aero-graphics

GEOSPATIAL SERVICES

# LiDAR MAPPING REPORT

## UMATILLA WALLOWA WHITMAN AERIAL SURVEY

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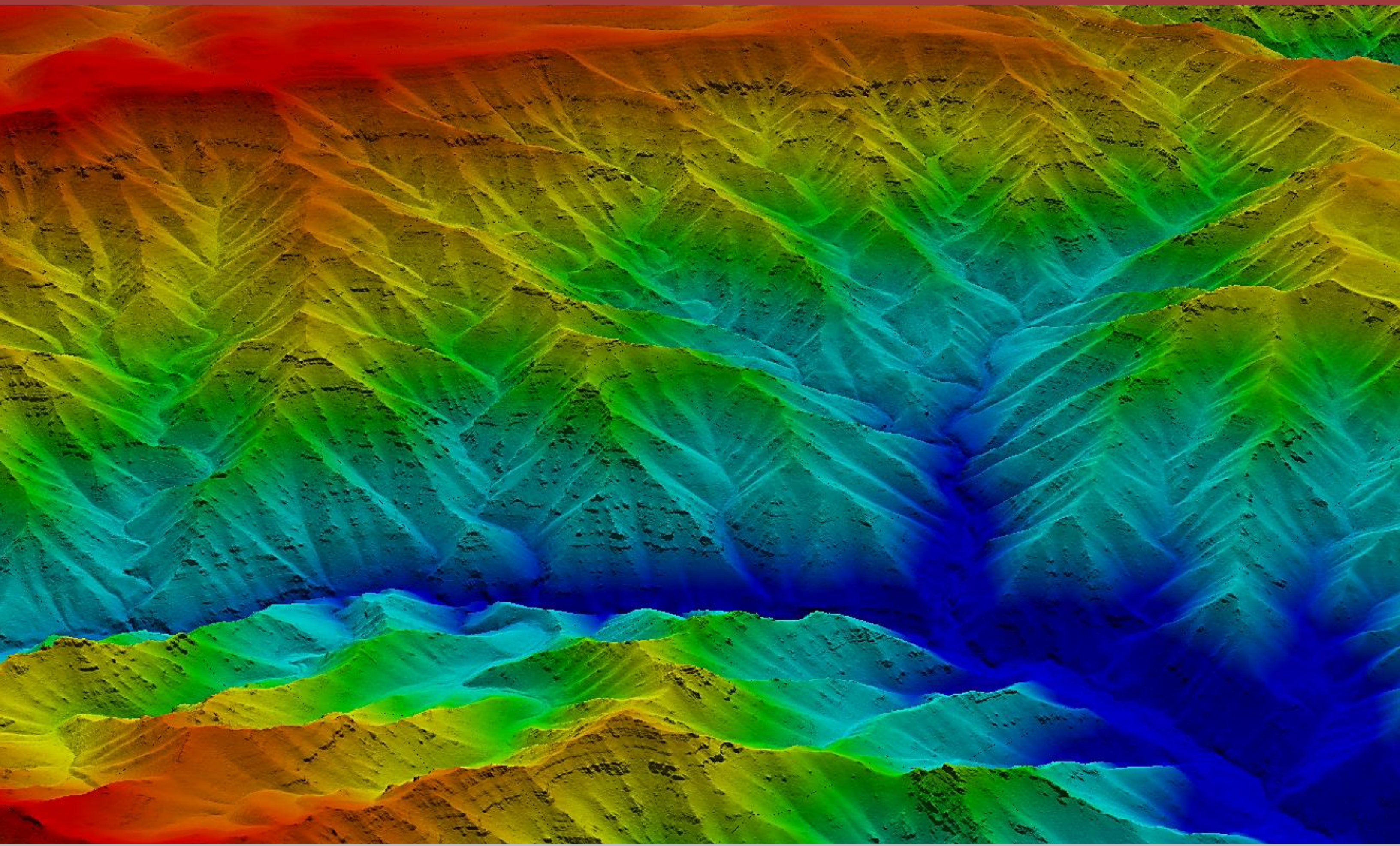

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# LiDAR Mapping Report
## Umatilla Wallowa Whitman Aerial Survey

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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.

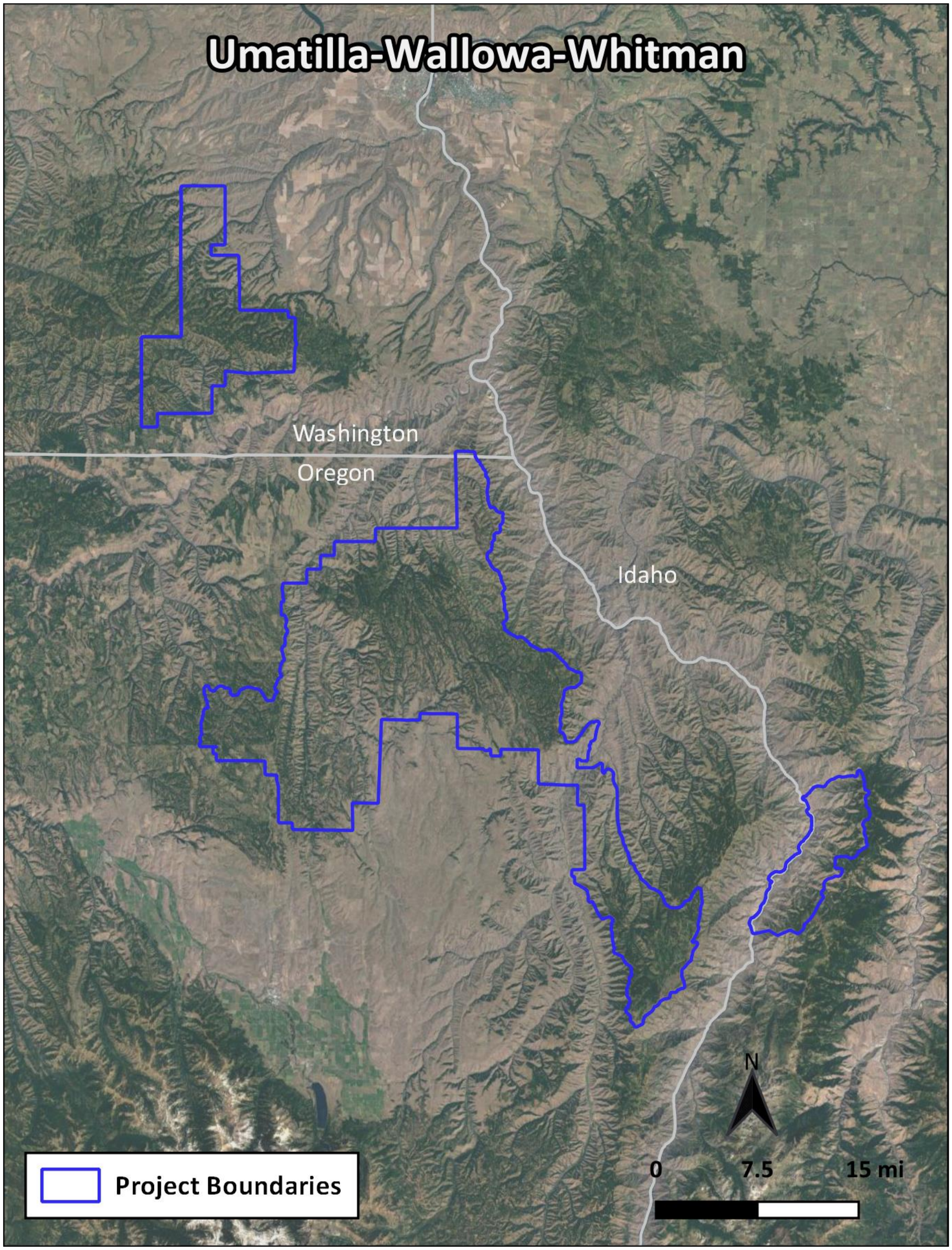
## 1.2 PROJECT DELIVERABLES

| | |
|---|---|
| **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**<br>▪ **MSHRs and swath separation images delivered in GeoTIFF format** |
| **Vector Data** | ▪ **Surveyed GCPs and checkpoints in .gpkg format**<br>▪ **Breaklines in geodatabase format**<br>▪ **Flight index in geodatabase format**<br>▪ **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** |

**Exhibit 1: 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

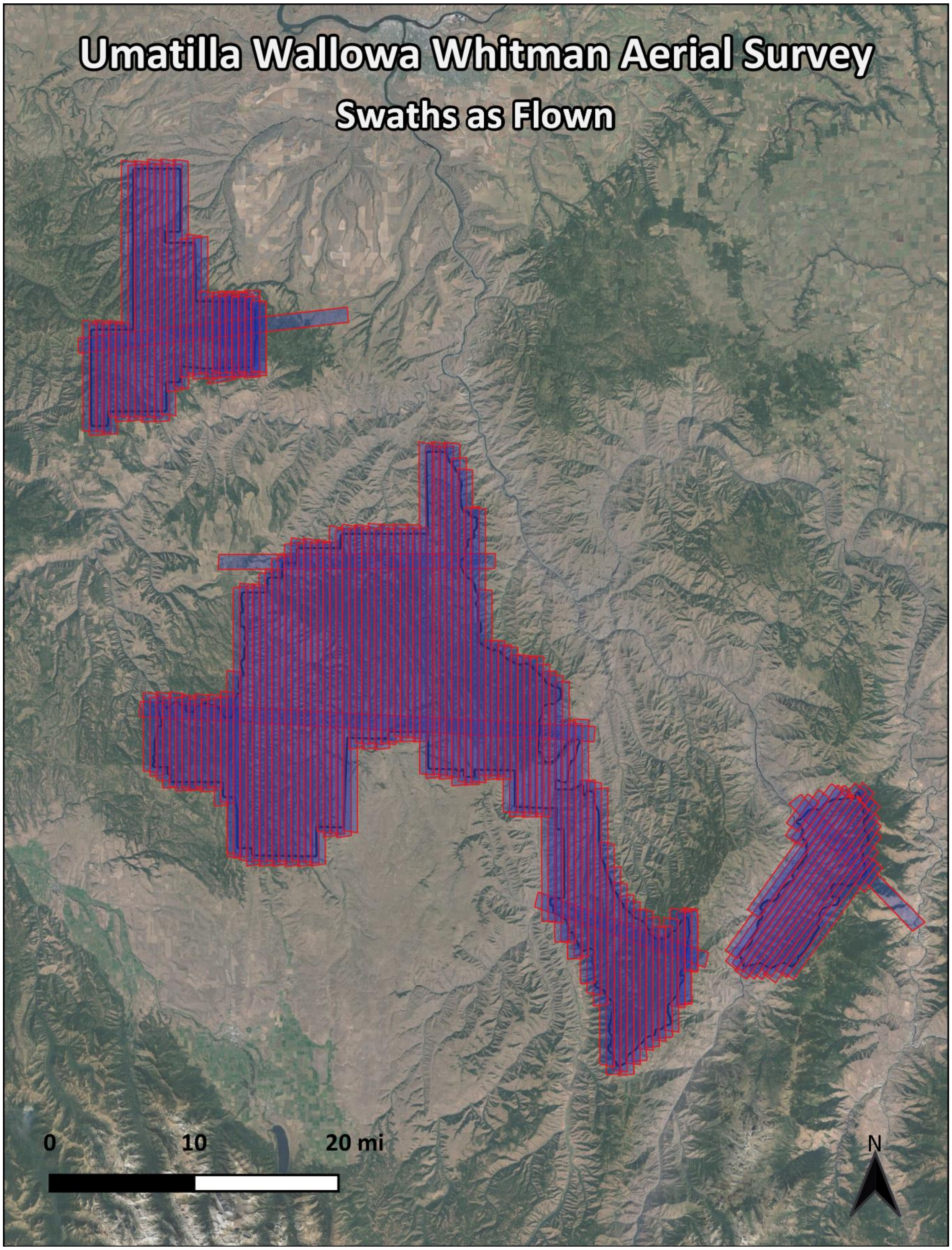
Aero-Graphics acquired LiDAR data throughout August 2022 with a turbocharged Cessna 310 (**Exhibit 3**). The stability of this platform is ideal for efficient data collection at high and low altitudes and at a variety of airspeeds. Additionally, our Cessna 310 has been customized to house a variety of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

**Exhibit 3: 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.

**Exhibit 4: The Optech Galaxy T2000 was used for data acquisition**

**<u>Exhibit 5:</u> 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.

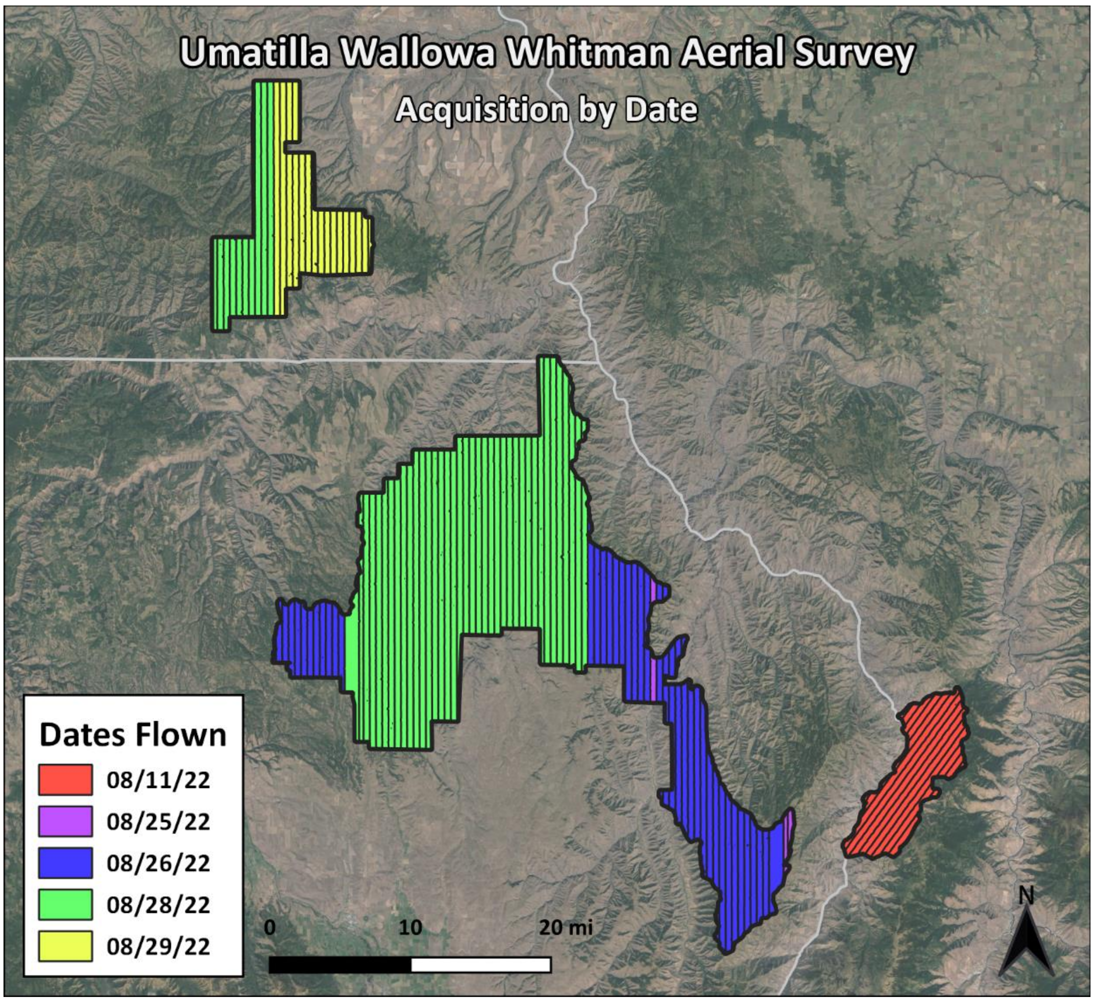



**Exhibit 6:** **The lines flown by date for the Umatilla Wallowa Whitman project**

## 2.4 Ground Control and Check Point Survey

Aero-Graphics' professional land surveyor identified, targeted, and surveyed 37 ground control points (**Exhibit 7**) for use in data calibration as well as 50 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**

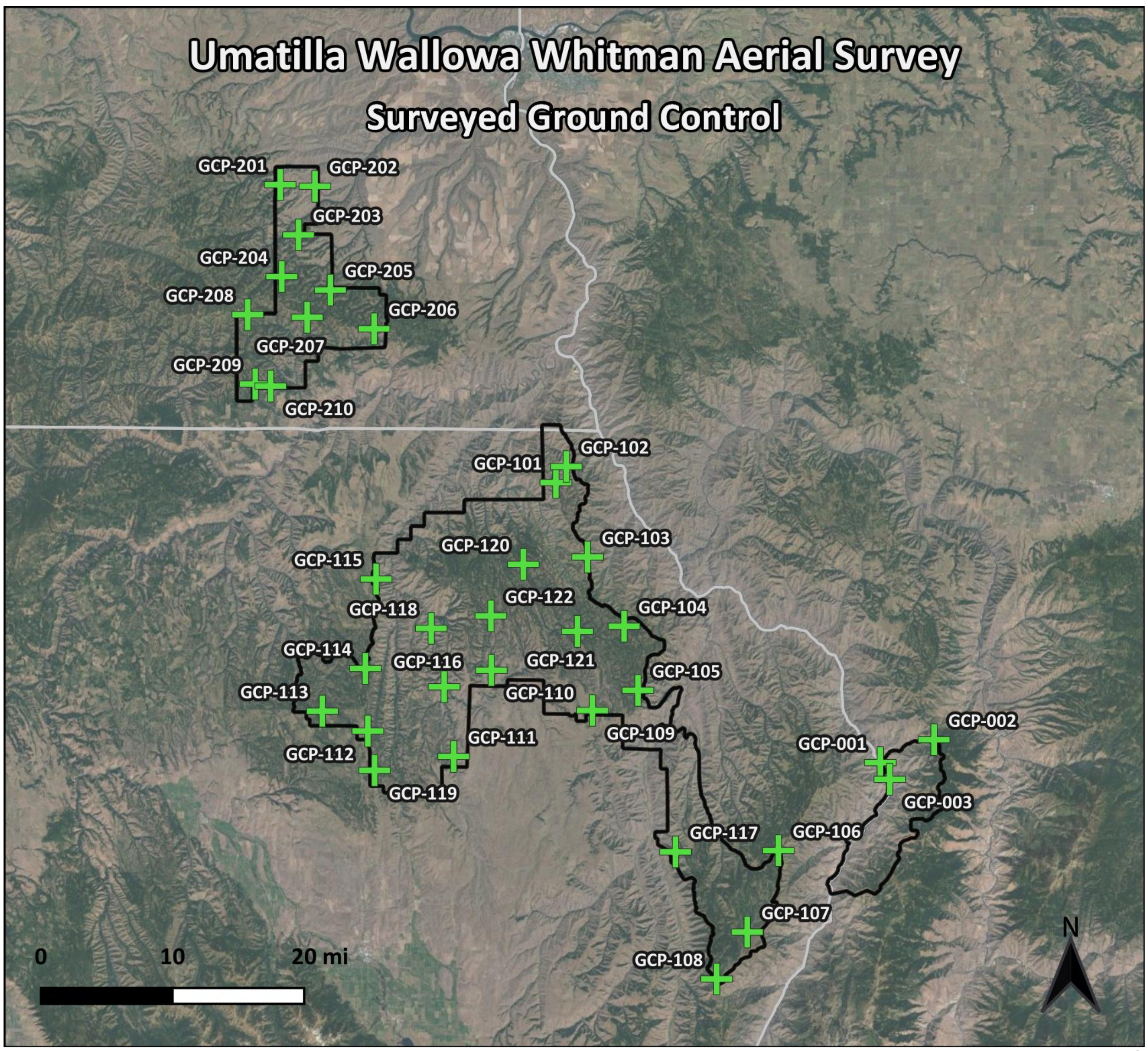
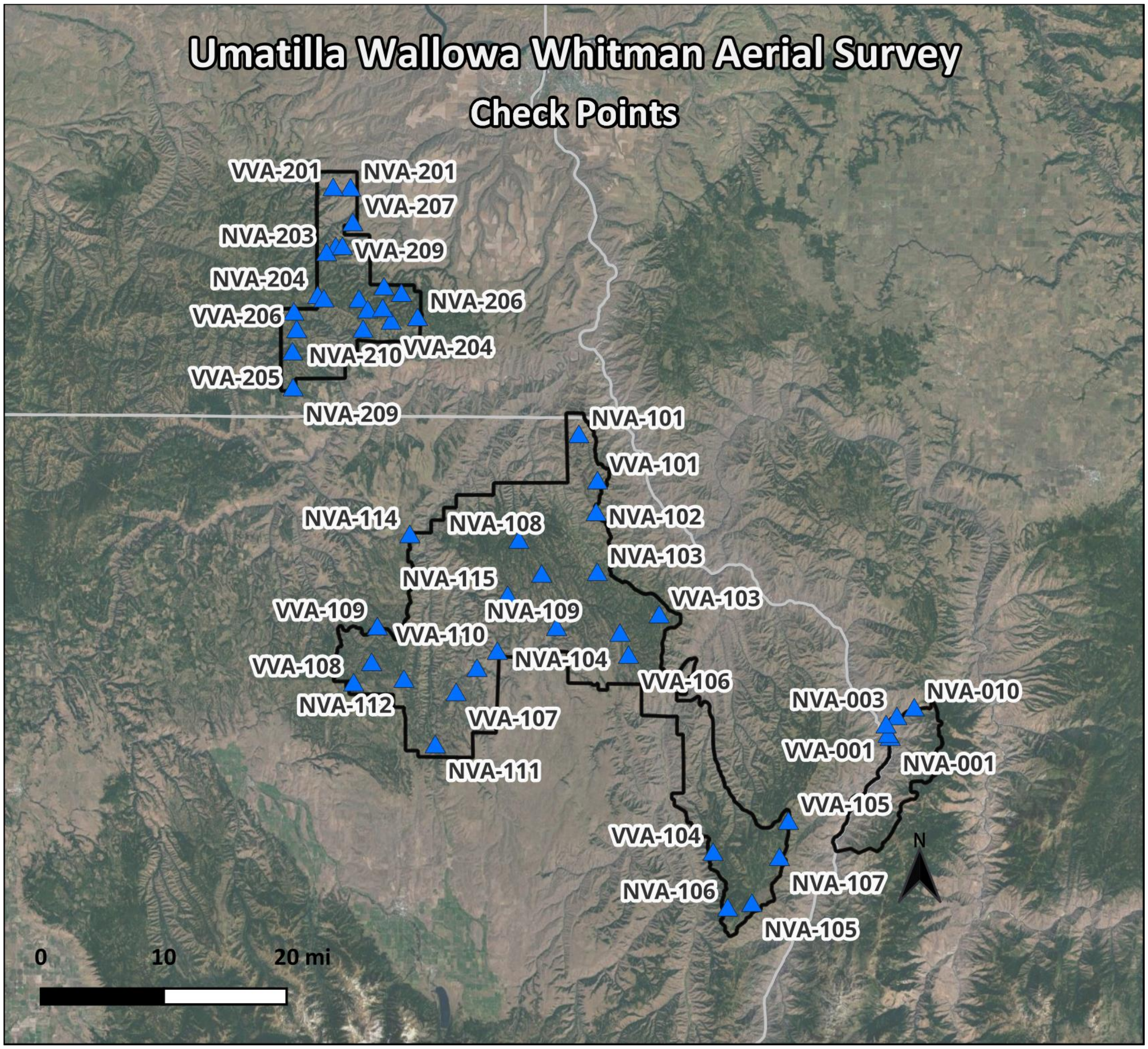


**Exhibit 8:** **Check Points for the Umatilla Wallowa Whitman project**



# 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

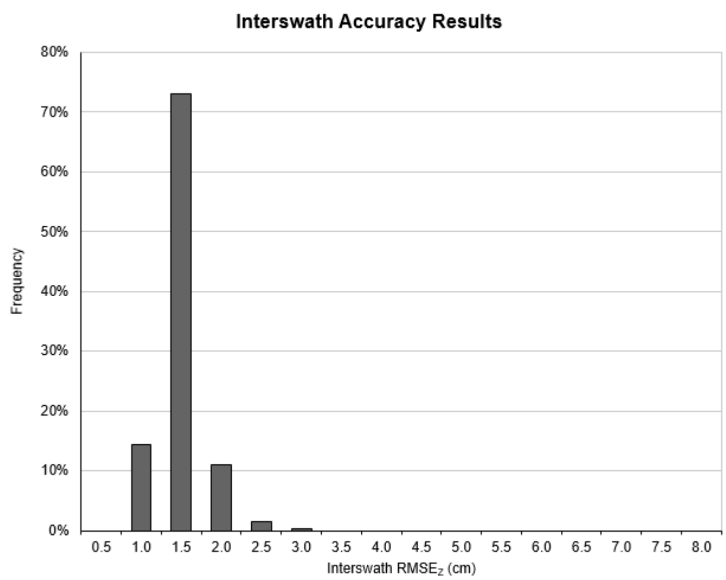



**Exhibit 11: Frequency distribution of interswath RMSDz results for the Umatilla Wallowa Whitman project.**

*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 35 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 $95^{th}$ 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.

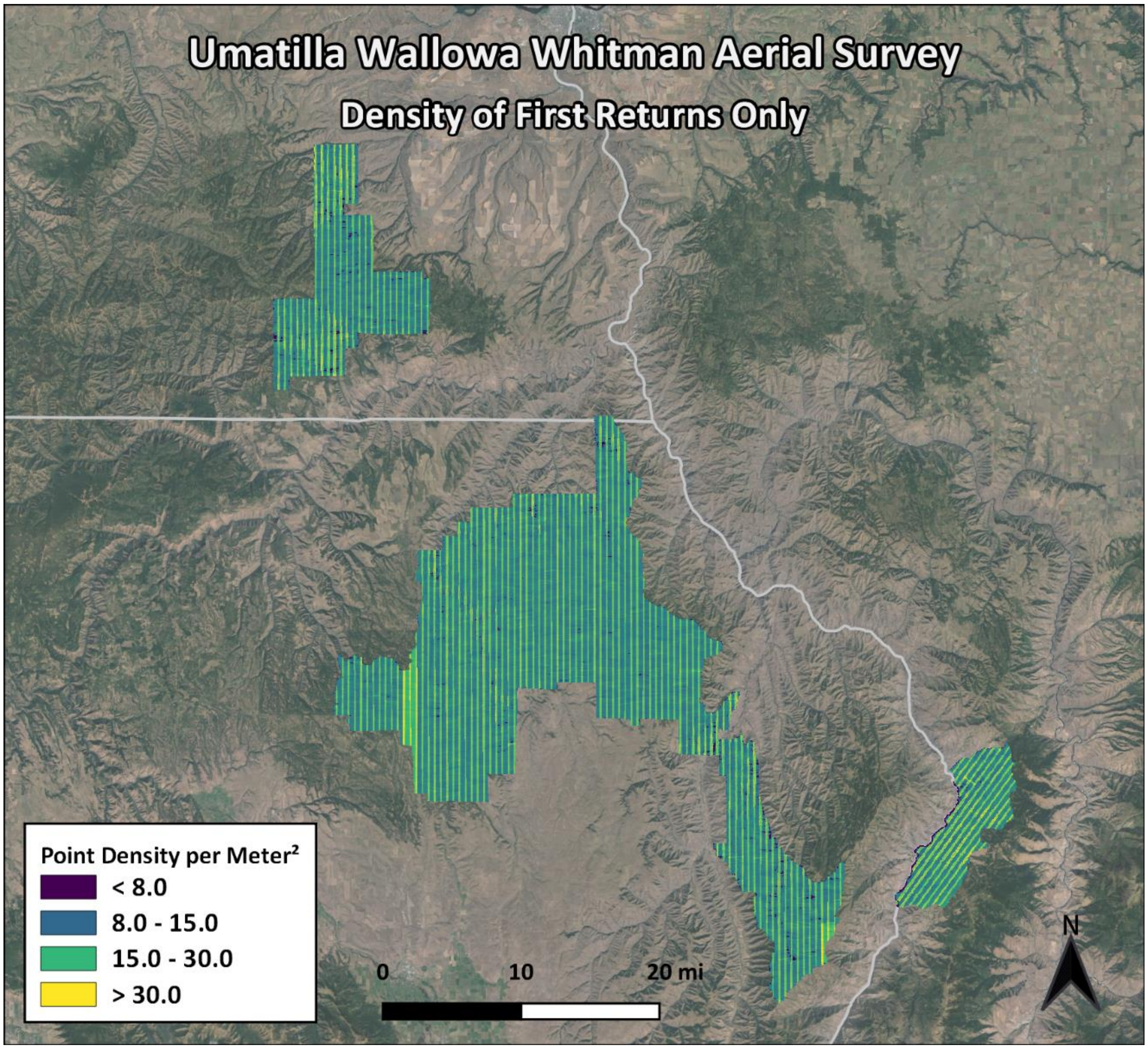



**Exhibit 13: Density of first returns only in points per meter² for the Umatilla Wallowa Whitman project.**

# Appendix A – Check Points

| Survey Point | Umatilla Wallowa Whitman Aerial Survey | | |
|---|---|---|---|
| | Easting | Northing | Elevation (m) |
| NVA-001 | 5052278.190 | 541772.425 | 390.900 |
| NVA-002 | 5052682.139 | 541487.303 | 390.030 |
| NVA-003 | 5054985.961 | 542609.882 | 576.124 |
| NVA-010 | 5056124.708 | 544859.909 | 818.434 |
| NVA-101 | 5091257.344 | 501227.006 | 849.363 |
| NVA-102 | 5081194.221 | 503484.290 | 1671.489 |
| NVA-103 | 5073474.222 | 503631.809 | 1572.324 |
| NVA-104 | 5065626.312 | 506581.194 | 1433.847 |
| NVA-105 | 5030646.414 | 523846.555 | 2026.933 |
| NVA-106 | 5030031.572 | 520686.366 | 1949.595 |
| NVA-107 | 5036630.905 | 527413.245 | 2037.796 |
| NVA-108 | 5077633.703 | 493461.774 | 1520.823 |
| NVA-109 | 5066371.589 | 498347.217 | 1154.728 |
| NVA-110 | 5061089.936 | 488003.146 | 1004.186 |
| NVA-111 | 5051215.716 | 482560.627 | 1162.116 |
| NVA-112 | 5059706.233 | 478513.212 | 1470.986 |
| NVA-113 | 5061885.841 | 474319.505 | 1351.387 |
| NVA-114 | 5078391.982 | 479333.290 | 1338.273 |
| NVA-115 | 5070514.954 | 492004.758 | 1530.828 |
| NVA-201 | 5122986.595 | 471863.378 | 832.692 |
| NVA-202 | 5115455.790 | 469928.484 | 1421.643 |
| NVA-203 | 5114703.945 | 468732.132 | 1477.852 |
| NVA-204 | 5109222.238 | 467563.587 | 1777.552 |
| NVA-205 | 5108707.376 | 472887.873 | 1558.549 |
| NVA-206 | 5106316.458 | 480428.472 | 1469.800 |
| NVA-207 | 5107331.311 | 473998.820 | 1530.182 |
| NVA-208 | 5104837.730 | 473400.181 | 1449.820 |
| NVA-209 | 5097360.606 | 464326.780 | 1086.801 |
| NVA-210 | 5104845.069 | 464828.407 | 1642.892 |
| VVA-001 | 5053915.165 | 541217.304 | 429.541 |
| VVA-101 | 5085296.890 | 503650.836 | 1485.577 |
| VVA-102 | 5073257.399 | 496418.058 | 1476.682 |
| VVA-103 | 5068014.466 | 511667.242 | 1635.034 |
| VVA-104 | 5037258.297 | 518763.186 | 1818.753 |
| VVA-105 | 5041329.470 | 528558.817 | 1982.968 |
| VVA-106 | 5062778.854 | 507694.901 | 1398.515 |
| VVA-107 | 5057967.810 | 485288.652 | 1097.504 |
| VVA-108 | 5059251.908 | 471971.380 | 1388.803 |

| | | | |
|---|---|---|---|
| VVA-109 | 5066507.118 | 475088.841 | 1424.996 |
| VVA-110 | 5063287.237 | 490654.916 | 1341.191 |
| VVA-201 | 5123044.406 | 469616.260 | 911.310 |
| VVA-202 | 5108761.648 | 468362.630 | 1763.127 |
| VVA-203 | 5110272.046 | 476108.852 | 1346.600 |
| VVA-204 | 5105868.824 | 477027.330 | 1515.197 |
| VVA-205 | 5101994.019 | 464278.477 | 1791.275 |
| VVA-206 | 5107115.549 | 464483.773 | 1846.044 |
| VVA-207 | 5118534.760 | 472126.059 | 1239.247 |
| VVA-208 | 5107511.371 | 475938.953 | 1481.823 |
| VVA-209 | 5115469.710 | 470793.171 | 1376.902 |
| VVA-210 | 5109439.049 | 478358.178 | 1332.256 |

# Appendix B – Calibration Control Accuracy Report

| Umatilla Wallowa Whitman Aerial Survey | | | |
|---|---|---|---|
| **Survey Point** | **Known Z (m)** | **Laser Z (m)** | **Dz (m)** |
| GCP-119 | 375.511 | 375.576 | 0.046 |
| GCP-116 | 1282.955 | 1283.035 | 0.032 |
| GCP-118 | 359.054 | 359.141 | 0.020 |
| GCP-114 | 1347.593 | 1347.631 | 0.014 |
| GCP-115 | 1618.534 | 1618.579 | 0.010 |
| GCP-110 | 1741.254 | 1741.312 | -0.002 |
| GCP-112 | 1527.166 | 1527.123 | -0.004 |
| GCP-107 | 1642.505 | 1642.470 | -0.033 |
| GCP-111 | 1607.927 | 1607.871 | -0.034 |
| GCP-103 | 1591.511 | 1591.451 | -0.035 |
| GCP-101 | 1915.072 | 1914.987 | -0.043 |
| GCP-109 | 2008.791 | 2008.758 | -0.047 |
| GCP-122 | 1988.240 | 1988.164 | -0.048 |
| GCP-104 | 1362.813 | 1362.766 | -0.056 |
| GCP-105 | 1097.989 | 1097.987 | -0.060 |
| GCP-117 | 1092.618 | 1092.584 | -0.062 |
| GCP-121 | 1476.736 | 1476.732 | -0.063 |
| GCP-113 | 1340.998 | 1340.932 | -0.066 |
| GCP-108 | 1473.709 | 1473.723 | -0.076 |
| GCP-120 | 1395.665 | 1395.675 | -0.077 |
| GCP-106 | 993.578 | 993.610 | -0.085 |
| GCP-003 | 1406.971 | 1406.909 | 0.087 |
| GCP-002 | 951.700 | 951.720 | 0.080 |
| GCP-001 | 1309.025 | 1309.071 | 0.065 |
| GCP-008 | 1560.643 | 1560.566 | 0.058 |
| GCP-007 | 1303.728 | 1303.665 | 0.045 |

| | | | |
|---|---|---|---|
| GCP-005 | 1281.590 | 1281.542 | 0.038 |
| GCP-210 | 977.599 | 977.654 | 0.082 |
| GCP-201 | 821.313 | 821.360 | 0.055 |
| GCP-209 | 1322.671 | 1322.689 | 0.050 |
| GCP-202 | 1597.508 | 1597.528 | 0.047 |
| GCP-204 | 1446.683 | 1446.626 | 0.020 |
| GCP-203 | 1424.851 | 1424.807 | 0.018 |
| GCP-208 | 1613.140 | 1613.101 | 0.004 |
| GCP-207 | 1857.805 | 1857.809 | -0.039 |
| GCP-206 | 1380.263 | 1380.313 | -0.044 |
| GCP-205 | 1154.729 | 1154.811 | -0.057 |

| | |
|---|---|
| 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 |