Lidar Mapping Report for the U.S. Geological Survey

Contractor: Woolpert Inc.
Date: March 2022
Contract: G16PC00022
Task Order: 140G0221D0013
Project Name: AZ Blackrock Lidar 2021 B21
Project ID: 223516
Work Unit ID: 223513

Table of Contents

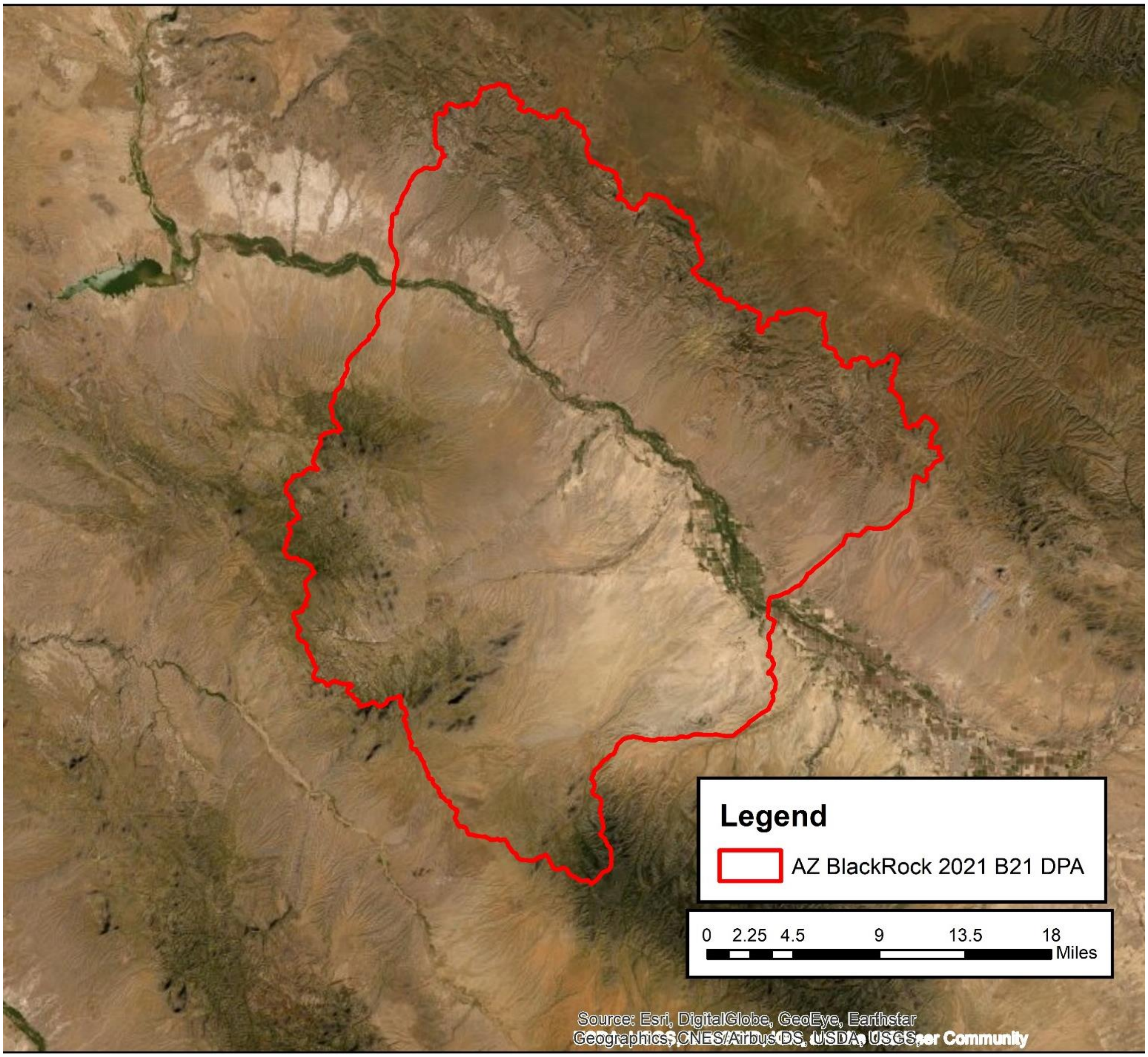
1. Overview

1.1. Description

The AZ Blackrock Lidar 2021 B21 task order called for the acquisition, processing, and derivative products of QL1 lidar data collected to an aggregate nominal pulse spacing (ANPS) of ≤0.35 and 8-points per square meter (ppsm) covering 786 square miles in the Graham County, Arizona area. In addition to high density lidar data acquisition, new horizontal/vertical survey data was collected to support lidar data production.

The entire task order is being delivered as Work Unit 223513.

Figure 1.1.1 – Defined Project Area



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, ...er Community

1.2. Purpose

This project will support the 3DEP mission and the Natural Resources Conservation Service (NRCS) high-resolution elevation enterprise program.

1.3. Specifications

Data and reporting for this task order was acquired and produced to meet the "*USGS Lidar Base Specification v2021 Revision A*", and the American Society of Photogrammetry and Remote Sensing (ASPRS) "*Positional Accuracy Standards for Digital Geospatial Data (Edition 1, Version 1.0)*".

1.4. Spatial Reference

Geospatial data products were produced using the following spatial data reference system:

- Horizontal Datum: NAD83 (2011)
- Horizontal Projection: UTM 12
- Horizontal Units: Meters
- Horizontal EPSG Code: 6341
- Vertical Datum: NAVD88
- Geoid Model: 18
- Vertical Units: Meters
- Height Type: Orthometric

1.5. Task Order Deliverables

All data products produced as part of this task order are listed below. All tiled deliverables had a tile size of 1,500-meters x 1,500-meters. Tiles are named in accordance with the US National Grid convention.

1.5.1. Lidar Data

- Classified lidar point cloud data in tiled .laz v1.4 format:
    - Class 1 – Default / Processed, but not Classified
    - Class 2 – Bare Earth Ground
    - Class 3 – Low Vegetation
    - Class 4 – Medium Vegetation
    - Class 5 – High Vegetation
    - Class 6 – Buildings
    - Class 7 – Low Noise
    - Class 9 – Water
    - Class 17 – Bridge Decks
    - Class 18 – High Noise
    - Class 20 – Ignored Ground
- Breaklines used for hydro-flattening
    - Waterbodies greater than 2-acres as PolygonZ feature classes in Esri geodatabase format
    - Bridges used in DEM generation as PointZ feature classes in Esri .shp format
- Hydro-flattened bare earth digital elevation model (DEM): 0.50-meter pixel size, 32-bit floating-point with no bridges or overpass structures, in GeoTIFF format
- Intensity imagery: 0.50-meter pixel size, 8-bit, 256 gray-scale (linear rescaling from 16-bit intensity) in GeoTIFF format

1.5.2. Control Data

- Lidar calibration points : Esri .gdb format
- Lidar NVA checkpoints : Esri .gdb format
- Lidar VVA checkpoints : Esri .gdb format

1.5.3. Spatial Metadata

- Data extent: Esri .shp format
- Tile index: Esri .shp format
- Interswath results: Esri .shp format
- Intraswath results: Esri .shp format
- Swath polygons: Georeferenced, polygonal representation of the detailed extents of each lidar swath as polygon feature class in an Esri file geodatabase format
- Maximum height separation rasters: 0.50-meter pixel size, 32-bit floating-point, GeoTIFF format
- Swath separation images: 0.50-meter pixel size, JPEG2000 format.

The DPA of this task order included 1,003 tiles.

2. Acquisition

2.1. Flight Planning

Acquisition was planned based on the specifications listed below:

- Resolution: 8 points per square meter, with 0.35-meter nominal point spacing
- Overlap: At contractor's discretion, but enough to ensure there are no data gaps between usable portions of the swath and to ensure the aggregate nominal point density (ANPD) is achieved
- Acquisition Window: Spring 2021 – Summer 2021
- Acquisition Conditions:
    - Cloud and fog-free between the aircraft and ground
    - Snow-free
    - No unusual flooding or inundation, except in cases where the goal of the collection is to map the inundation
    - After cheat grass has flowered
    - Leaf-off vegetation is preferred
    - Flown during daylight hours
- Control: Airborne Global Positioning System (ABGPS) and Inertial Measurement Unit (IMU) data to be used along with differentially-corrected GPS ground control points.
- Data Voids are not allowed except:
    - Where caused by waterbodies
    - Where caused by areas of low near infra-red (NIR) reflectivity (i.e. asphalt, composition roofing)
    - Where caused by lidar shadowing from buildings or other features
    - Where appropriately filled-in by another swath

2.2. Lidar Sensor Information

Aerial lidar data was acquired using the Leica Terrain Mapper lidar sensor system[1].

2.2.1. Sensor Specifications

- Operating Altitude: 300 - 5,500-m AGL at 10% reflective target
- Maximum Measurement Rate: 2000-kHz
- Scan Angle: 20°-40°
- Scan Width: Up to 70% of flight altitude
- Scan Frequency: Programmable up to 125-Hz (7,500 RPM), 250 scan lines per second
- Number of Returns: 15
- Number of intensity measurements: 15
- Pulse Mode(s:): Up to 35 pulses in air

2.2.2. Laser Specifications

- Laser Beam Divergence: 0.25-mrad (1/e)
- Laser Classification: Class 4 laser product

2.2.3. Accuracy

- Range Resolution: < 1 cm RMS
- Elevation Accuracy: < 5-cm 1 σ
- Horizontal Accuracy: < 13-cm 1 σ

2.2.4. Physical Specifications

- Scanner size: 37 W x 68 L x 26 H-cm
    - Scanner weight: 47-kg
    - Control Electronics size: 45 W x 47 D x 25 H-cm
    - Control Electronics weight: 33-kg
    - Scanner operating temperature: 0 - 40°C cabin-side temperature
    - Control Electronics operating temperature: 0 - 40°C
- Flight Management: Leica FlightPro
- Power Consumption: 922-W @ 22.0 – 30.3-VDC

2.3. Planned Flight Specifications

Flight plans were created using Leica Mission Pro v.12.5 software. Aerial lidar data was acquired for this project using the following lidar sensor systems:

---

[1] Source: Leica TerrainMapper Data Sheet. https://leica-geosystems.com/en-US/products/airborne-systems/topographic-lidar-sensors/leica-terrainmapper

- Terrain Mapper - serial number 90515, last calibrated December 12, 2018
- Terrain Mapper - serial number 90513, last calibrated February 25, 2019

The following settings for both Leica Terrain Mapper - serial number 90515 and Leica Terrain Mapper - serial number 90513 were used:

- Maximum Number of Returns: 15
- Nominal Point Spacing: 0.35-m
- Nominal Point Density: 8 ppsm
- Flying Height Above Ground Level: 2,133-m
- Flight Speed: 150-knots
- Scan Angle: 40°
- Scan Rate Used: 150-Hz
- Pulse Rate Used: 1580-kHz
- Multi-Pulse in Air: Enabled
- Overlap: Minimum 25%

2.4. Timeline

Lidar data was collected from October 4, 2021 through October 15, 2021. A total of 127 individual flight lines were collected. Flight logs are contained in Attachment 2: Flight Logs.

2.5. GNSS and IMU Equipment

Prior to mobilizing to the project site, flight crews coordinated with required air traffic control personnel to ensure airspace access. Crews were on-site, operating a Global Navigation Satellite System (GNSS) Base Station for airborne GPS support.

Flight navigation during acquisition was performed using Integrated Geospatial Innovations’ CCNS (Computer Controlled Navigation System). The pilots are skilled at maintaining their planned trajectory, while holding the aircraft steady and level. If atmospheric conditions were such that the trajectory, ground speed, roll, pitch and/or heading could not be properly maintained, the mission was aborted until suitable conditions occur.

Base stations were set by acquisition staff to support the aerial data acquisition. Table 2.5.2 lists the Station ID and coordinates for all base stations operated during acquisition. GPS/IMU graphics are contained in Attachment 3: GPS IMU Images.

Figure 2.5.1. Flight Coverage by Lift

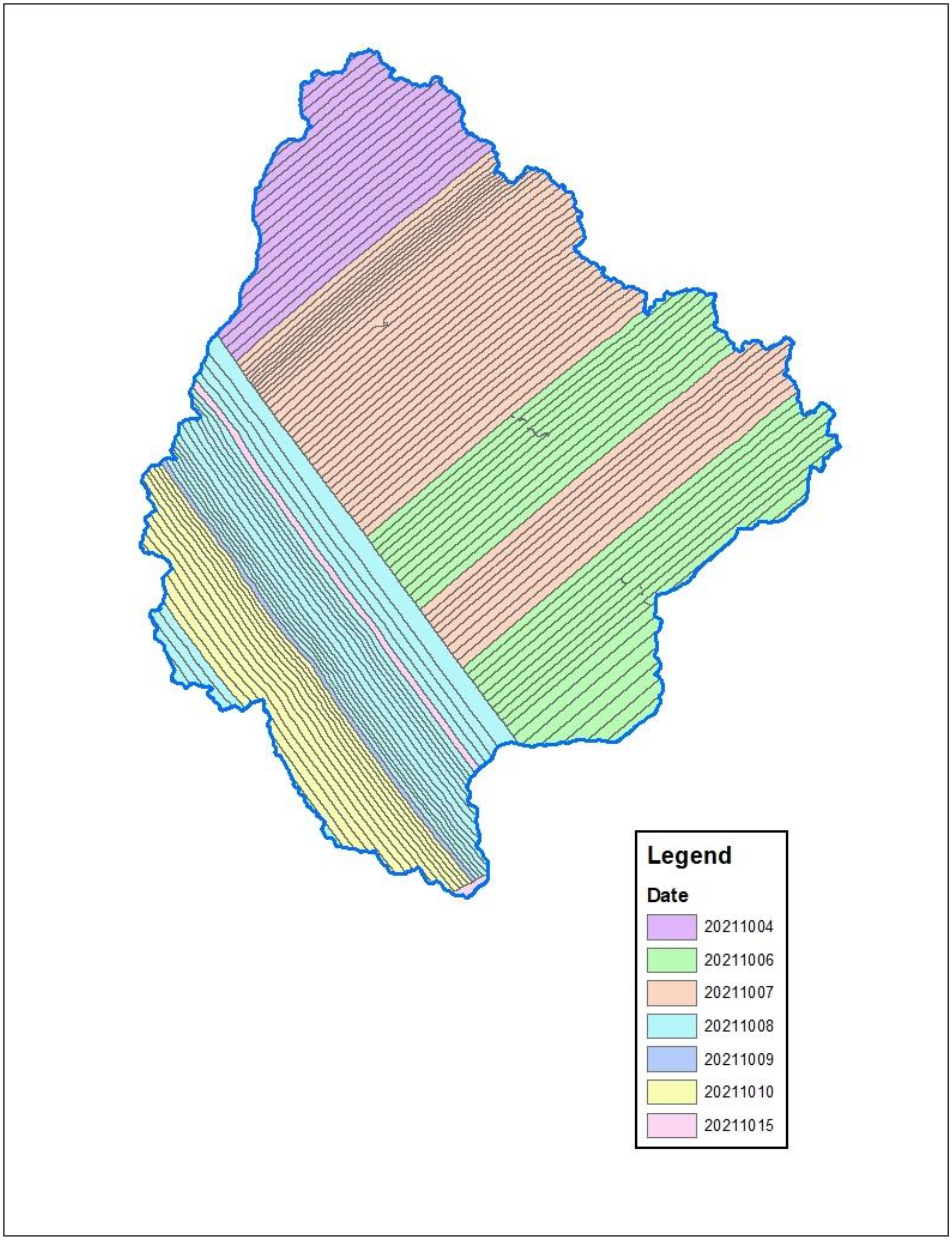


Table 2.5.2. GNSS Base Stations

Mission	Station Name	Longitude (DMS)	Latitude (DMS)	Ellipsoid Height L1 Phase Center (M)
Day28821_TM513	P014_CORS	31°58'22.40595"	-111°05'54.90206"	1068.972
Day28321_TM515	P014_CORS	31°58'22.40595"	-111°05'54.90206"	1068.972
Day28221_TM515	P014_CORS	31°58'22.40595"	-111°05'54.90206"	1068.972
Day28121_TM513	P014_CORS	31°58'22.40595"	-111°05'54.90206"	1068.972
Day28021_TM515	P014_CORS	31°58'22.40595"	-111°05'54.90206"	1068.972
Day28021_TM513	P014_CORS	31°58'22.40595"	-111°05'54.90206"	1068.972
Day27921_TM515	P014_CORS	31°58'22.40595"	-111°05'54.90206"	1068.972
Day27921_TM513	P014_CORS	31°58'22.40595"	-111°05'54.90206"	1068.972
Day27721_TM515	P014_CORS	31°58'22.40595"	-111°05'54.90206"	1068.972
Day28821_TM513	P014_CORS	31°58'22.40595"	-111°05'54.90206"	1068.972

2.6. Acquisition Quality Assurance

Woolpert developed a quality assurance and validation plan to ensure the acquired lidar data meets the USGS Lidar Base Specification. For quality assurance purposes, the lidar data was processed immediately following acquisition to verify the coverage has appropriate density, distribution, and no unacceptable data voids. Accompanying GPS data was post processed using differential and Kalman filter algorithms to derive a best estimate of trajectory. The quality of the solution was verified to be consistent with the accuracy requirements of the task order. Any required re-flights were scheduled at the earliest opportunity.

The spatial distribution of the geometrically usable first return lidar points was reviewed for density requirements. The first returns were also reviewed for regular and uniform point distribution - verifying the lidar data was spaced so that 90% of the cells in a 2*NPS grid placed over the data contain at least one lidar point. The Nominal Point Spacing (NPS) assessment was conducted against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath. Additionally, the data was reviewed for unacceptable data voids –no area greater than or equal to $(4 \text{ x ANPS})^2$ exhibited data coverage gaps. An initial quality control process was performed after each flight to review data coverage, airborne GPS data, and the trajectory solution.

3. Processing

3.1. Processing Summary

Once the lidar data passed initial QC, the dataset was corrected for aircraft orientation and movement. This process used airborne inertial, orientation, and GPS data collected during acquisition along with ground-based GPS data. The data was subject to geometric calibration that further corrected each laser point. This calibrated dataset was used to create the LAS point cloud. LAS point data was initially classified into “ground” and “non-ground”, then further refined using the classes specified by the task order. Breaklines were drawn to denote hydrological features. After the hydro-flattening process, the final deliverable products were created.

3.2. GPS-IMU Trajectory Processing

Kinematic corrections for the aircraft position were resolved using aircraft GPS and static ground GPS (1-Hz) for each geodetic control (base station) for three subsystems: inertial measurement unit (IMU), sensor orientation information, and airborne GPS data.

Post-processing of the IMU system data and aircraft position with attitude data was completed to compute an optimally accurate and blended navigation solution based on Kalman filtering technology, or the smoothed best estimate of trajectory (SBET).

For more information, see the GPS/IMU graphics in Attachment 3: GPS IMU Images. Software used included POSPac Software v. 5.3, IPAS Pro v.1.35., and Novatel Inertial Explorer v8.60.6129.

3.2.1. Trajectory Quality

The GNSS trajectory and high-quality IMU data are key factors in determining the overall positional accuracy of the final sensor data. Within the trajectory processing, there are many factors that affect the overall quality, but the most indicative are the combined separation, the estimated positional accuracy, and the Positional Dilution of Precision (PDOP).

3.2.2. Combination Separation

Combined separation is a measure of the difference between the forward-run and the backward-run solution of the trajectory. The Kalman filter was processed in both directions to remove the combined directional anomalies. In general, when these two solutions match closely, an optimally accurate and reliable solution is achieved. The data for this task order was processed with a goal to maintain a combined separation difference of less than 10-cm.

3.2.3. Estimated Positional Accuracy

Estimated positional accuracy plots the standard deviations of the east, north, and vertical directions along a time scale of the trajectory. It illustrates loss of satellite lock issues, as well as issues arising from long baselines, noise, and/or other atmospheric interference.

3.2.4. PDOP

The PDOP measures the precision of the GPS solution in regard to the geometry of the satellites acquired and used for the solution. Lidar data for this task order was processed with a goal to maintain an average PDOP value below 3.0. Brief periods of PDOP over 3.0 are acceptable due to the calibration and control process if other metrics are within specification.

3.3. Geometric Calibration

After the initial phase was complete, a formal reduction process was performed on the lidar data. Laser point position was calculated by associating the SBET position to each laser point return time, scan angle, intensity, etc. Raw laser point cloud data was created for the whole project area in LAS format. Automated line-to-line calibrations were then performed for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift. Statistical reports were generated for comparison and used to make the necessary adjustments to remove any residual systematic error.

For more information, see the Sensor Calibration Report(s) in Attachment 1: Sensor Calibration Reports. Software used included proprietary software, TerraMatch v20, and Leica CloudPro 1.2.4.

3.4. Relative Accuracy: Interswath (Overlap) Consistency

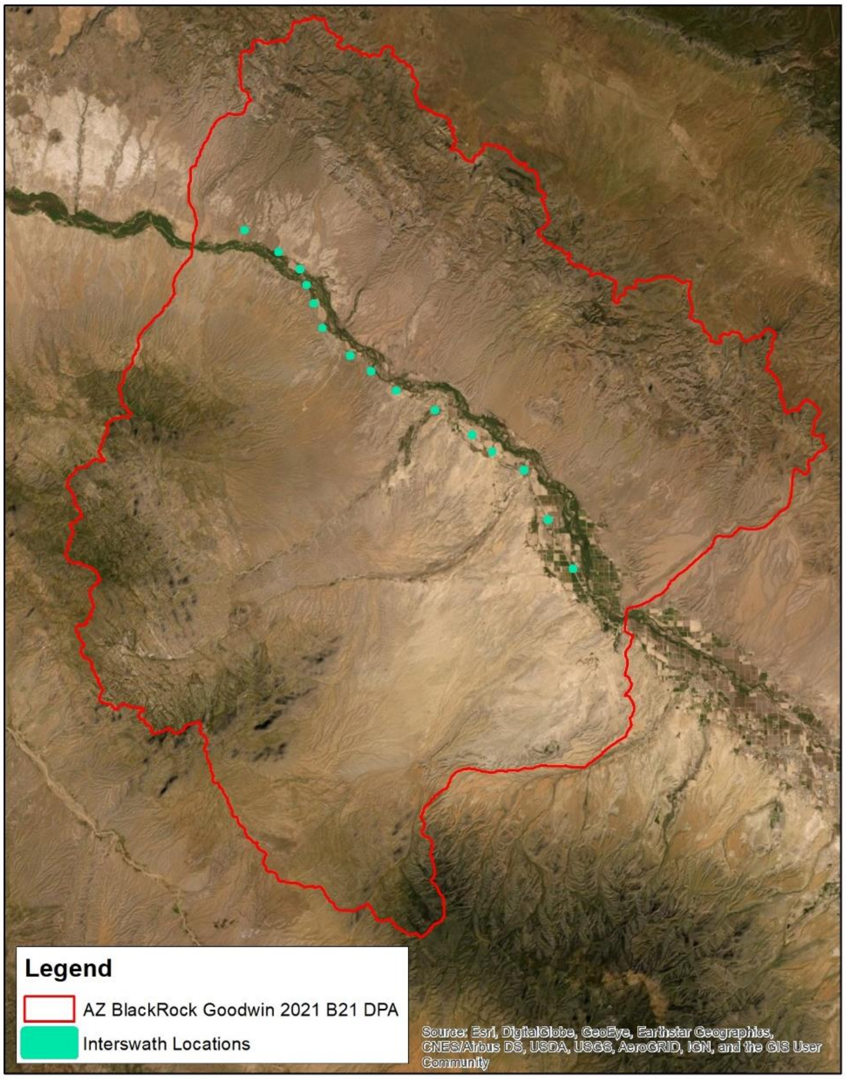
Interswath (overlap) consistency was assessed at multiple locations within overlap in non-vegetated areas containing only single returns and located in areas with slopes of less than 10-degrees. To the extent allowed by the data, test areas were chosen where the full width of the overlap was represented. These overlap areas include adjacent, overlapping parallel swaths within a project, cross-tie swaths, and a sample of intersecting project swaths in both flight directions, and adjacent, overlapping lifts. The interswath consistency results were produced as polygon features in Esri shapefile format.

This project required the interswath accuracy to meet ≤ 8-cm RMSDz. Accuracy was assessed in accordance with "*USGS Base Specification v2021, Revision A*".

Table 3.4.1 Interswath Results

FID	Minimum (m)	Maximum (m)	RMSDz (m)
0	-0.028	0.031	0.022
1	0.031	0.054	0.039
2	0.003	0.049	0.025
3	-0.004	0.02	0.01
4	0.000	0.019	0.013
5	-0.007	0.03	0.011
6	-0.012	0.012	0.007
7	0.001	0.017	0.007
8	0.005	0.022	0.013
9	-0.001	0.024	0.01
10	-0.001	0.027	0.017
11	0.003	0.025	0.017
12	-0.003	0.019	0.009
13	-0.012	0.009	0.006
14	-0.003	0.009	0.006

Figure 3.4.2 Interswath Testing Locations



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

3.5. Relative Accuracy: Intraswath Precision

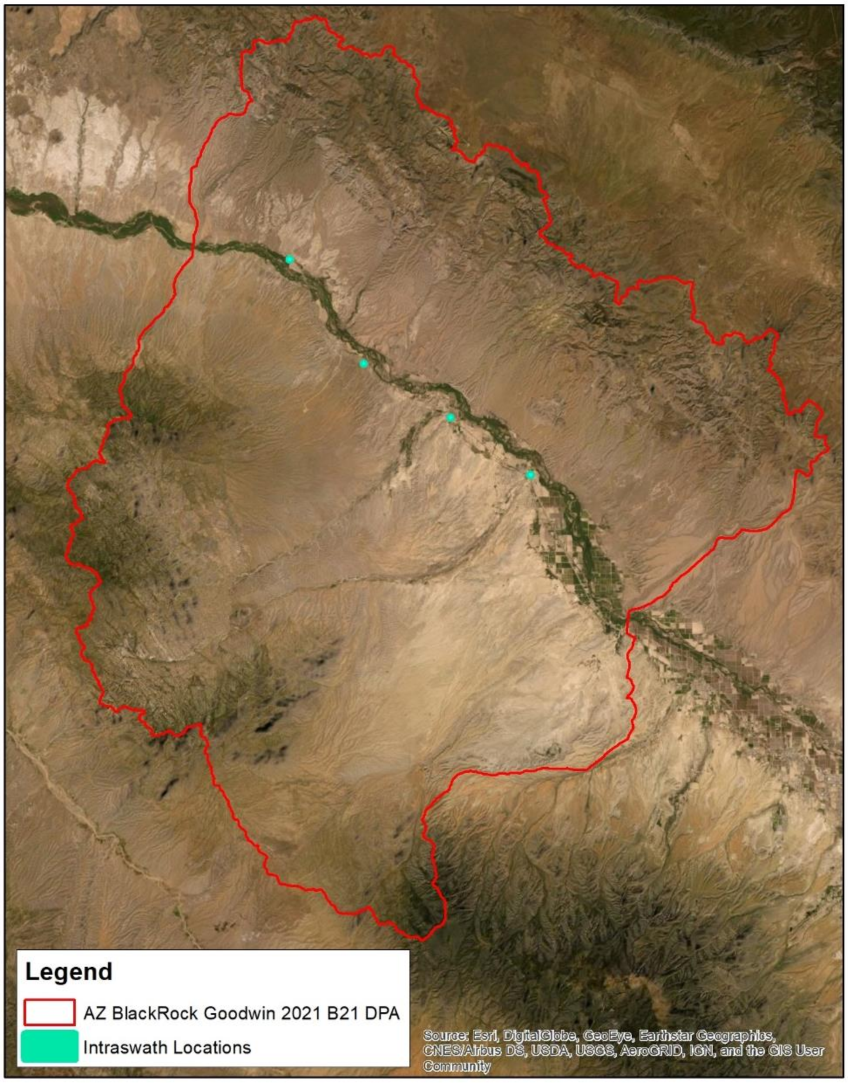
Intraswath precision (smooth surface precision) was performed on hard surfaces with areas consisting of approximately 100-pixels (ex.: parking lots, large rooftops) and containing only single return lidar points. Sample areas were selected where full width of the swath(s) (left, center, and right) were represented to the extent the data allowed. The intraswath precision results were produced as polygon features in Esri shapefile format.

This project required the intraswath accuracy to meet ≤ 6-cm RMSDz. Accuracy was assessed in accordance with the "*USGS Base Specification v2021, Revision A*".

Table 3.5.1 Intraswath Results

FID	**Minimum (m)**	**Maximum (m)**	**RMSDz (m)**
0	-0.021	0.040	0.017
1	-0.040	0.033	0.014
2	-0.032	0.030	0.013
3	-0.013	0.065	0.021

Figure 3.5.2 Intraswath Testing Locations



3.6. Lidar Data Classification

LAS data was initially classified as ground and non-ground points “first and only” as well as “last of many” lidar returns. Additional filters were created to meet the task order classification specifications. Statistical absolute accuracy was assessed by direct comparisons of ground classified points to ground RTK survey data. Based on the statistical analysis, the lidar data was then adjusted to reduce the vertical bias when compared to the survey ground control of higher accuracy.

The bare-earth (Class 2 - Ground) lidar points were subject to a manual quality control step to verify the quality of the Digital Elevation Model (DEM) as well as a peer-based review. This included a review of the DEM surface to remove artifacts and ensure topographic quality. After the bare-earth surface was finalized, it was used to generate all hydro-breaklines through a semi-automated process.

All Ground (Class 2) lidar data inside of the Lake Pond and Double Line Drain hydrological flattening breaklines were then classified to Water (Class 9) using TerraScan/LP360 algorithms. A buffer of 0.3-meters was also used around each hydro-flattened feature to classify these Ground (Class 2) points to Ignored Ground (Class 20). All Lake Pond Island and Double Line Drain Island features were checked to ensure that the Ground (Class 2) points were reclassified to the correct classification after the automated classification was completed.

All overlap data was processed through automated functionality provided by TerraScan to classify the overlapping flight line data to approved classes by USGS. The overlap data was classified using standard LAS overlap bit. These classes were created through automated processes only and were not verified for classification accuracy. Due to software limitations within TerraScan, these classes were used to trip the withheld bit within various software packages. These processes were reviewed and accepted by USGS through numerous conference calls and pilot study areas.

All data was manually reviewed and any remaining artifacts were removed. Industry-standard LAS files were then created. Final statistical analysis was performed per tile on the LAS files classes to verify final classification metrics and full LAS header information. Those classes include:

- Class 1: Processed, but Unclassified
- Class 2: Bare Earth
- Class 3: Low Vegetation (0.15-3m; automated only)
- Class 4: Medium Vegetation (3-7m; automated only)
- Class 5: High Vegetation (>7m; automated only)
- Class 7: Low Noise
- Class 9: Water
- Class 17: Bridge Deck
- Class 18: High Noise
- Class 20: Ignored Ground
- Class 21: Snow (If present and identifiable)
- Class 22: Temporal Exclusion (typical non-favored data in intertidal zones, used as necessary)

Classified LAS files were evaluated through a series of manual quality control steps as well as a peer-based review to eliminate remaining artifacts from the Ground class. This included a review of the DEM surface to remove artifacts and ensure topographic quality. Software used included proprietary software, GeoCue LP360, TerraScan v21, and Global Mapper v20.

3.7. Hydrologic Flattening

The lidar task order required compilation of breaklines defining the following types of waterbody features:

- Lakes, reservoirs, and ponds:
    - Minimum of 2-acres or greater
    - Compiled as closed polygons collected at a constant elevation
- Rivers and streams:
    - Nominal width of 30.5-meters / 100-feet
    - Compiled in direction of flow, with both sides maintaining an equal elevation gradient

Woolpert used the following steps to hydrologically flatten the waterbodies and for gradient hydrologic flattening of the double line streams within the existing lidar data:

1. Newly acquired lidar data was used to manually compile the hydrologic features in a 2D environment using the lidar intensity and bare earth surface. Open Source imagery was used as reference as necessary.
2. An integrated software approach combined the lidar data and 2D breaklines. This process “draped” the 2D breaklines onto the 3D lidar surface model to assign an elevation. A monotonic process was performed to ensure the streams flowed consistently in a downhill gradient. A secondary step within the program verified an equally matching elevation of both stream edges. The breaklines that characterize the closed waterbodies were draped onto the 3D lidar surface and assigned a constant elevation at or just below ground elevation.
3. All classified ground points inside the hydrologic feature polygons were reclassified to Water (Class 9).
4. All classified Ground points were reclassified from within a buffer along the hydrologic feature breaklines to Buffered Ground (Class 20). The buffer distance was approximately the task order designed Nominal Pulse Spacing distance.
5. Breaklines used for bridge removal during the hydrologic flattening were included with the hydrologic breakline geodatabase deliverable. These breaklines produce a more aesthetically pleasing DEM appearance.
6. The lidar ground points and breaklines were used to generate a DEM.
7. Quality control was performed by reviewing the hydrologically flattened DEM and hydrologic breakline features. An approach combining commercial off the shelf software and proprietary methods reviewed the overall connectivity of the hydrologic breaklines.

Breaklines defining waterbodies greater than 2-acres were provided as a PolygonZ feature class. All lake breaklines compiled as part of the flattening process were provided in an Esri file geodatabase. Breaklines used for DEM generation were provided as PointZ features in Esri shapefile format.

Software used included TerraScan v21, TerraModeler v21, Esri ArcMap v10.7, and GeoCue LP360.

TerraScan was used to add the hydrologic breakline vertices and export the lattice models.

3.8. Digital Elevation Model

TerraScan was used to add the hydrologic breakline vertices and export the lattice models. Ground lidar points in conjunction with the hydro breaklines and bridge breaklines were used to create 0.50-meter hydro-flattened bare-earth raster DEM files. Automated routines in ArcMap generated a 32-bit floating point raster GeoTIFF file for each tile. 1,003 files were produced and clipped to the data extent. Each surface was checked for surface anomalies or incorrect elevations found within the surface.

Software used included TerraScan v21, GDAL 2.4.0, Esri ArcMap v10.7, and Global Mapper v20.

3.9. Biomass and Tree Canopy

The biomass inventory was developed by rasterizing the lidar data into two separate surfaces. A normalized Digital Surface Model (nDSM) was generated to classify all objects 3-meters above the ground or higher. Because the nDSM includes anthropogenic features as well as vegetation, a Number of Returns (NOR) surface was generated to differentiate the two. The NOR surface measures number of returns per a given area, resulting in a drastic difference in the number of returns per square meter that indicates forest canopy.

Tree crowns were mapped by segmenting the classified vegetation to the pixel level. Each pixel with a greatest height-above-ground attribute within a 3-meter x 3-meter grid was classified. The output dataset consisted of the highest single point in a 3-meter x 3-meter grid, providing excellent estimations of individual tree crowns.

The biomass inventory and canopy tree crowns data will be stored in an ESRI Geodatabase using the following structure:

- Tree Canopy Feature Class– Polygon layer depicting the extent of the canopy.
    - Shape Length Attribute
    - Shape Area Attribute
- Crown Points – Point layer depicting each tree as a point.
    - Height Above Ground (HAG) Attribute

Software: ArcGIS10.7 (please list any others used).

3.10. Intensity Imagery

Lidar intensity data derived from the acquired lidar data was linearly rescaled from 16-bit intensity and provided as 0.50-meter pixel, 8-bit, 256 gray scale GeoTIFF files. 1,003 files were produced and clipped to the data extent.

Software used included TerraScan v21 and Esri ArcMap v10.7.

3.11. Swath Separation Image

The swath separation image was generated to visualize the DZ between the overlapping areas of the flight lines. To generate this surface a point insertion method was applied as the primary algorithm. Last returns for point classes except Classes 7 and 18 were used in the calculation for each cell. GSD and color ramp values were dependent on the Quality Level and point spacing for the project. The GSD for the surface was 0.50 meters.

Intensity values were modulated to 50% to ensure that there is no oversaturation of intensities values throughout the surface. After all calculations and surfaces were made a JPEG2000 mosaic was produced for the DPA.

Software used was LAStools and proprietary software to modulate the DZ rasters by the intensity images.

The color ramp for the swath separation image is as follows:

- Less than 8-cm: Green
- 8 to 16-cm: Yellow
- Greater than 16-cm: Red

3.12. Maximum Surface Height Raster

The maximum surface height rasters were generated using lasgrid, a part of the LAStools suite. The highest return of all the points falling in a cell excluding classes 7 and 18 was sampled. GSD for this surface was 0.50 meter. Cells containing no returns were coded with a no data value of -999999.

3.13. Metadata

FGDC CSDGM/USGS MetaParser-compliant metadata was produced in XML format. The metadata includes a complete description of the task order client information, contractor information, project purpose, lidar acquisition and ground survey collection parameters, lidar acquisition and ground survey collection dates, spatial reference system information, data processing including acquisition quality assurance procedures, GPS and base station processing, geometric calibration, lidar classification, hydrologic flattening, intensity imagery development, and final product development.

Other metadata deliverables included:

- Ground control and QA/QC points in ESRI Shapefile format
- Interswath and intraswath test results
- Data extent
- Tile index
- Georeferenced, polygonal representation of the detailed extents of each acquired lidar swath
- Swath separation images
- Maximum height separation rasters in GeoTIFF format

4. Accuracy Assessment

Testing was assessed and reported using guidelines developed by the National Digital Elevation Program (NDEP) and the American Society for Photogrammetry and Remote Sensing (ASPRS).

4.1. Horizontal Accuracy

This project dataset was produced to meet ASPRS “*Positional Accuracy Standards for Digital Geospatial Data (2014*)” for a 0.048-m RMSEx / RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 0.118-m at a 95% confidence level.

4.2. Classified Point Cloud Testing

This project required Non-Vegetated Vertical Accuracy (NVA) and Vegetated Vertical Accuracy (VVA) to be tested on the classified lidar point cloud data. The dataset was required to meet a target NVA value of 19.6-cm at a 95% confidence level using an RMSEz target value of 10-cm x 1.9600 and a target VVA value of 30-cm at the 95th percentile.

NVA and VVA values were calculated using independent checkpoints that were not used in the calibration or post processing of the lidar point cloud data. Checkpoints were distributed throughout the project area. NVA checkpoints were located in bare earth and urban (non-vegetated) land cover classes. VVA checkpoints were located in brush/tall grass/weeds (vegetated) land cover classes. These checkpoints were surveyed using GPS techniques. See the survey report for acquisition methodologies.

Testing was performed using Triangulated Irregular Networks (TINs) created from the final calibrated and controlled swath data. For each NVA checkpoint, an elevation value was derived from the TIN at the point’s x,y location. This value was compared to the checkpoint’s surveyed elevation value.

Table 4.2.1. Classified Point Cloud Vertical Accuracy

Test Type	**Result**	**Points Used**
NVA	0.049-m RMSEz	55
NVA	0.096-m at 95% CL	55
VVA	0.164-m at 95th Percentile	45

4.3. Digital Elevation Model Testing

This project required Non-Vegetated Accuracy (NVA) and Vegetated Vertical Accuracy (VVA) testing of the digital elevation model (DEM) dataset. Testing was assessed and reported using guidelines developed by the National Digital Elevation Program (NDEP) and the American Society for Photogrammetry and Remote Sensing (ASPRS).

Testing was performed using the bare earth DEM created as part of this task order. For each checkpoint, an elevation value was derived from the DEM at the point's x,y location. This value was compared to the checkpoint's surveyed elevation value. The calculated NVA value was required to meet 19.6-cm at a 95% confidence level using an RMSEz target value of 10-cm x 1.9600. VVA was required to meet 0.30-cm at the 95th percentile error.

NVA and VVA values were calculated using independent checkpoints that were not used in the calibration or post processing of the lidar point cloud data. Checkpoints were distributed throughout the project area. NVA checkpoints were located in bare earth and urban (non-vegetated) land cover classes. VVA checkpoints were located in brush/tall grass/weeds (vegetated) land cover classes. These checkpoints were surveyed using GPS techniques. See the survey report for acquisition methodologies.

Table 4.3.1. DEM Accuracy

Test Type	Result	Points Used
NVA	0.046-m RMSEz	55
NVA	0.091-m at 95% CL	55
VVA	0.249-m at 95th Percentile	46