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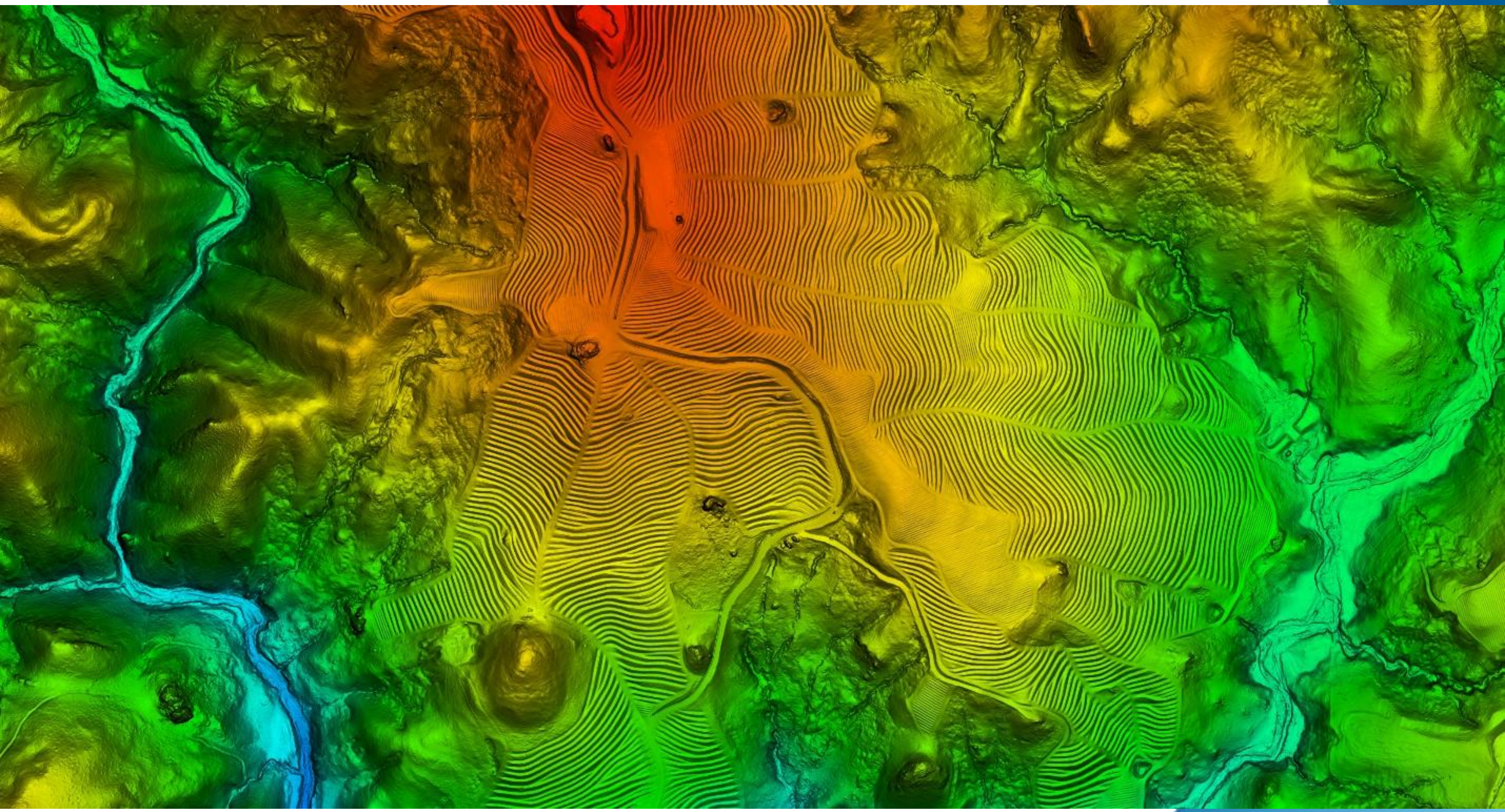

Submitted: February 19, 2024

Northern California B22 LIDAR PROCESSING REPORT

2024

Project ID: 224819
Work Unit: 300464

Prepared for:

USGS
science for a changing world

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1. Summary / Scope

1.1. Summary

This report contains a summary of the Northern California B22, Work Unit 300464 lidar acquisition task order, issued by USGS under their Contract 140G0221D0012 on August 18, 2022. The task order yielded a work unit area covering 4,241.105 square miles in Northern California at Quality Level QL1. This work unit was acquired and processed by NV5 GPSC4 team member Woolpert, under supervision by NV5. The intent of this document is only to provide specific validation information for the data acquisition/collection, processing, and production of deliverables completed as specified in the task order.

Some files were excluded from this dataset due to due to water bodies. There are 8 excluded LAS, INT, SSI, and MHSRS files:
10TFK8592
10TFK8693
10TFK8995
10TFK8996
10TFK8997
10TFL9002
10TFL9102
10TGL1852

1.2. Scope

Aerial topographic lidar was acquired using state of the art technology along with the necessary surveyed ground control points (GCPs) and airborne GPS and inertial navigation systems. The aerial data collection was designed with the following specifications listed in Table 1 below.

Table 1. Originally Planned Lidar Specifications

Average Point Density	Flight Altitude (AGL)	Field of View	Minimum Side Overlap	RMSEz
8 pts / m2	2,800 m	40°	55%	≤ 10 cm

1.3. Coverage

The work unit boundary covers 4,241.105363 square miles over Northern California. Work unit extents are shown in Figure 1.

1.4. Duration

Lidar data was acquired from September 3, 2022 to October 31, 2022 in 37 total lifts. See "Section: 2.4. Time Period" for more details.

Northern California B22 Work Unit 300464 Projected Coordinate System: UTM Zone 10N Horizontal Datum: NAD83 (2011) Vertical Datum: NAVD88 (GEOID 18) Units: Meters	
Lidar Point Cloud	Classified Point Cloud in .LAZ 1.4 format
Rasters	• 0.5-meter Hydro-flattened Bare Earth Digital Elevation Model (DEM) in GeoTIFF format • 0.5-meter Intensity images in GeoTIFF format • 1-meter Maximum Surface Height Raster • 1-meter Swath Seperation Images
Vectors	Shapefiles (*.shp) • Project Boundary • Lidar Tile Index • Hydro-flattened Breaklines • Flightlines Swath
Reports	Reports in PDF format • Processing Report
Metadata	XML Files (*.xml) • Breaklines • Classified Point Cloud • DEM • Intensity Imagery • Maximum Surface Height Raster

Northern California B22
Work Unit 300464 Boundary

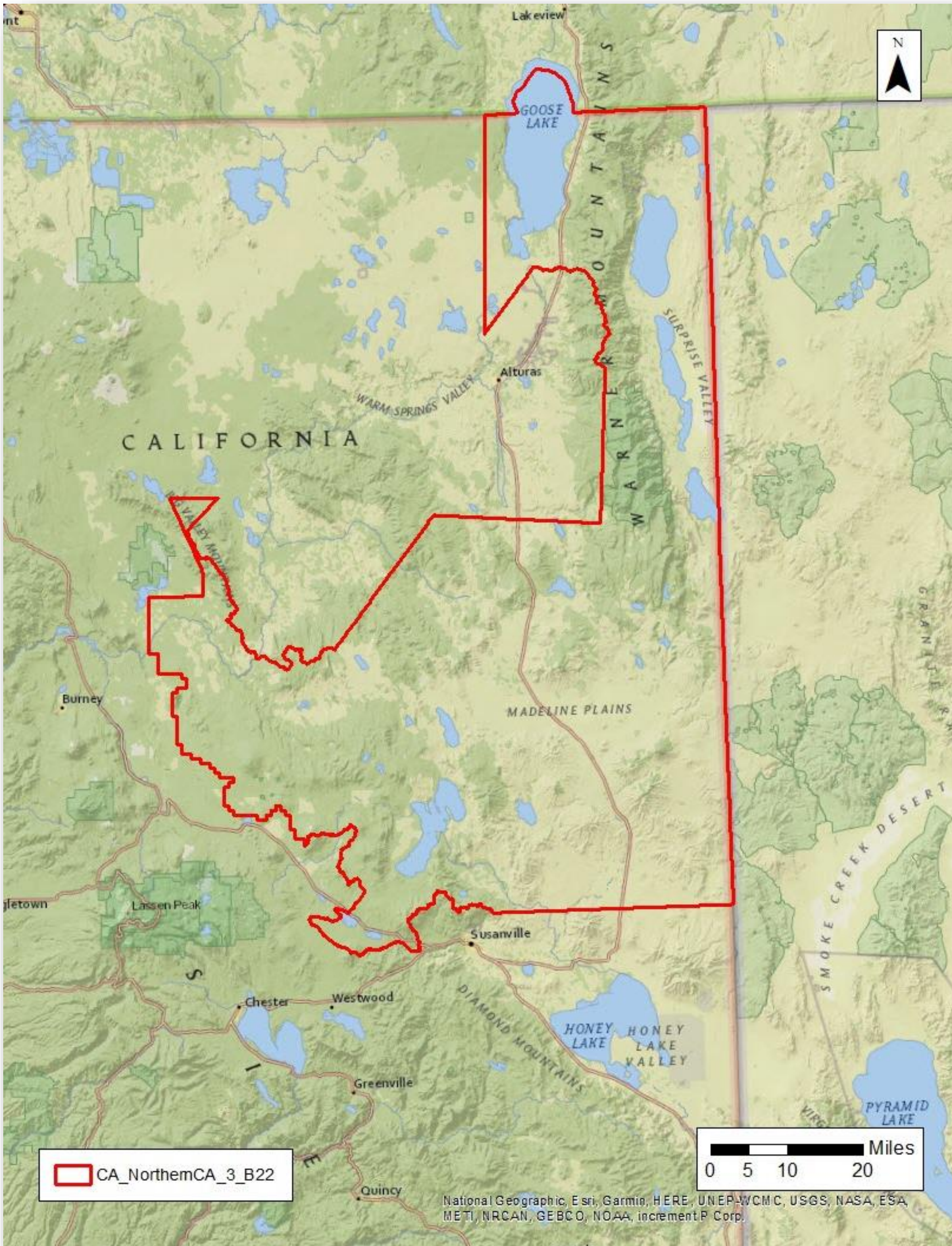


Figure 1. Work Unit Boundary

2. Planning / Equipment

2.1. Flight Planning

Flight planning was based on the unique project requirements and characteristics of the project site. The basis of planning included: required accuracies, type of development, amount / type of vegetation within project area, required data posting, and potential altitude restrictions for flights in project vicinity.

Flight plans were created using Leica Mission Pro v.12.5 software.

2.2. Lidar Sensor

Leica TerrainMapper lidar sensors (Figure 2), Leica Terrain Mapper – serial number 91513 , and Terrain Mapper – serial number 90511 were utilized for data acquisition.

Leica TerrainMapper is a compact laser-based system designed for the acquisition of high-density topographic and return signal intensity data from a variety of airborne platforms, at flying heights up to 5500 m AGL. The data is computed using digitised return signal waveforms from which range and return signal intensity measurements are derived in real time and recorded in-flight along with position and attitude measurements from an airborne GNSS/inertial sub-system. The TerrainMapper falls into the category of airborne instrumentation known as LiDAR (LIght Detection And Ranging).*

A brief summary of the aerial acquisition parameters for the project are shown in the lidar System Specifications in Table 2.

* https://leica-geosystems.com/en-us/products/airborne-systems/topographic-lidar-sensors/leica-terrainmapper-2

Table 2. Lidar System Specifications

		Leica TerrainMapper (SN 90511, & SN91513)
Terrain and Aircraft Scanner	Flying Height	2,800 m
	Recommended Ground Speed	140 kts
Scanner	Field of View	40°
	Scan Rate Setting Used	146 Hz
Laser	Laser Pulse Rate Used	1000 kHz
	Multi Pulse in Air Mode	yes
Coverage	Full Swath Width	2,038 m
	Line Spacing	varies
Point Spacing and Density	Average Nominal Point Spacing	0.35 m
	Average Point Density	8 pts / m^2

Figure 2. Leica Terrain Mapper Lidar Sensor

2.3. Aircraft

All flights for the project were accomplished through the use of customized aircraft. Plane type and tail numbers are listed below.

Lidar Collection Planes

- Cessna 404 Titan, Tail Number: N404CP
- Cessna 404 Titan, Tail Number: N532NM

This aircraft provided an ideal, stable aerial base for lidar acquisition. These aerial platforms have relatively fast cruise speeds, which are beneficial for project mobilization / demobilization while maintaining relatively slow stall speeds, proving ideal for collection of high-density, consistent data posting using a state-of-the-art lidar system.

Figure 3. NV5 Geospatial's Aircraft

2.4. Time Period

Project specific flights were conducted between September 3, 2022 and October 31, 2022. Thirty-seven (37) aircraft lifts were completed. Accomplished lifts are listed below.

Lift	Start UTC	End UTC
Day24622_TM511	09/03/2022 14:18:00	09/03/2022 15:30:00
Day24722_TM511	09/03/2022 16:07:00	09/03/2022 19:24:00
Day24722_TM513	09/04/2022 16:28:00	09/04/2022 22:19:00
Day24922_TM511	09/06/2022 16:10:00	09/06/2022 19:01:00
Day25022_TM511	09/07/2022 15:57:00	09/07/2022 19:07:00
Day25722_TM513	09/14/2022 17:47:00	09/14/2022 17:47:00
Day25822_TM513	09/15/2022 17:29:00	09/15/2022 20:15:00
Day26522_TM513	09/22/2022 15:58:00	09/22/2022 20:06:00
Day26622_TM513	09/23/2022 16:00:00	09/23/2022 21:01:00
Day26722_TM513	09/24/2022 16:13:00	09/24/2022 20:20:00
Day26822_TM511	09/25/2022 16:11:00	09/25/2022 20:23:00
Day27022_TM511	09/27/2022 15:46:00	09/27/2022 19:02:00
Day27222_TM513	09/29/2022 16:26:00	09/29/2022 19:41:00
Day27322_TM511	09/30/2022 16:05:00	09/30/2022 20:43:00
Day27422_TM511	10/01/2022 16:01:00	10/01/2022 21:06:00
Day27522_TM513	10/02/2022 17:48:00	10/02/2022 20:44:00
Day27722_TM513	10/04/2022 16:24:00	10/04/2022 19:36:00

Day27822_TM511	10/05/2022 16:41:00	10/05/2022 21:02:00
Day27822_TM513	10/05/2022 16:56:00	10/05/2022 20:27:00
Day27922_TM511	10/06/2022 17:27:00	10/06/2022 18:52:00
Day28022_TM511	10/07/2022 16:29:00	10/07/2022 19:27:00
Day28022_TM513	10/07/2022 16:38:00	10/07/2022 18:58:00
Day28122_TM511	10/08/2022 15:28:00	10/01/2022 19:10:00
Day28122_TM513	10/08/2022 15:26:00	10/08/2022 18:29:00
Day28222_TM513	10/09/2022 15:18:00	10/09/2022 18:23:00
Day28422TM513A	10/11/2022 16:37:00	10/11/2022 18:57:00
Day28422TM513B	10/11/2022 21:37:00	10/12/2022 00:17:00
Day28522_TM513	10/12/2022 16:43:00	10/12/2022 19:06:00
Day29122_TM513	10/18/2022 17:32:00	10/18/2022 21:30:00
Day29222_TM513	10/19/2022 22:05:00	10/19/2022 01:57:00
Day29322_TM513	10/20/2022 18:13:00	10/20/2022 21:37:00
Day29422_TM513	10/21/2022 20:50:00	10/21/2022 23:08:00
Day30022_TM513	10/27/2022 18:18:00	10/27/2022 22:28:00
Day30222_TM511	10/29/2022 15:14:00	10/29/2022 18:20:00
Day30322_TM511	10/30/2022 15:10:00	10/30/2022 15:10:00
Day30422_TM511	10/31/2022 15:28:00	10/31/2022 20:00:00
Day30422_TM513	10/31/2022 18:07:00	10/31/2022 21:30:00

3. Processing Summary

3.1. Flight Logs

Flight logs were completed by Lidar sensor technicians for each mission during acquisition. These logs depict a variety of information, including:

- Job / Project #
- Flight Date / Lift Number
- FOV (Field of View)
- Scan Rate (HZ)
- Pulse Rate Frequency (Hz)
- Ground Speed
- Altitude
- Base Station
- PDOP avoidance times
- Flight Line #
- Flight Line Start and Stop Times
- Flight Line Altitude (AMSL)
- Heading
- Speed
- Returns
- Crab

Notes: (Visibility, winds, ride, weather, temperature, dew point, pressure, etc). Project specific flight logs for each sortie are available in Appendix A.

3.2. 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. The Station ID and coordinates for all base stations operated during acquisition are listed below. GPS/IMU graphics are contained in Appendix B.

Station Name	Longitude (DMS)	Latitude (DMS)	Ellipsoid Height L1 Phase Center (M)
P349_CORS	40°43'51.89428"	-122°19'09.60926"	275.945
P348_CORS	40°54'19.95115"	-121°49'40.75612"	1668.637
P345_CORS	40°16'16.43038"	-122°16'14.84875"	134.647
P348_CORS	40°54'19.95115'	-121°49'40.75612"	1668.637
P148_CORS	40°25'06.90276"	-120°48'21.40665"	1585.046

3.3. Lidar Processing

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.

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).

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).

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.

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,

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.

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.

Software used for this task:

Software	Version
POSPac Software	5.3
IPAS Pro	1.35
Novatel Inertial Explorer	8.60.6129
Microstation Connect	10.16
Global Mapper	20
Esri ArcMap	10.7
TerraModeler	23
TerraScan	23
TerraMatch	23
GDAL	2.4.0

3.4. LAS Classification Scheme

The classification classes are determined by USGS Lidar Base Specification v2022 Revision A and are an industry standard for the classification of lidar point clouds. All data starts the process as Class 1 (Unclassified), and then through automated classification routines, the classifications are determined using TerraScan macro processing.

The classes used in the dataset are as follows and have the following descriptions:

Table 3. LAS Classifications

	Classification Name	Description
1	Processed, but Unclassified	Laser returns that are not included in the bare earth class, or any other project classification
2	Bare earth	Laser returns that are determined to be bare earth using automated and manual cleaning algorithms
7	Low Noise	Laser returns that are often associated with scattering from reflective surfaces, or artificial points below the bare earth surface
9	Water	Laser returns that are found inside of hydro features
17	Bridge Deck	Laser returns falling on bridge decks
18	High Noise	Laser returns that are often associated with birds or artificial points above the bare earth surface
20	Ignored Ground	Bare earth points that fall within the given threshold of a collected hydro feature.

3.5. Classified LAS Processing

LAS data was initially classified as ground and non-ground points "first and only" as well as "last of many" lidar returns. In determining ground classification steps were utilized that classify points to low noise in order to derive the best ground model. Not all points that theoretically could be bare earth get classified to ground class at the risk of impacting the surface model in the form of pits or spikes. 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 0.35-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 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.

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.

3.6. Hydro-Flattened Breakline Processing

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.

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

3.7. Hydro-Flattened Raster DEM Processing

TerraScan was used to add the hydrologic breakline vertices and export the lattice models using triangulated model-z interpolation method. Ground lidar points in conjunction with the hydro breaklines and bridge breaklines were used to create 0.5-meter hydro-flattened bare-earth raster DEM files. Automated routines in ArcMap generated a 32-bit floating point raster GeoTIFF file for each tile. 11,374 files were produced and clipped to the data extent. Each surface was checked for surface anomalies or incorrect elevations found within the surface.

3.8. Intensity Image Processing

Lidar intensity data derived from the acquired lidar data was linearly rescaled from 16-bit intensity and provided as 0.5-meter pixel, 8-bit, 256 gray scale GeoTIFF files. 11,366 files were produced and clipped to the data extent.

3.9. Swath Separation Raster Processing

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. All 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 is generated at twice the pixel size as the DEM deliverable.

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, 11,366 files were produced and clipped to the data extent.

Software used was GeoCue LP360.

Figure 4. Swath Separation Image

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

3.10. Maximum Surface Height Raster Processing

This raster is a proof of performance check that the withheld bit flag was used properly in the point cloud. Using all returns in the point cloud and excluding any points flagged as withheld, a raster is generated at twice the pixel size as the DEM deliverable using the same delivery tile index. This raster is generated as a 32-bit floating-point GeoTIFF with each pixel being generated as highest-hit elevation. The raster is then visually reviewed for anomalies that might indicate improperly classified noise. Any issues encountered are then corrected in the point cloud and a new/updated raster is generated.

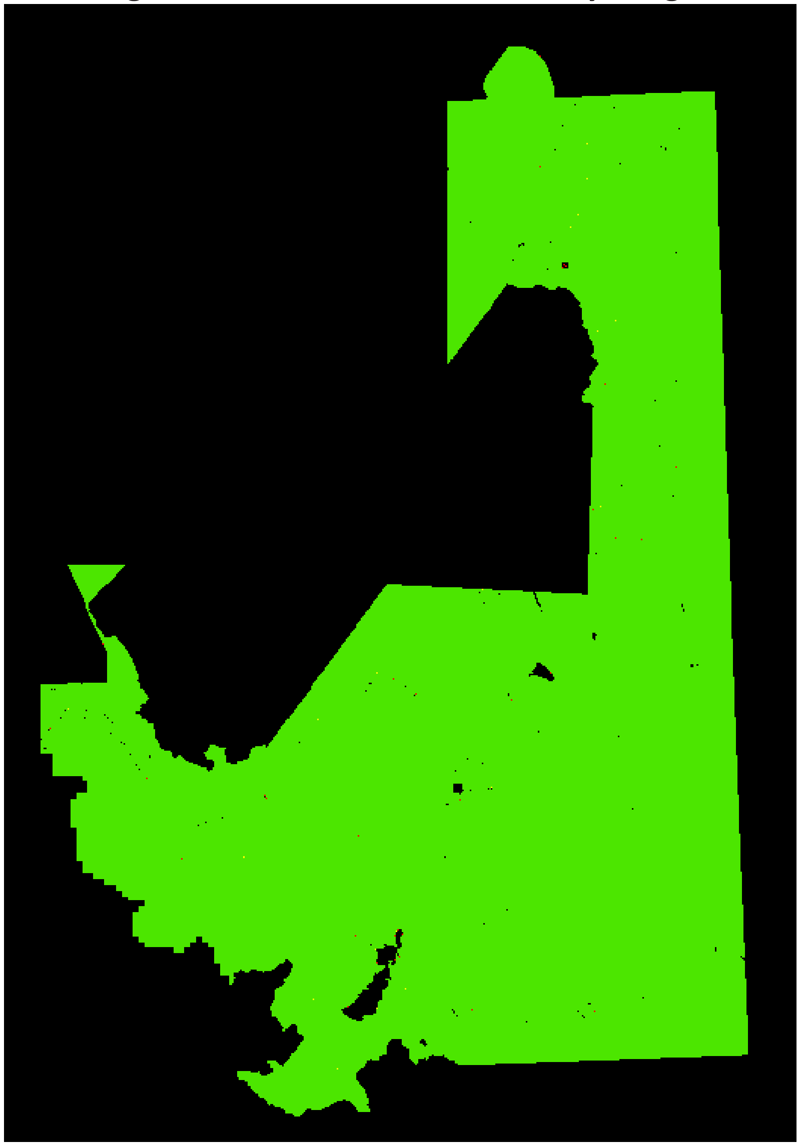
3.11. Point Density

The acquisition parameters were designed to acquire an average first-return density of 8 points/m2. First return density describes the density of pulses emitted from the laser that return at least one echo to the system. Multiple returns greater than 1 from a single pulse were not considered in first return density analysis. Some types of surfaces (e.g., breaks in terrain, water, and steep slopes) may have returned fewer pulses than originally emitted by the laser. First returns typically reflect off the highest feature on the landscape within the footprint of the pulse. In forested or urban areas, the highest feature could be a tree, building or power line, while in areas of unobstructed ground, the first return will be the only echo and represents the bare earth surface.

The density of ground-classified lidar returns was also analyzed for this project. Terrain character, land cover, and ground surface reflectivity all influenced the density of ground surface returns. In vegetated areas, fewer pulses may penetrate the canopy, resulting in lower ground density.

The average first return points density of lidar data for the project was 13.60 points m/2 while the average ground density of lidar data for the project was 7.09 points/m2.

Figure 5. First Return Point Density Image



The color ramp for the first return point density image is as follows:

- 8+ points per square meter: Green
- 1-7.99 points per square meter: Yellow
- 0-1 points per square meter: Red

Northern California B22
Work Unit 300464 Tile Layout

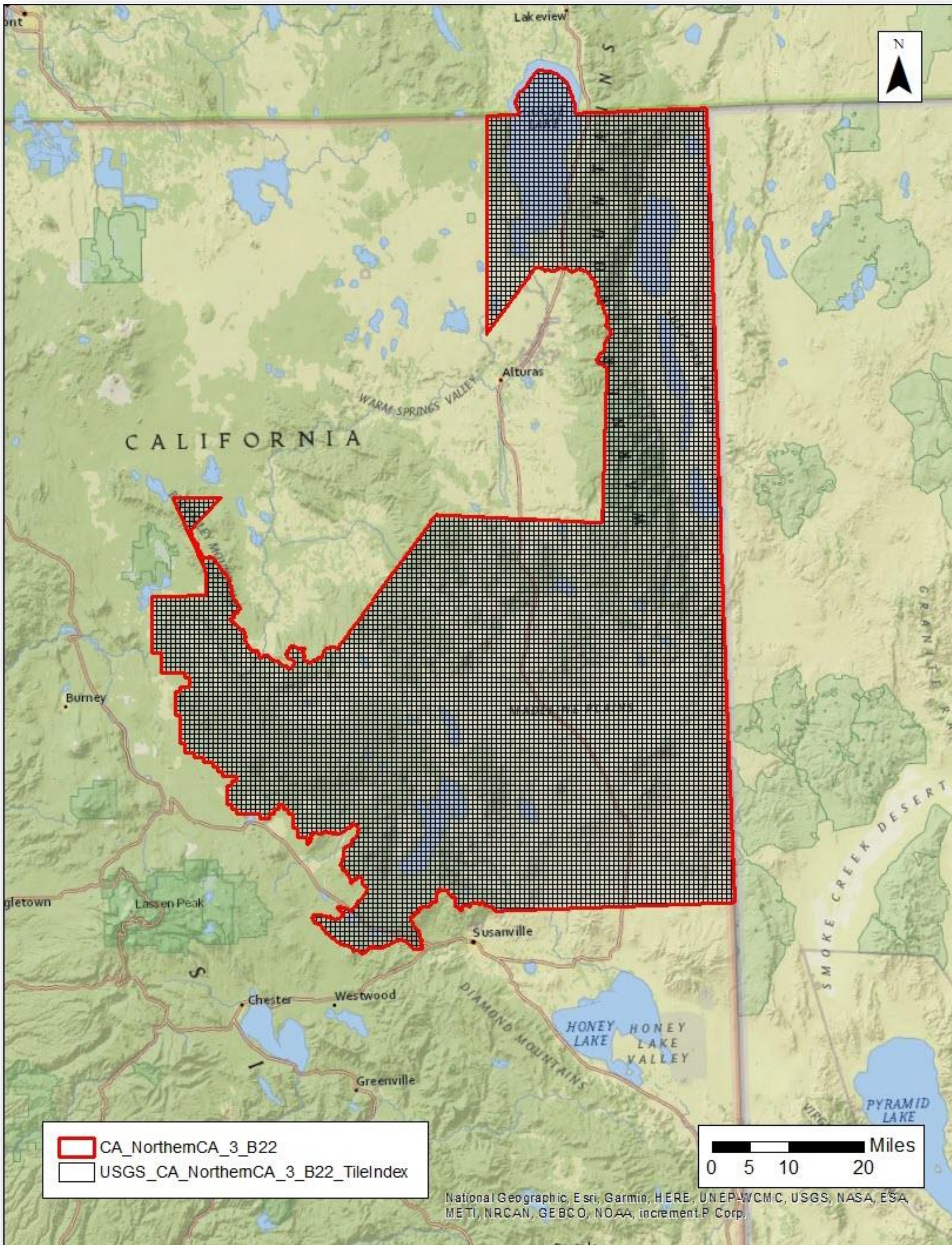


Figure 6 Lidar Tile Layout

These swath polygons are reviewed against the project boundary to verify adequate project coverage. Please refer to Figure 7.

Northern California B22
Work Unit 300464 Lidar Coverage

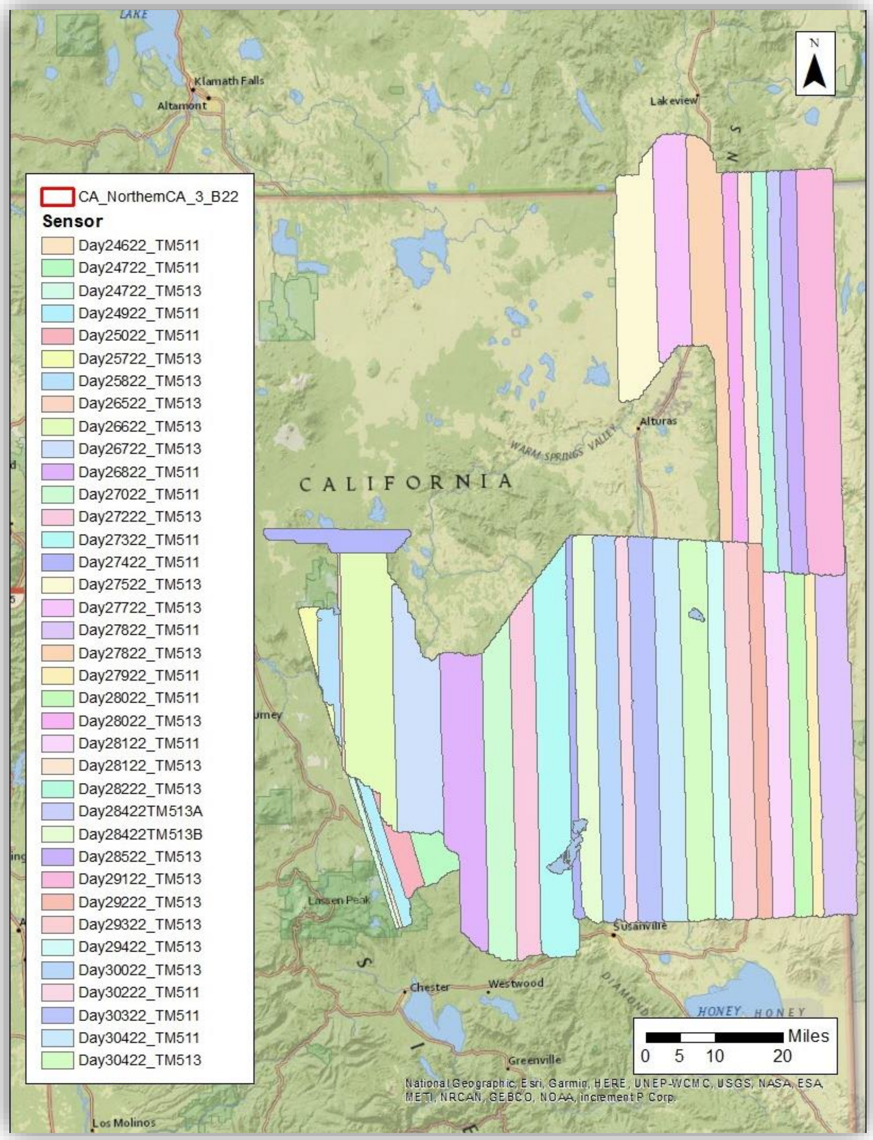


Figure 7. Lidar Coverage

5. Accuracy Testing

5.1. Point Cloud Testing

The project specifications require that only Non-Vegetated Vertical Accuracy (NVA) be computed for raw lidar point cloud swath files. The required accuracy (ACCz) is: 19.6 cm at a 95% confidence level, derived according to NSSDA, i.e., based on RMSE of 10 cm in the "bare earth" and "urban" land cover classes. The NVA was tested with 38 checkpoints located in bare earth and urban (non-vegetated) areas. These check points were not used in the calibration or post processing of the lidar point cloud data. The checkpoints were distributed throughout the project area and were surveyed using GPS techniques. See survey report for additional survey methodologies.

Elevations from the unclassified lidar surface were measured for the x,y location of each check point. Elevations interpolated from the lidar surface were then compared to the elevation values of the surveyed control points. AccuracyZ has been tested to meet 19.6 cm or better Non-Vegetated Vertical Accuracy at 95% confidence level using RMSE(z) x 1.9600 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines.

5.2. Digital Elevation Model (DEM) Testing

The project specifications require the accuracy (ACCz) of the derived DEM be calculated and reported in two ways:

1. The required NVA is: 19.6 cm at a 95% confidence level, derived according to NSSDA, i.e., based on RMSE of 10 cm in the "bare earth" and "urban" land cover classes. This is a required accuracy. The NVA was tested with 38 checkpoints located in bare earth and urban (non-vegetated) areas.
2. Vegetated Vertical Accuracy (VVA): VVA shall be reported for "brushlands/low trees" and "tall weeds/crops" land cover classes. The target VVA is: 29.4 cm at the 95th percentile, derived according to ASPRS Guidelines, Vertical Accuracy Reporting for lidar Data, i.e., based on the 95th percentile error in all vegetated land cover classes combined. This is a target accuracy. The VVA was tested with 50 checkpoints located in tall weeds/crops and brushlands/low trees (vegetated) areas. The checkpoints were distributed throughout the project area.

AccuracyZ has been tested to meet 19.6 cm or better Non-Vegetated Vertical Accuracy at 95% confidence level using RMSE(z) x 1.9600 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASRPS Guidelines.

A brief summary of results are listed below.

Table 4. VVA Accuracy Results

Parameter	NVA, as compared to classified LAS	NVA, as compared to bare earth DEM
Sample	**38 points**	**38 points**
95% Confidence (1.96*RMSE)	0.087 m	0.088 m
Average	-0.012 m	-0.017 m
Median	0.00 m	-0.011 m
RMSE	0.044 m	0.045 m
Standard Deviation (1σ)	0.043 m	0.042 m

Table 5. NVA Accuracy Results

Paramet er	VVA, as compared to classified LAS	VVA, as compared to bare earth DEM
Sample	**50 points**	**50 points**
95^{th} Percentile	0.273 m	0.284 m
Average	-0.089 m	-0.093 m
Median	0.076 m	0.081 m
RMSE	0.136 m	0.141 m
Standard Deviation (1σ)	0.103 m	0.107 m

6. Geometric Accuracy

6.1. Horizontal Accuracy

This data set was produced to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 0.207 (m) RMSEx / RMSEy Horizontal Accuracy Class which equates to Positional Horizontal Accuracy = +/- 0.509 (m) at a 95% confidence level.

6.2. Relative Vertical Accuracy (Interswath Accuracy)

This project required the interswath accuracy to meet ≤ 8-cm RMSDz. Accuracy was assessed in accordance with "USGS Base Specification v2022, Revision A".

The interswath (overlap) consistency was calculated using 6 sample locations in nonvegetated areas of swath overlap with only single returns. The achieved interswath accuracy is RMSDz= 0.034 meters.

Relative Vertical Accuracy	
Sample	
Average	0.004m
Median	0.02m
RMSE	0.034m
Standard Deviation (1σ)	0.033m
1.96σ	0.065m

6.3. Intraswath Precision (Smooth Surface Precision)

This project required the intraswath accuracy to meet ≤ 6-cm RMSDz. Accuracy was assessed in accordance with the "USGS Base Specification v2022, Revision A".

The intraswath precision was calculated using 6 sample locations in flat/open terrain against single swath and first-return points only. The achieved intraswath accuracy is RMSDz= 0.038 meters.

Project Report Appendices

The following section contains the appendices as listed in the Northern California B22 Lidar Project Report.

Appendix A

Flight Logs

Appendix B

GPS IMU Images