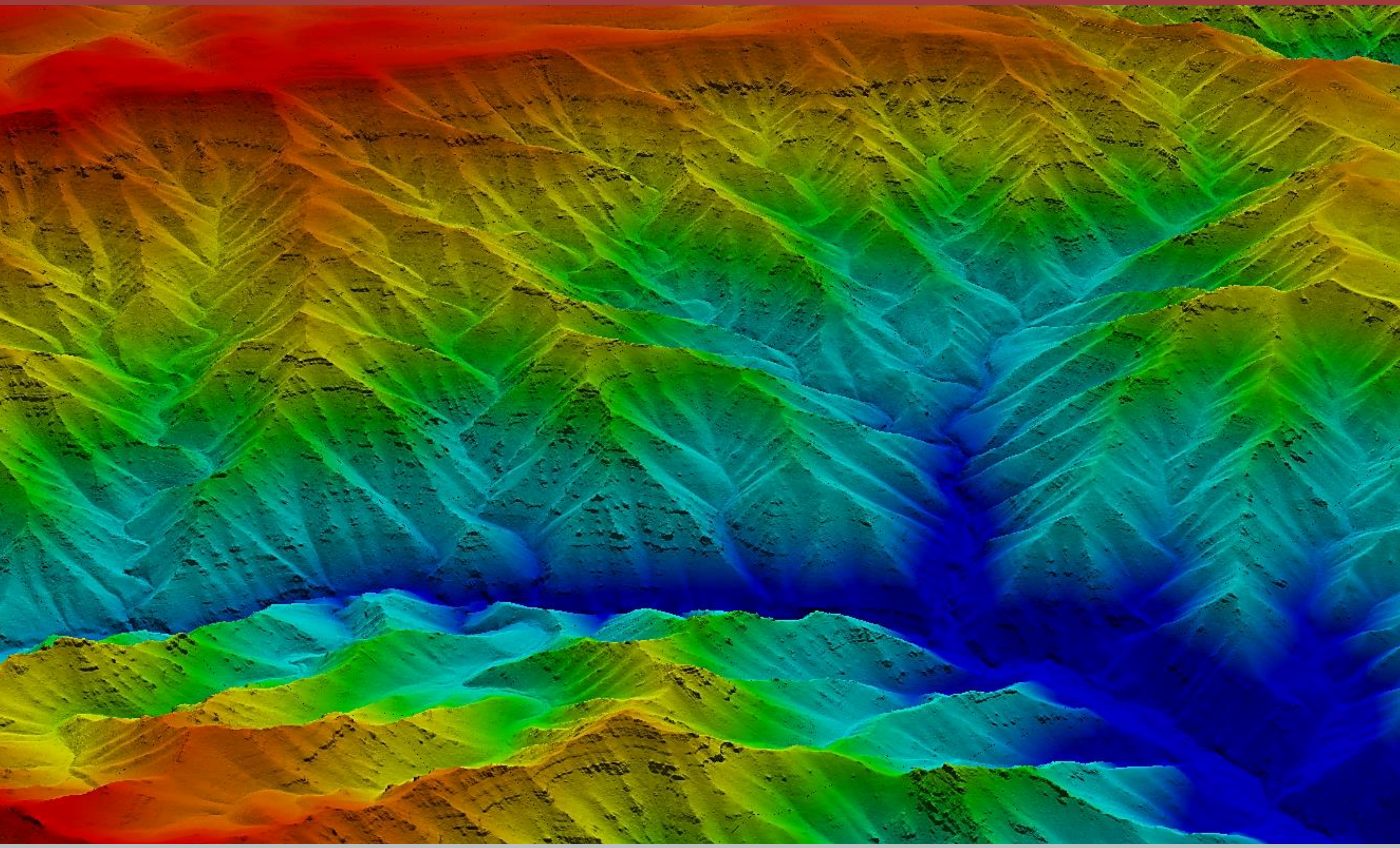
LiDAR MAPPING REPORT

UMATILLA WALLOWA WHITMAN AERIAL SURVEY

Task Order Name: OR_UmatillaWallowaWhitman_1_B22
Task Order Number: 140G0222F0079
PRJ_ID: 224846
WU_ID: 300194

Submitted: November 8, 2023



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Umatilla Wallowa Whitman Aerial Survey

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1. Overview

1.1 Project Area

Aero-Graphics, Inc., a full-service geospatial firm located in Salt Lake City, Utah, was contracted by the U.S. Geological Survey (USGS) and partners to acquire, process, and deliver leaf-on aerial lidar data and derivative products that adhere to U.S. Geological Survey (USGS) National Geospatial Program (NGP) Lidar Base Specification 2021, Revision A, QL1 standards. The assigned project area covers approximately 557 square miles in Wallowa County, OR, Asotin County, WA, and Idaho County, ID. This report describes the planning, acquisition, and processing of the LiDAR dataset as well as other deliverables.

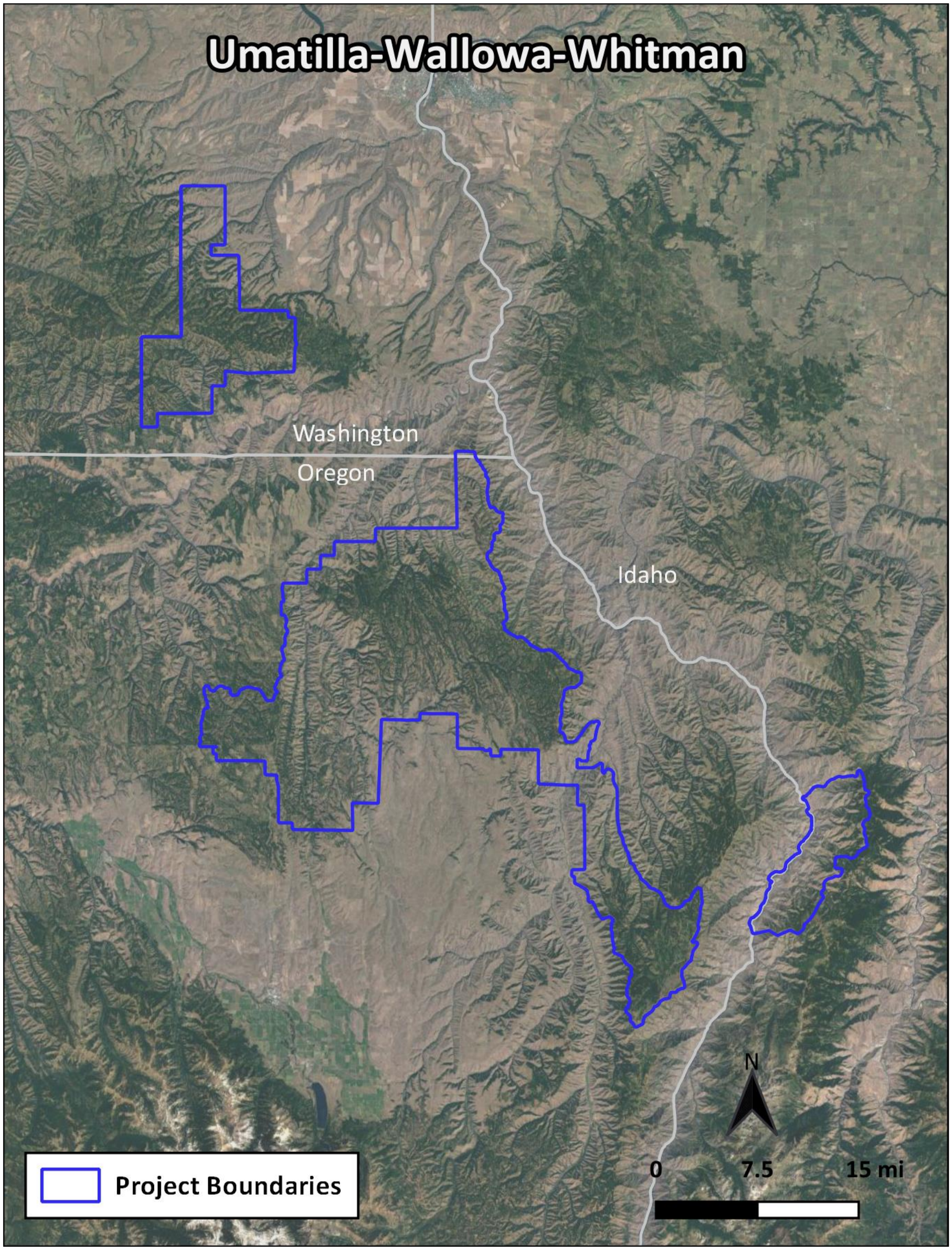
1.2 Project Deliverables

LiDAR Data	▪ Classified point cloud data in LAS v1.4 format, zipped to LAZ
Raster Data	▪ Bare-earth DEM with 0.5 meter resolution in .GeoTIFF format ▪ MSHRs and swath separation images delivered in GeoTIFF format
Vector Data	▪ Surveyed GCPs and checkpoints in .gpkg format ▪ Breaklines in geodatabase format ▪ Flight index in geodatabase format ▪ Relative accuracy, tile index, and AOI shapefiles
Report of Survey	▪ LiDAR Mapping Report including metadata, methodology, accuracy, and results

1.3 Projection, Datum, Units

Projection		UTM Zone 11N
EPSG		6340 & 5703
Datum	Vertical	NAVD88 (Geoid18)
	Horizontal	NAD83 (2011)
Units		Meters

<u>Exhibit 1:</u> Umatilla Wallowa Whitman project boundary



2. Acquisition

2.1 Flight Planning

Aero-Graphics Aerial Department created a unique flight plan for this project using Optech's Airborne Mission Manager (AMM) flight planning software. AMM simulates flight plans based on the project area's terrain, as well as the sensor's model, mount, and settings. These features helped ensure that all contract specifications are met in the most efficient way possible. Prior to mobilizing to the acquisition sites, Aero-Graphics' staff monitored all site conditions and potential weather hazards including wind, rain, snow, and blowing dust. Additionally, Aero-Graphics ensured all airspace clearances were secured by the proper officials before acquisition occurred. A summary of the flight parameters and sensor settings for the Umatilla Wallowa Whitman Aerial Survey are outlined in **Exhibit 2**.

Exhibit 2: Summary of planned flight parameters and sensor settings

Planned Specifications		
Aircraft		Cessna 310
Altitude (ft above ground level)		7,200
Speed (kts)		180
LiDAR Sensor		Optech Galaxy T2000
PRF (kHz)		1,000
Scan frequency (Hz)		107
Laser power		High
Scan Angle	Full	40°
	From nadir	± 20°
Planned Average Point Density (p/m²)		5.01
Planned Aggregate Point Density (p/m2)		10.02
Post Spacing at Nadir	Cross Track (m)	0.46
	Down Track (m)	0.43
Swath Width (m)		1,575
Sidelap (%)		55
No. of Flightlines		132

2.2 Data Acquisition

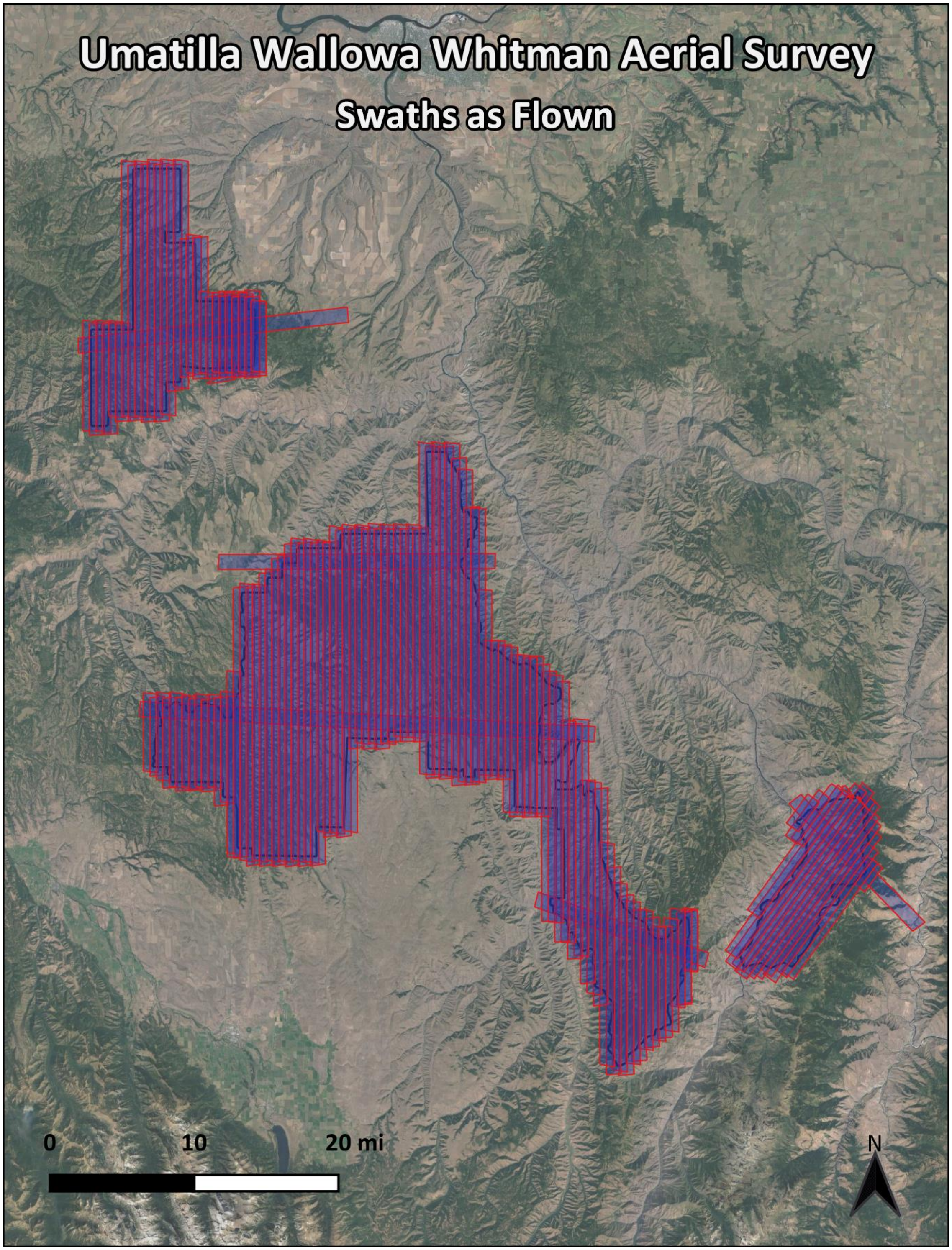
Aero-Graphics acquired LiDAR data throughout August 2022 with a turbocharged Cessna 310 (**Exhibit 3**). The stability of this platform is ideal for efficient data collection at high and low altitudes and at a variety of airspeeds. Additionally, our Cessna 310 has been customized to house a variety of airborne sensors, and the power system and avionics have been upgraded specifically to meet aerial survey needs.

<u>Exhibit 3</u>: A Cessna 310 was the acquisition platform for this project

The Optech Galaxy T2000 was selected for this project on account of its high accuracy and efficiency (**Exhibit 4**). This sensor uses SwathTrak technology, which dynamically adjusts the scan field of view in real time to maintain a constant swath width over a variety of terrains. It also features up to 8 returns per pulse, which increases the vertical resolution of complex terrains. The sensor is complemented with the use of FMS Nav, which allowed the system operator to monitor the point density and swath attributes of this project in real time, ensuring quality data and full coverage, as shown in **Exhibit 5**. More information about point density can be found in Section 4.4.

<u>Exhibit 4:</u> The Optech Galaxy T2000 was used for data acquisition

Exhibit 5: **Swath data for the Umatilla Wallowa Whitman project was recorded and viewed in real-time by the sensor operator.**



2.3 Acquisition Summary

Aero-Graphics acquired LiDAR data beginning August 11, 2022 and concluded acquisition on August 29, 2022. As specified in the work order acquisition took place during leaf-on conditions, while most trees and other types of vegetation retained their foliage. Prior to mobilization ground conditions were monitored to ensure the ground was free of snow, ice, and standing water. There were no technical issues such as LiDAR sensor problems during acquisition.

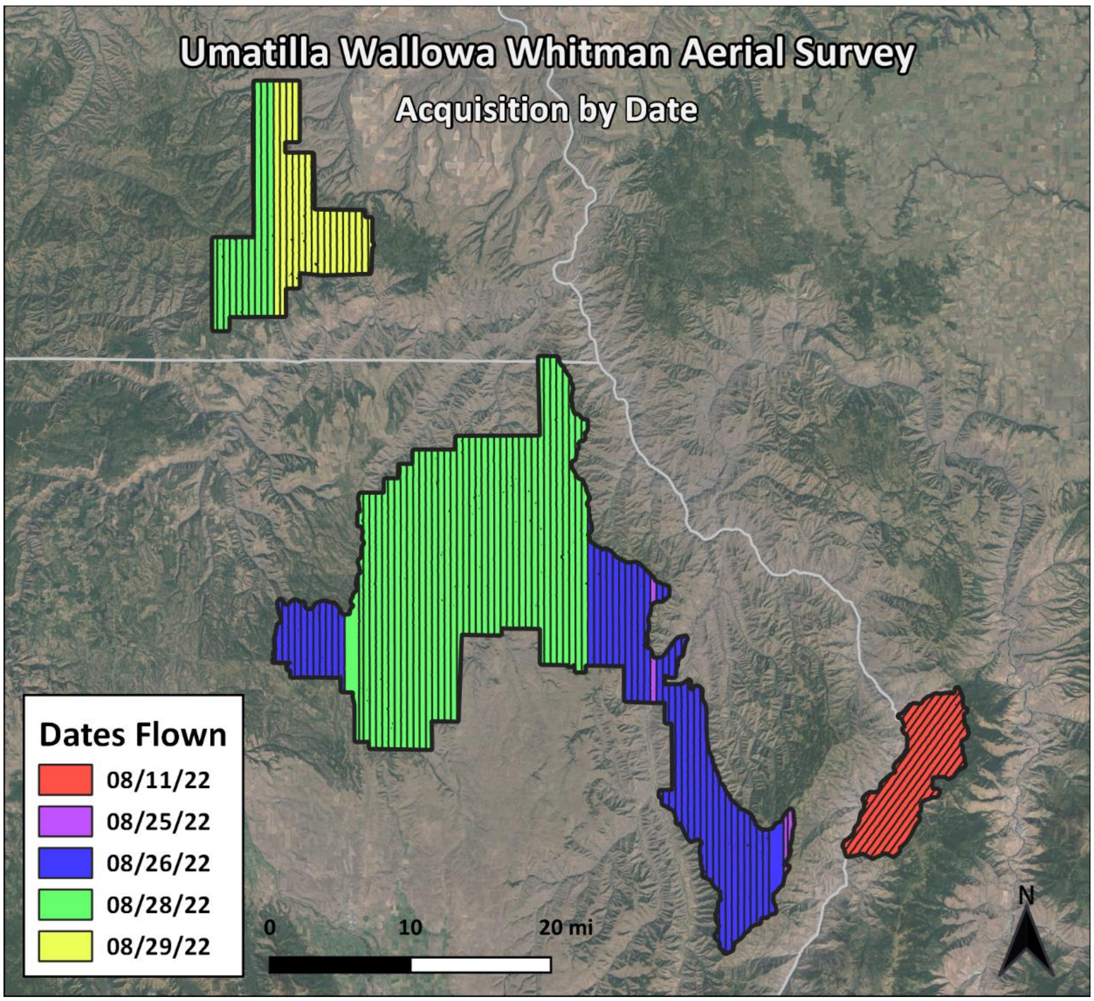


Exhibit 6: The lines flown by date for the Umatilla Wallowa Whitman project

2.4 GROUND CONTROL AND CHECK POINT SURVEY

Aero-Graphics' professional land surveyor identified, targeted, and surveyed 38 ground control points (**Exhibit 7**) for use in data calibration as well as 62 QC check points (**Exhibit 8**) in vegetated and non-vegetated land cover classification as an independent test of accuracy for this project. A combination of precise GPS surveying methods, including static and RTK observations were used to establish the 3D position of ground control points and QC check points. Ground control coordinates can be found in Appendix A. A summary of LiDAR calibration control vertical accuracy can be found in Section 4.2 with a more detailed report in Appendix B.

Exhibit 7: Static ground control for the Umatilla Wallowa Whitman project

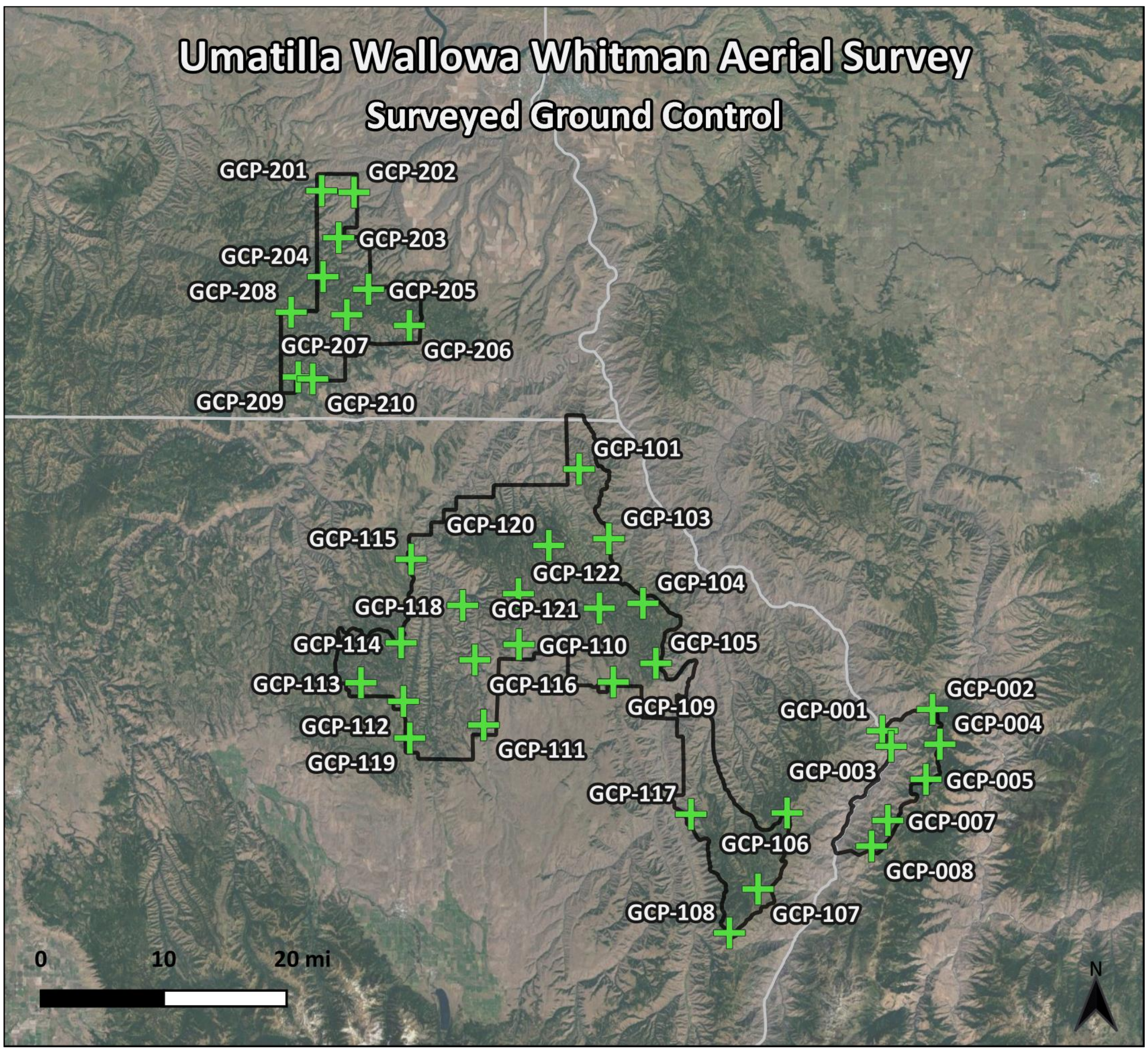
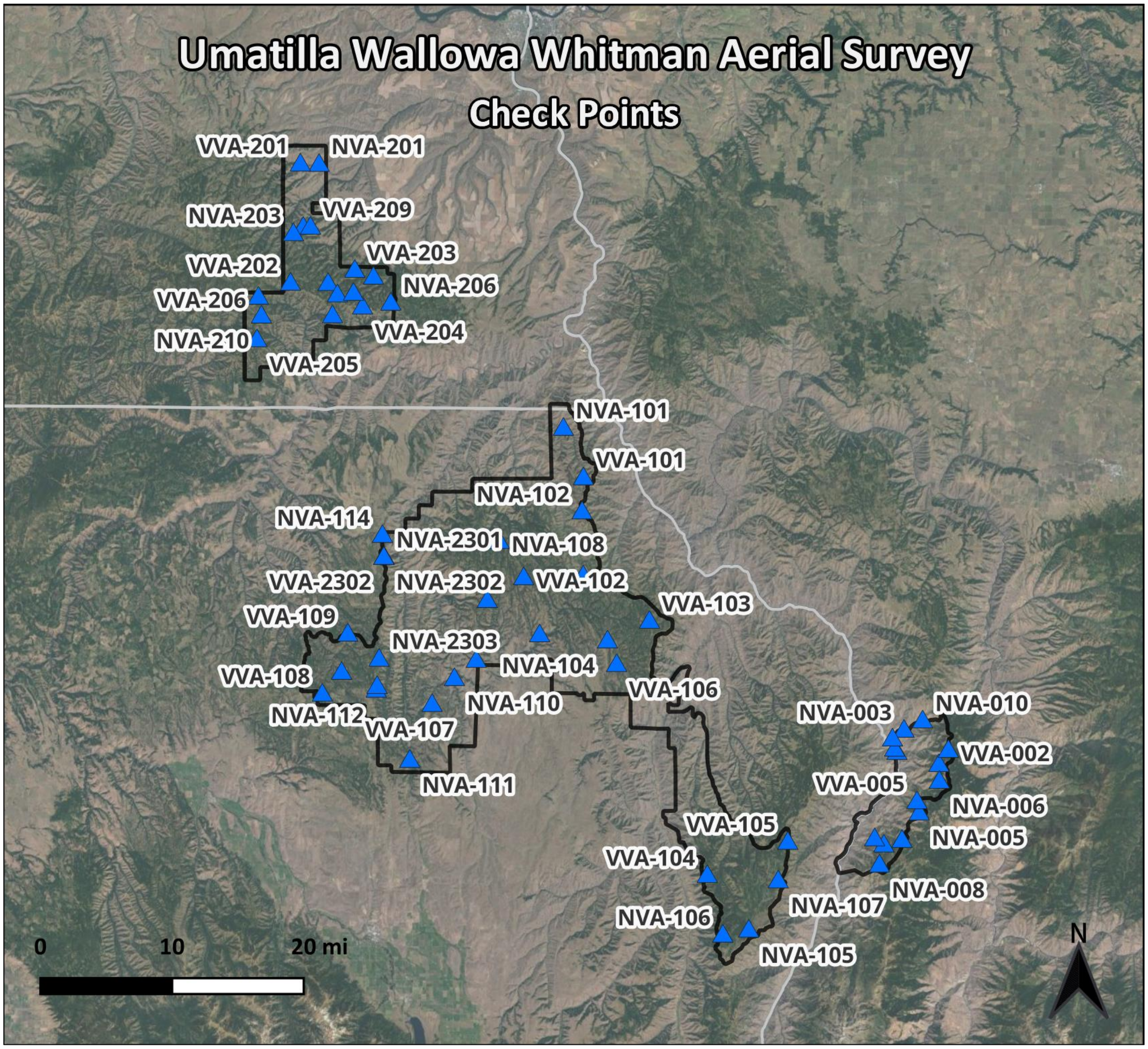


Exhibit 8: **Check Points for the Umatilla Wallowa Whitman project**



3. LIDAR PROCESSING WORKFLOW

1. **Absolute Sensor Calibration**. Following sensor installation, lever arm values were surveyed. A boresight mission was flown over our fully controlled local range, and when adjusted to the surveyed ground control for roll, pitch, heading, and scale errors, boresight angles were developed for application to the POS processing in subsequent steps.
2. **Kinematic Air Point Processing.** The airborne GPS positions (collected at 1-second intervals) were post-processed using Applanix's POSPac MMS GNSS Inertial software (PP-RTX). A smoothed best estimate of trajectory (SBET) was developed by combining the corrected GPS positions with 1/200-second inertial measurement unit (IMU) data, which tracked the plane's roll, pitch, and yaw throughout the flight.
3. **Raw LiDAR Point Processing (Calibration).** The SBET and LiDAR range data were combined to solve for the real-world positions of each laser point using Optech's LiDAR Mapping Suite (LMS) software, version 4.6.2. Point cloud data was produced by flight strip in ASPRS v1.4 LAS format. Flight strips were output in the project's coordinate system. LMS's internal noise filtering processes were utilized to flag atmospheric noise points and geometrically unreliable points at the far edges of the swaths as withheld.
4. **Relative Calibration.** Performed relative calibration by correcting for roll, pitch, heading, and scale discrepancies between adjacent flightlines; tested resulting relative accuracy. The Aero-Graphics Team generated swath separation images using LP360 software. These images were created from the last return of all points except points classified as noise and/or flagged as withheld. Point Insertion was used as the Surface Method and the cell size was set to 2x the deliverable DEM cell size. The three interval bins used are bulleted above and the parameter to "Modulate source differences by Intensity" was set to 50%. The output GeoTIFF rasters were tiled to the project tile grid, clipped to the master DPA, and formatted (including defining the CRS which matches the project CRS) using GDAL software, version 2.4.0. These results are presented in Section 4.1.

    a. A **Dz Ortho Raster** was generated as part of this process (**Exhibit 9**). This raster identifies clusters of large residuals and differences in measured elevations between overlapping flightlines. These errors are usually caused by topographic relief or environmental factors and require manual adjustments to correct. In most cases, multiple iterations of the Dz ortho raster are created to aid in fine tuning relative calibration parameters.

Exhibit 9: **A Dz ortho raster generated for the Umatilla Wallowa Whitman project**

5. **Vertical Accuracy Assessment** Height differences between each static survey point and the laser point surface were identified through comparative tests. Results are presented in Section 4.2.
6. **Tiling & Long/Short Filtering** Extremely long and short returns were also filtered out as outliers and classified to low or high noise and flagged as withheld in preparation for ground point classification.
7. **Classified LAS Processing.** The point classification was performed with the ASPRS classes described in **Exhibit 10**. The bare-earth surface was classified using a combination of TerraScan macro functionality as well as proprietary software. The bare-earth surface was then manually reviewed and corrected to ensure completeness and accuracy. All other classes were also reviewed and corrected manually in Terrascan. LP360 was then used as a final check of the bare-earth dataset. LP360 and TerraScan software were also used to perform statistical analysis of the classes in the LAS files on a per tile level to verify classification metrics and full LAS header information was present in all LAS files.

Exhibit 10: The ASPRS classes used in lidar point classification

ASPRS Version 1.4 minimum point cloud classification scheme		
CLASS #	**CLASS NAME**	**DESCRIPTION**
1	Processed, but unclassified	Points that do not fit any other classes
2	Bare earth	Bare earth surface
7	Low noise	Low points identified below surface
9	Water	Points inside of lakes/ponds
17	Bridge decks	Points on bridge decks
18	High noise	High points identified above surface
20	Ignored ground	Points near breakline features; ignored in DEM creation process

8. **Hydro-Flattened Breakline Collection**. Full point cloud intensity imagery, DEMs, and bare earth terrains were used to manually digitize 3D breaklines. Breakline features were collected for inland streams and rivers with a 30-meter nominal width, and inland ponds and lakes of 2 acres or greater surface area. Elevation values were assigned to all inland ponds and lakes, inland pond and lake islands, and inland stream and river islands, using ESRI and LP360 functionality.

9. **Hydro-Flattened Raster DEM Creation.** A hydro-flattened raster digital elevation model (DEM) was created from a TIN surface generated using the ground classified LiDAR points. The DEMs were generated in LP360 with breaklines enforced and clipped to the project tile grid. The tiled DEMs were reviewed at a scale of 1:5,000 to look for artifacts caused by the DEM generation process and to verify correct and complete hydro-flattening was applied. Upon correction of any outstanding issues, the DEM data was loaded into Global Mapper for its second review and to verify corrections. Final DEMs are formatted using GDAL software version 2.4.0.

10. **Maximum Surface Height Rasters Creation**. MSHRs were delivered as tiled GeoTIFFs (32-bit, floating point), with the tile size and naming convention matching the project tile grid. All points, excluding points flagged as withheld, were used to produce MSHRs. The rasters were produced with a binning method in which the highest elevation of all lidar points intersecting each pixel was applied as the pixel elevation in the resulting raster. Final MSHRs were formatted using GDAL software version 2.4.0, spatially defined to match the project CRS, and the cell size equaled 2x the deliverable DEM cell size.

4. Accuracy Testing and Results

4.1 Relative Calibration Accuracy Results

Inter-swath relative accuracy is defined as the elevation difference in the overlapping area of parallel swaths. Inter-swath polygons were created across the entire dataset in non-vegetated areas on slopes of less than 10 degrees. The generated polygons were attributed with the min, max, and RMSDz data derived from Swath Separation Images. The statistics below are based on the elevation differences calculated between swaths.

Umatilla Wallowa Whitman project area:

- Inter-swath relative accuracy **average** of 0.012 m

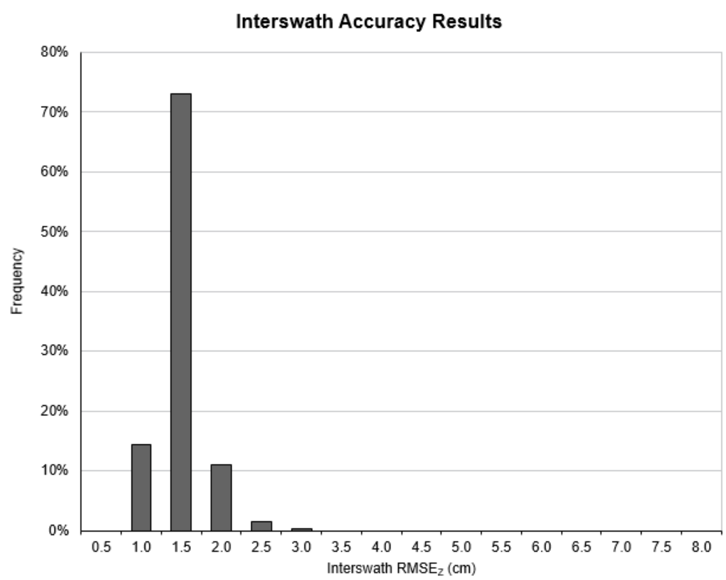


Exhibit 11: Frequency distribution of interswath RMSDz results for the Umatilla Wallowa Whitman project.

Intra-swath Precision is a measure of the noise present within the lidar sensor. Intra-swath accuracy measures the variations in elevations over a smooth, flat surface. Intra-swath polygons were manually created on level, hard surfaces. The generated polygons were attributed with the min, max, and RMSDz data across the polygon. The intra-swath relative accuracy average was found to be 0.043 m.

4.2 Calibration Control Vertical Accuracy

Vertical absolute accuracy reports were generated as a quality assurance check. The location of each control point is displayed in the Surveyed Ground Control map in **Exhibit 7**. Detailed results for each point are included in **Appendix B**.

Exhibit 12: Calibration control vertical accuracy results summary

Calibration Control Accuracy$_Z$: Umatilla Wallowa Whitman Project Area	
Average Error = +0.046 m	Average Magnitude = 0.046 m
Minimum Error = -0.085 m	RMSE = 0.051 m
Maximum Error = +0.087 m	σ = 0.052 m
Survey Sample Size: n = 37	

4.3 Point Cloud Testing

The project specifications require that only Non-Vegetated Vertical Accuracy (NVA) be computed for raw LiDAR point cloud swath files. NVA is defined as the elevation difference between the LiDAR surface and ground surveyed static points collected in open terrain (bare soil, sand, rocks, and short grass) as well as urban terrain (asphalt and concrete surfaces). The NVA for this project was tested with 36 check points. These check points were not used in the calibration or post-processing of the LiDAR point cloud data. Elevations from the unclassified LiDAR surface were measured for the xy location of each check point. Elevations interpolated from the LiDAR surface were then compared to the elevation values of the surveyed control points.

The bare-earth LiDAR dataset was designed to meet or exceed ASPRS Positional Accuracy Standards at the 10 cm vertical accuracy class. Absolute accuracy for non-vegetated areas (NVA) must be accurate within 10.0 cm (0.32 ft) RMSEz and 19.6 cm (0.64 ft) at the 95% confidence level. The tested NVA for this dataset was found to be accurate within 7.5 cm (0.25 ft) in terms of the RMSEz. The resulting NVA stated at the 95% confidence level (RMSEz x 1.96) is 14.6 cm (0.48 ft). Therefore, this dataset meets the required NVA of 10 cm (0.32 ft) at the 95% confidence level as defined by the National Standards for Spatial Data Accuracy (NSSDA).

4.4 Digital Elevation Model Testing

The project specifications require the accuracy of the derived DEM be calculated and reported in two ways: (1) Non-Vegetated Vertical Accuracy (NVA) calculated at a 95% confidence level in "bare earth" and "urban" land cover classes and (2) Vegetated Vertical Accuracy (VVA) in all vegetated land cover classes combined calculated based on the 95th percentile error. The NVA for this project was tested with 36 check points. The VVA was tested with 26 check points.

The tested Non-Vegetated Vertical Accuracy (NVA) for this dataset captured from the DEM using bi-linear interpolation to derive the DEM elevations was found to be 7.2 cm in terms of the RMSEz. The resulting accuracy stated as the 95% confidence level (RMSEz x 1.96) is 14.1 cm. Therefore, this dataset meets the required NVA of 19.6 cm at the 95% confidence level.

The tested Vegetated Vertical Accuracy (VVA) for this dataset captured from the DEM using bi-linear interpolation for all classes was found to be 15.8 cm. Therefore, this dataset meets the required VVA of 29.4 cm based on the 95th percentile error.

4.5 Data Density

The goal for this project was to achieve a minimum LiDAR point density of 8.0 points per square meter. First return density is the best representation of the quality of the acquisition because the density of first returns is independent of vegetation and other random factors that could increase the overall point density. The acquisition mission achieved an actual average of 13.8 points per square meter for first returns. Please note that loss of point density over water is to be expected.

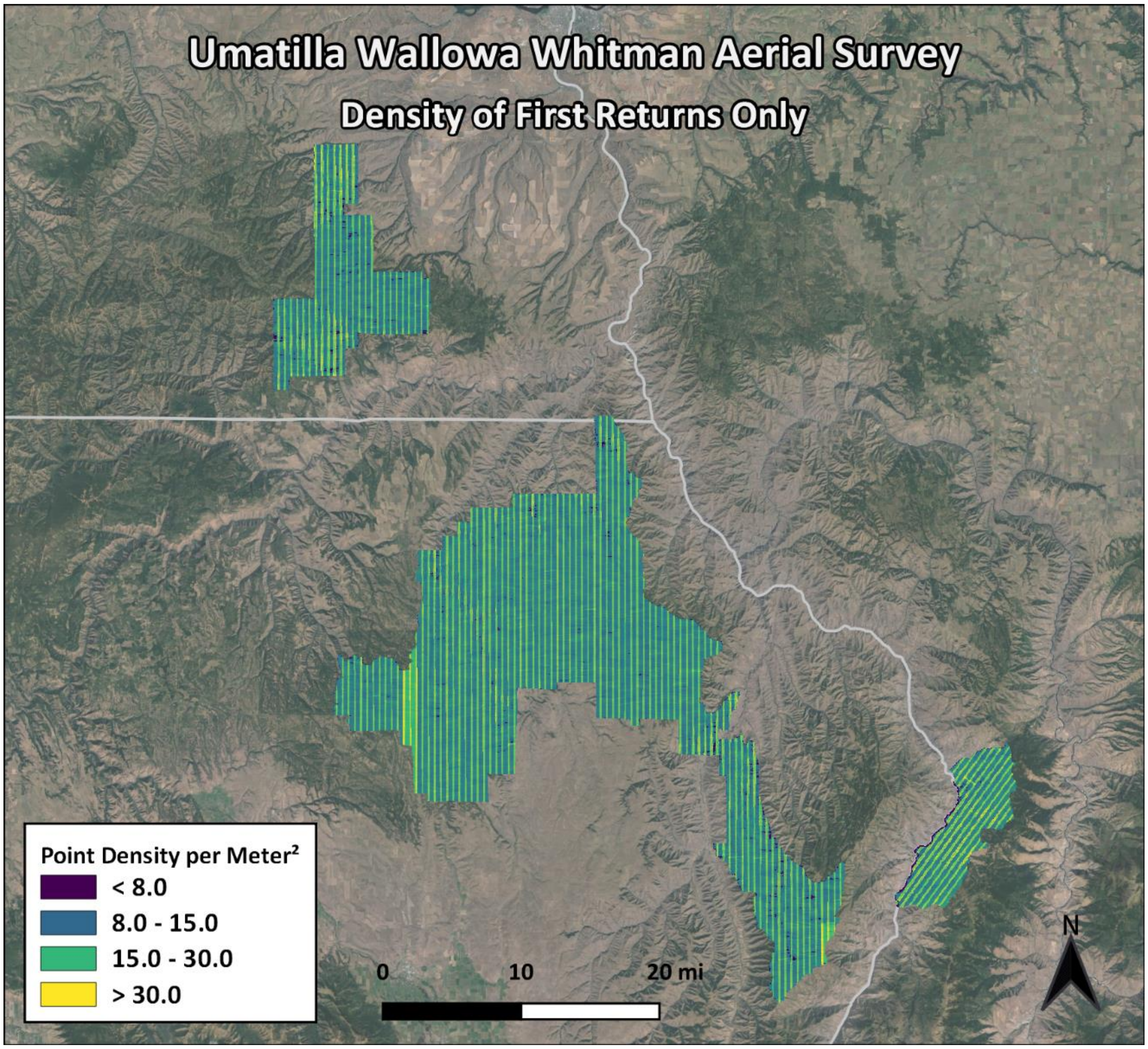


Exhibit 13: Density of first returns only in points per meter² for the Umatilla Wallowa Whitman project.

Appendix A – Check Points

Survey Point	Umatilla Wallowa Whitman Aerial Survey		
	Easting	Northing	Elevation (m)
NVA-001	541772.425	5052278.190	390.900
NVA-002	541487.303	5052682.139	390.030
NVA-003	542609.882	5054985.961	576.124
NVA-004	546883.275	5050859.599	1515.092
NVA-005	544521.887	5044964.667	1594.802
NVA-006	546951.776	5048827.261	1454.259
NVA-008	539728.919	5038626.904	1790.536
NVA-009	542454.213	5041631.568	1563.821
NVA-010	544859.909	5056124.708	818.434
NVA-101	501227.006	5091257.344	849.363
NVA-102	503484.290	5081194.221	1671.489
NVA-103	503631.809	5073474.222	1572.324
NVA-104	506581.194	5065626.312	1433.847
NVA-105	523846.555	5030646.414	2026.933
NVA-106	520686.366	5030031.572	1949.595
NVA-107	527413.245	5036630.905	2037.796
NVA-108	493461.774	5077633.703	1520.823
NVA-109	498347.217	5066371.589	1154.728
NVA-110	488003.146	5061089.936	1004.186
NVA-111	482560.627	5051215.716	1162.116
NVA-112	478513.212	5059706.233	1470.986
NVA-113	474319.505	5061885.841	1351.387
NVA-114	479333.290	5078391.982	1338.273
NVA-115	492004.758	5070514.954	1530.828
NVA-201	471863.378	5122986.595	832.692
NVA-202	469928.484	5115455.790	1421.643
NVA-203	468732.132	5114703.945	1477.852
NVA-205	472887.873	5108707.376	1558.549
NVA-206	480428.472	5106316.458	1469.800
NVA-207	473998.820	5107331.311	1530.182
NVA-208	473400.181	5104837.730	1449.820
NVA-210	464828.407	5104845.069	1642.892
NVA-2301	479511.975	5075739.527	1395.333
NVA-2302	479516.781	5075776.105	1395.875
NVA-2303	478881.037	5063448.989	1451.487
NVA-2304	478622.886	5060158.996	1481.140
VVA-001	541217.304	5053915.165	429.541
VVA-002	548019.768	5052571.462	1488.151

VVA-003	540251.490	5041061.930	1699.773
VVA-004	539123.022	5041800.535	1546.651
VVA-005	544244.524	5046335.522	1392.043
VVA-101	503650.836	5085296.890	1485.577
VVA-102	496418.058	5073257.399	1476.682
VVA-103	511667.242	5068014.466	1635.034
VVA-104	518763.186	5037258.297	1818.753
VVA-105	528558.817	5041329.470	1982.968
VVA-106	507694.901	5062778.854	1398.515
VVA-107	485288.652	5057967.810	1097.504
VVA-108	471971.380	5059251.908	1388.803
VVA-109	475088.841	5066507.118	1424.996
VVA-110	490654.916	5063287.237	1341.191
VVA-201	469616.260	5123044.406	911.310
VVA-202	468362.630	5108761.648	1763.127
VVA-203	476108.852	5110272.046	1346.600
VVA-204	477027.330	5105868.824	1515.197
VVA-205	464278.477	5101994.019	1791.275
VVA-206	464483.773	5107115.549	1846.044
VVA-208	475938.953	5107511.371	1481.823
VVA-209	470793.171	5115469.710	1376.902
VVA-210	478358.178	5109439.049	1332.256
VVA-2301	479480.543	5075731.792	1393.932
VVA-2302	479486.448	5075744.026	1394.521

APPENDIX B – CALIBRATION CONTROL ACCURACY REPORT

Umatilla Wallowa Whitman Aerial Survey			
Survey Point	**Known Z (m)**	**Laser Z (m)**	**Dz (m)**
GCP-001	375.511	375.576	0.065
GCP-002	1282.955	1283.035	0.080
GCP-003	359.054	359.141	0.087
GCP-005	1347.593	1347.631	0.038
GCP-007	1618.534	1618.579	0.045
GCP-008	1741.254	1741.312	0.058
GCP-101	1527.166	1527.123	-0.043
GCP-103	1642.505	1642.470	-0.035
GCP-104	1607.927	1607.871	-0.056
GCP-105	1591.511	1591.451	-0.060
GCP-106	1915.072	1914.987	-0.085
GCP-107	2008.791	2008.758	-0.033
GCP-108	1988.240	1988.164	-0.076

GCP-109	1362.813	1362.766	-0.047
GCP-110	1097.989	1097.987	-0.002
GCP-111	1092.618	1092.584	-0.034
GCP-112	1476.736	1476.732	-0.004
GCP-113	1340.998	1340.932	-0.066
GCP-114	1473.709	1473.723	0.014
GCP-115	1395.665	1395.675	0.010
GCP-116	993.578	993.610	0.032
GCP-117	1406.971	1406.909	-0.062
GCP-118	951.700	951.720	0.020
GCP-119	1309.025	1309.071	0.046
GCP-120	1560.643	1560.566	-0.077
GCP-121	1303.728	1303.665	-0.063
GCP-122	1281.590	1281.542	-0.048
GCP-201	977.599	977.654	0.055
GCP-202	821.313	821.360	0.047
GCP-203	1322.671	1322.689	0.018
GCP-204	1597.508	1597.528	0.020
GCP-205	1446.683	1446.626	-0.057
GCP-206	1424.851	1424.807	-0.044
GCP-207	1613.140	1613.101	-0.039
GCP-208	1857.805	1857.809	0.004
GCP-209	1380.263	1380.313	0.050
GCP-210	1154.729	1154.811	0.082

Average Dz (m)	+0.046
Minimum Dz (m)	-0.085
Maximum Dz (m)	+0.087
Average Magnitude (m)	0.046
RMSE (m)	0.051
Std. Deviation (m)	0.052